Annual Report 2025 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).

Summary of each workshop/activity held during the year
2024 was a productive year for storyline-driven research in this FPS. Below, we summarize research in this arena by institution.

Pacific Northwest National Laboratory: Prior research on climate change impacts on flooding has primarily focused on changes in extreme rainfall magnitudes, often neglecting snow processes and spatiotemporal storm patterns, such as hyetograph shapes and areal reduction factors (ARFs). This study examines projected changes in extreme water available for runoff (W) events in two snow-dominated basins in the western United States: the Yakima River Basin (YRB) in Washington State and the Walker River Basin (WRB) spanning the California-Nevada border (Yan et al. 2025). WRF simulations at 6 km grid spacing for the historical (1981-2010) and future (2041-2070) periods following the storyline approach with large-scale perturbations derived from five CMIP5 models for the RCP8.5 scenario are used to drive a distributed hydrology model (DHSVM). Results suggest increased extreme W magnitudes across a large portion of the basins, with steeper or flatter hyetographs, and higher ARF values under the future climate. These changes are driven by a shift from seasonal snowmelt to more rain-on-snow events at higher elevations and by increased rainfall at lower elevations. Using a single event-based rainfall-runoff model, flood hazard changes are estimated based on extreme W magnitudes, hyetograph shapes, ARFs, and their compounded impacts. Analysis reveals that focusing solely on the magnitude of changes in extreme W can significantly underestimate future flood hazards (Figure 1). For example, ignoring future changes in spatiotemporal patterns can underestimate future flood hazards by 63% in the WRB. These results underscore the importance of incorporating spatiotemporal dynamics into future flood hazard assessments to provide a more accurate evaluation of potential impacts.

Lawrence Berkeley National Laboratory: We used a storyline approach to recreate California-Nevada's infamous flood of record, the New Year's flood event of 1997 (December 31st, 1996 to January 4th, 1997), using the regionally refined capabilities of the Energy Exascale Earth System Model (RRM-E3SM). The 1997 flood was defined as a compound flood event that resulted from the interactions between extreme precipitation, high freezing levels, abrupt snowmelt, and saturated soils. The interaction between these flood drivers resulted in heavy runoff, widespread inundation, and high-water marks set throughout the Sacramento Valley, northern-to-central Sierra Nevada, and northern Nevada. We explored how much this flood event had already been influenced by climate change and how the flood event could respond to future warming

levels. The 1997 California-Nevada New Year's flood event caused over $1B in damages, remains a water management design storm, and is referred to by HyperFACETS stakeholders as the 1-in-100-year event. We test RRM-E3SM's ability to hindcast and project the 1997 flood event in past, present, and future climates using the Betacast framework. This testing ensures that RRM-E3SM can provide value in anticipating and planning for future flood events, particularly given the changing climate and how flood drivers might differentially respond to warming (Figure 2). This study also highlights several take-home messages for water resource management and emergency planners in how the character of rain-on-snow events could change through the 21st century. The 1997 flood event was notable not only because of its atmospheric flood drivers but also because of its land-atmosphere interactions (e.g., precipitation interacting with ripened snowpack and saturated soils). We identify that the peak flood hazard potential of a 1997 flood-like event occurs at warming levels of +1.7-2.5°C from pre-industrial conditions. At this warming level, snowpack can still exist throughout the Sierra Nevada, yet is more ripened and ready to produce meltwater, and antecedent soil conditions are wetter, particularly in the central-to-southern Sierra Nevada. Additionally, we show that although storm total precipitation does not significantly differ across warming levels, more intense short-duration rainfall occurs with more warming. We also estimate that the largest flood hazards will shift from the northern to southern portions of California-Nevada, along with enhanced leeside spillover.

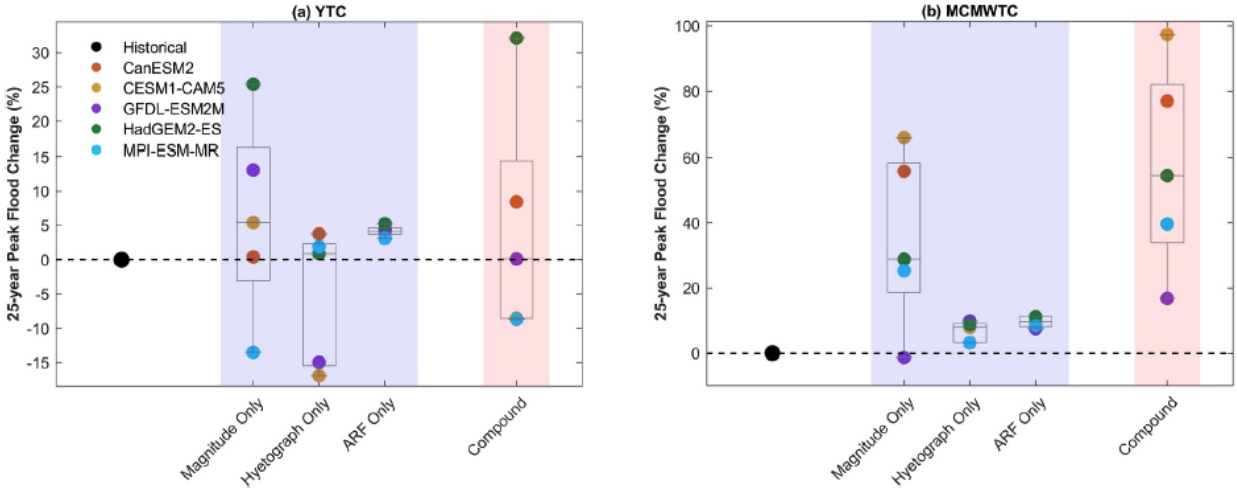

Figure 1. Estimated 25-year, 24-hr peak flood change using NG-IDF curves for the (a) DOD Yakima Training Center within the Yakima River basin and (b) DOD Marine Corps Mountain Warfare Training Center (MCMWTC) within the Walker River basin. Four projection scenarios (blue shaded and red shaded regions) are presented based: (1) solely on changes in NG-IDF curve magnitude, (2) solely on changes in W hyetograph, and (3) solely on changes in W ARF, and (4) changes in all three factors, indicating the compounded impacts. NG-IDF is next-generation intensity-duration-frequency calculated based on "total water for runoff" instead of just "rainfall". Hyetograph represents storm temporal distribution and ARF represents storm spatial distribution.

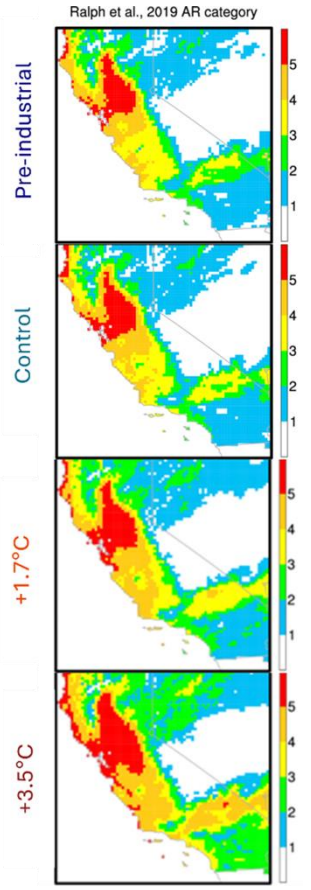

Figure 2. (left) Atmospheric River (AR) category under various scenarios for the 1997 flooding event: pre-industrial, present-day (control), +1.7°C, and +3.5°C (from top to bottom).

Iowa State University: We analyzed for a north-central U.S. region, short-term drought and agricultural heat stress during April-May-June-July, using PRISM observation and two RegCM4 simulations that used either GFDL- or MPI-GCM boundary conditions. Our analyses covered 1981-2000 and 2041-2060 (RCP 8.5). We used object-oriented analysis to identify events of interest in observations and simulations by identifying objects in a space-time domain that met specified criteria, such as exceeding a heat-stress temperature threshold. The event diagnosis allowed analysis of compound events, occurring when temperature and drought objects overlap. The observations and simulations showed similar spatial distributions of event frequencies across the analysis region, but the simulations attained this distribution by having fewer events that tend to cover larger areas compared to observed events, suggesting that the effective resolution of the simulations was coarser than their 25-km grids. Short-term drought frequency increased and heat-stress frequency decreased in transitioning to the scenario climate. When compounding occurred heat-stress events generally preceded the short-term drought events. Thus, prominent conditional behavior for storylines emerging from the work was that a heat-stress event should be a warning to watch for potential drought, as both could compound each other to more intense levels.

How intense the heat-stress, 1-day before and at start?

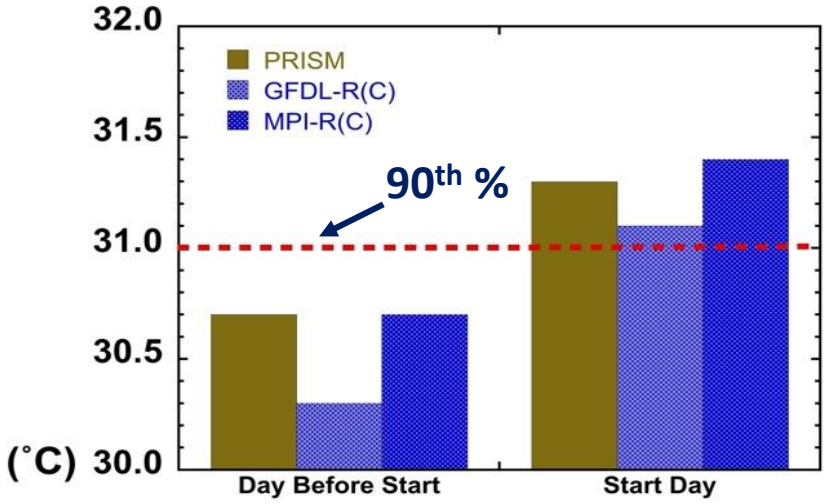

Figure 3. Median intensities of heat-stress events participating in compounding with short-term drought event, for 1 day before compounding and on the first day of compounding, for contemporary climate (1981-2000). The dashed line marks the 90th percentile of heat-stress intensities among all heat-stress events. Sources: PRISM observations and RegCM4 simulations driven by either GFDL or MPI GCMs.

National Center for Atmospheric Research (NCAR) and the University of Wyoming: RCM testing has been nearly finalized, specifically using WRF, for dynamically downscaling CMIP6 GCMs across the NA-CORDEX domain. The team has conducted dozens of year-long tests on a 12-km grid and will commence full production runs by early summer 2025. This group is also using the same workflow to support the productions of Central Asia CORDEX (CA-CORDEX) simulations which are currently being launched.

Publications during this past year

Yan, H., Z. Duan, M.S. Wigmosta, N. Sun, L.R. Leung, T.B. Thurber, E.D. Gutmann, B. Kruyt, and J.R. Arnold. 2025. "How Flood Hazards in a Warming Climate Could be Amplified by Changes in Spatiotemporal Patterns and Mechanisms of Water Available for Runoff." Earth's Future, 13, e2024EF005619, doi:10.1029/2024EF005619.

Feng, Z., X. Chen, and L.R. Leung. 2024. "How Might the May 2015 Flood in the U.S. Southern Great Plains Induced by Clustered MCSs Unfold in the Future?" J. Geophys. Res. Atmos., 129, e2023JD039605 doi:10.1029/2023JD039605.

Rhoades, Alan M., Colin M. Zarzycki, Benjamin J. Hatchett, Héctor Inda-Diaz, William J Rudisill, Benjamin Bass, Eli Dennis, et al. 2024. "Anticipating How Rain-On-Snow Events Will Change Through The 21St Century: Lessons From The 1997 New Year's Flood Event". Climate Dynamics. Springer Science and Business Media LLC. doi:10.1007/s00382-024-07351-7.

Fisel, B. J., S. Garbers, D. Haar, M. Zoerner, and W. J. Gutowski, Jr., 2024: Object-oriented analysis as a foundation for building climate storylines of compounding short-term drought and crop heat stress. *Frontiers in Climate,* https://doi.org/ 10.3389/fclim.2024.1357391.

Presentations

Gutowski, W. J., B. J. Fisel and L. S. Shenk 2024: Decision-Relevant Climate Storylines for Societal Partnerships & Climate Resilience. *Scientific Forum for Numerical Simulation of Asian Regional Climate Change and Earth System Process*, Nanjing University, October 2024. [invited keynote]

Gutowski, W., B. Fisel, A. Ellingworth, N. Erickson, E. Linde, C. Todesco and L. Shenk, 2024: Stakeholder-motivated Analyses for Building Probabilistic Climate Storylines. *HyperFACETS Project Spotlight Session*, virtual presentation, September 2024. [invited]

Gutowski, W. J., and B. J. Fisel, 2024: Projected future changes in crop heat-stress and short-term drought events. *New Frontiers in Climate Resilient Agriculture: Inference and Innovation*, Corteva Agriscience, Indianapolis, IN, June 2024. [invited]

Planned Activities over the next year

The University of Wyoming and NCAR team plan to dynamically downscaled 10 GCMs across the CA-CORDEX region in direct coordination with students and scientists spread amongst the following initiations.x

1. Kazakh British Technical University (Kazakhstan)
2. Central Asia University (Kyrgyz Republic)
3. Federal University of Itajubá (Brazil)
4. Ministry of Climate Change (Pakistan)
5. University of Reading (UK)

Contact persons:

William Gutowski: gutowski@iastate.edu
Alan Rhoades: arhoades@lbl.gov
Melissa Bukovsky: melissa.bukovsky@uwyo.edu
Bill Gutowski: gutowski@iastate.edu
Stefan Rahimi: srahimi@uwyo.edu
Rachel McCrary: rmccrary@ucar.edu
Ruby Leung: ruby.leung@pnnl.gov