Annual Scientific Report

CISESS NC TASK REPORTS

For the period:

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CISESS NC Director

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CISESS NC Overview

The operation of the Cooperative Institute for Satellite Earth System Studies in North Carolina (CISESS 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/CISESS NC is hosted by North Carolina State University (NCSU) and affiliated with all the UNC academic institutions as well as a number of other academic and community partners. CISESS NC is collocated with the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI) in Asheville, NC, and focuses on enhancing the understanding of how the natural atmosphere–ocean–land–biosphere components of Earth interact with human activities as a coupled system. CISESS NC engages in collaborative research and other related activities with NCEI and the National Environmental Satellite, Data, and Information Service (NESDIS) as well as other NOAA line offices and units, including the Office of the Chief Information Officer (OCIO), the National Weather Service (NWS), the Oceanic and Atmospheric Research (OAR) Climate Program Office (CPO) and the interagency National Integrated Drought Information System (NIDIS). CISESS NC also supports other federal agency collaborators with NOAA/NCEI, including the US Global Change Research Program (USGCRP), the US Department of State (DOS), and the Centers for Disease Control and Prevention (CDC).

CISESS NC is led by the Director of the IRC and includes numerous academic and community partners with specific expertise in the challenges of utilizing remotely sensed and in situ observations in Earth system research and applications, as well as the broader expertise needed to support Earth system/societal impact/societal response studies. Current community partners include the Asheville Museum of Science (AMOS), the North Carolina Arboretum, NCSU's The Science House, and the North Carolina State Climate Office. NCSU provides CISESS with access to strong graduate programs in Earth, engineering, data analytics, and life sciences, and many of the CISESS consortium partners offer complementary programs.

The CISESS scientific vision centers on 1) observation, using instruments on Earth-orbiting satellites and surface networks, and 2) 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 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 CISESS scientists work on projects that advance NOAA objectives. CISESS conducts collaborative research with NOAA scientists in three principal, interrelated Research Themes: Satellite Services, Earth System Observations and Services, and Earth System Research.

The CISESS NC mission focuses on collaborative research into the use of in situ and remotely sensed observations, the Earth system, and climate products and applications; 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 continuing science, technology, and applications development; engagement with corporate leaders and the public to develop climate-literate citizens and a climate-adaptive society; and the facilitation of regional economic development through its engagement activities.

CISESS NC activities primarily support NCEI program activities and enterprise services. Main collaborative and other research activities are currently organized by the following task streams:

1) Administration (Task I)
2) Access and Services Development
3) Assessments
4) Information Technology Services
5) Science and Services
6) Workforce Development
7) Other Projects

These streams are currently supported by the different divisions in NCEI; NOAA Line and Staff Offices including NESDIS, OAR, NWS, and OCIO; and NCSU. Other (non–cooperative institute) Projects led by the Institute's investigators are generally funded by other federal, state, or private sponsors but reflect broader Institute research efforts that complement CISESS mission goals.

Highlights

CISESS NC

CISESS NC highlights are arranged by task stream with task sponsors noted in brackets [ ]. Primary NOAA CI support comes from NCEI; however, the past year's activities were also supported by NESDIS/STAR, OAR's Climate Program Office (CPO) and the Interagency National Integrated Drought Information System (NIDIS), and the NOAA Office of the Chief Information Officer (OCIO). While CISESS NC activities remain primary, NCICS scientists are also engaged in research projects (Other Projects) supported by NOAA as well as other federal, state, or private sponsors that currently include: The National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), North Carolina Department of Transportation, and several non-federal sponsors.

Administration [NCSU/NOAA]

Institute Information Technology (IT) Support Services**:** Institute IT staff provide modern, scalable approaches to sustain CISESS NC at the competitive edge of technology advances and maintain core technologies as a stable base for staff operations. This year's accomplishments included security and monitoring improvements, transitioning projects into the Cloud, and continuing upgrades to the latest operating systems across all platforms.

Institute Communications**:** This year's key communications accomplishments included support for the 2022 updated State Climate Summaries and an international Climate Informatics conference, a new CISESS logo, and continued support for the CISESS Science Seminar Series, NCEI's State of the Climate report, and the Extended Continental Shelf report.

Access and Services Development [OCIO/CPO/NCEI]

NOAA Open Data Dissemination (NODD) Support**:** Utilizing the CISESS-NC-designed data hub/broker architecture, additional key NOAA datasets were deployed in near real time to the public cloud, including GOES-18 and JPSS data. Usage metrics across the three public cloud platforms (Amazon Web Services, Microsoft Azure, and Google Cloud Platform) are now available to NOAA stakeholders with authentication.

Strategic Engagement and Outreach for the NOAA Open Data Dissemination (NODD): Accomplishments included quarterly huddles with Line Offices, support for GOES-R engagement efforts, leading an engagement effort with users of HRRR data through NODD Office Hours, and convening of the 8th Annual NODD Town Hall Discussion at the 2023 American Meteorological Society meeting.

Development and Support of NOAA Climate Products and Services: UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) assisted in the U.S. Climate Resilience Toolkit redesign management and planning, maintenance of Climate Explorer 3, the launch of a National Climate Assessment author "sandbox," USGCRP Indicators graphics updates, and NIDIS drought.gov user research.

Assessment Activities [NCEI/CPO/DOS]

Assessment Scientific and Data Support Activities: The team completed analysis of several large datasets, including the LOCA2 and STAR statistically downscaled datasets, the CMIP6 suite of GCMs, and the CMIP5-based VIC simulations. The results were used to produce 29 original graphics for the Fifth National Climate Assessment.

Assessment Technical Support Activities: The team made performance and monitoring upgrades to the Assessment Collaboration Environment and provided extensive project management, editorial, graphic design, and website development support for the Fifth National Climate Assessment (NCA5). The editorial team also provided copyediting reviews of the Scientific Assessment of Ozone Depletion: 2022.

Climate Change Indicators**:** Eleven existing indicators were updated on the *USGCRP Indicator Platform* in support of the USGCRP's efforts to maintain a comprehensive suite of climate change indicators. A new *Indicators of Climate Change* web series was launched.

US–India Partnership for Climate Resilience (PCR) Activities Support**:** Under the US–India Partnership for Climate Resilience Phase II capacity-building activities, CISESS NC conducted extreme value statistical analysis of Uttarakhand gridded precipitation data and discussed findings with India partner The Energy and Resources Institute as part of ongoing planning for a technical climate projections workshop for India-based forestry managers.

The Energy and Resources Institute Support for the U.S.–India Partnership for Climate Resilience**:** As part of the U.S.–India Partnership for Climate Resilience (PCR) Phase II activities, The Energy and Resources Institute (TERI), NCEI, and CISESS collaborated in organizing technical virtual webinar with forestry managers in India focused on climate downscaling and potential impacts to forestry management.

Information Technology Services [NCEI]

NCEI INNOVATES 2021: Global Historical Climatology Network-Daily (GHCN-D) Graph Database: A prototype graph database was implemented with approximately 40% of the current reporting streams. To improve performance and accessibility of the GHCN-D, a pipeline was developed to feed a graph database in near-real time and performance test QA/QC algorithms using native graph-database approaches. These tests indicated that performance of the graph database approach exceeds that of tabular approaches.

NCEI Infrastructure Architecture Planning and Implementation: A scalable, highly configurable on-premises workflow data processing system, NiFi, is moving towards production capability. A cloud-based archive solution using highly scalable provider solutions is under development with components demonstrated and delivered to NESDIS and NCEI projects.

Science and Services [NCEI/CDC/CPO/STAR/]

Scientific Subject Matter Expertise Support**:** CISESS NC scientists served as Product Leads for 14 NCEI products and as Product Area Leads for one product area. https://www.ncdc.noaa.gov/cdr

Drought-related health impacts: advancing the science for public health applications: CISESS consortium partner University of Nebraska Medical Center conducted a series of drought- and health-related interviews with state-level health departments across the country to provide better understanding of their current response to drought. The project team also conducted a study to investigate the impact of drought on the occupational psychosocial stress of Midwestern farmers.

Spatiotemporal distribution and habitat use of major Snapper-Grouper species in the Atlantic Ocean off the southeastern U.S.: A species distribution modeling framework was developed, and preliminary model runs were conducted to model the spatiotemporal dynamics of reef fish communities along the Southeast U.S. Atlantic coast.

Strategic Engagement and Outreach: CISESS NC continued to build engagement capacity with sector engagement as an outcome of the Department of Commerce/NOAA Sector Listening Sessions to advance continued improvement of NOAA climate services, specifically with the retail sector.

Optimum Interpolation Sea Surface Temperature (OISST) Algorithm Upgrades: After upgrading the OISST algorithm from v2.1 to v2.1a by integrating the ACSPO L3S LEO satellite products as the algorithm's new satellite source in late 2021, the OISST scientific team completed their analyses of the new satellite sources and their interactions with the OISST operational algorithm. The team made significant progress towards upgrading the product to v3.0, which will include a historical reanalysis of the CDR during the modern satellite era and a significant re-architecting of the operational algorithm's software. https://www.ncdc.noaa.gov/oisst

Weather and Climate Change Monitoring and Research Support of the Atmospheric Turbulence and Diffusion Division of National Oceanic and Atmospheric Administration's Air Resources Laboratory: Oak Ridge Associated Universities (ORAU) works with the NOAA Air Resources Laboratory (ARL) to expand and sustain the U.S. Climate Reference Network's observational capability and supports other ARL atmospheric research, for example, the deployment of a new uncrewed aircraft into Hurricane Ian to monitor the growth and movement of the storm.

GOES Imager Fundamental Climate Data Record (FDCR): In support of the creation of an FCDR for all satellites from SMS-1 through GOES-15 (1974–2018), the team initiated surveys of calibration methods and completed a preliminary study comparing calibration from four different methods for the visible channel of GOES-8 through GOES-12.

HIRS-Like Data from New-Generation Sensors: HIRS-like data from the EUMETSAT's IASI data have been produced up to the current period, and results have been published in a peer-reviewed journal.

Century-Scale Variations and Trends in Heat Stress Metrics: The team processed more than 4,500 Global Historical Climate Network Hourly (GHCN-H) station records to apply quality control and evaluate the percent of available observations from the 1890s to 2021 for air temperature, dew point temperature, relative humidity, wet-bulb temperature, and station-level pressure. In addition, specific stations with high availability in the 1930s were selected as the core network of historical stations for this project.

US Climate Reference Network (USCRN) Applications and Quality Assurance: Data from USCRN stations were applied to evaluate the recently released HRRR model version 4. Comparisons revealed important differences and similarities that can inform model development. Comparisons of of NOAA-Atlas 14 threshold exceedances between USCRN and HPD and the development of machine learning methods for quality control continue. An earlier effort to develop spatial maps of USCRN observations was successfully transferred to USCRN's website, providing CONUS-wide maps of observations in near-real time conditions.

Development of Standardized Soil Moisture Datasets and Applications: An analysis of the capacity of ESA's standardized remotely sensed soil moisture data to capture the timing and severity of dry and wet extremes was submitted for publication. Estimates of remotely sensed FAW, standardized departures, and soil moisture percentiles prior to the Gatlinburg, TN, and Betty, OR, wildfires were evaluated. Supervised machine learning algorithms were used to explore the predictability of rapid drought change as measures from the USDM based on MJO and ENSO conditions.

Exploring the Impacts of Drought Events on Society: Droughts were found to increase the duration of heatwaves. While differences in heatwave intensity for compounded heatwaves were subtle, measures of heatwave exposure were generally higher. Differences in heatwave exposure and intensity were generally greater at night. Moist soils during compounded heatwaves limited nighttime cooling, especially in the western US. A journal article is currently in internal review at NCEI.

Evaluation and Elucidation of SCaMPR Performance in Complex Terrain Leveraging GOES-R Observations and Ground-based Precipitation Measurements: CISESS consortium partner UNC Asheville completed summer and fall 2022 data collection and maintenance rain gauge visits as part of this collaborative research effort to extend the period of observations of the Duke University Great Smoky Mountains.

Socioeconomic Value Assessment of Low Earth Orbiting Observations: Economic modeling methods were developed to assess the socio-economic value of the Joint Polar Satellite System (JPSS) Program satellite information for improved information regarding impacts in drought, flooding and severe weather.

Toward Fusing Humidity and Socioeconomic Data: This one-year project will work toward a homogenized humidity dataset at the spatial (US county) and temporal (daily) resolutions necessary for coordinated analysis with public health data. A literature review was conducted and relevant datasets explored and compared. HadISD data was selected as the in situ dataset and a combination of MODIS and AIRS was chosen as the remotely sensed dataset.

Drought Detection and Monitoring Using Remotely Sensed and In Situ Precipitation Datasets: A global daily SPI was implemented using precipitation satellite data from CMORPH-CDR to investigate its suitability for detecting and monitoring drought. Comparison of satellite SPI with an in situ drought index showed comparable patterns for drought events around the globe but important differences over areas with limited precipitation. The operational CMORPH-SPI is now available on drought.gov, and a high-resolution daily SPI was developed over CONUS from NClimGrid data. The process has been transitioned to the cloud for faster processing times.

Drought Detection and Relief Using In Situ Data from NClimGrid: The SPI code developed to generate the near-real-time CMORPH-SPI was adapted to the in –situ–based high resolution NClimGrid dataset (1952–present). The NClimGrid-SPI provides almost 70 years of daily SPI conditions over CONUS at a 5 x 5 km spatial resolution. Evaluations and comparisons with CMORPH-SPI and the US Drought Monitor were performed. In addition, the inversion of the high-resolution CONUS-wide NClimGrid-SPI will be used to produce a drought amelioration index, which can be aggregated at various levels (e.g., county or region). The inversion algorithm developed to produce an amelioration index will determine the rainfall deficit that would alleviate drought conditions by reaching a given target SPI.

Toward the Development of Climate Data Records (CDRs) for Precipitation: Global Evaluation of Satellite Based Quantitative Precipitation Estimates (QPEs): This effort is a long-term assessment of the different SPPs from four CDRs (PERSIANN-CDR; GPCP; CMORPH-CDR; AMSU A/B Hydro-bundle). The analysis was extended to evaluate the ability of three SPPs (PERSIANN-CDR; GPCP; CMORPH-CDR) to capture cold-season precipitation. The CDRs’ performance with respect to cold-season precipitation was compared to warm-season and full-year analysis for benchmarking purposes. A manuscript was submitted to the Journal of Hydrometeorology.

High-resolution Infrared Radiation Sounder (HIRS) Temperature and Humidity Profiles: The team is applying neural networks to HIRS data to develop a global temperature and humidity profile dataset for 1978–present. The dataset was extended through 2020, and a new cloud screening process is under development to address limited data over oceans.

Supporting the Development of Artificial Intelligence (AI) within NOAA and CISESS: CISESS NC assisted in the development of the NOAA Center for Artificial Intelligence, supported the execution of the 3rd annual NOAA AI Workshop series on Leveraging AI in Environmental Sciences, and will serve as hosted for the 11th International Conference on Climate Informatics.

Toward Visualizing and Analyzing Climate Data Records on the Cloud: NDVI CDR data are being converted from netCDF4 into a cloud-optimized Zarr format as a first step in in this pilot study to enable future AI/ML applications. The team explored three temporal data "chunking" options and determined that a monthly chunking strategy would best maximize the performance of Zarr format for storing spatiotemporal datasets.

ARC Data Derivative Product for Health Users: The project team completed development of an NCEI data product consisting of a daily time series for temperature (Tavg, Tmax, Tmin) and precipitation using NClimGrid for each census tract in the US (1981–present) to aid health and infectious disease modeling efforts. A new Python package is a companion to the existing EpiNOAA data product.

Collaborative Climate and Human Health Studies: Working with NCEI and CDC collaborators, CISESS NC advanced work on developing 1) baseline surveillance data to be used in an early warning system for harmful algal blooms (HABs) and 2) historical and real-time drought indicators in the US.

Climate Monitoring: NCEI's NClimGrid-Daily and IBTrACS datasets continue to be used in new and innovative ways to support NCEI's climate monitoring activities. The extreme rainfall in Hurricane Ian provided a unique opportunity to evaluate fidelity of the NClimGrid-Daily rainfall estimates.

Rapid Attribution of Extreme Events in the United States: A preliminary, area-weighted rank index was developed for the assessment of heat waves in terms of their abnormality for a variety of time scales for the CONUS. Computations are done at the county-level and can be summarized into a single heat wave index (HWI) for the entire county for a given day. https://ncics.org/pub/angel/hwi/. Modifications to the HWI to better account for severity of lower-recurrence interval events were carried out, and the process of producing the historical record, county- and state- subsetting, and indices has been automated.

Calibration of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures: Improvements to the calibration of HIRS brightness temperature between satellites were tested for channels 1–3, and calibration has been completed for the TIROS-N, NOAA 6–19, and METOP 1 and 2 satellites. Additional work is ongoing that compares this calibration of the HIRS brightness temperature measurement to a version of the HIRS calibration that is output by the FIDUCEO project.

Enhanced Rainfall Metric for Tropical Cyclones (TCs): NCEI's NClimGrid-Daily rainfall data provides an opportunity to analyze rainfall events in the United States associated with tropical cyclones TCs. The enhanced rainfall metric is developed and used to analyze how extreme rainfall events from TCs have changed over the last decade.

Evaluation and Development of a Southeast US Heat Vulnerability Index Using a Wet-Bulb Globe Temperature (WBGT) Approach: Testing of four WBGT estimation algorithms is nearly complete, with the Liljegren et al. (2008) methodology being the most accurate and robust. Final testing of the algorithms is underway with recently released data from the Range Commanders Council Meteorology Group's 2021 WBGT Campaign.

Monitoring and Detection of Unusualness Conducive to Wildfire: Initial stakeholder outreach has been completed, with interested parties displaying enthusiasm for a simple near real-time-wildfire monitoring product. Exploratory data analysis is underway to determine which datasets are best suited for identifying wildfire signals in an AI/ML framework.

Prediction of Wildland Fire Potential on Weekly to Seasonal Timescales: The team is working to develop a prediction system for wildland fire potential that is aligned with and informed by diverse stakeholder input such as from public, private, and academic sectors. The project will bring together multiple NOAA and other existing datasets, utilizing data science techniques and ML models to develop a probabilistic wildland fire potential outlook on weekly, monthly, and/or seasonal scales.

Other Projects

Developing an In Situ–Satellite Blended Marine Air Temperature Dataset Using Artificial Intelligence**:** The HIRS temperature profile retrieval processing workflow was updated, and reprocessing of HIRS temperature and humidity profiles (version 5) was completed for HIRS data going back to mid-1991 using the updated workflow and updated intersatellite calibration coefficient.

Climate Change Impacts in the Arctic, Northern Eurasia, and International Coastal Ocean Regions**:** Collaborative international research teams are investigating global environmental change challenges and impacts. Current projects are focused on the northern extratropics and five coastal ocean regions. The US team completed an assessment of the costs of climate change impacts on critical infrastructure in the Circumpolar Arctic and is going to determine governance and local and Indigenous practices that increase resilience and sustainability of the Frozen Commons in the Arctic.

America's Water Risk: Water System Data Pooling for Climate Vulnerability Assessment and Warning System: The project team found potential predictability of the North Atlantic Subtropical High (NASH) with a lead time of 6–12 months based on eastern Pacific sea surface temperatures.

Quantifying Future Precipitation Extremes within North Carolina for Resilient Design: Analysis revealed large differences in the calculated scaling factors for Intensity–Duration–Frequency (IDF) curves across different downscaling datasets.

Evaluation of Drought Indicators for Improved Decision-Making in Public Health and Emergency Preparedness: Reducing Drought's Burden on Health: Leeper devised an effort to measure the frequency at which a drought index is mentioned in a medical journal publication, which was incorporated into the ranking score of more than 53 drought indicators. In addition to duration and frequency, US county-level metrics of drought severity, seasonality of onset and termination, and timing of the worst drought on record were evaluated and compared to the US Drought Monitor. These indicators were also spatially and temporally evaluated over four well-known drought events.

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 comprehensively investigated the representation and associated uncertainties of rain microphysical processes in weather and climate models. The team developed an innovative Bayesian statistical framework that combines the extensive radar- and ground-based data, bin microphysical modeling, and a new bulk parameterization. This year, a PhD student successfully defended her thesis and two papers derived from the thesis are in preparation. A review paper on dual-polarization radar fingerprints of precipitation microphysics was published.

Global Near-Real-Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets**:** The team set up the SPI Python codebase on Azure and ported the CMPORH data**.** CMORPH-SPI was run on Azure and reproduced results from runs on the local NCICS cluster, with a 30% improvement in computational time. IMERG files computing the multi-day accumulations were prepared. The team is working to address technical issues on Azure that are preventing transfer of larger, more complex datasets to the cloud.

Environmental and Extreme Event Impacts on Human Health**:** Research efforts this year included studies of the impact of the COVID-19 pandemic on mental health for vulnerable children and adolescents, the crisis response in frontline essential workers and their children, and bereavement as a significant stressor shouldered by adolescents during the pandemic. Othe work examined the effect of compounding events on mental health consequences, the relationship between hot ambient temperatures and psychiatric emergency department admissions during pregnancy, and the effect of co-occurring drought and heat wave events on spatial pediatric mental health patterns.

Innovating a Community-Based Resilience Model on Climate and Health Equity in the Carolinas**:** A new NOAA Climate Adaptation Partnership (formerly the Regional Integrated Sciences and Assessments program), the Carolinas Collaborative on Climate, Health, and Equity (C3HE), was established at North Carolina State University. The team has established five community partnerships to develop a model for the end-to-end co-production of actionable and equitable climate resilience solutions in at-risk communities in the Carolinas.

Kelvin Waves and Easterly Waves in CYGNSS**:** NASA CYGNSS surface wind data identify differences in the surface wind speed anomalies with Kelvin waves that are dependent on the background flow regime.

Administration

Administrative, or Task I, activities provide a central shared resource for CISESS NC staff and partners. Primary activities include Institute and office administration, accounting and finance, pre-award proposal development/support, post-award contracts and grants management, human resources, information technology, national and international linkages, internal and external communications, oversight, and management of CISESS NC–initiated consortium projects, and coordination with CISESS and 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, the University of Maryland, College Park (UMD) and North Carolina State University (NCSU) are the lead institutions for the CISESS Consortium. CISESS NC serves as one of the two primary CISESS sites and is collocated with NCEI in the Veach–Baley Federal Complex in Asheville, NC. The operation of CISESS 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/CISESS NC is hosted and administered by NCSU as an administrative unit under NCSU's Office of Research and Innovation (ORI). The NCICS/CISESS NC Director reports to the NCSU Vice Chancellor for Research and Innovation. CISESS personnel are hired as NCSU employees and serve under NCSU policies and administrative guidelines. CISESS NC administrative staff implement, execute, and coordinate the Institute's administrative activities with pertinent CISESS, UNC, NCSU, ORI, NOAA, and NCEI administrative offices.

The CISESS NC Director, in coordination with the Business Manager and University Program Specialist, is responsible for the operations of CISESS NC. Administrative operations are primarily supported by NCSU, with additional support from NOAA via the Task I cooperative institute allocation. The NOAA Task I allocation currently provides partial salary support for the Director (two 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 facilitating research 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.

CISESS 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 (through February 28, 2023)
Erika Wagner, Program Specialist
Steven Marcus, IT Network Administrator II
Scott Wilkins, IT System Administrator II

Institute Information Technology (IT) Support Services	
Task Team	Steven Marcus, Scott Wilkins
Task Code	NC-ADM-01-NCICS-SM/SW

Highlight: Institute IT staff provide modern, scalable approaches to sustain CISESS NC at the competitive edge of technology advances and maintain core technologies as a stable base for staff operations. This year's accomplishments included security and monitoring improvements, transitioning projects into the Cloud, and continuing upgrades to the latest operating systems across all platforms.

Background

CISESS information technology (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 three areas: the user network, cluster and computing resources, and network and disk infrastructure (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.

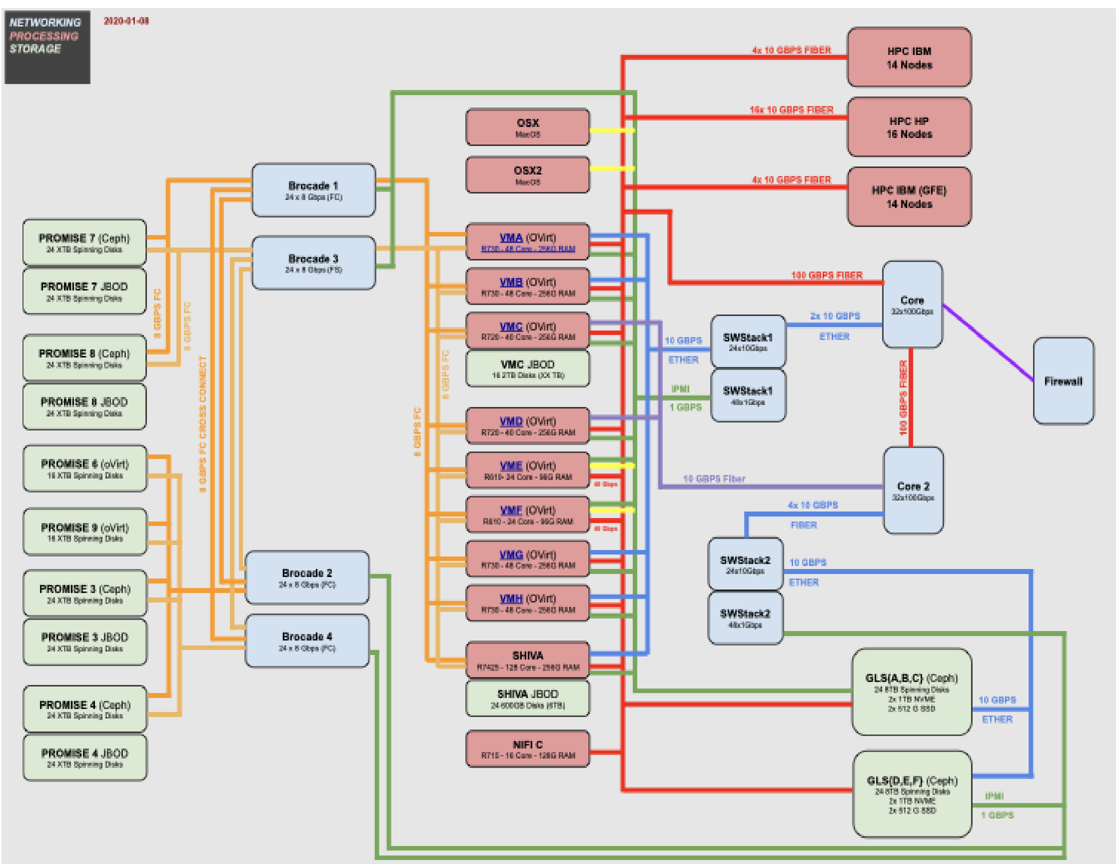


__Figure 1.__ Network and System Diagram.

Distributed Ceph file systems and the object gateway are provided for concurrent system-wide access to high-speed storage. Amazon S3 and Glacier Deep Archive provide offsite backup and disaster recovery for all data. A building-wide wireless network provides CISESS and other building partners with strong-signal, fast wireless coverage. This allows CISESS to quickly integrate and work side by side with its NCEI partners. There are 36 access points covering areas on the 1st through 3rd floors, fitness center, and NCEI archive, as well as full coverage on the 4th and 5th floors. The most populous areas utilize 802.11AX or gigabit Wi-Fi.

IT staff utilize a suite of monitoring tools, including Casper Suite, Zabbix, Elasticsearch, Kibana, Ganglia, and Uptime Robot. These and other open source and proprietary tools allow a very small IT staff to quickly address issues and efficiently monitor and maintain systems.

Accomplishments

Apple Silicon Workstations. As individual computers have grown older, it has given us an opportunity to replace them with Apple MacBooks that have newer processors made by Apple. This new processing power has changed the way that we deploy and update the new computers as we continue to support older hardware. We purchased and provisioned six new Apple Studio desktops for users who needed a lot of computational power and now have policies that make rolling out new systems easier. This is important as the number of people in our Institute increases.

Amazon AWS Project Accounts. IT staff developed a repeatable process to create AWS linked accounts for research projects. These linked accounts reside beneath the main CISESS account and permit segregation of individual project resources, workloads, and billing. The turnaround for having an account ready for use by the scientists is 4 hours. IT staff are currently supporting four administrative accounts and 14 project accounts. Single Sign On permits users to log in with one set of NCICS credentials to access any project account they need to access.

Operating System Upgrades. CISESS utilizes three primary operating systems: Linux, Windows, and MacOS. The VM cluster of Domain Controllers for Active Directory user identification and authentication and the VM that supports ArcGIS and SAS are all maintained at the latest level of Microsoft Server 2019. The CISESS deployment server now supports deployments to user workstations using MacOS Ventura, the latest version. The Ventura deployment required a large amount of configuration and package management adjustments while still supporting the older deployments. IT Staff are currently supporting Red Hat Enterprise Linux (RHEL) versions 7, 8, and 9 systems as we transition all servers and VMs to RHEL 9. There is no practical tool that allows an in-place upgrade without large dependency complications, so we are creating new RHEL 9 platforms and assisting users with transitioning from their older RHEL 7 and 8 services.

Website Support. CISESS hosts about 15 websites that provide access to different types of climate data information. Other sites provide a place for interaction between researchers and the National Climate Assessment. The CISESS IT staff provide storage and processing for these sites while working with site administrators to configure access to the sites as needed. We also handle the annual renewal and requesting of new digital certificates so that the websites can communicate securely.

NOAA and Other Building Tenant Support. The Institute provides its partners in the Veach–Baley Federal Building with IT support, including regular Wi-Fi, audiovisual, and video conferencing, as well as server support for meetings, customer engagement, training classes, and support to augment existing resources and provide the required functionality to make NCEI meetings and events possible. The Institute typically provides workstations, Wi-Fi, video conferencing, virtualization, and high-performance computing resources in support of various workforce development programs within the building, including the NASA DEVELOP and the NOAA Hollings Scholar internship programs. Interns are often without access to federal resources until halfway through their program due to the short internship period (10–12 weeks). Institute-provided equipment enables a fully productive internship.

Planned work

- Perform 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
- Replace OpenLava batch processing cluster
- Assist users with leveraging cloud-based technologies

Institute Communications	
Task Team	Tom Maycock, Jessicca Allen, Mark Essig, April Lamb, Angel Li, Andrea McCarrick
Task Code	NC-ADM-02-NCICS-TM/JA/ME/AL/AL/AM

Highlight: This year's key communications accomplishments included support for the 2022 updated State Climate Summaries and an international Climate Informatics conference, a new CISESS logo, and continued support for the CISESS Science Seminar Series, NCEI's State of the Climate report, and the Extended Continental Shelf report.

Background

Institute communication activities serve to raise awareness and highlight the accomplishments of the Institute and its staff. A primary focus is sharing research findings of Institute scientists and their NOAA NCEI colleagues through the Institute's website and *Trends* newsletter, press releases, social media, and outreach events. The team also provides science communication support for Institute staff, including editorial and graphic design contributions to papers, presentations, and reports.

As Science Public Information Officer (PIO), Tom Maycock coordinates communication efforts between the Institute and its various stakeholders, including NCEI, NCSU, and UMD. Jessicca Allen provides graphic design and visual communication support for the Institute and for NCEI's Communications and Outreach Branch. Graphics support includes image creation and editing for accuracy and readability, preparing graphics for various pre-release drafts, report production, 508 accessibility, and graphic design. Angel Li maintains the Institute's website and provides other web-related support. Mark Essig and Andrea McCarrick provide editorial support. April Lamb provides editorial and graphics design support and recently began overseeing metadata collection and curation for the Fifth National Climate Assessment.

Accomplishments

YouTube Channel and Indicators Videos. The Institute debuted its new YouTube channel this year, and CISESS intern Alexis Visovatti led the development of a series of videos highlighting the USGCRP climate change indicators. Maycock and Laura Stevens provided support for that project. More videos are planned for the coming year. See the Climate Change Indicators report for more details.

Promotional/Outreach Materials. Allen and Maycock developed a new two-pager describing CISESS NC's vision, mission, and selected accomplishments. Allen also developed a template for print versions of staff biographies. These materials were provided to several high-level government visitors and will be used for other outreach and engagement activities.

NOAA Institutional Repository. Several batches of publications by authors from CISESS NC authors and its predecessor the Cooperative Institute for Climate and Satellites–North Carolina were submitted to the NOAA Institutional Repository, and the PIO is working with the NCEI librarian to ensure timely submission of future publications.

Institute Editorial and Graphics Support. Maycock and Lamb gave presentations to participants in the inaugural CISESS NC Data Science Course on some best practices for scientific writing and graphic design.

Web Stories. Four web stories were published this year. They highlighted Institute participation at the annual American Geophysical Union (AGU) and American Meteorological Society (AMS) meetings, theUSGCRP Billion-Dollar Disasters Indicator, and the public release of a web tool providing access to new precipitation intensity–duration–frequency curves that account for climate change (a major outcome of a recently completed SERDP-funded [Strategic Environmental Research and Development Program] project to enhance the resilience of US military institutions to heavy precipitation by advancing understanding of future precipitation changes).

Social Media. Social media efforts this year included promoting Institute activities at the annual AGU and AMS meetings, sharing the Indicators YouTube series, and highlighting multiple job and internship opportunities.

***NCEI Graphics Support*.** Allen serves as a liaison between CISESS NC and NCEI's Communication and Outreach Branch to provide graphics design and production support for NCEI publications. Major projects this year included the annual State of the Climate Report for the *Bulletin of the American Meteorological Society* and the Extended Continental Shelf Report.

Planned work

- Continue providing support for and coordination with NCEI's Communications and Outreach Branch
- Produce two issues of *Trends* newsletter
- Develop and strengthen communications and outreach partnerships, including with the North Carolina State Climate Office
- Continue producing news stories and press releases highlighting research papers

Access and Services Development

Access and Services Development activities support improvements to mechanisms for accessing the expansive data and product holdings of NOAA NCEI. NOAA generates terabytes of data each day from satellites, radars, ships, weather models, and other sources, and NCEI currently archives more than 30 petabytes of data. Current petascale data holdings are forecasted to continue to grow, and NOAA's computational needs are projected to push exascale boundaries in the next year. The continued growth of the archive necessitates forward-thinking design and scalable algorithms and architectures. It is becoming increasingly important not only to manage the amount of data but also to harness this data to generate products that are of use by, and accessible to, decision-makers and the general public. Scientific data stewardship efforts focus on improving measures of stewardship, accessibility, and curation for NOAA's data holdings. This requires the input and guidance of scientific data management expertise, applicable user-interface enhancement design and implementation, and the integration of end-user needs into data products with the goal of providing useful tools and information to improve societal resilience to climate change.

The NOAA Big Data Project (BDP), now known as the NOAA Open Data Dissemination (NODD) Program, was created to explore 1) sustainable models to increase access to NOAA open data and 2) the potential benefits of storing copies of key observations and model outputs in the cloud in order to allow computing directly on the data without need of further distribution. CISESS NC's predecessor, the North Carolina campus of the Cooperative Institute for Climate and Satellites (CICS-NC), developed and implemented a data hub to facilitate data transfers to the cloud and served as a broker between NOAA and the public cloud providers, transferring and certifying multiple NOAA datasets to multiple cloud platforms. CISESS NC continues in the data broker role as NOAA transitioned to a contract model with the cloud service providers for continued provision of cloud datasets.

CICS-NC was also instrumental in the design, development, and implementation of the US Climate Resilience Toolkit (toolkit.climate.gov) and other associated navigational and visualization tools and data for NOAA's online climate services portal, climate.gov. Capitalizing on that initial tool and application development, CICS-NC expanded its work to identify synergies and integrate products and tools across various programs, including the Climate Services Portal, the National Climate Assessment, the National Climate Indicators, and the National Integrated Drought Information System drought-monitoring portal. CISESS NC continues to support these efforts to develop, enhance, and provide more useful tools and information for decision-makers and society.

NOAA Open Data Dissemination (NODD) Support	
Task Team	Otis Brown, Jonathan Brannock, Denis Willett
Task Code	NC-ASD-01-NCICS-OB/JB/DW

Highlight: Utilizing the CISESS-NC-designed data hub/broker architecture, additional key NOAA datasets were deployed in near real time to the public cloud, including GOES-18 and JPSS data. Usage metrics across the three public cloud platforms (Amazon Web Services, Microsoft Azure, and Google Cloud Platform) are now available to NOAA stakeholders with authentication. https://ncics.org/data/noaa-big-data-project/

Background

NOAA's environmental data holdings include comprehensive atmospheric, coastal, oceanographic, and geophysical data. While these datasets are publicly available, accessing and working with larger datasets can be difficult due to restrictions in access including protocols and throttling. NOAA's Open Data Dissemination (NODD) Program is designed to facilitate public use of key environmental datasets by providing NOAA's environmental information in the Cloud, making NOAA's data more easily accessible to the public and allowing users to perform analyses directly on the data. Figure 1 provides an overview of this process.

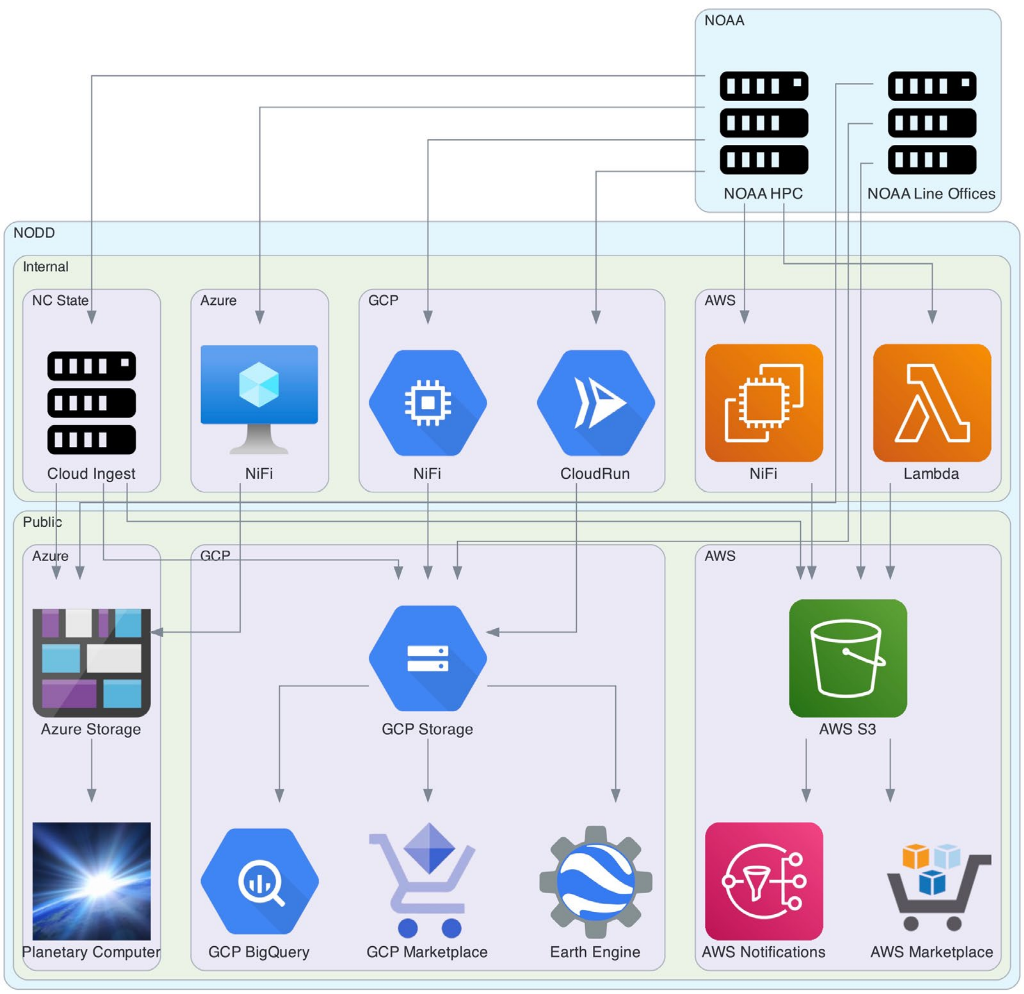


Figure 1. *Data hub/broker overview.*

CISESS NC is a NODD partner and currently acts as a broker between NOAA and the public cloud providers. Institute data and information technology experts work to help transfer and certify multiple NOAA datasets to several cloud platforms, including Amazon Web Services (AWS), Google Cloud Platform (GCP), and Microsoft Azure. Currently NODD datasets utilize approximately 30 PB of cloud storage.

The CISESS NC high-performance computing cluster and cloud infrastructure have served as a critical gateway for the near-real-time transfer of several datasets, including NEXRAD Level 2 radar data; NOAA-20, GOES-16, GOES-17 and GOES-18, Himawari-8 satellite data; and others.

Accomplishments

This year's NODD efforts focused on adding key additional NOAA datasets to NODD holdings, establishing the foundations of direct pushes from NOAA resources, and increasing accessibility of metrics. The team expanded the diversity of holdings, working closely with the NOAA line offices including NESDIS, NCEI, NWS, OAR, and National Marine Fisheries Service (NMFS). Accompanying this expansion, the team worked with stakeholders at NOAA line offices to establish direct pushes from NOAA computing resources to improve the performance of data flows. The team also expanded access to metrics through the development of an online authenticated portal.

Diversifying and Expanding NODD Datasets. The CISESS NC team facilitated the dramatic expansion of NOAA data cloud holdings with increases in large datasets such as High-Resolution Rapid Refresh (HRRR), Global Ensemble Forecast System (GEFS), and GOES products as well as the addition of a wide range of additional data products including GOES-18, JPSS, Multi-Radar Multi-Sensor (MRMS), and a suite of NMFS datasets. NODD holdings exceed 30 PB across all three cloud service providers. https://www.noaa.gov/nodd/datasets

Direct to NODD Pushes. To improve the performance and resilience of NODD data flows and establish a more robust platform for future expansion, NODD worked closely with key stakeholders in programs like JPSS to establish direct pushes to NODD from programs like the NESDIS Common Cloud Framework. This type of direct pipeline reduces latency and can improve the uptime of feeds when they are managed by upstream stakeholders. This architecture also creates a more scalable model for continued expansion of NODD holdings. Direct pushes are a big step to integrating more directly with the NOAA line offices and are the next step in moving towards the operational nature of NODD.

Metrics Accessibility. The CISESS NC team built on close relationships with cloud service providers to establish a metrics pipeline that improves the visibility of NOAA data usage on the public cloud. Expanding on this foundation allowed CISESS NC to improve accessibility of NODD metrics by developing an authenticated portal where authorized stakeholders across NOAA can access real time and historical metrics and reports on the cloud use of NOAA data. The insights from this work are driving an increased appreciation of which NOAA datasets are used more heavily on the cloud (Figure 2), the impact of NODD for artificial intelligence/machine learning applications, the ability of NODD to support high volumes of access exceeding on-prem capabilities, and the diverse nature of data use across the world.

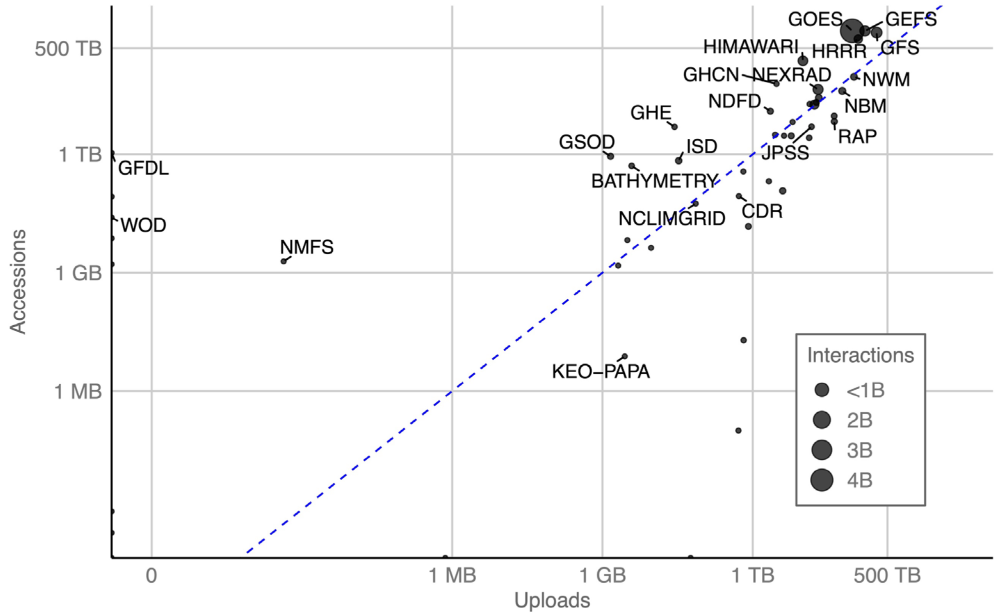


Figure 2. *Select NOAA datasets made publicly available on the cloud via NODD. Points denote median monthly accessions (y Axis), uploads (x Axis), and interactions (size of points) for the past five months across AWS, Azure, and GCP. Dotted blue line is a one-to-one ratio between accessions and uploads. Datasets above the blue line indicate more accessions than uploads.*

Data Transfer activities. Major activities included:

- Backfilling efforts for GFS, GEFS, and other datasets
- Added GOES-18, JPSS, GK2A, OAR Holdings, UFS-MRW, GEFS V13, Himawari 9, and GFS Warmstart
- Implemented automatic reconciliation of NOAA climate data record holdings across cloud service providers
- With access to WCOSS2, reengineered GFS Warmstart transfer to improve latency and performance.

Software Development. As NODD Data Broker, CISESS NC addressed numerous data transfer challenges with software development/software engineering solutions.

- Expanded infrastructure-as-code technologies to automate cloud resource deployment across all three cloud service providers.
- Deployed authenticated metrics portal in distributed Kubernetes environment. https://nodd.ncics.org/
- Developed consolidated serverless data transfer templates to facilitate rapid iteration and tuning of pipelines on AWS.
- Added and expanded advanced logging and traceability across NODD infrastructure using Fluent-Bit
- Expanded Apache NiFi polling and transfer of NWS, NCEI, and NEXRAD datasets to improve performance and reliability of transfers.
- Leveraged distributed data analysis platform to reprocess 100s TB of log data to derive new insights into NODD data usage on the cloud.

Operations and Automation Activities. CISESS NC performs various IT operations in each of the cloud service providers' clouds as well as on some on-premises computing resources as needed. When possible, processes are automated to reduce the time and effort required to manage these many resources. Some of the new operations activities in the last year include:

- Use of Pulumi to automate resource creation on all three CSPs.
- Deploying production Kubernetes clusters to support NODD Monitoring.
- Designed schema and ingest pipelines for automated log analysis of real-time feeds.
- NiFi update deployment to leverage continuous integration/continuous deployment pipelines.
- Expanded logging and traceability infrastructure

Planned work

- Expand and diversify NOAA data holdings publicly available on all three cloud service providers.
- Expand implementation of Kubernetes as a cross-cloud fabric layer for service deployments.
- Research approaches to supporting optimized data formats and dataset search and discovery.

Products – Datasets

Below is a selection of the 200+ new or enhanced datasets and data collections added in the past year and now available through NODD cloud service provider partners:

- GOES 18
- JPSS
- MRMS
- Himawari -9
- GK2A
- UFS Products
- ICOADS
- NDE
- GFS Waves Reforecast
- Additional datasets from NMFS, OAR, NWS, NESDIS, and NOS

Products – Other

- Authenticated Metrics Portal
- Enhanced Data Broker transfer structure
- Reprocessed NODD Data Use logs
- Dashboard for log data exploration

Publications

Willett, D.S., B. White, T. Augspurger, **J. Brannock**, **J. Dissen**, P. Keown, **O.B. Brown**, and A. Simonson, 2022: Expanding access to open environmental data: Advancements and next steps. *Bulletin of the American Meteorological Society*. http://dx.doi.org/10.1175/bams-d-22-0158.1

Presentations

Brannock, J.B., and **D.S. Willett,** 2022: Cloud Computing in Advancing Climate Informatics (panel discussion). *11th International Conference on Climate Informatics,* virtual. May 11, 2022.

Brannock, J.B., and **D.S. Willett**, 2022: NODD Technical Updates and Strategic Development. *NOAA CDO Visit*. December 7-8, 2022.

Brannock, J.B., and **D.S. Willett**, 2022: NODD Technical Updates. *Assistant Secretary of Commerce Overview.* December 15, 2022.

Strategic Engagement and Outreach for the NOAA Open Data Dissemination (NODD)	
Task Leader	Jenny Dissen
Task Code	NC-ASD-02-NCICS-JD

Highlight: Accomplishments included quarterly huddles with Line Offices, support for GOES-R engagement efforts, leading an engagement effort with users of HRRR data through NODD Office Hours, and convening of the 8th Annual NODD Town Hall Discussion at the 2023 American Meteorological Society meeting.

Background

The NOAA Open Data Dissemination (NODD) Program, formerly the NOAA Big Data Program, is one of NOAA's forerunner activities associated with NOAA's broader transition to the cloud. The new name was approved by Congress in the FY22 Consolidated Appropriations Act, with the direction to "improve public access to climate change data and to transition NOAA data to the cloud." NODD makes NOAA environmental datasets available to the public for free via the Cloud through a public–private partnership with three cloud service providers (CSPs)—Amazon Web Services (AWS), Google Cloud, and Microsoft. NODD is an enterprise service that supports the NOAA line offices in providing their open data to the public, with no egress costs to the agency or the users, in alignment with the Evidence Act. NODD's engagement and service delivery encourages use of NOAA data and collaboration among partners, while incorporating feedback from users. The open, free, and cloud-based access to NOAA data supports the NOAA line offices in addressing the Administration's priorities: Build a Climate Ready Nation; Make equity central to NOAA's mission; and Accelerate growth in an information-based blue economy.

Open and cloud-based access to NOAA's data benefits NOAA, NOAA stakeholders, and users including underserved communities, through the removal of obstacles, avoidance of costs and risks associated with federal data access services, and opportunities to leverage operational public–private partnerships with the cloud computing and information services industries. While NOAA recognizes the need to improve user access via the cloud, engagement with current and potential users in the cloud is complex, including ethical and legal considerations and requirements.

As the engagement lead for NODD, CISESS NC's efforts entail improving understanding of usage, users, users' experiences, and the value of the NOAA data through the applied context. The goals are to engage users and citizens across all sectors of the US and global economy as well as NOAA scientists and staff to improve their understanding, awareness, and use of NOAA information via the Cloud. These efforts extend the NODD Program goals of collaboration and creation of new business opportunities and align with Executive Order 14008 in supporting the advancement of environmental justice and improving local and community decision-making by democratizing data access.

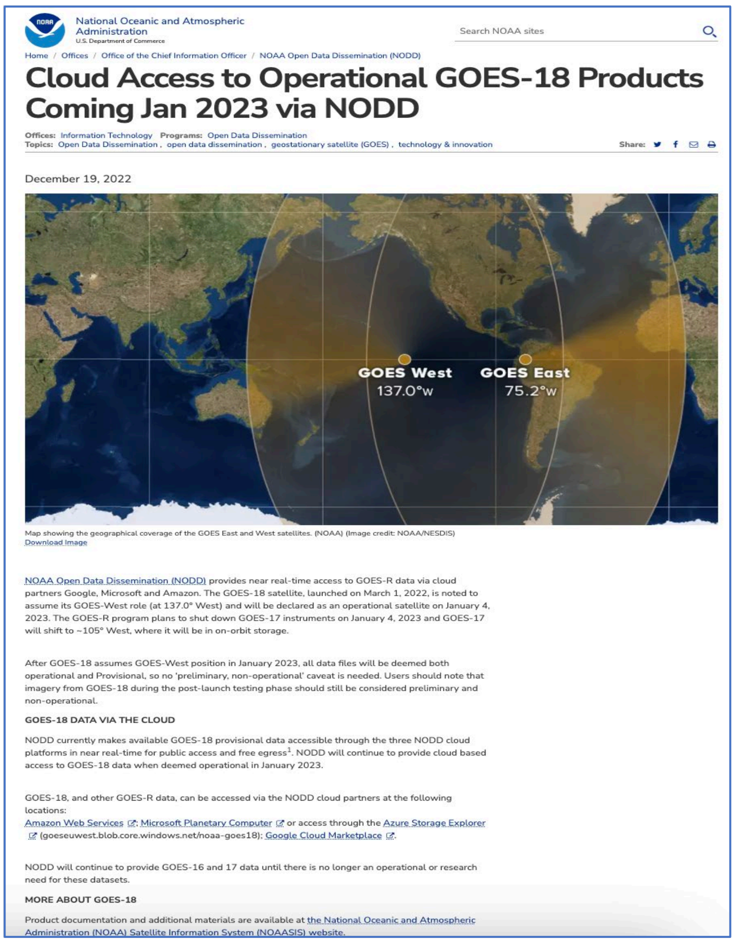
Engagement activities support the CISESS and NODD technical staff as they engage with NOAA line offices to address data transfers and flows and develop statistics and metrics that monitor dataset usage for each line office. Engagement efforts assist in increasing usage with end users through improved technical support and service delivery and encourage collaboration and feedback that benefits the Program.

Accomplishments

Current efforts engage a number of stakeholders: NOAA line office interactions, CSPs; cloud tool and analytics providers; public and private start-up and industry user community; and government/ interagency user communities. These iterative interactions between NOAA, CSPs, and end users highlight needs, requirements, perspectives and understanding that highlights demand for cloud access and the benefits of cloud tools as users analyze the information.

NODD NOAA Line Office Engagement. NODD is part of NOAA's service delivery capability via the cloud. NODD has cultivated engagements across all NOAA line offices by hosting quarterly huddles to share programmatic updates, information on metrics and usage, potential datasets of interest, and engagement activities related to the line office's datasets. Huddle outcomes indicate that there is interest in expanded user communities that are interacting with NOAA data via the cloud, highlighting that as user experience evolves, service delivery capabilities for NOAA will need to accommodate the cloud user.

NODD engagement continued tailored and targeted interactions with the NESDIS GOES-R program on a biweekly basis to prioritize new GOES-R datasets for cloud access. NODD supported the GOES-R program in bringing awareness to cloud users on the transition to the GOES-18 satellite and developed communications materials for the NODD and NOAA OCIO High Performance Computing and Communication websites providing information on access via the cloud partners (Link here).


National Oceanic and Atmospheric Administration
U.S. Department of Commerce
Search NOAA sites
Home / Offices / Office of the Chief Information Officer / NOAA Open Data Dissemination (NODD)

Cloud Access to Operational GOES-18 Products Coming Jan 2023 via NODD

Offices: Information Technology Programs: Open Data Dissemination
Topics: Open Data Dissemination, open data dissemination, geostationary satellite (GOES), technology & innovation
Share:

December 19, 2022

Map showing the geographical coverage of the GOES East and West satellites. (NOAA) (Image credit: NOAA/NESDIS)
Download Image

NOAA Open Data Dissemination (NODD) provides near real-time access to GOES-R data via cloud partners Google, Microsoft and Amazon. The GOES-18 satellite, launched on March 1, 2022, is noted to assume its GOES-West role (at 137.0° West) and will be declared as an operational satellite on January 4, 2023. The GOES-R program plans to shut down GOES-17 instruments on January 4, 2023 and GOES-17 will shift to ~105° West, where it will be in on-orbit storage.

After GOES-18 assumes GOES-West position in January 2023, all data files will be deemed both operational and Provisional, so no 'preliminary, non-operational' caveat is needed. Users should note that imagery from GOES-18 during the post-launch testing phase should still be considered preliminary and non-operational.

GOES-18 DATA VIA THE CLOUD

NODD currently makes available GOES-18 provisional data accessible through the three NODD cloud platforms in near real-time for public access and free egress[1]. NODD will continue to provide cloud based access to GOES-18 data when deemed operational in January 2023.

GOES-18, and other GOES-R data, can be accessed via the NODD cloud partners at the following locations:
Amazon Web Services; Microsoft Planetary Computer or access through the Azure Storage Explorer (goeseuwest.blob.core.windows.net/noaa-goes18); Google Cloud Marketplace.

NODD will continue to provide GOES-16 and 17 data until there is no longer an operational or research need for these datasets.

MORE ABOUT GOES-18

Product documentation and additional materials are available at the National Oceanic and Atmospheric Administration (NOAA) Satellite Information System (NOAASIS) website.

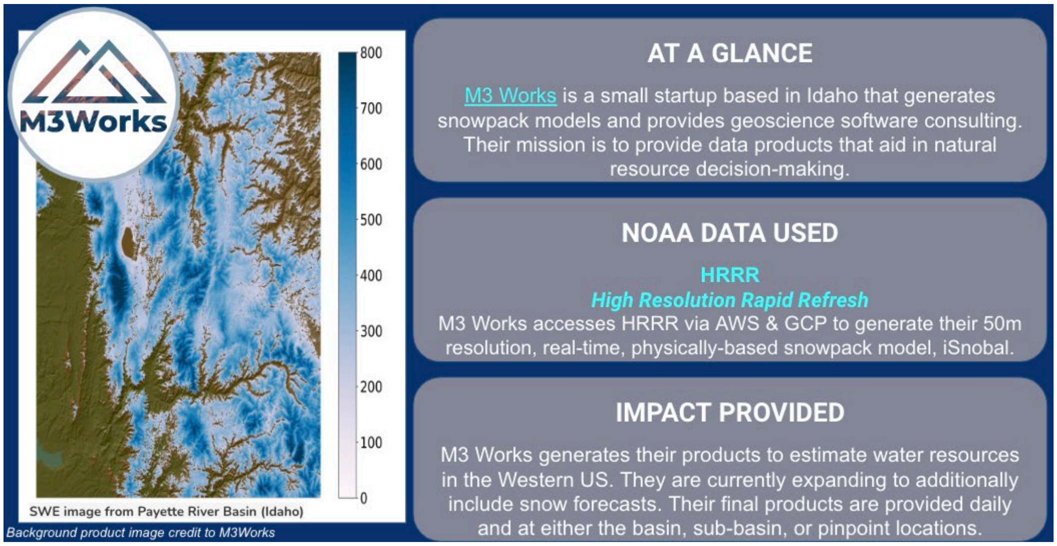
In collaboration with NWS Office of Organization Excellence, CISESS NC is leading an engagement effort with users of HRRR data through the NODD Office Hours. This collaboration with NWS, AWS, and NODD team resulted in approximately 80 participants discussing the use and value of HRRR data and benefits to cloud-based users.

NODD Partner Engagement. In 2021–22, NODD launched an inaugural activity called NODD Cloud Pathfinder's Project (NCPP), a partnership between NODD, Earth System Information Partners (ESIP), and AWS that provides a sandbox environment for NOAA scientists to build and experiment their projects in the cloud. The first batch of NCPP projects involved five projects. NODD engagement participated in the 2022 ESIP Summer Community meeting highlighting NOAA scientists' experiences and advancements with data analysis in the cloud. NODD cultivated interactions with the Open Geospatial Consortium as a result of one of the projects.

In December 2022, CISESS NC supported NODD in a presentation at the AWS re:Invent conference that convened the global cloud computing community in Session Track Title: Tech for Good. The NODD presentation "Open Data for Impact – Quantify and Manage Climate Related Risks" reached conference participants from a diversity of sectors that increased their awareness and understanding of NODD data with AWS.

In January 2023, CISESS led the NODD convening of the 8th Annual NODD Town Hall Discussion at the 2023 American Meteorological Society moderated by NOAA Chief Data Officer, Tony Lavoi. Panelists included founders of companies from M3Works, Zeus AI, CRCL solutions, and Microsoft Research Director Ranveer Chandra. Panelists described the critical need for NOAA data via the cloud and characterized needs for the NODD team ranging from documentation to cloud optimized format of data to optimal data pull approaches. *Recording available upon log-in at* [*AMS Town Hall Website*].

NODD Case Studies with Users. User engagement proactively identifies data demand and uses from traditional and emerging socioeconomic sectors. NODD engaged with climate and blue tech clusters, startups that serve emergency management, some public utilities, renewable energy companies, and the agriculture/agtech and space and aviation industries to name a few. NODD developed blog stories and case study presentations describing select users and their use-case of NOAA data via the cloud along with the outcomes and benefits. NODD identifies and captures end-user experience and use cases to understand and portray how end-users benefit from access to and use of NOAA data via the cloud. End-user interactions thus far included the following: M3Works, Zeus AI, Camus Energy, CRLC Solutions, Maydai AI, Pano AI, TempoQuest, Terrafuse AI, and Solcast.



CISESS NC engagement also supported the implementation of Salesforce as a customer information tracking solution to help understand user inquiries and user analysis.

NODD Supports NOAA Scientists and Operations. NODD data and engagement provide support for more efficient internal NOAA operations. The Office of Coast Survey is deploying its Operational Forecast System (OFS) in the cloud, which provides a nowcast and forecast (up to 120 hours) of water levels, currents, salinity, water temperatures, and winds for a given area. This dataset is pushed out to a NODD bucket and then used by the NOAA nowCOAST team, in their API. NowCOAST is a GIS-based web mapping portal displaying near-real-time observations, analyses, tide predictions, model guidance, watches, warnings, and forecasts for the coastal United States. NODD allows nowCOAST to easily access the OFS data, eliminating an existing barrier to sharing data between NOAA programs.

CISESS NC engagement efforts have also led to the NOAA Northeast Fisheries Science Center oceanography at sea information system (OASIS) project operationalizing cloud access to its conductivity, temperature, and depth data to their users in near real time.

Planned work

- Discuss NODD at May 2023 Climate Predictions and Applications Science workshop
- Continue to engage with NOAA line offices to determine datasets of interest for the cloud
- Build end-user case studies, including JPSS use cases
- Participate in scientific conferences such as ESIP, AGU, and AMS

    - Build AMS Short Course training for JPSS and GOES-R datasets
    - Host Town Hall discussions
- Build capacity of faculty and students through West Virginia University Cloud Faculty Fellows program
- Extend capacity into high school by partnering with NC School of Science and Math data science faculty

Presentations

Dissen, J., and A. Simonson, 2022: NODD Advances Interoperability (session co-chair). *2022 Environmental Data Management Workshop*, virtual. September 15, 2022.

Dissen, J., 2022: Cloud Computing in Advancing Climate Informatics (panel moderator). *11th International Conference on Climate Informatics,* virtual. May 11, 2022.

Dissen, J., 2022: Cloud Pathfinders… Assemble! (session facilitator). *2022 July Earth Science Information Partners (ESIP) Summer Meeting.* Pittsburgh, PA, July 21, *2022.*

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NODD Census Briefing. February 20, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NOAA Open Data Dissemination Program Overview. *103rd American Meteorological Society Annual Meeting*. January 12, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NOAA Open Data Dissemination Program Overview. *West Virginia University Cloud Faculty Fellows*, virtual. March 2, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2022: NOAA Open Data Dissemination Overview. *N-Wave Joint Engineering and Technical Interchange (JETI) Annual Meeting*, virtual. August 9, 2022.

Simonson, A., P. Keown, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2022: NOAA Open Data Dissemination Overview. *Department of Commerce Chief Data Office*. April 1, 2022.

Internal NOAA presentations to Line Offices, NOAA leaders and programs (17)

Other

- Presentation to Dr. Markus Richter, State Secretary at the Federal Ministry of the Interior and Community and Federal Government Commissioner for Information

Development and Support of NOAA Climate Products and Services

Task Leader	Karin Rogers
Task Code	NC-ASD-03-UNCA

Highlight: UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) assisted in the U.S. Climate Resilience Toolkit redesign management and planning, maintenance of Climate Explorer 3, the launch of a National Climate Assessment author "sandbox," USGCRP Indicators graphics updates, and NIDIS drought.gov user research.

Background

NOAA's stated service mission is "…the communication of NOAA's research, data, information and knowledge…" to help build a more resilient nation and a climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions. NOAA's *Climate.gov* portal and its sister site, the *U.S. Climate Resilience Toolkit* (CRT) were specifically designed to help make climate science and NOAA data products easier to access and use by the public, businesses, and decision-makers at all levels. NOAA communicates to more focused audiences through dedicated websites such as the National Integrated Drought Information System (NIDIS) Drought.gov site and supports the broader communication of climate science and environmental data through its collaborative participation as a member of the U.S. Global Change Research Program (USGCRP) advancing understanding of the changing Earth system through the sustained National Climate Assessment (NCA) process.

The University of North Carolina Asheville (UNCA)—a CISESS Consortium member—and its National Environmental Modeling and Analysis Center (NEMAC) have well-established expertise in visualization, geographic information systems, programming, multimedia, community engagement, outreach, and environmental science and are collaboratively addressing NOAA's growing needs for applications development, data visualization, content development, and content management system (CMS) development and management in this area. NEMAC facilitates the interaction between science producers and users, specializing in science communication and the development of decision support tools for local, regional, and national decision-makers, planners, and the public.

Accomplishments

The project team supported research and development activities for four programs: the NOAA Climate Program Office (CPO) Climate Portal, the NCA, the USGCRP Indicators Working Group, and NIDIS.

Climate Portal/U.S. Climate Resilience Toolkit (CRT): Project staff worked with CPO staff in the continuing development and/or enhancement of the US Climate Resilience Toolkit and provided editorial and content management support to the CRT and the Climate Explorer (CE).

Content and Editing

- Author team coordination, development, and publication of the Southeast, U.S. Caribbean, and Southern Great Plains regional content pages
- Coordination, development, and publication of the U.S. Caribbean regional content pages in Spanish
- Management of public inquiries via the CRT email address
- Consistent additions of new content and updates of outdated content
- Consistent engagement with NOAA Climate social media accounts to coordinate the promotion of new and updated CRT content

- Initial conversations with Fifth National Climate Assessment (NCA5) author teams to develop updated NCA5 topical and regional information
- Webinar content development featuring videos and narratives for the Steps to Resilience Training, sponsored by NOAA and the Climate Resilience Fund

User Research and Redesign

- Conducted user interviews on the US Climate Resilience Toolkit (CRT) current design; analyzed and summarized the results for the CRT team
- Developed user personas and created user journey map (from interviews) to guide the redesign
- Presented user research results and recommendations to the CRT team and at the National Adaptation Forum (2022) in Baltimore, MD
- Created CRT prototype and wireframes based on findings from user interviews and Climate Program Office and CRT team input
- Conducted several rounds of usability studies on prototype and wireframes and made revisions
- Prototype/wireframes sent to CPO development and design team to finalize

Web Development

- Implemented CSS changes and verbiage updates as requested on the CRT website (Drupal 7)
- Completed minor bug fixes and feature updates to the CRT website
- Maintained and hosted Climate Explorer

Stakeholder Engagement

- Partnered with the CRT team and Fernleaf to present at the National Adaptation Forum (2022, Baltimore, MD). Moderated a panel, “Beyond the Vulnerability Assessment: Experiences of local governments in the Southeast using the Steps to Resilience”.

National Climate Assessment (NCA): The project team worked with CISESS NC and the Assessment Technical Support Unit (TSU) to launch the NCA sandbox prototype.

- Worked with a NEMAC student intern to add climate projections via the Applied Climate Information System (ACIS) API as a placeholder.
- Completed several updates as requested by the Technical Support Unit

USGCRP Indicators: Indicators work focused on USGCRP Indicators website static and interactive indicator graphics design and data updates in collaboration with the CISESS NC/NCEI Indicators team.
Static graphics were updated for the following Indicators:

- Global Annual Sea Surface Temperatures
- Annual Heating and Cooling Degree Days in the Contiguous United States
- Global Sea Surface Temperatures
- Annual Surface Temperature Change for the Contiguous United States
- Global Monthly Average Carbon Dioxide Concentration
- U.S. Billion-Dollar Disaster Event Types by Year
- Annual Global Surface Temperature Change for Land and Ocean
- Heat Wave Characteristics in 50 Large U.S. Cities, 1961-2021 (Figure 1)
- Observed Change in Annual Precipitation Falling in the Heaviest 1% of Events
- Global Average Sea Level Change (Relative to 1880)
- Annual Start of Spring for the Contiguous United States
- Tropical Cyclone Days for the North Atlantic Region West of 60°W
- Annual Greenhouse Gas Index

- Annual Heating and Cooling Degree Days in the Contiguous United States
- Marine Species Distribution (still in progress)
- Arctic Sea Ice Extent (still in progress)
- Ocean Chlorophyll Concentrations (still in progress)

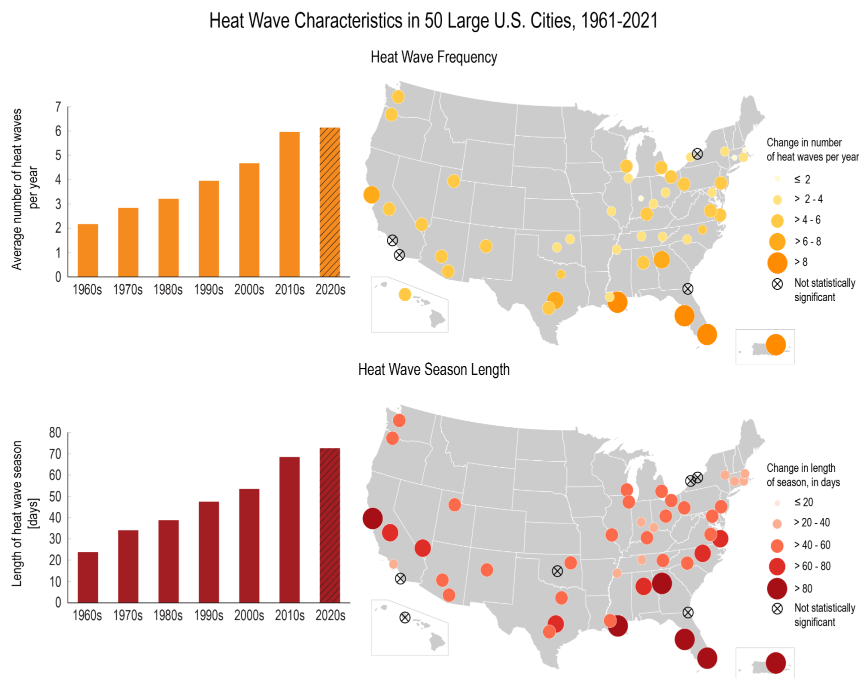


Figure 1. *Heat Wave Characteristics in 50 Large U.S. Cities, 1961-2021*

The NEMAC and CISESS NC/NCEI teams began a partnered effort to develop a cohesive Indicators social media campaign.

National Integrated Drought Information System (NIDIS): The NEMAC team supported the redesign of the drought.gov website, including leading user research and usability efforts, and content development.

- Performed three rounds of usability and user research on the new website: a sign-up for drought updates, a deep dive into the State pages/how people are using them, and a more general investigation into other parts of the site
- Converted past NIDIS user research and usability studies content into a new user research software platform and began re-analysis of the findings to guide the development of new initiatives across drought.gov
- Worked with NIDIS team to redesign State pages incorporating findings from user research, stakeholder feedback, and site analytics
- Created and conducted a user survey to get a better understanding about why users are visiting drought.gov and what they are looking for.
- Started creation of user personas based on Google analytics and user survey findings

Planned work

- CRT site maintenance and content development/management
- Continue documentation of current CRT content in preparation for site transfer
- Complete the CRT prototype, and launch of the redesign in fall 2023

- Publication of Practitioner's Guide training videos on CRT
- Updates and improvements to Climate Explorer v3, as needed
- Climate Portal and CRT stakeholder engagement
- Continue development and user testing of the NCA sandbox tool
- Continue NIDIS drought.gov website usability studies; Drought Planning Portal user research
- Indicator graphics development support and coordinated cohesive social media campaign

Products *(improved and/or redesigned)*

- U.S. Climate Resilience Toolkit (https://toolkit.climate.gov)
- USGCRP Indicator graphics (http://www.globalchange.gov/browse/indicators)
- U.S. Drought Portal (https://drought.gov)
- NCA Sandbox (https://sandbox.nemac.org/)

Presentations

Rogers, K., 2022: "Beyond the Vulnerability Assessment: Experiences of local governments in the Southeast using the Steps to Resilience" (panel). *5th National Adaptation Forum*, Baltimore, MD. October 27, 2022.

Shore, A., 2022: The US Climate Resilience Toolkit: User Research (World Café). *Southeast Climate Adaptation Science Center Regional Science Symposium,* Gulf Shores, AL. September 20, 2022.

Reports

Gardiner, N., M. Hutchins, J. Fox, A. Patel, K. Rhodes; United States National Oceanic and Atmospheric Administration Climate Program Office, 2022: Implementing the Steps to Resilience: A Practitioner's Guide. Series: Climate-Smart Communities Series; vol. 6 https://doi.org/10.25923/9hhx-2m82.

This is a user-friendly report containing a set of procedures to accompany each phase of the U.S. Climate Resilience Toolkit's Steps to Resilience (StR). The document aims to support climate service practitioners as they develop and implement equity-centered climate resilience plans in their communities.

Other

Four UNC Asheville undergraduate students were mentored: 2 writing/editing internships for the CRT, 1 user research for NIDIS, and 1 web development for the NCA sandbox.

- A Science Writer Intern collected relevant metadata from a database of case studies from the CRT in preparation for the site redesign. This task included updating topic and hazard information to align with NCA5 terms, collecting contact information and rewriting content summaries for each, and documenting tools and datasets utilized where applicable.
- A second Science Writer continued to assist in the publication of content pages for new reports, case study pointers, and tools. Notably, this student developed content pages to showcase the US Forest Service Climate Gallery - a collection of StoryMaps highlighting climate maps, tools, and resources supporting environment analyses.
- A UX design intern helped review and analyze Drought.gov usability studies.
- A web developer intern worked to add climate projections to the sandbox tool.

Assessment Activities

Assessment efforts support interagency activities for global, national, and regional assessments of climate change. NOAA conducts a number of global-, national-, regional-, and sectoral-level climate assessment activities, including participation in the high-level, visible, and legally mandated National Climate Assessment (NCA) process, which is responsive to greater emphasis on user-driven science needs under the auspices of the US Global Change Research Program (USGCRP). The USGCRP is an organization of 14 federal agencies (including NOAA, and with the recent addition of the Department of Homeland Security) that conduct research and develop and maintain capabilities supporting the Nation's response to global change. Climate assessments and associated special reports synthesize the state of scientific knowledge about climate change, including observed changes and potential future states. The goal of these assessments is to provide integrated analyses of impacts and vulnerabilities and to advance climate science understanding in the larger social, ecological, and policy systems.

NCEI and other parts of NOAA have provided leadership on climate assessment activities for more than two decades. 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.

In 2010, under the previous Cooperative Institute project, the Cooperative Institute for Climate and Satellites–North Carolina formed the Assessment Technical Support Unit (TSU) to provide an array of NCA scientific and report development and production support to NOAA and the USGCRP. The TSU's contribution was integral for the Third NCA, the Climate and Health Assessment, and Volumes I and II of the Fourth NCA. The team also built and continues to update a suite of online tools used for the report development, review, and delivery processes, including a collaborative metadata collection and management tool that provides readers with the full provenance of all figures in NCA4. Thanks to these efforts, the recent NCA reports have set a new standard for readability, accessibility, and transparency. The TSU, under CISESS NC, continues to provide and enhance scientific and technical support for these national interagency efforts.

The USGCRP Climate Indicator Platform was designed as a system of physical, natural, and societal indicators that communicate and inform decisions about key aspects of the physical climate, climate and social impacts, vulnerabilities, and preparedness. Its primary purpose is to support the sustained NCA process. The TSU continues to provide support for the USGCRP Indicator Platform through updates of the current indicators and the development of new indicators.

Assessment Scientific and Data Support Activities	
Task Team	Kenneth Kunkel (Lead), Sarah Champion, Linda Copley, Katharine Johnson, April Lamb, Angel Li, Laura Stevens, Liqiang Sun, Xia Sun, Xiangdong Zhang
Task Code	NC-AA-01-NCICS-KK/et al

Highlight: The team completed analysis of several large datasets, including the LOCA2 and STAR statistically downscaled datasets, the CMIP6 suite of GCMs, and the CMIP5-based VIC simulations. The results were used to produce 29 original graphics for the Fifth National Climate Assessment.

Background

NOAA is participating in several global-, national-, regional-, and sectoral-level climate assessment activities, including the high-level, visible, and legally mandated NCA process, which is responding to a greater emphasis on user-driven science needs under the auspices of the 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. NCEI, along with many other parts of NOAA, has provided leadership on climate assessment activities for more than two decades. 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.

The TSU, initially established under CICS-NC, continues to support these local –to global assessment activities. Within the TSU, a group focused on scientific and data support consists of a Lead Senior Scientist (Kenneth Kunkel), Deputy Scientist (Liqiang Sun), Senior Climate Scientist (Xiangdong Zhang), Data Architect (Sarah Champion), two climate Scientists (Laura Stevens, Xia Sun), Web Developer/GIS Specialist (Katharine Johnson), Web Developer (Angel Li), Software Engineer (Linda Copley), and metadata coordinator (April Lamb). The Lead Senior Scientist provides scientific oversight for the development of NOAA's assessment services supporting the NCA and broader assessment activities based on foundational climate science information. Report information is disseminated through websites providing access to reports, figure metadata, and figure data.

Accomplishments

The TSU worked with authors and the USGCRP to complete the Third Order Draft of the Fifth NCA, which was released in November 2022 for public comment and peer review by the National Academies of Science, Engineering, and Medicine. This was a major effort and accomplishment for all parts of the team, including editorial, graphics, web, and science. Analysis of the LOCA2 (Localized Constructed Analogues version 2) and STAR (Seasonal Trends and Analysis for Residuals) statistically downscaled datasets, consisting of over 100 TB of data files, was completed for a set of climate variables included in report graphics. Analysis of CMIP6 and VIC model data were completed to support other report graphics.

Fifth National Climate Assessment (NCA5). The science and data team continued to support preparation of the NCA5. The science team produced several analyses of large datasets to support the development of graphics for chapter authors. These analysis efforts include the following. Two large statistically downscaled datasets based on the CMIP6 suite of climate model simulations were obtained: LOCA2 and

STAR. Processing of these datasets on the Amazon cloud was performed to produce a suite of 16 climate variables that were requested by authors. The end products consisted of multimodel mean values for 16 CMIP6 models including both LOCA2 and STAR data. CMIP6 data were directly analyzed on the Amazon cloud to produce several graphics. Another large dataset that was analyzed and used in a number of NCA5 graphics comprised hydrologic simulations from the VIC (variable infiltration capacity) model driven by CMIP5 models. Extensive discussions and planning were undertaken to address numerous technical issues, particularly related to the question of climate model weighting.

In addition to LOCA2 and STAR data processing, the science team provided authors with data analysis and visualization support on an ad hoc basis. More than 20 NCA5 figures required GIS support, which included dataset acquisition, data pre-processing or transformation, data analysis, and/or map assembly. An additional 20+ figures required support in creating simple to complex data visualizations. For all science team contributions, significant effort was directed to the documentation of figure metadata.

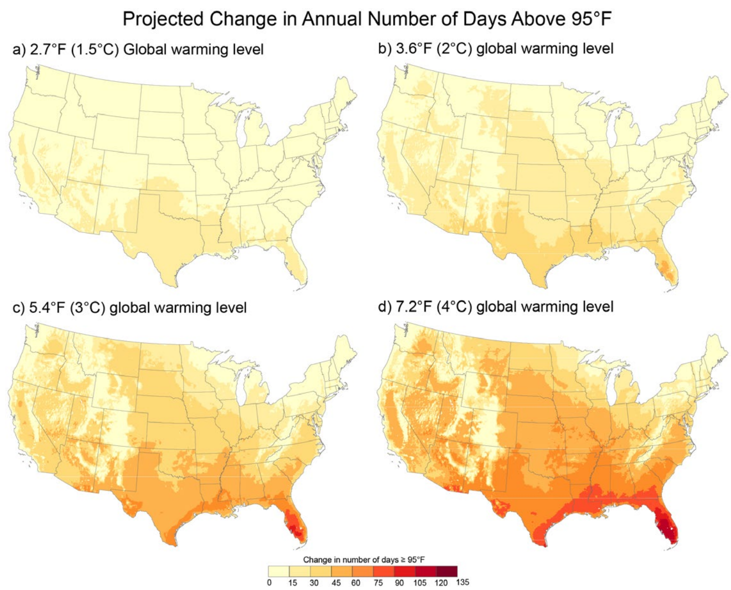


Figure 1. *Projected change in the number of days with daily maximum temperature equal to or above 95°F under four global warming levels (1.5°C, 2°C, 3°C, and 4°C). The reference period for determining the timing of reaching the particular global warming levels (GWLs) in the driving global models is 1851–1900. However, the reference period for the change in number of days is 1991–2020. Projections are averages from two downscaled datasets: LOCA2 and STAR. For each of these, 16 common global driving models are selected for averaging. As the GWL increases, the change in the number of days also increases everywhere. Data: CMIP6, LOCA2, and STAR.*

Assessment Collaboration Environment (ACE) and Information Quality. Work continued on the ACE collaborative system to improve system performance and capabilities. In an ongoing effort to comply with the Evidence-Based Policymaking Act (EBPA) and Information Quality Act (IQA), metadata collection and review was initiated for NCA5 figures. We continued interactions with the NOAA/Department of Commerce Chief Data Officer on EBPA and IQA applications to the NCA enterprise to include legally sound documentation on intellectual property and copyright permission for author contributions of text, figures, computer code, and data. Additional authors and technical contributors were successfully onboarded through the ACE registration process, with each individual personally evaluated and cleared for

Intellectual Property—a requirement in support of the EBPA in order to openly distribute their report contributions.

Data Sandbox. In support of the open data initiative of the EBPA, the TSU also deployed a Data Sandbox. This tool is meant, in part, to assist NCA authors with exploring the visualization of NCA and other climate data and parameters as part of figure development, but it will also eventually serve a broad user community. This tool is a collaborative effort with the National Environmental Modeling and Analysis Center (NEMAC). Data products were updated through 2021 to support author use in the NCA5.

Extremes Research. Research on extreme precipitation events continued. An updated analysis of historical trends was used for a figure in the NCA5 to show that upward trends remain widespread across the United States.

Products

- ACE updates
- Data analysis used for 29 figures in the NCA5 and co-production (with NCA5 authors) of an additional 40+ figures
- A suite of 16 climate variables derived from the STAR and LOCA2 datasets

Publications

Dagon, K., J. Truesdale, J.C. Biard, **K.E. Kunkel**, G.A. Meehl, and M.J. Molina, 2022: Machine learning-based detection of weather fronts and associated extreme precipitation in historical and future dlimates. *Journal of Geophysical Research: Atmospheres*, **127** (21), e2022JD037038. https://doi.org/10.1029/2022JD037038

Kunkel, K.E., T.R. Karl, D.R. Easterling, J. Biard, **S.M. Champion**, B.E. Gleason, **L.E. Stevens**, S.E. Stevens, **L. Sun**, X. Yin, and M.F. Wehner, 2022: A method for incorporation of anthropogenically-forced climate change into intensity-duration-frequency precipitation design values for the United States. *Journal of Hydrometeorology*, submitted.

Kunkel, K.E., X. Yin, **L. Sun**, **S.M. Champion**, **L.E. Stevens**, and **K.M. Johnson**, 2022: Extreme precipitation trends and meteorological causes over the Laurentian Great Lakes. *Frontiers in Water*, **4**. http://dx.doi.org/10.3389/frwa.2022.804799

Schlef, K.E., **K.E. Kunkel**, C. Brown, Y. Demissie, D.P. Lettenmaier, A. Wagner, M.S. Wigmosta, T.R. Karl, D.R. Easterling, K.J. Wang, B. François, and E. Yan, 2022: Review: Incorporating non-stationarity from climate change into rainfall frequency and intensity-duration-frequency (IDF) Curves. *Journal of Hydrology*, 128757. https://doi.org/10.1016/j.jhydrol.2022.128757

Shafiei Shiva, J., D.G. Chandler, and **K.E. Kunkel**, 2022: Mapping heat wave hazard in urban areas: A novel multi-criteria decision making approach. *Atmosphere*, **13** (7), 1037. https://dx.doi.org/10.3390/atmos13071037

Presentations

Kunkel, K.E., 2022: *"*Heavy Rain Is Increasing: Fact or Fiction" and "Climate 101." *Bureau of Reclamation Water School,* Boulder City, Nevada. October 26, 2022.

Kunkel, K.E., 2022: An Introduction to Methods to Generate High Resolution Climate Projections. *U.S.–India Partnership for Climate Resilience webinar on climate projections and precipitation data analysis for the State of Uttarakhand*, virtual. September 21, 2022.

Kunkel, K.E., 2022: Climate 101 (invited oral presentation). *Bureau of Reclamation Water School*, Boulder City, Nevada. October 26, 2022.

Kunkel, K.E., 2022: Climate Change (panel discussion). *Verisk Envision 2022 Conference,* Miami, FL. April 6, 2022.

Kunkel, K.E., 2022: Extreme Precipitation: Trends, Climatology, and Application to Precipitation Design Values, invited seminar presentation. *Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame*, Notre Dame, IN. April 19, 2022.

Kunkel, K.E., 2022: Incorporating Climate Change into Intensity-Duration-Frequency Values for the United States. *Florida International University (FIU) Institute of Environment Sea Level Solutions seminar series*, virtual. August 17, 2022.

Kunkel, K.E., 2022: Increasing Extreme Precipitation and Climate Change: Observations and Projections. *C-SAW extreme events scoping workshop, Ocean Carbon and Biogeochemistry Program*, Raleigh, NC. October 24, 2022.

Kunkel, K.E., 2022: Physical Climate Science: Downscaling & Regional Information (invited presentation). *Opening Plenary of Meeting #2 of the NCA5 Chapter Leadership*, virtual. April 4, 2022.

Kunkel, K.E., 2022: Rain Loads. *American Society of Civil Engineers Structural Engineering Institute Climate Impacts Workshop—Second Session*, virtual. May 11, 2022.

Kunkel, K.E., 2022: The Future Climate of North Carolina—Uncharted Waters (invited presentation). *North Carolina State University Osher Lifelong Learning Institute* “Our Rapidly Changing Climate” course, Raleigh, NC. November 9, 2022.

Kunkel, K.E., 2022: The Future Climate of North Carolina—Uncharted Waters (invited presentation). *Teaching for Community Resilience Fellowship Program*, Asheville, NC. April 29, 2022.

Kunkel, K.E., 2023: State of the Climate. *Electric Power Research Institute*, *Environmental Change Institute Webinar*. March 3, 2023.

Kunkel, K.E., and **X. Sun**, 2022: How Well Do CMIP6 Models Simulate Heavy Multi-Day Precipitation Events? (poster). *2022 American Geophysical Union (AGU) Fall Meeting* Chicago, IL, December 14, 2022.

Kunkle, K.E., 2022: Advancing the Estimation of Hydrometeorologic Extremes for Flood Preparedness in a Changing Climate, sessions I, II, III (co-convener). *2022 American Geophysical Union (AGU) Fall Meeting.* Chicago, IL, December 15, 2022.

Other

- Kenneth Kunkel serves as a Heavy Rainfall Expert for the American Society of Civil Engineers Structural Engineering Institute
- Kenneth Kunkel serves as graduate advisor and/or committee member for:
    - NCICS staff Brooke Stewart, NCSU/Marine, Earth, and Atmospheric Sciences (MEAS)—PhD advisor
    - Geneva Gray, NCSU/Marine, Earth, and Atmospheric Sciences (MEAS)—PhD advisor
    - Mike Madden, NCSU/MEAS—PhD committee
    - John Landy, Stony Brook University—PhD committee
- Laura Stevens serves as Chapter Lead Author for the NCA5 Indicators Appendix
- Liqiang Sun is a *Climate Explorer* team member

Assessment Technical Support Activities	
Task Team	Jessicca Allen, Sarah Champion, Linda Copley, Mark Essig, Katharine Johnson, April Lamb, Angel Li, Tom Maycock, Andrea McCarrick, Brooke Stewart-Garrod
Task Code	NC-AA-02-NCICS-JA/SC/LC/ME/KJ/AL/AL/TM/AM/BS

Highlight: The team made performance and monitoring upgrades to the Assessment Collaboration Environment and provided extensive project management, editorial, graphic design, and website development support for the Fifth National Climate Assessment (NCA5). The editorial team also provided copyediting reviews of the Scientific Assessment of Ozone Depletion: 2022.

Background

The NCA is conducted under the auspices of the USGCRP. The NCA is intended to provide the President, Congress, other stakeholders, and the public with a report on the current state of climate change science, the impacts of climate change across the Nation, and the effectiveness of mitigation and adaptation efforts. It is essential that the report be written in clear language and graphically represented in a way that is easily understood by a broad audience while maintaining the highest possible standards of accuracy and transparency. The TSU at NCEI serves as a major part of NOAA's contribution to the program as one of USGCRP's 14 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 Assessment science/data team and in coordination with NCA authors, NCEI, and USGCRP.

The CISESS TSU editorial team—Mark Essig, April Lamb, Tom Maycock, Andrea McCarrick, and Brooke Stewart-Garrod from CISESS, plus Ciara Lemery of ICF/US Global Change Research Program—provides scientific editing and writing services to the NCA authors as well as to in-house scientists/authors. They also provide technical writing/editing, copyediting, and coordination of, and contributions to, scientific figure development; coordinate in-house publication across multiple teams; and provide substantive input to product rollout and communications efforts. The team provides similar support for related assessment products that are created as part of the sustained assessment process. Team members assist CISESS 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 also help develop guidance documents that serve as foundational guidelines for NCA authors.

Jessicca Allen serves as the CISESS 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. Her tasks include creating new figures and editing other figures for accuracy and readability, preparing graphics for various pre-release drafts, graphic design work for PDF and website products, and coordinating the support for NCA5 provided by the other members of the visual communications team at NCEI.

The TSU web team—Angel Li and Katharine Johnson, with technical support from Linda Copley and requirements direction from Sarah Champion for the ACE system and metadata viewer—designs, develops, and implements online climate assessment reports (websites) with mobile device (e.g., phones and tablets) access, as well as web-based tools that support assessment processes.

Accomplishments

Updates to the Assessment Collaboration Environment (ACE) Website. The TSU Web and Data teams provided continuous updates to ACE including the following:

- Implemented performance monitoring for the ACE website and made significant performance improvements
- Refined and tested the mechanism for syncing data from ACE to USGCRP's Global Change Information System (GCIS); synced the Indicators project to GCIS

The Fifth National Climate Assessment (NCA5). The TSU continued working with USGCRP staff and NCA5 authors to support the development of report content.

- **Report Planning, Guidance, and Training:** The editorial team contributed to ongoing updates to guidance provided to authors, including enhancements to treatment of topics related to diversity, equity, and inclusion and for the "traceable accounts" sections of the report that document the processes authors follow to develop their key messages. Editors also provided planning and guidance for a new NCA5 text feature ("Focus on…" boxes) that will present cross-cutting findings on several key topics.
- **Chapter and Figure Development:** The editorial team provided detailed scientific editing and copyediting reviews of the First, Second, and Third Order Drafts of NCA5. The team prepared PDFs of each round of drafts. Editors, graphic designers, and science team staff worked closely with author teams on figure development, including participating in more than 100 meetings with authors to discuss figure ideas. Many of the more than 380 figures in the Third Order Draft were created or heavily revised by TSU staff; virtually every figure received extensive review by TSU staff, and most figures underwent multiple rounds of iteration. Authors are currently revising the Third Order Draft in response to public comments while awaiting the results of a peer review by the National Academies of Science, Engineering, and Medicine.
- **Figure Metadata and Copyright Support:** With more than 380 figures in the report, comprising approximately 1,000 figure panels, a major effort this year involved working with authors on the collection and curation of complete figure metadata and the large task of securing permissions to use figures adapted from other sources.
- **Report Website:** The web team has built the initial framework and components for the NCA5 website based on the US Web Design System and the website requirements defined by the USGCRP. Extensive work is underway to develop an innovative and attractive web presentation for the report content, including text, figures, citations, figure metadata, and other resources.
- **Art x Climate Project:** Jessicca Allen served as a committee member on the USGCRP Art x Climate project, which "seeks to strengthen partnerships between science and art and demonstrate the power of art to advance the national conversation around climate change." Selected artworks from both the youth and adult categories will be used to enhance the report and associated communication events/materials. In addition to helping select artworks, Allen is contributing to plans for incorporating pieces into the report.

Scientific Assessment of Ozone Depletion. The TSU editorial team contributed extensive copyediting reviews of the Scientific Assessment of Ozone Depletion: 2022, building on similar efforts in support of the 2018 report. The assessment, published every four years by the UN-backed Scientific Assessment Panel to the Montreal Protocol on Ozone Depleting Substances, was authored and reviewed by hundreds of experts from the World Meteorological Organization, UN Environment Programme, NOAA, NASA, and the European Union. The report notes the phase-out of nearly 99% of banned ozone-depleting substances, showing that the Montreal Protocol has succeeded in allowing the recovery of the ozone layer, thereby reducing human exposure to harmful ultraviolet rays. If current policies remain in place, the ozone layer is expected to recover to 1980 values (before the ozone hole appeared) by 2066 over the Antarctic, 2045 over the Arctic, and 2040 for the rest of the world. The assessment includes updates on trends in ozone-depleting substances, hydrofluorocarbons, and the link between stratospheric ozone changes and climate. For the first time, the assessment examines the potential effects on ozone of the intentional addition of aerosols into the stratosphere, known as stratospheric aerosol injection. The Executive Summary of the report is available at https://csl.noaa.gov/assessments/ozone/2022/, with publication of the full report expected soon.

Planned work

- Provide ongoing NCA5 user and technical support including, ACE updates and bug fixes as needed
- Support final NCA5 development stages and produce and release the web and PDF versions of the report in late 2023

Products

- Updated Assessment Collaboration Environment website

Publications

Kunkel, K.E., R. Frankson, **J. Runkle**, **S.M. Champion**, **L.E. Stevens**, D.R. Easterling, **B.C. Stewart**, **A. McCarrick**, and C.R. Lemery, Eds., 2022: State Climate Summaries for the United States 2022. NOAA Technical Report NESDIS 150. NOAA/NESDIS, Silver Spring, MD., 251 pp. https://statesummaries.ncics.org/

Climate Change Indicators	
Task Leader	Laura Stevens
Task Code	NC-AA-03-NCICS-LS

Highlight: Eleven existing indicators were updated on the *USGCRP Indicator Platform* in support of the USGCRP's efforts to maintain a comprehensive suite of climate change indicators. A new *Indicators of Climate Change* web series was launched.
http://www.globalchange.gov/indicators

Background

Indicators are observations or calculations that can be used to track conditions and trends. Indicators of climate change are designed to communicate key aspects of our changing environment, aid in assessing vulnerabilities, and inform decisions about policy, planning, and resource management. Such indicators provide foundational science in support of the sustained National Climate Assessment (NCA), including NCA5.

A set of climate change indicators is managed by the USGCRP, a consortium of 14 federal agencies, including NOAA. The current suite of 18 indicators is maintained within the USGCRP Indicator Platform, which serves as an authoritative resource highlighting data, research, and indicators-related activities. Building on USGCRP cross-agency partnerships, the platform supports NCA reports and provides scientific data that can help decision-makers understand and respond to climate change. The USGCRP Indicators Interagency Working Group (IndIWG) provides an interagency forum to support and facilitate the development and maintenance of USGCRP indicators.

CISESS NC and NCEI are working with the IndIWG to broker and administer the USGCRP indicators set, leveraging TSU expertise. Laura Stevens (CISESS NC) and Jessica Blunden (NOAA NCEI) provide scientific and technical expertise in support of the overall USGCRP Indicator Platform effort. Other CISESS NC staff aid with specific components, including metadata (Sarah Champion, April Lamb), editing (Tom Maycock, Andrea McCarrick), and website support (Katharine Johnson, Linda Copley). CISESS NC scientists Kenneth Kunkel and Carl Schreck also provide analyses for two indicators (Heavy Precipitation and Atlantic Tropical Cyclone Days, respectively). As part of the indicator update and development process, the TSU also works with CISESS NC consortium partner UNC Asheville's NEMAC in the creation of indicator graphics. Social media content and other communications products are developed in conjunction with USGCRP and NCEI.

Accomplishments

TSU staff participate in monthly calls with the IndIWG and engage with partner agencies in order to foster the development of indicators and advance indicator science. Recent efforts focused on a comprehensive update of the current indicator suite on the USGCRP Indicator Platform (Figure 1), the creation of an Indicators of Climate Change web series (Figure 2), and development of the NCA5 Indicators Appendix. The IndIWG plans to add 1–2 additional indicators to the platform in 2023, concurrent with the release of NCA5. New indicators currently in the planning stage include Regional Sea Level/Coastal Flooding, Urban Heat Island Intensity, and Wildfire Extent.

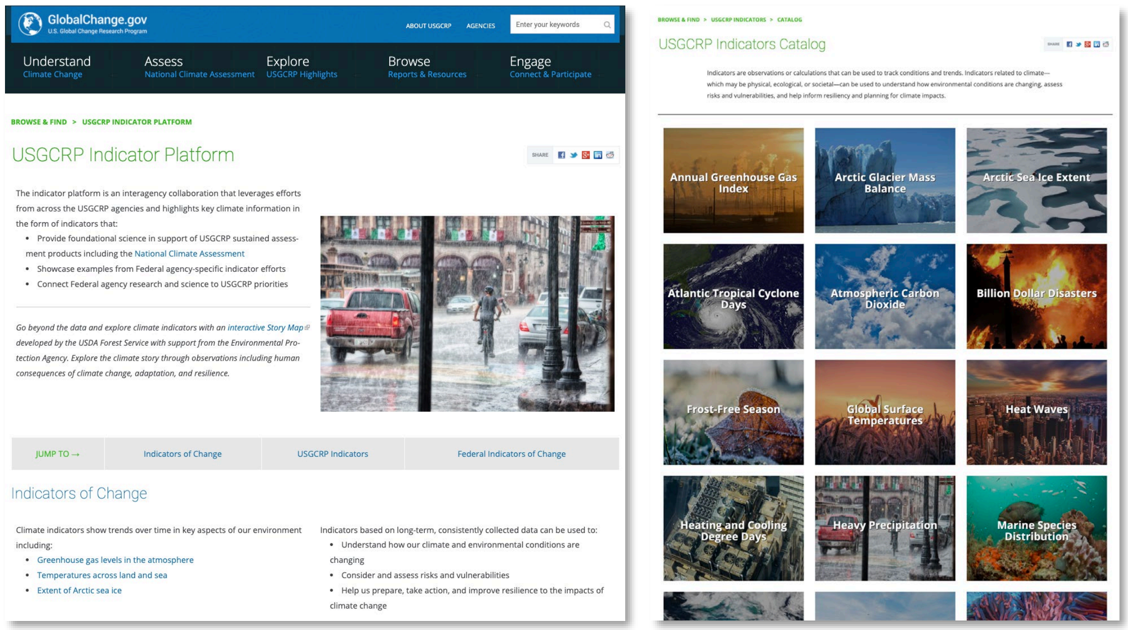


Figure 1. *The USGCRP Indicator Platform at http://www.globalchange.gov/indicators.*

Eleven indicators were updated this year on the USGCRP Indicator Platform. This included incorporation of the most up-to-date data, updated descriptions, and metadata compilation. Indicators metadata were migrated to ACE, and an improved metadata viewer was launched. Comprehensive metadata are collected annually for each indicator to provide full transparency, traceability, and reproducibility in line with NCA efforts to satisfy the IQA.

An Indicators of Climate Change web series (Figure 2) was created and launched on YouTube. This web series, developed by CISESS intern Alexis Visovatti, consists of four videos: Introduction to Climate Indicators, Global and US Temperatures, Marine Species Distribution, and Arctic Sea Ice. Associated social media content was developed, as well as a web story featuring the Billion-Dollar Disasters Indicator.

An Indicators Appendix is currently being prepared for NCA5 and has undergone both public and federal agency review. The appendix includes supplemental data and information on observed changes across the United States and will include both new and existing indicators. The appendix will support both the regional and sectoral chapters throughout the report. CISESS NC's Laura Stevens serves as Chapter Lead Author alongside EPA's Michael Kolian as the Federal Coordinating Lead Author. The rest of the author team is composed of IndIWG members associated with multiple federal agencies, including NOAA. Scientific and the TSU will provide technical support as the chapter progresses.

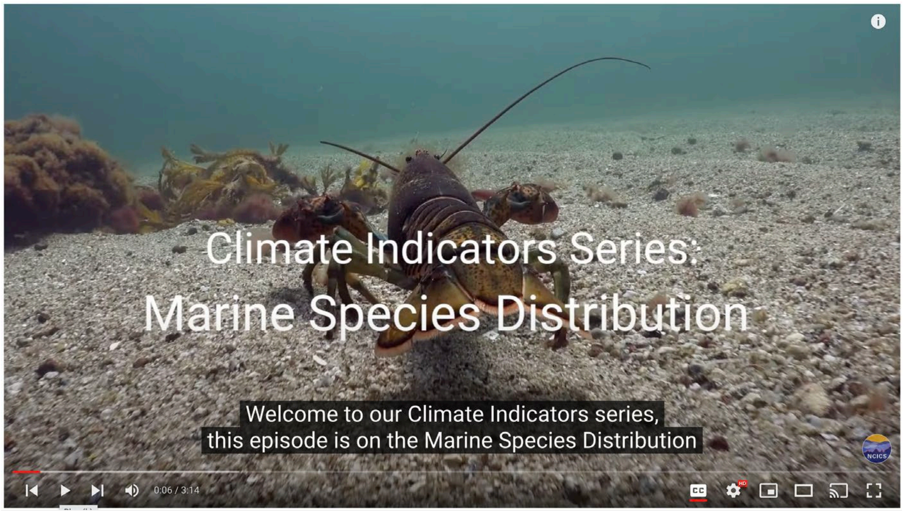


Figure 2. *A screenshot from a video featuring the Marine Species Distribution indicator. This is one component of the four-part Indicators of Climate Change series on YouTube. This web series (which includes closed captioning for accessibility purposes) explores several key indicators of our changing climate.*

Planned work

- Annual update of the USGCRP indicator suite
- Identification and development of new indicators for the USGCRP Indicator Platform in coordination with relevant federal agencies
- Coordination with other USGCRP working groups, including a workshop focused on advancing and operationalizing indicators
- Expansion of the Indicators of Climate Change web series
- Continued development of the NCA5 Indicators Appendix

Presentations

Visovatti, A., **L. Stevens**, and **T. Maycock**, 2022: Indicators: A Climate Communication Tool. *NCEI/NCICS Summer Intern Presentations*, virtual. August 10, 2022.

Products

- Eleven updated USGCRP indicators:
    - Annual Greenhouse Gas Index
    - Atlantic Tropical Cyclone Days
    - Atmospheric Carbon Dioxide
    - Billion Dollar Disasters
    - Global Surface Temperatures
    - Heat Waves
    - Heating and Cooling Degree Days
    - Sea Level Rise
    - Sea Surface Temperatures
    - Start of Spring
    - US Surface Temperatures
- Indicators of Climate Change Web Series

US–India Partnership for Climate Resilience (PCR) Activities Support	
Task Leaders	Kenneth Kunkel, Jenny Dissen
Task Code	NEC-AA-04-NCICS-KK/JD

Highlight: Under the US–India Partnership for Climate Resilience Phase II capacity-building activities, CISESS NC conducted extreme value statistical analysis of Uttarakhand gridded precipitation data and discussed findings with India partner The Energy and Resources Institute as part of ongoing planning for a technical climate projections workshop for India-based forestry managers.

Background

In September 2014, former US President Obama and Indian Prime Minister Modi agreed to a new strategic partnership on energy security, clean energy, and climate change. The US–India Partnership for Climate Resilience (PCR) aims to advance climate adaptation planning by supporting the development of climate resilience tools. Joint activities include downscaling global climate models for the Indian subcontinent, assessing climate risks at the subnational level, working with local technical institutes on capacity building, and engaging local decision-makers on climate information needs and planning for climate-resilient sustainable development, including India's State Action Plans on Climate Change.

Under a US Department of State (DOS) and NOAA interagency agreement, NCEI and CISESS continued their collaborative PCR program efforts with India government officials and climate experts to translate the previously defined needs into targeted activities for climate information analysis. Based on the successfully established partnerships with India institutions and organizations, the US and India team held technical information exchanges and climate downscaling workshops and initiated the development of other bilateral activities with the DoS. Under PCR Phase II, CISESS NC has expanded activities extending the collaboration between NCEI, CISESS NC, the Indian Institute of Tropical Meteorology, and The Energy and Resources Institute (TERI) to build the capacity of Indian scientists and policymakers in the areas of forest management, agriculture, and water resource planning.

Accomplishments

Due to continuing travel restrictions and the uncertainties of the global pandemic situation, the in-person technical workshop planned for the year was postponed. Planning for a virtual or hybrid training workshop is continuing with discussions between the CISESS/NCEI and TERI teams focused on training objectives and potential data analysis activities for the workshop participants.

CISESS NC completed initial data analysis focused on precipitation extremes in Uttarakhand. Statistical extreme value theory (EVT) was applied to Uttarakhand data supplied by TERI to better identify the magnitude and frequency of extreme precipitation events in Uttarakhand between 1970 and 2019. Preliminary data processing focused on identifying potential trends and spatiotemporal patterns in the gridded precipitation dataset across Uttarakhand. As a topographically diverse state, all-time daily maximum precipitation amounts were found to vary significantly across the state, with values ranging from 100 mm in the Himalayas to 425 mm in the northwestern foothills. Heavier precipitation totals were directly linked to the seasonal monsoon, with July being the wettest month of the year and November being the driest.

Following preliminary data exploration, more rigorous analytics activities included a variety of extreme values statistical analysis, including generalized extreme value (GEV) analysis and generalized Pareto analysis. GEV is considered a statistically rigorous method for analyzing data where the probability and occurrence of events are rare (e.g., annual maximum 24-hour precipitation).

Two primary approaches were applied: block maxima and peak over threshold (POT). These unique methods allowed the researchers to identify extreme events beyond simple quantile or percentile definitions of extreme events. The output of these methods come in the form of return intervals for different daily precipitation amounts, ranging from 1- to 100-year events. The team identified unique precipitation thresholds for extreme events across the geographically diverse state of Uttarakhand. Return intervals for each grid point vary significantly across Uttarakhand, with the lowest values (e.g., 95 mm for a 25-year return interval) generally being found in the high mountains near the Tibet border and the highest values (e.g., 240 mm for a 25-year return interval) in the southeast.

The team also assessed the potential influence of external contributing factors on extreme precipitation events to examine the role of changing climate on precipitation patterns globally. This work centered on assessing potential long-term trends in the precipitation dataset, with time and CO_2 emissions serving as contributing factors. The team also analyzed influential teleconnection patterns in the region (El Niño–Southern Oscillation [ENSO] and North Atlantic Oscillation [NAO]). GEV analysis was once again performed, with the inclusion of these covariates, but little to no influence on the modeled values has been found to date.

Data Analysis

Analysis results showed that there is significant spatiotemporal variability of precipitation in Uttarakhand, with a slight upward trend in annual precipitation over the last 50 years. Precipitation is generally heavier in the eastern region of the state, with some higher-elevation regions in the western part of Uttarakhand experiencing heavier precipitation due to orographic lifting. There are clear spatial patterns to precipitation extreme values in the region, with the northeastern (high-elevation) areas generally possessing lower extremes and the eastern plateau exhibiting higher extreme values. Figure 1 identifies the data characteristics for the analysis, whereas Figure 2 shows the role of geography in the state as it relates to extreme precipitation thresholds.

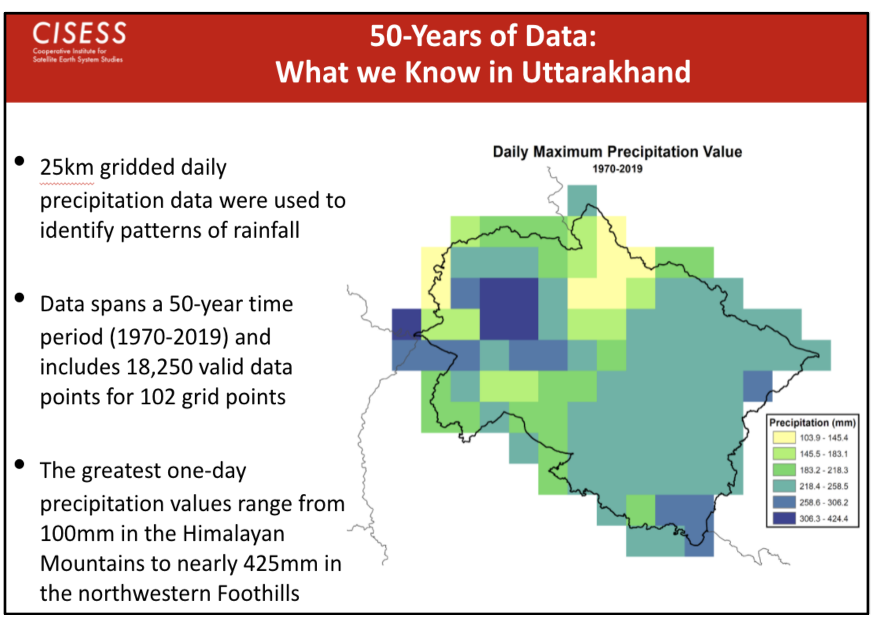


Figure 1. *Map of Uttarakhand, India, with daily maximum precipitation value. precipitation value. The data, provided by TERI, analyzed 25-kilometer gridded daily precipitation data from 1970 to 2019, representing 50 years of data.*

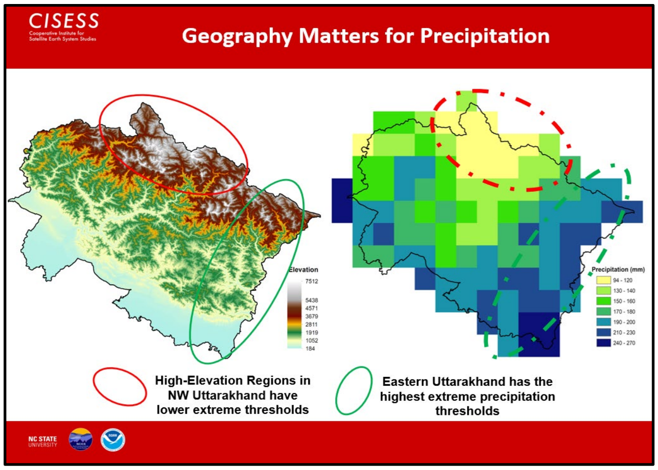


Figure 2. *Compares the elevation and topography of Uttarakhand with extreme precipitation thresholds.*

Summary of Key Findings

- Daily maximum precipitation values differ significantly between the monsoon (July–September) and non-monsoon seasons
- Four of the top 5 wettest one-day periods on record have occurred since 2000 (1985, 2011, 2013, 2010, 2003)
- A noteworthy "heavy tail" in the histogram of maximum daily precipitation across Uttarakhand indicates that EVT analyses are useful in assessing extreme events in the state
- The POT and block maxima approaches revealed generally similar estimates of extreme precipitation thresholds for each time interval
- EVT methods were successful in identifying extreme precipitation values across the state for 1-, 5-, 10-, 25-, 50-, and 100*-year periods. (*however, regional data go back only 50 years)

Analysis provided an improved understanding of extremes in the region and the ability to assess the frequency of these extreme precipitation events historically. There was a significant increase in the average number of precipitation events that exceed the 2-year return period with approximately 12+ events per decade in the 2000s and 2010s compared to approximately 8 of these events per year in the 1970s to 1990s. A majority of these exceedance events occurred in the monsoon season, in particular June–August. EVT analyses revealed significant differences in estimated precipitation thresholds of extreme precipitation across geographic and topographic regions of Uttarakhand. Expanding analyses across this diverse region will further reveal areas of concern for future extreme precipitation events.

Planned work

- USPCR activities concluded September 2022.

Presentations

Eck, M., 2022: Analyzing Extreme Precipitation Values in Uttarakhand. *U.S.-–India Partnership for Climate Resilience webinar on climate projections and precipitation data analysis for the State of Uttarakhand*, virtual. September 21, 2022.

Other

- Jenny Dissen mentored project graduate student Montana Eck

The Energy and Resources Institute Support for the U.S.–India Partnership for Climate Resilience	
Task Leader	Yogesh Gokhale
Task Code	NC-AA-05-TERI

Highlight: As part of the U.S.–India Partnership for Climate Resilience (PCR) Phase II activities, The Energy and Resources Institute (TERI), NCEI, and CISESS collaborated in organizing technical virtual webinar with forestry managers in India focused on climate downscaling and potential impacts to forestry management.

Background

The U.S.–India Partnership for Climate Resilience (PCR), launched in 2014 by former U.S. President Obama and India Prime Minister Modi, aims to advance capacity for climate adaptation planning. Under a previous interagency agreement between the U.S. Department of State (U.S. DOS) and NOAA, scientists and staff from NCEI and CICS-NC established initial U.S.–India collaborations and conducted several downscaling and capacity-building workshops for decision-makers. With the successful completion of initial PCR goals, the U.S. DOS and NCEI executed a new interagency agreement to continue PCR engagement and capacity-building activities in conjunction with CISESS. PCR Phase II goals focus on training Indian and other regional institutions, scientists, and policy makers on the technical aspects of high-resolution climate models and their applications in the areas of sustainable landscapes, natural resource management, and reforestation.

One of the initial PCR collaborations was established with The Energy and Resources Institute (TERI). TERI is a nonprofit, policy research organization based in India working in the fields of energy, environment, sustainable agriculture, forestry management, water resource planning, and climate resilience. As an organization with a vast network of professionals with expertise in climate change adaptation, mitigation, and science-based policies, TERI has the regional resources to support PCR training and other capacity-building activities.

Accomplishments

CISESS' Dr. Ken Kunkel, Jenny Dissen and intern Dr. Montana Eck worked with TERI to host a hybrid/virtual webinar entitled "Climate Data Analytics and Climate and Projections in India's Forestry Sector" on September 21st, 2022. The workshop focused on providing forestry managers in India with a background and overview of modeling and projections, the fundamentals of climate downscaling, and implications for planners looking to incorporate information into the India State Action Plan on Climate Change. The 112 participants attending the workshop represented state forestry managers from the Indira Gandhi National Forest Academy in Dehradun, Uttarakhand, India.

TERI's Dr Jitendra Vir Sharma, Senior Director of Land Resources, opened the workshop, followed by remarks from the Director of Indira Gandhi National Forest Academy. Speakers from the U.S. included Dr. Russ Vose, who spoke in place of Dr. Easterling, to provide overview, context, and background on the U.S. India Partnership for Climate Resilience. Dr. Ken Kunkel provided the overview on climate downscaling. Dr. Eck presented on applying extreme value theory to precipitation data from Uttarakhand to understand the magnitude and frequency of extreme precipitation events between 1970 and 2019. Dr. Eck also discussed findings from influential teleconnection patterns in the region (ENSO and NAO) and geographic influences as covariates in the analysis.

Planned work

This project was completed in September 2022.

Information Technology Services

Information Technology Services efforts focus on improving the underlying infrastructure support components required for NCEI to provide end-to-end services, from acquisition of environmental information to its delivery to users in a cost-effective and timely manner. The goal is to develop systems that provide acquisition, curation, archiving, analysis, and data access for the Federal Government's billion-dollar investment in high-quality environmental data.

Data are organizational assets. The quality of datasets and associated information is fundamental for achieving quality data services, ensuring the trustworthiness of the data holdings, and managing organizational risk. Requirements on research data continue to mount from scientific societies, scholarly publishers, and federal policies and laws. NCEI is the Nation's leading authority for environmental information and is responsible for shepherding that data throughout the dataset life cycle.

Effective movement of information through its life cycle requires a robust information technology infrastructure with an architecture designed to optimally address the needs of each step in the dataset life cycle. Existing NCEI architecture supporting data science, archiving, and access does not scale efficiently, redirect quickly, or shift to readily available solutions or services without redesign. The predecessor Cooperative Institute (CICS-NC) provided input and a prototyping environment to facilitate architecture development and optimize hardware and software environments to support the NCEI workflows and their migration to NOAA's Mission Science Network. CISESS NC is continuing these interactions and support.

The expanding ability of modern science to produce data presents a significant challenge to the traditional process of analyzing and interpreting that data. As NOAA positions itself to make its environmental data more readily available via commercial cloud partners through initiatives like the NOAA Open Data Dissemination (NODD) Program, the opportunity exists to collocate computation with the data. Researchers gain the ability to do computation on data located within these cloud providers, eliminating many of the data-transfer requirements that currently influence attempts to leverage cloud capabilities. Additionally, the availability of resources offered by cloud providers yields a nearly limitless opportunity to scale elastically on-demand. CISESS NC supports NCEI's information technology services efforts to deploy new technologies and move towards more efficient approaches and systems that minimize support needs and advance capability for the environmental information life cycle.

Global Historical Climatology Network-Daily (GHCN-D) Graph Database	
Task Leader	Denis Willett
Task Code	NC-ITS-01-NCICS-DW

Highlight: A prototype graph database was implemented with approximately 40% of the current reporting streams. To improve performance and accessibility of the GHCN-D, a pipeline was developed to feed a graph database in near-real time and performance test QA/QC algorithms using native graph-database approaches. These tests indicated that performance of the graph database approach exceeds that of tabular approaches.

Background

The Global Historical Climatology Network-Daily (GHCN-D) is a continually updated daily weather observation product that is assembled and standardized across more than 100,000 surface weather stations from more than a dozen different sensor networks. Each individual observation has been subjected to a common quality assurance methodology that vets the data to ensure that it is accurate and can be used as a climactically representative summary observation.

The GHCN-D dataflow process consists of a custom research code base run on machines in-house. GHCN-D contains more than 3 billion weather observations. While the database is growing at a rate of about only 1% per year in data volume, the GHCN-D processing platform is already facing challenges to its daily updating quality control process. Graph structured database technology is proposed as a solution because its native structure eliminates the need for several kinds of calculations and greatly enhances the speed with which other necessary calculations and station-to-station comparisons can be made. This project selected Neo4j as the graph database software choice, which is portable across commercial cloud vendors.

The application of graph database technologies opens the possibilities for more performant implementations of the calculations used in preparation and dissemination of GHCN-D. In addition, graph database technology immediately improves user accessibility, making it faster and more efficient to deliver users the exact data they requested.

Accomplishments

Initial Deployment. Deployment and basic import of GHCN-D data was performed from scratch in the AWS cloud based on the existing system and documentation. Its graph was then identified, analyzed, and considered against various use cases, including quality control and validation. A depiction of this graph structure (Figure 1) was shared and discussed with an NCEI Neo4j collaborative team for comparison of purpose and technique.

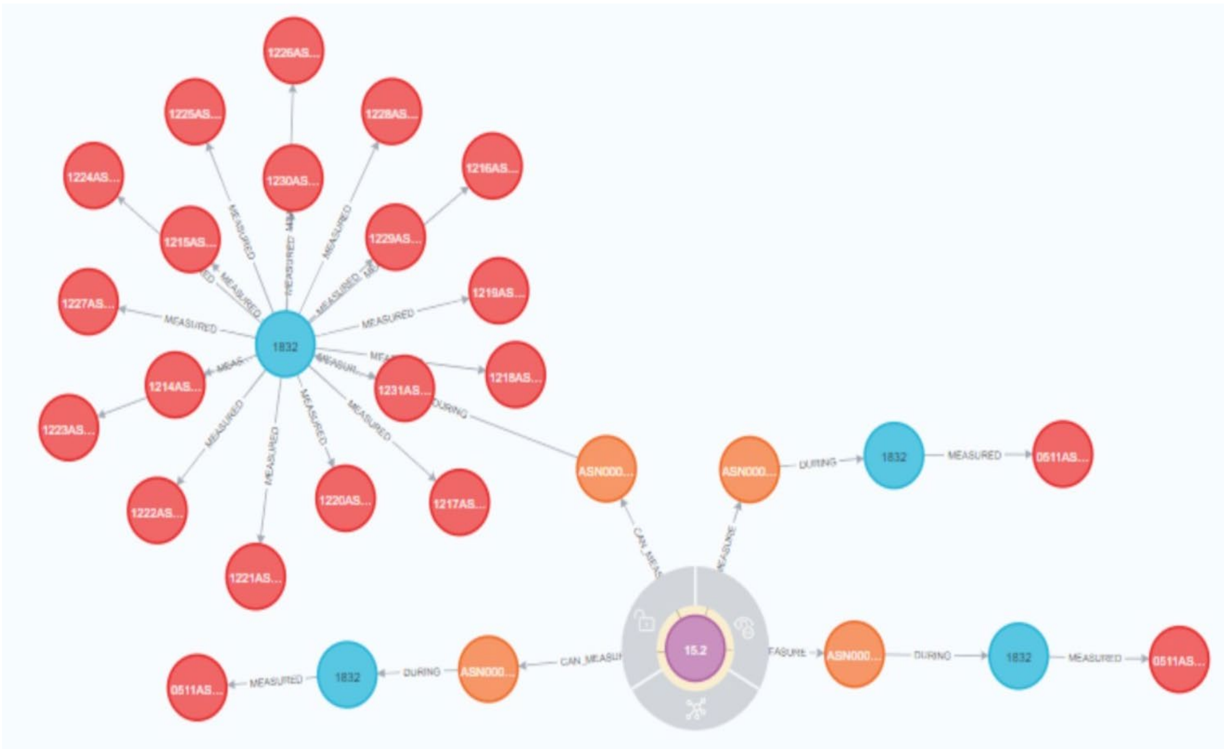


Figure 1. *GHCN-D graph data structure.*

Near-Real-Time Data Ingestion*.* To sustain the use of a graph database, data holdings must be updated as new information is available. Initial implementations of the GHCN-D graph database worked with historical data and did not have a real-time update mechanism. Our intern from NC State University developed an event-driven serverless pipeline to ingest new GHCN-D data into the NEO4j graph database directly from NODD holdings on the cloud in near-real-time.

Connecting this pipeline to the graph database allows for expanded use and utility of GHCN-D as new data are available in the same format alongside and connected with historical data.

Benchmarking Graph Database Performance for quality Assurance/Quality Control (QA/QC). A critical bottleneck in availability of GHCN-D is the calculations used to clean and process the raw data to package GHCN-D for public consumption. These QA/QC steps can take hours to run and spend an inordinate amount of time reorganizing the data to perform structured queries and nearest neighbor calculations. We compared the performance of the graph database to more traditional approaches in a benchmarking approach to determine the suitability of the graph database for facilitating these calculations. The graph database approach was orders of magnitude faster (more than 100x in some instances) in performing nearest neighbor calculations. In addition, the nature of the nearest neighbor calculations using the graph database means that algorithmic complexity scales linearly with the size of data (not quadratically nor exponentially). As we fed the benchmark tests more data, traditional calculations took exponentially more time (14 minutes for the largest test) while the graph database calculations remained flat (15 secs for the same test).

Planned work

- Expand access to GHCN-D through templated query scripts and user accessible portals.

- Implement near real-time ingest pipelines in future versions of GHCN-D graph databases.
- Disseminate results of GHCN-D performance benchmarking to incentivize use of this technology for QA/QC.

Products

- GHCN-D graph database ingest pipeline
- Performance benchmarks

Presentations

Vemuri, P., 2022: Graph Database Performance for GHCN-D. *2022 NCICS Science Seminar Speaker Series,* virtual. December 7, 2022.

Other

- Student Intern: Pradyumna Vemuri (NCSU)

NCEI Infrastructure Architecture Planning and Implementation	
Task Leader	Lou Vasquez
Task Code	NC-ITS-02-NCICS-LV

Highlight: A scalable, highly configurable on-premises workflow data processing system, NiFi, is moving towards production capability. A cloud-based archive solution using highly scalable provider solutions is under development with components demonstrated and delivered to NESDIS and NCEI projects.

Background

As NCEI user needs grow in volume, existing on-premises systems become untenable, failing to meet the expanding community requests for environmental data. Cloud services, while capable of scaling to the demand, require resources, time, and system overhaul to use effectively. Legacy systems promote continued existence, creating friction in moving to modern approaches. Increasing the core capabilities, ingest, archive, access, and discoverability, is critical to meet the expanding volume. Most importantly, improving these core capabilities promotes community use, advancing the NOAA mission to understand and predict changes in climate, weather, oceans, and coasts.

The following projects are integral to moving NCEI towards distributable, scalable architectures. The NESDIS Cloud Archive Program (NCAP) is committed to providing a cloud-based archive process, meeting the NCEI archive mission with the most up to date approaches to computing and data processing. It has leaned into the AWS cloud platform for these needs. It must provide a system to the NESDIS Common Cloud Framework (NCCF) group that works within the NCCF framework, where it is expected to operate for production uses. The Data Integration Visualization Exploration and Reporting (DIVER) project has embraced change as its goal at the center to meet its needs to archive specific customer datasets and leads the path for on-premises solutions with NCEI IT in providing the ability to meet existing and future data volume demands.

CISESS NC is well suited to learning, testing, and advising on new approaches, reducing NCEI resource re-allocation while moving NCEI forward at low risk and with high value. CISESS NC readily moves into cloud arenas as well, with fewer restrictions and other limitations commonly experienced within NCEI. This task brings value to the partnership by improving environmental data access for science and the community.

Accomplishments

The project team and its collaborators drive the development of NCEI IT infrastructure and architecture to support a modern, flexible, distributed approach to data science, archive, and access capabilities.

NESDIS Cloud Archive Program (NCAP). Renamed NCCF Archive and Access, this cross-centers team took advantage of cloud provider services and distributed modern, robust tools to support a core NCEI mission of archive.

The Archive System was designed around a Neptune knowledge graph, which encoded its configuration, storage templates, and records of processing. This graph, named vAIP (Virtual Archive Information Package), formed a core component of the system, allowing it to determine dataset processing, ontology of data, and record-keeping. This graph in turn provided a representation of the system and records of archival information packages (AIPs) for analytical querying, with internal representation by its W3C Web Ontology Language.

Integration of a real-time processing system with the knowledge graph required intelligent query approaches, a mapping tool to configure dataset processing, and performance testing to identify bottlenecks, all of which were built by this team.

Configuration mapping of graph-based information, from generalized Turtle descriptions to deployed graphs capable of processing a dataset, were performed in python via a YAML representation combined with a python tool. The YAML configuration contains variable completion from generalized graph patterns to prepared dataset templates, while a data structure mapped the disparate generic Turtle patterns into a complete, linked representation, along with key-value pairs that feed processing details to the deployed system (Figure 1.A). Upon "configuration," this process creates this structure and its components in the graph (Figure 1.B), comprising a configuration of the system, ready for processing. This configuration was then linked to files, and processing occurred both in the NCEI cloud sandbox, as well as its development cloud environment.

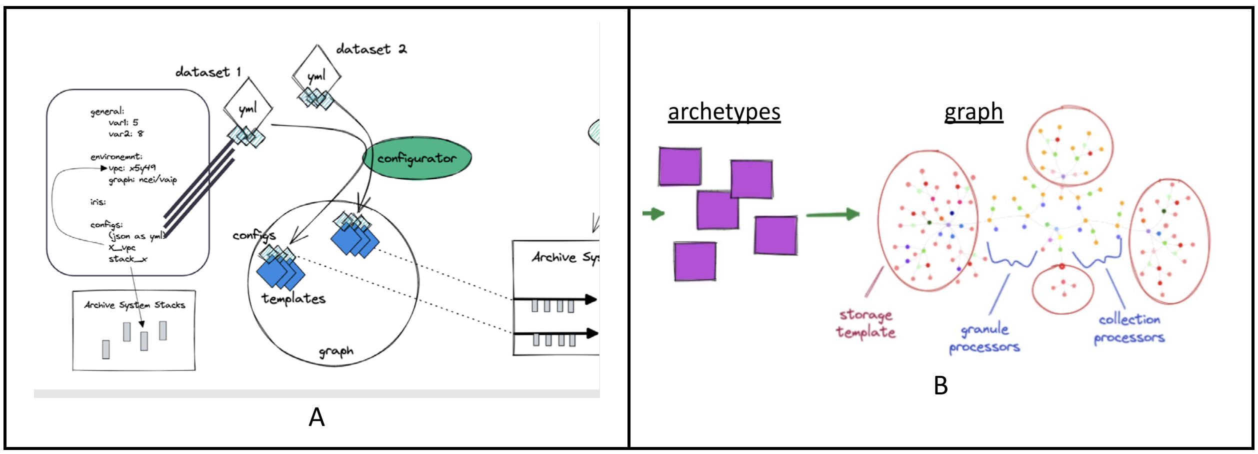


Figure 1. *Configurator Function.*

Once this Archive System was deployed along with a configured dataset, testing and debugging was performed by using the configuration tool to both deploy the system, and measure successful records created in the graph by tool functions. The results shown below (Figure 2) were then plotted for various features at multiple loads, with success/fail rates for detecting system bottlenecks, performance, and capacity.

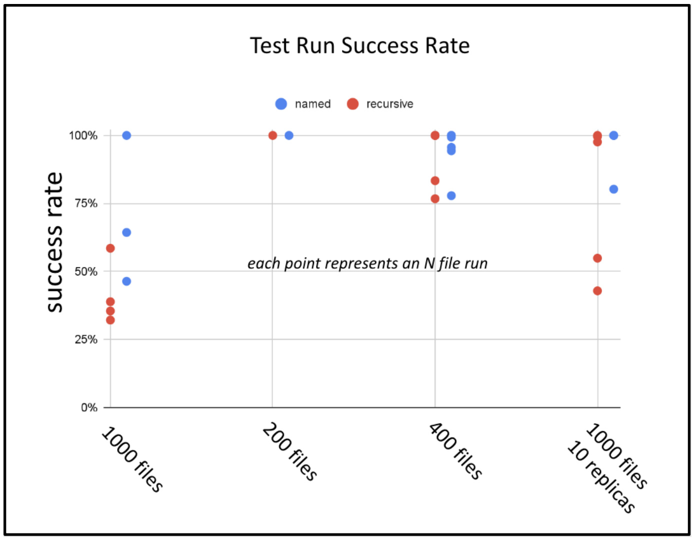


Figure 2. *Test results.*

As Neptune, an analytical database, was identified as a risk point for performance, multiple tests were performed in parallel using a testbed and the results plotted against significant features. Shown above (Figure 2) is a test of a "named graph" feature of Neptune. Due to the recursive nature of standard SPARQL queries, an indexed approach was tested, using an embedded feature of Neptune that allows a fourth field, "naming" subset of nodes and relationships, for convenient and more performant querying. This feature was implemented in the Archive System, along with the typical graph deployment, and the test results above indicate numerous tests of the feature on and off.

Figure 3 shows the testbed implemented to perform this testing with the tester modifying the configuration with a feature setting, performing configuration to deploy its graph, and kicking off a round of processing. The feature set in the graph configuration passed through the system as a configuration parameter for immediate comparison of the feature's effect, without redeploying the system itself—a lengthy process. This testbed was used by the team to compare multiple feature impacts, as they were considered for inclusion in the final system, and to debug bottlenecks encountered.

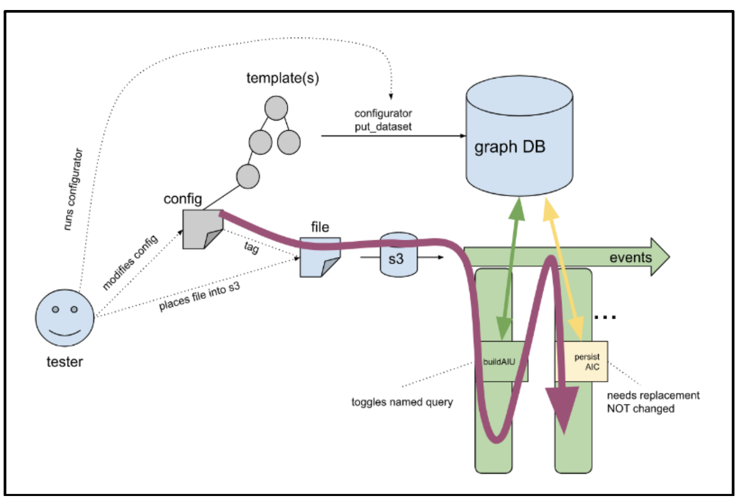


Figure 3. *Feature Testbed.*

NiFi development. This task promoted production and implementation of a NiFi processing system at the center on-premises infrastructure. Continued support was provided to project, including NiFi system debugging, custom processor package (NAR) templates for team developer completion, networking solution architecting to handle environment requirements outside of typical NiFi usage, and Jenkins job creation via NiFi CLI with NCEI IT to secure workflow deployment while allowing operator configurability.

This task continued to provide support to the NCEP Unrestricted Mesoscale Analysis (URMA) project NiFi flows while awaiting a NiFi production deployment at NCEI.

Products

- Promotion of NCCF Archive System from sandbox (5006 zone) to dev (5065 zone)
- Configuration tooling in complement of installation, for complete, operable system deploy
- Functioning named graph Archive System configuration deploy capability
- Testbed for Archive System performance testing
- NiFi workflow deploy Jenkins capability

Planned work

- This project has been completed.

Science and Services

Science and Services efforts support societal decision-making through the acquisition, monitoring, analysis, synthesis, and delivery of in situ and satellite observations; derived products; and associated information and engagement and outreach services.

CISESS NC science centers on 1) observations from instruments on Earth-orbiting satellites and surface networks and 2) predictions 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 these activities is the fundamental goal of understanding the state and evolution of the full Earth system and its interactions with human activities to promote a more environmentally responsible, resilient, and adaptive society. Collecting and processing the fundamental data on Earth system conditions, developing the models and algorithms to simulate natural cycles, assessing the possible projections, and communicating the information are critical activities in building resilience. As NCEI's collocated Cooperative Institute partner, CISESS NC provides collaborative science and services that directly support the NESDIS mission of providing "secure and timely access to global environmental data and information from satellites and other sources to promote and protect the Nation's security, environment, economy, and quality of life."

CISESS NC staff work with NCEI scientists in the development and production of new datasets, development of calibration and validation approaches for high-quality baseline climate datasets from satellite and in situ observations, reprocessing and/or reanalysis of environmental data in existing datasets, and transition of these climate-quality satellite and in situ observing datasets from research to operations. CISESS scientists also support NOAA's various climate-observing programs including the US Climate Reference Network (USCRN) and the US Historical Climatology Network (USHCN).

The public's awareness and understanding of Earth system variability, change, prediction, and projection continue to grow, and CISESS NC scientists utilize remotely sensed and in situ observations in a variety of studies to further that understanding with research focused on the Earth system's interaction with human activities such as climate (e.g., extreme heat or cold, drought, and flooding) and human health impacts. As the private sector explores practical and cost-effective approaches for addressing risks and opportunities resulting from changes in the Earth system, it continues to seek robust, reliable, and authoritative environmental information that supports its decision-making. CISESS NC will continue and/or expand these studies to help inform societal decision-making to foster healthy, resilient, and prosperous communities and businesses.

Scientific Subject Matter Expertise Support	
Task Team	Carl Schreck (Lead), Jenny Dissen, Anand Inamdar, Ronald Leeper, Olivier Prat
Task Code	NC-SAS-01-NCICS-CS/JD/AI/ RL/OP

Highlight: CISESS NC scientists served as Product Leads for 14 NCEI products and as Product Area Leads for one product area. https://www.ncdc.noaa.gov/cdr

Background

Science management practices at NCEI are evolving toward a new product-portfolio planning approach that borrows from the best practices used widely in both public and private sectors. The objective of this approach is to ensure a focus on stakeholder priorities and to align with today's government environment and expectations. To support this initiative, CISESS NC staff provide scientific and technical expertise and have been enlisted as Product and/or Product Area Leads for some of NCEI's 204 products and 15 product areas. Two of these scientists transitioned to the federal workforce during the past year.

Accomplishments

CISESS NC scientists acted as Product Lead for the following products during this reporting period:

- ISCCP-FH (Inamdar)
- AVHRR Radiances—NASA Climate Data Record (CDR) (Inamdar)
- AVHRR Cloud Properties—NASA CDR (Inamdar)
- Total Solar Irradiance CDR (Inamdar)
- Solar Spectral Irradiance CDR (Inamdar)
- CRN Science: Drought Indices (Leeper)
- CRN Science: Precipitation Extremes (Leeper)
- Blended Soil Moisture (Leeper)
- Precipitation—CMORPH (Prat)
- Standard Precipitation Index using CMORPH (Prat)
- Advanced Standard Precipitation Index using Precipitation CDRs (Prat)
- Outgoing Longwave Radiation—Monthly CDR (Schreck)
- Outgoing Longwave Radiation—Daily CDR (Schreck)
- Sectoral Engagement (Dissen)

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
- sustaining operational products 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 statements of work, as appropriate, for non-federal product development, transition, and/or sustainment activities

- providing regular status reports and participating in technical meetings

CISESS NC scientists acted as Product Area Lead for the following product areas during this reporting period:

- Extreme Storms (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, that are responsive to evolving user needs
- maintaining a life cycle management plan for portfolio products, as well as a high-level schedule to accomplish plans
- maintaining status and priority ranking of each product in the 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 acting as Product Leads and Product Area Leads to support the NOAA NCEI product inventory

Drought-related health impacts: advancing the science for public health applications	
Task Leader	Jesse E. Bell
Task Code	NC-SAS-02-UNMC

Highlight: CISESS consortium partner University of Nebraska Medical Center conducted a series of drought- and health-related interviews with state-level health departments across the country to provide better understanding of their current response to drought. The project team also conducted a study to investigate the impact of drought on the occupational psychosocial stress of Midwestern farmers.

Background

Over the last century, droughts caused more deaths internationally than any other weather-related extreme event (floods, hurricanes, etc.). Droughts in the United States, however, are not generally thought of as public health threats, even though there are known associations between droughts and negative health outcomes. By better understanding the linkages between droughts and human health and by advancing this understanding, 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. This work will inform and be incorporated into regional Drought Early Warning Systems and shared with key partners, such as state health departments, the National Drought Mitigation Center, and NOAA Regional Integrated Sciences and Assessments teams.

The project team worked on several activities in collaboration with NIDIS and CISESS to collectively address drought- and health-related issues. These project tasks will help advance the understanding of the impacts of drought on human health and identify opportunities to forge an alliance between drought and public health communities.

Accomplishments

Drought and all-cause mortality: This study explored the potential associations between drought and all-cause mortality in Nebraska from 1980 to 2014. The Evaporative Demand Drought Index (EDDI) was used to define short-, medium- and long-term drought exposures, respectively. A Bayesian zero-inflated censored negative binomial regression model was used to estimate the overall association between drought and annual mortality, first in the total population and second in stratified sub-populations based on age, race, sex, and the urbanicity class of the counties. The main findings indicate that there is a slightly negative association between all-cause mortality and all types of droughts in the total population, though the effect is statistically null. The joint-stratified analysis renders significant results for a few sub-groups. White population aged 25–34 and 45–64 in Nebraska metro counties and 45–54 in non-metro counties were more at risk. No positive associations were observed in any race besides white. Black males aged 20–24 and white females older than 85 showed protective effect against drought mainly in metro counties. Collectively, the project team also found that more sub-populations had higher rates of mortality with longer-term droughts compared to shorter-term droughts (12-month vs 1- or 6-month timescales) in both metro and non-metro counties. The results suggest that mortality in middle aged white population in Nebraska shows a greater association with drought. Moreover, women aged 45–54 were more affected than men in non-metro counties. With a projected increase in the frequency and severity of drought due to climate change, understanding these relationships between drought and human health will better inform drought mitigation planning to reduce potential impacts.

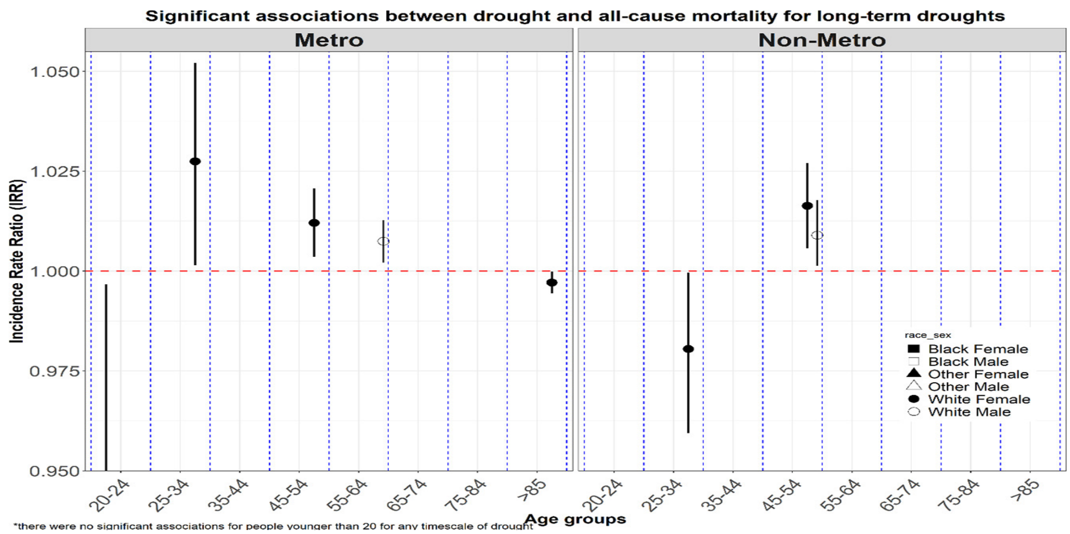


Figure 1. *Incidence rate ratios (IRRs) and their corresponding highest posterior density (HPD) intervals of the effect of short- to long-term droughts on all-cause mortality in age–race–sex population strata in metro and non-metro counties in Nebraska from 1980 to 2014. Only the significant results have been shown here, and the non-significant sub-groups have been removed from the plots. IRR values greater than 1 indicate an increase in mortality with increase in the drought exposure.*

NIDIS Drought and Public Health Strategy Document. A drought and public health strategy document was created for NIDIS. The guided discussions at the drought and health workshops and the health department interviews, and the information shared at the National Drought and Public Health Summit, identified a desire and demand for coordination, connection, and education to expand drought awareness and actions more effectively into the field of public health. This "Roadmap" is intended to serve as user-driven guidance for future investments by federal, state, and local agencies, including NIDIS and CDC that are working at the drought–public health nexus. Through shared understanding and dedicated resources, real progress can be made in meeting the goal to mitigate the public health impacts of drought events.

Figure 2. *Photograph of a guided discussion that helped inform the Drought and Public Health strategy document for NIDIS. These workshops were held at six strategic locations across the United States.*

Planned work

The project ended in December 2022; however, further distribution of the strategy document on drought and health for NIDIS will be completed in 2023.

Publications

Abadi, A.M., Y. Gwon, M.O. Gribble, J.D. Berman, R. Bilotta, M. Hobbins, and J.E. Bell, 2022: Drought and all-cause mortality in Nebraska from 1980 to 2014: Time-series analyses by age, sex, race, urbanicity and drought severity. *Science of The Total Environment*, 840, 156660. https://doi.org/10.1016/j.scitotenv.2022.156660

Jalalzadeh Fard, B., J. Puvvula, and J.E. Bell, 2022: Evaluating Changes in Health Risk from Drought over the Contiguous United States. *Int. J. Environ. Res. Public Health*, 19(8), 4628. https://doi.org/10.3390/ijerph19084628

Puvvula, J., L. Baccaglini, A. Johnson, Y. Du, J.E. Bell, and R.H. Rautiainen, 2022: Prevalence and risk factors for pulmonary conditions among farmers and ranchers in the central United States. *J. Agromedicine*, 27(4), 378-390. https://doi.org/10.1080/1059924X.2021.2025180

Presentations

Bell, J.E., 2022: Weathering Uncertainty: Conversations About Climate in Nebraska (panel discussion). Humanities Nebraska, June 15, 2022.

Bell, J.E., 2022: Climate-driven disasters. *World Federation of Public Health Associations (WFPHA) Global Public Health Week*, virtual, April 5, 2022.

Bell, J.E., 2022: Drought and Heat – Focus on Health. *NOAA Eastern Region Climate Services Webinar*, virtual, May 26, 2022.

Bell, J.E., 2022: Drought and Human Health Midwest and Missouri River Basin Workshops. *Midwest and Missouri River Basin Drought Early Warning System (DEWS) Partners Meeting*, Omaha, NE, October 13, 2022.

Bell, J.E., 2022: Extreme Weather Hazards. *Columbia University Climate Change and Health Bootcamp*, virtual, June 17, 2022.

Bell, J.E., 2022: Intersection between Drought and Human Health. *Upper Missouri River Basin Drought and Human Health Workshop*, Bozeman, MT, April 12, 2022.

Bell, J.E., 2022: Intersection between Drought and Human Health. *Pacific Northwest Drought and Human Health Workshop*, Portland, OR, October 19, 2022.

Fard, B., M. Penry, E. Kerns, and J.E. Bell, 2022: The Effect of Drought on Heat-Related Mortalities During 2000-2018 in the Conterminous United States (poster). *American Geophysical Union (AGU) Fall Meeting*, Chicago, IL, December 13, 2022.

Lookadoo, R. 2022: Drought and Health: Engaging Public Health and Other Stakeholders. *Water in the West: Towards Convergent Solutions to Water Security Regional Workshop*, Bozeman, MT, May 25, 2022.

Other

- Mentored Postdoctoral researcher: Dr. Babak J-Fard
- Advised 4 PhD students: Qianqian Li, Jagadeesh Puvvula, Hunter Jones, Abdoulaziz Abdoulaye
- Mentored MPH student: Conor O'Neill
- *The Mercury News*, California summer: why does drought make us scared, edgy, angry? (2022)
- Working Group Reviewer and Focus on the Midwest section co-author, The Lancet Countdown on Health and Climate Change: Policy Brief for the United States of America (October 2022).

Spatiotemporal distribution and habitat use of major Snapper-Grouper species in the Atlantic Ocean off the southeastern U.S.

Task Leader	Jie Cao
Task Code	NC-SAS-03-CMAST

Highlight: A species distribution modeling framework was developed, and preliminary model runs were conducted to model the spatio-temporal dynamics of reef fish communities along the Southeast U.S. Atlantic coast.

Background

Characterizing population distribution and abundance over space and time is central to population ecology and conservation of natural populations. Marine fish populations exhibit heterogeneous spatial structure driven by abiotic and biotic factors, such as habitat, environmental conditions, food, human impacts, etc. Understanding the spatiotemporal variability in distribution and abundance of marine fish population and identifying potential drivers are essential for their effective management and conservation. This is particularly important given the rapidly changing oceanic environment, which could result in habitat loss or distribution shift, either of which would have important management implications.

Studies have shown that many species on the U.S. Northeast Continental Shelf have been shifting northward or towards areas with cooler temperature. Such shifts may alter the traditional fishing ground and negatively affect local fishing communities. They also pose challenges to managers as more collaboration between fisheries managers in different regions will be required. Although many studies have been conducted to examine the shifts in distribution for species in the northeastern waters, few efforts have been made for species along the Southeast U.S. Atlantic coast.

The overall goal of this project is to better understand the spatiotemporal distribution and habitat use of major Snapper-Grouper species in the Atlantic Ocean off the southeastern U.S., including black seabass, gray triggerfish, red snapper, red porgy, and vermilion snapper. The project team aims to 1) develop species distribution models (SDMs) to map the distributions of these species; 2) validate the SDMs through hindcasting; 3) quantify habitat association for these species; 4) identify temporal changes in distributions; 5) estimate a spatial map of environmental conditions that are most correlated with the variability in the abundance of these species; and (6) forecast the distributions in the face of climate change.

Accomplishments

The project team constructed a joint species distribution (JSDM) model to simultaneously estimate the spatiotemporal distribution and densities for 21 reef fish species (Figure 1). The model separately estimates encounter probability and positive density and accounts for unobserved spatial and spatiotemporal variations using latent factors, where the correlations among species are induced. The model was applied to video data collected from a large-scale fishery-independent survey. A clustering method was applied to the results of the JSDM to group species based on spatial and spatiotemporal synchrony in encounter probability and positive density.

Strong associations were found among most of the reef fish species. However, species did exhibit differences in occupied habitat depending upon whether they have a continuous distribution throughout the shelf and/or their distribution is primarily inshore or offshore. Within their area of occupied habitat, almost all the species share similar spatial pattern of average density. However, species tend to respond to spatiotemporal drivers in different ways, so that their annual distributions may be less correlated compared with their expected average distributions. Some species show concerning declines in abundance, e.g., black sea bass, red porgy, blueline tilefish. Shifts in distribution were found for some species, e.g., black sea bass and sand tilefish.

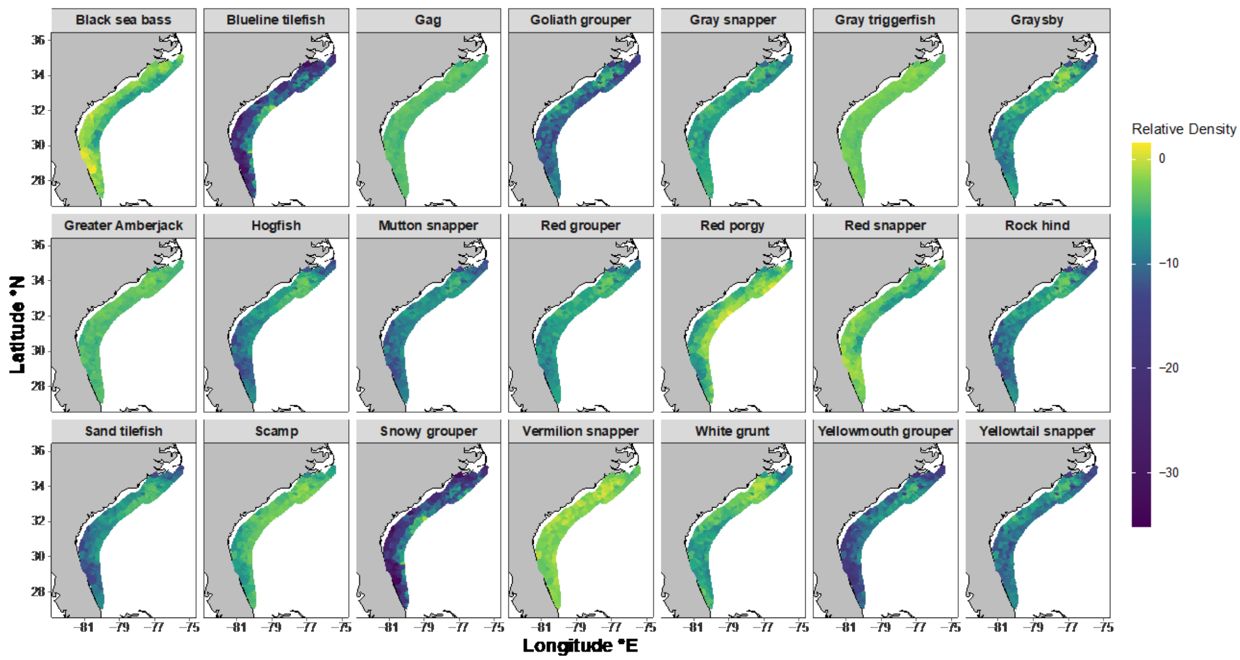


__Figure 1.__ Estimated average relative density (logarithmic scale) of each reef fish species across all Southeast Fishery Independent Survey years (2011-2021).

The findings suggest that spatiotemporal avoidance-management strategies may not be effective for reducing bycatch in these highly mixed reef fisheries due to high spatial correlations in occupied habitat and spatial pattern of density. Varying responses to environmental changes may influence the structure of emerging reef assemblages. Management attention is needed for some of the species with unknown status as they are showing a declining trend in abundance.

Planned work

- Diagnose and validate the developed joint-species distribution model
- Develop a manuscript and submit it to journal *Diversity and Distributions*
- Simulate a set of spatial management strategies and assess the ability of these strategies to meet the goal of minimizing bycatch of overfished and vulnerable species

Strategic Engagement and Outreach	
Task Leader	Jenny Dissen
Task Code	NC-SAS-04-NCICS-JD

Highlight: CISESS NC continued to build engagement capacity with sector engagement as an outcome of the Department of Commerce/NOAA Sector Listening Sessions to advance continued improvement of NOAA climate services, specifically with the retail sector.

Background

CISESS NC supports and extends NOAA mission goals of building a "Climate Ready Nation" by conducting activities in information services and user engagement through research and applied interactions with stakeholders. CISESS NC develops methods, modes, and capabilities that extend NOAA NCEI current activities in information services and service delivery. These interdisciplinary modes and methods reach a diversity of users across public and private sectors, with a focus on recognizing the demand and need to reach underserved communities.

Building upon traditional modes for engagement and outreach, CISESS NC uses both virtual and in-person methods to connect with broad members of the sectors and individual targeted members. Engagement spans business and industry, economic sectors, organizations, foundations, academia, other scientists, and the public. Activities include framing and analyzing information exchange, developing case studies, co-authoring blog stories, organizing sector-based engagement discussions and webinars, and building networks and partnerships that support capacity building.

Engagement interactions and feedback identify key needs, requirements, and information that 1) help NOAA strategically with sector interactions and 2) help guide the development of data and information products and services and their delivery. CISESS NC participates and develops new interactions with sectors to support NOAA in transforming from a scientific and technologically constrained set of products and services to recognizing the value of user input as a critical component of developing useful, actionable information.

Accomplishments

In the past year, CISESS NC activities have provided the following outcomes:

- Supporting NOAA NCEI and leadership in order to continue the dialogue with participants of the Listening Session
- Building targeted engagement capacity with the retail sector
- Conducting regional outreach and engagement with academic, university, and regional organizations/partners

NCEI Information Services Support. CISESS NC under NCEI's Climate Services and Support Division (CSSD) conducts engagement activities, and Task Leader Jenny Dissen serves as the Product Lead for CSSD sectoral engagement. CISESS NC leverages the development and use of Salesforce at NCEI to better understand user information inquiries, datasets of interest and priorities, and needs that arise from individuals or through engagement activities. CISESS NC provides input into the development of the State of the Services summary report that summarizes NCEI center-wide engagement activities and informs NCEI and NESDIS leadership about key interactions with users and sectors.

Dissen serves on the Planning Committee for the NWS Climate Prediction and Application Sciences Workshop, scheduled for May 2023. Planning activities involve abstract solicitation and review, agenda development, and organization of select panel discussion.

Department of Commerce/NOAA Listening Sessions. CISESS NC supported the development of the summary of Listening Session outcomes, which was then shared with the Department of Commerce National Travel and Tourism Office and other NOAA line offices.

CISESS NC led and supported NOAA NCEI in continuing discussions with the retail sector. Per the commitment made during the Listening Session discussions, NOAA prioritized circling back with the sector to refine input and needs so that they can be translated into products and services. CISSESS NC continued the following activities with the retail sector in collaboration with the Retail Industry Leaders Association (RILA):

- supporting co-development of a blog summary with NCEI and RILA, which is shared with RILA and other sector members via the RILA website (available here)
- hosting, along with RILA and its members, a webinar, “Using Weather and Climate Data to Advance Retail,” involving Argonne National Laboratory and Zebra Technologies
- hosting, along with RILA and NCEI, a follow-on roundtable discussion to further elucidate needs from previous engagement into actionable outcomes that were validated during the roundtable discussion

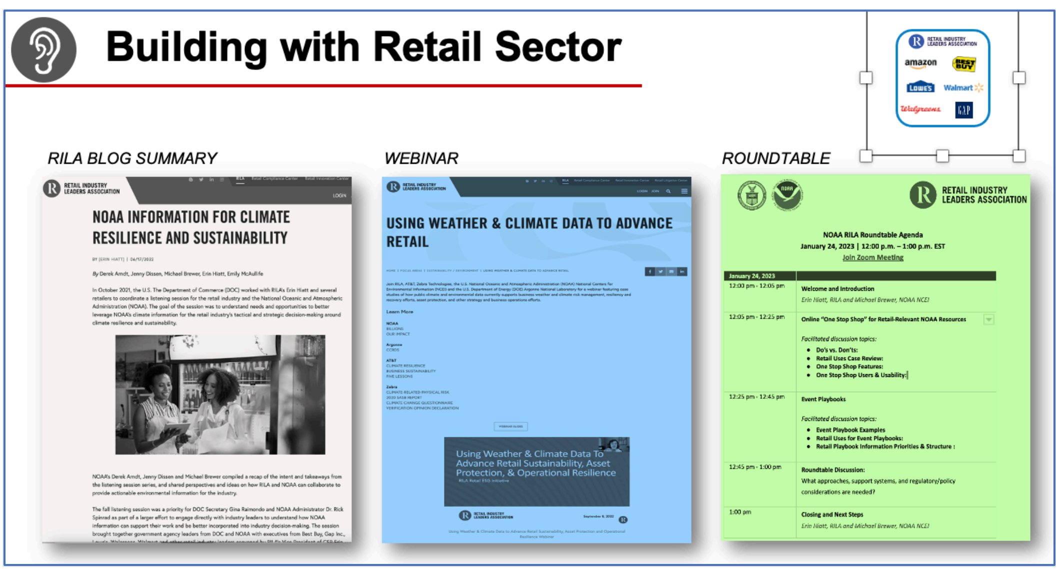


Figure 1. *Outcomes of virtual Listening Session with the Retail Industry Leaders Association, leading to follow-on engagement activities, including a blog summary, webinar, and roundtable discussion.*

The roundtable discussion highlighted several needs to which NOAA NCEI has identified actionable responses noting items that NOAA should improve or provide:

- Develop an integrated website for the retail sector that provides a links to useful NCEI and NWS datasets and expand the site based on input from RILA

- Develop tools to interact with the data (e.g., map viewers) to provide simple looks without having to download the information
- Convert products to GIS format for delivery (target products to be determined in consultation with Retail)
- Convert satellite images to GEOTIFF and make available via NCEI website
- Determine specific events (e.g., hurricane, tornado, flood, wind) and desired level of information (e.g., analysis and interpretation) to be delivered with data
- Determine pace of real-time event tracking and monitoring

Energy Sector Engagement. CISESS NC also engages with the electric energy industry. Dissen serves on the Electric Power Research Industry (EPRI) advisory board and engages with the EPRI Energy Systems and Climate Analysis group (esca.epri.com). Ken Kunkel and Dissen have been presenting to the group and its utilities members on climate information and predictions. Kunkel and Dissen gave their third presentation, "State of the Climate," at the annual State of Climate Science webcast organized by EPRI.

Education and General Public Outreach Activities. CISESS NC staff continue engagement in and advisory support for interdisciplinary outreach programs that reach K–12, higher education, other regional partners working in climate information, and the general public. The Institute conducts a robust student internship program (see Workforce Development activities) and has outreach partnerships with several regional organizations, including the Asheville Museum of Science (AMOS), Western North Carolina STEM Leaders, North Carolina School of Science and Mathematics (NCSSM), and other regional high schools. Institute staff respond to a variety of outreach requests throughout the region. While most in-person activities were curtailed or postponed due to the ongoing COVID-19 pandemic, staff were still able to provide a number of remote presentations for local groups, schools across the US, and even a class in Panama.

CISESS NC outreach activities during the past year included:
Outreach Presentations
- Schreck, C.J., 2022: Hurricanes and Natural Disasters. Skype a Scientist*, Dwight Elementary School* (New York, NY) second-grade class, virtual. April 6, 2022.
- Schreck, C.J., 2022: Weather Vocabulary and Impacts. Skype a Scientist, *Chapel Hill Christian Academy* (Clarksville, TN) pre-K class, virtual. April 21, 2022.
- Schreck, C.J., 2022: Climate Change. Enka Intermediate School sixth-grade classes. April 29, 2022.
- Schreck, C.J., 2022: Climate Change. *Black Mountain Elementary School* fifth-grade classes. May 10, 2022.
- Schreck, C.J., 2022: Becoming a Meteorologist. Career Day. *North Windy Ridge Intermediate School* (Weaverville, NC) fifth-grade classes. May 27, 2022.
- Schreck, C.J., 2022: Climate Change and Hurricanes. *North Buncombe Middle School* seventh-grade classes. October 12, 2022.
- Schreck, C.J. and L.E. Stevens, 2021: Science Communication, panel discussion. *NCICS Weekly Intern Seminar Series*, virtual. July 6, 2022.
- Schreck, C.J., 2022: The MJO and Equatorial Waves. *Rutgers University Subseasonal Forecast Contest* webinar. July 28, 2022.
- Schreck, C.J., 2022: Madden–Julien Oscillation (MJO). *University of North Carolina Asheville* Tropical Meteorology class. September 7, 2022.
- Willett, D., 2022: Machine Learning in Earth System Science. *University of North Carolina Asheville* Biology and Environmental Studies Departmental Seminar Series, October 20, 2022.

Outreach Events

- Douglas Rao and Erika Wagner hosted an outreach table at the *Conserving Carolina Earth Day Festival* (Tryon, NC), April 22, 2022.
- Emma Scott hosted an outreach table at the *Schiele Museum Weather Proof* event (Gastonia, NC), July 23, 2022.
- Laura Stevens, Douglas Rao, Carl Schreck, and NCEI's Jared Rennie and Deke Arndt taught a 5-week *North Carolina Arboretum* hybrid adult education course (Asheville, NC), "Climate Change Science," and presented:
    - "Climate Variability" (Schreck, virtual, October 4, 2022)
    - "Climate Trends and Extremes" (Stevens, virtual, October 11, 2022)
    - "Climate Projections" (Rao, virtual, October 13, 2022)
    - "Hurricanes and Climate Change" (Schreck, virtual, October 18, 2022)
    - "Lunch and Learn" (Schreck, Stevens, Rao, and Rennie, in-person, October 20, 2022)
    - "Lunch and Learn" (Stevens, Rao, and Arndt, in-person, November 1, 2022)

Planned work

- Continue engagement with RILA and retail sector by involving the industry solution-provider network for their feedback on products and services
- Convene and host retail panel discussion at the upcoming 2023 CPASW held in Asheville, NC
- Develop partnership for outreach support with AMOS, NCSSM, and Mountain True

Presentations

Brewer, M., D. Arndt, **J. Dissen**, J. Poplawski, J. Okrend, and A. Smith, 2023: Outcomes from NOAA Climate Listening Sessions, *103rd American Meteorological Society Annual Meeting Meeting*, virtual. January 11, 2023.

Dissen, J., 2022: Understanding and Valuing JPSS Data. *Joint Polar Satellite System (JPSS) Science Meeting.* Vandenberg Space Force Base, CA, November 9, 2022.

Dissen, J., 2022: Water and Society: Water Scarcity Impacts on Local Communities and Economies. (co-convener). *2022 American Geophysical Union (AGU) Fall Meeting,* virtual. December 15, 2022.

Dissen, J., and **L.E. Stevens**, 2022: Key Findings from the North Carolina Climate Science Report. *Independent Insurance Agents of North Carolina (IIANC) E&O and Disaster Symposium*, hybrid. Boone, NC, October 25, 2022.

Kunkel, K.E., and **J. Dissen**, 2023: "State of the Climate" Perspectives from Climate Science and National Climate Assessment. *Electric Power Research Institute Annual State of the Climate Webcast*, virtual. March 1, 2023.

Other

- Supported the Department of State–funded project, Developing the Next Generation of Female Environmentalists, at NCSU's Department of Marine, Earth and Atmospheric Sciences: https://us-pakistan-project-meas.wordpress.ncsu.edu/
- Supported AMOS: advisory support, summer camp planning, and selection of speakers
- Served on the NCSSM Morganton Campus External Engagement Steering Team: http://ncssm.edu/
- Served as a newly appointed board member of Mountain True.

Optimum Interpolation Sea Surface Temperature (OISST) Algorithm Upgrades	
Task Leader	Garrett Graham
Task Code	NC-SAS-05-NCICS-GG

Highlight: After upgrading the OISST algorithm from v2.1 to v2.1a by integrating the ACSPO L3S LEO satellite products as the algorithm's new satellite source in late 2021, the OISST scientific team completed their analyses of the new satellite sources and their interactions with the OISST operational algorithm. The team made significant progress towards upgrading the product to v3.0, which will include a historical reanalysis of the CDR during the modern satellite era and a significant re-architecting of the operational algorithm's software. https://www.ncdc.noaa.gov/oisst

Background

Since its launch in September 1981, NOAA's Optimum Interpolation Sea Surface Temperature (OISST) product has been one of the premier international satellite-based sea surface temperature datasets and is widely recognized as one of the best for climatological applications. Over the product's history, the OISST scientific team has repeatedly upgraded the operational algorithm in response to emergent challenges and improvements in scientific instrumentation and computational methodologies. In late 2021, the OISST team switched the algorithm's radiometry satellite sources from the European Space Agency's (ESA's) MetOpA and MetOpB satellite platforms to the NOAA STAR Advanced Clear Sky Processor for Ocean (ACPSO) L3S Low Earth Orbit (LEO) Sea Surface Temperature (SST) product. This switch was made in response to the ESA's planned deorbiting of the MetOpA satellite platform. Since the ACSPO product uses a mixture of both VIIRS and AVHRR FRAC instruments from a number of ESA and NOAA satellites, thorough analyses were performed to characterize the improvements in the OISST product.

Accomplishments

After characterizing the improvements to the OISST product that derived from the incorporation of the ACSPO L3S LEO SST products into the near real-time (NRT) operational algorithm, the OISST team performed detailed analyses of the ACSPO L3S LEO satellite products and their interaction with the OISST v2.1a NRT product to understand if further improvements could be made to the CDR product. Several improvements were identified and will be incorporated into the NRT product in the next algorithm version. The OISST team then set about preparing for the upgrade from OISST v2.1a to OISST v3.0. This upgrade will contain a number of significant improvements, including a completely re-architected OISST algorithm that uses an object-oriented scientific programming paradigm and Python in place of Bash scripting control layer; a historical reanalysis product that utilizes the ACSPO L3C datasets for satellites NOAA 07–19, which covers the period from 1981 to present; and a new sea ice dataset and an improved sea-ice-to-SST conversion method. Thus far, the scientific task team has written and tested the new Python control layer for the OISST algorithm, with preliminary benchmarking suggesting that it is several times faster than the older control layers while containing less code and being more flexible than its predecessors. In addition, in preparation for the historical reprocessing, the OISST team has characterized biases in the ACPSO L3C satellite products and analyzed how the biases remain after de-biasing with OISST's EOT bias-correction module. The team especially focused on the early NOAA satellites, from NOAA 07–12, which flew with early-generation AVHRR instruments and sometimes dealt with suboptimal orbits that introduced additional idiosyncrasies to their datasets. Finally, the OISST team performed in-depth analyses of the National Snow and Ice Data Center's (NSIDC's) Sea Ice Index CDR to characterize the product and ensure its successful integration into OISST v3.0.

Planned work

- Integrate NSIDC's Sea Ice Index CDR as OISST v3.0's sea ice source
- Incorporate Banzon et al.'s (2020) improved sea-ice-to-SST estimation algorithm into OISST v3.0
- Reprocess the entire OISST historical period (from 1981 to present) using the ACSPO L3C reanalysis dataset for OISST v3.0's reanalysis product
- Operationalize OISST v3.0

Publications

Huang, B., X. Yin, J.A. Carton, C. Liu, **G. Graham**, C. Liu, T. Smith, and H.-M. Zhang, 2023: Understanding differences in sea surface temperature intercomparison. *Journal of Atmospheric and Oceanic Technology*. https://doi.org/10.1175/JTECH-D-22-0081.1

Products

- Optimum Interpolation Sea Surface Temperature v2.1a

Weather and Climate Change Monitoring and Research Support of the Atmospheric Turbulence and Diffusion Division of National Oceanic and Atmospheric Administration's Air Resources Laboratory

Task Leader	Mark Hall
Task Code	NC-SAS-06-ORAU

Highlight: Oak Ridge Associated Universities (ORAU) works with the NOAA Air Resources Laboratory (ARL) to expand and sustain the U.S. Climate Reference Network's observational capability and supports other ARL atmospheric research, for example, the deployment of a new uncrewed aircraft into Hurricane Ian to monitor the growth and movement of the storm.

Background

NOAA ARL's Atmospheric Turbulence and Diffusion Division (ATDD) plays a vital role in supporting atmospheric science and technology research aligned with NOAA's objectives to build and maintain a Weather Ready Nation, enhance the nation's abilities in climate adaptation and mitigation, and promote a holistic understanding of the Earth system through research and the development of an integrated environmental modeling system. ATDD also provides critical expertise in the provision of high-quality data from climate reference networks and boundary layer instrumentation. These networks and instrumentation contribute to improved understanding of climate variability and change across the U.S. and understanding and prediction of weather systems affecting the nation.

In FY2008, ATDD and ORAU were named as the collaborative team to design, install, and maintain a U.S. Climate Reference Network (USCRN) and, in FY2010, to expand the USCRN into Alaska (ACRN). The USCRN is now a systematic and sustained network of climate monitoring stations deployed across the contiguous United States, Hawaiʻi, and Alaska. These stations use high-quality calibrated instrumentation to measure temperature, precipitation, wind speed, soil (temperature and moisture) conditions, humidity, land surface (infrared) 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. Highly accurate measurements and reliable reporting are therefore critical. Each station transmits data hourly to a geostationary satellite. Within minutes of transmission, raw data and computed summary statistics are made available on the USCRN web site.

Some of this work was completed by ORAU through the NOAA Cooperative Institute for Climate and Satellites (CICS). ORAU engineers and technicians are now maintaining and expanding the USCRN to ensure the climate observing systems continue to deliver high quality environmental data through CISESS.

Accomplishments

While expanding and sustaining USCRN's observational capability is the primary aim of this project, ORAU also supports other ATDD research and development activities throughout the year. Primary accomplishments during the last year included:

- Annual instrumentation calibration and site maintenance for all current 140 USCRN sites (115 sites in the lower 48, 2 in Hawaiʻi, and 23 in Alaska) was completed.
- A new uncrewed aircraft (Area-I Altius), designed with a slim, tubular body and a 4' wingspan, was deployed from NOAA WP-3 aircraft into Hurricane Ian near the west Florida coast. Data radioed from the drone as it flew into the eyewall and other critical parts of the storm were sent in near real-time to forecasters at the National Hurricane Center to better predict the hurricane's track

and intensity, as well as improve computer models used for future hurricane prediction. Data from this historic flight are still being analyzed, but promise to yield new insights into the structure of the eyewall and the energy exchange between the ocean's surface and the lowest layer of air in the storm, known as the boundary layer.

Figure 1. *Project staff conduct annual maintenance at the USCRN Yakutat site.*

Figure 2. *Project staff had to access the Denali USCRN site by helicopter for this year's maintenance because the road was impassable.*

- *A* balloon was launched on Friday, March 3, from ATDD for the local Morristown NWS Weather Forecast Office to help forecast the severe weather that moved through eastern Tennessee that afternoon.
- ORAU team members assisted with the upgrade of the DCNet measurement site atop the Herbert C. Hoover Building, home to the Commerce Department Headquarters. The 20-year-old aluminum towers were replaced with new, non-tapered triangular towers; all of the meteorological instrumentation (3-D sonic anemometers, T, RH, solar radiation, and propeller-driven wind vanes) were replaced with new equipment; TB4 tipping-bucket rain gauges were added to each tower; and the obsolete 3G communications modems were upgraded to 4G technology. Upgrades were completed in March 2023.
- Edward Dumas, ORAU drone operator/pilot, traveled to Norman, OK, for construction, flight testing, and training on the latest version of the University of Oklahoma's CopterSonde rotary-wing small uncrewed aircraft system (sUAS). This sUAS is custom built with temperature, pressure, and moisture sensors inside a 3D-printed ducted shell. The CopterSonde also features custom autopilot software that faces the sUAS into the wind, acting as a wind vane for optimal sensor aspiration and wind direction determination. Wind speed and direction is derived from inertial measurements. Observations will be used to better sample surface and boundary layer processes and improve the ability to parameterize them in weather forecasting models.

In August 2022, an ATDD team traveled to Prudhoe Bay in Alaska to finalize site locations to start ground-based observations to support the 2023 Flux Observations of Carbon from an Airborne Laboratory (FOCAL) campaign. FOCAL is designed to measure emissions of carbon dioxide and methane, nitrous oxide, and water vapor over the North Slope of Alaska. Funded by the National Science Foundation, FOCAL is a cooperative effort among the Anderson Group from Harvard University, Columbia University, Aurora

Flight Sciences, ORAU, and NOAA/ARL/ATDD. It aims to bridge the scale gap between local studies of carbon emissions in the Arctic, such as those from flux towers, and large regional estimates of emissions from inversion modeling by utilizing airborne measurements.

Planned work

• Annual instrumentation calibration and site maintenance for all current 140 USCRN sites.
• Installation of 2 new Alaska sites.
• Installation of temporary towers near Prudhoe Bay (Alaska).

Publications

Krishnan P., and S. Wang, 2023: Editorial for the Special Issue "Understanding Biosphere–Atmosphere Interactions with Remote Sensing." *Remote Sensing.* **15(2)**, 332. https://doi.org/10.3390/rs15020332

Gallo, K., and P. Krishnan, 2022: Evaluation of the Bias in the Use of Clear-Sky Compared with All-Sky Observations of Monthly and Annual Daytime Land Surface Temperature. *Journal of Applied Meteorology and Climatology*, **61**, 1485–1495. https://doi.org/10.1175/JAMC-D-21-0240.1

Wilson, T. B., J. Kochendorfer, H.J. Diamond, T.P. Meyers, M. Hall, B. French, L. Myles, and R.D. Saylor, 2022: A field evaluation of the SoilVUE10 soil moisture sensor. *Vadose Zone Journal*, **00**, e220241. https://doi.org/10.1002/vzj2.20241

Presentations

T. J. Schuyler, E. Dumas, F. Panwala and N. Clark, 2022: Utilizing (sUAS) to advance atmospheric science and sUAS flight collection of boundary layer meteorological data. *Appalachian Research Commission STEM camp*, July 2022.

GOES Imager Fundamental Climate Data Record (FDCR)	
Task Leader	Anand Inamdar
Task Code	NC-SAS-07-NCICS-AI

Highlight: In support of the creation of an FCDR for all satellites from SMS-1 through GOES-15 (1974–2018), the team initiated surveys of calibration methods and completed a preliminary study comparing calibration from four different methods for the visible channel of GOES-8 through GOES-12.

Background

Currently archived historical GOES imager data for SMS-1, SMS-2, and GOES-1 to GOES-15 are not easily accessible and useable for the following reasons:

- Archived data formats vary from one satellite to the other and are difficult to use
- There are gaps in the data archive
- Historical imagery has duplicates with no metadata explanation
- Calibration is not included
- The download process is arduous

This multiyear project will create a static GOES imager Fundamental Climate Data Record (FCDR) for all historical GOES imagers from SMS-1 through GOES-15 (1974–2018) with uniform format, data quality assessment, calibration, and navigation.

Accomplishments

- Extensive survey of various calibration methods for the GOES imager visible, infrared, and water vapor channels are underway.
- A recent study by Heidinger et al (2022) on using the full-disk reflectance shows great promise for performing calibration of earlier GOES imagery with insufficient data and spectral response functions.
- A preliminary study comparing calibration from four different methods (Figure 1) for visible channel of GOES-8 to GOES-12 satellites was completed.

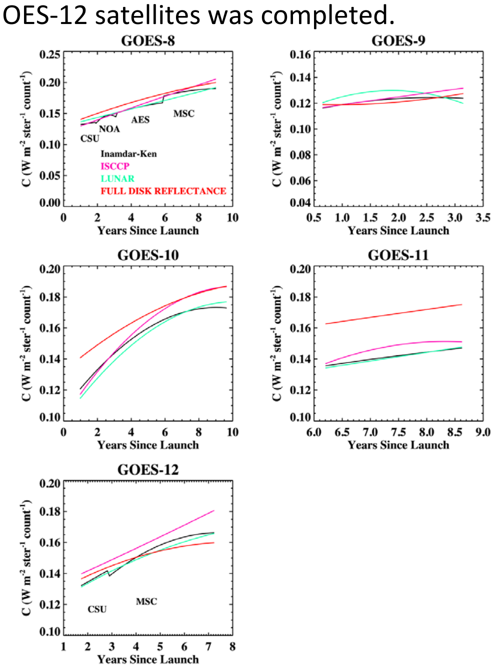


Figure 1. *Inter-comparison of GOES visible channel calibration for GOES-8 to GOES-12 using four different methods.*

Planned work

- Extend intercomparison to earlier GOES series (SMS-1 to GOES-7)
- Continue survey of existing literature on GOES imager channels calibration and assess and evaluate the different approaches
- Perform new calibrations as necessary
- Define the FCDR format using the GOES-R format as a template

Presentations

Matthews, J., K. Knapp, A. Heidinger, **A.K. Inamdar**, J. Robaidek, and D. Santek, 2023: GOES Imager Fundamental Climate Data Record (FCDR), *GSICS Annual Meeting,* virtual. March 2, 2023.

HIRS-Like Data from New-Generation Sensors	
Task Leader	Anand Inamdar
Task Code	NC-SAS-08-NCICS-AI

Highlight: HIRS-like data from the EUMETSAT's IASI data have been produced up to the current period, and results have been published in a peer-reviewed journal.

Background

The High-resolution Infrared Radiation Sounder (HIRS) instrument has flown on the NOAA series of polar satellites (TIROS-N to NOAA-19) and on the Metop-A and Metop-B platforms operated by the European Organisation for the Exploration of Meteorological Satellites (EUMETSAT). It has provided valuable data for short-term weather prediction and is useful for deriving long time series CDRs for atmospheric temperature, moisture, ozone, cloud climatology, upper-tropospheric moisture, outgoing longwave radiation, etc. For example, the atmospheric temperature and humidity profiles generated by the neural network analysis of HIRS data at 16 vertical levels form an important ancillary input to the International Satellite Cloud Climatology Project (ISCCP) processing at NCEI. With NOAA-19 being the last polar orbiter to carry the HIRS instrument, an effort is underway to employ next-generation sensors, such as the Infrared Atmospheric Sounding Interferometer (IASI) and NOAA's Cross-track Infrared Sounder (CrIS), to extend the record of HIRS-like data into the future. The multi-step process includes 1) developing the capability to process IASI and CrIS data to simulate HIRS, 2) performing limb correction of the resulting HIRS-like data, 3) developing schemes for cloud clearing, and 4) developing intersatellite calibration to produce the HIRS-like pixel data.

Accomplishments

- Inter-instrument and intersatellite calibrated IHIRS data have been produced up to the current period, and software for operational production is ready to be deployed. Results have been published in a peer-reviewed journal.
- IASI-simulated HIRS (IHIRS) data are being produced in-house.
- CrIS-simulated HIRS data are being produced in-house.
- Preliminary comparisons with HIRS showed good similarities (Figure 1).

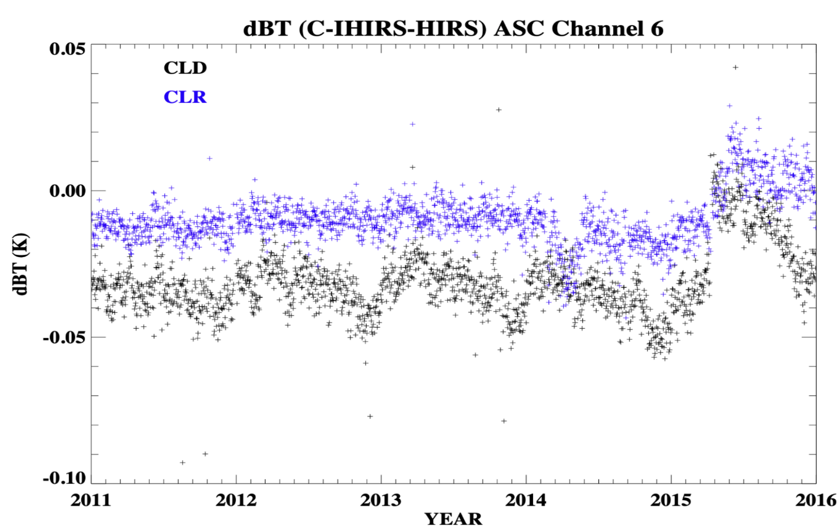


Figure 1. *Time series of difference in brightness temperatures between calibrated IHIRS (C-IHIRS) and HIRS (dBT) for channel 6 for cloudy (black) and clear (blue) sky conditions.*

Planned work

- Begin production of CrIS-simulated HIRS (CHIRS) data
- Apply limb-correction to the CHIRS data
- Develop table for intersatellite and inter-instrument calibration
- Produce calibrated C-CHIRS data
- Publish results

Presentations

Inamdar, A.K., L. Shi, H.-T. Lee, D.L. Jackson, and J.L. Matthews, 2023: Extending the HIRS Data Record Using Simulated HIRS Data Derived from the Infrared Atmospheric Sounding Interferometer (IASI). *103rd American Meteorological Society Annual Meeting.* Denver, CO, January 12, 2023.

Publications

Inamdar, A.K., L. Shi, H.-T. Lee, D.L. Jackson, and J.L. Matthews, 2023: Extending the HIRS data record with IASI measurements. *Remote Sensing*, **15** (3), 717. https://www.mdpi.com/2072-4292/15/3/717

Hydrological, Technical and Decision-Support System Development and Enhancement for the National Weather Service Office of Weather Prediction	
Task Leader	Michael Kane
Task Code	NC-SAS-09-RTI

Highlight: CISESS Consortium Research Triangle Institute (RTI) staff supported National Weather Service Office of Weather Prediction research and development efforts utilizing new cloud technology, the implementation and evaluation of a new flying platform for the Airborne Gamma Snow Survey, and the development of new products and internal data service software improvements.

Background

The National Weather Service (NWS) Office of Water Prediction (OWP) ingests daily ground-based, airborne, and satellite snow observations from all available electronic sources for the coterminous United States. These data are used along with estimates of snowpack characteristics generated by a physically based snow model to generate the operational, daily NOAA National Snow Analyses (NSA) for the coterminous U.S. The SNOW Data Assimilation System (SNODAS) snow model is an energy-and-mass-balance, spatially-uncoupled, vertically-distributed, multi-layer snow model run operationally at 1-km^2 spatial resolution and hourly temporal resolution for the United States. Ground-based and remotely sensed snow observations are assimilated daily into the simulated snow-model state variables. The NSA provide information about snow water equivalent, snow depth, surface and profile snowpack temperatures, snowmelt, surface and blowing snow sublimation, snow-surface energy exchanges, precipitation, and weather forcings in multiple formats.

OWP maintains the Airborne Gamma Radiation Snow Survey Program to make measurements of snow water equivalent (SWE) and soil moisture using gamma radiation remote sensing. This unique observation system includes low-flying aircraft, operated by the NOAA Corp officers, to conduct surveys in 37 states, including Alaska, as well as nine Canadian Provinces. The airborne snow survey is essential in maintaining the reliability of water resources forecasts, watches, and warnings and increases the effectiveness of impact-based decision-support systems. The airborne gamma SWE and soil moisture observations are used by the NWS Weather Forecast Offices and River Forecast Centers when issuing river and flood forecasts, water supply forecasts, and spring flood watches and warnings, and guidance. These observations are also incorporated into the OWP NSA via SNODAS. Additionally, numerous federal, state, and municipal agencies use airborne SWE and soil moisture data in their decision support systems and programs. Crucially, airborne observations are the only soil moisture and SWE observations the United States have in many remote areas.

In addition to snow data collection and modeling, the NWS OWP generates hourly, continental-scale streamflow forecasts via the National Water Model (NWM). NWM forecasts are used by the OWP Water Prediction Operations Division (WPOD) and NWS field offices to inform flood guidance and warnings. Evaluation of the operational NWM forecasts, particularly after significant flood events, is critical for WPOD and field offices to understand the reliability of the forecasts and how to best incorporate them into their guidance products. OWP also researches and develops precipitation frequency estimates for various areas of the US, published as volumes of NOAA Atlas 14.

Accomplishments

CISESS consortium partner the Research Triangle Institute (RTI), through its Center for Water Resources (CWR), is supporting NWS OWP research and development efforts focused on snow observations and related products. This year's activities included migration of several products to a cloud environment to expand OWP capabilities from in-house directed products to those that are more readily disseminated to the wider public, incorporation of a new flying platform for the Airborne Gamma Snow Survey and the associated development and distribution of new operational Airborne Gamma Products, internal data service improvements, and daily snow briefings in support of the WPOD.

National Snow Analyses to the Cloud. In addition to the flood inundation project that OWP is migrating to a cloud environment, OWP is finishing up the migration of the backup (secondary processing cluster) of the NSA system (www.nohrsc.noaa.gov) to the cloud, which is currently running on out-of-date hardware. This project is now live, providing backup support to the primary system. OWP is currently working on improving the cloud-native monitoring systems. Migration of the primary processing cluster to the cloud environment is planned for later this year.

Internal Water Resources Data Service Support. OWP deploys many internal services that serve data towards operational product generation, model output evaluation, and other projects under development. One of the pieces of software that ingests data into the system has been improved to simplify points of failure.

National Water Model Visualization Support. The OWP uses the water.noaa.gov website as a visualization and decision support tool for the output of the NWM. The system that acquires, reformats, and publishes these data is currently being migrated to the Cloud environment for improved system support.

National Snow Analyses Support. In support of operational continuity, general performance and resiliency improvements were made to the NSA system (www.nohrsc.noaa.gov) software whose primary processing cluster runs at the OWP office in Chanhassen, MN. In addition to software modifications, the 24/7 operational continuity of the NSA and SNODAS model system was maintained through coordination and collaboration within the Chanhassen office. SNODAS operations was additionally supported through system and hardware monitoring, model assimilation activities, Airborne Snow Survey operations, and product generation.

Airborne Gamma Snow and Soil Moisture Program. This year's activities included: execution of the FY23 NWS Airborne and Soil Moisture Mission per NOAA's Aircraft Allocation Plan and the NWS mission and coordination of the rapid response of data and photo collections, product generation, and decision support for the North Central River Forecast Center, Missouri River Basin, Northeast River Forecast Center, and Middle Atlantic Forecast Center during the snow season of 2023; all in direct communication with stakeholders and pilots to ensure needs and requirements were met. Snow and soil moisture observations collected by this mission provided critical, real-time data to forecasters and water resource managers in direct support of the NWS weather mission. Numerous media interviews were provided to support the program and mission.

- Developed and implemented metrics to evaluate the success and needs of the Airborne Snow and Soil Moisture mission.
- Evaluation and implementation of the new King Air 350CER N67RF airborne platform to support the operational mission; served as the SME and mission crew member. Continuing to validate and streamline operations.
- Supporting Physical Services Laboratory joint project in the Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology (SPLASH), year 2 of project.
- Developed documentation and SOPs for new King Air N67RF RSX and cameras, the installation, use, and transmission of data.

National Weather Center Water Prediction Operations Winter Hydrology and Remote Sensing Desk. In support of WPOD, participated and led daily Snow Briefings from Nov 1, 2022, through current. This includes daily presentations and participation in the WPOD daily shift and shift change briefings providing

Impact-based Decision Support Services on snow conditions to support WPOD operations. Project staff also provide support to the National Hydrologic Assessment, weekly NWS Leadership briefings during the snow season, numerous IDSS support to internal and external stakeholders, and training to WFO forecasters from numerous offices throughout the season.

Forecast Evaluation Support Services. To support various needs for forecast evaluation across OWP and external partners, team members researched and developed methods and software to evaluate key attributes of NWM derived forecast products that are used heavily by the WPOD, including the High Water Arrival Time and High Flow Magnitude products. This work included developing the code base to execute ingest, process, execute and visualize these evaluations. In parallel, team members developed additional procedures and software tools to execute post-event evaluations of NWM forecasts and used these tools to evaluate multiple high-impact flood events that occurred between August and December (St Louis, Eastern Kentucky, and Hurricane Ian).

Precipitation Frequency Research Activities. Research tasks included: quality control and analysis of extreme precipitation data used in Atlas 14, analysis of spatial patterns of extreme rainfall from point and regional precipitation data, analysis of statistical L-moments used in precipitation frequency analysis, investigation of peer reviewed comments from prior drafts of Atlas 14 volumes, investigations into the inclusion of non-stationarity in precipitation patterns and frequency, and preparation of documentation and web-based publication information related to the Atlas.

Planned Work

Planned work will transition to the new Cooperative Institute for Research to Operations in Hydrology (CIROH) in the coming year.

New Products

- New Winter Hydrology Dashboard for situational awareness.
- Automation of presentations and graphics for IDSS briefings.
- Products and evaluation of flightlines in support of the PSL SPLASH project.

Publications

de Boer, G., A.White, R.Cifelli, J. Intrieri, M. Hughes, K. Mahoney, T. Meyers, K. Lantz, J. Hamilton, R. Currier, J. Sedlar, C. Cox, E. Hulm, L. Riihimaki, B. Adler, L. Bianco, A. Morales, J. Wilczak, J. Elston, M.Stachura, D. Jackson, S. Morris, V. Chandrasekar, S. Biswas, B. Schmatz, F. Junyent, J. Reithel, E. Smith, K. Schloesser, J. Kochendorfer, M. Meyers, M.Gallagher, J. Longenecker, C. Olheiser, J. Bytheway, B. Moore, R. Calmer, M. Shupe, B. Butterworth, S. Heflin, R. Palladino, D. Feldman, K. Williams, J. Pinto, J. Osborn, D. Costa, E. Hall, C. Herrera, G. Hodges, L. Soldo, S. Stierle, and R. Webb, 2023: Supporting Advancement in Weather and Water Prediction in the Upper Colorado River Basin: The SPLASH Campaign, *Bulletin of the American Meteorological Society*, submitted.

Presentations

Olheiser, C., 2023: NOAA's Airborne Snow and Soil Moisture Program. *Stakeholders Workshop NOAA Aircraft Operations Center (AOC)*, Lakeland FL, January 19, 2023.

Olheiser, C., 2023: Snow Season 2022 Overview and Success. *NOAA Aircraft Operations Center (AOC)*, virtual, May 10, 2022.

Olheiser, C., 2023: UMRB NSA Program Overview and use of Data. *Upper Missouri River Basin Snow and Soil Moisture Partners Meeting*, Omaha, NE, January 23, 2023.

Olheiser, C. Buan, S., Walvert, S., 2023: Spring 2022 Spring Hydrologic and Climate Meeting. *St. Paul Corps of Engineers*, virtual, January 24, 2023.

van Werkhoven, K., 2022: Supporting Water Resources Risk Assessment and Real-Time Flood Forecasting, Appalachian State University Dept of Geology invited seminar, Boone, NC, September 16, 2022.

van Werkhoven, K., 2023: Evaluating High-Resolution Streamflow Forecasts from the NOAA National Water Model, *American Society of Civil Engineers (ASCE) Northern Colorado Branch Meeting*, Loveland, CO, January 12, 2023.

van Werkhoven, K. and Smith, M., 2023: Novel methods for high-resolution streamflow forecast evaluation, *2023 American Meteorological Society (AMS) Annual Meeting,* Denver, CO, January 9, 2023.

Century-Scale Variations and Trends in Heat Stress Metrics	
Task Team	Kenneth Kunkel (Lead), Ronald Leeper, Brooke Stewart-Garrod, Laura Stevens
Task Code	NC-SAS-10-NCICS-KK/RL/BS/LS

Highlight: The team processed more than 4,500 Global Historical Climate Network Hourly (GHCN-H) station records to apply quality control and evaluate the percent of available observations from the 1890s to 2021 for air temperature, dew point temperature, relative humidity, wet-bulb temperature, and station-level pressure. In addition, specific stations with high availability in the 1930s were selected as the core network of historical stations for this project.

Background

It is well understood that stress on the human body from high temperatures is exacerbated by high humidity. The National Weather Service uses a familiar metric (the heat index) that incorporates temperature and humidity to quantify this effect. However, long-term US monitoring of heat stress indicators relevant to human health has been limited to the period from around the middle of the 20th century to present because of a lack of digitally available humidity data prior to 1948. This omits some of the most important heat events in US history, namely, those associated with the 1930s Dust Bowl. On the basis of temperature alone, the Dust Bowl era includes some of the most intense and frequently occurring events across much of the eastern two-thirds of the country over the last 120 years. Extending the availability of heat stress metrics that combine both temperature and humidity over the past century is critically important for providing historical context to current heat wave trends.

The goal of this project is to utilize the keying of early hourly weather observations going back to the late 19th century from the Climate Database Modernization Program to characterize features of heat waves, including humidity in the contiguous United States over a century-plus time frame.

Accomplishments

- Hourly data from over 4,500 stations that include observations prior to 1940s were screened to access data availability from the 1890s to 2020.
- Specific stations with availabilities over 60% in the 1930s for air temperature and measures of humidity were identified as a core network of historical stations (Figure 1).
- Computing software was developed to derive 6 humidity-based heat metrics including:
  - Water vapor pressure
  - Heat index
  - Wet-bulb globe temperature
  - Humidex
  - Specific humidity
  - Equivalent potential temperature
- Software routines to calculate a station's hourly climatological conditions for any given variable have been written and verified.

Planned work

- Identify possible stations that may have moved over the century-plus period due to the opening of an airport or other reasons and consider merging their records.

- Develop techniques to backfill missing data using a combination of climatological-based statistical methods and 20th century reanalysis.

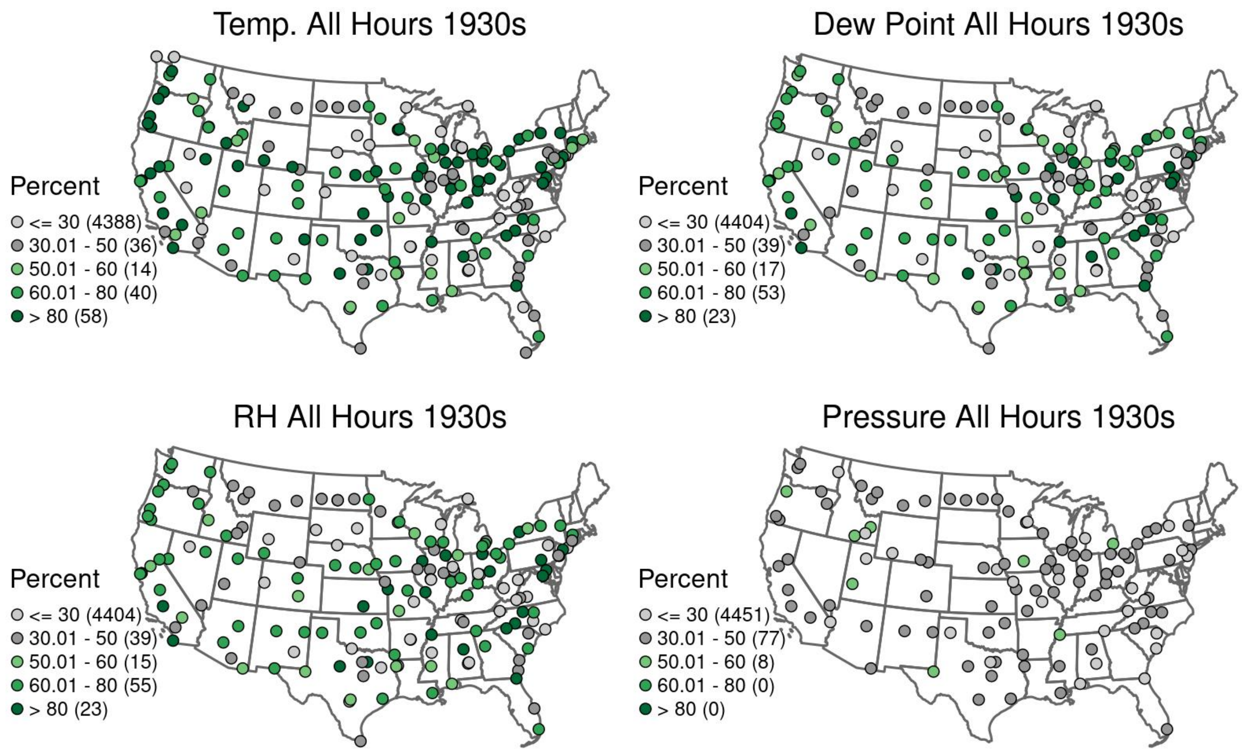


Figure 1. *The availability of (top-left) air temperature, (top-right) dew point temperature, (bottom-left) relative humidity, and (bottom-right) station-level pressure observations over the 1930s decade.*

US Climate Reference Network (USCRN) Applications and Quality Assurance	
Task Team	Ronald D. Leeper and Garrett Graham
Task Code	NC-SAS-11-NCICS-RL/GG

Highlight: Data from USCRN stations were applied to evaluate the recently released HRRR model version 4. Comparisons of revealed important differences and similarities that can inform model development. Comparisons of NOAA-Atlas 14 threshold exceedances between USCRN and HPD and the development of machine learning methods for quality control continue. An earlier effort to develop spatial maps of USCRN observations was successfully transferred to USCRN's website, providing CONUS-wide maps of observations in near-real time conditions.

Background

The USCRN is a systematic and sustained network of climate monitoring stations deployed across the contiguous United States (CONUS), Hawaiʻi, and Alaska. These stations use high-quality calibrated instrumentation to measure temperature, precipitation, wind speed, soil conditions (temperature and moisture), humidity, land surface (infrared) 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. NOAA initiated an evaluation of a new soil sensor (Acclima) to improve the network's capacity to monitor soil moisture conditions in high-clay-content soils, mostly in the southeastern US. This transition is expected to occur over several years as the new Acclima sensors gradually replace the original HydraProbe sensors.

Accomplishments

Comparisons between USCRN and the HRRR model version 4 revealed important deviations for both above- and below-ground measures. In general, model estimates of temperature, humidity, solar radiation, and soil moisture diminished as forecast time lengthened. However, deviations of above-ground measures were more notable when the model poorly estimated cloud cover, driving differences in solar radiation and, in turn, air temperature and humidity (Figure 1a, b). Below-ground measures tended to underestimate moderately wet and dry soil moisture conditions (Figure 1c, d). They led to both modeled dry and wet biases when USCRN observed wet and dry soil moisture conditions, respectively. The offsets in soil moisture were likely related to how the model parameterized soil characteristics such as wilting point (WP) and field capacity (FC), among others. These results were summarized in a manuscript to *Weather and Forecasting*.

Precipitation extremes for both USCRN and the hourly precipitation dataset (HPD) and their frequency of exceedance against NOAA Atlas-14 thresholds were compared as both a networkwide aggregate and individual nearest neighbor analysis. Differences between the network-wide and station-to-station comparisons revealed little differences nationally, suggesting that station density overall had little impact on the detection of extremes overall. However, these results did not hold regionally, with notable differences in the West, Southwest, and Ohio River valley regions (Figure 2). In the West, there were shape contrasts even at the station-to-station level given the sparsity of both networks over Nevada. These results indicate that importance of network density on the capture of precipitation extremes can vary regionally depending on the extreme type (synoptic versus local) of extreme (i.e., frontal boundary versus mesoscale convective system).

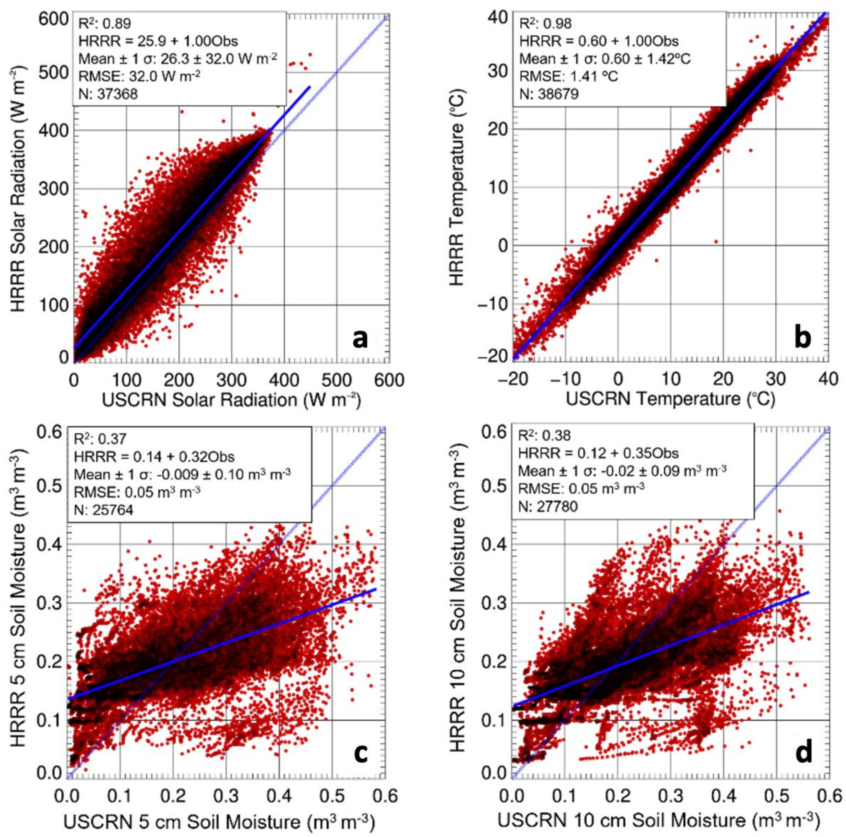


Figure 1. *Relationship between the HRRR 18-hour forecast and USCRN observations of downward solar radiation (a), 2-meter air temperature (b), and 5 cm (c) and 10 cm (d) soil moisture observations. Solid blue line shows the line of best fit, and the dashed blue line shows the 1:1 line. R2, line of best fit equation, root-mean-square error (RMSE), and number of samples (N) are shown in the top left of each panel.*

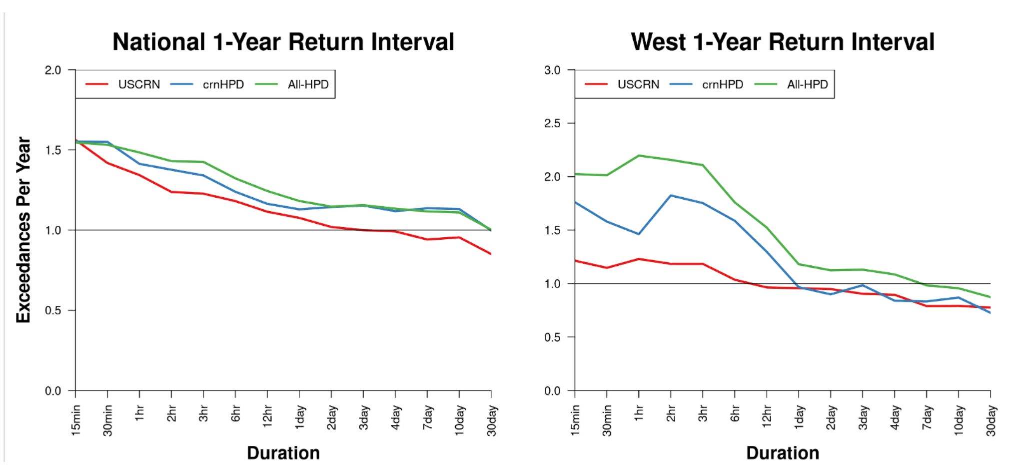


Figure 2. *Station weighted mean exceedances for the NOAA-Atlas 14 1-year return interval for 15-minute to 30-day durations averaged across all USCRN (left) and West (right) stations, which shows some of the regional variability in USCRN (red), all-HPD stations (green), and nearest neighbor HPD stations (blue).*

Since the addition of new USCRN software developers, the network has developed and deployed spatial maps of CONUS-wide observation in near-real time (Figure 3). This project was built upon an earlier effort to provide spatial maps of USCRN conditions at NCICS. These maps continue to be updated and improved based upon internal and external feedback.

The evaluation of machine learning–based anomaly detection algorithms continues with the onboarding of student intern Vivek Sudhakar from NCSU's Computer Science department. Sudhakar is working closely with Garrett Graham to explore both supervised and unsupervised algorithms to detect soil moisture sensor spikes and noise. Preliminary results using supervised decision trees (i.e., XGBoost) showed promise in detecting both anomaly types (spikes and noise) from a single sensor using precipitation and temperature as inputs.

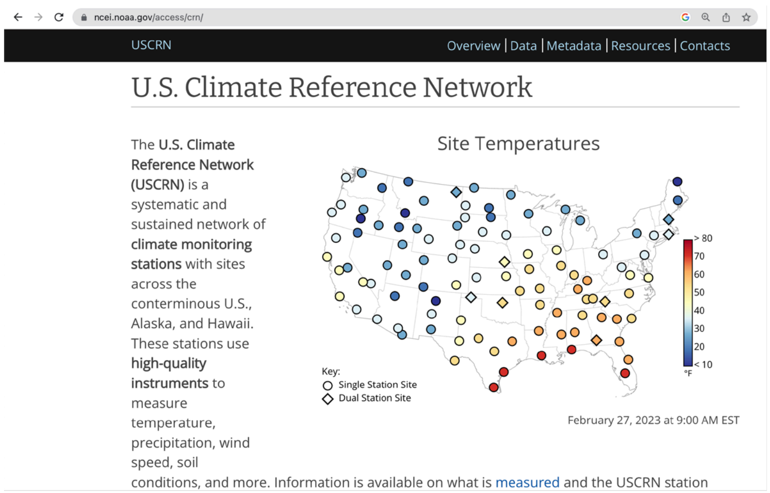


Figure 3. *Snapshot of USCRN's main webpage showing the spatial of near-real time USCRN air temperatures taken on February 27th, 2023, at 10:55 AM EST.*

Planned work

- Continue to support efforts to visualize USCRN observations in near-real time observations in user-engaging ways
- Continue to support efforts to summarize the HPD and USCRN exceedance comparisons in a manuscript
- Evaluate isolation forests as well as other machine learning methods that support sequence-wise processing and summarize results from our analysis in a report to the National Coordinated Soil Moisture Monitoring Network

Presentations

Leeper, R.D., **G. Graham**, and **Y. Rao**, 2022: An evaluation of Machine Learning Techniques to Quality Control Soil Moisture Observations for U.S. Climate Reference Network (poster). *11th International Conference on Climate Informatics,* virtual. May 10, 2022.

Publications

Lee, T., **Leeper R.D.**, T. Wilson, H. Diamond, T.P. Meyers, and D.D. Turner, 2023: Using the US Climate Reference Network to identify biases in near- and sub-surface meteorological fields in the High-Resolution Rapid Refresh (HRRR) weather prediction model *Journal of Weather and Forecasting.* https://doi.org/10.1175/WAF-D-22-0213.1

Development of Standardized Soil Moisture Datasets and Applications	
Task Leader	Ronald D. Leeper
Task Code	NC-SAS-12-NCICS-RL

Highlight: An analysis of the capacity of ESA's standardized remotely sensed soil moisture data to capture the timing and severity of dry and wet extremes was submitted for publication. Estimates of remotely sensed FAW, standardized departures, and soil moisture percentiles prior to the Gatlinburg, TN, and Betty, OR, wildfires were evaluated. Supervised machine learning algorithms were used to explore the predictability of rapid drought change as measures from the USDM based on MJO and ENSO conditions.

Background

Soil moisture observations are challenging to interpret and use from a monitoring perspective. 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 at what time of year the measurement was taken. This is further complicated by remotely sensed sensors that estimate soil moisture conditions using brightness temperatures. These challenges can be partially overcome by placing measurements into historical context by computing standardized departures from the climatological normals. Short-term (less than 10 years) standardization methods have been applied to all soil-moisture-observing USCRN stations and remotely sensed datasets, resulting in soil moisture climatologies, standardized departures, and percentiles that provide relative context to soil moisture conditions. An additional method of standardization that is based on the soil layer's ability to hold water in tension and provide an estimate of the water available to plants may be more useful in vegetation health–related analysis such as wildfires and vegetation green-up, among others.

Accomplishments

The combined and passive datasets of the European Space Agency (ESA), which include over 2 decades (to the 1980s) of soil moisture sensing satellites, have been standardized from each grid's respective normal conditions. Comparisons of the satellite's standardized departures against USCRN revealed that the remotely sensed datasets were able to reasonably detect the frequency of extremes events but often underestimated the severity of both wet and dry extreme conditions (Figure 1). In addition, the ESA's combined and passive datasets were both able to capture the evolution from onset to amelioration for the 2012 central US drought and the 2019 flood across the Upper Missouri river basin.

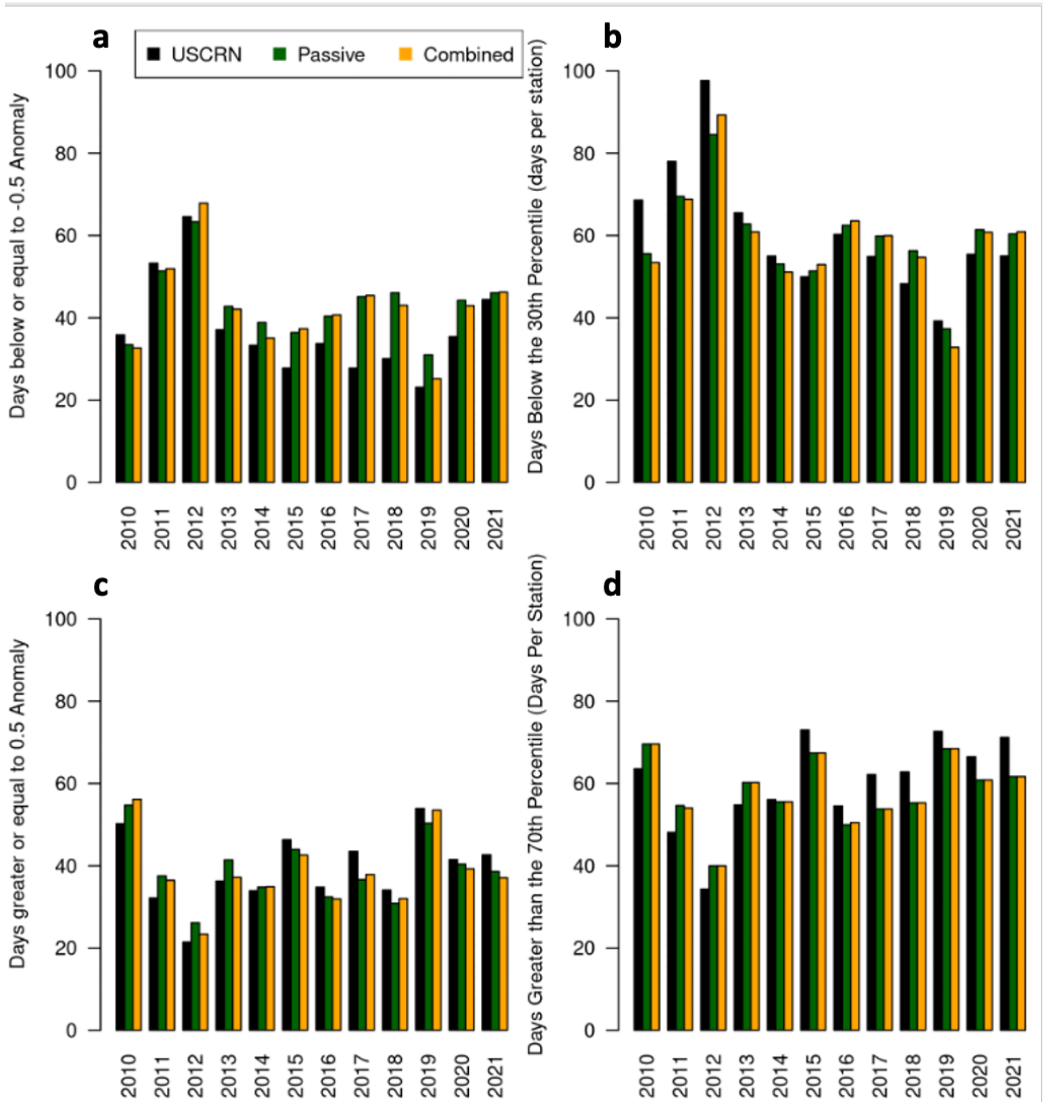


Figure 1. *Annual counts of extreme dry days for (a) standardized anomalies below the -0.5 and (b) percentiles below the 30th percentile; wet days for (c) standardized anomalies greater than 0.5; and (d) percentiles greater than the 70th percentile from 2010 to 2021.*

The ESA combined dataset was applied to evaluate several standardized soil moisture metrics 1 year prior to the Gatlinburg, TN and Betty, OR wildfires. The period-of-record percentiles correlated best with measures of Normalized Difference Vegetation Index, followed by standardized departures and factional available water (FAW; Figure 2). One of the main challenges of deriving FAW from remotely sensed soil moisture is its dependence on wilting point (WP) and field capacity (FC) of the soil, which can vary greatly over short distances. Estimating these values over the satellite footprint is one source of error, as is the remote estimate itself, which is not based on conditions in the soil. Further analysis of estimating WP and FC based on soil moisture time series could provide more meaningful values of FAW from remotely sensed soil moisture datasets.

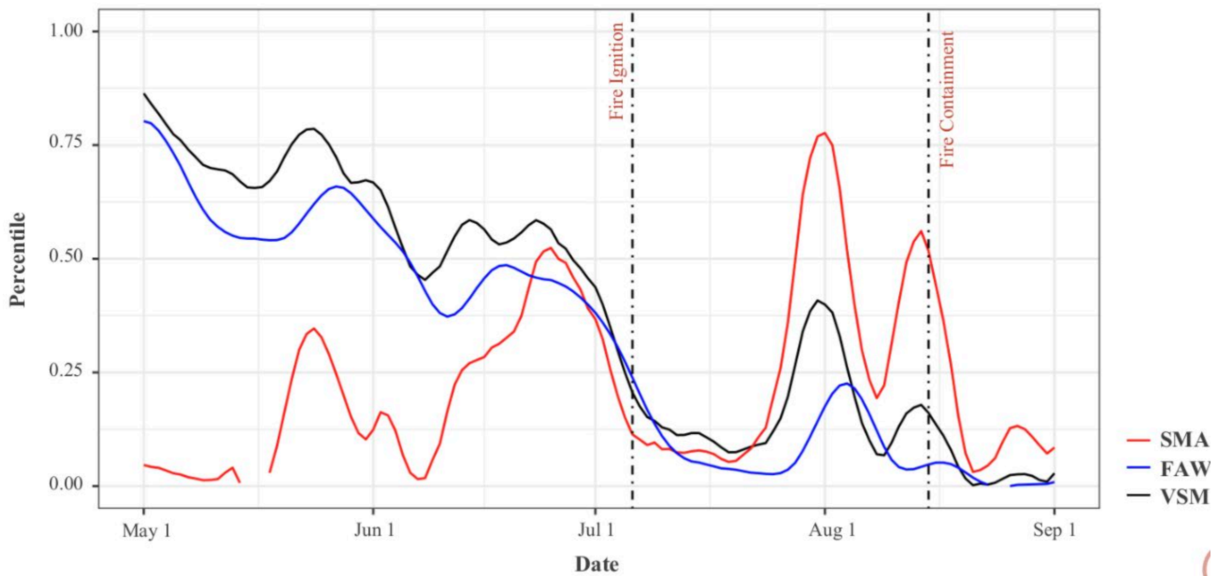


Figure 2. *Daily standardized soil moisture departures (red), fractional available water (blue), and period-of-record volumetric (black) percentiles leading up to and through the Betty Wildfire in Oregon.*

Machine learning was used to explore the predictability of rapid changes in drought conditions. Initially, three or more changes in US Drought Monitor status over a 5-week period were used to label periods of rapid drought change (Figure 3) This multi-label, supervised learning approach was used to determine how well machine learning could predict not only rapid drought change but also distinguish between flash drought and flash amelioration using the Madden-Julian Oscillation (MJO) and El Niño–Southern Oscillation (ENSO) as input parameters. Eventually, the goal is to extend this analysis by defining rapid changes based on the standardized precipitation evapotranspiration index and standardized soil moisture departures and to reevaluate the machine learning performance using these other drought metrics.

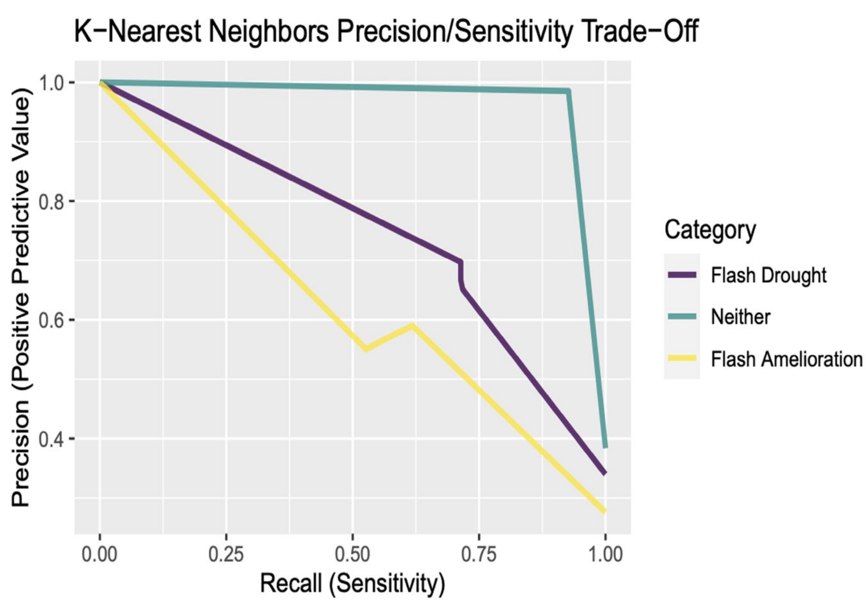


Figure 3. *PR curve trade-off for K-nearest neighbor machine learning model for (purple) flash drought, (yellow) flash amelioration, and (teal) non-rapid drought change.*

Planned work

- Publish the satellite detection of extremes manuscript
- Continue efforts to explore the utility of standardized soil moisture metrics in the context of wildfires
- Continue to explore the predictability of rapid drought changes based on MJO and ENSO phases using machine learning methods

Presentations

Leeper, R.D., 2022: An Evaluation of Remotely Sensed Soil Moisture Extremes. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Leeper, R.D., 2022: Evaluations of Soil Moisture During Extreme Conditions. *2022 National Soil Moisture Workshop,* Columbus, OH. August 9, 2022.

Leeper, R.D., 2022: USCRN's Standardized Soil Moisture. *Joint NCEI/ARL USCRN Science Meeting*, virtual. July 22, 2022.

Scott, E., R. Bilotta, **R. Leeper**, **D. Coates**, and **C. Schreck**, 2023: An Exploratory Analysis of Rapid Drought Changes in Relation to ENSO and MJO Modes of Variability. *103rd American Meteorological Society Annual Meeting,* Denver, CO. Jan 11, 2023.

Other

- Leeper mentored NASA DEVELOP interns Daniel Littleton, Kelli Roberts, and William Hadley

Exploring the Impacts of Drought Events on Society	
Task Leader	Ronald D. Leeper
Task Code	NC-SAS-13-NCICS-RL

Highlight: Droughts were found to increase the duration of heatwaves. While differences in heatwave intensity for compounded heatwaves were subtle, measures of heatwave exposure were generally higher. Differences in heatwave exposure and intensity were generally greater at night. Moist soils during compounded heatwaves limited nighttime cooling, especially in the western US. A journal article is currently in NCEI internal review.

Background

Moisture deficits due to drought can have profound societal and economic impacts and elevate risks of fire, landslides, adverse health outcomes, and other impacts. However, droughts are often defined according to a specific application: meteorological, agricultural, or hydrological. This approach can be challenging for assessing drought characteristics and linking drought to adverse societal outcomes. This is further complicated when droughts evolve and intensify in many ways due to regional and seasonal influences that can lead to varying societal outcomes. A more unifying definition of drought would be based on all aspects of the hydrological cycle, with clearly defined start and end dates that are applicable over time. The US Drought Monitor (USDM) provides a holistic view of drought across the hydrological cycle at weekly time scales since 2000. This dataset provides an opportunity to more broadly explore if and how drought events influence societal outcomes. This is particularly true when combined with other hydrological indicators (e.g., precipitation, soil moisture, evaporation, stream flow, etc.) that provide measures of exposure to specific types of moisture deficits.

Accomplishments

Heatwaves, based on air temperatures exceeding the 90th percentile, were identified at all USCRN stations. Heatwave events then split into two groups: those that occurred during a USDM-based drought (compound heatwaves) and those that did not (no-drought heatwaves). Comparisons between the two types of heatwaves revealed similar measures of heat intensity (Figure 1a); however, the compound events tended to last longer (Figure 1b): 12 to 48 hours for most (67 of 114) stations. Differences in heatwave intensity anomalies were largest at night for air temperature and the heat index, which includes both measures of humidity and temperature (Figure 2). However, the compound heatwaves had slightly cooler daytime heat index anomalies (Figure 2b) compared to [no-drought?] heatwaves. This is likely due to drier levels of humidity during drought that result in slightly cooler heat index conditions. Further analysis revealed that soil moisture conditions had a particularly notable impact on heatwave intensity (Figure 3) with much warmer nocturnal air temperatures and higher measures of heat index throughout the day. This was particularly notable for the western US and diminished as you moved eastward.

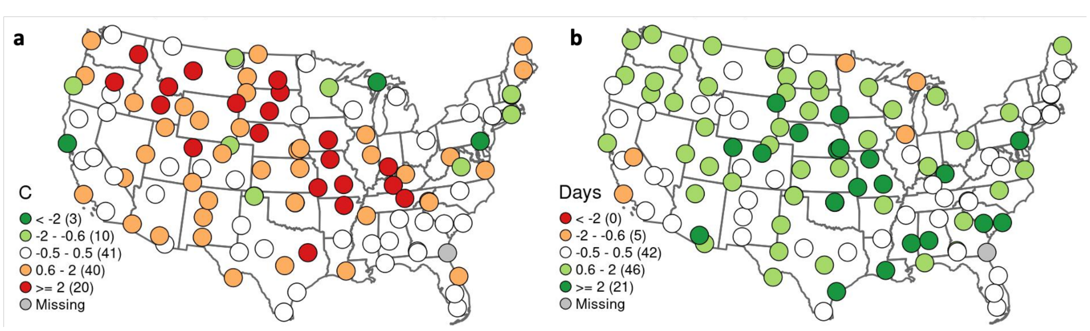


Figure 1. *Spatial plots of (a) daily maximum air temperature difference (compound heatwaves minus no-drought heatwaves) and (b) heatwave duration from 2010 through 2020.*

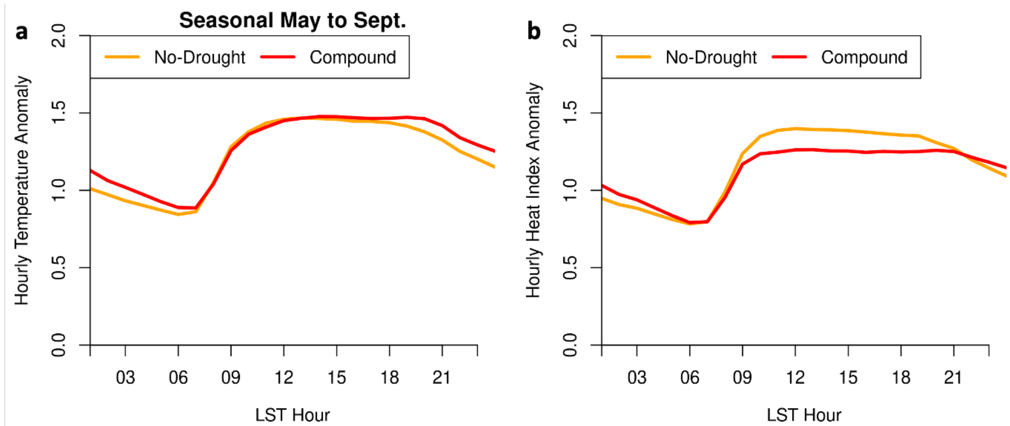


Figure 2. *Mean (a) air temperature and (b) heat index anomalies by local standard time hour for (red) compound and (orange) no-drought heatwaves.*

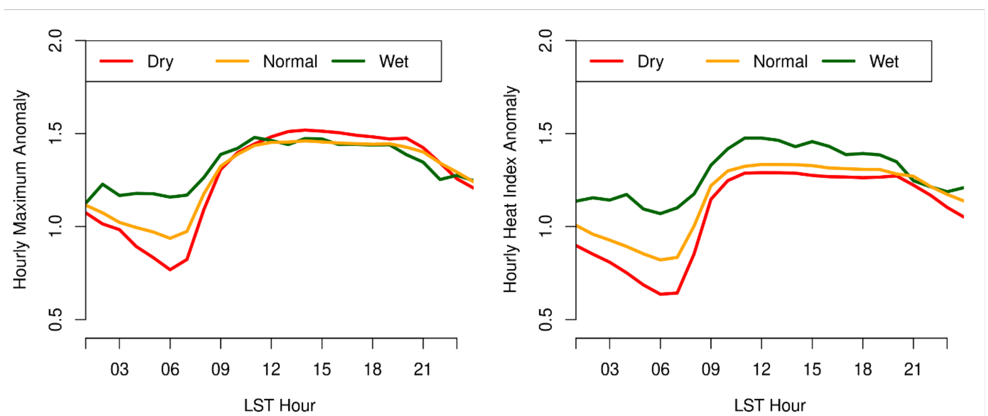


Figure 3. *Mean (a) air temperature and (b) heat index anomalies by local standard time hour for (red) dry (anomalies –0.5 standard deviations or less), (orange) normal (anomalies between –0.49 and 0.49 standard deviations), and (green) wet (anomalies 0.5 or greater standard deviations) soil moisture conditions.*

Leeper supported a dataset request from Dr. Jennifer Smetzer, a biologist of the US Fish and Wildlife Service (FWS), for the USDM climatology, which was developed last year and documented here (https://doi.org/10.1002/joc.7653). The FWS plan to evaluate the effect of drought frequency, duration, severity, and seasonality of onset/termination, among others, on the habitat spatial footprint of the Blanding's turtle in order to assess its sensitivity to drought and support its inclusion on the federal Endangered Species list.

Planned work

- Respond to reviewer comments and associated tasks to ensure the manuscript is accepted for publication
- Continue to support efforts to explore the impacts of compound hazards on human health in the Carolinas

Presentations

Leeper, R.D., 2022: USCRN's Drought Focused Research. *Joint NCEI/ARL USCRN Science Meeting*, virtual. July 22, 2022.

Publications

Leeper, R.D., R. Bilotta, B. Petersen, C.J. Stiles, R. Heim, B. Fuchs, **O.P. Prat**, M. Palecki, and S. Ansari, 2022: Characterizing U.S. drought over the past 20 years using the U.S. Drought Monitor. *International Journal of Climatology*. https://doi.org/10.1002/joc.7653

Products

- Supported the development of an interactive ArcGIS Online Drought Climatology Viewer: http://tiny.cc/rkesuz http://10.0.3.234/joc.7653

Other

- The compound heatwave project supported two student internships:
    - Kelley DePolt of North Carolina State University
    - Tyler Harrington of University Massachusetts Lowell
- Supported efforts at the FSW to include the Blanding's turtle on the Endangered Species list

Evaluation and Elucidation of SCaMPR Performance in Complex Terrain Leveraging GOES-R Observations and Ground-based Precipitation Measurements	
Task Leader	Douglas Miller
Task Code	NC-SAS-14-UNCA

Highlight: CISESS consortium partner UNC Asheville completed summer and fall 2022 data collection and maintenance rain gauge visits as part of this collaborative research effort to extend the period of observations of the Duke University Great Smoky Mountains.

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- (~3,400 feet) and high- (~6,600 feet) elevation locations in the Pigeon River basin, has collected observations since 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. Since 2016, NESDIS has helped maintain the network's observational capability and support the extension of the Duke GSMRGN period of observations in collaboration with CISESS consortium partner UNC Asheville. These activities in turn provide a unique learning experience and relevant research opportunities for UNC Asheville undergraduate students through the associated field work.

Accomplishments

Gauge visitation in support of the Duke GSMRGN occurred over 9–10 days spanning five weeks during each of the following cycles: summer 2022 (6 July – 5 August) and fall 2022 (7 October – 5 November). Volunteers accompanied student technicians to assist with personal safety (should someone become injured during a series of gauge visits) but were not directly involved in gauge visit tasks. The primary purpose of each gauge visit was to 1) perform downloads of gauge tip observations since the previous gauge visits (data collection), 2) complete maintenance tasks (general gauge maintenance and data logger condition monitoring), 3) clear vegetation and tree limbs within a 5-foot radius of the rain gauge, and 4) where necessary, calibrate the rain gauges (three calibration trials using 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 during the current and/or previous gauge site visits.

Summer 2022: 6 July–5 August

The field supervisor, one undergraduate student, and one volunteer at the Waynesville Watershed, completed the gauge visits and performed the required work. This was the third summer season that uniform electronic contact cleaning was performed at every rain gauge between the logger leads and the gauge switch connector to eliminate a reduced number of reported tips due to poor contact between the data logger leads and the gauge switch connector.

Gauge maintenance and data logger condition monitoring included:

- *"TA" resets for several data loggers.* The "Time Adjust" on some of the older loggers makes poor 'decisions' on correcting for time errors and must be set to "off" at several gauges (g #005; Deep Gap, g #106; Pinnacle Ridge, #109; Eaglesnest Ridge, and #306; Sunup Knob). These gauges were monitored carefully between summer and autumn 2022 and replaced, if necessary.
- Five older gauge data loggers (g #4; Lickstone Ridge South, #100T; Purchase Knob, #105; Hultquist Property, #108; Utah Mountain, and #112; Ore Knob) have shown abrupt changes of the date format corresponding to bucket tips that required manual editing of the rain rainfall observation files during the QA/QC procedure. One of these was replaced with a new ML1A-FL logger in summer 2022 (g #4), while the other four were replaced in autumn 2022.

- A new ML1A-FL logger (g #304; Big Cataloochee) was found during summer 2022 to have completely drained 24-h after it was installed in spring 2022. A temporary replacement logger was placed in the gauge and the new logger returned to the manufacturer. A replacement was shipped and installed in autumn 2022.

Specialized tasks completed:

- *g #110 (Hawkins property).* The gauge was pushed over in fall 2021 and early spring 2022. A fence was installed around the gauge in May 2022 with no further pushover incidents. A close encounter with a large bull elk near this location in the summer 2022 (Figure 1) led the field manager to suspect the elk was the source of the multiple pushovers of the gauge.
- *Gauge replacement along Balsam Mountain Ridge Trail (g #307).* The installation of a new TB3 rain gauge (g #307s) at a location in which a tree had fallen on and destroyed the old rain gauge on 3 January 2022 was completed in early June 2022.
- *Inoperable rain gauges.* Three gauges had periods of no reports due to one (#110) having been pushed over by an elk, another (#307) being destroyed by a fallen tree, and the third (#304) having a faulty circuit board on the newly installed ML1A-FL data logger.

The primary challenges encountered during some of the gauge visits in the summer 2022 centered around the Time Adjust (TA) settings on some of the older data loggers. A potential solution was discovered during the rain gauge visit campaign in the fall 2022 (see description below). A *Davis Pro* weather station has been installed near the Mount Sterling fire tower, next to gauge #310. This independent weather data would be helpful in discerning the source of bucket tips during the cool season; however, repeated inquiries to the owner of the weather station (and data) at Duke Power have thus far gone unanswered.

Figure 1. *Bull elk encountered by UNCA team in Summer 2022, suspected to be the source of the previous multiple gauge #110 pushovers (rather than a bear). A fence was installed around the gauge in May 2022 with no subsequent pushovers to date.*

Fall 2022: 7 October–5 November

Nine 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 g #310) to record air temperature during the cool season.

Gauge maintenance and data logger condition monitoring included:

- *Poor TA command response* from several ML1 loggers continued to be a problem in autumn 2022. However, it was discovered that changing the logger battery makes the logger's memory lose track of when the most recent "TA=hh:mm:ss" adjustment was made and gives the "At least 12hrs must elapse!" error when the "TA=hh:mm:ss" command is tried immediately after changing the battery. The solution is to update the time using TA ("TA=hh:mm:ss" command) ***before*** changing the battery. Changing the battery can cause the just-adjusted time to go bad, so another time update is needed AFTER the battery change is complete using the "T=hh:mm:ss" command, rather than "TA".
- *Rain gauge and base at g #010* was found tipped over by a bear in autumn 2022. The tip observations indicated that the knock-over likely happened on the morning of 14 October 2022. The gauge and base were releveled using rocks and the gauge base nut/bolt leveling system.
- *Rain gauge and base at g #005* was found partially tipped over by a bear in autumn 2022. It is likely a fence will need to be installed in the spring 2023 to protect the gauge in the future.
- *Battery voltage of data loggers at g #309 (Mt Sterling Ridge, nearest Big Cataloochee Mtn) and g #311 (Big Creek) were found to be completely or nearly drained, respectively.* A "new" data logger (old g#307; tree) replaced the old logger at g#311. The data logger at g#309 was found completely drained at the 15 October 2022 visit (record ceased after 10 September 2022 rain event). The battery was replaced, and the logger will need to be replaced if it is found to be drained during the spring 2023 visit.
- *Replaced data loggers* at g #100T, #105, #108, and #112 with new ML1A-FL data loggers.
- *Inoperable rain gauges.* Three gauges had periods of no reports due to two (#005 and #010) push overs and the third (#309) having a completely drained logger battery.

Project staff continued attempts to contact Duke Power (Mr. Edwin Warren) regarding the possibility of gaining access to weather station observations taken near the Mount Sterling fire tower, next to g #310 (~5,800 feet ASL). These weather observations will help discern the source of tips in the cool season: rain or melting snow.

The current 2022–2023 academic year technician roster includes Jackson Coley, Kaitlyn Duckett, Drew Griffith, Nick Kleis, Sara Michaelson, Wayne Morley, Zachary Moss, Brooks Rogow, Jacob Sonney, and Joshua Ward. New students will be recruited in fall 2023, as three students will graduate from UNC Asheville in May 2023.

Planned work

Spring 2023 (March–May) gauge visitation

• Scheduled data collection and regular gauge maintenance activities
• Calibration of all rain gauges (last calibration completed in Spring 2022)

Summer 2023 (July–August) gauge visitation

• Scheduled data collection and regular gauge maintenance activities
• Uniform electronic contact cleaning (Summer)

Details of every gauge visit along with each gauge precipitation record will be posted online with sub-folders for each gauge that include 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 an MS Word document that mirrors the notes made in the field journal during the visit.

Products

- Details of each GSMRGN gauge visit with quality-controlled precipitation CSV format files
    - Summer 2022: https://drive.google.com/file/d/1c_PCetb2kU9GyhWG5b1srUawqM6bMwhL/view?usp=sharing
    - Fall 2022: https://drive.google.com/file/d/1BhSFrlvK6bWIdomxdEoKmz_kNtkKIUg-/view?usp=share_link

Other

- Dylan Major, a UNCA undergraduate student and CISESS NC intern, is at the center of a collaborative research project that involves researchers from CISESS NC, UNCA, CISESS-MD, and NOAA/NCEI. The objective of the internship is to evaluate satellite precipitation products NASA IMERG, and NOAA CPC CMORPH over the Great Smoky Mountains near Asheville using observations of the Duke GSMRGN. The ongoing work conducted since June 2022 focuses on quality control (identification of erroneous data, reporting errors, and missing data) and statistical data analysis (computation of spatial and temporal correlations, conditional analysis, sub-grid scale variability) of in situ and satellite precipitation data.
- PI Miller will be supervising National Science Foundation Research Experiences for Undergraduate students in the summer 2023, in which rainfall observations of the Duke GSMRGN are incorporated into a catalog of heavy rainfall events, helpful for developing a tool for nowcasting flash flooding events in the southern Appalachian Mountains from lightning observations.

References

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

Socioeconomic Value Assessment of Low Earth Orbiting Observations	
Task Leader	Ash Morgan
Task Code	SAS-15-ASU

Highlight: Economic modeling methods were developed to assess the socio-economic value of the Joint Polar Satellite System (JPSS) Program satellite information for improved information regarding impacts in drought, flooding and severe weather.

Background

The Joint Polar Satellite System (JPSS) Program provides critical global backbone measurements for numerical weather prediction and other applications including drought monitoring, ocean remote sensing and atmospheric chemistry. NOAA is currently in the process of formulating the next generation of low earth orbiting (LEO) sensors after JPSS. The Program is in the initial stages of conducting socioeconomic value assessments of JPSS data, identifying the benefits to the U.S. economy and society to support the continuance of key JPSS satellite data being available in the future.

The goals of this initial research effort are to support the articulation of the value of JPSS and LEO observations in economic terms and, where possible, to quantify the economic benefits of JPSS data, which includes addressing stakeholder and users' inquiries related to the value and use of polar-orbiting observations. This involves developing a quantitative approach to the socioeconomic value of JPSS satellite information, which includes a high-level value chain understanding of JPSS data as it relates to select climate impacts and understanding the economic benefits of polar observations and information in environmental data products that are used to provide improved forecast information that consequently reduces the economic costs from those impacts.

Accomplishments

Appalachian State University is collaborating with CISESS NC in developing and refining a valuation methodology and approach for select case studies. The effort examines the largest cost associated with disasters using the Billion-Dollar Disaster dataset and how those costs have been lowered due to information made available from polar orbiting satellites that are used in products that are used in forecasting information. The case studies examined include the role of JPSS data in drought monitoring, wildfire detection and severe storms.

In this first phase, benefits are assessed by assessing the percentage contribution of JPSS information in products that are improve information for stressors including drought, flooding, and wildfire. The research effort assumes that with the improved information starting 2012, costs are reduced due to improved forecasting and monitoring information that is used by decision-makers and emergency managers, thus reducing the cost and impact of disasters such as flooding, drought, and wildfires.

Planned work

- Evolve the economic model assumptions in the percentage contribution of JPSS related products and information in forecasts
- Develop the value chain diagrams from sensor observations to NOAA products to its role in societal benefits
- Develop bottom-up analysis where to refine assumptions in the economic model

Toward Fusing Humidity and Socioeconomic Data

Task Team	Revathi Muralidharan and Jennifer Runkle
Task Code	NC-SAS-16-NCICS-RM/JR

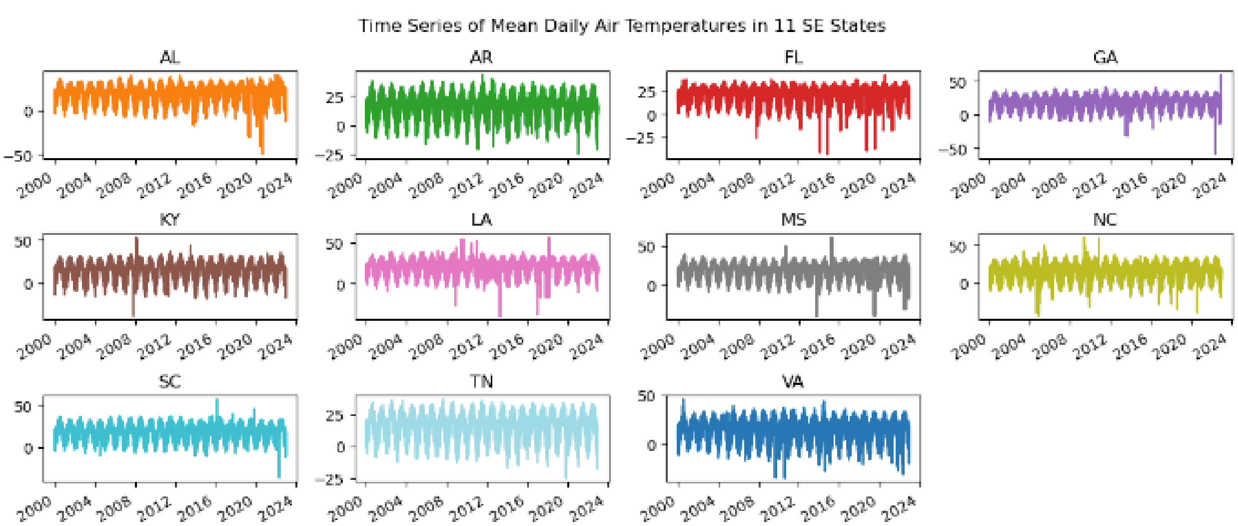
Highlight: This one-year project will work toward a homogenized humidity dataset at the spatial (US county) and temporal (daily) resolutions necessary for coordinated analysis with public health data. A literature review was conducted and relevant datasets explored and compared. HadISD data was selected as the in situ dataset and a combination of MODIS and AIRS was chosen as the remotely sensed dataset.

Background

The influence of humidity on human heat stress is an understudied mechanism. This is due, in part, to the lack of a homogenized humidity dataset at the spatial (e.g., US county) and temporal (e.g., daily) resolutions necessary for coordinated analysis with public health data. This project will demonstrate the utility of AI methods to create datasets leveraging the advantages of both in situ and remotely sensed observations.

Accomplishments

A review of the scientific literature on humidity as it relates to human health was conducted. This literature review resulted in the identification of a suite of humidity variables for inclusion in the final blended humidity data product. Following the successful completion of the review and variable identification, the available in situ (HadISD, ISD, GHCN) and remotely sensed (GOES, HIRS, AIRS, MODIS) humidity datasets were explored and compared for their relative merits. ISD and GOES were preliminarily selected as the candidate datasets for fusion. A thorough exploration of the ISD dataset was conducted, which revealed poor data quality and a lack of thorough QA/QC. This led to the selection of HadISD data as the in situ data input candidate. At the time of this report, the HadISD data have been converted into an analysis-ready, cloud-optimized (ARCO) format and made available in an S3 bucket. It is currently undergoing an exploratory data analysis. Since the historical GOES sounder data were found to be malformed and unusable, they were eliminated, and a combination of MODIS and AIRS will be used as the remotely sensed data input instead. At the time of this report, a data ingestion and processing pipeline are being developed for MODIS humidity data.



1Figure 1. *The exploratory data analysis of ISD data revealed concerning outliers and a lack of QA/QC, particularly in Alabama and Georgia.*

Planned work

This project will work toward the creation of a spatially complete surface humidity dataset by blending remotely sensed and in situ surface humidity data using AI methods. The resultant dataset will meet requirements to align with public health data and associated socioeconomic metrics. The following tasks remain to be done as part of this project:

- Co-development with environmental health experts to ensure appropriate dataset characteristics regarding variable selection, temporal and spatial resolution, etc.
- Development of an AI framework, including uncertainty quantification capabilities, to fuse in situ and remotely sensed humidity data into a homogenized humidity dataset

Products

1. Report detailing:
    a. Justification for humidity variable selected
    b. Review of existing humidity datasets and their characteristics, including quality
    c. Documented requirements from environmental health experts
    d. AI framework methodology for data fusion
2. Preliminary beta version of a homogenized humidity dataset
3. Demonstration of a heat health application with the preliminary dataset
4. Associated Jupyter notebooks

Drought Detection and Monitoring Using Remotely Sensed and In Situ Precipitation Datasets	
Task Team	Olivier Prat, David Coates, Ronald Leeper, Scott Wilkins
Task Code	NC-SAS-17-NCICS-OP

Highlight: A global daily SPI was implemented using precipitation satellite data from CMORPH-CDR to investigate its suitability for detecting and monitoring drought. Comparison of satellite SPI with an in situ drought index showed comparable patterns for drought events around the globe but important differences over areas with limited precipitation. The operational CMORPH-SPI is now available on drought.gov, and a high-resolution daily SPI was developed over CONUS from NClimGrid data. The process has been transitioned to the cloud for faster processing times.

Background

Satellite precipitation data from the CMORPH-CDR (Climate Prediction Center Morphing Technique-climate data record) program are being used to detect and monitor drought on a global scale. Precipitation data are used to compute and evaluate the Standardized Precipitation Index (SPI) over CONUS. 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 quantitative precipitation estimate (QPE), the near-real-time version of the satellite QPE, and a combination of gauge-adjusted and near-real-time versions of the satellite QPE. The drought indices are evaluated over CONUS, for which many in situ data and drought products exist.

Four drought episodes (the 1998–2004 western US drought, the 2006–2007 Southeast US drought, the 2010–2012 Texas–Mexican drought over the Southern Plains, and the 2012 summer Midwestern US drought) serve as case studies to assess the monitoring and prediction capabilities of drought products, as defined by the Drought Task Force (DTF) Protocol released in April 2013. These drought episodes, which influenced the development of the National Integrated Drought Information System (NIDIS) early warning system, are all within the record of the CMORPH-CDR dataset (1998–present).

Following the assessment metrics in the DTF Protocol, the SPI products are evaluated based on their ability to estimate drought onset and recovery, drought duration and severity, probability of drought condition, and the value given at the observed period (30, 90, 180, 270, 365, and 730 days). The goal of this work is to transition to operations a fully functional implementation of the daily SPI using CMORPH-CDR and CMORPH Interim CDR (CMORPH-ICDR) for drought detection and monitoring globally. Other products currently in development (NClimGrid-SPI, IMERG-SPI) will be made available once finalized.

Accomplishments

The quasi-operational CMORPH-SPI is available to the public through the NIDIS drought.gov portal along with other drought products. Near-real-time drought conditions can be assessed via interactive visualization techniques. The daily global CMORPH-SPI that uses the gamma formulation (McKee et al. 1993) is generated in near-real time; that is, within 48 hours to the actual day. The portal provides drought monitoring resources such as interactive mapping, visualizations, and data download capabilities. It builds upon previous work conducted at NCEI and CISESS NC.

Our efforts consisted of improving the efficiency of the SPI computation. Figure 1 displays the task breakdown for the full SPI computation using the CISESS NC server. Separately from pre-processing (30 minutes) and post-processing (2 hours), the actual SPI computation takes 6.5 hours for CMORPH-SPI and 16 hours for NClimGrid-SPI.

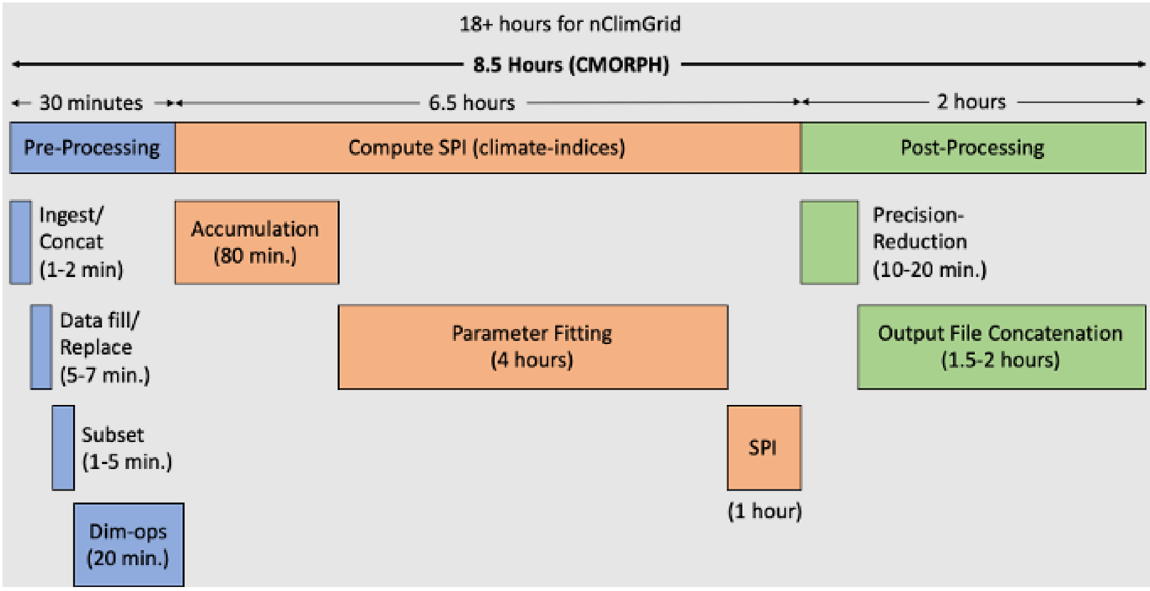


Figure 1. *Task breakdown for the full SPI computation using the CISESS NC server. The computational process is divided into three phases: input file preparation (pre-processing); the actual SPI computation that includes rainfall accumulation periods, distribution parameters, and the drought index computation; and the finalization of output files (post-processing; size reduction, retiling, and concatenation).*

A full SPI computation is divided into three tasks; computation of the accumulation periods, computation of the distribution parameters, and computation of the drought index (SPI). The accumulation periods and the distribution parameters are the most computationally expensive when compared with the actual SPI computation (15% of the total time). In addition to the long computation time, the process is memory intensive by holding loaded data in global arrays, while pre- and post-processing involve very large sets of files that do not fit well into memory even on large servers. Furthermore, the output files generated are enormous and difficult for users to access. For instance, in the case of CMORPH, a 20GB file, produces 6 x 20GB SPI files (one for each of the six accumulation periods considered) and a 30GB parameter file).

To reduce the computational time, the process has been adapted to cloud-scale computing. Figure 2 displays the current architecture for SPI computation using AWS cloud computing resources.

The DASK environment of AWS Fargate allows for massive parallel processing and for rapidly scaling resources from zero to a cluster of up to 500 workers and back to zero. AWS S3 is used for data storage and allows for fast parallel data access. All data including input (SPP datasets), intermediate (Accumulation, Distribution Parameters), and output files (SPI) are stored on S3. The SPI source code is in GitLab (Python) with Jupyterhub as the scientific computing environment. The framework set in place (i.e., Kubernetes) will ultimately allow the SPI code to be transferable to other cloud environments (Google, Microsoft Azure).

The framework has been tested for CMORPH-SPI and NClimGrid-SPI. A comparison against previous runs performed on the CISESS NC server indicated that the runs were identical and reproductible. The adaptation to the cloud environment allowed to reduce the computation time by two orders of magnitude. For instance, the CMORPH-SPI was reduced from 9 hours down to 5 minutes. Similarly, the NClimGrid-SPI was reduced from 18 hours to 8 minutes. Ultimately, the daily updates will take less than 1 minute for the daily SPI (bypassing the parameter computation).

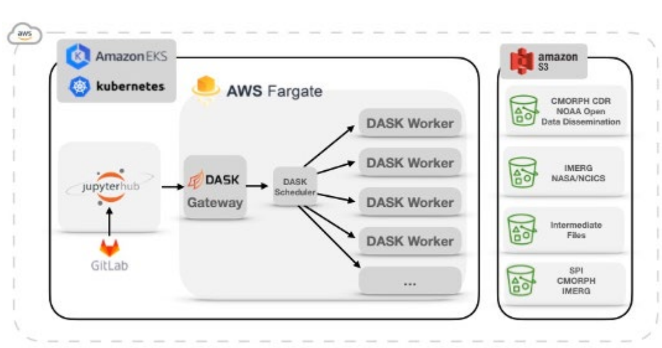


Figure 2. *Architecture for SPI cloud computation using AWS cloud computing resources.*

The team is currently extending the process to the satellite precipitation product IMERG to generate a higher-resolution global SPI (i.e., 6-fold increase with respect to CMORPH-SPI). As an element of comparison and as a further justification for moving to the cloud environment, each SPI file is 20GB for CMORPH, 80GB for NClimGrid, and will be 200GB for IMERG for a given accumulation period.

As part of possible long-term developments, the fast-processing time and flexible framework will allow the use of other precipitation products (SPPs, radar, in situ) to investigate the SPI variability to input datasets. From precipitation-only-driven indices, such as SPI presented here, with other datasets such as temperature, evapotranspiration, soil moisture, vegetation indices (NDVI, LAI), streamflow, and groundwater storage (GRACE) incorporated to develop more complex drought indices (i.e., SPEI, agricultural drought, hydrological drought).

Planned work

- Finalize the implementation of the global high-resolution IMERG-SPI.
- Compare the different daily drought indices computed: CMORPH-SPI with NClimGrid-SPI over CONUS, and IMERG-SPI over the globe (also part of the "Global Near-Real- Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets" project).
- Rewrite the SPI source code for a better optimization of the cloud computing resources. This step is necessary to move from the current cloud configuration that uses AWS Fargate (requires user management, which makes it less desirable for daily operations) to the more flexible AWS Lambda functions. While the first requires user management, which makes it less desirable for daily operations, the second configuration breaks the process into a multitude of tasks, each with running times of less than 12 minutes of computation per task.
- Implement and test the drought relief module to determine the amount of rain needed to end select drought conditions ("also part of the "Drought Detection and Relief Using In Situ Data from NClimGrid" project).

Products

- Operational near-real-time global daily CMORPH SPI available within 48 hours to the current day. The CMORPH-SPI is available via the drought.gov portal (https://gdis-noaa.hub.arcgis.com/).

Presentations

Prat, O.P., **D. Coates**, **S. Wilkins**, **R.D. Leeper**, B.R. Nelson, R. Bilotta, S. Ansari, and G.J. Huffman, 2022: Operational Framework for Near-real Time Drought Monitoring Using Global Remotely Sensed Precipitation Products and In-situ Datasets. *European Geophysical Union (EGU) General Assembly*, Vienna, Austria. May 25, 2022.

Drought Detection and Relief Using In Situ Data from NClimGrid	
Task Team	Olivier Prat, David Coates, Ronald Leeper, Scott Wilkins, Denis Willet
Task Code	NC-SAS-18-NCICS-OP

Highlight: The SPI code developed to generate the near-real-time CMORPH-SPI was adapted to the in –situ–based high resolution NClimGrid dataset (1952–present). The NClimGrid-SPI provides almost 70 years of daily SPI conditions over CONUS at a 5 x 5 km spatial resolution. Evaluations and comparisons with CMORPH-SPI and the US Drought Monitor were performed. In addition, the inversion of the high-resolution CONUS-wide NClimGrid-SPI will be used to produce a drought amelioration index, which can be aggregated at various levels (e.g., county or region). The inversion algorithm developed to produce an amelioration index will determine the rainfall deficit that would alleviate drought conditions by reaching a given target SPI.

Background

The use of satellite precipitation data from CMORPH-CDR has been proven effective to detect and monitor drought on a global scale in near-real time. Precipitation data are used to compute the Standardized Precipitation Index (SPI). The SPI has been recommended as a drought monitor (a drought index) by the World Meteorological Organization (WMO 2012), and it is widely used by meteorological and agricultural services around the world. The SPI is widely used to characterize meteorological drought on a range of timescales. It can characterize drought or abnormal wetness at different timescales which correspond with the time availability of different water resources and is more comparable across regions with different climates than the Palmer Drought Severity Index (PDSI). SPI is also less complex to calculate than PDSI.

Building on the availability of near-real-time satellite precipitation data, we have computed a global daily CMORPH-SPI. The availability of longer-term, gridded, near-real-time, in –situ–based precipitation datasets make them valuable candidates for drought detection and characterization at an even higher resolution. Over the past two years, CISESS NC scientists have worked with NCEI to enhance the process for calculation of global SPI values based on satellite climate data records (CMORPH-CDR). A near-real-time global CMORPH-SPI is now available quasi-operationally via the Interactive drought.gov portal (https://www.drought.gov/international).

The existing Python SPI code was downscaled to ingest precipitation data from NClimGrid. The Gridded 5 km Global Historical Climate Network-Daily (GHCN-D) temperature and precipitation dataset (NClimGrid) for CONUS consists of four climate variables derived from the GHCN-D dataset: maximum temperature, minimum temperature, average temperature, and precipitation. The use of NClimGrid precipitation data will provide long-term (1952–present), high-resolution (5 x 5 km), near-real-time 70-year daily SPI conditions over CONUS. Furthermore, the high-resolution daily NClimGrid-SPI values will be the basis of an inversion algorithm to produce a drought amelioration index, which can be aggregated at various levels (i.e., county or region). The USDM will be used as basis for initial "truth" percentiles to test the amelioration approaches.

Accomplishments

The CMORPH-SPI code was adapted to the in situ dataset NClimGrid. The adaption from the global satellite CMORPH dataset (0.25 x 0.25 degrees; daily, 1998–present) to the higher resolution in situ NClimGrid dataset (5 x 5 km; daily, 1952–present) required substantial modification to the code for process optimization (i.e., tests on the optimal size of the tiles, fixing exiting bugs, postprocessing to recombine the tiles, compression of result files, extraction of distribution parameters, etc.). The NClimGrid-SPI provides almost 70 years of daily SPI conditions over CONUS at a 5 x 5 km spatial resolution.

NClimGrid-SPI was evaluated with respect to the CMORPH-SPI over CONUS and with the USDM. Time series of NClimGrid-SPI extracted at selected locations across CONUS were compared with the those of CMORPH-SPI and for different locations over CONUS. A summer intern (A. Ikelheimer) used NClimGrid-SPI and CMORPH-SPI to investigate the seasonality of droughts. NClimGrid-SPI provides over 70 years of daily drought conditions (1952,present), which allowed the team to compute the time series of the percent area in drought over CONUS from 1952–present. The comparison of NClimgrid, CMORPH-SPI, and USDM (since 2000) showed that all products display similar time series in terms of percentage of CONUS under drought conditions. However, there are significant differences in terms of the extent of the area under drought conditions with USDM located between CMORPH-SPI (higher percent of area in drought) and NClimGrid-SPI (lower percent of area in drought).

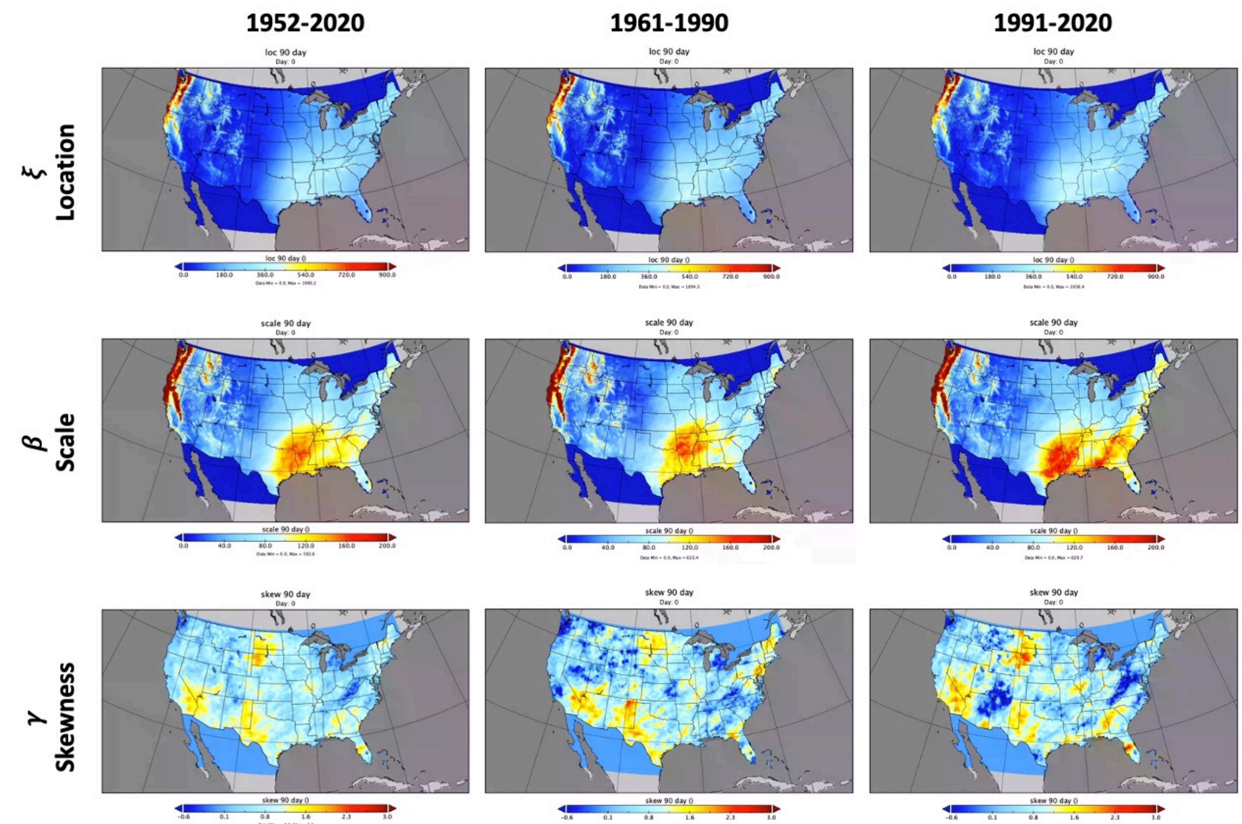


Figure 1. *Distribution parameters (location, scale, skewness) using the Pearson III formulation for the 90-day SPI derived over CONUS from NClimGrid for January 1st. The parameters are presented for three different periods: 1952–present, 1961–1990, and 1991–2020.*

A comparison of the daily NClimGrid-SPI with the daily CMORPH-SPI was performed. In particular, we analyzed the distribution parameters (Gamma: 2 parameters; Pearson III; 3 parameters) obtained for different timescales. The distribution parameters obtained for NClimGrid-SPI were compared with those obtained for CMORPH-SPI over a shorter time period (1998–present). Although we found some consistency between the distribution parameters obtained for NClimGrid-SPI and CMORPH-SPI in terms of seasonallity, we found some differences in terms of magnitude due to sensor characteristics (in situ versus remotely sensed) and differences in terms of reference period over which distributions parameters are computed. Figure 1 displays the differences for the Pearson III distribution parameters (location, scale, and skewness) computed over three different periods: 195–-present, 1961–1990, and 1991–2020. Those differences illustrate precipitation changes over time.

Another aspect of this work consists of implementing a drought amelioration index using SPI as the drought metric and NClimGrid as input. The goal is to determine the amount of missing rain to provide drought relief (i.e., the amount of rain needed to reach a target SPI value or drought category). The stand-alone code, yet to be implemented as an added value product of the near-real-time SPI computation, allows us to estimate the precipitation amount that would be needed (i.e., rainfall deficit) for drought relief at each given location.

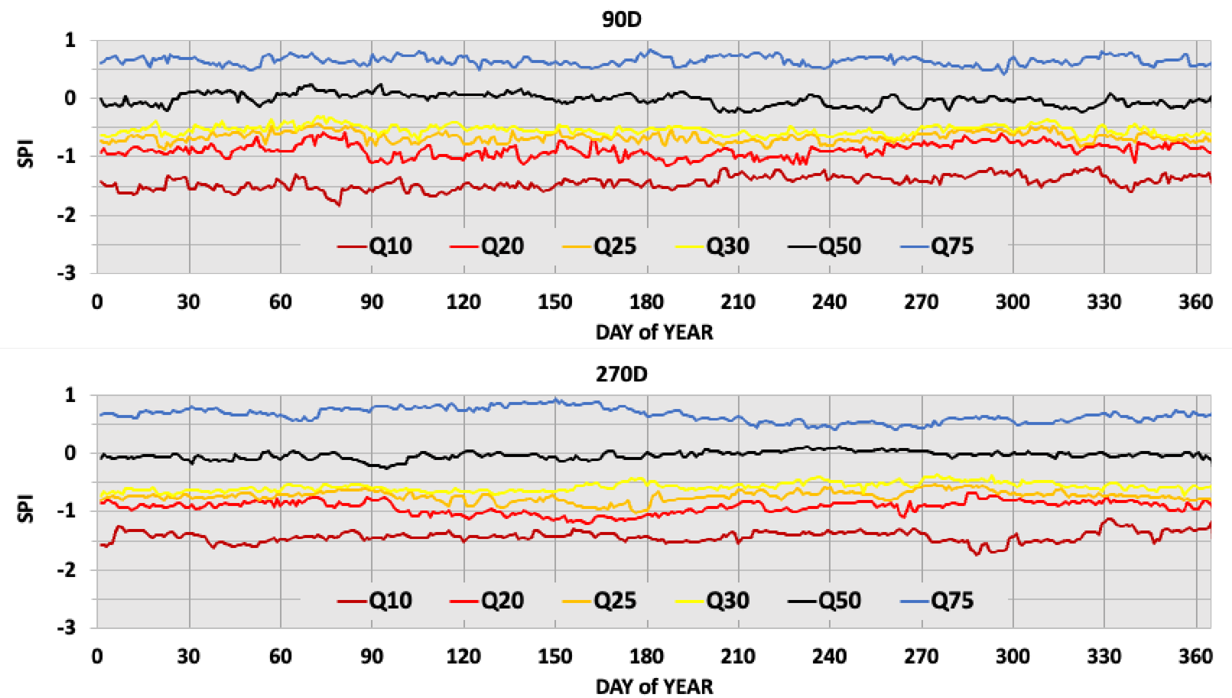


Figure 2. *Each line indicates the "wettest" conditions achievable (maximum SPI value) for a given precipitation quantile (Q = 10, 20, 25, 30, 50, and 75) for the 90-day SPI (top figure) and for the 270-day SPI (bottom figure).*

On another approach we used precipitation quantiles and corresponding SPI values to determine how any variation with respect to precipitation normals will impact hydrological conditions for each of the accumulation periods considered (30, 60, 90, 180, 270, and 360 days). Figure 2 displays the maximum SPI value possible (i.e., the "wettest" conditions achievable) as a function of precipitation quantile (Q = 10, 20, 25, 30, 50, and 75) with respect to the day of the year for two different accumulation periods (90 and 270 days) for a location in South Carolina. This representation accounts for both precipitation seasonality and precipitation changes over time.

This work is conducted in parallel with two other drought research projects: the ongoing evaluation of the quasi-operational CMORPH-SPI and the adaptation of the existing code to the higher-resolution satellite dataset IMERG in a cloud computing environment (see separate task descriptions). For the second task, we have adapted the SPI process to cloud-scale computing. CMORPH-SPI and NClimGrid-SPI have been successfully transferred to AWS cloud services and have allowed us to decrease the computation time by an order of magnitude of two (from several hours to less than 10 minutes). Ultimately, the fast-processing time and flexible framework will allow us to 1) use other gridded precipitation products 2) incorporate seasonal climate simulations to provide seasonal drought predictions and 3) combine other datasets (temperature, evapotranspiration, soil moisture, vegetation indices, streamflow, groundwater storage) to develop more complex drought indices.

Planned work

- Finalize the adaptation of the SPI source code to the AWS cloud computing environment; a rewrite of the SPI source code is necessary to further optimize the current cloud configuration (AWS Fargate) to a more flexible configuration (AWS Lambda functions)
- Continue the evaluation of the daily NClimGrid-SPI and comparison against CMORPH-SPI and USDM or other in –situ–based drought monitoring products
- Automatize the extraction of drought metrics to characterize drought conditions in near-real time (snapshots of drought conditions; time series of percent area in drought; local, regional, or global statistics)
- Implement the drought relief module to determine the conditions to end a drought (accumulation period, season, location)
- Use NClimGrid daily temperature information to generate a daily SPEI index over CONUS
- Use seasonal rainfall predictions (from 45 days to 6 months) for short term drought predictions
- Communicate the results to the community (conference presentations, journal publications)
- Help with the transition R2O of the NClimGrid-SPI to provide near-real-time daily drought conditions over CONUS

Presentations

Prat, O.P., D. Coates, S. Wilkins, D. Willett, R.D. Leeper, B.R. Nelson, R. Bilotta, S. Ansari, and G.J. Huffman, 2022: Near-real Time Daily Drought Monitoring Using Remotely Sensed and In-situ Gridded Precipitation Datasets. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 15, 2022.

Other

- Summer Internship: During Summer 2022, undergraduate Intern Anna Ikelheimer (University of Colorado Boulder) compared the differences between CMORPH-SPI and NClimGrid-SPI for different locations over CONUS. Ikelheimer used both datasets to investigate the seasonality of droughts. Science advisors: David Coates, Olivier Prat (10 weeks).

Toward the Development of Climate Data Records (CDRs) for Precipitation: Global Evaluation of Satellite Based Quantitative Precipitation Estimates (QPEs)	
Task Leader	Olivier Prat
Task Code	NC-SAS-19-NCICS-OP

Highlight: This effort is a long-term assessment of the different SPPs from four CDRs (PERSIANN-CDR; GPCP; CMORPH-CDR; AMSU A/B Hydro-bundle). The analysis was extended to evaluate the ability of three SPPs (PERSIANN-CDR; GPCP; CMORPH-CDR) to capture cold-season precipitation. The CDRs' performance with respect to cold-season precipitation was compared to warm-season and full-year analysis for benchmarking purposes. A manuscript was submitted to the Journal of Hydrometeorology.

Background

Four satellite-based precipitation products (SPPs) are part of the Climate Data Records (CDRs) portfolio: PERSIANN-CDR, GPCP, CMORPH, and AMSU-A/B Hydro-bundle. PERSIANN-CDR is a 40-year record of daily-adjusted global precipitation. GPCP is a more than 40-year record of monthly and pentad-adjusted global precipitation and a 27-year record of daily-adjusted global precipitation. CMORPH is a 25-year record of daily and sub-daily adjusted global precipitation. AMSU-A/B Hydro-bundle is a 22-year record of rain rate over land and ocean, snow cover and surface temperature over land, sea ice concentration, cloud liquid water, and total precipitable water over ocean, among others.

Over the last few years, the four SPP-derived quantitative precipitation estimations (QPEs) were evaluated, resulting in several publications and presentations. Product intercomparisons have been performed at various temporal (annual, seasonal, daily, or sub-daily, when possible) and spatial scales (global, over land and ocean, tropics or higher latitudes, high elevation). The evaluation of the different products included trend analysis and comparison with in situ datasets from the Global Historical Climatology Network (GHCN-Daily), the Global Precipitation Climatology Centre (GPCC) gridded full data daily product, and the U.S. Climate Reference Network (USCRN).

Accomplishments

The evaluation of SPP CDRs was extended to cold precipitation. The goal is to evaluate the ability of the three gridded satellite precipitation products (CMORPH-CDR, PERSIANN-CDR, GPCP) to capture cold-season precipitation. The evaluation was performed at the daily scale over CONUS for 2007–2018. The daily precipitation measurements at the ground and the atmospheric conditions (temperature, relative humidity) were obtained from the USCRN. The USCRN network (including associated local networks) is composed of about 240 stations. Among those USCRN stations, 70 are located between latitudes 40° and 60°N, and 65 are located above an altitude of 1,500 m. The USCRN network provides sub-hourly (5-minute), hourly, and daily precipitation measurements from shielded gauges in addition to air temperature and wind speed information at 1.5 m. The evaluation was performed by using the usual mathematical toolbox, which includes bias (conditional and unconditional), Kling–Gupta efficiency, Pearson's correlation coefficient, bias and variability ratio, contingency analysis, number of rainy days, percentiles, frequency bias, accuracy, false alarm ratio, probability of detection, and probability of false detection.

To date, the evaluation of the three CDRs (PERSIANN-CDR, GPCP, CMORPH) has been completed. Recent work focused on the ability of the three CDRs to capture cold-season precipitation. The evaluation was performed over CONUS against USCRN stations that aren't used in any bias-adjustment procedure of the three SPPs and that provide reference precipitation measurements and collocated atmospheric conditions (temperature) at the daily scale. This analysis extends previous work (Prat et al. 2021, https://doi.org/10.1175/JHM-D-20-0246.1) by quantifying the differences between cold- and warm-season performances.

Figure 1 displays the results for the conditional (i.e., precipitation observed simultaneously by the SPP and at the station) and unconditional (i.e., including zeros and non-zeros for USCRN and SPPs) analysis which include the Kling–Gupta efficiency (Figure 1a), Pearson’s correlation coefficient (Figure 1b), the bias (Figure 1c), and the variability ratio (Figure 1d).

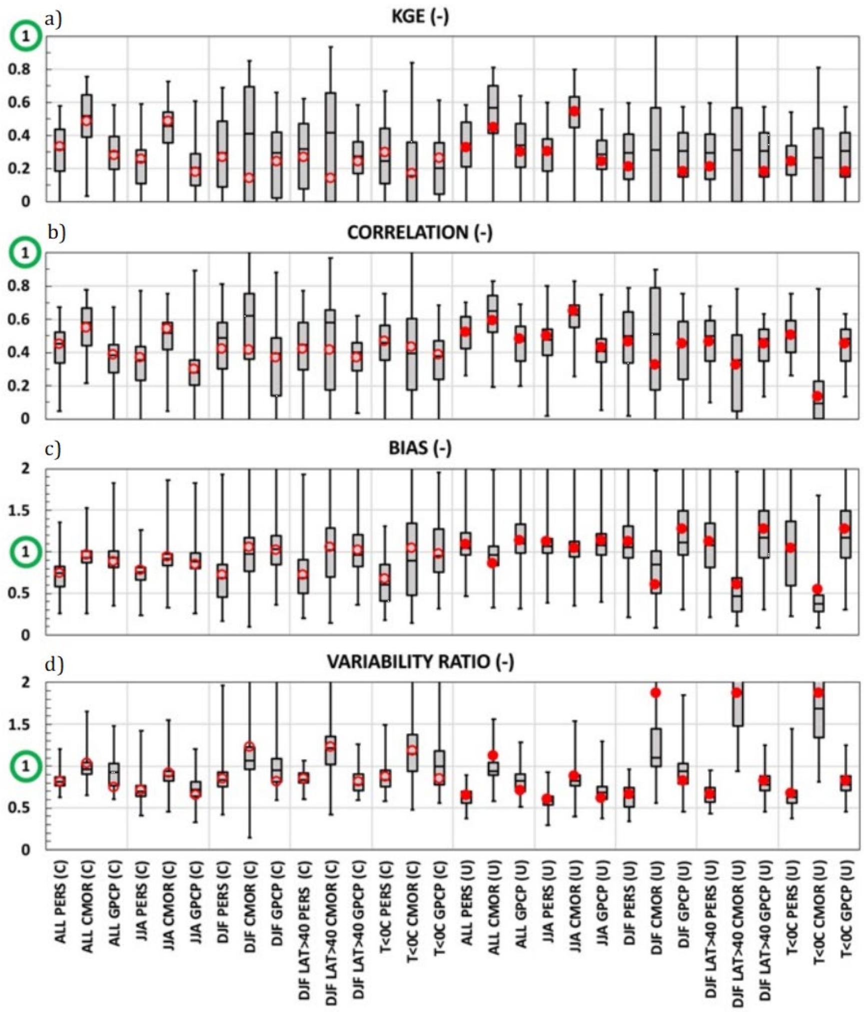


Figure 1. *(a) Kling–Gupta efficiency (KGE), (b) Bias, (c) Pearson’s correlation coefficient, and (d) variability ratio for daily precipitation with respect to USCRN stations for PERSIANN-CDR (PERS), CMORPH-CDR (CMOR), and GPCP. Statistics are provided for all the USCRN stations on an annual basis (ALL), for the warm season (JJA), for the cold season (DJF), for the cold season and for stations located above the latitude of 40°N (DJF LAT>40N), and for stations where average daily temperature is below 0°C (T<0). The whisker plots present the minimum, 25th percentile, median, 75th percentile, and maximum values. The red circles indicate the average value, and results are presented both conditionally (C: empty circles) and unconditionally (U: full circles). Only stations that had at least 30 days per year of average daily temperature below 0°C are considered. The green circles indicate the perfect score.*

The evaluation showed that CMORPH performed better on an annual basis and during the warm season both conditionally and unconditionally. However, during the cold season at higher latitudes in winter and for negative temperatures, CMORPH presented degraded performances when compared to the two other CDRs (PERSIANN-CDR, GPCP).

The CDR evaluation with respect to cold-season precipitation has been completed. The CDRs' performance with respect to cold-season precipitation was compared to warm-season and full-year analysis for benchmarking purposes. A manuscript was submitted for publication to the *Journal of Hydrometeorology* and is undergoing revisions. The main conclusions of the study can be summarized as follows:

1. The three datasets displayed better performances during the warm season when compared to the cold season. For the cold season, contingency statistics worsened for the three SPPs. Performances for CMORPH were highly dependent on seasonality while those for PERSIANN-CDR and GPCP were more consistent throughout the year.
2. Annually and for the warmer seasons (spring, summer, fall), CMORPH presented higher values of Kling–Gupta efficiency that combine correlation, bias, and variability into one objective performance score. In winter, CMORPH showed the worst performance when compared to the two other SPPs over areas experiencing recurring snow or frozen and mixed precipitation (above 40°N latitudes). The performance of CMORPH worsened for days with negative average temperature (T<0°C) due to a lack of rainfall detection over snow-covered surfaces.

The quantification of cold-season precipitation errors and biases of the three CDRs provides an objective basis for rainfall retrieval algorithm improvements for the next generation of SPPs such as the new generation of CMORPH-CDR (CMORPH2).

Additionally, we advised Dylan Major, an undergraduate student from the University of North Carolina at Asheville (UNCA). This internship is at the center of a collaborative research project that involves researchers from CISESS NC, UNCA, CISESS MD, and NOAA NCEI. The objective of the internship is to evaluate satellite precipitation products NASA IMERG, and NOAA CPC CMORPH over the Great Smoky Mountains, near Asheville, using in situ data collected for more than a decade by a high-density rain gauge network of about 30 rain gauges (known as the Duke Great Smoky Mountain Rain Gauge Network). The ongoing work conducted since June 2022 focused on quality control (identification of erroneous data, reporting errors, and missing data) and statistical data analysis (computation of spatial and temporal correlations, conditional analysis, sub-grid-scale variability) of in situ and satellite precipitation data.

Planned work

The evaluation of CDRs for precipitation has been completed. Current work is focused on finalizing the publication (revisions). A similar evaluation of the new CMORPH2 product will be conducted when available.

Publications

Prat, O.P., and B.R. Nelson, 2023: Evaluation of cold-season precipitation estimates derived from gridded daily satellite precipitation products. *Journal of Hydrometeorology* (accepted pending minor revisions).

Presentations

Prat, O.P., 2023: Applications of Precipitation Climate Data Records. *Workshop on Precipitation Estimation from LEO Satellites: Retrieval and Applications*, virtual. March 2, 2023.

High-resolution Infrared Radiation Sounder (HIRS) Temperature and Humidity Profiles	
Task Team	Yuhan (Douglas) Rao
Task Code	NC-SAS-20-NCICS-YR

Highlight: The team is applying neural networks to HIRS data to develop a global temperature and humidity profile dataset for 1978–present. The dataset was extended through 2020, and a new cloud screening process is under development to address limited data over oceans.

Background

The goal of this task is to derive temperature at 12 different altitudes/pressures (surface, 2 m, 1,000 mb, 850 mb, 700 mb, 600 mb, 500 mb, 400 mb, 300 mb, 200 mb, 100 mb, and 50 mb) and humidity at 8 different altitudes/pressures (2 m, 1,000 mb, 850 mb, 700 mb, 600 mb, 500 mb, 400 mb, and 300 mb) 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 for surface pressures lower than 850 mb and one for surface pressures greater than 850 mb. RTTOV (Radiative Transfer for TIROS Operational Vertical Sounder) data based on more than 62,000 profiles from the European Centre for Medium-Range Weather Forecasts (ECMWF) were used as inputs for neural network training.

The resultant neural networks were applied to produce global temperature and humidity profiles using a series of 13 satellites for 1978–2017. When processing the data, US Geological Survey (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 well-mixed globally) were obtained from the Scripps CO_2 Program.

The latest version of the dataset, v4, has been validated through evaluation of the stability of the intersatellite time series coupled with intercomparisons with independent observation platforms that have become available in more recent years. Among the 11 pairs of satellites carrying the HIRS instrument with overlapping time periods, correlation coefficients greater than 0.7 are achieved more than 90% of the time. Very high correlation is demonstrated at the surface and 2 m levels for both temperature (>0.99) and specific humidity (>0.93). Comparisons with independent datasets for 2006–2017 (e.g., RS92, COSMIC, COSMIC2013, IASI) show good agreement at all profile levels, but very close matching of surface and 2 m temperatures over a wide domain of values is depicted in all presented intercomparisons.

Accomplishments

Current work is focused on 1) improving intersatellite calibration of raw HIRS brightness temperatures; 2) creating a new dataset version, v5, incorporating a new approach to cloud –clearing; and 3) extending the data records by using newer sounding instruments (e.g., IASI and CrIS) on the polar orbiting satellites.

Improving quality flag in version 5 profile. The team recently updated the cloud screening procedures to add an additional quality flag by using a homogeneity test of the HIRS brightness temperature values in both spatial and temporal domains. During the reprocessing of the v5 of the temperature and humidity profiles from HIRS historical data, the project team discovered the inconsistency of the quality flag that was designed to reflect whether the HIRS observations are impacted by possible cloud cover. Therefore, the project team reengineered the cloud quality flag into a five-value system (see Table 1 to reflect the updated quality flag in v5 profile).

QF Value	Description	Change from v4
1	The observation is cloud-clear based on co-located PATMOS-x cloud fraction and cloud probability values.	No change
2	The observation is likely cloudy based on co-located PATMOS-x cloud fraction and cloud probability values.	No change
3	The observation is cloudy based on co-located PATMOS-x cloud fraction and cloud probability values.	No change
4	The observation is cloudy based on HIRS homogeneity test result. There are no co-located PATMOS-x data.	Newly added in version 5
5	The observation is cloud-clear based on HIRS homogeneity test result. There are no co-located PATMOS-x data.	Newly added in version 5

Table 1. *The updated quality flag to indicate whether HIRS observations are impacted by cloud coverage in Version 5 HIRS profile retrieval.*

The updated cloud screening procedures improved the clear sky data availability in the high-latitude regions. Additionally, the team is updating the production workflow to move the cloud screening procedure before the temperature and humidity profile retrieval process. The modified workflow is aimed to streamline the production process to generate intersatellite calibrated brightness temperature as an additional data product that can be used for other research projects.

A primary user of the dataset, the International Satellite Cloud Climatology Project (ISCCP), requested an extension of the dataset through 2021. Previously, the dataset ended mid-2017 due to instability in the HIRS sensor aboard the M-02 satellite. Intersatellite calibration of raw HIRS brightness temperatures was performed for M-01. The resultant calibrated HIRS input data from M-01, along with PATMOS-x data from M-01, were used to produce the dataset extension. The team also started the processing of N19 data after 2019 to extend HIRS data into 2021.

The team initiated the process to begin the research-to-operations transition with the formal request to archive the dataset with NCEI. While the request is under consideration, work continues to achieve archive milestones such as developing the code to convert the current ASCII format to netCDF output format and creating supporting algorithm theoretical basis documentation. The code for converting ASCII format to netCDF4 output format has been completed and is incorporated in the v5 data processing workflow.

To further extend the HIRS atmospheric profile products beyond 2020, the team is exploring ways to incorporate HIRS-like data generated from the current generation of high-resolution infrared sounding sensors (e.g., CrIS and IASI). During the transition from version 4 to version 5 of HIRS profile data, the team is refactoring the version 4 code using a modern programming language (i.e., Python) to streamline the data processing in version 5 product generation. The team also started the process to explore the retrieval of temperature and humidity profiles using homogenized HIRS-like IASI data in 2017 and 2018.

Planned work

- Complete the reprocessing of the time series of v5 HIRS temperature and humidity profiles to 2017 using HIRS only data
- Test the retrieval of temperature and humidity profile retrieval using calibrated HIRS-like IASI data

- Assist in meeting operational readiness review requirements for the dataset transition to Climate Data Record Initial Operating Capability
- Explore implementing bootstrap methodology to provide associated uncertainty estimates
- Continue collaborations with user groups (including the ISCCP and NASA's Surface Radiation Budget Team)

Presentation

Rao, Y., 2022: An Improved Neural Network-Based Satellite Record of Clear-Sky Atmospheric Temperature and Humidity Profiles (poster). *AMS Collective Madison Meeting.* Madison, WI. August 11, 2022.

Supporting the Development of Artificial Intelligence (AI) within NOAA and CISESS	
Task Leader	Yuhan (Douglas) Rao
Task Code	NC-SAS-21-NCICS-YR

Highlight: CISESS NC assisted in the development of the NOAA Center for Artificial Intelligence, supported the execution of the 3rd annual NOAA AI Workshop series on Leveraging AI in Environmental Sciences, and will serve as host for the 11th International Conference on Climate Informatics.

Background

Artificial intelligence (AI) is among the six science and technology strategies developed since 2019 to improve NOAA's mission. NOAA's AI strategy has five goals to transform and improve NOAA's mission, including "establish an efficient organizational structure and processes to advance AI across NOAA" and "promote AI proficiency in the workforce."

To accelerate the development of AI across all of NOAA's mission areas, NCEI spearheaded development of the NOAA Center for AI (NCAI) in the summer of 2020. The center performs multiple functions, including coordinating communities of practice around AI across all NOAA line offices, facilitating workforce development across the entire agency, and establishing collaboration within NOAA and external partnerships. The NCAI development team included CISESS NC staff who co-led development of the NCAI training framework with NOAA's Center for Satellite Applications and Research and collaborated with team members to facilitate the effort to assess the AI readiness of NOAA's data archive.

To further engagement with the community using AI for climate studies, CISESS NC agreed to host the 11th International Conference on Climate Informatics, which focuses on the intersection of climate science and data science. CISESS NC is also involved in the planning and execution of the NOAA annual workshop series on Leveraging AI in Environmental Sciences.

Accomplishments

NCAI.

CISESS NC continues to participate in the development of NCAI, supporting four major tasks, including:

- *Expansion of the NOAA community of practice on AI*: Through engagement at various national and international conferences and other events, the NOAA community of practice on AI doubled its membership in 2022 (more than 700 total members). CISESS NC supported the planning and implementation of AI-related sessions at the 2022 NOAA Environmental Data Management Workshop, 2022 AGU Fall Meeting, 2023 AMS Annual Meeting, and ESIP semiannual meetings to support partnership development and community engagement.
- *Workforce Development*: During the reporting period, CISESS NC coordinated the development of a pilot collection of AI learning journeys, a set of curated computational notebooks, to demonstrate the development of AI applications using NOAA open environmental data. Also, CISESS NC collaborated with NSF AI Institute for Research on Trustworthy AI in Weather, Climate, and Coastal Oceanography to teach the summer school of trustworthy AI for environmental science.
- *Development of AI-ready data standard*: CISESS NC, in collaboration with the ESIP Data Readiness Cluster, which comprises a diverse membership from more than 30 organizations, co-led the AI-ready data standard development. The collaboration led to a community-wide AI-ready data survey to understand user requirements for AI-ready open environmental data. The draft AI-ready data checklist was presented to the Department of Commerce Data Governance Board and the Interagency Council for Advancing Meteorological Services. CISESS-NC also collaborated with

partners to host a hands-on tutorial session during the 2022 NOAA Environmental Data Management Workshop and 2022 ESIP July Meeting to use the AI-ready data checklist to assess the readiness of open environmental data from NOAA and other data providers.

- *4th NOAA Workshop on Leveraging AI in Environmental Sciences*: Douglas Rao co-chaired the 4th NOAA Workshop on Leveraging AI in Environmental Sciences, executed by a team of 45 members from several NOAA line offices and external partners, with support from Earth Science Information Partners. The workshop focused on collaboration building on three high-priority themes for NOAA: fire weather and impacts, a digital twin for the Earth system, and AI for ocean science and conservation. It attracted more than 750 registered participants from public, private, and academic organizations. Featured speakers included UK Met Office Chief Scientist Dr. Stephen Belcher, NOAA Chief Scientist Sarah Kapnick, Nadine Alameh of the Open Geospatial Consortium, and NOAA Senior Advisor for Climate Ko Barrett. Partners included NASA, UK Met Office, ECMWF, US Forest Service, NVIDIA, Amazon Web Services, Kitware, Esri, NSF AI Institute, and many academic institutions.

11th International Conference on Climate Informatics.

CISESS NC hosted the 11th International Conference on Climate Informatics in May 2022. This conference series brought together researchers to forge international collaborations between climate science, data science, and computer science; share state-of-the-art developments in climate data and informatics; and accelerate the rate of discovery in climate science and adaptation of climate applications. Participants came from 15 countries, including developing countries such as India and Benin. The conference brought together researchers and users across different disciplines and sectors. This was a hybrid event with both in-person and virtual participation and included a hybrid hackathon on the topic of drought prediction using open environmental data in public cloud environments. https://ncics.org/news/events/ci2022/

Planned work

- Continue development of interactive training materials for the NCAI training effort through engagement with Office of Education, NOAA line offices, and academic partners.
- Plan and execute the 5th NOAA Workshop on Leveraging AI in Environmental Sciences

Publications

Watson-Parris, D., **Y. Rao**, D. Olivié, Ø. Seland, P. Nowack, G. Camps-Valls, P. Stier, S. Bouabid, M. Dewey, E. Fons, J. Gonzalez, P. Harder, K. Jeggle, J. Lenhardt, P. Manshausen, M. Novitasari, L. Ricard, and C. Roesch, 2022: ClimateBench v1.0: A Benchmark for data-driven climate projections. *Journal of Advances in Modeling Earth Systems*, **14** (10), e2021MS002954. https://doi.org/10.1029/2021MS002954

Presentations

Rao, Y., 2022: 20 Years of Data Science—an Assessment (panelist). *International Data Week 2022*, virtual. June 21, 2022.

Rao, Y., 2022: AI-ready Data. NSF *Inter-directorate Working Group on AI for Bio Data*, virtual. September 19, 2022.

Rao, Y., 2022: Artificial Intelligence Meets Earth and Space Science: Convergence to Address Grand Challenges I (session co-convener). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Building AI-Ready NOAA: Early Success, AI-ready Data, and Workforce Development (session chair). *2022 Environmental Data Management Workshop*, virtual. September 12, 2022.

Rao, Y., 2022: Cross-Agency Coordination for Advancing Machine Learning and Artificial Intelligence for Earth System Predictability Town Hall Meeting (panelist) *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 13, 2022.

Rao, Y., 2022: Enabling AI Application for Climate: Developing a Collection of AI-ready Open Data—Data-A-Thon (session leader). *2022 July Earth Science Information Partners (ESIP) Summer Meeting,* Pittsburgh, PA. July 20, 2022.

Rao, Y., 2022: FARR: A Research Coordination Network for FAIR, AI Readiness, and Reproducibility for AI. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Organizational Vision and Strategy on Leveraging AI/ML in Geosciences (moderator). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Public-Private-Academia Partnership: From Research Development to Societal Benefits (moderator). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Understanding the Community's Need for AI-Ready Open Environmental Data*. NCAR Computational and Information Systems Lab webinar series*, virtual. April 20, 2022.

Toward Visualizing and Analyzing Climate Data Records on the Cloud	
Task Leader	Yuhan (Douglas) Rao
Task Code	NC-SAS-22-NCICS-YR

Highlight: NDVI CDR data are being converted from netCDF4 into a cloud-optimized Zarr format as a first step in in this pilot study to enable future AI/ML applications. The team explored three temporal data "chunking" options and determined that a monthly chunking strategy would best maximize the performance of Zarr format for storing spatiotemporal datasets.

Background

Climate data records (CDRs) are long-term, consistent datasets, mostly derived from satellite observations, which are suitable to monitor climate change and impacts. There are currently more than 40 CDRs provided by NCEI in four categories—fundamental, terrestrial, atmospheric, and oceanic. Since September 2021, all CDRs have been available in their native format on three major cloud service providers (Amazon Web Services, Google Cloud Platform, and Microsoft Azure) through NOAA's Big Data Program (now known as the NOAA Open Data Dissemination Program).

However, the technical barriers to access and understand CDR data make it difficult for broad applications of CDRs for climate application development. This project aims to improve the usability/utility of CDR data on cloud computing platforms and develop tools and tutorials to support climate applications using CDR data on the cloud.

The project has three major tasks: 1) convert CDR data into analysis-ready cloud-optimized (ARCO) data to improve performance of data access on the cloud; (2) develop an interactive mapping tool to allow users to visualize and explore simple analyses with selected CDR data; and (3) develop tutorials on CDR data use in its native format and ARCO format.

Accomplishments

CISESS NC began the pilot project as part of the first cohort of the NOAA Cloud Pathfinder Project (NCPP). As a pilot, CISESS NC engaged with the NCEI CDR team to understand usage statistics for all CDR datasets and chose Normalized Difference Vegetation Index (NDVI) as the pilot CDR for exploration. CISESS NC began with three goals:

1. ***Convert CDR data into ARCO format.*** NDVI CDR data are stored as daily netCDF4 files using the climate forecast convention, which is not optimized for cloud-based computing and analysis. To maximize the performance of CDR data on the cloud, the NDVI CDR data are being converted from netCDF4 format into Zarr format, which is optimized for cloud storage and access. The performance of Zarr format for storing spatiotemporal datasets is related to how the dataset is chunked spatially and temporally. During the pilot development, the team explored three different temporal chunking options (daily, monthly, and yearly), with the corresponding spatial chunk size determined by ensuring each spatiotemporal chunk is roughly 50MB. After using three typical-use cases (single point time series extraction, local region data extraction, and large-scale regional analysis) to test the access performance using one year of NDVI data, the monthly data chunking strategy appears to outperform the other chunking strategies. Therefore, monthly chunking was selected for converting the entire NDVI CDR data collection.

2. ***Develop Interactive Mapping Tool.*** To further reduce the barriers for CDR data users, CISESS NC plans to develop a user interface for the interactive online mapping tool to visualize CDR data

using NDVI as the pilot. In collaboration with NCEI scientists, the team is designing a web interface following the interactive atlas from IPCC Working Group I. The mapping tool will allow users to select regions of interest to generate climatology and anomaly maps as well as regional average time series of anomalies. We completed the pilot phase development of the interactive mapping dashboard with pre-computed regional NDVI climatologies and anomalies based on the climate regions defined by IPCC Working Group I. The dashboard allows users to generate time series of NDVI anomalies for the time period of their choice (Figure 1).

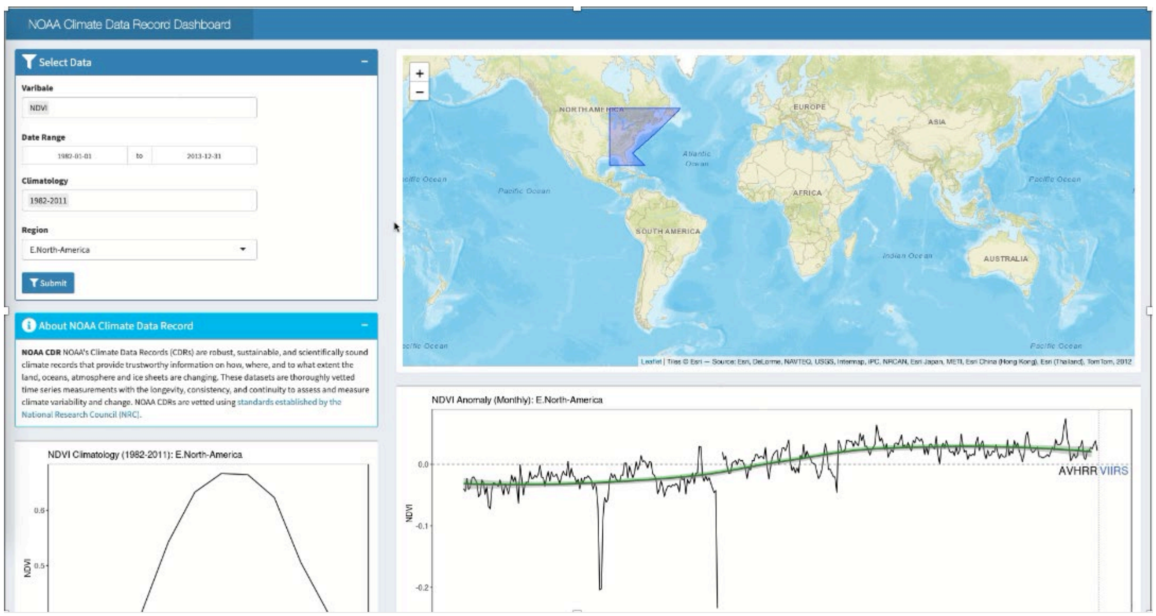


Figure 1. *Screenshot of the interactive mapping tool to visualize the NOAA NDVI CDR.*

3. ***Develop Tutorials for User Engagement***. To enable CDR data use on the cloud, the CISESS NC team also began development of tutorials demonstrating how to directly access data on the cloud and how to process, analyze, and visualize CDR data using Python packages (Figure 2). The pilot tutorial uses NDVI data and Python packages in the *Pangeo* ecosystem for regional data analysis and visualization. The tutorials covered five topics: 1) data access, 2) data visualization, 3) basic data exploratory, 4) long term climatology, and 5) anomaly analysis.

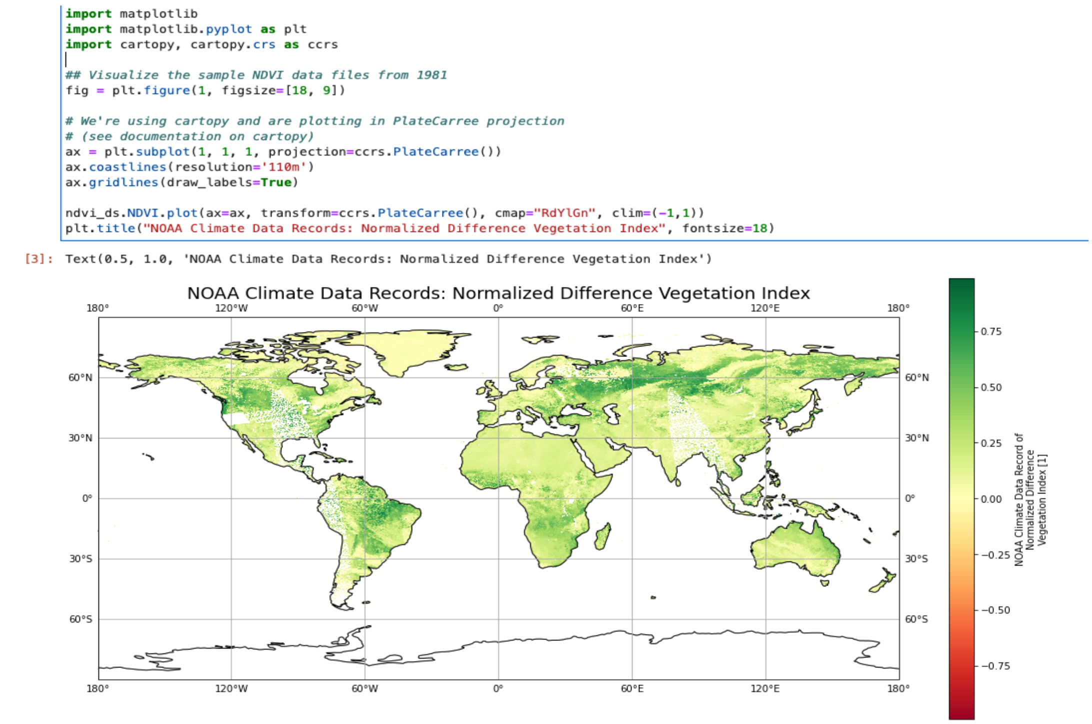


Figure 2. *Screenshot of the user tutorial in Jupyter notebook format to visualize NDVI data from Amazon Web Services.*

Planned work

This work is complete as a pilot project under NCPP and will be continued under a new Bipartisan Infrastructure Law-funded project in 2023.

Presentations

Rao, Y., 2022: Visualizing NOAA CDR Data on the Cloud. *July Earth Science Information Partners (ESIP) Summer Meeting,* Pittsburgh, PA. July 21, 2022.

Rao, Y., 2022: Climate Observatory - Analyzing and Visualizing NOAA Climate Data Records on the Cloud with Open Science Tools. *AMS Collective Madison Meeting,* Madison, WI. August 11, 2022.

Rao, Y., 2022: Informatics for Social Good: From Scientists to Bridge Builders (invited presentation). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

ARC Data Derivative Product for Health Users	
Task Leader	Jennifer Runkle
Task Code	NC-SAS-23-NCICS-JR

Highlight: The project team completed development of an NCEI data product consisting of a daily time series for temperature (Tavg, Tmax, Tmin) and precipitation using NClimGrid for each census tract in the US (1981–present) to aid health and infectious disease modeling efforts. A new Python package is a companion to the existing EpiNOAA data product.

Background

To address the need for daily time series of meteorological variables (e.g., temperature, humidity, precipitation) relevant to health and infectious disease modeling efforts, work was begun to develop a data derivative product to aid the health modeling community in accessing NOAA climate and weather data. The project team is composed of members representing NCEI, CISESS NC, and the NOAA Climate Program Office. To inform the development of the product, the team engaged in multiple meetings with Centers for Disease Control and Prevention (CDC) partners in the Climate and Health and the Environmental Public Health Tracking programs, as well as a diverse set of academic modelers from the Models of Infectious Disease Agent Study group. The data product will be complemented by an R package to streamline access and include relevant analytic functions (e.g., population-weighting, interpolation) to aid end-users in locating, manipulating, and analyzing the data at a scale relevant to health applications. The product will also be more broadly applicable to end-users representing other sectors (e.g., energy, agriculture). This data product will also complement the team's NOAA Environmental Data Themed page on climate.gov and be accessible to a diverse set of environmental and health modelers.

Accomplishments

The Applied Research Center (ARC) team updated and deployed an event-driven serverless data processing pipeline that automatically cleans, combines, reformats, and republishes NClimGrid data in near-real time (seconds). This pipeline is performant and processes 200+GB of historical data in less than an hour using parallel computing on AWS. The team is currently working on version 2 of the data product, aimed at developing a daily time series for Tavg, Tmax, Tmin, and Precip (NClimGrid daily metrics) for each census tract in the US. from 1981 to present as a complement to the county-scaled analysis-ready product. Data are retrievable using the following modes: direct download, EpiNOAA R package, new Python package, or web interface (Table 1).

Direct download	File format	AWS S3 Location
Monthly county (cte) and state (ste) files	Csv	https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/index.html#EpiNOAA/csv/
Decadal county (cte) and state (ste) files	Csv	https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/index.html#EpiNOAA/decadal/
Period of record for contiguous US (1951–present), one large file	Csv	https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/EpiNOAA/EpiNOAA_county.csv

Monthly county (cte) and state (ste) files	parquet	https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/index.html#EpiNOAA/parquet/
R package		Gitlab link https://gitlab.cicsnc.org/arc-project/arc-r-package/-/tree/main
Python		Gitlab link https://gitlab.cicsnc.org/arc-project/arc-r-package/-/tree/main
Web interface		R shiny app link http://shiny-app-lb-db29d17-1318539185.us-east-1.elb.amazonaws.com/arc-nclimgrid-downloader/

Table 1. *Overview of user access to these data on the cloud: 1) direct download, 2) R package, and 3) Web interface.*

Planned work

- Launch a communication campaign to publicize availability of the new dataset
- Provide recommendations on the inclusion of additional metrics in response to feedback from user community (e.g., humidity)
    - Explore re-analysis products (e.g., ERA-5, JA) and outline methods for integration into v2.0
    - Conduct literature review to examine best method for interpolation (e.g., smoothing spline and multinomial regression)

Products

- Cloud optimized nClimGrid monthly dataset, https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/index.html#EpiNOAA/csv/
- Cloud optimized nClimGrid decadal dataset, https://noaa-nclimgrid-daily-pds.s3.amazonaws .com/index.html#EpiNOAA/decadal/
- R package to access cloud optimized nClimGrid data, https://gitlab.cicsnc.org/arc-project/arc-r-package/-/tree/main
- R shiny app web interface to access cloud optimized nClimGrid data, http://shiny-app-lb-db29d17-1318539185.us-east-1.elb.amazonaws.com/arc-nclimgrid-downloader/

Collaborative Climate and Human Health Studies	
Task Leader	Jennifer Runkle
Task Code	NC-SAS-24-NCICS-JR

Highlight: Working with NCEI and CDC collaborators, CISESS NC advanced work on developing 1) baseline surveillance data to be used in an early warning system for harmful algal blooms (HABs) and 2) historical and real-time drought indicators in the US.

Background

NOAA and the CDC have mutual interests in the linkages between the health of the environment, humans, and animals and the shared responsibilities to protect human health and address environmental, social, and economic needs. They support Earth observation and surveillance and the integration and use of relevant environmental data and information to model, map, assess, predict, and communicate public health impacts to better inform decision- and policymaking and to reduce public and community health threats while adapting to climate change.

NCEI and CDC formalized a 5-year interagency agreement that recognizes a "One Health" approach to apply atmospheric, environmental, oceanographic, and ocean health knowledge, expertise, and methods to understand, assess, predict, communicate, and reduce public health impacts of climate change. Under the agreement, NOAA and CDC will engage in projects and programs of mutual interest and responsibility; exchange, integrate, and interpret data and leverage mutual expertise; and develop innovative and sustainable partnerships capitalizing on the strengths of both agencies to address existing or emerging public health issues.

CISESS NC is undertaking research and coordinating other activities in support of NOAA and CDC's ongoing mutual interests and objectives (Figure 1). Anticipated activities include updates of current CDC environmental data holdings; identifying relevant NCEI data products for epidemiologic studies, studies to better define and understand Earth system and public health interactions, and investigations into extreme event health impacts to better respond to and/or reduce those impacts; and creating new and/or merged environmental/health data products to enable CDC and its public health partners to understand, communicate, and respond to current or potential climate or disaster-related health risks.

Accomplishments

- Completed a data inventory of near-real-time or forecast products for extreme weather (e.g., flooding, tornadoes, hurricanes, drought)
- Through a multi-agency collaboration (CDC, NOAA, EPA, USGS, NASA), advanced an "exposure potential" metric for early warning of Cyanobacterial Harmful Algal Blooms (Cyano HABS) across the US
- Submitted a peer-reviewed paper for a pilot study that examined the acute respiratory effects of Cyano HABs

Proposal for Improving CDC Strategic Capacity

Modernizing inter-agency data pipelines to improve environmental hazard real-time monitoring and forecasting

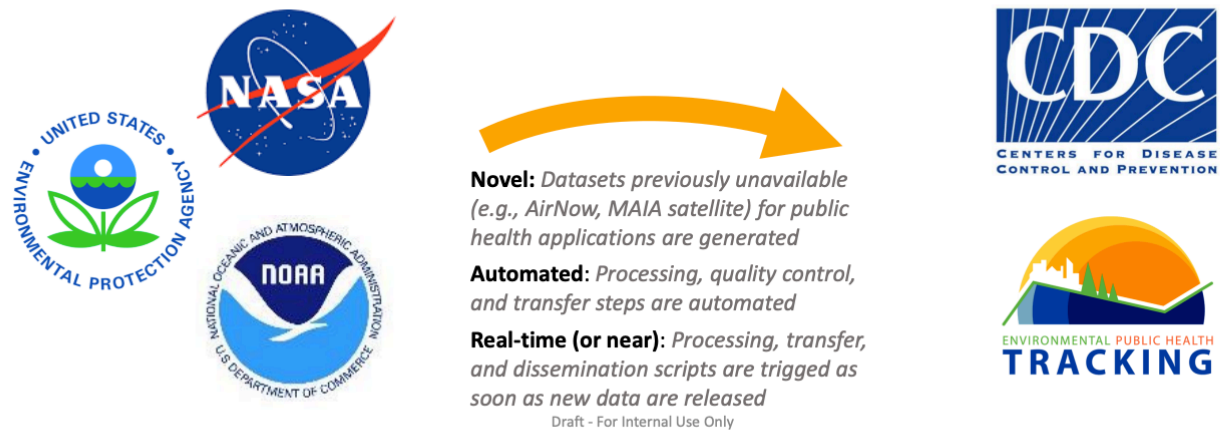


Figure 1. *Enhancing the CDC's capacity for environmental hazard real-time monitoring and forecasting.*

Planned work

- Move into Phase 2: early warning indicator development for a cross-agency collaboration seeking to modernize federal data pipelines for real-time data
- Continue work on developing a Cyano HABS surveillance metric for the Environmental Public Health Tracking (EPHT) portal
- Co-mentor a postdoctoral research scholar for EPHT projects and continue joint research collaboration on the acute health effects and economic impacts of extreme heat in the US

Publications

Murray, J., A.M. Lavary, B.A, Schaeffer, B.N. Seegers, A.F. Pennington, E. Hilborn, S. Boerger, **J.D. Runkle**, K. Loftin, J. Graham, R. Stumpf, A. Koch, and L. Backer, 2023: Assessing the relationship between cyanobacterial harmful algal blooms (CyanoHAB) biomass and residential respiratory hospital visits. *Science of the Total Environment*, submitted.

Climate Monitoring	
Task Leader	Carl Schreck
Task Code	NC-SAS-25-NCICS-CS

Highlight: NCEI's NClimGrid-Daily and IBTrACS datasets continue to be used in new and innovative ways to support NCEI's climate monitoring activities. The extreme rainfall in Hurricane Ian provided a unique opportunity to evaluate fidelity of the NClimGrid-Daily rainfall estimates.

Background

NCEI products are the gold standard for climate monitoring, which includes producing monthly and annual reports on climate anomalies, ranks, and extremes. However, several emerging NCEI datasets such as IBTrACSv4 and NClimGrid-Daily have yet to be fully tapped in these monitoring activities. Most of NCEI's monitoring reports can also be classified as describing "what" more than "why." Users are increasingly interested in the why, not only in terms of the effects of climate change but also to better understand the patterns and teleconnections that lead to significant weather events and anomalies. This project strives to provide answers to those questions while exploiting under-utilized NCEI datasets.

Accomplishments

This project contributed to the Tropics Chapter of the *Bulletin of the American Meteorological Society* (*BAMS*) *State of the Climate Report* for 2021 and to the monthly NCEI Climate reports. It also contributed to a special supplemental report on Hurricane Ian:
https://www.ncei.noaa.gov/access/monitoring/monthly-report/national/202209/supplemental/page-5

This report on Hurricane Ian was one of the first applications of NClimGrid-Daily following its transition from beta into a fully operational product. Ian proved to be a unique challenge for the NClimGrid-Daily processing. The storm affected Florida in the final days of September. When the final preliminary processing happened on October 3, some stations had not yet been ingested into NClimGrid-Daily's main data source: GHCN-Daily. The addition of these stations produced large differences in the scaled data when they were produced on October 7. Additional late-reporting stations continued to cause changes in the reprocessing during subsequent months. This variability highlighted potential issues with NClimGrid-Daily, particularly for events near the end of a month. These findings will inform improvements in the next version of the product.

In addition to the *BAMS State of the Climate*, this project contributed to three other publications that discussed recent trends in tropical climate extremes and variability. Shi et al. (2022) compared several satellite-derived estimates of upper-tropospheric humidity in the tropics. Klotzbach et al. (2022) demonstrated that sea level pressure was a better indicator of tropical cyclone size and destructiveness than maximum winds. Zhu et al. (2022) examined the unique life-cycle of Hurricane Ida around its time of landfall. Truchelet et al. (2022) quantified how the Atlantic hurricane season is trending toward an earlier start and how that is associated with warming sea surface temperatures.

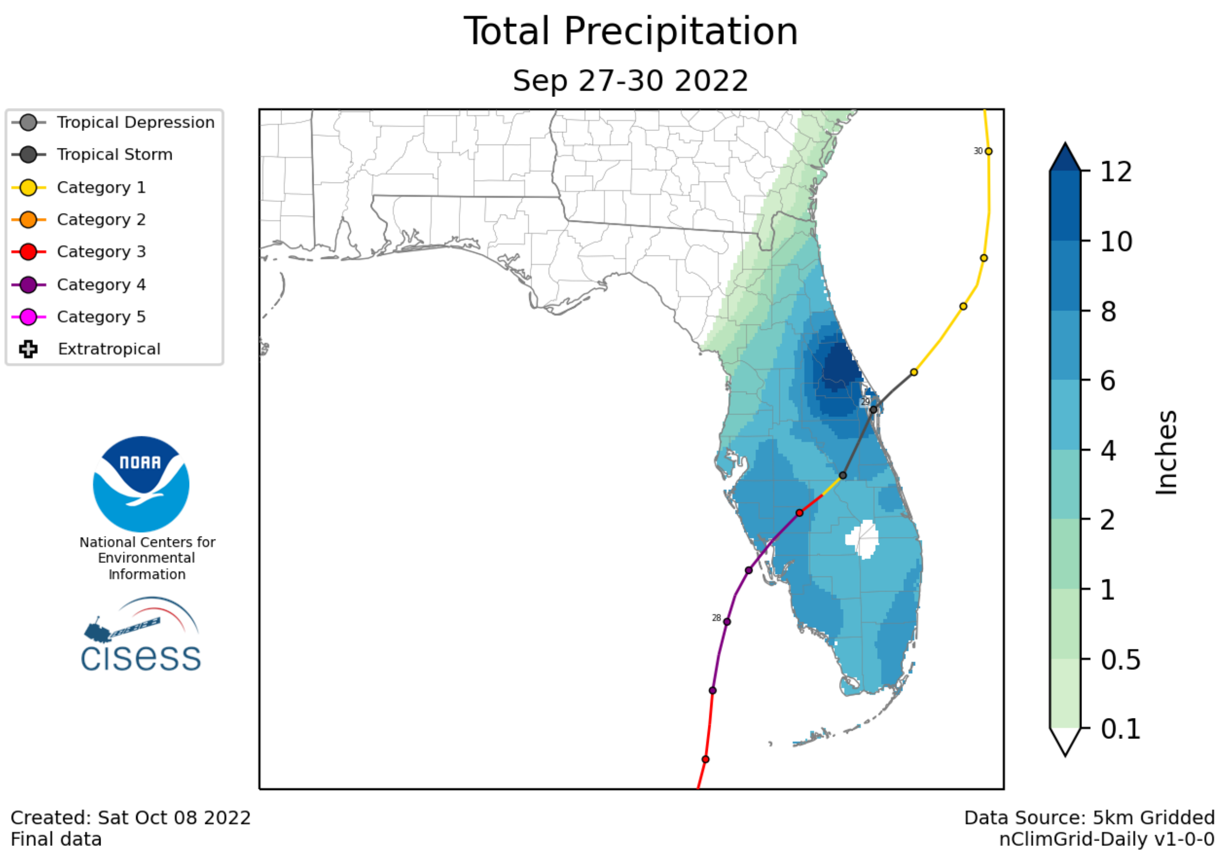


Figure 1. *Average temperature percentiles for December 24–31, 2021.*

Planned work

- Revise and publish the *BAMS State of the Climate* for 2022
- Prepare and edit the *BAMS State of the Climate* for 2023
- Draft monthly and annual NCEI State of the Climate "Synoptic Discussions" and "Tropical Cyclone" reports
- Develop a web interface for global historical tropical cyclone activity
- Develop quantitative metrics for associating climate anomalies with teleconnections

Publications

Diamond, H.J., and **C.J. Schreck**, Eds., 2022: The Tropics [in "State of the Climate in 2021"]. *Bulletin of the American Meteorological Society*, **103** (8), S193–S256. http://dx.doi.org/10.1175/bams-d-22-0069.1

Durre, I., A. Arguez, **C.J. Schreck III**, M.F. Squires, and R.S. Vose, 2022: Daily high-resolution temperature and precipitation dields for the xontiguous United States from 1951 to present. *Journal of Atmospheric and Oceanic Technology*. http://dx.doi.org/10.1175/jtech-d-22-0024.1

Klotzbach, P.J., D.R. Chavas, M.M. Bell, S.G. Bowen, E.J. Gibney, and **C.J. Schreck III**, 2022: Characterizing continental US hurricane risk: Which intensity metric is best? *Journal of Geophysical Research: Atmospheres*, **127** (18), e2022JD037030. http://dx.doi.org/10.1029/2022JD037030

Shi, L., **C.J. Schreck, III**, V.O. John, E.S. Chung, T. Lang, S.A. Buehler, and B.J. Soden, 2022: Assessing the consistency of satellite-derived upper tropospheric humidity measurements. *Atmospheric Measurement Techniques*, **15** (23), 6949–6963. http://dx.doi.org/10.5194/amt-15-6949-2022

Truchelut, R.E., P.J. Klotzbach, E.M. Staehling, K.M. Wood, D.J. Halperin, **C.J. Schreck**, and E.S. Blake, 2022: Earlier onset of North Atlantic hurricane season with warming oceans. *Nature Communications*, **13** (1), 4646. http://dx.doi.org/10.1038/s41467-022-31821-3

Zhu, Y.-J., J.M. Collins, P.J. Klotzbach, and **C.J. Schreck**, 2022: Hurricane Ida (2021): Rapid intensification followed by slow inland decay. *Bulletin of the American Meteorological Society*, **103** (10), E2354–E2369. http://dx.doi.org/10.1175/BAMS-D-21-0240.1

Products

- Monthly and Annual synoptic Discussions for NCEI's Annual Climate Reports: https://www.ncdc.noaa.gov/sotc/synoptic/
- Monthly and Annual Global Tropical Cyclone reports for NCEI's Climate Reports: https://www.ncdc.noaa.gov/sotc/tropical-cyclones/
- USGCRP Atlantic Tropical Cyclone Days Climate Change Indicator: https://www.globalchange.gov/browse/indicator-details/4206

Presentations

Schreck, C.J., 2022: The MJO and Equatorial Waves. *Rutgers University Subseasonal Forecast Contest* webinar. July 28, 2022.

Rapid Attribution of Extreme Events in the United States	
Task Team	Carl Schreck (Lead), Kenneth Kunkel, David Coates, John Uehling, Xiangdong Zhang
Task Code	NC-SAS-26-NCICS-CS/KK/DC/JU/XZ

Highlight: A preliminary, area-weighted rank index was developed for the assessment of heat waves in terms of their abnormality for a variety of time scales for the CONUS. Computations are done at the county-level and can be summarized into a single heat wave index (HWI) for the entire county for a given day. https://ncics.org/pub/angel/hwi/. Modifications to the HWI to better account for severity of lower-recurrence interval events were carried out, and the process of producing the historical record, county- and state- subsetting, and indices has been automated.

Background

The goal of this project is to assess the physical mechanisms from which extreme events occur and to further assess the increased risk of future extreme events occurring due to human-driven climate change. This is particularly important as extreme weather disaster events, particularly those resulting in damages greater than $1 billion, have been increasing over the last several decades. The need for a clear, rapid attribution of these events, their place in the historical context, and their causes are of increasing importance to the general public as a result of their increasing frequency. As such, the end goal is the establishment of an operational framework through which upcoming extreme events can be forecast more accurately and be more properly detailed to the general public.

In order to do so, several tasks are necessary. First, an objective standard by which extreme events are defined, driven by the physical mechanisms that cause them, must be established. This would require the creation and maintenance of a historical dataset with as much spatiotemporal coverage as is possible, derived from both in situ measurements and model hindcasts for coverage of areas where physical measurements are not feasible. With such a database, the historical context for atmospheric conditions can be established and the events can be defined, both in terms of their rarity (based on recurrence interval) and magnitude (related to their deviation from historical averages). This will allow the projection of future conditions via climate models in order to assess the increased risk of future extreme events due to climate change.

Accomplishments

Project work focused primarily on establishing the historical context for heat extremes. An algorithm was developed to compute a daily heat index on county-level data from NClimGrid. This involved several steps, each with its own challenges. First, there were several pieces of data in each NClimGrid file that did not pertain to the project needs and required removal. Next, the NClimGrid dataset, composed of daily files, needed to be merged into a single, well-organized file to analyze the entire dataset; this necessitated the removal of bad data, empty days, and incorrect county codes [the latter was accomplished by the Applied Research Center research group, who allowed the use of their corrected Federal Information Processing Standard (FIPS) codes]. Finally, this merged data file needed to be ranked in some fashion, and a simple rank ordering by magnitude for a variety of timescales was deemed sufficient for this purpose. The resulting heat wave index (HWI) is based on the return interval and the percent coverage of each rank in the form

$$HWI = 100 * \left(\frac{1}{r}\frac{A_{county}}{A_{CONUS}}\right)$$

where *A* is area and *r* is the rank of a particular day's X-day running maximum, minimum, or average temperature, referenced from the master rank data file as calculated above. This produces a parseable dataset of HWIs for the data period of record. The individual values can be summed in any geographical level to determine an integrated heat stress for quick comparison between time periods. This type of analysis was done for both maximum and minimum temperatures for the determination of both heat and cold wave indices, though plotting has only been carried out for heat wave indices at certain running time scales.

Time is the current limitation on this process: while an individual county's HWI does not take long to compute, the sheer amount of data that is available to work through means that computing a year's worth of HWIs currently takes over 16 hours. This necessitates further optimization of the algorithm or scaling the code in either parallelization or cloud computing.

Some climate analysis was performed regarding the "warming hole," a decades-long lack of maximum temperature increase in the central and southeast US. There is still much debate as to its physical cause; this project work has focused on analyzing the available climate data to determine differences between the early 1950s, specifically 1951–1970, and the current decades, 2001–2020, to evaluate whether the data can yield any new information that would not be gained from climate models. It's known that the warming hole is primarily seen in the maximum temperatures in the summer, so project analysis has specifically focused on the June–July–August months for those decades. Work by other members of the research group—and additionally by other peer-reviewed literature—suggests that the warming hole is primarily driven by internal climate variability. Observations indicate a large 11% increase in regional precipitation, and both observations and model simulations show an inverse correlation between precipitation and maximum temperatures, which is a significant indicator of why the warming hole exists. Analysis of precipitation days, acting as a proxy for cloud cover and its influence on radiative forcing, shows that both the warming hole and eastern coastal regions experienced similar increases in rainy days of varying accumulation thresholds between the analyzed decades. This led to a spatial analysis between precipitation and maximum and minimum temperatures, which indicates that there is a positive correlation between precipitation and minimum temperature but also that there is a moderate gradient in the negative correlation between the southern and northern states. The cause of this correlation is still not yet determined.

Enhancement of Heat Wave Index. The rank-based HWI has been replaced with a percentile-based one to more accurately represent potential severity of high- to moderate-ranked events, whose severity the rank-based index underrepresented. The new index formulation replaces the rank term with a percentile using a fitted generalized extreme value distribution and two-fold filtering: the first compares the raw county temperature of a given date with the mean temperature of the warmest month, which acts as a pure temperature threshold, and the second is a percentile filter, which removes any dates whose temperatures are not greater than the 90th percentile. The index was computed for both CONUS (Figure 1) and Texas specifically as part of an internal report on the Texas heat wave of the late spring and early summer. The trends seen in the national scale are not necessarily reflected in Texas as a whole—while many of the most extreme years are in the latest 40 years, Texas has also seen a large number of years with only modest heat events. Preliminary work for other states out West, such as Washington, Oregon, and Nevada, show much stronger trends in both Tmax and Tmin extreme events in recent years that reflect the overarching trend in CONUS. Additional work on the sensitivity of the index at a variety of spatial scales to the climatology of choice is necessary and has begun but has not yet been completed.

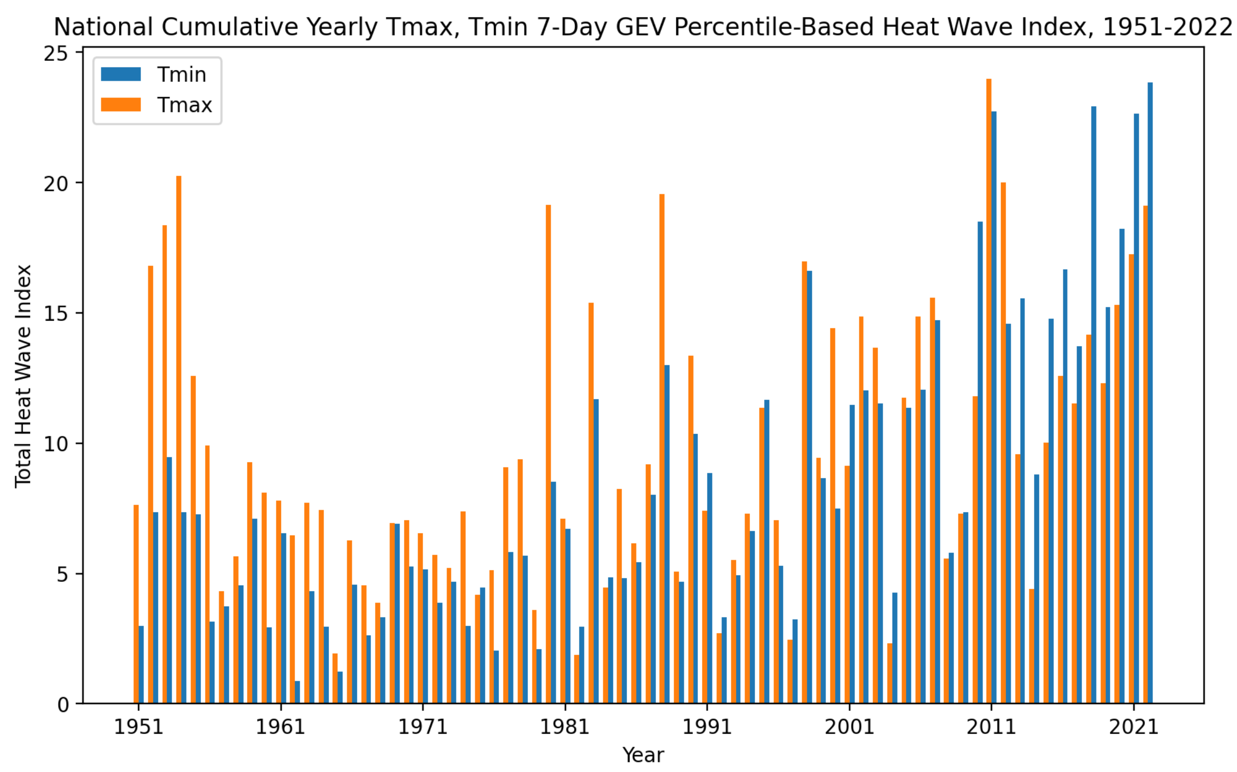


Figure 1. *Cumulative CONUS heat stress for maximum and minimum temperatures on a county-level basis. Preliminary results show a notable drop in maximum temperature–based HWI between 1955 and 1980, with a general rising trend thereafter. For minimum temperature, the trend is only positive. In comparison to pre-1980, the most recent 40 years show the occurrence of high-percentile, high-absolute-minimum-temperature days has increased considerably.*

Operationalization. A framework for the operationalization of monitoring future events and automation of our analysis codebase has been prototyped by the monitoring branch of the attribution team, and development is currently underway. Our current plan is to append Global Ensemble Forecast System model data to the end of the preliminary NClimGrid data, allowing us to forecast the percentiles of upcoming maximum and minimum temperatures at the county scale for up to 2 weeks out from the present day. This allows us to leverage the historical record we have been developing over the last year and a half as a physical, objective indicator of what events warrant observation and, following such events, attribution from the climate branch of the rapid attribution team. Regionalized subsets of the historical record have been created to send to the modeling branch to build a body of past events for comparison against potential future events, which we hope to have completely operational for use by the onset of the summer season this year.

Planned work

- Scale up the HWI algorithm to be run on cloud computing services, improving computation speed
- Continue HWI computation and extend it to cold events
- Begin analyzing extreme precipitation events
- Use and develop of other climate datasets for their historical contexts
- Determine the cause of the differing correlations between temperature and precipitation between the southern and northern US.
- Perform sensitivity analysis of the HWI against different input climatologies and fitted statistical distributions

- Further develop regionalized data subsets

Publications

Eischeid, J.K., M.P. Hoerling, X.-W. Quan, A. Kumar, J. Barsugli, Z.M. Labe, **K.E. Kunkel**, **C.J. Schreck**, D.R. Easterling, T. Zhang, **J. Uehling**, and **X. Zhang**, 2023: Why has the summertime central U.S. warming hole not disappeared? *Journal of Climate,* submitted.

Presentations

Coates, D.A., and **K.E. Kunkel**, 2022: Extreme heat and cold monitoring. *Rapid Attribution Team 2022 Workshop*, virtual. May 2022.

Kunkel, K.E., 2023: State of the Climate. *Electric Power Research Institute (EPRI) Environmental Change Institute Webinar*. March 3, 2023.

Products

- Data formatting, merging, and sorting algorithm for NClimGrid data
- Regionalized, sorted data for Tmax and Tmin for both state- and county-scale running averages
- Blueprint for operationalization of objective extreme hot and cold event monitoring using model outlook data
- Computational program for heat/cold wave indices
  https://ncics.org/pub/angel/hwi/

Calibration of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures	
Task Leader	Emma Scott
Task Code	NC-SAS-27-NCICS-ES

Highlight: Improvements to the calibration of HIRS brightness temperature between satellites were tested for channels 1–3, and calibration has been completed for the TIROS-N, NOAA 6–19, and METOP 1 and 2 satellites. Additional work is ongoing that compares this calibration of the HIRS brightness temperature measurement to a version of the HIRS calibration that is output by the FIDUCEO project.

Background

The HIRS instrument has provided measurements of brightness temperature for over 30 years, qualifying it to serve as an important CDR. However, these cumulative measurements have been taken from different satellites and with different versions of the HIRS instrument. Different rates of instrument degradation can introduce biases between satellites, while the instrument degradation itself introduces bias over time within the measurements from a single satellite launch. These biases can be accounted for by implementing intersatellite calibration.

HIRS measurements taken from onboard the NOAA and METOP satellite series were compared to find the magnitude of the bias between pairs of consecutive satellites. Because different satellites were launched with different versions of the HIRS instrument, this comparison also allows for determination of the bias between different versions of the sensor. Changes to the central wavelength measured by each channel between different versions of the instrument could cause inconsistencies in the height within the atmosphere that corresponds to the measured brightness temperature. Additional calibration can be performed to account for inconsistencies near the edges of the temperature range for each channel.

Accomplishments

Previous work resulted in a calibration methodology that could be used to correct for intersatellite differences in HIRS measurements. New improvements to this methodology were tested for channels 1–3 of the infrared sounder. The new methodology for these channels mimics that of channel 4, in which a multiple linear regression is used to find a set of three calibration coefficients that take into consideration observations from the surrounding channels. For instance, the channel 2 linear regression takes into account the corresponding channel 1 and channel 3 values. Because the channel numbers roughly correspond with the height level to which the brightness temperature corresponds, the extra information provides insight into the temperature of the overall surrounding air column, improving performance.

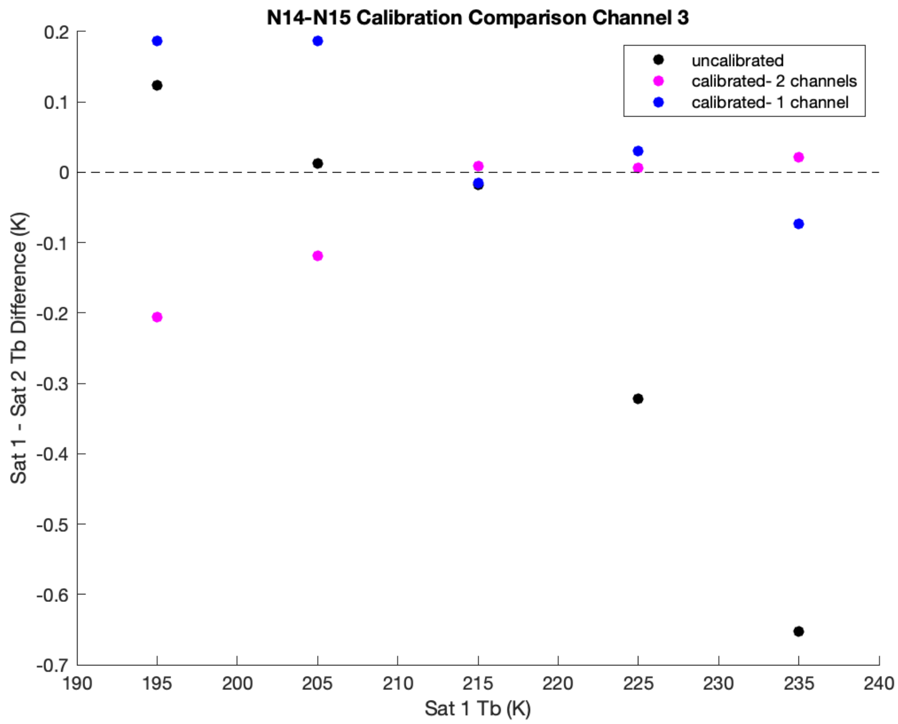


Figure 1. *Comparison of uncalibrated data (black), multiple regression calibrated data with 2 additional channels (magenta), and multiple regression calibrated data with one additional channel (blue) for channel 3 of the NOAA 14 and NOAA 15 satellite pair. Smaller satellite differences denote better calibration performance.*

Calibration coefficients have been calculated for satellite pairs that include the TIROS-N, NOAA 6–19, and METOP 1 and 2 satellites. Data from these satellites span the time frame between the late 1970s and the present. The calibration coefficients have been applied to create a calibrated dataset. This dataset is now being compared to a somewhat similar calibration effort called FIDelity and Uncertainty in Climate data records from Earth Observations (FIDUCEO) which is generated by the UK-based Centre for Environmental Data Analysis. The differences between collocated observations between satellite pairs are compared between our data and the FIDUCEO data in order to find which dataset minimizes the difference between satellite observations taken from the same location and at the same time.

Planned work

- Release resulting calibrated data for use as a new CDR
- Publish a methodology paper on the calibration process for reproducibility

Presentations

Scott, E., and L. Shi, 2023: Calibration Comparison of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures. *103rd American Meteorological Society Annual Meeting,* Denver, CO. January 12, 2023.

Enhanced Rainfall Metric for Tropical Cyclones (TCs)	
Task Leader	John Uehling
Task Code	NC-SAS-28-NCICS-JU

Highlight: NCEI's NClimGrid-Daily rainfall data provides an opportunity to analyze rainfall events in the United States associated with tropical cyclones (TCs). The enhanced rainfall metric is developed and used to analyze how extreme rainfall events from TCs have changed over the last decade.

Background

Numerous recent tropical cyclones (TCs) have caused extreme rainfall and flooding events in the United States. Climate change is contributing to heavier extreme rainfall around the world. Modeling studies have suggested that TCs may be particularly efficient engines for transferring the additional water vapor in the atmosphere into extreme rainfall. However, there are no readily available climate change indicators for quantifying observed changes in TC-related rainfall. This project aims to fill that gap by leveraging NCEI's IBTrACS tropical cyclone dataset alongside their new NClimGrid-Daily precipitation data. The enhanced rainfall metric (ERM) is used to identify how the frequency and/or intensity of extreme rainfall around TCs is changing. The ERM relates the amount of rain from a storm over a given location to the 5-year rainfall in that location to determine the severity of the event. The project determined that the intensity of the most extreme rainfall events is increasing over the United States, particularly along the southeast coast (Figure 1). The areas impacted by TC rainfall also appear to be increasing in recent decades. When looking at the 95th percentile of extreme precipitation, however, the trends are generally insignificant.

Accomplishments

This project contributed to the development of a potential new TC climate indicator surrounding the ERM. Some of the major accomplishments of this project include:

1. The development of datasets of all rainfall associated with each US-impacting TC, where any rain within 200 km or 500 km of a TC was mapped for all storms from 1951 to 2021
2. Development of a functional ERM that can be used to compare extreme TC rainfall events in different regions of the United States
3. Concept of a TC climate indicator based around the ERM that can be used to study and analyze changes in TC rainfall and the extreme events associated with them

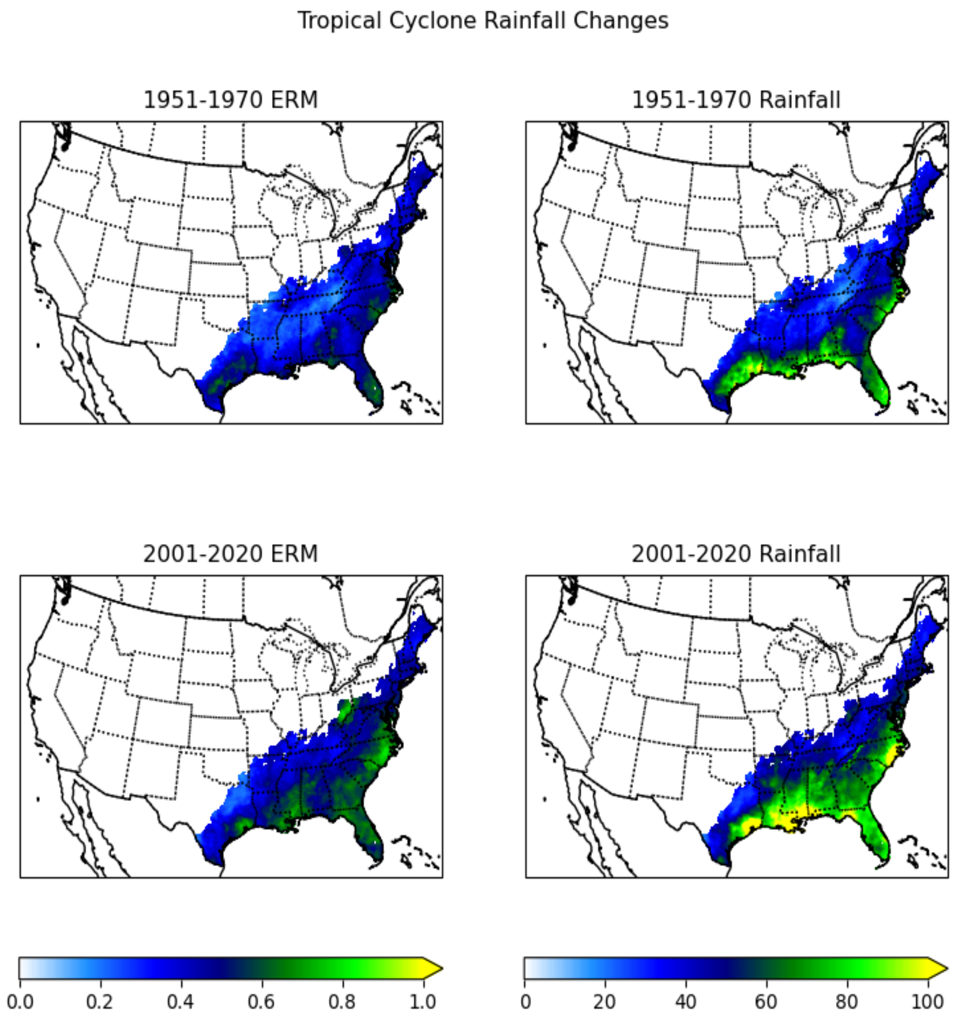


Figure 1. *Mean values of ERM and tropical cyclone–associated rainfall over the United States for the periods 1951–1970 versus 2001–2020. (Only the grid points with more than 20 storm impacts over the 1951–2021 period are shown.)*

This project also worked actively with the USGCRP Climate Change Indicators Working Group to develop new indicators for TC trends. The indicator will look at how extreme rainfall events (specifically associated with TCs) over the United States have changed as a result of anthropogenically forced climate change. Preparations are underway for a subsequent indicator that would focus on trends in heavy rainfall events over the US associated with TCs.

Planned work

- Revise and publish a paper based on the ERM and TC rainfall changes in the United States
- Finish and revise the TC rainfall indicator
    - An example of what the indicator may look like is shown in Figure 2.
- Begin work on studying TC extreme rainfall in other regions

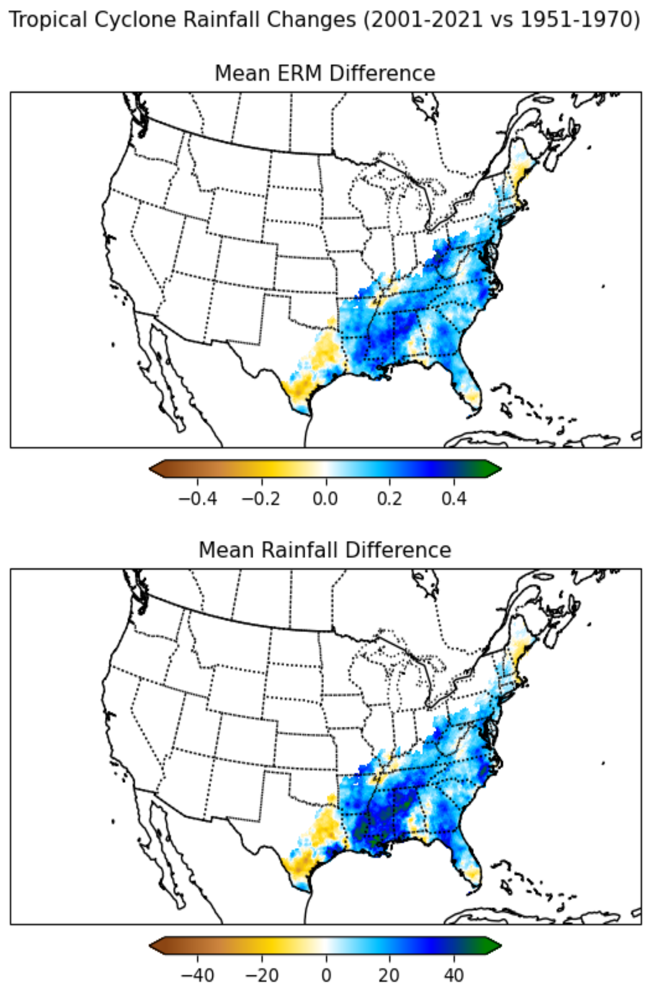


Figure 2. *Difference of mean values of ERM and tropical cyclone–associated rainfall over the United States for the periods 1951–1970 versus 2001–2020. (Only the grid points with more than 20 storm impacts over the 1951–2021 period are shown.)*

Evaluation and Development of a Southeast US Heat Vulnerability Index Using a Wet-Bulb Globe Temperature (WBGT) Approach

Task Leader or Team	Kyle R. Wodzicki
Task Code	NC-SAS-29-NCICS-KW

Highlight: Testing of four WBGT estimation algorithms is nearly complete, with the Liljegren et al. (2008) methodology being the most accurate and robust. Final testing of the algorithms is underway with recently released data from the Range Commanders Council Meteorology Group's 2021 WBGT Campaign.

Background

The Fourth National Climate Assessment identified extreme heat as one of the major human health climate risks for the US Southeast. Currently used indicators of heat stress (e.g., heat index) do not adequately measure the physiological impacts of heat stress on the body. Thus, wet-bulb globe temperature (WBGT) is being used to develop a new heat vulnerability index, as it better indicates how heat affects humans. However, WBGT is not widely measured, as it requires special instrumentation. Due to this, many studies have developed algorithms to estimate WBGT from meteorological variables commonly measured at weather stations. Following testing and validation to see which of these algorithms provides the most accurate results over a wide range of cases, the project team will be able to estimate WBGT at every surface observation station across the Southeast. This will enable the creation of gridded WBGT products and, ultimately, a new Heat Vulnerability Index from these data.

Accomplishments

Using data from North Carolina ECONet (Environment and Climate Observation Network) stations, four WBGT algorithms (Liljegren et al. 2008; Dimiceli et al. 2013; Ono and Tonouchi 2014; Bernard and Pourmoghani 1999) were evaluated to determine which most accurately match observations. When computing WBGT, three variables are required: natural wet-bulb temperature, black-globe temperature, and ambient temperature. Testing of the algorithms was performed by comparing estimations of WBGT and black-globe temperature from the various algorithms to the measurements taken at ECONet stations. As ECONet stations do not directly measure natural wet-bulb temperature, direct comparisons of that variable could not be made; it was assumed that the algorithm being used during post-processing of ECONet data to compute natural wet-bulb temperature is accurate.

This testing showed the two best algorithms to be the Liljegren et al. (2008) and Dimiceli et al. (2013). The Ono and Tonouchi (2014) algorithm was developed using data from Japan and does not appear to be generalizable to the Southeast US region. The Bernard and Pourmoghani (1999) method was initially developed for use in shaded environments and had to be heavily modified (using algorithms from the Liljegren et al. [2008] method) to include solar radiation inputs. After these modifications, the algorithm was still outperformed by the Liljegren et al. (2008) and Dimiceli et al. (2013) methods.

Further comparison of the Liljegren et al. (2008) and Dimiceli et al. (2013) methods showed the Liljegren et al. (2008) produced more accurate WBGT values (Figure 1) but less accurate black-globe temperature values. This indicates that the natural wet-bulb temperature estimations (which account for 70% of the WBGT) from Liljegren et al. (2008) are more accurate than those of Dimiceli et al. (2013). Comparisons of the influence that each input variable has on the estimation of WBGT were also performed. Figure 1 shows the impact that various wind speeds have on the estimations, with low wind speeds causing large positive biases and mean absolute errors in WBGT for both algorithms. Solar radiation was the second most important variable, with larger values leading to higher variability in WBGT. As noted, a limitation of this analysis is that natural wet-bulb temperature, which accounts for 70% of WBGT, is not directly measured at ECOnet sites. Fortunately, data from the Range Commanders Council (RCC) Meteorology Group 2021 WBGT Campaign was recently released and contains direct measurements of natural wet-bulb temperature. These data will be used for final testing of the Liljegren et al. (2008) and Dimiceli et al. (2013) algorithms before finalizing results, writing a manuscript, and moving to development of a gridded WBGT product.

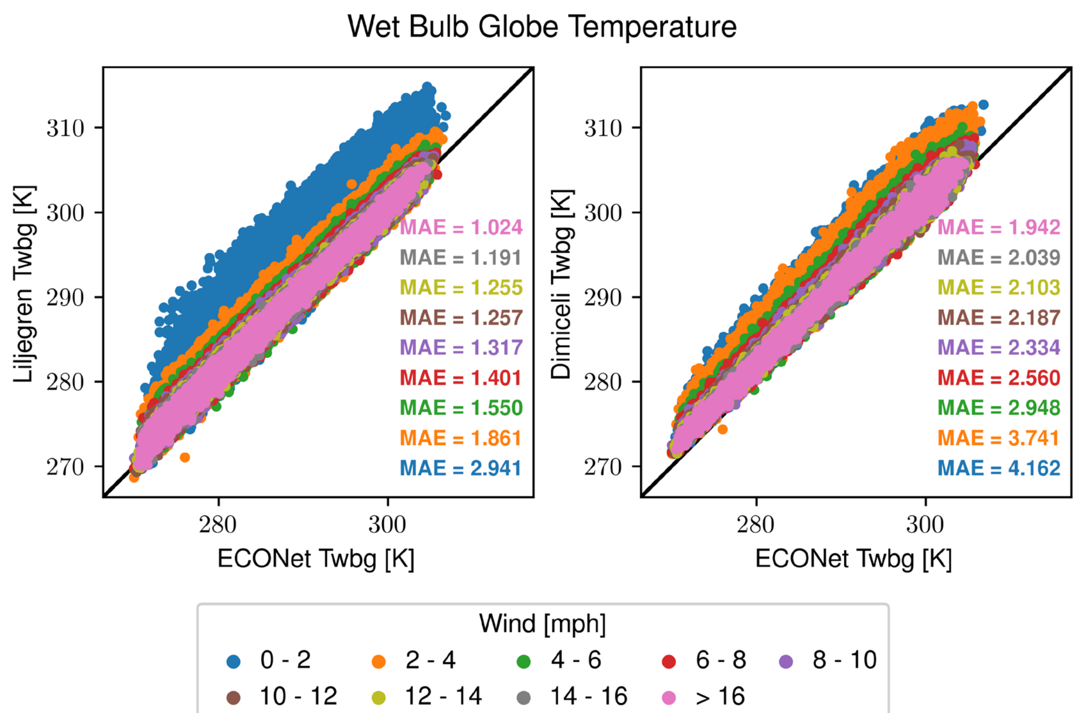


Figure 1. *Wet-bulb globe temperature from (ordinate) estimation algorithms and (abscissa) ECONet measurements for (left) the Liljegren et al. (2008) method and (right) the Dimiceli et al. (2013) method. Symbol color indicates the wind speed for the observation. Mean absolute errors (MAE) are shown for the various wind speed groups.*

Planned work

- Finalize testing of WBGT algorithms using data from the RCC Meteorology Group 2021 WBGT Campaign
- Create documentation for code and ensure it is in a portable environment for reproducibility
- Perform long-term trend analysis of WBGT for the Southeast US region
    - What regions show larges changes/trends?
    - When are trends the largest? What season, time of day?
- Write manuscript detailing WBGT algorithm and long-term trend analysis
- Coordinate with North Carolina State Climate Office and stakeholders to begin development of heat stress vulnerability metric

Presentations

Wodzicki, K.R., 2023: Wet-Bulb Globe Temperature: Algorithm Analysis and Testing. *American Industrial Hygiene Association Thermal Stress Working Group*, virtual. January 13, 2023.

Monitoring and Detection of Unusualness Conducive to Wildfire	
Task Team	Kyle R. Wodzicki, Alexa Zabaske
Task Code	NC-SAS-30-NCICS-KW/AZ

Highlight: Initial stakeholder outreach has been completed, with interested parties displaying enthusiasm for a simple near real-time-wildfire monitoring product. Exploratory data analysis is underway to determine which datasets are best suited for identifying wildfire signals in an AI/ML framework.

Background

NCEI monitors many aspects of the climate including multiple drought metrics, sea surface temperature–based climate indices, precipitation, snowfall, and sea ice extent. Monitoring is typically done retrospectively on recent events, such as their monthly climate reports that detail climate events and highlights from throughout the previous month. However, there is a desire to monitor climate closer to near-real time and within the context of historical climate events.

Wildfire events are not directly reported to or monitored by NCEI. Rather, monthly wildfire statistics are pulled from the National Interagency Fire Center and displayed in an interactive graph on NCEI's climate monitoring page. This project seeks to improve NCEI's wildfire monitoring capabilities and products.

The project aims to create a product to monitor environmental conditions in near-real time that may be conducive to wildfires. This tool would use data inputs from the NClimGrid) and, potentially, other datasets and variables. Various machine learning (ML) algorithms will be tested to systematically identify patterns associated with large wildland fire in the past.

Accomplishments

Although this project is in the beginning stages, much has been done in terms of outreach and planning. Team members met with the head of NCEI's Climate Analysis and Synthesis Branch Monitoring Section to discuss research goals, the retrospective nature of the Monitoring Section, and how the outcomes from this wildfire monitoring work should be a near-real-time product to aid in wildfire management. Outreach efforts from the "Prediction of Wildland Fire Potential on Weekly to Seasonal Timescales" project are also being used to inform this research, with recommendations for which datasets and variables are most influential for wildfire forecasting and monitoring being noted for integration into this project.

Dataset investigation and acquisition have begun, with the primary focus being the NClimGrid dataset due to its long record and availability in the cloud environment thanks to the NOAA Open Data Dissemination program. This exploratory data analysis is in the initial stages and may show that NClimGrid is not well suited for this task, allowing us to pivot to new data streams quickly.

Planned work

- Perform exploratory data analysis to determine if source datasets are usable
    - Do NClimGrid daily inputs provide adequate information?
    - Would the analysis timesteps of a numerical weather prediction model provide better information?
- Train simple supervised and unsupervised ML algorithms
- Determine patterns/relationships the models found and how they relate to physical processes
- Evaluate monitoring ability and validate predictive probability metrics
- Present preliminary results at April 2023 Southern Appalachian Weather and Climate Workshop

Prediction of Wildland Fire Potential on Weekly to Seasonal Timescales	
Task Team	Kyle R. Wodzicki, Alexa Zabaske
Task Code	NC-SAS-31-NCICS-KW/AZ

Highlight: The team is working to develop a prediction system for wildland fire potential that is aligned with and informed by diverse stakeholder input such as from public, private, and academic sectors. The project will bring together multiple NOAA and other existing datasets, utilizing data science techniques and ML models to develop a probabilistic wildland fire potential outlook on weekly, monthly, and/or seasonal scales.

Background

Wildfires have become a large source of societal and economic pain in recent decades. More than 7.5 million acres burned nationally, resulting in $3.1 billion in damages during the 2022 wildfire season alone (NOAA NCEI U.S. Billion-Dollar Weather and Climate Disasters). These impacts are predicted to become worse in the future as both current trends and climate models show the fire season growing longer. Climate models also indicate that fires will burn hotter, last longer, and expand in geographic extent as the climate continues to change. With the vast amounts of meteorological, hydrological, and biological data currently available, it has become impossible to analyze all these data using traditional methods. This means that valuable information is going unused and potentially life-saving predictive patterns are going unrecognized.

Using cloud computing, big data tools, and machine learning (ML) techniques, we aim to develop wildland fire prediction models to aid in fire management planning. This prediction product will provide probabilistic outlooks for wildland fire potential, such as the probability of ignition and/or rapid spread of ongoing fires, due to environmental factors. These outlooks will be at the weekly to seasonal time scales, enabling fire managers to confidently contract, position, and deploy resources into regions that are at the highest risk of severe wildfire events.

Accomplishments

By closely collaborating with our outreach and engagement lead, we have established connections with stakeholders in the public, private, and academic domains to gain an understanding of the wildland fire community's requirements. This outreach has been invaluable in focusing our efforts on what gaps in prediction need to be filled and what is feasible in terms of size and scope. In meeting with researchers from the Desert Research Institute and Western Regional Climate Center, it was clear that the 1–3-week prediction time scale is of great interest. Input from the chair of the National Wildfire Coordinating Group (NWCG) Fire Environment Committee made it clear that the development of a seasonal probabilistic outlook would be extremely valuable to the fire managers and planners. As a significant amount of time and resources go into creating the current outlooks, it was noted that even getting “25% of the way towards an outlook” through automated, objective means would be beneficial to the community.

A discussion with one of the researchers behind the Hot-Dry-Windy fire weather index provided insights into what is feasible using ML algorithms. Due to the complexity of modeling actual fire (which is done at the centimeter scale or finer) and the very random nature of fire ignition (e.g., human activities and lightning), it was clear that forecasting individual fires or burned area would be extremely difficult. This information, coupled with that from the NWCG Fire Environment Committee chair made it clear that a probabilistic outlook of potential for rapid fire growth due to environmental conditions would be the best path for development in terms of feasibility and return on investment. Further into our research efforts, the team could expand into probabilistic outlooks of new fire ignitions due to climatological factors. In order to quantitively predict wildland fire burned area and locations on a seasonal timescale, advanced methods would need to be developed and underlying assumptions fully realized. In other words, the means to make such a prediction that is reliable and verifiable currently does not exist. The environmental conditions (weather, climatology, vegetative fuels, etc.) could yield the most extreme wildland fire conditions; but without a spark, or ongoing flame, there will not be fire growth. This will be important to keep in mind as this project progresses.

Planned work

1. Exploratory data analysis of current wildfire predictors and data products, including:
    a. GHCN-Daily data
    b. Teleconnections: ENSO, MJO, etc.
    c. Humidity/soil moisture
    d. Vegetation and fuel load
2. Data cleaning and pre-processing to merge datasets into a uniform format that is analysis ready and cloud optimized (ARCO). Methods include:
    a. Spatiotemporal resampling
    b. Feature engineering such as empirical orthogonal function analysis
    c. Storing data in a form that is cloud optimized and easily digested by an ML algorithm.
    d. Designating predictor and predictand variables for ML algorithm
3. Test various ML algorithms:
    a. Supervised classification algorithms, clearly defined predictands
    b. Unsupervised pattern recognitions/anomaly detection
    c. Deep learning (artificial neural networks)
4. Compare the tested models' errors, computing needs, and end-user understandability
5. Continue stakeholder engagement throughout development process to ensure we are meeting user needs, asking questions such as:
    a. What data products are currently used/must be included in analysis?
    b. How can early versions of the product be improved?
    c. Have needs changed during the development period?
6. Planned presentations (abstracts submitted):
    a. 20th Annual Climate Prediction Applications Science Workshop, May 2023.
    b. 14th Fire and Forest Meteorology Symposium, May 2023.

Workforce Development

Workforce development is the long-term investment in NOAA's future workforce. NCEI has continuing research and workforce requirements that necessitate collaboration with the best climate science practitioners in the Nation. This requires hiring outstanding scientific staff with unique skills and backgrounds in Earth system science and using observations to define climate and its impacts. To meet this demand, CISESS NC employs a cadre of dedicated research staff and actively works to identify and train the next generation of scientifically and technically skilled scientists. Junior and/or aspiring scientists, including students and post-doctoral researchers, play an important role in conducting research at CISESS NC.

Research Faculty. Senior CISESS NC scientists hold research faculty positions in the Department of Marine, Earth, and Atmospheric Sciences (MEAS) in the College of Sciences (COS) at North Carolina State University (NCSU) and provide mentorship to junior scientists and students both in CISESS 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. CISESS NC scientists also mentor students formally and informally (NCICS student interns, NOAA Hollings Scholars, NASA DEVELOP team members, etc.) and engage in various outreach activities to promote awareness and increase interest in K–12 science studies.

- Otis Brown, Kenneth Kunkel, and Xiangdong Zhang hold Research Professor appointments in NCSU's MEAS/COS.
- Carl Schreck holds adjunct Research Assistant Professor appointments with NCSU MEAS and with NC A&T University.
- Jennifer Runkle holds an adjunct Research Assistant Professor appointment with Appalachian State University.

Graduate Level Training. NCICS Software Engineer Denis Willett designed and has been teaching a 4-module graduate level course to NCSU, NCICS, and NCEI scientists, providing data science paradigms, principles, and practices to scale research using cloud-native computing through an immersive hands-on, practicum-based approach. The modules cover: Scientific Programming in R and Python, Exploratory Data Analysis, Data Product Development, and Production Data Science.

Post-doctoral scholars. NCICS initiated its program in workforce development through the hiring of an initial group of post-doctoral research scholars working on applied research topics for the predecessor cooperative institute. CISESS NC continues to hire post-docs for a 2- to 3-year commitment to support identified current project needs. Senior scientists from CISESS NC and NCEI provide mentoring for these post-docs. CISESS NC currently hosts one post-doctoral scholar with a new cadre of post-docs under recruitment for the coming year.

- John Uehling (PhD, Meteorology, Florida State University) spent his first year at CISESS NC working in collaboration with Carl Schreck developing a climate change indicator for tropical cyclone rainfall as well as investigating the lack of a warming trend over the Central U.S. to improve rapid attribution of extreme events in the United States (see Science and Services project reports).

Students (graduate/undergraduate/high school). CISESS NC continues to be successful in recruiting and involving 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 CISESS NC and NCEI mentors. CISESS NC scientists also serve as mentors and advisors for NASA DEVELOP team members who complete their 10-week internship projects at NCEI.

Student Interns

- Alexis Visovatti, NCSU undergraduate, worked with Laura Stevens and Tom Maycock on USGCRP climate indicators communication, including the creation of multiple informational YouTube videos.
- Anna Ikelheimer, Univ of Colorado Boulder undergraduate, worked with Olivier Prat and David Coates on using the standardized precipitation index (SPI) to measure the seasonality of drought.
- Anup Desai, NCSU graduate student, worked with Douglas Rao on developing data science applications and training materials using interactive computing notebooks and NOAA open environmental data on the Cloud.
- Carolyn Pugh, worked with Jenny Dissen on user engagement approaches in climate data and urban planning.
- Dylan Major, UNC Asheville undergraduate, worked with Olivier Prat and Doug Miller (UNCA) on Great Smoky Mountain Rain Gauge Network precipitation studies.
- Karla Weidner, UNC Chapel Hill graduate student, worked with Jen Runkle to investigate the effects of prenatal exposure to ambient temperature extremes and socioeconomic disadvantage on infant health risks in a changing climate.
- Kelly Sewell, UNC Chapel Hill graduate student, worked with Jen Runkle investigating heatwave event effects on child health.
- Kristen Cowan, UNC Chapel Hill graduate student, worked with Jen Runkle on examining the association between extreme heat and maternal mental health outcomes among a cohort of births in South Carolina.
- Matthew Mair, Appalachian State University undergraduate, worked with Jenny Dissen on understanding Sea Level Rise and its impacts in North Carolina.
- Montana Eck, UNC Chapel Hill graduate, worked with Jenny Dissen and Kenneth Kunkel on US-India Partnership for Climate Resilience program data analysis applying extreme value theory.
- Pradyumna Vemuri, NCSU graduate student, worked with Lou Vasquez on using Global Historical Climatology Network daily (GHCN-d) on Neo4j and with Denis Willett on building a cloud native graph database using Neo4j for the daily climate summaries from various global land stations in the Global Historical Climatology Network daily (GHCNd).
- Ronald (Trey) Williamson, UNC Chapel Hill graduate student, worked with Jen Runkle to investigate the effects of devastating and recurring natural disasters on mental and maternal health.
- Stephen Pierce, Western Carolina University undergraduate, worked with Jessicca Allen and Jake Crouch (NCEI) on multiple projects to help promote science products across NCEI.
- Tyler Harrington, U Mass Lowell undergraduate student, completed his work with Ronnie Leeper to evaluate the impacts of drought on concurrent heatwave intensity and duration across the U.S.
- Vivek Sudhakar, NCSU graduate student, is working with Garrett Graham and Ronnie Leeper on detecting and classifying anomalies in distributed sensor networks using supervised and semi-supervised deep learning methods.
- The NASA DEVELOP team composed of Deirdre An (NCSU), Annie Britton (Johns Hopkins University), Seamus Geraty (University of Denver graduate), and Charles Nixon (NCSU) completed their project, "Evaluating Rock Pool Hydroperiod Fluctuation using Climate Variables to Inform Habitat Monitoring and Protection in the Western Sonoran Desert," under science co-advisor Douglas Rao.
- The NASA DEVELOP team composed of Elijah Dalton (UNC Wilmington), Aidan Harvey (University of Washington graduate), Kate Reynolds (University of Oregon), and Max Rock (University of Wisconsin – Milwaukee) completed their project, "Enhancing Crop Classification Mapping Using Optical and Radar

Satellite Sensors to Enhance Agricultural Management and Policymaking in Mato Grosso, Brazil," under science co-advisor Garrett Graham.

• The NASA DEVELOP team composed of Kathryn Caruso (UNC Asheville graduate), William Hadley (University of Arkansas graduate), Daniel Littleton (Temple University), and Kelli Roberts (University of Georgia graduate) completed their project, "Evaluating the Role of Soil Moisture in Determining Vegetation Health, Fuel Loads, and Wildfires in the Gatlinburg and Beatty Wildfires," under science co-advisor Ronald Leeper.

Intern Presentations

An, D., A. Britton, S. Geraty, and C. Nixon, 2022: Western Sonoran Desert Water Resources: Evaluating Rock Pool Hydroperiod Fluctuation using Climate Variables to Inform Habitat Monitoring and Protection in the Western Sonoran Desert. NCEI DEVELOP Closeout Presentation, virtual, August 3, 2022.

Cowan, K., 2022: Examining the association between Extreme Heat and maternal mental health outcomes among a cohort of births in South Carolina. NCEI Intern Closeout Presentations, virtual, July 27, 2022.

Dalton, E., A. Harvey, K. Reynolds, and M. Rock, 2022: Mato Grosso Agriculture: Enhancing Crop Classification Mapping Using Optical and Radar Satellite Sensors to Enhance Agricultural Management and Policymaking in Mato Grosso, Brazil. NCEI DEVELOP Closeout Presentation, virtual, August 3, 2022.

Eck, M., 2022: Analyzing Extreme Precipitation Values in Uttarakhand. U.S.-India Partnership for Climate Resilience webinar, virtual, September 21, 2022.

Ikelheimer, A., 2022: Using the Standardized Precipitation Index to Measure the Seasonality of Drought. NCEI Intern Closeout Presentations, virtual, August 10, 2022.

Karuso, K, W. Hadley, D. Littleton, and K. Roberts, 2022: Evaluating the Role of Soil Moisture in Determining Vegetation Health, Fuel Loads, and Wildfires in the Gatlinburg and Beatty Wildfires, virtual, November 17, 2022.

Mair, M., 2022: Understanding Sea Level Rise and its Impacts in North Carolina. NCEI Intern Closeout Presentations, virtual, August 10, 2022.

Major, D., 2022: A Description of Precipitation at High Elevations using the Great Smoky Mountain Rain Gauge Network. NCEI Intern Closeout Presentations, virtual, August 10, 2022.

Sewell, K., 2022: Heatwave events and child health. NCEI Intern Closeout Presentations, virtual, July 27, 2022.

Vemuri, P., 2022: Building a cloud native graph database using Neo4j for the daily climate summaries from various global land stations in the Global Historical Climatology Network daily (GHCNd), virtual, December 7, 2022.

Vemuri, P., 2022: Global Historical Climatology Network daily on Neo4j. NCEI Intern Closeout Presentations, virtual, July 27, 2022.

Visovatti, A., 2022: Indicators: A climate communication tool. NCEI Intern Closeout Presentations, virtual, August 10, 2022.

Weidner, K., 2022: Joint effects of prenatal exposure to ambient temperature extremes and socioeconomic disadvantage on infant health risks in a changing climate. NCEI Intern Closeout Presentations, virtual, July 27, 2022.

Williamson, R., 2022: Climate Hazards Impacting Population Health: Negative Effects of Devastating and Recurring Natural Disasters on Mental and Maternal Health Outcomes. NCEI Intern Closeout Presentations, virtual, July 27, 2022.

Other Projects

The vision of the North Carolina Institute for Climate Studies (NCICS) is to *inspire* innovative 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.

The vision of the Cooperative Institute for Satellite Earth System Studies (CISESS) is to advance NOAA's ability to generate data and information from the constellation of global observing platforms to understand and predict the different components of the Earth system through collaborative and transformative research and to transition this research into operational applications that produce societal benefits. 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 CISESS NC projects and activities under the CISESS cooperative agreement remain primary within NCICS, NCICS scientists also participate in and receive partial support from other sponsored research programs through competitive proposal solicitations. Individual and collaborative climate science proposals are submitted through NCSU in response to relevant federal, state, and other solicitations from such entities as the National Aeronautics and Space Administration (NASA), the National Science Foundation (NSF), NOAA, the Department of Energy (DOE), the Department of Defense (DOD), the National Institutes of Health (NIH), North Carolina State Department of Transportation, and various other public and private organizations.

Developing an In Situ–Satellite Blended Marine Air Temperature Dataset Using Artificial Intelligence	
Task Leader	Otis Brown / Yuhan (Douglas) Rao
Task Code	NC-OTH-01-NCICS-OB/YR
Sponsor	NOAA CPO

Highlight: The HIRS temperature profile retrieval processing workflow was updated and reprocessing of HIRS temperature and humidity profiles (version 5) was completed for HIRS data going back to mid-1991 using the updated workflow and updated intersatellite calibration coefficient.

Background

Marine air temperature (MAT) drives climate processes that have far-reaching downstream impacts, including an increase in extreme cyclones, sea level rise, and coastal flooding. As a key contributor to the estimation of global mean surface temperature, MAT observations are essential for climate monitoring. High-quality MAT data also play a crucial role in understanding air–sea fluxes and their impact on the physical and biological processes in the ocean and coastal system. The existing in situ only MAT datasets are insufficient for global and regional climate studies because of the sparse data coverage and notable data gaps in the polar regions, cross-platform (station, buoy, and ship) differences, and intrinsic data variability.

Satellite thermal remote sensing has provided pole-to-pole coverage daily since the 1970s. The High-resolution Infrared Sounder (HIRS), onboard NOAA Polar Orbiting Environmental Satellite series and EUMETSAT Polar System satellites, has provided a nearly 40-year Climate Data Record of daily atmospheric temperature and moisture data. This long-term temperature record has demonstrated its stability and accuracy when compared to in situ measurements. Thus, it may provide unique information that can be used to fill the data gap of regions with limited in situ temperature measurements.

The project team will use advanced machine learning (ML) tools to create a blended global gridded surface temperature dataset by leveraging the high-quality, long-term archive of in situ measurements and global HIRS temperature data. The final blended dataset will be a global, sub-daily surface temperature dataset with a grid size of 0.5° × 0.5° or higher since 1978 and should reduce the uncertainty for climate studies.

Accomplishments

Initial efforts focused on 1) collaborating with NCEI to implement the reprocessing of HIRS temperature and humidity profile retrievals (version 5) using updated intersatellite calibration coefficient and workflow, and 2) collaborating with UK National Oceanography Centre (NOC) on the assessment of performance of near surface marine air temperature retrieval for blended data development.

1. ***Reprocessing of HIRS Temperature and Humidity Profiles.*** The HIRS project team updated the processing workflow for HIRS temperature profile retrieval in three major areas for the version 5 product (Figure 1). The reprocessing of HIRS profiles was initiated in reverse chronological order, starting with the most recent satellite sensors then going through old sensor data. During the reprocessing, an inconsistency on a quality flag indicating whether the observation is affected by cloud was identified. A new value was added to the quality flag to indicate what methods were used in determining whether the observation was cloud clear or likely cloudy.

   Version 5 reprocessing is now complete for HIRS data from Metop-1, Metop-2, NOAA-17, NOAA-16, NOAA-15, NOAA-14, NOAA-12, NOAA-11, and NOAA-10 and consists of HIRS data going back to late-1986. The current reprocessing includes two formats of the output—ASCII and netCDF4. The decision to maintain ASCII data format in the current step was made to accommodate the main data user, International Satellite Cloud Climatology Project (ISCCP), while the ISCCP team updates their workflow to use the future netCDF4 file format, which netCDF4t will become the default format in the future.

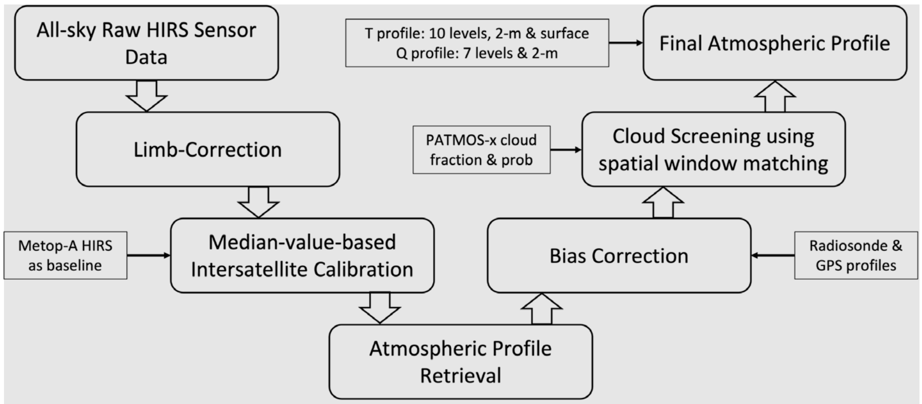


Figure 1. *Updated HIRS atmospheric profile retrieval workflow used in the version 5 dataset.*

2. ***Developing Machine Learning Models to Blend Near-Surface Marine Air.*** The HIRS temperature near ocean surface was evaluated against the height-adjusted ICOADS measurements using data since 2000. Overall, the HIRS near-surface temperature is close to the height-adjusted ICOADS measurements. However, there are notable differences between the HIRS retrieval quality during daytime and nighttime (bias: 0.11 K versus 0.04 K). The project team further investigated two ML models to blend in situ observations and HIRS temperature retrievals. The team extracted the matchup data pairs between HIRS temperature and ICOADS height-adjusted marine air temperature between 1995 and 2014 to train ML models for blended dataset development. Two ML models (gradient boosting tree and random forest) were tested with the 20 years of satellite–in situ match-up data pairs. Both ML models show satisfactory performance with root-mean-square error (RMSE) less than 1 K. Gradient boosting tree show slightly better performance when compared to the random forest model (RMSE: 0.73 K versus 0.82 K; Bias: 0.06 K versus –0.08 K).

Planned work

- Generate a daily HIRS temperature climatology and diurnal cycle model for surface temperature
- Create gridded HIRS temperature data in NetCDF4 format
- Complete first version of model development for ocean data and provide beta version of global ocean blended temperature dataset

Climate Change Impacts in the Arctic, Northern Eurasia, and International Coastal Ocean Regions	
Task Leader	Pavel Groisman
Task Code	NC-OTH-02-NCICS-PG
Other Sponsor	Multiple / NSF (Belmont Forum)

Highlight: Collaborative international research teams are investigating global environmental change challenges and impacts. Current projects are focused on the northern extratropics and five coastal ocean regions. The US team completed an assessment of the costs of climate change impacts on critical infrastructure in the Circumpolar Arctic and is going to determine governance and local and Indigenous practices that increase resilience and sustainability of the Frozen Commons in the Arctic.

Background

Contemporary environmental changes are not restricted to changes in major climatic characteristics such as temperature and precipitation. They are multi-faceted, affect and are affected by human activities, and may manifest themselves differently in different regions of the world and impact other regions. These manifestations and impacts 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. The Belmont Forum supports research focused on global environmental change challenges and impacts by teams of multinational researchers to promote more global solutions to these challenges. In the United States, the lead agency that supports the Arctic Studies is the National Science Foundation (NSF).

Accomplishments

Pavel Groisman serves as NEFI Project Scientist and as a co-investigator on three international projects.

Northern Eurasia Future Initiative (NEFI). (Project role: Project Scientist) The NEFI (http://nefi-neespi.org) program supports international Earth systems science research focused primarily on climate change and other issues in northern Eurasia that are relevant to regional and global scientific and decision-making communities. Service as the NEFI Project Scientist includes:

- Organizing NEFI-related workshops, international conference sessions, and matchmaking
- Acting as guest editor for the *Environmental Research Letters* Special Issue on Northern Eurasia; 75 papers were published in this Focus Issue during the past 5 years. The acceptance of new manuscripts to this Issue was terminated on December 31, 2022.
- Serving on the editorial board of
  - *Ice and Snow* (Russia)
  - *Environmental Research Communications* (UK)
  - *Water* (Switzerland)

Belmont Forum Collaborative Research: Rapid Arctic environmental Changes: Implications for Well-Being, Resilience and Evolution of Arctic communities (RACE). (Project role: Co-Investigator) This project supports integrated teams of scientists and stakeholders addressing the impacts of rapid climate and environmental changes in the Arctic on infrastructure and pan-Arctic and regional population dynamics. Large-scale climate diagnostics and projections will be used and translated into social indicators and further into demographic variables by using socioeconomic and demographic models to provide regional projections of the Arctic population dynamics.

Belmont Forum Collaborative Research: Coastal OceAn SusTainability in Changing Climate (COAST). (Project role: Co-Investigator) This project focuses on the sustainability of the coastal ocean under the impacts of ongoing and projected climate variability and change. The project is addressing impacts of climate change and increased human activity on five different coastal ocean regions by integrating the natural and social domains of the coastal ocean and tracking how changes will affect the use of infrastructure today and under different scenarios in the future.

Collaborative Research: NNA Research: Change, Resilience, and Sustainability of Frozen Commons (FC) in Alaskan and Northeastern Siberian Communities. (Project role: Co-Investigator) This is a new NSF-funded project awarded in February 2022 with US, Canadian, and Russian collaborators. During the kick-off meeting, team members presented their 5-year project visions, outlined their assigned research tasks, and discussed travel plans to four Indigenous communities in the Arctic (two in Alaska and two in the Sakha Republic of Russia). Travel plans for the forthcoming year have subsequently been revised due to the current political situation. The project focuses on the transformation of Frozen Commons (FC) driven by rapid natural and socioeconomic changes. FC, together with local and Indigenous communities and overlapping cultures of governance, form social–ecological–technological systems (SETS). Adaptation in governance (sharing, caring, use, and stewardship) of FC depends on characteristics of their change and types. Communities with stronger adaptive capacities and higher resilience are hypothesized to be more successful in governing transforming FC in conditions of changing climate, social, and other challenges. The project goal is to conceptualize FC as a critical element of Arctic SETS to determine governance and local and Indigenous practices that increase resilience and sustainability of these commons. Goal implementation will offer insights into the future research agenda for studies of the commons and their management.

Publications

Georgiadi, A.G., and **P.Y. Groisman**, 2022: Long-term changes of water flow, water temperature and heat flux of two largest arctic rivers of European Russia, Northern Dvina and Pechora. *Environmental Research Letters*, **17** (8), 085002. http://dx.doi.org/10.1088/1748-9326/ac82c1

Kukavskaya, E.A., E.G. Shvetsov, L.V. Buryak, P.D. Tretyakov, and **P.Y. Groisman**, 2023: Increasing fuel loads, fire hazard and emissions in central Siberia. *Fire*, **6** (2), 63. http://dx.doi.org/10.3390/fire6020063

Schulze, E.-D., N. Tchebakova, **P. Groisman**, A. Oltchev, O. Panferov, and J. Kurbatova, 2022: Remembering Natalya Nikolaevna Vygodskaya. *Forests*, **13** (7), 980. http://dx.doi.org/10.3390/f13070980

Tchebakova, N.M., E.I. Parfenova, E.V. Bazhina, A.J. Soja, and **P.Y. Groisman**, 2022: Droughts are not the likely primary cause for *Abies sibirica* and *Pinus sibirica* forest dieback in the South Siberian Mountains. *Forests*, **13**. http://dx.doi.org/10.3390/f13091378

Zhang, J., L. Chen, Y. Chen, and **P.Y. Groisman**, 2023: Comparing process-based models with the inventory approach to predict CH_4 emission of livestock enteric fermentation. *Environmental Research Letters*, **18** (3), 035002. http://dx.doi.org/10.1088/1748-9326/acb6a8

Presentations

Georgiadi A.G., and **P.Ya. Groisman**, 2022: Long-Term Changes of Geofluxes of Two Largest Arctic Rivers of European Russia. *Session 11 of the Future Earth Program and Northern Eurasia Future Initiative, ENVIROMIS 2022 Conference,* Tomsk, Russia. September 17, 2022.

Groisman, P.Y., 2022: Environmental, Socio-Economic and Climatic Changes in Northern Eurasia (convener, chair, 2 sessions). 2022 *Japan Geoscience Union* (JpGU) *Meeting*, virtual. May 26, 2022.

Groisman, P.Y., 2022: Long-term changes of Water Flow, Water Temperature and Heat Flux of two Largest Arctic Rivers of European Russia, Severnaya Dvina and Pechora, *ENVIROMIS-2022,* virtual. September 17, 2022.

Groisman, P.Y., 2022: Northern Eurasia Future Initiative (NEFI): Three Regional Groups of the NEFI Studies (poster) *ENVIROMIS-2022,* virtual. September 17, 2022.

Groisman, P.Y., 2022: The LCLUC NEESPI-NEFI: Accomplishments and Synthesis. *Land-Cover and Land-Use Change (LCLUC) Annual Meeting,* Bethesda, MD. October 18, 2022.

Groisman, P.Y., and J. Chen, 2022: Northern Eurasia Future Initiative (NEFI), Three Regional Groups of the NEFI Studies (poster). 2022 *Japan Geoscience Union (JpGU) Meeting*, virtual. June 3, 2022.

Groisman, P.Y., A.G. Georgiadi, and O.N. Bulygina, 2022: Geofluxes of Major Arctic Rivers of European Russia: Long-term Changes and Possible Causes (poster.) *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 15, 2022.

America's Water Risk: Water System Data Pooling for Climate Vulnerability Assessment and Warning System	
Task Lead	Kenneth Kunkel (Lead), Liqiang Sun
Task Code	NC-OTH-03-NCICS-KK
Other Sponsor	Columbia University/NSF
Highlight: The project team found potential predictability of the North Atlantic Subtropical High (NASH) with a lead time of 6–12 months based on eastern Pacific sea surface temperatures.	

Background

The Nation's water supplies and water suppliers, including public utilities and state and federal agencies, are disproportionately exposed to the risks of climate change. The goal of this multi-institutional project is to form a collaboration network to serve as the foundation for the conceptual design, development, and sharing of Artificial Intelligence (AI) and Machine Learning (ML) tools for quantifying America's water supply risk. The project will converge data, models, and insight from water suppliers and the fields of climate science, hydrology, economics, social sciences, data science, and decision analysis to develop new information and tools that enable comprehensive and transformative investigations into the dynamics, evolution, and trajectory of water demand and supply.

The Intergovernmental Panel on Climate Change Fifth Assessment Report and Volumes I and II of the US Fourth National Climate Assessment (USGCRP 2017, 2018) produced analyses of future climate based on the Coupled-Model Intercomparison Project Phase 5 (CMIP5) suite of global climate model simulations. These analyses show that the US straddles the transition between wetter future conditions at high latitudes and drier future conditions at subtropical latitudes. There is high confidence that extreme precipitation will increase everywhere, with a greater proportion of total precipitation occurring in the most extreme events. Temperature is also projected to increase everywhere, which will lead to increased evapotranspiration and more rapid depletion of soil moisture during dry periods. The CMIP5 suite includes simulations for several future emissions scenarios. These general findings apply under all of the scenarios, while the magnitude of the changes scale approximately with the amount of increased atmospheric greenhouse gas concentrations.

A new suite of climate model simulations, CMIP Phase 6 (CMIP6) will be used as the basis for this project's future climate change scenarios. NCSU scientists will provide the climate scenarios generated from the CMIP6 climate model simulations for selected climate variables.

Accomplishments

Research on the North Atlantic Subtropical High (NASH) indicated that NASH is potentially predictable with a lead time of 6–12 months, and the Niño3.4 SST Index is an important source of the summer NASH predictability. The NASH has profound effects on the climate over the United States, especially on the daily rainfall frequency, maximum 1-day rainfall, number of extremely hot days, and Palmer Drought Severity Index. However, the summer average temperature is not significantly correlated to the NASH. This work provides the basis for potential predictability on seasonal to decadal time scales.

Planned work

- This project is completed.

Quantifying Future Precipitation Extremes within North Carolina for Resilient Design	
Task Lead	Kenneth Kunkel
Task Code	NC-OTH-04-NCICS-KK
Other Sponsor	NC Department of Transportation

Highlight: Analysis revealed large differences in the calculated scaling factors for Intensity–Duration–Frequency (IDF) curves across different downscaling datasets.

Background

The frequency and intensity of both floods and droughts are expected to increase in response to climate change; however, significant uncertainties remain regarding regional changes, especially for extreme rainfall. In particular, North Carolina's geographic location makes it vulnerable to several natural hazards that pose significant flooding risks, including hurricanes, severe thunderstorms, and large winter storms. The most obvious problems within NC in recent years were the pluvial and fluvial flooding from notable hurricanes (Floyd 1999, Florence 2018, Dorian 2019), which paralyzed the eastern NC highway system for days to weeks and created a chain of transportation infrastructure problems that affected emergency response operations and the transportation of goods. Though hurricanes receive a lot of attention in resilient design, transportation engineers face additional challenges, including possible changes to rainfall intensity from localized thunderstorms and even drought.

The objective of this study is to improve confidence in climate change projections by quantifying future precipitation extremes within NC for resilient design (e.g., precipitation intensity-duration-frequency [IDF] curves). Guidance developed for the National Cooperative Highway Transportation Research Board will be incorporated in the project with additional methods and numerical model experiments to improve confidence in future precipitation extremes and to inform design concepts for potential future events.

Accomplishments

This study examines relative changes and scale factors, for daily (24-hour) Intensity-Duration-Frequency (IDF) curves for various periods and greenhouse gas emission scenarios using different statistical and dynamical downscaled projections. A comparison of scaling factors for the different downscaled datasets revealed large differences in scaling factors for future change. Diagnostic analysis of these results pointed to one particular dataset as likely producing physically unrealistic outcomes. This dataset will likely be removed from consideration for producing composite scaling factors.

Planned work

- Finalize the scaling factors to be uses to calculate rainfall design values and uncertainty ranges for use by the North Carolina Department of Transportation
- Contribute to the development of the final project report

Evaluation of Drought Indicators for Improved Decision-Making in Public Health and Emergency Preparedness: Reducing Drought's Burden on Health

Task Leader	Ronald D. Leeper
Task Code	NC-OTH-05-NCICS-RL

Highlight: Leeper devised an effort to measure the frequency at which a drought index is mentioned in a medical journal publication, which was incorporated into the ranking score of more than 53 drought indicators. In addition to duration and frequency, US county-level metrics of drought severity, seasonality of onset and termination, and timing of the worst drought on record were evaluated and compared to the US Drought Monitor. These indicators were also spatially and temporally evaluated over four well-known drought events.

Background

Deficits in moisture due to drought can have cascading societal and economic impacts and elevate the risks of adverse health outcomes (i.e., heat exposure, suicides, etc). While there are numerous drought-related indices for monitoring drought, it is not always clear which index is most suitable as an adverse outcome predictor. This is particularly true for human health. The goals of this project are three-fold. The first is to evaluate an extensive list of commonly used drought indicators and rank them from a human health professional perspective to investigate how accessible a precomputed drought dataset was for each index and the spatial extent, temporal resolution, and geographic specificity of the dataset. The second goal is to evaluate the higher-ranked drought indices against one of the most comprehensive composite measures of drought; the US Drought Monitor (USDM). The final goal is to evaluate the relationship, if any, between these drought indicators and resulting health outcomes across the US.

Accomplishments

A total of 53 drought indices were evaluated based on the availability of a precomputed dataset, as well as the dataset's spatial extent, temporal coverage, geographic specificity, and publication frequency. These metrics were then scored to rank these indicators. The top-ranked drought indicators (Figure 1) were generally remotely sensed datasets, which tend to have higher measures of spatial coverage. These were followed in rank by drought indices that are computed from readily available meteorological observations (i.e., precipitation and temperature) that can be easily gridded (i.e., Prism or NClimGrid).

Drought events were defined for each US county and selected hydrological indicators (Standardized Precipitation Index [SPI], Standardized Precipitation Evapotranspiration Index [SPEI], Evaporative Demand Drought Index [EDDI], and Evaporative Stress Index [ESI]) over several aggregation periods (1, 3, 6, and 12 months). The frequency, duration, severity (i.e., time at D3 or greater status), seasonality of onset and termination, and worst drought on record were compared to the USDM's monthly maximum and mode status from 2000 to 2019. Evaluations revealed that SPI and SPEI aggregations of 6- and 12-month moisture deficits were more in line with USDM mode drought frequency (Figure 2).

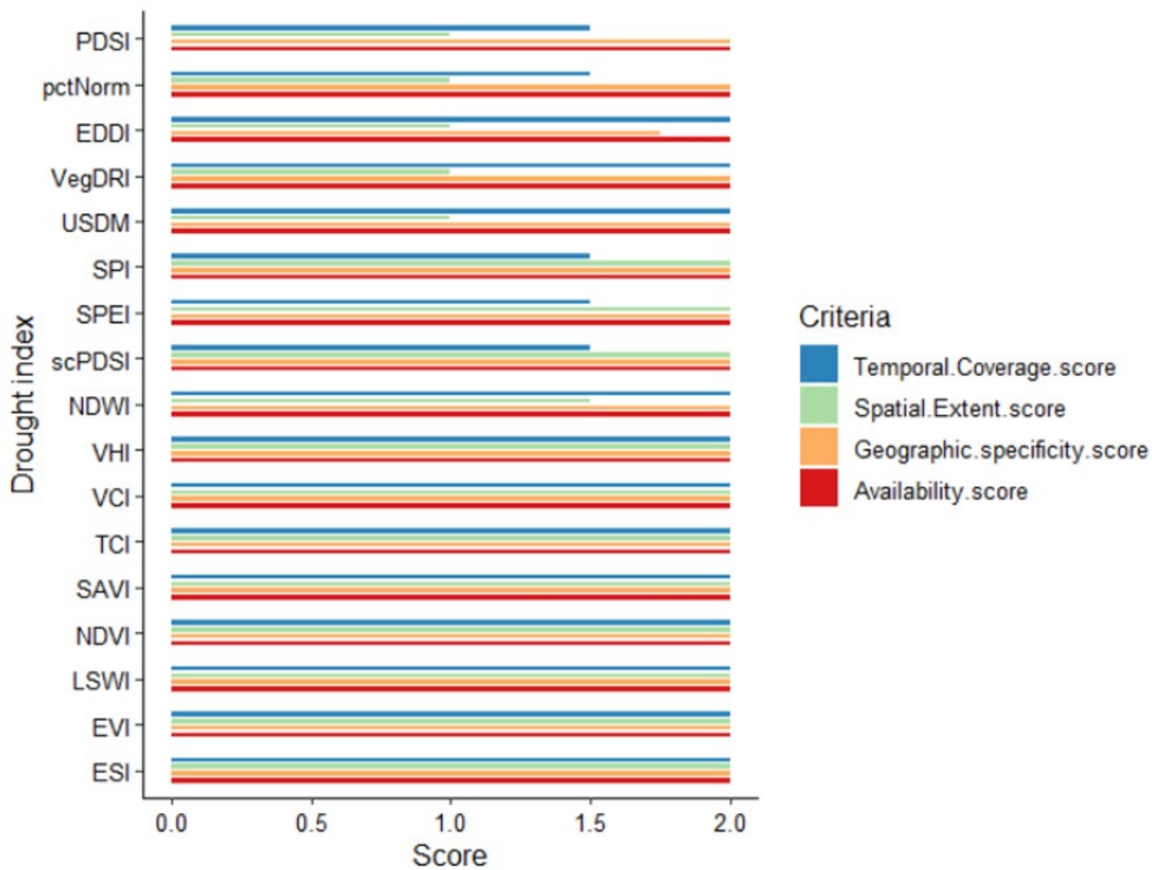


Figure 1. *The top-ranked drought index scores from 0 (poor) to 2 (great) by temporal coverage (blue), spatial extent (green), geographic specificity (orange), and availability (red).*

The spatial extent of each drought index and aggregation time were evaluated and compared against the USDM mode and maximum for notable drought events in the US: 2011 Texas drought (Figure 3), 2012 central US Drought, 2007 Southeast drought, and 2002 Southwest Drought. In addition to the spatial extent, the timing of drought onset and termination as well as the cumulative drought exposure for each drought event were evaluated. Overall, the EDDI metric tended to have both a greater spatial extent and measures of severity than the USDM and other drought indices. While the 6- and 12-month SPI and SPEI both matched the USDM best, no indicator was found to consistently match the USDM conditions in space and time.

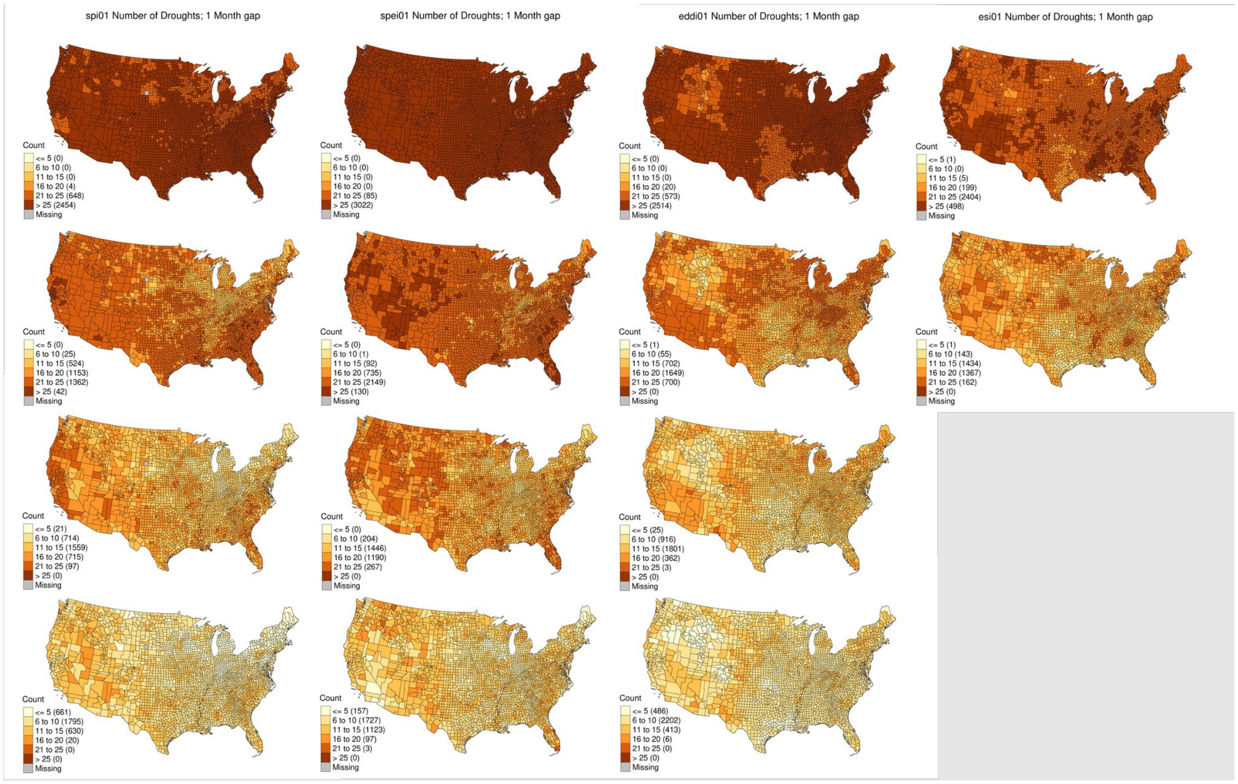


Figure 2. *Drought frequency for (left to right) SPI, SPEI, EDDI, and ESI and aggregation (top to bottom) for 1-, 3-, 6-, and 12-month periods from 2000 to 2020.*

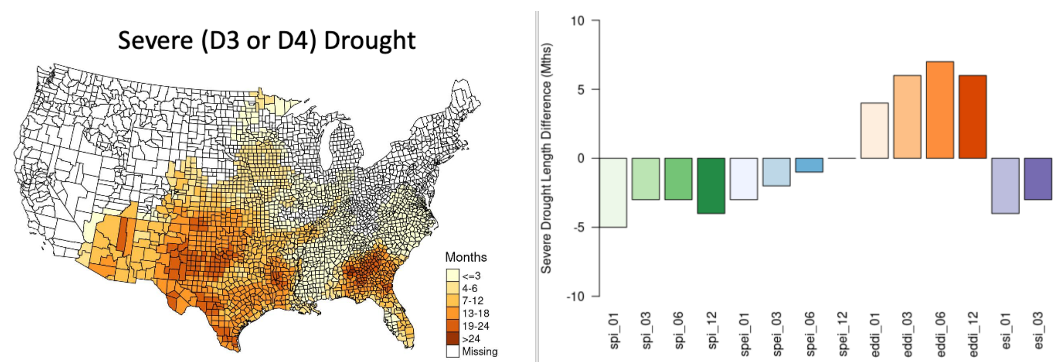


Figure 3. *The number of USDM D3 or greater months (left) and the difference (USDM minus indicator) during the Texas 2011 drought (right).*

Planned work

- Continue to support updates to the manuscript documenting the drought index rankings based on availability, geographic specificity, spatial extent, and temporal resolution
- Continue to summarize indicator differences in drought frequency, duration, and severity with respect to USDM
- Evaluate differences in the evolution of exposure to drought from the USDM-mode, SPI, SPEI, EDDI, and ESI perspectives for several drought events including the 2011 Texas drought, 2012 central US drought, 2007 Southeast drought, and 2002 Southwest drought.

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
Sponsor	Columbia University/US Department of Energy (DOE)

Highlight: This multi-institutional research project comprehensively investigated the representation and associated uncertainties of rain microphysical processes in weather and climate models. The team developed an innovative Bayesian statistical framework that combine extensive radar- and ground-based data, bin microphysical modeling, and a new bulk parameterization. This year, a PhD student successfully defended her thesis and two papers derived from the thesis are in preparation. A review paper on dual-polarization radar fingerprints of precipitation microphysics was published.

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, which in turn controls 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 availability of Atmospheric Radiation Measurement (ARM) polarimetric and zenith-pointing radars, allow for unprecedented information on rain microphysical processes. However, the current state of microphysical parameterization schemes complicates 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 can use any combination of prognostic drop size distribution (DSD) moments without assuming a prior 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, the development of a moment-based polarimetric-radar forward operator is required to determine the optimal combination of prognostic moments (2- or 3-moment scheme) that minimizes uncertainties. This Bayesian statistical approach combines real rainfall dual-polarization radar data from ARM field campaigns, bin microphysical modeling, and a new bulk parameterization. This work is conducted in collaboration with our partners, Dr. Marcus van Lier-Walqui (Columbia University), Dr. Matthew Kumjian (Pennsylvania State University), and Dr. Hughbert Morrison (National Center for Atmospheric Research).

Accomplishments

The project is completed. The project was under a no-cost extension until August 2021. Karly Reimel, PhD student from Pennsylvania State University, defended her thesis in May 2021. Two papers derived from the PhD thesis are still in preparation. During the last year, the group has published a review paper on dual-polarization radar fingerprints of precipitation microphysics. The paper built on the work and conclusions of the research project.

Planned work

- Finalize the two remaining manuscripts of the project

Publications

Kumjian, M.R., **O.P. Prat**, K.J. Reimel, M. van Lier-Walqui, and H.C. Morrison, 2022: Dual-polarization radar fingerprints of precipitation physics: A review. *Remote Sensing,* 14*,* (15). http://dx.doi.org/10.3390/rs14153706

Global Near-Real-Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets	
Task Team	Olivier Prat, David Coates, Scott Wilkins
Task Code	NC-OTH-07-NCICS-OP/DC/SW

Highlight: The team set up the SPI Python codebase on Azure and ported the CMPORH data**.** CMORPH-SPI was run on Azure and reproduced results from runs on the local NCICS cluster, with a 30% improvement in computational time. IMERG files computing the multi-day accumulations were prepared. The team is working to address technical issues on Azure that are preventing transfer of larger, more complex datasets to the cloud.

Background

The Standardized Precipitation Index (SPI) has been recommended as a drought monitor (a drought index) by the World Meteorological Organization (WMO 2012), and it is widely used by meteorological and agricultural services around the world. In recent years, researchers have taken advantage of the availability of near-real-time satellite precipitation data to merge land-based precipitation station data and space-based precipitation data. Our research group developed an operational near-real-time global SPI based on the daily gridded satellite precipitation CMORPH-CDR (CPC MORPHing technique-Climate Data Record). The CMORPH-CDR was developed by NOAA's Climate Prediction Center (CPC) in a procedure that "morphs" or extrapolates movement of precipitation rain clouds if they drift out of the line of sight of satellite coverage. As part of the subsequent launch of the Global Precipitation Mission (GPM) by NASA and the Japan Aerospace Exploration Agency (JAXA), the GPM active weather radar calibrates and refines the other satellite measurements while complementing additional satellites assembled within the Committee on Environmental Satellites virtual precipitation constellation. The GPM-IMERG (Integrated Multi-satellitE Retrievals for GPM) precipitation archive is built on the subcomponents of the NOAA geostationary satellite measurements (NOAA Hydro-Estimator), CMORPH, and PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks), from the University of California Irvine. The GPM-IMERG archive (at NASA Goddard Space Flight Center) also compares the assembled space-based precipitation measurements against the land-based precipitation station measurements within the Global Precipitation and Climatology Centre and the Global Precipitation Climatology Project for merged validation. In short, GPM-IMERG is a state-of-the-art, final (at this time) product that contains, complements, and supersedes both CMORPH and Hydro-Estimator.

The goal of this project is to adapt the existing CMORPH-SPI framework (daily SPI at 0.25° x 0.25°) to ingest the dataset GPM-IMERG to produce a GPM-SPI (daily SPI at 0.1° x 0.1°), resulting in a 6-fold increase in spatial resolution. In addition, the processing data pipeline will be optimized to further take advantages of innovations in cloud processing, using Microsoft Azure and data lake capacity, to decrease the processing time, bringing the overall system closer to real time and allowing for rapid updates while monitoring current drought conditions. This work will provide a more accurate geospatial mapping of daily drought and drying conditions than is currently available. The unprecedented daily precipitation data will allow meteorological drought to be calculated within a moving window, well beyond the current capabilities of the GDIS (Global Drought Information System) and GDO (Global Drought Observatory). The project is funded by GEO-Microsoft Planetary Computer Programme. It started in January 2022 and runs until December 2023.

Accomplishments

The project started in January 2022. The work is divided into the following tasks:

- Task 1: Set up the SPI Python codebase on Azure and move the CMORPH data to Azure.

- Task 2: Run CMORPH-SPI on Azure to reproduce the results obtained on the NCICS cluster. Compare results between the Azure cloud computer and the NCICS cluster in order to make sure that both runs provide similar results (drought patterns, distribution parameters).
- Task 3: Prepare the IMERG input file to be used in the computation of the Global IMERG-SPI. The IMERG dataset (30 minutes) is available on the Microsoft Planetary Computer. The 30-minute rainfall will be summed to provide daily accumulation.
- Task 4: Modify the SPI Python code to the GPM-IMERG precipitation dataset.
- Task 5: Run IMERG-SPI on Azure. Perform as many runs as needed for sensitivity analysis.
- Task 6: Analyze the IMERG-SPI results (SPI values, parameter distributions). Compare IMERG-SPI with CMORPH-SPI.
- Task 7: Automatize the process so that daily IMERG-SPI will be computed in near-real time using IMERG late run (available within 12 hours) and/or IMERG final run (gauge bias-adjusted with a latency of 3.5 months) when it becomes available.

Cloud-scale computing is fundamental for the success of this project. It will allow the project team to run higher-resolution SPI within a reasonable time frame every day. The high-resolution global SPI will be made available to the public on the Global Drought Information System website (https://gdis-noaa.hub.arcgis.com/pages/drought-monitoring). The IMERG-SPI will also complement Microsoft's Planetary Computer Data Catalog holdings. It will include SPI, a critical variable for global ecological studies, agriculture, and global climate change monitoring.

During the first year of the project, the working group completed Task 1, having created a virtual environment on the Azure platform as well as cloning the SPI Python codebase and transferring all required data. Task 2 was also completed, and initial tests running CMORPH-SPI on Azure reproduced local computing NCICS cluster results with a 30% gain in computational time. IMERG files computing the multiday accumulations were prepared (Task 3).

However, while we were able to successfully run CMORPH-SPI on Azure, a number of technical problems arose in trying to transition larger, more complex datasets (e.g., NOAA's US Climate Gridded dataset, NClimGrid, and the project's focus dataset, IMERG) to Azure for additional testing and processing. The one-year project was granted a one year no-cost extension (until December 2023) to allow time to address current technical issues on Azure, which are preventing progress toward project completion.

Planned work

- Continue and finalize the adaptation of the SPI code to Azure
- Run the IMERG-SPI code on Azure
- Compare and evaluate results obtained for IMERG-SPI with CMORPH-SPI (global) and NClimGrid-SPI (CONUS)
- Help with the transition of the IMERG-SPI to the drought.gov portal and to other possible platforms (Planetary Computer Data Catalog).
- Prepare and submit a manuscript.

Environmental and Extreme Event Impacts on Human Health	
Task Leader	Jennifer Runkle
Task Code	NC-OTH-08-NCICS-JR
Sponsor	multiple

Highlight: Research efforts this year included studies of the impact of the COVID-19 pandemic on mental health for vulnerable children and adolescents, the crisis response in frontline essential workers and their children, and bereavement as a significant stressor shouldered by adolescents during the pandemic. Other work examined the effect of compounding events on mental health consequences, the relationship between hot ambient temperatures and psychiatric emergency department admissions during pregnancy, and the effect of co-occurring drought and heat wave events on spatial pediatric mental health patterns.

Background

The World Health Organization has identified climate change as "the single biggest health threat facing humanity," affecting the social and environmental determinants of health including clean air, safe drinking water, sufficient food, and secure shelter. Climate change has been linked to an increase in the intensity and frequency of extreme weather and other climate-related events, which can disrupt lives and otherwise impact the health and well-being of those directly affected by these extreme events. The past decade has seen an increasing number and severity of such events in the US (e.g., heat waves, droughts, wildfires, flooding, hurricanes) with associated impacts on human health. Over the past couple of years, the impact of the climate crisis on overburdened communities has been compounded by the global COVID-19 pandemic.

Accomplishments

Research studies during the past year examined:

- The pandemic's impact on mental health for vulnerable children and adolescents, with a focus on racial/ethnic, non-conforming, and sexual minority groups
- Crisis response in frontline essential workers and their children to understand the impact of the pandemic on these overtaxed workers and their families
- Bereavement as a significant stressor shouldered by adolescents during the pandemic
- The effect of compounding events on mental health consequences (e.g., 2020 wildfire season)
- The relationship between hot ambient temperatures and psychiatric emergency department admissions during pregnancy
- The effect of co-occurring drought and heat wave events on spatial pediatric mental health patterns

Publications

Runkle, J.D., K. Risley, M. Roy, and M.M. Sugg, 2023: Association between perinatal mental health and pregnancy and neonatal complications: A retrospective birth cohort study. *Women's Health Issues,* **In press**. http://dx.doi.org/10.1016/j.whi.2022.12.001

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Wertis, L., **J.D. Runkle**, M.M. Sugg, and D. Singh, 2023: Examining Hurricane Ida's impact on mental health: Results from a quasi-experimental analysis. *GeoHealth*, **7**, e2022GH000707. http://dx.doi.org/10.1029/2022GH000707

Innovating a Community-Based Resilience Model on Climate and Health Equity in the Carolinas	
Task Team	Jennifer Runkle (Lead), Charlie Reed
Task Code	NC-OTH-09-NCICS-JR
Sponsor	NOAA (CPO/RISA)

Highlight: A new NOAA Climate Adaptation Partnership (formerly the Regional Integrated Sciences and Assessments program), the Carolinas Collaborative on Climate, Health, and Equity (C3HE), was established at North Carolina State University. The team has established five community partnerships to develop a model for the end-to-end co-production of actionable and equitable climate resilience solutions in at-risk communities in the Carolinas.

Background

Recent extreme weather and climate events in and/or directly affecting the Carolinas (e.g., 2016 Wildfires and Hurricanes Matthew [2016], Irma [2017], Florence [2018], and Dorian [2019]] signal a significant change from the past, causing unprecedented damage across the region. Across the Carolinas, many communities are in constant recovery mode, each disaster compounding the last. The Carolinas are also getting wetter, hotter, and more humid in a changing climate. The impacts of sea level rise on the North Carolina Outer Banks and the South Carolina Low Country are seen in the now regular occurrence of tidal flooding and rising temperatures, especially at night, which present a public health risk.

Climate change has and will continue to impact the health and well-being of every community, but not all communities are affected equally. The experiences of minority and underserved communities at the start of the climate crisis will be reproduced in other parts of society as climate change impacts become more pronounced and widespread. These communities are the canaries in the coal mines for the rest of society.

The multi-institutional RISA team will build upon years of regional work on climate science, tools, and assessments to move into a new phase that centers Justice, Equity, Diversity, and Inclusion (JEDI) principles at the forefront of climate research (Figure 1). A bottom-up participatory approach will be applied to develop a transferable model for end-to-end co-production of actionable and equitable climate resilience solutions in at-risk communities in the Carolinas.

Accomplishments

Year 1 work for the multi-institutional Regional Integrated Sciences and Assessments (now Climate Adaptation Partnership) was focused on building institutional capacity, especially with our Historically Black Colleges and Universities partners and establishing and strengthening connections with community partners. The major work and successes of the first year of the Carolinas Collaborative on Climate, Health, and Equity (C3HE) include:

- Assembling the project team with Principal Investigators at seven universities and organizations across the Carolinas,
- Establishing C3HE processes for identifying, engaging, and funding work with frontline communities in the Carolinas,
- Convening an advisory board comprising a diverse group of regional voices that will provide guidance on integrating JEDI principles into our work and establishing and maintaining community partnerships,
- partnering with the North Carolina Climate Justice Collective (NCCJC) to train and support their work in assessing climate vulnerabilities, and

- working in four diverse local communities, from tribal groups to health providers to majority minority towns that have recently experienced climate change impacts, with the groundwork laid for additional community engagement over the coming year.

Other work included preliminary scoping of climate concerns/priorities in partnering communities, recruiting graduate students and postdocs, and filling in gaps in technical expertise and regional focus on the team from the initial proposal. A research retreat was held in July 2022 and January 2023 to continue outlining an innovative research strategy for bringing the physical and social sciences together around priority climate and health concerns. The NCCJC led the C3HE team in JEDI training at the January retreat to develop a shared language around equity.

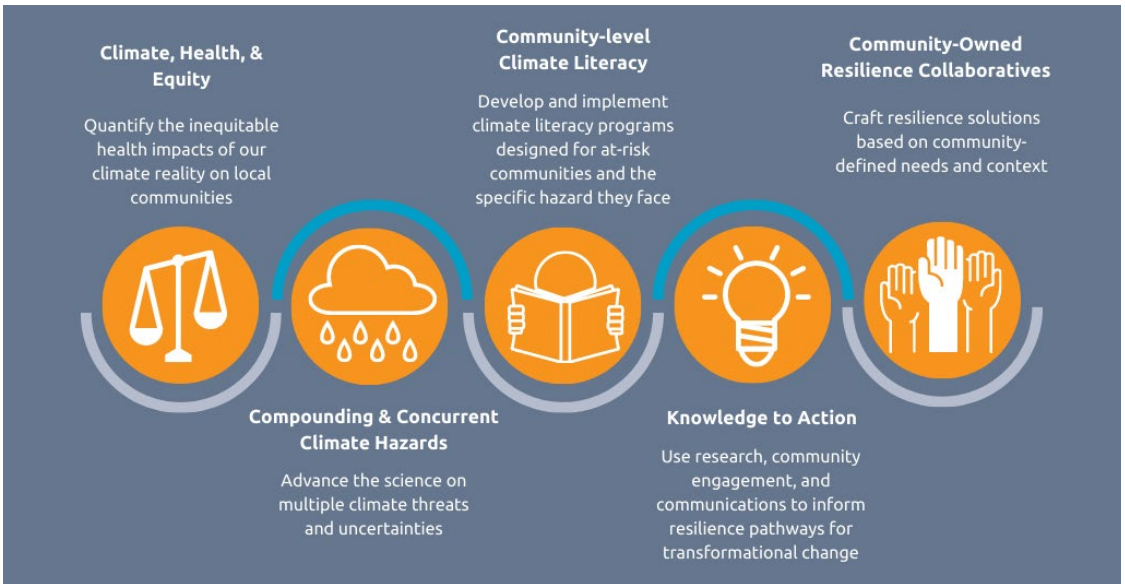

Figure 1. *Thematic areas for the new C3HE center.*

Planned work

- Co-develop a 100-year tribal climate action plan
- Complete recruitment of project students and postdocs
- Build and enhance local partnerships in overburdened communities in the Carolinas
- Conduct research to understand and predict how co-occurring and consecutive hazards interact with exposure and vulnerability to shape climate and health risks

Presentations

Runkle, J.D., 2022: Heat and Health Equity for Carolina Communities in a Changing Climate. *Climate Health Equity: The Effects of Heat & Air Pollution in the Southeast,* virtual. November 12, 2022.

Runkle, J.D., 2022: Health, Climate Change, and Environmental Toxicology: Emerging Research Needs (keynote address). *North Carolina Chapter of the Society of Toxicology annual Fall Meeting on Climate, Chemicals, and North Carolina.* North Carolina Central University, Durham, NC. October 19, 2022.

Runkle, J.D., 2022: Climate Change and Health, the National Climate Assessment. Climate and Respiratory Health—World Asthma Day. *The Collider*, Asheville, NC. May 3, 2022**.**

Runkle, J.D., 2022: The Future of Public Health in the Climate Crisis. *SC Upstate Research Symposium,* Spartanburg, SC. April 8, 2022.

Runkle, J.D., 2022: Climate Change in Rural Communities. *Climate Change and Health in Rural Mountain Environments: A Collaborative Workshop*, virtual. April 8, 2022. https://youtu.be/_Sm0encOHWU

Runkle, J.D., 2022: Climate, Health, and Equity. *CleanAIR NC: NC BREATHE Conference,* virtual. April 7, 2022. https://www.youtube.com/watch?v=Q2Sp_eXlneA

Kelvin Waves and Easterly Waves in CYGNSS	
Task Leader	Carl Schreck
Task Code	NC-OTH-10-NCICS-CS
Sponsor	NASA

Highlight: NASA CYGNSS surface wind data identify differences in the surface wind speed anomalies with Kelvin waves that are dependent on the background flow regime.

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 has wavelengths of 2,000–4,000 km.

Accomplishments

Figure 1 shows an example of the composite CYGNSS wind speed (shading) and vector winds from ERA5 for tropical cyclones that developed from African easterly waves (AEWs). CYGNSS clearly shows enhanced wind speed with the AEW up to three days before cyclogenesis. The CYGNSS surface flux data also provided new insights into cyclogenesis processes. These fluxes remained fairly constant before genesis. However, following genesis, there was a notable increase in the highest surface enthalpy fluxes within the system. The CYGNSS data also showed a negative radial gradient in enthalpy fluxes, which was consistent with a recent modeling study of cyclogenesis processes. These results are currently under review for publication in *Geophysical Research Letters.*

Figure 2 compares composite Kelvin wave surface winds speeds between ERA5 (left column) and CYGNSS (right column) for each ocean basin. These composites highlight one of the challenges of examining Kelvin waves with surface wind speed. The Kelvin wave circulation is dominated by zonal wind anomalies. However, the resulting wind speeds are dependent on whether the climatological background winds are easterlies (ITCZ) or westerlies (monsoons). For example, the Indian Ocean has background equatorial westerlies, so the westerly phase of the Kelvin wave creates stronger wind speeds. Meanwhile, the equatorial Pacific and Atlantic Oceans have trade wind regimes. In these basins, the westerly phase of the Kelvin wave has reduced wind speed, but the easterly phases have enhanced wind. Despite these challenges, the similarities in the composites between ERA5 and CYGNSS provide some confidence in these signals. We hope to publish these results in a future publication.

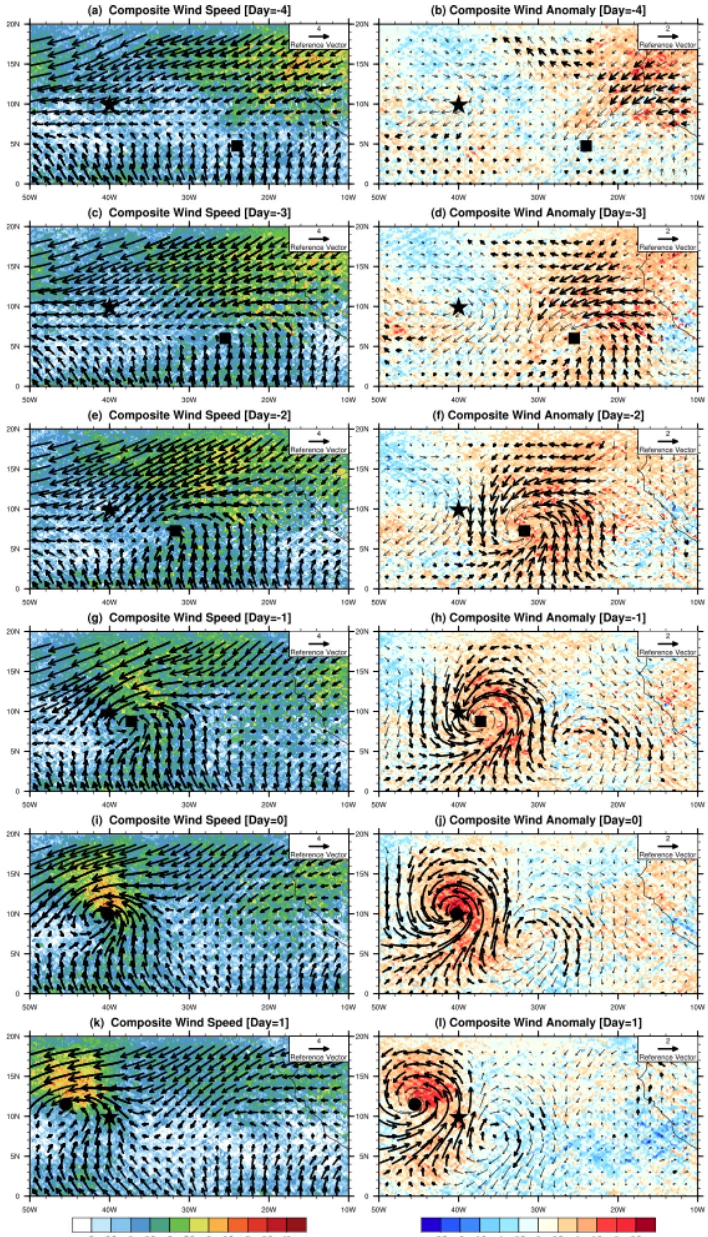

Figure 1. *Storm-centered lag composite mean (left column) and anomalies (right column) of CYGNSS FDS wind speeds (m s^{-1}; shaded) and ERA5 10 m wind vectors (m $^{s-1}$). The star symbol marks the center of the composite storm at the first recorded depression stage corresponding to Day 0. The black square shows the incipient vortex within the composite AEW, and the hurricane symbol marks the location of the composite tropical storm after it has formed.*

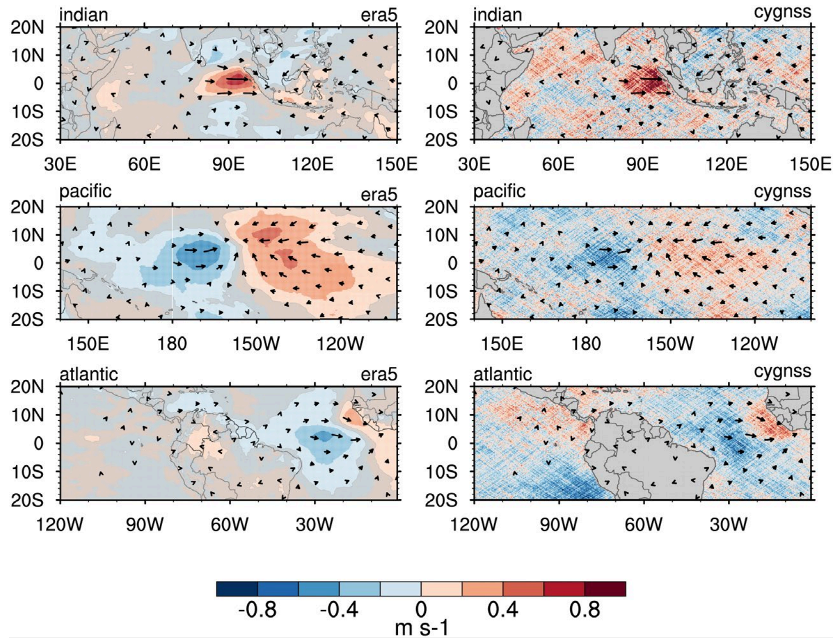

Figure 2. *Composite surface winds for Kelvin waves in each ocean basin. The vectors in all plots are from ERA5. The shading is 100-day high-pass filtered wind speed anomalies from ERA5 (left column) and CYGNSS (right column). For the ERA5 data, gray shading denotes wind speed anomalies that are not statistically significant at the 5% level.*

Planned work

Publish results on the depiction of Kelvin waves in CYGNSS wind data.

Publications

Aiyyer, A. and **C.J. Schreck**, 2023: Surface winds and enthalpy fluxes during tropical cyclone formation from easterly waves: A CYGNSS view. *Geophysical Research Letters,* **50** (e2022GL100823). http://dx.doi.org/10.1029/2022GL100823

Lawton, Q.A., S.J. Majumdar, K. Dotterer, C. Thorncroft, and **C.J. Schreck, III**, 2022: The influence of convectively coupled Kelvin waves on African easterly waves in a wave-following framework. *Monthly Weather Review*, **150** (8), 2055–2072. http://dx.doi.org/10.1175/mwr-d-21-0321.1

Appendix 1: CISESS Personnel and Performance Metrics

CISESS Personnel	Numbers[1]		CISESS Subcontractors	Numbers[2]
Scientists working ≥ 50% time	**25**		Scientists working ≥ 50% time	**12**
Scientists working < 50% time	**1**		Scientists working < 50% time	**15**
Scientists working at no cost	**1**		Scientists working at no cost	**0**
Total Scientists	**27**		**Total Scientists**	**26**
Administrative/technical staff	**11**		**Administrative/technical staff**	**22**
Graduate Students	**11**		Graduate Students	**2**
Undergraduate Students	**11**		Undergraduate Students	**13**
High School Students	**0**		High School Students	**0**
Total Students	**22**		**Total Students**	**15**
Total Personnel	**59**		**Total Personnel**	**64**

[1]*Excludes institute personnel supported solely by non-CISESS sponsors and unpaid student interns.*

[2]*Based on NOAA/CISESS budgeted support effort for this year's current subcontractor projects*

Performance Metrics	
# of new or improved products developed	**275[3]**
# of peer reviewed papers	**43[4]**
# of NOAA technical reports	**1**
# of presentations	**136[5]**
# of graduate students supported by CISESS task	**11**
# of graduate students formally advised	**0**
# of undergraduate students mentored during the year	**11**

[3] ***Products**: ≈200 new/enhanced datasets available through cloud service provider partners; 19 new or improved architectures and software products (including websites and web tools); 20 new or updated environmental data products; 3 new observational products; 32 reports and other communication products (see Appendix 4)*

[4] ***Publications:** peer-reviewed (23 CISESS, 20 Other) (see Appendix 2)*

[5]***Presentations:** 111 science presentations (105 CISESS, 6 Other); 15 intern presentations; 10 outreach and engagement presentations. (see Appendix 3)*

Appendix 2: Publications 2022-2023

CISESS Publications (*not peer reviewed)

Abadi, A.M., Y. Gwon, M.O. Gribble, J.D. Berman, R. Bilotta, M. Hobbins, and J.E. Bell, 2022: Drought and all-cause mortality in Nebraska from 1980 to 2014: Time-series analyses by age, sex, race, urbanicity and drought severity. *Science of The Total Environment*, 840, 156660. https://doi.org/10.1016/j.scitotenv.2022.156660

Dagon, K., J. Truesdale, J.C. Biard, **K.E. Kunkel**, G.A. Meehl, and M.J. Molina, 2022: Machine learning-based detection of weather fronts and associated extreme precipitation in historical and future climates. *Journal of Geophysical Research: Atmospheres,* **127** (21), e2022JD037038. http://dx.doi.org/https://doi.org/10.1029/2022JD037038

Diamond, H.J. and **C.J. Schreck, Eds.**, 2022: The Tropics [in "State of the Climate in 2021"]. In: *Bulletin of the American Meteorological Society*. S193-S256. http://dx.doi.org/10.1175/bams-d-22-0069.1

Durre, I., A. Arguez, **C.J. Schreck III**, M.F. Squires, and R.S. Vose, 2022: Daily high-resolution temperature and precipitation fields for the contiguous United States from 1951 to present. *Journal of Atmospheric and Oceanic Technology*. http://dx.doi.org/10.1175/jtech-d-22-0024.1

Inamdar, A.K., L. Shi, H.-T. Lee, D.L. Jackson, and J.L. Matthews, 2023: Extending the HIRS data record with IASI measurements. *Remote Sensing*, **15** (3), 717. https://www.mdpi.com/2072-4292/15/3/717

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Klotzbach, P.J., **C.J. Schreck, III**, G.P. Compo, K.M. Wood, E.C.J. Oliver, S.G. Bowen, and M.M. Bell, 2023: Influence of the Madden-Julian Oscillation on continental United States hurricane landfalls. *Geophysical Research Letters,* **50** (7), e2023GL102762. http://dx.doi.org/10.1029/2023GL102762

Krishnan P., and S. Wang, 2023: Editorial for the Special Issue "Understanding Biosphere–Atmosphere Interactions with Remote Sensing." *Remote Sensing.* **15(2)**, 332. https://doi.org/10.3390/rs15020332

Kunkel, K.E., X. Yin, **L. Sun**, **S.M. Champion**, **L.E. Stevens**, and **K.M. Johnson**, 2022: Extreme precipitation trends and meteorological causes over the Laurentian Great Lakes. *Frontiers in Water*, **4**. http://dx.doi.org/10.3389/frwa.2022.804799

Leeper, R.D., R. Bilotta, B. Petersen, C.J. Stiles, R. Heim, B. Fuchs, **O.P. Prat**, M. Palecki, and S. Ansari, 2022: Characterizing U.S. drought over the past 20 years using the U.S. drought monitor. *International Journal of Climatology,* **42** (12), 6616– 6630. http://dx.doi.org/10.1002/joc.7653

Puvvula, J., L. Baccaglini, A. Johnson, Y. Du, J.E. Bell, and R.H. Rautiainen, 2022: Prevalence and risk factors for pulmonary conditions among farmers and ranchers in the central United States. *J. Agromedicine*, 27(4), 378-390. https://doi.org/10.1080/1059924X.2021.2025180

Schlef, K.E., **K.E. Kunkel**, C. Brown, Y. Demissie, D.P. Lettenmaier, A. Wagner, M.S. Wigmosta, T.R. Karl, D.R. Easterling, K.J. Wang, B. François, and E. Yan, 2022: Review: Incorporating non-stationarity from climate change into rainfall frequency and intensity-duration-frequency (IDF) Curves. *Journal of Hydrology*, 128757. https://doi.org/10.1016/j.jhydrol.2022.128757

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Shi, L., **C.J. Schreck, III**, V.O. John, E.S. Chung, T. Lang, S.A. Buehler, and B.J. Soden, 2022: Assessing the consistency of satellite-derived upper tropospheric humidity measurements. *Atmospheric Measurement Techniques*, **15** (23), 6949–6963. http://dx.doi.org/10.5194/amt-15-6949-2022

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Technical Reports

Kunkel, K.E., R. Frankson, **J. Runkle**, **S.M. Champion**, **L.E. Stevens**, D.R. Easterling, **B.C. Stewart**, **A. McCarrick**, and C.R. Lemery, Eds., 2022: State Climate Summaries for the United States 2022. NOAA Technical Report NESDIS 150. NOAA/NESDIS, Silver Spring, MD., 251 pp. https://statesummaries.ncics.org/

Other Publications

Aiyyer, A. and **C.J. Schreck**, 2023: Surface winds and enthalpy fluxes during tropical cyclone formation from easterly waves: A CYGNSS view. *Geophysical Research Letters,* **50** (e2022GL100823). http://dx.doi.org/10.1029/2022GL100823

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Sun, X. and L. Xie, 2022: A comparative study on the performances of spectral nudging and scale-selective data assimilation techniques for hurricane track and intensity simulations. *Climate*, **10** (11), 168. http://dx.doi.org/10.3390/cli10110168

Tchebakova, N.M., E.I. Parfenova, E.V. Bazhina, A.J. Soja, and **P.Y. Groisman**, 2022: Droughts are not the likely primary cause for *Abies sibirica* and *Pinus sibirica* forest dieback in the South Siberian Mountains. *Forests*, **13**. http://dx.doi.org/10.3390/f13091378

Wertis, L., **J.D. Runkle**, M.M. Sugg, and D. Singh, 2023: Examining Hurricane Ida's impact on mental health: Results from a quasi-experimental analysis. *GeoHealth*, **7**, e2022GH000707. http://dx.doi.org/10.1029/2022GH000707

Wodzicki, K.R., and A.D. Rapp, 2022: More intense, organized deep convection with shrinking tropical ascent regions. *Geophysical Research Letters*, **49** (15), e2022GL098615. http://dx.doi.org/doi.org/10.1029/2022GL098615

Appendix 3: Presentations 2022–2023

Science / Project Presentations

Bell, J.E., 2022: Climate-driven disasters. *World Federation of Public Health Associations (WFPHA) Global Public Health Week*, virtual. April 5, 2022.

Bell, J.E., 2022: Drought and Heat – Focus on Health. *NOAA Eastern Region Climate Services Webinar*, virtual. May 26, 2022.

Bell, J.E., 2022: Drought and Human Health Midwest and Missouri River Basin Workshops. *Midwest and Missouri River Basin Drought Early Warning System (DEWS) Partners Meeting*, Omaha, NE. October 13, 2022.

Bell, J.E., 2022: Extreme Weather Hazards. *Columbia University Climate Change and Health Bootcamp*, virtual. June 17, 2022.

Bell, J.E., 2022: Intersection between Drought and Human Health. *Upper Missouri River Basin Drought and Human Health Workshop*, Bozeman, MT. April 12, 2022.

Bell, J.E., 2022: Intersection between Drought and Human Health. *Pacific Northwest Drought and Human Health Workshop*, Portland, OR. October 19, 2022.

Bell, J.E., 2022: Weathering Uncertainty: Conversations About Climate in Nebraska (panel discussion). Humanities, NE. June 15, 2022.

Brannock, J.B., and D.S. Willett, 2022: Cloud Computing in Advancing Climate Informatics (panel discussion). *11th International Conference on Climate Informatics,* virtual. May 11, 2022.

Brannock, J.B., and **D.S. Willett**, 2022: NODD Technical Updates and Strategic Development. *NOAA CDO Visit*. December 7-8, 2022.

Brannock, J.B., and **D.S. Willett**, 2022: NODD Technical Updates. *Assistant Secretary of Commerce Overview*. December 15, 2022.

Brewer, M., D. Arndt, **J. Dissen**, J. Poplawski, J. Okrend, and A. Smith, 2023: Outcomes from NOAA Climate Listening Sessions, *103rd American Meteorological Society Annual Meeting*. January 11, 2023.

Coates, D.A., and **K.E. Kunkel**, 2022: Extreme heat and cold monitoring. *Rapid Attribution Team 2022 Workshop*, virtual. May 2022.

Coates, D.A., and **K.E. Kunkel**, 2022: Extreme heat and cold monitoring. *Rapid Attribution Team 2022 Workshop*, virtual. May 2022.

Dissen, J., 2022: Cloud Computing in Advancing Climate Informatics (panel moderator). *11th International Conference on Climate Informatics,* virtual. May 11, 2022.

Dissen, J., 2022: Cloud Pathfinders… Assemble! (session facilitator). *2022 July Earth Science Information Partners (ESIP) Summer Meeting.* Pittsburgh, PA. July 21, *2022.*

Dissen, J., 2022: Understanding and Valuing JPSS Data. *Joint Polar Satellite System (JPSS) Science Meeting.* Vandenberg Space Force Base, CA. November 9, 2022.

Dissen, J., 2022: Water and Society: Water Scarcity Impacts on Local Communities and Economies (convener). *2022 American Geophysical Union (AGU) Fall Meeting,* virtual. December 15, 2022.

Dissen, J., 2022: Water and Society: Water Scarcity Impacts on Local Communities and Economies (co-convener). *2022 American Geophysical Union (AGU) Fall Meeting,* virtual. December 15, 2022.

Dissen, J., A. Simonson, P. Keown, K. Szura, and **D.S. Willett**, 2022: NOAA Open Data Dissemination (formerly BDP). *N-Wave Joint Engineering and Technical Interchange (JETI) Annual Meeting*, virtual. August 9, 2022.

Dissen, J., and A. Simonson, 2022: NODD Advances Interoperability (session co-chair). *2022 Environmental Data Management Workshop*, virtual. September 15, 2022.

Dissen, J., and **L.E. Stevens**, 2022: Key Findings from the North Carolina Climate Science Report. *Independent Insurance Agents of North Carolina (IIANC) E&O and Disaster Symposium*, Boone, NC. October 25, 2022.

Fard, B., M. Penry, E. Kerns, and J.E. Bell, 2022: The Effect of Drought on Heat-Related Mortalities During 2000-2018 in the Conterminous United States (poster). *American Geophysical Union (AGU) Fall Meeting*, Chicago, IL. December 13, 2022.

Georgiadi A.G., and **P.Ya. Groisman**, 2022: Long-Term Changes of Geofluxes of Two Largest Arctic Rivers of European Russia. *Session 11 of the Future Earth Program and Northern Eurasia Future Initiative, ENVIROMIS 2022 Conference.* Tomsk, Russia. September 17, 2022.

Groisman, P.Y., 2022: Environmental, Socio-Economic and Climatic Changes in Northern Eurasia (convener, chair, 2 sessions). 2022 *Japan Geoscience Union* (JpGU) *Meeting*, virtual. May 26, 2022.

Groisman, P.Y., 2022: Future Earth Program and Northern Eurasia Future Initiative (session co-chair). *ENVIROMIS 2022,* virtual. September 17, 2022.

Groisman, P.Y., 2022: Geofluxes of Major Arctic Rivers of European Russia: Long-term Changes and Possible Causes (poster). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 15, 2022.

Groisman, P.Y., 2022: Long-term changes of Water Flow, Water Temperature and Heat Flux of two Largest Arctic Rivers of European Russia, Severnaya Dvina and Pechora, *ENVIROMIS-2022,* virtual. September 17, 2022.

Groisman, P.Y., 2022: Northern Eurasia Future Initiative (NEFI), Three Regional Groups of the NEFI Studies (poster). 2022 *Japan Geoscience Union (JpGU) Meeting*, virtual. June 3, 2022.

Groisman, P.Y., 2022: Northern Eurasia Future Initiative (NEFI): Three Regional Groups of the NEFI Studies (poster). *ENVIROMIS-2022,* virtual. September 17, 2022.

Groisman, P.Y., 2022: The LCLUC NEESPI-NEFI: Accomplishments and Synthesis. *Land-Cover and Land-Use Change (LCLUC) Annual Meeting.* Bethesda, MD. October 18, 2022.

Groisman, P.Y., A.G. Georgiadi, and O.N. Bulygina, 2022: Geofluxes of Major Arctic Rivers of European Russia: Long-term Changes and Possible Causes (poster). *2022 American Geophysical Union (AGU) Fall Meeting.* Chicago, IL. December 15, 2022.

Groisman, P.Y., and J. Chen, 2022: Northern Eurasia Future Initiative (NEFI), Three Regional Groups of the NEFI Studies (poster). 2022 *Japan Geoscience Union (JpGU) Meeting*, virtual. June 3, 2022.

Inamdar, A.K., L. Shi, H.-T. Lee, D.L. Jackson, and J.L. Matthews, 2023: Extending the HIRS Data Record Using Simulated HIRS Data Derived from the Infrared Atmospheric Sounding Interferometer (IASI). *103rd American Meteorological Society Annual Meeting.* Denver, CO. January 12, 2023.

Kunkel, K.E., 2022: *"*Heavy Rain Is Increasing: Fact or Fiction" and "Climate 101." *Bureau of Reclamation Water School*, Boulder City, NV. October 26, 2022.

Kunkel, K.E., 2022: An Introduction to Methods to Generate High Resolution Climate Projections*. U.S.–India Partnership for Climate Resilience webinar on climate projections and precipitation data analysis for the State of Uttarakhand*, virtual. September 21, 2022.

Kunkel, K.E., 2022: Climate 101 (invited oral presentation). *Bureau of Reclamation Water School,* Boulder City, NV. October 26, 2022.

Kunkel, K.E., 2022: Climate Change (panel discussion). *Verisk Envision 2022 Conference,* Miami, FL. April 6, 2022.

Kunkel, K.E., 2022: Extreme Precipitation: Trends, Climatology, and Application to Precipitation Design Values. *University of Notre Dame Department of Civil and Environmental Engineering and Earth Sciences*, Notre Dame, IN. April 19, 2022.

Kunkel, K.E., 2022: Incorporating Climate Change into Intensity-Duration-Frequency Values for the United States. *Florida International University (FIU) Institute of Environment Sea Level Solutions seminar series*, virtual. August 17, 2022.

Kunkel, K.E., 2022: Increasing Extreme Precipitation and Climate Change: Observations and Projections. *C-SAW extreme events scoping workshop, Ocean Carbon and Biogeochemistry Program*, Raleigh, NC. October 24, 2022.

Kunkel, K.E., 2022: Physical Climate Science: Downscaling & Regional Information (invited presentation). *Opening Plenary of Meeting #2 of the NCA5 Chapter Leadership*, virtual. April 4, 2022.

Kunkel, K.E., 2022: Rain Loads. *American Society of Civil Engineers Structural Engineering Institute Climate Impacts Workshop—Second Session*, virtual. May 11, 2022.

Kunkel, K.E., 2022: SERDP project information. *Department of Transportation (DOT) and NC DOT project team meeting*, virtual. July 11, 2022.

Kunkel, K.E., 2022: The Future Climate of North Carolina—Uncharted Waters. *Teaching for Community Resilience Fellowship Program regional college faculty group meeting, University of North Carolina Asheville*. April 29, 2022.

Kunkel, K.E., 2022: The Future Climate of North Carolina—Uncharted Waters (invited presentation). *North Carolina State University Osher Lifelong Learning Institute* "Our Rapidly Changing Climate" course, Raleigh, NC. November 9, 2022.

Kunkel, K.E., 2022: The Future Climate of North Carolina—Uncharted Waters (invited presentation). *Teaching for Community Resilience Fellowship Program*, Asheville, NC. April 29, 2022.

Kunkel, K.E., 2023: State of the Climate. *Electric Power Research Institute (EPRI) Environmental Change Institute Webinar*. March 3, 2023.

Kunkel, K.E., 2023: State of the Climate. *Electric Power Research Institute (EPRI) Environmental Change Institute Webinar*. March 3, 2023.

Kunkel, K.E., and **J. Dissen**, 2023: "State of the Climate" Perspectives from Climate Science and National Climate Assessment. *Electric Power Research Institute Annual State of the Climate Webcast*, virtual. March 1, 2023.

Kunkel, K.E., and **X. Sun**, 2022: How Well Do CMIP6 Models Simulate Heavy Multi-Day Precipitation Events? (poster). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 14, 2022.

Kunkle, K.E., 2022: Advancing the Estimation of Hydrometeorologic Extremes for Flood Preparedness in a Changing Climate, sessions I, II, III (co-convener). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 15, 2022.

Leeper, R.D., 2022: An evaluation of Machine Learning Techniques to Quality Control Soil Moisture Observations for U.S. Climate Reference Network (poster). *11th International Conference on Climate Informatics,* virtual. May 10, 2022.

Leeper, R.D., 2022: An Evaluation of Remotely Sensed Soil Moisture Extremes. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Leeper, R.D., 2022: Evaluations of Soil Moisture During Extreme Conditions. *2022 National Soil Moisture Workshop,* Columbus, OH. August 9, 2022.

Leeper, R.D., 2022: USCRN's Drought Focused Research. *Joint NCEI/ARL USCRN Science Meeting*, virtual. July 22, 2022.

Leeper, R.D., 2022: USCRN's Standardized Soil Moisture. *Joint NCEI/ARL USCRN Science Meeting*, virtual. July 22, 2022.

Lookadoo, R. 2022: Drought and Health: Engaging Public Health and Other Stakeholders. *Water in the West: Towards Convergent Solutions to Water Security Regional Workshop*, Bozeman, MT. May 25, 2022.

Matthews, J., K. Knapp, A. Heidinger, **A.K. Inamdar**, J. Robaidek, and D. Santek, 2023: GOES Imager Fundamental Climate Data Record (FCDR), *GSICS Annual Meeting,* virtual. March 2, 2023.

Olheiser, C. Buan, S., Walvert, S., 2023: Spring 2022 Spring Hydrologic and Climate Meeting. *St. Paul Corps of Engineers*, virtual. January 24, 2023.

Olheiser, C., 2023: UMRB NSA Program Overview and use of Data. *Upper Missouri River Basin Snow and Soil Moisture Partners Meeting*, Omaha, NE. January 23, 2023.

Olheiser, C., 2023: NOAA's Airborne Snow and Soil Moisture Program. *Stakeholders Workshop NOAA Aircraft Operations Center (AOC)*, Lakeland FL. January 19, 2023.

Olheiser, C., 2023: Snow Season 2022 Overview and Success. *NOAA Aircraft Operations Center (AOC)*, virtual. May 10, 2022.

Prat, O.P., 2022: Operational Framework for Near-real Time Drought Monitoring Using Global Remotely Sensed Precipitation Products and In-situ Datasets. *European Geophysical Union (EGU) General Assembly*, Vienna, Austria. May 25, 2022.

Prat, O.P., 2023: Applications of Precipitation Climate Data Records. *Workshop on Precipitation Estimation from LEO Satellites: Retrieval and Applications*, virtual. March 2, 2023.

Prat, O.P., D. Coates, S. Wilkins, D. Willett, and **R. Leeper**, 2022: Near-real Time Daily Drought Monitoring Using Remotely Sensed and In-situ Gridded Precipitation Datasets. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 15, 2022.

Prat, O.P., D. Coates, S. Wilkins, D. Willett, R.D. Leeper, B.R. Nelson, R. Bilotta, S. Ansari, and G.J. Huffman, 2022: Near-real Time Daily Drought Monitoring Using Remotely Sensed and In-situ Gridded Precipitation Datasets. *2022 American Geophysical Union (AGU) Fall Meeting.* Chicago, IL. December 15, 2022.

Prat, O.P., **D. Coates**, **S. Wilkins**, **R.D. Leeper**, B.R. Nelson, R. Bilotta, S. Ansari, and G.J. Huffman, 2022: Operational Framework for Near-real Time Drought Monitoring Using Global Remotely Sensed

Precipitation Products and In-situ Datasets. *European Geophysical Union (EGU) General Assembly*. Vienna, Austria. May 25, 2022.

Rao, Y., 2022: 20 Years of Data Science—an Assessment (panelist). *International Data Week 2022*, virtual. June 21, 2022.

Rao, Y., 2022: AI-ready Data. NSF *Inter-directorate Working Group on AI for Bio Data*, virtual. September 19, 2022.

Rao, Y., 2022: An Improved Neural Network-Based Satellite Record of Clear-Sky Atmospheric Temperature and Humidity Profiles (poster). *AMS Collective Madison Meeting,* Madison, WI. August 11, 2022.

Rao, Y., 2022: Artificial Intelligence Meets Earth and Space Science: Convergence to Address Grand Challenges I (session co-convener). *2022 American Geophysical Union (AGU) Fall Meeting.* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Building AI-Ready NOAA: Early Success, AI-ready Data, and Workforce Development (session chair). *2022 Environmental Data Management Workshop*, virtual. September 12, 2022.

Rao, Y., 2022: Climate Observatory - Analyzing and Visualizing NOAA Climate Data Records on the Cloud with Open Science Tools. *AMS Collective Madison Meeting.* Madison, WI. August 11, 2022.

Rao, Y., 2022: Cross-Agency Coordination for Advancing Machine Learning and Artificial Intelligence for Earth System Predictability Town Hall Meeting (panelist) *2022 American Geophysical Union (AGU) Fall Meeting.* Chicago, IL. December 13, 2022.

Rao, Y., 2022: Enabling AI Application for Climate: Developing a Collection of AI-ready Open Data—Data-A-Thon (session leader). *2022 July Earth Science Information Partners (ESIP) Summer Meeting.* Pittsburgh, PA. July 20, 2022.

Rao, Y., 2022: FARR: A Research Coordination Network for FAIR, AI Readiness, and Reproducibility for AI. *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Informatics for Social Good: From Scientists to Bridge Builders (invited presentation). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Organizational Vision and Strategy on Leveraging AI/ML in Geosciences (moderator). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Public-Private-Academia Partnership: From Research Development to Societal Benefits (moderator). *2022 American Geophysical Union (AGU) Fall Meeting,* Chicago, IL. December 12, 2022.

Rao, Y., 2022: Understanding the Community's Need for AI-Ready Open Environmental Data. *NCAR Computational and Information Systems Lab webinar series*, virtual. April 20, 2022.

Rao, Y., 2022: Visualizing NOAA CDR Data on the Cloud. *July Earth Science Information Partners (ESIP) Summer Meeting,* Pittsburgh, PA. July 21, 2022.

Rogers, K., 2022: "Beyond the Vulnerability Assessment: Experiences of local governments in the Southeast using the Steps to Resilience" (panel discussion). *5th National Adaptation Forum*, Baltimore, MD. October 27, 2022.

Runkle, J.D., 2022: Climate Change and Health, the National Climate Assessment. Climate and Respiratory Health—World Asthma Day. *The Collider*, Asheville, NC. May 3, 2022.

Runkle, J.D., 2022: Climate Change in Rural Communities. *Climate Change and Health in Rural Mountain Environments: A Collaborative Workshop*, virtual. April 8, 2022. https://youtu.be/_Sm0encOHWU

Runkle, J.D., 2022: Climate, Health, and Equity. *CleanAIR NC: NC BREATHE Conference,* virtual. April 7, 2022. https://www.youtube.com/watch?v=Q2Sp_eXlneA

Runkle, J.D., 2022: Health, Climate Change, and Environmental Toxicology: Emerging Research Needs (keynote address). *North Carolina Chapter of the Society of Toxicology annual Fall Meeting on Climate, Chemicals, and North Carolina.* North Carolina Central University, Durham, NC. October 19, 2022.

Runkle, J.D., 2022: Heat and Health Equity for Carolina Communities in a Changing Climate. *Climate Health Equity: The Effects of Heat & Air Pollution in the Southeast,* virtual. November 12, 2022.

Runkle, J.D., 2022: Impact of the Climate Crisis on Health During Pregnancy: A Closer Look at Maternal Mental Health (invited speaker). *CACHE Climate Resilience in Medical Practice Grand Rounds.* December 9, 2022.

Runkle, J.D., 2022: Mental Health Response to Climate Disasters in U.S. Youth: Insights from a National Crisis Text Line. *EPA Social-Environmental Science Exchange webinar series*. September 21, 2022.

Runkle, J.D., 2022: The Future of Public Health in the Climate Crisis. *SC Upstate Research Symposium,* Spartanburg, SC. April 8, 2022.

Schreck, C.J., 2022: The MJO and Equatorial Waves. *Rutgers University Subseasonal Forecast Contest* webinar. July 28, 2022.

Scott, E., and L. Shi, 2023: Calibration Comparison of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures. *103rd American Meteorological Society Annual Meeting.* Denver, CO. January 12, 2023.

Scott, E., and L. Shi, 2023: Calibration Comparison of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures. *103rd American Meteorological Society Annual Meeting.* Denver, CO. January 12, 2023.

Scott, E., R. Bilotta, **R. Leeper**, **D. Coates**, and **C. Schreck**, 2023: An Exploratory Analysis of Rapid Drought Changes in Relation to ENSO and MJO Modes of Variability. *103rd American Meteorological Society Annual Meeting.* Denver, CO. Jan 11, 2023.

Shore, A., 2022: The US Climate Resilience Toolkit: User Research (World Café). *Southeast Climate Adaptation Science Center Regional Science Symposium,* Gulf Shores, AL. September 20, 2022.

Simonson, A., P. Keown, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2022: NOAA Open Data Dissemination Overview. *Department of Commerce Chief Data Office*, virtual. April 1, 2022.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NODD Census Briefing. February 20, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NOAA Open Data Dissemination Program Overview. *103rd American Meteorological Society Annual Meeting*, virtual. January 12, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2023: NOAA Open Data Dissemination Program Overview. *West Virginia University Cloud Faculty Fellows*, virtual. March 2, 2023.

Simonson, A., P. Keown, K. Willett, **J. Dissen**, **O. Brown**, **J. Brannock**, and **D. Willett**, 2022: NOAA Open Data Dissemination Overview. *N-Wave Joint Engineering and Technical Interchange (JETI) Annual Meeting*, virtual. August 9, 2022.

T. J. Schuyler, E. Dumas, F. Panwala and N. Clark, 2022: Utilizing (sUAS) to advance atmospheric science and sUAS flight collection of boundary layer meteorological data. *Appalachian Research Commission STEM camp*, July 2022.

van Werkhoven, K. and Smith, M., 2023: Novel methods for high-resolution streamflow forecast evaluation, *103rd American Meteorological Society Annual Meeting,* Denver, CO. January 9, 2023.

van Werkhoven, K., 2022: Supporting Water Resources Risk Assessment and Real-Time Flood Forecasting (invited seminar), *Appalachian State University Department of Geology*, Boone, NC. September 16, 2022.

van Werkhoven, K., 2023: Evaluating High-Resolution Streamflow Forecasts from the NOAA National Water Model, *American Society of Civil Engineers (ASCE) Northern Colorado Branch Meeting*, Loveland, CO. January 12, 2023.

Wodzicki, K.R., 2023: Wet-Bulb Globe Temperature: Algorithm Analysis and Testing. *American Industrial Hygiene Association Thermal Stress Working Group*, virtual. January 13, 2023.

Other Presentations

Kunkel, K.E., 2022: SERDP project information. *Department of Transportation (DOT) and NC DOT project team meeting*, virtual. July 11, 2022.

Rao, Y., 2022: "If It Ain't Broke, Why Fix it?"—Open Science Lessons Learned in the Field. *Open Science Pathways in the Earth, Space and Life Sciences,* virtual. May 9, 2022.

Rao, Y., 2022: Analyzing GOES-16 Data on the Cloud. *2022 July Earth Science Information Partners (ESIP) Summer Meeting.* Pittsburgh, PA. July 21, *2022.*

Runkle, J.D., 2022: Impact of the Climate Crisis on Health During Pregnancy: A Closer Look at Maternal Mental Health (invited speaker). *CACHE Climate Resilience in Medical Practice Grand Rounds.* December 9, 2022.

Runkle, J.D., 2022: Mental Health Response to Climate Disasters in U.S. Youth: Insights from a National Crisis Text Line. *EPA Social-Environmental Science Exchange webinar series*. September 21, 2022.

Willett, D.S., 2022: Machines and Machine Learning for Applied Nematology: Potential and Opportunity. *7th International Congress of Nematology (ICN),* virtual. May 2, 2022.

Intern Presentations

An, D., A. Britton, S. Geraty, and C. Nixon, 2022: Western Sonoran Desert Water Resources: Evaluating Rock Pool Hydroperiod Fluctuation using Climate Variables to Inform Habitat Monitoring and Protection in the Western Sonoran Desert. *NASA DEVELOP Closeout Presentation*, virtual, August 3, 2022.

Cowan, K., 2022: Examining the association between Extreme Heat and maternal mental health outcomes among a cohort of births in South Carolina. *NCEI/NCICS Intern Closeout Presentations*, virtual, July 27, 2022.

Dalton, E., A. Harvey, K. Reynolds, and M. Rock, 2022: Mato Grosso Agriculture: Enhancing Crop Classification Mapping Using Optical and Radar Satellite Sensors to Enhance Agricultural Management and Policymaking in Mato Grosso, Brazil. *NASA DEVELOP Closeout Presentation*, virtual, August 3, 2022.

Eck, M., 2022: Analyzing Extreme Precipitation Values in Uttarakhand. *U.S.-India Partnership for Climate Resilience webinar*, virtual, September 21, 2022.

Ikelheimer, A., 2022: Using the Standardized Precipitation Index to Measure the Seasonality of Drought. *NCEI/NCICS Intern Closeout Presentations*, virtual, August 10, 2022.

Karuso, K, W. Hadley, D. Littleton, and K. Roberts, 2022: Evaluating the Role of Soil Moisture in Determining Vegetation Health, Fuel Loads, and Wildfires in the Gatlinburg and Beatty Wildfires. *NASA DEVELOP Closeout Presentation*, virtual, November 17, 2022.

Mair, M., 2022: Understanding Sea Level Rise and its Impacts in North Carolina. *NCEI/NCICS Intern Closeout Presentations*, virtual, August 10, 2022.

Major, D., 2022: A Description of Precipitation at High Elevations using the Great Smoky Mountain Rain Gauge Network. *NCEI/NCICS Intern Closeout Presentations*, virtual, August 10, 2022.

Sewell, K., 2022: Heatwave events and child health. *NCEI/NCICS Intern Closeout Presentations*, virtual, July 27, 2022.

Vemuri, P., 2022: Building a cloud native graph database using Neo4j for the daily climate summaries from various global land stations in the Global Historical Climatology Network daily (GHCNd), virtual, December 7, 2022.

Vemuri, P., 2022: Global Historical Climatology Network daily on Neo4j. *NCEI/NCICS Intern Closeout Presentations*, virtual, July 27, 2022.

Vemuri, P., 2022: Graph Database Performance for GHCN-D. *2022 NCICS Science Seminar Speaker Series,* virtual. December 7, 2022.

Visovatti, A., 2022: Indicators: A climate communication tool. *NCEI/NCICS Intern Closeout Presentations*, virtual. August 10, 2022.

Weidner, K., 2022: Joint effects of prenatal exposure to ambient temperature extremes and socioeconomic disadvantage on infant health risks in a changing climate. *NCEI/NCICS Intern Closeout Presentations*, virtual, July 27, 2022.

Williamson, R., 2022: Climate Hazards Impacting Population Health: Negative Effects of Devastating and Recurring Natural Disasters on Mental and Maternal Health Outcomes. *NCEI/NCICS Intern Closeout Presentations*, virtual, July 27, 2022.

Outreach and Engagement Activities

Presentations

- Schreck, C.J., 2022: Hurricanes and Natural Disasters. Skype a Scientist*, Dwight Elementary School* (New York, NY) second-grade class, virtual. April 6, 2022.
- Schreck, C.J., 2022: Weather Vocabulary and Impacts. Skype a Scientist, *Chapel Hill Christian Academy* (Clarksville, TN) pre-K class, virtual. April 21, 2022.
- Schreck, C.J., 2022: Climate Change. Enka Intermediate School sixth-grade classes. April 29, 2022.
- Schreck, C.J., 2022: Climate Change. *Black Mountain Elementary School* fifth-grade classes. May 10, 2022.
- Schreck, C.J., 2022: Becoming a Meteorologist. Career Day. *North Windy Ridge Intermediate School* (Weaverville, NC) fifth-grade classes. May 27, 2022.
- Schreck, C.J., 2022: Climate Change and Hurricanes. *North Buncombe Middle School* seventh-grade classes. October 12, 2022.
- Schreck, C.J. and L.E. Stevens, 2021: Science Communication, panel discussion. *NCICS Weekly Intern Seminar Series*, virtual. July 6, 2022.

- Schreck, C.J., 2022: The MJO and Equatorial Waves. *Rutgers University Subseasonal Forecast Contest* webinar. July 28, 2022.
- Schreck, C.J., 2022: Madden–Julien Oscillation (MJO). *University of North Carolina Asheville* Tropical Meteorology class. September 7, 2022.
- Willett, D., 2022: Machine Learning in Earth System Science. *University of North Carolina Asheville* Biology and Environmental Studies Departmental Seminar Series, October 20, 2022.

Events

- Douglas Rao and Erika Wagner hosted an outreach table at the *Conserving Carolina Earth Day Festival* (Tryon, NC), April 22, 2022.
- Emma Scott hosted an outreach table at the *Schiele Museum Weather Proof* event (Gastonia, NC), July 23, 2022.
- Laura Stevens, Douglas Rao, Carl Schreck, and NCEI's Jared Rennie and Deke Arndt taught a 5-week *North Carolina Arboretum* hybrid adult education course (Asheville, NC), "Climate Change Science," and presented:
  - "Climate Variability" (Schreck, virtual, October 4, 2022)
  - "Climate Trends and Extremes" (Stevens, virtual, October 11, 2022)
  - "Climate Projections" (Rao, virtual, October 13, 2022)
  - "Hurricanes and Climate Change" (Schreck, virtual, October 18, 2022)
  - "Lunch and Learn" (Schreck, Stevens, Rao, and Rennie, in-person, October 20, 2022)
  - "Lunch and Learn" (Stevens, Rao, and Arndt, in-person, November 1, 2022)

Appendix 4: Products 2022-2023

CISESS Products

~200 New or enhanced BDP/NODD datasets and/or collections now available through BDP/NODD cloud service provider partners

- GOES 18
- Joint Polar Satellite System
- MRMS
- Himawari -9
- GK2A
- UFS Products
- ICOADS
- NDE
- GFS Waves Reforecast
- Additional datasets from NMFS, OAR, NWS, NESDIS, and NOS
- Authenticated Metrics Portal
- Enhanced Data Broker transfer structure
- Reprocessed NODD Data Use logs
- Dashboard for log data exploration

New or Improved Architectures and Software Products (including websites and web tools)

- Assessment Collaboration Environment (ACE) updates
- GHCN-D graph database ingest pipeline
- GHCN-D Performance benchmarks
- Promotion of NCCF Archive System from sandbox (5006 zone) to dev (5065 zone)
- Configuration tooling in complement of installation, for complete, operable system deploy
- Functioning named graph Archive System configuration deploy capability
- Testbed for Archive System performance testing
- NiFi workflow deploy Jenkins capability
- U.S. Climate Resilience Toolkit (improved), https://toolkit.climate.gov
- USGCRP Indicator graphics (updated), http://www.globalchange.gov/browse/indicators
- U.S. Drought Portal (improved), https://drought.gov
- NCA Sandbox (improved), https://sandbox.nemac.org/
- Data analysis used for 29 figures in the NCA5 and co-production (with NCA5 authors) of an additional 40+ figures
- A suite of 16 climate variables derived from the STAR and LOCA2 datasets.
- Data formatting, merging, and sorting algorithm for NClimGrid data
- Regionalized, sorted data for Tmax and Tmin for both state- and county-scale running averages
- Blueprint for operationalization of objective extreme hot and cold event monitoring using model outlook data
- Computational program for heat/cold wave indices: https://ncics.org/pub/angel/hwi/
- Supported the development of an interactive ArcGIS Online Drought Climatology Viewer: http://tiny.cc/rkesuz http://10.0.3.234/joc.7653

New or updated environmental data products

- Optimum Interpolation Sea Surface Temperature v2.1a

- Atlantic Tropical Cyclone Days Indicator, globalchange.gov/browse/indicator-details/4206
- 11 updated USGCRP (Climate Change) Indicators:
  - Annual Greenhouse Gas Index, globalchange.gov/browse/indicator-details/3651
  - Atlantic Tropical Cyclone Days, globalchange.gov/browse/indicator-details/4206
  - Atmospheric Carbon Dioxide, globalchange.gov/browse/indicator-details/3653
  - Billion Dollar Disasters, globalchange.gov/browse/indicator-details/4049
  - Global Surface Temperatures, globalchange.gov/browse/indicator-details/3656
  - Heat Waves, globalchange.gov/browse/indicator-details/3983
  - Heating and Cooling Degree Days, globalchange.gov/browse/indicator-details/3658
  - Sea Level Rise, globalchange.gov/browse/indicator-details/3977
  - Sea Surface Temperatures, globalchange.gov/browse/indicator-details/3660
  - Start of Spring, globalchange.gov/browse/indicator-details/3661
  - U.S. Surface Temperatures, globalchange.gov/browse/indicator-details/3663
- Cloud optimized nClimGrid monthly dataset: https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/index.html#EpiNOAA/csv/
- Cloud optimized nClimGrid decadal dataset: https://noaa-nclimgrid-daily-pds.s3.amazonaws .com/index.html#EpiNOAA/decadal/
- R package to access cloud optimized nClimGrid data: https://gitlab.cicsnc.org/arc-project/arc-r-package/-/tree/main
- R shiny app web interface to access cloud optimized nClimGrid data: http://shiny-app-lb-db29d17-1318539185.us-east-1.elb.amazonaws.com/arc-nclimgrid-downloader/
- Preliminary beta version of a homogenized humidity dataset
  - Demonstration of a heat health application with the preliminary dataset
  - Associated Jupyter notebooks
- Operational near-real-time global daily CMORPH SPI available within 48 hours to the current day: https://gdis-noaa.hub.arcgis.com/
- GSMRGN gauge visits with quality-controlled precipitation CSV format files
  - Summer 2022: https://drive.google.com/file/d/1c_PCetb2kU9GyhWG5b1srUawqM6bMwhL/view?usp=sharing
  - Fall 2022: https://drive.google.com/file/d/1BhSFrlvK6bWIdomxdEoKmz_kNtkKIUg-/view?usp=share_link

New Observational Products

- New Winter Hydrology Dashboard for situational awareness.
- Automation of presentations and graphics for IDSS briefings.
- Products and evaluation of flightlines in support of the PSL SPLASH project.

Reports and Other Communication Products

- 12 Monthly and 1 Annual Synoptic Discussions for NCEI's Annual State of the Climate: https://www.ncdc.noaa.gov/sotc/synoptic/
- 12Monthly and 1 Annual Global Tropical Cyclone reports for NCEI's State of the Climate: https://www.ncdc.noaa.gov/sotc/tropical-cyclones/
- USGCRP Atlantic Tropical Cyclone Days Climate Change Indicator: https://www.globalchange.gov/browse/indicator-details/4206

- Indicators of Climate Change web series (Four-part series on YouTube: Introduction to Climate Indicators, Global and US Temperatures, Marine Species Distribution, and Arctic Sea Ice)
- Report detailing:
    - Justification for humidity variable selected
    - Review of existing humidity datasets and their characteristics, including quality
    - Documented requirements from environmental health experts
    - AI framework methodology for data fusion