Annual Report 2024 for Flagship Pilot Study

North America

Assessing the Use of Regional Models in a Storyline Framework for Understanding Climate Hazards

Progress over the past year
We summarize the progress amongst the various storylines in HyperFACETS (funded by the U.S. Department of Energy).

California flooding: The storyline approach has been applied to the 1997 New Year's Atmospheric River event in California to test its sensitivity to warming using different dynamical downscaling frameworks. Specifically, Rhoades et al., (2023, 2024 in prep) have compared a regionally refined model (E3SM) to a limited area model (WRF) under various forecast lead times and at different resolutions to assess the hydrometeorological sensitivity of this design storm to thermodynamic global warming (TGW; see Figure 1). Additionally, Jones et al. (2023) have developed a dynamically downscaled TGW dataset across the conterminous U.S. that allows for many impactful meteorological events over the recent historical past to be examined in a climate change context.

Mid-Atlantic flooding: The Modeling Extreme Weather and Climate (MEWAC) Lab at Penn State University published a paper in the Journal of Hydrometeorology using a storyline framework to explore the climate impact on the 1996 mid-Atlantic floods. The event was reforecasted using a 14km version of E3SM, and additional counterfactual ensembles were generated using the same initial conditions under varying levels and spatial patterns of warming. The work found non-linear effects of surface-based hazards with warming. Since the 1996 flood resulted from rain falling onto existing snow, the flooding associated with the event (as estimated by either simulated surface runoff or river discharge) increased through approximately 1K of warming, due to increases in rainfall and surface temperature. At warmer levels (primarily +3K and above), projected flood risk decreases – while rain magnitude and surface temperature continue to increase, antecedent snowpack available to melt and release water decreases. Further, warmer temperatures lead to more permeable soil and less overland runoff. This work has been shared with various stakeholders in the mid-Atlantic region as part of the HyperFACETS project and they have noted its utility given that the 1996 event is still considered the "benchmark event" when they are forecasting rain-on-snow hazards during cool season months (see Figure 2 and Pettett and Zarzycki (2023)).

Great Plains Precipitation: Mesoscale convective systems (MCSs) account for most of the extreme precipitation in the U.S. Central Great Plains. Storyline simulations have been performed using the Weather Research and Forecasting (WRF) model at 4 km grid spacing over the U.S. to investigate the impacts of global warming on the 2015 Texas-Oklahoma flood (Feng et al. in review). The historic flood event, associated with record-breaking rainfall produced by a sequence of mesoscale convective systems (MCSs) passing over the region between 22-26 May 2015, caused 3 billion USD of damage in the region. Using the pseudo-global warming approach, simulations with

(PGW) and without (CTL) climate change perturbations added to the initial and boundary conditions of the WRF simulations show that warming strengthens the Great Plains low-level jet to transport warmer and more unstable air that fuels stronger convective storms. Future storms are characterized by wider and stronger updrafts, producing a threefold increase in extreme precipitation frequency with warming (Figure 3).

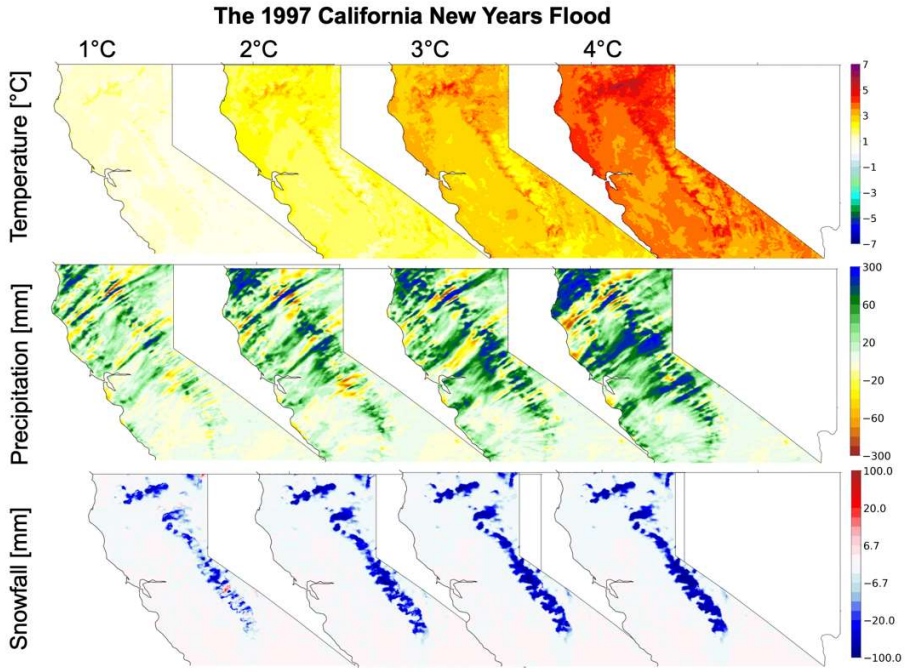

Figure 1. Changes in WRF-simulated event-mean (top) surface air temperature [°C], (middle) precipitation [mm], and (bottom) snowfall [mm] under different warming scenarios of increasing magnitude (1°, 2°, 3°, 4° from left to right).

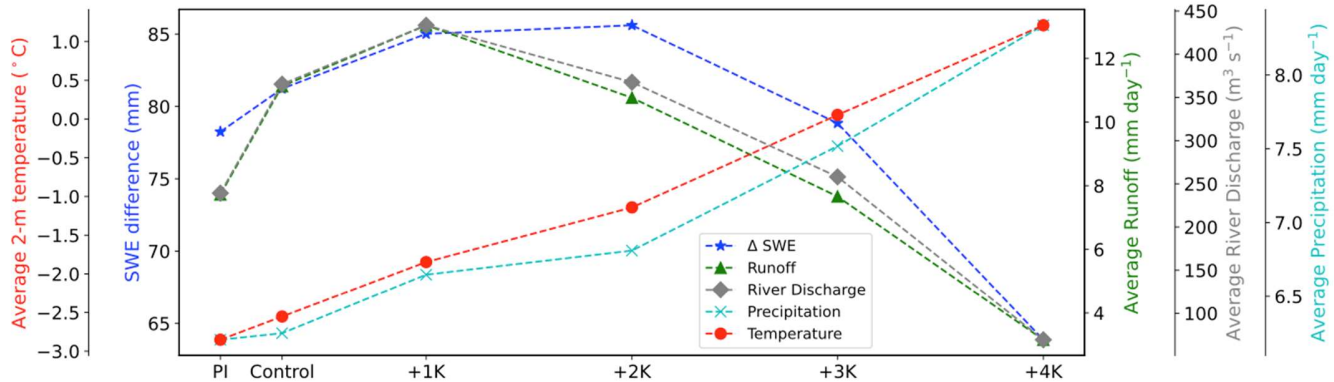

Figure 2. Trends of E3SM-simulated snowmelt (dSWE), runoff, river discharge, precipitation, and temperature over the Susquehanna River Basin for the 1996 flood event as a function of warming level (x-axis). Note the non-linear response in runoff and river discharge with warming even in the presence of monotonically increasing temperature and precipitation. From Pettett and Zarzycki (2023).

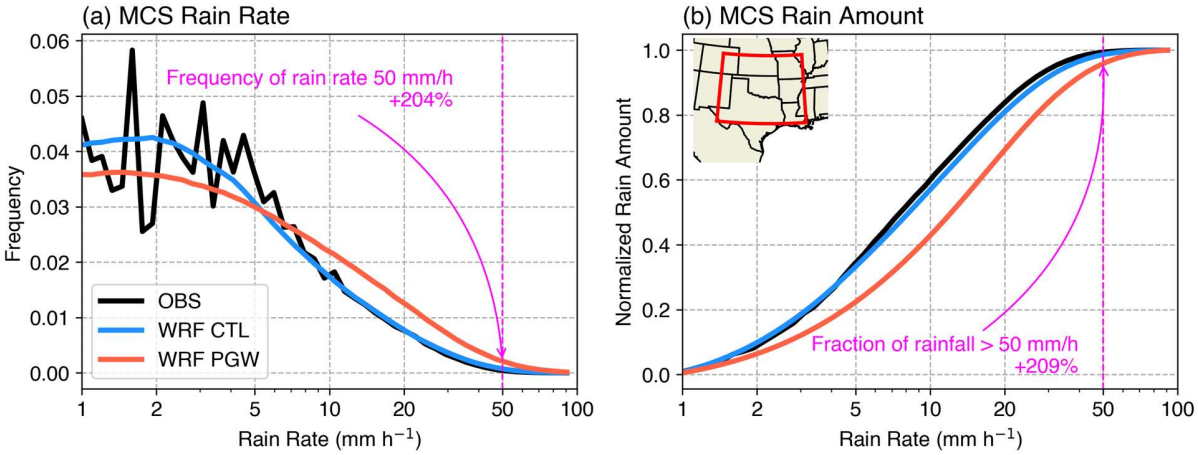

Figure 3. (a) Frequency distribution of MCS grid-point hourly rain rates, and (b) normalized cumulative distribution of rainfall amount by hourly rain rates. The frequency in (a) is calculated by dividing the histogram of rain rates by the total counts for each data source (OBS, CTL, PGW), respectively. The normalized rain amount in (b) is calculated by first multiplying the histogram counts by each rain rate bin values and subsequently divided by the total rain amount sum over all rain rate bins. The region of the data included is show in the inset.

Other Dynamical Downscaling: The UCLA Center for Climate Science has completed a 42-member dynamically downscaled ensemble of CMIP6 GCMs across the western U.S. from 1980-2100. While not CORDEX compliant, these simulations include 10 members from the CESM2 large ensemble in addition to 15 twin experiments in which one twin has its GCM boundary conditions bias corrected prior to downscaling and the other does not. These simulations comprise the Western U.S. Dynamically Downscaled Dataset (WUS-D3; Rahimi et al. 2023, in press; Rahimi et al. 2024, in revisions; Risser et al. 2024 in press). These simulations have revealed that the potential for distortionary effects on climate trends due to bias correction is minimal, setting our team up for NA-CORDEX-wide simulations which employ a simple and physically interpretable mean state bias correction to all simulations, dramatically improving historical bias, and creating more physically realistic trends.

Summary of each workshop/activity held during the year

Ullrich, McCrary, Bukovsky, Rhoades, Rahimi, U.S. Global Change Research Program Workshop on Understanding Decision-relevant Regional Climate Projections

Most HyperFACETS contributors attended the American Geophysical Union and American Meteorological Society annual meetings over the past year.

Publications during this past year

Title, journal and link to publication	Author/-s	Date
Evaluating Contemporary and Future-Scenario Substantial-Precipitation Events in the Missouri River Basin using Object-Oriented Analysis. *Climate* [DOI: 10.3390/cli11050112]	Fisel, B. J., N. E. Erickson, C. R. Young, A. L. Ellingworth	2023

	and W. J. Gutowski, Jr.,	
The 1996 Mid-Atlantic Winter Flood: Exploring Climate Risk through a Storyline Approach (https://journals.ametsoc.org/view/journals/hydr/24/12/JHM-D-22-0146.1.xml)	Pettett and Zarzycki	2023
Recreating the California New Year's Flood Event of 1997 in a Regionally Refined Earth System Model, Journal of Advances in Modeling Earth Systems, 15, e2023MS003793, https://doi.org/10.1029/2023MS003793.	Rhoades, A. M., Zarzycki, C. M., Inda-Diaz, H. A., Ombadi, M., Pasquier, U., Srivastava, A., Hatchett, B. J., Dennis, E., Heggli, A., McCrary, R., McGinnis, S., Rahimi-Esfarjani, S., Slinskey, E., Ullrich, P. A., Wehner, M., and Jones, A. D.:	2023
Continental United States climate projections based on thermodynamic modification of historical weather, Sci Data, 10, 664, https://doi.org/10.1038/s41597-023-02485-5, 2023.	Jones, A. D., Rastogi, D., Vahmani, P., Stansfield, A. M., Reed, K. A., Thurber, T., Ullrich, P. A., and Rice, J. S.:	2023
An Overview of the Western United States Dynamically Downscaled Dataset (WUS-D3), *Geosci. Mod. Dev*. In press, https://gmd.copernicus.org/preprints/gmd-2023-162/,	Rahimi, S., Huang, L., Norris, J., Hall, A., Goldenson, N., Krantz, W., Bass, B., Thackeray, C., Lin, H., Chen, D., Dennis, E., Collins, E., Lebo., J. Z., Slinskey, E., Graves, S.,	2023

	Biyani, S., and Wang B.:	
Understanding the Cascade: Removing GCM biases before improves dynamically downscaled climate projections, Geophys. Res. Lett., *in revisions*	Rahimi, S., Huang, L., Hall, A., Hall, Goldenson, N., A., Norris, J., Risser, M., Lebo, Z., Norris, J., Feldman, D., Dennis, E., and Thackeray, C.:	2023
Risser, M., Rahimi, S., Goldenson, G., Lebo, Z. J., Hall, A., and Feldman, D.: Is bias correction in dynamical downscaling defensible? *Geophys. Res. Lett.,* in press	Risser, M., Rahimi, S., Goldenson, G., Lebo, Z. J., Hall, A., and Feldman, D.:	2023

Planned Activities over the next year

MEWAC planning to develop pipelines to automate climate change storyline workflows in km-scale models. Our goal is to focus on tropical cyclones in the eastern United States that are high-impact events for water resource managers and emergency planners. William Gutowski et al. at Iowa State University plans to complete a brief paper on diagnosis of multi-year drought in the Northeast US, based on a large-ensemble simulation. Further, storyline simulations have been performed using a global model with regional refinement at 3.25 km grid spacing over the central-eastern U.S. to examine how different derecho events that occurred in the region may unfold in the future with global warming. Among 24 derecho events simulated, about half of the events are well captured by the model compared to observations. Analysis will be performed to quantify the changes in the derechos, with a goal of understanding the underlying mechanisms of the robust and distinct responses to global warming and how they may be connected to the large-scale and mesoscale environments under which the derechos develop.

New NA-CORDEX simulations: The National Science Foundation National Center for Atmospheric Research (NSF-NCAR) and the University of Wyoming are leading the effort to coordinate NA-CORDEX CMIP6 simulations in the United States. We had our initial planning meeting on February 13, 2024 with over 30 interested participants. The team at NSF-NCAR has committed to perform ~12km WRF simulations over the domain with ERA5, CanESM5, MPI-ESM1-2-LR, and CNRM-ESM2-1 forcings. Priority will be given for SSP3-7.0 in FY24. These simulations will complement those already performed by Ouranos in Canada. Other modeling groups across the U.S. have expressed interest in contributing so coordination will be ongoing. We hope to have comparable simulations performed with RegCM4 and potentially other configurations of WRF. As variable resolution modeling has been a major effort in the U.S., we will also be exploring including such simulations in our uncertainty matrix for NA-CORDEX. NCAR has also committed storage space for archiving and distributing NA-CORDEX

and there are ongoing discussions for how to link this to the ESGF and other groups have discussed providing computing resources.

Contact persons:
Colin Zarzycki: czarzycki@psu.edu
William Gutowski: gutowski@iastate.edu
Alan Rhoades: arhoades@lbl.gov
Melissa Bukovsky: melissa.bukovsky@uwyo.edu
Stefan Rahimi: srahimi@uwyo.edu
Rachel McCrary: rmccrary@ucar.edu
Andy Jones: adjones@lbl.gov
Ruby Leung: ruby.leung@pnnl.gov