COOPERATIVE INSTITUTE FOR SATELLITE EARTH SYSTEM STUDIES (CISESS)

Annual Scientific Report

CISESS NC TASK REPORTS

For the period:

April 1, 2021 – March 31, 2022

NOAA Grant NA19NES4320002
Subaward 80848-Z7553201

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Table of Contents

CISESS NC Overview **3**

Highlights **5**

Administration **12**
- Institute Information Technology Support Services 13
- Institute Communications 16

Access and Services Development **18**
- NOAA Big Data Program Support 19
- Strategic Engagement and Outreach for the NOAA Big Data Program 22
- Development and Support of NOAA Climate Products and Services 25

Assessment Activities **28**
- Assessment Scientific and Data Support Activities 29
- Assessment Technical Support Activities 34
- Climate Change Indicators 37
- U.S.–India Partnership for Climate Resilience Activities Support 41
- The Energy and Resources Institute Support for the U.S.–India Partnership for Climate Resilience 44

Information Technology Services **45**
- NCEI INNOVATES 2021 - Global Historical Climatology Network-Daily (GHCNd) Graph Database 46
- NCEI Infrastructure Architecture Planning and Implementation 49

Science and Services **52**
- Scientific Subject Matter Expertise Support 53
- Drought-related health impacts: advancing the science for public health applications 55
- Spatiotemporal distribution and habitat use of major Snapper-Grouper species in the Atlantic Ocean off the southeastern U.S. 59
- Strategic Engagement and Outreach 60
- Optimum Interpolation Sea Surface Temperature (OISST) Algorithm Upgrades 64
- 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 66
- GOES-R-Based Products 68
- HIRS-Like Data from New-Generation Sensors 69
- Hydrological, Technical and Decision-Support System Development and Enhancement for the National Weather Service Office of Weather Prediction 71
- Rapid Attribution of Extreme Events in the United States 74
- U.S. Climate Reference Network (USCRN) Applications and Quality Assurance 77
- Standardization of U.S. Climate Reference Network (USCRN) Soil Moisture Observations 79
- NCEI INNOVATES 2020 - Machine Learning Based Quality Control: USCRN Soil Moisture and Temperature Test Case 82
- Evaluation of air and soil temperatures for determining the onset of growing season 85
- Exploring the Impacts of Drought Events on Society 86
- HIRS Temperature and Humidity Profiles 89
- Evaluation and Elucidation of SCaMPR Performance in Complex Terrain Leveraging GOES-R Observations and Ground-based Precipitation Measurements 91
- Drought Detection and Relief Using In-Situ Data from NClimGrid 95

Toward the Development of Climate Data Records (CDRs) for Precipitation: Global Evaluation of Satellite Based Quantitative Precipitation Estimates (QPEs) ... 98
Drought Detection Using Remotely Sensed Precipitation Data from the Climate Data Record CMORPH ... 102
Toward visualizing and analyzing climate data records on the cloud ... 106
Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCNm) Dataset ... 108
Development of a Homogenized Sub-Monthly Temperature Monitoring Tool ... 109
Developing and Validating Heat Exposure Products Using the U.S. Climate Reference Network ... 110
Development of the United States Climate Reference Network (USCRN) National Precipitation Index ... 112
NCEI Innovates 2019 - Developing 1991–2020 Normals along the Northeast and Mid-Atlantic Coasts ... 113
ARC Data Derivative Product for Health Users ... 115
Collaborative Climate and Human Health Studies ... 117
Environmental Information and Analysis for the Real Estate Development Sector ... 119
Climate Monitoring ... 121
Calibration of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures ... 124

Workforce Development ... 126
Supporting the development of artificial intelligence within NOAA and CISESS ... 130

Other Projects ... 133
Developing an in situ-satellite blended marine air temperature dataset using artificial intelligence 134
Climate Change Impacts in the Arctic and International Coastal Ocean Regions ... 136
America’s Water Risk: Water System Data Pooling for Climate Vulnerability Assessment and Warning System ... 139
Quantifying Future Precipitation Extremes within North Carolina for Resilient Design ... 140
The Urban Resilience to Extremes Sustainability Research Network (UREx SRN) ... 141
Evaluation of Drought Indicators for Improved Decision-Making in Public Health and Emergency Preparedness: Reducing Drought’s Burden on Health ... 142
Synthesis of Observed and Simulated Rain Microphysics to Inform a New Bayesian Statistical Framework for Microphysical Parameterization in Climate Models ... 145
Global Near-Real Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets 146
COVID-19 and Environmental and Extreme Event Impacts on Human Health ... 147
Innovating a Community-Based Resilience Model on Climate and Health Equity in the Carolinas ... 150
Operational Transition of Novel Statistical-Dynamical Forecasts for Tropical Subseasonal to Seasonal Drivers ... 152
Kelvin Waves and Easterly Waves in CYGNSS ... 154

Appendix 1: CISESS Personnel and Performance Metrics ... 156

Appendix 2: Publications 2021-2022 ... 157

Appendix 3: Presentations 2021–2022 ... 166

Appendix 4: Products 2021-2022 ... 175

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 NOAA National Centers for Environmental Information (NCEI) and NOAA's Office of the Chief Information Officer (OCIO) 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 OCIO, the National Weather Service (NWS), Oceanic and Atmospheric Research's (OAR's) 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 United States Global Climate Research Program (USGCRP), the U.S. Department of State, 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 Collider, the North Carolina Arboretum, NCSU's The Science House, the North Carolina State Climate Office, and the Asheville Museum of Science. 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 observation, using instruments on Earth-orbiting satellites and surface networks, and prediction, using realistic mathematical models, of the present and future behavior of the Earth system. Observations include the development of new ways to use existing observations, the invention of new methods of observation, and the creation and application of ways to synthesize observations from many sources into a complete and coherent depiction of the full system. Prediction requires the development and application of coupled models of the complete climate system, including atmosphere, oceans, land surface, cryosphere, and ecosystems. Underpinning all 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 the NESDIS, OAR, NWS and OCIO; and North Carolina State University. Other Projects led by the Institute’s investigators are generally funded by other federal, state, or private (non-NOAA) 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 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 upcoming 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 Big Data Program Support: Utilizing the CISESS-NC-designed data hub/broker architecture, 10+PB of multiple NCEI and other NOAA datasets were deployed in near real time to the Public Cloud. Usage metrics across the three public cloud platforms (Amazon Web Services, Microsoft Azure, and Google Cloud Platform) are now available to NOAA stakeholders. https://ncics.org/data/noaa-big-data-project/

Strategic Engagement and Outreach for the Big Data Program: CISESS NC supported the NOAA Big Data Program (BDP) with extensive stakeholder engagement activities with internal NOAA line offices, external cloud partners, and BDP partners; development of cloud user engagement strategies; a NOAA Big Data Program Updates AMS Town Hall Meeting; and development of high-level data access monitoring dashboards and metrics.

Development and Support of NOAA Climate Products and Services: In support of the overall advancement of NOAA's Climate Products and Services program, 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 an author "sandbox" for the National Climate Assessment, USGCRP Indicators graphics updates, and NIDIS drought.gov user research.

Assessment Activities [NCEI/CPO/DOS]

Assessment Scientific and Data Support Activities: The update of NOAA's State Climate Summaries for the United States was completed and released. This extensive update featured the first example of compliance with the Evidence-Based Policy Act of 2018, including a full suite of metadata documentation and open access to software code.

Assessment Technical Support Activities: The team was instrumental in creating the final products for the State Summaries update including the website, metadata infrastructure, figure design components, and providing edits to the finalized content. The team also began initial work on the Fifth National Climate Assessment (NCA5).

Climate Change Indicators: Fifteen existing indicators were updated and a new tropical cyclone indicator was added to the USGCRP Indicator Platform in support of the U.S. Global Change Research Program efforts to maintain a comprehensive suite of climate change indicators.
http://www.globalchange.gov/indicators

U.S.–India Partnership for Climate Resilience Activities Support: Under the U.S.–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 partners The Energy and Resources Institute (TERI), as part of ongoing planning for a technical climate projections workshop for India based forestry managers.

The Energy and Resources Institute Supporting 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 are collaborating on plans for a technical training seminar (or webinar) for India-based forestry managers on understanding climate projections and their use in the State Action Planning for Climate Change as required by each state in India.

Information Technology Services [NCEI]
Global Historical Climatology Network-Daily (GHCNd) Graph Database: To improve accessibility of the graph database version of GHCNd, a detailed user accessibility study was conducted to identify bottlenecks, issues, and desired functionality, and a comparative cost assessment was made of this graph database solution versus a more commonly used NoSQL cloud database solutions, Amazon DynamoDB. A prototype graph database was implemented with ~40% of the current reporting streams.

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 28 NCEI products, and as Product Area Leads for 2 product areas. 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 spatio-temporal dynamics of reef fish communities along the Southeast U.S. Atlantic coast.

Strategic Engagement and Outreach: CISESS NC supported the execution of five Department of Commerce/NOAA Sector Listening Sessions to advance continued improvement of NOAA climate services, finalized a collaborative research study in climate risk to the real-estate sector, and continued national level engagement as well as regional and local outreach in climate science and STEM activities.

Optimum Interpolation Sea Surface Temperature (OISST) Algorithm Upgrades: The OISST operational algorithm was successfully upgraded to utilize a new suite of satellite data sources, in response to the planned de-orbiting of the European Space Agency's MetOpA satellite platform. Quality checks and analyses all indicate the new satellite data sources have improved OISST v2.1a product quality over previous versions of the algorithm. 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: CISESS NC collaborator, Oak Ridge Associated Universities (ORAU), is working with the NOAA Atmospheric Turbulence and Diffusion Division (ATDD) to expand and sustain the U.S. Climate Reference Network's observational capability and long-term homogenous observations. Annual calibration and maintenance activities were accomplished for USCRN sites in eight states.

GOES-R-Based Products: Analyses using U.S. Climate Reference Network (USCRN) in situ data and data from the NOAA-operated Surface Radiation Network (SURFARD) revealed that changes in the daytime land surface temperature (LST) reflect changes in the Surface Solar Absorption (SSA) parameter under most sky conditions, with potential for filling in gaps in the LST time series retrieved from geostationary satellites.

HIRS-Like Data from New-Generation Sensors: Three years (2011-2013) of EUMETSAT Metop-A satellite High-Resolution Infrared Radiation Sounder (HIRS) and Infrared Atmospheric Sounding Interferometer (IASI) instrumentation measurements were processed for use in generating HIRS-like data from the IASI sensor.

Hydrological, Technical and Decision-Support System Development and Enhancement for the National Weather Service Office of Weather Prediction: CISESS Consortium Research Triangle Institute (RTI) staff supported NWS Office of Weather Prediction OWP research and development efforts utilizing new cloud technology, the incorporation of a new flying platform for the Airborne Gamma Snow Survey, as well as the development of new snow products and internal data service software improvements.

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 continental United States. Computations are done on the county-level and can be summarized into a single index representing the heat wave index for the entire county for a given day. https://ncics.org/pub/angel/hwi/

U.S. Climate Reference Network (USCRN) Applications and Quality Assurance: Following an additional quality control check, Acclima sensor soil moisture and temperature observations were made available through the USCRN's soil moisture and temperature related products. USCRN precipitation observations were applied to evaluate the quality of NEXRAD estimates for high latitude regions of Alaska. Hourly

Precipitation Dataset's (HPDs) extreme precipitation event evaluations revealed greater than expected frequencies for 1-, 2-, and 5-year return intervals similar to USCRN.

Standardization of U.S. Climate Reference Network (USCRN) Soil Moisture Observations: USCRN's soil moisture standardization (soil climatologies and anomalies) and drought index products were transitioned to operations and are now publicly available on the web and updating in near-real time. Analysis of the European Space Agency's (ESA) standardized remotely sensed soil moisture data was found to capture the timing and severity of both dry and wet extremes; however, there were higher measures of daily variability over the satellite pixel.

Machine Learning Based Quality Control: USCRN Soil Moisture and Temperature Test Case: The non-deep learning phase of the U.S. Climate Reference Network (USCRN) machine learning-based anomaly detection project demonstrated that decision tree-based machine learners can successfully detect and classify anomalies in USCRN soil moisture time series data. The multiclass anomaly detectors were able to distinguish between anomalous and normal data 91.4% of the time and successfully distinguished between individual classes of anomalies.

Evaluation of air and soil temperatures for determining the onset of growing season: A study exploring the role and importance of soil moisture conditions in determining growing start dates was completed with mixed results. These results suggest that inter-annual anomalies of soil moisture, while useful for drought monitoring, may not explain plant stresses related to water availability.

Exploring the Impacts of Drought Events on Society: An evaluation of drought impacts on the severity and duration of heatwaves at USCRN locations was initiated. Overall results indicate that drought events increase the duration of heatwaves by 1 to 3 days or 20 to 60% longer than typical. This analysis was extended to U.S. Counties to explore the impacts of compound events on human health metrics (hospitalization) in the Carolinas.

HIRS Temperature and Humidity Profiles: The team is applying neural networks to High-Resolution Infrared Radiation Sounder (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.

Evaluation and Elucidation of SCaMPR Performance in Complex Terrain Leveraging GOES-R Observations and Ground-based Precipitation Measurements: Completed summer and fall 2021 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 National Park Rain Gauge Network (Duke GSMRGN).

Drought Detection and Relief Using In-Situ Data from NClimGrid: The Standardized Precipitation Index (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 5x5-km spatial resolution.

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 satellite-based precipitation products from four Climate Data Records (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 question of SPPs performance for cold season precipitation was extended to radar-based products (Stage IV).

Drought Detection Using Remotely Sensed Precipitation Data from the Climate Data Record CMORPH: Monthly and daily Standardized Precipitation Indices (SPIs) were implemented using precipitation satellite data from the CMORPH and PERSIANN climate data records to investigate their 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. Operational global daily SPIs were computed from CMORPH-CDR and CMORPH-ICDR to monitor drought conditions.

Toward visualizing and analyzing climate data records on the cloud: Normalized Difference Vegetation Index (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.

Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCNm) Dataset: The next iteration of NOAA's global temperature product (GHCNm version 4.0.1) is now operational. The codebase was put under version control and was successfully pilot tested on a commercial cloud platform. www.ncdc.noaa.gov/ghcnm/

Development of a Homogenized Sub-Monthly Temperature Monitoring Tool: The code base for the sub-monthly temperature tool was upgraded to Python version 3. The heat event database will be updated on an annual basis for use in continuing studies on extreme heat impacts on human health. https://ncics.org/portfolio/monitor/sub-monthly-temperatures/

Developing and Validating Heat Exposure Products Using the U.S. Climate Reference Network: Using hourly and sub-hourly data from the United States Climate Reference Network (USCRN), heat exposure indices, including heat index, apparent temperature, and wet-bulb globe temperature (WBGT), have been developed and validated against data from nearby sites. These derived products will be used to address heat health, combining climate data with available socioeconomic and hospital data.

Development of the United States Climate Reference Network (USCRN) National Precipitation Index: National Precipitation Index (NPI) data have been updated through June 2021 and planning is underway for the research-to-operations transition.

NCEI Innovates: Developing 1991–2020 Normals along the Northeast and Mid-Atlantic Coasts: Coastal normals for 1991–2020 were developed for areas around the Northeast and Mid-Atlantic regions, and an *ArcGIS Online* website was developed to allow users to interact with the data. https://coastal-normals-ncsu.hub.arcgis.com

ARC Data Derivative Product for Health Users: The project team completed development of an NCEI data product consisting of a daily time series for Tavg, Tmax, Tmin, and Precipitation using nClimGrid for each county in the U.S. (1981-present) to aid health and infectious disease modeling efforts. A new R package and Shiny Web App are companions to the NOAA data product.

Collaborative Climate and Human Health Activities: Working with NCEI and CDC collaborators, CISESS NC advanced work on 1) developing 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 U.S.

Environmental Information and Analysis for the Real Estate Development Sector: This collaborative research study examined the role of NOAA environmental data, and its usage in solution provider tools/applications, for understanding, analyzing, and detecting wildfire risk across the real estate value chain. Stakeholders will face a range of risks associated with the more frequent and intense wildfires occurring across the U.S. with an identified sector need for additional, higher resolution, and/or new data product offerings from NOAA NCEI.

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. Among these developments, a new USGCRP climate change indicator tracks the amount of tropical cyclone activity in the western Atlantic.

Calibration of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures: A subset of the data that can be used for calibration of HIRS brightness temperature between satellites was identified for all relevant satellite pairs and calibration is being completed, with calibration coefficients calculated for the TIROS-N, NOAA 6-19 and METOP 1 and 2 satellites.

Workforce Development [NCEI / NASA / NCSU]

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

Other Projects

Developing an in situ-satellite blended marine air temperature dataset using artificial intelligence [NOAA/CPO]*:* 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 and International Coastal Ocean Regions [multiple]***:*** 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 U.S. team completed an assessment of the costs of climate change impacts on critical infrastructure in the Circumpolar Arctic.

America's Water Risk: Water System Data Pooling for Climate Vulnerability Assessment and Warning System [NSF]***:*** The 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 [NC DOT]***:*** Preliminary analysis reveals that scaling the Intensity-Duration-Frequency (IDF) curves may be more sensitive to the downscaling method than the Global Climate Model (GCM) projections.

The Urban Resilience to Extremes Sustainability Research Network (UREx SRN) [NSF]***:*** Climate change scenarios for Valdivia, Chile were completed by the NCSU team as part of this multi-institutional project.

Evaluation of Drought Indicators for Improved Decision-Making in Public Health and Emergency Preparedness: Reducing Drought's Burden on Health [NOAA/CPO]***:*** Top ranked drought indices for potential health outcomes were identified [Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Evaporative Drought Demand Index (EDDI) and the Evaporative Stress Index (ESI)] and compared at several aggregation periods to U.S. Drought Monitor (USDM) metrics for four specific drought events. SPI, SPEI, and EDDI aggregations of 6- and 12-month moisture deficits and 3-month ESI were more in line with USDM mode drought frequency.

Synthesis of Observed and Simulated Rain Microphysics to Inform a New Bayesian Statistical Framework for Microphysical Parameterization in Climate Models [DOE]***:*** The project team developed an innovative Bayesian statistical framework to quantify the uncertainties associated with the representation of rain microphysical processes in weather and climate models.

Global Near-Real Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets [GEO-Microsoft]: The aim of this new project is to adapt the existing CMORPH-SPI framework to ingest the dataset GPM-IMERG to produce a GPM-SPI resulting in a 6-fold increase in spatial resolution and a more accurate geospatial mapping of daily drought and drying conditions than is currently available. The processing data pipeline will be optimized to take advantage of innovations in cloud processing.

Environmental and Extreme Event Impacts on Human Health [multiple]**:** A collaborative, multi-institution research team is exploring the myriad ways in which COVID-19 and other environmental and extreme events are impacting the health and well-being of vulnerable populations across the United States.

Innovating a Community-Based Resilience Model on Climate and Health Equity in the Carolinas [NOAA/CPO]***:*** A new NOAA Regional Integrated Science and Assessments (RISA) Program center, the Carolinas Collaborative on Climate, Health, and Equity (C3HE), was established at North Carolina State University. The team is working with community partners 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.

Operational Transition of Novel Statistical-Dynamical Forecasts for Tropical Subseasonal to Seasonal Drivers [NOAA/CPO]***:*** This project demonstrated the need for systematic forecasts of extreme rainfall events based on the MJO. MJO diagnostics developed by CISESS NC and used as routine inputs for CPC's Global Tropics Hazards (GTH) outlook were transitioned into operations.

Kelvin Waves and Easterly Waves in CYGNSS [NASA]***:*** NASA CYGNSS surface wind data are able to reveal the evolution of surface fluxes as African easterly waves foster tropical cyclogenesis. Initial results are being updated with the latest CYGNSS winds and fluxes data for publication.

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, North Carolina State University (NCSU) and the University of Maryland College Park (UMD) 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 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
Erika Wagner, Program Specialist
Steven Marcus, IT Network Administrator II
Scott Wilkins, IT System Administrator II

Presentations

Brown, O. B., 2022: CISESS NC Activities. *CISESS Executive Council meeting*, virtual, February 23, 2022.

Institute Information Technology Support Services	
Task Team	Jonathan Brannock, Steven Marcus, Scott Wilkins
Task Code	NC-ADM-01-NCICS-JB/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 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.

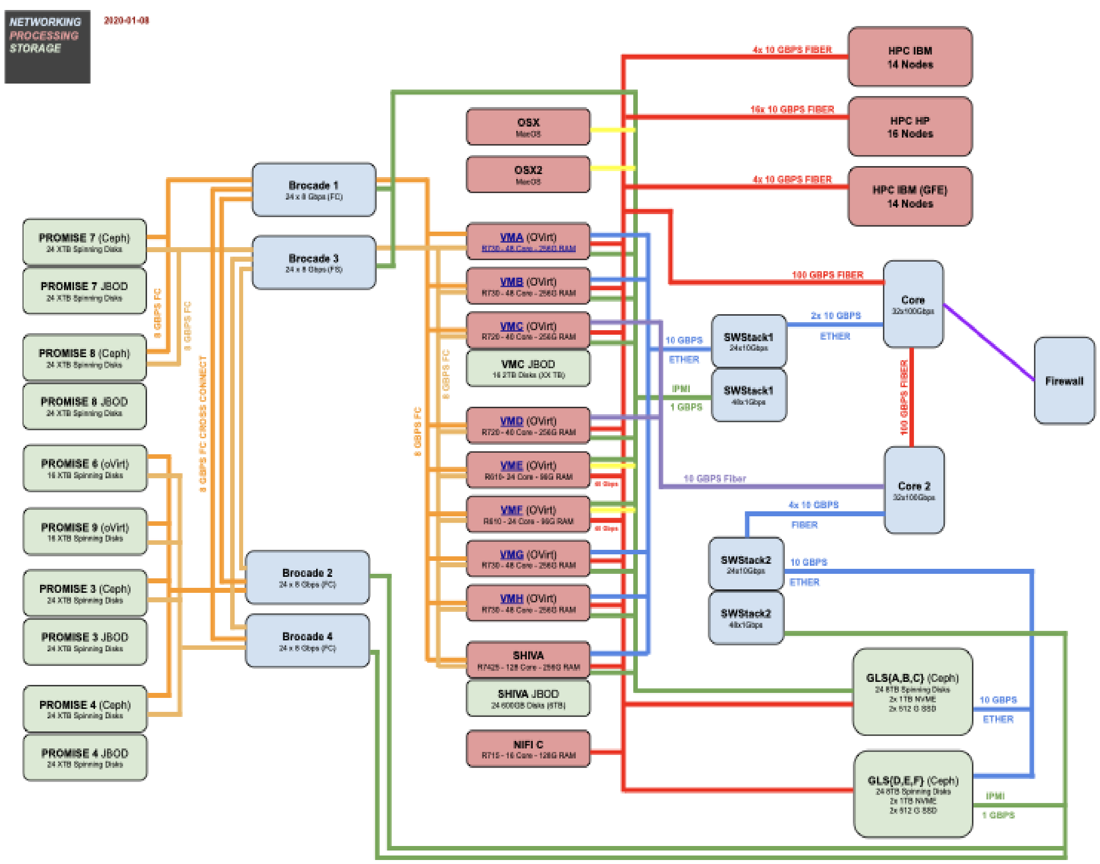


Figure 1. *Network and System Diagram.*

Distributed *Ceph* file systems are provided for concurrent system-wide access to high-speed storage. *Amazon S3* and *Glacier* provide offsite backup and disaster recovery for all data. A building-wide wireless network provides 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 37 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*, *Puppet OSE, Zabbix*, *Elasticsearch*, *Kibana*, *Ganglia*, and *CloudRadar*. These and other open source and proprietary tools allow IT staff to quickly address issues and efficiently monitor and maintain systems.

Accomplishments

Improved Wireless Access. Ten new wireless access points were purchased to replace older access points that are nearing end of life. These new access points are enabled for Wi-Fi 6, allowing more users and faster data speeds. The Institute is also enrolled in *Eduroam* international Wi-Fi internet access roaming service to ensure staff can maintain convenient internet access regardless of location.

Amazon AWS Gateway and Single Sign-On. To support the transition of processing and storage to cloud service providers, a gateway was installed to allow seamless communication between on-premise hosts and hosts created within Amazon Web Services (AWS). The gateway connects the on-premises Active Directory account hosts with AWS and allows CISESS NC users to log in to AWS using CISESS NC credentials. This function provides administrators with a single place to manage user accounts and access to AWS resources.

Amazon AWS Control Tower and Organizations. AWS Control Tower Suite of access and resource controls was implemented. These tools give CISESS NC the ability to create and manage linked accounts for projects beneath the main CISESS account to segregate individual project resources, workloads, and billing.

Operating System Upgrades. CISESS utilizes three primary operating systems: Linux, Windows and MacOS. The cluster of VMs that serve as Domain Controllers for user identification and authentication were updated to Server 2019 and the Active Directory services were updated accordingly. The CISESS deployment server now supports deployments to user workstations using MacOS Monterey, the latest version. The Monterey deployment required a large amount of configuration and package management adjustments, while still supporting the older deployments. Historically, the Red Hat Enterprise Linux (RHEL) releases were not compatible and there was no viable means of updating a server from version 7 to version 8 without requiring a fresh install. Working with NCSU and Red Hat, a process was developed to use a Red Hat provided tool to perform an in-place upgrade which reduces the need for administrators to configure a new server and transition services to it.

Updated External Monitoring. The Institute maintains both internal and external monitoring of the network infrastructure. This year, several external monitoring options were investigated to replace the existing service which no longer met Institute needs. *CloudRadar* service was implemented to quickly alert the team to outages without providing unnecessary features.

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, and 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

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

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

Highlight: This year's key communications accomplishments included support for the 2022 updated State Climate Summaries and an upcoming 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.

The Science Public Information Officer (PIO) coordinates communication efforts between the Institute and its various stakeholders, including NCEI, NCSU, and UMD. CISESS NC staff also provide graphic design, science writing, and editing support to NCEI's Communications and Outreach Branch.

Accomplishments

State Climate Summaries. Following a year of development work, the Institute released updated State Climate Summaries in January 2022. CISESS NC communications staff developed a web story highlighting the release and coordinated with NCEI to promote the release of this important resource via their social media channels. https://ncics.org/cics-news/new-us-state-climate-summaries/

CISESS Logo. A new CISESS logo and logomark was developed that incorporates key aspects of the scientific focus and elements of branding for both the North Carolina and Maryland locations of CISESS.

Figure 1. *The CISESS logo (left) and logomark, designed by CISESS NC's Jessicca Allen.*

Climate Informatics Conference. Institute communications staff worked with event coordinators to develop communications materials and web pages for the 11th International Conference on Climate Informatics currently scheduled for May 2022. A PDF flyer, the web pages, and accompanying social media posts provided prospective attendees with event details. The site is updated regularly as new information becomes available. https://ncics.org/news/events/ci2022/

NOAA Institutional Repository. In response to recently updated guidelines, Institute staff reviewed all publications authored by CISESS' and predecessor, the Cooperative Institute for Climate and Satellites' (CICS) scientists dating back to 2015 for submission to NOAA for inclusion in the Repository.

Institute Editorial and Graphics Support. The communications team provided editorial and graphics support for several staff publications, presentations, reports, and grant proposals.

Social Media. Social media efforts this year including promoting Institute activities at the annual AGU and AMS meetings and highlighting multiple job and internship opportunities.

***NCEI graphics support*.** The Institute visual communications specialist 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

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

Presentations

Allen, J., 2022: CISESS logo development. *CISESS MD leadership meeting*, virtual, February 14, 2022.

Allen, J., 2022: CISESS logo development. *CISESS Executive Council meeting*, virtual, February 23, 2022.

Maycock, T., 2021: Climate Change and Communication. *2021 Carolinas Climate Resilience Conference*, virtual, May 11, 2021.

Maycock, T., R. Ward, and A. Lee, 2021: How the Sausage Gets Made: What Goes into Creating All These Climate Reports? What policies and infrastructure may change as a result? *North Carolina Climate Education Network* meeting, virtual, June 29, 2021.

Products

- One issue of *Trends* newsletter

Access and Services Development

Access and Services Development activities support improvements to access mechanisms to the expansive data and product holdings of NOAA NCEI. NOAA daily generates terabytes of data 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 by 2023. 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 these data in ways that result in 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) 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 BDP Cloud datasets.

CICS-NC was also instrumental in the design, development, and implementation of the U.S. 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.

Data stewardship encompasses all activities that preserve and improve the information content, accessibility, and usability of data and metadata. CISESS NC supports continuing data maturity stewardship assessment, an ongoing effort initiated by CICS-NC to provide dataset users with a common set of indices for understanding various aspects of the stewardship for a specific dataset.

NOAA Big Data Program 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, 10+PB of multiple NCEI and other NOAA datasets were deployed in near real time to the Public Cloud. Usage metrics across the three public cloud platforms (Amazon Web Services, Microsoft Azure, and Google Cloud Platform) are now available to NOAA stakeholders. 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 Big Data Program (BDP) 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 general public, and allowing users to perform analyses directly on the data. Figure 1 provides an overview of this process.

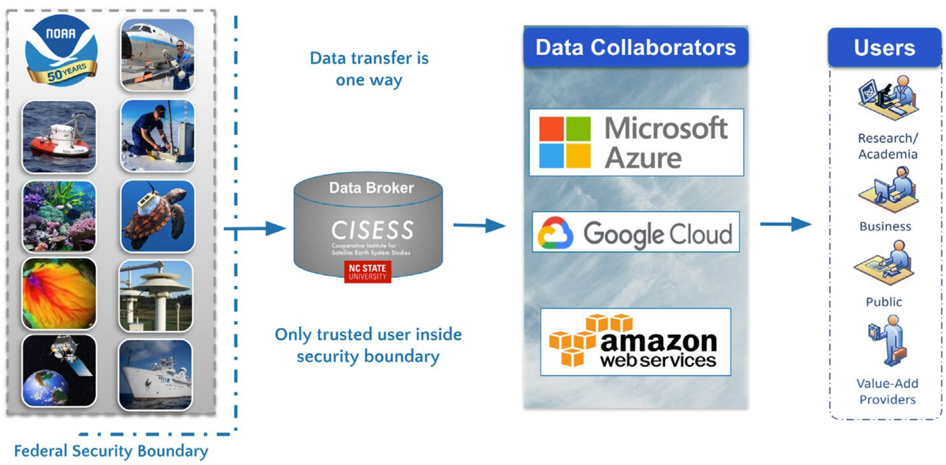


***Figure 1**. Data Hub/Broker Overview.*

CISESS NC is a partner in the BDP 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, and Microsoft Azure. Currently NOAA BDP datasets utilize ~18.9PB of cloud storage.

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

Accomplishments

This year's BDP efforts focused on expanding the diversity of NOAA datasets, improving performance and fault-tolerance of transfers, and increasing availability, accessibility, and presentation of metrics. The team expanded the diversity of holdings working closely with the NOAA line offices including NESDIS, NCEI, NWS, OAR, and NMFS. Accompanying this expansion, the team implemented new, more fault tolerant architectures, that are able to maintain performant data flows when upstream processing is restricted or fails. To enhance visibility, the team worked closely with cloud service provider partners to expand access to available metrics and incorporate metrics reporting into stakeholder offerings.

Diversifying and Expanding BDP datasets. The CISESS NC team facilitated the dramatic expansion of NOAA data cloud holdings with increases in large datasets such as HRRR, GEFS, and GOES products as well as the addition of a wide range of data products including the historical Himawari-8 holdings and NAM. Key efforts included adding and facilitating the transfer of JPSS and the addition of 30+ comprehensive climate data records including KEO and PAPA data and a suite of datasets from NMFS and nClimGrid. https://www.noaa.gov/organization/information-technology/list-of-big-data-program-datasets

BDP Performance. The CISESS NC team enhanced a robust production pipeline architecture using a fault-tolerant Apache NiFi core that coordinates a suite of Function as a Service workers across multiple cloud service providers. Key architecture features include its performance - transfer latencies can be as low as seconds - and the ability to scale quickly and intelligently to handle new data flows and the ability to adapt to failures upstream from the BDP. These abilities were highlighted in January 2022 when a NCEP FTPPRD outage affected access to multiple key datasets. The CISESS NC-designed BDP pipeline was able to adapt and load data from other sources ensuring critical NOAA data were publicly available and accessible while FTPPRD was offline.

Improved Metrics Reporting. The CISESS NC team worked closely with each of the cloud service providers to improve visibility of NOAA data usage on the public cloud through increased NOAA cloud data usage metrics connected via reporting pipelines to dashboards and reports for stakeholders. While this is an ongoing process, BDP currently makes available 18.9PB of NOAA data on the public cloud.

Data Transfer activities. Major activities included

- Backfilling efforts for GFS, GEFS and other datasets
- Himawari-8 complete historical holding transfer totaling 145+ TB
- Event-driven transfers of GFS, GEFS, RAP, HRRR, NWM, S111, WOD products
- Facilitation of large, one-time transfers of the GEFS and NWM v2.1 Retrospective datasets
- Trained line office and NCEI stakeholders in the initiation and use of big data transfers using cloud native technologies
- Built infrastructure to support new GOES transfers (in preparation for GOES-18 data)

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

- Adopted new infrastructure as code technologies to automate cloud resource deployment across all three CSPs
- Deployed ElasticSearch and Kibana monitoring platform in a production high availability Kubernetes environment
- Wrote serverless pipelines to collect metrics from all three CSPs
- Deployed NiFi and serverless workflows to facilitate data transfers to all three CSPs
- Automated packages to facilitate deploying cloud resources
- Created packages to deploy Kubernetes in production
- Continued automating services for reconciliation and backfilling of data
- Developed specialized serverless workflows to transfer CDRs to multiple cloud service providers while tracking real-time updates from NCEI

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 BDP Monitoring.
- Designed schema and ingest pipelines for automated log analysis of real-time feeds.
- NiFi update deployment.
- Updated resources to prevent log4j vulnerability.
- Enhanced alerting of data flow issues using messaging technologies.

Planned work

- Expand and diversify NOAA Data Holdings publicly available on all three CSPs.
- Expand implementation of Kubernetes as a cross-cloud fabric layer for service deployments.
- Enhance BDP metrics reporting to internal stakeholders.
- Develop standard metrics offering to internal stakeholders.

Products - Datasets

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

- National Water Model (NWM) Retrospective in original and Zarr Format
- North American Mesoscale Forecast (NAM)
- NCEP Real Time Mesoscale Analysis (RTMA)
- NClimGrid Daily & Monthly
- Unified Forecast System (UFS)
- Global Mosaic of Geostationary Satellite Imagery
- Global Surface Summary of the Day
- Joint Polar Satellite System (JPSS)
- Data Center for Digital Bathymetry
- Ocean Climate Stations Moorings (KEO and PAPA)
- 30+ Climate Data Records
- Additional datasets from NMFS, OAR, NWS, NESDIS, and NOS

Products - Other

- Production high availability Kubernetes environment for Elastisearch / Kabana monitoring platform
- Daily All CSP Metrics Status report
- Enhanced Data Broker transfer structure
- Common (cloud agnostic) Kubernetes foundation

Presentations

Willett, D., J. Dissen, P. Keown, B. White, T. Augspurger, and O. B. Brown, 2022: NOAA Big Data Program Updates, *American Meteorological Society Annual Meeting Town Hall*, virtual, January 25, 2022.

Strategic Engagement and Outreach for the NOAA Big Data Program	
Task Leader	Jenny Dissen
Task Code	NC-ASD-02-NCICS-JD

Highlight: CISESS NC supported the NOAA Big Data Program (BDP) with extensive stakeholder engagement activities with internal NOAA line offices, external cloud partners, and BDP partners; development of cloud user engagement strategies; a NOAA Big Data Program Updates AMS Town Hall Meeting; and development of high-level data access monitoring dashboards and metrics.

Background

The NOAA Big Data Program (BDP) is designed to facilitate public use of key environmental datasets by providing NOAA environmental data in the Cloud through a public-private partnership with three Cloud Service Providers (CSPs)—Amazon Web Services, Google Cloud, and Microsoft. Open and cloud-based access to NOAA's data benefits NOAA, NOAA stakeholders, and users including underserved communities by 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/or requirements. While usage statistics are now available, user statistics are more challenging and can be skewed, given machine-to-machine communication and processing.

CISESS NC is the engagement lead for BDP efforts to help NOAA gain value for its data. The BDP data engagement goals are to engage users and citizens across all sectors of the U.S. and global economy and NOAA scientists and staff to improve their understanding, awareness, and use of NOAA information via the Cloud. These efforts extend the BDP 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. Current efforts engage a number of stakeholders: cloud service provider partners (CSPs); cloud tool and analytics providers; public and private start-up and industry user community; and government/ interagency user communities, including the Department of Commerce Innovation Working Group and NOAA Line Offices. These iterative interactions between NOAA, CSPs, and end users provided early findings which helped NOAA and BDP note the value of enabling cloud-based access and analysis and further developed internal NOAA user engagement support for line office interactions.

Accomplishments

Engagement activities were widely spread over the past year creating "demand" around the "supply" of cloud-based NOAA data and information with

- BDP communications and messaging campaigns
    - social media presence on programmatic efforts
    - updates/maintenance of BDP website and the NOAA GitHub page
    - metadata for cloud partner NOAA data landing pages
    - user notification subscriptions
    - CSP blogs, tutorials, webinars
- Initial and on-going engagement discussions with stakeholders (internal NOAA, CSPs, users, etc.)
- 2022 American Meteorological Society Town Hall Meeting – NOAA Big Data Program Updates

For example, as part of the BDP National Weather Service (NWS) engagement efforts, BDP was integral in the NWS demonstration project that transitioned the delivery of GFS, RAP, and HRRR model guidance

(FTPPRD / HTTPS service) via NOAA BDP cloud partners. The goals were to test the users cloud access experience and obtain feedback from research-focused customers who do not require real-time availability and/or are not affected by any latency of the data. Engagement efforts identified the number of access requests and terabytes accessed, as well as a breakdown of users and their feedback, which was instrumental for NWS in their cloud access planning.

CISESS NC engages with the NESDIS GOES-R program on a bi-weekly basis to discuss new GOES-R datasets for cloud access. BDP and GOES-R team members collaborated on an AWS Education: Research Seminar on GOES-R, "Using the cloud to monitor the weather and environment in near-real time," which targeted the user community, researchers, and IT leaders. Additional engagement efforts provided information on the GOES-T launch and GOES-18 data via the Cloud as well as social media activity, including videos on LinkedIn regarding NESDIS JPSS data available through NOAA BDP and a NESDIS video about the BDP.

CISESS NC engagement led the inaugural collaboration with Annie Burgess (ESIP Lab) on the NOAA Cloud Pathfinder Project (NCPP), which is a project-based approach to accelerate NOAA scientists' understanding of cloud computing and analysis. BDP's AWS partner provided free credits to ESIP for NOAA scientists to have a sandbox for their research projects. The NCPP project hosts 5 project cohorts that have access to AWS solution architect expertise for their projects.

Some of the other CISESS NC led and/or supported BDP engagement discussions:

- Engagement with NOAA Climate Program Office on Climate Resilience Information System and Big Data Program (January 26, 2022)
- Organization of 2022 American Meteorological Society Town Hall Panel NOAA Big Data Program "Implications of Cloud Based Access to Environmental Data" (January 25, 2022)
- Presentation/discussion with Department of Commerce Minority Business Development Association (MBDA) (January 14, 2022)
- Panelist for National Science Foundation, Track E: The Networked Blue Economy within the Convergence Accelerator Program (15 December 2021)
- Podcast participation with Snowflake Data Champions "Expanding the Reach and Use of NOAA Data" (October 28, 2021)
- Participation at the Boston FinTech Panel "Parametric Insurance: Meeting Cover Needs Created by Climate Change" (September 29, 2021)
- Engagement with RTI International on NOAA BDP as part of their project for the Applied Sciences group in NASA's Earth Science Division (March 31, 2021)

Planned work

- Strengthen and evolve BDP data and engagement activities with NOAA line offices
    - GOES-R interactions, including webinar with Google and support access to GOES-18 data
    - NOAA Climate Program Office on Climate Resilience Information System
    - Develop cloud partner engagement opportunities on climate data records/other datasets
    - Demonstrate how BDP addresses diversity and inclusion topics
    - Develop communications and engagement materials for new data for the cloud
- Identify unique users across select sectors/develop use case summaries
    - Participate in AWS Public Sector Summit
- Support and build engagement with Department of Commerce Innovation Working Group
- Scientific and NOAA workshops/conference engagement, including NOAA EDMW, AMS and AGU
- Key sector specific discussions and workshops engagement
- Support strategic development and programmatic efforts addressing BDP interoperability

Presentations

Brown O. B., J. Dissen, and J. Brannock, 2021: BDP Updates. *NOAA Chief Data Officer Meeting*. virtual, July 23, 2021.

Dissen, J. and A. Simonson, 2021: Expanding the Reach and Use of NOAA Data. *Snowflake and Deloitte Data Champions Webinar*, October 28, 2021.

Dissen, J., A. Simonson, J. O'Neil, J., P. Keown, O. Brown, J. Brannock and D. Willett, 2021: Using Environmental Data on the Cloud with Open-Source Tools. Panel discussion. *2021 AGU Fall Meeting,* virtual, December 12, 2021.

Karna, H. and Dissen, J., 2021: Dynamic Pricing in Insurance: Leveraging NOAA Datasets to Predict Risk and Price, Google Financial Services Summit, virtual, May 27, 2021. Watch on-demand

Kent J., A. Simonson, J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA Big Data Program. *Microsoft AI4Earth Summit,* virtual, May 25, 2021.

Keown, P., A. Simonson, J. O'Neil, J., O. Brown, J. Dissen, J. Brannock, and D. Willett, 2022: NOAA Big Data Program Overview. Panel discussion. *2022 American Meteorological Society (AMS) Town Hall Panel*, virtual, January 25, 2022.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock. 2021: NOAA Big Data Program: Enabling Public, Private and Academic Collaborations. Panel discussion. *AMS 2021 Summer Community Meeting,* virtual, September 21, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, J. Brannock and D. Willett, 2022: Expanding the Reach and Use of NOAA Data. Panel discussion. *House Science and Technology Committee briefing*, virtual, January 13, 2022.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: Engaging Users in the Cloud. Panel discussion. *NOAA Environmental Data Management Workshop,* virtual, August 19, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA Big Data Program Update. Panel discussion. *Environment and Climate Change Canada*, virtual, August 5, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA's Big Data Program Operational Phase Overview. Panel discussion. *U.S. Department of Commerce update*, virtual, August 2, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NWS Partners Webinar: Leveraging the Cloud for Numerical Weather Prediction Data. Panel discussion. *NOAA National Weather Service Partners Webinar,* June 30, 2021.

Other

- Program name change from Big Data Program (BDP) to NOAA Open Data Dissemination (NODD)
- "NOAA Open Data Dissemination (formerly NOAA Big Data Project/Program)" chapter co-authored by Adrienne Simonson, Otis Brown, Jenny Dissen, Ed Kearns, Kate Szura and Jonathan Brannock in AGU *Big Earth Data Analytics* book currently in development with NOAA authors Tiffany C. Vance, Thomas Huang, and Christopher Lynnes

Development and Support of NOAA Climate Products and Services	
Task Leader	Karin Rogers
Task Code	NC-ASD-03-UNCA

Highlight: In support of the overall advancement of NOAA's Climate Products and Services program, 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 an author "sandbox" for the National Climate Assessment, 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 general 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 also 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 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 and editorial/content management of the CRT and the Climate Explorer (CE).

- Continued author team coordination and development of new regional sections of the CRT website for the Southeast, Northern Great Plains, and U.S. Caribbean regions
- Management of public inquiries via the CRT email address
- Launch of CRT redesign process: conducted user research and usability on the current CRT
- Presentation of user research and usability to CRT team, including a journey map and persona
- Worked with CRT and redesign teams to gather ideas to address user research findings
- Worked with CRT and redesign teams to develop information architecture and site map
- Performed "tree jack" studies based on information architecture
- Developed a prototype of new CRT design
- Implemented CSS fixes for the CRT website (notably front page, new courses content type)

- Minor bug fixes and adjustments to the US CRT and Climate Explorer
- Stakeholder engagement, including collaborative work with Metropolitan Mayors Caucus in the release of the 2021 Climate Action Plan for the Chicago Region

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

- Conducted usability studies with potential authors and TSU users
- Incorporated usability findings and fixes into the sandbox tool
- Added seasonal observed climate data and charts
- Added a formal way to submit a graphic figure to TSU
- Launched the first version to https://sandbox.nemac.org/
- Began work with NEMAC intern to investigate adding climate projections via the Applied Climate Information System (ACIS) API as a placeholder.

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. Graphics were updated for the following Indicators:

- Billion Dollar Disasters
- Sea Level Rise
- Frost-Free Season
- Arctic Sea Ice Extent
- Terrestrial Carbon Storage
- Arctic Glacier Mass Balance
- Annual Greenhouse Gas Index
- Global Monthly Average Atmospheric Carbon Dioxide
- Ocean Chlorophyll Concentrations

The design of the new Atlantic Tropical Cyclone Days Indicator was completed as both a static and interactive graphic. The interactive graphic combined web services of known storms, a web map, and responsive bar graph elements.

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

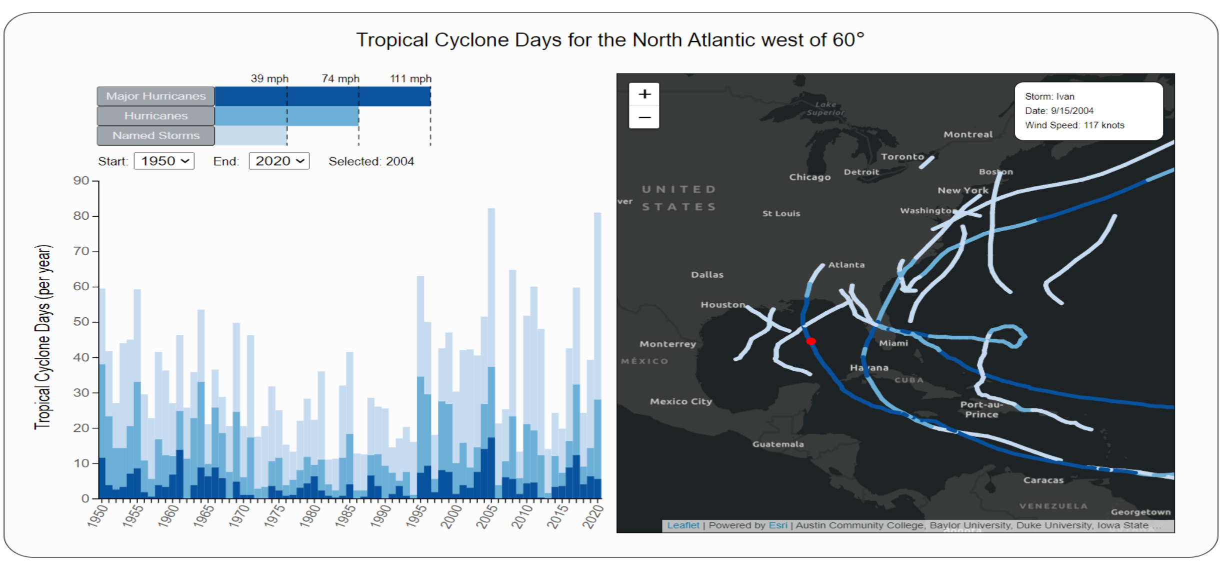


Figure 1. *Image of the interactive Tropical Cyclone Days Indicator.*

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 six rounds of usability and user research on various parts of the new drought.gov website, including a new interactive map for sharing NIDIS maps, state-level maps, email alerts, and the Appalachian-Chattahoochee-Flint (ACF) dashboard
- Conducted a large usability study that included an extensive dive into the ACF dashboard
- Participated in NIDIS annual retreat and presented an overview of usability and user research results to the larger NIDIS team
- Incorporated past NIDIS user research and usability into user research software and began re-analysis of the findings to guide the development of new initiatives across drought.gov

Planned work

- Site maintenance and content development/management for the CRT website
- Development and user testing of CRT prototype, potential launch of the redesign in 2022
- Updates and improvements to Climate Explorer v3, as needed
- Climate Portal and CRT stakeholder engagement
- Continued development and user testing of the NCA sandbox tool
- New NIDIS drought.gov website and upcoming Drought Planning Portal usability testing
- 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., 2021: The Economic Impact of the US Climate Resilience Toolkit (CRT) using Benefit-Cost Ratio. *Carolinas Climate Resilience Conference*, virtual, May 10, 2021.

Michelson, D., 2021: Climate Resilience Solutions. *Iowa Flood Center*, virtual, September 29, 2021.

Rogers, K., 2021: Climate Resilience and Adaptation: The US Climate Resilience Toolkit (CRT). *University of Cincinnati*, virtual, August 18, 2021.

Rogers, K., 2021: Climate Resilience and Adaptation: The US Climate Resilience Toolkit (CRT). *Southeast Sustainability Directors Network (SSDN) Annual Meeting*, virtual, May 6, 2021.

Reports

Makra, E., and N. Gardiner, 2021. Climate Action Plan for the Chicago Region, Metropolitan Mayors Caucus, NOAA, and U.S. Climate Resilience Toolkit. Contributor. https://mayorscaucus.org/wp-content/uploads/2021/06/RegionalCAP_primary_and_appendices_062321-02.pdf

Other

Three UNC Asheville undergraduate students were mentored in writing/editing internships for the CRT and/or NIDIS and one undergraduate student was mentored in usability.

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 U.S. Global Change Research Program (USGCRP). The USGCRP is an organization of 13 federal agencies (including NOAA) 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 over 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 (NCA4). 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, Angel Li, Laura Stevens, Liqiang Sun
Task Code	NC-AA-01-NCICS-KK/et al

Highlight: The update of NOAA's State Climate Summaries for the United States was completed and released. This extensive update featured the first example of compliance with the Evidence-Based Policy Act of 2018, including a full suite of metadata documentation and open access to software code.

Background

NOAA is participating in several global, national, regional, and sectoral-level climate assessment activities, including the high-level, visible, and legally mandated National Climate Assessment (NCA) process, which is responding to a greater emphasis on user-driven science needs under the auspices of the U.S. Global Change Research Program (USGCRP). National climate assessments are intended to advance the understanding of climate science in the larger social, ecological, and policy systems to provide integrated analyses of impacts and vulnerability. NCEI, along with many other parts of NOAA, has provided leadership on climate assessment activities for over 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 Assessment Technical Support Unit (TSU), initially established under the Cooperative Institute for Climate and Satellites-North Carolina, 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), a Support Scientist (Laura Stevens), Data Lead (Sarah Champion), Web Developer/GIS Specialist (Katharine Johnson), Web Developer (Angel Li), and Software Engineer (Linda Copley). 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. The Data Lead directs federal Foundations for Evidence-Based Policymaking Act (EBPA) and Information Quality Act (IQA) compliance efforts. Report information is disseminated through websites providing access to reports, figure metadata, and figure data.

Accomplishments

Past year accomplishments included the update and release of the NOAA State Climate Summaries, on-going planning and initial data analysis for the Fifth National Climate Assessment, enhancement of the Assessment Collaboration Environment, the deployment of a Data Sandbox tool, and progress in on-going research activities.

State Climate Summaries: The TSU successfully released a full update of *NOAA's State Climate Summaries for the United States*. Each state summary is 4 pages in length and summarizes historical climate trends as well as projections of temperature and precipitation. The TSU science team completed data analyses for all 50 states, plus Puerto Rico and the U.S. Virgin Islands, including the use of temperature and precipitation data from NOAA's Climate Divisional Database (nClimDiv) and Global Historical Climatology Network (GHCN). More than 350 core figures and more than 1,000 supplemental figures have been updated with data through 2020, resulting in a total of 547 core figures with 666 total figure panels. Figure

1 depicts one such figure example, indicating a rapid increase in very warm nights in the Washington, DC area. The project also included extensive writing, editing, graphics development, metadata, web development, and informal/formal review. This project serves as the first example of EBPA compliance with a full suite of metadata documentation that includes inaugural, open access to the software code used to analyze the data and visualize the report figures. An example of the comprehensive nature of the figure documentation can be found here.

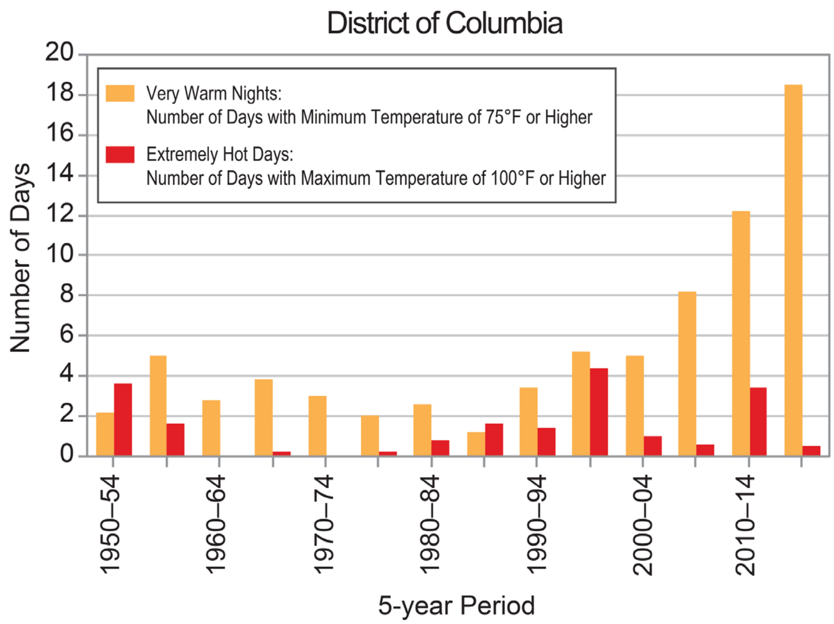


Figure 1. *Observed annual number of very warm nights (minimum temperature of 75°F or higher) and extremely hot days (maximum temperature of 100°F or higher) for the District of Columbia from 1950 to 2020. Bars show averages over 5-year periods (last bar is a 6-year average). Since 1950, there has been no trend in extremely hot days. By contrast, the number of very warm nights has been steadily increasing since 1985, with the highest multiyear averages occurring during the 2005–2020 interval. Sources: CISESS and NOAA NCEI. Data: GHCN-Daily from 1 long-term station (National Arboretum).*

Fifth National Climate Assessment (NCA5): The science and data team continued NCA5 planning, including numerous virtual meetings with the USGCRP National Coordination Office staff. The science team continued CMIP6 analyses, including the development and implementation of processes for cloud-based data analysis, and began supporting NCA5 authors with scientific analyses and figure development. A suite of CMIP6-based data products was developed using the cloud-based resources, including the following climate variables: temperature, precipitation, specific humidity, runoff, soil moisture, sea surface temperature, cloud cover, and downwelling shortwave radiation. Extensive discussions and planning were undertaken to address numerous technical issues, particularly related to the question of climate model weighting. A proposal for the addition of a technical appendix in NCA5 was developed. The proposed appendix would include projection maps for select climate variables.

Assessment Collaboration Environment (ACE): Work continued on the ACE collaborative system to improve project management, reporting, dataset library records, past project data migration, content syncing into the Global Change Information System (GCIS), and the development and redesign of a new metadata viewer in support of both the 2022 update to NOAA's State Climate Summaries and NCA5. In an ongoing effort to comply with the EBPA and IQA, and as part of the sustained assessment process, work continued in collaboration with NOAA General Counsel and 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. Nearly 600 NCA5 Authors, Technical Contributors, and Support Staff 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 will also eventually serve a broad user community. This tool is a collaborative effort with the National Environmental Modeling and Analysis Center (NEMAC).

Extremes Research: Research on extreme precipitation events found a very strong correlation between the magnitude of the events and the amount of atmospheric water vapor. Because future increases in water vapor if greenhouse gas concentrations continue to rise is one of the most confident projections associated with global warming, this provides a firm foundation for incorporating climate considerations into rainfall design values. The research also found that historical upward trends in extreme precipitation occur over a wide range of event duration and recurrence intervals.

North Atlantic Subtropical High: Research on the North Atlantic Subtropical High (NASH) indicated that NASH is potentially predictable with a lead time of 6-12 months, and the Nino3.4 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.

Planned work

- Continuation of CMIP6 climate model data analysis for NCA5
- Development of a technical appendix for NCA5 that includes foundational climate model projection information
- Scientific analysis and figure development for NCA5 authors
- Update of the project management and content syncing features in the TSU collaborative system
- Improvement of capabilities to provide access to NCA data, including GIS formats, standardized color palettes, and mapping standards
- New TSU Metadata Viewer
- Assembly of State Climate Summaries metadata for 1,000+ supplemental figures

Products

- Assessment Collaboration Environment (ACE) updates

Publications

Gutiérrez, J. M., R. G. Jones, G. T. Narisma, L. M. Alves, M. Amjad, I. V. Gorodetskaya, M. Grose, N. A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L. O. Mearns, S. H. Mernild, T. Ngo-Duc, B. van den Hurk, J-H. Yoon, 2021, Atlas. *In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, **T. K. Maycock**, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. (**K. E. Kunkel**, contributing author.) www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

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. statesummaries.ncics.org/

Stevens, L. E., **T. K. Maycock**, and **B. C. Stewart**, 2021: Climate change in the human environment: Indicators and impacts from the Fourth National Climate Assessment. *Journal of the Air & Waste Management Association*, **71**(10), 1210-1233. doi.org/10.1080/10962247.2021.1942321

Presentations

Kunkel, K. E., 2021: Extreme Precipitation and Climate Change: Observations and Projections. *The Centre for Energy Advancement through Technological Innovation's* Hydropower Operations and Planning and Dam Safety Working Groups, virtual, April 20, 2021.

Kunkel, K. E., 2021: Extreme Precipitation: Observed Trends and Climatological Relationships. *NASA Goddard Climate and Environmental Health* monthly meeting, virtual, November 22, 2021.

Kunkel, K. E., 2021: Global Climate Models: CMIP6 – what we know and don't know on projecting future precipitation. NOAA's *Our Changing Precipitation Webinar Series*, September 14, 2021.

Kunkel, K. E., 2021: Historical Trends and Future Projections of Virginia Climate Conditions. *Resilient Virginia 2021 Conference: From Recovery to Resilience; Moving to Vibrant, Healthy and Equitable Communities*, virtual, August 27, 2021.

Kunkel, K. E., 2021: Incorporating Climate Change into Intensity-Duration-Frequency Values for the United States. *NOAA Physical Sciences Laboratory* Attribution Sub-Group Meeting, virtual, October 6, 2021.

Kunkel, K. E., 2021: The Incorporation of Future Climate into Intensity-Duration-Frequency Curves. *SERDP & ESTCP Webinar Series,* October 7, 2021.

Kunkel, K. E., 2021: Carolina Impacts: What is the Data Telling Us? *Carolinas Air Pollution Control Association 2021 Fall Technical Workshop and Forum*, virtual, October 14, 2021.

Kunkel, K. E., 2021: The Future Climate of North Carolina – Uncharted Waters. *North Carolina State University Osher Lifelong Learning Institute* "Our Rapidly Changing Climate" course, Raleigh, NC, November 9, 2021.

Kunkel, K. E., 2022: State of the Climate. *Electric Power Research Institute* (EPRI). *Environmental Change Institute Webinar*, February 3, 2022.

Kunkel, K. E., 2022: Extreme Rain: Historical Trends and Projections. Pre-recorded presentation. *American Society of Civil Engineers* (ASCE) *Structural Engineering Institute*. Future Conditions/Climate Change Workshop for Standard and Code Development, virtual, March 10, 2022.

Kunkel, K. E., and J. Dissen, 2021: Climate Modeling: Considerations for Energy System Planning. *Electric Power Research Institute Advisory Council meeting*, virtual, October 21, 2021.

Kunkel, K. E., L. E. Stevens, S. Champion, and L. Sun, 2022: Extreme Precipitation in the Laurentian Great Lakes: Trends and Causes. Poster. *2022 American Meteorological Society (AMS) Annual Meeting*, virtual, January 24, 2022.

Stevens, L. E., and K. E. Kunkel, 2022: Climate modeling and downscaled data for impact and vulnerability assessments, *EPRI Enel Foundation Climate Resilience Workshop on Physical Climate Risk*, virtual, March 2, 2022.

Sun, L., and K. E. Kunkel, 2021: Predictability of North Atlantic Subtropical High and its Impact on the Climate over the United States. *2021 AGU Fall Meeting,* New Orleans, LA*,* December 16, 2021.

Other

- Kenneth Kunkel serves as graduate advisor and/or committee member for:
    - NCICS staff Brooke Stewart, NCSU/Marine, Earth, and Atmospheric Sciences (MEAS) - PhD advisor
    - Mike Madden, NCSU/MEAS - PhD committee
    - Alyssa Stanfield, 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, Katharine Johnson, Angel Li, Tom Maycock, Andrea McCarrick, Brooke Stewart-Garrod
Task Code	NC-AA-02-NCICS-JA/SC/LC/KJ/AL/TM/AM/BS

Highlight: The team was instrumental in creating the final products for the State Summaries update including the website, metadata infrastructure, figure design components, and providing edits to the finalized content. The team also began initial work on the Fifth National Climate Assessment (NCA5).

Background

The National Climate Assessment (NCA) is conducted under the auspices of the U.S. Global Change Research Program (USGCRP). The NCA is intended to provide the President, Congress, other stakeholders, and the 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 Assessment Technical Support Unit (TSU) at NCEI serves as a major part of NOAA's contribution to the program as one of USGCRP's 13 agency members and provides technical expertise to support the development, production, and publication of the NCA and other associated products. TSU technical staff work collaboratively with the Assessment science/data team and in coordination with NCA authors, NCEI, and USGCRP.

The TSU editorial team—Brooke Stewart-Garrod, Tom Maycock, and Andrea McCarrick—provides scientific editing and writing services to the NCA authors as well as to in-house scientists/authors. They also provide technical writing/editing, copy editing, and coordination of scientific figure development; coordinate in-house publication across multiple teams; and provide substantive input to product rollout and communications 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. Graphics support includes image creation and editing for accuracy and readability, preparing graphics for various pre-release drafts, and graphics design.

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:

- Migrated project data from the previous Meteor-based Resources site (also known as GDAS) to the current ACE system
- Rebuilt the registration process UI to handle new intellectual property requirements
- Updated the metadata viewer to handle an updated metadata schema
- Implemented API capabilities to allow metadata, including figure thumbnails and source code files, to be streamed directly from ACE for assessment report websites
- Performed dataset library reconciliation to move towards a universal NCA Dataset Library, where datasets can be referenced in any project, and serve as the authoritative NCA dataset record

The Fifth National Climate Assessment (NCA5)

The TSU worked with USGCRP staff and NCA5 authors to support the development of report content. TSU editors created zero and first order draft templates for use by report chapter authors. Feedback was provided to authors following an editorial team review of the NCA5 zero order draft of NCA5 and the editorial team is now engaged in an in-depth review of the first order draft. TSU editors, scientists, and graphic designers began working with authors on chapter figures development.

Members of the editorial team provided multiple author training presentations during the first NCA5 all-authors meeting and are now engaged in planning with USGCRP for the second meeting. The TSU editorial team also engaged in multiple NCA5 planning discussions, addressing complex topics such as the use of tribal and Indigenous knowledge, writing about scenarios with standardized language, and the approach for reporting economic impacts in NCA5.

Editors continue to update author guidance as needed and have contributed to other high-level efforts, including drafting the guidance for a new NCA5 text feature (currently referred to as cross-cutting boxes) and drafting the charge to USGCRP agencies to guide their review of the NCA5 zero order draft.

The web team received initial NCA5 website requirements from USGCRP and is working through them to determine a course of action based on discussions with the joint TSU/NCO design working group and the USGCRP Global Change Information System (GCIS) team to determine metadata support capabilities.

State Climate Summaries

In February 2022, the latest version of the NOAA State Climate Summaries for the United States was published for each US state, as well as Puerto Rico and the US Virgin Islands, as a website produced by TSU personnel (Figure 1). The 2022 version comprises a new and improved summary for each state, providing updated historical climate variations and trends extended to 2020, climate model projections of temperature and precipitation during the 21st century, and past and future conditions of sea level and coastal flooding. The project involved extensive scientific analyses, writing, editing, graphics development, metadata, web development, and informal/formal review. Each state's summary and accompanying supplemental figures were revised and reviewed by TSU staff, with input from the appropriate NOAA Regional Climate Center and, in some instances, the relevant state climatologist. Members of the TSU web team also developed an API for the Assessment Collaboration Environment (ACE) to handle streaming metadata from that platform to the State Summaries report website.

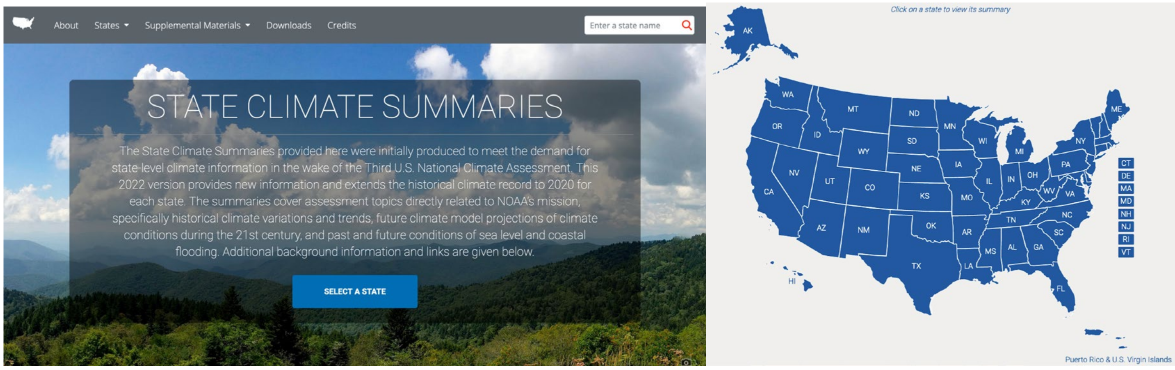


Figure 1. *Landing page and navigation map of the new State Summaries website for the 2022 release.*

Global and Regional Sea Level Rise Scenarios for the United States

The TSU provided editorial and graphics support for NOAA's latest sea level rise technical report. Which reflects the most up-to-date sea level rise projections out to 2150 for all US states and territories. The report provides information to decision-makers and communities to help them assess potential changes in average tide heights and height-specific threshold frequencies as they strive to adapt to sea level rise.

Planned work

- NCA5 user and technical support including
  - project management
  - author training sessions
  - graphics development
  - editing
  - communications
  - website development
- ACE updates and bug fixes as needed
- Migrate all Drupal 6 project websites (NCA3, Climate and Health report, State Summaries v.1) data into ACE and retire those sites
- Retire the *Drupal 7* Resources site; assess all Assessment *Drupal 7* websites and tools to create a migration or rebuild strategy
- Begin development on the NCA5 website

Products

- Updates to the Assessment Collaboration Environment website
- NOAA State Climate Summaries 2022 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. statesummaries.ncics.org/

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

Highlight: Fifteen existing indicators were updated and a new tropical cyclone indicator was added to the USGCRP Indicator Platform in support of the U.S. Global Change Research Program efforts to maintain a comprehensive suite of climate change indicators. 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 the Fifth National Climate Assessment (NCA5).

A set of climate change indicators is managed by the U.S. Global Change Research Program (USGCRP), a consortium of 13 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 efforts, 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 the USGCRP Indicators effort.

CISESS NC and NCEI are working with the IndIWG to broker and administer the USGCRP Indicators set, based on the synergy with, and similarity to, the work of the Technical Support Unit (TSU). Laura Stevens (CISESS NC) and Jessica Blunden (NOAA NCEI) provide scientific and technical expertise in support the overall USGCRP Indicator Platform effort. Other CISESS NC staff aid with specific components, including data/metadata (Sarah Champion), editing (Tom Maycock, Andrea McCarrick), and website support (Katharine Johnson, Angel Li). In 2021, CISESS NC scientist Carl Schreck provided analyses to develop a new tropical cyclone indicator. As part of the indicator update and development process, the TSU also works with CISESS NC consortium partner UNC Asheville's National Environmental Modeling and Analysis Center (NEMAC) in the creation of indicator graphics.

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 and the addition of a new indicator on the USGCRP Indicator Platform. The IndIWG plans to add 3–5 additional indicators (Figure 1) before the release of NCA5 in 2023. New indicators currently in the planning stage include Global Methane Concentrations, U.S. Land Cover Change, Regional Sea Level/Coastal Flooding, and Bark Beetle Prevalence.

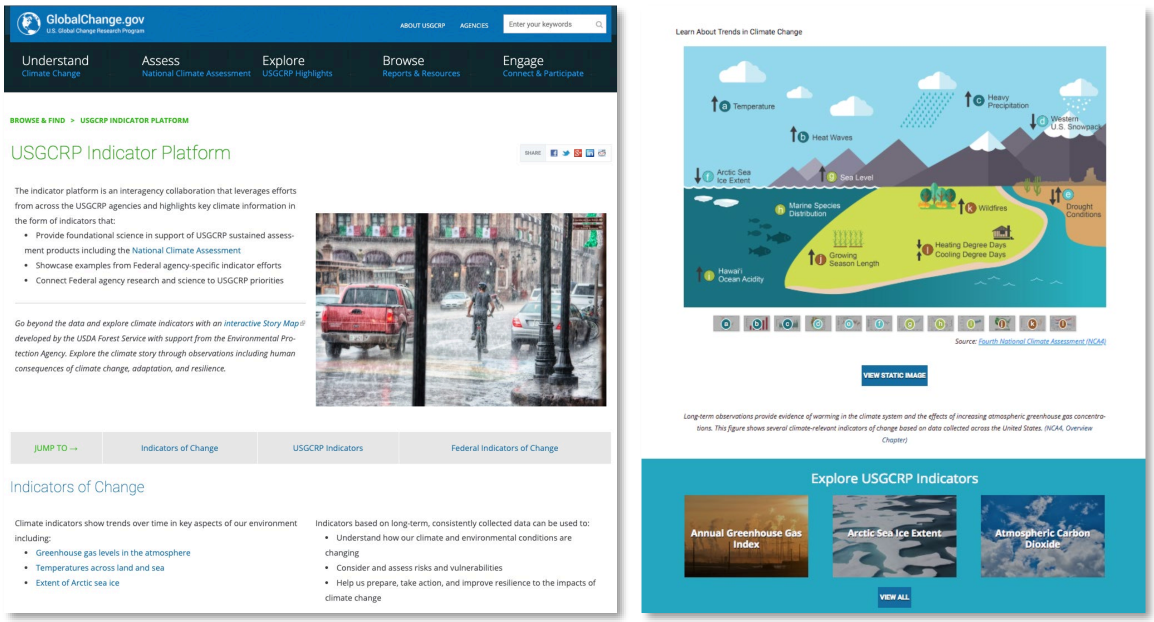


Figure 1. *The USGCRP Indicator Platform at* http://www.globalchange.gov/indicators*.*

Fifteen indicators on the USGCRP Indicator Platform were updated this year. This included incorporation of the most up-to-date data, updated descriptions, and metadata compilation. Comprehensive metadata are collected annually for each indicator to provide full transparency, traceability, and reproducibility, in line with NCA efforts to satisfy the Information Quality Act (IQA).

A new indicator, Atlantic Tropical Cyclone Days, was developed and added to the Platform. This indicator depicts changes in annual Atlantic tropical cyclone activity near land and highlights how such activity has increased since the 1970s (Figure 2). CISESS NC staff performed scientific analyses to create the indicator, worked with NEMAC to produce indicator graphics, aided the NCEI Communications and Outreach Branch in developing a web story, and coordinated with USGCRP communications staff to produce a variety of social media content.

Indicators are integral to the National Climate Assessment, and TSU staff co-authored a peer-reviewed paper in the Journal of the Air & Waste Management Association. This review paper summarizes the indicators and impacts of climate change in the human environment from the Fourth National Climate Assessment.

An Indicators Appendix is currently being prepared for NCA5. 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 also 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 comprised of IndIWG members associated with multiple Federal agencies, including NOAA. Scientific and technical support will also be provided by the TSU as the chapter progresses.

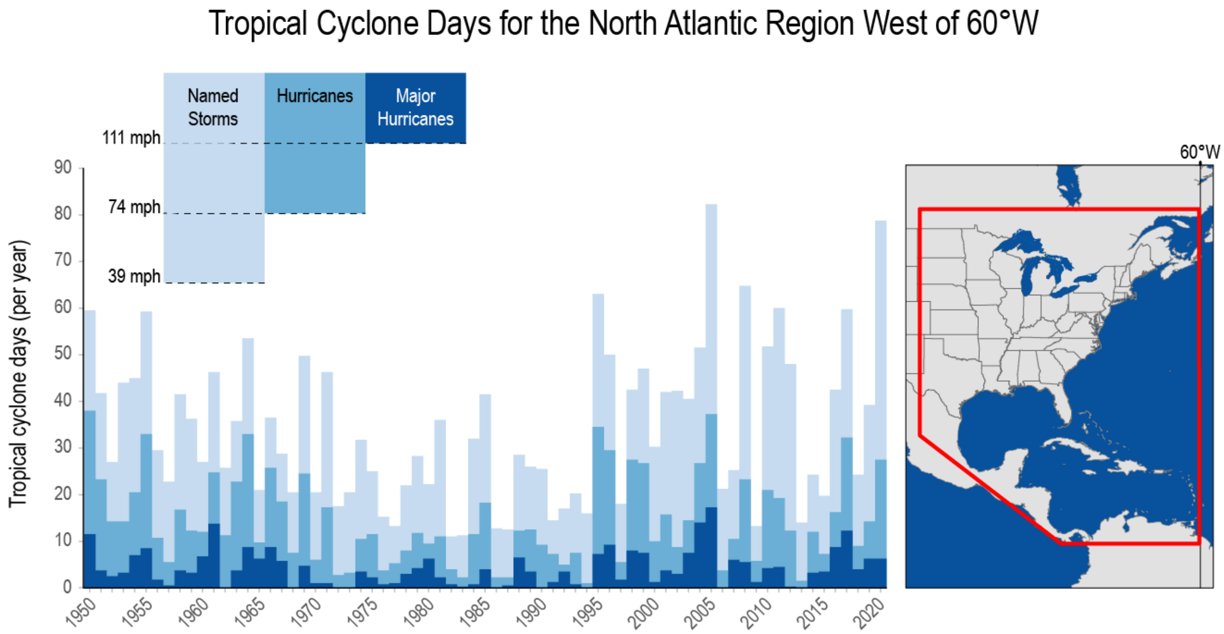


Figure 2. *The Atlantic Tropical Cyclone Days indicator is the latest addition to the USGCRP Indicator Platform. The graph shows the total number of tropical cyclone days (the number of active storms on any given day) per year for the North Atlantic region west of 60°W. The data are tabulated for each of three intensity thresholds: named storms (winds of at least 39 mph), hurricanes (at least 74 mph), and major hurricanes (111 mph or more). Adding up the number of tropical cyclone days in a year across each of the three categories gives an indication of tropical storm frequency, duration, and intensity for that year. For a full description of this indicator, see: https://www.globalchange.gov/browse/indicators/atlantic-tropical-cyclone-days*

Planned work

- Annual update of the USGCRP indicator suite
- Identify/develop new indicators for the USGCRP Indicator Platform in conjunction with relevant Federal agencies
- Continue development of the NCA5 Indicators Appendix

Publications

Stevens, L. E., **T. K. Maycock**, and **B. C. Stewart**, 2021: Climate change in the human environment: Indicators and impacts from the Fourth National Climate Assessment. *Journal of the Air & Waste Management Association*, **71**(10), 1210-1233. doi.org/10.1080/10962247.2021.1942321

Presentations

Stevens, L. E., 2021: Climate change in the human environment: Indicators and impacts from the Fourth National Climate Assessment. *Research Triangle Park Air & Waste Management Association* monthly technical lunch seminar, virtual, June 22, 2021.

Stevens, L. E., 2021: From Data to Indicator. *CCHHG Indicators Workstream Meeting*, virtual, May 25, 2021.

Products

- Fifteen updated USGCRP indicators
  - Annual Greenhouse Gas Index
  - Arctic Glacier Mass Balance
  - Arctic Sea Ice Extent
  - Atmospheric Carbon Dioxide
  - Billion Dollar Disasters
  - Frost-Free Season
  - Global Surface Temperatures
  - Heat Waves
  - Heating and Cooling Degree Days
  - Ocean Chlorophyll Concentrations
  - Sea Level Rise
  - Sea Surface Temperatures
  - Start of Spring
  - Terrestrial Carbon Storage
  - U.S. Surface Temperatures
- One new USGCRP indicator
  - Atlantic Tropical Cyclone Days

U.S.–India Partnership for Climate Resilience Activities Support	
Task Leaders	Kenneth Kunkel, Jenny Dissen
Task Code	NEC-AA-04-NCICS-KK/JD

Highlight: Under the U.S.–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 partners The Energy and Resources Institute (TERI), as part of ongoing planning for a technical climate projections workshop for India based forestry managers.

Background

In September 2014, former U.S. President Obama and Indian Prime Minister Modi agreed to a new strategic partnership on energy security, clean energy, and climate change. The U.S.–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 U.S. 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 U.S. and India team held technical information exchanges, 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 (IITM), and The Energy and Resources Institute (TERI) to build the capacity of Indian scientists and policy makers 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 100mm in the Himalayan mountains to 425mm 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.

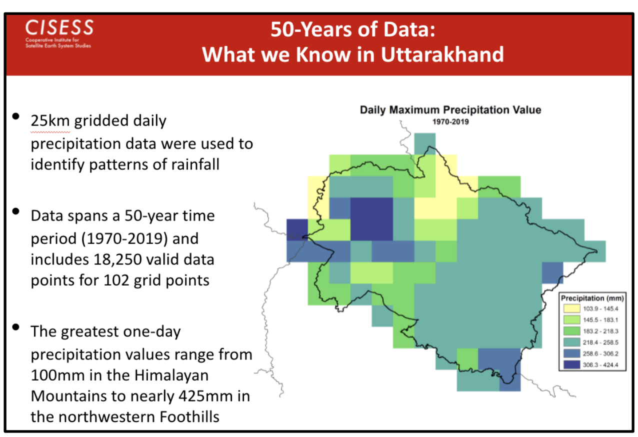
Following preliminary data exploration, more rigorous analytics activities included a variety of extreme values statistical analysis, including Generalized Extreme Value (GEV) Analysis and Generalized Pareto (GPD) analysis. GEV is considered a statistically rigorous method for analyzing data where the probability and occurrence of events are rare (ex: 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 year 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 (ex: 95mm for a 25-year return interval) generally being found in the high mountains near the Tibet border and the highest values (ex: 240mm for a 25-year return interval) in the southeast.

The team also assessed the potential influence of external contributing factors on the 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 (ENSO and 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 precipita-



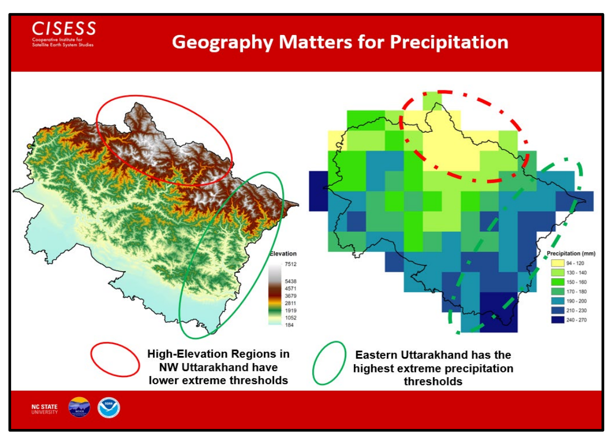


Figure 1: *Map of Uttarakhand, India, with daily maximum precipitation value. precipitation value. The data, provided by TERI, analyzed 25-kilometer gridded daily precipitation data from 1970 to 2019, representing 50 years of data.*
Figure 2: *Compares the elevation and topography of Uttarakhand with extreme precipitation thresholds.*

tion 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.

Summary of Key Findings

- Daily max precipitation values differ significantly between the monsoon (Jul-Sep) and non-monsoon seasons
- 4 of the top 5 wettest one-day periods on record have occurred since 2000 (1985, 2011, 2013, 2010, 2003)
- Noteworthy "heavy tail" in the histogram of maximum daily precipitation across Uttarakhand indicates that extreme value theory analyses are useful in assessing extreme events in the state
- POT and Block Maxima approach 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 only goes back 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 ~12+ events per decade in the 2000s and 2010s compared to ~8 of these events per year in the 1970s-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

- Identify trends in frequency of daily precipitation events exceeding historical extreme thresholds
    - Assess potential trends spatially across Uttarakhand
    - Incorporate other measures of precipitation extremes (e.g., 48-hours, weekly, etc.)
    - Validate the findings from the gridded data with point (observation) data in the region
    - Compare trends of exceedance events using other extreme methodologies
- Investigate potential covariates in extremes (NAO, ENSO, MJO, Monsoon season indices)
- Potentially expand analyses to other states in India and across the Himalayan Mountain region
- Work with India partners on impacts of extreme precipitation to workshop themes
- Continue discussions on applying climate downscaling method to Uttarakhand precipitation data

Presentations

Kunkel, K. E., M. Eck, and J. Dissen, 2022: Precipitation Extremes: Extreme Value Theory and Statistical Trends in Uttarakhand. *TERI team briefing*, virtual, January 12, 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 are collaborating on plans for a technical training seminar (or webinar) for India-based forestry managers on understanding climate projections and their use in the State Action Planning for Climate Change as required by each state in India.

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

Due to the continuing travel restrictions and uncertainties of the global pandemic, the in person technical workshop planned for the year was again postponed. A virtual or hybrid training workshop is being planned. Virtual discussions between the TERI team and CISESS/NCEI team during the year focused on extreme value statistical analysis and input and feedback on the precipitation data analysis completed by CISESS for Uttarakhand. TERI began a review of the analysis results and potential options for expansion of the method to other states of the Indian Himalayan Range, as well as identifying other covariates of interest in the Extreme Value Theory (EVT) analysis. TERI is also reviewing the initial findings with the India Forestry group to inform potential workshop activities.

Planned work

- Consider extreme value data analytics expansion to other states in the Indian Himalayan Range
- Determine other co-variates to examine
- Determine options for training on new downscaling method by Texas Tech
- Work with US team to finalize training workshop training objectives, agenda, etc.

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 (Cooperative Institute for Climate and Satellites-North Carolina [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 will continue 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 Big Data Project and the NESDIS Cloud Pilot, 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 will support 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.

NCEI INNOVATES 2021 - Global Historical Climatology Network-Daily (GHCNd) Graph Database	
Task Leader	Bjorn Brooks
Task Code	NC-ITS-01-NCICS-BB

Highlight: To improve accessibility of the graph database version of GHCNd, a detailed user accessibility study was conducted to identify bottlenecks, issues, and desired functionality, and a comparative cost assessment was made of this graph database solution versus a more commonly used NoSQL cloud database solutions, Amazon DynamoDB. A prototype graph database was implemented with ~40% of the current reporting streams.

Background

The Global Historical Climatology Network-Daily (GHCNd) 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 GHCNd dataflow process consists of a custom research code base that is run on machines in-house. GHCNd contains over 3 billion weather observations. While the database is growing at a rate of about only 1% per year in data volume, the GHCNd 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. Comparisons to more conventional NoSQL database alternatives were made to provide additional context.

Updating the entire GHCNd code base to Neo4j's cypher language is a long-term deliverable and was beyond the scope of this project. This work builds instead upon the hybrid database system that still uses GHCNd's legacy Fortran code but loads the results into a graph database. Graph database technology immediately improves user accessibility, making it faster and more efficient to deliver users the exact data they requested, but also provides a basis for future work if the decision is made to migrate the GHCNd code base to newer cloud technology.

Accomplishments

Understanding GHCNd user needs. A detailed qualitative analysis of more than a dozen expert and lay users of the database was conducted over three months. These interviews not only revealed how users are utilizing the database, but exposed discontinuities in station data due to metadata issues, such as station name changes.

Essential findings from this analysis include:

1. *Utilization of multiple data portals.* Novices and Experts used different data portals to the GHCNd (NOAA CDO, FTP), contributing to misunderstandings about accessibility options.
2. *Lack of metadata content.* Both groups saw room for improvement in metadata content, and smarter data delivery.

3. *Opportunity for expansion of the GHCNd user base.* Serving both novices and experts supports the overall goal of system improvement, where more effective usability helps strengthen buy-in from existing stakeholders and additionally attracts stakeholders from new sectors.
4. *Increased usability may lower Cloud operating costs*. The ability to deliver the specific data that users are interested in will save on commercial cloud egress data costs, which may be substantial. Currently GHCNd does not offer tailored subsets of data.
5. *Specific accessibility needs prioritization.* Interviewees were presented with wireframe interfaces to a new prototypical GHCNd portal (Figure 1) and asked to provide feedback on specific accessibility needs.

The analysis findings and lessons learned are archived in a permanent video, which may be of use to future decision-makers. See video here.

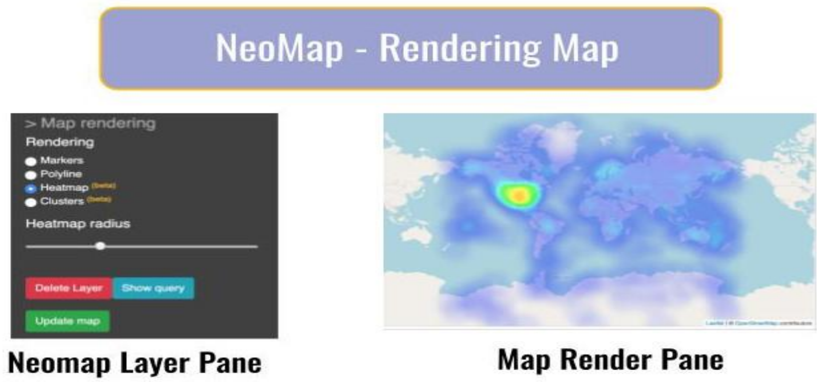


Figure 1*. A GHCNd wireframe interface used in testing user's interest and determining accessibility needs.*

Benchmarking two GHCNd database versions. Two different database versions of GHCNd were were built and compared, one utilizing Neo4j software (graph) and the second using Amazon DynamoDB (key-value NoSQL), which is a widely used off-the-shelf database service.

Both databases were built and tested for performance (speed and load handling) in order to assess their relative capability to handle the GHCNd user-base. Standard queries based on feedback from the accessibility study were used to simulate sustained query hits to the database (for example, 'return all the data for station X and year Y where temperature exceeded Z degrees').

Initial results:

1. *Cost.* The "store-brand" cloud database services (e.g., DynamoDB on AWS) are less expensive than Neo4j
2. *Design/build effort*. Graph database required substantially more person-hours to design and build than NoSQL key-value (359 person-hours for Neo4j vs 40 hours for DynamoDB)
3. *Versatility.* DynamoDB was less versatile than Neo4j, which limits querying capabilities and speeds
4. *Query response speed*. Graph database was more than ten times faster at returning filtered data queries
5. *Load handling.* Some NoSQL alternatives may not work at all with GHCNd. DynamoDB was not found to be a good fit for GHCNd because it is limited by the number of records that can be loaded into the database per unit time (≈300k records per 15 minutes). After 15 minutes, the Lambda function timed-out and killed the database population process. GHCNd contains about 30M

records per year, meaning that the database would have to be split into 100 data files per year and then loaded into DynamoDB.

Planned work

- Publish current project results in a technical climate and big data journal
- Convert the GHCNd Fortran update code to Neo4j cypher and BASH
- Implement a graph-based GHCNd database that can be queried through a web API

Products

- GHCNd graph database design

Presentations

Brooks, B., 2021: Cost-benefit analysis for recreating a climate dataset as a NoSQL database in the Cloud. *2021 NOAA Environmental Data Management Workshop,* virtual, August 17, 2021.

Other

- Student Interns: Devan Walton (University of New Hampshire) and Nirav Patel (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). This cross-centers team took advantage of cloud provider services and distributed modern, robust tools to support a core NCEI mission of archive. Workflow tools were tested, analyzed, and compared via capability matrix to determine both cloud native and cloud agnostic. An alpha workflow was developed utilizing AWS Step Functions and its performance was tested for the team to expand upon. Workflows were then developed as part of the NCAP team with AWS EventBridge as the intra system communication mechanism. This enabled the NCAP system (Figure 1) to grow covering preprocessing, generalized archive package (AIU), collection (AIC), and access (AA) processing.

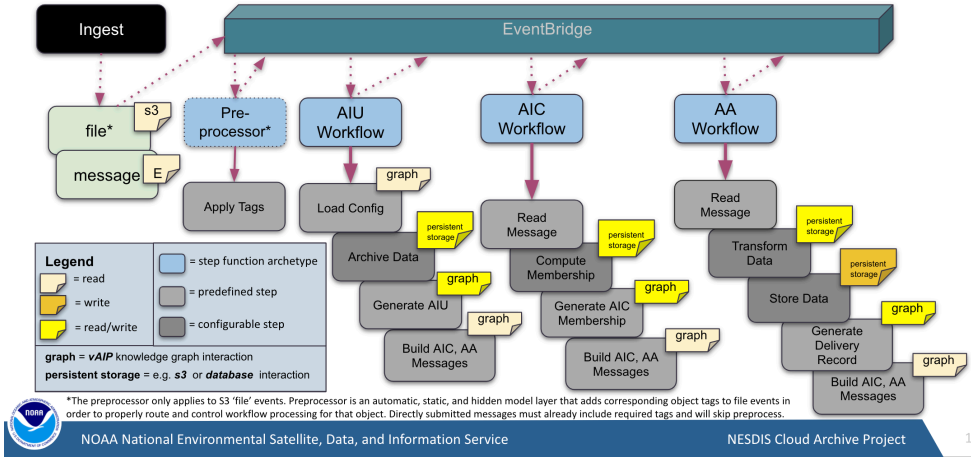


Figure 1. *NCAP System Workflow.*

A diverse toolset was implemented to support this system on the AWS platform, and included Serverless Application Model (SAM), CodeCommit, Lambdas, CloudFormation, CloudWatch and CodeBuild. CISESS NC provided the NCEI NCAP team with initial implementation for each of these tools and supports, as well as training sessions and documentation, leading the team towards implementation of the above system. Additionally, initial implementations for a CICD test system and ElasticSearch monitoring feeds were provided to support the system.

With NCAP project movement into the graph database domain for archive process metadata storage and generalized system processing, this CISESS NC task supported NCAP with AWS Neptune setup and various related technology tools (Figure 2). Example initial queries were provided in Lambdas, Jupyter Notebooks, and Bash shell. Recommendations on using graph databases effectively to reach metadata storage goals were made and often incorporated in the NCAP project as it tied the NCAP system to the Virual Archive Information Package (vAIP), an NCAP lead concept to represent and drive archive metadata and its processing through graph representations. In support of this, this CISESS NC task provided Sagemaker Jupyter notebook instance and related system installation tools. This was used by the CISESS NC task to generate a system deployer integrated with the graph database, usable by developers, automated tooling and end users via scripts, CodeBuild, and Jupyter Notebook. A shared ontology editor, VocBench, was investigated and deployed through this task to support NCAP team effort building the graph and its foundational schemas.

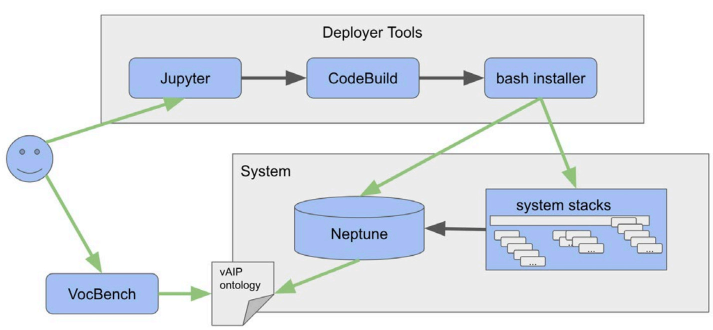


Figure 2. *System and Graph Tools.*

NiFi development. This task promoted production and implementation of a NiFi writing process, permissions, and roles document explaining deployment of systems to production in NCEI. This occurred through multiple stages of documentation and demonstration so that NCEI IT could confirm viability of a solution that met security guidelines, and NCEI management could commit to a production NiFi cluster. The task also supported this effort, with regular meetings to track, report on, and make recommendations to resolve technical obstacles and promote NiFi advancement into production. Obstacles encountered varied widely, from monitoring prototypes, flow-sensitive information management, privilege management, proxy issues, and general NiFi flow solutions, to debugging installation approaches.

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

Data Integration Visualization Exploration and Reporting (DIVER). CISESS NC participated in the NCEI DIVER project with a team of data managers, domain and metadata experts, and developers to both archive NOAA DIVER data and improve the processes at NCEI. This task supported DIVER use of NiFi to interact with CLASS for archive, as well as internal NCEI services related to metadata. The team also supported flow generation to perform cross-system integration, an operatable flow with related operator documentation, operator training in NiFi, general debugging, and assistance with NiFi useability.

As the DIVER project promoted and drove NiFi towards production to meet its own needs, this task worked with the project to support this goal and assist NCEI in meeting its commitment to deploy NiFi into production.

Planned work

- Assist NCEI to transition NiFi into production
- Work with NCAP to complete and deploy archive system to NCCF infrastructure
- Promote cloud-oriented solutions at NCEI as part of SDS
- Work with GHCNd innovates project and intern to provide graph database data searchable across metadata

Products

- NCAP Archive prototype system
- NCAP CICD test stack
- NCAP Archive system installation suite, including Jupyter Notebook
- NiFi general operator training documents, workflows, and weekly sessions
- NiFi queue monitoring flow and Graylog Dashboard
- NiFi living production tracking document
- NiFi solutions document with CLI/API setup, version migration steps, sensitive information approach

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 scientists and technicians 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 U.S. Climate Reference Network and the U.S. Historical Climatology Network.

The public's awareness and understanding of Earth system variability, change, prediction, and projection continues 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, Jessica Matthews*, Ronald Leeper, Olivier Prat, Jared Rennie*
Task Code	NC-SAS-01-NCICS-CS/JD/AI/ JM/RL/OP/JR

Highlight: CISESS NC scientists served as Product Leads for 28 NCEI products, and as Product Area Leads for 2 product areas. https://www.ncdc.noaa.gov/cdr

Background

Science management practices at NCEI are evolving towards 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 (indicated by asterisk *) 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 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)
- AVHRR Surface Reflectance CDR (Matthews*)
- Normalized Difference Vegetation Index CDR (Matthews*)
- Leaf Area Index and FAPAR CDR (Matthews*)
- GOES Albedo CDR (Matthews*)
- Gridded In Situ Normals (Rennie*)
- Precipitation – CMORPH (Prat)
- Standard Precipitation Index using CMORPH (Prat)
- Advanced Standard Precipitation Index using Precipitation CDRs (Prat)
- Extreme Snowfall (Rennie*)
- ISTI (Rennie*)
- Outgoing Longwave Radiation – Monthly CDR (Schreck)
- Outgoing Longwave Radiation – Daily CDR (Schreck)
- Sectoral Engagement (Dissen)
- ADT-HURSAT (Schreck)

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

- coordinating the following product phases (as appropriate):
    - development
    - assessment of maturity
    - transition to operations

    - sustainment in operations
    - upgrades, succession, and retirement
- 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:

- Land surface properties (Matthews*)
- 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 is working on several activities in collaboration with NIDIS and the Cooperative Institute for Satellite Earth System Studies (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 behavioral health: Severe drought is a globally relevant natural disaster linked to increased psychological distress. Although agricultural populations are particularly vulnerable to drought, no studies to date have examined its impact on occupational psychosocial stress among North American farmers. The project team used a longitudinal mixed effects model to estimate the association between drought conditions and a metric of occupational psychosocial stress (i.e., the job strain ratio based on results of the Job Content Questionnaire [JCQ]) among 498 Midwestern farmers surveyed at six-month intervals from 2012-2015. Data were collected as part of the *Musculoskeletal Symptoms among Agricultural Workers Cohort* study. During the growing season, the job strain ratio increased by 0.031 (95% CI: 0.012, 0.05) during drought conditions, an amount equivalent to a one-half standard deviation change, compared to non-drought conditions. The association between drought and the job strain ratio was driven mostly by increases in the psychological job demand (2.09; 95% CI: 0.94, 3.24) component of the JCQ. An increase in occupational stress was not observed for droughts that occurred during the non-growing season and stratified analysis revealed risk differences by sex, age group, or geographic region. The results suggest a previously unidentified association between drought conditions and increased occupational psychosocial stress among U.S. farmers.

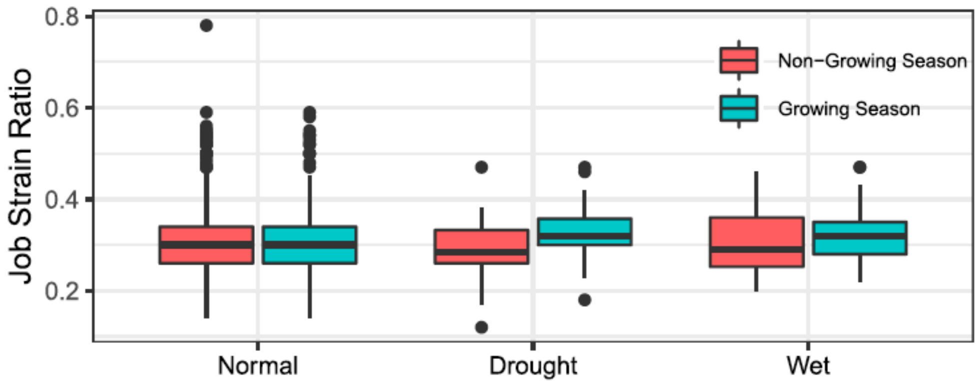


Figure 1. *Drought risk for farmer occupational psychosocial stress is unknown. Farmers are a vulnerable population to extreme weather events. A linear mixed effects longitudinal model evaluated farmer job strain. Growing season drought increased farmers occupational psychosocial stress. Drought planning should consider occupational psychosocial stress effects.*

Interaction opportunities between the drought and public health communities. Due to continuing COVID-19 pandemic conditions across the country, regional workshops were again postponed. Instead, a series of drought and health related interviews were initiated with state-level health departments across the country. A pool of 29 potential interviewees was developed focusing on those states and entities that had received funding from the CDC through involvement in either the BRACE (Building Resilience Against Climate Events) program or the Environmental Public Health Tracking program. Interviews were solicited through direct emails to relevant contacts at each of these health departments with 16 of the 29 health departments responding affirmatively. This information will provide better understanding of how public health departments are responding to drought and will be used in the NIDIS Drought and Health Strategy Document to improve best practices.

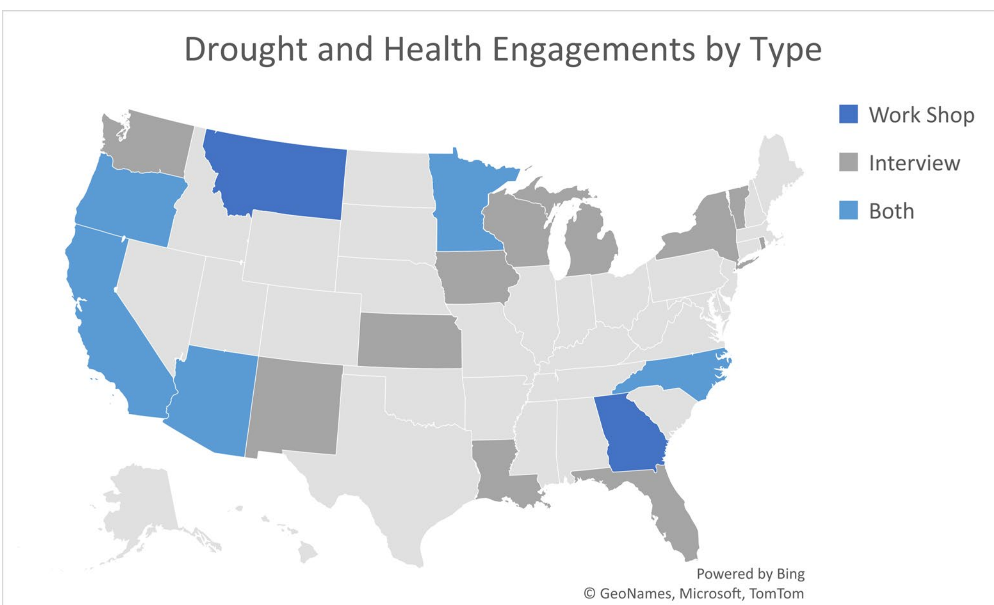


Figure 2. *Map of U.S. drought and health stakeholder engagement by engagement type (workshops, interviews, or both).*

Planned work

- Complete drought and health surveys
- Conduct state-level drought and health workshops for Northern Plains and Pacific NW
- Complete additional studies on the health impacts associated with droughts
- Develop strategy document on drought and health for NIDIS

Publications

Leeper, R. D., J. L. Matthews, M. S. Cesarini, J. E. Bell, 2021: Evaluation of air and soil temperatures for determining the onset of growing season. *Journal of Geophysical Research: Biogeosciences*. doi.org/10.1029/2020JG006171

McDermid, S. S., R. Mahmood, M. J. Hayes, J. E. Bell, and Z. Lieberman, 2021: Minimizing trade-offs for sustainable irrigation. *Nature Geoscience,* **14**, 706-709. doi.org/10.1038/s41561-021-00830-0

Berman, J. D., M. R. Ramirez, J. E. Bell, R. Bilotta, F. Gerr, and N. B. Fethke, 2021: The association between drought conditions and increased occupational psychosocial stress among US farmers: an occupational cohort study. *Science of The Total Environment,* 798, [149245]. doi.org/10.1016/j.scitotenv.2021.149245

Ebi, K. L., J. Vanos, J. W. Baldwin, J. E. Bell, D. M. Hondula, N. A. Errett, K. Hayes, C. E. Reid, S. Saha, J. Spector, and P. Berry, 2021: Extreme Weather and Climate Change: Population Health and Health System Implications, *Annual Review of Public Health* 2021, 42(1), 293-315. doi.org/10.1146/annurev-publhealth-012420-105026

FAO and UNCCD. 2021. Thinking ahead: Drought resilience and COVID-19. *WASAG working group on drought preparedness*. Rome, FAO. *doi.org/10.4060/cb5547en (J. E. Bell, contributing author)*

Presentations

Bell, J., 2021: Drought Impacts on Mental Health. Podcast. *USDA Southwest Climate Hub* and *DOI Southwest Climate Adaptation Science Center* "Come Rain or Shine," April 9, 2021.

Lookadoo, R., 2021: Effective Long-Term Strategies to Prepare for, Prevent, and Mitigate Health Impacts of Drought. *National Environmental Health Association Annual Education Conference*, virtual, July 15, 2021.

Bell, J., 2021: Impact of Climate Change. Society of Actuaries *Research Insights* (podcast), August 9, 2021.

Bell, J.: Building the Evidence Base to Advance Climate And Health Practice: Lessons Learned from Ongoing Translational Research Projects at the Centers for Disease Control and Prevention (CDC) and its partners. Panel discussion. *33rd Annual Conference of the International Society for Environmental Epidemiology*, virtual, August 25, 2021.

Bell, J., 2021: Sector and Community-based Perspectives on Cascading Drought Impacts and Needed Changes. Panel discussion. *NOAA NIDIS 2021 Southwest Drought Virtual Forum*, virtual, September 21, 2021.

Lookadoo, R., 2021: Drought and Health: Engaging Public Health and Policymakers. *Network for Public Health Law Conference*, virtual, September 22, 2021.

Bell, J., 2021: Impact of extreme events on water, food systems and human health. *University of Nebraska Water for Food Global Forum*, virtual, October 28, 2021.

Abadi, A., 2021: Assessment of the Effects of Different Types of Drought on Suicide in Nebraska from 2000 to 2018. *University of Nebraska Medical Center 1st Annual College of Public Health Innovation Expo*, Omaha, NE, November 12, 2021.

Abadi, A., 2021: Investigating the Impacts of Drought on All-cause Mortality in Nebraska in a Bayesian Framework. *2021 AGU Fall Meeting*, New Orleans, LA, December 14, 2021.

Bell, J., 2021: Comparative Review of Drought Metrics for Public Health Research Applications. *2021 AGU Fall Meeting*, New Orleans, LA, December 14, 2021.

Other

- Postdoctoral researcher mentored: Dr. Babak J-Fard
- Advised 4 PhD students: Qianqian Li, Jagadeesh Puvvula, Hunter Jones, Abdoulaziz Abdoulaye
- MPH student mentored: Conor O'Neill
- *Alta article*: California's Farms: Drought, Depression, and Suicide (Dean Kuipers). December 2021
- Working Group reviewer, *The Lancet Countdown on Health and Climate Change: Policy Brief for the United States of America (2021).*

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. In either case, it 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. It also poses a challenge 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

A latent and spatial factor analysis framework was used to model the spatio-temporal dynamics of reef fish communities and to estimate species co-occurrence and the strength of associations in space and time. The model was applied to a large-scale fishery independent survey, i.e., Southeast Reef Fish Survey (SERFS) from 2011 to 2018 to conduct preliminary model runs. The model simultaneously fits to data for multiple species at different locations and time intervals by modeling response variables as a multivariate process using latent factors representing spatial and spatio-temporal variations.

Planned work

- Complete model configurations
- Diagnose and validate the developed joint-species distribution model
- Interpret the model results
- 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 supported the execution of five Department of Commerce/NOAA Sector Listening Sessions to advance continued improvement of NOAA climate services, finalized a collaborative research study in climate risk to the real-estate sector, and continued national level engagement as well as regional and local outreach in climate science and STEM activities.

Background

CISESS NC supports and augments NOAA mission and operational activities in information services and user engagement through relevant research and development/application of interdisciplinary approaches for stakeholder engagement. As NOAA NCEI builds its capabilities in Information Services across sectors, departments, and public agencies, CISESS NC supports NOAA, via NCEI, in user engagement activities by developing interdisciplinary and modern methods for connecting with a broader and more diverse user community of stakeholders that span public and private sectors. CISESS also conducts research activities into underserved sectors and target audiences to reach different and diverse environmental information user groups.

CISESS NC utilizes and emphasizes multilateral engagement activities with user communities, building upon traditional modes for engagement and outreach to enable synchronous and asynchronous methods, particularly in light of cloud-enabled access. 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. Leveraging modern cloud-based technology methods and collaboration with cloud partners, engagement activities reach diverse user groups and build experience with diverse platforms. CISESS NC furthers NOAA's mission goals by working with partners to connect with user communities, ultimately in support of advancing adaptation, resilience, and a robust climate services sector.

Accomplishments

Engagement activities supporting NCEI/NOAA during the past year focused on

- Advisory and execution support for NOAA Listening Sessions
- A sector case study focused on environmental data in the real-estate sector
- Advancement of STEM activities through outreach and education

NCEI Information Services Support

CISESS NC supports NCEI's Climate Services and Support Division (CSSD) on strategic and operational sectoral engagement activities, and Task Leader Jenny Dissen continues to serve as the Product Lead for CSSD sectoral engagement. CISESS NC collaborates with the NCEI engagement team in leveraging the customer relationship management (CRM) tool to develop insights for the engagement, data, and science needs as noted from user interactions. CISESS NC also advises on the new framing of the NCEI State of the Services summary report intended for NCEI leadership and for external users on how NCEI reaches its users. The customer analytics tool and State of the Services reports are shared as illustrative examples to other parts of NESDIS and NOAA on various operational aspects of user engagement that are developing from frameworks and processes.

During the past year, CISESS NC completed a collaborative research project with CISESS subcontractor, Willis LTD (formerly Acclimatise), which focused on wildfire risk to the real-estate sector (See Willis report, page 119) and involved extensive stakeholder engagement. A final project report submitted to NOAA NCEI Information Services detailed the role of NCEI data currently being used, stakeholder needs that represent the solution providers' perspective, and the challenges in each of the value chain areas.

Department of Commerce / NOAA Listening Sessions

CISESS NC led and supported NOAA NCEI in the execution of the Department of Commerce (DoC) NOAA Listening Sessions with business and industry. Session goals are to better understand and support private sector work to incorporate NOAA's climate information in strategic decision-making. Through these sessions, Commerce and NOAA hope to receive input from a broad array of experts and stakeholders to inform continued improvement of NOAA climate services, as well as increased awareness, appreciation of, and support for, NOAA's roles in addressing sector challenges and opportunities in the climate arena. It also entailed increasing NOAA understanding of high priority sector needs, gaps, and opportunities for innovation.

CISESS NC led the planning, coordination, execution, and post-session summaries of 5 listening sessions in the sector areas of Retail (October 2021), Insurance/Reinsurance (December 2021), Architecture and Engineering (January 2022), NOAA New Blue Economy (February 2022), and Travel, Tourism, and Recreation (March 2022). This entailed identification of key association and society partners in the industry, collaboration with partners to determine participants, and guiding preparation across internal NOAA Line Office leads and administrators as they listened to the perspectives from business and industry on climate information needs. Session outcomes resulted in the summary document development for each individual session and formulation of a cross-sector summary that will be provided to the NOAA Administrator and shared with DoC Secretary Gina Raimondo, who spoke at the Travel Tourism and Recreation session.

Figure 1. *Virtual listening session with Reinsurance Industry Association President Frank Nutter and NOAA Administrator Dr. Rick Spinrad.*

Education and General Public Outreach Activities

CISESS NC staff continue involvement, advisory support, and general engagement in an interdisciplinary outreach program which includes activities 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, the NC Science Festival, The Callen Center, and Western North Carolina STEM Leaders. Institute staff normally support and respond to a variety of outreach requests throughout the region. While most in-person activities were curtailed or postponed due to the on-going COVID-19 pandemic, staff were still able to provide a number of remote presentations for local groups, schools across the U.S., and even a class in Panama.

CISESS NC outreach activities during the past year included:

- Leeper, R. D., 2021: Careers in meteorology. *AMS Asheville Chapter Meeting,* virtual, April 8, 2021.
- Schreck, C. J., 2021: Extreme weather and becoming a meteorologist. Skype a Scientist, *International School of Panama* (Panama City, Panama) 3rd grade class, virtual, April 7, 2021.
- Schreck, C. J., 2021: Extreme weather and becoming a meteorologist. Skype a Scientist, *McLean Montessori School* (McLean, VA) 4th grade class, virtual, April 27, 2021.
- Rennie, J. J., 2021: Weather and climate. Skype a Scientist, *Holden Christian Academy* (Holden, MA) 3rd-6th grade classes, virtual, May 4, 2021.
- Schreck, C. J., 2021: Climate change. *Enka Intermediate School* (Candler, NC) 5th grade classes, virtual, May 6, 2021.
- Graham, G., 2021: Artificial intelligence in the sciences: how machine learning helps understand the world. *Asheville Museum of Science* "Ask A Scientist series," virtual, May 7, 2021.
- Schreck, C. J., 2021: Climate change. *Enka Intermediate School* (Candler, NC) 6th grade classes, virtual, May 7, 2021.
- Rao, Y., 2021: Satellite climate data. *Asheville Museum of Science* summer camp class, virtual, June 24, 2021.
- Stevens, L. E., 2021: Career and work at NCICS. *NCICS Weekly Intern Seminar Series,* virtual, June 29, 2021.
- Stevens, L. E., 2021: Weather and climate. *CampVentures* summer camp class, Asheville, NC, August 4, 2021.
- Schreck, C. J., 2021: Climate Change Headlines from 2021. *Heritage Hills Retirement Community*, Hendersonville, NC, September 23, 2021.
- Schreck, C. J., 2021: Climate change and meteorology careers. Skype a Scientist, *Leland Public School* (Leland, MI) 8th grade class, *virtual,* October 22, 2021.
- Schreck, C. J., 2021: Climate change, weather tools, and meteorology careers. Skype a Scientist, *Highpoint Virtual Academy of Michigan* (Mesick, MI) 5th grade classes, virtual, November 2, 2021.
- Schreck, C. J., 2021: Climate change, weather tools, and meteorology careers. Skype a Scientist, *Baldwinsville Elementary School* (Baldwinsville, NY) 3rd grade class, virtual, November 3, 2021.
- Schreck, C. J., 2021: Hurricanes and climate change. *Fernleaf Community Charter School* (Fletcher, NC) 5th grade class, virtual, December 8, 2021.
- Schreck, C. J., 2022: Climate Change and Meteorology. Skype a Scientist, *Apex Elementary School*. Apex, NC, 5th grade class, virtual, February 3, 2022.
- Schreck, C. J., 2022: Weather and Climate. Skype a Scientist, *Campus School* (Memphis, TN) 3rd grade class, virtual, February 11, 2022.

Planned work

- Develop/assess Listening Session summary findings to guide strategic information services efforts
  - Conduct deep dive support for the Retail Industry, given their feedback and interest
- Determine interest and hosting of real estate industry sector listening session
- Support NCICS Outreach, including collaboration with Asheville Museum of Science on summer camp planning, STEM teacher activities, and mentoring

Other

- Continued engagement with Electric Power Research Institute (EPRI): participation in the EPRI Advisory Council Meetings and discussions on climate information exchange opportunities
- Supported Asheville City Schools in STEM skills
- Supported Asheville Museum of Science: advisory support, summer camp planning & speakers
- Service on the North Carolina School of Science and Mathematics Morganton Campus External Engagement Steering Team (Dissen) http://ncssm.edu/

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

Highlight: The OISST operational algorithm was successfully upgraded to utilize a new suite of satellite data sources, in response to the planned de-orbiting of the European Space Agency's MetOpA satellite platform. Quality checks and analyses all indicate the new satellite data sources have improved OISST v2.1a product quality over previous versions of the algorithm. 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 data sets 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 November 2021, the European Space Agency's (ESA's) MetOpA satellite platform was intentionally de-orbited, as that platform had reached the end of its viable operational lifespan. Since MetOpA's Advanced Very High Resolution Radiometer (AVHRR) Sea Surface Temperature (SST) instrument was one of two such satellite-based instruments contributing to OISST's global coverage, the OISST team needed to locate a suitable new satellite SST source. The NOAA STAR Advanced Clear Sky Processor for Ocean (ACPSO) L3S Low Earth Orbit (LEO) Sea Surface Temperature product was selected as the new data source, utilizing the NOAA-20 and Suomi NPP platform's Visible Infrared Imaging Radiometer Suite (VIIRS) and AVHRR FRAC instruments on the ESA's MetOpB and MetOpC platforms.

Accomplishments

After the planned deorbiting of the ESA's MetOpA satellite, the OISST team successfully operationalized OISST v2.1a, which utilizes the ACSPO SST product as its satellite SST source, instead of MetOpA and MetOpB swath data. Two versions of OISST v2.1a were created in order to verify successful integration of the replacement SST product. The output of the two versions was compared and shown to produce identical results over the recent period (2021-present). In addition, an in-depth analysis was conducted to compare OISST v2.1a with OISST v2.1 in reference to the Group for High Resolution Sea Surface Temperature's Multi-Product Ensemble Median Sea Surface Temperature product (GHRSST's GMPE-SST) for January 2016 to April 2020. The analysis demonstrated that OISST v2.1a had significantly reduced variability characteristics in comparison with OISST v2.1, indicating a substantial improvement in quality resulting from the incorporation of new satellite platforms (MetOpC, NOAA-20, and Suomi NPP) and new scientific instrumentation (VIIRS and AVHRR, as opposed to solely AVHRR).

Planned work

- Integrate the National Snow and Ice Data Center's Sea Ice Index Climate Data Record as a new source for OISST sea ice data
- Incorporate Banzon et al's (2020) improved sea ice-to-SST estimation algorithm into the current version of OISST
- Reprocess the entire OISST historical period (from 1981 to present) using the ACSPO reanalysis data set
- Investigate/test the use of a machine learning-based approach for satellite bias correction within the OISST algorithm

Publications

Huang, B., Z. Wang, X. Yin, A. Arguez, **G. Graham**, C. Liu, T. Smith, and H. M. Zhang, 2021: Prolonged Marine Heatwaves in the Arctic: 1982−2020. *Geophysical Research Letters,* 48(24), e2021GL096410. doi.org/10.1029/2021GL095590

Huang, B., C. Liu, E. Freeman, **G. Graham**, T. Smith, and H. M. Zhang, 2021: Assessment and intercomparison of NOAA daily optimum interpolation sea surface temperature (DOISST) version 2.1. *Journal of Climate*, ***34***(18), 7421-7441. doi.org/10.1175/JCLI-D-21-0001.1

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: CISESS NC collaborator, Oak Ridge Associated Universities (ORAU), is working with the NOAA Atmospheric Turbulence and Diffusion Division (ATDD) to expand and sustain the U.S. Climate Reference Network's observational capability and long-term homogenous observations. Annual calibration and maintenance activities were accomplished for USCRN sites in eight states.

Background

NOAA's Air Resources Laboratory (ARL) 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 Oak Ridge Associated Universities (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, Hawaii, 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.

Some of this work was completed by ORAU through the NOAA Cooperative Institute for Climate and Satellites (CICS). ORAU engineers and technicians will maintain and expand the USCRN to ensure the climate observing systems continue to deliver high quality environmental data through CICS's successor, the Cooperative Institute for Satellite Earth System Studies (CISESS).

Accomplishments

USCRN data are used in a variety of climate monitoring and research activities that include placing current climate anomalies into an historical perspective. Highly accurate measurements and reliable reporting are therefore critical. Station instruments (Figure 1) are calibrated annually and maintenance includes routine replacement of aging sensors to maintain/sustain the data. The performance of each station's measurements is also monitored on a daily basis and problems are addressed as quickly as possible to sustain long-term homogenous observations of air temperature, precipitation, and soil moisture/soil temperature. In addition to these parameters, each station measures ground surface (IR) temperature, solar radiation, wind speed, relative humidity, wetness from precipitation. 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.

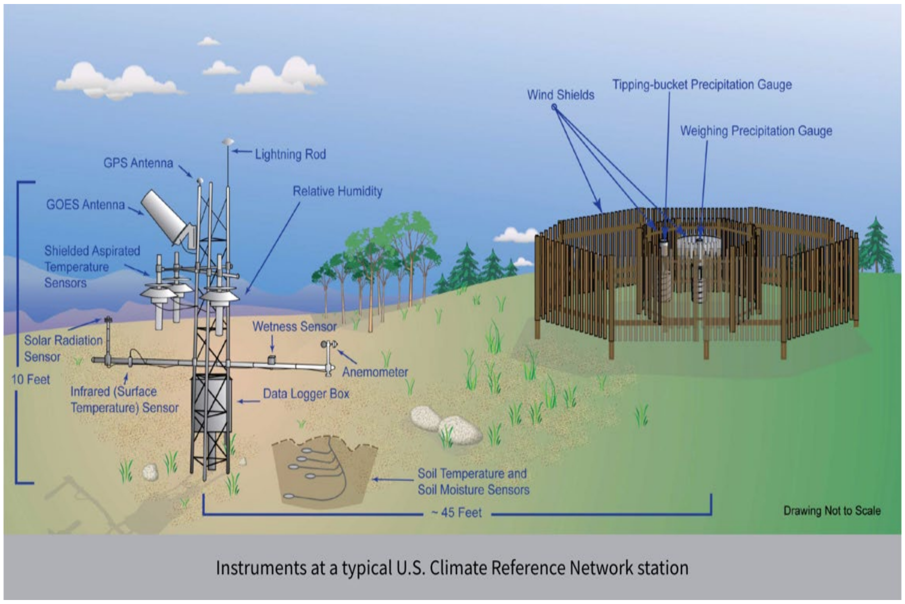


Figure 1. *Typical U.S. Climate Reference Network station instrumentation.*

Work during the past six months focused on annual instrumentation calibration and site maintenance performed at USCRN sites in Alabama, Arizona, California, Florida, George, Nevada, Texas, and Utah.

Planned work

• Continue instrumentation calibration and site maintenance for across the US including 23 sites in Alaska and 2 sites in Hawaii

• Installation of temporary towers near Prudhoe Bay (Alaska) in 2023

GOES-R-Based Products	
Task Team	Anand Inamdar, Ronald D. Leeper
Task Code	NC-SAS-07-NCICS-AI/RL

Highlight: Analyses using U.S. Climate Reference Network (USCRN) in situ data and data from the NOAA-operated Surface Radiation Network (SURFARD) revealed that changes in the daytime land surface temperature (LST) reflect changes in the Surface Solar Absorption (SSA) parameter under most sky conditions, with potential for filling in gaps in the LST time series retrieved from geostationary satellites.

Background

The CERES instrument is one of the best-calibrated sensors of the NASA Earth Observing System (optical emission spectrometer) era. The broadband shortwave (SW) radiometers provide a great opportunity for calibrating geostationary visible channels when employed in conjunction with radiative transfer simulations. Calibrating the NOAA GOES narrowband visible channels using the CERES broadband SW measurements as a reference also provides opportunities to estimate broadband fluxes from GOES narrowband channels and to employ the CERES subsystem's extensively validated top-of-atmosphere to surface flux algorithms. An extension of this to the GOES visible channel was successfully demonstrated in an earlier study using a narrowband-to-broadband conversion (Inamdar & Guillevic 2015).

Accomplishments

An algorithm to estimate surface solar absorption (SSA) in near real time using CERES FLASHFlux (Fast Longwave And SHortwave Radiative Fluxes) data was successfully implemented. Analyses were conducted using U.S. Climate Reference Network (USCRN) in situ data and the NOAA-operated Surface Radiation Network (SURFARD). Results show that changes in the daytime LST track the changes in the SSA parameter under most sky conditions. This has potential advantages for filling in time series gaps of LST retrieved from geostationary satellites such as GOES-R. Sample validation results (Figure 1) show that USCRN's Avondale, PA observations of hourly LST were lineally correlated with GOES-R estimated SSA measures during the morning (ascending) and afternoon (descending) periods on a partly cloudy day. SSA & GOES-R LST data was also loaded into a raster format to investigate gaps in the LST data and link SSA data with USCRN site in situ data.

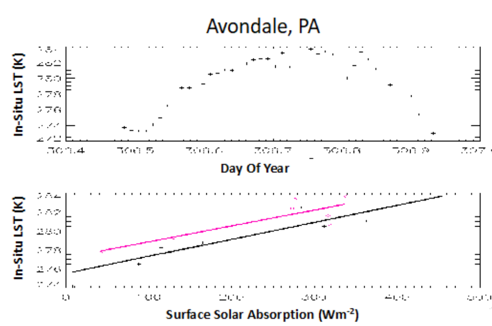


***Figure 1**. Hourly LST from USCRN's Avondale, PA station (top panel) and USCRN LST and GOES-R SSA pairs (bottom panel) showing their correlation for both ascending (black) and descending (magenta) branches on the November 2nd (306th day of year) 2019.*

Planned Work

- Process one of the latest months to derive SSA data to demonstrate near real time extraction

Other

- Student intern: Peyton Collado

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

Highlight: Three years (2011-2013) of EUMETSAT Metop-A satellite High-Resolution Infrared Radiation Sounder (HIRS) and Infrared Atmospheric Sounding Interferometer (IASI) instrumentation measurements were processed for use in generating HIRS-like data from the IASI sensor.

Background

The 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 EUMETSAT. It has provided valuable data for short-term weather prediction and is useful for deriving long time series climate data records (CDR) 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 satellites such as IASI and NOAA's Cross-track Infrared Sounder (CriS) data to extend the record of HIRS-like data into the future. The multi-step process includes: 1) developing the capability to process IASI and NOAA Cross-track Infrared Sounder (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

1) *Inter-instrument and inter-satellite calibration*
   An inter-instrument calibration methodology was developed and applied to three years (2011-2013) of IASI and HIRS data to generate calibration tables for each of the 12 HIRS channels as a function of the brightness temperature, orbit (ascending/descending), and cloudy/clear categories. Calibration results are very good as reflected in Figure 1 comparisons of brightness temperature differences (dBT) between HIRS/IASI and dBT values prior to and after calibration for the months of January and July.

2) *In-house production of IASI-simulated HIRS data*
   Software for producing IASI-simulated HIRS data from NOAA CLASS holdings was successfully implemented.

3) *In-house production of CrIS-simulated HIRS data*
   Software for producing IASI-simulated CrIS data from NOAA CLASS holdings was successfully implemented. Preliminary comparisons with HIRS showed good similarities.

4) *IHIRS Operational Production*
   Software for operational production of IASI-calibrated HIRS data (IHIRS) was developed and tested.

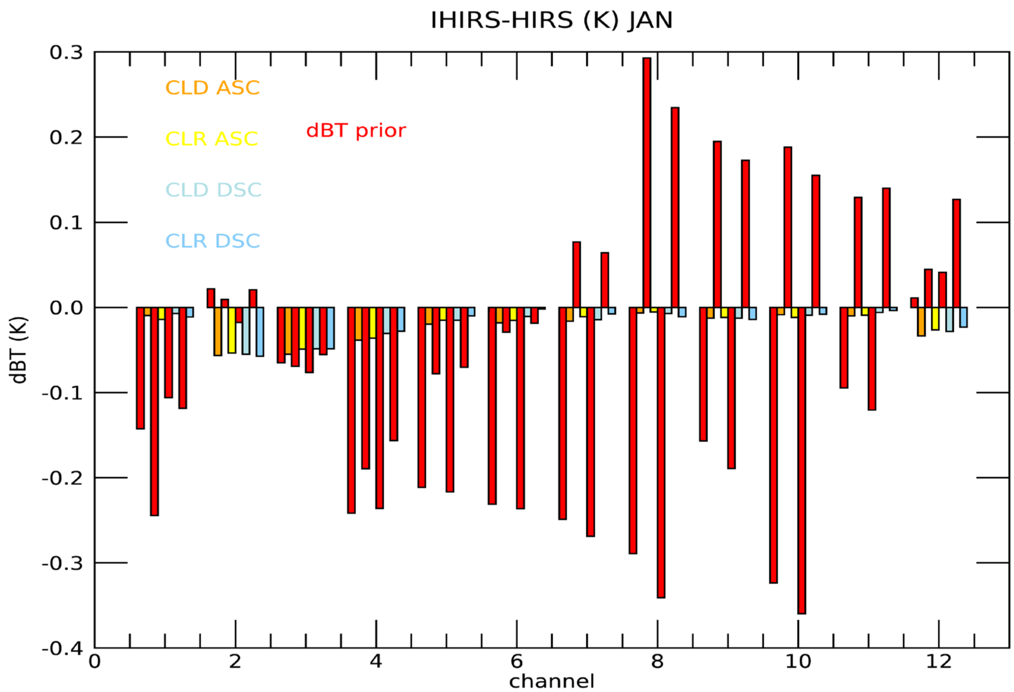


Figure 1. *Difference in brightness temperatures between calibrated HIRS (IHIRS) and HIRS before (shown in red) and after calibration for different categories of ascending (ASC), descending (DSC) orbits, and CLD (> 10% clouds), and clear (< 10% clouds), CLD ASC, CLR ASC, CLD DSC and CLR DSC for January (top) and July (bottom) for all channels 1 – 12.*

Planned work

- Reformat IHIRS data to make it consistent with the HIRS data and compatible for application of the neural network (nnHIRS) software to derive the atmospheric profiles of temperature and humidity
- Launch IHIRS data into operational production
- Publish project results
- Produce Cross-track Infrared Radiation Sounder (CrIS)-simulated HIRS data files and begin inter-instrument and inter-satellite calibration

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 NWS Office of Weather Prediction OWP research and development efforts utilizing new cloud technology, the incorporation of a new flying platform for the Airborne Gamma Snow Survey, as well as the development of new snow 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 U.S. 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-km² spatial resolution and hourly temporal resolution for the nation. 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 National Weather Service 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.

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, as well as daily snow briefings in support of the OWP Water Prediction Operations Division (WPOD).

Flood Inundation Mapping Ingest. As part of this effort using cloud technology, data in the form of text and modeled forecasts had to be ingested into the system. The text products were acquired, registered, and processed into database records that were used to feed the dynamic inundation mapping system.

National Snow Analyses to the Cloud. The second major project that the OWP is migrating to a cloud environment is the backup (secondary processing cluster) of the NSA system (www.nohrsc.noaa.gov), which is currently running on out-of-date hardware. Moving this processing to a hosted computing environment will allow, at minimum, parity with the primary cluster, in addition to potential expanded capabilities in the future combined with lower maintenance costs. This project is currently undergoing operator testing after completing all major configuration and software work. Successful implementation of this project will eventually lead to the migration of the primary processing cluster to the cloud environment.

Internal Water Resources Data Service Support. The OWP deploys many internal services that serve data towards operational product generation, model output evaluation, and other projects under development. The software that brings data into the system has been improved. It was made more resilient to host provider outages through dynamically switching to configurable backup sources as well as more bandwidth friendly through configurable throttling parameters and able to share with other fetching instances. This software is also used in other OWP projects.

Resiliency was also improved for other data streams used by the OWP (e.g., the satellite dish feed coming into the National Water Center). Used by Unidata's Local Data Manager software, virtual machines were set up to organize alternate data source streams that request data over the internet as hot backup when issues occur.

National Water Model Visualization Support. The OWP uses water.noaa.gov as a visualization and decision support tool for the output of the National Water Model. The system that acquires, reformats, and publishes these data for the website was upgraded to support the expanded processing domain of newer releases of the model. In addition, the processing software that serves up the corresponding web services to the map and hydrograph interfaces were made more resilient against service interruptions.

National Snow Analyses Support. In support of operational continuity, the software that makes up the NSA system (www.nohrsc.noaa.gov) whose primary processing cluster runs at the OWP office in Chanhassen, MN was updated with general performance and resiliency improvements. In addition to software modifications, the 24/7 operational continuity of the National Snow Analyses and SNODAS model system were 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. The NWS Airborne and Soil Moisture Mission was initiated in FY22 per NOAA's Aircraft Allocation Plan (AAP) and the National Weather Service Mission. The team coordinated 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, Middle Atlantic Forecast Center, and Ohio River Forecast Center during the snowmelt flood season of 2022. OWP was also 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 National Weather Service Weather mission.

- Evaluated and implemented the new King Air 350CER N67RF airborne platform to support the operational mission. RTI staff served as the SME and a mission crew member.
- Supporting Physical Services Laboratory joint project in the Study of Precipitation, the Lower Atmosphere and Surface for Hydrometeorology (SPLASH).

National Weather Center Water Prediction Operations Winter Hydrology and Remote Sensing Desk. In support of the OWP Water Prediction Operations Division (WPOD), team members participated and led daily Snow Briefings beginning on Nov 1, 2021, 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. Regular Snow Season updates were provided to the NWS Eastern Region Headquarters (18 weekly presentations) and to the Missouri River Basin River Forecast Center (4 bi-weekly presentations).

Planned Work

- Complete NSA Cloud system and replacement of the existing secondary processing system
- Continue evaluation of this system as hot backup during the snow season and prepare the primary replacement configuration
- Execute NWS Airborne Snow and Soil Moisture Mission tasks per NOAA's Aircraft Allocation Plan (AAP) and the NWS Mission
- Continued support of the NSA

New Products

- Operational Airborne Gamma Products from the new King Air 350 CER, N67RF
- Installation of 8 new flightlines in support of the PSL SPLASH project

Presentations

Olheiser, C., 2022: Overview of Olheiser's Career and Tips for Students. *Pathways Student Series*, virtual, Jan 12, 2022.

Olheiser, C., 2022: The Importance of Snow Observations. *National Weather Service Central Region Observational Services Virtual Conference*, January 19, 2022.

Olheiser, C., 2022: New Bird, New Challenges: The Calibration and Testing of the Airborne Gamma Snow Survey King Air 350CER. *2022 American Meteorological Society (AMS) Annual Meeting*, virtual, January 25, 2022.

Olheiser, C., Buan, S., Walvert, S., 2022: Winter Planning Meeting 2022. *St. Paul Corps of Engineers Spring 2022 Spring Hydrologic and Climate Meeting*, virtual, February 3, 2022.

Olheiser, C., 2022: Snow, Present, and Future - Overview of SNODAS. *Missouri River Forecasters Meeting*, virtual, February 16, 2022.

Rapid Attribution of Extreme Events in the United States	
Task Team	Kenneth Kunkel (Lead), Carl Schreck, David Coates
Task Code	NC-SAS-10-NCICS-AI

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 continental United States. Computations are done on the county-level and can be summarized into a single index representing the heat wave index for the entire county for a given day. https://ncics.org/pub/angel/hwi/

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 spatio-temporal 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, comprised 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 ARC research group, who allowed the use of their corrected 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 is based on the return interval and the percent coverage of each rank in the form

HWI=100 1rAcountyACONUS

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 parse-able 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 U.S. 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.

Planned work

- Scaling up the heat wave index algorithm to be run on cloud computing services, improving computation speed
- Full automation of the data merging, ranking, and index calculation processes
- Continuation of the heat wave index computation to cold events
- Begin analyzing extreme precipitation events
- Further development of the index itself, shifting from a simple land-weighted ranking to include the standardized anomaly as an additional magnitude weight
- Use and development of other climate datasets for their historical contexts
- Determine the cause of the differing correlations between temperature and precipitation between the southern and northern U.S.

Publications

Barsugli, J. J., and Coauthors [including **D. A. Coates**, **K. E. Kunkel** and **C. J. Schreck**], 2021: Development of a NOAA Rapid Response Capability to Evaluate Causes of Extreme Climate Events. *Bulletin of the American Meteorological Society*, **103**, S1–S7.

Presentations

Kunkel, K. E., 2021: Machine Learning-Based Feature Detection to Associate Precipitation Extremes with Synoptic Weather Events. *2021 AGU Fall Meeting,* New Orleans, LA*,* December 12, 2021.

Kunkel, K. E., D. A. Coates, D. R. Easterling, D. Arndt, J. Barsugli, T. Delworth, M. Hoerling, N. Johnson, A. Kumar, C. Schreck, R. Vose, and T. Zhang, 2021: Historical Perspective on the 2021 heat waves in western United States. *2021 AGU Fall Meeting,* New Orleans, LA*,* December 16, 2021.

Kunkel, K. E., D. A. Coates, D. R. Easterling, D. Arndt, J. Barsugli, T. Delworth, M. Hoerling, N. Johnson, A. Kumar, C. Schreck, R. Vose, and T. Zhang, 2022: Historical Perspective on the 2021 heat waves in the western United States. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 27, 2022.

Products

- Data formatting, merging, and sorting algorithm for nClimGrid data
- Computational program for heat/cold wave indices
  https://ncics.org/pub/angel/hwi/

U.S. Climate Reference Network (USCRN) Applications and Quality Assurance	
Task Leader	Ronald D. Leeper
Task Code	NC-SAS-11-NCICS-RL

Highlight: Following an additional quality control check, Acclima sensor soil moisture and temperature observations were made available through the USCRN's soil moisture and temperature related products. USCRN precipitation observations were applied to evaluate the quality of NEXRAD estimates for high latitude regions of Alaska. Hourly Precipitation Dataset's (HPDs) extreme precipitation event evaluations revealed greater than expected frequencies for 1-, 2-, and 5-year return intervals similar to USCRN.

Background

The U.S. Climate Reference Network (USCRN) is a systematic and sustained network of climate monitoring stations deployed across the contiguous United States, Hawaii, and Alaska. These stations use high-quality calibrated instrumentation to measure temperature, precipitation, wind speed, soil (temperature and moisture) conditions, humidity, land surface (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 U.S. This transition is expected to occur over several years as the new *Acclima* sensors gradually replace the original *HydraProbe* sensors.

Accomplishments

Soil. The *Acclima* sensor evaluation and review of the sensor impacts on USCRN products were completed in the summer of 2021 with results presented to the National Coordinated National Soil Moisture Network (NCNSMN). The *Acclima* the sensors' soil moisture records were re-quality controlled following the discovery and subsequent resolution of a scaling issue that impacted most stations within the network. Following these additional QC steps, the *Acclima* sensor observations were made live and allowed to populate the network's soil moisture and temperature related products.

Precipitation. Precipitation extremes for both USCRN and the Hourly Precipitation Dataset (HPD) and their frequency of exceedance against NOAA Atlas-14 thresholds were updated. A nearest-neighbor analysis was completed to evaluate the importance of network density on the detection of extreme conditions and if the more recent period has a higher likelihood exceedance. Comparisons between USCRN and HPD (Figure 1) revealed that station density had little overall influence on the frequency of precipitation extremes with HPD stations located at USCRN sites (98 stations) having similar frequency of exceedances as the whole HPD network (+1900 stations). Overall, both networks reported a greater number of extreme events than expected based on NOAA-Atlas 14 return intervals. This was particularly true of sub-daily durations, which diminished slightly for longer durations.

USCRN precipitation observations were also utilized in a study evaluating the quality of high latitude NEXRAD radar estimates of precipitation. These comparisons revealed NEXRAD under-reported precipitation estimates during frozen and mixed precipitation regimes with some of the largest biases detected during freezing conditions. In addition, efforts continued to support the evaluation of precipitation climate data records and remotely sensed precipitation datasets.

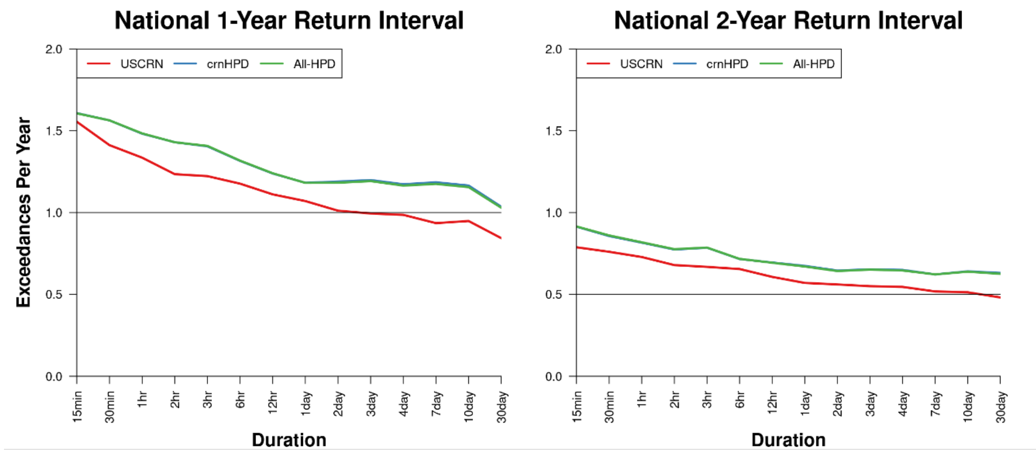


Figure 1. *Area weighted National averaged rates of extreme precipitation events per year for the 1- (left) and 2-year (right) return intervals by duration for USCRN (red), HPD stations nearest to USCRN stations (crnHPD; blue), and all HPD stations (green).*

Planned work

- Continue efforts to recalculate *Hydra*-based volmetric observations using station specific soil characteristics.
- Summarize the HPD and USCRN frequency of NOAA-Atlas 14 exceedence results in a paper**.**

Publications

Nelson, B. R., **O. P. Prat**, and **R. D. Leeper**, 2021: An Investigation of NEXRAD-Based Quantitative Precipitation Estimates in Alaska. *Remote Sensing*. doi.org/10.3390/rs13163202

Standardization of U.S. Climate Reference Network (USCRN) Soil Moisture Observations	
Task Leader	Ronald D. Leeper
Task Code	NC-SAS-12-NCICS-RL

Highlight: USCRN's soil moisture standardization (soil climatologies and anomalies) and drought index products were transitioned to operations and are now publicly available on the web and updating in near-real time. Analysis of the European Space Agency's (ESA) standardized remotely sensed soil moisture data was found to capture the timing and severity of both dry and wet extremes; however, there were higher measures of daily variability over the satellite pixel.

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. These challenges have been overcome by placing measurements into historical context, a technique referred to as standardization. The short-term (less than 10 years) standardization method has been applied to all soil-moisture-observing USCRN stations and made available at five depths (5, 10, 20, 50, and 100 cm) as well as Top (5 and 10 cm) and Column (5 through 100 cm) layer aggregates, resulting in soil moisture climatologies, anomalies, and percentiles that augment station observations.

Accomplishments

USCRN standardized soil moisture observations and U.S. Drought Monitor (USDM) based drought events were compared. A key finding of this analysis was that soil moisture anomalies and fraction of hours below the 30th percentile (drought hours) was often (+80% of the time) a leading indicator of drought onset (Fig 1). This was particularly true of shorter aggregation periods (Weeks 1 and 2) for near-surface (5cm, 10cm,

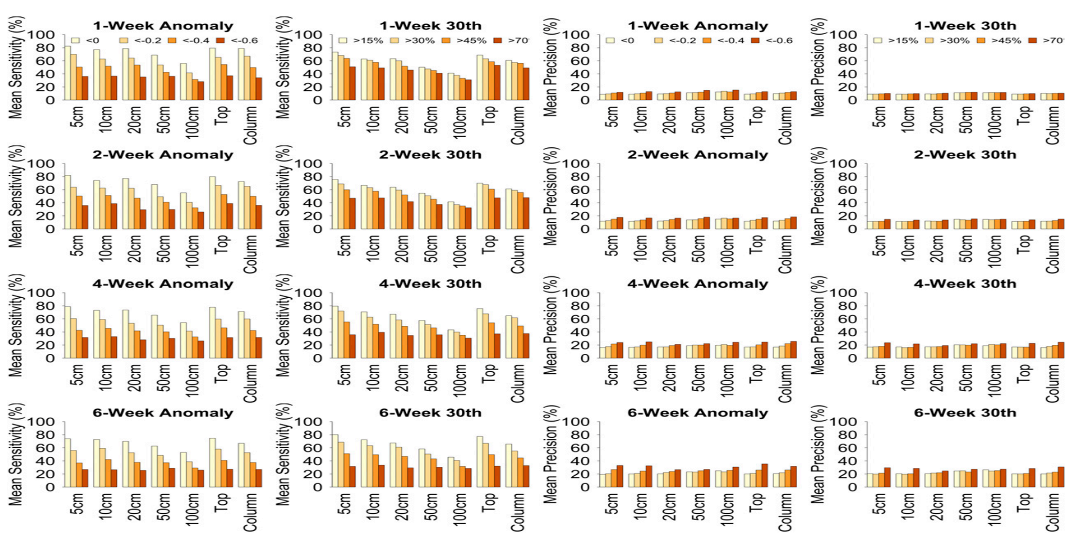


Figure 1. *Performance metrics (left),(left center) sensitivity and (right center),(right) precision for the (top) 1-, (top middle) 2-, (bottom middle) 4-, and (bottom) 6-week averaged standardized anomaly and fraction of hours below the 30th-percentile thresholds ending the week prior to drought onset.*

and Top layer) observations. However, lower levels of precision suggest that there were times when soil moisture conditions indicated drought onset, but no drought was detected by the USDM, which likely reflects the convergence of evidence approach that considers moisture deficits across the hydrological cycle.

Standardized measures of the European Space Agency's (ESA) combined remotely sensed soil moisture dataset was found to temporally align and have similar levels of intensity as USCRN stations during both the pluvial event in 2019 over the Upper Midwest and the 2012 drought (Fig 2). However, the satellite data tended to have some higher levels of variability that may be related to grid to pixel differences.

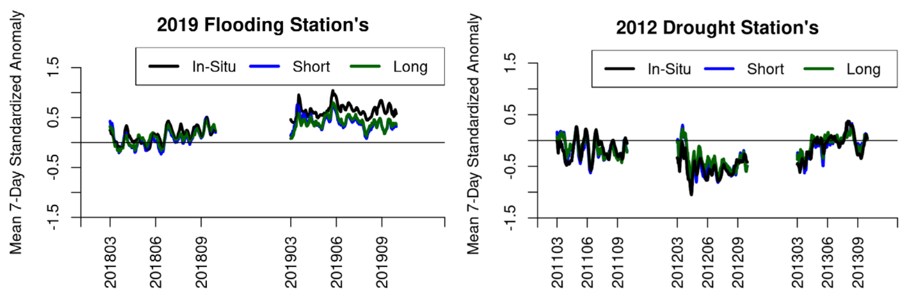


Figure 2. *Soil moisture anomalies from the USCRN (black) and ESA's short (10-year; blue) and long (30-year; green) term datasets for a flooding event in the Upper Midwest (left) and the Central U.S. drought in 2012 (right).*

CISESS NC served as science advisor for a NASA Develop team project looking into comparisons between in-situ, NASA Sport modeled, and SMAP observed soil moisture conditions across Illinois during hydrological extreme events. This project revealed important deviations in volumetric soil moisture related to soil characteristics and localized factors (i.e., slope, overlaying vegetation) that were particularly notable for NASA Sport. Overall, the three separate perspectives on soil moisture (in-situ, modeled, and remotely sensed) generally agreed well for most stations.

Planned work

- Publish drought climatology paper
- Summarize results from the ESA satellite analysis in a submitted manuscript
- Begin exploring the utility of standardized soil moisture datasets as an indicator for wildfire fuels

Products

- Hourly standardized soil moisture climatologies for each depth (5, 10, 20, 50, and 100cm) in addition to a Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates. https://ncei.noaa.gov/pub/data/uscrn/products/soil/soilclim01
- Hourly standardized soil moisture anomalies for each depth (5, 10, 20, 50, and 100cm) in addition to a Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates. https://ncei.noaa.gov/pub/data/uscrn/products/soil/soilanom01
- Seven day moving average of standardized soil moisture anomalies and faction of hours below the 30th percentile (drought hours) and above the 70th percentile (recovery hours) for each depth (5, 10, 20, 50, and 100cm) in addition to a Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates. https://ncei.noaa.gov/pub/data/uscrn/products/drought01

Publications

Leeper, R. D., B. Petersen, M. A. Palecki, and H. Diamond, 2021: Exploring the use of Standardized Soil Moisture as a Drought Indicator. *Journal of Applied Meteorology and Climatology*. doi.org/10.1175/JAMC-D-20-0275.1

Presentations

Leeper, R. D., 2022: An Evaluation of Remotely Sensed Standardized Soil Moisture during Hydrologically Extreme Conditions. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 25, 2022.

Leeper, R. D., 2022*:* Standardized satellite data captured trends in in-situ soil moisture during drought and flood conditions. Poster. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 25, 2022.

Leeper, R. D., 2022: An Overview of USCRN Soil Monitoring and Research. *Southeast Drought Early Warning System (DEWS) Soil Moisture Technical Workshop,* virtual, March 2, 2022.

Other

- NASA Develop interns: Emma Myrick, Joshua Green, Julia Marturano, Kyle Pecsok, and Victor Lange (mentored by Leeper)

NCEI INNOVATES 2020 - Machine Learning Based Quality Control: USCRN Soil Moisture and Temperature Test Case	
Task Team	Ronald D. Leeper, Garrett Graham
Task Code	NC-SAS-13-NCICS-RL/GG

Highlight: The non-deep learning phase of the U.S. Climate Reference Network (USCRN) machine learning-based anomaly detection project demonstrated that decision tree-based machine learners can successfully detect and classify anomalies in USCRN soil moisture time series data. The multiclass anomaly detectors were able to distinguish between anomalous and normal data 91.4% of the time and successfully distinguished between individual classes of anomalies.

Background

The USCRN utilizes more than 1500 soil moisture sensors in its network of climate monitoring stations across the continental United States. To ensure high-quality observations, the hourly soil moisture data points are manually quality controlled, which requires up to 60 hours of labor per month. In addition to its high labor-hours cost, the manual QC process can result in over-flagging, which can occur when many anomaly flags are dispersed across the time series. The scientific task team's goal is to develop an automated, machine learning-based anomaly detection method to augment the manual quality control checks of the data. Such a machine learning algorithm would decrease the amount of time needed to quality control the soil moisture data while improving the resulting data set by reducing over-flagging.

Accomplishments

The multiclass anomaly detectors were trained on manually flagged USCRN soil moisture data from 2017-2020. Two different decision tree-based training algorithm models were tested: random forests and XGBoost. While both types of algorithms performed well, the XGBoost detectors displayed slightly better performance when distinguishing between normal/unflagged data, data displaying spike anomalies, and data displaying noise anomalies, correctly flagging 91.4% of all time points. The algorithms were slightly better at identifying sensor noise than they were sensor spikes (92.2% of the time for noise versus 88.8% of the time for spikes; see Fig. 1 and Fig. 2). Most of the identification errors occurred when the algorithms misidentified anomalous data as normal, rather than confusing the classes of anomalous data as summarized in a test confusion matrix (Fig. 3). The confusion matrix represents the averaged testing results from a course of 10-fold stratified cross-validation using an optimized XGBoost classifier. After training a classifier with pre-identified optimal hyperparameters on the ten distinct combinations of training folds, the classifier was tasked with classifying those data from each combination's testing fold. The classification results were summed together and divided by the total number of testing examples, resulting in an averaged view of the classifier's behavior with respect to data it had been trained upon.

After proving that decision tree-based methods could successfully detect anomalous time points, the scientific task team investigated utilizing deep learning-based anomaly detection methods that could take advantage of the time series' history to identify anomalies. The team selected a variational autoencoder-long short-term memory network (VAE-LSTM) method to accomplish the initial phase of the deep learning portion of the project. VAE-LSTM methods are semi-supervised methods that only require being trained on normal, non-anomalous data to recognize anomalies. VAE-LSTMs have been successfully used in other fields for anomaly detection. The team successfully trained a preliminary VAE-LSTM learner that identifies anomaly windows for a single sensor, without the benefits of ever having been shown anomalies for the USCRN sensor network. In addition, the VAE-LSTM code base was successfully migrated to Amazon Web Services (AWS), where the deep learning-adapted graphical processing units (GPUs) provided on AWS' EC2 instances (Fig. 4) can be utilized.

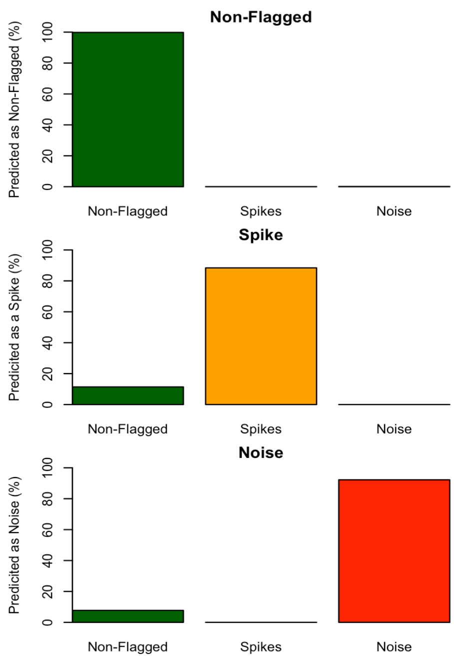


Figure 1. *The percentage of predicted non-flagged, spike, and noise for manually identified non-flagged (top), spike (middle), and noise (bottom) conditions.*

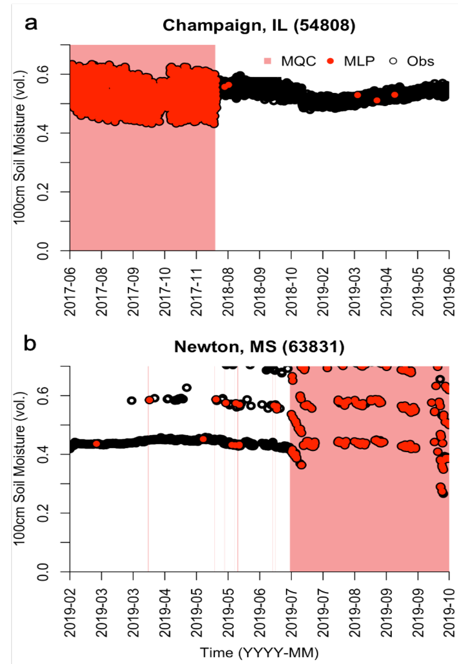


Figure 2. *Manual QC (MQC, red shading) and machine learning predicted (MLP, red dots) soil moisture quality Control flagging of observed (black dots) soil moisture conditions from (a) a noisy sensor at Champaign, IL and (b) data spikes at Newton, MS sites.*

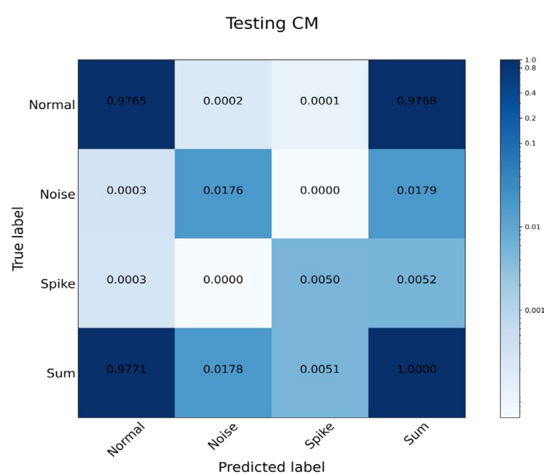


Figure 3. *Testing confusion matrix for XGBoost multiclass classifier. The confusion matrix represents the averaged testing results from a course of 10-fold stratified cross-validation using an optimized XGBoost classifier. The matrix represents how the classifier is expected to perform on as-yet-unseen data from the USCRN soil moisture sensor network. As can be seen from the preponderance of on-diagonal elements, the classifier generalizes extremely well to novel soil moisture data, with only rare instances of mislabeling anomalous data as normal and vice versa. These results suggest that, even when using a classification algorithm that is unable to take advantage of the historical context of the sensor data, our classifiers are still able to flag anomalous data much more quickly than a human operator could.*

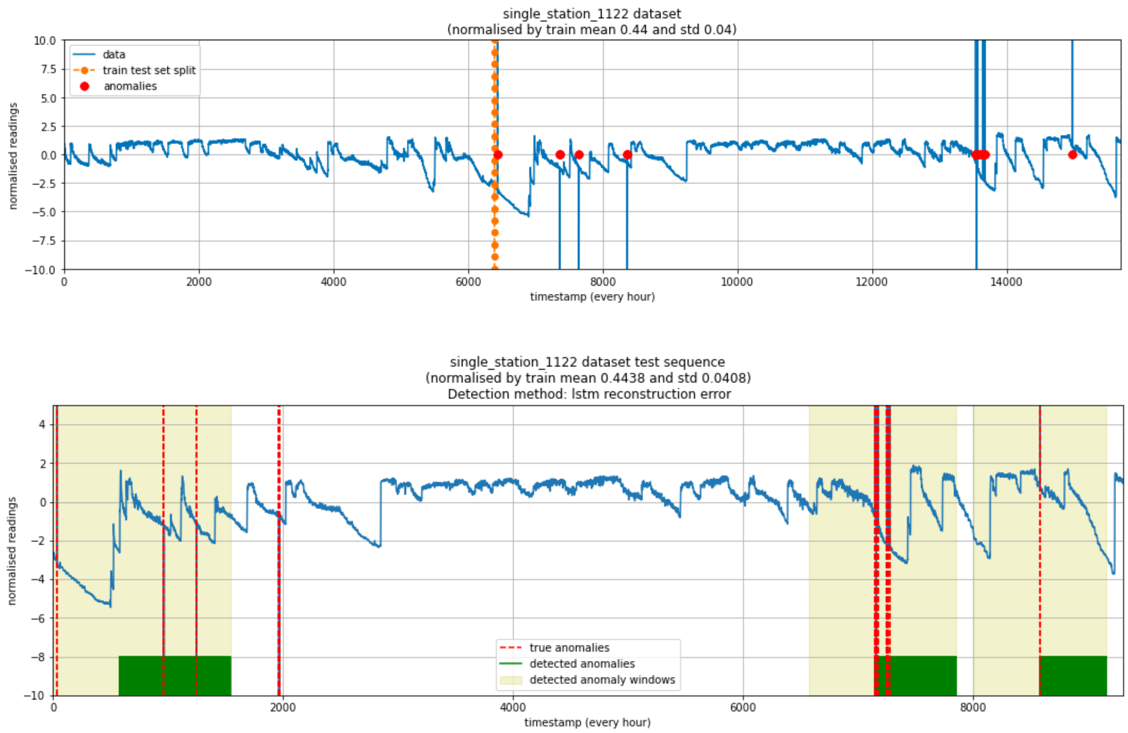


Figure 4. *The preliminary results of a GPU-trained VAE-LSTM deep learning anomaly detection algorithm. The top panel shows the structure of the time series from a single soil moisture sensor at over 18 months. The red dots indicate the presence of anomalies at those time points. All data to the left of the vertical orange dashes indicates the training data, which contains no anomalies. The data to the right of the vertical orange dashes is the testing data, which contains seven anomalies. The bottom panel shows the VAE-LSTM's preliminary anomaly detection results, with the vertical red dashes indicating actual anomalies, green boxes indicating VAE sequences and tan boxes indicating LSTM windows that were flagged anomalous. The scientific task team will be working to optimize the deep learning detector to narrow these windows and allow it to classify the anomaly types.*

Planned work

- Improve the VAE-LSTM's detection abilities by training across the full USCRN soil moisture data set and optimizing the detector's hyperparameters
- Move to an improved deep learning and/or machine learning ensemble model with the capacity to not only detect anomalies, but also to classify the anomaly types

Presentations

Leeper, R. D., 2021: Soil Sensor Transitions and Machine Learning as a Quality Control Strategy; USCRN Research Applications. *National Soil Moisture Workshop,* virtual, August 18, 2021.

Graham, G., R. D. Leeper, and Y. Rao, 2021: USCRN Anomaly Detection Team. NOAA-NVIDIA GPU AI Hackathon 2021, virtual, August 23-31, 2021.

Graham, G., 2021: A Feasibility Study on the Use of Machine Learning as a Quality Control Strategy. *3rd NOAA AI Workshop*, virtual, September 15, 2021.

Leeper, R. D., G. Graham, and Y. Rao, 2022: An Evaluation of Machine Learning Techniques to Quality Control Soil Moisture Observations. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 26, 2022.

Evaluation of air and soil temperatures for determining the onset of growing season	
Task Team	Ronald D. Leeper, Jessica Matthews
Task Code	NC-SAS-14-NCICS-RL/JM

Highlight: A study exploring the role and importance of soil moisture conditions in determining growing start dates was completed with mixed results. These results suggest that inter-annual anomalies of soil moisture, while useful for drought monitoring, may not explain plant stresses related to water availability.

Background

Climate observations of growing season are essential for understanding plant phenology and physiological development. Air temperature has traditionally been used to define the onset and end of the growing season when phenology measurements are not available. However, soil temperature conditions have recently been shown to be an indicator of root nutrient uptake and vegetative growth. Using start of season (SOS) estimates derived from remotely sensed MODIS normalized difference vegetation index (NDVI) data, comparisons were made with in situ-based SOS estimates from air, surface, and soil temperatures as measured by the U.S. Climate Reference Network (USCRN).

Accomplishments

Additional analysis exploring the role of soil moisture in explaining growing season onset dates, as recommended by reviewers, were mixed. These results suggest that inter-annual anomalies of soil moisture, while useful for drought monitoring, may not explain plant stresses related to water availability. For instance, it is still possible to be drier than usual and have enough moisture within the soil to support an active vegetation layer.

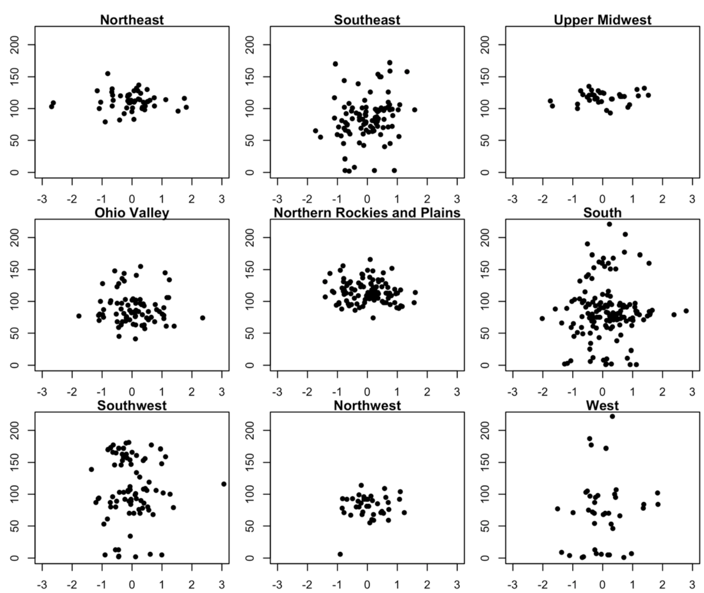


Figure 1. *Regional scatter plots of standardized soil moisture anomalies (x-axis) with SOS_{NDVI} dates (y-axis). Negative standardized soil moisture anomalies indicate drier than usual while positive values represent wetter than usual soil moisture conditions at the time of SOS_{NDVI}.*

Publications

Leeper, R. D., **J. L. Matthews**, M. S. Cesarini, and J. E. Bell, 2021: Evaluation of air and soil temperatures for determining the onset of growing season. *Journal of Geophysical Research: Biogeosciences*. doi.org/10.1029/2020JG006171

Exploring the Impacts of Drought Events on Society	
Task Leader	Ronald D. Leeper
Task Code	NC-SAS-15-NCICS-RL

Highlight: An evaluation of drought impacts on the severity and duration of heatwaves at USCRN locations was initiated. Overall results indicate that drought events increase the duration of heatwaves by 1 to 3 days or 20 to 60% longer than typical. This analysis was extended to U.S. Counties to explore the impacts of compound events on human health metrics (hospitalization) in the Carolinas.

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 based on a specific application: meteorological, agricultural, or hydrological. This approach can make drought characteristics assessment and linking drought to adverse societal outcomes a challenge. 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 U.S. 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 that provide measures of exposure to specific types (i.e., precipitation, soil moisture, evaporation, stream flow etc.) of moisture deficits.

Accomplishments

Analysis was completed exploring precipitation conditions during phases of drought intensification (onset to the first week of peak drought status) and amelioration (last week of peak drought status to termination). This was in addition to a flash drought analysis which reflected more frequent flash drought events over the Southeast U.S. (Fig 1) and rapid intensification in the first 5-weeks since drought onset for 94.9% of all flash droughts (Fig 2).

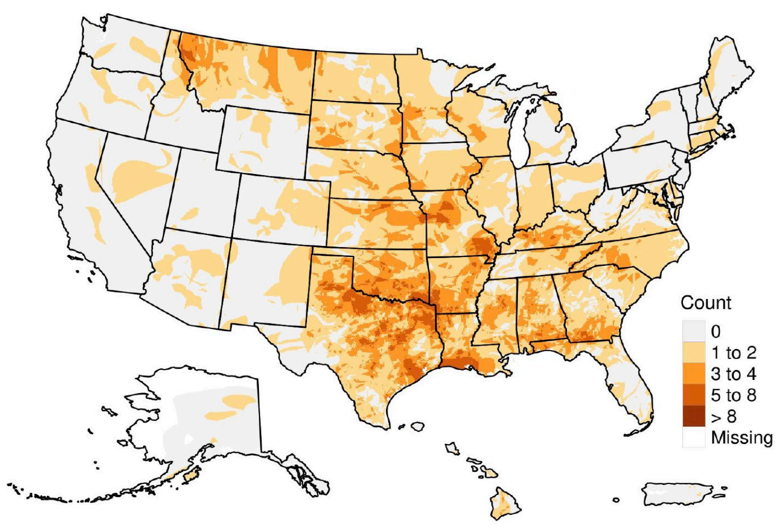


Figure 1. *The count of flash drought events where increases of three or more USDM statuses occurred within a five-week period from 2000 through 2019.*

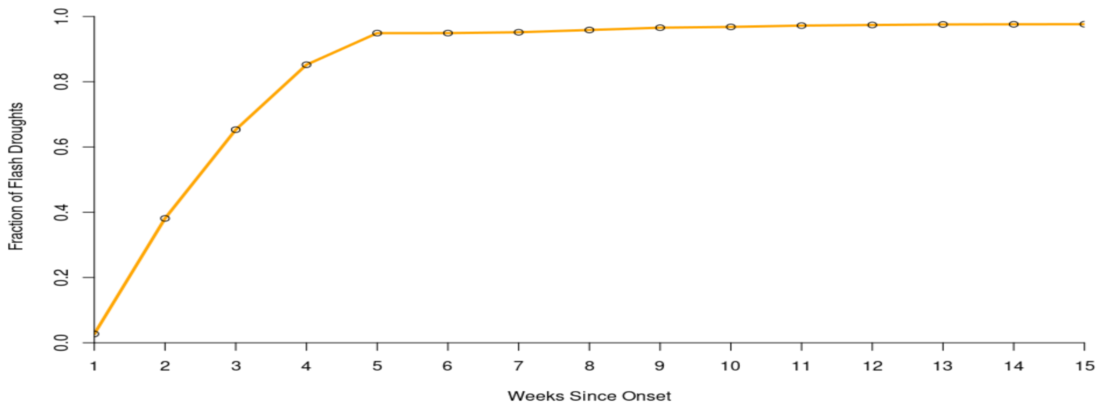


Figure 2. *The fraction of flash droughts that experienced rapid intensification by weeks since drought onset.*

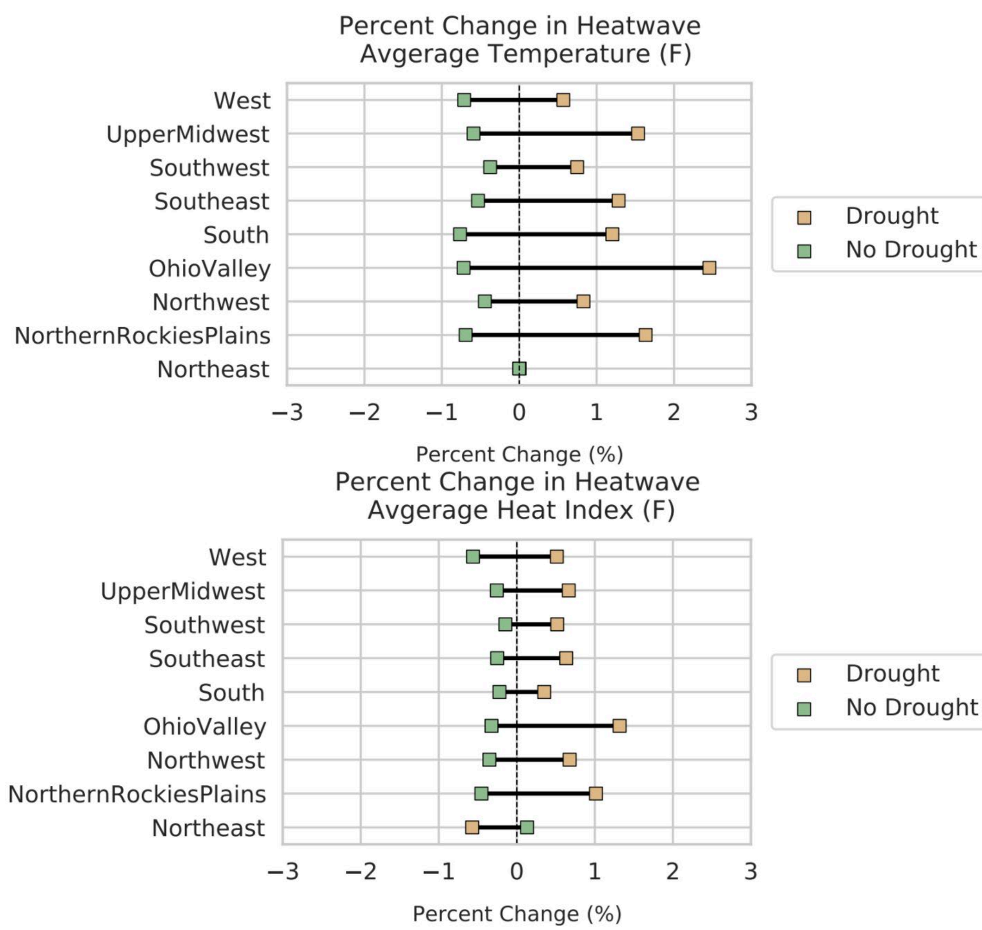


Figure 3. *Percent change in heatwave intensity from mean conditions for no drought and drought heatwaves based on air temperature (top) and heat index (bottom).*

An exploration of drought impacts on the severity and duration of heatwaves at USCRN locations was initiated. Overall results indicate that drought events increase the duration of heatwaves by 1 to 3 days or 20 to 60% longer than typical. Droughts were also found to increase the severity of heatwaves by several percentages (Fig 3), which was slightly less for the heat index-based heatwaves. This is thought to be due to the increase in evaporative demand during drought events, which results in a cooling effect for the heat index.

Two Appalachian State University (ASU) student-lead projects were conducted during the year in collaboration with CISESS NC and ASU and NCSU colleagues. The first project explored the spatial temporal trends in Palmer Drought Severity Index (PDSI) conditions using self organized maps from 1895 to 2016. This analysis revealed 12 of the most common drought patterns. An additional study assessed the vulnerability of populations to hydroclimatic extremes in Appalachia based on population demographics.

Planned work

- Continue to evaluate the impacts of heatwaves on drought duration and severity
- Summarize evaluations of the impacts of droughts on heatwave duration and severity and heatwave influences on drought duration and severity in a scholarly publication
- Explore the impacts of compound hazards on human health in the Carolinas

Publications

Handwerger; L. R., **J. D. Runkle, R. D. Leeper**, E. Shay, K. Dempsey, M. M. Sugg, 2021: An Assessment of Social and Physical Vulnerability to Hydroclimate Extremes in Appalachia. Research Square (on-line). doi.org/10.21203/rs.3.rs-469519/v1

Other

- Interns: Tyler Harrington (University of Massachusetts Lowell) and Kelley DePolt (East Carolina University) mentored by CISESS scientists Ronald Leeper and Jennifer Runkle

HIRS Temperature and Humidity Profiles	
Task Team	Jessica Matthews, Yuhan (Douglas) Rao
Task Code	NC-SAS-16-NCICS-JM/YR

Highlight: The team is applying neural networks to High-Resolution Infrared Radiation Sounder (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, 2m, 1,000mb, 850mb, 700mb, 600mb, 500mb, 400mb, 300mb, 200mb, 100mb, and 50mb) and humidity at 8 different altitudes/pressures (2m, 1,000mb, 850mb, 700mb, 600mb, 500mb, 400mb, 300mb) using High-Resolution Infrared Radiation Sounder (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 Television Infrared Observation Satellite Operational Vertical Sounder) data based on more than 62,000 profiles from the European Centre for Medium-Range Weather Forecasts 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, U.S. Geological Survey 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, as 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-meter 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-meter 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) leveraging the surface and 2-meter temperatures to create a blended product along with in situ observations, where the HIRS-based data can be especially useful to improve spatial coverage in regions where in situ stations are sparse (e.g., Arctic, Africa).

A primary user of the dataset, the International Satellite Cloud Climatology Project (ISCCP), requested extension of the dataset through 2020. 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, was used to produce the dataset extension. The team also started the processing of N19 data after 2019 to extend HIRS data into 2020.

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.

Previous analysis of the version 4 HIRS profile data revealed that the cloud-screening process is too conservative, which led to limited data availability over ocean. The team has been developing a new cloud-screening procedure using the PATMOS-x cloud property CDR. The new cloud screening procedure uses the spatial average of cloud fraction and probability from PATMOS-x CDR data within the spatial window that matches the HIRS pixel footprint instead of the nearest PATMOS-x pixel. When there is no PATMOS-x data available for the corresponding HIRS data, the cloud screening is executed using the spatial homogeneity test from version 4 HIRS 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.

Planned work

- Complete development of a new dataset version and produce reprocessed time series of HIRS temperature and humidity profiles to present
- 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 International Satellite Cloud Climatology Project and NASA's Surface Radiation Budget Team)

Publications

Cheng, S., B.A. Konomi, **J.L. Matthews**, G. Karagiannis, and E. Kang, 2021: Hierarchical Bayesian Nearest Neighbor Co-Kriging Gaussian Process Models; An Application to Intersatellite Calibration. *Spatial Statistics*. doi.org/10.1016/j.spasta.2021.100516

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-17-UNCA

Highlight: Completed summer and fall 2021 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 National Park Rain Gauge Network (Duke GSMRGN).

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, NOAA's National Environmental Satellite, Data and Information Service (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 2021 (1 July – 6 August) and fall 2021 (8 October–6 November). Volunteers accompanied student technicians to assist with personal safety (should someone become injured during a particular series of gauge visits) but were not directly involved in gauge visit tasks. The primary purpose of each gauge visit 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 2021: 1 July – 6 August

The field supervisor, six undergraduate students, and one volunteer at the Waynesville Watershed, completed the gauge visits and performed the required work. This was the second summer season that uniform electronic contact cleaning was performed at every rain gauge between the logger leads and the gauge switch connector. Over the 13+ years, residue had built up to a significant point that multiple gauges were experiencing a significantly reduced number of 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 #107; Lookout Point, g #106; Pinnacle Ridge, g #307; Balsam Mtn Trail, g #005; Deep Gap]. This must be monitored and, if problems persist, old loggers will need to be replaced.
- Voltage level on every rain gauge data logger was satisfactory (no battery replacements needed).

Specialized tasks completed:

- *Pivot bolt replacement.* A sheared pivot bolt at Gauge #304 (due to fatigued metal in the bolt supporting the tipping bucket) required replacement with an improvised pivot bolt on day of discovery in July. A proper replacement was made during the autumn 2021 visit.
- *Gauge cover stainless steel nut replacement.* Gauge #010 was found to have the threads stripped in one bolt port, requiring the installation of a stainless steel nut to secure the bolt to the gauge base.
- *Inoperable rain gauges.* Two gauges had periods of no reports due to one (#110) having been pushed over by a bear and the other (#005) being inhabited by a family of three mice.
- The mouse nest discovered inside the gauge was the first in the Duke GSMRGN 14 years history. Close inspection of the impacted rain gauge record (#005) to the two nearest gauges (#002 and #008) shows it is likely the mice "moved in" after 24 July 2021. The nest was discovered 6 August 2021.

The primary challenges encountered during some of the gauge visits in the summer 2021 centered around the active convection season on and after 9 July 2021. No data was lost between the spring and summer 2021 gauge visits other than at the two locations impacted by wildlife. However, continuous coverage will continue to be a challenge between the autumn and spring visits at a handful of gauges with ML1-FL loggers. It is likely these will have to be gradually replaced over the upcoming years of the study. 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.

Fall 2021: 8 October – 6 November

Eleven 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 five ML1 loggers ([g #112, g #107, g #106, g #110, and g #306), resulted in a shutting off of the TA command, in the hope the loggers will self-correct during the spring 2022 gauge visits.
- *Rain gauge #110* was again found knocked over (by a bear) in autumn 2021 and a motion-activated alarm was installed to discourage the bear from future 'interventions.' Continued problems will require the installation of ammonium-filled balloons in the spring 2022.
- *Rain gauge and base at g #005* was found knocked over by a bear (twice) in autumn 2021. Don E., the Waynesville Watershed assistant, re-leveled the gauge on 13 September and the gauge was again re-leveled during the 5 November 2021 visit. Repeated tip-overs will require the installation of motion-activated alarms and/or ammonium-filled balloons.
- *Underreported rain accumulation (low tip count)* was found at g #111 [8 October 2021], similar in behavior to what was found earlier in the study at g #106 and g #109. The consistent low tip count, even after electronic contact cleaning in the summer 2021, suggested a problem with the switch, which was replaced during the 8 October 2021 visit.
- *Replaced data logger* at g #308 with a new ML1-FL data logger.

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 2021–2022 academic year technician roster includes Meredith Avison, Marlee Burgess, Jackson Coley, Daniel Fairchild, Michelle Hauser, Sarah Langille, Alice Monroe, Zachary Moss, Samuel Peterson, Taylor Ross, Paige Stedina, and Joshua Ward. New students will be recruited in fall 2022, as seven students will graduate from UNC Asheville in May 2022.

Planned work

Spring 2022 (March – May) gauge visitation

• Scheduled data collection and regular gauge maintenance activities
• Calibration of all rain gauges (last calibration completed in Spring 2021)

Summer (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 2021: http://www.atms.unca.edu/dmiller/GSMRGN_report_10august2021.pdf https://drive.google.com/file/d/1k4HRCvP8PpmbJ9-Xv3jABzX3q70aZ4Rn/view?usp=sharing
    - Fall 2021: http://www.atms.unca.edu/dmiller/GSMRGN_report_15november2021.pdf https://drive.google.com/file/d/1AosZm1Rimn3-VU68K-78BW2vp9vHOLfV/view?usp=sharing

Publications

Miller, D., J. Forsythe, S. Kusselson, W. Straka III, J. Yin, X. Zhan, and R. Ferraro, 2021: A Study of Two Impactful Heavy Rainfall Events in the Southern Appalachian Mountains during Early 2020, Part I; Societal Impacts, Synoptic Overview, and Historical Context. *Remote Sens. 13*, 2452. doi.org/10.3390/rs13132452

Miller, D., M. Arulraj, R. Ferraro, C. Grassotti, B. Kuligowski, S. Liu, V. Petkovic, S. Wu, and P. Xie, 2021: A Study of Two Impactful Heavy Rainfall Events in the Southern Appalachian Mountains during Early 2020, Part II; Regional Overview, Rainfall Evolution, and Satellite QPE Utility. *Remote Sens. 13*, 2500. doi.org/10.3390/rs13132500

Presentations

Makowski, N. and K. Peco, 2022: The Influence of Climate Change on Locally-Produced Thunderstorm Genesis in the Southern Appalachians. *2022 American Meteorological Society (AMS) Annual Meeting*, New Orleans, LA, January 22, 2022.

Other

- Bob Kuligowski's (NESDIS/STAR) group continues to use Duke GSMRGN observations as part of their research validation efforts. Observations of the Duke GSMRGN were one of the cornerstones for interpreting the severity and timing of the two flooding events reflected in the two-part paper led by PI Miller.
- Twelve UNC Asheville undergraduate students received field research credit for project activities.
- Two undergraduate REU students (Nathaniel Makowski and Kyle Peco) worked on a research project utilizing observations of the Duke GSMRGN in summer 2021.

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.

Drought Detection and Relief Using In-Situ Data from NClimGrid	
Task Team	Olivier Prat, David Coates, Ronald D. Leeper, Scott Wilkins
Task Code	NC-SAS-18-NCICS-OP/DC/RL/SW

Highlight: The Standardized Precipitation Index (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 5x5-km spatial resolution.

Background

The use of satellite precipitation data from CMORPH-CDR (Climate Prediction Center Morphing technique-Climate Data Record) has 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). SPI was recommended as a drought monitor (a drought index) by the World Meteorological Organization (WMO 2012) and is widely used by meteorological and agricultural services around the world. SPI is 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 Severity Drought Index (PDSI). SPI calculations are also less complex than PDSI.

Building on the availability of near real-time satellite precipitation data, a global daily CMORPH-SPI was computed. 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 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 Global Drought Information Dashboard (https://gdis-noaa.hub.arcgis.com/).

The existing Python SPI code was downscaled to ingest precipitation data from NClimGrid. The Gridded 5km Global Historical Climate Network-Daily (GHCN-D) Temperature and Precipitation Dataset (NClimGrid) for the continental U.S. 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 (5x5-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

During the last year, the CMORPH-SPI code was adapted to the in-situ dataset NClimGrid. The adaption from the global satellite CMORPH dataset (0.25x0.25deg; daily, 1998-present) to the higher resolution in-situ NClimGrid dataset (5x5km; daily, 1952-present) required substantial modification to the code for process optimization. The NClimGrid-SPI provides almost 70-year of daily SPI conditions over CONUS at a 5x5-km spatial resolution. For example, Figure 1 displays the drought conditions over CONUS for three different dates corresponding to a well identified drought event that impacted CONUS between 1950 and the present. For each case, the SPIs computed for different accumulation periods (30-, 180-, 270-day) capture the evolution of each drought. The SPI for the 1950s Texas drought shows the extension of the drought from Texas to other southern states. During the 1980-1981 heat wave, CONUS experienced long term drought conditions due to the 1980 heat wave and rainfall deficit, which was partially alleviated by heavy rainfall in June 1981 over drought-stricken areas. Finally, for the 2010-2012 Texas-Mexican drought, NClimGrid-SPI indicates widespread drought conditions over CONUS.

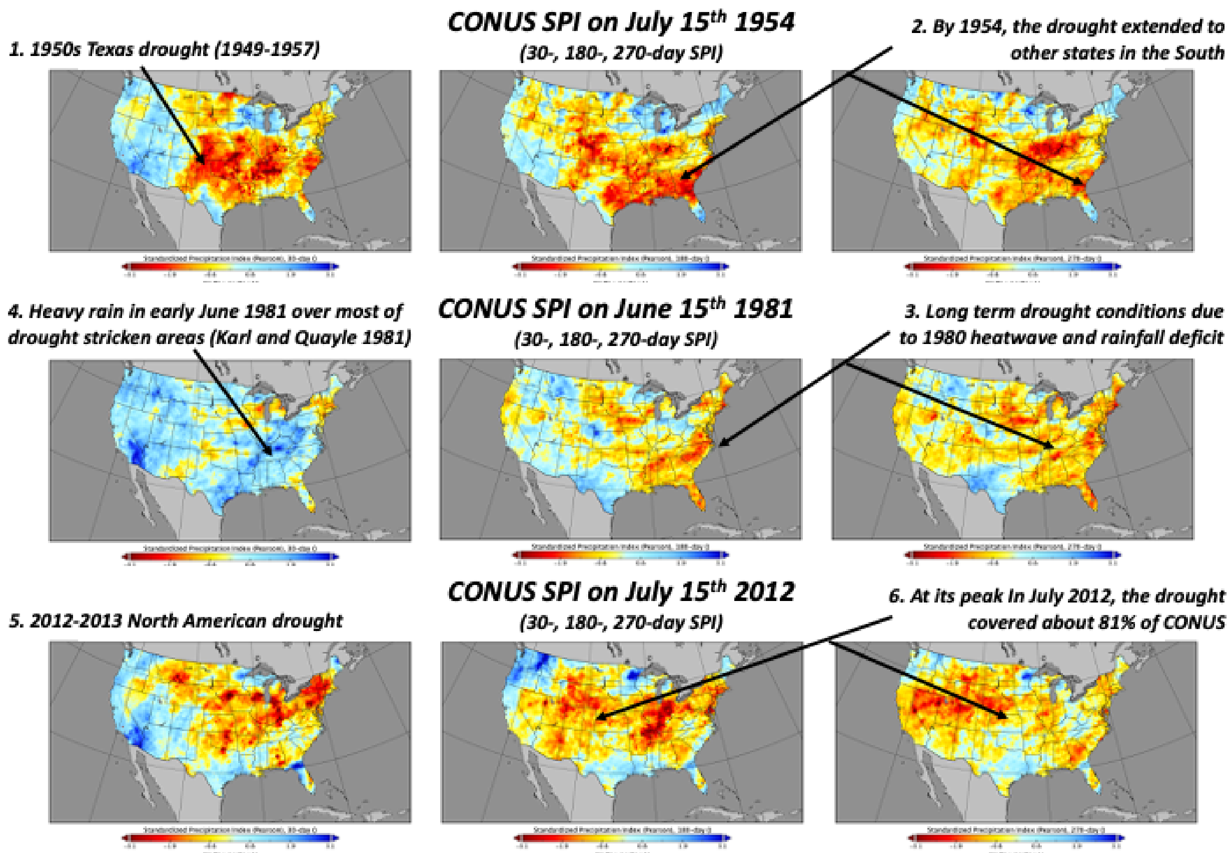


Figure 1. *Drought conditions over CONUS for three different dates: July 15th 1954, June 15th 1981, and July 15th 2012. The daily SPI is derived from nClimGrid and computed for 30-, 90-, 180-, 270-, 365-, and 730-day time scales. Presented here, are the 30-, 180-, and 270-day SPIs. Each example illustrates a drought event: 1950s Texas drought, 1980-1981 heat wave, and the 2010-2012 Texas-Mexican drought.*

From the NClimGrid-SPI, the team evaluated the adequacy of the completed runs for time series of CONUS percent area in drought from 1952-present and time series of SPI values at selected locations across CONUS and for different climate divisions as a function of the time period (30-, 90-, 180-, 270-, 365-, 730-day). A comparison was performed of the daily NClimGrid-SPI with the daily CMORPH-SPI were computed. In particular, distribution parameters (Gamma: 2 parameters; Pearson III; 3 parameters) for different time scales were analyzed. The distribution parameters obtained for NnClimGrid-SPI were compared with those from CMORPH-SPI over a shorted time period (1998-present). Results for the daily SPIs (NClimGrid & CMORPH) were compared with the U.S. Drought Monitor (USDM). Finally, because the computation of distribution parameters is decoupled from the computation of the SPI, the team analyzed the impact of the period of reference (1952-present, 1960-present, 1970-present, 1980-present, 1990-present, 1998-present) on the distribution parameters (Gamma and Pearson III). This allows compensation for the impacts of precipitation changes over time.

Another aspect of this work included the implementation of a drought amelioration index using SPI as the drought metric and nClimGrid as input estimating 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 was developed and tested against GHCN-D stations for different locations over CONUS. The drought relief module enables estimation of the precipitation amount that would be needed (i.e., rainfall deficit) for drought relief at each given location.

The amount of rainfall that corresponds to the passage from a situation of extreme drought (category D4: SPI£-2) to no-drought (D0: SPI=0), for example, or any other combination Dx-Dy, depends on the accumulation period considered (30-, 60-, 90-, 180-, 270-, 360-day) as seen in Figure 2. During the next year, the stand-alone drought relief algorithm will be implemented in the existing NnClimGrid-SPI Python code to quantify deficit precipitation over CONUS for a wide range of accumulation periods.

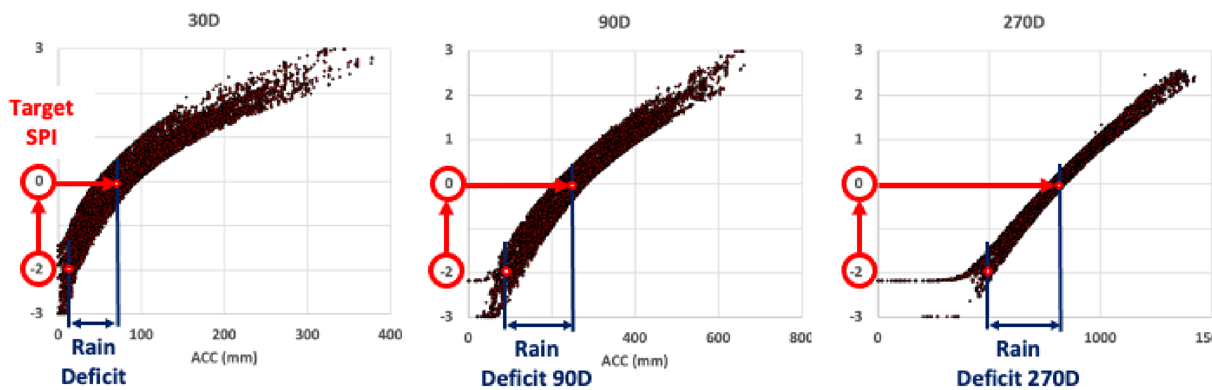


Figure 2*. Example rainfall deficit computed for different rainfall accumulations (30-, 90-, 270-day). In this example, rainfall is the precipitation amount that would be needed to evolve from a SPI value of -2 (extreme drought) to a SPI value of 0 (no drought). The rainfall deficit is a function of the accumulation period, the season, and the location. SPI values are computed from GHCN-D precipitation data for the period 1950-present. This example is for Gastonia (NC).*

This work is being conducted in parallel with two other drought research projects: the on-going 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).

Planned work

- Continue development of the NnClimGrid-SPI code for process optimization and possible transfer and adaptation to a cloud computing environment
- Continue evaluation of the daily NnClimGrid-SPI comparison to the CMORPH-SPI and the in-situ drought monitoring products (USDM)
- Continue analysis of different periods of reference and evaluate their impact on the distribution parameters (Gamma and Pearson III)
- Implement and test the stand-alone drought relief module to quantify the amount of rain needed to end a given drought (accumulation period, season, location)
- Assist with the NClimGrid-SPI transition from research to a quasi-operational status
- Explore use of NnClimGrid daily temperature information (maximum temperature, minimum temperature, average temperature) to generate a daily SPEI index over CONUS

Presentations

Prat, O.P., D. Coates, R. D. Leeper, B. R. Nelson, R. Bilotta, and S. Ansari, 2021: Operational Near-real Time Drought Monitoring Using Global Satellite Precipitation Products (CMORPH) and In-situ Datasets (NClimGrid). *2021 AGU Fall Meeting*, virtual, December 13, 2021.

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 satellite-based precipitation products from four Climate Data Records (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 question of SPPs performance for cold season precipitation was extended to radar-based products (Stage IV).

Background

Four satellite-based precipitation products (SPPs) are part of the Climate Data Records (CDRs) portfolio. Those products are PERSIANN-CDR, GPCP, CMORPH, and AMSU/MHS Hydro-bundle. PERSIANN-CDR is a 30-year record of daily-adjusted global precipitation. GPCP is an approximately 30-year record of monthly and pentad-adjusted global precipitation and a 17-year record of daily-adjusted global precipitation. CMORPH is a 17-year record of daily and sub-daily adjusted global precipitation. AMSU/MHS Hydro-bundle is a 15-year record of rain rate over land and ocean, snow cover, surface temperature over land, sea ice concentration, cloud liquid water, and total precipitable water over ocean, and others. Over the last few years, the four SPP-derived quantitative precipitation estimations (QPEs) were evaluated, resulting in a number of publications and presentations. Product intercomparisons were performed at various temporal (annual, seasonal, daily, or sub-daily, when possible) and spatial (global, over land and over ocean, tropics or higher latitudes, high elevation) scales. Evaluation of the 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

Evaluation of satellite precipitation products (SPP) CDRs was extended to cold precipitation, with the goal 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 the period 2007-2018. Daily precipitation measurements at the ground and including atmospheric conditions (temperature, relative humidity) were obtained from the U.S. Climate Reference Network (USCRN). The USCRN (including associated local networks) is composed of about 240 stations. Among those USCRN stations, 70 are located between latitudes 40°–60°N and 65 are located above an altitude of 1500m. The USCRN 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 a mathematical toolbox, which includes bias (conditional and unconditional), Kling–Gupta efficiency (KGE), Pearson's correlation coefficient (CORR), bias (BIAS) and variability ratio (VAR), Contingency analysis (YY, NY, YN), Number of rainy days, Percentiles, Frequency Bias, Accuracy (ACC), False Alarm Ratio (FAR), Probability of Detection (POD), and Probability of False Detection (POFD).

Figure 1 displays the Bias for daily precipitation with respect to USCRN data for the three SPPs for the period 2007-2018. In this case, biases are computed unconditionally (regardless of the presence of rainfall at the SPP pixel, at the USCRN station, or both). The results are presented on an annual basis (YEAR), for the warm season (JJA), for the cold season (DJF), and for stations where average daily temperature is below 0°C (T<0°C). On an annual basis (YEAR) and for summer (JJA), CMORPH presents lower biases than GPCP and PERSIANN-CDR, with GPCP presenting the most important rainfall overestimation over the

Rockies. During the cold season (DJF), biases over the Rockies and at higher latitude increase (rainfall overestimation) for PERSIANN-CDR and GPCP. While PERSIANN-CDR and GPCP exhibit an opposition in terms of biases between the Eastern US and the Rockies/Western US, for CMORPH that opposition presents a North/South pattern. At higher latitudes, CMORPH presents a severe rainfall underestimation (DJF). For stations with negative temperature at the time of the rain event (T< 0°C), the underestimation with respect to precipitation measured at the CRN site is flagrant for CMORPH, while PERSIANN-CDR and GPCP do not show the same underestimation and display moderate biases (close to 1) or an overestimation at some of the stations.

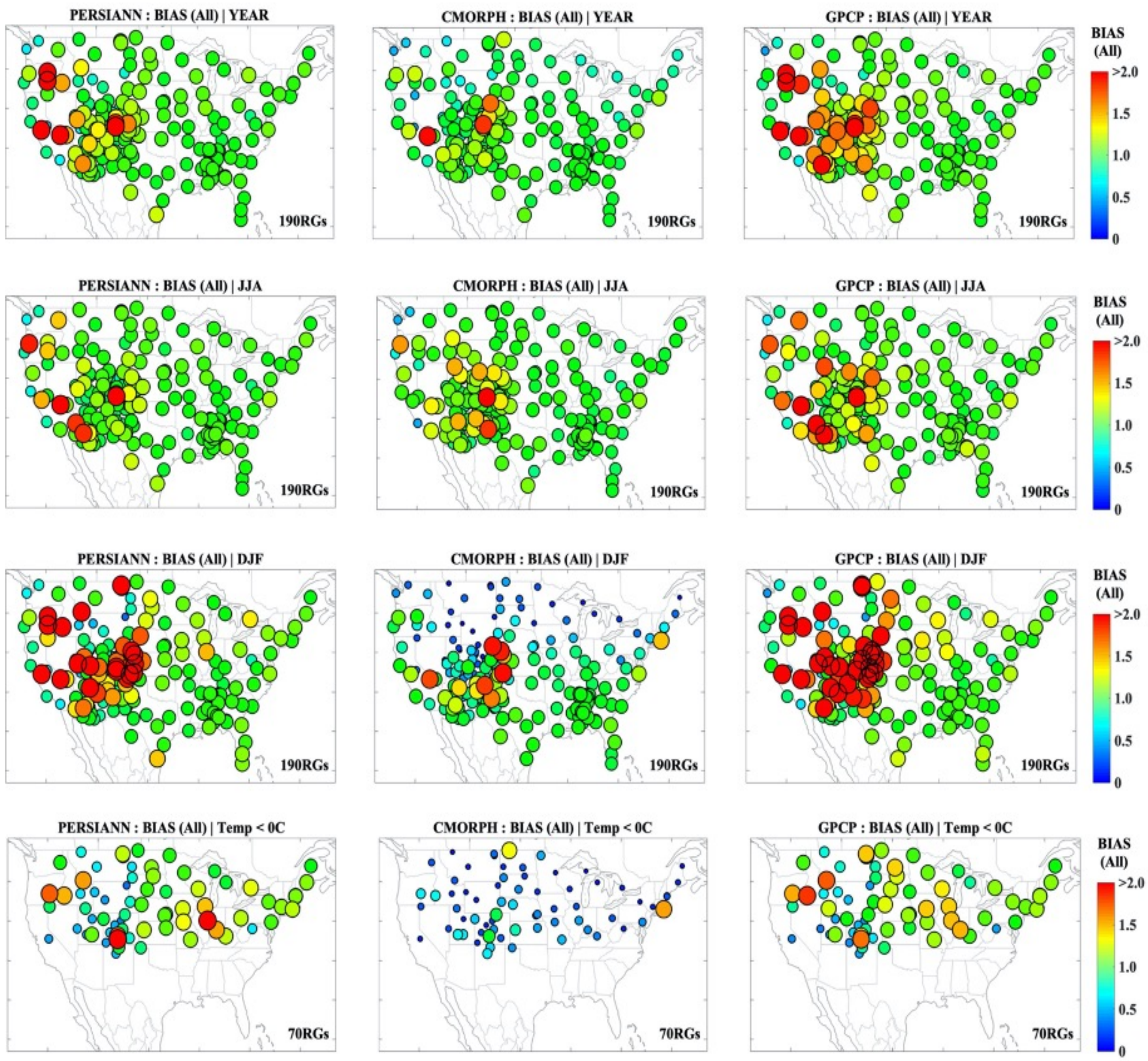


Figure 1. *Bias for daily precipitation with respect to USCRN data for PERSIANN-CDR, CMORPH-CDR, and GPCP for the period 2007-2018 for the USCRN and ALCRN stations and for 2009-2014 for the stations from the U.S. Regional Climate Reference Network over the four corner states (4CCRN). Biases are computed unconditionally. Results are presented on an annual basis (YEAR), for the warm season (JJA), for the cold season (DJF), and for stations where average daily temperature is below 0°C (T<0°C). Only stations that had at least 30 day by year of average daily temperature below 0°C are considered.*

Figure 2 provides a summary of the results for the ensemble of statistics, both conditionally (i.e., rain recorded simultaneously by the SPP and the USCRN station) (C) and unconditionally (U).

SEASON / TEMP			YY
ACC	FAR	POD	POFD
KGE C	CORR C	BIAS C	VAR C
KGE U	CORR U	BIAS U	VAR U

YEA			C
C	C	C	C
C	C	G	C
C	C	C	C

MAM			C
C	C	P	C
C	C	C	C
C	C	C	C

JJA			C
C	C	P	C
C	C	C	C
C	C	C/P	C

SON			C
C	C	P	C
C	C	C/G	C
C	C	C	C

DJF			P
G	G	P	C
P	C	G	G
P	P	C	G

T>0C			C
C	C	P	C
C	C	G	C
C	C	C	C

T<0C			P
G	G	P	C
P	P	C	P
G	P	G	G

***Figure 2**. SPP performance summary with respect to USCRN for annual (YEA), spring (MAM), summer (JJA), fall (SON), and winter (DJF). Metrics are accuracy (ACC), false alarm ratio (FAR), probability of detection (POD), probability of false detection (POFD), Kling-Gupta efficiency (KGE), Pearson correlation coefficient (CORR), bias (BIAS), and variability ratio (VAR). For the last four metrics, results are indicated conditionally (C), and unconditionally (U). For each situation, the team reported which SPP: CMORPH-CDR (C), PERSIANN-CDR (P), or GPCP (G) presents the best performance.*

Overall, CMORPH was found to perform better on an annual basis (YEA) and during the warm season (JJA), both conditionally (C) and unconditionally (U). However, during the cold season (DJF) and for negative temperatures (T<0°C), CMORPH presents degraded performances when compared to the two other SPPs (PERSIANN-CDR, GPCP). This long-term evaluation (11-years) is helpful in quantifying errors and biases of SPPs with respect to cold season precipitation and could provide an objective basis for rainfall retrieval algorithm improvement in the context of the new generation of CMORPH-CDR (CMORPH2).

A paper on the global evaluation of the three CDRs was published and another paper on their performance with respect to cold season precipitation is being finalized. In addition, the team published two papers on the quantification of NEXRAD-based products errors and biases over CONUS and Alaska.

Planned work

- Finalize the paper on SPPs performance in capturing cold precipitation

Publications

Nelson, B. R., **O. P. Prat**, and **R. D. Leeper**, 2021: An Investigation of NEXRAD-Based Quantitative Precipitation Estimates in Alaska. *Remote Sensing*. doi.org/10.3390/rs13163202

Prat, O., B. Nelson, E. Nickl, and **R. Leeper**, 2021: Global evaluation of gridded satellite precipitation products from the NOAA Climate Data Record program. *Journal of Hydrometeorology*. doi.org/10.1175/JHM-D-20-0246.1

Nelson, B. R, **O. P. Prat**, and **R. D. Leeper**, 2021: Using ancillary information from radar-based observations and rain gauges to identify error and bias. *Journal of Hydrometeorology*, **22**, 1249-1258. doi.org/10.1175/JHM-D-20-0193.1

Presentations

Prat, O. P., B. R. Nelson, R. D. Leeper, and S. Embler, 2021: Assessment of Cold-Season Precipitation Estimates Derived from Daily Satellite Precipitation Products over CONUS. *European Geosciences Union (EGU) General Assembly 2021*, virtual, April 26, 2021.

Drought Detection Using Remotely Sensed Precipitation Data from the Climate Data Record CMORPH	
Task Team	Olivier Prat, David Coates, Ronald Leeper, Scott Wilkins
Task Code	NC-SAS-20-NCICS-OP/DC/RL/SW

Highlight: Monthly and daily Standardized Precipitation Indices (SPIs) were implemented using precipitation satellite data from the CMORPH and PERSIANN climate data records to investigate their 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. Operational global daily SPIs were computed from CMORPH-CDR and CMORPH-ICDR to monitor drought conditions.

Background

Satellite precipitation data from the CMORPH-CDR (Climate Prediction Center Morphing technique-climate data record) program are being utilized to detect and monitor drought on a global scale. Precipitation data are used to compute and evaluate the Standardized Precipitation Index (SPI) over the continental United States (CONUS). To evaluate the relevance of satellite data usage for early drought detection and drought monitoring, several scenarios were 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 mixed combination of gauge-adjusted and near-real-time versions of the satellite QPE. The drought indices are evaluated over CONUS, for which numerous in situ data as well as drought products exist. In particular, the difference between indices obtained with the corrected (CMORPH-CDR) and interim near-real-time (CMORPH-ICDR) versions of CMORPH was evaluated.

Four drought episodes (the 1998–2004 western U.S. drought, the 2006–2007 Southeast U.S. drought, the 2010–2012 Texas–Mexican drought over the Southern Plains, and the 2012 summer Midwestern U.S. drought) 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 period of 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. The goal of this work is to transition to operations a fully functional implementation of the daily SPI using CMORPH-CDR and CMORPH-ICDR that will be used to detect and monitor drought episodes globally. Operational SPI products will be provided to the public through an Interactive Global Drought Information Dashboard. Near-real-time drought conditions will be accessible to the public via interactive visualization techniques.

Accomplishments

The CMORPH-SPI is in a quasi-operational status. The daily global CMORPH-SPI that uses the gamma formulation (McKee et al. 1993) is generated in near-real time; that is within 48-hrs to the actual day. The CMORPH-SPI is part of the interactive GDIS (Global Drought Information System) dashboard developed by the National Integrated Drought Information System (NIDIS) at https://www.drought.gov/international. The CMORPH-SPI is available at 30-, 90-, 180-, and 270-day time scale. Figure 1 presents the 90-day (3-month) global SPI from the GDIS dashboard. The dashboard provides drought monitoring resources such as interactive mapping, visualizations, and GIS data download capabilities. It builds upon previous work of NIDIS and the Global Drought Information System (GDIS) and CISESS NC. The GDIS website includes an interactive map hosted within the NOAA GeoPlatform (ArcGIS Online). There are currently 45 layers of drought indices and indicators available including the daily CMORPH SPI.

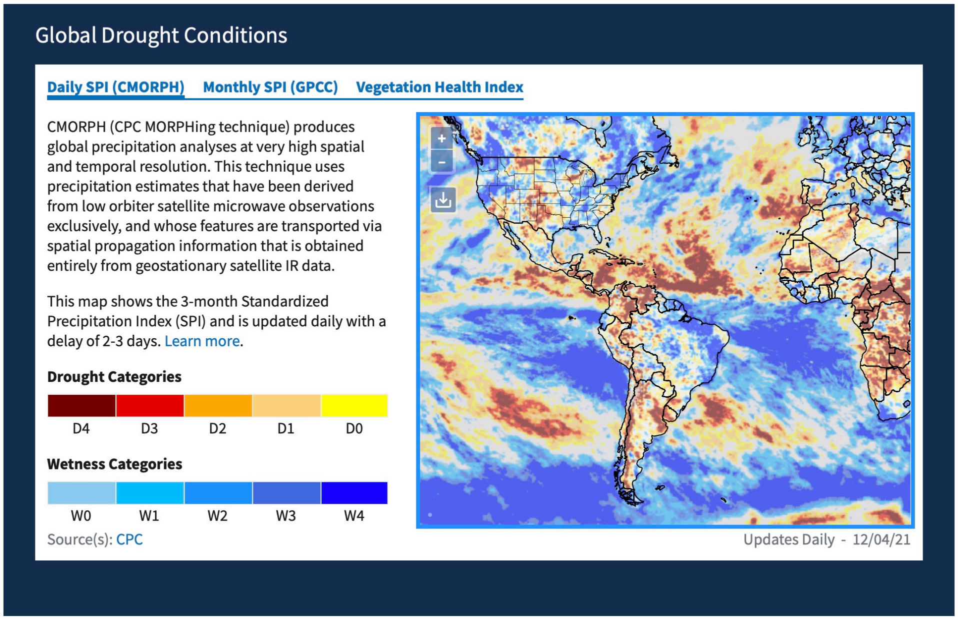


Figure 1. *CMORPH-SPI available in the GDIS dashboard displaying global drought conditions. The 90-day (3-month) Standardized Precipitation Index (SPI) and is updated daily with a delay of 2-3 days.*

During the last year, the SPI Python code was updated for increased computational efficiency. Further analysis was performed on the distribution parameters for both distributions used (Gamma, Pearson III). The CMORPH-SPI code was adapted to the in-situ based NClimGrid dataset. Substantial adjustments were necessary to adapt the Python code to a higher spatial resolution dataset (5-km) with a longer period of record (1952-present). The NClimGrid-SPI provides almost 70-year of daily SPI conditions over CONUS at a 5x5-km spatial resolution. The nClimGrid-SPI was compared with the CMORPH-SPI over CONUS. Figure 2a displays a comparison of the daily nClimGrid daily SPI on July 15th, 1954, with the monthly PDSI for July 1954. Similar spatial patterns are observed between the nClimGrid daily SPI and the monthly PDSI (Palmer Drought Severity Index). For a more recent period (July 15th, 2012), the comparison between the daily SPI derived from CMORPH and nClimGrid with the monthly PDSI for the same month (July 2012) show similar spatial patterns between the satellite (CMORPH) and in-situ based SPI (NClimGrid) and PDSI during the 2010-2013 Southern United States and Mexico drought (Fig. 2b). However, there are noticeable differences when it comes to the drought severity between NClimGrid and CMORPH. Differences are due to sensor differences (satellite vs. in-situ) and the period of reference (1998-2020 vs. 1952-2020).

Additional drought indices such as the non-parametric SPI (Farahmand and AghaKouchak 2015) were implemented and validated, performing benchmark comparisons with existing SPI formulations (Gamma distribution: McKee et al. 1993, L-moments and Pearson III distribution: Guttman 1998) to quantify differences between drought indices. A stand-alone algorithm (Fortran) was developed and tested using GHCN-D station data to compare the different SPI algorithms (Gamma, Pearson III, non-parametric SPI). Results have indicated the limitations of the non-parametric formulation (computation time, limited range) due in part to the small number of years available (n value too low). In addition, an algorithm was developed to determine the precipitation requirement to alleviate drought conditions. The algorithm uses an iterative process to determine the amount of rainfall deficit to reach a target SPI. The code will be implemented in the existing Python code and will be run for CMORPH-SPI and NClimGrid-SPI.

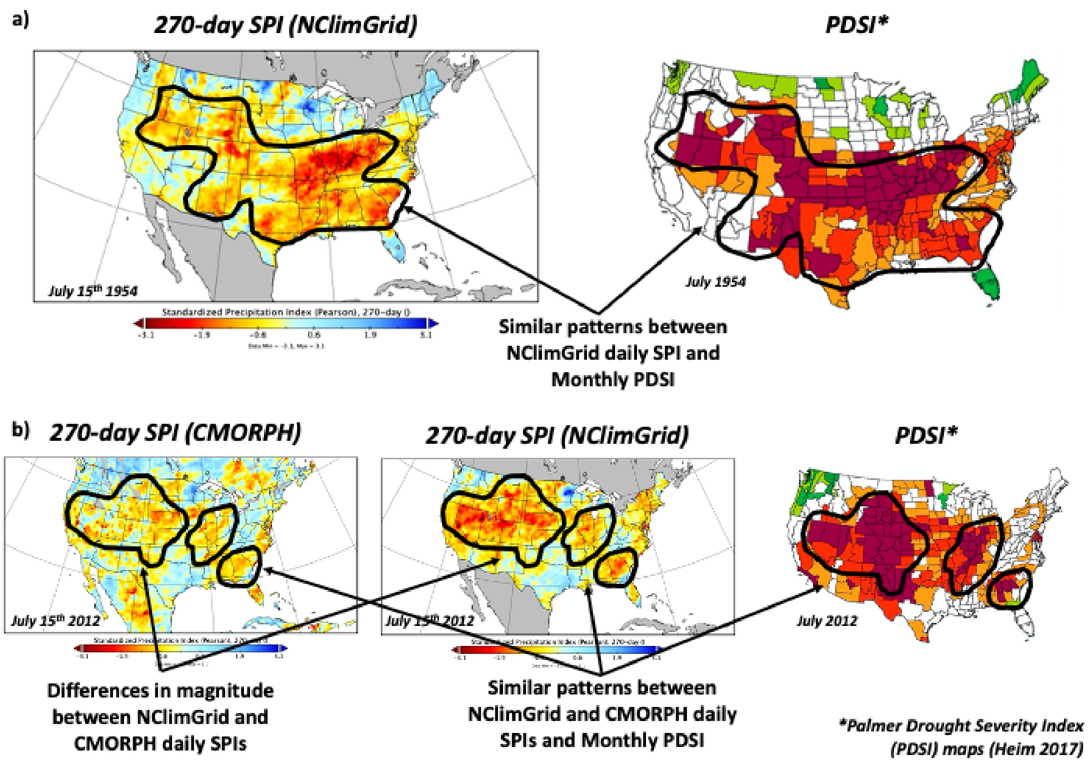


Figure 2. *a) Comparison of the computed nClimGrid daily SPI on July 15th 1954 with the monthly PDSI for July 1954. b) Comparison of the daily SPI derived from CMORPH and nClimGrid on July 15th 2012 with the monthly PDSI for July 2012 during the 2010-2013 Southern United States and Mexico drought.*

As part of possible long-term development of more complex drought indices, two exploratory NASA Develop projects were conducted that investigated the possibility of developing an evapotranspiration (ET) climatology from MODIS (Fall 2021) and a MODIS ET validation at the daily scale using in-situ measurements from AmeriFlux towers over the Midwest (Spring 2022). From precipitation driven indices only such as SPI presented here, the team plans to incorporate other datasets such as evapotranspiration, and later gridded soil moisture, vegetation indices, and streamflow to develop more complex drought indices.

Planned work

- On-going evaluation of the daily CMORPH-SPI against in situ drought monitoring products (USDM)
- On-going comparison of the daily CMORPH-SPI with the higher resolution NClimGrid-SPI over CONUS
- Adaption of the existing SPI code to a cloud environment to include other high-esolution datasets (IMERG)
- Comparison of the CMORPH-SPI with the higher resolution IMERG-SPI (GEO-Microsoft project)
- Implementation and testing of the drought relief module (determination of the amount of rain needed to end select drought conditions)
- Publish a paper on the daily and monthly SPI derived from CMORPH-SPI and NClimGrid-SPI
- Work on a potential collaboration with the Texas State Climate Office on computing drought indices using a climatology of in-situ data and observations made via remote sensing

Products

- Operational near-real-time global daily CMORPH SPI available within 48-hrs to the current day. The global CMORPH SPI is available via the Interactive Global Drought Information Dashboard (https://gdis-noaa.hub.arcgis.com/).

Presentations

Prat, O. P., R. D. Leeper, B. R. Nelson, R. Bilotta, and S. Ansari, 2021: Near-real Time Drought Monitoring Using Satellite and In-situ Precipitation Datasets and Application to the Carolinas. Poster. *2021 Carolinas Climate Resilience Conference*, virtual, May 10, 2021.

Other

- NASA Develop Project Interns: Emma Myrick, Alec Solberg, Erin Shives, Erica Barth-Naftilan. Science advisors: Olivier Prat (CISESS NC), Brian Nelson (NCEI)
- NASA DEVELOP Interns: Alec Solberg, Max Rock, Addison Pletcher, Erin Shives. Science advisors: Olivier Prat (CISESS NC), Brian Nelson (NCEI)

Toward visualizing and analyzing climate data records on the cloud	
Task Leader	Yuhan (Douglas) Rao
Task Code	NC-SAS-21-NCICS-YR

Highlight: Normalized Difference Vegetation Index (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 Service, Google Cloud, Microsoft Azure) through NOAA's Big Data Program (BDP).

However, the technical barriers to access and understand CDR data makes 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 is stored as daily netCDF4 files using climate forecast (CF) 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 is 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 50 Megabytes. 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.

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. The pilot tutorial uses NDVI data and Python packages in the Pangeo ecosystem for regional data analysis and visualization.

Planned work

- Complete NDVI data conversion into ARCO data and expand the conversion to another CDR dataset based on historical user statistics
- Develop the interactive mapping tool using AWS as the backend computing platform and using NDVI CDR as the pilot
- Develop 2-3 tutorials on how to access CDR data using open-source tools
- Pilot the development of spatial temporal asset catalog for CDR data on the cloud

Presentations

Rao, Y., 2022: Climate Observatory - Analyzing and Visualizing NOAA Climate Data Records on the Cloud. *Ocean Sciences Meeting 2022,* virtual, March 4, 2022.

Maintenance and Streamlining of the Global Historical Climatology Network-Monthly (GHCNm) Dataset	
Task Leader	Jared Rennie
Task Code	NC-SAS-22-NCICS-JR

Highlight: The next iteration of NOAA's global temperature product (GHCNm version 4.0.1) is now operational. The codebase was put under version control and was successfully pilot tested on a commercial cloud platform. www.ncdc.noaa.gov/ghcnm/

Background

Since the early 1990s, the Global Historical Climatology Network-Monthly (GHCNm) dataset has been an internationally recognized source of information for the study of observed variability and change in land surface temperature. Version 4 of this product has undergone many updates since its initial release in 2018 including incorporating monthly maximum and minimum temperature, improving processing run time, and providing user-driven products. Current version 4.0.1 includes over 25,000 stations globally.

GHCNm version 4's success stems from a need to address gaps in data coverage and improve documentation of data provenance. The International Surface Temperature Initiative (ISTI), developed in 2010, addressed these issues by creating a state-of-the-art databank of global surface temperature observations. Released in 2014, the first version of the databank contains data from more than 30,000 surface temperature stations, has an open and transparent design, and documents observations back to the original source data. Many international organizations have heralded this development and provided feedback that has been incorporated into subsequent updates. All versions are available online, and the current operational version, version 1.1.1, was released in late 2017.

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

Accomplishments

Updates are ongoing, based on an NCEI three-tiered system, i.e., development, test, and production environments. Nightly runs are performed internally and checked by the ISTI and GHCN teams to ensure adequate data quality. The code base for version control and portability were updated in 2020. Today, the code exists in an internal git repository and includes an installation script to execute the end-to-end process. A pilot project was performed by NESDIS to utilize the git repository, and run GHCNm version 4 using cloud technologies. Results were successful, with little change made to the code.

Work is underway to move this project from CISESS NC to NCEI staff. Testing is currently underway using the git repository and the CISESS NC test server environment. Once the code base has been set up and successfully run in production by NCEI staff, the work performed by CISESS NC will be complete.

Planned work

- Assist NCEI staff with version control and executing the GHCNm version 4 code base
- Assist in NESDIS efforts to utilize the code base in cloud technologies

Products

- Public, operational version of GHCNm version 4.0.1

Development of a Homogenized Sub-Monthly Temperature Monitoring Tool	
Task Team	Jared Rennie, Kenneth Kunkel
Task Code	NC-SAS-23-NCICS-JR/KK

Highlight: The code base for the sub-monthly temperature tool was upgraded to Python version 3. The heat event database will be updated on an annual basis for use in continuing studies on extreme heat impacts on human health. https://ncics.org/portfolio/monitor/sub-monthly-temperatures/

Background

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

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

Accomplishments

An automated system was established to extract the latest version of the following datasets each day: GHCN-D, Northam, the 1981–2010 Normals, and nClimDiv. Using these datasets, monthly adjustments are applied to daily data, and then anomalies are created using a base climatology defined by the 1981–2010 Normals. Station data are aggregated to the state level and then region level (as defined by the National Climate Assessment; NCA). Daily plots are made to analyze U.S. temperature values and anomalies. Once daily averages for each state and NCA region are computed, probability distribution functions are generated to provide ranks on different time scales.

Recently, the code base was upgraded to Python version 3, and the adjusted station data continues to update each day. The heat event database will be updated on an annual basis and will be used in continuing heat/health studies and other analyses.

Planned work

- Continue to engage with monitoring product users
- Upgrade normals period from 1981-2010 to 1991-2020
- Utilize other temperature sources, including the new nClimGrid daily product, currently in beta
- Work to identify heat events with available health and socioeconomic data
- Compare dataset with other climate metrics, such as soil moisture

Products

- Updated monitoring tool for sub-monthly data for the United States

Developing and Validating Heat Exposure Products Using the U.S. Climate Reference Network	
Task Leader	Jared Rennie
Task Code	NC-SAS-24-NCICS-JR

Highlight: Using hourly and sub-hourly data from the United States Climate Reference Network (USCRN), heat exposure indices, including heat index, apparent temperature, and wet-bulb globe temperature (WBGT), have been developed and validated against data from nearby sites. These derived products will be used to address heat health, combining climate data with available socioeconomic and hospital data.

Background

NCEI oversees the observations of the United States Climate Reference Network (USCRN). This network consists of 114 sites across the conterminous 48 states, with additional sites in Alaska and Hawaii. Stations are sited and installed in areas where land cover and land-use conditions are predicted to be stable for several decades. At each site, a suite of meteorological parameters is monitored, including triple redundancy for primary air temperature variables. Other variables recorded at USCRN sites include solar radiation, relative humidity, and 1.5-meter wind speed. Because these variables can play a role in heat exposure, it makes sense to explore, develop, and test heat-related indices using high-resolution USCRN data.

Using data at hourly and 5-minute resolution, three separate heat exposure indicators were developed. The first is the heat index (HI), which uses heat and humidity information, and is commonly used in National Weather Service (NWS) products. The second is apparent temperature (AT), defined by Steadman (1984), which uses temperature, relative humidity, and wind to differentiate between indoor and outdoor exposure. The third is wet-bulb globe temperature (WBGT), which is commonly used in industry, sports, and the military to determine outdoor human exposure. WBGT incorporates air temperature, wet-bulb temperature, and black-globe temperature (BgT), the latter requiring solar radiation information. The 5-minute values of these variables can be accumulated to better understand the total exposure to a heat event. For this project, data are validated using nearby networks maintained by the State Climate Office of North Carolina, and results are used to examine case studies of recent extreme heat events.

Accomplishments

A *Python* script was developed to take both hourly and 5-minute data from USCRN stations and calculate heat exposure indices, including HI, AT, and WBGT. In 2020, this script was utilized to incorporate all 139 USCRN sites, and a derived product of heat exposure indices from 2009-present was created. Data gaps were filled in using reanalysis data provided by Copernicus via ERA5. Hourly climatologies were also developed, following the protocols of NCEI’s 1991–2020 hourly normals. In 2021, the code base was transferred to the USCRN programming team to be incorporated as an official NCEI product. A beta version of the product is available, and an operational readiness review (ORR) is under preparation.

Work was begun to extend this project to build a heat vulnerability index for areas in the southeast United States. Using county level data from the US Census Bureau, Centers for Disease Control and Prevention (CDC) and the Multi-Resolution Land Characteristics Consortium (MRLC), a principal component analysis (PCA) was developed to take over 30 variables and simplify the data into four components. The components include socioeconomic, urban vs rural, elderly, and health prevalence. These four components were combined to generate a total vulnerability index, which can be seen in Figure 1. From this index, two studies are currently underway. First, the data is combined with USCRN heat exposure data (HI, AT, WBGT) to build a modified heat vulnerability index, based on current and future temperature conditions. Second, the index is matched with available hospital admission data to determine the point at which heat-related admissions increase.

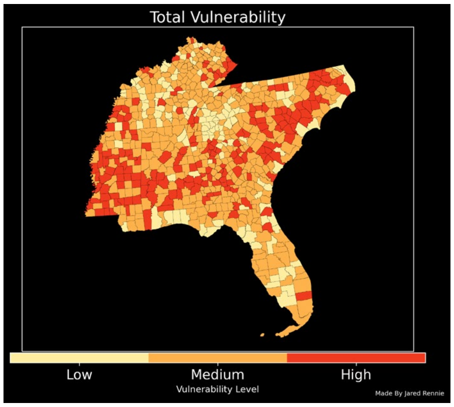


Figure 1. *Heat Vulnerability Index for the Southeastern US, using available socioeconomic data.*

Future work includes extending this heat exposure dataset to other in situ networks, such as ASOS, as well as providing a gridded product using data from National Digital Forecast Database (NDFD), High Resolution Rapid Refresh (HRRR), and ERA5. The vulnerability study continues by expanding to other areas of the United States, as well as using other publicly available health and socioeconomic data.

Planned work

- Validate BgT and WBGT values at other sites
- Extend the project to over 2,000 stations located at airports nationally
- Reconstruct a climatology of WBGT for the CONUS using NWS (NDFD) and ERA5 reanalysis
- Continue to build a heat vulnerability index, using the latest climate, socioeconomic, and health data for parts of the United States

Product

Hourly and sub-hourly heat exposure indices, including heat index (HI), apparent temperature (AT), and wet-bulb globe temperature (WBGT) - USCRN derived product

Publications

Rennie, J. J., M. A. Palecki, S. P. Heuser, and H. J. Diamond, 2021: Developing and validating heat exposure products using the US Climate Reference Network. *Journal of Applied Meteorology and Climatology*. doi.org/10.1175/jamc-d-20-0282.1

Presentations

Rennie, J. J., 2021: Heat Index and Wet Bulb Globe Temperature creation from USCRN sites and heat severity quantification. *OneNOAA Science Seminar Series,* virtual, April 6, 2021.

Rennie, J. J., 2021: It's All Relative: Developing heat exposure products using USCRN. *International Association of Emergency Managers* (IAEM) Climate Caucus, virtual, April 19, 2021.

Rennie, J. J., 2021: It's All Relative: Developing heat exposure products using USCRN. tomorrow.io, virtual, April 22, 2021.

Rennie, J.J., 2021: How Hot is Too Hot? AMS Weather Band Webinar, September 9, 2021.

Development of the United States Climate Reference Network (USCRN) National Precipitation Index	
Task Leader	Jared Rennie
Task Code	NC-SAS-25-NCICS-JR

Highlight: National Precipitation Index (NPI) data have been updated through June 2021 and planning is underway for the research-to-operations transition.

Background

NCEI produces a monthly National Temperature Index (NTI), a set of calculations of air temperature for the contiguous United States at the monthly, seasonal, and annual time scales. Two versions of NTI are displayed: one is derived using only the stations from the United States Climate Reference Network (USCRN), and the other is a compilation from thousands of stations across the United States interpolated onto a 5-kilometer-resolution gridded temperature product called nClimGrid. USCRN was developed to provide long-term homogeneous observations for the detection and attribution of present and future climate change and is used as a reference to evaluate how well the historical stations measure U.S. climate. To facilitate precipitation comparisons like those available for NTI, the USCRN team developed its own version of a National Precipitation Index (NPI).

An algorithm to build the NPI was developed and finalized under the prior cooperative institute agreement. Data from 107 USCRN station sites were used in this analysis. These precipitation values were calculated with the assistance of a wetness sensor beginning in 2006. A white paper describing the methodology was drafted and approved by members of the NCEI dataset section. The CISESS NC project team will continue the transition of NPI from research to operations.

Accomplishments

Data have been updated through June 2021. The project team began planning for the NPI transition from research to operations. Next steps will include porting over the code base to NCEI monitoring systems, updating figures when new data become available, and initiating an operational readiness review (ORR).

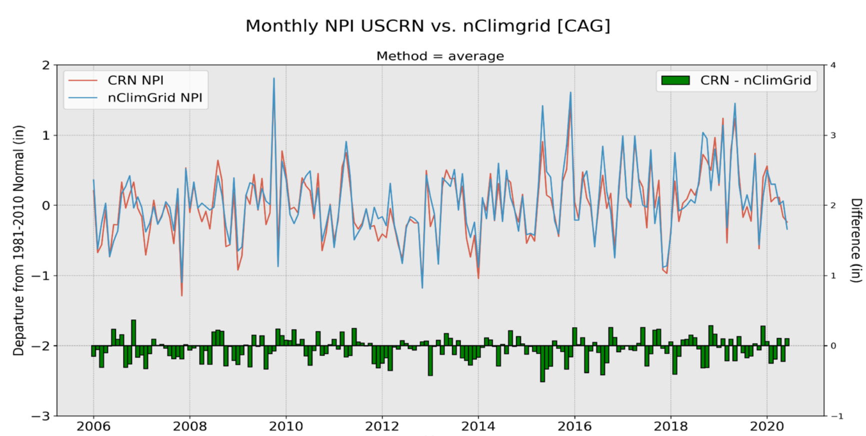


Figure 1. *Monthly time series of USCRN National Precipitation Index from 2006 to present (red) compared to precipitation data from NCEI's Climate at a Glance (CAG) tool (blue). Differences are noted in green.*

Planned work

- Work with NCEI monitoring team to transition the NPI into operations on NCEI's website
- Begin the Operational Readiness Review process

NCEI Innovates 2019 - Developing 1991–2020 Normals along the Northeast and Mid-Atlantic Coasts	
Task Leader	Jared Rennie
Task Code	NC-SAS-26-NCICS-JR

Highlight: Coastal normals for 1991–2020 were developed for areas around the Northeast and Mid-Atlantic regions, and an *ArcGIS Online* website was developed to allow users to interact with the data. https://coastal-normals-ncsu.hub.arcgis.com

Background

Conventional NCEI Climate Normals represent the average conditions to be expected at a time and place for any given hour/day/month of the year. These are one of NCEI's best-known products, and they are required by many sectors and seen on media weathercasts every day. NCEI will soon be producing the 1991–2020 Climate Normals suite of products per agreement with the World Meteorological Organization (WMO). In the past, NCEI has also leveraged this activity to produce normals customized for important user communities, such as agriculture, energy, and construction. Currently, new opportunities exist to expand normals to coastal and oceanic variables of importance to the expanded NCEI user community. An NCEI Innovates pilot project expanded normals production to meet the needs of coastal tourism and recreation and other coastal user communities by assembling a set of quality normals representing both atmospheric and oceanic conditions along the U.S. Mid-Atlantic/Northeast coastline.

The NCEI Innovates team collaborated with members of the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS) and their partners in the Mid-Atlantic region (MARACOOS).

Accomplishments

Climatologies were calculated for 1991–2020 for all datasets. Working with partners at NOAA's Eastern Region Climate Services, the Northeastern Regional Association of Coastal Ocean Observing Systems (NERACOOS), and its respective office in the Mid-Atlantic region (MARACOOS), a public website was created (Figure 1) to display all layers for all months of the year.

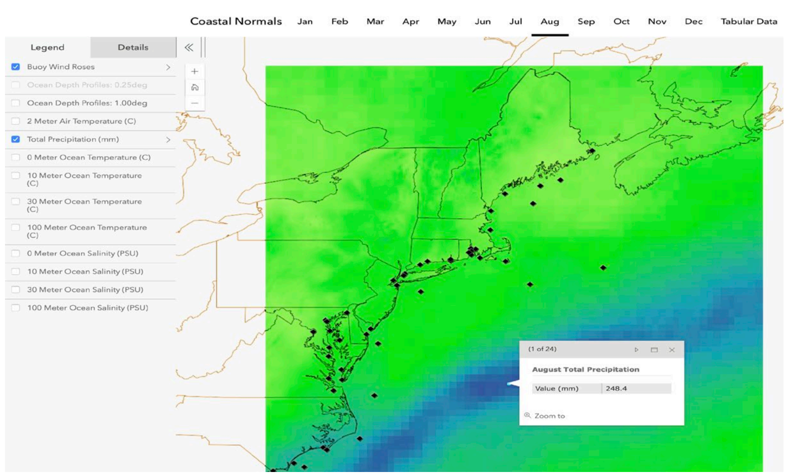


***Figure 1**. ArcGIS Online interactive website for the Coastal Normals project. Users can choose a month at the top, and toggle layers on and off on the side. The map is intended to be interactive, displaying relevant normals data and images where applicable.*

Users are able to toggle layers on and off and zoom in, depending on their specific needs. An innovative feature is the ability to interact with the map by clicking on a specific grid point or point location to see relevant information. Depending on the area, a graphic can also be provided, including wind roses (Figure 2) and ocean temperature and salinity profiles.

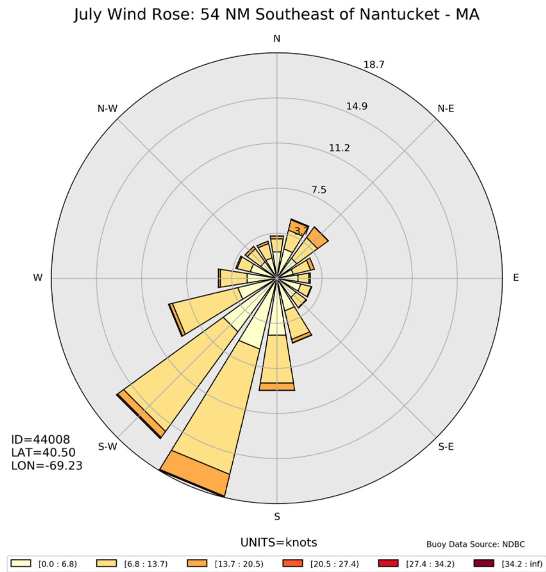


Figure 2. *Wind rose, taken from July data between 1991-2020, from a buoy off the coast of Nantucket, Massachusetts. Data are from NOAAs National Data Buoy Center.*

All code to generate the graphics and layers was placed in a git repository for reproducibility. The Southern Regional Climate Services program is currently working to produce the same results for their area of interest, which includes the Gulf of Mexico.

Planned work

- This project is complete; however, CISESS NC will assist the Southern Regional Climate Services program to provide results for their area of interest if needed.

Products

- Coastal normals data from 1991–2020 for areas around the U.S. Northeast and Mid-Atlantic
- ArcGIS Online interactive web page displaying the coastal normals layers

Presentations

Rennie, J. J., 2021: #ShowYourStripes: Making Climate Data Local in the Carolinas. *2021 Carolinas Climate Resilience Conference,* virtual, May 10, 2021.

ARC Data Derivative Product for Health Users	
Task Leader	Jennifer Runkle
Task Code	NC-SAS-27-NCICS-JR

Highlight: The project team completed development of an NCEI data product consisting of a daily time series for Tavg, Tmax, Tmin, and Precipitation using nClimGrid for each county in the U.S. (1981-present) to aid health and infectious disease modeling efforts. A new R package and Shiny Web App are companions to the NOAA 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 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 (MIDAS) 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 ARC team created 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 1* of the data product aimed at developing a daily time-series for Tavg, Tmax, Tmin, and Precip (nClimGrid daily metrics) for each county in the U.S. from 1981 to present. Data are retrievable using the following modes: direct download, EpiNOAA R package, or web interface (see 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 U.S. CONUS (1951-	Csv	https://noaa-nclimgrid-daily-pds.s3.amazonaws.com/EpiNOAA/EpiNOAA_county.csv

present) **one large file		
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.
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
- Develop a daily time-series for Tavg, Tmax, Tmin, and Precip (nClimGrid daily metrics) for each census tract and zip code in the U.S. from 1981 to present (v2. county + census tract and zip code)
  - Examine feasibility of averaging gridded data to these two scales
  - Determine methodological approach to aggregate data to two scales
  - Expand R package / Shiny App to include these two scales
  - Assemble expert group to obtain input on v2.0 of the data product
- Integrate 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-28-NCICS-JR

Highlight: Working with NCEI and CDC collaborators, CISESS NC advanced work on 1) developing 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 U.S.

Background

NOAA and the Centers for Disease Control and Prevention (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 policy making and to reduce public and community health threats while adapting to climate change.

NCEI and CDC formalized a five-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 with anticipated activities to include some or all of the following:

- update of current CDC environmental data holdings;
- review and identification of relevant NCEI data products for epidemiologic studies and their applicability for public health practitioners;
- environmental data processing and interpretation to facilitate use for health applications;
- studies to better define and understand Earth system and public health interactions;
- investigations into extreme event health impacts to better respond to and/or reduce those impacts; and
- creation of 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

Despite disruptions to the CDC workforce due to the COVID pandemic, the team made progress on the following tasks:

- Baseline surveillance data to be used in an early warning system for harmful algal blooms (HABs):
    - Began collaborative work on 1) linking health risks from electronic health records with HABS and other relevant environmental drivers; 2) developing a severity index that can be used nationally and is relevant across states.
    - Established a multi-agency collaboration (CDC, NOAA, EPA, USGS, NASA) to extend an existing U.S.-based CyanoHabs monitoring project relying on satellite data records to include prediction of freshwater harmful algal blooms (HABs) for early warning.

- Joint agency case study to explore the use of high-resolution local climate data to understand the acute health effects and economic impact of extreme heat for the nation.
- Update of drought data and data pipeline for SPEI drought indicators now incorporated in the Center for Disease Control and Prevention Environmental Public Health Tracking Portal (Fig 1).

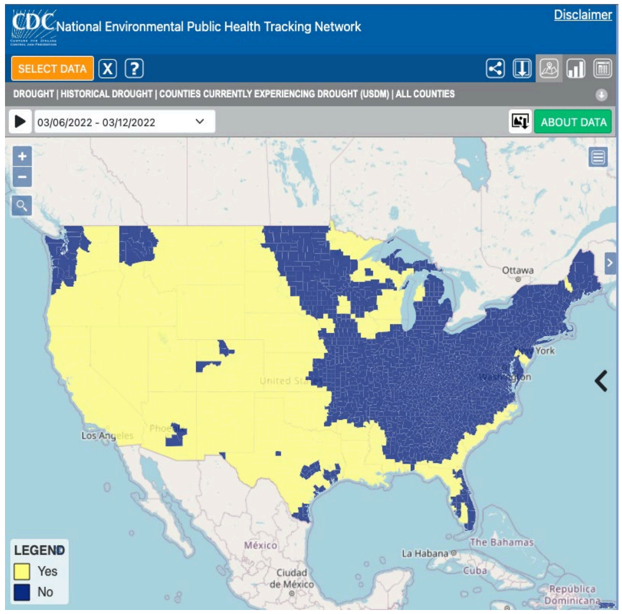


Figure 1. *USDM historical drought indicator for counties currently experiencing drought in the U.S., 2022.*

Planned work

- Publish paper on the acute health effects and economic impact of extreme heat
- Begin pilot HABS project focused on Ohio
    1) develop indicators and measures
    2) develop the methods/technology to use satellite imagery for early warning
    3) operationalize the indicators and measures
- Co-mentor a postdoctoral research scholar for EPHT projects

Publications

Grant, E., and **J. D. Runkle**, 2021: Long-term health effects of wildfire exposure: A scoping review. *The Journal of Climate Change and Health,* **6**, 100110. doi.org/10.1016/j.joclim.2021.100110

Other

- PI Runkle mentored graduate student Emily Grant (UNC) on long-term health effects of wildfires

Environmental Information and Analysis for the Real Estate Development Sector

Task Leader	Amanda Rycerz
Task Code	NC-SAS-29-Willis LTD (formerly Acclimatise)

Highlight: This collaborative research study examined the role of NOAA environmental data, and its usage in solution provider tools/applications, for understanding, analyzing, and detecting wildfire risk across the real estate value chain. Stakeholders will face a range of risks associated with the more frequent and intense wildfires occurring across the U.S. with an identified sector need for additional, higher resolution, and/or new data product offerings from NOAA NCEI.

Background

The U.S. has experienced devastating wildfires since 2017, with 2020 bring the worst wildfire season on record, causing extensive property damage, business disruption and loss of life. Despite the high risk that wildfire poses to physical structures, real estate development continues in the fringes of urban and forested areas in the 'wild-land urban interface' (WUI) where housing affordability and proximity to nature come with high risk. As development continues to expand into fire prone areas, understanding and incorporating wildfire information into real estate planning and decision-making is of critical importance across the real estate value chain. Some of the key real estate stakeholders include those involved in finance (including insurance), asset management, property development, and ownership and transaction (including leasing and managing).

NOAA/NCEI observes and makes available environmental information (e.g., temperature, precipitation, drought, wind-speed, relative humidity, etc.) that are important inputs to models, tools, and applications that can help end users in the real estate sector analyze and understand wildfire risk. As using climate and weather data involves a degree of technical literacy and time, current research shows that real estate stakeholders concerned with wildfire risk tend to use value-added tools to analyze wildfire risk and exposure.

This project extended a previous NCEI case study in real estate with a deep dive focus on the role and usage of environmental data in select areas of the real estate sector. Three primary research questions were examined: 1) What are the stakeholder-specific requirements for tools and information to support wildfire risk? 2) What are the tools and applications (public and private) available to support decision-making? 3) What are the gaps and/or potential areas for improvement that NOAA and service providers could address to provide more serviceable data, products, and tools for the real estate sector?

Accomplishments

A literature review was completed previously that focused on how environmental information is being used in the real estate sector, as well as an initial series of stakeholder interviews to identify current climate risk management practices and specific sector data needs and requirements (specifically related to property development, asset management and insurance, and ownership and transaction). The results of the literature review and initial interviews reflected that real estate stakeholders do not access NOAA data directly, and rather rely on third party providers that often integrate NOAA data as an input into their tools/applications.

To complete the analysis of current environmental data application and sector needs and requirements, engagement discussions were held with additional targeted stakeholders and solution providers during the past year. The summary view of the real estate value chain (Figure 1) was updated with an emphasis on solution providers as the direct "users" of NOAA environmental data in the development of their products and services tools/applications. Interview responses from the solution providers were further analyzed to better understand the role and value of environmental information in the risk analysis.

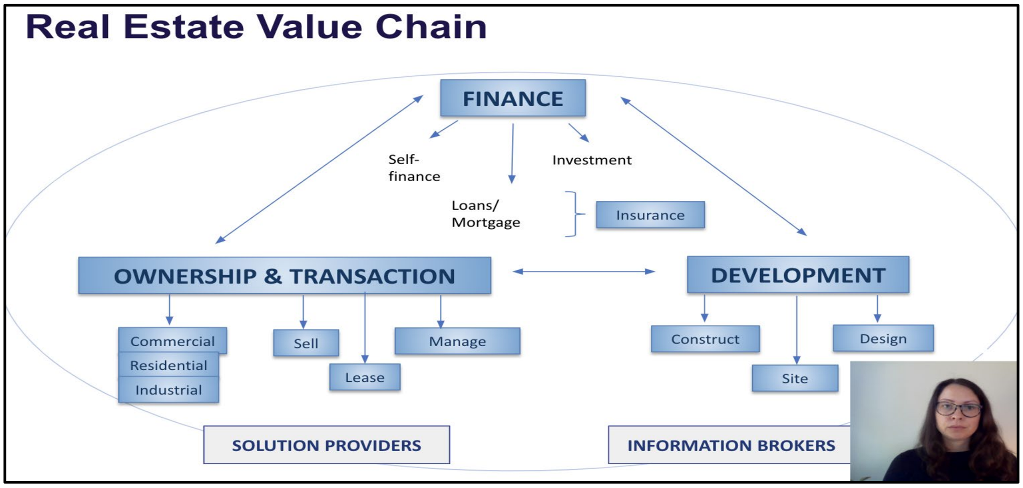


Figure 1. *Summary view of the real estate value chain.*

Full results of this project were compiled into a summary report provided to CISESS NC and NOAA NCEI. Some of the key findings included the following:

- Stakeholders in the real estate value chain face a range of risks associated with the more frequent and intense wildfires occurring across the U.S.
- Current demand for broader climate risk and/or specific wildfire tools varies across the real estate value chain stakeholders (e.g., very high demand for tools to serve the re/insurance sector versus lower demand from project developers)
- There is an increasing need to develop a user-friendly interface for wildfire risk analysis (akin to the current NOAA Sea Level Rise Viewer)
- The interviewed service providers (NOAA data users) would greatly benefit from additional and higher resolution environmental data (e.g., enhanced spatial and temporal resolution of satellite imagery, a centralized repository for snowpack measurements, additional meteorological variables absent from station data such as humidity and solar radiation, etc.)

Planned work

This project is complete; however, NOAA NCEI is considering a future Listening Session with real estate industry leaders as part of the Department of Commerce / NOAA Series of Sector Based Listening Sessions.

Products

- Summary project report submitted to CISESS and NCEI

Presentations

Dissen, J., and A. Rycerz, 2021: Examining the role of NOAA environmental data in developing applications to understand wildfire risk across the real estate value chain. *4th Annual National Cohesive Wildland Fire Management Strategy Workshop*, virtual, October 5, 2021.

Dissen, J., 2022: The Role of Environmental Data in Wildfire Risk Assessment in the Real Estate Industry. *NCEI Seminar Series*, virtual, March 15, 2022.

Climate Monitoring	
Task Leader	Carl Schreck
Task Code	NC-SAS-30-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. Among these developments, a new USGCRP climate change indicator tracks the amount of tropical cyclone activity in the western Atlantic.

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 2020 and to the monthly NCEI State of the Climate Reports. Three new innovations were introduced into those monthly reports:

1. The Monthly and Annual Tropical Cyclone report now includes track maps of basin-wide tropical cyclone activity and maps for each individual storm. The basin-wide maps have also been incorporated into the BAMS State of the Climate.
2. A key portion of the Synoptic Discussion is identifying key teleconnection drivers for anomalies. The code for plotting these teleconnections was improved for stability and to improve the aesthetics of the plots.
3. In support of NOAA's new Rapid-response Attribution Team, the monthly Synoptic Discussion now includes maps of rank percentiles based on NClimGrid-daily to mirror existing monthly products.

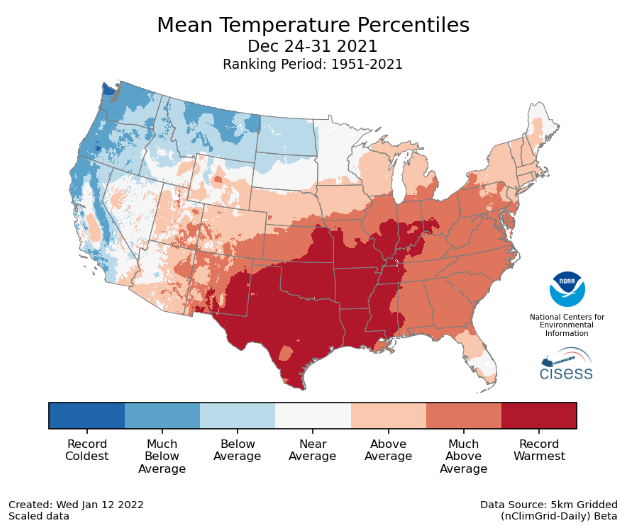


Figure 1. *Average temperature percentiles for December 24-31, 2021.*

This project actively worked with the USGCRP Climate Change Indicators Working Group to develop new indicators for tropical cyclone trends. The first was released this year and counts the number of active storms on each day of the year and then sums these totals for the year. Preparations are underway for a subsequent indicator that would focus on trends in heavy rainfall events over the U.S. associated with tropical cyclones.

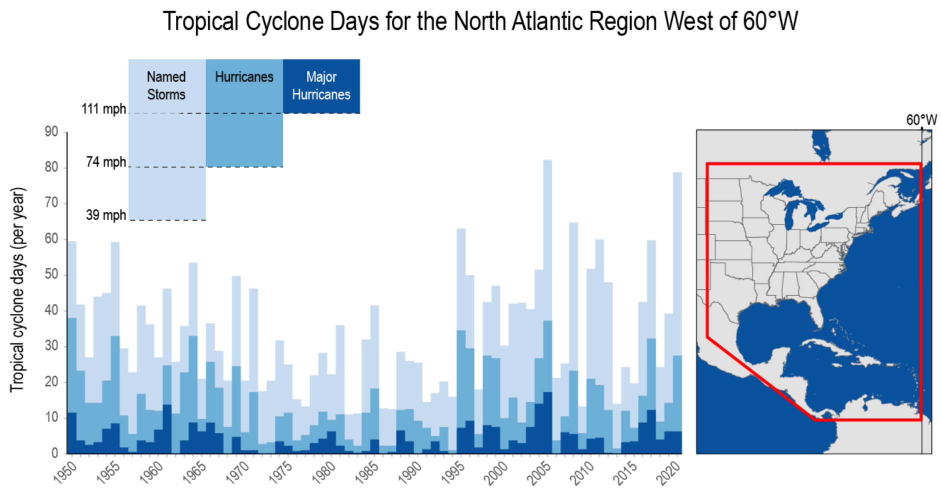


Figure 2. *This graph shows the total number of tropical cyclone days (the number of active storms on any given day) per year for the North Atlantic region west of 60°W. The data are tabulated for each of three intensity thresholds: named storms (winds of at least 39 mph), hurricanes (at least 74 mph), and major hurricanes (111 mph or more). Adding up the number of tropical cyclone days in a year across each of the three categories gives an indication of tropical storm frequency, duration, and intensity for that year.*

In addition to the BAMS State of the Climate, this project contributed to three other publications that discussed recent trends in tropical cyclone activity. The first documented the optimal period of record for calculating tropical cyclone climatologies for the Atlantic. The second examined the exceptionally strong end to the 2020 Atlantic hurricane season and identified potential predictors for future seasons. The last provided a one-stop-shop for trend in tropical cyclone activity for multiple metrics across all global basins.

Planned work

- Revise and publish the *BAMS* State of the Climate for 2021
- Prepare and edit the *BAMS* State of the Climate for 2022
- Draft monthly NCEI State of the Climate "Synoptic Discussions" and "Tropical Cyclone" reports
- Develop a USGCRP climate change indicator for tropical cyclones
- Develop code for examining evaluating the strength of subseasonal anomalies

Publications

Diamond, H. J., and **C. J. Schreck**, eds., 2021: The Tropics [in "State of the Climate in 2020"]. *Bulletin of the American Meteorological Society*, 102, S199–S262. doi.org/10.1175/BAMS-D-21-0080.1

Schreck, C. J., P. J. Klotzbach, and M. M. Bell, 2021: Optimal Climate Normals for North Atlantic Hurricane Activity. *Geophysical Research Letters*, 48, e2021GL092864. doi.org/10.1029/2021GL092864.

Klotzbach, P. J., K. M. Wood, **C. J. Schreck**, S. G. Bowen, C. M. Patricola, and M. M. Bell, 2021: Trends in Global Tropical Cyclone Activity: 1990–2020. *Geophysical Research Letters*. doi.org/10.1002/essoar.10507864.1

Klotzbach, P. J., K. M. Wood, M. M. Bell, S. G. Bowen, L.-P. Caron, J. M. Collins, E. J. Gibney, and **C. J. Schreck**, 2021: A Hyperactive End to the Atlantic Hurricane Season: October–November 2020. *Bulletin of the American Meteorological Society*. doi.org/10.1175/BAMS-D-20-0312.1

Products

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

Calibration of High-resolution Infrared Radiation Sounder (HIRS) Brightness Temperatures	
Task Leader	Emma Scott
Task Code	NC-SAS-31-NCICS-ES

Highlight: A subset of the data that can be used for calibration of HIRS brightness temperature between satellites was identified for all relevant satellite pairs and calibration is being completed, with calibration coefficients calculated for the TIROS-N, NOAA 6-19 and METOP 1 and 2 satellites.

Background

The High-resolution Infrared Radiation Sounder (HIRS) instrument has provided measurements of brightness temperature for over 30 years, qualifying it to serve as an important climate data record (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 dataset that can be used for intersatellite calibration of HIRS brightness temperature. These data are a subset of the current clear-sky, limb-corrected HIRS data. To create a set of observations that could be used for direct comparison between satellites, points were identified where pairs of satellites had simultaneous nadir overpasses (SNOs) located within 0.02° latitude and longitude of each other within a 15-minute window of time. For each channel of HIRS measurements taken by each satellite pair, brightness temperature measurements that correspond to SNOs are sorted by latitude and filtered to create a dataset on which the calibration can be based without undue influence from outliers. The remaining data is placed into 10°C bins based on the brightness temperature measured in each channel by the first satellite of the pair, except for channel 12 which uses a 2°C bin size. Channel 12 encompasses a small range of temperatures and therefore requires a finer-scale approach.

Within each bin, the difference between the temperature measurements of both satellites is found, and then the median is taken to find a representative offset between the two satellites. This value is used as the calibration coefficient. Applying the calibration coefficient correction reduces the intersatellite difference in brightness temperature, as shown in the example from the N11-N12 pair seen in Figure 1. Many satellite pairs only have SNOs located within polar regions due to the geometry and timing of their orbits, but some pairs have SNOs located across the full range of latitudes. In cases where overlapping data is only available at the poles, the higher part of the temperature range is supplemented with the mean of all monthly mean brightness temperatures taken over an area of the Pacific Ocean spanning from -20° to 20° latitude and 200° to 260° longitude. In these cases, the inter-satellite difference between the grid box monthly mean brightness temperature is used as a supplement to the bin median in the calibration process. Differences between the two approaches remain minimal, so for temperature bins where both a Pacific grid point average and a bin median difference are available the average is taken of the two coefficient derivation methods. Channel 4 also required special consideration and employs a multiple linear regression to find a set of three calibration coefficients that take into consider observations from the surrounding channels. 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 spans the timeframe between the late 1970s and the present. Final steps will look for ways in which the calibration can be further improved for channels that regularly include noisy data, such as channels 1-3. This may be accomplished through the addition of multiple linear regression solutions like the method employed for channel 4.

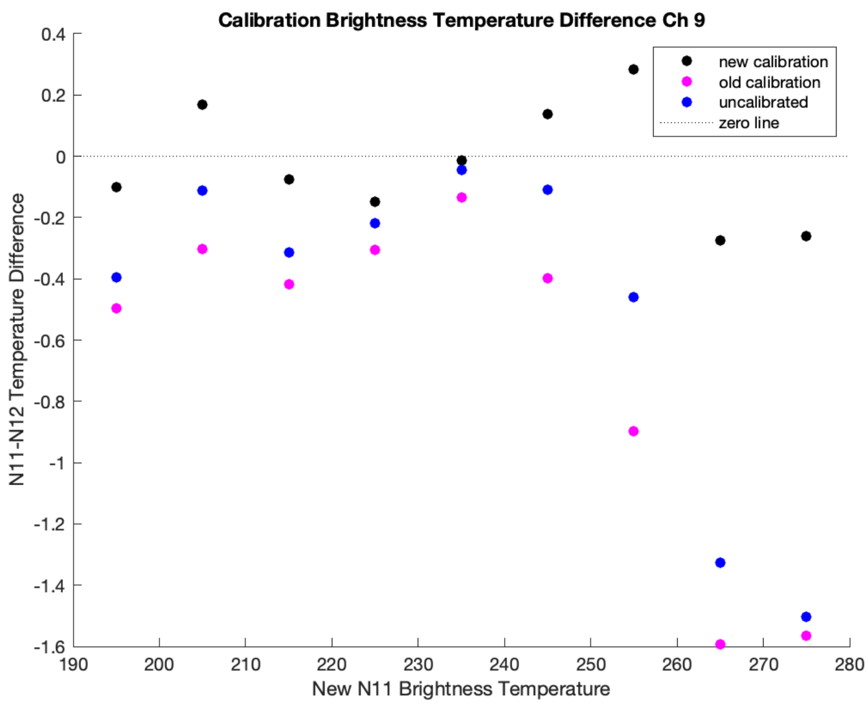


Figure 1. *Average intersatellite difference in brightness temperature for Channel 9 of the NOAA-11 and NOAA-12 satellite pair for each 10 degree Kelvin bin. Points representing data calibrated with the new coefficients (in black) tend to be closer to the zero line, showing better agreement between satellites than with either the old calibration (magenta) or uncalibrated data (blue), with a more pronounced improvement at the higher end of the measured temperature range.*

Planned work

- Investigate potential channels 1-3 improvements for each satellite pair by implementing multiple linear regression to find calibration coefficients, in the style of the channel 4 calibration process
- Release resulting calibrated data for use as a new CDR
- Publish a methodology paper on the calibration process for reproducibility

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 climate 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 climate science studies.

- Otis Brown and Kenneth Kunkel hold Research Professor appointments in NCSU's MEAS/COS. Kunkel serves as PhD committee chair for CISESS NC research staff member Brooke Stewart-Garrod and NCSU MEAS student Geneva Gray.
- Carl Schreck holds adjunct Research Assistant Professor appointments with NCSU MEAS and with NC A&T University.
- Jessica Matthews holds an adjunct Research Assistant Professor appointment with NCSU's Mathematics Department. Dr. Matthews transitioned to the NCEI federal workforce in August 2021.
- Jennifer Runkle holds an adjunct Research Assistant Professor appointment with Appalachian State University.

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.

- Douglas Rao (PhD, Geographical Sciences, University of Maryland) spent his third year at CISESS NC working in collaboration with Jessica Matthews on HIRS temperature and humidity profiles and a pilot study to develop cloud-optimized, analysis ready data for climate data records in the public cloud (see Science and Services project reports), as well as co-leading a machine learning training series and contributing to the establishment of the NOAA Center for Artificial Intelligence.

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.

Spring 2021:

- *Parvathy Menon*, NCSU undergraduate student, worked with Bjorn Brooks on combining GHCNd temperature observations with North Carolina energy grid data in a predictive AI model.
- *Eric Robinson*, University of Maryland undergraduate student, worked with Jessica Matthews and Douglas Rao to assess the quality of vegetation status simulated by CMIP6 models using climate data records.
- *Shrinkanth Yadav*, NCSU graduate student, worked with Jennifer Runkle to investigate the impacts of climate on mental health.
- *Caroline Zuber*, NCSU undergraduate student, worked with Olivier Prat to analyze NDVI datasets from the CDR program over the Southeastern United States.

Summer 2021:

- *Kelley DePolt*, Eastern Carolina University graduate student, worked with Jen Runkle and Ronald Leeper to evaluate concurrent heatwave and drought events and how they spatially overlay with vulnerable populations in the Carolinas.
- *Tyler Harrington*, U Mass Lowell undergraduate student, worked with Ronnie Leeper worked with Ronald Leeper to evaluate the impacts of drought on concurrent heatwave intensity and duration across the U.S.
- *Kathryn Konrad*, UNC Chapel Hill undergraduate student, worked with Jessica Matthews and Douglas Rao on resampling CMIP6 historical simulation of leaf area index (LAI) for comparison with satellite-based LAI products to evaluate model simulation performance.
- *Nirav Patel*, NCSU graduate student, worked with Bjorn Brooks on building web accessibility into GHCNd in the cloud using Amazon Web Services.
- *Katherine Slyman*, UNC Chapel Hill graduate student, worked with Jessica Matthews and Douglas Rao on evaluating CMIP6 historical simulations of leaf area index (LAI) using NOAA obs4MIPs LAI product derived from AVHRR data.
- *Devan Walton*, University of New Hampshire graduate student, worked with Bjorn Brooks on building workable frontends for the Global Historical Climatology Network daily (GHCNd) graph database and exploring smart tools for automated training of cypher querying for GHCNd developers.
- *Shrinkanth Yadav*, NCSU graduate student, completed his work with Jennifer Runkle, investigating the impacts of climate on mental health.
- The NASA DEVELOP team composed of *Joshua Green* (University of British Columbia graduate), *Julia Marturano* (Arizona State University graduate), *Emma Myrick* (Appalachian State University graduate), *Kyle Pecsok* (Clark University graduate), and *Victor Schultz* (University of Illinois Chicago) completed their science project under science co-advisor Ronald Leeper. The team evaluated the suitability of remotely sensed and modeled soil moisture datasets to support effective drought monitoring in Illinois.

Fall 2021:

- *Peyton Collado*, University of North Florida undergraduate student, worked with Ronald Leeper and Anand Inamdar to explore the frequency and duration of missing GOES-R land surface

temperature observations across the U.S. A main goal of this analysis is to evaluate the feasibility of backfilling these missing satellite records using surf solar absorption.
- *Kelley DePolt*, Eastern Carolina University graduate student, worked with Jen Runkle and Ronald Leeper to evaluate concurrent heatwave and drought events and how they spatially overlay with vulnerable populations in the Carolinas.
- *Montana Eck*, UNC Chapel Hill graduate student, worked with Jenny Dissen and Kenneth Kunkel on US-India Partnership for Climate Resilience program data analysis applying extreme value theory.
- *Tyler Harrington*, U Mass Lowell undergraduate student, worked with Ronald Leeper to evaluate the impacts of drought on concurrent heatwave intensity and duration across the U.S.
- *Natalie Luftman*, NCSU graduate student, worked with Jen Runkle to understand the impact of climate disasters on pediatric mental health in the US.
- *Katherine Slyman*, UNC Chapel Hill graduate student, worked with Douglas Rao on evaluating CMIP6 historical simulations of leaf area index (LAI) using NOAA obs4MIPs LAI product derived from AVHRR data.
- The NASA DEVELOP team composed of *Erica Barth-Naftilan* (Yale School of the Environment graduate), *Emma Myrick* (Appalachian State University graduate), *Erin Shives* (San Diego State University graduate), and *Alec Solberg* (Northeastern Illinois University) completed their science project, "Midwest Water Resources: Developing an Evapotranspiration Climatology to Analyze Spatiotemporal Water Budget Patterns for Agriculture and Natural Resources Managers in the Midwest" under science co-advisor Olivier Prat. The team worked to create evapotranspiration and water balance climatologies for the Midwestern United States.

Spring 2022:
- *Peyton Collado*, University of North Florida undergraduate student, continued work with Ronald Leeper and Anand Inamdar to explore the frequency and duration of missing GOES-R land surface temperature observations across the U.S.
- *Montana Eck*, UNC Chapel Hill graduate student, is working with Jenny Dissen and Kenneth Kunkel on US-India Partnership for Climate Resilience program data analysis applying extreme value theory.
- *Tyler Harrington*, U Mass Lowell undergraduate student, continued work with Ronald Leeper to evaluate the impacts of drought on concurrent heatwave intensity and duration across the U.S.
- *Natalie Luftman*, NCSU graduate student, continued work with Jennifer Runkle to understand the impact of climate disasters on pediatric mental health in the US.
- *Naga Usha Mahathi Lanka*, NCSU graduate student, is working with Douglas Rao on evaluating CMIP6 historical simulations of leaf area index (LAI) using GIMMS LAI3g product derived from AVHRR data.
- *Sai Venkata Vinay Kumar Samudrala*, NCSU graduate student, worked with Lou Vasquez and Denis Willett on optimizing weather dataset processing and delivery.
- *Katherine Slyman*, UNC Chapel Hill graduate student, is working with Douglas Rao on evaluating CMIP6 historical simulations of leaf area index (LAI) using NOAA obs4MIPs LAI product derived from AVHRR data.
- *Andrew Terry*, NCSU undergraduate student, is working with Carl Schreck is working with Carl Schreck to identify climate drivers for hurricane activity from four subregions of the North Atlantic and their impacts on the U.S.
- The NASA DEVELOP team composed of *Addison Pletcher* (Michigan State University graduate), *Max Rock* (University of Wisconsin-Madison), *Erin Shives* (San Diego State University graduate),

and *Alec Solberg* (Northeastern Illinois University) completed their science project, "Midwest Water Resources II," under science co-advisor Olivier Prat. The team extended fall project work, further investigating evapotranspiration variability in the Midwest.

Presentations

Barth-Naftilan, E., E. Myrick, E. Shives, and A. Solberg, 2021: Midwest Water Resources: Developing an Evapotranspiration Climatology to Analyze Spatiotemporal Water Budget Patterns for Agriculture and Natural Resources Managers in the Midwest. NCEI DEVELOP Closeout Presentation, virtual, November 15, 2021.

DePolt, K., and T. Harrington, 2021: Advancing research on compounding risk of drought and extreme heat events in the U.S. NCEI Intern Closeout Presentations, virtual, August 12, 2021.

Green, J., J. Marturano, V. Schultz, K. Pecsok, and E. Myrick, 2021: Utilizing NASA Earth Observations to Enhance Drought Monitoring in Illinois. NCEI Intern Closeout Presentations, virtual, August 5, 2021.

Konrad, K., and K. Slyman, 2021: Evaluation of vegetation status in Earth system models using satellite climate data records. NCEI Intern Closeout Presentations, virtual, August 12, 2021.

Kunkel, K. E., M. Eck, and J. Dissen, 2022: Precipitation Extremes: Extreme Value Theory and Statistical Trends in Uttarakhand. *TERI team briefing*, virtual, January 12, 2022.

Pletcher, A., M. Rock, E. Shives, and A. Solberg, 2022: Midwest Water Resources II. DEVELOP at NCEI Closeout Presentation, virtual, March 30, 2022.

Supporting the development of artificial intelligence within NOAA and CISESS	
Task Leader	Yuhan (Douglas) Rao
Task Code	NC-WFD-01-NCICS-YR

Highlight: CISESS NC assisted in the development of the NOAA Center for Artificial Intelligence, supported the execution of the 3rd NOAA Workshop 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 STAR 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

NOAA Center for Artificial Intelligence (NCAI)

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

- *Expand the NOAA Community of Practice on AI*: Since the start of the NOAA Community of Practice on AI in summer 2020, the community is growing steadily, with 350 new members added during this reporting period.
- *Develop NCAI web presence*: During the past year, the NCAI development team partnered with the NCEI Communications Team to develop a NOAA-level public website for NCAI as a central location for communicating the most recent NOAA AI activities. The website (https://noaa.gov/ai) was released in August 2021 and has been highlighted by Office of Science and Technology Policy (OSTP) National AI Initiative (https://ai.gov).
- *Develop NCAI training framework*: Working with NESDIS/STAR colleagues, CISESS NC developed the Open Science Framework for Future Workforce Development on AI, including a common tutorial template and guide for contributors to ensure reproducibility and accessibility. The NCAI training team worked with members from different NOAA line offices, including National Ocean Services (NOS), National Weather Services, National Marine and Fishery Services, and Office of Ocean and Atmospheric Research, to develop training materials relevant to NOAA mission areas.
- *Develop AI-ready data standard*: CISESS NC and NOS, in collaboration with the ESIP Data Readiness Cluster which includes 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 AI-ready data survey

captured responses from 104 AI practitioners for a diverse range of environmental science topic areas. The survey results are currently being summarized and will be distributed publicly as a final report.

- *3rd NOAA Workshop on Leveraging AI in Environmental Sciences*: Douglas Rao co-chaired the 3rd NOAA Workshop on Leveraging AI in Environmental Sciences, executed by a team of 27 members from several NOAA line offices and external partners, with support from Earth Science Information Partners. The workshop included more than 180 presentations (both oral and poster) across six thematic areas and eight high level plenary sessions focused on the status and challenges for applying AI in the environmental sciences. Plenary session speakers included NOAA Administrator Dr. Rick Spinrad, OSTP National AI Initiative Director Dr. Lynne Parker, UK Met Office Chief Scientist Dr. Stephen Belcher, and National AI Research Resource Task Force member Dr. Elham Tabassi.

11th Climate Informatics Conference

CISESS NC will host the 11th International Conference on Climate Informatics. This international conference series aims to bring together researchers and users across different disciplines and sectors to forge international collaborations between climate science, data science, and computer science; share state-of-art developments in climate data and informatics; and accelerate the rate of discovery in climate science and adaptation of climate applications. The conference has received 57 submissions, including 22 full papers and 35 extended abstracts. It will be a hybrid event with both in person and virtual participation, and will include a hybrid hackathon on the topic of drought prediction using open environmental data in public cloud environments.

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
- Coordinate the AI-ready data working group effort to define the maturity matrix for AI-ready environmental data
- Pilot the development of AI-ready data collection for 1-2 thematic areas
- Plan and execute the 4th NOAA Workshop on Leveraging AI in Environmental Sciences

Publications

Peer reviewed

Hills, D., J. Damerow, B. Ahmmed, N. Catolico, S. Chakraborty, T. Y. Chen, C. Coward, R. Crystal-Ornelas, W. Duncan, L. Goparaju, C. Lin, Z. Liu, M. Mudunuru, **Y. Rao**, R. Rovetto, Z. Sun, B. Whitehead, L. Wyborn, and T. Yao, 2021: Earth and Space Science Informatics Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science. *Earth and Space Science Open Archive*. doi.org/10.1002/essoar.10508448.1

Sun, Z., L. Sandoval, R. Crystal-Ornelas, S.M. Mousavi, J. Wang, C. Lin, N. Cristea, D. Tong, W.H. Carande, X. Ma, **Y. Rao**, J.A. Bednar, A. Tan, J. Wang, S. Purushotham, T.E. Gill, J. Chastang, D. Howard, B. Holt, C. Gangodagamage, P. Zhao, P. Rivas, Z. Chester, J. Orduz, and A. John, 2022: A review of Earth Artificial Intelligence. *Computers & Geosciences,* **159**, 105034. doi.org/10.1016/j.cageo.2022.105034

White paper

Voisin, N., A. Bennett, Y. Fang, G. Nearing, B. Nijssen, Bart, and **Y. Rao**, 2021: A science paradigm shift is needed for Earth and Environmental Systems Sciences (EESS) to integrate Knowledge-Guided Artificial Intelligence (KGAI) and lead new EESS-KGAI theories. United States. doi.org/10.2172/1769651

Presentations

Redmon, R., E. Kihn, Y. Rao, C. Slocum, B. Meyer, 2021: NOAA Center for Artificial Intelligence (NCAI) development. *ClimaCon 2021* "The Surprising State of AI in the Weather Industry" session, virtual, April 28, 2021.

Redmon, R., E. Kihn, Y. Rao, C. Slocum, B. Meyer, 2021: NOAA's Center for Artificial Intelligence: Progress Towards an AI Ready Agency and Workforce. *2021 AGU Fall Meeting,* New Orleans, LA*,* December 13, 2021.

Rao, Y., 2021: Promoting NOAA Workforce Proficiency on Artificial Intelligence through Open Science and Partnership. Poster. *2021 AGU Fall Meeting,* New Orleans, LA*,* December 15, 2021.

Rao, Y., 2022: Towards AI-ready Data for Wildfire Applications. *2022 Earth Science Information Partners (ESIP) January Meeting,* virtual, January 20, 2022.

Other Projects

The vision of the North Carolina Institute for Climate Studies (NCICS) is to *inspire* cutting-edge research and collaboration; *advance* understanding of the current and future state of the climate; and *engage* with business, academia, government, and the public to enhance decision-making. The Institute's main objectives are to promote discovery of new knowledge about global, regional, and local climate variability and its impacts and to provide information that is critical for determining trends and validating climate forecasts at all these spatial scales.

The vision of CISESS is to advance NOAA's ability to generate data and information from the constellation of global observing platforms in order 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 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 as well as to various other public and private entities.

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 which 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 its 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 (POES) series and EUMETSAT Polar System (EPS) satellites, has provided a nearly 40-year Climate Data Record (CDR) 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 version 5 product (see 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. Version 5 is complete for HIRS data from Metop-1, Metop-2, NOAA-17, NOAA-16, NOAA-15, NOAA-14, and NOAA-12, which consists of HIRS data going back to mid-1991. The current reprocessing still uses ASCII data format for both temperature and humidity profiles but has the optional function to convert to netCDF4 output format. 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 is updating their workflow to use the future netCDF4 file format.

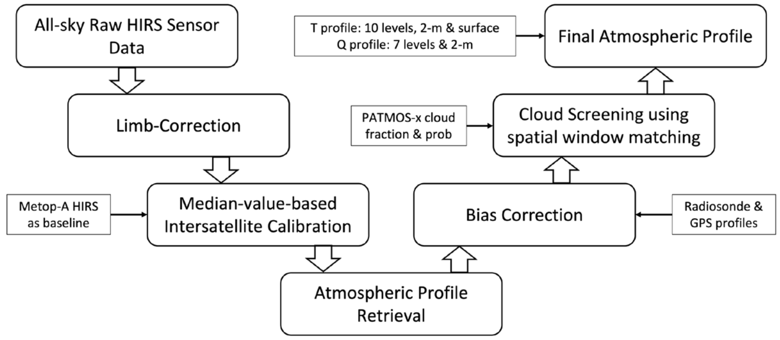


Figure 1. *Updated HIRS atmospheric profile retrieval workflow used in version 5 dataset.*

2. *Evaluation of near-surface marine air temperature for blended data development*. To develop the blended data using HIRS as a main input, an understanding of the quality of HIRS temperature retrieval is needed. During version 4, HIRS retrieval was evaluated using land surface observations and radiosonde profiles. However, the assessment over ocean surface is insufficient due to the lack of available data. The project team is collaborating with UK NOC to use height-adjusted near-surface marine air temperature data at 2-meter height from International Comprehensive Ocean-Atmosphere Data Set (ICOADS) to evaluate the quality of version 5 HIRS near surface temperature retrieval. The assessment utilizes matchup data pairs between HIRS and ICOADS during 2005-2014 with results reflected in Figure 2. 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 v.s. 0.04 K). The larger differences during daytime may be attributed to the uncertain of ICOADS observation adjustment to the daytime heating effect. More investigation is needed to understand HIRS retrieval quality.

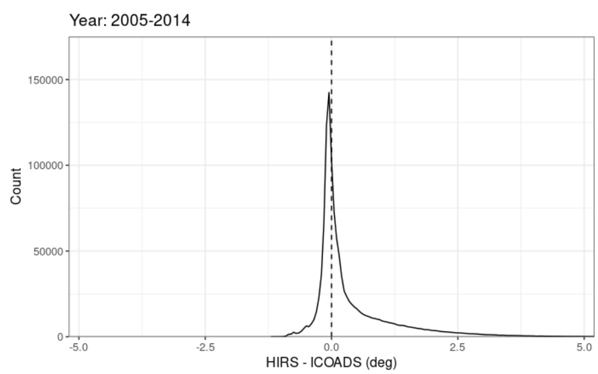


Figure 2. *The histogram of the difference between HIRS near-surface temperature retrieval matched up with height-adjusted ICOADS near-surface marine air temperature observations at 2-meter height.*

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

Presentations

Rao, Y., J. Matthews, and L. Shi, 2022: Improvement and Evaluation of a Neural Network-based HIRS Atmospheric Profile over Global Oceans. *Ocean Sciences Meeting 2022,* virtual, February 28, 2022.

Climate Change Impacts in the Arctic 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 U.S. team completed an assessment of the costs of climate change impacts on critical infrastructure in the Circumpolar Arctic.

Background

Contemporary environmental changes are not restricted to changes in major climatic characteristics such as temperature and precipitation, but are multi-faceted, affect and are affected by human activities, and may manifest themselves differently in different regions of the world and 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 four 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:

- Organization of NEFI-related workshops, international conference sessions, and matchmaking
- Acting as guest editor for the *Environmental Research Letters* Special Issue on Northern Eurasia; 58 papers were published during the past 4 years.
- Member of the Editorial Board of
  - *Ice and Snow* (Russia)
  - *Environmental Research Communications* (UK)
- Program Committee Member of the All-Russia Annual Science of the Future Conference, Forum, and Early Career Scientists Competition (Autumn 2021)

Belmont Forum Collaborative Research: ARCTIC climate change and its impact on Environment, infrastructure, and Resource Availability (ARCTIC ERA). (Project role: Co-Investigator)

The U.S. team of this international project completed an assessment of the costs of climate change impacts on critical infrastructure in the Circumpolar Arctic and updated the circumpolar infrastructure database which will be used in the coming year to improve regional estimates of climate change impacts on Arctic infrastructure. *This project was completed in December 2021.*

Belmont Forum Collaborative Research: Rapid Arctic environmental Changes: Implications for well-being, resilience and Evolution of Arctic communities (RACE). (Project role: Co-Investigator)

This new 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: COAST (Coastal OceAn SusTainability in Changing Climate). (Project role: Co-Investigator)
This new project awarded in 2021 focuses on the sustainability of the coastal ocean under the impacts of ongoing and projected climate variability and change. The project will address 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 and the infrastructure of today and in different scenarios for the future.

Collaborative Research: NNA Research: Change, Resilience, and Sustainability of Frozen Commons in Alaskan and Northeastern Siberian Communities. (Project role: Co-Investigator)
This is a new NSF-funded project awarded in February 2022 with U.S., Canada, and Russia 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

Grebenets, V. I., V. A. Tolmanov, F. D. Iurov, and **P. Y. Groisman**, 2021: The problem of storage of solid waste in permafrost. *Environmental Research Letters*. doi.org/10.1088/1748-9326/ac2375

Hosseini-Moghari, S.-M., S. Sun, Q. Tang, and **P.Y. Groisman**, 2022: Scaling of precipitation extremes with temperature in China's mainland: Evaluation of satellite precipitation data. *Journal of Hydrology,* **606**, 127391. doi.org/10.1016/j.jhydrol.2021.127391

Chen, J., R. John, J. Yuan, E. A. Mack, **P. Y. Groisman,** J. Wu, G. Allington, K. M. de Beurs, A. Karnieli, P. Fan, G. Gutman, M. Kappas, Z. Ouyang, B. Şat, Z. Xue, G. Dong, F. Zhao, G. M. Henebry, M. Kussainova, N. A. Graham, A. Amartuvshin, Ch. Shao, A. K. Graham, l. Qu, H. Park, X. Xin, J. Chen, A. A, Pearson, L. Tian, C. Knight, F. Li, and J. Qi, 2021: Sustainability Challenges for the Social-Environmental Systems across the Asian Drylands Belt. *Environmental Research Lett*ers, **17**, 023001. doi.org/10.1088/1748-9326/ac472f

Vova, O., M. Kappas, **P. Groisman**, Ts. Renchin, and S. Fassnacht, 2022: Development of a new Drought index using SMOS satellite soil moisture products: Case Study in Southwestern Mongolia. *Geo-Eko*. doi.org/10.1002/essoar.10509117.1

Presentations

Groisman, P. Y., 2021: Changing Climates across Central Asia. *Central Asia Regional Information Network (CARIN) Annual Meeting*, virtual, May 7, 2021.

Groisman, P. Y., 2021: Environmental, socio-economic, and climatic changes in Northern Eurasia. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Groisman, P. Y., 2021: Northern Eurasia Future Initiative (NEFI), Update. Poster. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Tchebakova, N., E. I. Parfenova, E. V. Bazhina, A. J. Soja, and P. Y. Groisman, 2021: Dark conifer forests dieback at mid-to-highlands in the southern Siberia's mountains is not caused by drought stress. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Groisman, P. Y., 2021: International Environmental Studies in Northern Eurasia: the Arctic, Boreal Forest Zone, and Dryland Belt. *All-Russia Scientific Forum Science of the Future - Science of the Youth* conference, virtual, November 17, 2021.

Groisman, P. Y., V. I. Grebenets, N. M. Tchebakova, and O. Vova, 2021: Northern Eurasia Future Initiative (NEFI) update. *Computational Information Technologies for Environmental Sciences (CITES)-2021* conference, virtual, November 26, 2021.

Groisman, P. Y., 2021: Northern Eurasia Future Initiative (NEFI): The Current Status. Poster. *2021 AGU Fall Meeting,* virtual, December 17, 2021.

Groisman, P. Y., 2021: Environmental, Socioeconomic, and Climatic Changes in Northern Eurasia. Poster. *2021 AGU Fall Meeting,* virtual, *December 17, 2021.*

Vova, O., M. Kappas, P. Y. Groisman, T. Renchin, and S. Fassnacht, 2021: Development of a New Soil Moisture Index Using SMOS Satellite Soil Moisture Products: Case study in Southwestern Mongolia. *2021 AGU Fall Meeting,* virtual, December 17, 2021.

Groisman, P. Y., 2022: Task 4.2: Environmental thresholds. *Frozen Commons International Workshop*, Tempe, Arizona, February 19, 2022.

Georgiadi, A. 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. *International Symposium on Pan-Arctic Water-Carbon Cycles and Terrestrial Changes in the Arctic: For resilient Arctic Communities*, virtual, March 11, 2022.

Other

- Panel Chair, Russian Science Foundation (RSF) MEGA GRANTS Earth Sciences competition 2021/2022
- PhD committee member for Oyudari Vova (Georg-August-Universitat, Göttingen Germany)

America's Water Risk: Water System Data Pooling for Climate Vulnerability Assessment and Warning System	
Task Lead	Kenneth Kunkel
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 (IPCC) Fifth Assessment Report (AR5) and the U.S. Fourth National Climate Assessment (NCA4; USGCRP 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 U.S. 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. North Carolina State University 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 Nino3.4 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-decadal timescales.

Planned work

- Complete work on NASH predictability

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: Preliminary analysis reveals that scaling the Intensity-Duration-Frequency (IDF) curves may be more sensitive to the downscaling method than the Global Climate Model (GCM) projections.

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 position 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 are 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.

This 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 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 (24hr) Intensity, Duration, Frequency (IDF) curves for various periods and greenhouse gas emission scenarios using different statistical and dynamical downscaled projections. Preliminary analysis reveals that scaling the IDF curves may be more sensitive to the downscaling method than the GCM projections.

Planned work

- Continue to investigate the differences in various statistical and dynamical downscaling methods
- Develop rainfall design values and uncertainty ranges for use by the North Carolina Department of Transportation

The Urban Resilience to Extremes Sustainability Research Network (UREx SRN)	
Task Lead	Kenneth Kunkel
Task Code	NC-OTH-05-NCICS-KK
Other Sponsor	Arizona State University/NSF

Highlight: Climate change scenarios for Valdivia, Chile were completed by the NCSU team as part of this multi-institutional project.

Background

Climate change is widely considered one of the greatest challenges to global sustainability, with extreme events being the most immediate way that people experience this phenomenon. Urban areas are particularly vulnerable to these events depending on their location and given their population density and increasingly complex and interdependent infrastructure. The highly interdisciplinary and geographically dispersed Urban Resilience to Extremes Sustainability Research Network (UREx SRN) team developed a diverse suite of methods and tools to assess how infrastructure can be resilient, provide ecosystem services, improve social well-being, and exploit new technologies in ways that benefit all segments of urban populations. The team worked with several pilot cities to co-produce the knowledge needed to transition to resilient Social, Ecological, and Technical Systems (SETS) infrastructure in the future. The cities include Portland (Oregon), Phoenix, New York City, Baltimore, Syracuse, Miami, San Juan (Puerto Rico), Hermosillo (Mexico), and Valdivia (Chile). The NCSU portion of the project included characterizations of recent historical trends of climate extremes and the development of future climate extreme scenarios. NCSU project researchers were members of the Climate and Hydrologic Extremes Working Group tasked with developing climate extremes products for the nine cities, tailored to the city-specific vulnerabilities, and communicating information about those products to other members of the network.

Accomplishments

Work was completed in two task areas in support of overall project aims.

LOCA-downscaled gridded climate model data analyses for pilot cities

The Asynchronous Regional Regression Model (ARRM) was used to produce downscaled climate model data for Valdivia, Chile. The downscaled data was summarized and described in a written document for use by other members of the project team. The dataset was provided to a Ph.D. student working on the project as input into a flood model.

High-resolution modeling of extreme precipitation events

The Weather Research and Forecasting (WRF) model was used to perform additional simulations of the Ellicott City, Maryland, flood event of July 2016 and the October 2015 event in Portland, Oregon, using the constructed analogues approach to examine the potential impact of global warming.

Planned work

This project ended in June 2021.

Other

- PI K. Kunkel is PhD advisor of Geneva Gray (NCSU Marine, Earth, and Atmospheric Sciences Department)

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-06-NCICS-RL

Highlight: Top ranked drought indices for potential health outcomes were identified [Standardized Precipitation Index (SPI), Standardized Precipitation Evapotranspiration Index (SPEI), Evaporative Drought Demand Index (EDDI) and the Evaporative Stress Index (ESI)] and compared at several aggregation periods to U.S. Drought Monitor (USDM) metrics for four specific drought events. SPI, SPEI, and EDDI aggregations of 6- and 12-month moisture deficits and 3-month ESI were more in line with USDM mode drought frequency.

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 from which to monitor drought, it may not always be 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 U.S. Drought Monitor (USDM). The final goal is to evaluate the relationship, if any, between these drought indicators and resulting health outcomes across the U.S.

Accomplishments

A total of 53 drought indices were evaluated based on the availability of a precomputed dataset, and the dataset's spatial extent, temporal coverage, and geographic specificity. The indices were scored out of a possible 2 points for each measure for a total possible score of 8 points. The total scores were then used to rank the drought indicators. Table 1 shows the top ranked drought indicators with the highest rank 1 generally given to remotely sensed datasets, which tend to have higher measures of spatial coverage. This is followed 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 U.S. 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-month). The frequency and duration of these drought events 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 (Fig. 1). This was also the case for EDDI and 3-month ESI.

In addition, the spatial extent each of these drought metrics and aggregation times were compared against the USDM mode and maximum for notable drought events in the U.S.: 2011 Texas Drought, 2012 Central U.S. Drought, 2007 Southeast drought, and the 2002 Southwest Drought (Fig. 2). Preliminary results revealed EDDI tended to have larger extents of drought conditions than the USDM mode or max conditions.

Drought Index	Rank by Score 2
Enhanced Vegetation Index (EVI)	1
Temperature Condition Index (TCI)	1
Land Surface Water Index (LSWI)	1
Soil Adjusted Vegetation Index (SAVI)	1
Evaporative Stress Index (ESI)	1
Normalized Difference Vegetation Index (NDVI)	1
Vegetation Condition Index (VCI)	1
Vegetation Health Index (VHI)	1
Self-Calibrated Palmer Drought Severity Index (scPDSI)	3
Normalized Difference Water Index (NDWI)	1
Vegetation Drought Response Index (VegDRI)	1
United States Drought Monitor (USDM)	1
Evaporative Demand drought Index (EDDI)	2
Percent of Normal Precipitation (pctNorm)	3
Standardized Precipitation Index (SPI)	3
Standardized Precipitation Evapotranspiration Index (SPEI)	3
Palmer Drought Severity Index (PDSI)	3

Table 1. *Top ranked drought indices based on availability, spatial extent, temporal coverage, and geographic specificity.*

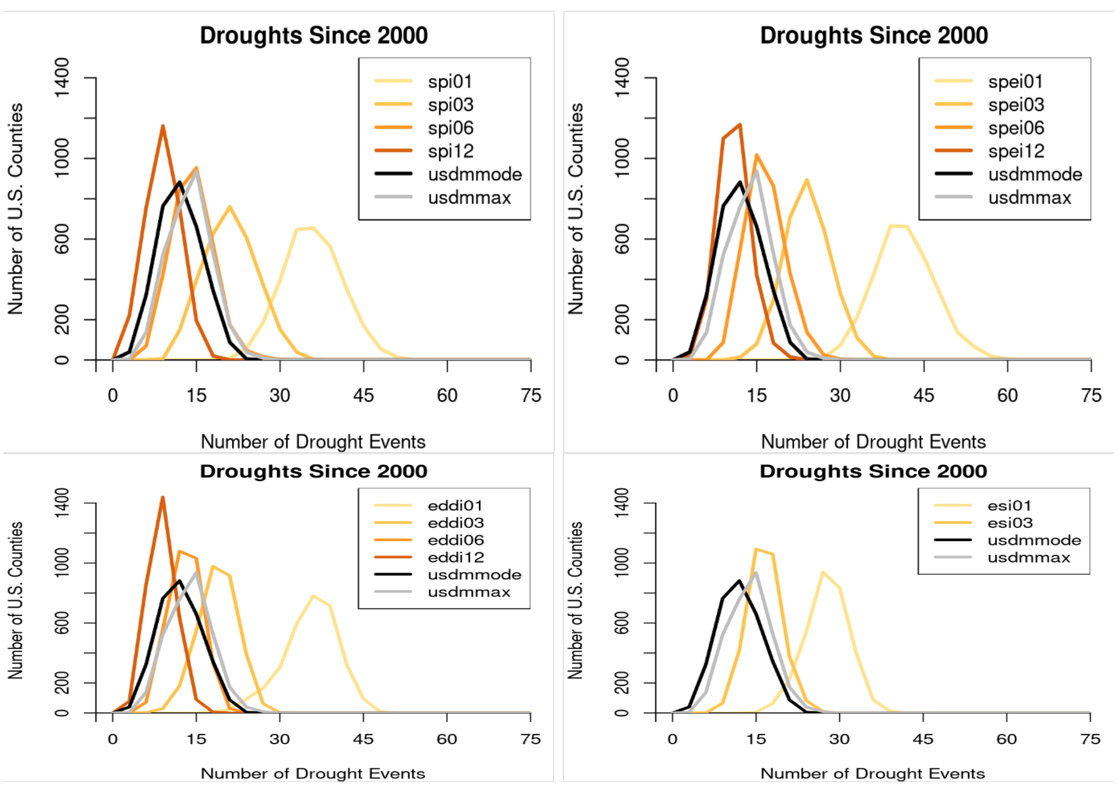


Figure 1*. The frequency distribution of U.S. Counties based on the number of drought events for SPI (top left), SPEI (top right), EDDI (bottom left) and ESI (bottom right) for aggregations periods 1-month to 12-months. ESI was only available at the 1- and 3-month timescales. USDM mode (black) and max (gray) are provided for comparisons.*

The SPI and SPEI 6-month results tended to align best with the USDM extent; however, this varied slightly between separate drought events.

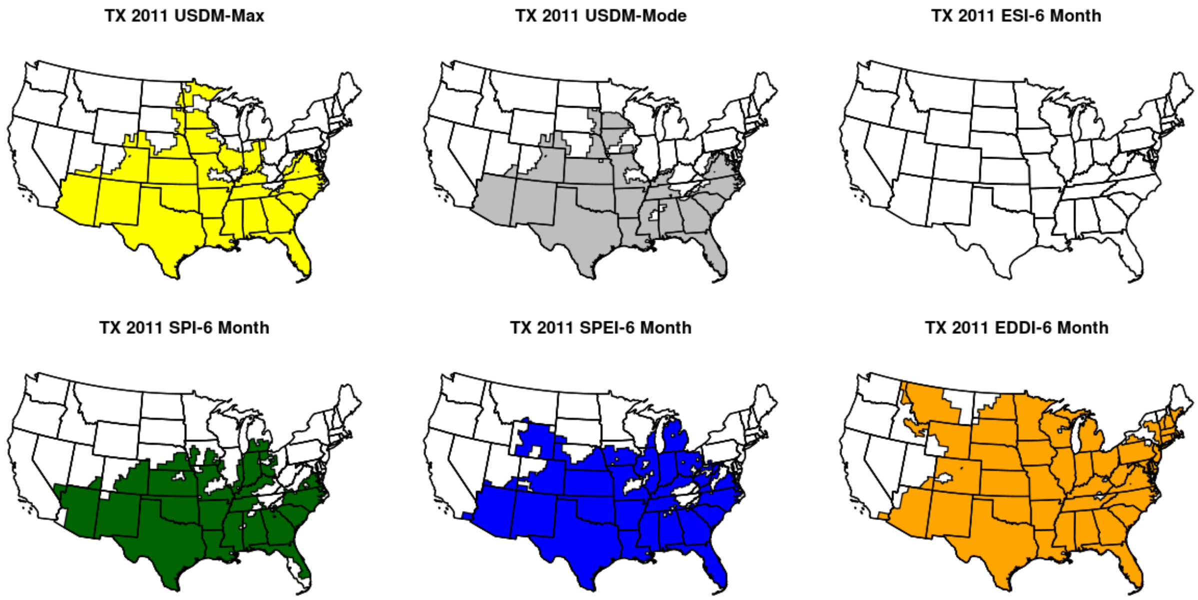


Figure 2. *The spatial extent of the USDM maximum (yellow), mode (gray), ESI (doesn't have 6-month variant), SPI-6-month (green), SPEI-6-month (blue) and EDDI-6-month (orange) for the 2011 Texas Drought events*

Planned work

- Submit a manuscript documenting the drought index rankings based on availability, geographic specificity, spatial extent, and temporal resolution.
- Summarize the results of the various drought frequency and duration differences with respect to USDM in a publication.
- 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 U.S. drought, the 2007 Southeast drought, and the 2002 southwest drought.

<u>Presentations</u>

Leeper, R. D., 2021: A Comparative Review of Drought Metrics for Public Health Research Applications. Poster. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, December 14, 2021.

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-07-NCICS-OP
Sponsor	Columbia University/US Department of Energy (DOE)

Highlight: The project team developed an innovative Bayesian statistical framework to quantify the uncertainties associated with the representation of rain microphysical processes in weather and climate models.

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.

The collaborative project team, with scientists from Columbia University, Pennsylvania State University, North Carolina State University, and the National Center for Atmospheric Research, investigated the uncertainties in the representation of microphysical processes in climate models and developed an innovative Bayesian statistical framework that combines the extensive radar and ground-based data from the Department of Energy Atmospheric Radiation Measurement (ARM) field campaigns, bin microphysical modeling, and a new bulk parameterization.

Accomplishments

Project PhD student Karly Reimel (Pennsylvania State University) defended her dissertation in May 2021.

Planned work

This project ended in August 2021.

Presentations

Reimel, K. J., M. van Lier-Walqui, M. Kumjian, H. Morrison, and O. P. Prat, 2021: Learning about microphysical processes from polarimetric radar observations with BOSS. *2021 AGU Fall Meeting,* virtual, December 14, 2021.

Reimel, K. J., M. van Lier-Walqui, H. Morrison, M. Kumjian, and O. P. Prat, 2021: Novel insights into rain physics from synthetic polarimetric radar observations and BOSS. Poster. *ARM/ASR Joint User Facility and PI Meeting*, virtual, June 23, 2021.

Reimel, K. J., M. van Lier-Walqui, M. Kumjian, H. Morrison, and O. P. Prat, 2021: Using BOSS to learn microphysical process rate information from polarimetric radar observations. *European Geosciences Union (EGU) General Assembly 2021*, virtual, April 30, 2021.

Global Near-Real Time Drought Monitoring Using High-Resolution Satellite Precipitation Datasets	
Task Team	Olivier Prat (Lead), David Coates, Scott Wilkins
Task Code	NC-OTH-08-NCICS-OP/DC/SW
Sponsor	GEO-Microsoft Planetary Computer Programme

Highlight: The aim of this new project is to adapt the existing CMORPH-SPI framework to ingest the dataset GPM-IMERG to produce a GPM-SPI resulting in a 6-fold increase in spatial resolution and a more accurate geospatial mapping of daily drought and drying conditions than is currently available. The processing data pipeline will be optimized to take advantage of innovations in cloud processing.

Background

The Standardized Precipitation Index (SPI) was recommended as a drought monitor (a drought index) by the World Meteorological Organization (WMO 2012) and 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 satellite precipitation data. The team previously developed an operational near-real time global SPI based on the daily gridded satellite precipitation CMORPH-CDR (NOAA Climate Prediction Center MORPHing technique-Climate Data Record). The CMORPH-CDR was developed in a process which “morphs” or extrapolates movement of precipitation rain clouds which drift out of the line of sight of satellite coverage. As part of the subsequent launch of the Global Precipitation Measurement (GPM) mission, with its active weather radar by JAXA and NASA, GPM calibrates and refines the other satellite measurements, while complementing additional satellites, all assembled within the Committee on Environmental Satellites (CEOS) virtual precipitation constellation. The GPM-IMERG precipitation archive is built upon the subcomponents of the NOAA geostationary satellite measurements (NOAA Hydro Estimator), CMORPH, and PERSIANN from the University of California Irvine. The GPM-IMERG archive (located at NASA Goddard Space Flight Center) also compares assembled space-based precipitation measurements against land-based precipitation station measurements within GPCC and Global Precipitation Climatology Project for merged validation. GPM-IMERG is the current state of the art, final product which 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 0.25x0.25deg) to ingest the dataset GPM-IMERG to produce a GPM-SPI (daily SPI at 0.1x0.1deg) resulting in a 6-fold increase in spatial resolution. In addition, the processing data pipeline will be optimized to further take advantage of innovations in cloud processing, using Microsoft Azure and data lake capacity, to decrease processing time, bringing the overall system closer to real time and allowing for rapid updates while monitoring current drought conditions.

Accomplishments

The project was initiated in January 2022. The team has created a virtual environment on the Azure platform, cloned the SPI Python codebase, and transferred the code and CMORPH satellite precipitation dataset for the entire period of record to Azure.

Planned work

- Run the CMORPH-SPI code on Azure to ensure code portability and compare with previous runs
- Run the IMERG-SPI code on Azure and compare CMORPH-SPI and IMERG-SPI
- Transfer the IMERG-SPI to the GDIS dashboard and other relevant platforms (Planetary Computer Data Catalog)

COVID-19 and Environmental and Extreme Event Impacts on Human Health	
Task Leader	Jennifer Runkle
Task Code	NC-OTH-09-NCICS-JR
Sponsor	multiple

Highlight: A collaborative, multi-institution research team is exploring the myriad ways in which COVID-19 and other environmental and extreme events are impacting the health and well-being of vulnerable populations across the United States.

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 climate events which can disrupt lives and otherwise impact the health and wellbeing of those directly affected by these extreme events. The past decade has seen an increasing number and severity of such events in the U.S. (e.g., heat waves, droughts, wildfires, flooding, hurricanes, etc.) with associated impacts on human health – and all compounded the past two years by the global COVID-19 pandemic. A collaborative, multi-institution research team is conducting a number of innovative studies on COVID-19 and environmental and extreme event impacts on human health.

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).

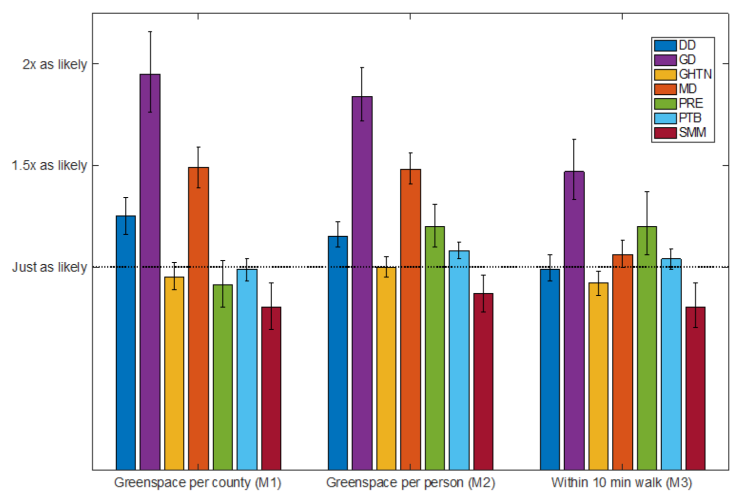


Figure 1. *Adjusted relative risk showing the association between leading maternal complications and greenspace metrics for 1) available greenspace (M1), 2) available greenspace per person (M2), and 3) accessible greenspace within a 10-minute walk, South Carolina 2013-2017. DD= Depressive disorders, GD = Gestational diabetes, GHTN = Gestational hypertension, MD= Mental Disorders of pregnancy, PRE = Preeclampsia, PTB= Preterm birth, and SMM=Severe maternal morbidity.*

Planned work

• Publish paper on the sensitivity of heat wave metrics on predicting maternal morbidity in South Carolina

• Collaborative research with Appalachian State University to provide new insights into the timing and incidence of the mental health consequences in youth impacted by climate disasters

Publications

Handwerger, L. R., M. M. Sugg, and **J. D. Runkle**, 2021: Present and future sea level rise at the intersection of race and poverty in the Carolinas: A geospatial analysis. *Journal of Climate Change and Health*. doi.org/10.1016/j.joclim.2021.100028

Harden, S., **J. D. Runkle**, and M. M. Sugg, 2022: A Spatiotemporal Analysis of Socio-Environmental Patterns in Severe Maternal Morbidity: A Retrospective Birth Cohort. *Maternal and Child Health Journal.* doi.org/10.1007/s10995-021-03330-0

Harden, S., M. M. Sugg, and **J. D. Runkle**, 2021: Spatial Clustering of Adolescent Bereavement in U.S. During the COVID-19 Pandemic. *Journal of Adolescent Health*. doi.org/10.1016/j.jadohealth.2021.04.035

Hass, A., **J. D. Runkle**, and M. M. Sugg, 2021: The driving influences of human perception to extreme heat: A scoping review. *Environmental Research*. doi.org/10.1016/j.envres.2021.111173

Mitchell, J. H., **J. D. Runkle**, L. M. Andersen, E. Shay, and M. M. Sugg, 2022: Health Disparities in Life Expectancy across North Carolina: A Spatial Analysis of the Social Determinants of Health and the Index Concentrations of Extremes. *Family & Community Health.* **45**(2):77-90, April/June 2022. doi.org/10.1097/FCH.0000000000000318

Moreno, C., J. Sugg, **J. Runkle, R. D. Leeper**, L. B. Perry, and M. Sugg, 2022: Examining spatiotemporal trends of drought in the conterminous United States using self-organizing maps. *Physical Geography*, 1-20. http://dx.doi.org/10.1080/02723646.2022.2035891

Runkle, J. D., J. L. Matthews, L. Sparks, L. McNichol, and M. M. Sugg, 2021: Racial and ethnic disparities in pregnancy complications and the protective role of greenspace: A retrospective birth cohort study. *Science of the Total Environment*, 808. doi.org/10.1016/j.scitotenv.2021.152145

Runkle, J. D., K. D. Michael, **S. E. Stevens**, and M. M. Sugg, 2021: Quasi-experimental evaluation of text-based crisis patterns in youth following Hurricane Florence in the Carolinas, 2018. *Science of The Total Environment*, **750**, 141702. doi.org/10.1016/j.scitotenv.2020.141702

Runkle, J. D., M. M. Sugg, **G. Graham**, B. Hodge, T. March, J. Mullendore, F. Tove, M. Salyers, S. Valeika, and E. Vaughan, 2021: Participatory COVID-19 surveillance tool in rural Appalachia: real-time disease monitoring and regional response. *Public Health Reports*. doi.org/10.1177/0033354921990372

Runkle, J.D., M. M. Sugg, S. McCrory, and C. C. Coulson, 2021: Examining the feasibility of smart blood pressure home monitoring: advancing remote prenatal care in rural Appalachia. *Telemedicine Reports,* 2(1), 125–134. doi.org/10.1089/tmr.2020.0021

Runkle, J. D., M. M. Sugg, **S. Yadav**, S. Harden, J. Weiser, and K. Michael, 2021: Real-time Mental Health Crisis Response in the United States to COVID-19: Insights from a National Text-based Platform. *Crisis*. doi.org/10.1027/0227-5910/a000826

Runkle, J. D., S. Yadav, K. Michael, S. Green, J. Weiser, and M. Sugg, 2021: Crisis Response and Suicidal Patterns in U.S. Youth before and during COVID-19: A latent class analysis. *Journal of Adolescent Health*, 70(1):48-56. doi.org/10.1016/j.jadohealth.2021.10.003

Sugg, M., L. Andersen, E. Shay, J. S. Tyson, and **J. Runkle**, 2021: Climate, environment, and public health in Western North Carolina. *The Journal of the Blue Cross NC Institute For Health & Human Services,* 1. issuu.com/appalachianstateuniversity/docs/sustainablehealth/76

Sugg, M. M., **J. D. Runkle**, L. Andersen, J. Weiser, and K. D. Michael, 2021: Crisis response among essential workers and their children during the COVID-19 pandemic. *Preventive Medicine,* 153, 106852. doi.org/10.1016/j.ypmed.2021.106852

Sugg, M. M., **J. D. Runkle**, S. N. Hajnos, S. Greene, and K. Michael, 2021: Understanding the concurrent risk of mental health and dangerous wildfire events in the COVID-19 pandemic. *Science of The Total Environment*. doi.org/10.1016/j.scitotenv.2021.150391

Sugg, M. M., S. Woolard, M. Lawrimore, K. D. Michael, and **J. D. Runkle**, 2021: Spatial clustering of suicides and neighborhood determinants in North Carolina, 2000 to 2017. *Applied Spatial Analysis and Policy,* **14**(2), 395-413. doi.org/10.1007/s12061-020-09364-1

Presentations

Runkle, J. R., 2021: Looking Forward - Mitigation, Adaptation, and Resilience. Panel discussion. *2021 NC BREATHE Health, Equity and the Climate Crisis in North Carolina Conference*, virtual, April 7, 2021.

Michael, M., M. M. Sugg, and J. D. Runkle, 2021: Crisis Help-Seeking Among Essential Workers and School-Aged Children of Frontline Workers during the COVID-19 Pandemic. *Society for Prevention Research Annual Meeting: Addressing Racism and Disparities when Considering Biology and Context*, virtual, June 2, 2021.

Barnes, J., J. D. Runkle, and C. VonKolnitz, 2021: Understanding Extreme Heat Risk in a Lowcountry Oasis: Engaging a Coastal Healthcare System in Climate-readiness Solutions. Panel discussion. *2021 Carolinas Climate Resilience Conference*, virtual, May 11, 2021.

Conrad, C., J. D. Runkle, and J. Barnes, 2021: Extreme Heat and Human Health. Panel discussion. *Medical University of South Carolina Conversation Café*, virtual, July 14, 2021.

Runkle, J. R., 2021: Exploring the Heat Hazard on Individual Monitoring of Temperature Exposure at Work: A Sensor-based Approach. Panel discussion. *NIHHIS Urban Heat Island Community of Practice Webinar Series*, July 29, 2021.

Runkle, J. R., 2021: Exploring the Connection Between Maternal Near Miss and the Climate Crisis. *UNC-Chapel Hill* Environmental/Occupational Epidemiology Seminar, Chapel Hill, NC, October 1, 2021.

Runkle, J. R., 2021: Why human communities matter? An Epidemiologist's perspective. *SE CASC Global Fellows Seminar Series*, virtual, Dec 7, 2021.

Runkle, J. R., and M. M. Sugg, 2022: Local Heat-Health Monitoring in Outdoor Workers: Results from a Participatory Sensing Study in Charleston, SC. *CISA Team meeting*, virtual, March 4, 2022.

Other

PI Runkle supervised/mentored 5 graduate students: Shrikanth Yadav (NCSU), climate/mental health investigations; Laurel Sparks (University of Georgia) / Leo McNicholas (UNC Chapel Hill), protective role of greenspace in pregnancy health; Leah Handwerger (AppState), present and future sea-level rise impacts for at-risk communities; and Jessica Mitchell (AppState), disparities in life expectancy in NC

Innovating a Community-Based Resilience Model on Climate and Health Equity in the Carolinas	
Task Leader	Jennifer Runkle
Task Code	NC-OTH-10-NCICS-JR
Sponsor	NOAA (CPO/RISA)

Highlight: A new NOAA Regional Integrated Science and Assessments (RISA) Program center, the Carolinas Collaborative on Climate, Health, and Equity (C3HE), was established at North Carolina State University. The team is working with community partners 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, 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. A bottom-up participatory approach will be applied to develop a transferrable model for end-to-end co-production of actionable and equitable climate resilience solutions in at-risk communities in the Carolinas.

Accomplishments

The team made progress on the following tasks:

- Year 1 workplan was developed by the co-lead directors and PIs
- Advisory board members were recruited with first meeting planned for April 2022
- Work is planned in collaboration with three community partners
- Development of a plan for identifying and engaging with frontline communities
- Two Institutional Review Board (IRB) applications (e.g., 72+documents) were submitted, one involving a tribal community (IRB) approval process, Public Health Board, and tribal council approval
- Capacity-building with an environmental justice community in eastern North Carolina has begun to aid more than 20 counties in engaging local resilience hubs and community members
- A project website was developed: carolinasc3he.org
- Recruitment for students, postdocs, and community partners is underway

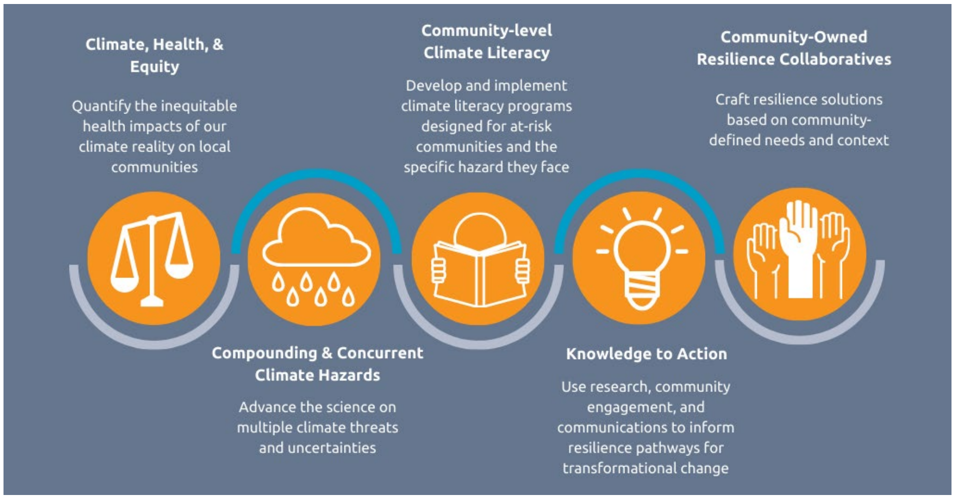


Figure 1*. Thematic areas for the new C3HE center.*

Planned work

- Co-develop a 100-year tribal climate action plan
- Complete recruitment of project students and postdocs
- Build and enhance local partnerships in underserved communities in the Carolinas
- Conduct research to understand and predict how co-occurring and consecutive hazards interact with exposure and vulnerability to shape climate risk

Presentations

Runkle, J. R., 2021: A Coalition Around Heat Research in Charleston, South Carolina. Panel discussion. *Consortium for Climate Risk in the Urban Northeast*, virtual, October 6, 2021.

Runkle, J. R., K. Dello, and L. Rivers, 2022: Overview of Climate, Health, and Equity in the Carolinas (C3HE). Panel discussion. C*enter for Human Health and the Environment (CHHE) Climate Change and Health Sixth Annual CHHE Symposium,* virtual, February 24, 2022.

Operational Transition of Novel Statistical-Dynamical Forecasts for Tropical Subseasonal to Seasonal Drivers	
Task Leader	Carl Schreck
Task Code	NC-OTH-11-NCICS-CS
Sponsor	OAR/CPO
Highlight: This project demonstrated the need for systematic forecasts of extreme rainfall events based on the MJO. MJO diagnostics developed by CISESS NC and used as routine inputs for CPC's Global Tropics Hazards (GTH) outlook were transitioned into operations.	

Background

Subseasonal to seasonal (S2S) forecasting has emerged as one of the frontiers for atmospheric predictability. These time scales of weeks to months are at the heart of the mission for NOAA's Climate Prediction Center (CPC), which has been particularly focused on expanding and improving 3- to 4-week forecasts. Dynamical S2S models have improved significantly over recent years, but they have yet to fully tap the potential predictability of coherent tropical modes like the Madden–Julian Oscillation (MJO). A unique approach to this problem was implemented on ncics.org/mjo. This website takes recent observations and appends them with 45-day forecasts from the Climate Forecast System Version 2 (CFSv2). The combined data are then Fourier filtered in space and time for some of the dominant modes of S2S variability in the tropics: the MJO, convectively coupled equatorial waves, and low-frequency variability such as the El Niño–Southern Oscillation (ENSO). This filtering highlights the most predictable aspects of the S2S system. The website includes numerous maps, Hovmöller diagrams, and indices for identifying and predicting these modes. It has been updating daily since 2011 with several upgrades and iterations over the years. These diagnostics have become routine inputs for CPC's Global Tropics Hazards (GTH) outlook.

Accomplishments

The MJO diagnostics were transitioned into operations at the CPC. Figure 1 shows the relative number of 2-year rainfall events that happen over the Mediterranean and the Middle East during December–February. These events tend to be more frequent during Phases 7/8/1/2 and less common during phases 3/4/5/6. MJO influences in these subtropical regions were surprising.

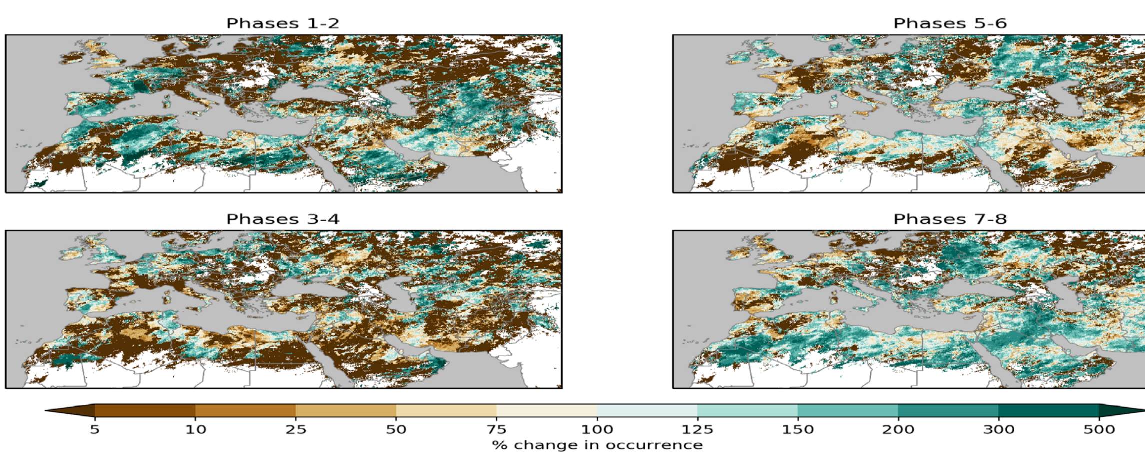


Figure 1. *Percentage changes in the frequency of December–February extreme rainfall events by MJO phase. Green colors mean those events are more likely, brown means less, and white means that they do not occur during those months.*

Planned Work

Project was completed in July 2021.

Publications

Schreck, C. J., 2021: Global Survey of the MJO and Extreme Precipitation. *Geophysical Research Letters*, 48, e2021GL094691. doi.org/10.1029/2021GL094691

Presentations

Schreck, C. J., 2021: An Interactive Mapping Tool from the NCICS Website: Introduction and Interpretation. *16th Annual Indonesia–U.S. BMKG–NOAA Partnership Workshop,* virtual, September 30, 2021.

Schreck, C. J., 2021: Predicting the MJO, Equatorial Waves, and Extreme Rainfall. *16th Annual Indonesia–U.S. BMKG–NOAA Partnership Workshop*, virtual, September 30, 2021.

Schreck, C. J., 2021: Sources of Tropical Subseasonal Skill in the CFSv2. Panel discussion. *AMS 34th Conference on Hurricanes and Tropical Meteorology*, virtual, May 10, 2021.

Kelvin Waves and Easterly Waves in CYGNSS	
Task Leader	Carl Schreck
Task Code	NC-OTH-12-NCICS-CS
Sponsor	NASA

Highlight: NASA CYGNSS surface wind data are able to reveal the evolution of surface fluxes as African easterly waves foster tropical cyclogenesis. Initial results are being updated with the latest CYGNSS winds and fluxes data for publication.

Background

Kelvin waves and easterly waves are among the most prominent modes of synoptic-scale convective variability in the tropics. Recent studies suggest that interactions between these waves can lead to tropical cyclogenesis. However, many questions remain regarding how these waves affect one another and how cyclogenesis ensues.

Two of the most significant ways that Kelvin waves might affect easterly waves relate to their modulation of low-level winds, which may alter the background shear and gradient of vorticity and enhance wave–mean flow interaction. The Kelvin wave westerlies could also enhance surface enthalpy fluxes within the easterly wave, which would lead to intensification through diabatic heating. While the kinematic view of the interaction appears simple, the inherent dynamics are expected to be complex and nonlinear.

The recent launch of NASA’s Cyclone Global Navigation Satellite System (CYGNSS) provides an unprecedented opportunity to observe and model these interactions. The high spatial and temporal resolution of CYGNSS is ideally suited for studying Kelvin waves and easterly waves, which have a phase speed of ~20 m s^{-1} relative to one another and each have wavelengths of 2,000–4,000 km.

Accomplishments

Significant progress was made towards a new publication documenting the evolution of surface winds and fluxes from CYGNSS in African Easterly Waves in the days leading up to tropical cyclogenesis. The initial results are being updated with the latest versions of CYGNSS winds and fluxes, which were recently released.

Figure 1 shows an example of the results from this study. To get a sense of the mean evolution of the surface winds during the transition of an AEW to TC, a storm relative composite was created wherein the data grids were shifted such that each tropical storm was located at the center of the domain shown. The wind anomalies are defined relative to the 7-day mean for each day that was a part of the composite. A coherent surface wind signal associated with the AEWs can be clearly seen even three days before cyclogenesis. The peak winds in the composite means are about 9m s^{-1}. This is important because the canonical easterly wave is typically described as a westward propagating disturbance with a peak signal at 850 hPa. The existence of a surface signal implies potential activation of surface enthalpy fluxes that are critical for the intensification of a tropical cyclone after genesis.

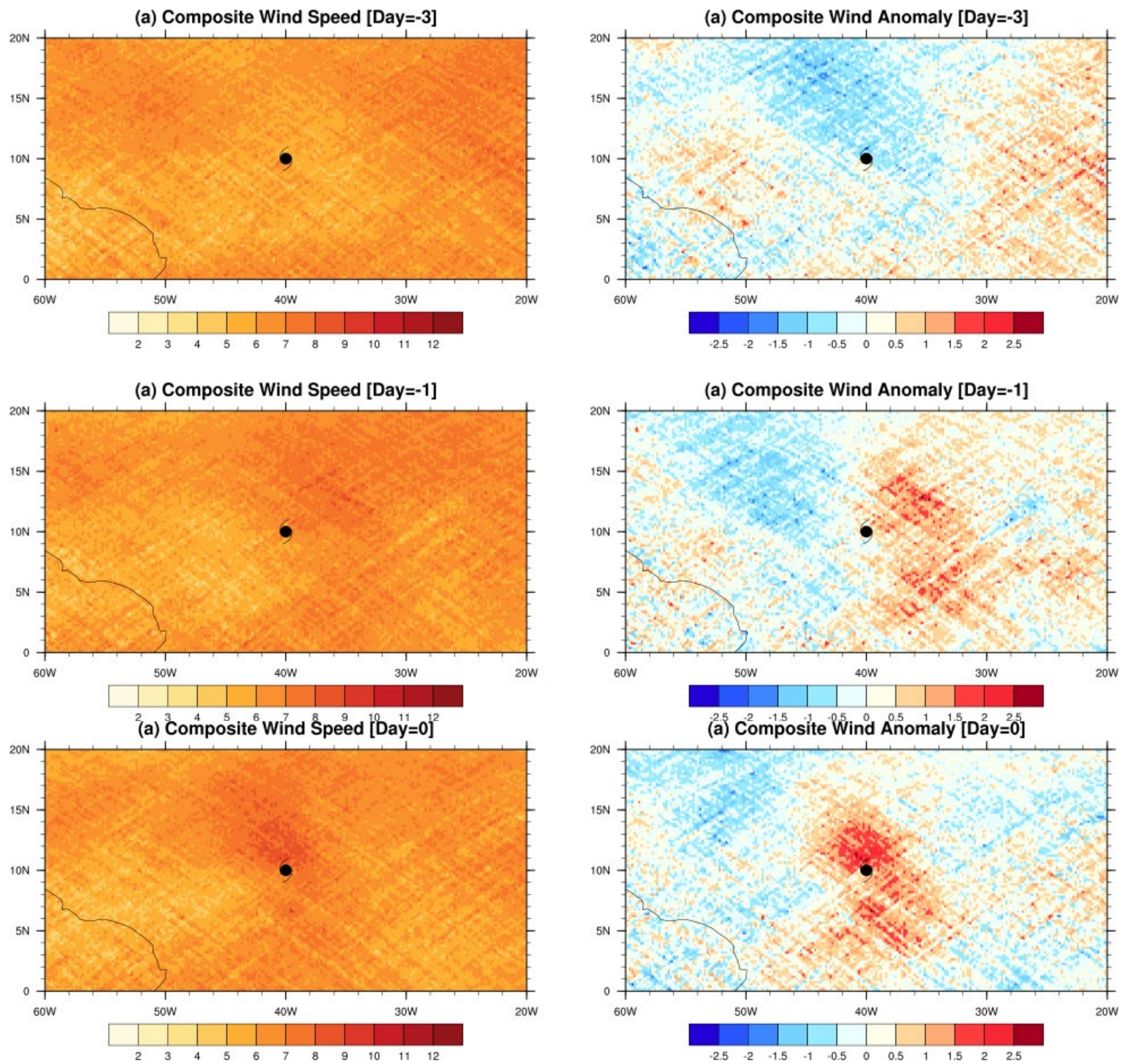


Figure 1*. Storm relative composite (see text) wind speed and wind speed anomaly for days marked on each panel. Day 0 refers to the day NHC deemed a system to be a tropical depression.*

Planned work

- Publish results on the evolution of surface fluxes in African easterly waves during tropical cyclogenesis
- Publish results on the depiction of Kelvin waves in CYGNSS wind data

Publications

Mantripragada, R. S. S., **C. J. Schreck**, and A. Aiyyer, 2021: Energetics of Interactions between African Easterly Waves and Convectively Coupled Kelvin Waves. Monthly Weather Review, 149, 3821–3835. doi.org/10.1175/MWR-D-21-0003.1

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	**2**		Scientists working < 50% time	**14**
Scientists working at no cost	**1**		Scientists working at no cost	**0**
Total Scientists	**28**		**Total Scientists**	**26**
Administrative/technical staff	**8**		**Administrative/technical staff**	**22**
Graduate Students	**9**		Graduate Students	**2**
Undergraduate Students	**6**		Undergraduate Students	**13**
High School Students	**0**		High School Students	**0**
Total Students	**15**		**Total Students**	**15**
Total Personnel	**51**		**Total Personnel**	**63**

[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	**333[3]**
# of peer reviewed papers	**58[4]**
# of NOAA technical reports	**52**
# of presentations	**140[5]**
# of graduate students supported by CISESS task	**10**
# of graduate students formally advised	**2**
# of undergraduate students mentored during the year	**19**

[3] ***Products**: ≈200 new/enhanced datasets available through cloud service provider partners; 23 new or improved architectures and software products (including websites and web tools); 26 new or updated environmental data products; 2 new observational products; 82 reports and other communication products (see Appendix 4)*

[4] ***Publications:** peer-reviewed (28 CISESS, 30 Other), not peer-reviewed (3 CISESS) (see Appendix 2)*

[5] ***Presentations:** 123 science presentations (93 CISESS, 30 Other); 17 outreach and engagement presentations. (see Appendix 3)*

Appendix 2: Publications 2021-2022

CISESS Publications (*not peer reviewed)

Barsugli, J. J., and Coauthors [including **D. A. Coates**, **K. E. Kunkel** and **C. J. Schreck**], 2021: Development of a NOAA Rapid Response Capability to Evaluate Causes of Extreme Climate Events. *Bulletin of the American Meteorological Society*, **103**, S1–S7. doi.org/10.1175/BAMS-D-21-0237.1

Berman, J. D., M. R. Ramirez, J. E. Bell, R. Bilotta, F. Gerr, and N. B. Fethke, 2021: The association between drought conditions and increased occupational psychosocial stress among US farmers: an occupational cohort study. *Science of The Total Environment,* 798, [149245]. doi.org/10.1016/j.scitotenv.2021.149245

Cheng, S., B. A. Konomi, **J. L. Matthews**, G. Karagiannis, and E. Kang, 2021: Hierarchical Bayesian Nearest Neighbor Co-Kriging Gaussian Process Models; An Application to Intersatellite Calibration. *Spatial Statistics*. doi.org/10.1016/j.spasta.2021.100516

Diamond, H. J., and **C. J. Schreck**, eds., 2021: The Tropics [in "State of the Climate in 2020"]. *Bulletin of the American Meteorological Society*, **102**, S199–S262. doi.org/10.1175/BAMS-D-21-0080.1

Downs, R.R., H.K. Ramapriyan, **G. Peng**, and Y. Wei, 2021: Perspectives on Citizen Science Data Quality. *Frontiers in Climate,* **3**(25). doi.org/10.3389/fclim.2021.615032

Ebi, K. L., J. Vanos, J. W. Baldwin, J. E. Bell, D. M. Hondula, N. A. Errett, K. Hayes, C. E. Reid, S. Saha, J. Spector, and P. Berry, 2021: Extreme Weather and Climate Change: Population Health and Health System Implications, *Annual Review of Public Health* 2021, 42(1), 293-315. doi.org/10.1146/annurev-publhealth-012420-105026

Grant, E. and **J. D. Runkle**, 2021: Long-term health effects of wildfire exposure: A scoping review. *The Journal of Climate Change and Health,* **6**, 100110. doi.org/10.1016/j.joclim.2021.100110

Gutiérrez, J. M., R. G. Jones, G. T. Narisma, L. M. Alves, M. Amjad, I. V. Gorodetskaya, M. Grose, N. A.B. Klutse, S. Krakovska, J. Li, D. Martínez-Castro, L. O. Mearns, S. H. Mernild, T. Ngo-Duc, B. van den Hurk, J-H. Yoon, 2021, Atlas. *In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, **T. K. Maycock**, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. (**K. E. Kunkel**, contributing author.) www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf

*Handwerger; L. R., **J. D. Runkle, R. D. Leeper**, E. Shay, K. Dempsey, M. M. Sugg, 2021: An Assessment of Social and Physical Vulnerability to Hydroclimate Extremes in Appalachia. *Research Square* (on-line). doi.org/10.21203/rs.3.rs-469519/v1

*Hills, D., J. Damerow, B. Ahmmed, N. Catolico, S. Chakraborty, T. Y. Chen, C. Coward, R. Crystal-Ornelas, W. Duncan, L. Goparaju, C. Lin, Z. Liu, M. Mudunuru, **Y. Rao**, R. Rovetto, Z. Sun, B. Whitehead, L. Wyborn, and T. Yao, 2021: Earth and Space Science Informatics Perspectives on Integrated, Coordinated, Open, Networked (ICON) Science. *Earth and Space Science Open Archive*. doi.org/10.1002/essoar.10508448.1

Huang, B., Z. Wang, X. Yin, A. Arguez, **G. Graham**, C. Liu, T. Smith, and H. M. Zhang, 2021: Prolonged Marine Heatwaves in the Arctic: 1982–2020. *Geophysical Research Letters,* 48(24), e2021GL096410. doi.org/10.1029/2021GL095590

Huang, B., C. Liu, E. Freeman, **G. Graham**, T. Smith, and H. M. Zhang, 2021: Assessment and intercomparison of NOAA daily optimum interpolation sea surface temperature (DOISST) version 2.1. *Journal of Climate*, ***34***(18), 7421-7441. doi.org/10.1175/JCLI-D-21-0001.1

Klotzbach, P. J., K. M. Wood, **C. J. Schreck**, S. G. Bowen, C. M. Patricola, and M. M. Bell, 2021: Trends in Global Tropical Cyclone Activity: 1990–2021. *Geophysical Research Letters*. doi.org/10.1029/2021GL095774

Klotzbach, P. J., K. M. Wood, M. M. Bell, S. G. Bowen, L.-P. Caron, J. M. Collins, E. J. Gibney, and **C. J. Schreck**, 2021: A Hyperactive End to the Atlantic Hurricane Season: October–November 2020. *Bulletin of the American Meteorological Society*. doi.org/10.1175/BAMS-D-20-0312.1

Leeper, R. D., B. Petersen, M. A. Palecki, and H. Diamond, 2021: Exploring the use of Standardized Soil Moisture as a Drought Indicator. *Journal of Applied Meteorology and Climatology*. doi.org/10.1175/JAMC-D-20-0275.1

Leeper, R. D., **J. L. Matthews**, M. S. Cesarini, J. E. Bell, 2021: Evaluation of air and soil temperatures for determining the onset of growing season. *Journal of Geophysical Research: Biogeosciences*. doi.org/10.1029/2020JG006171

Makra, E., and N. Gardiner, 2021. Climate Action Plan for the Chicago Region, Metropolitan Mayors Caucus, NOAA, and U.S. Climate Resilience Toolkit. Contributor. https://mayorscaucus.org/wp-content/uploads/2021/06/RegionalCAP_primary_and_appendices_062321-02.pdf

McDermid, S. S., R. Mahmood, M. J. Hayes, J. E. Bell, and Z. Lieberman, 2021: Minimizing trade-offs for sustainable irrigation*. Nat. Geosci.* 14, 706-709*.* doi:10.1038/s41561-021-00830-0

Miller, D., J. Forsythe, S. Kusselson, W. Straka III, J. Yin, X. Zhan, and R. Ferraro, 2021: A Study of Two Impactful Heavy Rainfall Events in the Southern Appalachian Mountains during Early 2020, Part I; Societal Impacts, Synoptic Overview, and Historical Context. *Remote Sens. 13*, 2452. doi.org/10.3390/rs13132452

Miller, D., M. Arulraj, R. Ferraro, C. Grassotti, B. Kuligowski, S. Liu, V. Petkovic, S. Wu, and P. Xie, 2021: A Study of Two Impactful Heavy Rainfall Events in the Southern Appalachian Mountains during Early 2020, Part II; Regional Overview, Rainfall Evolution, and Satellite QPE Utility. *Remote Sens. 13*, 2500. doi.org/10.3390/rs13132500

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Sugg, M. M., **J. D. Runkle**, S. N. Hajnos, S. Greene, and K. Michael, 2021: Understanding the concurrent risk of mental health and dangerous wildfire events in the COVID-19 pandemic. *Science of The Total Environment*. doi.org/10.1016/j.scitotenv.2021.150391

Sugg, M. M., S. Woolard, **M. Lawrimore**, K. D. Michael, and **J. D. Runkle**, 2021: Spatial clustering of suicides and neighborhood determinants in North Carolina, 2000 to 2017. *Applied Spatial Analysis and Policy,* **14**(2), 395-413. doi.org/10.1007/s12061-020-09364-1

Suh J. W., E. Anderson, W. Ouimet, **K. M. Johnson**, and C. Witharana, 2021: Mapping Relict Charcoal Hearths in New England Using Deep Convolutional Neural Networks and LiDAR Data. *Remote Sensing*, **13**(22): 4630. doi.org/10.3390/rs13224630

Szopa, S., V. Naik, B. Adhikary, P. Artaxo, T. Berntsen, W.D. Collins, S. Fuzzi, L. Gallardo, A. Kiendler Scharr, Z. Klimont, H. Liao, N. Unger, and P. Zanis, 2021: Short-Lived Climate Forcers. In Climate Change 2021: The Physical Sciencde Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J. B. R. Matthews, **T. K. Maycock**, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

Vova, O., M. Kappas, **P. Groisman**, Ts. Renchin, and S. Fassnacht, 2022: Development of a new Drought index using SMOS satellite soil moisture products: Case Study in Southwestern Mongolia. *Geo-Eko*. doi.org/10.1002/essoar.10509117.1

Appendix 3: Presentations 2021–2022

Science / Project Presentations

Abadi, A., 2021: Assessment of the Effects of Different Types of Drought on Suicide in Nebraska from 2000 to 2018. *University of Nebraska Medical Center 1st Annual College of Public Health Innovation Expo*, Omaha, NE, November 12, 2021.

Abadi, A., 2021: Investigating the Impacts of Drought on All-cause Mortality in Nebraska in a Bayesian Framework. *2021 American Geophysical Union (AGU) Fall Meeting*, New Orleans, LA, December 14, 2021.

Allen, J., 2022: CISESS logo development. *CISESS MD leadership meeting*, virtual, February 14, 2022.

Allen, J., 2022: CISESS logo development. *CISESS Executive Council meeting*, virtual, February 23, 2022.

Barnes, J., J. D. Runkle, and C. VonKolnitz, 2021: Understanding Extreme Heat Risk in a Lowcountry Oasis: Engaging a Coastal Healthcare System in Climate-readiness Solutions. Panel discussion. *2021 Carolinas Climate Resilience Conference*, virtual, May 11, 2021.

Bell, J., 2021: Drought Impacts on Mental Health._*USDA Southwest Climate Hub* and *DOI Southwest Climate Adaptation Science Center* “Come Rain or Shine” Podcast, April 9, 2021.

Bell, J., 2021: Impact of Climate Change. Society of Actuaries *Research Insights* (podcast), August 9, 2021.

Bell, J.: Building the Evidence Base to Advance Climate And Health Practice: Lessons Learned from Ongoing Translational Research Projects at the Centers for Disease Control and Prevention (CDC) and its partners. Panel discussion. *33rd Annual Conference of the International Society for Environmental Epidemiology*, virtual, August 25, 2021.

Bell, J., 2021: Sector and Community-based Perspectives on Cascading Drought Impacts and Needed Changes. Panel discussion. *NOAA NIDIS 2021 Southwest Drought Virtual Forum*, virtual, September 21, 2021.

Bell, J., 2021: Impact of extreme events on water, food systems and human health. *University of Nebraska Water for Food Global Forum*, virtual, October 28, 2021.

Bell, J., 2021: Comparative Review of Drought Metrics for Public Health Research Applications. *2021 American Geophysical Union (AGU) Fall Meeting*, New Orleans, LA, December 14, 2021.

Brooks, B., 2021: Developing a Multi-hazard Climate Risk Index for Adaptive Land and Resource Management in Complex Terrain. *2021 Carolinas Climate Resilience Conference*, virtual, May 11, 2021.

Brooks, B., 2021: Cost-benefit analysis for recreating a climate dataset as a NoSQL database in the Cloud. *2021 NOAA Environmental Data Management Workshop,* virtual, August 17, 2021.

Brown, O. B., 2022: CISESS NC Activities. *CISESS Executive Council meeting*, virtual, February 23, 2022.

Brown O. B., J. Dissen, and J. Brannock, 2021: BDP Updates. *NOAA Chief Data Officer meeting*. virtual, July 23, 2021.

Conrad, C., J. D. Runkle, and J. Barnes, 2021: Extreme Heat and Human Health. Panel discussion. *Medical University of South Carolina Conversation Café*, virtual, July 14, 2021.

DePolt, K., and T. Harrington, 2021: Advancing research on compounding risk of drought and extreme heat events in the U.S. NCEI Intern Closeout Presentations, virtual, August 12, 2021.

Dissen, J., *2022:* Environmental Data and Wildfire Risk in the Real Estate Value Chain. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 26, 2022.

Dissen, J., 2022: The Role of Environmental Data in Wildfire Risk Assessment in the Real Estate Industry. *NCEI Seminar Series*, virtual, March 15, 2022.

Dissen, J., and A. Rycerz, 2021: Examining the role of NOAA environmental data in developing applications to understand wildfire risk across the real estate value chain. *4th Annual National Cohesive Wildland Fire Management Strategy Workshop*, virtual, October 5, 2021.

Dissen, J., and A. Simonson, 2021: Expanding the Reach and Use of NOAA Data. *Snowflake and Deloitte Data Champions Webinar*, October 28, 2021.

Dissen, J., A. Simonson, J. O'Neil, J., P. Keown, O. Brown, J. Brannock and D. Willett, 2021: Using Environmental Data on the Cloud with Open-Source Tools. Panel discussion. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, December 12, 2021.

Georgiadi, A., 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. *International Symposium on Pan-Arctic Water-Carbon Cycles and Terrestrial Changes in the Arctic: For resilient Arctic Communities*, virtual, March 11, 2022.

Graham, G., R. D. Leeper, and Y. Rao, 2021: USCRN Anomaly Detection Team. NOAA-NVIDIA GPU AI Hackathon 2021, virtual, August 23-31, 2021.

Graham, G., 2021: A Feasibility Study on the Use of Machine Learning as a Quality Control Strategy. *3rd NOAA AI Workshop*, virtual, September 15, 2021.

Groisman, P. Y., 2021: Changing Climates across Central Asia. *Central Asia Regional Information Network (CARIN) Annual Meeting*, virtual, May 7, 2021.

Groisman, P. Y., 2021: Northern Eurasia Future Initiative (NEFI), Update. Poster. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Groisman, P. Y., 2021: Environmental, socio-economic, and climatic changes in Northern Eurasia. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Groisman, P. Y., 2021: International Environmental Studies in Northern Eurasia: the Arctic, Boreal Forest Zone, and Dryland Belt. *All-Russia Scientific Forum Science of the Future - Science of the Youth* conference, virtual, November 17, 2021.

Groisman, P. Y., 2021: Environmental, Socioeconomic, and Climatic Changes in Northern Eurasia. Poster. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, *December 17, 2021.*

Groisman, P. Y., 2021: Northern Eurasia Future Initiative (NEFI): The Current Status. Poster. *2021 AGU Fall Meeting,* virtual, December 17, 2021.

Groisman, P. Y., 2022: Task 4.2: Environmental thresholds. *Frozen Commons International Workshop*, Tempe, Arizona, February 19, 2022.

Groisman, P. Y., V. I. Grebenets, N. M. Tchebakova, and O. Vova, 2021: Northern Eurasia Future Initiative (NEFI) update. *Computational Information Technologies for Environmental Sciences (CITES)-2021* conference, virtual, November 26, 2021.

Johnson, K. M. 2022: Using Light Detection and Ranging (lidar) and geospatial analysis for archaeology and historical land use studies. *Jacksonville State University Geography Colloquium,* virtual, March 4, 2022.

Karna, H., and Dissen, J., 2021: Dynamic Pricing in Insurance: Leveraging NOAA Datasets to Predict Risk and Price, Google Financial Services Summit, virtual, May 27, 2021. Watch on-demand

Kent J., A. Simonson, J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA Big Data Program. *Microsoft AI4Earth Summit,* virtual, May 25, 2021.

Keown, P., A. Simonson, J. O'Neil, J., O. Brown, J. Dissen, J. Brannock, and D. Willett, 2022: NOAA Big Data Program Overview. Panel discussion. *2022 American Meteorological Society (AMS) Town Hall Panel*, virtual, January 25, 2022.

Konrad, K., and K. Slyman, 2021: Evaluation of vegetation status in Earth system models using satellite climate data records. NCEI Intern Closeout Presentations, virtual, August 12, 2021.

Kunkel, K. E., 2021: Extreme Precipitation and Climate Change: Observations and Projections. *The Centre for Energy Advancement through Technological Innovation's* Hydropower Operations and Planning and Dam Safety Working Groups, virtual, April 20, 2021.

Kunkel, K. E., 2021: Historical Trends and Future Projections of Virginia Climate Conditions. *Resilient Virginia 2021 Conference: From Recovery to Resilience; Moving to Vibrant, Healthy and Equitable Communities*, virtual, August 27, 2021.

Kunkel, K. E., 2021: Global Climate Models: CMIP6 – what we know and don't know on projecting future precipitation. NOAA's *Our Changing Precipitation Webinar Series*, September 14, 2021.

Kunkel, K. E., 2021: Incorporating Climate Change into Intensity-Duration-Frequency Values for the United States. *NOAA Physical Sciences Laboratory* Attribution Sub-Group Meeting, virtual, October 6, 2021.

Kunkel, K. E., 2021: The Incorporation of Future Climate into Intensity-Duration-Frequency Curves. *SERDP & ESTCP Webinar Series,* October 7, 2021.

Kunkel, K. E., 2021: Carolina Impacts: What is the Data Telling Us? *Carolinas Air Pollution Control Association 2021 Fall Technical Workshop and Forum*, virtual, October 14, 2021.

Kunkel, K. E., 2021: The Future Climate of North Carolina – Uncharted Waters. *North Carolina State University Osher Lifelong Learning Institute* "Our Rapidly Changing Climate" course, Raleigh, NC, November 9, 2021.

Kunkel, K. E., 2021: Extreme Precipitation: Observed Trends and Climatological Relationships. *NASA Goddard Climate and Environmental Health* monthly meeting, virtual, November 22, 2021.

Kunkel, K. E., 2021: Machine Learning-Based Feature Detection to Associate Precipitation Extremes with Synoptic Weather Events. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 12, 2021.

Kunkel, K. E., 2022: State of the Climate. *Electric Power Research Institute* (EPRI). *Environmental Change Institute Webinar*, February 3, 2022.

Kunkel, K. E., 2022: Extreme Rain: Historical Trends and Projections. Pre-recorded presentation. *American Society of Civil Engineers* (ASCE) *Structural Engineering Institute*. Future Conditions/Climate Change Workshop for Standard and Code Development, virtual, March 10, 2022.

Kunkel, K. E., D. A. Coates, D. R. Easterling, D. Arndt, J. Barsugli, T. Delworth, M. Hoerling, N. Johnson, A. Kumar, C. Schreck, R. Vose, and T. Zhang, 2021: Historical Perspective on the 2021 heat waves in western United States. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 16, 2021.

Kunkel, K. E., D. A. Coates, D. R. Easterling, D. Arndt, J. Barsugli, T. Delworth, M. Hoerling, N. Johnson, A. Kumar, C. Schreck, R. Vose, and T. Zhang, 2022: Historical Perspective on the 2021 heat waves in the western United States. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 27, 2022.

Kunkel, K. E., and J. Dissen, 2021: Climate Modeling: Considerations for Energy System Planning. *Electric Power Research Institute Advisory Council meeting*, virtual, October 21, 2021.

Kunkel, K. E., M. Eck, and J. Dissen, 2022: Precipitation Extremes: Extreme Value Theory and Statistical Trends in Uttarakhand. The *Energy and Resources Institute (TERI) team briefing*, virtual, January 12, 2022.

Kunkel, K. E., L. E. Stevens, S. Champion, and L. Sun, 2022: Extreme Precipitation in the Laurentian Great Lakes: Trends and Causes. Poster. *2022 American Meteorological Society (AMS) Annual Meeting*, virtual, January 24, 2022.

Leeper, R. D., 2021: Careers in meteorology. Panel discussion. *American Meteorological Society (AMS) Asheville Chapter Meeting,* virtual, April 8, 2021.

Leeper, R. D., 2021: Soil Sensor Transitions and Machine Learning as a Quality Control Strategy; USCRN Research Applications. *National Soil Moisture Workshop,* virtual, August 18, 2021.

Leeper, R. D., 2021: A Comparative Review of Drought Metrics for Public Health Research Applications. Poster. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, December 14, 2021.

Leeper, R. D., 2021: Trends in short-duration precipitation extremes in the U.S. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, December 14, 2021.

Leeper, R. D., 2022*:* Standardized satellite data captured trends in in-situ soil moisture during drought and flood conditions. Poster. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 25, 2022.

Leeper, R. D., 2022: An Evaluation of Remotely Sensed Standardized Soil Moisture during Hydrologically Extreme Conditions. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 25, 2022.

Leeper, R. D. 2022: U.S. Climate Reference Network Precipitation: Filling Gaps, Characterizing Extremes. *102nd American Meteorological Society (AMS) Annual Meeting*, virtual, January 25, 2022.

Leeper, R. D., 2022: An Overview of USCRN Soil Monitoring and Research. *Southeast Drought Early Warning System (DEWS) Soil Moisture Technical Workshop,* virtual, March 2, 2022.

Leeper, R. D., G. Graham, and Y. Rao, 2022: An Evaluation of Machine Learning Techniques to Quality Control Soil Moisture Observations. *2022 American Meteorological Society (AMS) Annual Meeting,* virtual, January 26, 2022.

Lookadoo, R., 2021: Effective Long-Term Strategies to Prepare for, Prevent, and Mitigate Health Impacts of Drought. *National Environmental Health Association (NEHA) Annual Education Conference*, virtual, July 15, 2021.

Lookadoo, R., 2021: Drought and Health: Engaging Public Health and Policymakers. *Network for Public Health Law Conference*, virtual, September 22, 2021.

Makowski, N., and K. Peco, 2022: The Influence of Climate Change on Locally-Produced Thunderstorm Genesis in the Southern Appalachians. *2022 American Meteorological Society (AMS) Annual Meeting*, New Orleans, LA, January 22, 2022.

Maycock, T., 2021: Climate Change and Communication. *2021 Carolinas Climate Resilience Conference*, virtual, May 11, 2021.

Maycock, T., R. Ward, and A. Lee, 2021: How the Sausage Gets Made: What Goes into Creating All These Climate Reports? What policies and infrastructure may change as a result? *North Carolina Climate Education Network* meeting, virtual, June 29, 2021.

Michael, M., M. M. Sugg, and J. D. Runkle, 2021: Crisis Help-Seeking Among Essential Workers and School-Aged Children of Frontline Workers during the COVID-19 Pandemic. *Society for Prevention Research Annual Meeting: Addressing Racism and Disparities when Considering Biology and Context*, virtual, June 2, 2021.

Michelson, D., 2021: Climate Resilience Solutions. *Iowa Flood Center*, virtual, September 29, 2021.

Olheiser, C., 2022: Overview of Olheiser's Career and Tips for Students, *Pathways Student Series*, virtual, Jan 12, 2022.

Olheiser, C., 2022: The Importance of Snow Observations. *National Weather Service Central Region Observational Services Virtual Conference*, January 19, 2022.

Olheiser, C., 2022: New Bird, New Challenges: The Calibration and Testing of the Airborne Gamma Snow Survey King Air 350CER. *2022 American Meteorological Society (AMS) Annual Meeting*, virtual, January 25, 2022.

Olheiser, C., Buan, S., Walvert, S., 2022: Winter Planning Meeting 2022. *St. Paul Corps of Engineers Spring 2022 Spring Hydrologic and Climate Meeting*, virtual, February 3, 2022.

Olheiser, C., 2022: Snow, Present, and Future - Overview of SNODAS, *Missouri River Forecasters Meeting*, virtual, February 16, 2022.

Prat, O. P., D. Coates, R. D. Leeper, B. R. Nelson, R. Bilotta, and S. Ansari, 2021: Operational Near-real Time Drought Monitoring Using Global Satellite Precipitation Products (CMORPH) and In-situ Datasets (NClimGrid). *2021 American Geophysical Union (AGU) Fall Meeting*, virtual, December 13, 2021.

Prat, O. P., R. D. Leeper, B. R. Nelson, R. Bilotta, and S. Ansari, 2021: Near-real Time Drought Monitoring Using Satellite and In-situ Precipitation Datasets and Application to the Carolinas. Poster. *2021 Carolinas Climate Resilience Conference*, virtual, May 10, 2021.

Prat, O. P., B. R. Nelson, R. D. Leeper, and S. Embler, 2021: Assessment of Cold-Season Precipitation Estimates Derived from Daily Satellite Precipitation Products over CONUS. *European Geosciences Union (EGU) General Assembly 2021*, virtual, April 26, 2021.

Rao, Y., 2021: Developing guidelines for reproducibility for machine learning applications in Earth and space science. Poster. *Federation of Earth Science Information Partners* (ESIP) *2021 Summer Meeting,* virtual, July 21, 2021.

Rao, Y., 2021: Student and Early-Career Voices at AGU. Panel discussion. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 14, 2021.

Rao, Y., 2021: 'What we wish we had learned in Graduate School' - a data management training roadmap for graduate students. Poster. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 15, 2021.

Rao, Y., 2021: Promoting NOAA Workforce Proficiency on Artificial Intelligence through Open Science and Partnership. Poster. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 15, 2021.

Rao, Y., 2021: Enabling an Equitable Future with Open Science. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA*,* December 16, 2021.

Rao, Y., 2022: Towards AI-ready Data for Wildfire Applications. *2022 Earth Science Information Partners (ESIP) January Meeting,* virtual, January 20, 2022.

Rao, Y., 2022: Climate Observatory - Analyzing and Visualizing NOAA Climate Data Records on the Cloud". *Ocean Sciences Meeting 2022,* virtual, *March 4, 2022*.

Rao, Y., J. Matthews, and L. Shi, 2022: Improvement and Evaluation of a Neural Network-based HIRS Atmospheric Profile over Global Oceans. *Ocean Sciences Meeting 2022,* virtual, February 28, 2022.

Redmon, R., E. Kihn, Y. Rao, C. Slocum, B. Meyer, 2021: NOAA Center for Artificial Intelligence (NCAI) development. *ClimaCon 2021* "The Surprising State of AI in the Weather Industry" session, virtual, April 28, 2021.

Redmon, R., E. Kihn, Y. Rao, C. Slocum, B. Meyer, 2021: NOAA's Center for Artificial Intelligence: Progress Towards an AI Ready Agency and Workforce. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA*,* December 13, 2021.

Reimel, K. J., M. van Lier-Walqui, M. Kumjian, H. Morrison, and O. P. Prat, 2021: Learning about microphysical processes from polarimetric radar observations with BOSS. *2021 AGU Fall Meeting,* virtual, December 14, 2021.

Reimel, K. J., M. van Lier-Walqui, H. Morrison, M. Kumjian, and O. P. Prat, 2021: Novel insights into rain physics from synthetic polarimetric radar observations and BOSS. Poster. *ARM/ASR Joint User Facility and PI Meeting*, virtual, June 23, 2021.

Reimel, K. J., M. van Lier-Walqui, M. Kumjian, H. Morrison, and O. P. Prat, 2021: Using BOSS to learn microphysical process rate information from polarimetric radar observations. *European Geosciences Union (EGU) General Assembly 2021*, virtual, April 30, 2021.

Rennie, J. J., 2021: Heat Index and Wet Bulb Globe Temperature creation from USCRN sites and heat severity quantification. *OneNOAA Science Seminar Series,* virtual, April 6, 2021.

Rennie, J. J., 2021: It's All Relative: Developing heat exposure products using USCRN. *International Association of Emergency Managers* (IAEM) Climate Caucus, virtual, April 19, 2021.

Rennie, J. J., 2021: It's All Relative: Developing heat exposure products using USCRN. tomorrow.io, virtual, April 22, 2021.

Rennie, J. J., 2021: #ShowYourStripes: Making Climate Data Local in the Carolinas. *2021 Carolinas Climate Resilience Conference*, virtual, May 10, 2021.

Rennie, J. J., 2021: How Hot is Too Hot? *AMS Weather Band Webinar*, September 9, 2021.

Rogers, K., 2021: Climate Resilience and Adaptation: The US Climate Resilience Toolkit (CRT). *Southeast Sustainability Directors Network (SSDN) Annual Meeting*, virtual, May 6, 2021.

Rogers, K., 2021: The Economic Impact of the US Climate Resilience Toolkit (CRT) using Benefit-Cost Ratio. *Carolinas Climate Resilience Conference*, virtual, May 10, 2021.

Rogers, K., 2021: Climate Resilience and Adaptation: The US Climate Resilience Toolkit (CRT). *University of Cincinnati*, virtual, August 18, 2021.

Runkle, J. R., 2021: Looking Forward - Mitigation, Adaptation, and Resilience. Panel discussion. *2021 NC BREATHE Health, Equity and the Climate Crisis in North Carolina Conference*, virtual, April 7, 2021.

Runkle, J. R., 2021: Exploring the Heat Hazard on Individual Monitoring of Temperature Exposure at Work: A Sensor-based Approach. Panel discussion. *NIHHIS Urban Heat Island Community of Practice Webinar Series* July 29, 2021.

Runkle, J. R., 2021: Exploring the Connection Between Maternal Near Miss and the Climate Crisis. *UNC-Chapel Hill* Environmental/Occupational Epidemiology Seminar, Chapel Hill, NC, October 1, 2021.

Runkle, J. R., 2021: A Coalition Around Heat Research in Charleston, South Carolina. Panel discussion. *Consortium for Climate Risk in the Urban Northeast*, virtual, October 6, 2021.

Runkle, J. R., 2021: Why human communities matter? An Epidemiologist's perspective. *SE CASC Global Fellows Seminar Series*, virtual, Dec 7, 2021.

Runkle, J. R., 2022: Overview of Climate, Health, and Equity in the Carolinas (C3HE). Panel discussion. C*enter for Human Health and the Environment (CHHE) Climate Change and Health Sixth Annual CHHE Symposium,* virtual, February 24, 2022.

Runkle, J. R., and M. M. Sugg, 2022: Local Heat-Health Monitoring in Outdoor Workers: Results from a Participatory Sensing Study in Charleston, SC. *CISA Team meeting*, virtual, March 4, 2022.

Schreck, C. J., 2021: Sources of Tropical Subseasonal Skill in the CFSv2. Panel discussion. *AMS 34th Conference on Hurricanes and Tropical Meteorology*, virtual, May 10, 2021.

Schreck, C. J., 2021: An Interactive Mapping Tool from the NCICS Website: Introduction and Interpretation. *16th Annual Indonesia–U.S. BMKG–NOAA Partnership Workshop,* virtual, September 30, 2021.

Schreck, C. J., 2021: Predicting the MJO, Equatorial Waves, and Extreme Rainfall. *16th Annual Indonesia–U.S. BMKG–NOAA Partnership Workshop*, virtual, September 30, 2021.

Schreck, C. J., 2022: The MJO. *North Carolina State University* "Special Topics Climate Predictability" course, virtual, March 28, 2022.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NWS Partners Webinar: Leveraging the Cloud for Numerical Weather Prediction Data. Panel discussion. *NOAA National Weather Service Partners Webinar,* June 30, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA's Big Data Program Operational Phase Overview. Panel discussion. *U.S. Department of Commerce update*, virtual, August 2, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: NOAA Big Data Program Update. Panel discussion. *Environment and Climate Change Canada*, virtual, August 5, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock, 2021: Engaging Users in the Cloud. Panel discussion. *NOAA Environmental Data Management Workshop,* virtual, August 19, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, and J. Brannock. 2021: NOAA Big Data Program: Enabling Public, Private and Academic Collaborations. Panel discussion. *American Meteorological Society (AMS) 2021 Summer Community Meeting,* virtual, September 21, 2021.

Simonson, A., J. O'Neil, J., P. Keown, O. Brown, J. Dissen, J. Brannock and D. Willett, 2022: Expanding the Reach and Use of NOAA Data. Panel discussion. *House Science and Technology Committee briefing*, virtual, January 13, 2022.

Stevens, L. E., 2021: From Data to Indicator, *CCHHG Indicators Workstream Meeting*, virtual, May 25, 2021.

Stevens, L. E., 2021: Climate change in the human environment: Indicators and impacts from the Fourth National Climate Assessment. *Research Triangle Park Air & Waste Management Association* monthly technical lunch seminar, virtual, June 22, 2021.

Stevens, L. E., and K. E. Kunkel, 2022: Climate modeling and downscaled data for impact and vulnerability assessments, *EPRI Enel Foundation Climate Resilience Workshop on Physical Climate Risk*, virtual, March 2, 2022.

Sun, L., and K. E. Kunkel, 2021: Predictability of North Atlantic Subtropical High and its Impact on the Climate over the United States. *2021 American Geophysical Union (AGU) Fall Meeting,* New Orleans, LA, December 16, 2021.

Tchebakova, N., E. I. Parfenova, E. V. Bazhina, A. J. Soja, and P. Y. Groisman, 2021: Dark conifer forests dieback at mid-to-highlands in the southern Siberia's mountains is not caused by drought stress. *Japan Geoscience Union Meeting (JpGU) 2021*, virtual, June 6, 2021.

Vova, O., M. Kappas, P. Y. Groisman, T. Renchin, and S. Fassnacht, 2021: Development of a New Soil Moisture Index Using SMOS Satellite Soil Moisture Products: Case study in Southwestern Mongolia. *2021 American Geophysical Union (AGU) Fall Meeting,* virtual, December 17, 2021.

Willett, D., J. Dissen, P. Keown, B. White, T. Augspurger, and O. B. Brown, 2022: NOAA Big Data Program Updates, *American Meteorological Society Annual Meeting Town Hall*, virtual, January 25, 2022.

Outreach and Engagement Presentations

- Graham, G., 2021: Artificial intelligence in the sciences: how machine learning helps understand the world. *Asheville Museum of Science* "Ask A Scientist series," virtual, May 7, 2021.
- Leeper, R. D., 2021: Careers in meteorology. *AMS Asheville Chapter Meeting,* virtual, April 8, 2021.
- Rao, Y., 2021: Satellite climate data. *Asheville Museum of Science* summer camp class, virtual, June 24, 2021.
- Rennie, J. J., 2021: Weather and climate. Skype a Scientist, *Holden Christian Academy* (Holden, MA) 3rd-6th grade classes, virtual, May 4, 2021.
- Schreck, C. J., 2021: Climate change and meteorology careers. Skype a Scientist, *Leland Public School* (Leland, MI) 8th grade class, *virtual,* October 22, 2021.
- Schreck, C. J., 2021: Climate Change Headlines from 2021. *Heritage Hills Retirement Community*, Hendersonville, NC, September 23, 2021.
- Schreck, C. J., 2021: Climate change, weather tools, and meteorology careers. Skype a Scientist, *Highpoint Virtual Academy of Michigan* (Mesick, MI) 5th grade classes, virtual, November 2, 2021.
- Schreck, C. J., 2021: Climate change, weather tools, and meteorology careers. Skype a Scientist, *Baldwinsville Elementary School* (Baldwinsville, NY) 3rd grade class, virtual, November 3, 2021.
- Schreck, C. J., 2021: Climate change. *Enka Intermediate School* (Candler, NC) 5th grade classes, virtual, May 6, 2021.
- Schreck, C. J., 2021: Climate change. *Enka Intermediate School* (Candler, NC) 6th grade classes, virtual, May 7, 2021.
- Schreck, C. J., 2021: Extreme weather and becoming a meteorologist. Skype a Scientist, *International School of Panama* (Panama City, Panama) 3rd grade class, virtual, April 7, 2021.
- Schreck, C. J., 2021: Extreme weather and becoming a meteorologist. Skype a Scientist, *McLean Montessori School* (McLean, VA) 4th grade class, virtual, April 27, 2021.
- Schreck, C. J., 2021: Hurricanes and climate change. *Fernleaf Community Charter School* (Fletcher, NC) 5th grade class, virtual, December 8, 2021.

- Schreck, C. J., 2022: Climate Change and Meteorology. Skype a Scientist, *Apex Elementary School*. Apex, NC, 5th grade class, virtual, February 3, 2022.
- Schreck, C. J., 2022: Weather and Climate. Skype a Scientist, *Campus School* (Memphis, TN) 3rd grade class, virtual, February 11, 2022.
- Stevens, L. E., 2021: Career and work at NCICS. *NCICS Weekly Intern Seminar Series,* virtual, June 29, 2021.
- Stevens, L. E., 2021: Weather and climate. *CampVentures* summer camp, Asheville, NC, August 4, 2021.

Appendix 4: Products 2021-2022

CISESS Products

~200 New or enhanced BDP/NODD datasets and/or collections now available through BDP/NODD cloud service provider partners

- National Water Model (NWM) Retrospective in original and Zarr Format
- North American Mesoscale Forecast (NAM)
- NCEP Real Time Mesoscale Analysis (RTMA)
- NClimGrid Daily & Monthly
- Unified Forecast System (UFS)
- Global Mosaic of Geostationary Satellite Imagery
- Global Surface Summary of the Day
- Joint Polar Satellite System (JPSS)
- Data Center for Digital Bathymetry
- Ocean Climate Stations Moorings (KEO and PAPA)
- 30+ Climate Data Records
- Additional datasets from NMFS, OAR, NWS, NESDIS, and NOS

New or Improved Architectures and Software Products (including websites and web tools)

- Assessment Collaboration Environment (ACE) updates
- GHCNd graph database design
- NOAA/NESDIS Cloud Archive Pilot (NCAP) Archive prototype system
- NCAP archive system installation suite (including Jupyter Notebook)
- NCAP CICD test stack
- Algorithm for nClimGrid data formatting, merging, and sorting
- Computational program for heat/cold wave indices, https://ncics.org/pub/angel/hwi/
- 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/
- Production high availability Kubernetes environment for Elastisearch / Kabana monitoring platform
- Daily Combined Cloud Service Provider (CSP) Metrics status report
- Enhanced Data Broker transfer structure
- Common (cloud agnostic) Kubernetes foundation
- NiFi queue monitoring flow and Graylog Dashboard
- NiFi general operator training documents, workflows, and weekly sessions
- NiFi living production tracking document
- NiFi solutions document with CLI/API setup, version migration steps, sensitive information approach
- Updated monitoring tool for sub-monthly data for the United States
- NOAA State Climate Summaries 2022 website (new), https://statesummaries.ncics.org
- U.S. Climate Resilience Toolkit (improved), https://toolkit.climate.gov
- USGCRP Indicator Platform (updated), http://www.globalchange.gov/browse/indicators

- U.S. Drought Portal (redesigned/improved), https://drought.gov
- NCA Sandbox, https://sandbox.nemac.org/

New or updated environmental data products

- Public, operational version of GHCNm version 4.0.1
- Optimum Interpolation Sea Surface Temperature v2.1a
- Atlantic Tropical Cyclone Days Indicator, globalchange.gov/browse/indicator-details/4206
- 15 updated USGCRP (Climate Change) Indicators
    - Annual Greenhouse Gas Index, globalchange.gov/browse/indicator-details/3651
    - Arctic Glacier Mass Balance, globalchange.gov/browse/indicator-details/3941
    - Arctic Sea Ice Extent, globalchange.gov/browse/indicator-details/3652
    - Atmospheric Carbon Dioxide, globalchange.gov/browse/indicator-details/3653
    - Billion Dollar Disasters, globalchange.gov/browse/indicator-details/4049
    - Frost-Free Season, globalchange.gov/browse/indicator-details/3655
    - 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
    - Ocean Chlorophyll Concentrations, globalchange.gov/browse/indicator-details/3659
    - 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
    - Terrestrial Carbon Storage, globalchange.gov/browse/indicator-details/3662
    - U.S. Surface Temperatures, globalchange.gov/browse/indicator-details/3663
- Hourly standardized soil moisture climatologies for each depth (5, 10, 20, 50, and 100cm) with Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates https://ncei.noaa.gov/pub/data/uscrn/products/soil/soilclim01
- Hourly standardized soil moisture anomalies for each depth (5, 10, 20, 50, and 100cm) with Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates https://ncei.noaa.gov/pub/data/uscrn/products/soil/soilanom01
- Seven day moving average of standardized soil moisture anomalies and fraction of hours below the 30th percentile (drought hours) and above the 70th percentile (recovery hours) for each depth (5, 10, 20, 50, and 100cm) with Top (5 & 10 cm) and Column (5 – 100 cm) layer aggregates. https://ncei.noaa.gov/pub/data/uscrn/products/drought01
- Global CMORPH SPI, available through the Interactive Global Drought Information Dashboard: https://gdis-noaa.hub.arcgis.com/
- 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/
- Hourly and sub-hourly heat exposure indices, including heat index (HI), apparent temperature (AT), and wet-bulb globe temperature (WBGT) - USCRN derived product
- Coastal normals data from 1991–2020 for areas around the U.S. Northeast and Mid-Atlantic ArcGIS Online interactive web page displaying the coastal normals layers

New Observational Products

- Operational Airborne Gamma Products from the new King Air 350 CER, N67RF
- Installation of 8 new flightlines in support of the PSL SPLASH project

Reports and Other Communication Products

- 52 Updated (2022) State Climate Summaries (Full Technical Report and 51 individual state summaries plus Puerto Rico) https://statesummaries.ncics.org
- 12 Monthly and 1 Annual synoptic Discussions for NCEI's Annual State of the Climate https://www.ncdc.noaa.gov/sotc/synoptic/
- 12 Monthly and 1 Annual Global Tropical Cyclone reports for NCEI's State of the Climate https://www.ncdc.noaa.gov/sotc/tropical-cyclones/
- Great Smokey Mountain Rain Gauge Network (GSMRGN) Field reports
    - Summer 2021: http://www.atms.unca.edu/dmiller/GSMRGN_report_10august2021.pdf https://drive.google.com/file/d/1k4HRCvP8PpmbJ9-Xv3jABzX3q70aZ4Rn/view?usp=sharing
    - Fall 2021: http://www.atms.unca.edu/dmiller/GSMRGN_report_15november2021.pdf https://drive.google.com/file/d/1AosZm1Rimn3-VU68K-78BW2vp9vHOLfV/view?usp=sharing
- Summary Real Estate Development Sector project report
- One issue of *Trends* newsletter, April 2021, https://ncics.org/news/trends-newsletter/