High-Resolution Integrated Drought Monitoring
Final Project Report

1. General Information

Project Title: High-Resolution Integrated Drought Monitoring

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co-PI Michael Ek, NOAA/NCEP/EMC

Final report
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2. Main goals of the project

- Develop a national, reliable, high-resolution precipitation data set for drought monitoring
- Generate and produce products derived from a suite of drought indices calculated from the high-resolution precipitation data set
- Test the impact and benefit of incorporating the high-resolution bias-corrected MPE into NLDAS

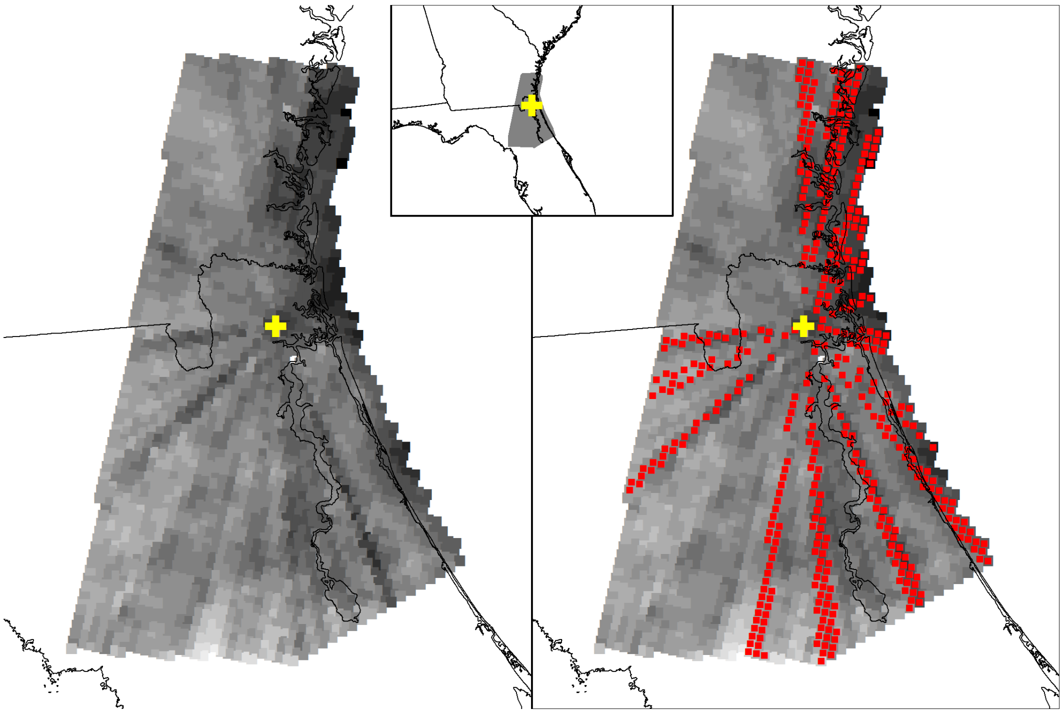
3. Results and accomplishments

The development of a national, reliable, high-resolution precipitation data set for drought monitoring has proceeded along parallel paths. The investigators at Texas A&M University have focused on improving the accuracy of the precipitation data set, while the investigators at North Carolina State University have focused on generating and producing products from a suite of drought indices.

The precipitation accuracy work proceeded in two stages. The first stage, an initial development and implementation of bias correction, was completed during the first few months of the project and resulted in a Ph.D. dissertation by D. Brent McRoberts. During the remainder of the project, these bias correction algorithms were fined and optimized, with results presented at national conferences and submitted for publication.

The first component of the algorithm is a beam blockage correction step. We have improved upon the initial algorithm, implementing physically-based constraints on possible locations of blockage and improving the technique for grouping blocked radials into blocked sectors. The first guess correction for beam blockage now uses the same model as the beam blockage detection algorithm. We assign fractions of HRAP grid cells to individual radials and estimate the extent of blockage along each radial. Adjoining blocked radials are grouped together, and the location of the obstacle is estimated. Then at each totally or partially blocked grid cell, the magnitude of artificial precipitation reduction is estimated from the product of the blockage strength and the fraction of the grid cell subject to blockage.

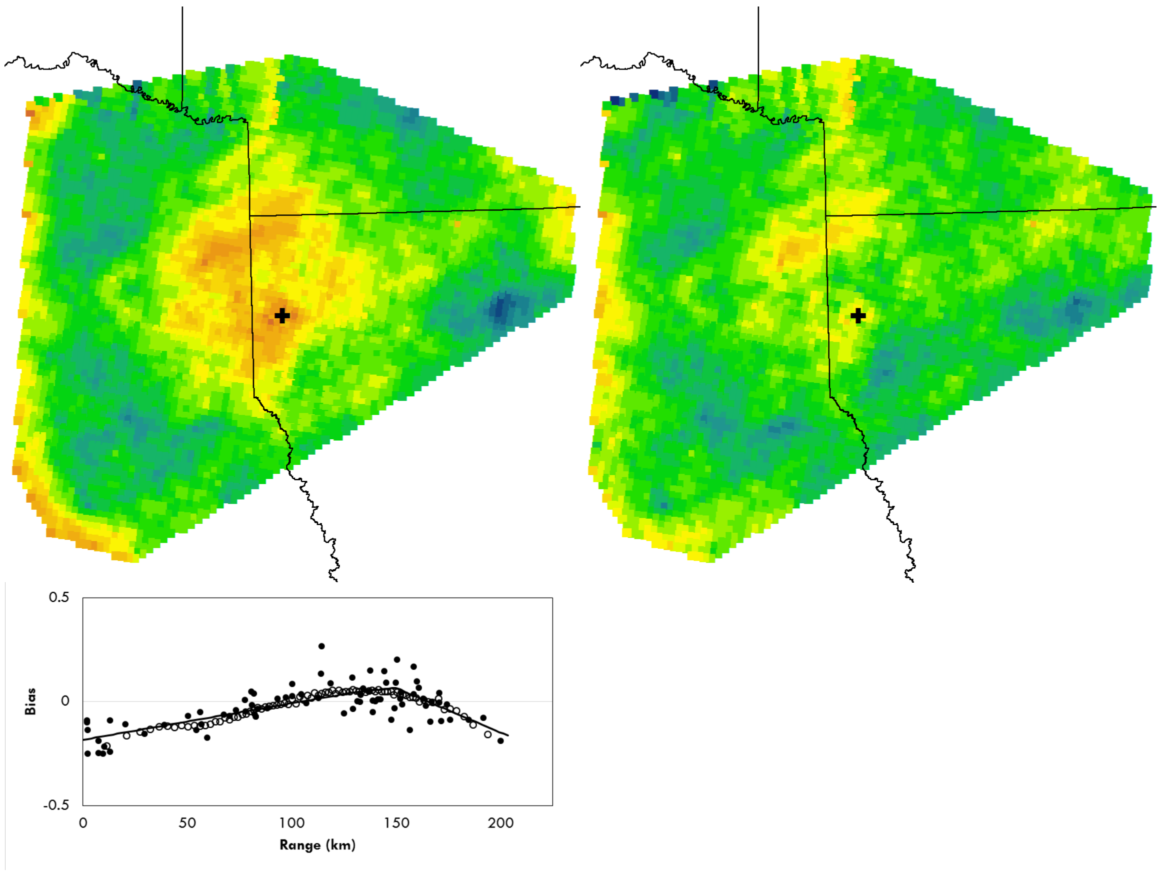
Our methodology requires only a long-term precipitation climatology with no prerequisite knowledge of topography or known obstructions needed. For each radar domain, the quantitative precipitation estimates (QPEs) are normalized by climatology and a low-pass Fourier series fit captures the expected precipitation as a function of azimuth angle. Beam blockage signatures are identified as radially coherent regions with normalized values that are systematically lower than the Fourier fit. While our immediate objective is to improve NCEP QPE values, the methodology is flexible enough to be useful for most radar installations and geographical regions with at least a few years of data.



The figure above shows an example of the algorithm's identification of cells affected by partial beam blockage at the Jacksonville (Florida) radar. On the left is the raw precipitation estimate, with lighter colors indicating greater amounts of estimated precipitation. On the right are grid cells identified by the algorithm as having too-low precipitation estimates due to beam blockage. Not all blocked cells are identified, because the sensitivity of the algorithm is tuned to avoid false positives.

The second component of the algorithm is a mean field bias and range-dependent bias correction step. We have developed an innovative approach that utilizes two independent estimates of range-dependent bias, using a model for range-dependent bias that is based upon beam height and common patterns of variation of reflectivity with height in precipitating systems, including bright bands. One estimate is derived from a statistical model fit to the differences between gauge observations and Stage IV precipitation estimates over extended periods. The other estimate is derived from a statistical model fit to systematic departures of the radial variations of precipitation from a uniform surface. The latter approach is completely new, as far as we know, and enhances the robustness of the bias correction. The two estimates are combined using a maximum likelihood approach.

A cross validation procedure was used to determine the performance of the range-dependent bias model. We use gauge precipitation data as a proxy for the true surface precipitation. The cross validation procedure looked at several different time scales, ranging from the single-month data used to develop the model to 36-month accumulation data. Results demonstrate that the range-dependent model provides a better bias adjustment for longer time scales than shorter time scales. There is more statistical confidence in the assessment of biases when time scales increase as random errors have less influence on the bias data points. Even at the 1-month time scale, there is a small improvement in the estimates despite the noise in the bias data used to create the model.



The figure above shows a 36-month precipitation estimate for the domain surrounding the NEXRAD radar in Shreveport, Louisiana. On the left is the raw Stage 4 precipitation estimate from the National Weather Service. Below it is a plot of bias as a function of distance from the radar. The black dots represent gauge-based estimates of bias, while the open circles represent estimates of bias based on systematic range-dependent variations in precipitation. The curved line is our modeled best estimate of the range-dependent bias, and the map on the right is the estimated pattern of precipitation after correcting for the modeled range-dependent bias. It is visually apparent that most of the systematic concentric variations of estimated precipitation have been removed in the bias correction step.

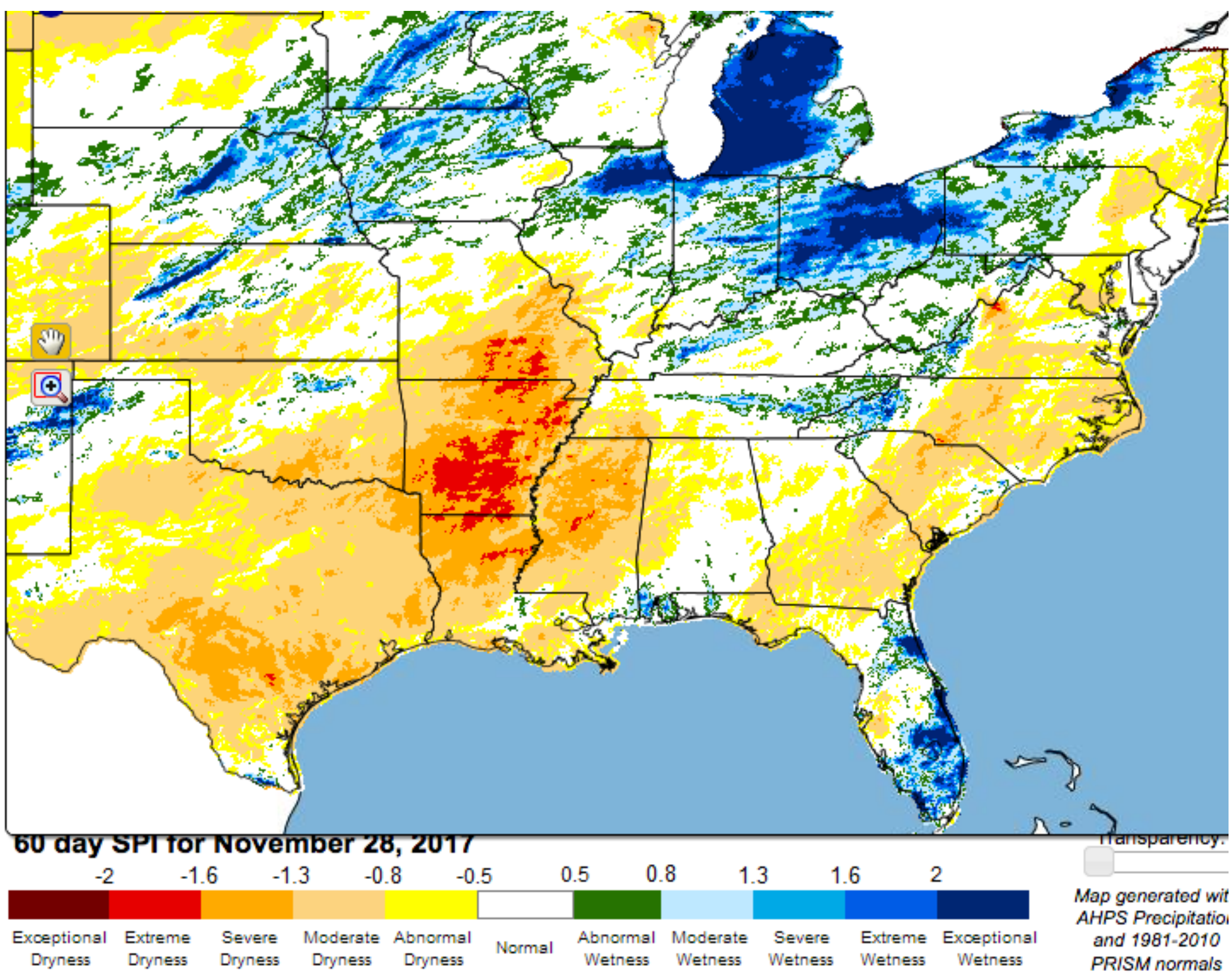
The final component of the algorithm is a conventional two-dimensional spatial analysis of bias, using the output from the first two components as an improved first guess that reflects the inherent anisotropies in the radar bias fields. Statistical validation demonstrates that not only does the bias correction step improve the accuracy of the precipitation analyses, but the prior correction of spatially systematic biases improves the ultimate accuracy of the overall bias correction.

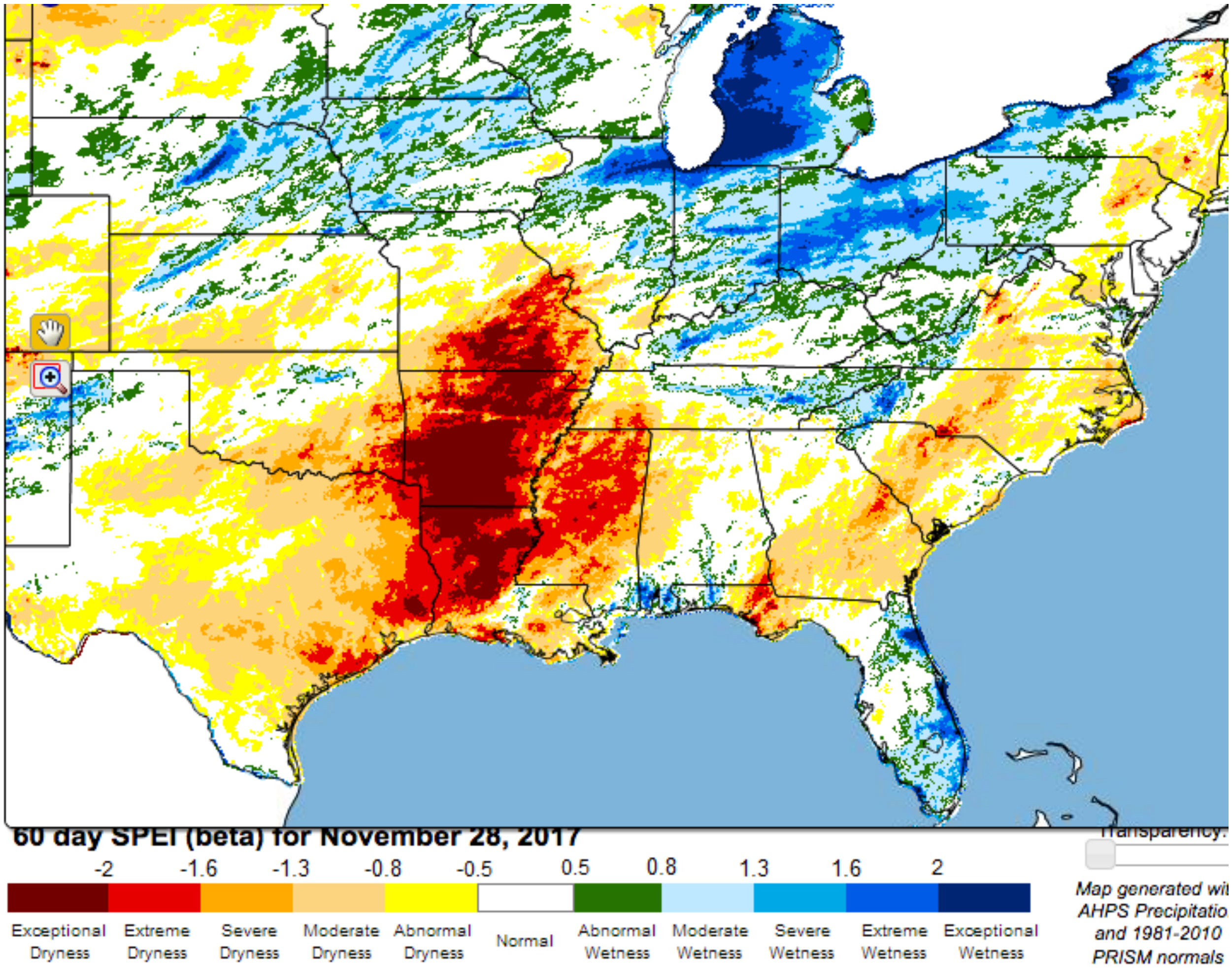
Meanwhile, the product generation work focused on creation of drought indices that incorporate temperature information in addition to high-resolution precipitation information.

SPEI grids based on AHPS precipitation and PRISM temperatures are now being operationally produced over the contiguous US at daily intervals and for timescales ranging from 30 days to 36 months. These grids are based on the accumulated difference between AHPS precipitation and potential evapotranspiration, or P-PET, calculated using daily PRISM temperature grids and the Hargreaves PET equation. The steps involved in the SPEI calculation method are outlined below:

- Identified long-term NWS COOP sites having both temperature and precipitation records.
- Clustered these COOP sites into homogeneous groups based on characteristics describing their location (latitude, longitude, elevation), and annual precipitation and potential evapotranspiration characteristics (1981-2010 average annual P-PET and the 2-month periods where the average maximum and minimum P-PET occurred).
- The parameters of the log-logistic distribution were calculated using historical data from the clustered COOP sites. Parameters were calculated for 14 time scales ranging from 30 days to 36 months ending on each calendar day. The parameter describing the location of the historical distribution also includes monthly PRISM normals data.
- Daily AHPS precipitation and daily PET are summed over a period of interest for a given ending date, and the difference is then taken.

The summed P-PET is mapped to the historical log-logistic distribution for the given calendar day and period of accumulation to determine the cumulative probability. This is subsequently transformed to a normal distribution, resulting in the SPEI.





The maps on this page and the previous page show the most recent SPI and SPEI maps for the central and eastern United States. The maps highlight the dry conditions that have developed across much of the southern United States during the fall of 2017. Within the cores of the drought areas in the lower Mississippi River Valley and the Southeast, the intensity of the drought as measured by the SPEI is greater than that measured by the SPI, indicating the enhancement of drought conditions caused by above-normal temperatures, even warmer than those normally accompanying precipitation deficits in the region. In contrast, the wetness across the Midwest is lessened in the SPEI, indicating how enhanced evaporation is likely to be partially counteracting the wetness impacts from precipitation.

The SPEI were re-analyzed against other comparative SPEI datasets from the Western Regional Climate Center and National Centers for Environmental Information, revealing them to be strongly correlated with small differences. Additional analyses were undertaken to compare SPEI grids to soil moisture, streamflow, and groundwater measurements from sites in North Carolina and the southeast US for a 10+ year period. SPEI captured fluctuations in these drought indicators better than SPI. Shorter timescales of each drought index performed the best overall for streamflow and soil moisture, while longer timescales better captured groundwater fluctuations.

SPEI grid point values generated as part of this project were compared to subjective assessments of drought levels determined by citizen scientists as part of the CoCoRaHS Condition Monitoring pilot project with the Carolinas Integrated Sciences and Assessments (CISA). Quantitative and qualitative analysis indicate that SPEI captures a large portion of the variability and magnitude of a range of observed on-the-ground conditions (both dry and wet).

Another objective of the project was to calculate a monthly suite of Palmer Drought Indices (PDI) and develop an updated-daily PDI methodology. Algorithms to calculate monthly PDI, which include the Palmer Z-Index (Z-Index), Palmer Drought Severity Index (PDSI), Palmer Modified-Drought Severity Index (PMDI), and Palmer Hydrologic Drought Index (PHDI) were completed and tested using monthly historical PRISM grids of temperature and precipitation and current precipitation observations from the NWS Advanced Hydrologic Prediction Service. Assessments of these CONUS grids against independently-calculated PDI from the Western Regional Climate Center's WestWide Drought tracker revealed them to be strongly correlated. Additional analysis of Z-index, PDSI, and PMDI distributions revealed the values of each index fall within expected ranges.

Daily Palmer Z-index grids have been generated for the contiguous US for the time period 1951-2016 using the Northeast Regional Climate Center's (NRCC's) gridded temperature and precipitation grids. These grids use 30-day moving windows ending on each date to calculate climate balances used in the Z-index, and subsequent Palmer Drought Index, calculations. The daily moving-window Z-index grids have been evaluated against monthly Z-index grids, which are also calculated using NRCC temperature and precipitation data. An ideal daily Z-index should match the monthly grids on their corresponding dates, with smooth transitions between these dates. The daily Z-index grids do exhibit smooth transitions between end-of-month dates. Differences for equivalent dates are small and correlations are large over the majority of the US, with the exception of the upper Midwest and parts of the western coast. We are investigating the source of these differences.

The code base that generates these grids has been set up to allow other gridded datasets, such as daily PRISM and AHPS precipitation, to be used and will facilitate incorporation into the existing suite of drought indexes housed on the NC SCO's gridded data servers.

As a result of the ongoing work to improve and refine the precipitation estimates, the project did not accomplish its third objective, testing the impact of the improved precipitation estimates in NLDAS. The refined precipitation estimates were judged not to be ready for that step by the time of project completion. We are, however, undertaking additional projects with funding and collaboration with NOAA that will include using our technology to improve the precipitation inputs into NLDAS.

4. Highlights of Accomplishments

- Developed and tested a correction algorithm for beam blockage in radar-based precipitation estimates.
- Developed and tested a successful correction algorithm for range-dependent biases in radar-based precipitation estimates.
- Demonstrated improved long-term drought and precipitation estimates through implementation of correction algorithms for beam blockage and range-dependent biases.
- Developed and implemented a web site for providing a comprehensive suite of real-time high-resolution drought products (http://climate.ncsu.edu/drought).
- Began generation of drought products beyond the Standardized Precipitation Index (SPI) and SPI blends, including Standardized Precipitation-Evaporation Index (SPEI) and Palmer Drought Indices.

- Validated SPEI and Palmer drought indices against existing low-resolution monthly products, other observable indicators of drought severity such as soil moisture, and subjective reports of drought severity.

5. Transitions to Applications

The bias correction algorithm should soon be integrated into the radar precipitation estimates used in the suite of drought indices produced by the NC State University team. McRoberts and Nielsen-Gammon will continue further work on the third primary objective, testing the benefit and impact of incorporating the bias correction of radar precipitation estimates in a land surface model, as part of a new NOAA-funded project. Over the course of the next 3 years, a great deal of effort will be spent on thoroughly testing the integration of long-term bias information to radar-based QPEs at hourly and daily time scales.

A broad suite of options were developed for users to interact with SPEI data, including more sophisticated download options for grids and time series. A direct feed was set up to allow US Drought Monitor authors easy access to the SPEI, as well as other drought index grids available from the NCSU data servers. PDI grids will be available to download in the future.

The State Climate Office of North Carolina is releasing a new website in December 2017. As part of the content migration and software updates with this new website, tools that display the drought index grids developed under this project have been migrated to new web servers with associated back-end updates to maintain or increase functionality.

The drought products created under this project are presently widely used as input to the US Drought Monitor, both by local experts and by the drought monitor authors themselves. The products are believed to have improved the accuracy and spatial specificity of the US Drought Monitor, with consequent benefits for accurate and timely awareness of drought conditions and availability of funding to compensate for agricultural impacts of drought.

6. Publications from the Project

Cumbie-Ward, R. V., and R.P. Boyles, 2016: Evaluation of a High-Resolution SPI for Monitoring Local Drought Severity. Journal of Applied Meteorology and Climatology, 55, 2248-2262, doi: 10.1175/JAMC-D-16-0106.1.

McRoberts, D. B., and J. W. Nielsen-Gammon, 2017: Detecting beam blockage in radar-based precipitation estimates. Journal of Atmospheric and Oceanic Technology, 34, 1407-1422, doi: 10.1175/JTECH-D-16-0174.1.

Several additional publications are presently being readied for submission. These publications will report on the recent accomplishments of the project and make the results available for community-wide benefit.

7. PI Contact Information

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