FINAL REPORT

1. Administrative

Project Title: Foundational Science Area: Ecological Drought, Climate Extremes, and the Water Cycle in the North Central U.S.

USGS Award Number: G17AP00096
CSU Award Number: G-52119-01
CU Project Number: 1556044
Total Award: $99,950.00

Principal Investigator: Imtiaz Rangwala (imtiaz.rangwala@colorado.edu)
Research Team: Lesley Smith (CIRES/NOAA), Joe Barsugli (CIRES/NOAA), Candida Dewes (CIRES/NOAA), Mike Hobbins (CIRES/NOAA), Gabriel Senay (USGS) and Brian Miller (USGS)
Institution: CIRES, University of Colorado-Boulder; Physical Sciences Division, NOAA ESRL, Boulder; USGS

Project Duration: October 1, 2017 – March 31, 2019
Reporting Date: June 26, 2019

2. Public Summary

This project facilitated the engagement of the North Central Climate Adaptation Science Center's (NC CASC) *Climate* Foundational Science Area (FSA) to identify and address the physical climate science challenges that are important for ecologists and natural resource managers in the NC CASC region, as well as meet their needs for climate information to assess impacts to their desired system and develop strategies for effective climate adaptation. A drought index called the Landscape Evaporative Response Index (LERI) was developed to provide a near real-time assessment of soil moisture conditions across the Contiguous United States (CONUS) based on satellite observations. This projects also supported development of climate scenarios for different stakeholder-driven projects. New utilities were added to another drought index, the Evaporative Demand Drought Index (EDDI), that our team has previously developed. The project team also put together a book chapter that examines the relevance of the concept of evaporative demand and extremes in evaporative demand during the 21st century for drought assessment and monitoring.

3. Project Summary

This project supported the activities of the Climate Foundational Science Area (FSA) at the North Central Climate Science Adaptation Center (NC CASC). Climate FSA identifies and addresses the physical climate science challenges that are important for ecologists and natural resource

managers in the NC CASC region. This project supported both research and outreach activities associated with relevant climate science, information and data needs recognized by the network of NC CASC scientists and stakeholders.

In this project, we developed a drought index called the Landscape Evaporative Response Index (LERI) to provide a near real-time assessment of land surface dryness (i.e., root-zone soil moisture conditions) across the Contiguous United States (CONUS) based on satellite observations. We developed a webtool to disseminate LERI data and maps to the public.

We also provided data, guidance and oversight in the production of climate scenarios for different stakeholder-driven projects including (a) Colorado Nature Conservancy's Climate Impacts and Opportunities project, (b) Ecological drivers FSA work across the whole of central US domain, (c) National Park Service project in Devils Tower National Monument and (d) the US Fish and Wildlife's Species Status Assessment on White Tailed Ptarmigan and Skiff milkvetch. The project team also engaged with Montana's Fish, Wildlife and Parks on a Structured Decision Making (SDM) process related to mountain goats in the state.

We added new utilities to the Evaporative Demand Drought Index (EDDI) tool including a historical archive of EDDI maps and bi-weekly synopsis of EDDI conditions, and presented a webinar to discuss all the available web-resources on EDDI. We wrote a book chapter that discusses and reviews the role of evaporative demand and extremes in evaporative demand during the 21st century for drought assessment and monitoring.

4. Report Body: Project Results, Analysis and Findings

A. Development of the Landscape Evaporative Response Index (LERI)

Landscape Evaporative Response Index (LERI) is remotely-sensed high-resolution information of the evaporative response from the land in near real time. LERI assesses anomalies in actual evapotranspiration (ETa), as percentiles, across the Contiguous US and northern Mexico at a 1-km spatial resolution. LERI is based on the ETa data produced by the U. S. Geological Survey using the operational Simplified Surface Energy Balance (SSEBop) model. SSEBop combines evapotranspiration fraction generated from remotely sensed MODIS thermal imagery, acquired every 8 days, with climatological atmospheric evaporative demand.

To quantify LERI, a rank-based, non-parametric method is used to estimate percentiles of the SSEBop ETa, over a period of ETa accumulation, compared to the available period of record (January 2000 to present). LERI percentiles are also binned into four drought categories (LD0 - LD3) analogous to the US Drought Monitor (USDM) categories (i.e. D0-D3) and using the same percentile breaks that USDM considers for soil moisture.

By its numerical design, LERI essentially represents the evaporative response of the landscape driven primarily by the anomalous state of soil moisture to meet the climatological atmospheric demand through a combination of evaporation (from soil and leaf surfaces) and transpiration (root-stomata-air) processes. Real-time and high-resolution assessment of this soil moisture state is extremely salient to understanding and forecasting ecological responses. LERI serves as an experimental drought-monitoring and early warning guidance tool and has the potential to inform research into understanding characteristics of Ecological Drought.

Preliminary work focused on the Northern Great Plains finds LERI to closely track modeled moisture conditions in the upper soil layers (~10 cm)[1]. LERI complements other drought-monitoring indices and modeled soil moisture products. Work is ongoing to assess LERI's ability to capture signals of drought early warning, and its unique ability to assess land-surface moisture state. We developed a webtool (https://www.esrl.noaa.gov/psd/leri/) to access LERI maps, and spatial and historical time series data.

B. Regional Climate Scenarios Development

We provided data, guidance and oversight in the production of climate scenarios for different stakeholder-driven projects:

(a) Colorado Nature Conservancy's Climate Impacts and Opportunities project: Rangwala provided climate expertise on this one-year project led by Colorado's Nature Conservancy. The intention of this project was to develop a better understanding of climate change impacts in the different conservation targets of the Nature Conservancy across Colorado for next three decades. Rangwala helped in the development of four climate scenarios, and work closely with the Colorado Natural Heritage Program staff to develop relevant quantitative climate and ecological data for the project, participate in several science meetings at the TNC office and remotely, and help with contributing to the final report (TNC, 2018).

(b) Ecological Drivers FSA: We collaborated with Hansen and Adhikari to provide guidance in selection of climate scenarios for the north central US region, and downscaled data for those scenarios that we further spatially disaggregated to 1 km spatial resolution.

(c) National Park Service (NPS) project in Devils Tower National Monument: Rangwala worked with the staff of NPS's Climate Change Response Program (CCRP) to develop climate metrics relevant to freeze/thaw processes and heat stress. Rangwala also guided the team in the selection of appropriate downscaled data and selection of scenarios.

(d) US Fish and Wildlife's Species Status Assessment on White-tailed Ptarmigan and Skiff milkvetch: Rangwala and Barsugli engaged with John Guinotte (USFWS) to evaluate future climate risk to White-tailed Ptarmigan in Colorado. We brought in experts on snow and monsoons to these conversations, and also developed write-up based on the expert views and our best understanding of the subject. Rangwala also worked with Dara Taylor (USFWS) to provide climate scenarios information relevant to Skiff milkvetch SSA in the Upper Gunnison Basin. Rangwala specifically updated the climate scenarios table, previously developed for the Southwest Colorado SECR project, to reflect a 2050 future time horizon and to quantify changes in new additional metrics.

[1] https://www.esrl.noaa.gov/psd/leri/resources/pdf/LERI_Poster_CPASW-2018_Final.pdf

C. Evaporative Demand Drought Index: New utilities, outreach and publication

We added new utility to the Evaporative Demand Drought Index (EDDI) tool to provide users with easy browsing ability of the historical archive of EDDI maps[2]. The archive contains EDDI maps at 24 different time scales (1 week to 12 weeks, and 1 month to 12 months). The user has the ability to browse forward to back in time, by either a week or month, between 1979 and present. The feature is very useful in the assessment of how the atmospheric dryness, and relatedly the drought stress, is evolving through time.

Starting the spring of 2018, we are started to provide weekly to bi-weekly synopses of current EDDI conditions[3]. These synopses were also separately emailed to the US Drought Monitor authors. The project team also organized a webinar[4] on March 14, 2018, to discuss all the available web-resources on EDDI. The webinar has about 100 attendees.

Continuing our research into evaporative demand and its relevance to drought assessment and monitoring in the 21st century, the project team (Hobbins, Rangwala, Barsugli and Dewes) wrote a book chapter (Hobbins et al., 2019) to bring together all the best available research and understanding on the subject.

5. Outreach and Products

We were involved in both short- and long-term engagement with multiple stakeholders across the NC CASC region as part of this FSA project. Several significant engagements included:

a. Colorado Nature Conservancy – In developing climate scenarios and providing overall climate expertise to the Nature Conservancy's 1-year Climate Impacts and Opportunities project.
b. Montana's Fish Wildlife and Parks – In providing climate expertise in their SDM process related to mountain goat management in the state.
c. US Fish and Wildlife Service –
    i. In providing and soliciting more specific hydro-climate expertise for the SSA related to White-tailed Ptarmigan, as well as, developing a short write-up to provide our best understanding to the subject matter (USFWS contact – John Guinotte).
    ii. Consulting and helping with updating climate scenarios information (see Appendix 1) relevant to the SSA related to Skiff milkvetch in the Upper Gunnison Basin (USFWS contact – Dara Taylor).
d. NPS's Climate Change Response Program – helped in the development of climate metrics relevant to freeze/thaw processes and heat stress for the Devils Tower National Monument, and guiding the project team in the selection of appropriate downscaled data and selection of scenarios.

[2] https://www.esrl.noaa.gov/psd/eddi/#archive
[3] https://www.esrl.noaa.gov/psd/eddi/#current_conditions
[4] https://www.esrl.noaa.gov/psd/eddi/resources/EDDI-webinar-March-14-2018.mp4

e. NCASC Ecological Drought – provided multiple different datasets (e.g., EDDI, LERI, SPI, FDSI, VPD, temperature) for the Missouri Headwaters region to support the research work on this project. Rangwala also participated in a 3-day workshop and later as an author team to put together a review paper on the subject (i.e., Crausbay et al., 2019).
f. Organized a Manager's workshop at the MtnClim 2018 conference in Gothic, CO, to discuss the strategy for identifying climate refugia on a landscape. This half-day workshop brought together managers and scientists to discuss this issue both in the indoor and outdoor (field visit) setting. A report from this workshop has been published (Buono et al., 2019[5]).
g. Ecological Drivers FSA team – helped with selection of scenarios and provision of downscaled dataset at 1 km spatial resolution and multiple different periods during the 21st century. This dataset was later published at USGS ScienceBase (Rangwala and Dewes, 2018[6]). Rangwala also co-authored a paper with the team (Adhikari et al., 2019)
h. US Forest Service/USDA – performed climate analysis and co-authored a chapter on drought related issues in the Great Plains (Hanberry et al., 2019)

6. Publications

Crausbay S., …I. Rangwala, and others (2019). Unfamiliar territory: emerging themes for ecological drought research and management. One Earth (submitted).

Adhikari A., A. J. Hansen and I. Rangwala (2019). Ecological water stress under projected climate change across hydroclimate gradients in the north central United States. Journal of Applied Meteorology and Climatology (conditionally accepted).

Hanberry, B., M. C. Reeves, A. Brischke, M. Hannemann, T. Hudson, R. Mayberry, D. Ojima, H. R. Prendeville, and I. Rangwala. (2019). Management effects of drought in the Great Plains. Chapter in Effects of Drought on Forests and Rangelands in the US: Translating Science into Management Responses. Edited by J. M. Vose, D. L. Peterson, C. H. Luce. T. Patel-Weynand (in press).

Hobbins M.T., I. Rangwala, J. J. Barsugli, and C. Dewes (2019), Extremes in evaporative demand and their implications for drought and drought monitoring in the 21st Century. Chapter 25 in Extreme Hydrology and Climate Variability: Monitoring, Modeling, Adaptation and Mitigation, edited by A. M. Melesse, W. Abtew, and G. B. Senay; Elsevier, New York, ISBN-9780128159989[7].

Rangwala, I., Smith, L.L., Senay, G., Barsugli, J., Kagone, S., and Hobbins, M. (2019). Landscape Evaporative Response Index (LERI): A high resolution monitoring and assessment of evapotranspiration across the Contiguous United States. ScienceBase, https://doi.org/10.21429/43r4-3q68

[5] https://www.fs.fed.us/psw/cirmount/publications/pdf/Mtn_Views_dec_18.pdf
[6] https://doi.org/10.21429/C9704J
[7] https://www.elsevier.com/books/extreme-hydrology-and-climate-variability/melesse/978-0-12-815998-9

Lyon N. J., D. M. Debinski and I. Rangwala. (2019). Evaluating the Utility of Species Distribution Models in Informing Climate Change-Resilient Grassland Restoration Strategy. Frontiers in Ecology and Evolution. https://doi.org/10.3389/fevo.2019.00033

Buono P., I. Rangwala, R. Rondeau and M. Bidwell (2018). Identifying Climate Refugia in the Spruce-Fir Ecosystem: Connecting Modeling Outputs with Field Characteristics and Managers' Needs in the Upper Gunnison Basin. Mountain Views, Vol. 12(2), Dec. 2018, pg 6-10. https://www.fs.fed.us/psw/cirmount/publications/pdf/Mtn_Views_dec_18.pdf

Rangwala I. and C. Dewes (2018). Downscaled climate projections at 800m spatial resolution for the north central United States based on the Multivariate Adaptive Constructed Analog (MACA) method from selective CMIP5 models. ScienceBase, https://doi.org/10.21429/C9704J

The Nature Conservancy (2018). Colorado Climate Impacts and Opportunities. Final Report. November 2018.

7. Presentations

Rangwala I., Smith L.L., Senay G., Barsugli, J., Kagone S. and Hobbins M. (September 24, 2018). Landscape Evaporative Response Index (LERI): High-resolution monitoring of evapotranspiration across the Contiguous US. NOAA NIDIS Brown Bag. https://www.esrl.noaa.gov/psd/leri/resources/LERI_Rangwala_NIDIS-BrownBag_092418_PDF.pdf

Rangwala I., Smith L.L., Senay G., Barsugli, J., Kagone S. and Hobbins M. (September 21, 2018). Landscape Evaporative Response Index (LERI): High-resolution monitoring of evapotranspiration across the Contiguous US. MtnClim 2018 Conference, Gothic, CO.

Rangwala I., (July 12, 2018). Future Climate Scenarios for the Upper Gunnison Basin. Adapting to Future Climate in the Gunnison Basin, Colorado: Opportunities, Barriers and Next Steps Workshop, Gunnison, CO.

Rangwala I., Hoell A., Perlwitz J., Wolter K., Dewes C. and Eischied J. (May 23, 2018). Did Climate Change Increase the Intensity and Likelihood of the 2017 U.S. Northern Plains Drought?16th Annual Climate Prediction Applications Science Workshop (CPASW), Fargo, ND. https://www.ag.ndsu.edu/cpasw/documents/program-pdfs/session-6/05-rangwala-cpasw18-wedsess6-npdx-updated.pdf

Rangwala I., Barsugli J., Smith L.L., Senay G., Dewes C. and Hobbins M. (May 23, 2018). High-resolution monitoring of evapotranspiration across the Contiguous US. 16th Annual Climate Prediction Applications Science Workshop (CPASW), Fargo, ND.

Dewes C., Rangwala I. and Smith L.L. (April 11, 2018). Downscaled Projections of Extremes in Evaporative Demand. Great Plains Grassland Summit, Denver, CO.

Yocum H.M. and Rangwala I. (April 11, 2018). Stakeholder Engagement and Applications for the Evaporative Demand Drought Index (EDDI). Great Plains Grassland Summit, Denver, CO.

Rangwala I. (Mar 9, 2018) Climate Change in Colorado: Past & Future. Colorado Natural Heritage Program Stakeholder Meeting, Ft. Collins, CO. (Invited) https://cnhp.colostate.edu/aboutus/meetings/cnhp-partners-meeting/

Hobbins MT, Barsugli J, Dewes C, Huntington J, Lukas J, McEvoy D, Morton C, Rangwala I, Ray A, Smith C, Wood A, and Yocum Y (Mar 25, 2018), The Evaporative Demand Drought Index (EDDI): early warning and monitoring of drought from the demand side. American Water Works Association Sustainable Water Management Conference, Seattle, WA, 25 March. (Invited)

Hobbins MT, Barsugli J, Dewes C, Huntington J, Lukas J, McEvoy D, Morton C, Rangwala I, Ray A, Smith C, Wood A, and Yocum H (Mar 14, 2018), The Evaporative Demand Drought Index (EDDI): early warning and monitoring of drought from the demand side. NOAA-Physical Sciences Division Webinar, Boulder, CO.