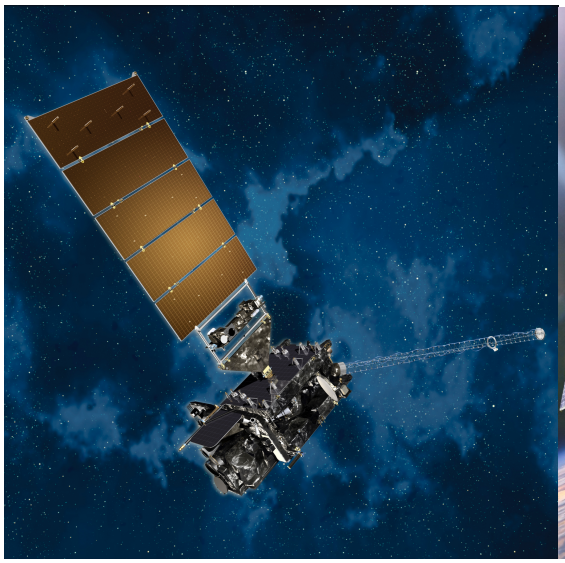


GOES-R

JPSS

# COOPERATIVE INSTITUTE FOR CLIMATE and SATELLITES (CICS)

## Annual Scientific Report

# VOLUME III: CICS-NC TASK REPORTS

For the period:
April 1, 2018 – March 31, 2019
NOAA Grant NA14NES4320003

**Dr. Fernando Miralles-Wilhelm, Director**
April 30, 2019

# Table of Contents

# CICS-NC Overview

The operation of the Cooperative Institute for Climate and Satellites-North Carolina (CICS-NC) is the primary activity of the North Carolina Institute for Climate Studies (NCICS), an Inter-Institutional Research Center (IRC) of the University of North Carolina (UNC) System. NCICS/CICS-NC is hosted by North Carolina State University (NCSU) and affiliated with the UNC academic institutions as well as a number of other academic and community partners. CICS-NC is collocated with the NOAA/NESDIS National Centers for Environmental Information (NCEI, formerly known as the National Climatic Data Center) in Asheville, NC, and focuses primarily on collaborative research into the use of satellite and surface observations in climate research and applications that is coordinated with NCEI. CICS-NC also engages in collaborative research and other climate activities with other NOAA line offices and units, including the National Weather Service (NWS), Oceanic and Atmospheric Research's (OAR's) Climate Program Office (CPO), and the Air Resources Laboratory's (ARL's) Atmospheric Turbulence and Diffusion Division (ATDD) as well as other federal agency collaborators with NOAA/NCEI, including the United States Global Climate Research Program (USGCRP), the Federal Emergency Management Agency (FEMA), the National Aeronautics and Space Administration (NASA), the U.S. Department of Defense, and the U.S. Department of State.

CICS-NC is led by the Director of the IRC and includes numerous partners from academic institutions with specific expertise in the challenges of utilizing remotely sensed and in situ observations in climate research and applications and related science expertise. NCSU provides CICS-NC with access to a strong graduate program in Earth, engineering, and life sciences, and many of the CICS partners offer complementary programs. A variety of needed skills and/or information sets have been requested by NOAA that were not originally envisaged in the original CI proposal and additional partners have been added to the CICS Consortium. Additions include: Oak Ridge Associated Universities (ORAU), the Institute for Global Environmental Strategies (IGES), the University of South Carolina, the University of Michigan, the Center for Climate and Energy Solutions (C2ES), the University of Illinois Urbana-Champaign, the University of Alabama Huntsville, and the University of Nebraska Medical Center. Additional collaboration and support for community engagement and outreach is provided by the North Carolina Arboretum, an affiliate member of the UNC System, and the Economic Development Coalition for Asheville-Buncombe County Coalition (Asheville EDC).

CICS' scientific vision centers on observation, using instruments on Earth-orbiting satellites and surface networks, and prediction, using realistic mathematical models, of the present and future behavior of the Earth System. Observations include the development of new ways to use existing observations, the invention of new methods of observation, and the creation and application of ways to synthesize observations from many sources into a complete and coherent depiction of the full system. Prediction requires the development and application of coupled models of the complete climate system, including atmosphere, oceans, land surface, cryosphere, and ecosystems. Underpinning all of these activities is the fundamental goal of enhancing our collective interdisciplinary understanding of the state and evolution of the full Earth System. This vision is consistent with NOAA's Mission and Goals and CICS scientists' work on projects that advance NOAA objectives. CICS conducts collaborative research with NOAA scientists in three principal Themes: Satellite Applications, Observations and Modeling, and Modeling and Prediction.

CICS-NC's mission focuses on collaborative research into the use of in situ and remotely sensed observations in climate and environmental research and applications that is led by NCEI; innovation of new products and creation of new methods to understand the state and evolution of the full Earth System through cutting-edge research; preparation of the workforce needed to address needed science and its

applications; engagement with corporate leaders to develop climate-literate citizens and a climate-adaptive society; and the facilitation of regional economic development through its Engagement activities.

CICS-NC activities primarily support NCEI activities and enterprise services. Main collaborative activities are currently organized and CICS is structured thematically by the following 8 task streams:

1) Administration (Task I)
2) Access and Services Development
3) Assessments
4) Climate Data Records and Scientific Data Stewardship
5) Climate Literacy, Outreach, Engagement, and Communications
6) Surface Observing Networks
7) Workforce Development
8) Consortium and/or Other CICS PI Projects

These streams are currently supported by the different divisions in NCEI; NOAA Line Offices including the National Environmental Satellite, Data and Information Service (NESDIS), Oceanic and Atmospheric Research (OAR), and the National Weather Service (NWS); and North Carolina State University. Other CICS PI projects are generally supported through other (non-NOAA) sponsors.

# Highlights

**CICS-NC**

CICS-NC highlights are arranged by task stream with task sponsors noted in brackets [ ]. Primary NOAA support comes from NESDIS/NCEI; however, the past year's activities were also supported by NESDIS/STAR, OAR's Climate Program Office (CPO), and the NOAA Office of the Chief Information Officer (OCIO). While CICS-NC activities remain primary, NCICS scientists are also engaged in research projects (Other CICS PI Projects) supported by other sponsors that currently include: The National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), the U.S. Department of Energy (DOE), the U.S. Department of Defense (DoD), and the National Institute Institutes of Health (NIH).

**Administration [NCSU/NOAA]**

*Information Technology Systems Improvement, Management, and Maintenance*: CICS-NC IT staff provide modern, scalable approaches to keep CICS-NC at the competitive edge of technology advances, as well as maintaining core technologies as a stable base for staff operations. Improvements are focused on system reliability and providing a flexible and scalable infrastructure.

**Access and Services Development [OCIO/CPO/NCEI]**

*NOAA Big Data Project Support:* A pilot data hub/broker architecture was designed and implemented to facilitate transfer of key NOAA environmental datasets to commercial public cloud providers, allowing users to do analyses of data and extract information without having to transfer and store these massive datasets themselves. https://ncics.org/data/noaa-big-data-project

*Programming and Applications Development for Climate Portal*: In support of NOAA's Climate Services Portal program, UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) assisted with the continuing U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) development and the new Climate Explorer Climate by Location design (https://crt-climate-explorer.nemac.org/). NEMAC also provided graphics, GIS, and mapping support for USGCRP Indicators and National Climate Assessment, and graphics design support for the NIDIS Drought.gov redesign.

*Website Information Architecture Development and User Interface Design for NOAA's National Centers for Environmental Information and NOAA OneStop*: CICS-NC collaborator, Mediacurrent, completed a review and user and usability testing of the updated OneStop Showcase User Interface v2 that incorporated many of last year's recommendations for improved user interaction. The assessment included an end-to-end strategy audit, a web accessibility audit, and a full competitive analysis on the existing NOAA Data Catalog and NCEI Geoportal. https://data.noaa.gov/onestop/#/

*Embracing the Cloud: Data Storage and Processing on the Amazon Web Services (AWS) Platform*: Two pilot projects were performed to examine cost and performance benefits of storing and processing NOAA NCEI data on the *Amazon Web Services* platform.

*NCEI Infrastructure Architecture Planning and Implementation*: This cross-functional collaborative team is driving IT infrastructure and architecture solutions that will support a modern, flexible, distributed approach to data science, archive, and access capabilities. Its goal is to support new and existing projects not handled using current infrastructure by implementing architecture using known upcoming technological advances (e.g., cloud computing), and preventing the NCEI IT infrastructure from falling behind currently available approaches (e.g., advanced workflow).

**Assessment Activities [NCEI/CPO/DOS]**

*National Climate Assessment Scientific and Data Support Activities*: The TSU science/data team was integral to the successful completion and delivery of the Fourth National Climate Assessment through authorship contributions to several chapters, development of numerous specialized scientific analyses and graphs, and successful metadata collection completion and metadata viewer improvement. https://nca2018.globalchange.gov/

*National Climate Assessment Technical Support* Activities: TSU technical staff provided technical and scientific writing and editing, graphics, and web development expertise in support of multiple National Climate Assessment (NCA) related products, including Volume II of the Fourth NCA and other associated publications. The team also provided overall project coordination and contributed substantive content to multiple author guidance documents and other tools. https://nca2018.globalchange.gov/

*World Resources Institute (WRI) / Partnership for Resilience and Preparedness (PREP) Supporting the U.S.–India Partnership for Climate Resilience*: CICS-NC collaborator, the World Resources Institute (WRI),and the Partnership for Resilience and Preparedness (PREP) worked with two Indian states, Madhya Pradesh and Uttarakhand, to help implement their respective State Action Plans on Climate Change through collaboration in the development and use of tailored "climate preparedness dashboards" on the PREP platform. https://www.prepdata.org/dashboards

*U.S.–India Partnership for Climate Resilience (PCR) Workshop Support*: This CICS-NC project with collaborator, Texas Tech University, supports the development of state-of-the-art climate products and analysis tools for resilience planning and sustainable development and provision to PCR collaborators. The Asynchronous Regional Regression Model version 2 (ARRM2) was updated and incorporated into the Seasonal Trends and Analysis of Residuals (STAR) analysis framework as the Empirical Statistical Downscaling Model (ESDM) for that software package.

*The Energy and Resources Institute (TERI)/ Understanding Climate and Heath Association in India (UCHAI) Initiative Supporting the U.S. – India Partnership for Climate Resilience*: CICS-NC and collaborator TERI worked to build capacity and climate health linkage awareness through support of multiple activities to reduce the India population's vulnerability to climate risk and extreme weather events. http://www.teriin.org/event/us-india-partnership-climate-resilience-workshop-climate-and-health

*Climate Change Indicators*: The TSU provided support for USGCRP efforts to maintain and expand a comprehensive suite of Climate Change Indicators. Significant progress was made in the development of new indicators and collection of indicator metadata. Three new indicators, developed with TSU input, were recently added to the newly redesigned USGCRP Indicators Platform. www.globalchange.gov/browse/indicators

*An investigation into current and future trends in severe thunderstorms and their environments*: A 12-year (2000–2011) MRMS radar-based hail climatology using the hail proxy Maximum Expected Size of Hail (MESH) was previously completed and short-term trends in the MESH climatology and long-term trends in the NARR-based hail environments were analyzed. Results were summarized in a peer-reviewed publication.

**Climate Data Records and Scientific Data Stewardship [NCEI]**

*Scientific Subject Matter Expertise Support*: Several CICS-NC scientists have served or currently serve as subject matter experts on multiple CDR Integrated Product Teams. They are also acting as Product Leads

and Portfolio Area Leads for a number of NOAA-NCEI products and portfolios.

*Common Ingest Agile Development Team*: This software development team works in concert with NCEI staff to continually enhance, modify, and deploy the new Common Ingest (CI) system at NCEI-NC. This year the team designed and developed several solutions to support the NCEI-NC Operations team in migrating the remaining datasets from the legacy ingest system to the new CI system and expanded the capabilities of the Ingest Engines.

*Spatial–Temporal Reconstruction of Land Surface Temperature from Daily Max/Min Temperatures*: An algorithm was developed to reconstruct LST under almost all-sky conditions by combining time series of daily maximum and minimum temperatures with estimates of net surface solar radiation (or surface solar absorption) derived from geostationary visible channel data. This strategy has potential applications for the new 5 km gridded daily nClimDiv max/min temperature dataset that is being produced at NOAA.

*Transitioning of the International Satellite Cloud Climatology Project Process to NCEI-NC*: The ISCCP-H series product for the extended period 2010 to mid-2015 was completed and archived. Production for the period mid-2015 to mid-2017 was also completed and archived as an interim CDR (ICDR) pending availability of the nnHIRS profile database. The drifting NOAA-18 polar orbiter was replaced with NOAA-19 as the afternoon anchor satellite beginning with year 2013. https://www.ncdc.noaa.gov/isccp

*Implementation of Geostationary Surface Albedo (GSA) Algorithm with GOES Data*: The GSA algorithm is being implemented as the U.S. contribution to an international collaboration between Europe, Japan, and the United States to produce a joint climate data record. www.scope-cm.org/projects/scm-03/

*HIRS Temperature and Humidity Profiles*: The team is developing a global temperature and humidity profile dataset for the time period of 1978–present. The data are produced by applying neural networks to High-resolution Infrared Radiation Sounder (HIRS) Data.

*Scientific Data Stewardship for Digital Environmental Data Products*: The NCEI/CICS-NC data stewardship maturity matrix (DSMM) has been applied to more than 800 individual NCEI datasets: 300+ of those DSMM assessment ratings have been captured by ISO-standard collection-level metadata and used by the NOAA OneStop Search and Discovery system for relevancy ranking. International groups including the Working Group on Information System and Services (WGISS) of Committee on Earth Observation Satellites (CEOS) and the WMO Commission for Climatology (CCl) International Expert Group on Climate Data Modernization (IEG-CDM) have also adapted the DSMM.

*Regional Variability of Sea Ice Coverage*: This project focuses on examining and characterizing temporal and spatial variability of Arctic sea ice coverage and sensitivity of their trends and statistical projections. The climate normals, i.e., the averages over the last three decades of sea ice concentration, area, and extent for the Arctic and sub-Arctic regions were evaluated and transitioned to NOAA.

*Toward the Development of Reference Environmental Data Records (REDRs) for Precipitation: Global Evaluation of Satellite Based Quantitative Precipitation Estimates (QPEs)*: The project team conducted a long-term assessment of the different satellite-based precipitation products from four Climate Data Records (PERSIANN-CDR; GPCP; CMORPH-CDR; AMSU A-B Hydro-bundle) and derived long-term global precipitation characteristics at fine spatial and temporal resolution. This work is part of a broader effort to evaluate long-term multi-sensor QPEs and to develop Climate Data Records (CDRs) for precipitation.

*Toward Earlier Drought Detection Using Remotely Sensed Precipitation Data from the Reference Environmental Data Record (REDR) CMORPH*: The feasibility of using satellite precipitation data from the CDR program (CMORPH) to detect and monitor drought on a global scale is being investigated with a focus on the implementation of the drought indices and their evaluation over CONUS.

*Identifying Tropical Variability with CDRs*: CICS-NC and UNC Asheville co-hosted a Workshop on Global Tropical Cyclone Reanalysis in May 2017 to discuss how to address the challenges posed by discrepancies in the historical tropical cyclone record. Two manuscripts were published this year that compared the interactions of teleconnections with various CDRs. https://ncics.org/mjo

*El Niño–Southern Oscillation (ENSO) Normals*: A manuscript documenting the project team's unique methodology for developing U.S. Normals from nClimGrid–Monthly conditioned on both climate change and the phase of ENSO was submitted.

*Relationship Between Occurrence of Precipitation and Incidence of Traffic Fatalities using NEXRAD Reanalysis*: The project team utilized six years of the NEXRAD Level 2 reanalysis along with coincident traffic fatality information to form a quantifiable link between precipitation and an increased risk of traffic fatalities.

**Climate Literacy, Outreach, Engagement, and Communications [NCEI/NCSU]**

*Climate Literacy, Outreach, Engagement, and Communications*: CICS-NC conducts numerous focused and interdisciplinary engagement, outreach, and literacy activities to enhance awareness and utility of NOAA and NCEI environmental data and information to support planning, decision-making, and advancements in science and innovation. https://ncics.org/events/; https://ncics.org/expertise/engagement/

*CICS-NC Communications*: This task promotes the Institute's research and other activities to its stakeholders and advances the external and internal communications efforts of NOAA's National Centers for Environmental Information. The Institute's Trends newsletter was redesigned and several research projects and their associated publications were highlighted on the Institute website. https://ncics.org/

**Surface Observing Networks [NCEI/ATDD]**

*Drought-related health impacts: advancing the science for public health applications*: Two studies were initiated to help identify linkages between drought and public health impacts—the first to determine the role of soil moisture on the 2017 Valley Fever outbreak and the second to evaluate historical drought-related mortality events. An initial epidemiological methodology was developed for analysis of the complex health and climate data, with results indicating that a relationship could be established between drought and extreme human health impacts (mortality).

*U.S. Climate Reference Network (USCRN) Applications and Quality Assurance*: The high data quality and temporal resolution of the U.S. Climate Reference Network precipitation and surface IR temperature data were leveraged to verify the Hourly Precipitation Dataset (HPD) network's new quality control (QC) algorithm and for validation of a novel approach to estimate remotely sensed land surface temperatures under all sky conditions. In addition, USCRN's temperature data were utilized to support measurements from a field campaign investigating the impact of urban encroachment on air temperature.

*The Utility of In Situ Observations for the 2017 Great American Solar Eclipse*: Sub-hourly observations from the U.S. Climate Reference Network (USCRN) were analyzed during the 2017 Great American Solar Eclipse, revealing important changes to the diurnal cycle of air and surface temperature measurements. USCRN

stations under clear skies conditions in the path of totality had the largest change in both air and surface temperatures (up to 5° and 15°C, respectively); the magnitude of these changes gradually diminished with distance from the path of totality. The importance of a solar eclipse on climatological data is not fully understood, but may have an impact on the distribution (lower end) of daily maximums for stations impacted by an eclipse just before or during the time of maximum temperature.

*Standardization of U.S. Climate Reference Network Soil Moisture Observations*: Various methods to standardize hourly soil moisture data from short-term records were evaluated. Percentile differences among these approaches were negligible when aggregated at national and regional scales; however, individual stations at times reflected differences >10%. Comparisons with U.S. Drought Monitor and other drought metrics (i.e., standardized precipitation index and Palmer Drought Severity Index) revealed important nuances between various types of drought (agricultural versus hydrological), which suggests that standardized soil moisture can provide context about trends from worsening to improving drought conditions. The same sampling methodology was also extended to remotely sensed AMSR-E soil moisture data.

*Extension of the Great Smoky Mountain rain gauge mesonet and exploration of the origins of extreme precipitation events in the southern Appalachian Mountains and their signatures as observed by GOES-R*: The team completed Spring, Summer, and Fall 2018 maintenance and data collection gauge visits as part of this collaborative research effort to extend the period of observations of the Duke University Great Smoky Mountains National Park Rain Gauge Network (Duke GSMRGN).

*Development of the United States Climate Reference Network (USCRN) National Precipitation Index*: An algorithm to build a national precipitation index (NPI) using 100+ stations from the United States Climate Reference Network is in development and is close to completion. A technical report is nearing completion as well, and the NPI will soon become operational.

*Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCN-M) Dataset*: The next iteration of NOAA's global temperature product has been developed and is operational. A manuscript has been submitted and accepted. Updates are ongoing and provided as necessary. www.ncdc.noaa.gov/ghcnm/

*Development of a Homogenized Sub-Monthly Temperature Monitoring Tool*: A sub-monthly tool for monitoring impacts of temperature extremes in the United States was created. The resulting dataset was used to assess heat extreme events in the United States from 1895–2018, and a manuscript was developed for publication. https://ncics.org/portfolio/monitor/sub-monthly-temperatures/

*Simplified and Optimal Analysis of NOAA Global Temperature Data: Data Validation, New Insights, Climate Dynamics, and Uncertainty Quantification*: Improvements were made in the software technology, 4DVD (4-Dimensional Visual Delivery of big climate data), and Amazon entered a big data partnership with 4DVD in December 2018 to host the 4DVD big database. The system has the capability to rapidly deliver NOAA environmental data to classrooms, the scientific community, and the general public.

*Night Marine Air Temperature Near Real-Time Dataset Development*: A preliminary gridded NCEI NMAT dataset from 2002–August 2017 was generated that includes NMATs adjusted in the boundary layer to a homogenized height of 10m and gridded using a distance weighting scheme. Differences between NCEI NMAT and HadNMAT2 were investigated and documentation was provided to transition the project activity to NCEI.

*International Comprehensive Ocean–Atmosphere Data Set (ICOADS)*: The International Comprehensive Ocean–Atmosphere Data Set (ICOADS) is the most complete and heterogeneous collection of surface marine data in existence. Work is being done to migrate the high-impact scripts and workflow used to retrieve and process this data to a new, more robust computation environment.

*Investigation of Trends in Airport Weather Conditions*: Several decades of surface observations were assessed to quantify a trend in the frequency of low-visibility conditions at the nation's busiest airports. Results reflected a marked decrease in the frequency of Instrument Flight Rule (IFR) conditions at 29 of 30 airports in all seasons.

**Workforce Development [NCEI / NSF / NASA / NCSU]**

CICS-NC actively works to identify and train the next generation of scientifically and technically skilled climate scientists. Junior and/or aspiring scientists, including post-doctoral researchers and students, play an important role in the conduct of research at CICS-NC. High School, Undergraduate, and Graduate level students and recent post-docs support projects across the CICS-NC task streams.

**Other CICS PI Projects**

*Changes in the Frequency of Freezing Precipitation*: International environmental change studies focused on the northern extratropics were conducted to better inform vulnerable societies and better prepare them for potential future developments. One of these studies devoted to Eurasian drylands is near completion (peer-reviewed papers were published and a book is in press). The BELMONT Arctic ERA study is under way.

*The Urban Resilience to Extremes Sustainability Research Network (UREx SRN)*: The team quantified the projected effects of future increases in temperature and humidity on the number of days with dangerous heat levels.

*Incorporation of the Effects of Future Anthropogenically Forced Climate Change in Intensity–Duration–Frequency Design Values*: An algorithm to automatically identify weather fronts in climate model and reanalysis data was refined and applied to historical and future climate model simulations. Analysis of weather system changes indicates decreases in summer fronts, but the number of summer fronts may not correlate with extreme precipitation. Also, increases in slow-moving cyclones and high moisture convergence in the North American Monsoon are projected.

*IPCC Special Report on 1.5°C of Global Warming*: NCICS provided editorial and technical support for the Intergovernmental Panel on Climate Change (IPCC) Special Report on 1.5°C of Global Warming, which quickly became one of the most significant and policy-relevant international climate assessments produced to date. Support efforts included leading the copyediting team for the full report, editorial and science communication input on the report's Summary for Policymakers, the provision of a figure and metadata management web portal, and on-site technical support at the report approval session in Incheon, Korea. https://www.ipcc.ch/sr15

*Climate Indicators to Track the Seasonal Evolution of the Arctic Sea Ice Cover*: This effort focuses on examining long-term average and temporal variability of the new sea ice climate indicators, including snow melt onset, sea ice retreat, advance, and freeze-up dates. A dataset was released by National Snow and Ice Data Center (NSIDC). The NCICS project PI was lead-author/co-author of two peer-reviewed papers and lead-author/co-author of two posters presented at the AGU 2018 Fall Meeting.

*Synthesis of Observed and Simulated Rain Microphysics to Inform a New Bayesian Statistical Framework for Microphysical Parameterization in Climate Models*: This multi-institutional research project aims to comprehensively investigate the representation and associated uncertainties of rain microphysical processes in weather and climate models. In order to quantify those uncertainties in microphysical formulations, the team developed an innovative Bayesian statistical framework that combines the extensive radar and ground-based data from the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) field campaigns, bin microphysical modeling, and a new bulk parameterization.

*Climate Change Impacts on Human Health*: This year resulted in a number of publications, as well as the ascertainment of three large public health data sets to be used in indicator surveillance work to examine the impacts of climate change and vulnerability on mental health and maternal health in 2019–2020.

*Continuous Monitoring of Individual Exposure to Cold Work Environment: A Participatory Sensing Study*: This pilot study utilized new wearable sensor technology to test and implement more sensitive means of evaluating cold temperatures as an occupational hazard and developed effective report-back strategies as a means to communicate with participants about harmful occupational exposures and their associated health risks.

*Multiscale Convection and the Maritime Continent*: Comparing TRMM and ISCCP data provides a more complete picture of the diurnal cycle of convection over the Maritime Continent and its interactions with the MJO. https://ncics.org/portfolio/monitor/mjo/

*Investigations Between Kelvin Waves and Easterly Waves Using CYGNSS Data*: This team is using NASA's new Cyclone Global Navigation Satellite System (CYGNSS) retrievals to investigate the surface interactions between Kelvin waves and easterly waves.

*Developing New Forecast Tools for the USAF 14th Weather Squadron's Tropical Pacific Convective Outlook*: This team delivered software for transitioning key tropical subseasonal metrics from CICS-NC's Madden–Julian Oscillation (MJO) monitoring page into operations in the Air Force's 14th Weather Squadron. https://ncics.org/mjo

*Operational Transition of Novel Statistical–Dynamical Forecasts for Tropical Subseasonal to Seasonal Drivers*: This team is transitioning key tropical subseasonal metrics from CICS-NC's Madden–Julian Oscillation (MJO) monitoring page into operations in the Climate Prediction Center. https://ncics.org/mjo

*Collaborative Support for the Development of the Quantitative Urban-Scale Microclimatic Modeling Tool (QUEST)*: An interface package between global datasets and the high-resolution regional model was developed, and hourly data with resolution of 1 km x 1 km was generated to establish average and hot-test historical baseline climate scenarios over Singapore.

# Administration

Administrative or Task I activities provide a central shared resource for CICS-NC staff and partners. Primary Task I activities include institute and office administration, accounting and finance, proposal development/support, contracts and grants management, human resources, information technology, international linkages, internal and external communications, oversight and management of CICS-NC-initiated consortium projects, and coordination with National Centers for Environmental Information (NCEI) administration and leadership. Other Task I activities include coordination of student intern opportunities and K-12 outreach activities.

Under the current NOAA Cooperative Agreement, CICS-NC serves as one of two CICS campuses and is collocated with NCEI in the Veach-Baley Federal Complex in Asheville, NC. The operation of CICS-NC is the primary activity of the North Carolina Institute for Climate Studies (NCICS), an Inter-Institutional Research Center (IRC) of the University of North Carolina (UNC) System. NCICS/CICS-NC is hosted and administered by North Carolina State University (NCSU) as an administrative unit under NCSU's Office of Research and Innovation (ORI). The NCICS/CICS-NC Director reports to the NCSU Vice Chancellor for ORI. CICS personnel are hired as NCSU employees and serve under NCSU policies and administrative guidelines. CICS-NC administrative staff implement, execute, and coordinate administrative activities with pertinent CICS-MD, UNC, NCSU, ORI, NOAA, and NCEI administrative offices.

The CICS-NC Director, in coordination with the Business Manager and University Program Specialist, is responsible for the operations of CICS-NC. Administrative operations are primarily supported by NCSU, with additional support from NOAA via the Task I cooperative agreement. The NOAA Task I allocation currently provides partial support for the director (2 summer months), a business manager (20%), a program specialist (10%), IT operations and systems support (10%), and travel funds, primarily for the Director, for administration and research facilitation purposes with the diverse climate science and applications community. NCSU provides support for the Director and administrative staff, basic office and institute operations, and a substantial investment in IT infrastructure associated with the goal of providing state of the art visualization and connectivity (including Wi-Fi access and telepresence) tools for the Asheville-based staff.

CICS-NC/NCICS administrative activities are currently led by Dr. Otis B. Brown, Director, and are implemented and executed by the following administrative team:

Janice Mills, Business Manager
Erika Wagner, Program Specialist
Jonathan Brannock, Network/Systems Analyst
Scott Wilkins, Operations/Systems Specialist

| Information Technology Systems Improvement, Management, and Maintenance | |
|---|---|
| **Task Team** | Jonathan Brannock, Scott Wilkins |
| **Task Code** | NC-ADM-01-NCICS-JB/SW |
| **NOAA Sponsor** | Task I (partial support) |
| **NOAA Office** | NESDIS/NCEI (and other line offices) |
| **Contribution to CICS Research Themes** | Theme 1: 33.3%; Theme 2: 33.3%; Theme 3: 33.3% |
| **Main CICS Research Topic** | Data Access and Services Development |
| **Contribution to NOAA goals** | Goal 1: 45%; Goal 2: 45%; Goal 3: 8%; Goal 4: 2% |
| **NOAA Strategic Research Priorities** | All |

**Highlight:** CICS-NC IT staff provide modern, scalable approaches to keep CICS-NC at the competitive edge of technology advances, as well as maintaining core technologies as a stable base for staff operations. Improvements are focused on system reliability and providing a flexible and scalable infrastructure. Without current IT resources, CICS-NC staff would be unable to complete their support and research tasks.

**Background**

CICS-NC IT staff support a well-rounded set of IT resources and services and maintain the necessary infrastructure required to do so. Institute IT services are organized into 3 areas: the user network, cluster and computing resources, and network and disk infrastructure (see Figure 1). The user network consists of wireless network services, Google telecommunications services, and end-user software on *Apple* desktops and laptops. The cluster and computing resources are centered on a high-performance computing cluster with 528 processing cores and 3 terabytes of memory. The cluster head node is a powerful server where users can prototype ideas and perform light work tasks, including coding and testing. The head node can then queue heavy workloads onto the cluster where a number of different processing queues are available to suit computing requirements.

CICS-NC provides distributed *Gluster* file systems for concurrent system-wide access to high-speed storage. *Amazon S3* and *Glacier* provide offsite backup and disaster recovery for all data.

A building-wide wireless network provides both CICS-NC and other building partners with strong-signal, fast wireless coverage. This allows CICS-NC to quickly integrate and work side-by-side with our NCEI partners. There are 37 access points covering areas on the 1st through 3rd floors, fitness center, and NCEI archive, and full coverage on the 4th and 5th floors. The most populous areas utilize 802.11AC or gigabit Wi-Fi. Heat maps and simulations were used to optimize access point locations.

CICS-NC IT staff utilize a suite of monitoring tools, including *Casper Suite*, *Puppet OSE, Nagios, Cacti*, *Splunk*, *Elasticsearch*, *Kibana*, *Ganglia*, and *Monitis*. These and other open source and proprietary tools allow IT staff to quickly address issues and efficiently monitor and maintain systems.

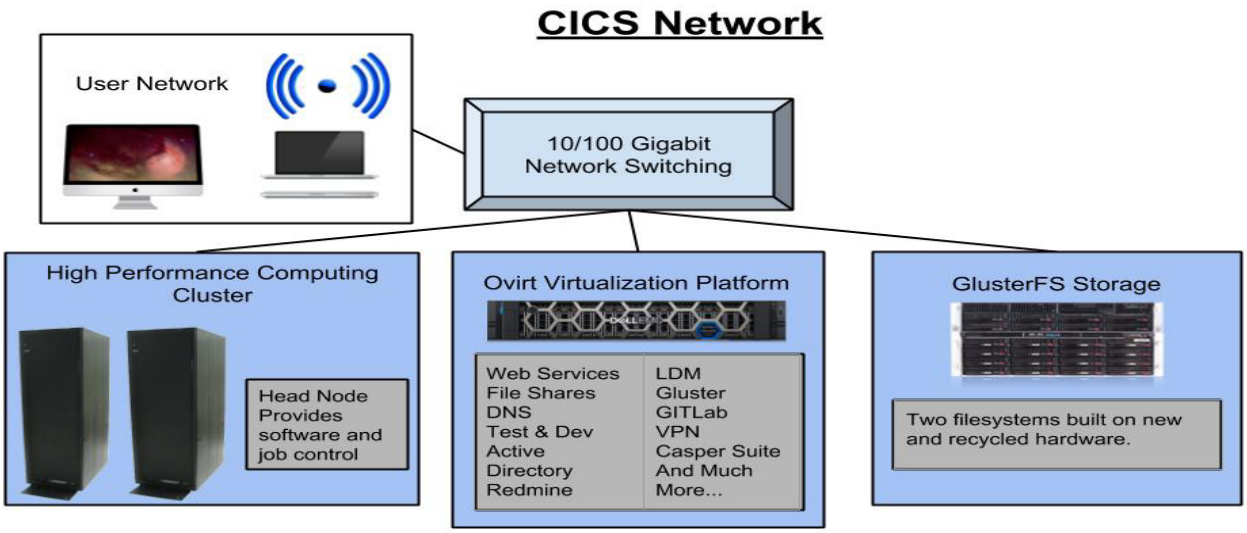



***Figure 1**. Network and System Diagram.*

**Accomplishments**

***Server replacement.*** The compute cluster head node hardware was replaced to better support user needs. The new hardware has four times as many CPUs and double the memory of the old hardware. Many researchers use interactive software environments like *RStudio*, *IDL,* and *MatLab*. These processes are often CPU and memory intensive and the old server was unable to satisfy the demand. CICS scientists typically develop and test new processes interactively on this head node before submitting them as batch jobs to the compute cluster.

**Network upgrades**. The end of life firewall was replaced with a current model which is able to fully support our newly upgraded symmetrical 10 Gigabit internet connection. Other upgrades include connecting additional hosts to 100 Gigabit interfaces. Another major change is that all critical hosts now have redundant network paths and can maintain network connectivity if one network path goes down. These changes add to the performance and resiliency of the network.

***Gluster file systems and tape library replacement.*** The *Quantum Stornext* file systems and tape library were replaced with *Gluster* file systems. *Gluster* is a distributed, replicated file system platform that integrates seamlessly with our existing infrastructure. Six new *Red Hat* configured servers with internal disk storage were purchased to host the output data file system. Four *Promise SANs* and two *Stornext Metadata Controllers* were repurposed to host the input data file system. All data was moved to *Amazon Glacier* to decommission the *iScalar 6000* tape library. The previous *Stornext* servers and clients could not be updated past *Red Hat* version 7.4 so this replacement provided CICS-NC with a more stable and sustainable environment.

***NOAA and other building tenant support.*** CICS-NC IT provides IT support to its partners in the federal building including regular Wi-Fi, audiovisual, and video conferencing support of various meetings and engagements and support to augment existing resources and provide the required functionality to make NCEI meetings and events possible. CICS-NC typically provides workstations, Wi-Fi, video conferencing, virtualization, and high-performance computing resources in support of various internship programs

within the building including the NASA DEVELOP and the NOAA Hollings internship programs. The short nature of the internships often means interns are without access to federal resources until they are halfway through the program. With CICS-NC-provided equipment, they are able to start and complete projects within the internship period.

**Planned work**

- Continue ongoing monitoring and maintenance tasks.
- Plan for upcoming equipment end of life and associated replacements.
- Improve security scanning regularity and address issues.
- Continue support for our federal partners and internship programs.
- Continue assisting users to leverage cloud-based technologies.
- Work with NOAA BDP and support the CICS Data Hub.

**Publications**

Knapp, K. R., and **S. L. Wilkins**, 2018: Gridded Satellite (GridSat) GOES and CONUS data. *Earth System Science Data*, **10,** 1417-1425. http://dx.doi.org/10.5194/essd-10-1417-2018

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Access and Services Development

Access and services development activities support improvements to access mechanisms for NOAA's National Centers for Environmental Information (NCEI)'s expansive data and product holdings. NOAA generates terabytes of data a day from satellites, radars, ships, weather models and other sources. NCEI has ongoing requirements to improve conveyance of data products and services to its stakeholders and clients. Current NCEI services include interaction with data users, providing data products to users, and communicating unmet user needs to the science and stewardship components of NCEI. The NOAA Big Data Project (BDP) was created in 2015 to explore sustainable models to increase access to NOAA open data. Increasing and improving access requires the input and guidance of scientific data management staff, software engineers, and other technical specialists with expertise to design, develop and/or enhance and provide tools and information to provide new and/or improvements to the current access mechanisms for NCEI's data and product holdings and, through improved access to information, facilitate improvement of society resilience to climate change.

CICS-NC continues to support the enhancement and expansion of NOAA's Climate Services Portal applications under this task umbrella. The Climate Resilience Toolkit website (toolkit.climate.gov) was launched in November 2014 and work continues on enhancement of the site as well as other related tasks and climate interactive tools. Capitalizing on this current tool and application development, work was also expanded to identify synergies and integrate products and tools (data visualization capabilities, on-line mapping applications, etc.) across programs including the Climate Services Portal, the National Climate Indicators, the National Climate Assessment, and the National Integrated Drought Information System (NIDIS) U.S. Drought Portal. The new NCEI website, launched in April 2015 following the merger of NOAA's three data centers, offered the opportunity to update and enhance current services to customers with a more user-friendly design and interface to enable current and future users to more easily identify, locate, and access specific data products and services. The development of the NOAA OneStop portal launched in late 2017 provided yet another opportunity to enhance and expand data access services. To meet this demand, CICS-NC provides experts in data architecture, management, web services, and user interface design and development. In support of the Big Data Project, CICS-NC designed and implemented a pilot data hub architecture to facilitate transfer of key NOAA environmental datasets to public cloud providers.

While consistent support remains a challenge, CICS-NC continues to work to identify prospective future skilled practitioners, broaden its software engineering staff and utilize partner expertise as needed, and continue to nurture community interest in climate applications to provide opportunities for improvement of NCEI's user experience.

| | |
|---|---|
| **NOAA Big Data Project Support** | |
| **Task Leader** | Otis Brown, Jonathan Brannock |
| **Task Code** | NC-ASD-01-NCICS-OB/JB |
| **NOAA Sponsor** | Ed Kearns |
| **NOAA Office** | NESDIS/OCIO |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Data Access and Services Development |
| **Contribution to NOAA goals** | Goal 1: 40%; Goal 2: 40%; Goal 3: 15%; Goal 4: 5% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** A pilot data hub/broker architecture was designed and implemented to facilitate transfer of key NOAA environmental datasets to commercial public cloud providers, allowing users to do analyses of data and extract information without having to transfer and store these massive datasets themselves. https://ncics.org/data/noaa-big-data-project/

**Background**

NOAA's environmental data holdings include more than 27 petabytes of comprehensive atmospheric, coastal, oceanographic, and geophysical data. While this data is publicly available, it can be difficult to access and work with larger datasets. NOAA's Big Data Project (BDP) is designed to facilitate public use of key environmental datasets by providing copies of NOAA's environmental information in the Cloud, making NOAA's data more easily accessible to the general public and allowing users to perform analyses directly on the data. Figure 1 below provides an overview of this process.

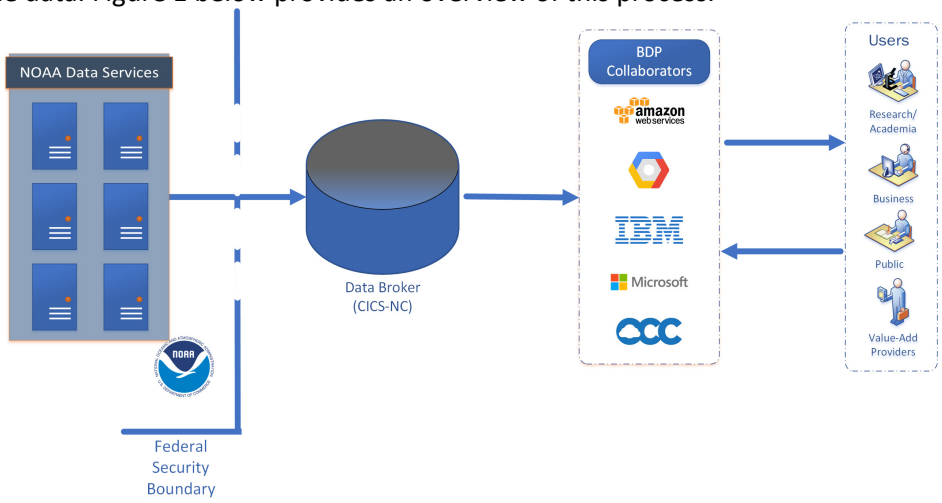



***Figure** 1. Data Hub/Broker Overview.*

CICS-NC is a partner in the BDP and acts as a broker between NOAA and the public cloud providers. CICS-NC data and information technology experts work to help transfer and certify multiple NOAA data sets to several Cloud platforms, including *Amazon Web Services* (AWS), *Google Cloud Platform* (GCP), IBM *NOAA Earth Systems Data Portal*, and the *Open Commons Consortium* (OCC).

The CICS-NC high-performance computing cluster serves as a critical gateway for the near-real-time transfer of several datasets, including NEXRAD Level 2 radar data, GOES-16 satellite data, and others. A highlight of this year's efforts is the institution of a cloud-based transfer activity based on the open source tool *NiFi*.

**Accomplishments**

The second year of BDP efforts focused on broadening the availability of NOAA datasets while maintaining performance and on the use of cloud-based agents to mediate transfers. Datasets were added from NOAA/NCEP, NOAA/NCEI, and NOAA/PDA's holdings. New NCEP datasets made available to the BDP collaborators include the National Water Model (NWM), Climate Forecast System (CFS), Global Forecast System (GFS), Global Ensemble Forecast System (GEFS), and Operational Forecast System (OFS). New NCEI datasets include the Global Historical Climate Network Daily (GHCNd), Integrated Surface Database (ISD), and Global Hourly. New datasets from the PDA include products from GOES-17 and NOAA-20.

New datasets brought onboard from the NOAA's NESDIS Environmental Satellite Processing Center's (ESPC) Product Distribution and Access (PDA) include GOES-17 and NOAA-20, as noted. This is in addition to GOES-15 and GOES-16. GOES-17 is configured to pull the same product mix as GOES-16 and includes ABI Level 1b Radiances and ABI Level 2 Cloud Moisture products. In addition to ABI, the GLM Lightning mapper data is also transferred. The other addition from the PDA is the NOAA-20 VIIRS Day Night band data.

New tools were implemented to support the rapid expansion in the quantity and volume of datasets brokered by BDP. *Apache NiFi* is a workflow management tool that easily integrates with the file-based FTP and HTTPS services offered by a number of data sources. *NiFi* supports writing the data directly into cloud native object stores and can be configured to interface with cloud event processing streams to further facilitate the end-to-end transfer of data. We have begun using *NiFi* in two environments. One is on premise to transfer data to and from the *NC State University* systems and to push data to BDP partners that have not provided compute resources or where that configuration is not feasible. The second environment is the *AWS* cloud. We have been running *NiFi* in i3.xlarge instances to facilitate data transfers to that partner. *NiFi* facilitates onboarding datasets, particularly from NCEP.

The daily transfer volume to the collaborators increased from ~500GB a day in 2017 to ~7.75 TB a day in 2018.

Another technology that was expanded is the use of serverless *lambda* functions on *AWS*. One application sets up an event stream so that GHCNd files are automatically decompressed on creation. As soon as a gzipped object is created in the GHCNd bucket, a *lambda* function extracts this data into a new decompressed CSV representation. A second application of *lambda* functions increases download performance. A *NiFi* instance may poll an FTP server like the ones at NCEP and find tens of thousands of files. In these cases, downloading them sequentially is very inefficient. *NiFi* will populate an *AWS SQS* queue which triggers hundreds to thousands of parallel downloads over HTTP from NCEP. This has greatly reduced the latency of datasets with large numbers of files.

The holdings of a collaborator's datasets frequently require reconciliation with the NOAA archive. For NEXRAD Level 2 this has become a monthly to yearly activity. Cloud holdings can be quickly reconciled utilizing APIs provided by NCEI. Issues can be dispatched to containers either on-premise or in the cloud to manage placing orders, receiving orders, then transferring the orders once they are fulfilled. Another occurrence has been to modify or remove variables from the published data set. This was the case for the NWM Retrospective data. Containers were setup on-premise, then *AWS Fargate* was used to process each partner's entire dataset and remove the invalid parameters.

**Planned work**

- Continue prototype operation of the BDP broker function for NOAA.
- Add NOAA datasets as requested by the collaborators.
- Move broker activities into NOAA operations.

**Products**

- Cloud based *NiFi* data hub
- Pilot data hub/data broker
- Lambda Functions

**Presentations**

**Brown, O**., and **J. Brannock**, 2018: Big Data Project (BDP) Data Broker Update. *2018 Earth Science Information Partner (ESIP) Summer Meeting*, Tucson, AZ, July 17, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **3** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Programming and Applications Development for Climate Portal** | |
|---|---|
| **Task Leader:** | James Fox |
| **Task Code** | NC-ASD-02- UNCA |
| **NOAA Sponsor** | David Herring / Dan Berrie / David Easterling |
| **NOAA Office** | OAR/CPO |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Data Fusion and Algorithm Development |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** In support of the overall advancement of NOAA's Climate Services Portal program, UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) assisted with continuing U.S. Climate Resilience Toolkit (https://toolkit.climate.gov/) development and the new Climate Explorer Climate by Location design (https://crt-climate-explorer.nemac.org/). NEMAC also provided graphics, GIS, and mapping support for the USGCRP Indicators and National Climate Assessment, and graphics design support for the NIDIS https://www.drought.gov redesign.

**Background**

To address NOAA's increasing need to incorporate climate services across NOAA and enhance NOAA's web presence in response to customer requirements, NOAA's Climate Services Portal (NCSP) has a continuing need for expertise and resources to support programming work for applications development and data visualization in support of the following tasks:

- Drupal Content Management System for Climate.gov
- U.S. Climate Resilience Toolkit
- Global Climate Dashboard
- Climate Explorer and online map viewers (Climate Explorer 1 & 2)
- Climate Interactive tools
- Maps and Data Section Leadership for Climate.gov

Supplemental task areas for coordinated development and integration with current task areas include:

1. Graphics for Indicators and the National Climate Assessment (NCA)
2. GIS/climate projections for NCA
3. Regional, state, local products
4. Internal management portals
5. Decision support and user engagement
6. NIDIS support for drought.gov

**Accomplishments**

***Drupal CMS for Climate.gov.*** NEMAC provided maintenance and development support for the Climate.gov team, including section support and maintenance for Data Snapshots, assistance in the launch of new data sources, and feedback on Climate.gov redesign.

***U.S. Climate Resilience Toolkit.*** NEMAC contributed to continued U.S Climate Resilience Toolkit (CRT) development and editorial/content management including: (a) a *new Great Lakes regional section* published in December 2018; (b) initial development for a *new Midwest regional section*; (c) an *editorial*

*initiative* to review/test adding summary information/key messages to case studies; (d) *updated topic, subtopic, and regional narratives* and other content to reflect key messages/content of the Fourth National Climate Assessment; (e) *updated website home page and key interior pages, and a streamlined navigation path* to be tested at the 2019 National Adaptation Forum; (f) *a newly implemented functionality* to cross-link content with EcoAdapt's CAKE and Georgetown Climate Center's Adaptation Clearinghouse; (g) five new *case studies* (total of 147); and (h) ten additional *tools* (total of 404).

***Global Climate Dashboard.*** Discussed the redesign/redeployment of this module as part of a larger strategic discussion on data and information services modularity, and assisted with the migration of this module to the *Drupal 8* redesign of climate.gov.

***Climate Explorer.*** In collaboration with FernLeaf Interactive, NEMAC developed and deployed CE2.5 in May 2018, featuring more climate projection variables and a new threshold tool. NEMAC began hosting the Climate Explorer in May 2018. The NEMAC-FernLeaf Collaborative is currently developing CE3, which will be tested at the 2019 National Adaptation Forum to obtain user feedback. The development plan combines existing functionality with map viewers found in CE1, coordination with the CRT editorial team to ensure proper navigation and an improved user experience, and expected deployment in Summer/Fall 2019.

***Climate Interactive Tools/Maps & Data.*** NEMAC participated in calls regarding the Climate by Location tool and worked with NOAA personnel to create *Drupal* code in support of the project. NEMAC hosted and maintained a development server to allows developers to work outside the NOAA firewall for testing and review purposes.

***Static Graphic Indicators.*** NEMAC supported the Indicators Working Group with design and data updates of static indicator graphics for the USGCRP website, including close collaboration with the CICS-NC/NCEI Indicators team (Laura Stevens and Jessica Blunden). Updated graphics completed in Fall 2018 include: Annual Start of Spring, Ocean Chlorophyll, Heating and Cooling Days, Terrestrial Carbon, Sea Surface Temperature, Global Surface Temperature, U.S. Surface Temperature, Sea Level Rise, Atmospheric $CO_2$, and Annual Greenhouse Gas Index. NEMAC helped update the Indicators Style Guide to meet new design requirements and implement these changes within the above-listed graphics.

***Interactive Graphics for NCA4.*** NEMAC supported CICS-NC and the NCA team (Tom Maycock, Angel Li, Kate Johnson) in the design and development of 13 interactive graphics approved and implemented into the online version of the Fourth National Climate Assessment: Figures 1.1, 1.2, 2.1, 5.1, 5.2, 7.5, 8.2, 12.3, 14.3, 29.1 and 29.2.

***NCA Regional and State Map Products.*** NEMAC supported NCA mapping needs by creating maps at different scales displaying specific climate models, time periods, and variables, including three main map sets: (1) projected seasonal precipitation and temperature scenarios for Puerto Rico and the U.S. Virgin Islands; (2) projected annual and seasonal precipitation scenarios for the United States, including CONUS, Hawaii, and Alaska (Figure 1); and (3) observed and projected annual temperature scenarios for the United States, including CONUS, Hawaii, and Alaska (Figure 2). For each map, original data files were processed

at the global scale and then filtered to the scale of interest for the map. Appropriate hatching, stippling, and white-out overlays were added to the maps to represent statistical significance values in the data.

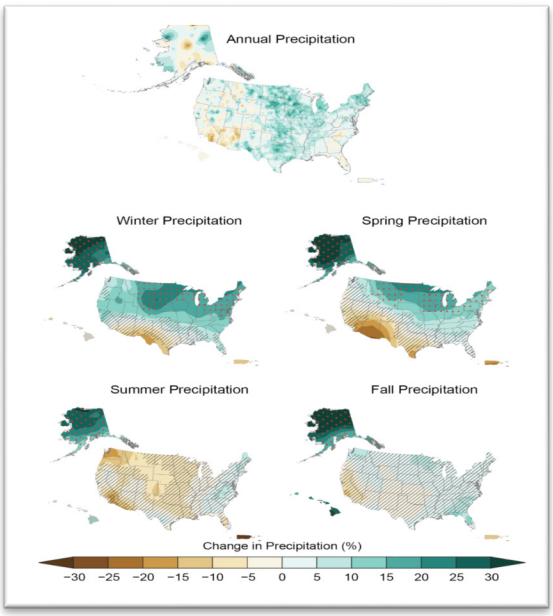



***Figure 1**. Projected annual and seasonal precipitation scenarios for the United States.*

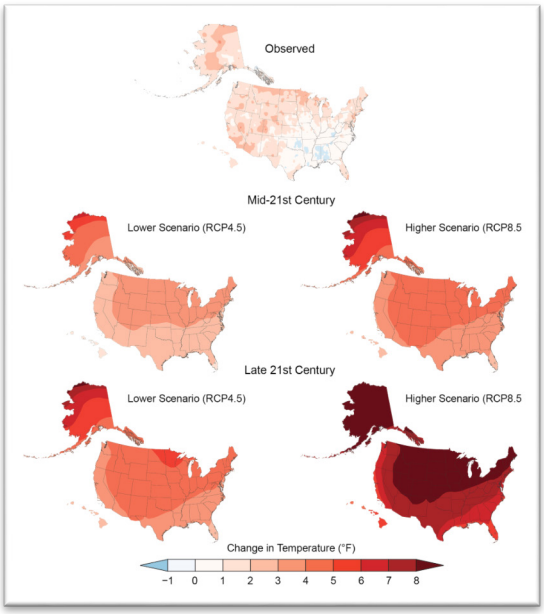



***Figure 2**. Observed and projected annual temperature scenarios for the United States.*

***Portals.*** NEMAC supported CICS-NC and NCEI by maintaining a portal for developing the Explaining Extreme Events Report.

***Decision Support/User Engagement***. NEMAC's Jim Fox and Nina Hall work with the Resilience Ecosystem partners ASAP, EcoAdapt, Georgetown Climate Center, and others. NEMAC supports projects funded by NOAA and the Climate Resilience Fund, and the NEMAC team served on the grants review board for the 2019 funding round. Nina Hall served on the Steering and Program Committees for the 2019 National Adaptation Forum. NEMAC supported David Herring in the creation of presentations for ACCO workshops and other events, as well as presentations about the CRT made at conferences nationwide. NEMAC is working with David Herring to prepare an economic impact report of the CRT for NOAA CPO leadership.

***NIDIS Support.*** NEMAC supported the NIDIS team with the initial phases of the redesign of https://www.drought.gov and its simultaneous migration from Drupal 7 to Drupal 8. NEMAC facilitated meetings that outlined goals and foci for the new https://www.drought.gov, as well as writing the first drafts of content for new site sections.

**Planned work**

Pending a new agreement, work will continue on the U.S. Climate Resilience Toolkit, the Climate Explorer, and other interactive tools.

**Publications**

Gardiner, E. P., D. D. Herring, and J. F. Fox, 2018: The U.S. Climate Resilience Toolkit: Evidence of Progress. *Climatic Change*. https://doi.org/10.1007/s10584-018-2216-0

Hutchins, M., K. Rogers, J. Fox, and N. F. Hall, 2018: Reducing Uncertainty in Climate Resilience Planning: How the Components of Vulnerability and Risk Help Inform the Assessment Process. *Carolina Planning Journal,* **43**, 12-19. https://issuu.com/carolinaplanningjournal/docs/2018_issue_layout_43_r3_web__1_

**Products**

- Data snapshots on Climate.gov: https://www.climate.gov/maps-data/data-snapshots/start
- U.S. Climate Resilience Toolkit: https://toolkit.climate.gov
- Climate Explorer 1: http://climate-explorer.nemac.org
- Climate Explorer 2 (CE2.5): https://crt-climate-explorer.nemac.org/
- USGCRP Indicator graphics: http://www.globalchange.gov/browse/indicators
- NCA Regional and State Map Products: https://statesummaries.ncics.org/

**Presentations**

- Fox, J., 2019: Collaborations and Knowledge for Confronting Climate Risk. *UNC Asheville STEM lecture*, *UNC Asheville*, Asheville, NC, March 6, 2019.
- Rogers, K., and M. Hutchins, 2019: The NCA and Community Resilience. *Climate Resilience in Cities & Conservancy: A 4th NCA Panel*, *The Collider*, Asheville, NC, February 21, 2019.
- Hutchins, M., 2018: How Assessments Can Inform—And Empower—Community Resilience. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.
- Rogers, K., 2018: Applying the Steps to Resilience: Success at multiple scales. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.
- Fox, J., 2018: Building Resilience to Flooding: A Complex—but Achievable—Challenge. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 30, 2018.
- Fox, J., 2018: Revisiting the Floods of 1916—Moving from Risk to Resilience. *Western Carolina University*, Cullowhee, NC, October 16, 2018.

**Other**

Three undergraduate students were mentored in CRT writing/editing internships.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **7** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **7** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **6** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **3** |

*Products improved and/or redesigned: the U.S. Climate Resilience Toolkit, the Climate Explorer v2.5 (CE2), and the Climate by Location tool (3). Several products were generated including graphics (static and interactive) for the USGCRP, regional and state products for the National Climate Assessment, and internal management portals for the CICS TSU and NCEI (3). Several workshops were also held for the purpose of decision support and transfer of the CRT Steps to Resilience (1).*

| **Website Information Architecture Development and User Interface Design for NOAA's National Centers for Environmental Information and NOAA OneStop** | |
|---|---|
| **Task Leader:** | Brian Manning |
| **Task Code** | NC-ASD-03-Mediacurrent |
| **NOAA Sponsor** | Scott Hausman / Ken Casey |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Access and Services Development |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** CICS-NC collaborator, Mediacurrent, completed a review and user and usability testing of the updated OneStop Showcase User Interface v2 that incorporated many of last year's recommendations for improved user interaction. The assessment included an end-to-end strategy audit, a web accessibility audit, and a full competitive analysis on the existing NOAA Data Catalog and NCEI Geoportal. https://data.noaa.gov/onestop

**Background**

In response to Public Law 113-235 Consolidated and Further Continuing Appropriations Act, 2015, which expresses the promise that "users will see an improvement in the overall value of our environmental data archives," NOAA developed and launched a version 2 web portal of OneStop in July 2018. OneStop was designed to improve accessibility to NOAA's extensive collections of environmental data by providing a user interface that makes the data more discoverable and usable. While OneStop does not replace other NOAA data web portals, OneStop features include a search engine geared to promote relevant discovery of data at faster speeds and a user interface that provides an experience tailored to the user.

Mediacurrent was originally engaged to research and present solutions for providing improved access to high-value environmental data and information through informational architecture development, user interface design, and user testing for the NOAA National Centers for Environmental Information (NCEI) website. This included recommendations for an enhanced user interface design based on nine primary user groups using one of three lenses (novice, expert, or disabled) that would improve the overall user experience with site navigation, content, and layout. This past year, Mediacurrent completed supplemental work testing and assessing the OneStop Showcase User Interface using user and usability best practices to quantify results in a manner that supports and improves the OneStop initiative (in both the short and long term).

**Accomplishments**

Working with NOAA's Cooperative Institute for Climate and Satellites–North Carolina (CICS-NC) and building on their previous research with the NCEI website, Mediacurrent utilized a similar data-driven approach to gain an understanding of how users were interacting with the new NOAA OneStop website. As part of the discovery, we analyzed data via the Users Personas groups to provide an array of perceived strengths, weaknesses, and accessibility improvements that would enhance the NOAA OneStop user experience. Mediacurrent conducted user testing to provide an objective view of the usability of the website—which included an assessment of how the site addresses those with disabilities and compliance with Section 508, WCAG 2.0. We also performed a full competitive analysis on the existing NOAA Data Catalog and NCEI Geoportal.

**Outcomes**

- Strategic Approach for NOAA OneStop Website
    - Key Performance Indicators (KPIs)
    - Assessment of Current Website Analytics
    - Target Audience Research
    - Competitive Analysis
    - Content Audit & Gap Analysis on Top Pages
    - Search Engine Optimization (SEO) Audit
    - Recommended Sitemap and Information Architecture

**Presentations** (internal to OneStop team)
11/28/18 - NOAA UX & Content Audit
12/13/18 - Comparative Analysis

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Embracing the Cloud: Data Storage and Processing on the Amazon Web Services (AWS) Platform** | |
|---|---|
| **Task Leader** | Jessica Matthews, Jared Rennie |
| **Task Code** | NC-ASD-04-JM/JR |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Data Fusion and Algorithm Development, Surface Observing Networks, Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** Two pilot projects were performed to examine cost and performance benefits of storing and processing NOAA NCEI data on the *Amazon Web Services* platform.

**Background**

NCEI currently archives more than 27 Petabytes (PB) of data, and these holdings are expected to grow at a rate of 6 PB per year. It has become increasingly important to not only manage the amount of data but also to provide products that are of use to the public. Storing and processing this data locally has become problematic and, in some cases, processing time can take weeks and months instead of hours and days. Efforts have been made to utilize cloud service providers, such as *Amazon Web Services* (AWS). Through NOAAs Big Data Project (BDP), numerous satellite and in situ datasets have been placed into *Amazon*'s cloud storage. To date, over 70 datasets have been put in the cloud. Another advantage of using cloud technologies is optimizing and parallelizing code bases, without having to worry about hardware purchasing and maintenance costs. For a relatively low price, algorithms can be sent to a cloud virtual server and run to increase productivity and decrease runtimes.

Recognizing the opportunities of the cloud, CICS-NC welcomed Dr. Brad Rubin, Director of the Center of Excellence of Big Data, from the *University of St. Thomas* in St Paul, Minnesota, for a sabbatical visit during the Spring of 2018. During his time in Asheville, he worked on two "proof of concept" projects, using the *Amazon Web Service* platform. The first was processing hundreds of terabytes (TB) of data, and the other was running a 30-hour process hundreds of times in parallel. The working hypothesis was that time and money would be saved.

**Accomplishments**

***Albedo in the AWS Cloud****.* An algorithm exists to retrieve land surface albedo observations based on NOAA's Geostationary Operational Environmental Satellite (GOES) data. The input data for this product is large: 12.5 million files totaling about 270 TB. Acquiring the data is time consuming and storing the inputs on a local system is expensive. The aim of this project was to evaluate how the algorithm processing would perform in the cloud: Are the results scientifically comparable? Is time and/or money saved?

Dr. Rubin designed an approach to address these questions. First, *Git* was implemented for version control. Then all code and current operating system characteristics were *Dockerized*. A workflow designed with *Python* scripting using both *AWS* batch and instance capabilities was implemented. Finally, *AWS* settings and parameters were researched and tuned.

Processing was executed for one 10-day time period for each of two satellite positions on both the CICS cluster and *AWS* platforms. The times and costs were then extrapolated to approximate the costs of

processing a 20-year time series for two satellite positions. Results of the comparisons are presented in Table 1. The scientific results were comparable. There was approximately a 50-fold savings in processing time using AWS due to less limiting parallel processing conditions. Calculated cost savings was approximately 34%.

| | **AWS** | **CICS cluster** |
|---|---|---|
| **Processing time (2 satellite positions, 20 years)** | ~20 hours | ~1000 hours |
| **Total cost** | ~$29k* | ~$84k |
| **Scientific value** | SAME RESULT | SAME RESULT |

***Table 1.*** *Cross-platform comparison metrics: AWS vs. CICS cluster. *Spot pricing and AWS storage tiers could be explored to lower this further. This price assumes staging from CLASS to Glacier, S3 storage for 1 day, but does not include long-term Glacier storage cost ($4.10/Tb/month).*

***Temperature Homogenization in the AWS Cloud.*** The Global Historical Climatology Network–Monthly (GHCNm) dataset features over 25,000 global stations reporting surface temperature. This dataset serves as the baseline for monthly and annual climate reports provided by NOAA NCEI. A major feature of GHCNm is the utilization of the Pairwise Homogeneity Algorithm (PHA), which removes non-climatic influences in the temperature record (i.e., station moves, instrument changes, observer practices). Due to the complexity of the algorithm, the system requires a large amount of CPU and RAM technology. As a result, the PHA process takes nearly 30 hours to run on NCEI's system. In addition, a 100-member ensemble is run annually to calculate uncertainty metrics in the temperature record. Since NCEI's computing environment does not allow for much parallelization, running this ensemble can take several weeks.

With the help of Dr. Rubin and the GHCN-Monthly team, the PHA code was pushed into the cloud for processing on an elastic computing node (EC2) provided by *AWS*. Because the input dataset is small (hundreds of megabytes), the dataset was easily stored in an *AWS S3* bucket. Using a *Docker* container with the appropriate software packages, a python script was developed to send the deterministic, as well as each ensemble run, into a cloud-based compute node. Due to *AWS* limitations, only 15 runs could be completed in parallel (however, a request for all ensembles to run at the same time can be made). Also, spot pricing was performed to help reduce the cost of each compute node. Based upon supply and demand of the type of computing power needed, tests showed the process could be run successfully at 25% of the cost.

As a result, the entire process took under 7 days to run. While processing time differed between each run, the average run time was about 18 hours, a half a day shorter than the runtime on NCEI (30 hours). If a request had been made to run all ensembles at the same time, the entire process could have been completed in under 24 hours. Finally, thanks to the 25% spot pricing, the entire cost of using the system decreased from about $500 to $140.

**Planned work**

- Compare *AWS* experience with other cloud platforms (i.e. *Google*, *Microsoft*) with the coordination of the NOAA Big Data Project.
- Investigate the feasibility or placing the entire GHCN-Monthly process in the cloud.

**Presentations**

**Matthews, J.**, and **J. J. Rennie**, 2018: Embracing Big Data + Cloud Computing. *The Collider*, Asheville, NC, October 2, 2018.

**Matthews, J.**, and **J. J. Rennie**, 2018: The process of moving 2 applications to the cloud. *NCEI Science Council meeting*, Asheville, NC, August 9, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| NCEI Infrastructure Architecture Planning and Implementation | |
|---|---|
| **Task Leader** | Lou Vasquez |
| **Task Code** | NC-ASD-05-NCICS-LV |
| **NOAA Sponsor** | Scott Hausman / Drew Saunders |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: 33%; Theme 2: 33%; Theme 3: 34% |
| **Main CICS Research Topic** | (Data) Access and Services Development |
| **Contribution to NOAA goals** | Goal 1: 25%; Goal 2: 25%; Goal 3: 25%; Goal 4: 25%; |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** This cross-function collaborative team is driving IT infrastructure and architecture solutions that will support a modern, flexible, distributed approach to data science, archive, and access capabilities. Its goal is to support new and existing projects not handled using current infrastructure by implementing architecture using known upcoming technological advances (e.g., cloud computing), and preventing the NCEI IT infrastructure from falling behind currently available approaches (e.g., advanced workflow).

**Background**

Existing NCEI architecture supporting data science, archive, and access is based on block storage, VM server, integrations business logic, and service-oriented solutions. This architecture does not scale efficiently, redirect quickly, or shift to readily available solutions or services without redesign. In addition to the general need to be current and have effective infrastructure, specific new projects such as the Mission Science Network (MSN) and the *OneStop* access project make these approaches a requirement, while existing projects such as Common Ingest (CI) Migration are experiencing the limitations of current NCEI infrastructure.

This project both explores and deploys modern, industry-accepted approaches used to avoid these pitfalls including infrastructure-as-a-service (IaaS) for resource management, containers for processing, object store for data, scalable workflow automation for data and metadata, and the architecture that ties them together in a flexible, effective way for NCEI. As tying these pieces together requires an understanding of NCEIs processes, from science to hardware, this team is cross-layer, including members with backgrounds in science, architecture, software, and hardware. As it also must support a variety of project goals and NCEI architectural components, often seen from the *OAIS* framework, the team includes people involved in data ingest, archive, management, preservation, and access. This has been absent in several prior attempts to drive NCEI architectural solutions.

This project is in its preliminary phase, with partial time commitment for several months. It has begun with equipment purchasing, security review, and initial deployment of object storage, data, and metadata workflow systems. Consideration and recommendations have been made for IaaS and container approaches. Initial demonstration of capability and integration of data and metadata workflow systems have been performed.

**Accomplishments**

The work on this project was performed in partnership to meet NCEI's infrastructural needs. Its purpose is for NCEI IT services to rapidly deploy new technologies and move the Center toward approaches and systems that minimize support needs and advance capability. This project drew together resources to expedite testing, integration, and deployment of solutions. The infrastructural components being utilized cut across technology spaces, including containerization, resource management, storage, and distributed

processing. These technologies are inherently cloud-ready and were chosen to support that and similar forward-looking requirements.

System infrastructure was assessed in support of the GOES-R L0 ICD archive project. Filesystems, network, and transfer clients were analyzed to identify bottlenecks and alternate solutions in order to complete data retrieval and processing at the desired rate. Investigation of readily available, file-oriented workflow tools and scalable storage solutions were promoted to mitigate timeline risk and to better position NCEI. This includes *NiFi* for file-based workflow processing and *Ceph* for scalable object storage.

The team attended a storage summit convened to define technologies required in support of the Mission Science Network storage solutions before and during its move to cloud services. Integration feedback was provided for various existing and planned NCEI systems, with technology recommendations related to capabilities such as container management and object store, while discussions covered broader needs such as network topology.

The team also collaborated with a NCEI CO development team, attending the *OneStop Mission Science Network* meeting, and participated as the *OneStop* data access tool next step was clarified. This effort plans for cross-site components such as inventory manager, ingest, access, and data tools, as they are integrated to support the NCEI mission. Additionally, it was crucial for a common architecture to have good communication, so that geographically separated sites fully understand each other's needs and goals.

This project has driven NCEI towards rapid-deploy, fail-fast approaches by including individuals across the key mission components in the infrastructure development process. Doing this allows technologies to be quickly validated, tested, and deployed. These can then be promoted to drive NCEI progress through the complex phases of managerial direction, procurement, and security review.

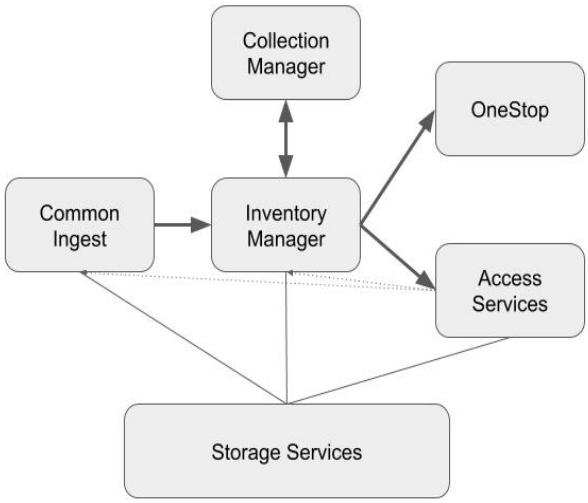



***Figure** 2. NCEI Common Systems Notional Architecture.*

The architecture developed to date, NCEI Common Systems Notional Architecture (Fig. 1), underlies the technology selections made by this team. This diagram represents the general view proposed and developed in Mission Science Network meetings. Each component performs a major NCEI function: Inventory Manager at the center collecting event information from all services and processing it through

center-defined workflows to generate comprehensive metadata and events for end-user oriented views; Common Ingest taking files into the center, preparing and storing them via Storage Services; Collection Manager allowing users to interact with existing stored collection metadata; Access Services providing a front-end for users external to the system to obtain data and related information; *OneStop* offering a flexible query-based view for locating data throughout known storage.

**Planned work**

- Begin integration of Inventory Manager with Common Ingest, initially in support of upcoming Mission Science Network demonstration of capabilities.
- Support *NiFi* workflow implementation for incoming data and prompt object data storage.
- Assist in implementation of *Kafka* and *Kafka Streams* and comprehension of intended use to meet Inventory Manager demands.
- Create initial Inventory Manager workflows, supporting needs of the team in defining events, processing goals, and correlating output records to object storage.

**Products**

- Initial connection of *NiFi* workflow system to live provider ingest data, selection of appropriate data, and configuration
- Proposed system architecture including integration path for related components, primarily with respect to *NiFi* workflow, CI ingest, and Inventory Manager metadata systems

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **2** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Assessment Activities

Assessment efforts support interagency activities for global, national, and regional assessments of climate change. NOAA has a number of global, national, regional, and sectoral-level climate assessment activities underway and a sustained assessment process that includes ongoing engagement with public and private partners and targeted, scientifically rigorous reports as well as participation in the high-level, legally mandated National Climate Assessment (NCA) process, which is responsive to greater emphasis on user-driven science needs under the auspices of the U.S. Global Change Research Program (USGCRP). USGCRP is a federation of 13 Federal agencies (including NOAA) that conduct research and develop and maintain capabilities that support the Nation's response to global change. National climate assessments, based on observations made across the country in comparison to predictions from climate system models, are intended to advance the understanding of climate science in the larger social, ecological, and policy systems to provide integrated analyses of impacts and vulnerability.

NCEI and other parts of NOAA have provided leadership on climate assessment activities for over a decade. Decisions related to adaptation at all scales, as well as mitigation and other climate-sensitive decisions, will be supported through an assessment design that is collaborative, authoritative, responsive, and transparent. NOAA is working through an interagency process and investing in partnerships across many scales to support this comprehensive assessment activity. The agency is also investing in core competencies including modeling, data management, visualization, communication, web management, and other expertise.

The Third National Climate Assessment (NCA3), released in May 2014, was the result of four years of development and production involving a team of 300+ experts guided by a 60-member Federal Advisory Committee. Under the preceding and current projects, CICS-NC established an assessment task group, the Technical Support Unit (TSU), that contributed to many aspects of the report by providing scientific, editorial, graphics, project management, metadata, software engineering, and web design expertise. CICS-NC also coordinated an outside evaluation of the NCA3 process which helped inform the Fourth National Climate Assessment (NCA4) process and its release in November 2018. The NCA process has emerged as a template for other interagency assessments and for other countries/nations looking to implement their own comprehensive climate assessments at the national, regional and local scale. CICS-NC and its consortium partners are leveraging the experience and capacity gained during the development of NCA3 and NCA4 to continue to address assessment priorities including the sustained assessment process, interim assessments, and technical and special reports, support of other interagency assessment efforts, support of international assessment activities and continuing support of USGCRP activities.

| National Climate Assessment Scientific and Data Support Activities | |
|---|---|
| **Task Leader** | Kenneth Kunkel (leader), James Biard, Sarah Champion, Jennifer Runkle, Laura Stevens, Liqiang Sun, Andrew Thrasher |
| **Task Code** | NC-CAA-01-NCICS-KK/et al |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI and OAR/CPO |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** The science/data team was integral to the successful completion of the Fourth National Climate Assessment through authorship contributions to several chapters, development of numerous specialized scientific analyses and graphs, and completion of metadata collection and viewer improvement**.**
https://nca2018.globalchange.gov/

**Background**

NOAA is participating in the high-level, visible, and legally mandated National Climate Assessment (NCA) process, and is responding to a greater emphasis on user-driven science needs under the auspices of the US Global Change Research Program (USGCRP). National climate assessments are intended to advance the understanding of climate science in the larger social, ecological, and policy systems to provide integrated analyses of impacts and vulnerability. NOAA's National Centers for Environmental Information (NCEI), along with many other parts of NOAA, has provided leadership on climate assessment activities for over a decade. A renewed focus on national and regional climate assessments to support improved decision-making across the country continues to emerge. Decisions related to adaptation at all scales as well as mitigation and other climate-sensitive decisions will be supported through an assessment design that is collaborative, authoritative, responsive, and transparent. NOAA is working through an interagency process and investing in partnerships across many scales to support this comprehensive assessment activity.

To support these activities, CICS-NC formed a technical support unit (TSU). Within the TSU, a group focused on scientific support was assembled, consisting of a Lead Senior Scientist (Kenneth Kunkel), Deputy Scientist (Liqiang Sun), Support Scientist (Laura Stevens), Data Lead (Sarah Champion), and two Software Engineers (James Biard, Andrew Thrasher). The Lead Senior Scientist provides scientific oversight for the development of NOAA's assessment services, focusing on a contribution to the NCA and, in support of the NCA and in conjunction with NOAA and other agency expertise, provides scientific oversight and guidance to coordinate and implement distributed and centralized high-resolution modeling capabilities. In an ongoing effort to satisfy Information Quality Act (IQA) compliance, and as part of the Sustained Assessment process, work continued on improved design and capabilities of a metadata documentation, archive, and delivery end-to-end process. Adhering to the federal agency documentation standard of ISO-19115, team staff contributed to the improved functionality of a web-based metadata survey and interactive metadata viewer in support of the Fourth National Climate Assessment.

**Accomplishments**

Substantial contributions were made to Volume II of the Fourth National Climate Assessment (NCA4), published in November 2018. This included lead or contributing authorship to 4 of the chapters

(Southeast, Midwest, Data Tools and Scenario Products, and Frequently Asked Questions); data analysis and development of 18 specialized graphics for several chapters; and collection and quality control of figure metadata for the entire report.

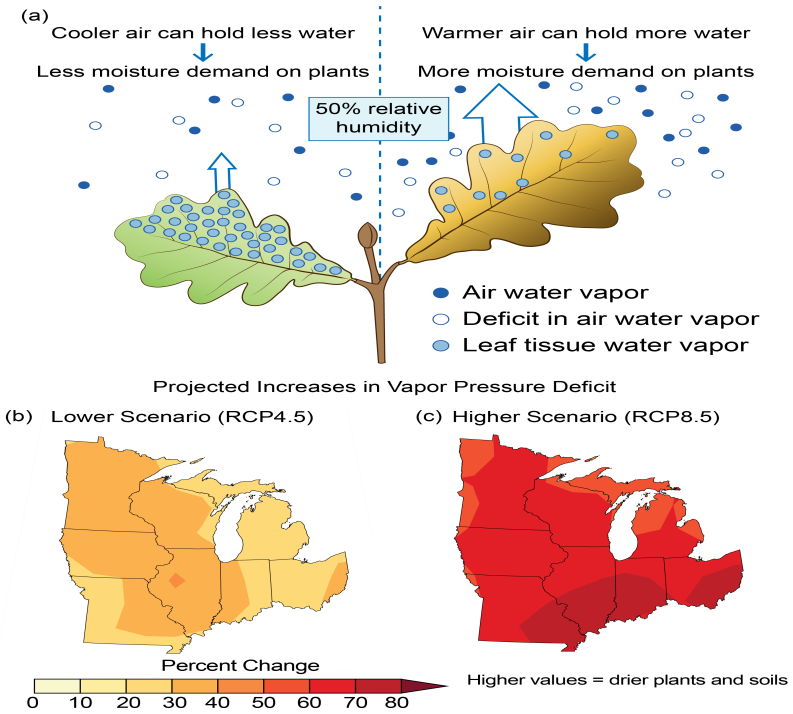



***Figure 1***. *As air temperature increases in a warming climate, vapor pressure deficit (VPD) is projected to increase. VPD is the difference between how much moisture is in the air and the amount of moisture in the air at saturation (at 100% relative humidity). Increased VPD has a drying effect on plants and soils, as moisture transpires (from plants) and evaporates (from soil) into the air. (a) Cooler air can maintain less water as vapor, putting less demand for moisture on plants, while warmer air can maintain more water as vapor, putting more demand for moisture on plants. (b, c) The maps show the percent change in the moisture deficit of the air based on the projected maximum 5-day VPD by the late 21st century (2070–2099) compared to 1976–2005 for (b) lower and (c) higher scenarios (RCP4.5 and RCP8.5). Source: Fourth National Climate Assessment.*

A full set of metadata were successfully released alongside the delivery of the NCA, Vol. II. The data and figure metadata were documented following the federal and NOAA mandated documentation standard and at a level that ensured data transparency, accessibility, and scientific reproducibility. Compliance with the Information Quality Act was obtained a record three months in advance of the report release: this is an unprecedented accomplishment. In conjunction with the production of the NCA, Vol. II, the metadata were synced into an updated data model with the Global Change Information System (GCIS), maximizing the technical partnership between both the TSU and the GCIS. The updated data models and syncing processes were greatly improved via an enhanced and more automated user interface. The metadata viewer on the report website was improved to enhance the user experience and accessibility of the underlying data and scientific methods. For the first time for any assessment report, the metadata viewer also provided direct data access to TSU-derived datasets in multiple downloadable file formats with accompanying ReadMe files.

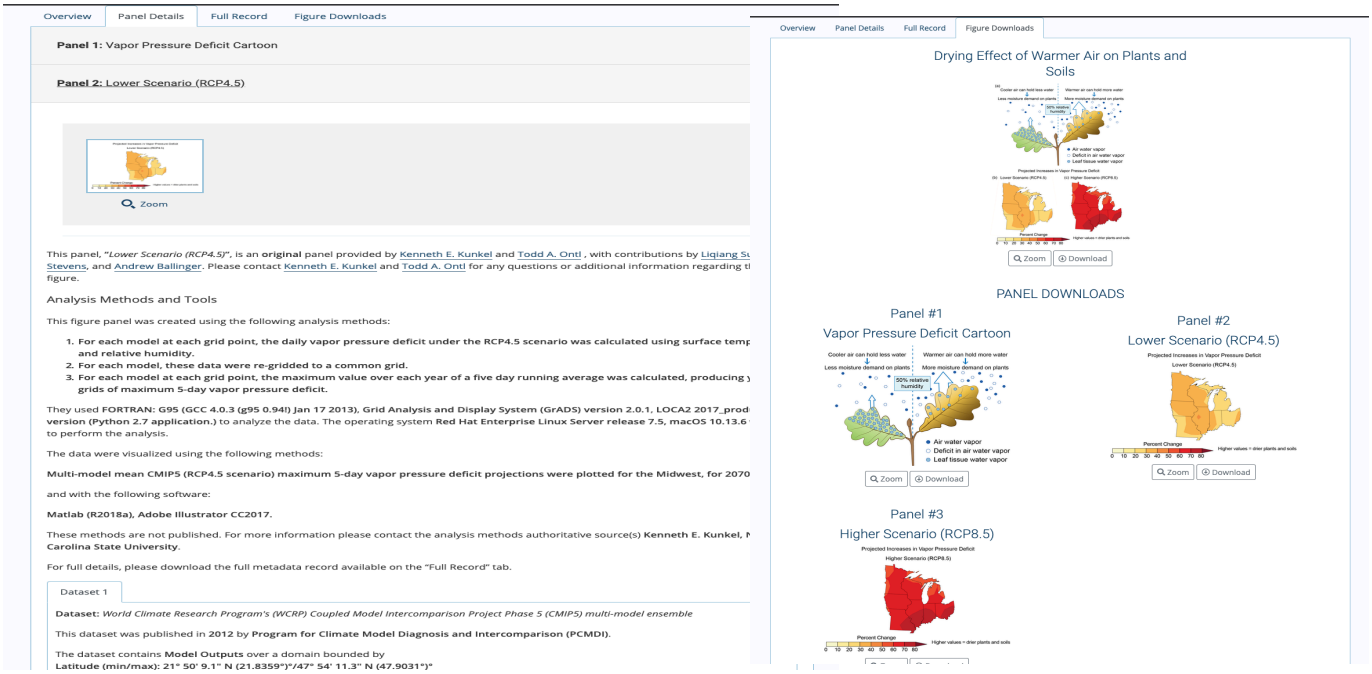



***Figure 2****. These screenshots of the metadata viewer included in the NCA4 Volume II website display some of the metadata available to users of the website for the vapor pressure deficit figure shown in Figure 1 above. The derived dataset used for this figure is made available on the CICS-NC website, and a link to that dataset is provided in the metadata viewer.*

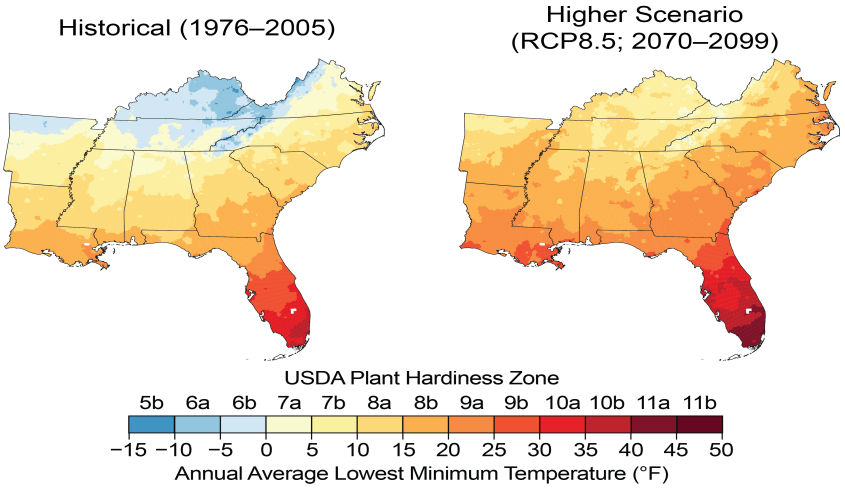



***Figure 3.*** *Increasing winter temperatures are expected to result in a northward shift of the zones conducive to growing various types of plants, known as plant hardiness zones. These maps show the mean projected changes in the plant hardiness zones, as defined by the U.S. Department of Agriculture (USDA), by the late 21st century (2070–2099) under a higher scenario (RCP8.5). The USDA plant hardiness zones are based on the average lowest minimum temperature for the year, divided into increments of 5°F. Based on these projected changes, freeze-sensitive plants, like oranges, papayas, and mangoes, would be able to survive in new areas. Note that large changes are projected across the region, but especially in Kentucky, Tennessee, and northern Arkansas. Source: Fourth National Climate Assessment.*

In support of the NCA4, processing of the Localized Constructed Analogs (LOCA) dataset produced 47 derived temperature- and precipitation-based climate variables. Data pertaining to NCA4 figures were compiled, reformatted, and made available via the interactive metadata viewer. The full suite of data was also made available for download on the NCA4 Scenarios website (https://scenarios.globalchange.gov/).

Support of NCA4 Volume II included development of graphics for several chapters. The following special products were developed for chapter authors:

- Vapor pressure deficit (VPD) is the difference between how much moisture is in the air and the amount of moisture in the air at saturation. VPD is projected to increase over the Midwest in the late 21st century for lower and higher scenarios (RCP4.5 and RCP8.5). Increased VPD has a drying effect on plants and soils, as moisture transpires and evaporates (Figure 1).
- Hydrologic changes across the Northern Great Plains. Changes in snowpack and streamflow are projected, related to warming across the region.
- Spatial analysis of LOCA data for multiple time periods and emissions scenarios. One example is that USDA plant hardiness zones are projected to shift northward with warming (Figure 3). Nine figures were included across five NCA4 chapters.
- Regional analyses of LOCA temperature and precipitation extremes for multiple U.S. cities. Figures were included in three NCA4 chapters.

In addition, a NOAA State Climate Summary for Puerto Rico and the U.S. Virgin Islands was completed and published (NOAA Technical Report NESDIS 149-PR). TSU Science Team members co-authored the document, which summarizes historical climate trends as well as Coupled Model Intercomparison Project, Phase 5 (CMIP5) projections of temperature and precipitation for the islands. The project included development, editing, and review of climate text, graphics, metadata, and web development, including coordination with regional climate experts.

**Planned work**

- Initiation of analysis of CMIP6 climate model data, in anticipation of the Fifth National Climate Assessment.
- Updates of the NOAA State Climate Summaries, including updating all graphics through 2018.
- Redesign and update of TSU Collaborative system, currently branded as the Global Data Acquisition System (GDAS) for more inclusive project management, editorial, and tracking/reporting features and updated collection tools.

**Publications**

Angel, J., C. Swanson, B. M. Boustead, K. C. Conlon, K. R. Hall, J. L. Jorns, **K. E. Kunkel**, M. C. Lemos, B. Lofgren, T. A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 872-940. http://dx.doi.org/10.7930/NCA4.2018.CH21

Avery, C. W., D. R. Reidmiller, M. Kolian, **K. E. Kunkel**, D. Herring, R. Sherman, W. V. Sweet, K. Tipton, and C. Weaver, 2018: Data Tools and Scenarios Products. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1413–1430. http://dx.doi.org/10.7930/NCA4.2018.AP3

Carter, L., A. Terando, K. Dow, K. Hiers, **K. E. Kunkel**, A. Lascurain, D. Marcy, M. Osland, and P. Schramm, 2018: Southeast. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 743–808. http://dx.doi.org/10.7930/NCA4.2018.CH19

Dai, Y., H. Li, and **L. Sun**, 2018: The Simulation of East Asian Summer Monsoon Precipitation With a Regional Ocean-Atmosphere Coupled Model. *Journal of Geophysical Research: Atmospheres*, **123,** 11,362-11,376. http://dx.doi.org/10.1029/2018JD028541

Demaria, E. M. C., D. Goodrich, and **K. E. Kunkel**, 2018: Evaluating the reliability of the U.S. Cooperative Observer Program precipitation observations for extreme events analysis using the LTAR network. *Journal of Atmospheric and Oceanic Technology*, **36**, 317-332. http://dx.doi.org/10.1175/JTECH-D-18-0128.1

Dzaugis, M., C. W. Avery, A. Crimmins, L. Dahlman, D. R. Easterling, R. Gaal, E. Greenhalgh, D. Herring, **K. E. Kunkel**, R. Lindsey, **T. K. Maycock**, R. Molar, D. R. Reidmiller, **B. C. Stewart**, and R. S. Vose, 2018: Frequently Asked Questions. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1444–1515. http://dx.doi.org/10.7930/NCA4.2018.AP5

**Runkle, J.**, **K. Kunkel**, and **L. Stevens**, 2018: Puerto Rico and the U.S. Virgin Islands State Climate Summary. NOAA Technical Report NESDIS 149-PR, 4 pp., https://statesummaries.ncics.org/pr

Shiva, J. S., D. G. Chandler, and **K. E. Kunkel**, 2019: Localized Changes in Heat Wave Properties across the USA. *Earth's Future*, in press. http://dx.doi.org/10.1029/2018EF001085

**Stegall, S. T.**, and **K. E. Kunkel**, 2019: Simulation of Daily Extreme Precipitation Over the United States in the CMIP5 30-yr Decadal Prediction Experiment. *Journal of Applied Meteorology and Climatology*. http://dx.doi.org/10.1175/JAMC-D-18-0057.1

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 1506 pp. http://dx.doi.org/10.7930/NCA4.2018

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 186 pp. http://dx.doi.org/10.7930/NCA4.2018.RiB

Wuebbles, D., B. Cardinale, K. Cherkauer, R. Davidson-Arnott, J. Hellmann, D. Infante, L. Johnson, R. Deloe, B. Lofgren, A. Packman, F. Seglenieks, A. Sharma, B. Sohngen, M. Tiboris, D. Vimont, R. Wilson, **K. Kunkel**, and **A. Ballinger**, 2019: *An Assessment of the Impacts of Climate Change on the Great Lakes*. Environmental Law and Policy Center, 71 pp. http://elpc.org/wp-content/uploads/2019/03/Great-Lakes-Climate-Change-Report.pdf

**Products**

- Improved interactive web-based metadata viewer, providing additional downloadable content, most notably including direct access to TSU derived datasets

- NOAA State Climate Summary for Puerto Rico and the U.S. Virgin Islands

**Presentations**

Angel, J. R., C. Swanston, B. M. Boustead, K. Conlon, K. Hall, J. L. Jorns, **K. Kunkel**, M. C. Lemos, B. M. Lofgren, T. Ontl, J. Posey, K. Stone, E. S. Takle, and D. Todey, 2018: The Fourth National Climate Assessment: Midwest. *American Geophysical Union Fall Meeting*. Washington, DC, December 12, 2018.

**Champion, S.**, 2019: You Can Have Data without Information, but You Cannot have Information without Data. *AMOS Science Pub: Understanding the Importance of Data, The Collider*, Asheville, NC, March 29, 2019.

Hayhoe, K., D. R. Easterling, D. W. Fahey, S. J. Doherty, J. Kossin, W. Sweet, R. S. Vose, M. F. Wehner, D. J. Wuebbles, R. E. Kopp, **K. Kunkel**, and J. W. Nielsen-Gammon, 2018: Climate Science in the Fourth US National Climate Assessment. *American Geophysical Union Fall Meeting*. Washington, DC, December 11, 2018.

**Kunkel, K. E**., 2018: Effects of Global Warming on Building Design Values. *Facades+ NYC Conference*, New York City, NY, April 19, 2018.

**Kunkel, K. E**., 2018: Gibson Dam Storm Analysis. *Colorado-New Mexico Regional Extreme Precipitation Study Workshop #6*, Denver, CO, April 19, 2018.

**Kunkel, K. E.**, 2018: Climate Science in the National Climate Assessment. *Air and Waste Management Association - Research Triangle Park Chapter Meeting*, Durham, NC, May 15, 2018.

**Kunkel, K. E**., 2018: Historical Perspective on Hurricane Harvey Rainfall. *SAMSI Climate Extremes Workshop*, Research Triangle Park, NC, May 16, 2018.

**Kunkel, K. E**., 2018: Advances in Understanding of Climate Extremes. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 16, 2018.

**Kunkel, K. E**., 2018: Changing Climate Evidence and Future Directions for the Southeast Region. *EcoStream: Stream Ecology and Restoration Conference*, Asheville, NC, August 14, 2018.

**Kunkel, K. E**., 2018: Climate Change Impacts on Telecommunications. *2018 Environmental, Health & Safety Communications Panel Symposium*, Arlington, TX, September 19, 2018.

**Kunkel, K. E.**, 2018: Historical Perspective on Rainfall in Recent Hurricanes. *American Statistical Association's ENVR 2018 Workshop: Statistics for the Environment: Research, Practice and Policy, The Collider*, Asheville, NC, October 13, 2018.

**Kunkel, K. E.**, 2019: Historical Perspective on Rainfall from Hurricane Florence. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.

**Kunkel, K. E**., and R. L. Smith, 2019: Historical Perspective on Hurricane Harvey Rainfall. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.

**Kunkel, K. E**., 2019: Climate Change Liability for Owners, Designers and Manufacturers: National Climate Assessment. *2019 American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Winter Conference*, Atlanta, GA, January 16, 2019.

**Kunkel, K. E**., 2019: Fourth National Climate Assessment: Southeast Region. *4th National Climate Assessment Panel Series, The Collider*, Asheville, NC, January 24, 2019.

**Sun, L.**, 2018: Extratropical Cyclones over the Contiguous United States: Current Variability and Future Change. *NOAA's 43rd Climate Diagnostics and Prediction Workshop*, Santa Barbara, CA, October 23, 2018.

Terando, A. J., L. Carter, K. Dow, J. K. Hiers, **K. Kunkel**, A. Lascurain, D. Marcy, M. J. Osland, P. Schramm, and A. Lustig, 2018: Assessing climate risks and adaptation opportunities in the Southeast U.S. as part of the Fourth National Climate Assessment, *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

Wehner, M. F., Hayhoe, K., D. J. Wuebbles, D. R. Easterling, D. W. Fahey, S. J. Doherty, J. P. Kossin, W. Sweet, R. S. Vose, and **K. Kunkel**, 2018: Our Changing Climate: National Climate Assessment NCA4 Vol. 2, Chapter 2, *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

**Other**

TSU staff members, Brooke Stewart and Sarah Champion, are being advised by Kenneth Kunkel in the Ph.D. program of the NCSU Department of Marine, Earth, and Atmospheric Sciences.

Kenneth Kunkel serves on the Ph.D. committee of Mike Madden of the NCSU Department of Marine, Earth, and Atmospheric Sciences.

Kenneth Kunkel advises Qing Dong, a visiting Ph.D. student from Nanjing University.

Liqiang Sun is a Climate Explorer team member. The Climate Explorer offers customizable graphs, maps, and data downloads of observed and projected climate variables for every county in the United States.

| **Performance Metrics** | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **2** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **12** |
| **# of NOAA technical reports** | **1** |
| **# of presentations** | **18** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **3** |
| **# of undergraduate students mentored during the year** | **0** |

*Improved interactive web-based metadata viewer, NOAA State Climate Summary for Puerto Rico and the U.S. Virgin Islands*

| National Climate Assessment Technical Support Activities | |
|---|---|
| **Task Leader/Task Team:** | Brooke Stewart / Tom Maycock / Jessicca Griffin / Angel Li / Andrea McCarrick / Tiffany Means |
| **Task Code** | NC-CAA-02-NCICS-BS / TM / JG / AL / AM / TM |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI and OAR/CPO |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: 50%; Goal 2: 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** TSU technical staff provided technical and scientific writing and editing, graphics, and web development expertise in support of multiple National Climate Assessment (NCA) related products, including Volume II of the Fourth NCA and other associated publications. The team also provided overall project coordination and contributed substantive content to multiple author guidance documents and other tools. https://nca2018.globalchange.gov/

**Background**

The National Climate Assessment (NCA) is conducted under the auspices of the U.S. Global Change Research Program (USGCRP). The NCA is intended to provide the President, Congress, other stakeholders, and the general public with a report on the current state of climate change science, the impacts of climate change, and the effectiveness of mitigation and adaptation efforts. It is essential that the report is written and graphically represented in clear language that is easily understood by a broad audience while maintaining the highest possible standards of accuracy and transparency. The Technical Support Unit (TSU) at NCEI serves as a major part of NOAA's contribution to the program as one of USGCRP's 13 agency members and provides technical expertise to support the development, production, and publication of the NCA and other associated products. TSU technical staff work collaboratively with the TSU Assessment Science team and in coordination with NCA authors, NCEI, and USGCRP.

The TSU *editorial team* provides scientific editing and writing services to the NCA authors as well as to in-house scientists/authors. They also provide technical writing/editing, copy editing, and coordination of scientific figure development; coordinate in-house publication across multiple teams; and provide substantive input to product rollout and communications plans. The team provides similar support for related assessment products that are created as part of the sustained assessment process. Team members assist CICS-NC and NCEI management as well as USGCRP management and staff with project planning and coordination including development of the overarching NCA project timeline. They independently develop as well as assist other staff with the creation of author guidance documents that serve as foundational guidelines for the generation of report content.

Editorial Team members include Brooke Stewart (managing editor & science writer/editor), Tom Maycock (science writer/editor), Andrea McCarrick (technical editor), and Tiffany Means (temporary technical editor).

Jessicca Griffin serves as CICS-NC liaison between the TSU and NCEI's Communication and Outreach Branch to provide *graphics design and production* support for the NCA and other publications. Graphics support includes image creation and editing for accuracy and readability, preparing graphics for various pre-release drafts, and graphics design and implementation of final report print and pdf documents.

Angel Li coordinates a small TSU *web team* that designs, develops, and implements online climate assessment reports (websites) with mobile device (e.g., phones and tablets) access.

**Accomplishments**

***Volume II of the Fourth National Climate Assessment: Impacts, Risks, and Adaptation in the United States*** was released on November 23, 2018. The TSU technical staff successfully shepherded the design, development, production, and publication and release of the report in print, digital, and web formats. The editorial team provided extensive project planning and management support and substantive science editing and copyediting following revisions in response to concurrent public and National Academies reviews and again after federal interagency review. The editorial team also coordinated with in-house designers, reference managers, web developers, data specialists, and USGCRP's National Coordination Office (NCO) managers and staff to finalize report publication and release.


***Figure 1***. *(left) The Report-in-Brief version of the Fourth National Climate Assessment, Volume II: Impacts, Risks, and Adaptation in the United States (NCA4). The editorial, graphics, and web teams made major contributions to development, production, and delivery of NCA4. (right) The Executive Summary of the Scientific Assessment of Ozone Depletion: 2018. Members of the editorial team served as the science editor and technical editors for the ozone assessment.*

Graphic design support services for the development of the Fourth National Climate Assessment included the report's PDF design template and ongoing revisions, new figure creation, and extensive image and figure editing. Production services included preparing graphics for various pre-release drafts as well as creating the final PDF and print products. Griffin also provided graphics and visual communication support to NCEI's Communications and Outreach Branch, including for the annual State of the Climate report published in the *Bulletin of the American Meteorological Society*.

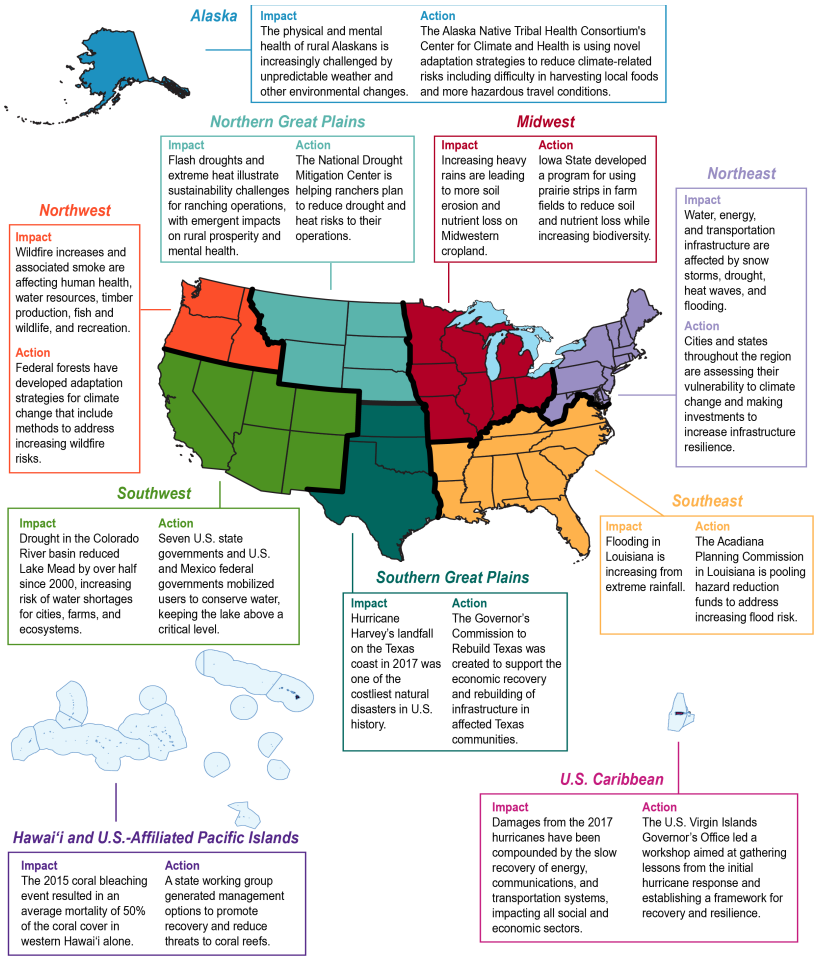



***Figure 2***. *The TSU graphics team works with authors and report leadership to develop scientific figures and infographics, including the figure above describing regional climate impacts and associated adaptation activities, which appears as Figure 1.1 in NCA4.*

The NCA4 website (http://nca2018.globalchange.gov/) design began in January 2018 in consultation with USGCRP staff and officially launched on Friday, November 23rd 2018, a few weeks earlier than originally planned. The site was implemented using the static site generator *Hugo*, building on the experience gained in coding and implementing the site for the Climate Science Special Report, released in 2017 (https://science2017.globalchange.gov).

In parallel, a new metadata display routine written in Javascript was launched to fully display all the figure metadata collected for the NCA4. The option to download the data file(s) that generated all figures produced by the TSU was added to the viewer.

**Other Technical Support.** The TSU technical support team contributed to various other projects during the past year, including finalization of the Puerto Rico and U.S. Virgin Islands State Summary technical document and significant editorial support for the *Scientific Assessment of Ozone Depletion: 2018*.

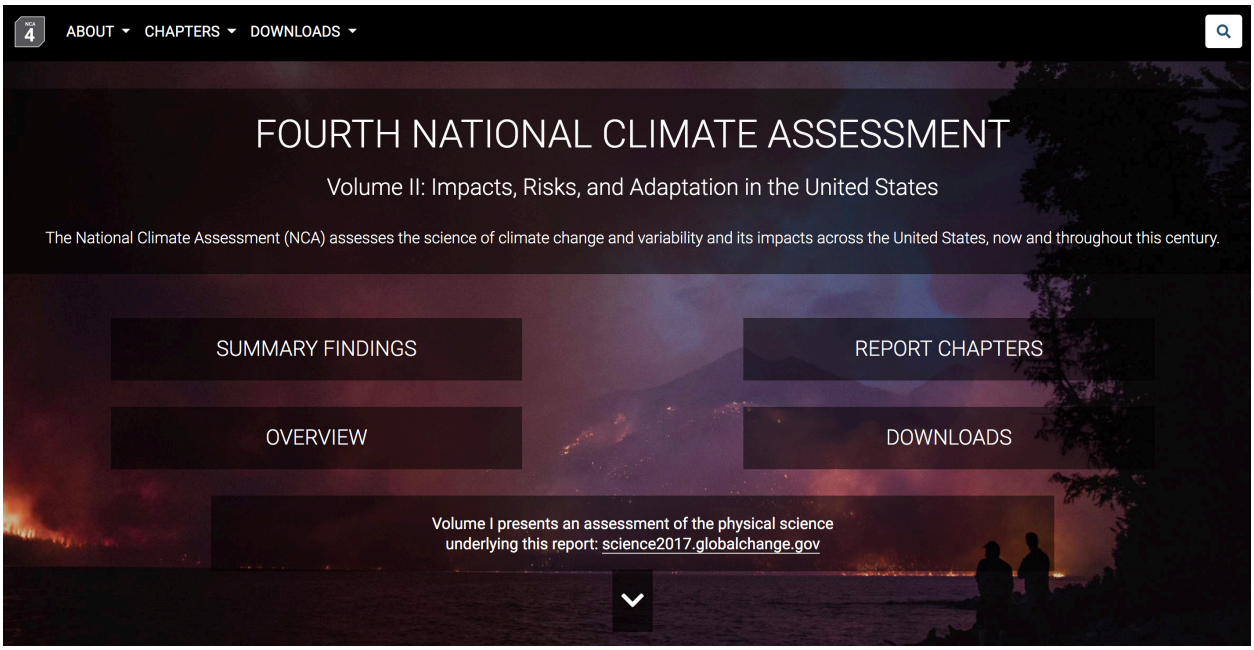



***Figure 3.*** *Fourth National Climate Assessment Volume II website.*

**Planned work**

- A full HTML website for the *State of the Carbon Cycle Report 2018* (launched in PDF form at the same time as the NCA4) with anticipated release in April 2019.
- Update of the State Summaries website (https://statesummaries.ncics.org) with recent data and new graphics and conversion of the site from *Drupal* to *Hugo.*
- Identify lessons learned from the NCA4 development and production process.
- Work with USGCRP to identify opportunities to improve processes and products for future reports.
- Provide technical support for other projects and assessment products as needed.

**Products**

- ***Fourth National Climate Assessment, Volume II*** (November 2018) – print, digital, and web formats https://nca2018.globalchange.gov
- ***Fourth National Climate Assessment, Volume II: Report-in-Brief*** (November 2018) – print and digital formats
- ***Fourth National Climate Assessment, Volume II*** (November 2018) – authorship of four chapters
- ***The Scientific Assessment of Ozone Depletion: 2018*** – *editorial support*

**Publications**

Angel, J., C. Swanson, B. M. Boustead, K. C. Conlon, K. R. Hall, J. L. Jorns, **K. E. Kunkel**, M. C. Lemos, B. Lofgren, T. A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 872-940. http://dx.doi.org/10.7930/NCA4.2018.CH21

Avery, C. W., D. R. Reidmiller, M. Kolian, **K. E. Kunkel**, D. Herring, R. Sherman, W. V. Sweet, K. Tipton, and C. Weaver, 2018: Data Tools and Scenarios Products. *Impacts, Risks, and Adaptation in the United States:*

*Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1413-1430. http://dx.doi.org/10.7930/NCA4.2018.AP3

Carter, L., A. Terando, K. Dow, K. Hiers, **K. E. Kunkel**, A. Lascurain, D. Marcy, M. Osland, and P. Schramm, 2018: Southeast. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 743-808. http://dx.doi.org/10.7930/NCA4.2018.CH19

Dzaugis, M., C. W. Avery, A. Crimmins, L. Dahlman, D. R. Easterling, R. Gaal, E. Greenhalgh, D. Herring, **K. E. Kunkel**, R. Lindsey, **T. K. Maycock**, R. Molar, D. R. Reidmiller, **B. C. Stewart**, and R. S. Vose, 2018: Frequently Asked Questions. *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1444-1515. http://dx.doi.org/10.7930/NCA4.2018.AP5

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 1506 pp. http://dx.doi.org/10.7930/NCA4.2018

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 186 pp. http://dx.doi.org/10.7930/NCA4.2018.RiB

**Presentations**

**Maycock, T.**, 2019: An Introduction and Overview of NCA4. *4th National Climate Assessment Panel Series*, *The Collider*, Asheville, NC, January 24, 2019.

**Maycock, T.**, 2019: Adaptation and Resilience in NCA4. *4th National Climate Assessment Panel Series*, *The Collider*, Asheville, NC, February 21, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **4** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **6** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*Products: NCA4, NCA4 Report-in-Brief, the ozone assessment, and the BAMS State of the Climate report.*

| World Resources Institute (WRI) / Partnership for Resilience and Preparedness (PREP) Supporting the U.S.–India Partnership for Climate Resilience | |
|---|---|
| **Task Leader:** | Lauretta Burke |
| **Task Code** | NC-CAA-03-WRI |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI (DOS) |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** In support of the U.S.-India Partnership for Climate Resilience, the World Resources Institute (WRI) and the Partnership for Resilience and Preparedness (PREP) worked with two Indian states, Madhya Pradesh and Uttarakhand, to help implement their respective State Action Plans on Climate Change through collaboration in the development and use of tailored "climate preparedness dashboards" on the PREP platform. https://www.prepdata.org/dashboards

**Background**

In September 2014, U.S. President Obama and Indian Prime Minister Modi agreed to a new strategic partnership on energy security, clean energy, and climate change. The resulting U.S.-India Partnership for Climate Resilience (PCR) aims to advance capacity for climate adaptation planning by supporting climate resilience tool development. Joint activities include downscaling global climate models for the Indian sub-continent, assessing climate risks at the sub-national level, working with local technical institutes on capacity building, and engaging local decision-makers in the process of addressing climate information needs and informing planning and climate resilient sustainable development, including for India's State Action Plans. The NOAA National Centers for Environmental Information (NCEI), the NOAA Cooperative Institute for Climate and Satellites North Carolina (CICS-NC), and CICS-NC subcontractors (including the World Resources Institute; WRI) are providing key technical support for the PCR bilateral activities in collaboration with the U.S. Department of State.

Jointly coordinated by the U.S. Global Change Research Program (USGCRP) and WRI, the Partnership for Resilience and Preparedness (PREP) is a public–private collaboration that seeks to empower a data-driven approach to building climate resilience. PREP aims to facilitate the process for diverse stakeholders to routinely incorporate climate risks into their decisions by enhancing access to relevant data and facilitating collective learning. PREPdata is a map-based, open-data online platform (https://www.prepdata.org/) that allows users to access and visualize climate, physical, and socioeconomic data for climate adaptation and resilience planning.

The PREP initiative, which promotes tailor-made climate information services to the operational context, has enormous relevance, use, and value for India, one of the most vulnerable countries to the impacts of climate change. WRI and PREP are working with governments in two Indian states, Madhya Pradesh (MP) and Uttarakhand, to support implementation of their respective State Action Plans on Climate Change through use of PREPdata.

**Accomplishments**

MP and Uttarakhand PREPdata application involved multiple steps, including: consultation with end users to understand specific needs (user needs, barriers to climate risk evaluation and adaptation planning, and

data needs and availability); data acquisition, cleaning (translation, formatting, and/or processing), and registration on the PREPdata platform (including metadata documentation); collaborative dashboard development; end-user training (capacity building); and communication of results.

The pilot applications resulted in improved data content for India (80 new datasets for India: 9 national; 40 Uttarakhand; 31 MP); five new dashboards (MP Agriculture and Forestry, Uttarakhand Tourism, Agriculture, and Water Resources); one in-depth climate vulnerability story for Uttarakhand; much-improved and integrated data access for both states; and capacity to use PREPdata in both states. PREPdata platform improvements/enhancements to consolidate and highlight new content for India were also implemented, including options for country-level selection and individual country "core datasets"; dashboard download as PDF; dashboard search and filter functions; and layer interaction for vector datasets (ability to point at location and get value for some data layers).

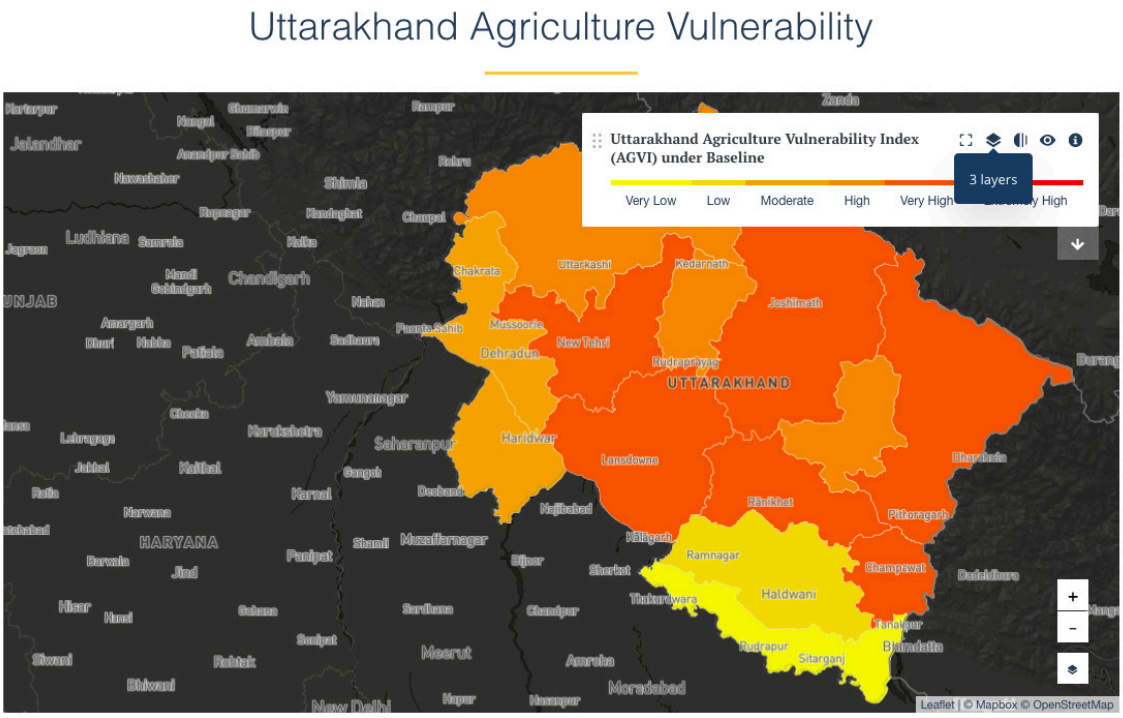



***Figure 1.*** *Uttarkhand Agriculture Vulnerability Index (Uttarakhand State Climate Change Centre) data as displayed on the PREPdata dashboard for Uttarakhand Agriculture. The agriculture vulnerability index (AGVI) was arrived at by aggregating and weighing a cross section of 13 indicators (such as crop yields, net sown area, net irrigated area, fertilizer consumption, livestock units, small landholdings, etc.). The map indicates that by mid-century under the moderate scenario (RCP4.5), plain districts like Nainital and Udham Singh Nagar, and to a lesser extent, Haridwar and Dehradun will have very low to moderate agricultural vulnerability.*

The project involved significant engagement and capacity-building activities, including:

- *WRI staff presentations* on India resilience efforts, the PREP partnership and platform, and the use of dashboards to support state-level resilience planning in March 2017.
- *PREP inception workshops and user needs assessments* to gain insights on key sectors and stake-holders' interest and data and visualization needs, assess the state's most important economic activities' sectors and their vulnerability to climate change, foster collaboration by bringing different stakeholders together, discuss availability of data for decision making, and share information on data sources, formats, and priorities.

- *Collaborative dashboard development discussions* with various stakeholders.
- *PREPdata training workshops* with sectoral departments to help launch the PREPdata platforms (June 2018 in MP / August 2018 in Uttarakhand) and share the PREPdata content (Explore and dashboards) with users—showing platform enhancement in response to their expressed needs, how their data contribution was reflected in the platform, and the dashboards developed for the selected sectors.
- *Follow-on one-on-one training* for interested users in both states.

***Figure 2.*** *Stakeholder meetings in Bhopal, Madhya Pradesh and Dehradun, Uttarakhand.*

**Key Outcomes**

Project key outcomes include:

- *increased access and usability of data for decision making* with data from multiple sectors/sources integrated in a single, easy-to-use platform, for joint data visualization. PREP also made access to published Vulnerability and Risk Assessments (VRAs) results simpler and more user friendly, increasing technical results, understanding, and use.
- *mainstreaming climate data use* by allowing people from many sectors with varying technical ability to easily visualize and understand projected changes in climate and the uncertainty associated with those projections.
- *improved climate data access for State Climate Cells* with PREPdata "Explore" functionality embedded on the SKMCCC and SCCC's websites providing access to all mapped data for the states.
- *data integration for multiple scales and extents* with national, state, and local data now complimenting PREPdata global datasets.
- *investment in capacity building* of various government officials to increase use of relevant data in program and project planning. Other goals include helping unlock more funding from the *India Department of Science and Technology* and assisting other departments and agencies in strengthening the evidence base on climate risk in developing proposals for domestic and external climate funding.

**Planned Work**

This project was completed in August 2018, but WRI and PREP will continue to engage with MP and Uttarakhand on their respective dashboards and/or other Indian states that express interest in similar PREPdata applications. MP is looking at fundraising to support additional registration of data (e.g., new healthcare datasets) and adding and innovating new forms of data visualizations on PREP for greater impact. Additional states such as Telangana and Gujarat are also interested in PREPdata applications.

**Products**

- ***PREP Training Videos***
  - Introduction to PREPdata
  - PREPdata: Explore
  - PREPdata India Explore
- ***PREP India Dashboards***
  - Uttarakhand Water Resources
  - Uttarakhand Tourism
  - Uttarakhand Agriculture
  - Wheat in Madhya Pradesh
  - Forestry in Madhya Pradesh
- ***PREP Curated India Datasets***
  - India Core Datasets
  - Madhya Pradesh Datasets
  - Uttarakhand Datasets

**Presentations**

- Satkowski, L., and Pandey P., 2018: PREP Demo – Exploring PREP and Creating Dashboards*, PREP Launch workshop*, Bhopal, India, June 12, 2018.
- Ginoya, N., 2018: PREP India – Madhya Pradesh Dashboards*, PREP Launch workshop*, Bhopal, India, June 12, 2018.
- Burke, L., 2018: An Introduction to PREP Platform, *PREP Launch workshop*, Bhopal, India, June 12, 2018.
- Satkowski, L., and Pandey P., 2018: PREP Demo – Exploring PREP and Creating Dashboards*, PREP Launch workshop*, Dehradun, India, August 18, 2018.
- Jogesh, A., 2018: PREP India – Uttarakhand Dashboards*, PREP Launch workshop*, Dehradun, India, August 18, 2018.
- Ginoya, N., 2018: An Introduction to PREP Platform, *PREP Launch workshop*, Dehradun, India, August 18, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **11** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **6** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*PREP training videos (3), dashboards (5), and curated datasets (3)*

| U.S.–India Partnership for Climate Resilience (PCR) Workshop Support | |
|---|---|
| **Task Leader:** | Katharine Hayhoe |
| **Task Code** | NC-CAA-04-TTU |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI (DOS) |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** This project with CICS-NC collaborator, Texas Tech University, supports the development of state-of-the-art climate products and analysis tools for resilience planning and sustainable development and provision to U.S.–India Partnership for Climate Resilience (PCR) collaborators. The Asynchronous Regional Regression Model version 2 (ARRM2) was updated and incorporated into the Seasonal Trends and Analysis of Residuals (STAR) analysis framework as the Empirical Statistical Downscaling Model (ESDM) for that software package.

**Background**

In September 2014, former U.S. President Obama and Indian Prime Minister Modi agreed to a new strategic partnership on energy security, clean energy, and climate change. The resulting U.S.–India Partnership for Climate Resilience (PCR) aims to advance capacity for climate adaptation planning by supporting climate resilience tool development. Joint activities include downscaling global climate models for the Indian sub-continent to a much higher resolution than currently available, assessing climate risks at the sub-national level, working with local technical institutes on capacity building, and engaging local decision-makers in the process of addressing climate information needs and informing planning and climate resilient sustainable development, including for India's State Action Plans. The NOAA National Centers for Environmental Information (NCEI), the NOAA Cooperative Institute for Climate and Satellites North Carolina (CICS-NC), and CICS-NC subcontractors (including Texas Tech University; TTU) are providing key technical support for the PCR bilateral activities in collaboration with the U.S. State Department.

TTU's Katharine Hayhoe, a lead author for the U.S. National Climate Assessments since 2007, and Texas Tech Climate Science Center researchers Anne Stoner and Ian Scott-Fleming are supporting multiple PCR workshops and associated research activities aimed at equipping the Indian Institutes with the ability to generate and analyze high-resolution climate projections and apply these to quantify the impacts of climate change at the local to regional scale.

**Accomplishments**

Over the last year, the team continued to expand the scope and capability of the data products available to share with Indian practitioners and researchers and participate in the development of a web interface designed to facilitate the provision and use of these products with a non-specialist audience. They also continued to build long-term collaborations with Indian practitioners, researchers, and other experts to expand on the original products. Each of these steps is described briefly below.

**Climate Data and Analysis Tools**. To generate climate information for resilience planning and sustainable development, long-term daily temperature and precipitation observations from available Global Historical Climatology Network (GHCN) stations and from additional stations provided by Indian Institute colleagues

(Figure 1) was previously assembled and quality-controlled. Additional long-term weather records not archived in GHCN were solicited from Indian colleagues over this past year and added to the database.

Observational records were previously down-scaled using the Asynchronous Regional Regression Model version 2 (ARRM2), a non-parametric and significantly improved version of the original ARRM model used in the Second and Third U.S. National Climate Assessments. This year, ARRM2 was updated and incorporated into the Seasonal Trends and Analysis of Residuals (STAR) analysis framework as the Empirical Statistical Downscaling Model (ESDM) for that software package. Working with colleagues at NCEI, this code has been updated and ported across institutions to allow for real-time analysis of observations and global climate model outputs, and generation of high-resolution projections for both stations, as with the original ARRM2 code, as well as daily gridded temperature and precipitation at 0.25° resolution across the India sub-continent.

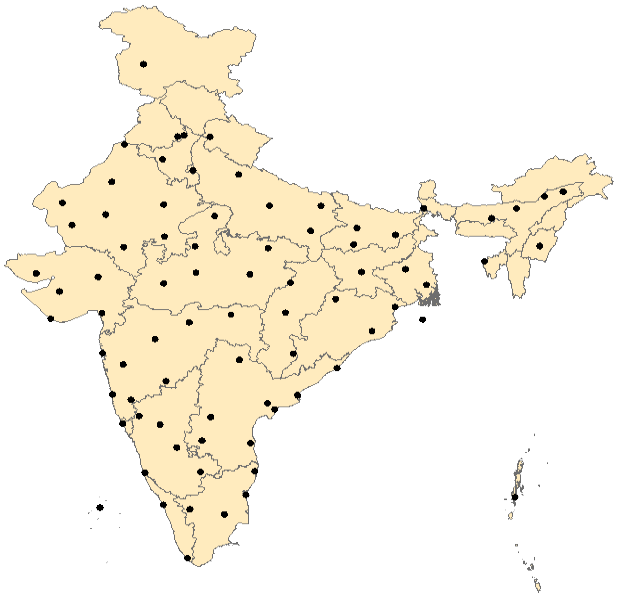


***Figure 1.*** *Location of long-term weather stations for which daily projections were generated.*

**Long-Term Collaborations and Web Portal**. Through working relationships established with workshop participants, we have collaborated with the Environmental Protection Training and Research Institute (EPTRI) to provide review and guidance for the web-based interface development activities.

**Planned Work**

- Continue to work with Indian colleagues and practitioners to obtain and quality control additional weather station records supplied by collaborators and generate high-resolution climate projections for these locations.
- Provide final review of EPTRI's user-friendly online dataset.
- Participate in a workshop in the Himalayas.
- Provide documentation in the form of peer-reviewed publications (three are currently in manuscript form with submission anticipated in summer 2019).

**Products**

Products that were expanded during the past year include:

- Quality controlled daily temperature and precipitation data for additional weather stations across India
- Portable STAR-ESDM code that advances the treatment of temperature and precipitation extremes
- Updated and continuing expansion of the comments and documentation on the generation, application, and use of climate information relevant to quantifying the potential impacts of climate change at the local to regional scale across India

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **3** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*Temperature and precipitation data for additional India stations, Seasonal Trends and Analysis of Residuals (STAR) - Empirical Statistical Downscaling Model (ESDM), updated and expanded documentation on using climate information at local to regional scales in India.*

| **The Energy and Resources Institute (TERI)/ Understanding Climate and Heath Association in India (UCHAI) Initiative Supporting the U.S. – India Partnership for Climate Resilience** | |
|---|---|
| **Task Leader:** | Meena Sehgal |
| **Task Code** | NC-CAA-05-TERI |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI (DOS) |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** In support of the India-US Partnership for Climate Resilience (PCR), CICS-NC and collaborator TERI are working to build capacity and climate health linkage awareness through support of activities to reduce the India population's vulnerability to climate risk and extreme weather events. http://www.teriin.org/event/us-india-partnership-climate-resilience-workshop-climate-and-health

**Background**

In September 2014, U.S. President Obama and Indian Prime Minister Modi agreed to a new strategic partnership on energy security, clean energy, and climate change. The resulting U.S.-India Partnership for Climate Resilience (PCR) aims to advance capacity for climate adaptation planning by supporting climate resilience tool development. Joint activities include downscaling global climate models for the Indian sub-continent, assessing climate risks at the sub-national level, working with local technical institutes on capacity building, and engaging local decision-makers in the process of addressing climate information needs and informing planning and climate resilient sustainable development, including for India's State Action Plans. The NOAA National Centers for Environmental Information (NCEI), the NOAA Cooperative Institute for Climate and Satellites North Carolina (CICS-NC), and CICS-NC subcontractors (including The Energy and Resources Institute; TERI) are providing key technical support for the PCR bilateral activities in collaboration with the U.S. Department of State.

TERI is a non-profit, policy research organization based in India working in the fields of energy, environment, sustainable agriculture, and climate resilience. TERI serves as the current secretariat for the Understanding Climate and Health Associations in India (UCHAI) initiative, a network of professionals, experts, organizations, and knowledge systems to address climate change and health issues in India. The UCHAI initiative aims to build capacity for use of downscaled climate data and enhance resilience of the health sector in India, with a focus on strengthening state-level adaptation plans.

**Accomplishments**

TERI and its UCHAI initiative led, participated in and/or coordinated numerous activities and events in the past year to raise awareness of the effects of climate vulnerability and extreme weather patterns on human health, and adoption of risk reduction measures.

***Workshop on Climate and Health.*** TERI organized and hosted a collaborative two-day Workshop on Climate and Health on October 23–24, 2018, in New Delhi, India, with participation from various government and non-government organizations across India. Participants were a mix of academicians, research professionals, and students working in the field of climate and health across India. Workshop speakers included experts from the All India Institute of Medical Sciences, Indian Institute of Public Health-Gandhinagar, Amity University, Indian Institute of Health Management Research, Directorate General

Health Services, Department of Health and Family Welfare, National Centre for Disease Control, and from the U.S. National Institute of Environmental Health Sciences, CICS-NC, and others. Workshop aims were to showcase global and national efforts of quantifying climate and health risks; present tools under development to help predict malaria using meteorology data; discuss innovative strategies to reduce human suffering and share efforts in the hill state and plains to combat heat stress linked effects on health. The participants also gained hands-on knowledge of methods for climate modeling. http://www.teriin.org/event/us-india-partnership-climate-resilience-workshop-climate-and-health.

***UCHAI website*.** UCHAI maintains a website for its diverse network to address climate change and health issues in India. The website is a moderated, open platform enhanced by social media and instant messaging. Users network through the website to share information, resources, and services with each other on best practices to mitigate the effects of climate vulnerability. The website home page (http://www.uchai.net/) highlights recent updates with a banner on upcoming events, an infographic corner, recent news, and reports on climate-linked health issues. The website shares an email address to enable the users to send their comments, queries, and observations and continues to attract world-wide users.


***Figure 1.*** *Updated UCHAI website home page.*

***Infographics.*** The UCHAI team prepared several infographics on climate-sensitive health conditions aimed at presenting the information quickly and clearly to enhance viewer knowledge retention and recall through the use of visually compelling charts, images, and other such elements.

- Understanding the health impacts of heat stress in India: http://www.teriin.org/infographics/understanding-health-impacts-heat-stress-india
- Combating mosquito-related diseases in India: http://www.teriin.org/infographics/combating-mosquito-related-diseases-india
- How climate change impacts health: http://www.teriin.org/infographics/how-climate-change-impacts-health

***Videos.*** UCHAI team members helped prepare TERI YouTube videos on climate challenges and health effects.

- Fortifying against climate change: https://youtu.be/jtx3_DNUFZE
- Millets to the rescue: https://youtu.be/bCF4cnmPgR8
- Superfoods for the poor: https://youtu.be/dhPuP3o_8uY
- A Climate Antidote: Building climate resilience in public health: https://www.youtube.com/watch?time_continue=2&v=cBnYa8KRiD4

***Analysis of remote-sensing and meteorology data for the state of Andhra Pradesh.*** An exploratory study, Spatial analysis and mapping of malaria risk zones for districts of Andhra Pradesh using Analytical Hierarchical Process (AHP), was completed using environmental data to map malaria risk zones. India Meteorological Department data (minimum temperature, maximum temperature, humidity, and rainfall) and physical variables from remote sensing inputs were collected. Physical variables included vegetation index (NDVI), water index (NDBI) and elevation. Using AHP, weights were given to each variable and a weighted average was used to generate the malaria risk zone map. Findings were validated using the recorded number of malaria cases that were reported within a district. All the analysis was done for the year of 2014–2016. The results of the spatial analysis showed a close and appropriate match with the reported malaria cases. The three high risk districts were Vizianagram, Vishakhapatnam, and East Godavari. An analysis was also done to classify Community Health Centres (CHCs) and Primary Health Centres (PHCs) of Andhra Pradesh under the classes of malaria risk to identify the PHC and CHC with the highest malaria risk and most urgent preventive approach needs.

***World Sustainable Development Summit (WSDS) 2019.*** TERI/UCHAI supported the WSDS thematic track on climate services held at TERI, New Delhi, February 11–13, 2019. WSDS has become a focal point for global leaders and practitioners to congregate at a single platform to discuss and deliberate over climate issues of universal importance. The summit included a series of regional dialogues, a corporate conclave, plenary sessions, thematic tracks, international dialogue, exhibitions, and youth programs. This event helped improve awareness on innovations in climate finance, achieving sustainability in clean environment, energy for tomorrow, and habitat. This event included more than 100 participants and reached hundreds of thousands of people through media (http://wsds.teriin.org/index.php).


***Figure 2.*** *The World Sustainable Development Summit 2019 panel discussion, Climate Services in India – Moving the Needle, highlighted current government climate services initiatives, climate extremes in India, climate products and services for regional modeling, climate tools under development, and current challenges for mountainous regions.*

**Planned work**

This project was completed in January 2019.

**Publications**

Gupta, V., and B. Mahadevan, 2018: Heatwaves are health and economic risks, *Livemint* e-paper, https://www.livemint.com/Opinion/fwqXTntE5ZYCXMJOSeet0H/Heatwaves-are-health-and-economic-risks.html

Sehgal, M., and J. Mosahari, 2019: Climate Change and Health Challenges in India, *TerraGreen* e-zine, **11**(12). http://terragreen.teriin.org/index.php

Sehgal, M., S. K. Ghosh, K. N. Singh, V. Gupta, and A. Mathur, 2019: Child health status and climate related agricultural variability: case study of India, *BMC Public Health*, submitted.

Sehgal, M., and S. Ghosh, 2019: Exploring usefulness of meteorology data for predicting malaria cases in Visakhapatnam, AP, *American Meteorological Society Weather, Climate and Society*, submitted.

**Presentations**

Sehgal, M., 2018: Indicators for Vulnerability Assessment of Human Health to Climate Variability, *10th International Conference on Climate Change: Impacts and Responses*, Berkeley, CA, April 21, 2018.

Gupta, V., 2018: Child health status and climate related agricultural variability: case study India, *50th Annual National Conference of Nutrition Society of India* (NSI), Hyderabad, India, November 17, 2018.

Sehgal, M., 2019: Exploring Usefulness of Meteorology Data for Predicting Malaria Cases, *99th American Meteorological Society Annual Meeting*, Phoenix, AZ, January 9, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| | |
|---|---|
| **Climate Change Indicators** | |
| **Task Leader** | Laura Stevens |
| **Task Code** | NC-CAA-06-NCICS-LS |
| **NOAA Sponsor** | David Easterling/Derek Arndt |
| **NOAA Office** | OAR/CPO |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 75% |
| | Theme 3: Climate Research and Modeling 25% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** The TSU provided support for USGCRP efforts to maintain and expand a comprehensive suite of Climate Change Indicators. Significant progress was made in the development of new indicators and collection of indicator metadata. Three new indicators, developed with TSU input, were recently added to the newly redesigned USGCRP Indicators Platform: www.globalchange.gov/browse/indicators.

**Background**

Indicators are observations or calculations that can be used to track conditions and trends. Indicators of climate change can communicate key aspects of the changing environment, point out vulnerabilities, and inform decisions about policy, planning, and resource management. Such Indicators are an important part of the vision for the sustained National Climate Assessment (NCA).

A set of climate change indicators, initially intended as a prototype for evaluation by scientists and user communities, exists to inform the development of a more comprehensive, dynamic system encompassing climate changes, impacts, and responses. This suite of indicators is managed by the U.S. Global Change Research Program (USGCRP), a consortium of 13 Federal Agencies that deal with global change. Currently, 16 indicators reside online within the USGCRP Indicators Platform, which serves as an authoritative resource highlighting data, research, and indicators-related activities. Uniting and building on efforts from across USGCRP agencies, the Indicators Platform will support future NCA reports and provide scientific data that can help decision-makers understand and respond to climate change. The USGCRP Indicators Interagency Working Group (IndIWG) currently serves to provide an interagency forum for supporting and facilitating the development of a USGCRP indicators effort.

CICS-NC and NOAA National Centers for Environmental Information (NCEI) continued working with the IndIWG in order to better broker and administer the indicator set, based on the synergy with, and similarity to, the work of the NCA Technical Support Unit (TSU). Laura Stevens (CICS-NC) and Jessica Blunden (NCEI) are supporting the overall USGCRP effort with scientific and technical expertise. Other CICS-NC staff aid with specific components, including data/metadata (Sarah Champion and Andrew Thrasher), editing (Tom Maycock and Brooke Stewart), and website support (Angel Li).

**Accomplishments**

NCA Technical Support Unit (TSU) staff members participate in monthly calls with the IndIWG, as well as an annual in-person meeting. Over the past year, efforts were primarily focused on a comprehensive update of the full indicators suite, which included updating data, completing metadata collection, and revising textual descriptions. Another major accomplishment for 2018 was the launch of a new USGCRP Indicators Platform (Figure 1). This newly redesigned website, produced in collaboration with the IndIWG

and the USGCRP web team, includes the interactive “Indicators of Change” figure from the Fourth National Climate Assessment, as well as the full updated suite of USGCRP Climate Change Indicators.

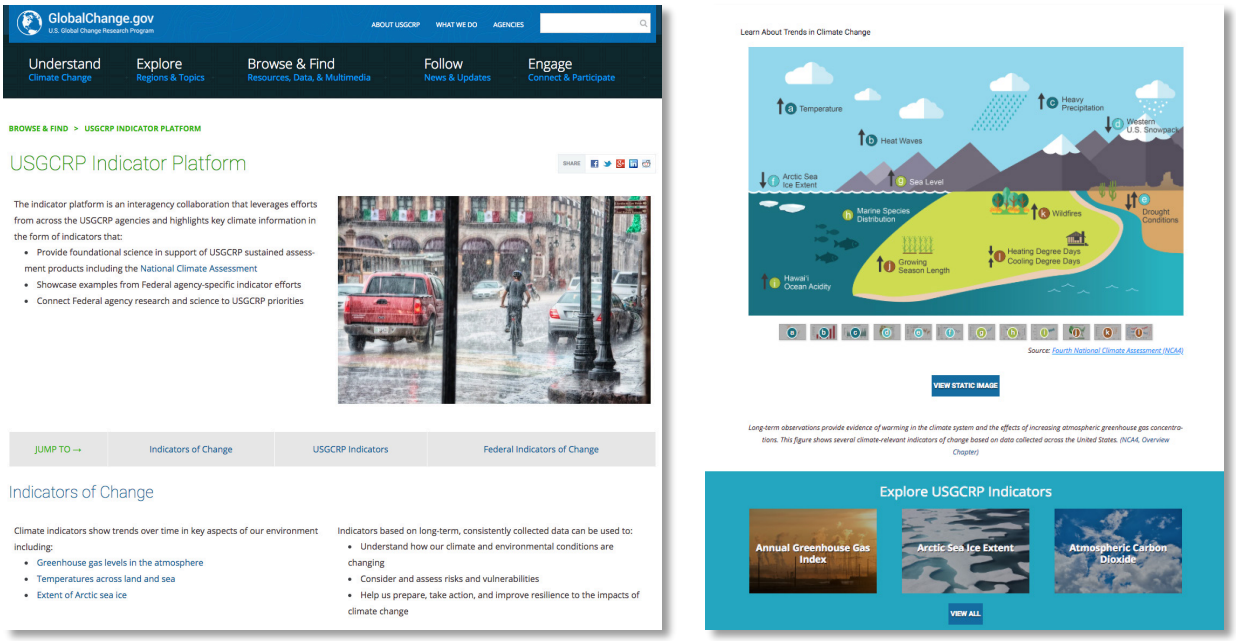



***Figure 1.*** *The USGCRP Indicators Platform at [https://www.globalchange.gov/browse/indicators](https://www.globalchange.gov/browse/indicators)*

Three new indicators (“Global Average Sea Level Change,” “Heat Wave Characteristics in 50 Large U.S. Cities,” and “U.S. Billion Dollar Weather and Climate Disasters”) were recently added to the Indicators Platform; these were created with significant contributions from the TSU. NOAA NCEI expertise led to the creation of the Billion Dollar Disasters graphic (Figure 2), using in-house data to create a simple but compelling indicator. This is the first indicator in the USGCRP suite to extend outside the pure climate science realm and describe climate-related impacts.

The development of a new indicator is multi-step process. The TSU works directly with indicator “champions” (members of partner agencies designated as experts responsible for each indicator) throughout this process in order to:

- gather the most relevant and up-to-date data;
- present the indicator to the IndIWG for approval;
- facilitate the development of the indicator;
- create an informative description of the indicator;
- gather comprehensive metadata;
- deploy the indicator online;
- implement timely updates going forward.

As part of this Indicators development process, the TSU also works with CICS consortium partner UNC Asheville’s National Environmental Modeling and Analysis Center (NEMAC) in the creation of new Indicator graphics.

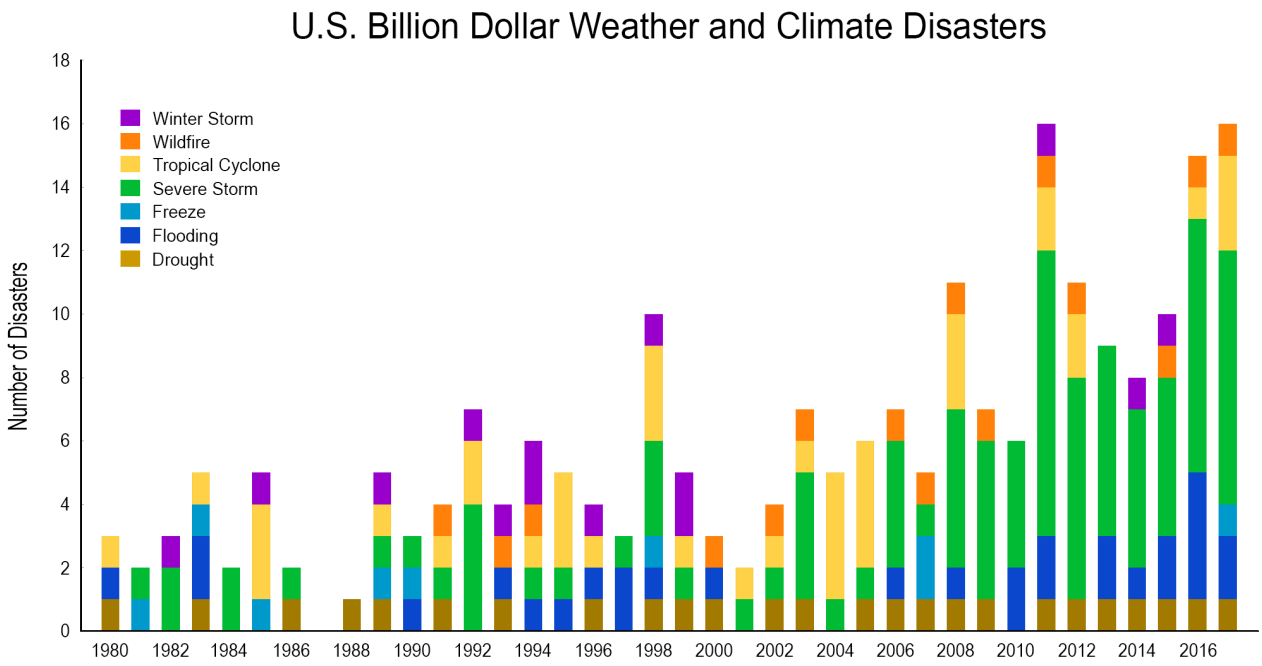



***Figure 2.*** *A recent addition to the USGCRP indicators suite – U.S. Billion Dollar Weather and Climate Disasters. The bar graph shows the number of individual climate and weather events that caused more than one billion dollars of direct losses each year. The length of each bar corresponds to the annual number of events. These events are binned into seven hazard types, each represented by its own color.*

Comprehensive metadata is collected for each indicator in order to provide full transparency, traceability, and reproducibility In line with National Climate Assessment efforts to satisfy the Information Quality Act. Due to the successful use of the NCA metadata collection system, plans are currently underway for implementing the NCA metadata viewer into the USGCRP Indicators Portal. The metadata viewer will ultimately enhance the user experience and provide access to the underlying data and scientific methods.

**Planned work**

- Update the full suite of current indicators with data through 2018;
- Assist the IndIWG with the addition of new indicators;
- Implement the NCA metadata viewer into the Indicators Platform;
- Explore what is needed for the creation of high quality ecological and social science indicators;
- Work with the IndIWG to define the role of indicators in the Fifth National Climate Assessment (NCA5), and other USGCRP products and priorities.

**Products**

- Deployed new Indicators Platform
- Released new indicator: Global Average Sea Level Change
- Released new indicator: Heat Wave Characteristics in 50 Large U.S. Cities
- Released new indicator: U.S. Billion Dollar Weather and Climate Disasters

**Presentations**

**Stevens, L.E.**, and D.S. Arndt, 2018: Managing a multi-agency set of climate indicators, *NCEI Seminar Series*, Asheville, NC, August 28, 2018.

**Stevens, L.E.**, D.S. Arndt, and J. Blunden, 2019: From Climate Indicators to Action, *The Collider Lunch & Learn Series*, Asheville, NC, February 5, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **4** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*NCA Technical Support Unit (TSU) staff members contributed to the redesign and launch of a new USGCRP Indicators Portal. Three new indicators were developed and added to the Indicators Platform: 1) Global Average Sea Level Change, 2) Heat Wave Characteristics in 50 Large U.S. Cities, and 3) U.S. Billion Dollar Weather and Climate Disasters.*

| **An investigation into current and future trends in severe thunderstorms and their environments** | |
|---|---|
| **Task Leader:** | Robert J. Trapp |
| **Task Code** | NC-CAA-07-UIUC |
| **NOAA Sponsor** | David Easterling |
| **NOAA Office** | NESDIS/NCEI (OAR/CPO) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 75% |
| | Theme 3: Climate Research and Modeling 25% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** A 12-year (2000–2011) MRMS radar-based hail climatology using the hail proxy Maximum Expected Size of Hail (MESH) was previously completed and short-term trends in the MESH climatology and long-term trends in the NARR-based hail environments were analyzed. Project results were summarized in a peer-reviewed publication.

**Background**

Historically, climate-scale studies of severe hail have been limited due to inherent biases within report-based databases (Schaefer and Edwards 1999; Schaefer et al. 2004; Doswell et al. 2005; Allen and Tippett 2015). Little information can be obtained regarding the size or path of hail swaths, given that reports are limited to single observers, separated by a minimum of 16 km or 15 minutes (Schaefer et al. 2004). This limits the study of "severe hail outbreaks," which are challenging to identify given that reports are "point based" whereas actual events will cover a larger area for a longer time (Doswell et al. 2005). The NEXRAD/in situ gauge Climate Data Record (CDR) dataset provides an opportunity to greatly expand upon the understanding of severe hail events in the United States.

Brooks et al. (2014) found that the frequency of tornado outbreaks could be increasing. Because a considerable fraction of severe hail events coincides with tornado events (Brooks et al. 2003), a similar trend in severe hail outbreaks is likely. A traditional way of locally parameterizing the occurrence of severe thunderstorms is through a combination of convective available potential energy (CAPE) and vertical wind shear (VWS) (Brooks et al. 2003, 2009). Trapp et al. (2007, 2009) developed the NDSEV (number of severe thunderstorm days) parameter using CAPE and 0–6 km VWS to estimate the number of days with potential for severe thunderstorms. This general method of analyzing environments could also be utilized to study historical severe hail and tornado outbreak events.

Our objective was to investigate changes in historical severe convective weather, specifically the spatial extent and frequency of severe hail and tornado outbreaks over the United States using reanalysis data, with NEXRAD/in-situ gauge Climate Data Record (CDR) data as a constraint.

**Accomplishments**

This study, which ended in June 2018, highlighted the overall utility of a radar-based hail proxy to quantify occurrences of severe hail outbreaks. A 12-year (2000–2011) severe hail dataset was developed using the maximum estimated size of hail (MESH) radar product, with automated quality control measures applied to eliminate erroneous severe hail signatures.

The North American Regional Reanalysis (NARR) was utilized to study trends in the frequency and spatial

extent of environments supportive of severe hail and tornado outbreaks from 1980–2015. The MESH dataset developed previously as part of this project was used along with SPC tornado reports as "ground truth" to determine proper thresholds for environments supportive of tornado or severe hail outbreaks respectively. While results show that the linear relationship between the MESH area and reports weakens with increasing MESH area and reports, selected cases show MESH more consistently captures severe hail outbreaks compared to reports, regardless of the population of the region affected by an outbreak. Additionally, the relationship between MESH and reports, for smaller hail days, could potentially be utilized when interpreting severe hail reports and subsequent biases in reports.

The correlation between yearly outbreak days and median area in NARR environments supports the hypothesis that the increase in outbreak area is related to the larger-scale forcing of environments supportive of outbreak events. This research will provide useful insights for possible future studies investigating the synoptic scale changes leading to this increase in area and days of environments supportive of severe hail and tornado outbreaks.

**Publications**

Schlie, E., D. Wuebbles, **S. Stevens**, R. Trapp, and B. Jewett, 2019: A radar-based study of severe hail outbreaks over the contiguous United States for 2000-2011. *International Journal of Climatology*, **39**, 278-291. https://doi.org/10.1002/joc.5805

**Other**

This grant supported the completion of Dr. Emily Schlie-Janssen's Ph.D. dissertation, awarded in August 2017.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **1** |
| **# of graduate students formally advised** | **1** |
| **# of undergraduate students mentored during the year** | **0** |

# Climate Data Records and Science Data Stewardship

Climate Data Records (CDRs), also known as Reference Environmental Data Records (REDRs), provide climate-quality satellite and in situ observing datasets that document the Earth's climate and are part of the vast data holdings of the National Centers for Environmental Information (NCEI). NCEI is also responsible for preserving, stewarding, and maximizing the utility of the Federal government's billion-dollar investment in high-quality environmental data. Key objectives include the development and sustainment of as complete and consistent a climate record as possible; ensuring the scientific quality, integrity, and long-term utility of existing datasets and products; and ensuring that all new datasets and any major changes meet internal standards for traceability, lineage, and provenance.

CICS-NC supports efforts at NCEI for the development of interim CDRs for early use of climate-relevant observations, development and transition from research to operations (R2O) of CDRs, and exploration of methods for more effective data ingest, quality assurance, product processing, and data archival.

An appreciation for the functional development from concept to mature observation and agency roles is provided by a slide updated from Bates, et. al., (2008), excerpted in the figure below.

**CDR Name Here**

maturity level as of mm/dd/yyyy

**Climate Data Record (CDR) Maturity Matrix**

| Maturity | Software Readiness | Metadata | Documentation | Product Validation | Public Access | Utility |
|---|---|---|---|---|---|---|
| 1 | Conceptual development | Little or none | Draft Climate Algorithm Theoretical Basis Document (C-ATBD); paper on algorithm submitted | Little or None | Restricted to a select few | Little or none |
| 2 | Significant code changes expected | Research grade | C-ATBD Version 1+ ; paper on algorithm reviewed | Minimal | Limited data availability to develop familiarity | Limited or ongoing |
| 3 | Moderate code changes expected | Research grade; Meets int'l standards: ISO or FGDC for collection; netCDF for file | Public C-ATBD; Peer-reviewed publication on algorithm | Uncertainty estimated for select locations/times | Data and source code archived and available; caveats required for use. | Assessments have demonstrated positive value. |
| 4 | Some code changes expected | Exists at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset | Public C-ATBD; Draft Operational Algorithm Description (OAD); Peer-reviewed publication on algorithm; paper on product submitted | Uncertainty estimated over widely distributed times/location by multiple investigators; Differences understood. | Data and source code archived and publicly available; uncertainty estimates provided; Known issues public | May be used in applications; assessments demonstrating positive value. |
| 5 | Minimal code changes expected; Stable, portable and reproducible | Complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets international standards for dataset | Public C-ATBD, Review version of OAD, Peer-reviewed publications on algorithm and product | Consistent uncertainties estimated over most environmental conditions by multiple investigators | Record is archived and publicly available with associated uncertainty estimate; Known issues public. Periodically updated | May be used in applications by other investigators; assessments demonstrating positive value |
| 6 | No code changes expected; Stable and reproducible; portable and operationally efficient | Updated and complete at file and collection level. Stable. Allows provenance tracking and reproducibility of dataset. Meets current international standards for dataset | Public C-ATBD and OAD; Multiple peer-reviewed publications on algortihm and product | Observation strategy designed to reveal systematic errors through independent cross-checks, open inspection, and continuous interrogation; quantified errors | Record is publicly available from Long-Term archive; Regularly updated | Used in published applications; may be used by industry; assessments demonstrating positive value |

| | |
|---|---|
| 1 & 2 | Research |
| 3 & 4 | IOC |
| 5 & 6 | FOC |

CDRP-MTX-0008 V4.0 (12/20/2011)

***Figure 1.*** *Updated Bates, et. al. CDR Maturity Matrix.*

CICS-NC provides climate and instrument researchers and scientific support staff with specialized scientific and technical experience in support of the life cycle of climate data records at NCEI, providing necessary skills in areas including the following:

- Coordination and development of calibration and validation activities and approaches for high-quality baseline climate data sets from satellite and in situ observations
- Development, refinement, and implementation of algorithms for daily, global, multi-sensor, optimally interpolated Climate Data Records (CDRs); characterization of the sources and magnitudes of errors and biases in the CDRs and development of methodologies for the reduction of these errors and biases
- Development of high-quality baseline climate data sets from satellite and in situ climate data and development of the relationship(s) between the observed tropospheric and stratospheric trends from the ground-based network with those observed from satellite
- Software engineering to support coding, code refactoring, code review, database development, and the transition of scientific codes into operationally executable and maintainable processes
- Development of scientifically based quality control algorithms for in situ climate data of various time scales (hourly, daily, monthly, annually), methods to detect and adjust for inhomogeneities due to issues such as instrumentation changes or observing station relocations, and scientific analyses of structural uncertainty due to these methods
- Research to operation transitions
- "Transitions management" of various externally developed CDRs to NCEI
- Interim CDRs development and implementation for early use of climate-relevant observations
- Stewardship of archival and current climate observations and enhancement of data curation, standards-based data management, metadata, and other data documentation
- Enhancement of all aspects of NCEI data discovery and access services, including data interoperability, semantic technologies, no-SQL and graph database technologies, linked open data standards, and other related technologies and standards
- Exploration of methods for more effective data ingest, quality assurance, product processing, and data archival

| Scientific Subject Matter Expertise Support | |
|---|---|
| **Task Leader:** | Anand Inamdar, Jessica Matthews, Ge Peng, Olivier Prat |
| **Task Code** | NC-CDR/SDS-01-NCICS-AI/JM/GP/OP |
| **NOAA Sponsor** | Jay Lawrimore/Imke Durre |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50% |
| | Theme 2: Climate and Satellite Observations and Monitoring 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities:** | Environmental Observations |

**Highlight:** Several CICS-NC scientists have served or currently serve as subject matter experts on multiple CDR Integrated Product Teams. They are also acting as Product Leads and Portfolio Area Leads for a number of NOAA-NCEI products and portfolios. https://www.ncdc.noaa.gov/cdr

**Background**

Climate Data Record (CDR) Integrated Project Teams (IPTs) are multi-disciplinary teams comprised of members from offices and organizations supporting the transition of research-grade CDRs into an initial operational capability (IOC) status. IPTs provide efficient and effective collaboration, coordination, execution, and reporting of member's office/organization tasks required to transition the CDR to an IOC state.

The science management practices at NCEI are evolving towards a new product portfolio planning approach that follows best practices used widely in both public and private sectors. The objective of this approach is to ensure the focus on stakeholder priorities and to align with today's government environment and expectations. To support this initiative, CICS-NC staff have been enlisted to act as Product Leads for 21 of 208 products, and as Product Area Leads for 3 of 15 product areas.

**Accomplishments**

CICS-NC has participated in six CDR IPTs during this reporting period: Total Solar and Solar Spectral Irradiance (Inamdar), Land Surface Bundle (Matthews), Global Surface Albedo (Matthews), Sea Ice Concentration – Annual (Peng), Ocean Surface Bundle (Peng), and Precipitation – CMORPH (Prat).

Subject Matter Expert IPT responsibilities include:

- leading and scheduling IPT meetings to resolve product technical issues with the PI,
- conducting initial assessment of CDR readiness for transition from scientific perspective,
- reviewing PI-submitted draft products against IOC requirements,
- providing feedback to PI on draft products,
- verifying PI-submitted final products conform to IOC requirements,
- participating in management and technical meetings,
- working with PI, IPT, and O&M Project Manager to complete each CR and route for signatures
- attending Change Control Board meetings when needed,
- reviewing PI-submitted documents delivered as part of the WA (C-ATBD, Maturity Matrix, Data Flow Diagram, Implementation Plan) and providing feedback,
- reviewing PI-submitted documents delivered as part of the WA (QA procedure, QA results, VDD, annual reports) for information only, and
- delivering a CDR presentation to the NCEI User Engagement Branch.

CICS-NC staff acted as ***Product Lead*** for the following products during this reporting period:

- CRN Science: Soil moisture (Bell)
- CRN Science: Heat Health Indices (Bell)
- CRN Science: Drought indices (Bell, Leeper)
- CRN Science: Precipitation Extremes (Leeper)
- Sectoral Engagement (Dissen)
- Total Solar Irradiance CDR (Inamdar)
- Solar Spectral Irradiance CDR (Inamdar)
- AVHRR Surface Reflectance CDR (Matthews)
- Normalized Difference Vegetation Index CDR (Matthews)
- Leaf Area Index and FAPAR CDR (Matthews)
- GOES Albedo CDR (Matthews)
- Sea Surface Temperature – WHOI CDR (Peng)
- Near Surface Atmospheric Properties over Ocean CDR (Peng)
- Heat Fluxes over Ocean – CDR (Peng)
- Sea Ice Concentration CDR (Peng)
- Sea Ice Normals (Peng)
- Precipitation – CMORPH (Prat)
- Extreme Snowfall (Rennie)
- ISTI (Rennie)
- Outgoing Longwave Radiation – Monthly CDR (Schreck)
- Outgoing Longwave Radiation – Daily CDR (Schreck)

The objective of a Product Lead is management of the product, which includes:

- Coordinating the following product phases (as appropriate)
    - Development,
    - Assessment of maturity,
    - Transition to operations,
    - Sustainment in operations,
    - Upgrades, succession, and retirement.
- For operational products, sustaining the product if internally generated or serving as the liaison to external providers.
- Maintaining technical knowledge of the product, including characteristics, status, algorithmic approach, dependencies, limitations, sustainment activities, and uses and user requirements, as appropriate.
- Drafting annual work agreements or SOWs, as appropriate, for non-Federal product development, transition, and/or sustainment activities.
- Providing regular status reports and participating in technical meetings.

CICS-NC staff acted as ***Product Area Lead*** for the following product areas during this reporting period:

- Land surface properties (Matthews)
- Snow and ice (Peng)
- Radiative fluxes (Schreck)

The objective of a Product Area Lead is strategic and coherent planning and management of the product portfolio, which includes:

- Maintaining a coherent strategic portfolio vision and plan, including potential new work activities, responsive to evolving user needs.
- Maintaining a life cycle management plan for portfolio products and maintain a high-level schedule to accomplish plans.
- Maintaining status and priority ranking of each product in portfolio.
- Reviewing and providing input on product change requests.
- Reviewing and recommending annual work agreements, as needed, for product development, improvement, sustainment, and/or support.

**Planned work**

- Continue participating on CDR IPTs as requested to transition CDRs to initial operating capability status.
- Continue acting as Product Leads and Product Area Leads to support the NOAA NCEI product inventory.

**Presentations**

**Matthews, J.**, 2018: Mathematics in Climate Science. *University of Tennessee Mathematics Department Undergraduate Math Conference*, Knoxville, TN, April 21, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Common Ingest Agile Development Team** | |
|---|---|
| **Task Leader** | Lou Vasquez, Linda Copley |
| **Task Code** | NC-CDR/SDS-02-NCICS-LV/LC |
| **NOAA Sponsor** | Scott Hausman |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: 40%; Goal 2: 40%; Goal 3: 20% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** This software development team works in concert with NCEI staff to continually enhance, modify, and deploy the new Common Ingest (CI) system at NCEI-NC. This year the team designed and developed several solutions to support the NCEI-NC Operations team in migrating the remaining datasets from the legacy ingest system to the new CI system and expanded the capabilities of the Ingest Engines.

**Background**

Common Ingest is the solution delivered by the Common Ingest Agile Development Team for the ingest and archive of environmental information at NCEI. Common Ingest is currently being deployed at NCEI-NC for the ingest and archive of up to 6.7 terabytes per day of weather and climate data archives, processing over 150,000 files, packaged and stored in as many as 13,000 archive information packages.

The Common Ingest system implements a modern software architecture and provides a browser-based interface for configuration and monitoring. The system is composed of an Ingest Manager and multiple Ingest Engines. Ingest Manager is responsible for submitting granules through the system for processing and monitoring the result of these submissions. Ingest Engines are responsible for processing granules as they pass through the system. Some engines are capable of routing processing to the next engine, removing the necessity to pass all processing through the Manager.

The system stores all desired file processing steps as it traverses the system, resulting in persistent system status and full file provenance throughout the ingest process. Common Ingest employs a centralized message broker for asynchronous routing of processing control and status throughout the system.

Common Ingest is built so that data streams can be user-configured by defining the processing steps using multiple processing engines, as in a workflow system. This allows Common Ingest to be configured to handle multiple, complex data streams, without the need for additional programming.

**Accomplishments**

As members of an agile software development team, CICS-NC staff work in concert with Federal employees and contractors to continually enhance, modify, and deploy the new Common Ingest system at NCEI-NC. A major effort this year involved supporting the NCEI-NC Operations team in migrating the remaining datasets from the legacy ingest system to the new Common Ingest system. As the migration progressed and new requirements were identified, the team designed and developed solutions in ways that could be generically applied for the ingest of current and future datasets.

The team enhanced Common Ingest to handle the processing required to ingest the Nexrad3 data stream to archive. This dataset is received packaged in files that each contain a few minutes of data for all Nexrad

stations and Nexrad3 models, but archived in daily files by station. The Common Ingest system is required to unpackage the ingested data and re-organize it for archive. We receive approximately 6,000 package files each day, break them open into about 2.5 million station/model data files, reorganize them into station directories, then archive them as daily files for each of 200 stations. As we implemented these enhancements, we were challenged by the physical architecture of the system, which had problems handling the 2.5 million files per day. Several options involving new Common Ingest Engines and changes to the underlying architecture were attempted before we settled on a workable solution. Nexrad3 is the last NCEI-NC legacy data stream to be migrated to Common Ingest and is on track to be migrated this spring.

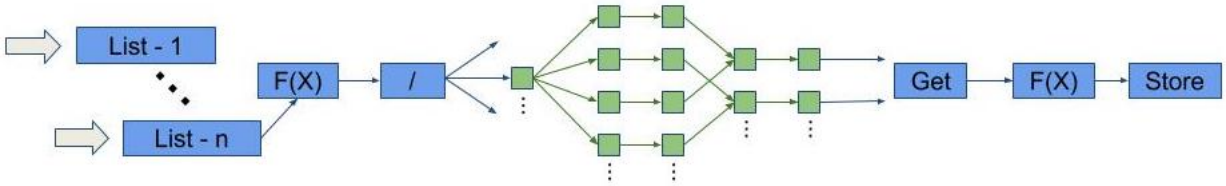



***Figure 3.*** *Common Ingest Nexrad3 Processing Flow.*

The capabilities of the Ingest Engines were expanded during this period. We added or updated engines that allow Common Ingest to append to a tar file, to tar files by directory (instead of using a list of files), and to create tar files separate from the time-out mechanism that determines when to package a tar file. We implemented an engine for the SRRS data streams that splits data out of the provider-specific data format and stores it in files suitable for archive. We implemented other features that allow us to skip engines when we restart processing on a data stream, rename files with current system time appended as they are fetched onto our system to prevent filename collisions, allow recursing into directories when listing files on a providers system, and a time tolerance used to ignore small differences in file timestamp when listing files. Other engines were modified to use multiple queues as they progressed through steps in the engine, which allows for more granular control of processes within an engine.

In support of a more agile, Continuous Integration / Continuous Deployment process, the team worked with the lead infrastructure support implementer to streamline the process and become more responsive to the operator and centers' needs. The effect of this can be seen in our ability to produce 35 releases over the period of this annual report, whereas prior releases sometimes took as much as a month, if not weeks, to deploy. Specific process improvements included a developer-based initial code review for early deploy with additional deeper follow up reviews for hotfix oriented deploys, self-managed automated test and deploy tools, and a simpler configuration management system.

**Planned work**

- Reduce engine JVM memory footprint through combination of VM options and broader engine function.
- Scale system horizontally, adding servers as needed. Resolve complications related to NCEI implementation. Resolve CI system sharding issues.
- Implement configuration template capability to promote more atomic, idempotent, and therefore composable, robust workflows. This would also make operator stream configuration simpler.

- Increase message system partitioning to support sharding and scaling, and prevent problematic streams from affecting the entire system.
- Move functionality, such as routing and object tracking out of manager, reducing interdependence and making system more cloud-ready.
- Integrate with external center services for inventory, object store, remote-access workflow tools, and other metadata tracking.
- Provide user with insight and control over aggregation state.
- Integrate archive system response with stream completion process.
- Manage transfer process, using chunk transfer approach to report, limit, and control slow transfers.

**Products**

Common Ingest components deployed in NCEI production:

- Common Ingest v2.0.2 Nexrad enhancements/fixes; time-aggregator fix; simplified home page
- Common Ingest v2.0.3 Message acknowledgements
- Common Ingest v2.0.4 Partitionor and time-aggregator fixes
- Common Ingest v2.0.5 feedingWindowOffset, concurrent feeds; hpss-archiver fixes
- Common Ingest v2.1.0 New engines; UI improvements; bug fixes
- Common Ingest v2.1.1 Correct tar-creator gzip bug
- Common Ingest v2.2.0 Path-transform skippable and fix future date; rename on fetch; heartbeat
- Common Ingest v2.2.1 manifestReader txMog algorithm; file recursion bug fix; feedingWindowOffset fix
- Common Ingest v2.3.0 improve nd-file-splitter memory; manifestReader restart fix
- Common Ingest v2.3.1 Bug Fixes for nd-file-splitter, Cleanup, and Restarts
- Common Ingest v2.4.0 SHA256, file recurse; restart perf; class archiver manifest; timestamp on fetch
- Common Ingest v2.4.1 manifest size limit, notification stream ordered, manifested relative path
- Common Ingest v2.4.2 nexrad3 alternate directory; file recursion fix; nd-splitter improvements
- Common Ingest v2.4.3 db sourcePath increased to 2000 characters; default grab all files local recursion
- Common Ingest v2.5.0 Nd-file-splitter; ACCEPT_ALL; Driver upgrade
- Common Ingest v2.5.1 NR2/NR3/NDFD enhancements
- Common Ingest v2.5.2 timestampOnFetch for feedingWindowOffset
- Common Ingest v2.5.3 SFTP fetch connection; dfeeder infoStream
- Common Ingest v2.6.0 Engine Upgrades; Logging/UI/Restart Enhancements
- Common Ingest v2.7.0 Zero-byte files; failed queue; UI enhancements
- Common Ingest v2.7.3 tar-creator enhancements; infinite loop bug fix; silent failure bug fix
- Common Ingest v2.7.4 Prevent duplicate files; handle tar errors
- Common Ingest v2.7.5 HPSS Gluster workaround; NR3 changes
- Common Ingest v2.7.6 HPSS Gluster workaround and improved logging
- Common Ingest v2.7.7 hpss-archiver path check
- Common Ingest v2.7.8 metaObject streams optional continue on failure
- Common Ingest v2.7.9 log error enhancement
- Common Ingest v2.8.0 remote-io local transfer
- Common Ingest v2.8.1 local transfer; relative location; hpss-archiver refinement; remove errant spaces

- Common Ingest v2.9.0 Timestamp tolerance; retry CLASS manifests
- Common Ingest v2.9.2 NR3 Restart; NR2 dupe fix; Various enhancements
- Common Ingest v2.10.0 Aggregations view; more retries; close streams
- Common Ingest v2.10.1 untarToFilenameDir
- Common Ingest v2.10.2 Fix CLASS manifest stream closure
- Common Ingest v2.10.3 NR3 untar fix

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **35** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **35** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*Delivered 35 Common Ingest components (see 'Products') that are deployed in the NCEI production environment.*

| Spatial–Temporal Reconstruction of Land Surface Temperature from Daily Max/Min Temperatures | |
|---|---|
| **Task Leader** | Anand Inamdar |
| **Task Code** | NC-CDR/SDS-03-NCICS-AI |
| **NOAA Sponsor** | Jeff Privette |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Data Fusion and Algorithm Development |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight**: An algorithm was developed to reconstruct LST under almost all-sky conditions by combining time series of daily maximum and minimum temperatures with estimates of net surface solar radiation (or surface solar absorption) derived from geostationary visible channel data. This strategy has potential applications for the new 5 km gridded daily nClimDiv max/min temperature dataset that is being produced at NOAA.

**Background**

Land surface temperature (LST) and its diurnal variation play a major role in the study of land-atmosphere interactions, climate change, hydrological cycle, vegetation, and soil moisture conditions. They are also critical in the study of epidemiology, agriculture, urban heat island effects, and varying demands on energy consumption. Physically based approaches that use thermal infrared measurements from remote sensing satellites and a combination of harmonic and exponential decay functions to model daytime and nighttime variation of LST are applicable only under clear-sky conditions. Missing LST values due to the presence of clouds limits the potential application of available satellite LST products. Diurnal evolution of the LST is strongly correlated with the diurnal pattern of surface absorbed solar radiation. Results from a companion study on the diurnal variation of net surface solar radiation (Inamdar and Guillevic, 2015) provides a promising option for filling in the spatial and temporal gaps in LST values, even under partially cloud-contaminated conditions.

**Accomplishments**

The approach for reconstructing LST has been further refined by subdividing the available in situ and model data into training, test, and validation sub-groups and applying a non-linear Lavenberg-Marquardt least square fit technique (Markwardt 2009). The validation was extended further by including the vast network of U.S. Climate Reference Network (USCRN) site data for the year 2018 through employing the surface incident insolation data in lieu of the surface absorbed solar radiation. Since most of the available max/min temperature data is acquired from in situ measurements of air temperature, such as data from Global Historical Climatology Network (GHCN) sites and the new NOAA-produced nClimGrid data), a study was conducted to investigate the interrelationship between the surface air temperature (measured in situ) and skin temperature represented by LST. This empirical relationship, which depends on the latitude, vegetation fraction, and proximity to coast, will be valuable in converting the in situ max/min temperatures to corresponding LST values. Figure 1 shows the performance of the LST reconstruction scheme for the USCRN site in Bowling Green, KY, for different days in January, April, May, and August 2018, ranging in complexity from a clear day to cloudy days, which are more challenging for the reconstruction process.

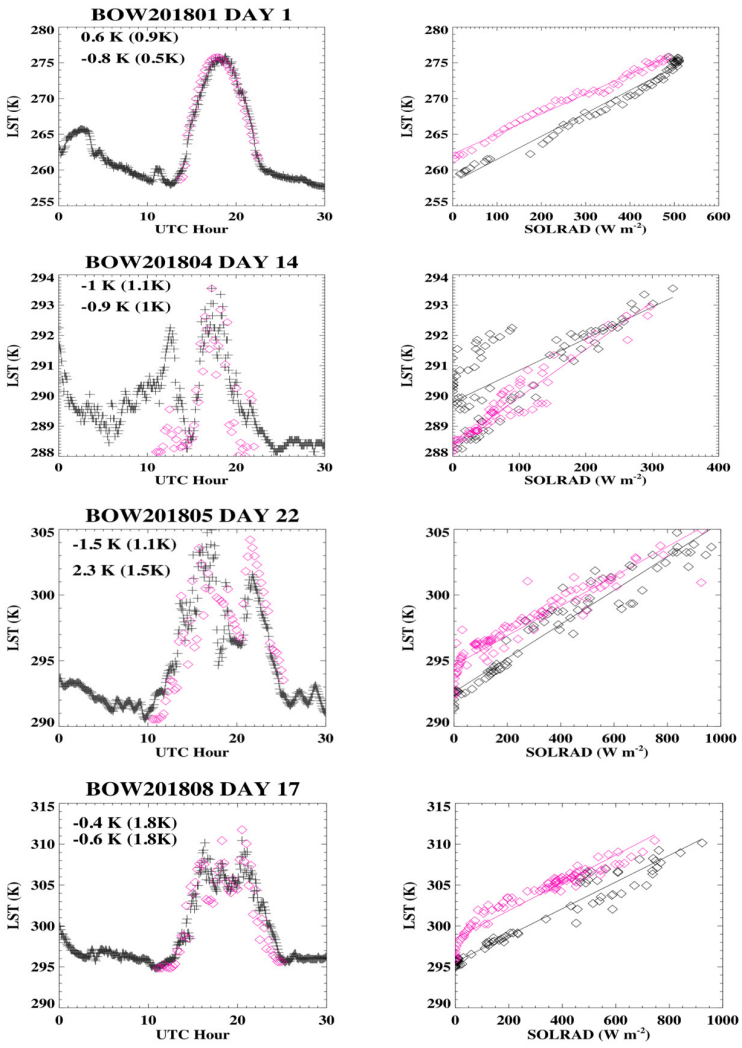



***Figure 1. Left****: In situ measurements of LST at Bowling Green (KY) (+ symbols) for the days marked at the top title and reconstructed LST (shown in magenta diamond symbols).* ***Right****: Observed LST vs incident solar insolation for ascending and descending (magenta) solar legs. The inset numbers represent the mean error and standard deviation in K.*

**Planned work**

- Investigate adding MODIS LST as additional constraints to improve performance.
- Explore other sources of funding or collaboration (funded) to extend the work.
- Submit methodology paper to *Geophysical Research Letters.*

**Products**

- Algorithm to reconstruct LST from daily max/min temperatures and solar data (incident solar radiation or surface absorbed solar radiation)

**Presentations**

**Inamdar, A.**, 2018: Spatio-temporal reconstruction of land surface temperature from record of daily max/min temperatures. *University of Maryland Department of Atmospheric and Oceanic Science (AOSC) Seminar Series*, College Park, MD, October 11, 2018.

**Inamdar, A.**, 2018: Spatio-temporal reconstruction of LST. *NCEI Science Council meeting*, Asheville, NC, November 8, 2018.

**Inamdar, A.**, and **R. Leeper**, 2019: On the Inter-relationship Between Land Surface Air Temperature and Skin Temperature. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **1** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*Algorithm to reconstruct LST from daily max/min temperatures and solar data*

| Transitioning of the International Satellite Cloud Climatology Project Process to NCEI-NC | |
|---|---|
| **Task Leader** | Anand Inamdar |
| **Task Code** | NC-CDR/SDS-04-NCICS-AI |
| **NOAA Sponsor** | Jeff Privette |
| **NOAA Office** | NESDIS/NCEI; NESDIS/STAR |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** The ISCCP-H series product for the extended period 2010 to mid-2015 was completed and archived. Production for the period mid-2015 to mid-2017 was also completed and archived as an interim CDR (ICDR) pending availability of the nnHIRS profile. The drifting NOAA-18 polar orbiter was replaced with NOAA-19 as the afternoon anchor satellite beginning with year 2013.
https://www.ncdc.noaa.gov/isccp

**Background**

The International Satellite Cloud Climatology Project (ISCCP) began in 1983 under the leadership of Dr. William Rossow (CCNY and GISS) as an activity of the World Climate Research Programme (WCRP) Global Energy and Water Exchange (GEWEX) core project. ISCCP's objective is to derive a cloud climatology of the Earth by pooling the radiances from the suite of geosynchronous meteorological satellites around the globe and the polar orbiting AVHRR sensors. It is one of the longest-lived and most widely used satellite climate datasets in existence and has been extensively cited in the peer-reviewed literature. An example of its widespread application is the ISCCP simulator, an algorithm developed to mimic ISCCP observations from Global Climate Models (GCMs) in order to evaluate model simulations of the current environment. Furthermore, ISCCP data (and its derivative datasets) have been used to study and understand a wide array of weather and climate phenomena, including clouds, Earth's radiation budget, aerosols, surface radiation budgets, renewable energy, hurricanes, tropical cyclone genesis, climate modeling, stratospheric moisture, weather states, cloud forcing and cloud feedbacks, and the relationship of clouds with numerous other phenomena.

The ISCCP H-series cloud product has several improvements over its predecessor, the ISCCP D-series. These include higher-resolution input satellite data, an expanded period of record (1983-2015 and continuing beyond), temporally stable atmospheric profiles derived through the neural network approach, higher-resolution (1 degree) gridded products and radiances, and the availability of cloud information at pixel-level (10 km, every 3 hours).

**Accomplishments**

Production for the extended period of 2010 to mid-2017 has been completed. The 2010–2015 period was reviewed and approved by the PI (Dr. William Rossow) and the output files were archived. The drifting NOAA-18 polar orbiter was replaced by the introduction of the next in series, NOAA-19, beginning with year 2013. The team also revised the ISCCP calibration procedure with a new approach to derive the normalized and absolute calibration. NOAA-19 and new GEO satellites HIMAWARI -8 and GOES-16 (GOES-R) have been added along with the associated HBT (counts to radiance calibration) tables which have been produced and made available to process production. Due to non-availability of the nnHIRS profiles of temperature and water vapor and also of ozone beyond mid-2015, a climatology of nnHIRS was developed

for each day of the year using years 1983–1995 and employed in extending production from mid-2015 to mid-2017. The archived product for this period represents an interim (ICDR) product pending production of new nnHIRS profiles. Generation of ICDR also fulfills the mandated requirement of frequent updates to the NCEI Climate and Weather Center (CWC). A detailed investigation into the impact of using climatology versus the actual profiles was launched, employing the year 2012 as a test. The results for three specific parameters of cloud amount, cloud-top pressure, and cloud-top temperature are shown in Figure 1, which suggests that use of climatology doesn't significantly alter the results.

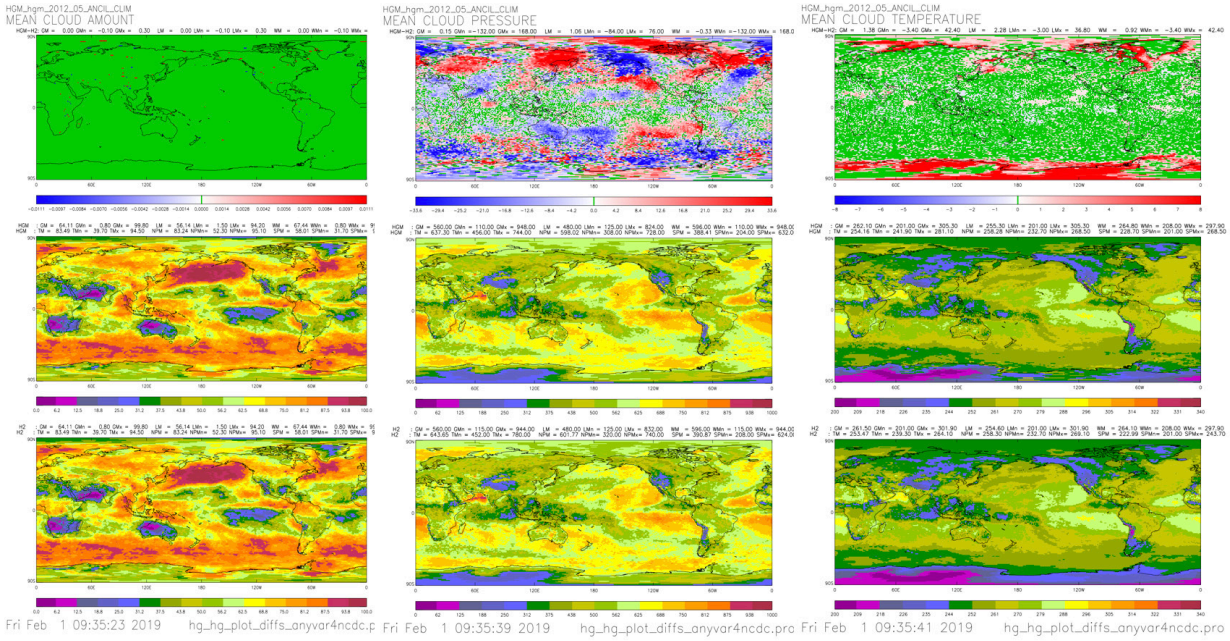



***Figure 1.*** *Impact of using nnHIRS and ozone climatology on three parameters (cloud amount, cloud pressure, and cloud temperature) versus actual data for year 2012. The middle panel represents the H-series gridded monthly (HGM) using the actual data, the bottom panel employs the developed climatology, and the top panel represents the difference.*

**Planned work**

- Employ and convert the next-generation polar satellite sensor Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the Suomi NPP, replacing the current NOAA series Global Area Coverage (GAC) AVHRR data. The new transformed data will be archived as VGAC data similar in structure and format to the legacy AVHRR GAC.
- Perform an intercomparison study between ISCCP and GOES-16–based products, as many of the baseline operational products from the GOES-16 sensor overlap with what ISCCP produces.
- Form an independent calibration approach for GOES-16 employing the NASA Cloud and Earth's Radiant Energy System (CERES) broadband sensor as an anchor. This approach allows back-testing the visible channel calibration of GEOs back to year 1998 and has the potential to produce the net surface shortwave radiation as a byproduct without much additional effort.

**Products**

- H-series cloud product for the extended period (2010–2015), including the new NOAA-19 sensor from 2013 to 2015

- Climatology of nnHIRS profiles and ozone for each day of year to enable frequent updates and produce ICDRs
- HBT Calibration tables for the period mid-2015 to June 2017, including the new sensors NOAA-19, HIMAWARI-8, GOES-16, and MSG-1 (INS segment)

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **3** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*H-series cloud product for the extended period (2010–2015); climatology of nnHIRS profiles and ozone; HBT Calibration tables for the mid-2015 to June 2017*

| Implementation of Geostationary Surface Albedo (GSA) Algorithm with GOES Data | |
|---|---|
| **Task Leader** | Jessica Matthews |
| **Task Code** | NC-CDR/SDS-05-NCICS-JM |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** The GSA algorithm is being implemented as the U.S. contribution to an international collaboration between Europe, Japan, and the United States to produce a joint climate data record. www.scope-cm.org/projects/scm-03/

**Background**

Surface albedo is the fraction of incoming solar radiation reflected by the land surface, and therefore is a sensitive indicator of environmental changes. To this end, surface albedo is identified as an Essential Climate Variable (ECV) by the Global Climate Observing System (GCOS). In support of the Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM), NCEI is implementing the GSA algorithm for GOES data to contribute to an international effort in collaboration with EUMETSAT, JMA, and Meteo-Swiss. Currently, the GSA algorithm generates products operationally at EUMETSAT using geostationary data from satellites at 0° and 63°E and at JMA using 140°E geostationary data. To create the stitched global Level 3 product as illustrated in Figure 1, NCEI is tasked with implementing the algorithm for GOES-E (75°W) and GOES-W (135°W).

Previously, as part of the SCOPE-CM agreement, the GSA algorithm was run with GOES data for a pilot period of 2000–2003. A project charter was developed in July 2014 describing the implementation of a related land surface albedo product, the so-called Albedo of the Americas (AOTA). This product will be focused on the Americas, which is the primary user base of the CDRP, and will provide greater temporal resolution and historical extent than other available albedo datasets. In short, the scope of the plan is to process 1995–2018 GOES-GVAR data (GOES-8 through 15) using the SCOPE-CM algorithm with a unified approach to calibration, handling of NWP inputs, and cloud masking.

**Accomplishments**

This project is one of only 10 selected by the SCOPE-CM Executive Panel from an open competition. We proposed to extend the international collaboration into Phase 2 which is planned to last 5 years and includes activities such as a common cloud mask approach, a common intercalibration method, exploration of different temporal resolutions and formats of output, and validation of Level 2 products. We are in the last year of this 5-year plan.

Looking forward to next generation reprocessing efforts, a pilot study is underway using this project to explore satellite data reprocessing in the cloud. Current commercial practice computing techniques are being implemented to replicate traditional high-performance cluster computing in the cloud environment. Careful cost comparisons, in terms of both dollars and time, are being calculated to understand the scale of future reprocessing of massive next generation remote sensing data.

In the current phase, each agency is focused on producing Level 2 data from their own satellites. The long-term plan involves the fusion of the five Level 2 products to form a near-global product. In preparation for this activity we are collaborating with statisticians from University of California, Santa Cruz to create a framework leveraging spatial statistics methods.

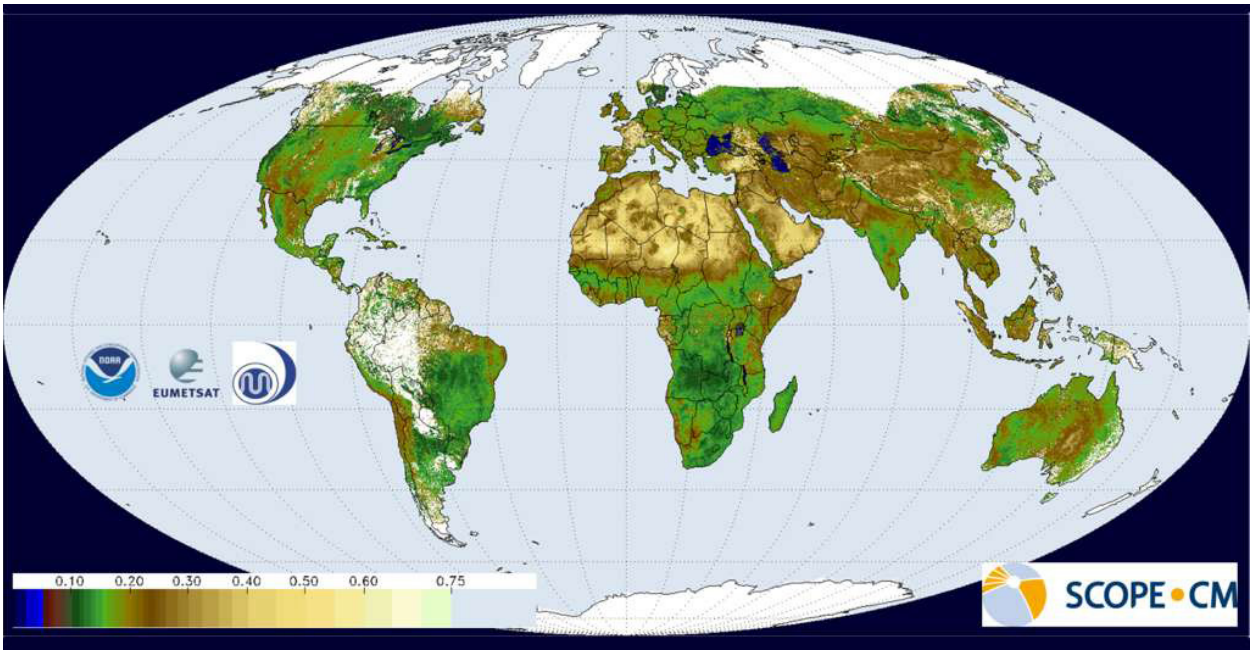



***Figure 1.*** *Broadband black sky albedo spatial composite product for the period 1-10 May 2001.*

**Planned work**

- Implement and test cloud mask as developed by the Satellite Application Facility on Climate Monitoring.
- Re-process GOES-E and GOES-W data for 1995–2018 with this cloud mask.
- Perform validation of GSA products with MODIS and in situ observational data.
- Begin transition to Initial Operating Capability within NOAA's Climate Data Records Program.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| HIRS Temperature and Humidity Profiles | |
|---|---|
| **Task Leader** | Jessica Matthews |
| **Task Code** | NC-CDR/SDS-06-NCICS-JM |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50% |
| | Theme 2: Climate and Satellite Observations and Monitoring 50% |
| **Main CICS Research Topic** | Data Fusion and Algorithm Development |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** The team is developing a global temperature and humidity profile dataset for the time period of 1978–present. The data are produced by applying neural networks to High-resolution Infrared Radiation Sounder (HIRS) Data.

**Background**

The goal of this task is to derive temperature at 12 different altitudes/pressures (surface, 2m, 1000mb, 850mb, 700mb, 600mb, 500mb, 400mb, 300mb, 200mb, 100mb, and 50mb) and humidity at 8 different altitudes/pressures (2m, 1000mb, 850mb, 700mb, 600mb, 500mb, 400mb, 300mb) using HIRS data.

In previous dataset versions, HIRS Channels 2–12 were used for the temperature profiles, while HIRS Channels 4–8 and 10–12 were used as inputs for the humidity profiles. These selections were based on the known relations of the channel information to the different physical variables. The HIRS data coupled with $CO_2$ data were used as inputs to a neural network. The neural networks were calibrated according to surface pressure bins. There are two different neural nets, one each for surface pressures less than 850mb and surface pressures greater than 850mb. Radiative Transfer for Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (TOVS) (RTTOV) data based on more than 62,000 ECMWF profiles were used as inputs for neural network training purposes.

The resultant neural networks were applied to produce global temperature and humidity profiles using a series of 13 satellites during the 1978–2017 time period. When processing the data, USGS topography information on a 1° grid was used to define topography (and thus surface pressure) to select which of the three neural nets to apply. Additionally, monthly $CO_2$ inputs (assumed to be global) were obtained from the Scripps $CO_2$ program.

**Accomplishments**

A v2018 dataset has been completed. Key updates in this version include:

- Removal of the HIRS channel 10 dependencies from the neural networks based on the detection of long-term instability
- Removal of unreliable Metop-02 data from May 2011 through March 2013
- Simplifying from three neural networks to two
- Using 3 years of RS92 and COSMIC2013 data for bias correction (2008-2010)
- A statistical methodology to remove extreme outliers
- Additional quality control flags

To validate this long-term dataset, evaluation of the intersatellite time series stability is coupled with intercomparisons with independent observation platforms as available in more recent years. Twelve polar

orbiting satellites with the HIRS instrument were used to produce the retrievals: N-6, N-7, N-8, N-9, N-10, N-11, N-12, N-14, N-15, N-16, N-17, and Metop-2. Eleven pairs of satellites carrying the HIRS instrument with time periods that overlap were examined. Correlation coefficients were calculated for the retrieval of each atmospheric pressure level and for each satellite pair. Figure 1 illustrates the correlation coefficients, which may be interpreted as a measure of the agreement between the two set of observations. When evaluating all cases for both temperature and humidity (11 satellite pairs * (8 humidity levels + 12 temperature levels) = 220 cases), correlation coefficients greater than 0.7 are achieved more than 90% of the time. Very high correlation is demonstrated at the surface and 2-meter levels for both temperature (>0.99) and specific humidity (>0.93).

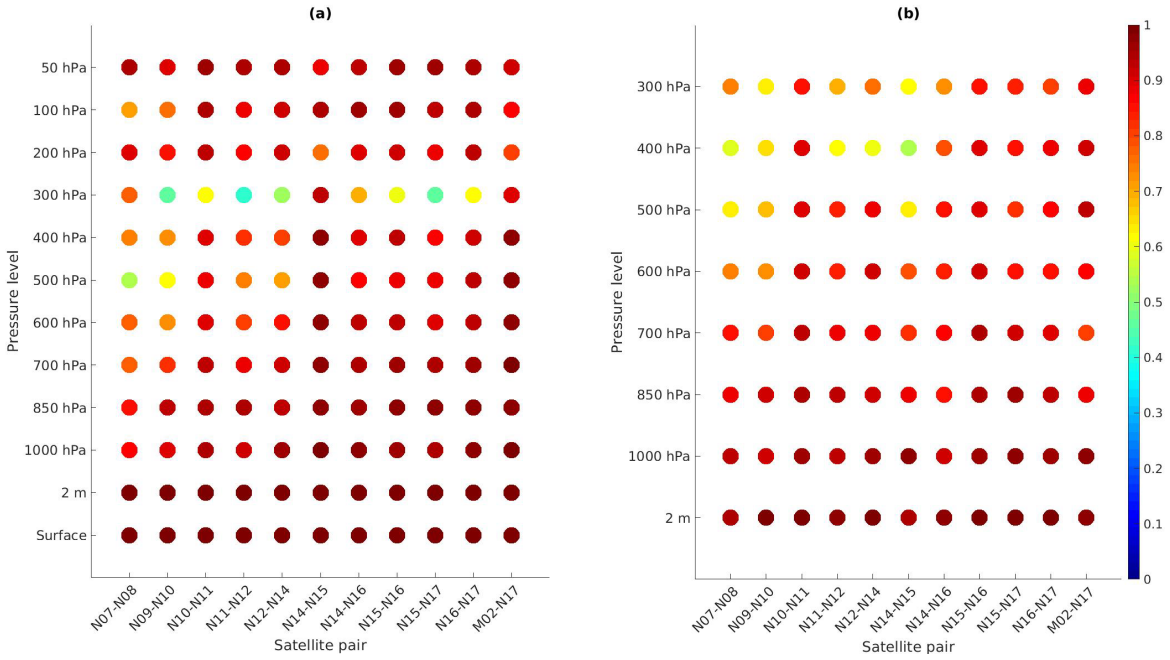



***Figure 1.*** *Correlation coefficients by standard atmospheric pressure level of eleven satellite pairs for (a) temperature and (b) specific humidity.*

For the period of 2006–2017, intercomparisons are performed with four independent observation platforms: radiosonde (RS92), Constellation Observing System for Meteorology Ionosphere and Climate (COSMIC), Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN), and Infrared Atmospheric Sounding Interferometer (IASI). Good agreement is seen at all profile levels but, notably, very close matching of surface and 2-meter temperatures over a wide domain of values is depicted in all presented intercomparisons. Figure 2 illustrates comparisons with a Level 2 product derived from a hyperspectral instrument also onboard the MetOp series, the Infrared Atmospheric Sounding Interferometer (IASI).

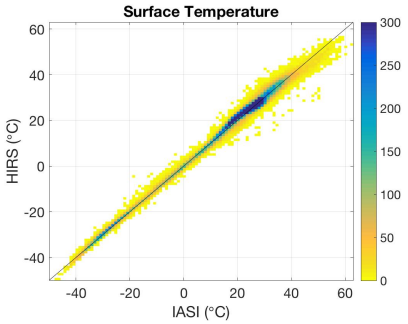



***Figure 2.*** *Histogram of surface temperature for IASI vs. HIRS in January 2014.*

**Planned work**

- Implement conversion to netCDF format
- Explore implementing bootstrap methodology to provide associated uncertainty estimates
- Investigate extending the record to include CriS inputs to replace HIRS
- Submit a manuscript on validation of full time series and initial analysis
- Continue collaborations with user groups (including ISCCP and NASA's Surface Radiation Budget Team)

**Products**

- v2018 HIRS Temperature and Humidity Profiles dataset (1978–2017)

**Presentations**

- **Matthews, J.**, 2018: Optimization Methods in Remote Sensing. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 14, 2018.
- **Matthews, J.**, 2018: Remotely sensed retrievals of atmospheric temperature and humidity profiles. *University of Minnesota Institute for Research on Statistics and its Applications (IRSA) Annual Conference*, Minneapolis, MN, May 3, 2018.
- **Matthews, J. L.**, 2018: Remotely sensed retrievals of atmospheric temperature and humidity profiles. *NOAA Cooperative Institute for Climate and Satellites Executive Board Meeting*. College Park, MD, April 30, 2018.
- **Matthews, J. L.**, and L. Shi, 2018: Long-term HIRS-based Temperature and Humidity Profiles. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **4** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*v2018 HIRS Temperature and Humidity Profiles dataset (1978–2017)*

| Scientific Data Stewardship for Digital Environmental Data Products | |
|---|---|
| **Task Leader** | Ge Peng |
| **Task Code** | NC-CDR/SDS-07-NCICS-GP |
| **NOAA Sponsor** | Kenneth Casey |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 80%<br>Goal 3: Healthy Oceans 20% |
| **NOAA Strategic Research Priorities** | Other |

**Highlight**: The NCEI/CICS-NC data stewardship maturity matrix (DSMM) has been applied to more than 800 individual NCEI datasets: 300+ of those DSMM assessment ratings have been captured by ISO-standard collection-level metadata and used by the NOAA *OneStop* Search and Discovery system for relevancy ranking. International groups including the Working Group on Information System and Services (WGISS) of Committee on Earth Observation Satellites (CEOS) and the WMO Commission for Climatology (CCl) International Expert Group on Climate Data Modernization (IEG-CDM) have also adapted the DSMM.

**Background**

U.S. governmental directives, e.g., the Information Quality Act of 2001 and the Federal Information Security Management Act of 2002, and expert bodies' recommendations require that environmental data be (Peng 2018):

- *scientifically sound and utilized,*
- *fully documented and transparent,*
- *well-preserved and integrated,*
- *readily obtainable and usable*.

Any improvement process requires the knowledge of the current status and needed improvements. In collaboration with the NOAA *OneStop* program, NCEI's Data Stewardship Division, and NCEI's Center for Weather and Climate, a consistent framework, the Data Stewardship Maturity Matrix (DSMM), has been applied to over 800 individual datasets. The DSMM assessed the quality of stewardship practices applied to these digital environmental datasets to provide consistent information such as the state of data integrity and usability to users and stakeholders. The DSMM has been discussed and adapted by international groups such as the Working Group on Information System and Services (WGISS) of Committee on Earth Observation Satellites (CEOS) (WGISS Data Stewardship Interest Group 2017) and the International Expert Group on Climate Data Modernization (IEG-CDM) of WMO Commission for Climatology (CCl) (WMO SMM-CD Working Group 2019).

Cutting-edge research in scientific data stewardship of federally funded digital environmental data products led to a peer-reviewed paper on an enterprise framework for managing scientific data stewardship (Figure 1; Peng et al. 2018).

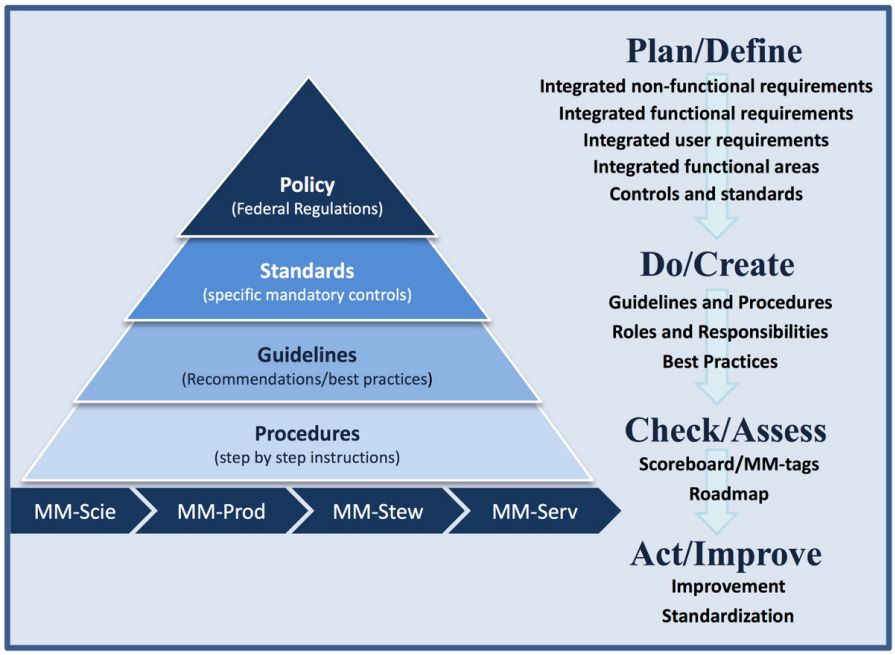



***Figure 2.*** *Conceptual diagram of the data-centric, enterprise scientific data stewardship framework. The staggered pyramid represents the interconnectedness of federal regulations, mandatory controls, recommendations, and instructions. The MM-tags beneath the pyramid represent maturity assessments through the entire data product life cycle. The text on the right represents each step of the PDCA cycle and summarizes high-level outcomes at each step.*

**Accomplishments**

- Supported *OneStop* application of DSMM and coordinated the development of a data use/service maturity matrix.
- Communicated with the community to increase the awareness of DSMM and of consistently curating data quality descriptive information for both human and machine end-users.
- Lead-authored a paper reviewing maturity assessment models, published by a peer-reviewed journal (Peng 2018).
- Lead-authored a peer-reviewed paper on a conceptual enterprise framework for managing scientific data stewardship (Peng et al. 2018).
- Led the development of the WMO Stewardship Maturity Matrix for Climate Data (SMM-CD) and the guidance booklet to facilitate the SMM-CD assessment of individual WMO datasets as a part of the WMO CCl High Quality Global Data Management Framework for Climate (HQ-GDMF).
- Organized/co-chaired several conference sessions and lead/co-authored several conference presentations on systematically curating and presenting data quality information to users.

**Planned work**

- Continue to support the WMO CCl HQ-GDMF as an associate member of WMO CCl Expert Team for Data Development and Stewardship (ET-DDS).
- Participate in the Research Data Alliance (RDA) FAIR Data Maturity Model Working Group for developing a maturity assessment model of datasets being FAIR (Findable, Accessible, Interoperable, and Reusable).
- Continue to engage stakeholders and the Earth Science community by participating in NOAA, national, and international data stewardship working groups and attending relevant conferences.

**Publications**

*Peer-reviewed*

**Peng, G.**, J. L. Privette, C. Tilmes, S. Bristol, **T. Maycock**, J. J. Bates, S. Hausman, **O. Brown**, and E. J. Kearns, 2018: A Conceptual Enterprise Framework for Managing Scientific Data Stewardship. *Data Science Journal.* ***17****.* http://doi.org/10.5334/dsj-2018-015

**Peng, G.**, A. Milan, N. Ritchey, R. P. Partee II, S. Zinn, P. E. McQuinn, Lemieux III, R. Ionin, D. Collins, P. Jones, A. Jakositz, and K. S. Casey, 2018: Practical Application of a Stewardship Maturity Matrix for the NOAA OneStop Program. *Data Science Journal.* Submitted for a special PV2018 issue.

Ramapriyan, H. K., R. R. Downs, J. Dozier, R. Duerr, M. Folk, J. Frew, N. Hoebelheinrich, C. A. Mattmann, and **G. Peng**, 2019: Bruce Barkstrom (1944–2018), *Eos*, **100**. http://doi.org/10.1029/2019EO115561

*Non-peer-reviewed*

Aich, V., O. Baddour, C. Lief, **G. Peng**, and W. Wright, 2019: A WMO-Wide Stewardship Maturity Matrix for Climate Data. Document ID: WMO-SMM-CD-0001. Version: v03r00 20190128. *Figshare*. http://doi.org/10.6084/m9.figshare.7006028

Aich, V., O. Baddour, C. Lief, **G. Peng**, and W. Wright, 2019: The guidance booklet on the WMO-Wide Stewardship Maturity Matrix for Climate Data. Document ID: WMO-SMM-CD-0002. Version: v03r00 20190131. *Figshare*. http://doi.org/10.6084/m9.figshare.7002482

Lief, C., and **G. Peng**, 2019: The WMO Stewardship Maturity Matrix for Climate Data (SMM- CD) Template. Document ID: WMO-SMM-CD-0003. Version: v03r01–20190224*. Figshare*. http://doi.org/10.6084/m9.figshare.7003709

**Presentations**

Gallaher, D. W., N. J. Hoebelheinrich, **G. Peng**, and R. Davis, 2018: Research Data Management: Developing Standards for Data Usability and Trust and Building Capacity with Targeted Data Training for the Research Team I. *American Geophysical Union Fall Meeting*, Washington DC, December 12, 2018.

Gallaher, D. W., N. J. Hoebelheinrich, **G. Peng**, and R. Davis, 2018: Research Data Management: Developing Standards for Data Usability and Trust and Building Capacity with Targeted Data Training for the Research Team Poster. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.

Lemieux III, P. A., R. P. Partee II, R. Ionin, and **G. Peng**, 2019: Development of the Data Stewardship Maturity Questionnaire for Assessing Stewardship Quality of NOAA Datasets: Lessons Learned and Practical Applications. *2019 ESIP Winter Meeting*, Bethesda, MD, January 16, 2019. https://doi.org/10.6084/m9.figshare.7588538

Moroni, D. F., H. K. Ramapriyan, and **G. Peng**, 2018: Background for CEOS WGISS data management and stewardship maturity matrix. *NASA Earth Science Data System Working Group meeting*, Annapolis, MD, April 19, 2018.

Moroni, D. F., H. K. Ramapriyan, and **G. Peng**, 2018: Surveying the Approaches and Advances in Earth Science Data Uncertainty Quantification, Characterization, Communication, and Utilization. *American Geophysical Union Fall Meeting*, Washington DC, December 13, 2018.

Moroni, D. F., Y. Wei, H. Ramapriyan, D. Scott. R. Downs, Z. Liu, and **G. Peng**, 2019: Operational Solutions for Increasing the Value and Usability of Earth Science Data via a Data Quality Framework. *22nd Atmospheric Science Librarians International Conference*, *AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.

Partee II, R. P., P. Lemieux III, R. Ionin, and **G. Peng**, 2018: A streamlined approach to assessing the stewardship practices of NOAA datasets. *2018 NOAA Environmental Data Management Workshop*, Silver Spring, MD, April 23, 2018.

**Peng, G.**, 2018: Maturity models for assessing maturity of Earth Science datasets. *WMO Expert Meeting on Climate Data Modernisation*, KNMI, De Bilt, Netherlands, April 16, 2018.

**Peng, G.**, 2018: An Introduction to WMO Stewardship Maturity Matrix for Climate Data. *46th Meeting of the CEOS Working Group on Information Systems & Services (WGISS)*, Oberpfaffenhoffen, Germany, October 22, 2018.

**Peng, G.**, 2018: An Overview of Maturity Assessment Models for Consistent Data Product Quality Ratings. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.

**Peng, G.**, 2019: Assessing and Representing Maturity Information on the Usability of Data Product and Services. *2019 ESIP Winter Meeting*, Bethesda, MD, January 16, 2019.

**Peng, G**., H. Ramapriyan, and D. Moroni, 2019: A brief overview of maturity models for consistent data quality ratings. *Joint webinar between Australian Research Data Common and ESIP Information Quality Cluster*. March 1, 2019.

**Peng, G.,** M. J. Brewer, R. Duerr, W. Wright, and C. Lief, 2018: Seeking Feedback from the ESIP Community on Two Developing Dataset Maturity Assessment Models. *2018 Earth Science Information Partner (ESIP) Summer Meeting*, Tucson, AZ, July 17, 2018.

Ritchey, N. A., R. P. Partee II, P. Lemieux, **G. Peng**, P. Jones, A. Milan, K. S. Casey, 2018: Practical Application of the Data Stewardship Maturity Model for NOAA's *OneStop* Project. *PV2018 Conference*, Harwell, UK, May 16, 2018.

Ritchey, N. A., R. Partee II, P. Lemieux III, R. Ionin, and **G. Peng**, 2018: Application of the Data Stewardship Maturity Model for Assessing Data Usability and Trustworthiness of Data Management Practices. *American Geophysical Union Fall Meeting*, Washington DC, December 12, 2018.

Wei, Y., D. Moroni, H.K. Ramapriyan, and **G. Peng**, 2018: Four Years of Progress within NASA and ESIP on Earth Science Data and Information Quality - Challenges, Solutions, and Best Practices. *2018 Open Geospatial Consortium (OGC) Technical Committee Meeting*, Charlotte, NC, December 12, 2018.

**Other**

- Earth Science System Data journal – Chief Editor
- MDPI Remote Sensing and Atmosphere journals – external reviewer
- ESIP Data Stewardship Committee - member
- ESIP Information Quality Cluster – co-chair
- NCEI Use/Services Maturity Matrix Working Group - coordinator

- WMO Stewardship Maturity Matrix for Climate Data Working Group – lead
- RDA FAIR Data Maturity Model Working Group - member

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **16** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

**Reference**

CEOS WGISS Data Stewardship Interest Group, 2017: WGISS Data Management and Stewardship Maturity Matrix. Version 1.0.

| **Regional Variability of Sea Ice Coverage** | |
|---|---|
| **Task Leader** | Ge Peng |
| **Task Code** | NC-CDR/SDS-08-NCICS-GP |
| **NOAA Sponsor** | **I**mke Durre |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Arctic |

**Highlight:** This project focuses on examining and characterizing temporal and spatial variability of Arctic sea ice coverage and sensitivity of their trends and statistical projections. The climate normals, i.e., the averages over the last three decades of sea ice concentration, area, and extent for the Arctic and sub-Arctic regions were evaluated and transitioned to NOAA.

**Background**

By 2012, reductions of approximately 49% in sea ice extent and 80% in volume dating back to the late 1970s were observable. With rapid and accelerated Arctic sea ice coverage depletion, it is critical to examine these historical changes and monitor the current sea ice state to understand the associated vulnerabilities and to provide reliable projections for climate adaptation and risk mitigation. A consistent, intercalibrated, long-term time series of sea ice can help put these changes into perspective.

Not all sea ice changes are uniform in space and time. Spatial sea ice variability may lead to a large spread in climate model sea ice projections and therefore induces high uncertainty on regional scales. Baselining the long-term mean ice state on both regional and local scales is important for monitoring how the current regional and local states depart from their normal, in order to understand vulnerability. Combining this information with up-to-date observations and reliable projections is essential to business strategic planning, climate adaptation, and risk mitigation.

This year's focus was on evaluating and transitioning to NOAA the climate normals, *i.e.*, the averages over the last three decades of sea ice concentration, area, and extent for the Arctic and sub-Arctic regions. One of the unique aspects of these sea ice coverage climate normal products is representing data uncertainty estimates by using the spread (represented by the difference between the maximum and minimum), standard deviation, 10th and 90th percentiles, and the first, second, and third quartile distribution of all monthly values. This additional uncertainty information to help improve climate projections for better strategic planning on climate adaptation and risk mitigation.

**Accomplishments**

The CDR sea ice extent monthly climate normal values were compared with that of other products, including those from the National Snow and Ice Center (NSIDC) and the Copernicus Climate Change Service (C3S) derived from the ERA-Interim and v5 sea ice concentration data.

The results show that the CDR sea ice extent normals are in good agreement with those computed by the C3S for ERA v5 and also with that of ERA-interim in later winter and early spring. Large differences between CDR and ERA-Interim extent occurs in summer. Conversely, the extent normals from NSIDC are systematically lower than those from CDR (Figure 1). The results show slight sensitivity based on whether the sea ice extents are computed from the daily or monthly sea ice concentration fields (see Figure 1b).

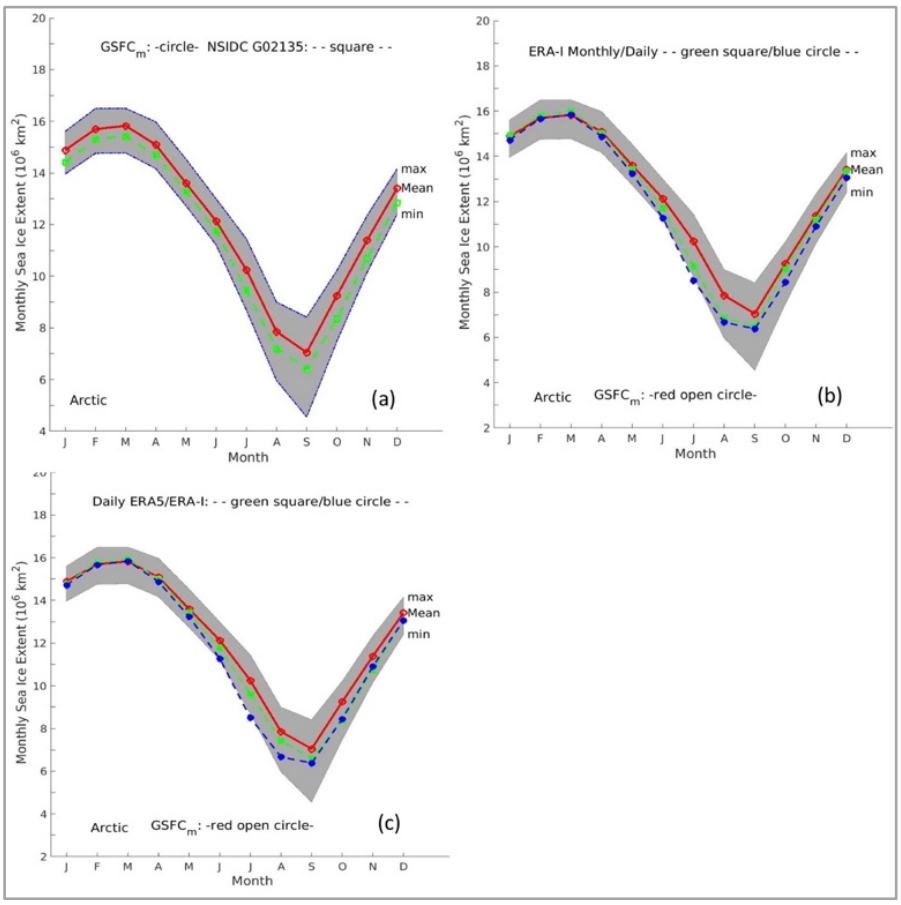



***Figure 1.*** *(a) Seasonal cycle of monthly SIE climate normal values ($10^6$ km$^2$, thick red line with filled circles) and the maximum and minimum values for each month (dashed blue lines) over the climate normal period for the Arctic region, superimposed with NSIDC SIE climate normal values (dashed lines with green squares). (b) Same as (a) except superimposed with monthly ERA-I SIE climate normal values computed from ERA-I daily SICs (dashed line with blue circles) and ERA-I monthly SICs (dashed line with green squares), respectively. (c) Same as (b) except with ERA-5 monthly SIEs computed from daily SICs (dashed line with green squares).*

**Planned work**

- Complete the research-to-operation transition process.
- Submit manuscript describing the dataset to a peer-reviewed data journal.
- Support the integration of the sea ice normal products into NCEI climate monitoring as experimental regional sea ice monitoring products.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Toward the Development of Reference Environmental Data Records (REDRs) for Precipitation: Global Evaluation of Satellite Based Quantitative Precipitation Estimates (QPEs)** | |
|---|---|
| **Task Leader** | Olivier Prat |
| **Task Code** | NC-CDR/SDS-09-NCICS-OP |
| **NOAA Sponsor** | Brian Nelson |
| **NOAA Office** | NESDIS/NCEI/CWC |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research Applications 50% |
| | Theme 2: Climate and Satellite Observations and Monitoring 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight**: The project team conducted a long-term assessment of the different satellite-based precipitation products from four Climate Data Records (PERSIANN-CDR; GPCP; CMORPH-CDR; AMSU A-B Hydro-bundle) and derived long-term global precipitation characteristics at fine spatial and temporal resolution. This work is part of a broader effort to evaluate long-term multi-sensor QPEs and to develop Climate Data Records (CDRs) for precipitation.

**Background**

Four satellite-based precipitation Climate Data Records (CDRs) were evaluated (PERSIANN-CDR; GPCP; CMORPH; AMSU/MHS Hydrological Bundle). PERSIANN-CDR is a 30-year record of daily-adjusted global precipitation. GPCP is an approximately 30-year record of monthly and pentad-adjusted global precipitation and a 17-year record of daily-adjusted global precipitation. CMORPH is a 17-year record of daily and sub-daily adjusted global precipitation. AMSU/MHS Hydro-bundle is a 15-year record of rain rate over land and ocean, snow cover and surface temperature over land, and sea ice concentration, cloud liquid water, and total precipitable water over ocean, among others. The different satellite-based QPEs are evaluated over the concurrent period. Product intercomparisons are performed at various temporal (annual, seasonal, daily, or sub-daily when possible) and spatial scales (global, overland and over ocean, tropics or higher latitudes, high elevation). The evaluation of the different products includes trend analysis and comparison with in situ data sets from the Global Historical Climatology Network (GHCN-Daily), the Global Precipitation Climatology Centre (GPCC) gridded full data daily product (GPCC), and the U.S. Climate Reference Network (CRN).

**Accomplishments**

Last year, the evaluation of four satellite precipitation CDRs was finalized. We completed the evaluation of those CDRs at the daily scale with a focus on extreme events (top percentiles). Satellite QPEs were compared with USCRN data for which hourly totals were accumulated at the daily scale to match the satellite daily accumulation (0Z–0Z). Figure 1 displays the values of the 99th percentile of daily rainfall accumulation for the three precipitation CDRs (PERSIANN, CMORPH, and GPCP) and USCRN in situ data at each station site. Among the three satellite products, CMORPH presents the highest values for the 99th percentile of daily rainfall when compared to PERSIANN and GPCP. Despite displaying higher values than the two other satellite products, those values remain lower than the 99th percentile values retrieved from in situ USCRN stations.

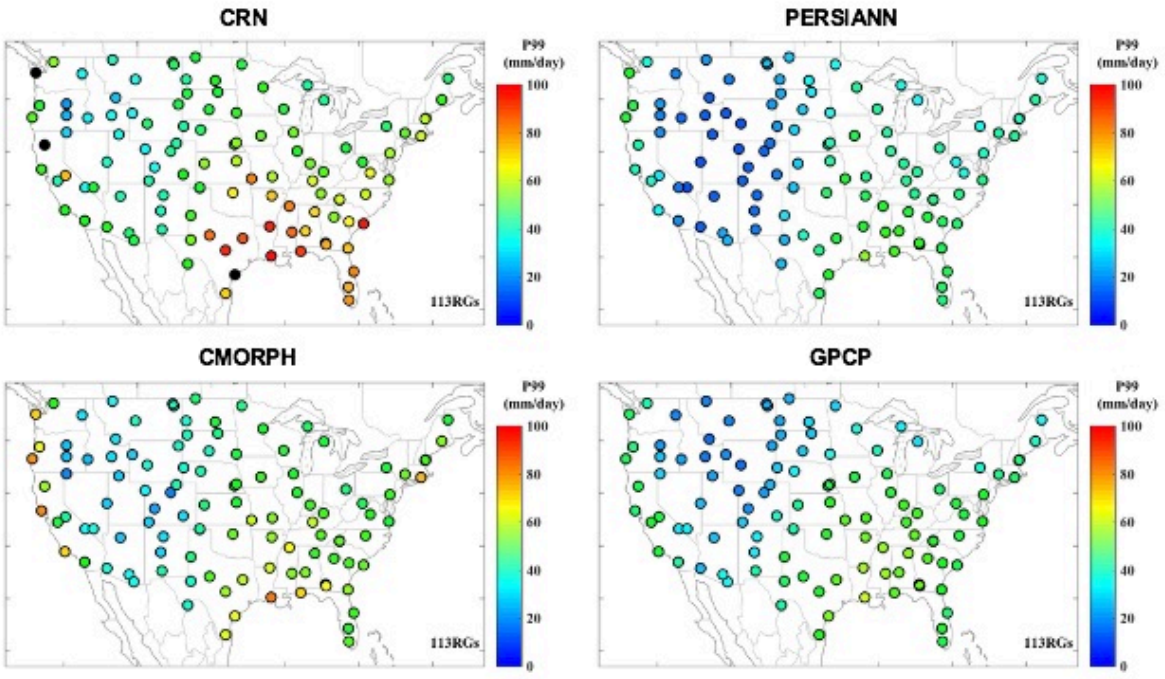



***Figure 1****. Value of the 99th percentile daily rainfall retrieved from in situ data (USCRN), and satellite products (PERSIANN-CDR, CMORPH, GPCP) for the period 2007–2015.*

As part of the evaluation of the ability of satellite precipitation products to capture extreme precipitation, the maximum daily precipitation derived from the three CDRs (GPCP, PERSIANN, CMORPH) was compared against radar (Stage IV), and in situ (GHCN-D) data. Maximum data from these data sets were compared with empirical upper limit rainfall accumulations as a function of the duration (i.e. $R=16.4D^{0.48}$, where R is in Inches, D in hours). This exercise showed that there was a wide range of maximum values due to the varying periods of records as well as differences in observation platforms and retrieval algorithms. A large part of the work described above on the evaluation of the ability of satellites to capture extreme precipitation was used in the book chapter "Satellite precipitation measurement and extreme rainfall" that is currently under review.

The evaluation of the AMSU/MHS Hydro-Bundle was completed as part as a group effort and an article was published in *Remote Sensing* (Ferraro et al. 2018). Figure 2 presents a quantitative comparison of the precipitation estimates derived from the Hydro-Bundle against the other precipitation CDRs over different areas (ocean, land, global, tropics). Results indicate that the performance of the AMSU/MHS Hydro-Bundle with respect to other CDRs depends on the area considered (ocean, land, tropics). Differences are expected since the AMSU/MHS Hydro-Bundle is a satellite-only product, while the other CDRs are bias-adjusted. For all areas (50°N–50°S), comparisons are closer because ocean (Figure 2a) and land (Figure 2b) biases compensate each other (Figure 2c). The evaluation of the AMSU/MHS Hydro-Bundle indicated that the quality of the product was comparable with that of other products that have been derived from satellites. The study pointed out the fact that usefulness of the AMSU/MHS Hydro-Bundle because it provides information on several of Earth's hydrological cycle environment variables, including precipitation, water vapor, snow cover, and sea-ice, which reinforces the uniqueness of the product when compared to other similar data sets.

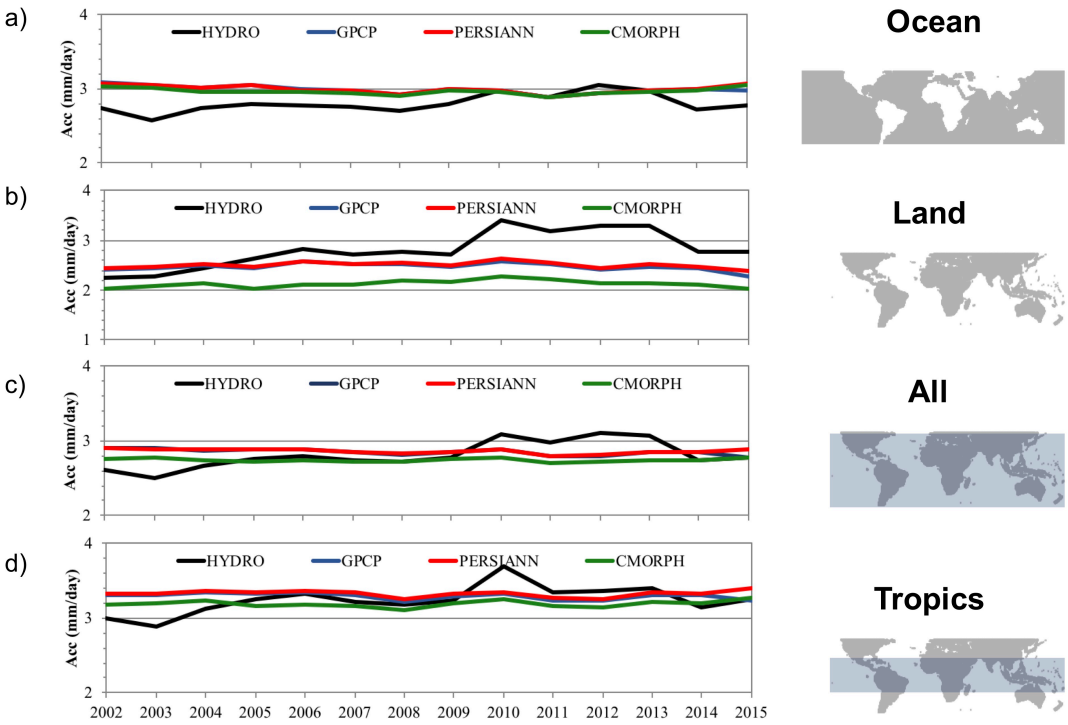



***Figure 2**. Comparison of average annual precipitation for the AMSU/MHS Hydro-Bundle and other gridded satellite products of the CDR program (GPCP, PERSIANN, CMORPH). Comparisons are conducted for the band 50°N–50°S: (a) over ocean, (b) over land, (c) globally, and (d) for the tropics 23°N–23°S.*

**Planned work**

- Finalize the book chapter on "Satellite precipitation measurement and extreme rainfall" for the book "Satellite precipitation measurement" (Springer, Editor in Chief: Vincenzo Levizzani).
- Finalize a manuscript on the evaluation of the precipitation REDRs (CMORPH, PERSIANN, GPCP).
- Submit error and bias identification paper to *Journal of Hydrometeorology*.

**Publications**

Ferraro, R. R., B. R. Nelson, T. Smith, and **O. P. Prat**, 2018: The AMSU-Based Hydrological Bundle Climate Data Record—Description and Comparison with Other Data Sets. *Remote Sensing*, **10**. http://dx.doi.org/10.3390/rs10101640

**Prat, O. P.**, and B. R. Nelson, 2019. Satellite precipitation measurements and extreme rainfall. In: *Satellite Precipitation Measurement*, V. Levizzani, C. Kidd, D. B. Kirshbaum, C.D. Kummerow, K. Nakamura, and F.J. Turk, Eds., Springer, submitted.

**Presentations**

Nelson, B. R., and **O. Prat**, 2018: Maximum Precipitation Estimates from Five Environmental Data Records with Varying Resolutions and Periods of Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.

Shannon, A., S. Ingram, M. VonHegel, **O. P. Prat**, B. R. Nelson, M. Hutchins, and A. Stein, 2018. Utilizing precipitation estimates from NASA and NOAA earth observations satellites to enhance decision support

for extreme events in the Carolinas. *2018 Carolinas Climate Resilience Conference*. Columbia, SC, October 29, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Toward Earlier Drought Detection Using Remotely Sensed Precipitation Data from the Reference Environmental Data Record (REDR) CMORPH** | |
|---|---|
| **Task Leader/Task Team** | Olivier Prat, Ronald Leeper, Jessica Matthews |
| **Task Code** | NC-CDR/SDS-10-NCICS-OP/RL/JB |
| **NOAA Sponsor** | Steve Ansari |
| **NOAA Office** | NIDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight**: The feasibility of using satellite precipitation data from the CDR program (CMORPH) to detect and monitor drought on a global scale is being investigated with a focus on the implementation of the drought indices and their evaluation over CONUS.

**Background**

Satellite precipitation data from the CDR program (CMORPH-CDR) are being utilized to detect and monitor drought on a global scale. Precipitation data are used to compute the Standardized Precipitation Index (SPI) and their evaluation over the continental United States. In order to evaluate the relevance of using satellite data for the purpose of early drought detection and drought monitoring, several scenarios have been tested using the rain-gauge adjusted version of the satellite QPE, the near real-time version of the satellite QPE, and a mixed combination of gauge-adjusted and near-real-time versions of the satellite QPE. The drought indices are evaluated over CONUS for which numerous in situ data as well as drought products exist. In particular, the difference between indices obtained with the corrected (CMORPH-CDR) and near-real-time (CMORPH-ICDR) versions of CMORPH is evaluated. Additionally, showcases of selected severe drought events are used for validation. The four drought episodes (the 1998–2004 western U.S. drought, the 2006–2007 Southeast U.S. drought, the 2010–2012 Texas–Mexican drought over the Southern Plains, and the 2012 summer Midwestern U.S. drought) are the drought testbeds selected as case studies to assess the capabilities of drought products to monitor and predict as defined by the Drought Task Force (DTF) Protocol released on April 2013. These drought episodes which influenced the development of the NIDIS early warning system are all within the period of record of the CMORPH-CDR dataset (1998–present). Following the assessment metrics in the DTF Protocol, the SPI products are evaluated on the basis of their ability to estimate the onset and recovery, duration and severity, probability of drought condition, and the value given at the observed period. The goal of this work is to transition to operations a fully functional implementation of the daily SPI using CMORPH-CDR that will be used to detect and monitor drought episodes around the world. In order to communicate global drought conditions in near real time, we develop statistical and visualization tools that allow the identification and interpretation of SPI trends. The GIS-based web application developed for this project will be utilized to disseminate the daily SPI and provide global to local overview of meteorological drought conditions.

**Accomplishments**

The Drought Group ingested and developed algorithms for the implementation of the drought indices (SPI) using the CMORPH precipitation data sets. Different sensitivity runs were conducted to account for a variety of parameters (i.e. input data: uncorrected (ICDR) vs. bias-adjusted (CDR) CMORPPH; SPI algorithms: Gamma vs. Pearson III functions; frequency: daily vs. monthly). Figure 1 presents time series comparing daily and monthly SPIs at various time scales from 30-, 90-, and 270-day (resp. 1-, 3-, 9-month)

SPIs for San Antonio, Texas. Figure 1 shows that daily and monthly SPIs remain generally close. However, differences are noticeable with a daily SPI displaying lower (toward drier conditions) or higher (toward wetter conditions) values in the case of rainfall deficit or abundance, respectively. Those results are encouraging in the sense that they seem to suggest that a daily SPI could provide a better detection of drier conditions leading toward the onset of a drought, help better characterize the severity of the drought, and indicate the relief from drought conditions faster than with monthly SPI. One of the key factors for future assessment is to evaluate the differences between daily and monthly SPI values in order to quantify the improvement gained by using near-real time rainfall input.

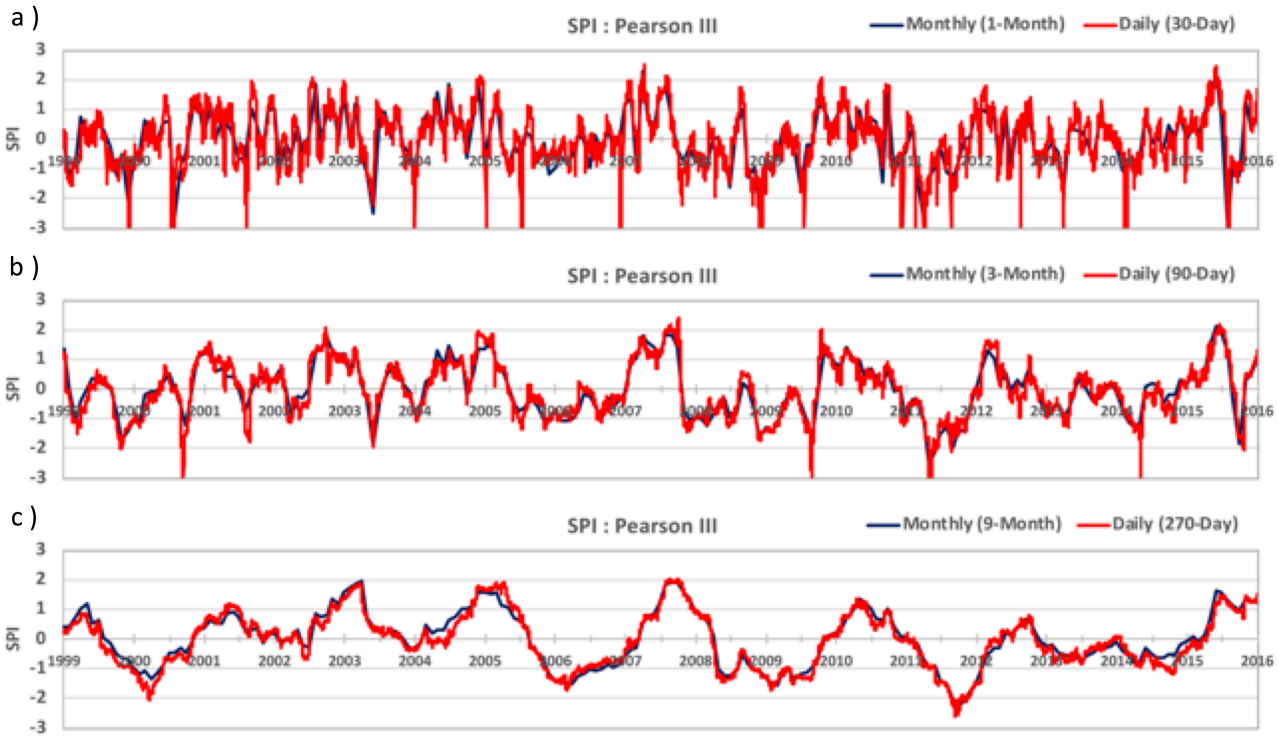



***Figure 1.*** *Comparison of daily and monthly SPI for San Antonio (Texas). Daily SPI is computed for 30-day (Fig. 1a), 90-day (Fig. 1b), and 270-day (Fig. 1c) time scales, corresponding to monthly SPIs for 1-, 3-, and 9-month respectively.*

Preliminary results indicated that both monthly and daily SPIs present the same timing and area for the major drought episodes over the continental United States as well as for selected drought events around the globe. Figure 2 displays an example of global drought conditions for December 2012 derived from CMORPH-CDR that would be provided routinely by the web-based GIS interface. Fig. 2a displays the 9-month SPI indicating the different drought categories from mild to extreme. Fig. 2b presents the same information but with hydrological conditions expressed in term of their equivalency with the drought categories defined by the USDM from abnormally dry conditions (D0) to exceptional drought (D4). The spatial extent of the Midwestern drought of 2012–2013 is visible over CONUS on both figures. Also, clearly distinguishable are the dry conditions over the Northeast Region of Brazil, which correspond to the worst drought in decades for the region. While those results are encouraging when it comes to the ability of satellite precipitation data to identify meteorological droughts episodes on a global scale, further validation is needed as results may differ in term of magnitude and severity when compared to SPI or other drought indices derived from in situ data.

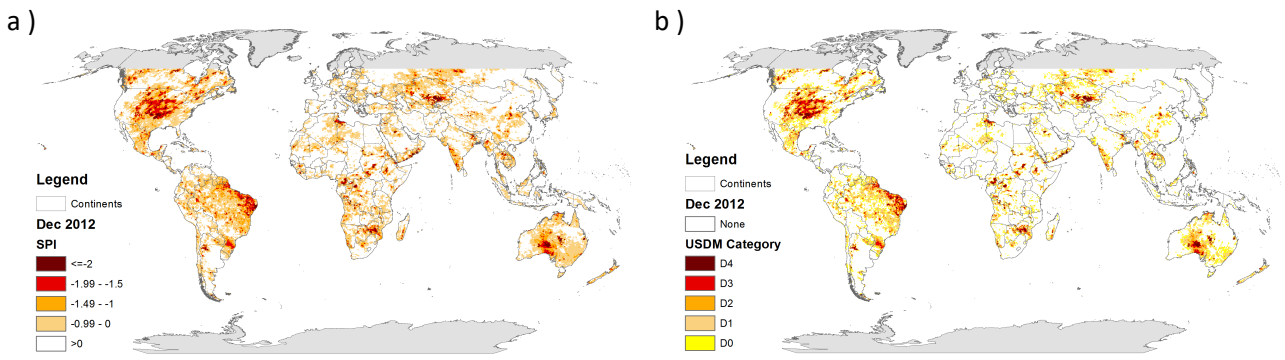



***Figure 2**. Global meteorological drought conditions derived from CMORPH-CDR for December 2012. Fig. 2a: 9-month SPI and corresponding drought categories; Fig. 2b: 9-month SPI values binned corresponding to USDM classifications D0-D4.*

**Planned work**

- Finalize a manuscript on the daily and monthly SPI derived from CMORPH-CDR.
- Compute daily and monthly CMORPH-CDR SPI in a semi-operational mode. The daily SPI is to be routinely updated daily, while the monthly SPI will be updated at the beginning of the month for the previous month. The daily SPI uses the ICR-version of the CMORPH-CDR that are replaced with bias-adjusted daily files when available. Other possible frequency updates include weekly SPI to match the USDM PDSI release (Thursdays).
- Perform an evaluation of the CMORPH-CDR daily and monthly SPI against in situ drought monitoring products [USDM, nClimGrid derived SPI, WestWide Drought Tracker (WWDT) derived from PRISM].
- Finalize the development and implementation of the interactive visualization tool that uses geographic information system (GIS) technologies.
- Extend the CMORPH-CDR work to other available CDRs (PERSIANN-CDR). Consideration for doing so is that PERSIANN-CDR covers a longer period (1983–present). It will allow SPI sensitivity quantification for different precipitation datasets and various lengths of record.
- Compare SPI meteorological drought episodes with drought metrics derived from the vegetation response as measured by the AVHRR Normalized Difference Vegetation Index CDR (NDVI-CDR). This constitutes a longer-term effort to develop a hybridized drought detection approach by incorporating both near-real time precipitation and near-real time vegetation remotely sensed information.

**Products**

- Short- and long-term SPI updated daily to be used for drought detection and monitoring
- GIS-based visualization and analysis tool to display global droughts conditions in near-real time

**Presentations**

**Prat, O. P.**, 2018: Toward Earlier Drought Detection Using Remotely Sensed Precipitation Data and Applications to the Carolinas. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 29, 2018.

**Prat, O. P.**, **R. Leeper**, **J. L. Matthews**, B. R. Nelson, S. Ansari, and J. Adams, 2018: Toward Earlier Drought Detection Using Remotely Sensed Precipitation Information and Vegetation Observations from the

Reference Environmental Data Record (REDR) Program. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.

**Prat, O. P.**, **R. D. Leeper**, **J. E. Bell**, B. R. Nelson, J. Adams, and S. Ansari, 2018: Toward earlier drought detection using remotely sensed precipitation data from the Reference Environmental Data Record (REDR) CMORPH. *2018 EGU General Assembly*, Vienna, Austria, April 11, 2018.

**Prat, O. P.**, **R. D. Leeper**, **J. L. Matthews**, B. R. Nelson, J. Adams, and S. Ansari, 2019: Using Remotely Sensed Precipitation Information and Vegetation Observations for Early Drought Detection and Near-Real Time Monitoring on a Global Scale. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.

| **Performance Metrics** | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **4** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Identifying Tropical Variability with CDRs** | |
|---|---|
| **Task Leader:** | Carl Schreck |
| **Task Code** | NC-CDR/SDS-11-NCICS-CS |
| **NOAA Sponsor** | Imke Durre |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modelling 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** CICS-NC and UNC Asheville co-hosted a *Workshop on Global Tropical Cyclone Reanalysis* in May 2017 to discuss how to address the challenges posed by discrepancies in the historical tropical cyclone record. Two manuscripts were published this year that compared the interactions of teleconnections with various CDRs. https://ncics.org/mjo

**Background**

The Madden–Julian Oscillation (MJO), equatorial Rossby waves, and Kelvin waves are the dominant sources of synoptic-to-subseasonal variability in the tropics. The divergent circulations from their convection can influence tropical cyclones and other weather patterns around the globe. Forecasters in the energy industry pay particular attention to these modes, harnessing their long time-scales and global impacts to anticipate energy demand in the United States. Climate Data Records (CDRs) play a key role in the identification and forecasting of these modes. This project endeavors to develop new diagnostics for tracking tropical modes using CDRs.

**Accomplishments**

Two manuscripts were published this year that compared the interactions of teleconnections with various CDRs. One, Shi et al. (2018), compared the relationships between various teleconnections and water vapor using CDRs of precipitable water and upper-tropospheric humidity (UTH). The other, Schreck et al. (2018), compared a previous NOAA version of outgoing longwave radiation (OLR) based on the Advanced Very High Resolution Radiometer (AVHRR) with the NOAA CDR of OLR based on the High-Resolution Infrared Radiation Sounder (HIRS). The latter paper specifically focused on the application of these datasets for identifying the MJO and equatorial waves. Figure 1 shows an example of the differences between the datasets. HIRS OLR generally has a higher mean because of calibration differences. Those differences are particularly apparent in the subtropics where HIRS is more sensitive to OLR variations from water vapor.

New diagnostics using NCEI's OISST climate data record were added to https://ncics.org/mjo to monitor how the MJO and equatorial waves interact with ocean temperatures.

CICS-NC also played key roles in the rollouts of two new NCEI datasets: the v4 of the International Best Track Archive for Climate Stewardship (IBTrACS) and nClimGrid-Daily. IBTrACS v4 is a major upgrade over the previous version. It streamlines the number of formats provided and gives users easier access to the high-impact tracks from the National Hurricane Center and the U.S. Department of Defense (DOD) Joint Typhoon Warning Center (JTWC). It also builds on code from https://ncics.org/mjo to provide these data in near real time. In order to plot tropical cyclone tracks in real-time, https://ncics.org/mjo downloads "tcvitals" data from NCEP. These are essentially the operational tropical cyclone tracks from the National

Hurricane Center and the U.S. DOD's Joint Typhoon Warning Center. The latest version of IBTrACS leverages that same code in order to provide best track data to users in near real time.

nClimGrid-Daily provides daily temperature and precipitation data for the contiguous United States from 1951 to the present. It has a nominal 5-km grid that can be aggregated to a variety of levels including census tracts, climate divisions, and states. Figure 2 shows samples of these data for four of the most extreme days.

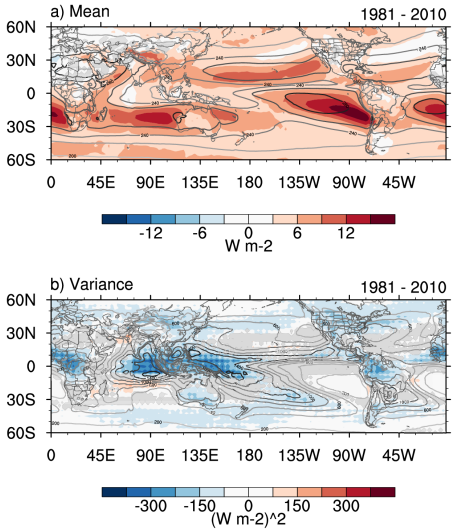



***Figure 1.*** *Comparison of mean (a) and daily variance (b) between HIRS and AVHRR OLR. The difference is shaded and the HIRS average is contoured. Gray shading masks regions where the differences are not statistically significant at the 95% level.*

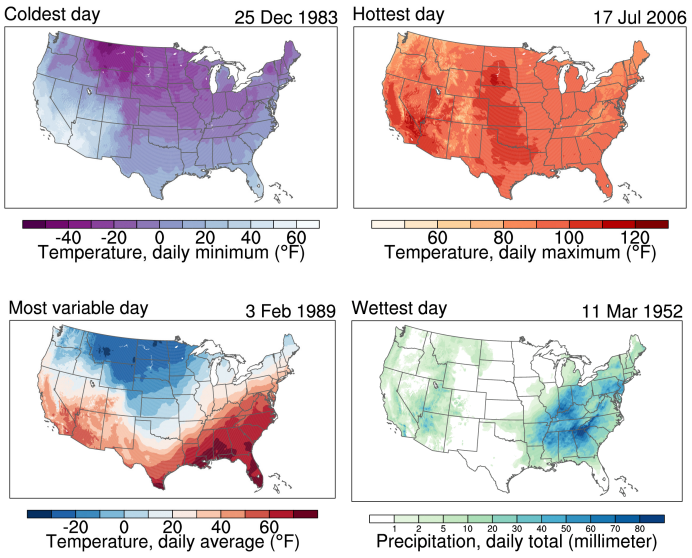



***Figure 2.*** *Most extreme days chosen based on Contiguous U.S. (CONUS) values. Coldest and Hottest Days are based on CONUS-averages. Most Variable Day is the day with the largest spatial standard deviation. Wettest Day has the largest area over 25 mm.*

**Planned work**

- Continue using CDRs to support the annual State of the Climate report
- Investigate how to leverage NCEI's archives to reanalyze historical tropical cyclone tracks
- Compare impacts of teleconnections on state temperatures in nClimDiv-Monthly
- Explore correlations between Arctic sea ice, snow cover, and teleconnections

**Publications**

Diamond, H. J., **C. J. Schreck**, Eds., 2018: The tropics [in "State of the Climate in 2017"]. In: *Bulletin of the American Meteorological Society*, G. Hartfield, J. Blunden, and D. S. Arndt, Eds., American Meteorological Society, S101-S142. http://dx.doi.org/10.1175/2018BAMSStateoftheClimate.1

Klotzbach, P. J., **C. J. Schreck**, J. M. Collins, M. M. Bell, E. S. Blake, and D. Roache, 2018: The Extremely Active 2017 North Atlantic Hurricane Season. *Monthly Weather Review*, **146,** 3425-3443. http://dx.doi.org/10.1175/MWR-D-18-0078.1

**Schreck, C.,** H.-T. Lee, K. Knapp, 2018: HIRS Outgoing Longwave Radiation—Daily Climate Data Record: Application toward Identifying Tropical Subseasonal Variability. *Remote Sensing*, **10**. http://dx.doi.org/10.3390/rs10091325

Shi, L., **C. J. Schreck**, and M. Schröder, 2018: Assessing the Pattern Differences between Satellite-Observed Upper Tropospheric Humidity and Total Column Water Vapor during Major El Niño Events. *Remote Sensing*, **10**. http://dx.doi.org/doi:10.3390/rs10081188

**Presentations**

Durre, I., R. Vose, and **C. J. Schreck**, 2019: Tales of Two Products: What Can We Learn from NCEI's New Daily Grids and Area Averages of Temperature and Precipitation? *AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.

**Schreck, C.**, 2019: Large Scale Tropical Dynamics: From Monsoon Troughs to Equatorial Waves. *John Molinari Retirement Celebration, University at Albany*, Albany, NY, March 8, 2019.

**Schreck, C. J.**, 2019: Climate, Hurricanes, and Reinsurance. *Lunch and Learn*, *The Collider*, Asheville, NC, January 22, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **2** |
| **# of peer reviewed papers** | **4** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| El Niño–Southern Oscillation (ENSO) Normals | |
|---|---|
| **Task Leader** | Carl Schreck, Anand Inamdar |
| **Task Code** | NC-CDR/SDS-12-NCICS-CS/AI |
| **NOAA Sponsor** | Imke Durre |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50% |
| | Theme 3: Climate Research and Modelling 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** The team submitted a manuscript documenting a unique methodology for developing U.S. Normals from nClimGrid–Monthly conditioned on both climate change and the phase of ENSO.

**Background**

Climate normals have traditionally been calculated every decade or so as the average values over a long period of time, often 30 years. Such an approach assumes a stationary climate, so several so-called alternative normals have been recently introduced. These alternative normals attempt to account for trends associated with global climate change by using a shorter averaging period, updating more frequently, and/or extrapolating the linear trend. While such approaches account for monotonic climate change, they fail to harness known interannual climate variability such as that associated with the El Niño–Southern Oscillation (ENSO). Similar to climate change, ENSO systematically alters the background state of the climate. These effects and their uncertainties are relatively well established, but they are not reflected in any readily available climate normals datasets. This project seeks to fill that gap by developing normals for temperature and precipitation for the contiguous United States using nClimGrid.

**Accomplishments**

We completed development of a methodology for calculating these normals. It is a three-step process. First, the optimal climate normal (OCN) is subtracted as a running mean from all the data. This OCN is an 11-year mean for temperature and a 15-year mean for precipitation. It is represented by the black lines in Figs. 1a–c. Second, we then parse the years by the phase of ENSO (colored dots) and calculate the statistics for each phase (Fig. 1d). Finally, these anomaly statistics are added to the current OCN to produce the final normals.

Figure 2 shows an example of the mean maximum temperature anomalies for December–February in each phase of ENSO. The strong La Niña (Fig. 2a) and El Niño (Fig. 2b) are consistent with previous studies showing a dipole of temperature anomalies between the Northern Plains and the Southeast. Interestingly, the weaker events have a more east–west dipole (Figs. 2c, d). These methods and results are currently under peer review for publication.

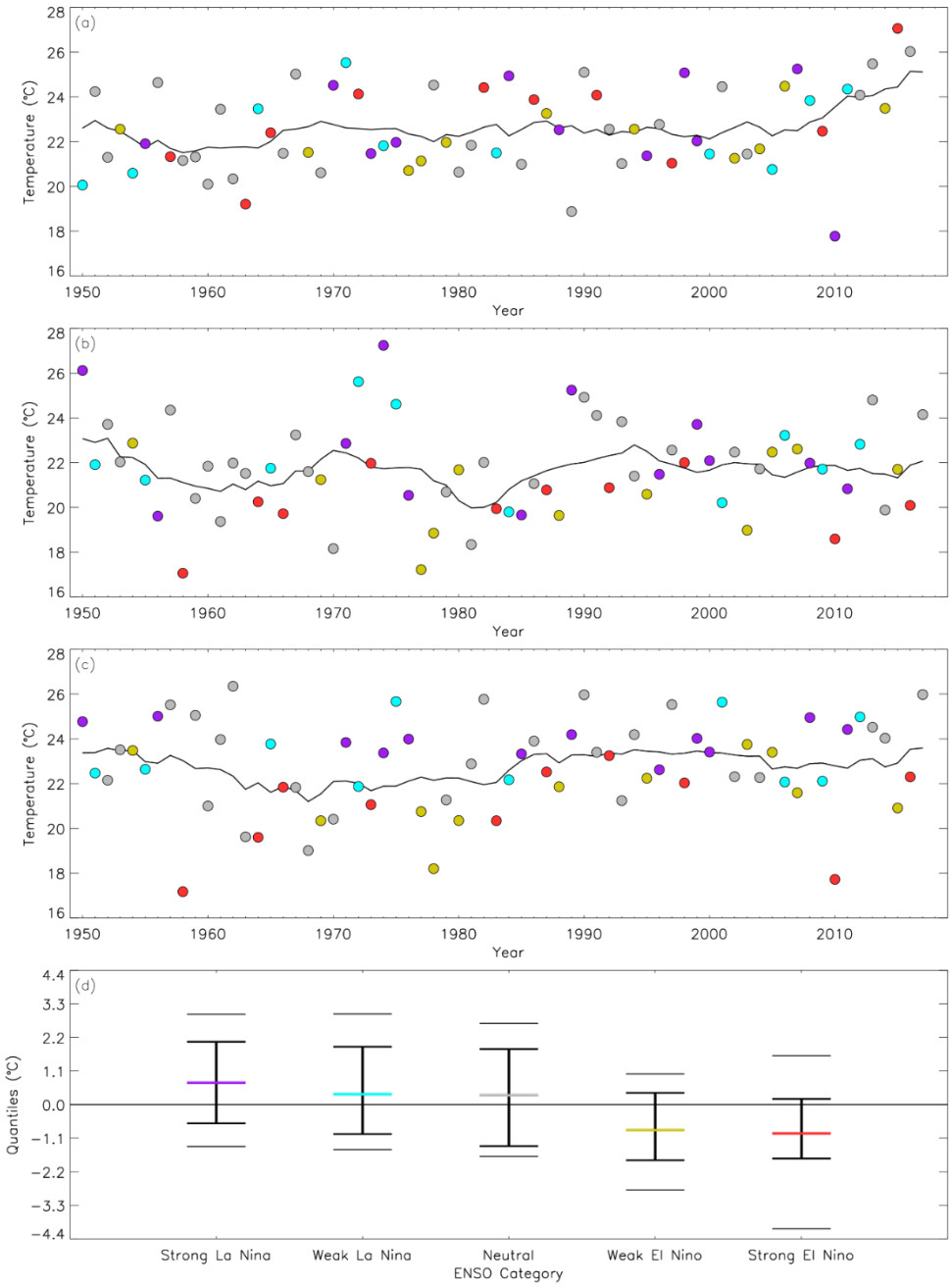



***Figure 1.*** *Mean monthly maximum temperatures (°C) for Orlando, Florida (28.5208°N, 81.3958°W) from 1951–2017 for (a) December, (b) January, and (c) February. The color of each circle indicates the ENSO phase of the corresponding DJF season: Strong La Niña (purple), Weak La Niña (blue), Neutral (gray), Weak El Niño (yellow), and Strong El Niño (red). The solid black curve indicates the running 11-year average with estimates for 2013–2017 computed following Mann (2004). (d) Associated quantile values (°C) of January temperature anomalies for each ENSO phase. Solid (bold) horizontal black lines indicate the 10th and 90th (25th and 75th) quantiles. The composite mean is shown as the middle horizontal bar color-coded as in panels (a-c).*

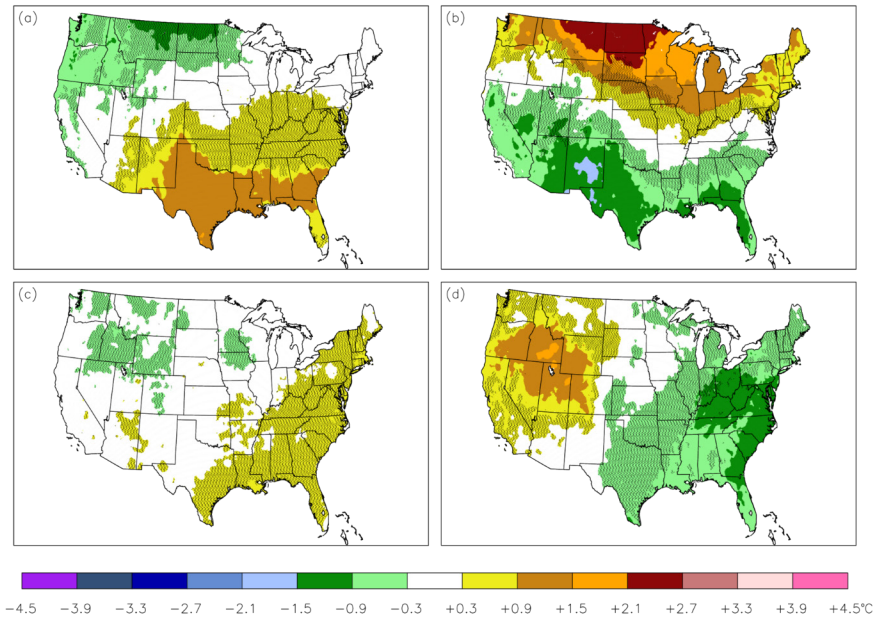



***Figure 2.*** *ENSO composites of DJF mean monthly maximum temperature for (a) Strong La Niña, (b) Strong El Niño, (c) Weak La Niña, and (d) Weak El Niño. Hatching indicates values outside of the near-zero interval (white) that are not significantly different from zero at 90% confidence.*

**Planned work**

- Complete revisions to manuscript
- Explore other ENSO indices to better capture variations in impacts from different flavors of events
- Explore developing a similar methodology for the probabilities of extreme events

**Publications**

Arguez, A., **A. Inamdar**, M. A. Palecki, **C. J. Schreck**, and A. H. Young, 2019: ENSO Normals: A New Normals Product Conditioned by ENSO Phase and Intensity and Accounting for Secular Trends. *Journal of Applied Meteorology and Climatology*, submitted.

**Presentations**

**Schreck, C. J.**, A. Arguez, **A. K. Inamdar**, M. Palecki, and A. Ho. Young, 2019: ENSO Normals: A New Normals Product Conditioned by ENSO Phase and Intensity and Accounting for Secular Trends. *AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Relationship Between Occurrence of Precipitation and Incidence of Traffic Fatalities using NEXRAD Reanalysis** | |
|---|---|
| **Task Leader:** | Scott Stevens, Carl Schreck, Jesse Bell, Kenneth Kunkel |
| **Task Code** | NC-CDR/SDS-13-NCICS-SS/CS/JB/KK |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** The project team utilized six years of the NEXRAD Level 2 reanalysis along with coincident traffic fatality information to form a quantifiable link between precipitation and an increased risk of traffic fatalities.

**Background**

The high-resolution NEXRAD Level 2 reanalysis provides the ability to study precipitation at a very fine scale in both space and time. Using data from the Fatality Analysis Reporting System (FARS), we are able to cross-reference the time and location of every fatal car accident in the United States with radar-based precipitation estimates over a six-year period (2006–2011), which includes nearly 200,000 fatal accidents. This allows us to determine if the incidence of precipitation has a measurable impact on the frequency of fatal crashes under a variety of conditions such as time of day, region, and season.

**Accomplishments**

We have drawn a conclusive link between the occurrence of precipitation and an increased risk of traffic fatalities. We have shown this link to be present in all seasons, at all times of day, and at all precipitation intensities, although there is variation in the magnitude of the risk as these variables change. In particular, the risk increases with heavier precipitation, contributing as much as 60% of the attributable risk at precipitation rates greater than 7.6 mm/hr (Figure 1).

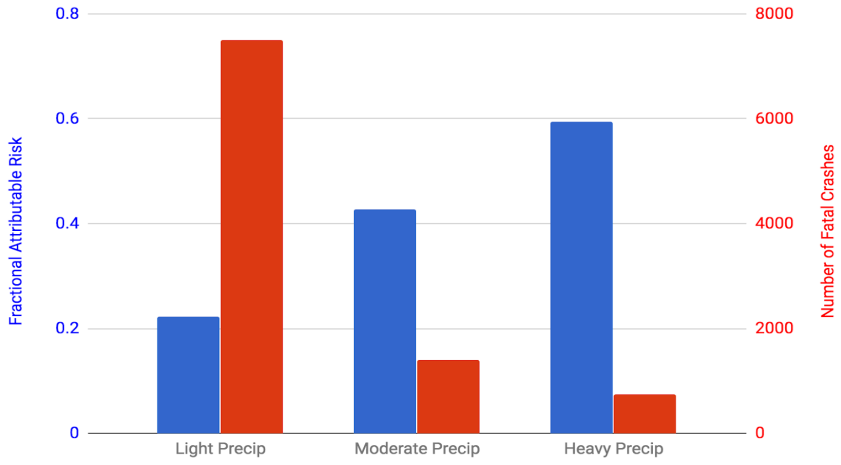



***Figure 1**. Fractional attributable risk and number of fatal crashes associated with light, moderate, and heavy precipitation.*

**Planned work**

- Study is complete.

**Publications**

**Stevens, S. E.**, **C. J. Schreck**, S. Saha, **J. E. Bell**, and **K. E. Kunkel**, 2019: Precipitation and Fatal Motor Vehicle Crashes: Continental Analysis with High-Resolution Radar Data. *Bulletin of the American Meteorological Society*. http://dx.doi.org/10.1175/BAMS-D-18-0001.1

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Climate Literacy, Outreach, Engagement, and Communications

CICS-NC climate literacy, outreach, engagement, and communication efforts are focused on improving the public's knowledge and understanding of climate information. CICS-NC supports NCEI's engagement strategic plan to foster a climate-literate public that understands climate risks, vulnerabilities to a changing climate, and opportunities for innovation and makes informed decisions using climate data.

Over the last decade, understanding changes in our climate has emerged as one of the most important areas of scientific endeavor. There is an increasing realization that profound changes in Earth's climate system are already occurring and the consequent impacts are already being experienced. It is well recognized globally that there is a need to mitigate the effects of climate change by reducing the aggregate carbon intensity. The magnitude and scale of climate change and its impacts are unpredictable, arguably underestimated, and certain to intensify as past emission levels impact weather patterns today and into the future. As the discussion on reducing emissions shifts into mainstream awareness, questions still remain about understanding the impacts that are already occurring and how we can strategically adapt to these changing conditions.

Anticipated climatic changes, which vary regionally, can include more intense precipitation events, warmer temperatures, shorter snow seasons, and changes in growing seasons, among others. Collecting and processing the fundamental data on climatic conditions, developing the models and algorithms to simulate natural cycles, assessing the possible projections, and communicating the information are critical activities in building resiliency to the changing environment.

CICS-NC supports NOAA's commitment to the development of a society that is environmentally responsible, climate resilient and adaptive, and utilizes effective, science-based problem-solving skills in building climate literacy. Working collaboratively with partners, stakeholders, and the private sector, CICS-NC supports and engages in various educational, engagement, and outreach-related activities that:

- Advance the development engagement, education, and outreach activities about climate, oceanic, and atmospheric sciences with the intent to:
    - Increase awareness of climate science and changes in the climate system
    - Grow the understanding of how climate data is collected, observed, analyzed, and used in research purposes
    - Increase awareness of NCEI climate datasets and products, and how various stakeholders can make use of climate data products for their respective purposes
- Advance climate literacy for private sector partnerships through interdisciplinary activities, including engagement with select business solution providers and industry leaders on uses and applications of climate data for climate risk management or innovative opportunities
- Provide support to NCEI activities in advancing their engagement activities with customers
- Support outreach and engagement activities on climate applications to local economic development groups and non-profits

| Climate Literacy, Outreach, Engagement, and Communications | |
|---|---|
| **Task Leader** | Jenny Dissen |
| **Task Code** | NC-CLOEC-01-NCICS-JD |
| **NOAA Sponsor** | Tim Owen / Michael Brewer |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: 40%; Theme 2: 40%; Theme 3: 20% |
| **Main CICS Research Topic** | Climate Literacy, Outreach, Engagement and Communications |
| **Contribution to NOAA goals** | Goal 1: 40%; Goal 2: 40%; Goal 4: 20% |
| **NOAA Strategic Research Priorities** | Scientific Outreach and Education |

**Highlight:** CICS-NC conducts numerous focused and interdisciplinary engagement, outreach, and literacy activities to enhance awareness and utility of NOAA and NCEI environmental data and information to support planning, decision-making, and advancements in science and innovation.
https://ncics.org/events/**;** https://ncics.org/expertise/engagement/

**Background**

Stakeholders across public and private sectors continue to seek improved access and understanding of environmental information to inform their decisions. They are also exploring innovative ways to incorporate this suite of information for adaptation, resilience, and sustainability-related opportunities. Improving the utility of environmental information enables science and data producers to derive new and innovative science based on applications and utility. improved analytics on users and their applications and needs become essential to enable this improved system. Connecting stakeholders with science providers is a more holistic approach to climate services. The exchange between practitioners, solution providers, applied scientists, and scientists requires engagement and collaboration across a wide range the range of stakeholders.

To that end, CICS-NC engages in targeted and interdisciplinary literacy, engagement, and outreach activities for business and industry, academia, other scientists, organizations, and the general public. Activities include framing and analyzing the information exchange, developing case studies, organizing sector-based engagement discussions, and building networks and partnerships that support capacity building. In addition, CICS-NC supports catalytic and innovative activities in the use of climate data and information that supports NOAA and NCEI mission goals in advancing their science and services capabilities.

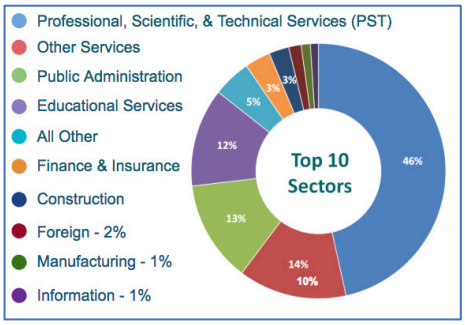
**Accomplishments**

The past year's highlights include:

- Operational support to NOAA NCEI Center for Weather and Climate (CWC) in customer engagement and assessments, nationally and internationally
- Targeted sector- or topic-specific engagement discussions
- A robust regional outreach program that promotes STEM and environmental information

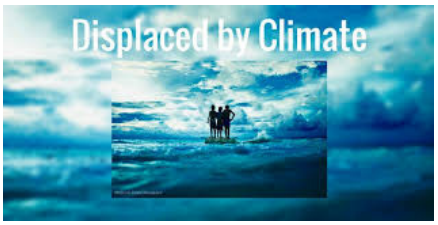
CICS-NC supports and advises NCEI CWC Climatic Information Services and Customer Engagement on strategic and operational stakeholder engagement activities and supports the NCEI CWC Climatic Analysis and Synthesis Branch (CASB). Efforts and initiatives are primarily aimed at building capabilities within NCEI information services, engagement with business and industry, support for the NOAA and Department of State interagency agreement, and other interdisciplinary activities that advance NCEI and NOAA mission

goals with partners. Task Leader Jenny Dissen serves as the Product Lead for NCEI CWC sectoral engagement.




CICS-NC support continues for NCEI User Engagement activities that document, analyze, and report NCEI data users' experiences including improvements in customer interactions documentation via a web form and additional sector success stories showcasing the value of the environmental data. Key highlights included development of an NCEI Executive Sheet, new Success Stories, and Sector Information Sheets, shared on the NCEI website at https://www.ncdc.noaa.gov/success. NCEI will further this engagement through the upcoming NCEI Users' Workshop scheduled for May 2019 that focuses on the data uses and needs in following topic areas: Agriculture, Retail, Finance, Service Providers, Logistics & Transportation, 1991–2020 Normals, and Blue Economy.

NCICS/CICS-NC engagement activities occur in collaboration with various partners, including NCEI, its subcontractors, and other companies or organizations. Dissen, in collaboration with *CASE Consultants International* and *the Yale MacMillan Center for Climate*, supported the organization of a technical workshop,"Displaced by Climate – Technical Workshop." This workshop discussed the issues and knowledge gaps in climate data and information for law and policy frameworks associated with climate- induced population displacements. NCEI and CICS-NC scientists presented on the State of the Climate – Science pertinent to Climate-Induced Displacement topics. This workshop laid the groundwork for the subsequent discussion that Yale University MacMillan Center Climate Induced Displacement: Challenges and Opportunities held in October 2018.




NCICS and/or NCEI scientists were speakers, advisors, or leads at engagement events that shared research and data applications; these interactions also identified needs that can be catalogued for the NCEI requirements repository, which included:

- Climate Adaptive Design Symposium, November 2018, led by CASE Consultants International
- American Bar Association (ABA) Webinar**,** June 2018, with NCEI scientists to discuss applications of NOAA NCEI Data Information to the Legal Community
- Carolinas Climate Resilience Conference (October 2018, Columbia, SC) with presentations and discussions ranging from communicating science, engagement driving innovation and data-driven climate innovation

CICS-NC and NCEI subcontractor GST staff led engagement activities at the 2019 Annual American Meteorological Society including a Town Hall session, "Upcoming NCEI Data Users Conference: An Agriculture Example," three presentations, and two posters that shared the progress of customer engagement at NCEI (website).

***Engagement with the NCEI Climatic Analysis and Synthesis Branch***

CICS-NC continued engagement activities with India- based partners to advance technical and scientific information sharing on climate projections and capacity- building goals as part of the NOAA – Department

of State Inter-Agency Agreement on the U.S.-India Partnership for Climate Resilience (USPCR). Two workshops were held and a third is being planned.

CICS-NC partnered with The Energy Resource Institute (TERI India) to organize the "Workshop on Climate and Health" October 23–24, 2018, in New Delhi, which included topics on impacts of future climate on health in India, the relationship of vector-borne diseases to temperature changes, health impacts and adaptation plans for urban heat, tools for citizen science, and climate-smart health systems and methods for climate projections and modeling. TERI produced a short film on the issue of climate and health titled "A Climate Antidote: Building climate resilience in public health."

CLIMATE SERVICES IN INDIA—MOVING THE NEEDLE

**Panellists:** Dr Akhilesh Gupta, Head, SPLICE Division, Department of Science and Technology; Mr Saurabh Bhardwaj, Fellow and Area Convenor, TERI; Dr Ashwini Kulkarni, Climate Scientist, IITM; Dr Krishna Achuta Rao, Professor, IIT-Delhi; Ms Anu Jogesh, Acclimatise; Ms Jenny Dissen and Dr Andrew Ballinger, NOAA CICS-NC / NC State University

Dr Akhilesh Gupta highlighted the initiatives undertaken by the government in the field of climate sciences, modelling services as well as dissemination of climate products to the end users.

Mr Saurabh Bhardwaj stressed on the use of climate products and services and how the regional modelling products have been used at national, state as well as local levels for reliable projection of temperature and precipitation.

Dr Ashwini Kulkarni reiterated on the problems and challenges faced in the mountainous regions, particularly the Hindukush Himalayan region.

Dr Achuta Rao focussed his discussion on the climate extremes in India, emphasizing the role of global framework for climate services (GFCS) in the 5 priority areas— agriculture, disaster, water, health, and energy.

Ms Anu Jogesh spoke about the climate tool, PREP, developed by Acclimitize, together in partnership with World Resources Institute . This tool focussed on Uttarakhand which integrates global and local earth observation, climate change, and socio-economic data.

Ms Jenny and Dr Andrew also demonstrated their tool developed at NOAA's North Carolina Institute of Climate Services together in partnership with Value Labs.

As part of the panel discussion, Mr Abhishek Goyal shared relevant insights from the sustainability practices undertaken at the Tata Sustainability Group.

Dr Siva Prasad, Environment Protection Training and Research Institute, shared his experience as an agriculture expert where he utilized the climate services and products for improving agriculture facilities in Telangana.

Mr Mihir Mathur stressed upon the need for capacity building for self-informed and self-advised decision making in the field of climate services.

CICS-NC staff Dissen and Ballinger organized the session, "Climate Services in India – Moving the Needle," at the TERI World Sustainable Development Summit in February 2019, which involved a presentation on the USPCR activities and the facilitation of panelists on the topic of "Capacity Building and Climate Services: Perspectives from Public and Private Sectors."

***Education and General Public Outreach Activities***

NCICS/CICS-NC staff engage in a robust interdisciplinary outreach program, which includes leading and participating in activities that reach K–12, higher education, and the general public. In this role, NCICS staff advance NOAA mission goals in promoting STEM and disseminating environmental information for capacity building and education.

In addition to fulfilling requests for outreach support, NCICS has strategically noted regional partnerships with the Asheville Museum of Science, NC Science Festival, the Collider, and Western North Carolina STEM Leaders to name a few.

This year, NCICS/CICS-NC staff participated in more than 25 outreach activities, including presentations to a wide range of audiences and a variety of educational events:

- 4/14/18: North Carolina Arboretum Mountain Science Expo, Asheville, NC. Scott Stevens and Erika Wagner hosted an interactive information/activity table at this STEM event with ~2000 people in attendance.
- 4/20/18: Isothermal Community College Annual Science and Technology Expo, Spindale, NC. Scott Stevens presented information on data collection and analysis to ~300 6th grade students.
- 4/26/18: University of North Carolina at Asheville, Asheville, NC. Laura Stevens and Andrew Ballinger presented "Climate Communications and Careers" to 9 graduate students.

- 5/8/18: Enka Intermediate School Career Day, Asheville, NC. Scott Stevens discussed careers in data science with ~100 5th-6th grade students.
- 5/18/18: IC Imagine Public Charter School, Asheville, NC. Scott Stevens participated in a panel discussion on climate change, with ~80 6th-12th grade students, teachers, and parents.
- 6/14/18: Asheville Museum of Science (AMOS) Under the Stars, Highland Brewing Company, Asheville, NC. Andrew Ballinger, Jenny Dissen, and Caroline Wright hosted an information table at this climate-related public event.
- 7/9/18: Ardenwoods Retirement Community, Arden, NC. Scott Stevens presented, "Signs of a Changing Climate" to ~20 retirees.
- 7/23/18: Ardenwoods Retirement Community, Arden, NC. Scott Stevens gave a follow-up presentation, "Communicating Climate Change" to ~20 retirees.
- 7/27/18: Asheville Museum of Science (AMOS) An Astronaut Lands in Asheville, Asheville, NC. Jenny Dissen and Erika Wagner assisted with event set-up and execution.
- 8/1/18: Trinity Presbyterian Church, Hendersonville, NC. Carl Schreck led a group discussion, "Decoding the Weather," involving ~100 participants.
- 8/14/18: World View Global Education Summit. Laura Stevens and Erika Wagner hosted an information table at this event for K–12 teachers and administrators focusing on global issues.
- 8/25/18: Schiele Museum Weather Proof! Event, Gastonia, NC. Jared Rennie and Erika Wagner hosted an information table at the event designed to expose the public to forecasting, weather data, and weather emergency response professionals. There were ~370 in attendance.
- 10/13/18: American Statistical Association's ENVR 2018 Workshop: Statistics for the Environment: Research, Practice and Policy, The Collider, Asheville, NC. Kenneth Kunkel participated in the "Public Policy Issues in Environmental Research and the Role of Statisticians" panel discussion.
- 11/8/18: Leicester Elementary School, Leicester, NC. Jessica Matthews presented information on weather and satellites to a class of ~20 kindergarteners.
- 12/3/18: Waynesville Middle School, Waynesville, NC. Jared Rennie gave an "Hour of Code" presentation to ~50 6th graders as a part of Code.org's Hour of Code.
- 12/4/18: Ira B. Jones Elementary School, Asheville, NC. Jared Rennie gave an "Hour of Code" presentation to ~100 5th graders as a part of Code.org's Hour of Code.
- 12/5/18: Vance Elementary School, Asheville, NC. Jared Rennie gave an "Hour of Code" presentation to ~150 4th and 5th graders as a part of Code.org's Hour of Code.
- 12/10/18: Kennedy Community School, St. Joseph, MN. Jared Rennie remotely presented "Weather, Climate, and Coding" to ~20 6th grade students.
- 1/24/19: 4th National Climate Assessment Panel Series, The Collider, Asheville, NC. Kenneth Kunkel, Tom Maycock, and Laura Stevens participated in a panel discussion, "An Introduction to the National Climate Assessment."
- 2/7/19: Transylvania County Library, Brevard, NC. Jared Rennie gave a presentation, "Mountain Weather," with ~80 in attendance.
- 2/14/19: Christ School, Arden, NC. Jared Rennie presented information on data processing and coding to ~20 AP Computer Science students.
- 2/20/19-2/21/19: 2019 Region 8 Western Regional Science Fair at Western Carolina University in Cullowhee, NC. Tom Maycock, Jared Rennie, Laura Stevens, Scott Stevens, Andrew Thrasher, and Erika Wagner hosted an information/activity table with ~150 elementary, middle, and high school students and educators in attendance.

- 3/1/19: Pacifica Senior Living Heritage Hills, Hendersonville, NC. Carl Schreck presented "Climate Change, Hurricanes, and North Carolina" with ~40 residents in attendance.
- 3/7/19: University of North Carolina – Asheville AMS meeting, Asheville, NC. Jared Rennie and Scott Stevens served on a career discussion panel with ~30 Atmospheric Science students.
- 3/21/19: Boys and Girls Club of Henderson County, Hendersonville, NC. Scott Stevens presented information on data analysis to ~80 2nd-4th grade students.
- 3/27/19: Asheville-Buncombe Technical Community College, Asheville, NC. Laura Stevens presented "Climate Change in the United States" to 10 Environmental Biology students.

**Planned work**

- Support NCEI customer information and services activities in environmental information use and analytics, including the NCEI Data Users Conference.
- Plan and coordinate USPCR Workshop – Utility of Climate Projections in High Elevation Regions of India.
- Further develop USPCR collaborative tool "Climate Analysis Tool" to incorporate more India station-based observations and 21 models.
- Continue corporate sector engagement at the Collider.
- Support North Carolina State Assessment activities.
- Support engagement activities in wind analysis for Western North Carolina.

**Publications**

McGuirk, M., S. C. Herring, and **J. Dissen**, 2019: The Climate Resilient Grid Forum. *Bulletin of the American Meteorological Society*, **100,** 173-176. http://dx.doi.org/10.1175/BAMS-D-18-0018.1

**Products**

Climate Analysis Tool (USPCR collaboration with India based organizations: IITM, EPTRI and ValueLabs)

**Presentations**

Brewer, M., A. Hollingshead, N. Jones, **J. Dissen**, A. Rycerz, T. G. Houston, and K. V. Matthews, 2019: The Value of Environmental Data from NOAA's National Centers for Environmental Information. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.

**Dissen, J.**, 2018: Climate and Data Sciences (panel discussion). *North Carolina School of Science and Mathematics (NCSSM) Data Science Series Visits Asheville*, *The Collider*, Asheville, NC, November 6, 2018.

**Dissen, J.**, 2018: Data-Driven Climate Innovation (panel discussion). *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 30, 2018.

**Dissen, J.**, 2018: In Times of Seismic Sorrows (panel discussion). *The Collider and The Center for Craft Joint Exhibition*, Asheville, NC, September 25, 2018.

**Dissen, J.**, 2018: Key Findings from the U.S.-India Partnership for Climate Resilience Workshop on Development and Application of High-Resolution Climate Modeling. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.

**Dissen, J.**, 2018: Sectoral Analysis Approach. *National Water Initiative Service Delivery & Decision Support Group* web conference, June 14, 2018.

**Dissen, J.**, 2019: Upcoming NCEI Data Users Conference: An Agriculture Example Town Hall (panel discussion). *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.

**Dissen, J.**, 2019: Climate Services in India – Moving the Needle (panel discussion). *2019 World Sustainable Development Summit,* New Delhi, India, February 11, 2019.

**Dissen, J.**, and **A. Ballinger**, 2018: Climate Projections and the Climate Analysis Tool. *Workshop on Climate and Health, The Energy and Resources Institute (TERI)*, New Delhi, India, October 24, 2018.

**Dissen, J.,** and M. Brewer, 2018: NCEI Customer Engagement Initiatives to Guide Opportunities for Innovation. *2018 Carolinas Climate Resilience Conference,* Columbia, SC, October 30, 2018.

**Dissen, J.**, **A. Ballinger**, D. R. Easterling, **K. E. Kunkel**, K. Hayhoe, F. Akhtar, 2019: U.S.-India Partnership for Climate Resilience. *2019 World Sustainable Development Summit,* New Delhi, India, February 11, 2019.

**Dissen, J.,** A. Hollingshead, N. Jones, M. Brewer, T. Houston, A. Allegra, 2019**:** Lessons Learned from Implementation of Customer Requirements Solution. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.

**Dissen, J.,** D. R. Easterling, **K. E. Kunkel**, K. Hayhoe, 2018: Innovative Web Based Applications of High-Resolution Climate Modeling and Projections Techniques. *2018 Carolinas Climate Resilience Conference,* Columbia, SC, October 31, 2018.

**Dissen, J.**, M. Brewer, and D. Arndt, 2018: The Application of NOAA National Centers of Environmental Information Data and Information to the Legal Community. *American Bar Association* webinar, June 6, 2018.

Easterling, D. R., **J. Dissen**, **K. Kunkel**, and K. Hayhoe, 2018: An Overview of the U.S.-India Partnership for Climate Resilience. *American Geophysical Union Fall Meeting*. Washington, DC, December 10, 2018.

Easterling, D. R., **J. Dissen**, **K. E. Kunkel**, K. Hayhoe, 2019: The U.S.–India Partnership for Climate Resilience. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.

Hollingshead, A., M. J. Brewer, N. Jones, and **J. Dissen**, 2019: Exploring and Advancing Customer Engagement at NOAA National Centers for Environmental Information. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.

**Kunkel, K. E.**, 2018: Future Climate Change and Implications in the Context of the Health and Diseases. *U.S.-India Partnership for Climate Resilience Workshop on Climate and Health*, New Delhi, India, October 23, 2018.

McGuirk, M., E. Shea, M. Prabhu, D. Ratliff, **J. Dissen**, E. Gardiner, 2019: Climate-Induced Displacement: Where Social and Climate Sciences Intersect. *AMS 99th Annual Meeting,* Phoenix, AZ, January 9, 2019.

**Other**

- CICS-NC staff Dissen and Maycock interview: CICS-NC activities and the growth of climate opportunities in Asheville (interview). Melanie Kaplan, *U.S. News & World Report*, November 30, 2018.
- Dissen serves on the External Engagement Steering Team for the North Carolina School of Science and Mathematics Morganton Campus (http://ncssm.edu/).
- CICS-NC staff supports engagement activities for and with the Collider, Asheville based think-tank organization aiming at catalyzing innovative solutions in climate services (http://www.thecollider.org/).
- CICS-NC outreach in discussion to support the Asheville Museum of Science Weather and Climate Exhibit (http://ashevillescience.org/).

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **38*** |
| **# of graduate students supported by your CICS task** | **1** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate (high school) students mentored during the year** | **0** |

**19 Engagement presentations, 19 Outreach presentations*

| CICS-NC Communications | |
|---|---|
| **Task Leader** | Tom Maycock |
| **Task Code** | NC-CLOEC-02-NCICS-TM |
| **NOAA Sponsor** | Tim Owen / Katy Matthews |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: 33%; Theme 2: 33%; Theme 3: 33% |
| **Main CICS Research Topic** | Climate Literacy and Outreach |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Scientific Outreach and Education |

**Highlight:** This task promotes the Institute and its research activities to its stakeholders and advances the external and internal communications efforts of NOAA's National Centers for Environmental Information. The Institute's *Trends* newsletter was redesigned and several research studies and associated publications were highlighted on the Institute's website. https://ncics.org/

**Background**

CICS-NC communication activities serve to raise awareness and highlight the accomplishments of the Institute and its staff. A primary focus is sharing research findings of CICS-NC scientists and their NOAA NCEI colleagues through web stories, press releases, social media, and outreach events. Other activities include working to improve the science communication capabilities of CICS-NC staff, including editorial and graphic design support for papers and presentations. CICS-NC also provides science writing, editing, and graphic design support to NCEI's Communications and Outreach Branch. The Science Public Information Officer works to coordinate communication efforts between NCEI and CICS-NC.

**Accomplishments**

CICS-NC communication activities this year concluded with the publication of largest-ever edition of the Institute *Trends* newsletter, which also featured a new magazine-style visual design. The newsletter highlighted significant accomplishments throughout the year across all of our NOAA-funded task streams.

Four news and research highlight stories were published on the Institute website, including one story that highlighted two important papers on changes in Arctic Sea Ice that involved collaborators from the National Snow and Ice Data Center (NSIDC) and two universities. The papers relied on a data from a sea ice Climate Data Record produced through a collaboration between CICS-NC, NOAA, NASA, and NSIDC.

We were also able to highlight numerous appearances by CICS-NC staff and Institute research outcomes in various print, online, and broadcast outlets. Much of the activity arose from recent extreme precipitation and hurricane events. More than a dozen of these media items are linked from our website at https://ncics.org/in-the-media.

Science Public Information Officer Tom Maycock participated in two events hosted by *The Collider* in Asheville that highlighted the Fourth National Climate Assessment (NCA4). Both events were open to the general public. At the first event, attended by about 100 people, Maycock presented an overview of NCA4 and some of its key messages, while CICS-NC scientist Ken Kunkel presented the key findings of the Southeast chapter of the report. They were joined on a panel by CICS-NC scientist Laura Stevens and climate communications expert Susan Hassol, a former CICS-NC contractor, for a wide-ranging audience Q&A session. The second event focused on adaptation and resilience, with Maycock providing an overview

of adaptation topics in NCA4 and participating in another panel discussion. This event drew about 60 people.

The Institute's social media accounts continued to see modest growth, with Twitter followers expanding from 343 to 445 and the Facebook audience growing from 634 to 659. Facebook generally serves as a useful mechanism for outreach efforts related to upcoming events, particularly for the local Asheville audience, while Twitter is generally better suited to sharing research outcomes and information of interest to the public and subject matter experts as well as our partners and potential collaborators.

Internal communications efforts included contributions to the development of new materials for educational outreach events and editorial and graphic design support for papers and posters produced by Institute staff during the year. Maycock and visual communications specialist Jessicca Griffin are part of the NOAA NCEI Communications and Outreach Branch, where Maycock helps coordinate communications efforts between NCEI and CICS-NC and contributes to various planning activities while Griffin provides extensive graphic design and visual communications support for a variety of NCEI activities.

**Planned work**

- Expand focus on promoting research outcomes through press releases and media outreach
- Produce two issues of *Trends* newsletter
- Continue to build and leverage our social media audience
- Provide additional communications support to Institute scientists with a goal of enhancing the communications effectiveness of papers and conference abstracts and presentations
- Build relationship with communications staff at NC State

**Products**

• One *Trends* newsletter (redesigned format)

**Selected Interviews**

- **Kenneth Kunkel**: Record-breaking rain behind U.P. floods is something we can export more of, *Interlochen Public Radio*, June 28, 2018
- **Jared Rennie**: Weather Wednesday: Understanding how drought conditions are measured. *Salisbury Post*, July 18, 2018.
- **Carl Schreck**: Near-term Trend Analyses Using Earth Observational Data, *Acclimatise*, August 24, 2018.
- **Carl Schreck**: Some hurricane experts say global warming is contributing to storms like Florence, *WLOS TV*, September 14, 2018.
- **Carl Schreck**: Hurricane Florence's Effects on the Weekend's Football Games. ACC Today, *SiriusXM Radio*, September 14, 2018.
- **Kenneth Kunkel**: Florence is nations' second wettest storm, behind Harvey, *Associated Press*, September 25, 2018.
- **Carl Schreck**: Disaster-Related Citizen Science Projects, *RAND Corporation*, September 25, 2018.
- **Carl Schreck**: Climate change worsened 2017's hurricane season from hell, *Earther*, September 27, 2018.
- **Jennifer Runkle**: Climate change experts planning for a planet in flux, The State of Things, *Blue Ridge Public Radio*, October 11, 2018.

- **Scott Stevens**: Good news, pilots—the weather's getting better, *Smithsonian Air & Space*, January 24, 2019.
- **Kenneth Kunkel**: Dangerous cold snaps feel even worse because they're now so rare, *Bloomberg*, January 31, 2019.
- **Kenneth Kunkel**: Think this polar vortex was cold? It should have been colder, *National Geographic*, February 1, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **1** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Surface Observing Networks

Surface observing network activities address the sustainment and quality improvement of in situ climate observations and observing networks.

The National Centers for Environmental Information (NCEI), along with NOAA partner institutions, leads two national climate-observing programs, the U.S. Climate Reference Network (USCRN) and the U.S. Historical Climatology Network-Modernized (USHCN-M). USCRN consists of 114 stations across the continental United States, 22 stations in Alaska, 2 stations in Hawaii, and 1 station in Canada. These stations are collecting sustainable observational climate data to provide a 50-year picture of climate change. Deployment of seven additional stations in Alaska to enhance the detection of regional climate change signals is ongoing under the management of NCEI, in partnership with NOAA's Air Resources Laboratory (ARL) Atmospheric Turbulence and Diffusion Division.

NCEI also manages a number of other climate network initiatives, including the Global Historical Climatology Network (GHCN) and the Hourly Precipitation Data (HPD) Network. NCEI archives and maintains observational data for such systems as the Hydrometeorological Automated Data System (HADS) and the Automated Surface Observing Systems (ASOS). Primary activities associated with these programs and systems include 1) collection and analysis of observations of soil moisture and soil temperature; 2) climate-related studies and analyses involving climate change and variation, climate monitoring, and visualization; and 3) development of quality control processes to ensure the fidelity of the climate record.

To support these activities, CICS-NC has assembled a group of research scientists supporting various climate observing network initiatives and providing relevant scientific, technical, and software engineering expertise in the following areas:

- Integration of surface, model, and satellite fields focusing on surface temperature dataset construction.
- Quality Assurance in the USCRN program through comparison of USCRN observations with those from other surface observing networks (*e.g.*, COOP, ASOS, *etc.*).
- Drought data monitoring and establishing drought monitoring products for the USCRN network.
- Maintenance and streamlining of the GHCN-M and HPD datasets.
- Global Temperature Portfolio, targeting specific activities in ocean (sea surface temperature) and land temperature fields and products.

| **Drought-related health impacts: advancing the science for public health applications** | |
|---|---|
| **Task Leader:** | Jesse E. Bell |
| **Task Code** | NC-SON-01-UNMC |
| **NOAA Sponsor** | Veva Deheza |
| **NOAA Office** | OAR/CPO/NIDIS |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** Two studies were initiated to help identify linkages between drought and public health impacts—the first to determine the role of soil moisture on the 2017 Valley Fever outbreak and the second to evaluate historical drought-related mortality events. An initial epidemiological methodology was developed for analysis of the complex health and climate data, with results indicating that a relationship could be established between drought and extreme human health impacts (mortality).

**Background**

Drought, as characterized by the United Nations, is the "most far-reaching" of all natural disasters and internationally has caused more deaths than other weather-related extreme events (floods, hurricanes, etc.). However, due to lack of understanding of the adverse health linkages, droughts are not considered a public health threat in the United States. Drought's slow-evolving nature and delayed impacts make health studies more challenging, as the health outcomes are mainly indirect. The impact of drought on human health is a matter of growing concern as drought frequency and duration are projected to increase in the context of climate change. Many studies have investigated the secondary exposure pathways through which drought can affect human health, such as exposure to wildfire smoke, vector-borne habitat change, etc., but little is known about extreme exposures that can lead to death. A few studies have found connections between drought and suicide among Australian rural communities and increased cardiovascular and respiratory-related deaths in the United States. The existing literature still faces a gap as those studies are geographically limited and only target specific population subgroups such as older adults and do not embrace the whole nation. This broader analysis is especially important because drought manifests differently across the United States, and health outcomes are regionally specific. Some of this regional variability is the result of population demographics, socioeconomic status, and occupational and environmental exposures. By advancing our understanding of the impacts of drought on human health, the National Integrated Drought Information System (NIDIS) and its partners in the drought community will be able to more effectively communicate drought forecasts, drought conditions, and drought impacts to public health officials and health care professionals. Improved communication will foster the development of plans and preparedness efforts in the health community to respond to drought events.

**Accomplishments**

***Valley Fever/soil moisture study.*** Coccidioidomycosis, also called Valley fever, is caused by the fungus *Coccidioides* spp., which is found in the soils of the southwestern United States and in regions of South America, Central America, and Mexico. People contract coccidioidomycosis by breathing in fungal spores carried in the air. In 2017, a large outbreak of coccidioidomycosis occurred in the southwestern United States. While previous outbreaks reflected similar patterns across the southwest, the 2017 outbreak showed unique differences between California and Arizona. Recent drought in California, and subsequent

changes in the environment, likely caused the differences in the way the outbreak manifested. Coopersmith et al (2017) was the first to study the incidence of coccidioidomycosis as related to actual changes in soil moisture conditions and the University of Nebraska Medical Center (UNMC) research team will be applying the Coopersmith approach to investigate the role soil moisture had on the 2017 Valley fever outbreak. NOAA soil moisture data and Centers for Disease Control and Prevention (CDC) coccidioidomycosis incidence records were compiled for analysis which is currently underway.

***Drought-related mortality study***. For this retrospective study, the UNMC team is utilizing CDC annual counts of all-cause mortality on a county level from 1980–2014 for all age groups in the 48 U.S. contiguous states and several drought indices to investigate drought event impact on regional and national mortality rates. An initial epidemiological methodology was developed to analyze the CDC mortality data with NOAA's Standardized Precipitation-Evapotranspiration Index (SPEI), a multiscalar drought index than is used to detect, monitor, and analyze droughts and allows comparison of drought severity through time and space. Analysis results using the methodology applied to the SPEI data reflected that a relationship can be established between drought and extreme human health impacts (mortality).

The methodology was further refined utilizing the Evaporative Demand Drought Index (EDDI; Hobbins et al. 2016) and applied to the data for Nebraska. EDDI is a measure of drying potential of the atmosphere that can serve as an indicator of both flash (rapid-onset droughts) and sustained droughts and was deemed to be a more robust dataset for this study. To cover different types of meteorological and hydrological droughts, EDDI values for three time-scales of 1, 6, and 12 months (based on 12 months accumulated moisture deficit) were used. Major drought events were identified based on the EDDI time series on a county level, and a continuous annual drought score was calculated for comparison to the annual health data. A generalized linear mixed model was used to investigate the relationship between mortality counts and drought events, broken down by demographic characteristics (county, age, sex, race). To incorporate the left-censoring events on mortality, Poisson and Negative binomial meta regression models with random effects was considered to account for heterogeneity. Figure 1 summarizes the Incidence Rate Ratio (IRR) of all-cause mortality per increasing drought severity by demographic subgroups. IRR >1 suggests increasing mortality rates with increasing drought severity. Results confirm the relevance of studying different drought time scales, as the 12-month drought IRRs show an increase in mortality with prolonged hydrological droughts compared to the short-scale meteorological droughts.

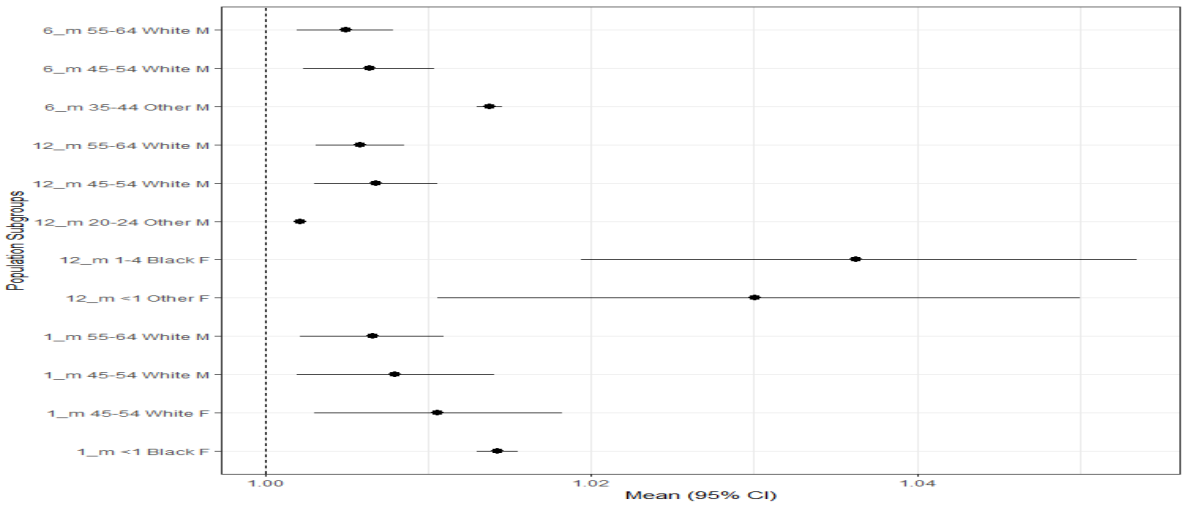



***Figure 1.*** *Incidence Rate Ratio (IRR) of all-cause mortality per increasing drought severity by demographic subgroup with 95% confidence intervals for three drought time scales of 1-, 6- and 12- months in Nebraska, USA.*

***Interaction opportunities between the drought and public health communities***. The PI developed a drought and health working group to scope engagement and plan the National Drought and Health Summit in Atlanta, Georgia. This working group brings together experts from CDC, NOAA, NIDIS, EPA, and a variety of other institutions and convenes monthly.

**Planned work**

- Continue/complete the Valley fever/soil moisture study
- Submit methodology paper to *Environmental Health Perspectives*
- Apply the refined drought-related mortality methodology to greater CONUS
- Coordinate Drought and Health Working Group activities
- Coordinate and host a national drought and health summit in June 2019

**Publications**

**Bell, J. E.**, C. L. Brown, K. Conlon, S. Herring, **K. E. Kunkel**, J. Lawrimore, G. Luber, **C. Schreck**, A. Smith, and C. Uejio, 2018. Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association*, **68**, 265-287. https://doi.org/10.1080/10962247.2017.1401017

**Products**

- Center for Disease Control and Prevention's *Preparing for the Health Effects of Drought: A Resource Guide for Public Health Professionals*. Jesse Bell served as a subject matter expert for the development of this CDC resource guide. https://www.cdc.gov/nceh/hsb/cwh/docs/CDC_Drought_Resource_Guide-508.pdf

**Presentations**

**Bell, J.**, 2018: How changes in intensity and frequency of extreme events alters human health. *University of Miami Climate and Health Symposium*, Miami, FL, April 14, 2018.

**Bell, J. E.**, 2018: The Relationship between Extreme Events and Human Health in a Changing Climate. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 15, 2018.

**Bell, J.**, 2018: Health Hazards Associated with Drought, *Council of State and Territorial Epidemiologists Disaster Epidemiology Community of Practice Meeting* (webinar), July 19, 2018.

Abadi, A., 2019: Drought Associations with All-Cause Mortality Rates in Nebraska, *American Meteorological Society Annual Meeting*, Phoenix, AZ, January 8, 2019.

Shriber, J., **J. E. Bell**, Z. Jeddy, **J. Rennie**, and H. Strosnider, 2019: Assessment of Potential Health Impacts from Extreme and Exceptional Drought, 2012-16, *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.

Lynch, K., **J. Bell**, and M. Gribble, 2019: Drought Associations with All-Cause Mortality Rates in the United States, *American Meteorological Society Annual Meeting*, Phoenix, AZ, January 9, 2019.

**Bell, J.**, 2019: Drought and Health Impacts, *California Climate Action Team Public Health Workgroup (CAT-PHWG) Preparing for the Health Effects of Drought: A Workshop for Public Health Professionals and Partners*, Sacramento, CA, February 4, 2019.

**Other**

- Postdoctoral researcher mentored: Dr. Azar Abadi
- PhD students mentored: Qianqian Li and Jagadeesh Puvvula
- MPH student mentored: Zackery Rodriguez

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **1** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **7** |
| **# of graduate students supported by your CICS task** | **2** |
| **# of graduate students formally advised** | **3** |
| **# of undergraduate students mentored during the year** | **0** |

*Center for Disease Control and Prevention's Preparing for the Health Effects of Drought: A Resource Guide for Public Health Professionals. Jesse Bell served as a subject matter expert for this CDC resource guide.*
*https://www.cdc.gov/nceh/hsb/cwh/docs/CDC_Drought_Resource_Guide-508.pdf*

| U.S. Climate Reference Network (USCRN) Applications and Quality Assurance | |
|---|---|
| **Task Leader** | Ronald D. Leeper |
| **Task Code** | NC-SON-02-NCICS-RL |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 20% |
| | Theme 2: Climate and Satellite Observations and Monitoring 80% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** The high data quality and temporal resolution of the U.S. Climate Reference Network precipitation and surface IR temperature data were leveraged to verify the Hourly Precipitation Dataset (HPD) network's new quality control (QC) algorithm and for validation of a novel approach to estimate remotely sensed land surface temperatures under all sky conditions. In addition, USCRN's temperature data were utilized to support measurements from a field campaign investigating the impact of urban encroachment on air temperature.

**Background**

The U.S. Climate Reference Network (USCRN) is a systematic and sustained network of climate monitoring stations deployed across the conterminous United States, Hawaii, and Alaska. These stations use high-quality, calibrated instrumentation to measure temperature, precipitation, wind speed, soil (temperature and moisture) conditions, humidity, land surface (IR) temperature, and solar radiation. In addition to monitoring weather and climate, the network can be leveraged as a reference to other in situ and remotely sensed datasets and to support the development of products that are both internal and external to USCRN.

**Accomplishments**

***Precipitation:*** Hourly USCRN precipitation data were used in an evaluation to verify a new automated quality control (QC) algorithm for the hourly precipitation data (HPD) network. HPD gauges were recently modernized from analog tape to digital, with QC applied to the digital era. Comparisons against USCRN measurements revealed fewer instances of trace/false precipitation events in addition to more similar counts of higher total events in the digital era compared to legacy. These results were used to validate HPD's new QC process. In an additional analysis, the frequency of exceedance was applied to USCRN precipitation data for various NOAA Atlas-14 durations and thresholds. These counts were evaluated to compare against similar GHCN-D frequency analysis used in the SERDP project.

***Surface IR Temperature:*** Cloudy conditions can obscure satellite-based measurements of land surface temperature (LST), challenging efforts to estimate/model the diurnal cycle of LST. A novel approach that combines in situ air temperature measurements with remotely sensed data from multiple satellite platforms to estimate LST under all sky conditions was applied to select USCRN and SURFRAD stations (see figure on page 72). Estimates of LST using this approach is currently being evaluated against USCRN observed surface IR observations.

***Urban Encroachment:*** It is well understood that encroachment of small-scale urban areas around in situ stations can impact temperature observations. The impacts of encroachment on temperature sensors was largest (0.84°C warmer) on evenings following sunny days with a light breeze from the urban area (Figure

1). This signal diminished with distance and was undetectable from the site located 124 meters from the urban area. Slight differences were detected between sensors with differing types of aspiration: fan versus natural ventilation of sensor shielding. The results of this study were submitted for publication in the *Journal of Applied Meteorology and Climatology*.

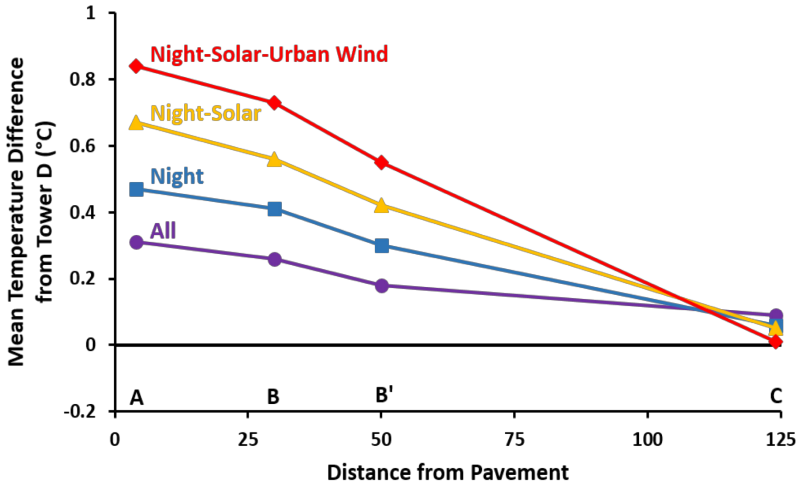



***Figure 1.*** *Mean aspirated temperature differences with respect to tower D for all conditions (black line), nocturnal observations (blue), nocturnal observations on days receiving more than 20 MJ solar radiation (yellow), and nocturnal observations on high solar receipt days with wind from the urban area compass directions 225-315° (red).*

**Planned work**

- Continue to support comparisons between USCRN and HPD precipitation datasets
- Complete validation analysis of the remotely sensed and in situ-based approach to estimating LST under all sky conditions.
- Continue to serve in a supportive role for the SERDP project.

**Publications**

**Leeper, R. D.**, J. Kochendorfer, T. Henderson, and A. M. Palecki, 2019: Impacts of Small-Scale Urban Encroachment on Air Temperature Observations, *Journal of Applied Meteorology and Climatology*, submitted.

**Presentations**

**Leeper, R. D., J.** Kochendorfer, T. Henderson, and A. M. Palecki, 2019: The Sensitivity of Temperature Measurements to Built-Up Environments; A Case Study in Oak Ridge, TN. *AMS 99th Annual Meeting,* Phoenix, AZ, January 8, 2019.

**Other**

Leeper received the 2018 NOAA National Environmental Satellite, Data, and Information Service Outstanding Information Technology and Engineering Employees award for his previous effort on the development and implementation of USCRN new precipitation algorithm.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **The Utility of In Situ Observations for the 2017 Great American Solar Eclipse** | |
|---|---|
| **Task Leader** | Ronald D. Leeper |
| **Task Code** | NC-SON-03-NCICS-RL |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 90% |
| | Goal 2: Weather-Ready Nation 10% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** Sub-hourly observations from the U.S. Climate Reference Network (USCRN) were analyzed during the 2017 Great American Solar Eclipse, revealing important changes to the diurnal cycle of air and surface temperature measurements. USCRN stations under clear skies conditions in the path of totality had the largest change in both air and surface temperatures (up to 5° and 15°C, respectively); the magnitude of these changes gradually diminished with distance from the path of totality. The importance of a solar eclipse on climatological data is not fully understood, but may have an impact on the distribution (lower end) of daily maximums for stations impacted by an eclipse just before or during the time of maximum temperature.

**Background**

The Great American Solar Eclipse of 2017 was the first time in over a century that the path of a total eclipse of the Sun traversed the United States from coast to coast. This track provided spectators a rare opportunity to view a total solar eclipse along the path, provided that weather (i.e., clouds) did not obscure one's view. In addition, the eclipse presented an opportunity to monitor the impact of the solar eclipse on surface measurements of air and surface temperatures, solar radiation, and humidity.

**Accomplishments**

Analysis of the 5-minute data from the U.S. Climate Reference Network (USCRN) revealed that stations impacted most by the solar eclipse had cloud-free mornings and were nearest to the path of totality. These stations had changes in air and surface temperatures of up to 5° and 15°C, respectively, which rapidly decreased with distance from the path of totality. The impacts of the solar eclipse on climate data records was difficult to assess, but likely limited to sub-monthly products and those stations when the timing of maximum totality occurred near daytime maximums. In these situations, the cooler than expected maximums may impact the distribution low daily maximums in an extreme analysis sense. These results were published in an *EOS* manuscript this year.

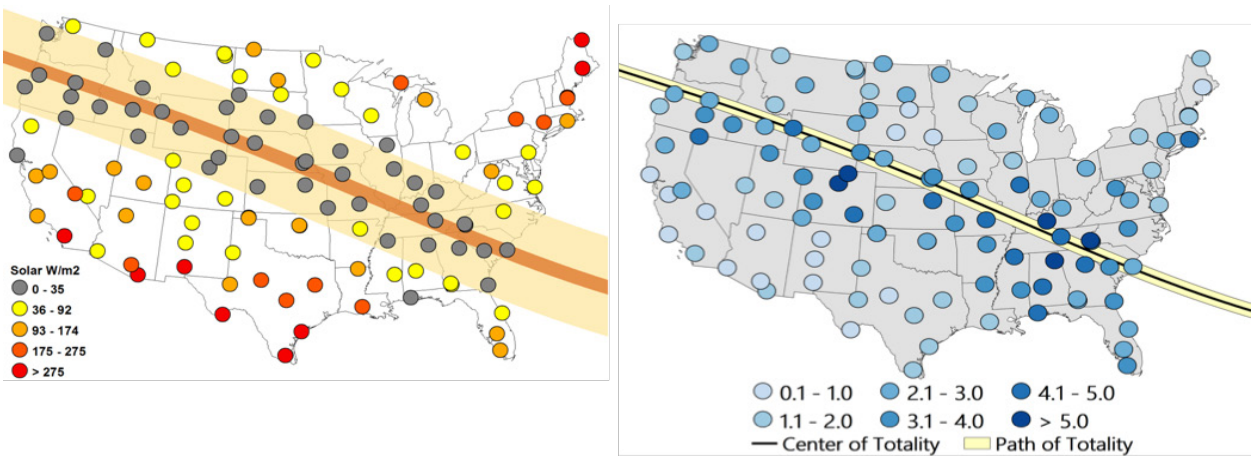



***Figure 1.*** *Solar radiation (left) and air temperature change (right) during the moment of totality at USCRN stations across the U.S.*

**Planned work**

Once the new hourly cloud climate normals are available, this project could be extended to include additional near-future U.S. solar eclipses.

**Publications**

Lee, T. R., M. Buban, M. A. Palecki, **R. D. Leeper**, H. J. Diamond, E. Dumas, T. P. Meyers, and C. B. Baker, 2018: Great American Eclipse data may fine-tune weather forecasts, *EOS*, 99. http://dx.doi.org/10.1029/2018EO103931

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| Standardization of U.S. Climate Reference Network Soil Moisture Observations | |
|---|---|
| **Task Leader** | Ronald D. Leeper |
| **Task Code** | NC-SON-04-NCICS-RL |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** Various methods to standardize hourly soil moisture data from short-term records were evaluated. Percentile differences among these approaches were negligible when aggregated at national and regional scales; however, there were times at individual stations where percent differences exceeded 10%. Comparisons with U.S. Drought Monitor and other drought metrics (i.e., standardized precipitation index and Palmer Drought Severity Index) revealed important nuances between various types of drought (agricultural versus hydrological), which suggests that standardized soil moisture can provide context about trends from worsening to improving drought conditions. The same sampling methodology has also been extended to remotely sensed AMSR-E soil moisture data.

**Background**

Soil moisture observations are challenging to interpret and use. The interoperability issues stem from the sensitivity of observations to localized factors such as soil characteristics, vegetation cover, topography, and climate (*e.g.*, precipitation patterns). As such, the same soil moisture observation can have very different meanings depending on where and time of year the measurement was taken. These challenges can be overcome by placing measurements into historical context, which is referred to as standardization. For short term datasets (less than 10 years), the historical reference period is often described by sampling a period of days on either side of the date of interest. For soil moisture, this sampling period is 31-days or 15 days on either side. The standardized measures are important metrics that provide critical information about how wet or dry soil moisture conditions are compared to normal.

**Accomplishments**

Additional measures of soil moisture departures including the climatological mean, median, and standardized median (median divided by interquartile range) were compared (Fig. 1). Comparisons of soil moisture percentiles for the separate departures and one additional approach from the literature using volumetric observations revealed little differences when aggregated across national and regional scales. This suggests that the base period, or sampling technique used to define the historical reference period, takes precedence over processing technique. However, soil moisture departures provide an additional measure in units of volumetric that may be more suitable when aggregating over time than soil moisture percentiles. This is particularly true for standardized departures.

The same approach to standardizing USCRN soil moisture observations was extended to satellite based measures of soil moisture conditions. Soil moisture percentiles, based on the same 31-day sampling methodology, were generated for both the ascending and descending branches of the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) 11-year level 3 soil moisture product (Figure 2). While results from this pilot project using AMSR-E revealed some major limitations in the satellite product, the methodology was successfully applied to remotely sensed data and could be easily extended to other

satellite platforms, including Soil Moisture Active Passive (SMAP) or Soil Moisture and Ocean Salinity (SMOS).

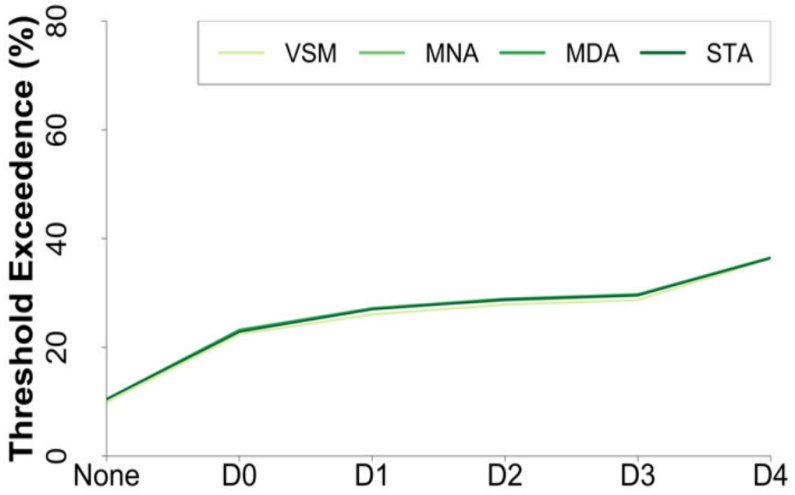



***Fig. 1.*** *National averaged percent of hours below the 20th volumetric (VSM), mean (MNA), median (MDA), and standardized median (STA) percentiles over USDM weeks by USDM status.*

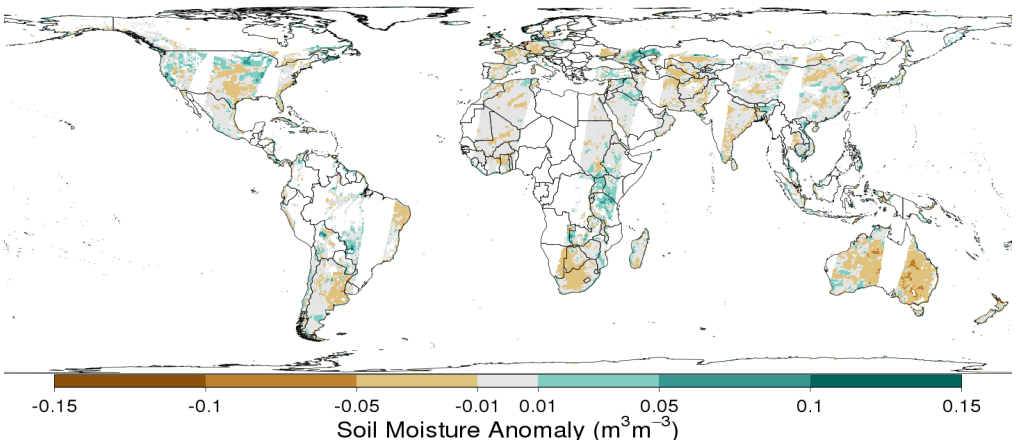



***Fig. 2.*** *Daily descending soil moisture anomalies from AMSR-E level-3 soil moisture product for March 22, 2011.*

**Planned work**

- Develop a soil moisture-based drought index using USCRN soil moisture data.
- Apply the sampling methodology to other remotely sensed soil moisture datasets.
- Compare standardized measures of soil moisture conditions to other hydrological indicators.
- Describe standardized soil moisture and temperature conditions during instances of U.S. heat events.

**Publications**

**Leeper, R. D.**, **E. J. Bell**, and A. M. Palecki, 2019: A Description and Evaluation of U.S. Climate Reference Network Standardized Soil Moisture Dataset. *Journal of Applied Meteorology and Climatology*, In press. https://doi.org/10.1175/JAMC-D-18-0269.1

**Products**

- A second version of the alpha product has been submitted in preparation for an operational readiness review

**Presentations**

**Leeper, R. D.**, 2018: Standardizing short-term satellite soil moisture datasets. *5th Satellite Soil Moisture Validation and Applications Workshop*, Fairfax, VA, October 24, 2018.

**Leeper, R. D.**, A. M. Palecki, and N. Casey 2018: Standardizing short-term satellite soil moisture datasets. *Soil Moisture Active Passive (SMAP) Cal/Val Workshop #9*, Fairfax, VA, October 22, 2018.

**Leeper, R. D.**, **E. J. Bell**, and A. M. Palecki, 2018: Standardizing USCRN Soil Moisture Observations for Near-Real Time Applications. *MOISST Workshop*, Lincoln, NE, June 5, 2018.

**Other**

A technical document describing the methodology was prepared to guide USCRN developers to aid in the transition of research to operations and in preparation for the operational readiness review.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **1** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| | |
|---|---|
| **Extension of the Great Smoky Mountain rain gauge mesonet and exploration of the origins of extreme precipitation events in the southern Appalachian Mountains and their signatures as observed by GOES-R** | |
| **Task Leader:** | Douglas Miller |
| **Task Code** | NC-SON-05-UNCA |
| **NOAA Sponsor** | Dan Lindsay |
| **NOAA Office** | NESDIS/GOESPO |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50% |
| | Theme 2: Climate and Satellite Observations and Modeling 50% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities:** | Environmental Observations |

**Highlight:** The team completed Spring, Summer, and Fall 2018 maintenance and data collection gauge visits as part of this collaborative research effort to extend the period of observations of the Duke University Great Smoky Mountains National Park Rain Gauge Network (Duke GSMRGN). Details of each gauge visit with quality-controlled precipitation CSV format files can be accessed at:

Spring 2018, https://drive.google.com/file/d/1zxqP8sMWJMSZ8ve5oW0MmYiUnPH68-vi
https://drive.google.com/file/d/1VxTw-nxyPi4wTv5en-1ktLHsasWLUi5u
Summer 2018, https://drive.google.com/file/d/1SiGGYPDJJbsBvCJ2DVkJ72opSBAYA-AY
https://drive.google.com/file/d/170mohZ6hNdZDoY44McA_YEXEQUmEJq3b
Fall 2018, https://drive.google.com/file/d/1vO7J_X8EHhz7IkqoLkIV8ITW3HVd21H9
https://drive.google.com/file/d/1cfXDeTihg7mT7sMBchpKj6dJ-28F9RSz

**Background**

The Duke University Great Smoky Mountains National Park Rain Gauge Network (Duke GSMRGN), originally funded by NASA to measure rainfall accumulation at 32 mid- (~3400 feet) and high- (~6600 feet) elevation locations in the Pigeon River basin (Figure 1 and Table 1 of Miller et al. 2018), has collected observations since the first gauges were installed in June 2007. One of the overarching goals of the NASA-funded study (Barros et al. 2014) was to advance the understanding of physical processes responsible for precipitation production in a temperate mountain range and to incorporate knowledge of these processes in NASA-derived rain-rate retrieval algorithms. Although analysis of the ten-year (July 2007–June 2017) record of precipitation observations continues, significant findings have emerged and been publicized (e.g., Wilson and Barros 2014, Duan et al. 2015, Miller et al. 2018, Miller et al. 2019).

NASA funding for the Duke GSMRGN ended with calendar year 2014, and other internal ad hoc Duke University grant support ended in calendar year 2015. This project represents a collaborative research effort to extend the period of observations of the Duke GSMRGN for three years beyond 1 July 2016, with funding provided by UNC Asheville, the Scripps Institution of Oceanography Center for Western Weather and Water Extremes, and NOAA-NESDIS.

**Accomplishments**

Gauge visitation in support of the Duke Great Smoky Mountain Rain Gauge Network (GSMRGN) occurred over 10 days spanning a seven-week period during each of the following cycles: spring 2018 (16 March – 25 May 2018), summer 2018 (2 – 27 July 2018), and fall 2018 (5 October – 18 December 2018). Volunteers

accompanied technicians to assist with personal safety (should someone become injured during a particular series of gauge visits) but were not directly involved in gauge visit tasks. The primary purpose of each gauge visit is to 1) perform downloads of gauge tip observations since the previous gauge visits, 2) complete maintenance tasks (general gauge maintenance and data logger condition monitoring), 3) clear vegetation and tree limbs within a five-foot radius of the rain gauge, and, 4) where necessary, calibrate the rain gauges (three calibration trials using the 50, 100, and 300 mm nozzles) and/or replace lithium batteries that have drained to a low voltage. Tasks may vary slightly depending on the season and/or issues identified in previous gauge visits.

**Spring 2018: March 16–May 25, 2018**
Ten technicians and volunteers made the visits and performed the required work. In addition to the general tasks completed at every gauge visit, specialized tasks were to calibrate all of the field rain gauges as the last calibration was completed in fall 2016.

ALL data logger lithium batteries were refreshed in the fall of 2017; however, batteries were replaced this visit at gauges having an unacceptably low voltage (g010, g300, g302). The first (g010) was due to the gauge cover having been torn off by a bear during the 2017–2018 winter. A potential solution is being tested (updating the CR1225 coin cell batteries that help keep accurate time) to deal with the premature voltage drop by the other two gauge loggers. The ML1 logger at g106 and g110 is also having difficulty converging on an accurate TA setting, despite several attempts using software to get it back on track.

Two gauge sites (g311, g308) will require a clever solution to remove higher tree branches starting to encroach over the gauge. A rope saw attached to a rope, deployed using a bow and arrow will be tested as a method for cutting back higher tree branches.

Challenges encountered during the spring visits included: 1) a faulty terminal on the g106 switch that functioned properly when the logger cables were changed to the other terminal (however, g106 winter 2017–2018 rainfall observations are unreliable until the gauge visit on 28 March 2018), 2) extended Heintooga Loop Road closure required the assistance of Mr. Paul Super (Great Smoky Mountains National Park) to gain access to the Balsam Mountain Ridge trailhead on 25 April 2018 to visit g307 and g304, 3) the siphon at g110 was difficult to loosen and tighten and, consequently, the protective mesh was looser than what it should have been; a replacement funnel cover is likely as the threads are likely stripped, and 4) the rusty replacement nut/bolt at g108 was incapable of being loosened using pliers and wrenches.

**Summer 2018; July 2 – 27, 2018**
Seven technicians and volunteers made the visits and performed the required work. In addition to the general tasks completed at every gauge visit, the specialized task was to install a new gauge funnel cover (old g401 cover) at g110 to ensure a proper fit between the mesh and siphon and restrict debris to the interior of the rain gauge. We learned that 'TA' doesn't handle adjusting across different hours gracefully. In other words, if the true GPS time is after the hour, and the ML1 logger time is slow (before the hour), the TA may not allow a time re-setting using 'TA' if the adjustment cuts across the 'top of the hour.' It is best if the 'TA' is done when both GPS and ML1 logger time have the same hour before adjustment.

The lithium battery voltage of the ML1-420 and ML1-FL loggers was uniformly good (greater than 3.50 Volts) at all but g008, g010, g103, g300, g301, g302, g304 and g311 of the gauge locations during the summer months. Lithium batteries were replaced at these eight locations.

Challenges encountered during these summer visits included: 1) ant nests in the interior of g010, g112, and g103 during a relatively wet spring and summer, 2) rusty replacement nuts and bolts at g101 and g108; Liquid Wrench helped loosen the nut and bolt at g101, but had NO effect on the nut and bolt at g108. Fortunately, the fitting at g108 is loose enough that the gauge cover can be removed by loosening the other two nuts and bolts. 3) erosion at g301 requires the sinking of a new fence post and attachment of a cable between the fence post and gauge post to re-stabilize the leveling of the gauge.

**Fall 2018; October 5–December 18, 2018**

Eight technicians and volunteers made the visits and performed the required work. In addition to the general tasks completed at every gauge visit, specialized tasks included replacement of ALL lithium data logger or HOBO batteries in anticipation of cold winter weather (when lithium batteries respond with a drop in operating voltage) and the replacement of four AA batteries of the T/RH sensor at the fire tower on Mount Sterling (near g310) to record air temperature during the cool season.

Two ML1 loggers showed a poor response using the TA command (g011 and g110, TA error "Adjustment too big") and may require replacement during the spring 2019 visit. One gauge site (g105) had tree limbs removed using a hand saw and four locations (g008, g105, g308, and g311) will need tree limbs cleared during the spring 2019 visit via the extension saw or rope saw. The lithium battery voltage of the ML1-420 and ML1-FL loggers was good (greater than 3.50 Volts) at all but four (g010 [replaced logger], g302 [replaced logger], g304 [replaced logger], g300 ['touchy battery connection') of the gauge locations upon arrival.

Challenges encountered during these gauge visits included: 1) severe time drift at g011, g110, and g308 due to the ineffectiveness of the 'TA' command to make the proper drift adjustment (the latter gauge {g308} seemed to be 'fixed' using TA=hh:mm:ss EDT as the FIRST use of TA flag during future visits), 2) the continued de-rusting of nuts and bolts via Liquid Wrench at gauges g101 and g103, and 3) the inability to visit g301 in the fall of 2018 due to snow and ice on 18 December 2018. The stabilizing fence post for g301 was left at g302 and will need to be installed, and cable attached, during the gauge visit in spring 2019.

**Additional Outcomes**

- Ralph Ferraro's group, including two University of Maryland undergraduate interns, used collocated 24-h Duke GSMRGN precipitation observations for examining GOES-16 Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR, Kuligowksi et al. 2002) over a seven-month period in 2017; it was found that performance varied significantly depending on the synoptic conditions of the rain event, as well as the elevation of the gauges. In addition, his group used rain gauge observations for NESDIS validation activities related to the following precipitation products: NOAA's Multi-Radar/Multi-Sensor (MRMS) system, NOAA's Hydro Estimator (HYDROE), and NASA's Integrated Multi-SatellitE Retrievals for GPM (IMERG).

- Bob Kuligowski's group have been using observations of the Duke GSMRGN as part of validation efforts in their research (Kuligowski 2002).

**Planned work**

• **Spring 2019 gauge visitation (March–May 2019)**: In addition to the general visit tasks, all rain gauges will be calibrated [last calibration in spring 2018]. Calibrations are scheduled at ALL rain gauge locations during the spring season due to the increased availability of daylight hours and to a seasonal (March, April, May) minimum in precipitation observed in the Pigeon River Basin (Miller et al. 2018).

• **Summer/Fall 2019 (pending additional funding)**: Duke GSMRGN gauge visitation will focus on downloading precipitation observations, performing maintenance, clearing vegetation and tree branches from overhanging gauges (if applicable) and replacing data logger lithium batteries (during fall 2019 visits).

Details of every gauge visit along with each gauge precipitation record will be posted online and shall contain sub-folders for each gauge that consist of the individual data files (often having at least two different formats), pictures taken at the gauge site during the visit, screenshots of the GPS (laptop) and ML1 logger time comparison, and a MS Word document that mirrors the notes made in the field journal during the visit.

The current technician roster during the 2018–2019 academic year consists of Meredith Avison, Marlee Burgess, Lyn Comer, Alex Flynt, Andrew Hill, Alice Monroe, Jacob Thome, and Zachary Tuggle. New undergraduate research students at UNC Asheville will be recruited as field technicians for the Duke GSMRGN project in the fall 2019, as two students will be graduating from UNC Asheville in May 2019.

**Publications**

Miller, D. K., C. F. Miniat, R. M. Wooten, and A. P. Barros, 2019. An Expanded Investigation of Atmospheric Rivers in the Southern Appalachian Mountains and Their Connection to Landslides. *atmosphere*, **10**, 71. https://doi.org/10.3390/atmos10020071

**Presentations**

Ferraro, R., D. Miller, A. Barros, P. Meyers, R. Kuligowski, B. Bush and J. Hill, 2018: Validation of satellite precipitation estimates over the continental United States using unique rain gauge data sets. *Ninth Workshop of the International Precipitation Working Group*, Seoul, Korea, November 6, 2018.

Miller, D.K., C.F. Miniat, R.M. Wooten, A.P. Barros, and K. Kelly, 2018: An expanded view on the climatology of atmospheric rivers impacting the southern Appalachian Mountains. *2018 International Atmospheric Rivers Conference, Scripps Institute of Oceanography*, San Diego, CA, June 27, 2018.

**Other**

Ten undergraduate students of the University of North Carolina Asheville received field research credit based on their assisting PI Miller with the activities described in the Accomplishments section.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **12** |

**References**

Barros, A. P., W. Petersen, M. Schwaller, R. Cifelli, K. Mahoney, C. Peters-Liddard, M. Shepherd, S. Nesbitt, D. Wolff, G. Heymsfield, D. Starr, E. Anognostou, J. J. Gourley, E. Kim, W. Krajewski, G. Lackman, T. Lang, D. Miller, G. Mace, M. Petters, J. Smith, W.-K. Tao, S.-C. Tsay, and E. Zipser, 2014: *NASA GPM-Ground Validation: Integrated Precipitation and Hydrology Experiment 2014 Science Plan*, Duke University, Durham, NC, 64 pp. https://doi.org/10.7924/G8CC0XMR

Duan, Y., A. M. Wilson, and A. P. Barros, 2015: Scoping a field experiment: error diagnostics of TRMM precipitation radar estimates in complex terrain as a basis for IPHEx2014. *Hydrology and Earth System Sciences*, **19**, 1501-1520. https://doi.org/10.5194/hess-19-1501-2015

Kuligowski, R. J., 2002: A self-calibrating real-time GOES rainfall algorithm for short-term rainfall estimates. *Journal of Hydrometeorology*, **3**, 112-130. https://doi.org/10.1175/1525-7541(2002)003%3c0112:ASCRTG%3e2.0.CO;2

Miller, D. K., D. Hotz, J. Winton, and L. Stewart, 2018: Investigation of atmospheric rivers impacting the Pigeon River Basin of the southern Appalachian Mountains. *Weather Forecasting*, **33**, 283-299. https://doi.org/10.1175/WAF-D-17-0060.1

Wilson, A. M. and A. P. Barros, 2014: An investigation of warm rainfall microphysics in the southern Appalachians: Orographic enhancement via low-level seeder–feeder interactions, *Journal of Atmospheric Science*, **71**, 1783-1805. https://doi.org/10.1175/jas-d-13-0228.1

| **Development of the United States Climate Reference Network (USCRN) National Precipitation Index** | |
|---|---|
| **Task Leader** | Jared Rennie |
| **TaskCode** | NC-SON-06-NCICS-JR |
| **NOAA Sponsor** | Michael Palecki, Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50%<br>Theme 2: Climate and Satellite Observations and Monitoring 50% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** An algorithm to build a national precipitation index (NPI) using 100+ stations from the United States Climate Reference Network has been in development and is close to completion. A technical report is nearing completion as well, and the NPI will soon become operational.

**Background**

NOAA's National Centers for Environmental Information (NCEI) produces a monthly National Temperature Index (NTI), a set of calculations of air temperature for the contiguous United States at the monthly, seasonal, and annual time scales. Two versions of NTI are displayed, one of which is derived using only the stations from the United States Climate Reference Network (USCRN), and the other a compilation from thousands of stations across the United States interpolated onto a 5-kilometer resolution gridded temperature product called nClimGrid. USCRN was developed to provide long-term homogeneous observations for the detection and attribution of present and future climate change and is used as a reference to evaluate how well the historical stations measure U.S. climate.

To date, no National Precipitation Index (NPI) set analogous to the NTI set has been developed. NCEI's Climate at a Glance (CAG) tool provides national estimates of precipitation at the monthly, seasonal, and annual scale based on the nClimGrid 5 km gridded product. For a similar comparison as NTI, the USCRN team has developed its own NPI version. This report will discuss the development of the USCRN NPI, including methodological tests, and compare it against the NPI from CAG.

**Accomplishments**

An algorithm was developed and finalized. 107 stations from the 114 United States Climate Reference Network sites encompassing the contiguous United States were used in this analysis. For the 7 sites with paired stations, one was chosen from each pair based on data availability and quality. Monthly measurements of precipitation (in millimeters) were extracted for each station from the monthly product on the USCRN website. For continuous and ubiquitous coverage of precipitation, data from the years 2006–2018 were used. These precipitation values were calculated with the assistance of a wetness sensor beginning in 2007.

In order to compute a precipitation departure from normal, a climatology of the area needs to be defined. Normals are traditionally defined by the World Meteorological Organization as a homogenous average for a period of 30 years. Since USCRN observations begin in the early 21st century, providing a robust 30-year climatology of USCRN is not feasible. While "pseudo" normals for temperature have been developed for USCRN stations, a similar set of estimated normals for precipitation is not currently in use. A new approach to estimating precipitation normals was based on 1981–2010 averages of precipitation derived from

nClimGrid. For a more robust analysis, the four nearest grid points from each USCRN station are used to build the normal.

In addition to performing a network-wide comparison at the monthly time frame, individual stations were subject to regression with the nClimGrid neighbors on a monthly basis. Using the linear regression equation for each station month, the nClimGrid normals for the location were adjusted to better represent the normals for each station and month. Finally, the monthly departures from normal were calculated both as depth anomalies and percentage anomalies, for both adjusted and unadjusted normals. For seasonal and annual values, monthly data were summed first before a departure was calculated.

Three methods were tested to aggregate the station departures into a CONUS averaged value for each month, season, or year:

- METHOD 1: Interpolate to 0.25° x 0.25° grid over the lower 48 states, then combine in an area weighted average for the whole United States. Values are estimated for each grid cell regardless of whether a station exists in the grid or not.
- METHOD 2: Average all stations in each 2.5° longitude by 3.5° latitude over the United States, then calculate an area-weighted average for the whole country. If there was no station in a grid box, it was not included in the U.S. average.
- METHOD 3: Simple average of all stations.

The first method (interpolation) is what is currently used to generate the USCRN temperature departure time series in the NTI. The second method was used prior to the creation of nClimGrid to create national time series from the 1,218 United States Historical Climatology Network (USHCN) stations. The third and simplest method was tested since the USCRN stations are located so as to explain most of the annual national precipitation variance when compared to other networks. A comparison with NCEI's Climate at a Glance (CAG) tool showed that a simple average is the best method for calculating NPI. Results for all months between 2006 and 2018 are noted below.

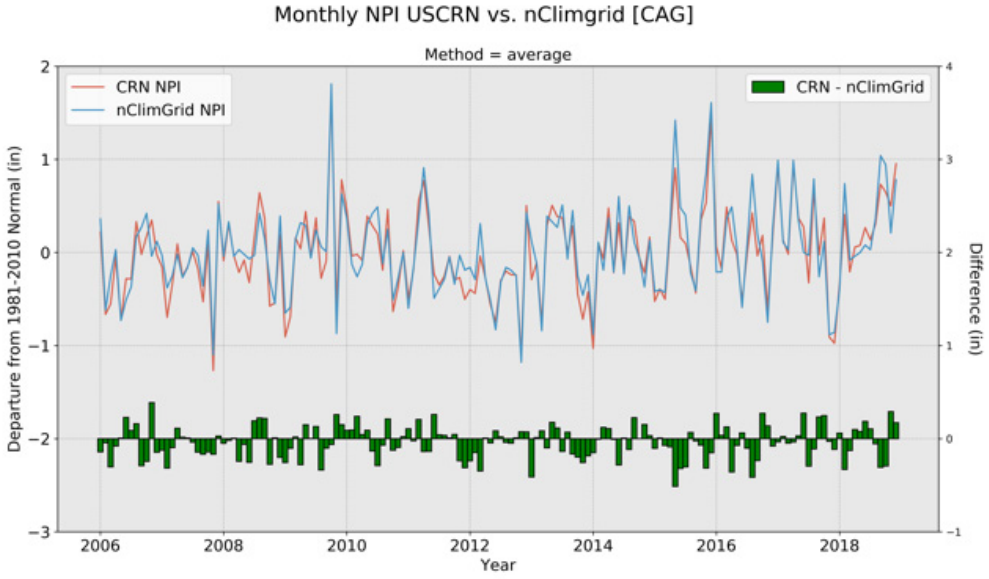



***Figure 1.*** *Prototype of the monthly USCRN National Precipitation Index (Red) from 2006–2018. For context, NCEI's Climate at a Glance precipitation product (blue) and differences (green) are noted.*

**Planned work**

- Finalize white paper and submit to USCRN program manager for approval.
- Work with NCEI monitoring team to transition product into operations on website.
- Develop NOAA technical report.

**Products**

- Annual, seasonal, and monthly analysis of the National Precipitation Index, using stations from the United States Climate Reference Network

**Other**

- NCEI's National Temperature Index: https://www.ncdc.noaa.gov/temp-and-precip/national-temperature-index/
- NCEI's Climate at a Glance: https://www.ncdc.noaa.gov/cag

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*The product is being considered to supplement the National Temperature Index on the NCEI webpage.*

| **Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCN-M) Dataset** | |
|---|---|
| **Task Leader** | Jared Rennie |
| **Task Code** | NC-SON-07-NCICS-JR |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA Goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** The next iteration of NOAA's global temperature product has been developed and is operational. A manuscript has been submitted and accepted. Updates are ongoing and provided as necessary. www.ncdc.noaa.gov/ghcnm/

**Background**

Since the early 1990s, the Global Historical Climatology Network-Monthly (GHCNm) dataset has been an internationally recognized source of information for the study of observed variability and change in land surface temperature. The third version of this product has undergone many updates since its initial release in 2011. Updates include incorporating monthly maximum and minimum temperature, improving processing run time, and providing user-driven products. Currently the product is at version 3.3.0 and includes 7,280 stations globally.

Recently, there has been a need to address gaps in data coverage and improve documentation of data provenance. The International Surface Temperature Initiative (ISTI), developed in 2010, has addressed these issues by developing a state-of-the-art databank of global surface temperature observations. Released in 2014, the first version of the databank contains data from more than 30,000 surface temperature stations, has an open and transparent design, and documents observations back to the original source data. Many international organizations have heralded this development and provided feedback that has gone into subsequent updates. All versions are available online, and the current operational version, v1.1.1, was released in late 2017.

Because of the increase in the number of stations, along with its transparency, this databank serves as the starting point for the next version (version 4) of GHCNm. In order to accommodate this, a new end-to-end processing system was established with updates, ingest, and quality control procedures. In addition, the algorithm to remove non-climatic influences in the observations needs to be updated to incorporate the addition of stations and to adhere to NCEI coding standards.

**Accomplishments**

At the time of writing, the ISTI databank remains at version 1.1.1. However, much work has been done to GHCN-M version 4. Since the second beta release (v4.b.2), the Pairwise Homogeneity Algorithm (PHA) was updated to produce a third version of GHCNm Version 4. Existing versions include quality controlled, unadjusted data (QCU), and quality controlled, adjusted data (QCF) from the PHA. Adjustments are made from detecting non-climatic influences in the station data via the PHA. The latest version includes estimated station data, known as the QFE. The publicly provided QFE product is intended for monitoring climate activities (e.g., using a 30-year climatology to estimate trends). This estimation is done in order to have the most robust data over a 30-year period, as is needed before an anomaly can be calculated for

any given station. Since numerous organizations use different 30-year periods, the QFE has been updated to provide estimated data between 1961 and 2010. Using QFE data will expand the number of stations available for climate analysis and for use in other products, including NASA's temperature product (known as GISS) and NCEI's merged land/ocean product, known as NOAAGlobalTemp.

Updates are developed on an NCEI-provided three-tiered system, including development, test, and production environments. Nightly runs are performed internally and checked by the ISTI and GHCN teams to ensure adequate data quality. A manuscript was developed and accepted into publication in the *Journal of Climate*. The article describes the workflow of product development and goes into detail about the uncertainty methods applied to the data. These uncertainties are a result of running a 100-member ensemble of the pairwise homogeneity algorithm (PHA). CICS-NC assisted in this task using Amazon Web Services (AWS) to optimize runtime from weeks to days. From these ensembles, error estimates are provided based upon uncertainties in homogenization, normal estimation, instrument exposure, sampling error, and spatial coverage. These estimates are combined into one global time series; an example is provided in Figure 1. The article was submitted and accepted in the Fall of 2018, and as a result, GHCNm version 4.0.0 was publicly released as an operational product in late October 2018.

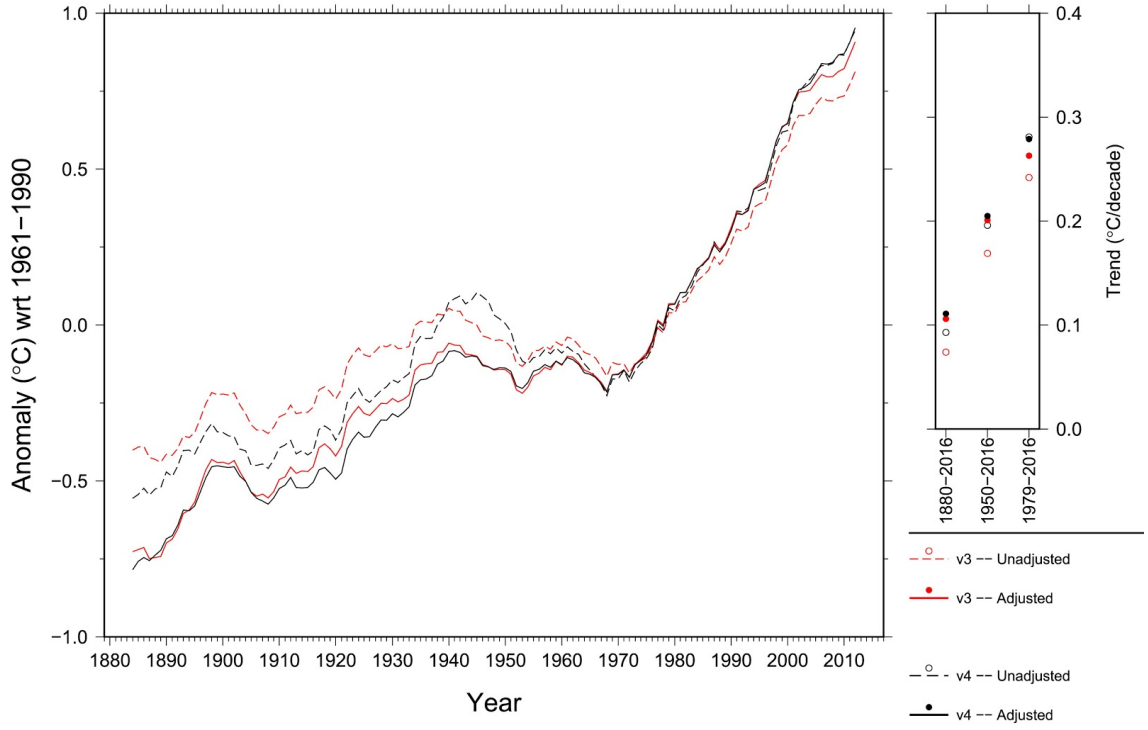



***Figure 1:*** *Global land surface temperatures from versions 3 and 4 of GHCNm. Values are shown for "adjusted" and "unadjusted" versions of both datasets. The panel on the right shows the calculated trends in global land surface temperature for the various datasets for three different time period. Source: Menne et al. 2018.*

Although operational, GHCNm continues to undergo updates as needed. A small update (known as version 4.0.1) is underway, which includes updating the world record extremes check to incorporate the Death Valley, California, record set in July 2018 (monthly average value of 108.1°F), as well as an update to the station metadata files, which is necessary for the Pairwise Homogeneity Algorithm. Testing is currently being performed on the three-tier system, and once results are satisfactory, the update will be applied operationally.

**Planned work**

- Continue to engage with public on feedback regarding GHCNm version 4. Provide updates to processing as needed.
- Push out new version of GHCNm (version 4.0.1) into operations.
- Incorporate GHCNm v4.0.1 into the NOAA Global Temperature product (version 5), which merges land temperature data with sea surface temperatures (ERSST).
- Apply latest versions of the land, ocean, and global datasets into NCEI monthly monitoring operations.

**Products**

- Public, operational version of GHCNm version 4.0.0, with journal article published describing methods

**Publications**

Menne, M. J., C. N. Williams, B. E. Gleason, **J. J. Rennie**, and J. H. Lawrimore, 2018: The Global Historical Climatology Network Monthly Temperature Dataset, Version 4. *Journal of Climate*, **31,** 9835-9854. http://dx.doi.org/10.1175/JCLI-D-18-0094.1

**Presentations**

**Rennie, J. J.**, 2018: Climate in Your Neck of the Woods: A Real-Time, Interactive Product to Assess Historical and Current Trends in Temperature and Precipitation. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 29, 2018.

**Rennie, J.**, 2018: Climate in Your Neck of the Woods: A Real-Time, Interactive Product to Assess Historical and Current Trends in Temperature and Precipitation. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.

**Other**

- The International Surface Temperature Initiative: www.surfacetemperatures.org
- FTP site of GHCN-M version 4: ftp://ftp.ncdc.noaa.gov/pub/data/ghcn/v4/

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **1** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

*GHCN-Monthly version 4.0.0 has become operational, and a paper has been published in Journal of Climate.*

| Development of a Homogenized Sub-Monthly Temperature Monitoring Tool | |
|---|---|
| **Task Leader/Task Team** | Jared Rennie, Kenneth Kunkel, Jesse Bell |
| **Task Code** | NC-SON-08-NCICS-JR/KK/JB |
| **NOAA Sponsor** | Jay Lawrimore |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50% |
| | Theme 2: Climate and Satellite Observations and Monitoring 50% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Environmental Observations |

**Highlight:** A sub-monthly tool for monitoring impacts of temperature extremes in the United States has been created. The resulting dataset was used to assess heat extreme events in the United States from 1895–2018, and a manuscript was developed for publication.
https://ncics.org/portfolio/monitor/sub-monthly-temperatures/

**Background**

Land surface air temperature products have been essential for monitoring the evolution of the climate system. Most temperature datasets require homogenization schemes to remove or change non-climatic influences that occur over time so the dataset is considered homogenous. Inhomogeneities include changes in station location, instrumentation, and observing practices. While many homogenized products exist on the monthly time scale, few daily products exist, due to the complication of removing break points that are truly inhomogeneous rather than effects due to natural variability (for example, sharp temperature changes due to synoptic conditions such as cold fronts). However, there is a demand for sub-monthly monitoring tools and thus a need to address these issues.

The Global Historical Climatology Network-Daily (GHCN-D) dataset provides a strong foundation of the Earth's climate on the daily scale and is the official archive of daily data in the United States. While the dataset adheres to a strict set of quality assurance practices, no daily adjustments are applied. However, this dataset lays the groundwork for other NCEI products, including the climate divisional dataset (nClimDiv), the North American monthly homogenized product (Northam), and the 1981–2010 Normals. Since these downstream products provide homogenization and base period schemes, it makes sense to combine these datasets to provide a sub-monthly monitoring tool for the United States.

**Accomplishments**

A system has been established at CICS-NC to extract the latest version of the following datasets: GHCN-D, Northam, the 1981–2010 Normals, and nClimDiv. Using these datasets, monthly adjustments are applied to daily data, and then anomalies are created using a base climatology defined by the 1981–2010 Normals. Station data is aggregated to the state level and then region level (as defined by the National Climate Assessment; NCA). Daily plots are made to analyze U.S. temperature values and anomalies. Once daily averages for each state and NCA region are computed, probability distribution functions are generated to provide ranks on different time scales. These are important for understanding recent extremes in a changing climate. The process runs every morning to incorporate the latest data from GHCN-D and can be found at: https://ncics.org/portfolio/monitor/sub-monthly-temperatures/.

The dataset has been updated through 2018, and heat events are identified using this quasi-homogenized data. To identify an event, the distribution of temperature for a particular area is taken for the period of record, and the 98th percentile of the distribution is taken as the threshold for a much higher than normal heat event. Using this temperature threshold, data are analyzed to search for a consecutive period of three or more days where the value exceeds this threshold. Once an event is found, information including the onset, length, and severity is extracted. Statistics are calculated, including departure from normal, extreme daily maximum and minimum temperatures, as well as ranks against its period of record. Probability density functions are used to determine how severe the event is against its period of record. Trends are calculated using the Mann-Kendall method, which assesses the significance of a monotonic upward or downward trend over time. An example of the product is provided in Figure 1, where a notable increase of overnight minimum events since the early 1990s can be seen in the southeastern part of the United States.

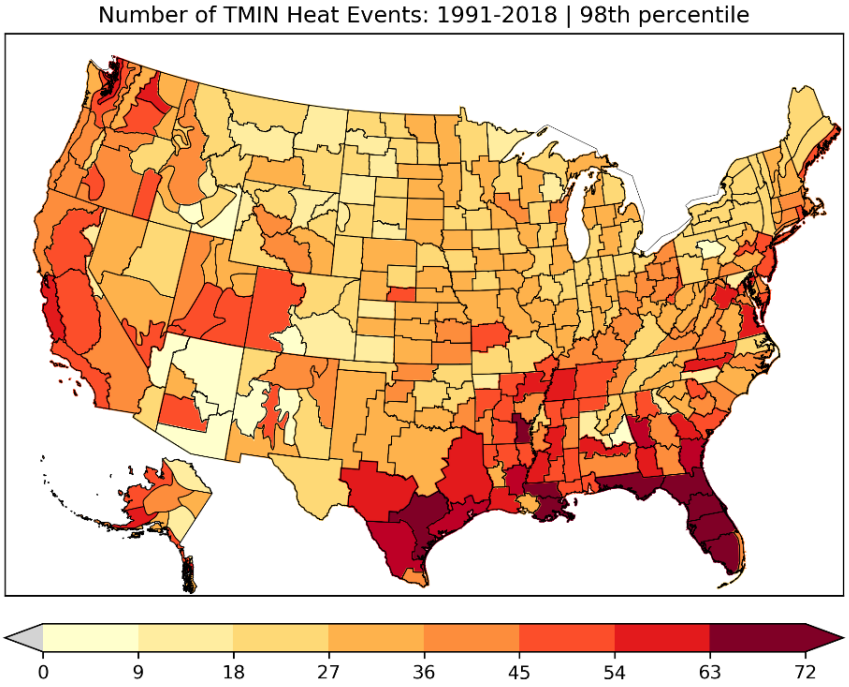



***Figure 1.*** *Number of heat events in the United States from 1991-2018. Results are organized by divisions defined by NCEI.*

A manuscript is in preparation for submission. It has gone through NCEI internal review, and changes have been made based upon constructive comments provided by NCEI colleagues. An extra analysis was performed as a result, developing the product two different ways. The first was providing the adjustments stated above, and the other was providing no adjustments. The non-parametric Wilcoxon statistic was used to test the differences between the two products. While the differences were not statistically significant, the authors felt it was important to keep the monthly adjustments in, as accounting for some inhomogeneity would be better than none.

Once accepted, this dataset will be used as the baseline to match heat event data with available health data provided by the University of Nebraska Medical Center (UNMC), the University of Pittsburgh, and the

North Carolina Detect (NC DETECT) organizations. Future work also includes comparison with available data from the United States Climate Reference Network (USCRN), including soil moisture.

**Planned work**

- Continue to engage with users on the monitoring product.
- Submit manuscript to *Journal of Applied Meteorology and Climatology*.
- Work with the University of Nebraska Medical Center and other health related organizations to identify heat events with available health data.
- Compare dataset with other climate metrics, such as soil moisture.

**Products**

- A new, state-of-the-art monitoring tool for sub-monthly data for the United States
- Public facing website to display updated maps and ranks
- Database of heat events, based on a 98th percentile threshold, from 1895-2018

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **3** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Simplified and Optimal Analysis of NOAA Global Temperature Data: Data Validation, New Insights, Climate Dynamics, and Uncertainty Quantification** | |
|---|---|
| **Task Leader:** | Samuel Shen |
| **Task Code** | NC-SON-09-SDSURF |
| **NOAA Sponsor** | Jeff Privette |
| **NOAA Office** | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Data Fusion and Algorithm Development |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready nation 50% |
| **NOAA Strategic Research Priorities:** | Environmental Observations |

**Highlight:** Improvements were made in the software technology, 4DVD (4-Dimensional Visual Delivery of big climate data), and *Amazon* entered a big data partnership with 4DVD in December 2018 to host the 4DVD big database. The system has the capability to rapidly deliver NOAA environmental data to classrooms, the scientific community, and the general public.

**Background**

Modern climate data have helped deepen the understanding of climate dynamics that operate in the background of global temperature increase and have also called for more careful, transparent, and independent analyses of relevant climate datasets, including the blended NOAAGlobalTemp. The general public has enormous interest in climate variation, wants to have an easy access to climate data, and needs the quantitative description of the climate data accuracy. These give rise to many research questions on climate data delivery, climate data accuracy quantification, and the climate dynamics that can reasonably explain the climate data. As the last phase of this project, we focused on product development and release.

**Accomplishments**

***Python programming***. The suite of R codes previously developed for the project for the short R course at CICS-NC/NCEI was translated to Python programming for fast delivery and monitoring of climate and satellite observation data to both the science community and the general public. Both R codes and Python codes will be on the website of the book, "Climate Mathematics: Theory and Applications," authored by Samuel Shen and Richard Somerville, to be published in August 2019. Figure 1 on the next page shows a screenshot of the Python code.

***4DVD [4-Dimensional Visual Delivery (4DVD) of big climate data] enhancement***. The rapid visual delivery 4DVD system (demo: www.4dvd.org) was improved as a distributed file service application based on web browser, database, server, and Hadoop technology. 4DVD delivers data in a 4D space-time box and allows users to visualize the climate data as maps (e.g., Figure 2) or time series for a point on a map. Figure 2 reflects January 1983 NOAAGlobalTemp. This is a map on a globe but can also be displayed in a 2D lat-long map. Data can be downloaded for maps or time series, after the maps and time series are found useful. The 4DVD system is scalable to any data size. The 4DVD's fast speed and beautiful maps are attractive to students and could assist with NOAA climate literacy and outreach activities. These make 4DVD very different from the traditional data downloads and the existing online plotting systems at NOAA and NASA, such as NOAA's Climate at a Glance, climate.gov, Explorer, and NASA's Giovanni. See Pierret and Shen (2017) for 4DVD's details.

In December 2018, *Amazon* entered a big data partnership with 4DVD and granted us $25,000 *Amazon Web Services* (AWS) credit to deliver big climate data via 4DVD operated on the AWS cloud. The new platform will be released by May 2019.

```
# draw filled contours
cnplot = smap.contourf(x, y, mapmat, clevs, cmap = plt.cm.jet)

# add colorbar
# pad: distance between map and colorbar
cbar = smap.colorbar(cnplot, location = 'right', pad = "2%")
# add colorbar title string
cbar.set_label('[oC]', verticalalignment = 'top')

# add plot title
plt.title('Tropic Pacific SAT Anomalies Dec 1997 [deg C]')

# label x and y
plt.xlabel('Longitude', labelpad = 20)
plt.ylabel('Latitude', labelpad = 40)

# display on screen
plt.show()
```

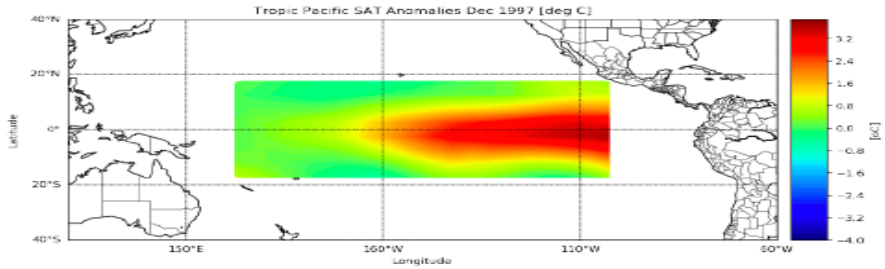



***Figure 1.*** *Sample Python code for the book "Climate Mathematics" by Shen and Somerville.*

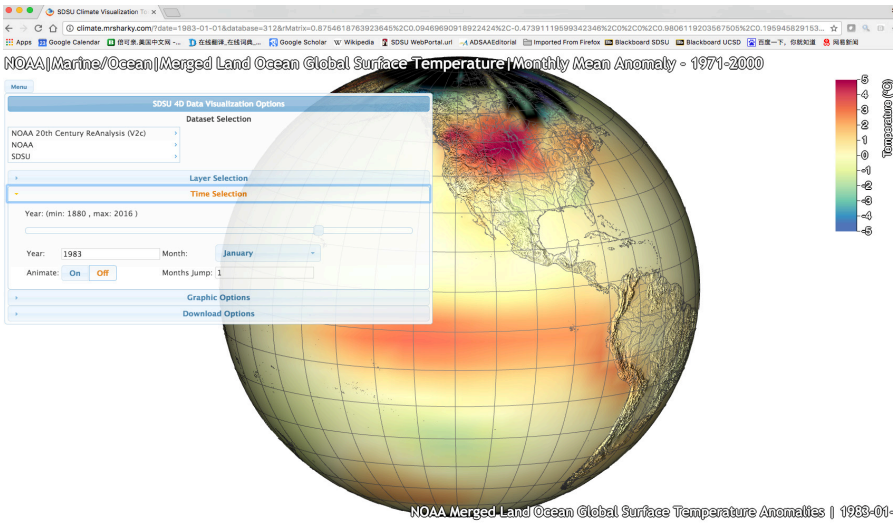



***Figure 2.*** *4DVD display of NOAAGlobalTemp data: January 1983 temperature anomalies.*

**Planned work**

This project ended in February 2019.

**Products**

- 4DVD (4Dimensional visual delivery) visual delivery system for big climate data: www.4dvd.org
- Python codes for the book, "*Climate Mathematics: Theory and Applications*"

**Publications**

*Peer-reviewed*

Tucker, T. and S. S. P. Shen, 2018: A toolkit for snow cover area calculation and display based on the Interactive Multisensor Snow and Ice Mapping System and an example for the Tibetan Plateau region. *Advances in Data Science and Adaptive Analysis,* **10**. http://doi.org/10.1142/S2424922X18500031

*Non-peer-reviewed*

Shen, S. S. P. and R. C. J. Somerville, 2019: *Climate Mathematics: Theory and Applications*, Cambridge University Press, New York, 432pp. (publication in August 2019)

**Presentations**

Shen, S., 2018: Statistical prediction of the United States spring-summer precipitation from the Western US spring surface temperature anomalies using canonical correlation analysis, *International Workshop of First Phase of GEWEX/GASS LS4P Initiative and TPEMIP*, Washington, DC, December 8, 2018.

**Other**

- Advised a NOAA EPP undergraduate student: Louis Selstad, 2018.
- Taught a new course, "Climate Change Solutions" at San Diego State University, Fall 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **2** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **3** |
| **# of undergraduate students mentored during the year** | **1** |

***4DVD (4-dimensional visual delivery) of big climate data:*** *The full application will be made available to CICS-NC/NCEI upon request. Demo: www.4dvd.org*

***Argo data visualizer****: Argo data visualization software, named Argovis, linked to Argo website. Demo: http://www.argovis.com/map*

**Reference**

Pierret, J., and S.S.P. Shen, 2017: 4D visual delivery of big climate data: A fast web database application system. *Advances in Data Science and Adaptive Analysis*, **9**. http://doi.org/10.1142/S2424922X17500061

| **Night Marine Air Temperature Near Real-Time Dataset Development** | |
|---|---|
| **Task Leader:** | Steve Stegall |
| **Task Code** | NC-SON-10-NICS-SS |
| **NOAA Sponsor** | Huai-min Zhang |
| NOAA Office | NESDIS/NCEI |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Climate Adaptation and Mitigation: 100% |
| **NOAA Strategic Research Priorities:** | Environmental Observations |

**Highlight:** A preliminary gridded NCEI NMAT dataset from 2002–August 2017 was generated that includes NMATs adjusted in the boundary layer to a homogenized height of 10m and gridded using a distance weighting scheme. Differences between NCEI NMAT and HadNMAT2 were investigated and documentation was provided to transition the project activity to NCEI.

**Background**

Night marine air temperature (NMAT) provides the ocean's complement to land surface temperatures and allows for a global representation of surface temperature. NMAT also complements sea surface temperature (SST) and is used to bias correct SST data. NMAT is one of many observed variables in the International Comprehensive Ocean-Atmosphere Data Set (ICOADS). Many of the inputs into ICOADS are from the Voluntary Observing Ships (VOS) in the "International List of Selected, Supplementary and Auxiliary Ships," Publication Mo. 47 (Pub. 47).

**Accomplishments**

The Large and Yeager (2004) approach was used to adjust NMAT temperatures measured at different heights above the ocean surface to a common height (homogenized height) set to 10m. A distance weighted gridding scheme was implemented for the corrected temperatures to 5° x 5° lat/lon grid. A preliminary global ocean monthly NMAT was generated on a 5° x 5° grid from January 2002 to August 2017. This year, differences between NCEI NMAT and HadNMAT2 were investigated with the largest differences reflected in the Arctic and the Southern Ocean as well as the east coasts of both North America and Asia.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| International Comprehensive Ocean–Atmosphere Data Set (ICOADS) | |
|---|---|
| **Task Leader:** | Scott Stevens |
| **Task Code** | NC-SON-11-NCICS-SS |
| **Other Sponsor** | |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** The International Comprehensive Ocean–Atmosphere Data Set (ICOADS) is the most complete and heterogeneous collection of surface marine data in existence. Work is being done to migrate the high-impact scripts and workflow used to retrieve and process this data to a new, more robust computation environment.

**Background**

The International Comprehensive Ocean–Atmosphere Data Set (ICOADS) offers surface marine data spanning the past three centuries, and simple gridded monthly summary products for 2° latitude x 2° longitude boxes back to 1800 (and 1° x 1° boxes since 1960)—these data and products are freely distributed worldwide. As it contains observations from many different observing systems encompassing the evolution of measurement technology over hundreds of years, ICOADS is the most complete and heterogeneous collection of surface marine data in existence. The most recent version, ICOADS Release 3.0 (R3.0; Freeman et al. 2017) released in June 2016, contains over 455 million individual marine reports covering years 1662–2014, with Near-Real-Time (NRT) extensions from 2015-present.

**Accomplishments**

The task of migrating this process to a new, more robust computing environment at NCEI is progressing as planned. Scripts to retrieve and process incoming data have been streamlined and made less dependent on software that requires frequent updates. All processing is now being done with native Linux applications to ensure portability and robustness.

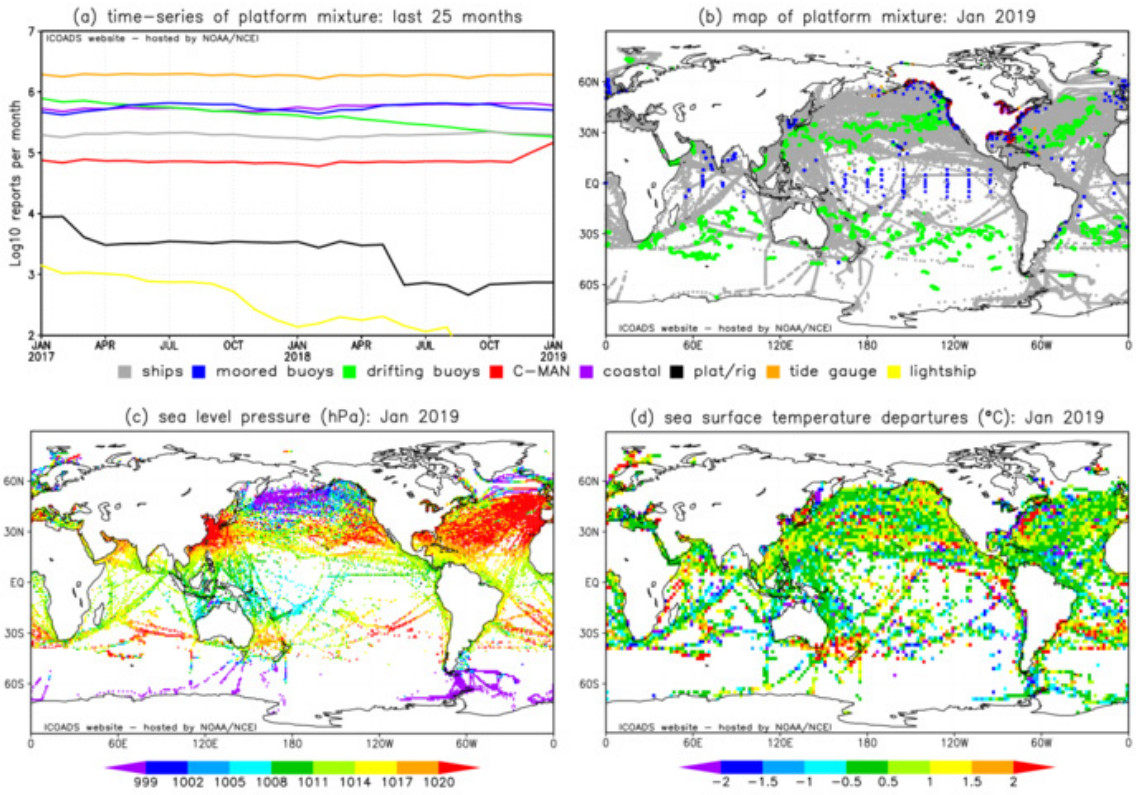



***Figure 1.*** *Example of several variables available through ICOADS.*

**Planned work**

- Complete process of replicating data flow for ICOADS
- Compare results to operational version to ensure accuracy
- Migrate process to new operational architecture

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Investigation of Trends in Airport Weather Conditions** | |
|---|---|
| **Task Leader** | Scott Stevens |
| **Task Code** | NC-SON-12-NCICS-SS |
| **Other Sponsor** | NCEI |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 100% |
| **Main CICS Research Topic** | Surface Observing Networks |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** Several decades of surface observations have been assessed to quantify a trend in the frequency of low-visibility conditions at the nation's busiest airports. Results showed a marked decrease in the frequency of Instrument Flight Rule (IFR) conditions at 29 of 30 airports in all seasons.

**Background**

Aviation is profoundly impacted by weather, which causes billions of dollars in lost revenue each year. One such avenue by which flights can be delayed or canceled is through reduced visibility and low cloud ceilings, which force aircraft to rely on separation provided by radar, referred to as Instrument Flight Rules (IFR), causing a need for greater spacing and therefore diminished capacity for an airport to land aircraft. Given that these conditions are very often tied to atmospheric moisture content, specifically saturation in the form of fog, mist, and clouds, one may posit that a trend exists in the frequency of IFR conditions over recent decades, as the changing climate includes changes in moisture. This study aims to quantify these trends if any exist and examine the characteristics of IFR events in space and time.

**Accomplishments**

A study of 45 years of hourly weather observations was completed for the 30 busiest airports in the United States, showing a marked decrease in the frequency of IFR conditions at 29 of 30 airports in all seasons, driven primarily by a decreasing frequency of hours in which visibility is low (Figure 1). The resulting paper was published in the *Journal of Applied Meteorology and Climatology*.

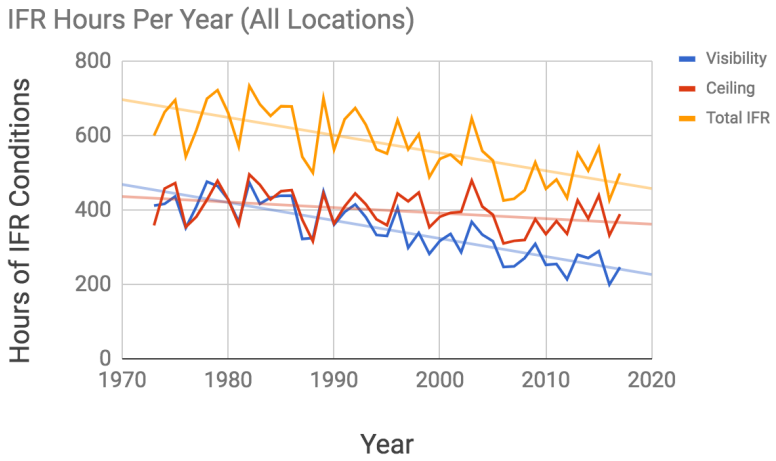



***Figure 1.*** *Annual hours of IFR conditions across all locations.*

**Planned work**

Study is complete, but conversations at conferences have led to ideas for expansion or refinement.

**Publications**

Stevens, S. E., 2019: Trends in Instrument Flight Rules (IFR) conditions at major airports in the United States. *Journal of Applied Meteorology and Climatology*, **58**, 615-620. http://dx.doi.org/10.1175/JAMC-D-18-0301.1

**Presentations**

**Stevens, S.**, 2019: Trends in IFR Conditions at Major Airports in the United States. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Workforce Development

Workforce development is long-term investment in NOAA's future workforce. The National Centers for Environmental Information (NCEI) has a continuing number of research and workforce requirements that necessitate collaboration with the best climate science practitioners in the nation. This requires the hiring of outstanding scientific staff with unique skills and backgrounds in Earth System Science and the use of observations for defining climate and its impacts. To meet this demand, CICS-NC has hired a cadre of dedicated research staff and is actively working to identify and train the next generation of scientifically and technically skilled climate scientists. Junior and/or aspiring scientists, including students and post-doctoral researchers, play an important role in the conduct of research at CICS-NC. While consistent funding remains a challenge, CICS-NC is nevertheless working to identify prospective future scientists, to nurture interest in climate applications, and to provide opportunities for training and mentorship on various levels.

***Research Faculty.*** Senior CICS-NC scientists hold research faculty positions in the Marine, Earth, and Atmospheric Sciences Department (MEAS) in the College of Sciences (COS) at NCSU and provide mentorship to junior scientists and students both in CICS-NC and MEAS. Several junior scientists have also secured adjunct appointments in pertinent NCSU departments and at other universities to gain experience and exposure with their academic peers and to mentor graduate students. CICS-NC scientists also mentor students formally and informally (CICS-NC student internships, NOAA Hollings Scholars, NASA DEVELOP team members, etc.) and engage in various outreach activities to promote awareness and increase interest in K–12 climate science studies.

- Otis Brown and Kenneth Kunkel hold Research Professor appointments in NCSU's MEAS/COS. Kunkel serves as Ph.D. committee chair for CICS-NC research staff members Brooke Stewart and Sarah Champion.
- Carl Schreck holds adjunct Research Assistant Professor appointments with NCSU MEAS and with NC A&T University.
- Jessica Matthews holds an adjunct Research Assistant Professor with NCSU's Mathematics Department.
- Jennifer Runkle holds an adjunct Research Assistant Professor appointment with Appalachian State University.

***Post-doctoral Scholars.*** CICS-NC initiated its program in workforce development through the hiring of an initial group of post-doctoral research scholars working on applied research topics in Climate Data Records and Surface Observing Networks. CICS-NC continues to hire post-docs for a 2–3 year commitment to support identified project needs. Senior scientists from CICS-NC and NCEI provide mentoring for these post-docs. Currently, CICS-NC personnel includes one post-doctoral scholar:

- Andrew Ballinger, post-doctoral Research Scholar, completed his second year working with Kenneth Kunkel and collaborating on the multi-institutional, NSF-sponsored Urban Resilience to Extremes—Sustainability Research Network (UREx SRN) project assisting with project onboarding of graduate student, Geneva Gray (see project report under *Other CICS-NC PI Projects*). In Fall 2018, he began work with Kunkel and Jenny Dissen supporting the U.S. –India Partnership for Climate Resilience efforts. (see project reports under *Assessment and Engagement*).

***Students (Graduate/Undergraduate/High School).*** CICS-NC continues to be successful in recruiting and involving local high school students and other area undergraduate and graduate students in temporary student internships, providing an opportunity for the students to explore their interest in science and/or apply their ongoing education to current projects within the institute under the oversight of CICS-NC and NCEI mentors. CICS-NC scientists also serve as mentors and advisors for the NOAA Hollings Scholars and NASA DEVELOP team members that complete their 10-week internship projects at NCEI.

Spring 2018:

- *Elijah Byrd*, Nesbitt Discovery Academy senior, completed a semester internship working with Jenny Dissen on understanding NOAA NCEI customers and their use of NCEI's environmental data. Eli also completed a research project comparing inclement weather Buncombe County school closures with NCEI records to understand any patterns and trends and determine whether the analysis could help inform school closure decision-making.
- *Laura Thompson*, Appalachian State University undergraduate student, worked with Jennifer Runkle on a pilot study with ASU outdoor grounds maintenance workers, utilizing wearable sensors to assess cold exposure in population health and climate change studies.
- *Can Cui,* North Carolina State University Statistics PhD student*,* worked with Jennifer Runkle on the pilot cold study data analysis.
- *Katie Lynch*, Emory University Rollins School of Public Health MPH student, completed her work with Jesse Bell studying the impacts of drought on human health.

Summer 2018:

- The NASA DEVELOP team composed of *Brooke Adams* (Texas A&M University graduate), *Forest Cook* (Middle Tennessee State University graduate), and *Conor Mulderrig* (UNC Asheville) completed their project, "South Dakota Ecological Forecasting," under project advisor Jessica Matthews. The project looked at monitoring the spread of invasive grasses and the impacts on grassland management practices in the Great Plains using NASA Earth Observations and NOAA Climate Data Records. https://develop.larc.nasa.gov/2018/summer/SouthDakotaEco.html

Summer and Fall 2018:

- *Emily Pauline*, University of Georgia Masters student, worked with Jessica Matthews to design a framework to validate remote sensing retrievals of land surface albedo with in situ observations.
- *Caroline Wright*, recent Appalachian State University graduate, worked with Angel Li and the TSU developing interactive web maps for the Fourth National Climate Assessment.

Spring 2019:

- The NASA DEVELOP team composed of *Nicholas Roberts* (NCSU graduate), *Sally Ross* (University of Tennessee), *Amelia Smith* (Virginia Polytechnic Institute and State University), and *Anna Stamatogiannakis* (UNC Chapel Hill graduate) completed their project, "Analyzing Drought-related Impacts on Urban Tree Inventory Conditions and Recovery in Texas" under science advisor Jessica Matthews. The project focused on urban forestry impacts due to the historic 2011 drought in Houston and Austin by leveraging fine-scale imagery to classify canopy loss. https://arcg.is/0i8en8

Ongoing:

- *Qing Dong,* Hohai University (Nanjing, China) PhD student, is working as a Visiting Research Scholar with Kenneth Kunkel on her graduate research studies involving trends in extreme rainfall and flooding using historical change analyses and future climate model simulations.
- *Geneva Gray,* NCSU PhD student, is working with Kenneth Kunkel on the multi-institutional, NSF-sponsored Urban Resilience to Extremes—Sustainability Research Network (UREx SRN) project.
- *Sridhar Mantripragada*, NCSU PhD student, is working with Carl Schreck on his NASA project, using NASA's new Cyclone Global Navigation Satellite System (CYGNSS) retrievals to investigate the surface interactions between Kelvin waves and easterly waves.
- *Lakemarium Worku*, North Carolina A&T PhD student, worked with Carl Schreck on his NASA Maritime Continent grant, examining the strong diurnal cycle of convection over the Maritime Continent and demonstrating how it impacts subseasonal-to-seasonal forecasts.

# Other CICS PI Projects

The North Carolina Institute for Climate Studies (NCICS) vision is to: *inspire* cutting-edge research and collaboration, *advance* understanding of the current and future state of the climate, and *engage* with business, academia, government, and the public to enhance decision-making. The institute's main objectives are to promote discovery of new knowledge about global, regional, and local climate variability and its impacts and to provide information that is critical for determining trends and validating climate forecasts at all these spatial scales.

CICS' scientific vision centers on the observation, using instruments on Earth–orbiting satellites and surface networks, and prediction, using realistic mathematical models, of the present and future behavior of the Earth System. In this context, observations include the development of new ways to use existing observations, the invention of new methods of observation, and the creation and application of ways to synthesize observations from many sources into a complete and coherent depiction of the full system. Prediction requires the development and application of coupled models of the complete climate system, including atmosphere, oceans, land surface, cryosphere and ecosystems. Underpinning all institute projects and activities is the fundamental goal of enhancing our collective interdisciplinary understanding of the state and evolution of the full Earth System.

While CICS-NC projects and activities under the CICS cooperative agreement are primary within NCICS, NCICS scientists also participate in and receive partial support through other sponsored research programs awarded through competitive proposal solicitations. Individual and collaborative climate science proposals are submitted through NCSU to relevant federal solicitations from NASA, NSF, NOAA, DOE, DOD, and NIH (including CDC and NIOSH) and to various other non-federal entities.

| **Changes in the Frequency of Freezing Precipitation** | |
|---|---|
| **Task Leader** | Pavel Groisman |
| **Task Code** | NC-OTH-01-NCICS-PG |
| **Other Sponsor** | Multiple |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Climate Research, Data Assimilation and Modeling |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication;<br>Environmental Observations |

**Highlight:** International environmental change studies focused on the northern extratropics were conducted to better inform vulnerable societies and better prepare them for potential future developments. One of these studies devoted to Eurasian drylands is near completion (peer-reviewed papers were published and a book is in press). BELMONT Arctic ERA study is under way. Two more international studies devoted to the Arctic water cycle and extreme events over Europe are proposed.

**Background**

Contemporary environmental changes are not restricted to changes in major climatic characteristics such as temperature and precipitation, but are multi-faceted, affect and are affected by human activities, and may manifest themselves differently in different regions of the world and feedback to other regions. These manifestations and feedbacks are not well understood and require thorough attention and integrated multidisciplinary approaches to assess, as they may affect the environment, including in regions many miles away from the areas of initial forcing, in unexpected ways. In the past year, our studies focused on two regions of northern extratropics:

- drylands of Northern Eurasia that are susceptible to external harmful forcing such as droughts, floods, and other harmful weather anomalies, and
- the Arctic, where large environmental changes have occurred (atmospheric and oceanic warming, sea ice and permafrost retreats) and are projected to continue at accelerated rates.

**Accomplishments**

***Northern Eurasia Future Initiative (NEFI).*** The Northern Eurasia Future Initiative (NEFI; http://nefi-neespi.org), designed as an essential continuation of the Northern Eurasia Earth Science Partnership Initiative (NEESPI), was launched in 2017. NEESPI sought to elucidate all aspects of ongoing environmental change, to inform societies and better prepare them for future developments. A key principle of NEFI is that these developments should be secured through science-based strategies co-designed with regional decision makers. Nine NEFI research foci were identified: warming of the Arctic; changing frequency, pattern, and intensity of extreme and inclement environmental conditions; retreat of the cryosphere; changes in terrestrial water cycles; changes in the biosphere; pressures on land-use; changes in infrastructure; societal actions in response to environmental change; and quantification of Northern Eurasia's role in the global Earth system. Integrated Assessment Models are deemed needed as the final stage of global change assessment. NEFI Project Scientist Pavel Groisman:

(a) organized NEFI-related sessions at international conferences (JpGU and AGU in Makuhari and Washington, DC respectively) and a NEFI-related Workshop (at the ENVIROMIS Conference in Tomsk);

(b) served as a guest-editor of the Special NEFI Issue of *Environmental Research Letters*; and

(c) conducted his own studies for the Eurasian drylands and the Arctic.

***GEWEX project*.** To improve understanding of future changes in hazardous cold/shoulder season precipitation and storms, especially occurring near 0°C, an international GEWEX project was launched to study human-related extreme events that occur around 0°C. We studied the occurrence of freezing precipitation (freezing rain and drizzle, FR and FD) events over the northern extratropics and documented the major changes that occurred during the past decade at high latitudes. An algorithm was developed to define the weather conditions conducive to freezing rain (WCCFR) using the synoptic and aerologic networks. Climatology and dynamics of these WCCFR changes were estimated over the northern extratropics using the modern reanalysis output. Figure 1 below presents the WCCFR climatology for Northern Eurasia based on the CFSRv2 reanalysis while Figure 2 shows changes (in percent) in the last 13 years (2005–2017) compared to the previous 26 years.

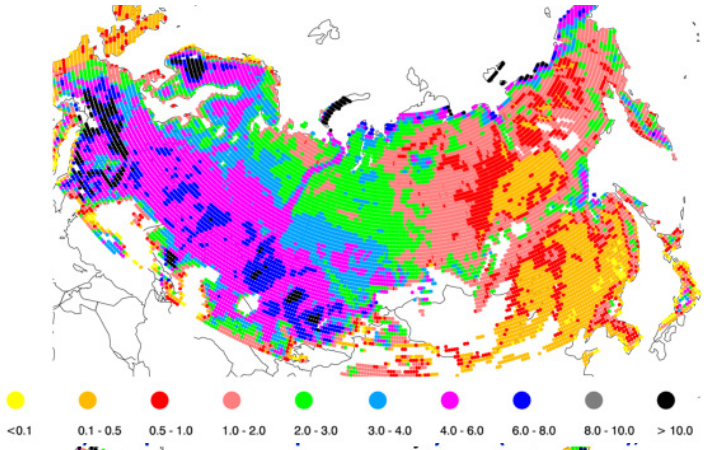



***Figure 1.*** *Freezing rain climatology of Northern Eurasia at elevations below 1200 m (days per year) based on our algorithm of weather conditions conducive to freezing rain (WCCFR). The algorithm was developed using the synoptic and aerologic networks of the northern extratropics and is now applied to the output of the CFSRv2 reanalysis.*

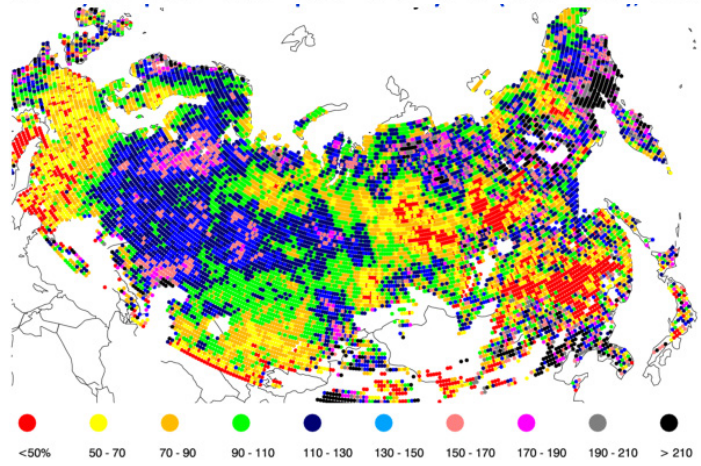



***Figure 2.*** *Freezing rain days change in the past 13 years (2005–2017) compared to the previous 26 years (1979–2004), %*

- ***Dryland Belt of Northern Eurasia (DLB) study***. The DLB is a region where environmental changes are becoming more controlled by human activity. Following an international workshop in Mongolia (June 2017), a multidisciplinary international study was initiated to address changes in the DLB and to develop a sustainable strategy of its development. Currently, this work is close to completion. Several peer-reviewed papers have been published and a book by Gutman *et al.* (eds), *Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems* was compiled, peer-reviewed, and submitted to the Springer Publishing House.
- ***Global temperature time series homogeneity.*** Progress in documenting global climate change (e.g., new instruments) created concerns about the homogeneity of global temperature time series. Our perspective is to maintain a "conservative" estimate of global and zonal surface air temperature

changes since 1881 using fixed in situ station networks and the optimal area-averaging technique, which has not changed in the past 150 years.

**Planned work**

- Present latest project results at appropriate international conferences.
- Submit WCCFR paper(s) to peer-reviewed journals.
- Submit proposal to U.S. funding agencies to facilitate development of the WCCFR product for climatological projections of FR occurrence and risk management associated with these events.
- Support development of NEFI studies including: (a) convening international NEFI Conferences and Sessions at large International Conferences; (b) maintaining major NEFI publication outlet (presently, *Environmental Research Letters* Special Issues); and (c) promoting NEFI Science Plan science questions. (http://nefi-neespi.org)
- Update the homogeneous time series of global, zonal, and regional mean monthly near-surface air temperature from 1881 to date with time delay of several months.

**Publications**

Chen, J., R. John, G. Sun, P. Fan, G. M. Henebry, M. E. Fernández-Giménez, Y. Zhang, H. Park, L. Tian, **P. Groisman**, Z. Ouyang, G. Allington, J. Wu, C. Shao, A. Amarjargal, G. Dong, G. Gutman, F. Huettmann, R. Lafortezza, C. Crank, and J. Qi, 2018: Prospects for the sustainability of social-ecological systems (SES) on the Mongolian plateau: five critical issues. *Environmental Research Letters*, **13,** 123004. http://dx.doi.org/10.1088/1748-9326/aaf27b

Chen, J., Z. Ouyang, R. John, G. M. Henebry, P. Y. Groisman, A. Karnieli, M. Kussainova, A. Amartuvshin, A., Tulobaev, E. T. Isabaevich, C. Crank, K. Kadhim, J. Qi, J., and G. Gutman, 2019: Chapter 10: Social-ecological systems across the Asian Drylands Belt (ADB). In: *Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems*, Gutman et al., Eds., Springer, **in press**.

Fan, P., J. Chen, Z. Ouyang, **P. Groisman**, T. Loboda, G. Gutman, A. V. Prishchepov, A. Kvashnina, J. Messina, N. Moore, S. W. Myint, and J. Qi, 2018: Urbanization and sustainability under transitional economies: a synthesis for Asian Russia. *Environmental Research Letters*, **13,** 095007. http://dx.doi.org/10.1088/1748-9326/aadbf8

**Groisman, P.**, O. Bulygina, G. Henebry, N. Speranskaya, A. Shiklomanov, Y. Chen, N. Tchebakova, E. Parfenova, N. Tilinina, O. Zolina, A. Dufour, J. Chen, R. John, P. Fan, C. Mátyás, I. Yesserkepova, and I. Kaipov, 2018: Dryland belt of Northern Eurasia: contemporary environmental changes and their consequences. *Environmental Research Letters*, **13,** 115008. http://dx.doi.org/10.1088/1748-9326/aae43c

Groisman, P. Y., O. N. Bulygina, G. M. Henebry, N. A. Speranskaya, A. I. Shiklomanov, Y. Chen, N. M. Tchebakova, E. I. Parfenova, N. D. Tilinina, O. G. Zolina, A. Dufour, J. Chen, R. John, and P. Fan, 2019: Chapter 2: Dry Land Belt of Northern Eurasia: Contemporary environmental changes. *In:* Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems, Gutman et al., Eds., Springer, **in press**.

Liu, X., Q. Tang, W. Liu, H. Yang, **P. Y. Groisman**, G. Leng, P. Ciais, X. Zhang, and S. Sun, 2019: The asymmetric impact of abundant preceding rainfall on heat stress in low latitudes. *Environmental Research Letters*, **in press**. http://dx.doi.org/10.1088/1748-9326/ab018a

Soja, A., and **P. Groisman**, 2018: Earth science and the integral climatic and socio-economic drivers of change across northern Eurasia: The NEESPI legacy and future direction. *Environmental Research Letters*, **13,** 040401. http://dx.doi.org/10.1088/1748-9326/aab834

**Products**

- Algorithm of defining weather conditions conducive to freezing rain (WCCFR) was refined and applied to North America and Northern Eurasia reanalysis data

**Presentations**

Chen, J., Y. Zhang, R. John, G. Sun, P. Fan, J. Wu, H. Park, C. Shao, **P. Y. Groisman**, G. RH. Alington, G. Gutman, M. Fernandez-Gimenez, L. Tian, A. Amartuvshin, R. Lafortezza, F. Huettmann, R. Reid, and J. Qi, 2018: Socio-Environmental Systems (SES) on the Changing Mongolian Plateau: A review. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

Chen, Y., W. Ju, **P. Y. Groisman**, J. Li, X. Fei, and H. Ruan, 2018: Quantification of grazing impact on C sequestration over Temperate Eurasian Steppe. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

**Groisman P.**, 2018: Achievements and New Directions of Environmental Change Studies in Northern Eurasia. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.

**Groisman, P.**, 2018: Freezing precipitation, characterization of weather conditions associated with it, and changes of the frequency of its occurrences. *International Conference ENVIROMIS-2018*, Tomsk, Russia, July 5, 2018.

**Groisman, P.** and R. Stewart, 2018: Near 0°C Precipitation Cross-Cut GHP Project Annual Progress Report. *GEWEX GHP Panel Meeting*, Santiago, Chile, October 25, 2018.

**Groisman, P.**, G. M. Henebry, A. I. Shiklomanov, N. Speranskaya, Y. Chen, N. M. Tchebakova, E. I. Parfenova, N. Tilinina, O. G. Zolina, A. Dufour, J. Chen, R. John, P. Fan, C. Mátyás, I. Yesserkepova, and I. Kaipov, 2018: Contemporary Environmental Changes over the Dry Land Belt of Northern Eurasia and their Consequences. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

**Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev and I. Danilovich, 2018: Human-Associated Extreme Events: Freezing Precipitation. *8th International GEWEX Scientific Conference*, Canmore, Alberta, Canada, May 8, 2018.

**Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev and I. Danilovich, 2018: Human-Associated Extreme Events: Freezing Precipitation. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.

**Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev, and I. Danilovich, 2018: Human-associated extreme events. *22nd International Conference for Young Scientists*, Maykop, Adygeya Republic, Russia, September 24, 2018.

Parfenova, E. I., N. M. Tchebakova, N. A. Kuzmina, S. R. Kuzmin, E. Shvetsov, A. J. Soja, and **P. Y. Groisman**, 2018: Climate Change Consequences for Siberia's Forest Land Adaptation in the Warming Climate of the 21st Century. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

Streletskiy, D. and **P. Groisman**, 2018: From the Northern Eurasia Earth Science Partnership Initiative (NEESPI) towards the Northern Eurasia Future Initiative (NEFI)**.** *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.

Tchebakova N. M., E. I. Parfenova, E. G. Shvetsov, A. J. Soja, S. G. Conard, and **P. Y. Groisman**, 2018: Siberian potential forests and phytomass projected from CMIP5 climates in the 21st century. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.

**Other**
Two lectures were delivered at the *International Conferences of Early Career Scientists* in Tomsk and Maykop, Russia.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | 0 |
| **# of products or techniques submitted to NOAA for consideration in operations use** | 0 |
| **# of peer reviewed papers** | 7 |
| **# of NOAA technical reports** | 0 |
| **# of presentations** | 12 |
| **# of graduate students supported by your CICS task** | 0 |
| **# of graduate students formally advised** | 0 |
| **# of undergraduate students mentored during the year** | 0 |

| The Urban Resilience to Extremes Sustainability Research Network (UREx SRN) | |
|---|---|
| **Task Leader:** | Kenneth Kunkel (Leader), Andrew Ballinger, Geneva Gray |
| **Task Code** | NC-OTH-02-NCICS-KK/AB/GG |
| **Other Sponsor** | Arizona State University/National Science Foundation (NSF) |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 20%;<br>Goal 2: Weather-Ready Nation 80% |
| **NOAA Strategic Research Priorities:** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** The team quantified the projected effects of future increases in temperature and humidity on the number of days with dangerous heat levels.

**Background**

The Urban Resilience to Extremes Sustainability Research Network (UREx SRN) is an NSF-funded multi-institutional project led by Arizona State University. The project is developing and implementing a new framework for integrating Social, Ecological, and Technical System (SETS) dimensions for conceptualizing, analyzing, and supporting urban infrastructure decisions in the face of climatic uncertainty in a more holistic way.

Climate change is widely considered one of the greatest challenges to global sustainability, with extreme events being the most immediate way that people experience this phenomenon. Urban areas are particularly vulnerable to these events given their location, concentration of people, and increasingly complex and interdependent infrastructure. The highly interdisciplinary and geographically dispersed UREx SRN team is developing a diverse suite of methods and tools to assess how infrastructure can be resilient, provide ecosystem services, improve social well-being, and exploit new technologies in ways that benefit all segments of urban populations. The team is working with several pilot cities to co-produce the knowledge needed to transition to resilient SETS infrastructure in cities of the future. The cities include Portland (OR), Phoenix, New York City, Baltimore, Syracuse, Miami, San Juan (PR), Hermosillo (Mexico), and Valdivia (Chile). NCSU is leading the project's characterization of recent historical trends of climate extremes and the development of future climate extreme scenarios.

Serving as members of the Climate and Hydrologic Extremes Working Group (CHExWG) of UREx SRN are NCICS scientists Dr. K. Kunkel (lead), Dr. A. Ballinger (postdoctoral scholar), and Geneva Gray (Ph.D. student). The CHExWG is tasked with developing climate extremes products for the nine cities tailored to the city-specific vulnerabilities and the communication and explanation of those products to other members of the network. These products will be supported by the development and analysis of statistically downscaled data sets and/or the application of dynamically-downscaled simulations as available and appropriate.

**Accomplishments**

The past year's progress can be broadly summarized under the following task areas.

***Analyzed LOCA-downscaled gridded climate model data for cities in US and Mexico:*** The Localized Constructed Analogs (LOCA) technique statistically downscales climate model data (maximum/minimum temperature, precipitation, and humidity) to a ~6 km grid over CONUS and regions of Mexico and Canada. The team continued the analysis of the 32 LOCA-downscaled climate models (from CMIP5) for each of the

7 UREx SRN pilot cities within this domain: Baltimore, Hermosillo, Miami, NYC, Phoenix, Portland and Syracuse. Humidity data were recently added to the LOCA dataset. These new data were used to estimate the Heat Index, a parameter used by the National Weather Service to estimate the combined effects of heat and humidity on human comfort. An analysis of future changes in the number of days above thresholds used by the NWS was completed for New York City (Figure 1). This analysis indicates that future changes in humidity will result in many more days above dangerous heat levels than indicated by temperature changes alone.

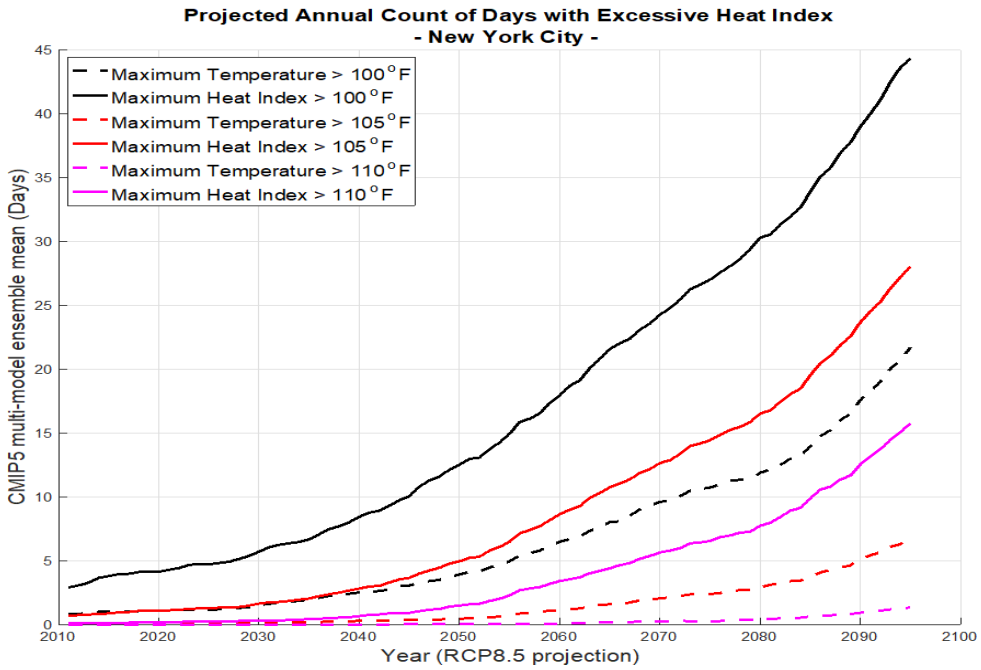



***Figure 1****. The multi-model ensemble-mean number of days exceeding thresholds of 100, 105, and 110 for daily maximum temperature and daily maximum heat index for New York City.*

***High-resolution modeling of extreme precipitation events:***

The Weather Research and Forecasting (WRF) model was used to perform simulations of the Ellicott City flood event of July 2016 event.

**Planned work**

- Run and analyze WRF simulations of the 2016 Ellicott City flood event of 2016 and examine the potential impact of global warming on that event using the pseudo-global warming methodology.
- Work with Baltimore practitioners to evaluate how to incorporate results of simulations into practice.
- Identify historical extreme precipitation events in other UREX cities.
- Use WRF to simulate these events and examine potential impacts of global warming on precipitation amounts and spatial distribution

**Publications**

Shiva, J. S., D. G. Chandler, and **K. E. Kunkel**, 2019: Localized Changes in Heat Wave Properties across the USA. *Earth's Future*, **in press**. http://dx.doi.org/10.1029/2018EF001085

**Presentations**

**Kunkel, K. E.** and **A. Ballinger**, 2018: Climate Projections and Tipping Points. Conference on Climate-Induced Displacement Technical Working Group and Planning Meeting, Asheville, NC, June 21, 2018.

**Kunkel, K. E.** and **A. Ballinger**, 2018: Future Risks of Extreme Heat, American Geophysical Union Fall Meeting. Washington, DC, December 11, 2018.

**Gray, G. M. E.**, **K. E. Kunkel**, and **A. P. Ballinger**, 2019: Incorporation of Climate Change into Design Storms: The Challenges. AMS 99th Annual Meeting, Phoenix, AZ, January 7, 2019.

**Other**

K. Kunkel advised/examined (as a PhD committee member) a CHExWG graduate student, Javad Shafiei Shiva (Syracuse University), on his UREx SRN research related to the changing nature of heatwaves in different network cities.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Incorporation of the Effects of Future Anthropogenically Forced Climate Change in Intensity–Duration–Frequency Design Values** | |
|---|---|
| **Task Leader** | Kenneth Kunkel (Leader), James Biard, Sarah Champion, Ronnie Leeper, Olivier Prat, Laura Stevens, Scott Stevens, Liqiang Sun |
| **Task Code** | NC-OTH-03-NCICS-KK/et al |
| **Other Sponsor** | DOD/SERDP |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment, and Risk Communication |

**Highlight:** An algorithm to automatically identify weather fronts in climate model and reanalysis data was refined and applied to historical and future climate model simulations. Analysis of weather system changes indicates decreases in summer fronts, but the number of summer fronts may not correlate with extreme precipitation. Also, increases in slow-moving cyclones and high moisture convergence in the North American Monsoon are projected.

**Background**

There is overwhelming evidence that today's climate system is non-stationary and is expected to remain so for the foreseeable future. Primary drivers include human-caused changes in atmospheric greenhouse gas concentrations. Increases in heavy precipitation events are one of the more robust climate change signals in the observed record. Previous work examined the meteorological causes of historical trends in the United States and found significant upward trends in the number of events from fronts and tropical cyclones but no increases from other meteorological causes. The likelihood that heavy precipitation will continue to increase is considered high because atmospheric water vapor concentrations will increase with global warming. Thus, the capacity of the atmosphere to produce intense precipitation will be higher in a warmer world. At the local scale, actual changes in heavy precipitation event occurrence will arise from changes in atmospheric capacity and opportunity (the frequency and intensity of weather systems causing heavy precipitation). While it is virtually certain that capacity will increase, it is less certain how opportunities will change and it is likely that the changes in opportunity will be spatially variable, modulating water vapor increases.

The overriding objective of this project is to develop a framework for incorporating the potential impact of future climate change into the Intensity-Duration-Frequency (IDF) values of heavy precipitation. Actual changes in IDF values will result from changes in atmospheric **capacity** (water vapor concentrations) and **opportunity** (the number and intensity of heavy precipitation-producing storm systems). In this project, these two components will be evaluated to determine the potential impact for a wide range of frequencies and durations used by civil engineers. Then a means for adjusting and delivering the IDF values and uncertainty estimates, similar to the National Oceanic and Atmospheric Administration Atlas 14, will be provided.

**Accomplishments**

Several analyses explored the potential role of atmospheric water vapor in the observed upward trends in extreme precipitation. One analysis found there to be a positive relationship between precipitable water (PW) and the associated annual maximum daily precipitation at the majority of stations across the contiguous United States (Figure 1). Another analysis found that days with a large number of extreme

precipitation events exceeding a 1-year recurrence interval happen only on days with high PW. An examination of the relationship between water vapor and all precipitation days on a regional scale found that high PW values provided the potential for large-magnitude precipitation events, with the biggest events requiring a minimum value of PW to occur, most notably in the southern and eastern United States.

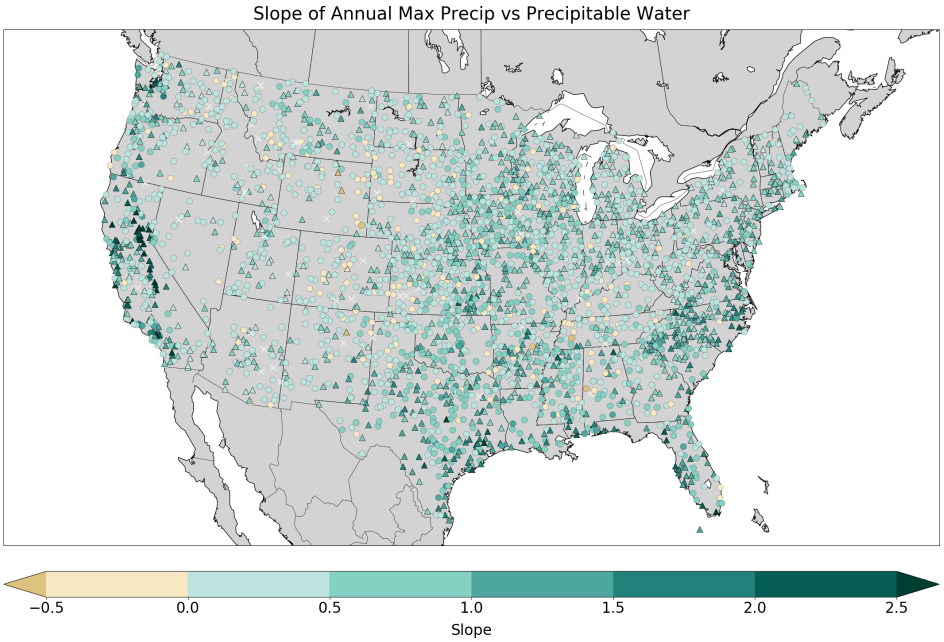



***Figure 1.*** *Slopes of the regression between annual maximum daily precipitation and the precipitable water in the vicinity of each event, for individual stations across the contiguous U.S.*

The other major component proposed for IDF adjustments is weather system changes. We have implemented automated software to identify relevant weather system types in climate model simulation data. A major technical challenge that confronted us was the automated detection of fronts. Working in collaboration with Lawrence Berkeley National Laboratory, this algorithm was refined and applied to a suite of climate model simulations from the NCAR Community Atmospheric Model, version 5 (CAM5) and the NOAA Geophysical Fluid Dynamics Laboratory (GLFDL) CM3 model. The total number of fronts in the future simulations does not change in the fall, winter, and spring. However, there is a decrease in the number of summer fronts, likely caused by a northward retreat of the jet stream under global warming.

Summer fronts are the dominant cause of extreme events in the interior north-central part of the country. Interestingly, no correlation was found between the number of extreme precipitation events caused by summer fronts and the total number of summer fronts. This means that other meteorological factors determine the occurrence of extreme precipitation events.

Analysis of CMIP5 extratropical cyclones (ETCs) generally shows decreases in the total number of cyclones but increases in the strongest cyclones. Furthermore, extreme precipitation events are correlated with the speed of movement of ETCs, occurring preferentially with slower-moving systems. Analysis of future climate simulations indicates a slowing of such systems.

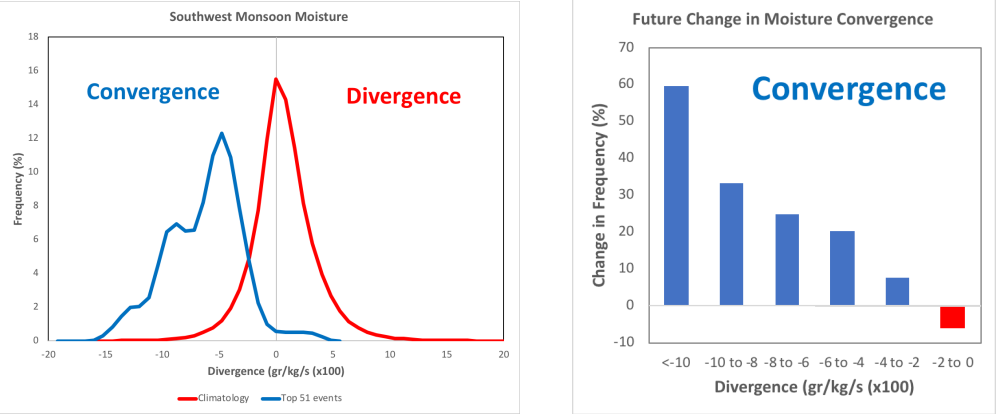



***Figure 2.*** *(left) Frequency distribution function of moisture divergence at 700 hPa for the 50 largest daily precipitation events in Arizona and New Mexico (blue) and for all June-September days (red) for 1980–2016; and (right) Change in frequency of moisture convergence days for 2070–2099 under the RCP8.5 scenario.*

Analysis of extreme daily precipitation in the North American Monsoon found that nearly all of the heavy precipitation events are associated with low-level moisture flux convergence in Arizona and New Mexico (Figure 2, left). Both extreme precipitation events and occurrence of moderate-to-strong moisture flux convergence are projected to increase over Arizona and New Mexico in the late 21st century for the RCP8.5 scenarios (Figure 2, right).

**Planned work**

- Complete historical analysis of Alaska, Hawaii, and Guam data.
- Complete the development of factors for adjusting current IDF values for future climate change.
- Complete the online system for access to adjusted IDF values.
- Extend analysis of contributions of tropical cyclones to full period of record and extend analysis to extratropical cyclones.

**Presentations**

**Biard, J.** and **K. E. Kunkel**, 2018: Atmospheric Fronts in Climate Models: Inter-comparison Across Historical and Future Scenarios. *American Geophysical Union Fall Meeting*, Washington, DC, December 10, 2018.

Kashinath, K., M. Prabhat, M. Mudigonda, A. Mahesh, S. K. Kim, Y. Liu, S. Kahou, B. A. Toms, E. Racah, C. Beckham, C. Pal, T. Maharaj, **J. Biard**, **K. Kunkel**, D. N. Williams, T. A. O'Brien, M. F. Wehner, and W. D. Collins, 2018: Deep Learning Recognizes Weather and Climate Patterns. *American Geophysical Union Fall Meeting*, Washington, DC, December 10, 2018.

**Kunkel, K. E.**, 2018: Advances in Understanding of Climate Extremes. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 16, 2018.

**Kunkel, K. E.**, 2018: Effects of Global Warming on Weather Systems Causing Extreme Precipitation. *SERDP & ESTCP Symposium 2018: Enhancing DoD's Missions Effectiveness*, Washington, DC., November 27, 2018.

**Kunkel, K. E.**, 2018: Effects of Global Warming on Building Design Values. *Facades+ NYC Conference*, New York City, NY, April 19, 2018.

**Kunkel, K. E.**, 2018: Gibson Dam Storm Analysis. *Colorado-New Mexico Regional Extreme Precipitation Study Workshop #6*, Denver, CO, April 19, 2018.

**Kunkel, K. E.**, 2018: Historical Perspective on Hurricane Harvey Rainfall. *SAMSI Climate Extremes Workshop*, Research Triangle Park, NC, May 16, 2018.

**Kunkel, K. E.**, 2018: Historical Perspective on Rainfall in Recent Hurricanes. *American Statistical Association's ENVR 2018 Workshop: Statistics for the Environment: Research, Practice and Policy*, *The Collider*, Asheville, NC, October 13, 2018.

**Kunkel, K. E.**, 2018: Precipitation Intensity-Duration-Frequency (IDF) Relationships and Climate Change. *Inter-Agency Forum on Climate Risks, Impacts and Adaptation*, Washington, DC, November 30, 2018.

**Kunkel, K. E.**, 2019: Climate Change Liability for Owners, Designers and Manufacturers: National Climate Assessment. *2019 American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Winter Conference*, Atlanta, GA, January 16, 2019.

**Kunkel, K. E.**, 2019: Historical Perspective on Rainfall from Hurricane Florence. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.

**Kunkel, K. E.**, and R. L. Smith, 2019: Historical Perspective on Hurricane Harvey Rainfall. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.

**Kunkel, K. E.**, **J. Biard,** and **L. Sun**, 2018: Impacts of Weather System Changes on Future Extreme Precipitation Design Values. *American Geophysical Union Fall Meeting*, Washington, DC, December 11, 2018.

**Other**

Sarah Champion is a project scientist who is pursuing a Ph.D. degree in the Department of Marine, Earth, and Atmospheric Sciences of North Carolina State University. She is advised by Kenneth Kunkel and her research supports the objectives of this project.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **13** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **1** |
| **# of undergraduate students mentored during the year** | **0** |

| IPCC Special Report on 1.5°C of Global Warming | |
|---|---|
| **Task Leader** | Tom Maycock |
| **Task Code** | NC-OTH-04-NCICS-TM |
| **Other Sponsor** | IPCC WGI Technical Support Unit |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Assessment |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** NCICS provided editorial and technical support for the Intergovernmental Panel on Climate Change (IPCC) *Special Report on 1.5°C of Global Warming*, which quickly became one of the most significant and policy-relevant international climate assessments produced to date. Support efforts included leading the copyediting team for the full report, editorial and science communication input on the report's Summary for Policymakers, the provision of a figure and metadata management web portal, and on-site technical support at the report approval session in Incheon, Korea.
https://www.ipcc.ch/sr15

**Background**

In December 2015, the Parties to the UN Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement, which aims to limit global warming to "well below" 2°C above preindustrial levels and to pursue efforts to "limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change." The decision document adopting the Paris Agreement asked the IPCC to produce a special report on the impacts of 1.5°C warming.

The IPCC accepted this request and agreed to produce a special report on "impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty." The resulting Summary for Policymakers (SPM) and the underlying technical report were approved and released in October 2018. In the first 48 hours after the release of the approved SPM, the report website received more than 8 million website hits and was the subject of more than 15,000 online and print news articles. The report served as a key input to the 24th UNFCCC Conference of the Parties in December 2018 and will continue to inform international and national climate policy discussions.

**Accomplishments**

Through an agreement with the IPCC Working Group I Technical Support Unit at the University of Paris-Saclay in France, NCICS's Tom Maycock served as science editor for the report, providing scientific copyediting of several chapters of the full report, coordinating the work of two freelance copyeditors, and reviewing final edits made by authors to the full report chapters.

Maycock also provided significant editorial input on the Summary for Policymakers as the drafting team worked to finalize a draft of the SPM prior to the approval meeting. During the approval meeting, Maycock led the document management and version control function and provided support for official Contact Group sessions held to develop a consensus on Figure 1 of the SPM. Once the SPM content was approved section by section, Maycock assembled the final approved draft that was released to the public on the following Monday. Additional work included copyediting the approved SPM and proofing the PDF layouts.

In addition, NCICS provided the IPCC WGI TSU with an instance of the Institute's Resources web portal for managing scientific figures and figure metadata. Staff at the WGI TSU used the web portal, which is hosted on Institute servers, to manage final revisions to the more than 80 figures in the report and used the site's metadata survey features to store metadata describing underlying datasets and analysis methods used to create the figures. This data will eventually be made available to the public via the final version of the special report website, which is currently in final development stages.

**Planned work**
Work on this project was completed in December 2018.

**Publications**
IPCC, 2018: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, **T. Maycock**, M. Tignor, and T. Waterfield, Eds. World Meteorological Organization.

IPCC, 2018: Summary for Policymakers. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, **T. Maycock**, M. Tignor, and T. Waterfield, Eds., World Meteorological Organization, 32 pp.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| Climate Indicators to Track the Seasonal Evolution of the Arctic Sea Ice Cover | |
|---|---|
| **Task Leader** | Ge Peng |
| **Task Code** | NC-OTH-05-NCICS-GP |
| **Other Sponsor** | National Aeronautics and Space Administration (NASA) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 100% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 75% |
| | Goal 4: Resilient Coastal Communities and Economies 25% |
| **NOAA Strategic Research Priorities** | Arctic |

**Highlight** This effort focuses on examining long-term average and temporal variability of the new sea ice climate indicators, including snow melt onset, sea ice retreat, advance, and freeze-up dates. Peng lead-authored/co-authored two peer-reviewed papers and lead-authored/co-authored two posters presented at the AGU 2018 Fall Meeting. A dataset has been released by National Snow and Ice Data Center (NSIDC).

**Background**

Since 1979, satellite sea ice concentration data has been used to track climate change and variability. Sea ice extent (the area within the 15% concentration contour) and area (the area-integrated concentration) have long been considered key sea ice coverage climate indicators. However, these two parameters provide only limited information about the character of the sea ice; in addition, they have limited skill as indicators of future sea ice conditions, both seasonal and inter-annually.

This 4-year collaborative project with NASA Goddard, University of Washington, and NCSU/NCICS scientists aims to utilize the NOAA/NSIDC (National Snow and Ice Data Center) Sea Ice Concentration Climate Data Record (CDR) to develop a consistent, high-quality suite of sea ice climate indicators that track the seasonal evolution (sea ice melt onset, opening, retreat, freeze-up, and advance) of the Arctic sea ice cover from spring through fall, in addition to commonly used sea ice coverage indicators (area and extent).

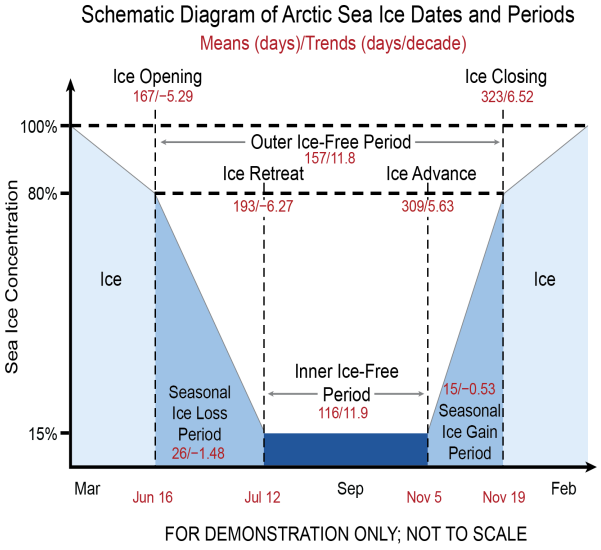
**Accomplishments**

- Characterized temporal variability of Arctic sea ice climate indicators.
- Examined regional variability of sea ice climate indicators.

The results have shown that over the Arctic region, anomalies of snow and ice melt onset and ice opening and retreat dates are starting earlier in the year at a rate of more than 5 days per decade, while those of ice advance and closing dates are happening later at a rate of more than 5 days per decade. These significant trends resulted in significant upward trends for anomalies of inner and outer ice-free periods at a rate of nearly 12 days per decade. Small but significant downward trends of seasonal ice loss and gain period anomalies were also observed at a rate of –1.48 and –0.53 days per decade, respectively (Figure 1; Peng et al. 2018).

The seasonal ice zone (SIZ)—the area in which sea ice advances and retreats each year—is generally expanding (Figure 2; Bliss et al. 2019). Statistically significant negative trends (SIZ is shrinking) are seen in the Sea of Okhotsk, Baffin Bay, Greenland Sea, and Barents Sea regions, which are geographically open to the oceans and influenced by reduced winter sea ice extent. Within regions of the Arctic Ocean, statistically significant positive trends indicate that the extent of the SIZ is expanding as Arctic summer sea ice declines. This is consistent with the declining trend in overall sea ice extent.

On the local scales, statistically significant positive trends are seen in the length of the melt season (outer ice-free period) for most of the eastern Arctic, the Bering Sea, and Hudson and Baffin Bays with trends as large as 11.9 days per decade observed in the Kara Sea (Bliss et al. 2019).



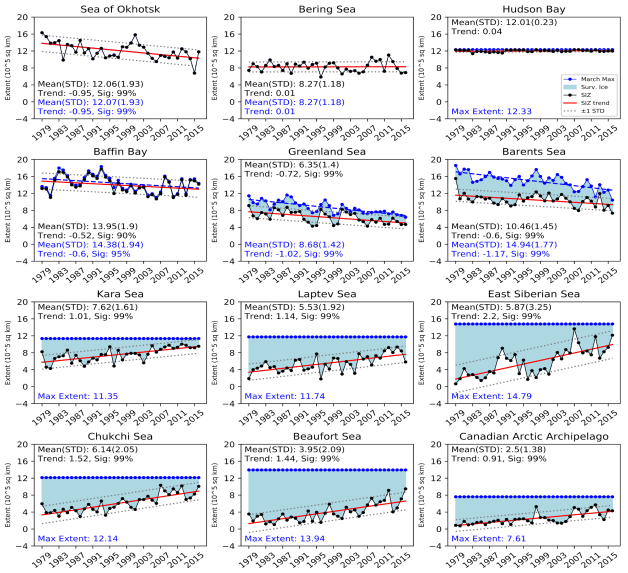




***Figure 1***. *Schematic diagram of Arctic sea ice dates and periods. Values in red are the date and period means (days) and their decadal trends (days/decade) that are significant at the 95% confidence level. From Peng et al. (2018).*

***Figure 2***. *Regional time series and statistics for March monthly sea ice extent (SIE) in dark blue and seasonal ice zone (SIZ) extent in black for 1979–2016. The light blue shaded area is representative of the surviving SIE at the end of the melt season. . The least squares linear trend in SIZ extent is shown in red with dotted lines to indicate ±1 standard deviation. The confidence level for statistically significant trends is noted. From Bliss et al. (2019).*

**Planned work**

- Compute the climate normals of all dates and periods and explore the possibility of integrating the data product into NCEI climate monitoring services.
- Continue to seek input and feedback from stakeholders and provide feedback to the project PI and Co-PI to improve the scientific quality of the derived indicator products.

**Publications**

**Peng, G**., M. Steele, A. Bliss, W. N. Meier, and S. Dickinson, 2018: Temporal means and Variability of Arctic Sea Ice Melt and Freeze Season Climate Indicators Using a Satellite Climate Data Record. *Remote Sensing*, **10**, 1328. http://doi.org/10.3390/rs10091328

Bliss, A. C., M. Steele, **G. Peng**, W. N. Meier, and S. Dickinson, 2019: Regional variability of Arctic sea ice seasonal change climate indicators from a passive microwave climate data record. *Environmental Research Letters*, **in press**. http://dx.doi.org/10.1088/1748-9326/aafb84

**Products**

- Steele, M., A.C. Bliss, **G. Peng**, W.N. Meier, and S. Dickinson, 2019. Arctic sea ice seasonal change and melt/freeze climate indicators from satellite data. Boulder, Colorado USA. National Snow and Ice Data Center Distributed Active Archive Center. http://doi.org/10.5067/KINANQKEZI4T

**Presentations**

Bliss, Steele, M., **G. Peng,** W.N. Meier, and S. Dickinson, 2018: Arctic sea ice cover climate indicators: melt season evolution and regional variability. *Drivers of Ecosystem Change: Marine Ecosystems Collaboration Team August 2018 Meeting,* August 22, 2018.

**Peng, G.**, M. Steele, A. C. Bliss, W. Meier, and S. Dickinson, 2018: Temporal Variability of Arctic Sea Ice Melt and Freeze Season Climate Indicators Using a Satellite Passive Microwave Climate Data Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.

Steele, M., A. C. Bliss, **G. Peng**, W. Meier, and S. Dickinson, 2018: Regional Variability of Arctic Sea Ice Seasonal Change Climate Indicators from a Passive Microwave Climate Data Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.

**Other**

Reviewed IPCC Special Report on the Ocean and Cryosphere in a Changing Climate during the Government and Expert Review.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1*** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

** The dataset was released by the National Snow and Ice Data Center (NSIDC); ongoing discussion to potentially integrate the product into NOAA regional sea ice climate monitoring services, pending future update availability.*

| **Synthesis of Observed and Simulated Rain Microphysics to Inform a New Bayesian Statistical Framework for Microphysical Parameterization in Climate Models** | |
|---|---|
| **Task Leader** | Olivier Prat |
| **Task Code** | NC-OTH-06-NCICS-OP |
| **Other Sponsor** | Columbia University /US Department of Energy (DOE) |
| **Contribution to CICS Research Themes** | Theme 1: Climate and Satellite Research and Applications 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Climate Research, Data Assimilation and Modeling |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50%<br>Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight**: This multi-institutional research project aims to comprehensively investigate the representation and associated uncertainties of rain microphysical processes in weather and climate models. In order to quantify those uncertainties in microphysical formulations, the team developed an innovative Bayesian statistical framework that combines the extensive radar and ground-based data from the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) field campaigns, bin microphysical modeling, and a new bulk parameterization.

**Background**

Rain microphysical processes exert a critical control on the evolution and impact of weather systems, including deep convection. In particular, the microphysical characteristics of rain determine evaporation and hydrometeor loading that, in turn, control downdraft characteristics and subsequent cold pool formation and convective structure and organization. It has never been more important to accurately represent these effects, as the increasingly fine resolution of regional and global climate models can now explicitly simulate these processes and quantify their impacts. Recent advances in observational capabilities, such as available ARM polarimetric and zenith-pointing radars, allow for unprecedented information on rain microphysical processes. However, the current state of microphysical parameterization schemes renders problematic the assimilation of observational insights into models. Microphysics schemes contain numerous assumptions, ad-hoc parameter choices, and structural uncertainties. In this work, we are investigating the uncertainties in the representation of microphysical processes in climate models. The goal is to develop a novel warm rain microphysics scheme that uses Bayesian inference to estimate parameter uncertainties and reduce unnecessary assumptions. The Bayesian Observationally-constrained Statistical-physical Scheme (BOSS) can use any combination of prognostic drop size distribution (DSD) moments without assuming an a-priori DSD. Dual-polarization radar observations provide a probabilistic constraint on scheme structure and microphysical sensitivities to environmental conditions. Because the same value of a given prognostic moment can correspond to an infinite number of DSDs, we need to develop a moment-based polarimetric radar forward operator in order to determine the optimal combination of prognostic moments (2 or 3 moment scheme) that minimizes uncertainties. The Bayesian statistical approach combines real rainfall dual-pol radar data from ARM field campaigns, bin microphysical modeling, and a new bulk parameterization. This work is conducted in collaboration our partners: Dr. Marcus van Lier-Walqui (Columbia University), Dr. Matthew Kumjian (Penn. State University), and Dr. Hughbert Morrison (NCAR).

**Accomplishments**

Our contribution to the project, consisted in providing one-dimensional bin-model simulations (Prat et al. 2012) covering the totality of realistic DSDs encountered in nature. From approximately 10,000 initial conditions imposed at the top of the one-dimensional model, we generated about 199 million DSDs. From this ensemble, and for a given moment combination Mx-My, we investigate how uncertainties propagate to the integral properties (Liquid Water Content: LWC; Rain Rate: RNT, Reflectivity: Z) and to the microphysical processes (coalescence, breakup, evaporation).

Last year, we quantified the microphysical processes contribution and related uncertainties as a function of the initial DSD. Those results from bin-microphysical simulations are used as a benchmark to compare with the model developed using the Bayesian approach for statistical-physical bulk parameterization of rain microphysics (BOSS model). Figure 1 displays an ensemble of results obtained with the bin-microphysical model for the microphysical processes contribution (coalescence, breakup) using a large number of exponential DSD as initial conditions (exponent=0).

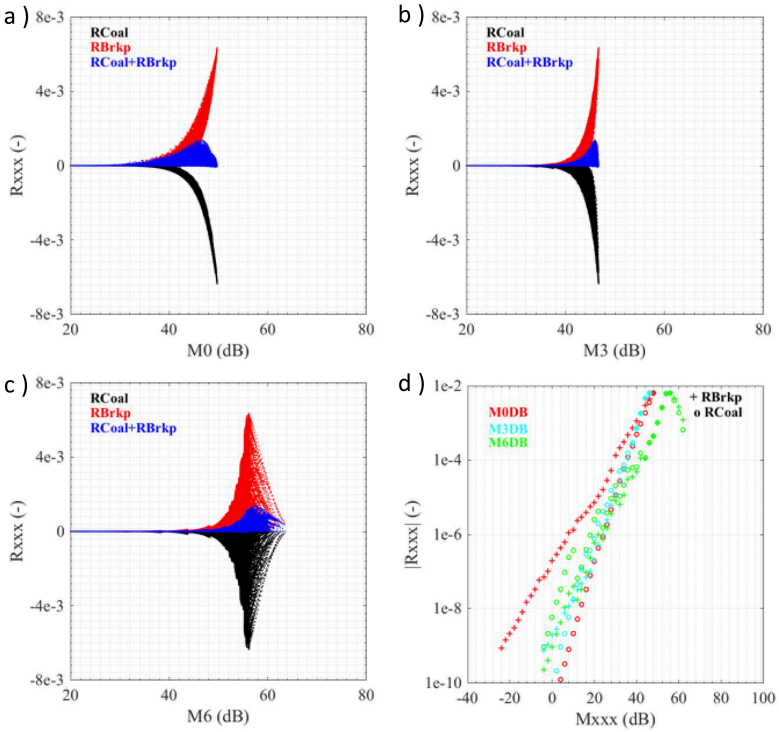



***Figure 1****. Microphysical processes contribution (coalescence, breakup, combined) for all possible exponential DSDs as a function of M0 (Fig. 1a), M3 (Fig. 1b), and M6 (Fig. 1c) which are homogeneous to drop number concentration, total mass, and reflectivity respectively. Fig. 1d: average microphysical processes contribution with respect to the moments of the DSD (M0, M3, M6) using 2dB increments.*

The bin-microphysical model was extended to include evaporation processes. The parametric study has been extended to include, in addition to all possible DSDs, a realistic ensemble of temperature (T) and relative humidity (RH) vertical profiles (constant, linear, experimental from vertical soundings). Figure 2 presents an example of the resulting vertical profiles of the contribution of the microphysical processes (Fig. 2a-d) and of the integral properties of the DSDs (Fig. 2e-h) obtained for an exponential DSD with a rain rate of 50mm/h. The simulation uses linear profiles for the temperature varying from 15°C (top) to 40°C (bottom) and the relative humidity (99% to 25%).

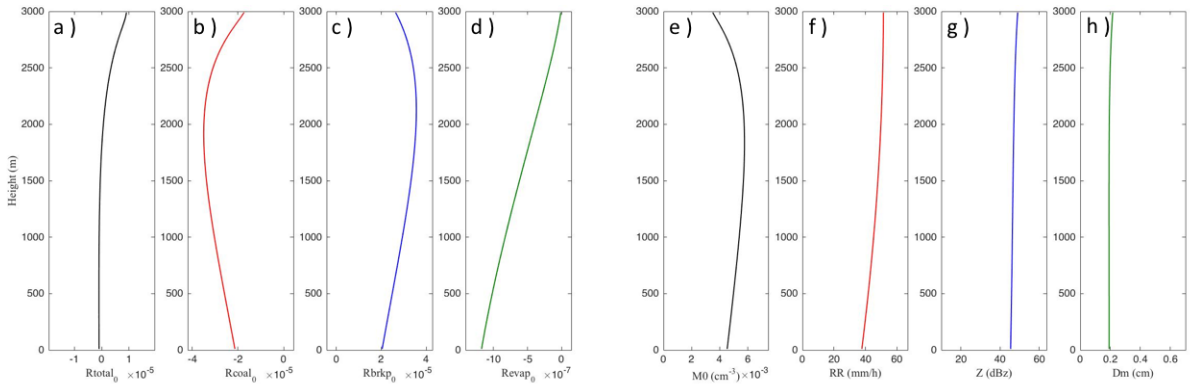



***Figure 2.*** *Fig. 2a-d: Microphysical processes contributions: coalescence (Fig. 2b), breakup (Fig. 2c), and evaporation (Fig. 2c), along with their combined contribution (Fig. 2a). Fig. 2e-h: Integral properties: drop number concentration (Fig. 2e), rain rate (Fig. 2f), radar reflectivity (Fig. 2g), and mean drop diameter (Fig. 2h). The vertical profiles are obtained after a simulated time of 1-hr.*

The work in progress includes the refinement of the evaporation module and the implementation of additional microphysical parameterizations (coalescence, breakup). A paper summarizing the bin-microphysical component of the project (model development, microphysical module description, parametric study) is in preparation. Finally, for the project as a whole, two papers have been published this year and two papers have been submitted for publication. Other papers are in preparation.

**Planned work**

- Refine the evaporation module and run an ensemble of simulations as needed
- Finalize implementation of other coalescence and breakup kernels and quantify the impact of the different formulations on microphysical processes and the resulting dual-pol variables
- Draft paper for the bin microphysical component of the project as the lead author
- Contribute to the other planned project papers as a co-author

**Publications**

Kumjian, M. R., C. P. Martinkus, **O. P. Prat**, S. Collis, M. van Lier-Walqui, and H. C. Morrison, 2019: A Moment-Based Polarimetric Radar Forward Operator for Rain Microphysics. *Journal of Applied Meteorology and Climatology*, **58,** 113-130. http://dx.doi.org/10.1175/JAMC-D-18-0121.1

Morrison, H., M. R. Kumjian, C. P. Martinkus, **O. P. Prat**, and M. van Lier-Walqui, 2019: A general N-moment Normalization Method for Deriving Rain Drop Size Distribution Scaling Relationships. *Journal of Applied Meteorology and Climatology*, **58,** 247-267. http://dx.doi.org/10.1175/JAMC-D-18-0060.1

Morrison, H., M. Van Lier-Walqui, M. Kumjian, and **O. P. Prat**, 2019: A Bayesian approach for statistical-physical bulk parameterization of rain microphysics, Part I: Scheme description. *Journal of the Atmospheric Sciences*, submitted.

van Lier-Walqui, M, H. Morrison, M. Kumjian, K. J. Reimel, **O. P. Prat**, S. Lunderman, and M. Morzfeld, 2019: A Bayesian approach for statistical-physical bulk parameterization of rain microphysics, Part II: Idealized Markov chain Monte Carlo experiments. *Journal of the Atmospheric Sciences*, submitted.

**Presentations**

Kumjian, M. R., C. P. Martinkus, **O. P. Prat**, S. Collis, H. C. Morrison, and M. Van Lier-Walqui, 2018: A moment-based polarimetric radar forward operator for rain microphysics. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 3, 2018.

Morrison, H., M. van Lier-Walqui, M. R. Kumjian, and **O. P. Prat**, 2018: Uncertainty in microphysical models and the development of a Bayesian approach for statistical-physical parameterization of warm microphysics. *15th Conference on Cloud Physics*, Vancouver, Canada, July 9, 2018.

Riemel, K. J., M. Van Lier-Walqui, M. R. Kumjian, **O. P. Prat**, and H. C. Morrison, 2018: How much can we learn about rain microphysics from polarimetric radar observations? An investigation of information content and parameter estimation using the Bayesian Observationally-constrained Statistical-physical Scheme (BOSS). *American Geophysical Union Fall Meeting*, Washington DC, December 10, 2018.

van Lier-Walqui, M., H. C. Morrison, M. R. Kumjian, **O. P. Prat**, and K. Riemel, 2018: How best to add structural complexity to cloud microphysics parameterizations? *American Geophysical Union Fall Meeting*, Washington DC, December 12, 2018.

van Lier-Walqui, M., M. R. Kumjian, H. C. Morrison, **O. P. Prat**, J. Turk, K. Riemel, J. Harrington, A. Jensen, and R. Schrom, 2018: Estimation of observational and forward-simulators uncertainties in the context of microphysical studies using doppler spectra and polarimetric radar observations. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 5, 2018.

van Lier-Walqui, M., M. R. Kumjian, H. C. Morrison, **O. P. Prat**, K. Riemel, J. Harrington, A. Jensen, and R. Schrom, 2018: Leveraging radar observations to probabilistically inform new classes of microphysical parameterization schemes. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 5, 2018.

| **Performance Metrics** | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **2** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **6** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| Climate Change Impacts on Human Health | |
|---|---|
| **Task Leader** | Jennifer Runkle |
| **Task Code** | NC-OTH-07-NCICS-JR |
| **Other Sponsor** | MAHEC (MOA); in kind partnerships |
| **Contribution to CICS Research Themes** | |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** This year resulted in a number of publications, as well as the ascertainment of three large public health data sets to be used in indicator surveillance work to examine the impacts of climate change and vulnerability on mental health and maternal health in 2019–2020.

**Background**

The goal of this exploratory work is to examine the impact of climate change—a known environmental determinant—on maternal and mental health risks. Surveillance of the impacts of climate change on human health is an urgent and understudied research priority. Results will address a significant research gap in understanding climate and health and inform the development of a scalable population-based indicator to be used in climate-health surveillance efforts.

**Accomplishments**

- Partnered with Mountain Area Health Education Center (MAHEC) to continue work on digital health intervention in pregnant women
- Partnered with academic researchers and non-profit organization to characterize climate-sensitivities in anonymously warm temperatures and patterns of help-seeking behavior in youth and young adults
- Six peer-reviewed publications, three grant applications, and a National Academies of Sciences, Engineering, and Medicine (NASEM) early career research application

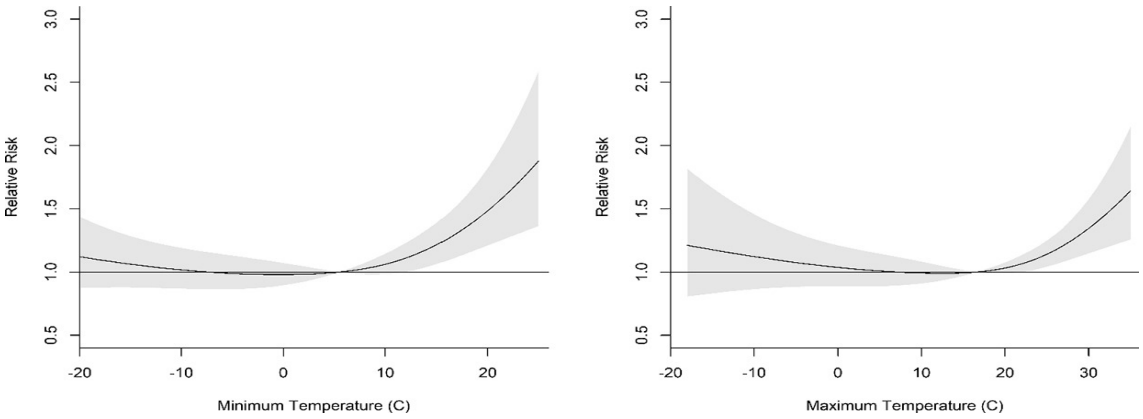



***Figure 1.*** *The exposure lag-response association between minimum and maximum temperature and crisis support-seeking behavior relative to median temperature in Chicago, IL, over a 7-day period (6-day lag), a study location with a strong temperature–crisis relationship at the highest temperatures. From Sugg et al. 2019 at: https://authors.elsevier.com/a/1Yk13B8cckMIP*

**Planned work**

- Continue work with Crisis Text Line to conduct research to improve understanding on the linkage between increases in ambient temperature and extreme weather events (e.g., hurricane-associated flooding) and crisis help-seeking behavior in youth and young adults
- Explore new avenue for applying personal sensor monitoring to reduce physiologic heat strain in urban outdoor workers in New Delhi, India
- Outline four areas of research to develop and obtain external federal funding for the following topic areas:
    - Heat and Outdoor Worker Health and Safety
    - Climate Impacts on Mental Health and Well-being
    - Public Health Adaptation Planning for Local Health Departments and Hospital Systems
    - Climate Impacts on Reproductive Health

**Publications**

**Runkle, J.**, E. R. Svendsen, M. Hamann, R. Kwok, and J. Pearce, 2018: Population Health Adaptation Approaches to the Increasing Severity and Frequency of Weather- Related Disasters Resulting From our Changing Climate: A Literature Review and Application to Charleston, South Carolina. *Current Environmental Health Reports*. http://doi.org/10.1007/s40572-018-0223-y

**Runkle, J.**, M. Sugg, D. Boase, S. Galvin, and C. Coulson, 2019: Use of wearable sensors for pregnancy health and environmental monitoring: Descriptive findings from the perspective of patients and providers. *Digital Health*, **5**. https://doi.org/10.1177/2055207619828220

Sugg, M., G. Dixon, and **J. D. Runkle**, 2019: Crisis Support-Seeking Behavior and Temperature in the United States: Is there an Association in Young Adults and Adolescents? *Science of the Total Environment*, **in press**. https://doi.org/10.1016/j.scitotenv.2019.02.434

Sugg, M. M., C. M. Fuhrmann, and **J. D. Runkle**, 2019: Geospatial Approaches to Measuring Personal Heat Exposure and Related Health Effects in Urban Settings. *In:* Geospatial Technologies for Urban Health, L. Yongmei and E. Delmelle, Eds., Springer Nature, **in press**.

**Thompson, L.**, M. Sugg, and **J. Runkle**, 2018: Adolescents in crisis: A geographic exploration of help-seeking behavior using data from Crisis Text Line. *Social Science & Medicine*, **215**, 69-79. http://doi.10.1016/j.socscimed.2018.08.025

**Thompson, L. K.**, K. Michael, **J. R. Runkle**, and M. M. Sugg, 2019: Crisis text Line usage following the release of 13 Reasons Why: A Temporal Analysis of Youth Help-Seeking Behavior. *Preventive Medicine Reports*, **14**, 100825. https://doi.org/10.1016/j.pmedr.2019.100825

**Presentations**

**Runkle, J.**, 2018: Climate Change (interview). *The State of Things, Blue Ridge Public Radio*, October 11, 2018. bpr.org/post/climate-change-expertsplanning-planet-flux

**Thompson, L. K**., M. M. Sugg, **J. R. Runkle**, 2018: Adolescents in Crisis: A Spatial Exploration of Mental Distress Using Data from Crisis Text Line. *American Association of Geographers Annual Meeting*, New Orleans, LA, April 14, 2018.

**Thompson, L. K.**, M. M. Sugg, **J. R. Runkle**, 2018: Adolescents in Crisis: A Spatial Exploration of Mental Distress Using Data from Crisis Text Line. *Appalachian State University Celebration of Student Research and Creative Endeavors*, Boone, NC, April 19, 2018.

**Other**

• Partnership established with the UNC Gillings School of Global Public Health Master of Public Health program in Asheville.

• Submitted a joint application in collaboration with the above to serve as a host site for the Centers for Disease Control and Prevention Public Health Associate Program (PHAP). The PHAP trainee will be assigned to work on a number of climate and health projects over a 2-year training period.

• Summer 2019 mentorship/supervision of two UNC Gillings School of Global Public Health Master of Public Health program students in summer internship focused on two distinct climate and health projects.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **6** |
| **# of NOAA technical reports** | **1** |
| **# of presentations** | **3** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **1** |
| **# of undergraduate students mentored during the year** | **0** |

| **Continuous Monitoring of Individual Exposure to Cold Work Environment: A Participatory Sensing Study** | |
|---|---|
| **Task Leader** | Jennifer Runkle |
| **Task Code** | NC-OTH-08-NCICS-JR |
| **Other Sponsor** | University of South Florida / National Institute for Occupational Safety and Health (NIOSH) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 10%<br>Theme 3: Climate Research and Modeling 90% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 100% |
| **NOAA Strategic Research Priorities** | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** This pilot study utilized new wearable sensor technology to test and implement more sensitive means of evaluating cold temperatures as an occupational hazard and developed effective report-back strategies as a means to communicate with participants about harmful occupational exposures and their associated health risks.

**Background**

The National Institute for Occupational Safety and Health (NIOSH) acknowledges the dangers of working in "moderately cold environments" and the associated negative impacts on worker performance and increased injury risk. The effect of a cold environment for both indoor and outdoor workers is an understudied health and safety concern, and there is a need for updated guidelines and educational materials tailored to employees working in both cold and moderately cold environments. Fixed-site monitoring of ambient temperatures provides a large amount of temporal data; however, these data are constrained to one location with limited spatial availability. New technology exists to supplement these weather station networks, allowing for individual monitoring of actual temperature experience. This study leverages the new sensor technology in an effort to test and implement more sensitive means of evaluating cold temperatures as an occupational hazard, develop effective data report-back strategies as a means to communicate with participants about harmful occupational exposures and their associated health risks, and help targeted vulnerable exposure groups move from understanding environmental health risks to acting upon these risks by engaging in workplace prevention strategies. The larger objective is to apply a sensor-based approach to develop an early warning temperature-health system to be used in the surveillance of illness, injury, and behavioral modification in the workplace.

**Accomplishments**

For the cold environment study, the PIs recruited grounds management workers at the same two geographic locations as a previous pilot high-temperature study: North Carolina State University in Raleigh, NC, and Appalachian State University in Boone, NC. Three data collection periods were completed during the months of January and February and analysis of the data is currently underway.

- Completed data analysis.
- Completed report back sessions with the project participants.
- Submitted project results manuscript to peer reviewed journal.

**Planned work**

- Obtain R01 federal funding from NSF or NIEHS to expand upon this work.

**Publications**

Sugg, M. M., C. M. Fuhrmann, and **J. D. Runkle**, 2018: Temporal and Spatial Variation in Personal Ambient Temperatures for Outdoor Working Populations in the Southeastern USA. *International Journal of Biometeorology*, **8,** 1521-1534. http://dx.doi.org/10.1007/s00484-018-1553-z

Sugg, M. M., **S. S. Stevens**, and **J. D. Runkle**, 2019: Estimating Personal Ambient Temperature in Moderately Cold Environments for Occupationally Exposed Populations. *Environmental Research*, **in press**. https://doi.org/10.1016/j.envres.2019.03.066

**Thompson, L.**, M. Sugg, and **J. Runkle**, 2018: Report-Back for Geo-Referenced Environmental Data: A Case Study on Personal Monitoring of Temperature in Outdoor Workers. *Geospatial Health*, **13**. http://dx.doi.org/10.4081/gh.2018.629

**Presentations**

Sugg, M. M., **J. R. Runkle**, C. M. Fuhrmann, and **S. Stevens**, 2018: Continuous Monitoring of Individual Exposure in Extreme Thermal Environments: A Participatory Geo-Sensing Study. *American Association of Geographers Annual Meeting*, New Orleans, LA, April 10, 2018.

| **Performance Metrics** | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **3** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **2** |
| **# of graduate students formally advised** | **5** |
| **# of undergraduate students mentored during the year** | **2** |

| **Multiscale Convection and the Maritime Continent** | |
|---|---|
| **Task Leader** | Carl Schreck |
| **Task Code** | NC-OTH-09-NCICS-CS |
| **Other Sponsor** | National Aeronautics and Space Administration (NASA) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** Comparing TRMM and ISCCP data provides a more complete picture of the diurnal cycle of convection over the Maritime Continent and its interactions with the MJO.
https://ncics.org/portfolio/monitor/mjo/

**Background**

The Madden–Julian Oscillation (MJO) is the largest source of tropical intraseasonal variability with impacts spanning the globe. Unfortunately, numerical models fail to adequately simulate its convection, limiting their opportunity to harness its long-range predictability. Nowhere is this shortcoming more apparent than over the Maritime Continent (MC). Many MJO events terminate before crossing the MC, a tendency that is exaggerated in most numerical models. The MC poses complex topography that may reduce the MJO's moisture source from surface fluxes and impede the MJO's low-level circulation. The exceptional diurnal cycles in the vicinity of the large islands in the MC can also drain the MJO's energy. Most models fail to capture this diurnal cycle properly and result in large biases in rainfall over the MC.

Many studies have examined the interactions between the MJO and convection over the MC. Far fewer have looked at the role of convectively coupled equatorial waves, even though models that faithfully represent these waves also tend to produce more representative MJO signals. This study identifies avenues for model improvement by investigating the interactions between the MJO, equatorial waves, and the diurnal cycle over the MC. It will complement a major international field campaign, the *Year of Maritime Convection*, proposed for 2017–2019.

**Accomplishments**

The project is split into two main components. One is led by Co-I Ademe Mekonnen (NC A&T) investigating the diurnal cycle of convection over the Maritime Continent (MC) using a variety of TRMM and ISCCP datasets. The other is led by PI Schreck and Co-I Anantha Aiyyer (NCSU). They are exploring the skill of a novel Fourier filtering of combined observations and CFSv2 hindcasts in the region.

Figure 1 highlights some of the results from the first branch of the project. It shows that rainfall (top row) over the MC islands peaks around 1800 LST in association with organized deep convection (IR-WS12, middle row). Rainfall over the coastal and oceanic regions peaks in the early morning hours and does not have as clear of a connection to the convective variations. The diurnal cycles for both rainfall and convection throughout the MC are greater during boreal winter (left) than summer (right). These results have been resubmitted to *International Journal of Climatology* following major revisions. In the coming year, we will perform and publish similar analyses for each phase of the MJO, Kelvin, and equatorial Rossby waves.

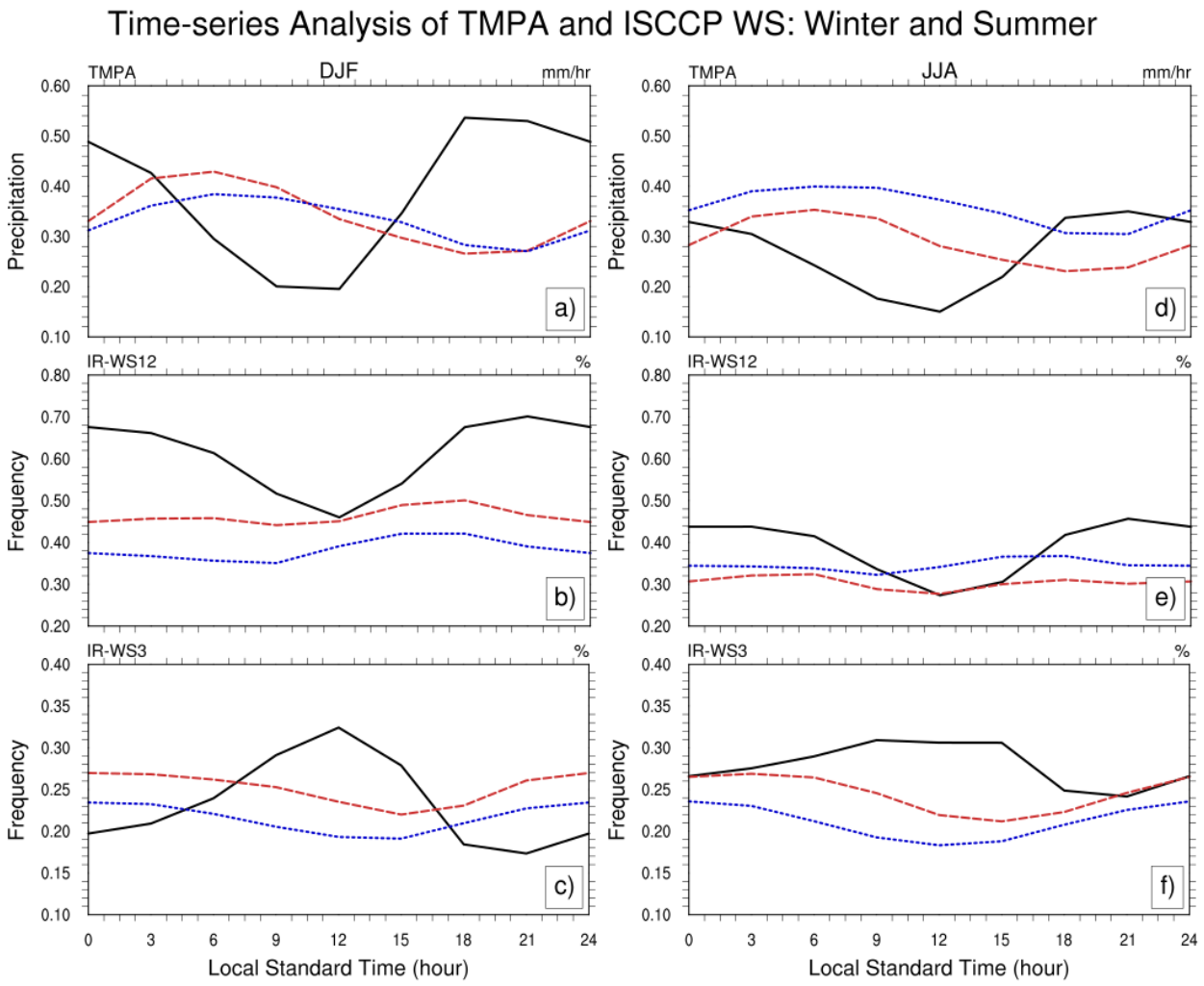



***Figure 1**. Diurnal cycles of over land (black), coasts (red) and ocean (blue) of TMPA rainfall (top), ISCCP weather states: IR-WS12 (middle) and IR-WS3 (bottom). Boreal winter (DJF) is shown in the left column and boreal summer (JJA) in the right.*

Figure 2 highlights the key results of the other branch of this research. It verifies some of the forecast diagnostics from https://ncics.org/mjo/. The novel methodology uses 1+ years of observed TRMM TMPA rainfall and appends it with CFSv2 hindcasts for 45 days and then climatology thereafter. These combined data are filtered for the MJO and key equatorial waves.

Within the ENSO region of the Central Pacific, the unfiltered bias-corrected CFS (top row) remains skillful beyond 42 days. This pattern is nearly identical to that of the low-pass filtered forecasts (second row), which suggests that much of that skill essentially comes from persistence. Adding the MJO-filtered anomalies (third row) extends the skill beyond 21 days over most of the Indian Ocean. Portions of that

region can be extended beyond 35 days with the inclusion of the ER-filtered anomalies. The Kelvin filter, however, does not significantly contribute to skill in any region. These results will be submitted for publication during the next year.

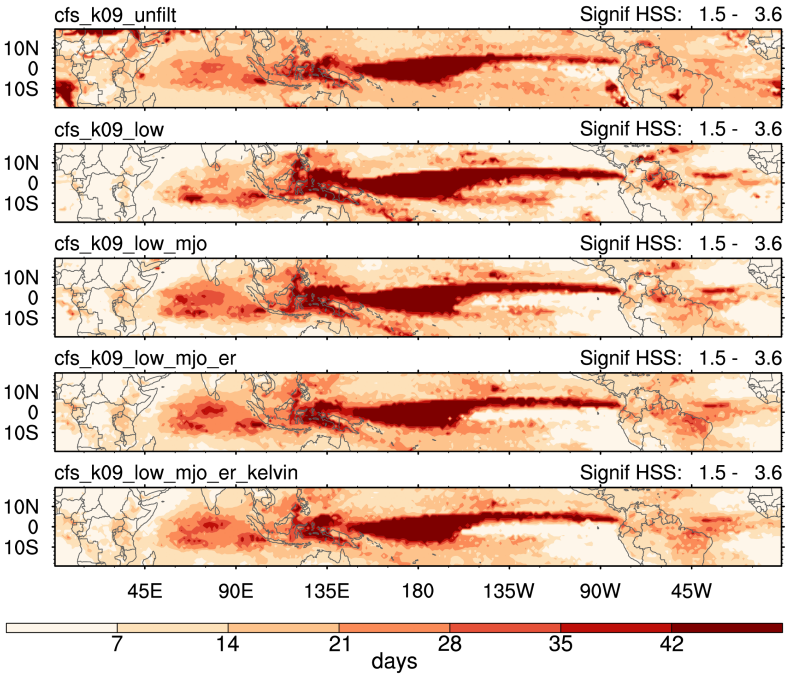



***Figure 2****. Maps of the lead (in days) at which the Heidke skill score for CFS rainfall forecasts are no longer significantly different than zero: (top row) bias-corrected unfiltered CFS forecasts; (second row) low-pass filtered anomalies; (third row) the sum of the low-pass and MJO-filtered anomalies; (fourth row) the sum of low-pass, MJO, and ER-filtered anomalies; and (bottom row) the sum of the low-pass, MJO, ER, and Kelvin-filtered anomalies.*

**Planned work**

- Publish manuscript comparing diurnal cycles between the TRMM and ISCCP datasets.
- Submit manuscript describing variations in those diurnal cycles with respect to the MJO and Kelvin waves.
- Submit a publication on the skill of the MJO and equatorial wave projections in the CFS.

**Publications**

Janiga, M. A., **C. Schreck**, J. A. Ridout, M. Flatau, N. Barton, E. J. Metzger, and C. Reynolds, 2018: Subseasonal Forecasts of Convectively Coupled Equatorial Waves and the MJO: Activity and Predictive Skill. *Monthly Weather Review*. http://dx.doi.org/10.1175/MWR-D-17-0261.1

**Worku, L. W.**, A. Mekonnen, and **C.J. Schreck**, 2018: Diurnal Cycle of Rainfall and Convection over the Maritime Continent using TRMM and ISCCP. *International Journal of Climatology*, submitted.

**Presentations**

**Mantripragada, S.**, **C. J. Schreck**, and A. R. Aiyyer, 2018: CFSv2 Hindcast Skill at Predicting Interactions between Kelvin Waves and AEWs. *PMM Science Team Meeting*, Phoenix, AZ, October 10, 2018.

**Schreck, C. J.**, M. A. Janiga, and A. R. Aiyyer, 2019: Variability in CFSv2 Hindcast Skill for the MJO and Equatorial Waves. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019. https://ams.confex.com/ams/2019Annual/meetingapp.cgi/Paper/350296

**Worku, L. W.**, A. Mekonnen, and **C. J. Schreck** 2019: Multiscale Interactions between the MJO, Equatorial Waves, and the Diurnal Cycle over the Maritime Continent: Part I. *33rd Conf. on Hurricanes and Tropical Meteorology*, Ponte Vedra Beach, FL, April 20, 2018. https://ams.confex.com/ams/33HURRICANE/webprogram/Paper340211.html

**Worku, L. W.**, **C. J. Schreck**, and A. Mekonnen, 2018: Multi-scale Interaction between the Diurnal Cycle, MJO, and Kelvin Waves over the Maritime Continent. *PMM Science Team Meeting,* Phoenix, AZ, October 10, 2018.

**Other**
Advising PhD students Lakemarium Worku (NC A&T University) and Sridhar Mantripragada (NCSU).

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **1** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **4** |
| **# of graduate students supported by your CICS task** | **2** |
| **# of graduate students formally advised** | **2** |
| **# of undergraduate students mentored during the year** | **0** |

| Investigations Between Kelvin Waves and Easterly Waves Using CYGNSS Data | |
|---|---|
| **Task Leader** | Carl Schreck |
| **Task Code** | NC-OTH-10-NCICS-CS |
| **Other Sponsor** | National Aeronautics and Space Administration (NASA) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Climate Data and Information Records and Scientific Data Stewardship |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** This team is using NASA's new Cyclone Global Navigation Satellite System (CYGNSS) retrievals to investigate the surface interactions between Kelvin waves and easterly waves.

**Background**

Kelvin waves and easterly waves are among the most prominent modes of synoptic-scale convective variability in the tropics. Recent studies suggest that interactions between these waves can lead to tropical cyclogenesis. However, many questions remain regarding how these waves affect one another and how cyclogenesis ensues.

Two of the most significant ways that Kelvin waves might affect easterly waves relate to their modulation of low-level winds, which may alter the background shear and gradient of vorticity and enhance wave-mean flow interaction. The Kelvin wave westerlies could also enhance surface enthalpy fluxes within the easterly wave, which would lead to intensification through diabatic heating. While the kinematic view of the interaction appears simple, the inherent dynamics are expected to be complex and nonlinear.

The recent launch of NASA's Cyclone Global Navigation Satellite System (CYGNSS) provides an unprecedented opportunity to observe and model these interactions. The high spatial and temporal resolution of CYGNSS is ideally suited for studying Kelvin waves and easterly waves, which have a phase speed of ~20 m $s^{-1}$ relative to one another and each have wavelengths of just 2000–4000 km.

**Accomplishments**

This project continues to progress towards the goals and objectives as outlined in the original statement of work. NCSU Ph.D. student Sridhar Mantripragada is performing the primary tasks under the joint supervision of PI Schreck and NCSU Co-I Anantha Aiyyer. Mantripragada is making progress on all three phases of the proposed work in parallel with one another. However, this parallel approach has slowed the progress towards the individual goals.

Phase 1 is a climatological investigation of interactions between Kelvin and easterly waves. This remains the primary focus of the research. Mantripragada has been using ERA-Interim reanalysis data to verify the enhancement of easterly wave eddy kinetic energy (EKE) following the passage of a Kelvin wave in the Atlantic. The differing speeds, directions, and scales between the two wave types has created some challenges, but the results are encouraging. The next step will be examining composites of the EKE and moist static energy (MSE) budgets to explain the intensification of the easterly waves. We anticipate submitting these results for publication early next year.

Phase 2 focuses on case studies of Kelvin–easterly wave interactions from the CYGNSS era. Preliminary results suggest that the easterly wave that led to Hurricane Harvey was one of the most likely to have

been affected by a Kelvin wave (Figure 1). CYGNSS data show enhanced surface winds ahead of the Kelvin waves when their easterly anomalies add to the climatological trade easterlies. Similarly, CYGNSS wind speeds decrease in the wake of the Kelvin waves. Analysis of the 2018 season and the details of these wind signals is ongoing, and we hope to prepare a publication later next year.

Phase 3 involves idealized WRF simulations of one of the cases identified in Phase 2. Mantripragada has performed preliminary simulations of the Hurricane Harvey case. Consistent with our hypotheses, these initial runs showed a much stronger cyclogenesis event in the control run than the experimental run in which the Kelvin-related anomalies were filtered out. These preliminary results were reported at the AMS Tropical Conference, but further sensitivity studies are needed before publication.

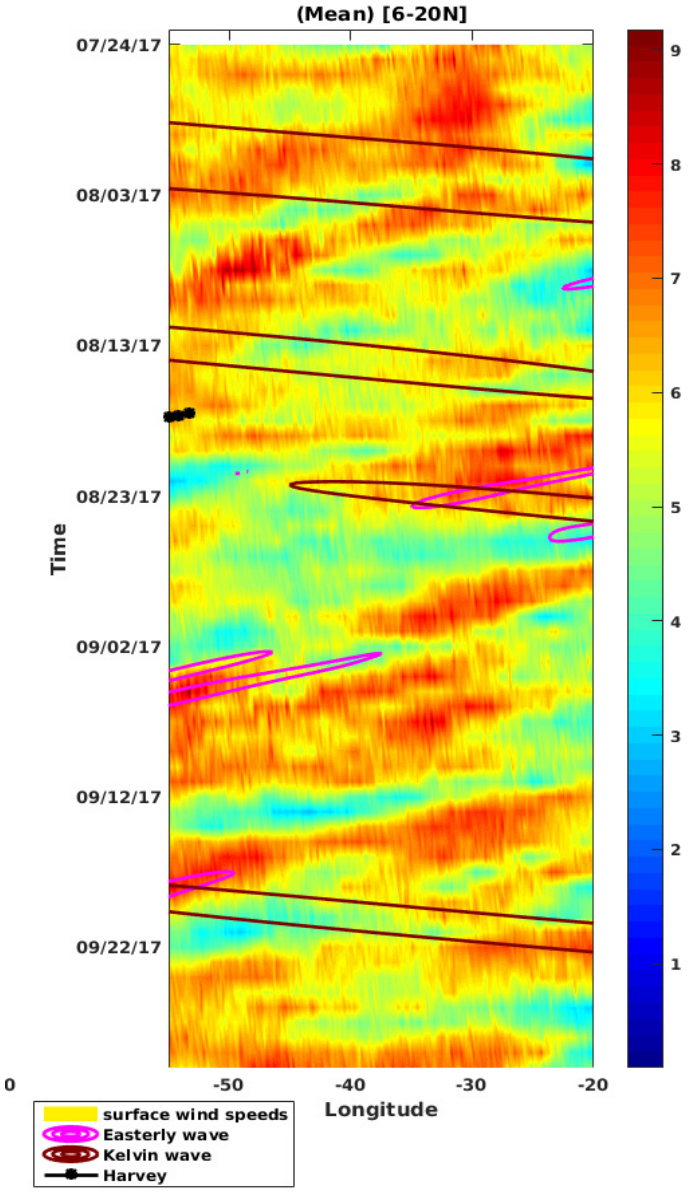



***Figure 1.*** *Hovmöller of CYGNSS surface winds (shading), Kelvin-filtered 200-hPa velocity potential (brown), and easterly wave-filtered 600-hPa EKE (magenta).*

**Planned work**

- Calculate budgets of MSE and EKE for the Kelvin waves to identify their impacts on the easterly waves
- Prepare and submit a results paper to a peer-reviewed journal.
- Publish the case studies of Kelvin waves from the CYGNSS period.

**Presentations**

Mantripragada, S., A. Aiyyer, and **C. J. Schreck**, 2018: Interaction of Kelvin and Easterly Waves Over the Atlantic and Implications for Tropical Cyclogenesis. 33rd Conf. on Hurricanes and Tropical Meteorology. *American Meteorological Society*, Ponte Vedra Beach, FL, April 16, 2018.
https://ams.confex.com/ams/33HURRICANE/webprogram/Paper340571.html

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **1** |
| **# of graduate students supported by your CICS task** | **1** |
| **# of graduate students formally advised** | **1** |
| **# of undergraduate students mentored during the year** | **0** |

| **Developing New Forecast Tools for the USAF 14th Weather Squadron's Tropical Pacific Convective Outlook** | |
|---|---|
| **Task Leader** | Carl Schreck, Jared Rennie |
| **Task Code** | NC-OTH-11-NCICS-CS/JR |
| **Other Sponsor** | Dignitas/DoD (Air Force) |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** This team delivered software for transitioning key tropical subseasonal metrics from CICS-NC's Madden–Julian Oscillation (MJO) monitoring page into operations in the Air Force's 14th Weather Squadron. https://ncics.org/mjo

**Background**

Subseasonal-to-seasonal (S2S) forecasting has emerged as one of the great frontiers for atmospheric predictability. Dynamical S2S models have improved significantly over recent years, but they have yet to fully tap the potential predictability of coherent tropical modes like the Madden–Julian Oscillation (MJO).

A unique approach to this problem has been implemented on https://ncics.org/mjo. This website takes recent observations and appends them with 45-day forecasts from the Climate Forecast System version 2 (CFSv2). The combined data are then Fourier filtered in space and time for some of the dominant modes of S2S variability in the tropics: the MJO, convectively coupled equatorial waves, and low-frequency variability like the El Niño–Southern Oscillation (ENSO). This filtering highlights the most predictable aspects of the S2S system. The website includes numerous maps, Hovmöller diagrams, and indices for identifying and predicting these modes. The website has been updated daily since 2011 with several upgrades and iterations over the years. This level of maturity makes them prime candidates to be transitioned into operations at the Air Force's 14th Weather Squadron (14WS).

**Accomplishments**

The tools at https://ncics.org/mjo are currently based on NCAR's Command Language (NCL). However, the 14WS requested the processing software code be delivered in Python version 3. The primary functions were refactored in Python 3 and delivered to the 14WS. Figure 1 shows an example of Hovmöller diagrams generated with the new Python code. A technical report highlighting the skill of these products was produced and provided to the 14WS.The project team continues to support the 14WS as they work to implement it.

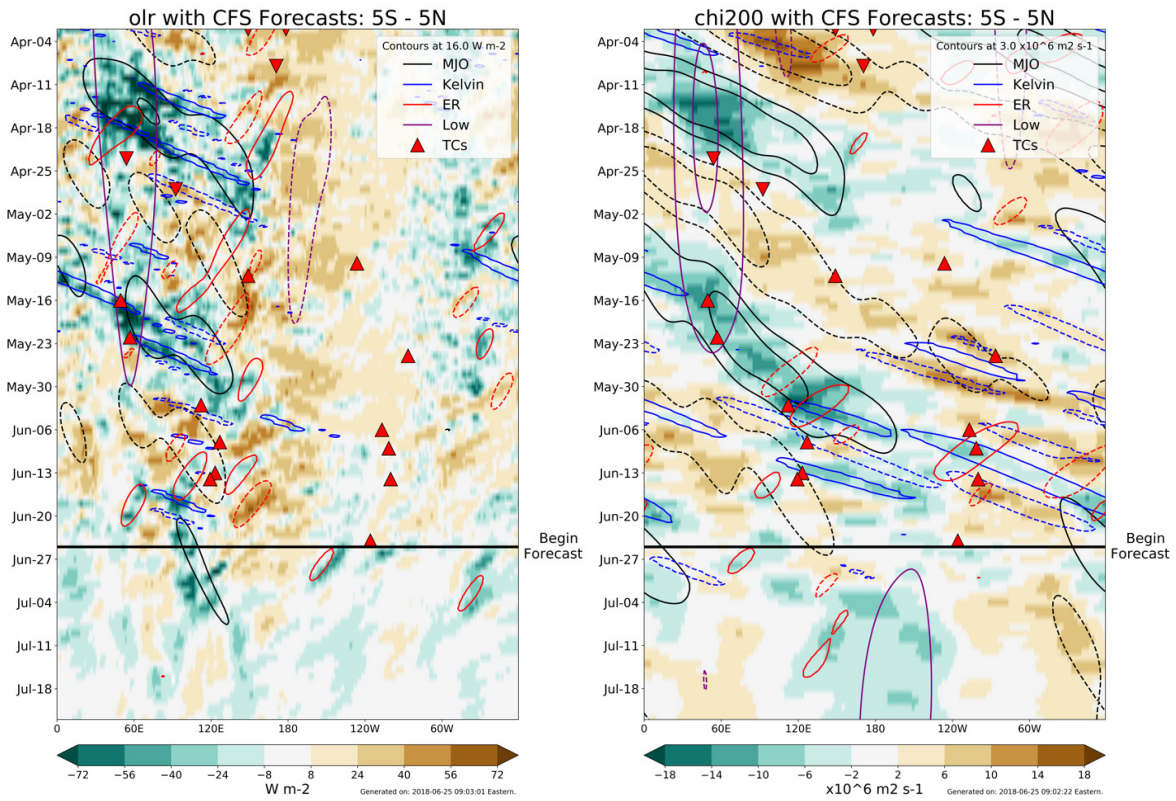



***Figure 1.*** *Example Hovmöllers for OLR (left) and 200-hPa velocity potential (chi200, right). Shading denotes anomalies from the daily 1981–2010 climatology. Observed analyses appear above the horizontal line and CFS forecasts below. Contours identify the anomalies associated with each of the four S2S modes with implied ascent in solid and descent in dashed lines. Triangles denote tropical cyclogenesis locations with upward triangles indicating Northern Hemisphere storms and downward triangles for the Southern Hemisphere.*

**Planned work**

Project was completed 30 June 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Operational Transition of Novel Statistical–Dynamical Forecasts for Tropical Subseasonal to Seasonal Drivers** | |
|---|---|
| **Task Leader** | Carl Schreck, Jared Rennie |
| **Task Code** | NC-OTH-12-NCICS-CS/JR |
| **Other Sponsor** | Office of Weather and Air Quality, Dignitas Technologies, LLC |
| **Contribution to CICS Research Themes** | Theme 2: Climate and Satellite Observations and Monitoring 50%<br>Theme 3: Climate Research and Modeling 50% |
| **Main CICS Research Topic** | Environmental Decision Support Science |
| **Contribution to NOAA goals** | Goal 2: Weather-Ready Nation 100% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |

**Highlight:** This team is transitioning key tropical subseasonal metrics from CICS-NC's Madden–Julian Oscillation (MJO) monitoring page into operations in the Climate Prediction Center. https://ncics.org/mjo

**Background**

Subseasonal-to-seasonal (S2S) forecasting has emerged as one of the great frontiers for atmospheric predictability. These time scales of weeks-to-months are at the heart of the mission for NOAA's Climate Prediction Center (CPC), which has been particularly focused on expanding and improving their 3–4-week forecasts. Dynamical S2S models have improved significantly over recent years, but they have yet to fully tap the potential predictability of coherent tropical modes like the Madden–Julian Oscillation (MJO).

A unique approach to this problem has been implemented on https://ncics.org/mjo. This website takes recent observations and appends them with 45-day forecasts from the Climate Forecast System version 2 (CFSv2). The combined data are then Fourier filtered in space and time for some of the dominant modes of S2S variability in the tropics: the MJO, convectively coupled equatorial waves, and low-frequency variability like the El Niño–Southern Oscillation (ENSO). This filtering highlights the most predictable aspects of the S2S system. The website includes numerous maps, Hovmöller diagrams, and indices for identifying and predicting these modes. It has been updating daily since 2011 with several upgrades and iterations over the years. These diagnostics have become routine inputs for CPC's Global Tropical Hazards (GTH) outlook. This level of maturity makes them prime candidates to be transitioned into operations at the CPC.

**Accomplishments**

Figure 1 shows the week-3 forecast skill of these methods. Most of the CFS's raw skill (Fig. 1a) comes from the persistent signals associated with ENSO (Fig. 1b). The MJO primarily contributes skill in the Indian Ocean (Fig. 1c). Adding the filtered anomalies together can provide even more skill (Figs. 1e,f). These filtered anomalies barely meet, let alone exceed, that of the raw CFS. However, they provide valuable tools for identifying where the CFS's most skillful components come from. In other words, a forecaster may trust the CFS forecast more when it is associated with ENSO or the MJO.

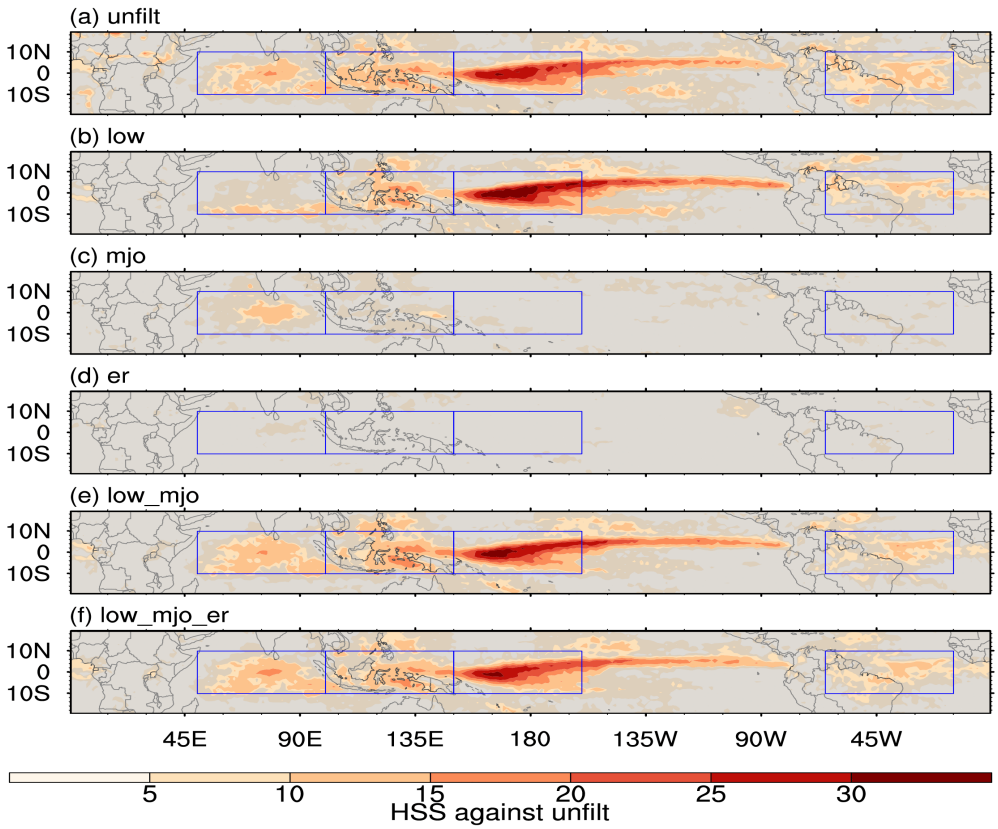



***Figure 1**. Map of Heidke Skill Score for week-3 rainfall for (a) unfiltered CFS forecasts and forecasts filtered for (b) 100-day low-pass filter, (c) MJO, (d) equatorial Rossby (ER) waves, (e) the sum of the low-pass and MJO, and (f) the sum of low-pass, MJO, and ER-filtered anomalies.*

**Planned work**

- Add rainfall diagnostics using CMORPH
- Publish manuscript describing the skill for various seasons and MJO states
- Work with CPC to develop skill masks for the products
- Develop tropical cyclogenesis with CPC based on these forecasts

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **1** |
| **# of peer reviewed papers** | **0** |
| **# of NOAA technical reports** | **0** |
| **# of presentations** | **0** |
| **# of graduate students supported by your CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

| **Collaborative Support for the Development of the Quantitative Urban-Scale Microclimatic Modeling Tool (QUEST)** | |
|---|---|
| **Task Leader** | Liqiang Sun |
| **Task Code** | NC-OTH-13-NCICS-LS |
| **Other Sponsor** | Urban Redevelopment Authority of Singapore |
| **Contribution to CICS Research Themes** | Theme 3: Climate Research and Modeling 100% |
| **Main CICS Research Topic** | Climate Research and Modeling |
| **Contribution to NOAA goals** | Goal 1: Climate Adaptation and Mitigation 50% |
| | Goal 2: Weather-Ready Nation 50% |
| **NOAA Strategic Research Priorities** | Integrated Earth System Processes and Predictions |
| | Decision Science, Risk Assessment and Risk Communication |

**Highlight:** An interface package between global datasets and the high-resolution regional model was developed, and hourly data with resolution of 1 km x 1 km was generated to establish average and hot-test historical baseline climate scenarios over Singapore.

**Background**

With climate change, the frequency, severity, and duration of heat waves associated with urban heat island (UHI) effects are increasing in Singapore. As such, Singapore is likely to experience more climate-related health risks. The availability of high-resolution geospatial data; monitoring of land, coastal and water resources; and high-resolution environmental modelling at local scales can support timely and reliable climate-sensitive urban planning. A well-formulated cyber-infrastructure design, incorporating recent advances in informatics and geographic information systems (GIS), is essential for successful climate-sensitive urban planning efforts to track and adapt to a changing climate and changing environments. The project's overarching objective is to develop a climate information system for urban heat island effect for urban planning in Singapore.

The objectives of the collaboration between CICS-NC and Urban Redevelopment Authority (URA) of Singapore were to:

- Provide support for sourcing and customization of the global/regional environmental data sets;
- Optimize the integration of the global/regional climate data with various urban models to ensure timely turnaround time for urban heat island and thermal comfort analyses and simulations in order to support modelling and simulation requirements for urban planning in Singapore.

**Accomplishments**

- The following 6-hr datasets were downloaded and provided to URA:
    - NCEP/DOE Reanalysis 2,
    - NCEP Climate Forecast System Reanalysis (CFSR) and Forecasts, and
    - NCEP Global Forecast System (GFS) forecasts.

- An interface package was developed to read 6-hr global datasets (e.g., NCEP/DOE Reanalysis 2), and convert them into spectral space as inputs for the NCEP Mesoscale Model (MSM);

- NCEP MSM simulations with the resolution of 1 km x 1 km were completed over Singapore, to evaluate the model performance and generate baseline climate scenarios.

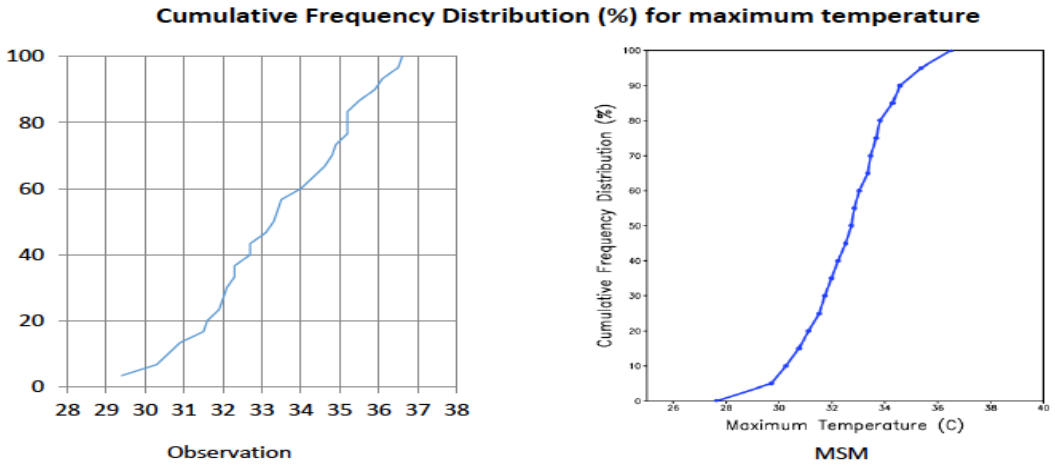



***Figure 1.*** *Cumulative Frequency Distribution for daily maximum temperature over Singapore: observation (left panel) and MSM simulation (right panel).*

**Planned work**

Project is completed.

**Presentations**

Lim, T. K. and **L. Sun**, 2018: Islandwide Climate Baselines and Scenarios. *QUEST Annual Workshop*, Singapore, November 12, 2018.

Lim, T. K. and **L. Sun**, 2018: Islandwide Climate Baselines and Scenarios: An Update. *Urban Redevelopment Authority Annual Meeting*, Singapore, December 4, 2018.

| Performance Metrics | |
|---|---|
| **# of new or improved products developed (please identify below the table)** | **0** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **0** |
| **# of peer reviewed papers** | **0** |
| **# of non-peered reviewed papers** | **0** |
| **# of presentations** | **2** |
| **# of graduate students supported by a CICS task** | **0** |
| **# of graduate students formally advised** | **0** |
| **# of undergraduate students mentored during the year** | **0** |

# Appendix 1: CICS-NC Personnel and Performance Metrics

| CICS-NC Personnel | Numbers* | | CICS-NC Subcontractors | Numbers** |
|---|---|---|---|---|
| Scientists working ≥ 50% time | **22** | | Scientists working ≥ 50% time | **0** |
| Scientists working < 50% time | **3** | | Scientists working < 50% time | **21** |
| Scientists working at no cost | **1** | | Scientists working at no cost | **3** |
| **Total Scientists** | **26** | | **Total Scientists** | **24** |
| **Administrative/technical staff** | **9** | | **Administrative/technical staff** | **6** |
| Graduate Students | **1** | | Graduate Students | **3** |
| Undergraduate Students | **0** | | Undergraduate Students | **3** |
| High School Students | **0** | | High School Students | **0** |
| **Total Students** | **0** | | **Total Students** | **6** |
| **Total Personnel** | **36** | | **Total Personnel** | **36** |

**Excludes institute personnel supported solely by non-NOAA sponsors and unpaid student interns.*

***Based on NOAA/CICS-NC budgeted support effort for this year's current subcontractor projects*

| Performance Metrics | |
|---|---|
| **# of new or improved products developed that became operational** | **73** |
| **# of products or techniques submitted to NOAA for consideration in operations use** | **61** |
| **# of peer reviewed papers** | **59** |
| **# of NOAA technical reports** | **3** |
| **# of presentations** | **175*** ** |
| **# of graduate students supported by your CICS task** | **9** |
| **# of graduate students formally advised** | **20** |
| **# of undergraduate students mentored during the year** | **18** |

****Presentations: 152 science presentations; 23 outreach and engagement presentations.*

# Appendix 2: CICS-NC Publications 2018–2019


*Aich, V., O. Baddour, C. Lief, **G. Peng**, and W. Wright, 2019: A WMO-Wide Stewardship Maturity Matrix for Climate Data. Document ID: WMO-SMM-CD-0001. Version: v03r00 20190128. *Figshare*. http://doi.org/10.6084/m9.figshare.7006028

*Aich, V., O. Baddour, C. Lief, **G. Peng**, and W. Wright, 2019: The guidance booklet on the WMO-Wide Stewardship Maturity Matrix for Climate Data. Document ID: WMO-SMM-CD-0002. Version: v03r00 20190131. *Figshare*. http://doi.org/10.6084/m9.figshare.7002482

Angel, J., C. Swanson, B. M. Boustead, K. C. Conlon, K. R. Hall, J. L. Jorns, **K. E. Kunkel**, M. C. Lemos, B. Lofgren, T. A. Ontl, J. Posey, K. Stone, G. Takle, and D. Todey, 2018: Midwest. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 872-940. http://dx.doi.org/10.7930/NCA4.2018.CH21

Avery, C. W., D. R. Reidmiller, M. Kolian, **K. E. Kunkel**, D. Herring, R. Sherman, W. V. Sweet, K. Tipton, and C. Weaver, 2018: Data Tools and Scenarios Products. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1413–1430. http://dx.doi.org/10.7930/NCA4.2018.AP3

**Bell, J. E.**, C. L. Brown, K. Conlon, S. Herring, **K. E. Kunkel**, J. Lawrimore, G. Luber, **C. Schreck**, A. Smith, and C. Uejio, 2018. Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association*, **68**, 265-287. https://doi.org/10.1080/10962247.2017.1401017

Bliss, A. C., M. Steele, **G. Peng**, W. N. Meier, and S. Dickinson, 2019: Regional Variability of Arctic Sea Ice Seasonal Change Climate Indicators from a Passive Microwave Climate Data Record. *Environmental Research Letters*, **in press**. http://dx.doi.org/10.1088/1748-9326/aafb84

Carter, L., A. Terando, K. Dow, K. Hiers, **K. E. Kunkel**, A. Lascurain, D. Marcy, M. Osland, and P. Schramm, 2018: Southeast. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 743–808. http://dx.doi.org/10.7930/NCA4.2018.CH19

Chen, J., R. John, G. Sun, P. Fan, G. M. Henebry, M. E. Fernández-Giménez, Y. Zhang, H. Park, L. Tian, **P. Groisman**, Z. Ouyang, G. Allington, J. Wu, C. Shao, A. Amarjargal, G. Dong, G. Gutman, F. Huettmann, R. Lafortezza, C. Crank, and J. Qi, 2018: Prospects for the Sustainability of Social-Ecological Systems (SES) on the Mongolian Plateau: Five Critical Issues. *Environmental Research Letters*, **13,** 123004. http://dx.doi.org/10.1088/1748-9326/aaf27b

Chen, J., Z. Ouyang, R. John, G. M. Henebry, P. Y. Groisman, A. Karnieli, M. Kussainova, A. Amartuvshin, A., Tulobaev, E. T. Isabaevich, C. Crank, K. Kadhim, J. Qi, J., and G. Gutman, 2019: Chapter 10: Social-ecological systems across the Asian Drylands Belt (ADB). In: *Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems*, Gutman et al., Eds., Springer, **in press**.

Dai, Y., H. Li, and **L. Sun**, 2018: The Simulation of East Asian Summer Monsoon Precipitation With a Regional Ocean-Atmosphere Coupled Model. *Journal of Geophysical Research: Atmospheres*, **123,** 11,362-11,376. http://dx.doi.org/10.1029/2018JD028541

Demaria, E. M. C., D. Goodrich, and **K. E. Kunkel**, 2018: Evaluating the Reliability of the U.S. Cooperative Observer Program Precipitation Observations for Extreme Events Analysis Using the LTAR Network. *Journal of Atmospheric and Oceanic Technology*, **36**, 317-332. http://dx.doi.org/10.1175/JTECH-D-18-0128.1

Diamond, H. J., **C. J. Schreck**, Eds., 2018: The tropics [in "State of the Climate in 2017"]. In: *Bulletin of the American Meteorological Society*, G. Hartfield, J. Blunden, and D. S. Arndt, Eds., American Meteorological Society, S101-S142. http://dx.doi.org/10.1175/2018BAMSStateoftheClimate.1

Dzaugis, M., C. W. Avery, A. Crimmins, L. Dahlman, D. R. Easterling, R. Gaal, E. Greenhalgh, D. Herring, **K. E. Kunkel**, R. Lindsey, **T. K. Maycock**, R. Molar, D. R. Reidmiller, **B. C. Stewart**, and R. S. Vose, 2018: Frequently Asked Questions. In: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II*, D. R. Reidmiller, C. W. Avery, D. Easterling, **K. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds., U.S. Global Change Research Program, 1444–1515. http://dx.doi.org/10.7930/NCA4.2018.AP5

Fan, P., J. Chen, Z. Ouyang, **P. Groisman**, T. Loboda, G. Gutman, A. V. Prishchepov, A. Kvashnina, J. Messina, N. Moore, S. W. Myint, and J. Qi, 2018: Urbanization and Sustainability under Transitional Economies: a Synthesis for Asian Russia. *Environmental Research Letters*, **13,** 095007. http://dx.doi.org/10.1088/1748-9326/aadbf8

Ferraro, R. R., B. R. Nelson, T. Smith, and **O. P. Prat**, 2018: The AMSU-Based Hydrological Bundle Climate Data Record—Description and Comparison with Other Data Sets. *Remote Sensing*, **10**. http://dx.doi.org/10.3390/rs10101640

Gardiner, E. P., D. D. Herring, and J. F. Fox, 2018: The U.S. Climate Resilience Toolkit: Evidence of Progress. *Climatic Change*. https://doi.org/10.1007/s10584-018-2216-0

Green, T. A., **C. J. Schreck, III**, N. S. Johnson, and S. S. Heath, 2019: Educational Backgrounds of TV Weathercasters. *Bulletin of the American Meteorological Society*, **in press**. http://dx.doi.org/10.1175/BAMS-D-17-0047.1

**Groisman, P.**, O. Bulygina, G. Henebry, N. Speranskaya, A. Shiklomanov, Y. Chen, N. Tchebakova, E. Parfenova, N. Tilinina, O. Zolina, A. Dufour, J. Chen, R. John, P. Fan, C. Mátyás, I. Yesserkepova, and I. Kaipov, 2018: Dryland Belt of Northern Eurasia: Contemporary Environmental Changes and their Consequences. *Environmental Research Letters*, **13,** 115008. http://dx.doi.org/10.1088/1748-9326/aae43c

**Groisman, P. Y.**, O. N. Bulygina, G. M. Henebry, N. A. Speranskaya, A. I. Shiklomanov, Y. Chen, N. M. Tchebakova, E. I. Parfenova, N. D. Tilinina, O. G. Zolina, A. Dufour, J. Chen, R. John, and P. Fan, 2019: Chapter 2: Dry Land Belt of Northern Eurasia: Contemporary environmental changes. In: *Landscape Dynamics of Drylands across Greater Central Asia: People, Societies and Ecosystems*, Gutman et al., Ed., Springer, **in press**.

Gupta, V., and B. Mahadevan, 2018: Heatwaves are health and economic risks, *Livemint* e-paper, https://www.livemint.com/Opinion/fwqXTntE5ZYCXMJOSeet0H/Heatwaves-are-health-and-economic-risks.html

Hutchins, M., K. Rogers, J. Fox, and N. F. Hall, 2018: Reducing Uncertainty in Climate Resilience Planning: How the Components of Vulnerability and Risk Help Inform the Assessment Process. *Carolina Planning Journal,* **43**, 12-19. https://issuu.com/carolinaplanningjournal/docs/2018_issue_layout_43_r3_web__1_

IPCC, 2018: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty.* V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, **T. Maycock**, M. Tignor, and T. Waterfield, Eds. World Meteorological Organization.

IPCC, 2018: Summary for Policymakers. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, **T. Maycock**, M. Tignor, and T. Waterfield, Eds., World Meteorological Organization, 32 pp.

Janiga, M. A., **C. Schreck**, J. A. Ridout, M. Flatau, N. Barton, E. J. Metzger, and C. Reynolds, 2018: Subseasonal Forecasts of Convectively Coupled Equatorial Waves and the MJO: Activity and Predictive Skill. *Monthly Weather Review*. http://dx.doi.org/10.1175/MWR-D-17-0261.1

Klotzbach, P. J., **C. J. Schreck**, J. M. Collins, M. M. Bell, E. S. Blake, and D. Roache, 2018: The Extremely Active 2017 North Atlantic Hurricane Season. *Monthly Weather Review*, **146,** 3425-3443. http://dx.doi.org/10.1175/MWR-D-18-0078.1

Knapp, K. R., and **S. L. Wilkins**, 2018: Gridded Satellite (GridSat) GOES and CONUS Data. *Earth System Science Data*, **10,** 1417-1425. http://dx.doi.org/10.5194/essd-10-1417-2018

Kumjian, M. R., C. P. Martinkus, **O. P. Prat**, S. Collis, M. van Lier-Walqui, and H. C. Morrison, 2019: A Moment-Based Polarimetric Radar Forward Operator for Rain Microphysics. *Journal of Applied Meteorology and Climatology*, **58,** 113-130. http://dx.doi.org/10.1175/JAMC-D-18-0121.1

Lee, T. R., M. Buban, M. A. Palecki, **R. D. Leeper**, H. J. Diamond, E. Dumas, T. P. Meyers, and C. B. Baker, 2018: Great American Eclipse Data May Fine-Tune Weather Forecasts. *EOS*, **99,** 18-22. http://dx.doi.org/10.1029/2018EO103931

**Leeper, R. D.**, **E. J. Bell**, and A. M. Palecki, 2019: A Description and Evaluation of U.S. Climate Reference Network Standardized Soil Moisture Dataset. *Journal of Applied Meteorology and Climatology*, **In press**. https://doi.org/10.1175/JAMC-D-18-0269.1

*Lief, C., and **G. Peng**, 2019: The WMO Stewardship Maturity Matrix for Climate Data (SMM- CD) Template. Document ID: WMO-SMM-CD-0003. Version: v03r01–20190224. *Figshare*.

http://doi.org/10.6084/m9.figshare.7003709

Liu, X., Q. Tang, W. Liu, H. Yang, **P. Y. Groisman**, G. Leng, P. Ciais, X. Zhang, and S. Sun, 2019: The Asymmetric Impact of Abundant Preceding Rainfall on Heat Stress in Low Latitudes. *Environmental Research Letters*, **in press**. http://dx.doi.org/10.1088/1748-9326/ab018a

McGuirk, M., S. C. Herring, and **J. Dissen**, 2019: The Climate Resilient Grid Forum. *Bulletin of the American Meteorological Society*, **100,** 173-176. http://dx.doi.org/10.1175/BAMS-D-18-0018.1
Menne, M. J., C. N. Williams, B. E. Gleason, **J. J. Rennie**, and J. H. Lawrimore, 2018: The Global Historical Climatology Network Monthly Temperature Dataset, Version 4. *Journal of Climate*, **31,** 9835-9854. http://dx.doi.org/10.1175/JCLI-D-18-0094.1

Menne, M. J., C. N. Williams, B. E. Gleason, J. J. Rennie, and J. H. Lawrimore, 2018: The Global Historical Climatology Network Monthly Temperature Dataset, Version 4. *Journal of Climate*, **31**, 9835-9854. http://dx.doi.org/10.1175/JCLI-D-18-0094.1

Miller, D. K., C. F. Miniat, R. M. Wooten, and A. P. Barros, 2019. An Expanded Investigation of Atmospheric Rivers in the Southern Appalachian Mountains and Their Connection to Landslides. *atmosphere*, **10**, 71. https://doi.org/10.3390/atmos10020071

Morrison, H., M. R. Kumjian, C. P. Martinkus, **O. P. Prat**, and M. van Lier-Walqui, 2019: A general N-moment Normalization Method for Deriving Rain Drop Size Distribution Scaling Relationships. *Journal of Applied Meteorology and Climatology*, **58,** 247-267. http://dx.doi.org/10.1175/JAMC-D-18-0060.1

**Peng, G.,** M. Steele, A. Bliss, W. N. Meier, and S. Dickinson, 2018: Temporal means and Variability of Arctic Sea Ice Melt and Freeze Season Climate Indicators Using a Satellite Climate Data Record. *Remote Sensing*, **10**. http://dx.doi.org/10.3390/rs10091328

**Peng, G.**, J. L. Privette, C. Tilmes, S. Bristol, **T. Maycock**, J. J. Bates, S. Hausman, **O. Brown**, and E. J. Kearns, 2018: A Conceptual Enterprise Framework for Managing Scientific Data Stewardship. *Data Science Journal*, **17,** 15. http://dx.doi.org/10.5334/dsj-2018-015

Ramapriyan, H. K., R. R. Downs, J. Dozier, R. Duerr, M. Folk, J. Frew, N. Hoebelheinrich, C. A. Mattmann, and **G. Peng**, 2019: Bruce Barkstrom (1944–2018), *Eos*, 100. http://doi.org/10.1029/2019EO115561

Rogers, W., R. Mahmood, **R. Leeper**, and J. Yan, 2018: Land Cover Change, Surface Mining, and Their Impacts on a Heavy Rain Event in the Appalachia. *Annals of the American Association of Geographers*, **108**(5), 1187-1209. http://doi.org/10.1080/24694452.2018.1460249

**Runkle, J.**, **K. Kunkel**, and **L. Stevens**, 2018: Puerto Rico and the U.S. Virgin Islands State Climate Summary. NOAA Technical Report NESDIS 149-PR, 4 pp., https://statesummaries.ncics.org/pr

**Runkle, J.**, M. Sugg, D. Boase, S. L. Galvin, and C. C. Coulson, 2019: Use of Wearable Sensors for Pregnancy Health and Environmental Monitoring: Descriptive Findings from the Perspective of Patients and Providers. *Digital Health*, **5,** 2055207619828220. http://dx.doi.org/10.1177/2055207619828220

**Runkle, J.**, E. R. Svendsen, M. Hamann, R. K. Kwok, and J. Pearce, 2018: Population Health Adaptation Approaches to the Increasing Severity and Frequency of Weather-Related Disasters Resulting From our

Changing Climate: A Literature Review and Application to Charleston, South Carolina. *Current Environmental Health Reports*, **5,** 439-452. http://dx.doi.org/10.1007/s40572-018-0223-y

Rusch, M., J. Nakitandwe, S. Shurtleff, S. Newman, Z. Zhang, M. N. Edmonson, M. Parker, Y. Jiao, X. Ma, Y. Liu, J. Gu, M. F. Walsh, J. Becksfort, **A. Thrasher**, Y. Li, J. McMurry, E. Hedlund, A. Patel, J. Easton, D. Yergeau, B. Vadodaria, R. G. Tatevossian, S. Raimondi, D. Hedges, X. Chen, K. Hagiwara, R. McGee, G. W. Robinson, J. M. Klco, T. A. Gruber, D. W. Ellison, J. R. Downing, and J. Zhang, 2018: Clinical Cancer Genomic Profiling by Three-Platform Sequencing of Whole Genome, Whole Exome and Transcriptome. *Nature Communications*, **9,** 3962. http://dx.doi.org/10.1038/s41467-018-06485-7

Schlie, E. E.-J., D. Wuebbles, **S. Stevens**, R. Trapp, and B. Jewett, 2019: A Radar-Based Study of Severe Hail Outbreaks over the Contiguous United States for 2000–2011. *International Journal of Climatology*, **39,** 278-291. http://dx.doi.org/10.1002/joc.5805

**Schreck, C.,** H.-T. Lee, K. Knapp, 2018: HIRS Outgoing Longwave Radiation—Daily Climate Data Record: Application toward Identifying Tropical Subseasonal Variability. *Remote Sensing*, **10**. http://dx.doi.org/10.3390/rs10091325

Sehgal, M., and J. Mosahari, 2019: Climate Change and Health Challenges in India, *TerraGreen* e-zine, **11**(12). http://terragreen.teriin.org/index.php

*Shen, S. S. P., and R. C. J. Somerville, 2019: *Climate Mathematics: Theory and Applications*, Cambridge University Press, New York, 432pp. (publication in August 2019)

Shi, L., **C. J. Schreck**, and M. Schröder, 2018: Assessing the Pattern Differences between Satellite-Observed Upper Tropospheric Humidity and Total Column Water Vapor during Major El Niño Events. *Remote Sensing*, **10**. http://dx.doi.org/doi:10.3390/rs10081188

Shiva, J. S., D. G. Chandler, and **K. E. Kunkel**, 2019: Localized Changes in Heat Wave Properties across the USA. *Earth's Future*, **in press**. http://dx.doi.org/10.1029/2018EF001085

Soja, A., and **P. Groisman**, 2018: Earth Science and the Integral Climatic and Socio-Economic Drivers of Change across Northern Eurasia: The NEESPI Legacy and Future Direction. *Environmental Research Letters*, **13,** 040401. http://dx.doi.org/10.1088/1748-9326/aab834

**Stegall, S. T.**, and **K. E. Kunkel**, 2019: Simulation of Daily Extreme Precipitation Over the United States in the CMIP5 30-yr Decadal Prediction Experiment. *Journal of Applied Meteorology and Climatology*. http://dx.doi.org/10.1175/JAMC-D-18-0057.1

**Stevens, S. E.**, 2019: Trends in Instrument Flight Rules (IFR) Conditions at Major Airports in the United States. *Journal of Applied Meteorology and Climatology*, **58**, 615-620. http://dx.doi.org/10.1175/JAMC-D-18-0301.1

**Stevens, S. E.**, **C. J. Schreck**, S. Saha, **J. E. Bell**, and **K. E. Kunkel**, 2019: Precipitation and Fatal Motor Vehicle Crashes: Continental Analysis with High-Resolution Radar Data. *Bulletin of the American Meteorological Society*. http://dx.doi.org/10.1175/BAMS-D-18-0001.1

Sugg, M., G. Dixon, and **J. D. Runkle**, 2019: Crisis Support-Seeking Behavior and Temperature in the United States: Is there an Association in Young Adults and Adolescents? *Science of the Total Environment*, **in press**. https://doi.org/10.1016/j.scitotenv.2019.02.434

Sugg, M., C. M. Fuhrmann, and **J. D. Runkle**, 2019: Geospatial Approaches to Measuring Personal Heat Exposure and Related Health Effects in Urban Settings. In: *Geospatial Technologies for Urban Health*, L. Yongmei, and E. Delmelle, Eds., Springer Nature, **in press**.

Sugg, M. M., C. M. Fuhrmann, and **J. D. Runkle**, 2018: Temporal and Spatial Variation in Personal Ambient Temperatures for Outdoor Working Populations in the Southeastern USA. *International Journal of Biometeorology*, **8,** 1521-1534. http://dx.doi.org/10.1007/s00484-018-1553-z

Sugg, M. M., **S. S. Stevens**, and **J. D. Runkle**, 2019: Estimating Personal Ambient Temperature in Moderately Cold Environments for Occupationally Exposed Populations. *Environmental Research*, **in press**. **https://doi.org/10.1016/j.envres.2019.03.066**

**Thompson, L.**, M. Sugg, and **J. Runkle**, 2018: Report-Back for Geo-Referenced Environmental Data: A Case Study on Personal Monitoring of Temperature in Outdoor Workers. *Geo spatial Health*, **13**. http://dx.doi.org/10.4081/gh.2018.629

**Thompson, L. K.**, K. D. Michael, **J. Runkle**, and M. M. Sugg, 2019: Crisis Text Line Use Following the Release of Netflix Series 13 Reasons Why Season 1: Time-Series Analysis of Help-Seeking Behavior in Youth. *Preventive Medicine Reports*, **14,** 100825. http://dx.doi.org/10.1016/j.pmedr.2019.100825

**Thompson, L. K.**, M. M. Sugg, and **J. R. Runkle**, 2018: Adolescents in crisis: A Geographic Exploration of Help-Seeking Behavior Using Data from Crisis Text Line. *Social Science & Medicine*, **215,** 69-79. http://dx.doi.org/10.1016/j.socscimed.2018.08.025

Tucker, T. and S. S. P. Shen, 2018: A toolkit for snow cover area calculation and display based on the Interactive Multisensor Snow and Ice Mapping System and an example for the Tibetan Plateau region. *Advances in Data Science and Adaptive Analysis,* **10**. http://doi.org/10.1142/S2424922X18500031

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 1506 pp. http://dx.doi.org/10.7930/NCA4.2018

USGCRP, 2018: *Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II: Report-in-Brief.* D. R. Reidmiller, C. W. Avery, D. R. Easterling, **K. E. Kunkel**, K. L. M. Lewis, **T. K. Maycock**, and **B. C. Stewart**, Eds. U.S. Global Change Research Program, 186 pp. http://dx.doi.org/10.7930/NCA4.2018.RiB

*Wuebbles, D., B. Cardinale, K. Cherkauer, R. Davidson-Arnott, J. Hellmann, D. Infante, L. Johnson, R. Deloe, B. Lofgren, A. Packman, F. Seglenieks, A. Sharma, B. Sohngen, M. Tiboris, D. Vimont, R. Wilson, **K. Kunkel**, and **A. Ballinger**, 2019: *An Assessment of the Impacts of Climate Change on the Great Lakes*. Environmental Law and Policy Center, 71 pp. http://elpc.org/wp-content/uploads/2019/03/Great-Lakes-Climate-Change-Report.pdf

**Non-peer-reviewed*

# Appendix 3: CICS-NC Presentations 2018–2019

**Science / Project Presentations**

- Abadi, A., 2019: Drought Associations with All-Cause Mortality Rates in Nebraska, *American Meteorological Society Annual Meeting*, Phoenix, AZ, January 8, 2019.
- Angel, J. R., C. Swanston, B. M. Boustead, K. Conlon, K. Hall, J. L. Jorns, **K. Kunkel**, M. C. Lemos, B. M. Lofgren, T. Ontl, J. Posey, K. Stone, E. S. Takle, and D. Todey, 2018: The Fourth National Climate Assessment: Midwest. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- Banzon, P. V. F., T. M. Smith, M. Steele, H.-M. Zhang, B. Huang, C. Strong, K. M. Golden, and **J. C. Biard**, 2018: Validation and Improvement of a Blended Sea Surface Temperature Analysis using Recent Buoy Observations in the Arctic. *American Geophysical Union Fall Meeting*, Washington, DC, December 11, 2018.
- **Bell, J.**, 2018: How changes in intensity and frequency of extreme events alters human health. *University of Miami Climate and Health Symposium*, Miami, FL, April 14, 2018.
- **Bell, J.**, 2018: Health Hazards Associated with Drought, *Council of State and Territorial Epidemiologists Disaster Epidemiology Community of Practice Meeting* (webinar), July 19, 2018.
- **Bell, J.**, 2019: Drought and Health Impacts, *California Climate Action Team Public Health Workgroup (CAT-PHWG) Preparing for the Health Effects of Drought: A Workshop for Public Health Professionals and Partners*, Sacramento, CA, February 4, 2019.
- **Bell, J.**, J. Shriber, Z. Jeddy, **J. Rennie**, and H. Strosnider, 2019: Assessment of Potential Health Impacts from Extreme and Exceptional Drought, 2012-16, *American Meteorological Society Annual Meeting*, Phoenix, AZ, January 8, 2019.
- **Bell, J. E.**, 2018: The Relationship between Extreme Events and Human Health in a Changing Climate. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 15, 2018.
- **Biard, J.**, and **K. E. Kunkel**, 2018: Atmospheric Fronts in Climate Models: Inter-comparison Across Historical and Future Scenarios. *American Geophysical Union Fall Meeting*, Washington, DC, December 10, 2018.
- Bliss, Steele, M., **G. Peng,** W.N. Meier, and S. Dickinson, 2018: Arctic sea ice cover climate indicators: melt season evolution and regional variability. *Drivers of Ecosystem Change: Marine Ecosystems Collaboration Team August 2018 Meeting,* August 22, 2018.
- Brewer, M., A. Hollingshead, N. Jones, **J. Dissen**, A. Rycerz, T. G. Houston, and K. V. Matthews, 2019: The Value of Environmental Data from NOAA's National Centers for Environmental Information. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.
- **Brown, O.**, and **J. Brannock**, 2018: Big Data Project (BDP) Data Broker Update. *2018 Earth Science Information Partner (ESIP) Summer Meeting*, Tucson, AZ, July 17, 2018.
- Burke, L., 2018: An Introduction to PREP Platform, *PREP Launch workshop*, Bhopal, India, June 12, 2018.
- **Champion, S.**, 2019: You Can Have Data without Information, but You Cannot have Information without Data. *AMOS Science Pub: Understanding the Importance of Data, The Collider*, Asheville, NC, March 29, 2019.
- Chen, J., Y. Zhang, R. John, G. Sun, P. Fan, J. Wu, H. Park, C. Shao, **P. Y. Groisman**, G. RH. Alington, G. Gutman, M. Fernandez-Gimenez, L. Tian, A. Amartuvshin, R. Lafortezza, F. Huettmann, R. Reid,

and J. Qi, 2018: Socio-Environmental Systems (SES) on the Changing Mongolian Plateau: A review. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.

- Chen, Y., W. Ju, **P. Y. Groisman**, J. Li, X. Fei, and H. Ruan, 2018: Quantification of grazing impact on C sequestration over Temperate Eurasian Steppe. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- Davis, E. R., C. S. Zender, D. Arctur, K. M., O'Brien, A. Jelenak, D. Santek, M. J. Dixon, T. Whiteaker, K. Yang, J. Yu, **J. C. Biard**, and D. Hassell, 2018: NetCDF-CF: Supporting Earth System Science with Data Access, Analysis, and Visualization. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.
- **Dissen, J.**, 2018: Key Findings from the U.S.-India Partnership for Climate Resilience Workshop on Development and Application of High-Resolution Climate Modeling. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.
- **Dissen, J.**, 2018: Sectoral Analysis Approach. *National Water Initiative Service Delivery & Decision Support Group* web conference, June 14, 2018.
- **Dissen, J.**, A. Hollingshead, N. Jones, M. J. Brewer, T. G. Houston, and A. Allegra, 2019: Lessons Learned from Implementation of Customer Requirements Solution. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.
- **Dissen, J.**, and **A. Ballinger**, 2018: Climate Projections and the Climate Analysis Tool. *Workshop on Climate and Health, The Energy and Resources Institute (TERI)*, New Delhi, India, October 24, 2018.
- **Dissen, J.,** and M. Brewer, 2018: NCEI Customer Engagement Initiatives to Guide Opportunities for Innovation. *2018 Carolinas Climate Resilience Conference,* Columbia, SC, October 30, 2018.
- **Dissen, J.**, **A. Ballinger**, D. R. Easterling, **K. E. Kunkel**, K. Hayhoe, F. Akhtar, 2019: U.S.-India Partnership for Climate Resilience. *2019 World Sustainable Development Summit,* New Delhi, India, February 11, 2019.
- **Dissen, J.,** D. R. Easterling, **K. E. Kunkel**, K. Hayhoe, 2018: Innovative Web Based Applications of High-Resolution Climate Modeling and Projections Techniques. *2018 Carolinas Climate Resilience Conference,* Columbia, SC, October 30, 2018.
- **Dissen, J.**, M. Brewer, and D. Arndt, 2018: The Application of NOAA National Centers of Environmental Information Data and Information to the Legal Community. *American Bar Association* webinar, June 6, 2018.
- Durre, I., R. Vose, and **C. J. Schreck**, 2019: Tales of Two Products: What Can We Learn from NCEI's New Daily Grids and Area Averages of Temperature and Precipitation? *AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.
- Easterling, D. R., **J. Dissen**, **K. Kunkel**, and K. Hayhoe, 2018: An Overview of the U.S.-India Partnership for Climate Resilience. *American Geophysical Union Fall Meeting*. Washington, DC, December 10, 2018.
- Easterling, D. R., **J. Dissen**, **K. E. Kunkel**, and K. Hayhoe, 2019: The U.S.-India Partnership for Climate Resilience. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.
- Ferraro, R., D. Miller, A. Barros, P. Meyers, R. Kuligowski, B. Bush and J. Hill, 2018: Validation of satellite precipitation estimates over the continental United States using unique rain gauge data sets. *Ninth Workshop of the International Precipitation Working Group*, Seoul, Korea, November 6, 2018.
- Fox, J., 2018: Building Resilience to Flooding: A Complex—but Achievable—Challenge. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 30, 2018.

- Fox, J., 2018: Revisiting the Floods of 1916—Moving from Risk to Resilience. *Western Carolina University*, Cullowhee, NC, October 16, 2018.
- Fox, J., 2019: Collaborations and Knowledge for Confronting Climate Risk. *UNC Asheville STEM lecture*, *UNC Asheville*, Asheville, NC, March 6, 2019.
- Gallaher, D. W., N. J. Hoebelheinrich, **G. Peng**, and R. Davis, 2018: Research Data Management: Developing Standards for Data Usability and Trust and Building Capacity with Targeted Data Training for the Research Team I. *American Geophysical Union Fall Meeting*, Washington DC, December 12, 2018.
- Gallaher, D. W., N. J. Hoebelheinrich, **G. Peng**, and R. Davis, 2018: Research Data Management: Developing Standards for Data Usability and Trust and Building Capacity with Targeted Data Training for the Research Team Poster. *American Geophysical Union Fall Meeting*, Washington DC, December 13, 2018.
- Ginoya, N., 2018: PREP India – Madhya Pradesh Dashboards*, PREP Launch workshop*, Bhopal, India, June 12, 2018.
- Ginoya, N., 2018: An Introduction to PREP Platform, *PREP Launch workshop*, Dehradun, India, August 18, 2018.
- **Gray, G. M. E.**, **K. E. Kunkel**, and **A. P. Ballinger**, 2019: Incorporation of Climate Change into Design Storms: The Challenges. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.
- **Groisman P.**, 2018: Achievements and New Directions of Environmental Change Studies in Northern Eurasia. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.
- **Groisman, P.**, 2018: Freezing precipitation, characterization of weather conditions associated with it, and changes of the frequency of its occurrences. *International Conference ENVIROMIS-2018*, Tomsk, Russia, July 5, 2018.
- **Groisman, P.**, and R. Stewart, 2018: Near 0°C Precipitation Cross-Cut GHP Project Annual Progress Report. *GEWEX GHP Panel Meeting*, Santiago, Chile, October 25, 2018.
- **Groisman, P.**, G. M. Henebry, A. I. Shiklomanov, N. Speranskaya, Y. Chen, N. M. Tchebakova, E. I. Parfenova, N. Tilinina, O. G. Zolina, A. Dufour, J. Chen, R. John, P. Fan, C. Mátyás, I. Yesserkepova, and I. Kaipov, 2018: Contemporary Environmental Changes over the Dry Land Belt of Northern Eurasia and their Consequences. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- **Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev, and I. Danilovich, 2018: Human-associated extreme events. *22nd International Conference for Young Scientists*, Maykop, Adygeya Republic, Russia, September 24, 2018.
- **Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev and I. Danilovich, 2018: Human-Associated Extreme Events: Freezing Precipitation. *8th International GEWEX Scientific Conference*, Canmore, Alberta, Canada, May 8, 2018.
- **Groisman, P.**, X. Yin, O. N. Bulygina, S. K. Gulev and I. Danilovich, 2018: Human-Associated Extreme Events: Freezing Precipitation. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.
- Gupta, V., 2018: Child health status and climate related agricultural variability: case study India, *50th Annual National Conference of Nutrition Society of India* (NSI), Hyderabad, India, November 17, 2018.
- Hayhoe, K., D. R. Easterling, D. W. Fahey, S. J. Doherty, J. Kossin, W. Sweet, R. S. Vose, M. F. Wehner, D. J. Wuebbles, R. E. Kopp, **K. Kunkel**, and J. W. Nielsen-Gammon, 2018: Climate Science

in the Fourth US National Climate Assessment. *American Geophysical Union Fall Meeting*. Washington, DC, December 11, 2018.

- Hollingshead, A., M. J. Brewer, N. Jones, and **J. Dissen**, 2019: Exploring and Advancing Customer Engagement at NOAA National Centers for Environmental Information. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.
- Hutchins, M., 2018: How Assessments Can Inform—And Empower—Community Resilience. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.
- **Inamdar, A.**, 2018: Spatio-temporal reconstruction of land surface temperature from record of daily max/min temperatures. *University of Maryland Department of Atmospheric and Oceanic Science (AOSC) Seminar Series*, College Park, MD, October 11, 2018.
- **Inamdar, A.**, 2018: Spatio-temporal reconstruction of LST. *NCEI Science Council meeting*, Asheville, NC, November 8, 2018.
- **Inamdar, A.**, and **R. Leeper**, 2019: On the Inter-relationship Between Land Surface Air Temperature and Skin Temperature. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Janiga, M. A., **C. J. Schreck**, J. Ridout, M. Flatau, N. Barton, W. A. Komaromi, and C. A. Reynolds, 2019: MJO Predictive Skill and Impacts in the Navy Earth System Model. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Jogesh, A., 2018: PREP India – Uttarakhand Dashboards*, PREP Launch workshop*, Dehradun, India, August 18, 2018.
- Kashinath, K., M. Prabhat, M. Mudigonda, A. Mahesh, S. K. Kim, Y. Liu, S. Kahou, B. A. Toms, E. Racah, C. Beckham, C. Pal, T. Maharaj, **J. Biard**, **K. Kunkel**, D. N. Williams, T. A. O'Brien, M. F. Wehner, and W. D. Collins, 2018: Deep Learning Recognizes Weather and Climate Patterns. *American Geophysical Union Fall Meeting*, Washington, DC, December 10, 2018.
- Kumjian, M. R., C. P. Martinkus, **O. P. Prat**, S. Collis, H. C. Morrison, and M. Van Lier-Walqui, 2018: A moment-based polarimetric radar forward operator for rain microphysics. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 3, 2018.
- **Kunkel, K. E.**, 2018: Advances in Understanding of Climate Extremes. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 16, 2018.
- **Kunkel, K. E.**, 2018: Changing Climate Evidence and Future Directions for the Southeast Region. *EcoStream: Stream Ecology and Restoration Conference*, Asheville, NC, August 14, 2018.
- **Kunkel, K. E.**, 2018: Climate Change Impacts on Telecommunications. *2018 Environmental, Health & Safety Communications Panel Symposium*, Arlington, TX, September 19, 2018.
- **Kunkel, K. E.**, 2018: Climate Science in the National Climate Assessment. *Air and Waste Management Association - Research Triangle Park Chapter Meeting*, Durham, NC, May 15, 2018.
- **Kunkel, K. E.**, 2018: Effects of Global Warming on Weather Systems Causing Extreme Precipitation. *SERDP & ESTCP Symposium 2018: Enhancing DoD's Missions Effectiveness*, Washington, DC., November 27, 2018.
- **Kunkel, K. E.**, 2018: Effects of Global Warming on Building Design Values. *Facades+ NYC Conference*, New York City, NY, April 19, 2018.
- **Kunkel, K. E.**, 2018: Future Climate Change and Implications in the Context of the Health and Diseases. *U.S.-India Partnership for Climate Resilience Workshop on Climate and Health*, New Delhi, India, October 23, 2018.

- **Kunkel, K. E.**, 2018: Gibson Dam Storm Analysis. *Colorado-New Mexico Regional Extreme Precipitation Study Workshop #6*, Denver, CO, April 19, 2018.
- **Kunkel, K. E.**, 2018: Historical Perspective on Hurricane Harvey Rainfall. *SAMSI Climate Extremes Workshop*, Research Triangle Park, NC, May 16, 2018.
- **Kunkel, K. E.**, 2018: Historical Perspective on Rainfall in Recent Hurricanes. *American Statistical Association's ENVR 2018 Workshop: Statistics for the Environment: Research, Practice and Policy, The Collider,* Asheville, NC, October 13, 2018.
- **Kunkel, K. E.,** 2018: Precipitation Intensity-Duration-Frequency (IDF) Relationships and Climate Change. *Inter-Agency Forum on Climate Risks*, Impacts and Adaptation, Washington, DC., November 30, 2018.
- **Kunkel, K. E.**, 2019: Climate Change Liability for Owners, Designers and Manufacturers: National Climate Assessment. *2019 American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Winter Conference*, Atlanta, GA, January 16, 2019.
- **Kunkel, K. E.**, 2019: Fourth National Climate Assessment: Southeast Region. *4th National Climate Assessment Panel Series*, *The Collider,* Asheville, NC, January 24, 2019.
- **Kunkel, K. E.**, 2019: Historical Perspective on Rainfall from Hurricane Florence. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.
- **Kunkel, K. E.**, and R. L. Smith, 2019: Historical Perspective on Hurricane Harvey Rainfall. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- **Kunkel, K. E.**, and **A. Ballinger**, 2018: Climate Projections and Tipping Points. *Conference on Climate-Induced Displacement Technical Working Group and Planning Meeting*, Asheville, NC, June 21, 2018.
- **Kunkel, K. E.**, and **A. Ballinger**, 2018: Future Risks of Extreme Heat, *American Geophysical Union Fall Meeting*, Washington, DC, December 11, 2018.
- **Kunkel, K. E.**, **J. Biard**, and **L. Sun**, 2018: Impacts of Weather System Changes on Future Extreme Precipitation Design Values. *American Geophysical Union Fall Meeting*, Washington, DC, December 11, 2018.
- **Leeper, R. D.**, 2018: Standardizing USCRN Soil Moisture Observations for Near-Real Time Applications. *MOISST Workshop*, Lincoln, NE, June 5, 2018.
- **Leeper, R. D.**, A. M. Palecki, and N. Casey 2018: Standardizing short-term satellite soil moisture datasets. *Soil Moisture Active Passive (SMAP) Cal/Val Workshop #9*, Fairfax, VA, October 22, 2018.
- **Leeper, R. D.**, **E. J. Bell**, and A. M. Palecki, 2018: Standardizing USCRN Soil Moisture Observations for Near-Real Time Applications. *MOISST Workshop*, Lincoln, NE, June 5, 2018.
- **Leeper, R. D.**, J. Kochendorfer, T. Henderson, and A. M. Palecki, 2019: The Sensitivity of Temperature Measurements to Built-Up Environments; A Case Study In Oak Ridge, TN. *AMS 99th Annual Meeting,* Phoenix, AZ, January 8, 2019.
- Lemieux III, P. A., R. P. Partee II, R. Ionin, and **G. Peng**, 2019: Development of the Data Stewardship Maturity Questionnaire for Assessing Stewardship Quality of NOAA Datasets: Lessons Learned and Practical Applications. *2019 ESIP Winter Meeting*, Bethesda, MD, January 16, 2019. https://doi.org/10.6084/m9.figshare.7588538
- Lim, T. K., and **L. Sun**, 2018: Islandwide Climate Baselines and Scenarios. *QUEST Annual Workshop*, Singapore, November 12, 2018.

- Lim, T. K., and **L. Sun**, 2018: Islandwide Climate Baselines and Scenarios: An Update. *Urban Redevelopment Authority Annual Meeting*, Singapore, December 4, 2018.
- Lynch, K., **J. Bell**, and M. Gribble, 2019: Drought Associations with All-Cause Mortality Rates in the United States, *American Meteorological Society Annual Meeting*, Phoenix, AZ, January 9, 2019.
- **Mantripragada, S.**, A. Aiyyer, and **C. J. Schreck**, 2018: Interaction of Kelvin and Easterly Waves Over the Atlantic and Implications for Tropical Cyclogenesis. 33rd Conf. on Hurricanes and Tropical Meteorology. *American Meteorological Society*, Ponte Vedra Beach, FL, April 16, 2018. https://ams.confex.com/ams/33HURRICANE/webprogram/Paper340571.html
- **Mantripragada, S.**, **C. J. Schreck**, and A. R. Aiyyer, 2018: CFSv2 Hindcast Skill at Predicting Interactions between Kelvin Waves and AEWs. *PMM Science Team Meeting*, Phoenix, AZ, October 10, 2018.
- **Matthews, J.**, 2018: Mathematics in Climate Science. *University of Tennessee Mathematics Department Undergraduate Math Conference*, Knoxville, TN, April 21, 2018.
- **Matthews, J.**, 2018: Optimization Methods in Remote Sensing. *SAMSI Climate Transition Workshop*, Research Triangle Park, NC, May 14, 2018.
- **Matthews, J.**, 2018: Remotely sensed retrievals of atmospheric temperature and humidity profiles. *University of Minnesota Institute for Research on Statistics and its Applications (IRSA) Annual Conference*, Minneapolis, MN, May 3, 2018.
- **Matthews, J.**, and **J. J. Rennie**, 2018: Embracing Big Data + Cloud Computing. *The Collider*, Asheville, NC, October 2, 2018
- **Matthews, J.**, and **J. J. Rennie**, 2018: The process of moving 2 applications to the cloud. *NCEI Science Council meeting*, Asheville, NC, August 9, 2018.
- **Matthews, J. L.**, 2018: Remotely sensed retrievals of atmospheric temperature and humidity profiles. *NOAA Cooperative Institute for Climate and Satellites Executive Board Meeting*. College Park, MD, April 30, 2018.
- **Matthews, J. L.,** and L. Shi, 2018: Long-term HIRS-based Temperature and Humidity Profiles. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- **Maycock, T.**, 2019: An Introduction and Overview of NCA4. *4th National Climate Assessment Panel Series*, *The Collider*, Asheville, NC, January 24, 2019.
- **Maycock, T.**, 2019: Adaptation and Resilience in NCA4. *4th National Climate Assessment Panel Series*, *The Collider*, Asheville, NC, February 21, 2019.
- McGuirk, M., E. Shea, M. Prabhu, D. Ratliff, **J. Dissen**, and E. Gardiner, 2019: Climate-Induced Displacement: Where Social and Climate Sciences Intersect. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Miller, D.K., C.F. Miniat, R.M. Wooten, A.P. Barros, and K. Kelly, 2018: An expanded view on the climatology of atmospheric rivers impacting the southern Appalachian Mountains. *2018 International Atmospheric Rivers Conference, Scripps Institute of Oceanography*, San Diego, CA, June 27, 2018.
- Moroni, D. F., H. K. Ramapriyan, and **G. Peng**, 2018: Background for CEOS WGISS data management and stewardship maturity matrix. *NASA Earth Science Data System Working Group Meeting*, Annapolis, MD, April 19, 2018.
- Moroni, D. F., H. K. Ramapriyan, and **G. Peng**, 2018: Surveying the Approaches and Advances in Earth Science Data Uncertainty Quantification, Characterization, Communication, and Utilization. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.

- Moroni, D. F., Y. Wei, H. Ramapriyan, D. Scott, R. Downs, Z. Liu, and **G. Peng**, 2019: Operational Solutions for Increasing the Value and Usability of Earth Science Data via a Data Quality Framework. *Atmospheric Science Librarians International Conference, AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.
- Morrison, H., M. van Lier-Walqui, M. R. Kumjian, and **O. Prat**, 2018: Uncertainty in microphysical models and the development of a Bayesian approach for statistical-physical parameterization of warm microphysics. *15th Conference on Cloud Physics*, Vancouver, Canada, July 9, 2018.
- Nelson, B. R., and **O. Prat**, 2018: Maximum Precipitation Estimates from Five Environmental Data Records with Varying Resolutions and Periods of Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.
- Parfenova, E. I., N. M. Tchebakova, N. A. Kuzmina, S. R. Kuzmin, E. Shvetsov, A. J. Soja, and **P. Y. Groisman**, 2018: Climate Change Consequences for Siberia's Forest Land Adaptation in the Warming Climate of the 21st Century. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- Partee II, R. P., P. Lemieux III, R. Ionin, and **G. Peng**, 2018: A streamlined approach to assessing the stewardship practices of NOAA datasets. *2018 NOAA Environmental Data Management Workshop*, Silver Spring, MD, April 23, 2018.
- **Peng, G.**, 2018: An Introduction to WMO Stewardship Maturity Matrix for Climate Data. *46th Meeting of the CEOS Working Group on Information Systems & Services (WGISS)*, Oberpfaffenhoffen, Germany, October 22, 2018.
- **Peng, G.**, 2018: An Overview of Maturity Assessment Models for Consistent Data Product Quality Ratings. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.
- **Peng, G.**, 2018: Maturity models for assessing maturity of Earth Science datasets. *WMO Expert Meeting on Climate Data Modernisation*, KNMI, De Bilt, Netherlands, April 16, 2018.
- **Peng, G.**, 2019: Assessing and Representing Maturity Information on the Usability of Data Product and Services. *2019 ESIP Winter Meeting*, Bethesda, MD, January 16, 2019.
- **Peng, G**., H. Ramapriyan, and D. Moroni, 2019: A brief overview of maturity models for consistent data quality ratings. *Joint webinar between Australian Research Data Common and ESIP Information Quality Cluster*. March 1, 2019.
- **Peng, G.**, M. Steele, A. C. Bliss, W. Meier, and S. Dickinson, 2018: Temporal Variability of Arctic Sea Ice Melt and Freeze Season Climate Indicators Using a Satellite Passive Microwave Climate Data Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.
- **Peng, G.**, M. J. Brewer, R. Duerr, W. Wright, and C. Lief, 2018: Seeking Feedback from the ESIP Community on Two Developing Dataset Maturity Assessment Models. *2018 Earth Science Information Partner (ESIP) Summer Meeting*, Tucson, AZ, July 17, 2018.
- Prabhat, M., K. Kashinath, T. Kurth, M. Mudigonda, A. Mahesh, B. A. Toms, **J. Biard**, S. K. Kim, S. Kahou, B. Loring, J. Stewart, S. Ganguly, T. A. O'Brien, **K. Kunkel**, M. F. Wehner, and W. D. Collins, 2018: ClimateNet: Bringing the Power of Deep Learning to the Climate Community via Open Datasets and Architectures. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.
- **Prat, O. P.**, 2018: Toward Earlier Drought Detection Using Remotely Sensed Precipitation Data and Applications to the Carolinas. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 29, 2018.

- **Prat, O. P.**, **R. D. Leeper**, **J. E. Bell**, B. R. Nelson, J. Adams, and S. Ansari, 2018: Toward earlier drought detection using remotely sensed precipitation data from the Reference Environmental Data Record (REDR) CMORPH. *2018 EGU General Assembly*, Vienna, Austria, April 11, 2018.
- **Prat, O. P.**, **R. Leeper**, **J. L. Matthews**, B. R. Nelson, S. Ansari, and J. Adams, 2018: Toward Earlier Drought Detection Using Remotely Sensed Precipitation Information and Vegetation Observations from the Reference Environmental Data Record (REDR) Program. *American Geophysical Union Fall Meeting*, Washington, DC, December 13, 2018.
- **Prat, O. P.**, **R. D. Leeper**, **J. L. Matthews**, B. R. Nelson, J. Adams, and S. Ansari, 2019: Using Remotely Sensed Precipitation Information and Vegetation Observations for Early Drought Detection and Near-Real Time Monitoring on a Global Scale. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- **Rennie, J. J.**, 2018: Climate in Your Neck of the Woods: A Real-Time, Interactive Product to Assess Historical and Current Trends in Temperature and Precipitation. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 29, 2018.
- **Rennie, J.**, 2018: Climate in Your Neck of the Woods: A Real-Time, Interactive Product to Assess Historical and Current Trends in Temperature and Precipitation. *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.
- Riemel, K. J., M. Van Lier-Walqui, M. R. Kumjian, **O. P. Prat**, and H. C. Morrison, 2018: How much can we learn about rain microphysics from polarimetric radar observations? An investigation of information content and parameter estimation using the Bayesian Observationally-constrained Statistical-physical Scheme (BOSS). *American Geophysical Union Fall Meeting*, Washington DC, December 10, 2018.
- Ritchey, N. A., R. Partee II., P. Lemieux III, R. Ionin, and **G. Peng**, 2018: Application of the Data Stewardship Maturity Model for Assessing Data Usability and Trustworthiness of Data Management Practices. *American Geophysical Union Fall Meeting*, Washington, DC, December 12, 2018.
- Ritchey, N. A., R. P. Partee II, P. Lemieux, **G. Peng**, P. Jones, A. Milan, K. S. Casey, 2018: Practical Application of the Data Stewardship Maturity Model for NOAA's *OneStop* Project. *PV2018 Conference*, Harwell, UK, May 16, 2018.
- Rogers, K., 2018: Applying the Steps to Resilience: Success at multiple scales. *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 31, 2018.
- Rogers, K., and M. Hutchins, 2019: The NCA and Community Resilience. *Climate Resilience in Cities & Conservancy: A 4th NCA Panel*, *The Collider*, Asheville, NC, February 21, 2019.
- Satkowski, L., and Pandey P., 2018: PREP Demo – Exploring PREP and Creating Dashboards*, PREP Launch workshop*, Bhopal, India, June 12, 2018.
- Satkowski, L., and Pandey P., 2018: PREP Demo – Exploring PREP and Creating Dashboards*, PREP Launch workshop*, Dehradun, India, August 18, 2018.
- Schattman, R., S. Wiener, G. Roesch-McNally, M. Niles, **S. M. Champion**, and J. Cobb, 2018: Socio-environmental Synthesis: Exploring the Relationship between Climate Events, Agricultural Crop Loss, and Climate/Weather Perceptions of USDA Employees. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.
- **Schreck, C. J.**, 2019: Climate, Hurricanes, and Reinsurance. *Lunch and Learn*, *The Collider*, Asheville, NC, January 22, 2019.

- **Schreck, C.**, 2019: Large Scale Tropical Dynamics: From Monsoon Troughs to Equatorial Waves. *John Molinari Retirement Celebration, University at Albany*, Albany, NY, March 8, 2019.
- **Schreck, C. J.**, A. Arguez, **A. K. Inamdar**, M. Palecki, and A. Ho. Young, 2019: ENSO Normals: A New Normals Product Conditioned by ENSO Phase and Intensity and Accounting for Secular Trends. *AMS 99th Annual Meeting*, Phoenix, AZ, January 10, 2019.
- **Schreck, C. J.**, M. A. Janiga, and A. R. Aiyyer, 2019: Variability in CFSv2 Hindcast Skill for the MJO and Equatorial Waves. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Sehgal, M., 2018: Indicators for Vulnerability Assessment of Human Health to Climate Variability, *10th International Conference on Climate Change: Impacts and Responses*, Berkeley, CA, April 21, 2018.
- Sehgal, M., 2019: Exploring Usefulness of Meteorology Data for Predicting Malaria Cases, *99th American Meteorological Society Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Shannon, A., S. Ingram, M. VonHegel, **O. P. Prat**, B. R. Nelson, M. Hutchins, and A. Stein, 2018. Utilizing precipitation estimates from NASA and NOAA earth observations satellites to enhance decision support for extreme events in the Carolinas. *2018 Carolinas Climate Resilience Conference*. Columbia, SC, October 29, 2018.
- Shen, S., 2018: Statistical prediction of the United States spring-summer precipitation from the Western US spring surface temperature anomalies using canonical correlation analysis, *International Workshop of First Phase of GEWEX/GASS LS4P Initiative and TPEMIP*, Washington, DC, December 8, 2018.
- Shriber, J., **J. E. Bell**, Z. Jeddy, **J. Rennie**, and H. Strosnider, 2018: Assessment of Potential Health Impacts from Extreme and Exceptional Drought, 2012−16. *AMS 99th Annual Meeting*, Phoenix, AZ, January 8, 2019.
- Steele, M., A. C. Bliss, **G. Peng**, W. Meier, and S. Dickinson, 2018: Regional Variability of Arctic Sea Ice Seasonal Change Climate Indicators from a Passive Microwave Climate Data Record. *American Geophysical Union Fall Meeting*, Washington, DC, December 14, 2018.
- **Stevens, L.**, 2019: From Climate Indicators to Action. *Lunch and Learn*, *The Collider*, Asheville, NC, February 5, 2019.
- **Stevens, L.E.**, and D.S. Arndt, 2018: Managing a multi-agency set of climate indicators, *NCEI Seminar Series*, Asheville, NC, August 28, 2018.
- **Stevens, L.E.**, D.S. Arndt, and J. Blunden, 2019: From Climate Indicators to Action, *The Collider Lunch & Learn Series*, Asheville, NC, February 5, 2019.
- **Stevens, S.**, 2019: Trends in IFR Conditions at Major Airports in the United States. *AMS 99th Annual Meeting*, Phoenix, AZ, January 9, 2019.
- Strerletskiy, D., and **P. Groisman**, 2018: From the Northern Eurasia Earth Science Partnership Initiative (NEESPI) towards the Northern Eurasia Future Initiative (NEFI)**.** *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.
- Sugg, M. M., **J. R. Runkle**, C. M. Fuhrmann, and **S. Stevens**, 2018: Continuous Monitoring of Individual Exposure in Extreme Thermal Environments: A Participatory Geo-Sensing Study. *American Association of Geographers Annual Meeting*, New Orleans, LA, April 10, 2018.
- **Sun, L.**, 2018: Extratropical Cyclones over the Contiguous United States: Current Variability and Future Change. *NOAA's 43rd Climate Diagnostics and Prediction Workshop*, Santa Barbara, CA, October 23, 2018.

- Tchebakova N. M., E. I. Parfenova, E. G. Shvetsov, A. J. Soja, S. G. Conard, and **P. Y. Groisman**, 2018: Siberian potential forests and phytomass projected from CMIP5 climates in the 21st century. *Annual JpGU Meeting*, Makuhari, Chiba, Japan, May 22, 2018.
- Terando, A. J., L. Carter, K. Dow, J. K. Hiers, **K. Kunkel**, A. Lascurain, D. Marcy, M. J. Osland, P. Schramm, and A. Lustig, 2018: Assessing climate risks and adaptation opportunities in the Southeast U.S. as part of the Fourth National Climate Assessment, *American Geophysical Union Fall Meeting*. Washington, DC, December 12, 2018.
- **Thompson, L.C**., M. M. Sugg, **J. R. Runkle**, 2018: Adolescents in Crisis: A Spatial Exploration of Mental Distress Using Data from Crisis Text Line. *American Association of Geographers Annual Meeting*, New Orleans, LA, April 14, 2018.
- **Thompson, L. C.**, M. M. Sugg, **J. R. Runkle**, 2018: Adolescents in Crisis: A Spatial Exploration of Mental Distress Using Data from Crisis Text Line. *Appalachian State University Celebration of Student Research and Creative Endeavors*, Boone, NC, April 19, 2018.
- van Lier-Walqui, M., H. C. Morrison, M. R. Kumjian, **O. P. Prat**, and K. Riemel, 2018: How best to add structural complexity to cloud microphysics parameterizations? *American Geophysical Union Fall Meeting*, Washington DC, December 12, 2018.
- van Lier-Walqui, M., M. R. Kumjian, H. C. Morrison, **O. P. Prat**, J. Turk, K. Riemel, J. Harrington, A. Jensen, and R. Schrom, 2018: Estimation of observational and forward-simulators uncertainties in the context of microphysical studies using doppler spectra and polarimetric radar observations. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 5, 2018.
- van Lier-Walqui, M., M. R. Kumjian, H. C. Morrison, **O. P. Prat**, K. Riemel, J. Harrington, A. Jensen, and R. Schrom, 2018: Leveraging radar observations to probabilistically inform new classes of microphysical parameterization schemes. *ERAD 2018: 10th European Conference on Radar in Meteorology and Hydrology*, Ede-Wageningen, Netherlands, July 5, 2018.
- Wehner, M. F., Hayhoe, K., D. J. Wuebbles, D. R. Easterling, D. W. Fahey, S. J. Doherty, J. P. Kossin, W. Sweet, R. S. Vose, and **K. Kunkel**, 2018: Our Changing Climate: National Climate Assessment NCA4 Vol. 2, Chapter 2, *American Geophysical Union Fall Meeting*. Washington, DC, December 12, 2018.
- Wei, Y., D. Moroni, H. K. Ramapriyan, and **G. Peng**, 2018: Four Years of Progress within NASA and ESIP on Earth Science Data and Information Quality - Challenges, Solutions, and Best Practices. *2018 Open Geospatial Consortium (OGC) Technical Committee Meeting*, Charlotte, NC, December 12, 2018.
- **Worku, L. W.**, **C. J. Schreck**, and A. Mekonnen, 2018: Multi-scale Interaction between the Diurnal Cycle, MJO, and Kelvin Waves over the Maritime Continent. *PMM Science Team Meeting,* Phoenix, AZ, October 10, 2018.
- **Worku, L. W.**, A. Mekonnen, and **C. J. Schreck** 2019: Multiscale Interactions between the MJO, Equatorial Waves, and the Diurnal Cycle over the Maritime Continent: Part I. *33rd Conf. on Hurricanes and Tropical Meteorology*, Ponte Vedra Beach, FL, April 20, 2018.
- Yu, J., A. Leadbetter, M. Hedley, and **J. Biard**, 2018: NetCDF-LD: Updates on a Linked Data Profile for NetCDF Files. *American Geophysical Union Fall Meeting*, Washington, DC, December 11, 2018.

**Outreach and Engagement Presentations**

- **Dissen, J.**, 2018: Climate and Data Sciences (panel discussion). *North Carolina School of Science and Mathematics (NCSSM) Data Science Series Visits Asheville, The Collider*, Asheville, NC, November 6, 2018.
- **Dissen, J.**, 2018: Data-Driven Climate Innovation (panel discussion). *2018 Carolinas Climate Resilience Conference*, Columbia, SC, October 30, 2018.
- **Dissen, J.**, 2018: In Times of Seismic Sorrows (panel discussion). *The Collider and The Center for Craft Joint Exhibition*, Asheville, NC, September 25, 2018.
- **Dissen, J.**, 2019: Upcoming NCEI Data Users Conference: An Agriculture Example Town Hall (panel discussion). *AMS 99th Annual Meeting*, Phoenix, AZ, January 7, 2019.
- **Kunkel, K. E.**, 2018: Public policy issues in environmental research and the role of statisticians (panel discussion). *American Statistical Association's ENVR 2018 Workshop: Statistics for the Environment: Research, Practice and Policy, The Collider*, Asheville, NC, October 13, 2018.
- **Kunkel, K. E.**, **T. Maycock,** and **L. Stevens**, 2019: 4th National Climate Assessment (panel discussion). *4th National Climate Assessment Panel Series, The Collider*, Asheville, NC, January 24, 2019.
- **Matthews, J.**, 2018: Weather and Satellites. *Leicester Elementary School*, Leicester, NC, November 8, 2018.
- **Rennie, J. J.**, 2018: Hour of Code. *Waynesville Middle School*, Waynesville, NC, December 3, 2018.
- **Rennie, J. J.**, 2018: Hour of Code. *Ira B. Jones Elementary School*, Asheville, NC, December 4, 2018.
- **Rennie, J. J.**, 2018: Hour of Code. *Vance Elementary School*, Asheville, NC, December 5, 2018.
- **Rennie, J. J.**, 2018: Weather, Climate, and Coding (remote video). *Kennedy Community School*, St. Joseph, MN, December 10, 2018.
- **Rennie, J. J.**, 2019: Mountain Weather. *Transylvania County Library*, Brevard, NC, February 7, 2019.
- **Rennie, J. J.**, 2019: CICS-NC Date Processing and Coding Activities. *Christ School*, Arden, NC, February 14, 2019.
- **Rennie, J. J.**, and **S. Stevens**, 2019: Careers in Meteorology (panel discussion). *Asheville AMS* chapter meeting, *University of North Carolina at Asheville*, Asheville, NC, March 7, 2019.
- **Schreck, C.**, 2019: Climate Change, Hurricanes, and North Carolina. *Pacifica Senior Living Heritage Hills*, Hendersonville, NC, March 1, 2019.
- **Stevens, L.**, 2019: Climate Change in the United States. *Asheville-Buncombe Technical Community College* Environmental Biology class, Asheville, NC, March 27, 2019.
- **Stevens, L**., and **A. Ballinger**, 2018: Climate Communications and Careers. Visiting *UNC Asheville* graduate students, Asheville, NC, April 26, 2018.
- **Stevens, S.,** 2018: Data Collection and Analysis. *Isothermal Community College Annual Science and Technology Expo*, Spindale, NC, April 20, 2018.
- **Stevens, S.**, 2018: Careers in Data Science. *Enka Intermediate School Career Day*, Asheville, NC, May 8, 2018.
- **Stevens, S.**, 2018: Climate Change (panel discussion). *IC Imagine Public Charter School*, Asheville, NC, May 18, 2018.
- **Stevens, S.**, 2018: Signs of a Changing Climate. *Ardenwoods Retirement Community*, Arden, NC, July 9, 2018.
- **Stevens, S.**, 2018: Communicating Climate Change. *Ardenwoods Retirement Community*, Arden, NC, July 23, 2018.

- **Stevens, S.**, 2019: Data Analysis. *Boys and Girls Club of Henderson County*, Hendersonville, NC, March 21, 2019.

# Appendix 4: CICS-NC Products 2018–2019

**New or Enhanced NOAA Products**

- **Big Data Project**
  - Cloud-based *NiFi* data hub
  - Pilot data hub/data broker function for Big Data Project
  - Expanded use of serverless Lambda Functions on Amazon Web Services

- **Programming and Applications Development for Climate Portal**
  - Data snapshots on Climate.gov: https://www.climate.gov/maps-data/data-snapshots/start
  - U.S. Climate Resilience Toolkit: https://toolkit.climate.gov
  - Climate Explorer 1: http://climate-explorer.nemac.org
  - Climate Explorer 2 (CE2.5): https://crt-climate-explorer.nemac.org/
  - USGCRP Indicator graphics: http://www.globalchange.gov/browse/indicators
  - NCA Regional and State Map Products: https://statesummaries.ncics.org/

- **NCEI Infrastructure Architecture Planning and Implementation**
  - Initial connection of *NiFi* workflow system to live provider ingest data, selection of appropriate data, and configuration
  - Proposed system architecture, including integration path for related components, primarily with respect to *NiFi* workflow, CI ingest, and Inventory Manager metadata systems

- **National Climate Assessment Scientific and Data Support Activities**
  - Improved interactive web-based metadata viewer, providing additional downloadable content, most notably including direct access to TSU derived datasets
  - NOAA State Climate Summary for Puerto Rico and the U.S. Virgin Islands
  - Author/co-author of four *Fourth National Climate Assessment Volume II* chapters

- **National Climate Assessment Technical Support Activities**
  - *Fourth National Climate Assessment, Volume II* (November 2018) – print, digital, and web formats https://nca2018.globalchange.gov
  - *Fourth National Climate Assessment, Volume II: Report-in-Brief* (November 2018) – print and digital formats
  - *The Scientific Assessment of Ozone Depletion: 2018* – print and digital formats (collaboration with NOAA ESRL staff)

- **Climate Change Indicators**
  - Deployed new U.S. Global Change Research Program Indicators Platform
  - Released new indicator: Global Average Sea Level Change
  - Released new indicator: Heat Wave Characteristics in 50 Large U.S. Cities
  - Released new indicator: U.S. Billion Dollar Weather and Climate Disasters

- **Common Ingest Agile Development Team**
  - Delivered 35 components for the NCEI Common Ingest system

- **Spatial–Temporal Reconstruction of Land Surface Temperature from Daily Max/Min Temperatures**
    - Algorithm to reconstruct LST from daily max/min temperatures and solar data (incident solar radiation or surface absorbed solar radiation)

- **Transitioning of the International Satellite Cloud Climatology Project Process to NCEI-NC**
    - H-series cloud product for the extended period (2010–2015), including the new NOAA-19 sensor from 2013 to 2015
    - Climatology of nnHIRS profiles and ozone for each day of year to enable frequent updates and produce ICDRs
    - HBT Calibration tables for the period mid-2015 to June 2017, including the new sensors NOAA-19, HIMAWARI-8, GOES-16, and MSG-1 (INS segment)

- **HIRS Temperature and Humidity Profiles**
    - v2018 HIRS Temperature and Humidity Profiles dataset (1978–2017)

- **Toward Earlier Drought Detection Using Remotely Sensed Precipitation Data from the Reference Environmental Data Record (REDR) CMORPH**
    - Short- and long-term SPI updated daily to be used for drought detection and monitoring
    - GIS-based visualization and analysis tool to display global droughts conditions in near-real time

- **Standardization of U.S. Climate Reference Network Soil Moisture Observations**
    - A second version of the alpha soil moisture product has been submitted in preparation for an operational readiness review

- **Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCN-M)**
    - Public, operational version of GHCNm version 4.0.0, with journal article published describing methods

**Other Products**

- **World Resources Institute (WRI) / Partnership for Resilience and Preparedness (PREP) Supporting the U.S.–India Partnership for Climate Resilience**
    - ***PREP Training Videos***
        - Introduction to PREPdata
        - PREPdata: Explore
        - PREPdata India Explore
    - ***PREP India Dashboards***
        - Uttarakhand Water Resources
        - Uttarakhand Tourism
        - Uttarakhand Agriculture
        - Wheat in Madhya Pradesh
        - Forestry in Madhya Pradesh
    - ***PREP Curated India Datasets***
        - India Core Datasets
        - Madhya Pradesh Datasets
        - Uttarakhand Datasets

- **U.S.–India Partnership for Climate Resilience (PCR) Workshop Support**
    - Quality-controlled daily temperature and precipitation data for additional weather stations across India
    - Portable STAR-ESDM code that advances the treatment of temperature and precipitation extremes
    - Updated and continuing expansion of the comments and documentation on the generation, application, and use of climate information relevant to quantifying the potential impacts of climate change at the local to regional scale across India

- **Climate Literacy, Outreach, Engagement, and Communications**
    - Climate Analysis Tool (USPCR collaboration with India-based organizations: IITM, EPTRI and ValueLabs)

- **CICS-NC Communications**
    - One issue of *Trends* newsletter

- **Drought-Related Health Impacts: Advancing the Science for Public Health Applications**
    - Center for Disease Control and Prevention's *Preparing for the Health Effects of Drought: A Resource Guide for Public Health Professionals*. (Jesse Bell served as a subject matter expert for the development of this CDC resource guide.) https://www.cdc.gov/nceh/hsb/cwh/docs/CDC_Drought_Resource_Guide-508.pdf