Evaluating Existing & Developing New Drought Indices Using Modeled Soil Moisture Time Series

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Post-doctoral Researcher and Graduate Student: Trevor McKellar (Environmental Science)

End Users: Land managers from USDA-Natural Resource Conservation Service; U.S. Bureau of Land Management; U.S. Forest Service; Drought monitoring committees, such as the AZ Governor's Drought Task Force; U.S. Drought Monitor

Additional Resource Support: Arizona Space Grant Consortium; U.S. Department of Agriculture Southwest Climate Hub

Project Dates: 2017 – 2023

Summary of Impact

Developing climate services for drought management: This project supported the development of new climate services and educational resources to help land managers better understand and manage drought in the U.S. Southwest. Researchers explored relationships between common drought indices and soil moisture and discovered ways that land managers could more effectively monitor drought conditions at various depths.

Increasing understanding and use of drought indices: End users have a better understanding of how different drought indices work, and how to choose the right one, at the right timescale, for their land management decisions.

Building partnerships through collaboration: The project tracked drought on rangelands across southern Arizona, New Mexico, and California, constituting millions of acres of grazing lands. By co-developing this project with land managers and presenting research findings to other end users, researchers have improved the utility of existing drought monitoring indices across the southwest.

Problem Statement

Several drought indices exist, but there is little understanding about how to use them in decision making about drought. A system is needed to help people choose the right drought index at the right timescale and use it effectively to address their specific needs.

Research Focus

This project assessed the effectiveness of two common drought indices, the Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index

(SPEI), by comparing them to past soil moisture conditions. Researchers used HYDRUS-1D, a soil water model, to simulate how water moves through soil over long periods (over 50 years) at a daily resolution. Historical soil water profile climatologies – detailed pictures of soil moisture changes due to varying climate conditions – were developed for various locations in Arizona, New Mexico, and California. Researchers compared simulated soil moisture data with SPI and SPEI values calculated for the same locations and time periods to demonstrate how well the indices captured actual soil moisture variability. They explored how SPEI, which incorporates temperature data along with precipitation, showed how rising temperatures might be influencing drought stress in the Southwest.

The initial project study area focused on the Las Cienegas National Conservation Area (LCNCA), in partnership with the Nature Conservancy. The study area was then extended to include semi-arid lands from southern New Mexico to southern California.

Project Activities

Data collection and analysis: Trevor McKellar collected data, created the dataset, developed a new model runs for study areas, and assessed drought indices.

Web app development: McKellar developed a prototype web app to explore model data for the Las Cienegas NCA study area.

Stakeholder engagement: Researchers held several meetings and workshops with stakeholder partners, including The Nature Conservancy, Bureau of Land Management, and National Resource Conservation Service field personnel to gather feedback on the research process and app development.

Project collaboration: Worked with Nature Conservancy partners on project visioning, research question development, research design.

Project Outputs

Data:

Data from this project are publicly available: McKellar, T. T., M. Crimmins, M. Schaap, C. Rasmussen. 2023. Defining the multiscalar index timescale – Soil water depth continuum for the southwestern United States [Dataset]. Zenodo. https://doi.org/10.5281/zenodo.7983357

Peer-reviewed Publications:

McKellar, T.T., M.A. Crimmins, M.G. Schaap, C. Rasmussen. 2023. Defining the multiscalar index timescale—Soil water depth continuum for the southwestern United States. *Journal of Geophysical Research: Atmospheres* 128:e2023JD039348. https://doi.org/10.1029/2023JD039348

McKellar, T.T., M.A. Crimmins. The Relationships Between Multiscalar Index Timescale and Soil Water Availability for the Southwestern United States *Journal of Agriculture and Forest Meteorology*, in Review.

Thesis and Dissertation:

McKellar, T. T. 2022. Drought monitoring in the southwestern United States: Analysis of seasonal precipitation, multiscalar indices, and soil water. Doctoral dissertation. Environmental Science, University of Arizona.

McKellar, T.T. 2017. Evaluating How Representative Simple Multiscalar Drought Indices are of Modeled Soil Moisture Across the Desert Southwest United States. Master's Thesis. University of Arizona, Dept. of Soil, Water, and Environmental Science.

Workshops and Planning Meetings:

LCNCA Bioplanning Meeting. 2018. Watershed group members and federal land managers met with researchers to discuss project planning and needs.

Improving Use of Drought Tracking Tools and Developing a Drought Monitoring Guidebook - Workshop. 2019. USDA-NRCS Office, Tucson, AZ. NRCS rangeland conservation personnel provided feedback on preliminary results and project guidance.

Soil Moisture Modeling Update. 2019. Project update provided for Nature Conservancy project partners.

LCNCA Bioplanning Meeting. 2019. Project update provided for LCNCA project partners.

Presentations:

Drought Monitoring Tools for Arizona Rangelands. 2019. NIDIS/USDA Climate Hub Monitoring and Reporting Drought in Arizona, Phoenix, AZ.

The Drought Monitoring Guidebook: Using Soil Moisture Modeling to Improve Drought Monitoring Techniques in Southern Arizona. 2019. UofA Space Grant Spring meeting.

Drought monitoring in Arizona's changing hydroclimate. 2019. Southwest Extreme Precipitation Symposium, La Jolla, CA.

Improving Use of Drought Indices by Using Soil Moisture Modeling. 2019. Pima County Local Drought Impact group.

Using HYDRUS Soil Moisture Modeling to Improve Drought Index Usage on Arizona's Rangelands. 2019. Science on the Sonoita Plain.

Using HYDRUS Soil Moisture Modeling to Improve Drought Index Usage on Arizona's Rangelands. 2019. Space Grant Fall Update.

Using HYDRUS Soil Moisture Modeling to Improve Drought Index Usage on Arizona's Rangelands. 2019. American Geophysical Union Annual Meeting.

Using HYDRUS Soil Moisture Modeling to Improve Drought Index Usage on Arizona's Rangelands. 2020. RainManSR Project Meeting.

Using HYDRUS Soil Moisture Modeling to Improve Drought Index Usage on Arizona's Rangelands. 2020. Space Grant Spring Update.

ENVision Graduate Research Workshop. 2022. Dept. of Environmental Science, University of Arizona.

How do multiscalar indices relate to soil water availability in the Southwest? 2023. Winter Meeting of the Arizona Section of the Society for Range Management.

Selected Scientific Findings:

Effectiveness of drought indices:
Multiscalar drought indices like the Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) correlate highly with soil moisture variability at various depths and across soil types. Both are reasonable proxies for soil moisture drought, allowing index users to better track drought development on their lands.

Variables that impact effectiveness:
The SPI and SPEI are most effective at tracking changes in soil moisture when the timescale of the drought index is adjusted to the depth of soil being monitored. For example, shorter timescales (1-3 months) track changes in shallow (~10cm) soil moisture variability, while longer timescales (9-12 months) track changes in deeper soil moisture (~30 to 50 cm). Correlations were consistent across low desert areas of the southwest U.S but varied by soil type, with indices better matching drought conditions in soils with higher clay content. Overall, the SPI captured drought development in soils slightly better than the SPEI. This was attributed to the inclusion of potential and not actual evapotranspiration in the SPEI calculation.

On using drought indices effectively:

Without soil moisture data, people use drought indices as proxies for estimating soil moisture. The focus of my dissertation was to understand if that worked. And the answer is yes. But people can also use drought indices at different timescales - one month, two months, three months, etc. Depending on the depth of soil moisture, the timescale length will change. So, a main outcome of this work is being able to effectively communicate this connection, like "If you want to get an idea of what soil moisture looks like at 30 cm, use a 6-month SPI timescale." That's valuable information for land managers, especially if they're trying to look at a specific type of crop or a specific type of vegetation on their landscape that might be changing. How and when it rains will impact when land managers might start seeing anomalies in their soil moisture

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Trevor McKellar, CLIMAS

Optimizing drought indices for use: Drought events at different soil depths are strongly related to seasonal patterns in precipitation. Drought indices can be optimized to follow these patterns by varying the timescale length during different calendar months (i.e. using shorter timescales during the rainy seasons and longer timescales during the dry seasons).

Adjusting for soil type: Accuracy can be further improved by considering the type of soil (sandy soil, for example, requires short timescales to track changes). SPI better represented soil water availability in soils of the semi-arid southwest.

Societal Impacts by Category

Connectivity:

- Partnerships with The Nature Conservancy, USDA - Natural Resource Conservation Service, U.S. Bureau of Land Management, and land managers were strengthened through ongoing meetings, presentations, and research outputs. These connections led to conversations about future climate service development to support community-based adaptation planning.

On using the right information:

The climate science enterprise has produced a tremendous amount of information – more every year. My job is to help people filter the relevant info out of that firehose.

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Mike Crimmins, CLIMAS

Conceptual:

- Land managers increased their understanding about how drought indices relate to soil moisture and about the techniques used by different drought indices and tracking tools. This project introduced better ways to interpret drought metrics and soil moisture values and how to use these metrics to better manage arid lands.

Capacity Building:

- This research resulted in a modeled soil moisture dataset for the Southwest which will aid land managers and researchers in continued decision making and research around drought and soil moisture in the Southwest.
- Trevor McKellar completed a master's thesis and doctoral dissertation through this project. After graduating, he accepted a new position as a post-doctoral researcher with CLIMAS to continue his work in climate modeling and developing climate services with societal partners. He has since transitioned to a staff research scientist in the Environmental Science department at the University of Arizona.
- The research frameworks from this project have been extended into new climate services around drought and climate adaptation planning, teaching people how to better use different drought indices in the Southwest.

Instrumental:

- Results helped guide the selection of drought indices and optimal timescales for other drought monitoring projects, such as one with the U.S. Forest Service to develop custom climate reports for national forests in Arizona and New Mexico.

On improving decision making:

We want to help land managers understand the strengths and weaknesses of these tools, so they don't have to do all the homework to figure out if they need to use this index versus that index. When our partners need to make high stakes decisions, and the data from the drought indices is kind of mediocre, we know how to help them get the best information for those decisions.

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Mike Crimmins, CLIMAS