Final Report

Developing National Soil Moisture Products to Improve Drought Monitoring

Lead PI: Steven Quiring

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Accomplishments

(1) Assess the fidelity of various satellite remote sensing- and model-based soil moisture products using the North American Soil Moisture Database as a benchmark
(2) Integrate remote sensing and modeled soil moisture information with in situ measurements to develop a national-scale, near-real time soil moisture product for drought monitoring
(3) Design and develop a proof-of-concept

What was accomplished under these goals?

Objective 1: We have constructed a validation framework for in situ, model, and remote sensing soil moisture platforms and have deployed this framework for validating numerous datasets. We combine relative observation error (Dirmeyer et al. 2016) with triple colocation (Gruber et al. 2013) to robustly assess soil moisture measurement/estimation error and spatial representativeness, both of which are important for data inclusion in the National Soil Moisture Network (NSMN) and related drought monitoring products. The development and testing of this framework, as well as comprehensive evaluation of multiple in situ, model, and satellite soil moisture products are detailed in Ford and Quiring (2019). We have found that land surface models as part of the North American Land Data Assimilation System (NLDAS-2) and Soil Moisture Active-Passive (SMAP) soil moisture consistently outperformed other model and satellite remote sensing products, respectively. This framework has subsequently been deployed to evaluate the quality of in situ measurements at more than 1,000 stations that can potentially be included in the NSMN. This analysis and results are detailed in a manuscript currently in review with Journal of Hydrometeorology (Ford et al. 2021). We have used the results of this evaluation to determine the in situ stations best suited for use in the development of gridded drought monitoring products.

Objective 2: We have experimented with various methods for vertical interpolation to achieve consistent vertical depths across different datasets, as well as various methods for blending in situ, model, and satellite data. Our results have shown that a simple linear interpolation is the most effective and efficient method for vertical interpolation of soil moisture across diverse datasets (Zhang et al., 2017). In addition, a simple average blending approach has shown promise to achieve accurate blending results with in situ, NLDAS-2 model, and SMAP satellite data sources (Zhang et al., in review). We have produced blended (in situ, model, satellite) soil moisture drought products as well as primarily in situ-informed products, the latter of which is interpolated using a regression kriging approach with PRISM precipitation (Zhao et al. 2020).

Objective 3: We have developed a system to ingest in situ, model, and satellite soil moisture datasets, process these data, and produce high resolution gridded soil moisture and drought maps based on the data. This can all be done with daily latency, and updated maps are online at nationalsoilmoisture.com.

What opportunities for training and professional development has the project provided?
The project has provided the opportunity for training and education of 3 graduate student researchers (1 at SIU, 2 at OSU) and 2 undergraduate student researchers (2 at SIU). Graduate student researchers have aided in the development of the quality assurance/validation framework, and have lead the validation of NSMN data. The undergraduate student researchers have aided in the validation of NSMN data, as well as leading related research in understanding connections between soil moisture and tangible drought impacts. Through this work, the student researchers have gained invaluable skills in hydrological data acquisition, processing, and analysis, as well as research acumen. One undergraduate student at SIU has used her work on the project to kindle an interest in research, and began her pursuit of a Masters degree at the University of Wisconsin-Milwaukee in fall 2019. Another undergraduate student at SIU has used her work on the project to initiate an independent, internally-funded research project examining drought impacts across the United States. She has since graduated with her Bachelor Degree, and will begin her pursuit of a Masters degree at the University of Colorado-Boulder in fall 2020. The project has also provided the opportunity for professional development for an early career scientist (PI Ford) through presentations and invited talks at national conferences as well as meetings of various working groups, including the NOAA Drought Task Force and NSMN Working Group.

How were the results disseminated to communities of interest?
During the report period, results have been disseminated to communities of interest via 15 presentations and 6 peer-reviewed publications.
In addition, gridded soil moisture products developed as part of this project are live at https://nationalsoilmoisture.com, and are updated daily with the most recent soil moisture and precipitation observations. In situ soil moisture observations that make up these gridded data are available for download on this website.

Participants & other collaborating organizations

What individuals have worked on this project?
Southern Illinois University - Trent Ford (PI), Christian Landry (MS student), Makenzee Loft (undergraduate student), Angel Arcuri (undergraduate student)
Ohio State University - Steven Quiring (PI), Chen Zhao (PhD student), Zack Leasor (PhD student), Ning Zhang (PhD student), and Shanshui Yuan (Postdoc)
USGS - Laura DeCicco (PI); Roland Viger (PI)

What other organizations have been involved as partners?
USDM Authors, National Drought Mitigation Center, USDA Office of Chief Economist

Have other collaborators or contacts been involved?
National Soil Moisture Network steering committee

What was the impact on the development of the principal discipline(s) of the project?
The primary impacts for climate science include (1) development of a system for ingesting, processing, quality-controlling, and delivering soil moisture data from diverse sources in near-real time, (2) development and application of a framework for robust validation and quality control of soil moisture data from diverse sources, and (3) development of high quality, gridded soil moisture products based on multiple, diverse datasets for drought monitoring. More broadly, this project is providing systematically evaluated and created information products that provide an important new datum against which the soil moisture research community can discuss its advances.

What was the impact on other disciplines?
More broadly, geoscience disciplines are likely impacted by the availability of high quality, national-scale, point-based and gridded soil moisture data in near-real time as well as the development of robust methods for gridding discrete soil moisture data. Operational climate forecasting, including drought and flood forecasting, is likely impacted by the availability of high quality, gridded soil moisture in near-real time, and comprehensive error assessment of these products. This project has also developed an important source of information for use in national hydrologic modeling efforts, such as the NOAA-NWS National Water Model and the USGS National Water Census. Streamflow and other fluxes simulated by these modeling efforts are extremely sensitive to changes in soil moisture parameters. Having a nationally consistent set of observation-based data against which to evaluate model performance is critical to improve model conceptualization and to properly characterize uncertainty of the simulated quantities.

What was the impact on the development of human resources?
The project has provided the opportunity for 4 graduate students and 2 undergraduate students to become familiar with climate research, and has directly resulted in the development of the students' skills in data management and processing and hypothesis testing. The project has resulted in one undergraduate student continuing her STEM education pursuing a Masters degree in Geography at UW-Milwaukee, and another undergraduate student receiving a competitive, internally-funded research grant based on her work on this project. The second undergraduate student will begin her MS education at the University of Colorado-Boulder in Fall 2020. The project has also provided the opportunity for an early career scientist (PI Ford) to manage a funded research project. This project has also been useful in bringing together both student and faculty researchers from academia with those of the USGS and NOAA-NIDIS, and is expected to result in future collaborations.

What was the impact on physical, institutional, and information resources that form infrastructure?

A website and data portal have been developed based on the work on this project (http://nationalsoilmoisture.com). The background engine ingests and processes soil moisture data from diverse sources, which are then delivered via the website, all in near-real time. This infrastructure has - and will continue to - strongly inform the construction of the NSMN and its web presence. This project has engendered the interest in migrating this information infrastructure from its prototype home into a more permanent or operational setting, from both NOAA-NIDIS and the USGS, and is generally supported by the Executive Committee for the National Soil Moisture Network.Box 41: What was the impact on technology transfer?

By the end of the period of this project, this system will be available as an open-source software product capable of running on standard computing environments using container technology for the software execution environment. This means that, in addition to journal publications, the actual technological implementation of the researched methodologies and algorithms will be readily available to the scientific community and general public. Pending subsequent support to transfer this system to an operational environment at a *.gov endpoint, the system will continue to provide data outputs from the nationalsoilmoisture.com endpoint.

What was the impact on society beyond science and technology?

High quality soil moisture datasets, based on in situ observations, are integral for accurate and timely drought monitoring and forecasting. These products, developed and delivered as part of this project, will fill a tremendous data need and will inform drought and flood related decisions. Through our participation on the NSMN Working Group, the work on this project has, and is expected to continue, to inform the development of the NSMN, which will have a large impact beyond science and technology.

What were the outcomes of the award?

The major outcomes of the award are:

(1) the development of a framework for soil moisture data assessment, and application of this framework on numerous model- and satellite-based products, and over 1,200 in situ stations.

(2) the development of a system that ingests, processes, and delivers soil moisture data from multiple, diverse sources, both in point (i.e., station) and gridded formats in near-real time

(3) the development of high quality, gridded soil moisture products, informed by in situ observations, for drought monitoring at a national scale

Developing National Soil Moisture Products to Improve Drought Monitoring -- *Final Report*

Project Title: Developing National Soil Moisture Products to Improve Drought Monitoring

PI/co-PI names and institutions: Steven Quiring (co-PI; Ohio State University), Trent Ford (PI; University of Illinois), Roland Viger (co-PI; United States Geologic Survey)

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29. Publications, conference papers, and presentations

Publications:

Ford, T. W., Quiring, S. M., Zhao, C., Leasor, Z. T., and C. Landry (2020) Statistical Evaluation of In Situ Soil Moisture Observations from 1,200+ Stations as part of the U.S. National Soil Moisture Network. *Journal of Hydrometeorology*, 21 (11): 2537–2549. https://doi.org/10.1175/JHM-D-20-0108.1

Zhang, N., Quiring, S. M., and T. W. Ford (under review) Blending SMAP, Noah and In Situ Soil Moisture Using Multiple Error Estimation Methods. *Journal of Hydrometeorology.*

Zhao, C., Quiring, S. M., Yuan, S., McRoberts, D. B., Zhang, N. and Z. Leasor (2020) Developing and Evaluating National Soil Moisture Percentile Maps. *Soil Science Society of America Journal*, 84: 443-460. https://doi.org/10.1002/saj2.20045

Clayton, J.A., Quiring, S.M., Ochsner, T., Cosh, M., Baker, C.B., Ford, T.W., Bolten, J.D., and M. Woloszyn (2019) Building a one-stop shop for soil moisture information. *EOS*, 100, https://doi.org/10.1029/2019EO123631.

Ford, T.W., and S.M. Quiring (2019). Comparison of contemporary in situ, model, and satellite remote sensing soil moisture with a focus on drought monitoring. *Water Resources Research.* 55, 1565-1582.

Ford, T.W., and S.M. Quiring. The Importance of Soil Moisture Monitoring in the Midwest. *The Climate Observer*, August, 2018.

Conference Presentations:

Quiring, S. M., and T. W. Ford (2021) Developing National Soil Moisture Products Using In Situ, Satellite and Model-derived Data. Contributed presentation given at the 35th Conference on Hydrology, Annual Meeting of the American Meteorological Society, January 2021.

Quiring, S. M., T. W. Ford and R. Viger (2020) Developing National Soil Moisture Products Using In Situ, Satellite and Model-derived Data. Contributed presentation given at the National Soil Moisture Workshop (online), August 2020.

Quiring, S. M. and T. W. Ford (2020) Developing Improved Forest Soil Moisture Products from In Situ, Satellite and Land-Surface Models. Contributed presentation given at the USFS – NASA Joint Applications Workshop: "Earth Observations in Support of Forest and Rangeland Response to Changing Environmental Conditions", June 2020.

Quiring, S. M., Ford, T., Zhang, N., Zhao, C. and Z. Leasor (2020) Developing National Soil Moisture Products Using In Situ, Satellite and Model-derived Data. Contributed paper presented at the Annual Meeting of the American Association of Geographers, Denver, April 2020. Canceled due to COVID.

Zhang, N., Quiring, S. M. and T. W. Ford (2019) Soil moisture mapping in south central United States by blending in-situ and modeled data. Contributed poster to be presented at the Annual Meeting of the American Geophysical Union, San Francisco, December 2019.

Cosh, M. and others (including S. M. Quiring) (2019) The National Soil Moisture Network: Building a strategy from the ground up. Contributed poster to be presented at the Annual Meeting of the American Geophysical Union, San Francisco, December 2019.

Quiring, S. M. and T. W. Ford (2019) Integrating In Situ, Satellite and Modeled Data for the National Soil Moisture Map. Contributed paper presented at the National Soil Moisture Network Meeting, Kansas State University, May 2019.

Arcuri, A., and T.W. Ford (2019) "How Often Do Statistical Drought Indices Concur with Tangible Drought Impacts?" American Geophysical Union Fall Meeting, San Francisco, CA, December 2019.

Leasor, Z. and S. M. Quiring (2019) Developing Daily Blended Soil Moisture Products in Near Real-Time. Contributed poster presented at the National Soil Moisture Network Meeting, Kansas State University, May 2019.

Zhang, N. and S. M. Quiring (2019) A hybrid soil moisture product using model simulated and in-situ measured soil moisture. Contributed poster presented at the National Soil Moisture Network Meeting, Kansas State University, May 2019.

Zhang, N. and S. M. Quiring (2019) Root-zone soil moisture estimation using in-situ measurements and remote sensing data. Contributed poster presented at the Annual Meeting of the American Association of Geographers, Washington, DC, April 2019.

Zhang, N. and S. M. Quiring (2018) A hybrid root-zone soil moisture product based on in-situ measurements and remote sensing data. Contributed poster presented at the at the Annual Meeting of the American Geophysical Union, Washington, December 2018.

Ford, T.W., Quiring, S.M., Leasor, Z., Strobel, M., Loft, M., and A. Arcuri (2018) "Developing Integrating Soil Moisture Products to Improve Drought Monitoring in the United States." The 5th Satellite Soil Moisture Validation and Application Workshop. October 23, 2018. Fairfax, Virginia.

Quiring, S. M. (2018) National Soil Moisture Monitoring Network. Monitoring Forest Soil Moisture for a Changing World. Michigan Tech Research Institute, Ann Arbor, MI, May 2018.

Quiring, S. M., Ford, T., Leasor, Z. and C. Zhao (2018) Developing National Soil Moisture Products Using In Situ, Satellite and Model-derived Data. Invited poster presented at the at the Annual Meeting of the American Geophysical Union, Washington, December 2018.

30. Technologies or techniques

1) A prototype automated system for collecting soil moisture observations from a variety of providers

2) A prototype automated software for using soil moisture observations to interpolate national daily raster maps

3) A prototype cloud-based web map interface for browsing and downloading the contents of the data system