Incorporating Climate Data into Emergency Planning and Exercises – A Primer for Emergency Management Practitioners and Data Developers

Christine M. Albano[1]
Maureen I. McCarthy[1]
Stephanie A. McAfee[2]
Anne M. Wein[2]
Michael D. Dettinger[1]

August 2024

Publication No. 41303

Prepared by
[1]Desert Research Institute
[2]U.S. Geological Survey

Prepared for
California Department of Water Resources

THIS PAGE INTENTIONALLY LEFT BLANK

Incorporating Climate Data into Emergency Planning and Exercises – A Primer for Emergency Management Practitioners and Data Developers

Christine M. Albano[1]
Maureen I. McCarthy[1]
Stephanie A. McAfee[2]
Anne M. Wein[2]
Michael D. Dettinger[1]

August 2024

Publication No. 41303

Prepared by
[1]Desert Research Institute
[2]U.S. Geological Survey

Prepared for
California Department of Water Resources

THIS PAGE INTENTIONALLY LEFT BLANK

ABSTRACT

Climate change has and will continue to sharpen climate-related risks to communities and natural resources in California and elsewhere, as the probabilities of more extreme weather, floods, and fires continue to increase. This poses a problem of novel situations for emergency management. Progress has been made in terms of formally incorporating climate projections, data, and research on expected changes in climate-driven hazards into long-term hazard mitigation and climate adaptation strategies at both state and national levels. However, there are fewer examples of how climate change considerations have, or could be, incorporated into shorter-term emergency preparedness and response strategies. This is an important gap to fill, as climate resilience depends not only on mitigation and prevention measures, but also on the ability of agencies to coordinate and effectively minimize impacts when prevention measures fall short.

The goal of this primer is to provide guidance on how to incorporate the best available information on climate variability and change into emergency management planning, with a focus on the development and use of extreme weather event scenarios for use in exercises. The first section is aimed toward a broad audience, including ***emergency management practitioners who use extreme weather event scenarios.*** It provides an overview of available data and tools that can inform scenario design as well as techniques for scenario design based on the hazard of interest, the audience and application, and the technical skills and resources required to develop, summarize, and/or visualize the data. This section concludes with an overview of approaches and lessons learned related to extreme event response planning and exercise design. Overall, this section highlights the advantages of developing quantitative scenarios based on spatial data, which allows visualizations and interactive data explorations that can provide greater specificity in discussions related to preparedness and response strategies. It further highlights the advantages of developing a core expert working group to guide planning, holding pre-exercise workshops to engage diverse communities outside of the emergency management sector, and engaging decision-makers post-exercise to communicate key issues and outcomes as well as potential approaches for mitigating consequences that were identified by participants.

The second section is aimed toward the ***scientific community and data developers involved in the creation of extreme weather event scenarios.*** This section provides technical guidance and detailed descriptions of four types of data resources and five analytical approaches that can be used to create extreme weather event scenarios based on the design considerations highlighted in section one. The computational resources and expertise required varies substantially across the options presented and is a primary consideration. These requirements, in addition to considerations related to audience and application, may determine the novelty and detail of the event, the detail of weather forecast information that can be provided, and the spatial extent across which the event can reasonably be modeled. The importance of, and approaches for, delivering information in a form that is accessible to emergency management practitioners is also discussed.

ACKNOWLEDGEMENTS

The authors wish to thank the many individuals who provided feedback on early drafts of this report, including Elissa Lynn, Brian Smith, Michael Anderson, and Andrew Schwarz (California Department of Water Resources), James Done (National Center for Atmospheric Research), Daniel Swain (University of California, Los Angeles), Nina Oakley (California Geological Survey), Michael Matthews (Cybersecurity and Infrastructure Security Agency), Kevin Schaller (Resiliency Partners), Julie Kalansky (Scripps Institution of Oceanography), Loney HaleyNelson (San Francisco Dept. of Emergency Management), and Alan Rhoades (Lawrence Berkeley National Laboratory). The authors also wish to thank Maria Vasquez for assistance with report production and review, and Jack Friedman (U.S. Geological Survey), Dennis Hallema, and Mariana Webb (DRI) for their reviews and suggestions that helped to improve this report. Funding was provided by the California Department of Water Resources through Scripps Institution of Oceanography under grant agreement number 4600013538.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

A@T	ARkStorm@Tahoe
AR	Atmospheric River
Core-EG	Core Expert Working Group
DHS/CISA	Department of Homeland Security Cyber and Infrastructure Security Agency
EAD	Expected Annual Damages
EEIs	Essential Elements of Information
ESS	Emergency Service Sectors
FEMA	Federal Emergency Management Agency
GCM	Global Climate Model
GIS	Geographic Information System
HSEEP	Homeland Security Exercise and Evaluation Program
NGOs	Non-governmental Organizations
NWS	National Weather Service
PSAs	Protective Security Advisors
RCM	Regional Climate Model
SWG	Stochastic Weather Generator
THIRA	Threat and Hazard Identification and Risk Assessments
TTX	Tabletop Exercise
USGS	U.S. Geological Survey
WRF	Weather Research and Forecasting

THIS PAGE INTENTIONALLY LEFT BLANK

INTRODUCTION

The goal of this primer is to provide guidance on how to incorporate the best available information on climate variability and change into emergency management planning, with a focus on development and use of extreme weather event scenarios for use in emergency response and recovery exercises.

Climate change will continue to increase climate-related risks to communities and natural resources in California and the West. The [California Climate Adaptation Strategy] outlines several priority actions involving the emergency management sector. These actions require understanding current and future hazards, risks, and vulnerabilities related to climate variability and change. The goal of this primer is to provide guidance on how to incorporate the best available information on climate variability and change into emergency management planning, with a focus on the development and use of extreme weather event scenarios for emergency preparedness, response, and recovery exercises. The use of extreme weather event scenarios is emphasized here, in recognition that climate data comes in multiple forms and formats, and the relevance of different types to planning and decision making can vary across phases of the emergency management life cycle (Figure 1). For example, preparation and response strategies that are tactical or operational in nature may benefit from using individual extreme weather event scenarios and exploration of impacts to help planners identify unanticipated points of failure and potential mitigation actions. In contrast, information on historical and anticipated future frequencies and severities of climate-driven hazards and impacts can be more informative for hazard mitigation and climate adaptation strategies that involve long-term infrastructure and land use planning (Cal OES, 2018, 2020).

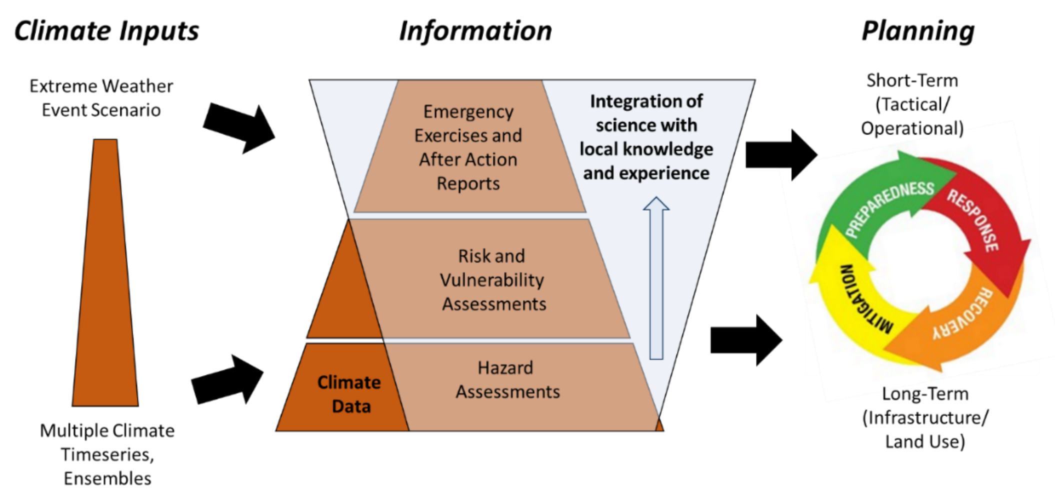

Figure 1. Climate data and local knowledge contribute to planning at different phases within the emergency management lifecycle. For recovery and hazard mitigation phases, climate data ensembles capture a wide range of uncertainty that are useful for hazard mitigation, infrastructure, and land use planning. While this information is integrated into preparedness and response phases, detailed extreme weather event scenarios and local knowledge are needed for emergency exercises to provide the resolution and expertise needed to identify improvements to tactical and operational planning.

The California Climate Adaptation Strategy, Hazard Mitigation Plan (CalOES, 2018), and Climate Adaptation Planning Guide (CalOES, 2020) demonstrate the progress that has already been made in terms of formally incorporating climate projections, data, and research on expected changes in climate-driven hazards into long-term hazard mitigation and climate adaptation strategies at both state and national levels. However, there are fewer examples of how climate change considerations have, or could be, incorporated into shorter-term emergency preparedness and response strategies. This primer identifies ways to use extreme weather event scenarios to fill this gap, as climate resilience depends not only on mitigation and prevention measures, but also on the ability of agencies to coordinate and effectively minimize impacts when prevention measures fail.

EXTREME WEATHER EVENT SCENARIOS

Extreme weather event scenarios can range from qualitative narrative descriptions of the event and its impacts to quantitative depictions using data derived from maps and/or models. The focus in this document is on the use of climate data (e.g., temperature, precipitation, wind) to create the latter, more quantitative type of scenarios. While this level of detail may initially take more effort to develop , there are several advantages, including the ability to 1) feed extreme weather event scenarios derived from climate data into hydrologic, hydraulic, ecological, or fire models to characterize secondary or cascading hazards and impacts that are otherwise difficult to anticipate, 2) readily overlay climate and/or secondary hazard data with key facilities, lifelines, or infrastructure and populations to characterize and quantify impacts, and 3) create engaging maps and visualizations that are plausible and are similar to information that would be available during an actual event. All of these enable realistic specificity in discussions related to preparedness and response strategies. This is especially the case when accounting for climate change is an objective, as impacts will likely exceed those previously experienced by emergency management personnel. In this case, visualizations of hazards and impacts based on conditions that are outside the historically observed record provide an opportunity to stretch participants' conceptions of potential impacts beyond what they have experienced in the past or are familiar with, while also being grounded in best available science.

> *Scenarios that are developed from spatial data enable visualizations of how the timing and locations of impacts might play out. This can help provide greater specificity in discussions related to preparedness and response strategies. This can be especially helpful when accounting for climate change is an objective, as visualizations may help to stretch participants' conceptions of impacts beyond what they have experienced in the past.*

PRIMER ORGANIZATION

This document consists of two main sections. The first is aimed toward a broad audience, including ***emergency management practitioners who use extreme weather event scenarios*.** This section provides an overview of extreme weather event scenario design including available climate data sources and considerations for their use based on the hazard of interest, the audience and application, and the technical skills and resources required to develop, summarize, and/or visualize the data. This section also includes an overview of approaches and lessons learned for using the extreme weather event to engage diverse communities in response planning and exercise design. The second section is aimed toward the ***scientific community and data developers involved in the creation of extreme weather event scenarios.*** This section provides technical guidance and detailed descriptions of data resources and analytical approaches that can be used to create extreme weather event scenarios for use in emergency response and recovery exercises. It also provides recommendations on how to deliver these data in a form that is accessible to emergency management practitioners.

GUIDANCE FOR PRACTITIONERS

READILY AVAILABLE DATA FOR USE IN EMERGENCY PLANNING AND EXERCISES

A few extreme weather event scenario datasets providing a basis for emergency management and exercise planning are currently available (Table 1). Use of these datasets requires expertise in processing and managing multi-dimensional meteorological data, which are commonly in the form of NetCDF files. In addition to extreme weather event scenarios, datasets developed for climate vulnerability, risk, and hazard assessments can provide insights and visuals that are useful for exploring and discussing infrastructure and population vulnerabilities, utility and transportation infrastructure interdependencies, critical resources and facilities, and functionalities and restorations of services. These are increasingly available as GIS layers or online mapping platforms that can be overlayed with population and infrastructure data (Table 2). Included are many new resources that can be used to characterize impacts to underserved or vulnerable communities that may have been omitted in past emergency planning. These data and resources provide a convenient way to spatially integrate climate and hazard information with local conditions and experience, which is valuable for emergency exercise design. Facilitating these discussions across emergency service sectors (ESS) and geographies could improve information sharing, communication, and coordination among land use, community, emergency management, health, business, and other domains. As part of these discussions, determining the sources and formats of data is important for interagency collaboration. Table 2 summarizes a selection of currently available datasets that may be useful for hazard, risk, and vulnerability discussions with community members concerned about impacts from inland and coastal flooding, wildfires, elevated streamflows, droughts, landslides, and multi-hazard events.

DESIGN CONSIDERATIONS FOR CUSTOMIZED EXTREME WEATHER EVENT SCENARIOS

Multiple data sources and analytical techniques are available for creating a customized extreme weather event scenario. Choices about which to use depend on the climate hazard of interest and how its impacts are expected to affect communities, the scope and scale (i.e., local to national) of impacts to be explored, the data needed to reasonably represent impacts, as well as the community members involved and resources available to develop the scenario. An overview of considerations related to the design, development, and use of a customized extreme weather event scenario is provided below, including the data and resources that may be required to create a realistic quantitative simulation of the climate hazard of interest. Technical details on data sources and analytical techniques for scenario creation are included in the Guidance for Data Developers section.

Table 1. Existing, 'off-the-shelf' extreme weather event scenarios that could be used for emergency response exercises.

Weather Event Type	Name	Extent	Source/Reference
Drought (5- year)	California's Drought of the Future	CA-wide	Ullrich *et al.*, 2018; https://zenodo.org/record/1340744
Extreme Winter Storm (23-day)	ARkStorm	CA-wide	Porter et al., 2011 https://pubs.usgs.gov/publication/ofr20101312
Extreme Winter Storm (30-day)	ARkStorm 2.0	CA-wide	Huang and Swain, 2021 https://www.designsafe-ci.org/data/browser/public/designsafe.storage.published/PRJ-3499
Extreme Winter Storm	1997 New Years Storm under Climate Change	CA/NV	Rhoades *et al.*, 2023, 2024 https://portal.nersc.gov/archive/home/a/arhoades/Shared/www/California_New_Years_Flood_1997

The resources required to create a customized extreme weather event scenario can vary substantially. At a minimum, a baseline level of expertise in processing and managing multi-dimensional meteorological data is required. In the simplest cases, existing data could be adjusted to create a more extreme version of a historical event and may take on the order of a month to create. A more complex or novel scenario that involves atmospheric, hydraulic, hydrologic, or other detailed simulations could require considerably more time, resources, and expertise to develop and could take well over a year.

Climate Hazard of Interest

Choice of the climate hazard of interest will be influenced by broader considerations related to exercise goals and objectives (HSEEP, 2020), such as testing emergency plans. Choices can also be informed by the best available science describing changing hazard profiles with climate change for a given region. This type of information can be such found in resources such as the National Climate Assessment, the California Climate Change Assessment or local, regional, and national Threat and Hazard Identification and Risk Assessments (THIRA). Within California, adaptation strategies for extended droughts, extreme wildfires, flooding, long-duration heatwaves, and climate-driven sea level rise are of particular concern, but the importance of these varies regionally (California Climate Adaptation Strategy, 2021) and may also differ among different types of emergency managers.

Scope and Scale of the Event

The scale of the region impacted (i.e., spatial extent) and the locations where the most severe impacts are expected to occur can influence the type of data needed to simulate the extreme weather event. While some data types like weather station observations can be useful when the focus is on local impacts (e.g., a community or small watershed), they may be less applicable if the scenario is intended to focus on a larger (e.g., state or regional) area because incorporating a sufficient number of representative point observations may be impossible, or the scope of data and analysis needed may outstrip available resources. Data sources that characterize the extreme weather event over broad areas will be required when the exercise is intended to test coordination across multiple jurisdictions or assess impacts related to accessibility of external resources relative to the community of interest. In this case, gridded (i.e., map-based) datasets likely have greater utility and can be used more readily.

Timing and Antecedent Conditions of the Event

Event timing, antecedent conditions (e.g., dry or wet soils, vegetation (fuel) status, high severity fire scars, full reservoirs), or sequencing (e.g., Figure 2) can influence the magnitude or spatial extent of impacts, as well as the probability of compound events. With or without climate change, these may differ from past events in ways that could magnify the consequences. Incorporating expected future changes in hazard interactions into exercise scenarios is one strategy for adapting emergency response activities to climate change. For example, expected increases in post-fire flood and debris flow hazards with climate change may be addressed using a scenario depicting an extreme winter storm following an extreme wildfire season. Similarly, increased risks to human life and health due to extreme heat and air pollution due to wildfire could be addressed using a scenario involving the co-occurrence of extreme heat and wildfire.

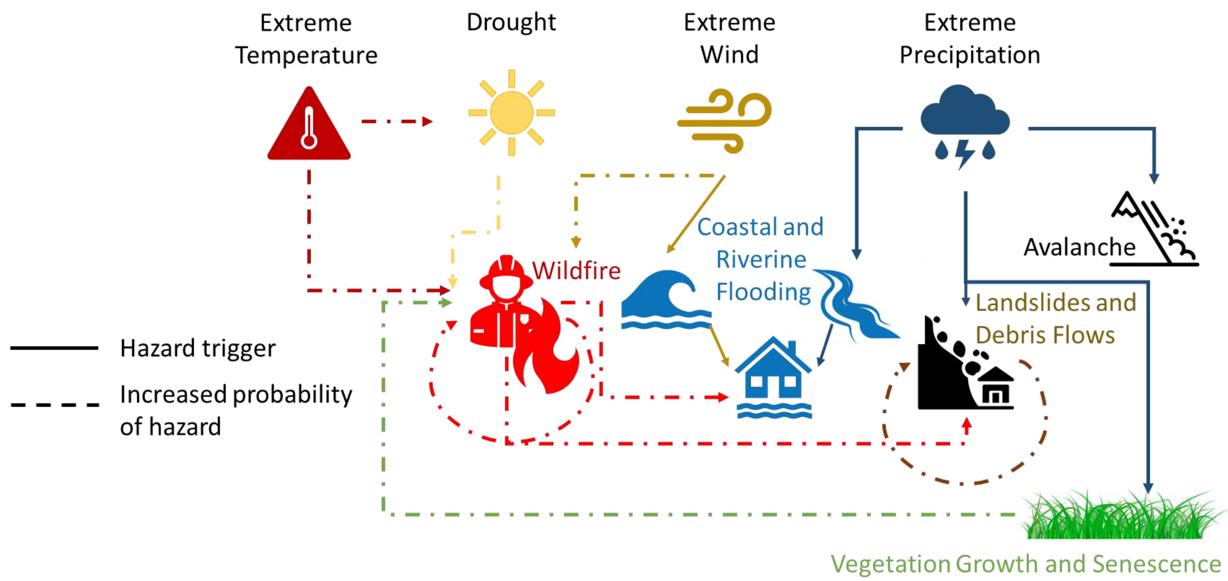

Figure 2. Compound natural hazard event linkages to consider for exercise scenarios. Extreme precipitation can act as a direct trigger for flooding, landslides or debris flows, avalanches, and vegetation growth, while factors such as increased fuels (due to vegetation growth), wind, temperature, and drought conditions indirectly increase the probability of wildfire, which is triggered by an ignition.

Table 2. Hazard, Risk, and Vulnerability Datasets and Tools.

Source	Hazard or Data Type	Name	Link	Spatial Extent	Infrastructure/ population overlays
Current/Real-time/Historically Based Hazard, Vulnerability and Risk Maps					
California Department of Water Resources	flood	Flood Emergency Response Information Exchange	https://ferix.water.ca.gov/webapp/home.jsp	CA	Flood infrastructure
U.S. Geological Survey	Streamflow, flood, drought	WaterWatch	https://waterwatch.usgs.gov/index.php?id=ww	CONUS	
U.S. Department of Agriculture	wildfire	Wildfire Risk to Communities	https://www.fs.usda.gov/rds/archive/Catalog/RDS-2020-0016	CONUS	Social vulnerability and homes
Office of the State Fire Marshall	wildfire	Fire Hazard Severity Zones in State Responsibility Area	https://osfm.fire.ca.gov/divisions/community-wildfire-preparedness-and-mitigation/wildfire-preparedness/fire-hazard-severity-zones/	CA	
U.S. Geological Survey	wildfire	Wildland Fire Trends Tool	https://www.usgs.gov/centers/forest-and-rangeland-ecosystem-science-center/science/wildland-fire-trends-tool	Western U.S.	Ecosystems
U.S. Geological Survey	wildfire	Fire Danger Forecast Viewer	https://firedanger.cr.usgs.gov/viewer/index.html	CONUS	
California Geological Survey	geologic	Landslide Inventory and Deep Landslide Susceptibility Map	https://maps.conservation.ca.gov/cgs/lsi/	CA	
	geologic	Recent Fire and Landslide Susceptibility	https://maps.conservation.ca.gov/cgs/firelandslide/	CA	
U.S. Geological Survey	geologic	Emergency Assessment of Post-Fire Debris-Flow Hazards	https://usgs.maps.arcgis.com/apps/dashboards/c09fa874362e48a9afe79432f2efe6fe	CONUS	
U.S. Global Change Research Program (USGCRP)	multi-hazard	Climate Mapping for Resilience and Adaptation	https://livingatlas.arcgis.com/assessment-tool/search	CONUS	Community status, building codes hazard resistance, population

Table 2. Hazard, Risk, and Vulnerability Datasets and Tools (continued).

Source	Hazard or Data Type	Name	Link	Spatial Extent	Infrastructure/ population overlays
U.S. Geological Survey	multi-hazard	Hazards Data Distribution System	https://hddsexplorer.usgs.gov/	Global	
FEMA	multi-hazard	Resilience Analysis and Planning Tool	https://fema.maps.arcgis.com/apps/webappviewer/index.html?id=90c0c996a5e242a79345cdbc5f758fc6	CONUS	Population indicators, infrastructure, public ArcGIS Online resources
FEMA	multi-hazard	National Risk Index	https://hazards.fema.gov/nri/map	CONUS	Expected annual economic loss, social vulnerability, community resilience
California Office of Emergency Services	multi-hazard	MyPlan	https://www.myplan.caloes.ca.gov/	CA	
Governor's Office of Planning and Research	multi-hazard	OPR General Plan Guidelines Tool	https://maps.gis.ca.gov/cageneralplan/map.aspx	CA	Administrative boundaries, circulation, land use, health
California Office of Environmental Health Hazard Assessment	pollution	CalEnviroScreen 4.0	https://oehha.ca.gov/calenviroscreen/report/calenviroscreen-40	CA	Population characteristics
Headwaters Economics	emergency response capacity	Rural Capacity Map	https://headwaterseconomics.org/equity/rural-capacity-map/	CONUS	
Future Projection Based Maps					
California State Lands Commission	coastal flooding	Sea Level Rise Viewer	https://cslc.maps.arcgis.com/apps/webappviewer/index.html?id=9d545ba8f5b446aaa32596b97d0e7ee6	CA	Critical infrastructure, population vulnerability, sensitive habitats
U.S. Geological Survey	coastal flooding	Hazard Exposure and Reporting Analytics (HERA)	https://www.usgs.gov/apps/hera/	CONUS	Population, economy, land type, infrastructure, critical facilities
Cal-Adapt	coastal flooding	Projected water levels with sea level rise – coastal inundation scenarios	https://cal-adapt.org/tools/slr-coastal-inundation	CA	

Table 2. Hazard, Risk, and Vulnerability Datasets and Tools (continued).

Source	Hazard or Data Type	Name	Link	Spatial Extent	Infrastructure/ population overlays
	wildfire	Projected wildfire likelihood and area burned	https://cal-adapt.org/tools/wildfire	CA	
	flood	Projected monthly streamflows	https://cal-adapt.org/tools/streamflow	CA	
California Natural Resources Agency	heat	California Heat Assessment Tool	https://www.cal-heat.org/explore	CA	Vulnerability indicators
California Department of Public Health	multi-hazard	Climate Change & Health Vulnerability Indicators	https://skylab.cdph.ca.gov/CCHVIz/	CA	Population sensitivity, adaptive capacity
RAND Corporation	multi-hazard	California Emergency Response Infrastructure Climate Vulnerability Tool	https://public.tableau.com/app/profile/rand4185/viz/CJ302-1000_CERI-Climate_20180625/Title	CA	Emergency response critical infrastructure
U.S. Global Change Research Program (USGCRP)	multi-hazard	Climate Mapping for Resilience and Adaptation	https://livingatlas.arcgis.com/assessment-tool/search	CONUS	Community status, building codes hazard resistance, population

Climate Variables Needed to Represent the Extreme Weather Event and its Impacts

Exercises focused on hazards caused by extreme precipitation intensities such as flooding, flash flooding, or post-fire debris flows typically require shorter duration data including sub-daily or even sub-hourly precipitation data (Figure 3). For fire, variables such as wind, solar radiation, and humidity are also needed. These requirements constrain the data sources that can be used, as many available data sources are at daily or coarser resolution and/or do not include all relevant variables (See Table 4 in Guidance for Data Developers section). In contrast, longer-duration scenarios that are focused on extreme heat or extended drought may not require high temporal resolution and can be represented with temperature and precipitation variables, opening options to use data from a broader set sources. Spatial resolution may also need to be considered and may be a limiting factor in locations with complex terrain, where finer spatial resolution (e.g., on the order of a few km or less) is needed to reasonably capture sharp gradients in temperature, precipitation, or other meteorological variables of interest. Finer spatial and temporal resolution data require more computational resources to process, but are becoming increasingly available (See Table 4 in Guidance for Data Developers section).

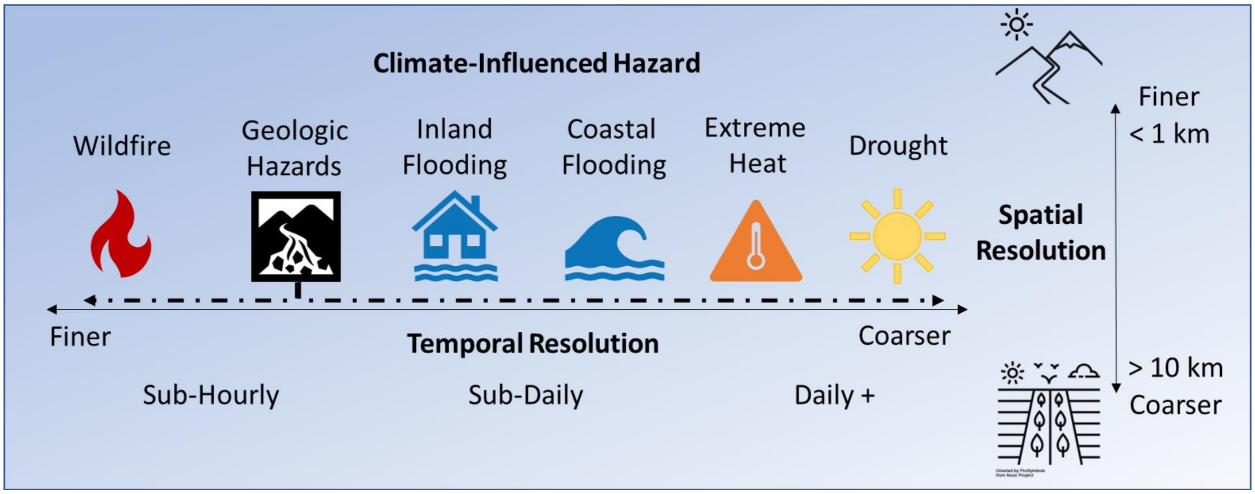

Figure 3. Climate data considerations for creating extreme weather event scenarios. Finer temporal resolution data are needed to reasonably simulate extreme weather scenarios for fire, some types of geologic hazards (e.g., debris flows), and flooding. Finer spatial resolution may also be needed to simulate extreme weather in more complex terrain.

Consider the Audience

The level of expertise, personal experiences with extreme weather events, and familiarity with climate science of exercise participants is worth considering when selecting data sources for scenario creation. For example, scenarios drawn from end-of-century climate change projections may not be accepted by all participants, even if scientific evidence suggests that they are climatologically plausible in the near term. In these cases, modifying historical events to reflect observed trends in climate (e.g., increasing the temperature profile to match climate projections) or using paleoclimatic variability information may foster more productive engagement. In cases where climate change considerations are a focus, climate projections may be the preferred option, as these represent the best available knowledge on potential climate futures. In cases where there is a desire to present novel conditions that could challenge participants in unexpected ways, using paleoclimate or future climate projections provides opportunities to look at more challenging or novel “worst-case” scenarios that are unlikely to have been captured in the contemporary climate record.

Consider Available Resources

The availability of resources (i.e., data, models, and technical expertise) to develop the extreme weather event scenario and assess its consequences is an important and overarching determinant of what data sources and analytical approaches can be used, and several tradeoffs exist. Several readily available datasets cover the entire state and region at spatial resolutions that reasonably capture variations across elevational gradients (e.g., 1-6 km) but are generally at daily or monthly temporal resolutions that are too coarse to represent some types of extreme weather events. In recent years, datasets that are more suitable for emergency planning for the types of extreme weather event scenarios that require fine temporal resolution (sub-hourly to sub-daily, see Figure 3) have become increasingly available, making them excellent choices if the resources and expertise for processing and managing these datasets are available. Similarly, extreme weather events could potentially be extracted from climate and impact datasets that were developed for longer term planning and risk analysis (e.g., Decision Scaling), offering opportunity to explore their implications for both short and long-term emergency management using common data and scenarios. Analytical techniques for creating extreme weather event scenarios are discussed in detail in the Guidance for Data Developers section. They generally involve either modifying historical events to reflect trends in climate or creating entirely novel events using climate projections or synthetic data (Figure 4). Simplest and least resource intensive approaches involve **Splicing** together multiple historical events in ways that compound hazards, increase duration, or increase severity by changing the antecedent conditions leading up to the event (e.g., dry or wet soils, vegetation (fuel) status, high severity fire scars, full reservoirs) using readily available data. Similarly, several approaches exist for **incrementally adjusting** a historical event to make it hotter, wetter, or drier, and these can range from relatively simple to more complex, depending on the need to accurately simulate weather dynamics. Creating novel events by **mining** downscaled future climate projections, weather forecast ensembles, or simulations of impacts (i.e., **Scenario Discovery**; Figure 4) can challenge participants to consider impacts outside of the norm of historical experiences and are a good choice if resources are available.

Incremental adjustments to meteorological variables or splicing readily available historical data are among the simplest and least resource intensive approaches for creating an extreme weather event scenario. Creating novel events by mining downscaled future climate projections, weather forecast ensembles, or simulations of impacts (i.e., Scenario Discovery) can challenge participants to consider impacts outside the norm and are good choices if resources are available.

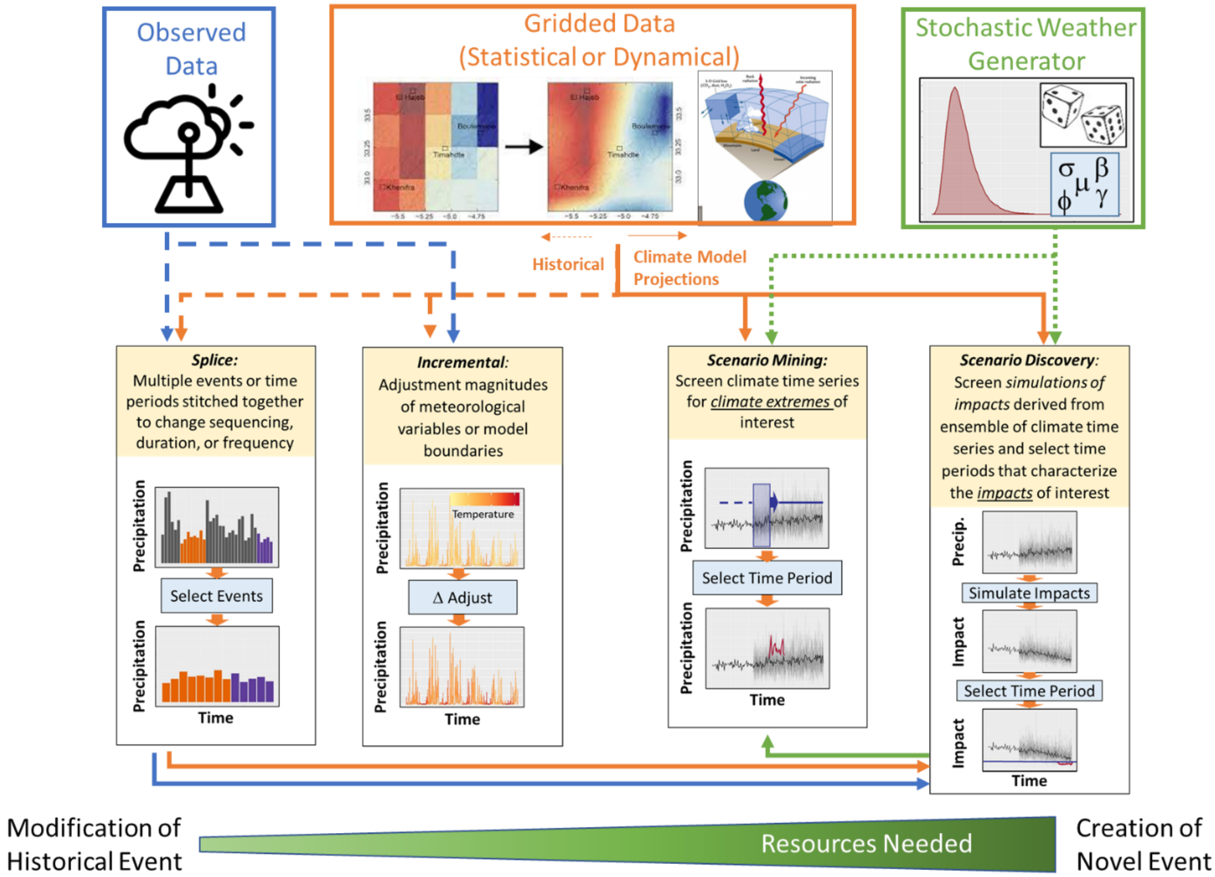

Figure 4. Analytical methods for creating extreme weather event scenarios, connections to data sources, and the general gradient of resources needed (time, money, expertise) associated with each method. See Guidance for Data Developers section for technical details.

Community Engagement in Emergency Planning and Exercise Design

Integration of local knowledge through community engagement using a scenario that represents a plausible threat is critical for helping communities update existing emergency response plans to incorporate a new level of climate-driven impacts, synchronize plans among many partners, and, when appropriate, support emergency response exercise design. Inclusive community engagement allows diverse participants to evaluate response capabilities and plans, practice coordination and communications, familiarize themselves with procedures and protocols, and identify potential impact mitigation or adaptation actions. Early acceptance ("buy-in") of the extreme weather event scenario is important to keep participants engaged through a process that may appear too overwhelming to contemplate, e.g., worst case scenarios for which there are few viable options for local response and recovery. Soliciting input from participants throughout the process can facilitate this early acceptance and ensures the scenario is developed in ways that address community concerns and support emergency management objectives related to different phases of the emergency management lifecycle, including preparedness, response, and recovery.

Given the inherent long duration of some types of extremes (e.g., a storm sequence lasting days to weeks) and a widespread geographical area impacted, scenarios designed to test community preparedness during and after these events, are usually best suited for use indiscussion-based exercises that are designed to validate plans, policies, procedures and agreements; clarify roles and responsibilities; and identify resource gaps. Elements of these plans, if they are well-developed, may also be tested in operations-based exercises that include testing real-time actions and communications, personnel deployment, evacuations, and/or other urgent community-based actions. Extreme weather scenarios are also well-suited for use in educational seminars, workshops designed to stimulate coordination and synchronization among community plans, and cross-sector tabletop exercises (TTX) that are designed to test communications and coordination on a regional scale. FEMA's Homeland Security Exercise and Evaluation Program (HSEEP, 2020) provides extensive guidance on preparedness planning and exercise design.

The USGS-sponsored ARkStorm@Tahoe Project provides an example of how these types of scenarios have been used in discussion-based exercises. This project used a historically modified extreme storm scenario to stimulate preparedness discussions, response plan updates, and cross-sector coordination in response to extreme snow and rain-on-snow induced flooding in the communities around Lake Tahoe and downstream in Reno, Carson City, and the surrounding region. The ARkStorm@Tahoe Project Report (Albano *et al.*, 2015) provides a detailed description of the design and outcomes of community workshops and a regional tabletop exercise that involved participants from California, Nevada, and Utah.

A key component of the ARkStorm@Tahoe project was the establishment of a Core Expert Working Group (Core-EG) comprised of emergency manager experts and others who had established and trusted relationships in their communities. This was an essential first step for reaching broad, diverse, and representative community members. Engaging the Core-EG group in extreme weather event scenario design, after-action reporting, and the development of resilience action plans provided opportunities for a wide range of community members to participate in complex, multi-hazard event discussions.

As described in the ARkStorm@Tahoe project feature, broad engagement with diverse participants in pre-exercise workshops enabled local knowledge and concerns to be integrated into exercises as 'injects', sub-events within the exercise that were intended to challenge participants and test capabilities. Beyond this, pre-exercise workshops provided an opportunity to share best available science related to the focal climate hazards, identify additional science needs, and identify broader issues related to longer-term adaptation and mitigation planning that were not explicitly addressed in the exercise.

Pre-exercise workshops provide an opportunity to share best available science on focal climate hazards, identify additional science needs, and identify broader issues related to longer-term adaptation and mitigation planning that may not be addressed in the exercise.

ARkStorm@Tahoe

One example of integrating local knowledge building up to an exercise is the ARkStorm@Tahoe (A@T) project (Albano *et al.*, 2015, 2016), which took place in 2013-2014. The project engaged local water and environmental resource managers, emergency responders and managers, private sector infrastructure providers, and other groups from mountain communities in California and Nevada around Lake Tahoe and the leeside urban and rural areas in and around Reno/Sparks, Carson City, and the Washoe valley in northwestern Nevada. The A@T project demonstrated the value of a ground-up (rather than top-down) approach for engaging communities in extreme Atmospheric River (AR) scenario planning prior to conducting larger regional-scale events or exercises. Focused workshops that reviewed the scenario and sought input from community-based or sector-specific groups provided opportunities for these groups to recognize their vulnerabilities and stakes in the scenario and enhanced participation in the regional exercise. It also surfaced local and sector-specific impacts that could have regional and national consequences that served as the basis developing regional-scale exercise injects.

The A@T project included a tabletop exercise (TTX) that was structured to force cross-sector communications and collective problem solving. Representatives from different sectors were seated together and given time to respond to exercise injects as a group. Injects included mock weather forecasts developed by NWS meteorologists at several points during the 23-day extreme event scenario that reflected uncertainties in predicting AR landfall location, storm intensity and duration, snow vs. rain levels at higher elevations, and anticipated flooding. Simulated flood maps that showed impacts of the AR scenario compared to recent historical storms provided immediate context to emergency responders and infrastructure operators to assess risks and evaluate the adequacy and capacity of their response capabilities at several points during and following the AR event.

Injects developed from information provided by the participants demonstrated how local impacts can very quickly have regional consequences; these included issues such as, infrastructure workers prevented from returning to their job sites due to flooding, avalanches, and landslides on mountain roadways or lack of credentials to access restricted areas, wastewater failures due to overtopped storm sewers, downstream transport of environmental contaminants into underserved communities, Major resource outlets (e.g., Walmart) taken off-line due to storm damage, mountain communities and vulnerable residents cut-off and isolated without access to potable water, energy, and/or food during extreme winter conditions, cloud-server facility failures in the area impacting emergency responder access to critical data and national communications, critical military assets relocated from California to Nevada during the early days of the storm that are then at risk as the AR series progresses, state and national response resources already tied up due to concurrent emergencies.

Establishing a Core Expert Working Group

Engaging the Core-EG is important for optimizing the utility of extreme weather event scenarios for the emergency management community and for incorporating broad perspectives into exercise design, adaptation, and mitigation strategies. Drawing on findings from A@T and recent interviews with project partners, engaging representatives from the following groups can help bridge local to regional emergency response planning challenges, recognizing that an expanded group of representatives is needed to support exercises that are more focused on recovery:

- Federal agency representatives in the region with extensive networks including, Protective Security Advisors (PSAs) from Department of Homeland Security Cyber and Infrastructure Security Agency (DHS/CISA)
- National Weather Service emergency communications directors with established networks of local public and private emergency responders
- Intertribal emergency management coordinators
- State and local Emergency Managers and National Guard emergency response leaders
- Tribal entities and community-based organizations in underserved communities
- Water and wastewater purveyors and energy providers
- Transportation sector managers
- Private sector leaders integral to logistics supply chains and other key resources
- Federal, Tribal, and state dam and reservoir operators and Federal Water Masters
- Environmental agency and NGOs with responsibility for threatened/endangered species protection, wetlands, and other critical natural resources
- Emergency medicine and public health practitioners

Engagement with a Core-EG can be especially important for regional-scale emergency management exercises. These take more resources to conduct and are less frequent, which can hinder the development of comprehensive plans to prepare for, respond to, and recover from extreme climate-driven hazards. Moreover, how extreme event impacts vary across communities and geographies is complex, necessitating high-level guidance on the conditions under which disaster response coordination among local, state, regional, and federal command and control needs to occur.

Developing an appropriate climate change hazard event scenario and exercise includes working with the Core-EG to identify factors that challenge both immediate response and recovery, as well as longer-term resiliency. In terms of the extreme weather event scenario design, this group should be engaged to identify the exercise objectives, climate hazard of interest, the scope and scale of the event (i.e., local to regional), locations where impacts are of particular concern, and aspects of extreme events that might intensify risks. These could include the timing, duration, or sequencing in relation to other extreme conditions (e.g., high-intensity precipitation following wildfires in steep terrain), as outlined in the Climate Hazard Scenario Design section above. A proposed process for designing the relevant climate metrics based on the management issue or question at hand is described in Jagannathan *et al.* (2021). These decisions may be further informed by discussions of local considerations outlined in Table 3. Extreme event attributes that

Core-EG members identify provide the basis for hazard assessments and a framework for estimating risks and vulnerabilities to people, infrastructure, the economy, and the environment locally, and provide context for understanding how regional disruptions are manifested on a national scale.

Pre-Exercise Workshops

Information and lessons gleaned from pre-exercise workshops that engage a diversity of perspectives can provide information that is just as valuable as–and possibly quite different from -- that coming from the exercise itself. Beyond this, these discussions can help to shape the exercise by providing fodder for injects that reflect specific concerns and perspectives. An aspect of the A@T project that set this effort apart from traditional emergency response exercising planning was the engagement of participants in a series of pre-Tabletop Exercise (TTX), facilitated workshops engaging a wide range of public and private sectors and locations throughout the impacted region (Lake Tahoe, Reno/Sparks, Carson Valleys, Pyramid Lake Paiute tribal lands). In these workshops, an overview of the climate hazard scenario was presented along with map overlays of infrastructure with probabilistic or historical hazards (e.g., FEMA flood maps, 1997 flood extent in Reno).

Information and lessons gleaned from pre-exercise workshops that engage a diversity of perspectives can provide information that is just as valuable as–and possibly quite different from -- that coming from the exercise itself.

Maps provided a tangible foundation upon which to initiate discussions about participant's concerns. Comparing the scenario to a known, and relatively recent, historical event - the flood of 1997 - was particularly useful (Albano et al. 2015). Such contrasts allow participants to draw connections between the timing and magnitude of impacts of future events in the context of known historical events (Brewer, 2007; Marx *et al.*, 2007). Using a combination of datasets and visual aids of multiple hazards (e.g., avalanche zones, landslide potential, and flood inundation) encouraged emergency responders and other participants to explore aspects of A@T that they may not have considered when assessing risks of a single flood hazard. Discussions were facilitated to elicit participant perspectives on a variety of topics, including potential cascading multi-hazard risks; social, cultural, and ecological vulnerabilities; interdependencies among systems, individuals, and agencies; critical resources and functionalities that could be compromised; science, visualization, and information needs that could help participants assess risks; and proactive steps that could help mitigate impacts. Additional details on discussion points are provided in Table 3.

Based on lessons learned from the ARkStorm@Tahoe project, additional recommendations for pre-exercise workshops include: 1) employ workshop facilitators with cultural awareness to encourage inclusive participation, 2) recognize and address the importance of social, cultural, and ecological impacts as integral elements of adaptation, response, and recovery planning, and 3) ensure participant input is documented so that it can be reflected in regional exercises and future scenario designs.

Table 3. Discussion points to address with core community of practice as part of exercise and pre-exercise workshop design.

Local Considerations
Geographical areas that need to be considered especially underserved communities that may have unique socioeconomic, cultural, and governance aspects, e.g., Tribes with sovereign governments, minority communities with language or communication barriers, migrant populations without fixed addresses, groups with strong antithesis and distrust of government organizations, high-risk areas with recent and/or rapid population growth.
Variations in emergency response capabilities and resources among jurisdictions in montane, urban, foothill, and agricultural communities, availability and variations in broadband service and communication capabilities.
Critical facilities and infrastructure that may be stressed during or after the event e.g., police/fire stations, schools, water/wastewater/energy/communication supply lines, transportation hubs, medical care networks, dams/reservoirs/levees, military bases, single-source suppliers, etc. Temporary housing and shelters (locally).
Unique environments that may be stressed directly or indirectly e.g., wetlands, habitats, sanctuaries, lakes/rivers, old growth forests, etc.
Critical private sector installations that serve populations on regional to national scales e.g., Amazon/Walmart warehouses, large-scale virtual communication servers and assets, major manufacturing facilities.
Other factors that may pose secondary risks e.g., mine tailings, hazardous waste sites, recent wildfire burn scars, wastewater treatment plants adjacent to major waterways, etc.
Recent historical events such as the unrelenting storms of 2022-2023, flood events of 2017, 2005, 1997 that have significantly stressed response/recovery.
Specific attributes that made historical events extreme or catastrophic, e.g., precipitation form, duration, and rate, snow versus rain at different elevations.
Antecedent conditions that will affect response/recovery e.g., reservoir levels, ground saturation, wildfire burn area.
Regional to National Considerations
Critical supply chain disruptions in ports, manufacturing hubs, and rail depots that can cause long term recovery challenges nationally.
Critical food, water, energy, medical supplies disruptions that may impact populations centers across the country. Temporary housing and shelters (regionally).
Disruptions of law enforcement and emergency response mutual aid arrangements with states outside of the impacted areas.
Economic disruptions with regional to national consequences.
National security vulnerabilities resulting from large areas of the country focused on response and recovery.
Civil unrest resulting from prolonged impacts and inequitable or slow response/recovery from the federal government.
Loss of critical ecosystems that contribute to wildlife protection, forest health, water availability, food production, and local economies.

USE OF DATA ANALYSIS AND VISUALIZATIONS FOR THE EXERCISE

Emergency preparedness, response and recovery actions among State and Federal agencies are integrated and coordinated through a shared base Concept of Operations (e.g., CalOES, 2008) with variations depending on the nature of the incident. Intelligence and information sharing within the joint planning section of the Unified Coordination Group is focused on Essential Elements of Information (EEIs) – "critical items of information needed by the commander by a particular time to relate with other available information and intelligence to assist in reaching a logical decision". Data that are needed to derive EEIs include weather, streamflow, fire, or other relevant forecast data depending on the hazard, boundaries and access points to the disaster area, as well as population and infrastructure data within the affected area. Examples of EEIs include (FEMA, 2006):

- Lifesaving needs, such as evacuation and search and rescue.
- The status of critical infrastructure, such as transportation, utilities, communication systems, and fuel and water supplies.
- The status of critical facilities, such as police and fire stations, medical providers, shelters, schools, water and sewage treatment facilities, and media outlets.
- The risk of damage to the community (e.g., dams and levees, facilities producing or storing hazardous materials) from imminent hazards.
- The number of residents who have been displaced as a result of the event and the estimated extent of damage to their dwellings.

In the context of an exercise, realistic EEIs can be derived from simulations of extreme weather event scenarios and their impacts, from datasets that represent contemporary or potential future hazards, vulnerabilities, and/or risks (e.g., Table 2), and from pre-exercise discussions with community members (Figure 5). For example, scenario meteorology (e.g., precipitation, wind, temperature, snow) or hazard simulation outputs (e.g., flood inundation, fire spread, landslides) can be overlayed with critical infrastructure and lifelines, at key points in time for exercise play and can be used to derive damage estimates. This information provides baseline narratives and technical details useful for depicting the scenario conditions and characteristics, events allowing participants to demonstrate innovative ways to meet exercise objectives (US Dept. of Homeland Security, 2020).

Post-Exercise Engagement

Given the complexity and regional-to-national scale impacts of climate-driven extreme events, post-exercise engagement at multiple levels is essential. In addition to following up with local participants to share exercise outcomes (e.g., through After-Action reporting and evaluation; (HSEEP, 2020), it is also critical to engage industry leaders and other key decision-makers in the region. A recommendation from A@T partners is to conduct "capstone discussions" with industry C-suite representatives and key decision makers from both public and private sectors. These are typically high-level abbreviated discussions, often conducted under confidentiality assurances, focused on sharing exercise outcomes and identifying continuity of operations issues that overlay local and regional impacts. Knowledge shared during these capstone discussions (either individually or in very small groups) that spotlights multi-sector impacts for key decision makers can inform national and international logistics and continuity of operations planning, which in turn can mitigate consequences and strengthen response and early recovery, both locally and regionally.

Figure 5. Essential Elements of Information (EEIs; (FEMA, 2006)) for an exercise can be drawn from the extreme weather event scenario and any impact models it has been run through, community member concerns, and existing hazard, risk, and vulnerability assessment data (Table 2). EEIs listed here are select examples taken from the 2018 Northern California Catastrophic Flood Response Plan.

SUMMARY AND RECOMMENDATIONS FOR PRACTITIONERS

There are multiple points of entry for use of climate change information in emergency management planning. This section of the primer focuses on using extreme weather event scenarios, with an emphasis on their use for emergency response planning and exercises. In doing so, the primer outlines 1) current data resources for scenario development and impact assessments and considerations for their use, given objectives, engagement partners, and resources available and 2) recommendations for engaging diverse community members and incorporating their knowledge into exercise planning, as well as climate resiliency planning more broadly. Overall, this section highlights the advantages of developing quantitative scenarios based on spatial data, which allows visualizations and interactive data explorations that can provide greater specificity in discussions related to preparedness and response strategies. It further highlights the advantages of developing a core expert working group to guide planning, holding pre-exercise workshops to engage diverse communities outside of the emergency management sector, and engaging decision-makers post-exercise to communicate key issues and outcomes as well as potential approaches for mitigating consequences that were identified by participants. The following Guidance for Data Developers section provides detailed technical information related to potential sources of climate data and analytical techniques for primary and secondary hazard scenario creation.

GUIDANCE FOR DATA DEVELOPERS

Multiple data sources and techniques can be used to create extreme weather event scenarios. The strengths and weaknesses of these are discussed individually below, as are ways to combine these to meet exercise objectives. This section concludes with considerations for data developers on making data useful and available to the emergency management community.

DATA SOURCES AND TYPES

Data sources include **paleoclimatic reconstructions**, **historical data** (from weather stations, remote sensing, or gridded data developed from statistical interpolations of station data or dynamical weather models), **climate model projections** that have been statistically or dynamically downscaled, or synthetic timeseries derived from **stochastic weather generators** (Figure 6). These data can be combined and adjusted to create extreme weather event scenarios that are based on historical events or that represent entirely novel events derived from climate change projections or stochastic weather simulations. Importantly, characteristics of the most extreme events are likely not captured by historical records, so paleoclimate information and large ensembles of climate or weather data are especially useful for characterizing these most extreme events.

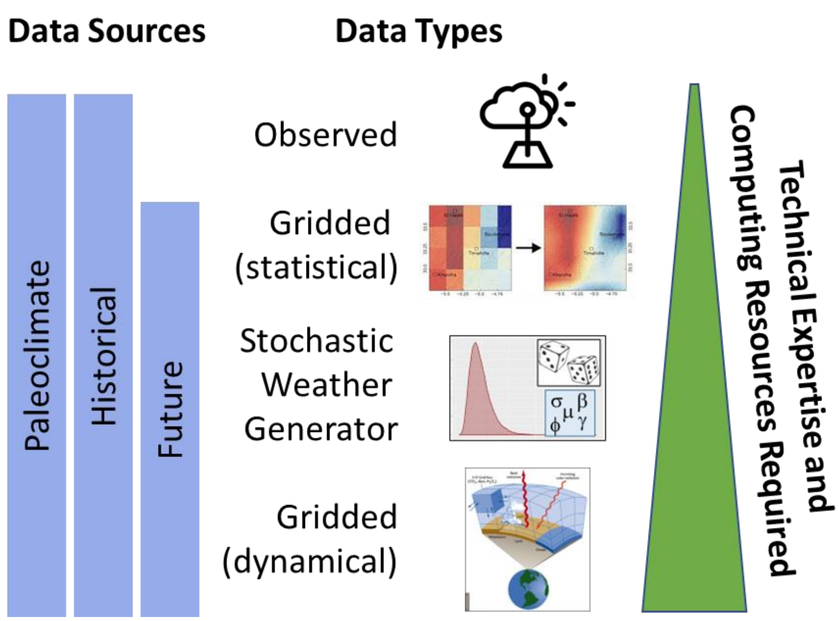

Figure 6. Data sources and types that could be used to create an extreme weather event scenario.

Historical Data

Historical climate records from weather stations, remotely sensed data, or gridded climate or weather forecast products are among the most readily available sources of climate time series (See Table 4) that can be used to construct a climate hazard scenario. One of the greatest strengths of using historical data is that scenarios can be loosely based on events that were recently experienced by, or are familiar to, exercise participants. They provide a tangible starting point for discussions of climate change risks as participants can draw from their past experiences (i.e., historical analogues) as a reference point (Ford *et al.*, 2010; Albano *et al.*, 2016) or explore plausible variations on historical extreme events using alternative weather forecast ensemble members (i.e., the 'downward counterfactual' Lin *et al.*, 2020; Rye & Boyd, 2022). For some audiences, scenarios based on familiar events or historical data are much more likely to resonate (Vasileiadou & Botzen, 2014) and be viewed as plausible (Alexander, 2000). Historical events can be modified to reflect current trends and understanding of changing climate (as described in analytical section below) and may offer the advantage that workflows for inputting datasets already exist, making them easy to use. In addition, weather and other forecast data archives are likely readily available (Table 4), which reduces the time and computation resources needed to prepare the exercise. Weather forecast ensembles that represent variations

The main disadvantage of using historical climate data to create scenarios is that observational records cover a limited time span, and thus may not capture the most extreme events, which occur less frequently. Moreover, historical datasets don't reflect novel weather sequences or conditions that may arise due to climate change. If such changes are seen in ensembles of climate model projections and are likely to challenge emergency management, other data sources (as opposed to historical) may have greater utility for exploring these aspects of climate change.

Paleoclimate Reconstructions

Paleoclimate reconstructions based on proxy data provide an alternative source for developing scenarios that are more extreme and/or novel than those available from the historical record. A variety of proxy data, such as ice or sediment cores, pollen, or biological organisms (e.g., tree rings, corals, plankton, diatoms) are available (See Table 4). These can be useful for characterizing a variety of past climate conditions and are especially helpful in quantifying their variability and persistence, given the long-term records they provide (Sorooshian & Martinson, 1995). Overall, the strength of paleoclimate proxy-based scenarios is that they can represent real-world events that are outside the bounds of what participants have experienced. They may also capture a wider range of variability than is contained in future climate projections, which are often limited to one hundred years. Using paleoclimate proxies of climate extremes may also be more accepted by some individuals who are skeptical of climate models or by Indigenous groups with traditional knowledge of the impact of past climatic events on their communities (Norton-Smith *et al.,* 2016). Conversely, these data can be more challenging to work with compared to others because they tend to have relatively coarse (seasonal, annual, decadal, or longer) temporal resolution. There are several examples where proxy information has been integrated with historical (Dettinger *et al.*, 2017) or synthetic time series (California Water Plan Update 2023 Supporting Document, 2023; Dettinger *et al.*, 2017; Gangopadhyay *et al.*, 2009, 2015; Sauchyn & Ilich, 2017) to generate higher temporal resolution, if needed. Many of these approaches require significant resources and expertise to implement, but simple techniques, such as those described in Dettinger *et al.* (2017), are available.

Climate Model Projections

Statistically or dynamically downscaled global (GCM) or regional (RCM) climate model projections are another good resource for creation of exercise scenarios. The advantages of using climate projections are that their outputs have become readily available in recent years, they provide the best-known representations of potential futures, and they can simulate novel connections and changes that can surprise exercise participants in useful ways. One potential limitation is that the downscaled projection must have the spatial and temporal resolution to reasonably represent the climate hazard of interest. Statistical downscaling methods can differ substantially in their abilities to reproduce different types of climate and hydrologic extremes (Kotamarthi *et al.,* 2021; Werner & Cannon, 2016), with some resolving these with finer spatial and temporal detail than others, and this should be considered when selecting statistically downscaled projections. If finer than daily resolution is required, as might be the case for short duration events such as storms or fires, a regional climate model (RCM) such as the Weather Research and Forecasting (WRF; Skamarock *et al.*, 2008) model may be used to dynamically downscale an event to get the necessary spatial and temporal detail, using a bias-corrected GCM to supply the boundary conditions. Although expertise is required to generate such data, dynamically downscaled projections are becoming increasingly available. For example, a select set of climate model projections downscaled to hourly temporal resolution and 3 km spatial resolution will soon be available from CalAdapt and the CONUS II dataset provides 4 km spatial resolution climate projections.

Stochastic Weather Generator

Synthetic time series developed using stochastic weather generators are increasingly used within the water resource management community to conduct "bottom-up" assessments (e.g., Decision Scaling, (Brown *et al.*, 2012) of system performance and vulnerabilities under a wide range of conditions. These generators draw random values from probability distributions fitted to a reference climate record (past or future) to simulate novel weather sequences that preserve statistical attributes such as means and variances, as well as the spatial and temporal autocorrelation in the data (Wilks & Wilby, 1999). Outputs from stochastic weather generators have the spatial and temporal resolutions and extents that can reasonably capture many climate hazards, provided that the space-time characteristics of the simulation are plausible (Winter *et al.*, 2020). Stochastic weather generator simulations have been conducted to assess climate vulnerabilities within several watersheds in CA (California Water Plan Update 2023 Supporting Document, 2023; Rahat *et al.*, 2022; Schwarz *et al.*, 2019; Steinschneider *et al.*, 2019) as well as on a statewide scale (Najibi et al., 2024b, 2024a; Najibi & Steinschneider, 2023). The strength of using this type of synthetic time series is that they enable the creation of entirely novel weather sequences that can challenge and surprise emergency managers in potentially useful ways. Until more recently, use of these for extreme event scenario development was limited due to challenges capturing variability, extremes, or spatial patterns well (Chen & Brissette, 2014). Recent developments in this field have overcome many of these challenges, as evidenced by use of the tool to develop scenarios that plausibly capture extreme precipitation variability and weather regime characteristics (Rahat *et al.*, 2022; Steinschneider *et al.*, 2019).

ANALYTICAL METHODS FOR SCENARIO CREATION

Techniques for creating climate hazard scenarios generally involve either modifying historical events to reflect trends in climate or creating novel events using climate projections or synthetic data (Figure 4). Modifying historical events can be accomplished in several ways, for example, **incremental changes to climate variables** could be used to make it hotter, wetter, or drier. Alternatively, the antecedent conditions leading up to the event (e.g., dry or wet soils, vegetation (fuel) status, high severity fire scars, full reservoirs) could be altered to increase the severity of the event. If resources are available, **incremental changes to numerical weather model inputs** can be applied to simulate the event more realistically under climate changed conditions (i.e., pseudo-global warming). If even greater realism is needed, weather forecast ensemble archives that already contain incremental changes could be used to identify an alternative outcome of a historical event that would have likely resulted in more serious consequences (i.e., downward counterfactual analysis). Yet another approach could involve sequencing, overlaying, or **splicing** multiple historical events in ways that reflect the compounding hazards and response challenges expected to occur with climate change. The **scenario mining** and **scenario discovery** approaches can be used to draw scenarios from climate model projections, which have the advantage of representing new weather sequences or conditions that could arise due to climate change. In contrast, modifying historical events may present more routine conditions that are potentially less challenging but have the advantage of using data that are often more readily available. This can be particularly important in cases where weather forecasts are an integral part of the exercise, as existing weather forecast archives can be modified to simulate this aspect of the exercise. Developing forecast data for novel events may require significant resources, and there is a need to to identify approaches for accomplishing this in ways that are efficient. Thus, the lead time needed to create an extreme weather event scenario can vary substantially depending on the data source, approach, and data products that need to be generated.

Modifying historical events may present more routine conditions that are potentially less challenging but have the advantage of using data that are often more readily available. This can be particularly important in cases where weather forecasts are an integral part of the exercise, as existing weather forecast archives can be modified to simulate this aspect of the exercise. Developing forecast data for novel events may require significant resources, and there is a need to identify approaches for accomplishing this in ways that are efficient.

Incremental Change of Climate Variables

Incrementally adjusting one or more climate variables from a historical event is one of the simplest and most straightforward approaches for creating an extreme weather event scenario. For example, a drought period could be made warmer and drier, or an extreme storm could be made warmer and wetter in ways that reflect expected climate changes and effects on fire, water supply, or flood risks. Antecedent land surface conditions such as fuel moisture, snowpack, or soil moisture could also be adjusted to reflect those expected to occur in the future. Adjustments to variables could involve simple application of uniform changes (i.e., change factors) informed by climate projections or paleoclimate or could be based on data distributions, as in the case of the Quantile Delta Mapping approach (Cannon *et al.*, 2015). If more resources are available and greater novelty is desired, more complex space- and time-varying adjustments (e.g., to modify variance or to make season-specific adjustments) could be applied. Aside from the simplicity of this approach, the ability to readily incorporate and adjust archival forecast data provides another important advantage.

Table 4. Selected data resources for extreme weather event scenarios. All historical and climate model projection data sources include precipitation, minimum temperature, and maximum temperature. Additional variables included are indicated with superscripts in table footnote.

Data Type		Name	Resolution		Spatial Extent	Link
			Temporal	Spatial		
Historical Data	Station data	Climate Data Online[1]	Variable	point	Global	https://www.ncdc.noaa.gov/cdo-web/
			Hourly/ Sub-Hourly	point	US	https://www.ncei.noaa.gov/maps/hourly/
			Daily	point	US	https://www.ncei.noaa.gov/maps/daily/
			Monthly	point	Global	https://www.ncei.noaa.gov/maps/monthly/
	Historical event data	Hazards Data Distribution Center	Event	variable	Global	https://hddsexplorer.usgs.gov/
		CA 1997 New Year's Storm	Hourly	3.5/7/ 14 km	CA/Western US	https://portal.nersc.gov/archive/home/a/arhoades/Shared/www/California_New_Years_Flood_1997 includes 14-member ensemble forecast at 8,5,2, and 1 day lead times
	Gridded data (statistical)	Livneh	Daily	~ 6km	CONUS	Extreme Preserving: ftp://livnehpublicstorage.colorado.edu/public/sulu/Prec_unsplit_CONUS_Canada_1915_2018/ L15: https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.nodc:0129374;view=html
		PRISM[2]	Daily	~ 4km	CONUS	https://prism.oregonstate.edu/recent/
		Gridmet[3]	Daily	~ 4km	CONUS	https://www.climatologylab.org/gridmet.html
	Dynamical weather model outputs	CONUS404[4]	15 min- Daily	4 km	CONUS	https://www.sciencebase.gov/catalog/item/6372cd09d34ed907bf6c6ab1
	Forecast data	HEFS[5]	6-hr - Daily	~4 km - lumped	CA-NV	https://www.cnrfc.noaa.gov/arc_search.php
		GEFS[6]	6-hr	~27 km	Global	https://www.ncei.noaa.gov/products/weather-climate-models/global-ensemble-forecast
		EMCWF[7]	6-hr	~16-32 km	Global	https://www.ecmwf.int/en/forecasts/dataset/thorpex-interactive-grand-global-ensemble
Incrementally adjusted historical data	Quantile delta mapping method	California DWR 2070 extreme climate change scenarios[8]	Daily	~6 km	CA	https://data.cnra.ca.gov/dataset/sgma-climate-change-resources

Table 4. Selected data resources for extreme weather event scenarios. All historical and climate model projection data sources include precipitation, minimum temperature, and maximum temperature. Additional variables included are indicated with superscripts in table footnote (continued).

Data Type		Name	Resolution		Spatial Extent	Link
			Temporal	Spatial		
Paleoclimate proxy data		Paleoclimate Data[1]	Variable	Variable	Global	https://www.ncei.noaa.gov/maps/paleo/
Climate Model Projections	Statistically downscaled	LOCA (CMIP5, CMIP6)	Daily	~ 6 km	CONUS	https://loca.ucsd.edu/
		MACA[3] (CMIP5)	Daily	~4 km	CONUS	https://climate.northwestknowledge.net/MACA/
	Dynamically downscaled	WRF (CMIP6)	Hourly	~3 km	CA	https://analytics.cal-adapt.org/
		CONUS II[9]	5 min- Daily	~4 km	CONUS	https://rda.ucar.edu/datasets/ds612-5/
		IM3/HyperFACETS Simulation Datasets[10]	1-3 Hourly	12 km	CONUS	https://tgw-data.msdlive.org/
Stochastic weather generator		California Department of Water Resources Stochastic Climate Change Ensemble	Daily	~6 km	CA	https://water.ca.gov/Programs/All-Programs/Climate-Change-Program/Resources-for-Water-Managers https://data.cnra.ca.gov/dataset/ca-weather-generator-gridded-climate-pr-tmin-tmax-2023

[1] available variables are dependent on primary source;
[2] dewpoint temperature, vapor pressure deficit
[3] humidity, incoming solar radiation, wind;
[4] https://www.sciencebase.gov/catalog/item/6372cd09d34ed907bf6c6ab1;
[5]precipitation, temperature, freezing levels, streamflow;
[6] https://www.nco.ncep.noaa.gov/pmb/products/gens/gec00.t12z.pgrb2af06.shtml;
[7]https://confluence.ecmwf.int/display/TIGGE/Parameters;
[8] runoff, baseflow, soil moisture, evapotranspiration, snowmelt
[9]https://rda.ucar.edu/datasets/ds612.5/detailed_metadata/?view=level;
[10]https://tgw-data.msdlive.org/variables;

Incremental Change of Model Boundary Conditions

Incremental adjustments to one or more climate variables as described above, whether uniform or selective, do not realistically capture the physics behind spatial and temporal variations of change. In cases where such internal consistency and realism is important (e.g., when synergistic interactions between different climate variables may be as important as any single variable), incremental methods can be used to adjust the boundary conditions (i.e., external forcings) of numerical weather models (Dominguez *et al.*, 2017; Mahoney *et al.*, 2018; Ullrich *et al.*, 2018). In cases where adjustments are based on expected changes in climate this method is often referred to as the 'pseudo global warming' method (Kawase *et al.*, 2009) This approach can provide a more internally consistent depiction of how the event would unfold relative to a simple adjustment of the climate record, albeit at significantly greater computational cost. One additional caveat related to the pseudo global warming method is that it may still not produce physically realistic results if changes in boundary conditions are inappropriate, which may be the case for the most extreme climate states, which are not well understood.

Splicing

Another relatively simple approach that may be particularly useful for creating multi-hazard weather event scenarios, is to splice together historical events in space and/or time. For example, Porter *et al.* (2011) developed the 23-day ARkStorm extreme winter storm scenario for California by selecting and splicing together two large historical storm sequences (1969 and 1986) to create a long flood event on par with those that affected California in 1861-1862. In a similar approach, (Cifelli *et al.*, 2021) created a compound coastal and inland flooding scenario by splicing together the December 2012 storm event in Napa, the estimated 50-year return interval of non-tidal water levels based on a coastal storm at San Francisco Bay in February 1998, and spring tidal period from November 2010 that had a large tidal range. Numerous other possibilities exist - a 'weather whiplash' scenario could be created that sets up a wet year with high vegetation growth and fuel production followed by a hotter and drier drought year and active wildfire season, followed by a warm and wet winter storm, resulting in a multi-hazard scenario that includes compound impacts of flooding, post-fire debris flows or other geologic hazards. Although this method may require some expertise to create plausible and internally consistent event sequences or overlays, this approach is relatively simple to implement, as a scenario can be developed by making straightforward adjustments such as increasing the duration of an event or changing its sequencing, without adjusting observed magnitudes of meteorological variables.

Scenario Mining

Scenario mining (Albano *et al.*, 2021) involves screening climate timeseries to identify time periods representative of the climate hazard of interest (Figure 7). In the case of historical events, weather forecast ensembles for a historical event could be mined to identify plausible alternatives that would have had greater impacts due to differences in the location, magnitude, or duration of the event (i.e., downward counterfactual analysis, Rye and Boyd 2022). In the case of potential future events, climate model projections could be used. The ARkStorm 2.0 scenario (Huang & Swain, 2022) provides an example of this approach. In this case, spatial averages of precipitation were calculated across the state of California for each timestep within 40 runs of the CESM-LENS model. The model was run for historical (1950-2005) and future (2006-2100) time periods, and a 30-day running sum of precipitation was then calculated to identify the 30-day window with the largest precipitation totals during each time period. These two 30- day periods (ARkHist and ARkFuture) were then downscaled using a numerical weather model to generate two hourly, 3-km resolution extreme winter storm scenarios. Variations on this approach could involve screening focused on watersheds or communities of high concern, or screening for sequencing, timing, or runs of climate that are likely to result in the hazards of concern.

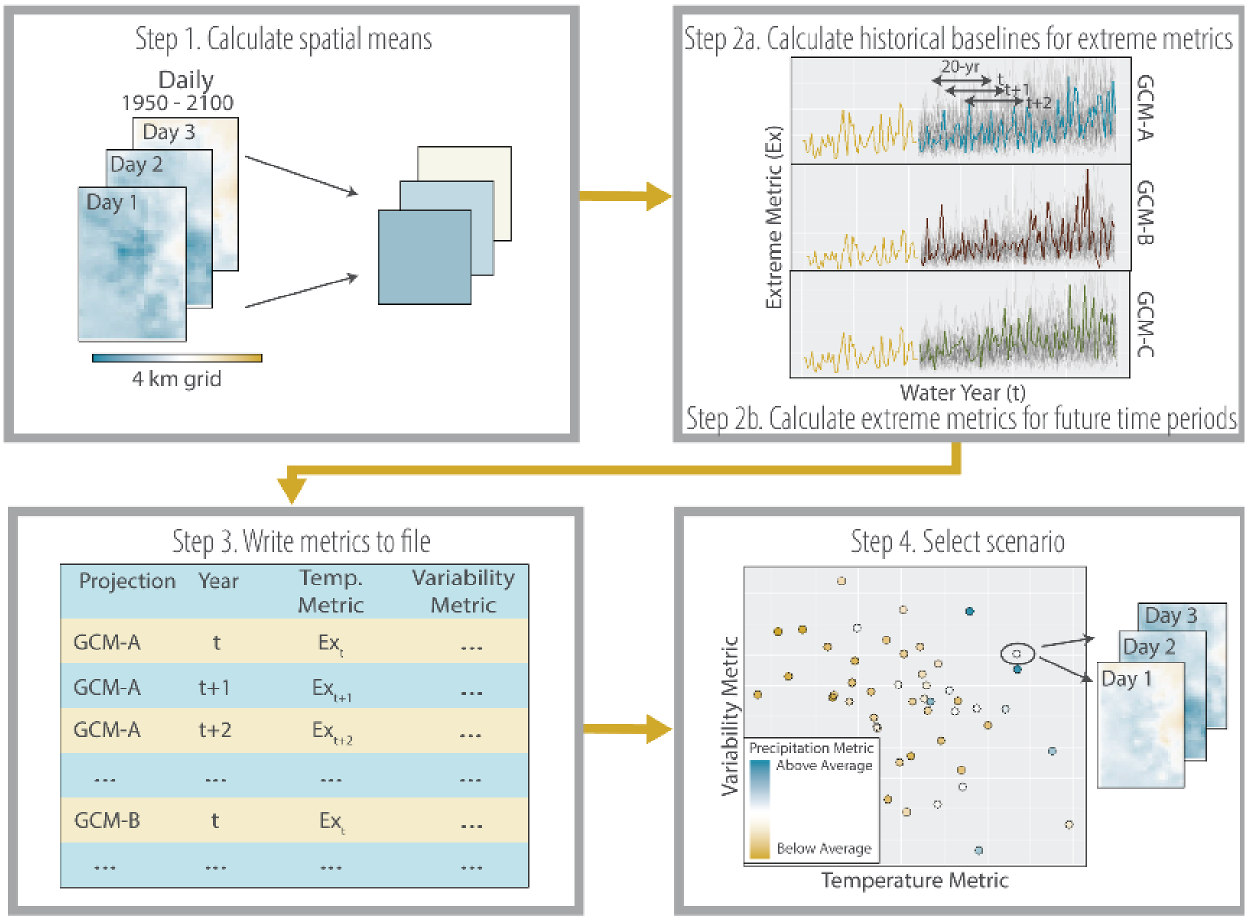

Figure 7. Example scenario mining approach (Albano *et al.*, 2021) for creating a five-year scenario based on interannual precipitation variability and temperature. A ‘weather whiplash’ scenario might be created by including additional metrics characterizing winter floods and summer dry spells.

For example, a combination of metrics could be screened to identify the three-year ‘weather whiplash’ scenario described in the splicing section above by screening for three-year periods with high annual precipitation variability, including an anomalously wet cold season, high temperature and low precipitation during the warm season in year two, and high 15-30 day winter precipitation totals during year three. One advantage of scenario mining climate model projections is the potential to explore novel events, which can challenge participants in new ways. A disadvantage of using climate model projections is that these datasets do not provide multiple iterations of the event, so unlike the case of using historical events where weather forecast ensembles may be available to allow weather forecast uncertainty to quantified for the exercise, these data are not readily available for climate model projections. Minor adjustments to the initial boundary conditions used for dynamical downscaling could be made to simulate multiple versions of the event and create an uncertainty plume that could be used as a proxy weather forecast (Rhoades et al., 2023). Alternatively, weather forecast uncertainty could be incorporated into the exercise in a more qualitative way by relying on expert knowledge, or a more limited quantitative uncertainty plume could be simulated by varying antecedent conditions in forecast or other physical models that simulate impact (e.g., hydrologic, hydraulic, fire, geohazard models).

Scenario Discovery

In contrast to the scenario mining approach described above which involves *screening the climate timeseries*, scenario discovery (Bryant & Lempert, 2010; Lempert & Groves, 2010) is used to identify scenarios based on *screening impact simulations* that use climate timeseries as inputs. Input climate sequences could take the form of an ensemble of climate projections or weather forecasts, incrementally adjusted historical or paleoclimate time series, or stochastically generated time series (Figure 4), which are run through one or more impact models to characterize a large range of possible outcomes. Outputs are then used to identify the circumstances under which the system of interest succeeds or fails (e.g., ability to manage a reservoir system to meet flood protection objectives, while also delivering water supplies). In an approach referred to as Decision Scaling (Brown and Wilby 2012), impact simulations are combined with climate model projections to estimate probabilities of system failures, based on their occurrences in climate model projections. Several of these analyses have already been conducted within the state of California (California Water Plan Update 2023 Supporting Document, 2023; Rahat *et al.*, 2022; Schwarz *et al.*, 2019; Steinschneider *et al.*, 2019). Provided stochastic weather generator simulation results provide sufficient detail and plausibility for in-depth exploration with community members, scenarios can be extracted from these outputs or from the associated climate model projection simulations (Figure 8; DiFrancesco *et al.*, 2020).

The ability to objectively identify climate hazard (and impact) scenarios based on a comprehensive analysis of simulated impacts is a key advantage of the scenario discovery method, as it ensures that the climate hazard scenario that is selected results in impacts that participants can explore in detail. The primary disadvantages of this approach are its substantial data and computational requirements and the expertise required to generate the impact simulations. That said, the existence of outputs from decision scaling analyses conducted as part of climate adaptation and hazard planning make this a feasible option and offers opportunities to more rigorously connect communities and strategies associated with longer term infrastructure and land use planning with the emergency response community through use of the same data sources.

SUMMARY AND RECOMMENDATIONS FOR DATA DEVELOPERS

The Guidance for Data Developers section provides detailed technical information related to potential sources of climate data and analytical techniques for primary and secondary hazard scenario creation, taking into account the design considerations discussed in the Guidance for

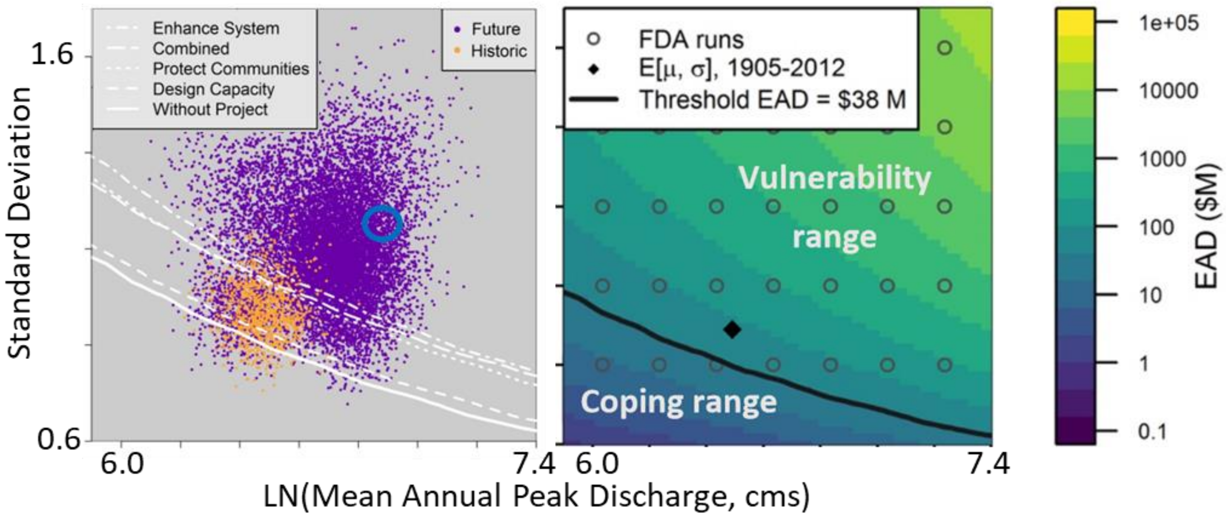

Figure 8. Example decision scaling response surface (right) and distribution of annual peak discharge values from historic (orange) and future (purple) climate model projections (left) for the American River from DiFrancesco *et al.*, 2020. White lines indicate 'coping thresholds', above which expected annual damages (EAD) exceed $38 million. A climate hazard scenario could be drawn from these results based on a time period that represents the occurrence of high expected flood damages (point with blue circle). Figure adapted from (DiFrancesco *et al.*, 2020).

Practitioners section. The computational resources and expertise required varies substantially across the options presented and many tradeoffs exist. Some forms of data (e.g., historical) are more readily available than others and although events can be modeled in greater detail with less effort, other data sources may be more optimal for creating novel or extreme events. Ultimately, the advantages, disadvantages, and tradeoffs discussed here may help to inform data developers to collaboratively produce an extreme weather event scenario that meets emergency manager objectives.

Another important consideration for data developers is that high temporal and spatial resolution extreme weather event scenario data over large areas can require substantial expertise to manage and analyze; expertise that most emergency managers do not have. Thus, delivering these data in ways that are useful to the emergency response community is an important consideration. An example visualization tool (still in development) for the ARkStorm 2.0 scenario (Huang and Swain, 2022) can be found at links provided on this page: https://www.dri.edu/project/arkstormsierrafront-2-0/. Currently, the tool enables users to view maps of meteorological data, flood inundation, and landslide hazards at daily timesteps over the course of the 30-day scenario and overlay these with infrastructure and population datasets. The tool will also have querying capabilities that enable rapid quantification of impacts that the emergency response community could use for exercise design and simulation. Creation of visualization tools such as those described above and others such as those described in Cifelli et al. (2021), the Rhode Island Coastal Hazards, Analysis, Modeling & Prediction (RI-CHAMP) online dashboard, or with functionalities similar to the FEMA Resilience Analysis and Planning tool may take time to develop, but offer the advantages of enabling non-technical experts to view and explore such scenarios in ways that are highly efficient and effective.

REFERENCES

Albano, C., Cox, D. A., Dettinger, M. D., Schaller, K. D., Welborn, T. L., & McCarthy, M. I. (2015). ARkStorm@Tahoe, Stakeholder Perspectives on Vulnerabilities and Preparedness for an Extreme Storm Event in the Greater Lake Tahoe, Reno and Carson City region. *University of Nevada Cooperative Extension*, *Special Publication-14-16*, 48.

Alexander, D. (2000). Scenario methodology for teaching principles of emergency management. *Disaster Prevention and Management: An International Journal*, *9*(2), 89–97. https://doi.org/10.1108/09653560010326969

Brewer, G. D. (2007). Inventing the future: scenarios, imagination, mastery and control. *Sustainability Science*, *2*(2), 159–177. https://doi.org/10.1007/s11625-007-0028-7

Brown, C., Ghile, Y., Laverty, M., & Li, K. (2012). Decision scaling: Linking bottom-up vulnerability analysis with climate projections in the water sector. *Water Resources Research*, *48*(9), 2011WR011212. https://doi.org/10.1029/2011WR011212

Bryant, B. P., & Lempert, R. J. (2010). Thinking inside the box: A participatory, computer-assisted approach to scenario discovery. *Technological Forecasting and Social Change*, *77*(1), 34–49. https://doi.org/10.1016/j.techfore.2009.08.002

Cal OES. (2018). California State Hazard Mitigation Plan. Retrieved from https://www.caloes.ca.gov/wp-content/uploads/002-2018-SHMP_FINAL_ENTIRE-PLAN.pdf

Cal OES. (2020). California Adaptation Planning Guide. Retrieved from https://www.caloes.ca.gov/wp-content/uploads/Hazard-Mitigation/Documents/CA-Adaptation-Planning-Guide-FINAL-June-2020-Accessible.pdf

California Water Plan Update 2023 Supporting Document. (2023). WEAP-Model-Application-to-Decision-Scaling-Using-Paleo-Climate---Pilot-Study.pdf. Retrieved from https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/California-Water-Plan/Docs/Update2023/Supporting-Documents/WEAP-Model-Application-to-Decision-Scaling-Using-Paleo-Climate---Pilot-Study.pdf

Cannon, A. J., Sobie, S. R., & Murdock, T. Q. (2015). Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes? *Journal of Climate*, *28*(17), 6938–6959. https://doi.org/10.1175/JCLI-D-14-00754.1

Chen, J., & Brissette, F. (2014). Stochastic generation of daily precipitation amounts: review and evaluation of different models. *Climate Research*, *59*(3), 189–206. https://doi.org/10.3354/cr01214

Cifelli, R., Johnson, L. E., Kim, J., Coleman, T., Pratt, G., Herdman, L., et al. (2021). Assessment of Flood Forecast Products for a Coupled Tributary-Coastal Model. *Water*, *13*(3), 312. https://doi.org/10.3390/w13030312

Dettinger, M., Sterle, K., Simpson, K., Singletary, L., Fitzgerald, K., & McCarthy, M. I. (2017). Climate Scenarios for the Truckee-Carson River System. *University of Nevada Cooperative Extension*, *Special Publication 17-05*.

DiFrancesco, K., Gitelman, A., & Purkey, D. (2020). Bottom-Up Assessment of Climate Risk and the Robustness of Proposed Flood Management Strategies in the American River, CA. *Water*, *12*(3), 907. https://doi.org/10.3390/w12030907

FEMA. (2006). Principles of Emergency Management. Retrieved from https://training.fema.gov/emiweb/downloads/is230.pdf

Gangopadhyay, S., Harding, B. L., Rajagopalan, B., Lukas, J. J., & Fulp, T. J. (2009). A nonparametric approach for paleohydrologic reconstruction of annual streamflow ensembles. *Water Resources Research*, *45*(6). https://doi.org/10.1029/2008WR007201

Gangopadhyay, S., McCabe, G. J., & Woodhouse, C. A. (2015). Beyond annual streamflow reconstructions for the Upper Colorado River Basin: A paleo-water-balance approach. *Water Resources Research*, *51*(12), 9763–9774. https://doi.org/10.1002/2015WR017283

Huang, X., & Swain, D. L. (2022). Climate change is increasing the risk of a California megaflood. *Science Advances*, *8*(32), eabq0995. https://doi.org/10.1126/sciadv.abq0995

Jagannathan, K., Jones, A. D., & Ray, I. (2021). The Making of a Metric: Co-Producing Decision-Relevant Climate Science. *Bulletin of the American Meteorological Society*, *102*(8), E1579–E1590. https://doi.org/10.1175/BAMS-D-19-0296.1

Kawase, H., Yoshikane, T., Hara, M., Kimura, F., Yasunari, T., Ailikun, B., et al. (2009). Intermodel variability of future changes in the Baiu rainband estimated by the pseudo global warming downscaling method. *Journal of Geophysical Research*, *114*(D24), D24110. https://doi.org/10.1029/2009JD011803

Kotamarthi, R., Hayhoe, K., Wuebbles, D., Mearns, L. O., Jacobs, J., & Jurado, J. (2021). *Downscaling Techniques for High-Resolution Climate Projections: From Global Change to Local Impacts*. Cambridge University Press.

Lempert, R. J., & Groves, D. G. (2010). Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American west. *Technological Forecasting and Social Change*, *77*(6), 960–974. https://doi.org/10.1016/j.techfore.2010.04.007

Lin, Y. C., Jenkins, S. F., Chow, J. R., Biass, S., Woo, G., & Lallemant, D. (2020). Modeling Downward Counterfactual Events: Unrealized Disasters and why they Matter. *Frontiers in Earth Science*, *8*, 575048. https://doi.org/10.3389/feart.2020.575048

Marx, S. M., Weber, E. U., Orlove, B. S., Leiserowitz, A., Krantz, D. H., Roncoli, C., & Phillips, J. (2007). Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Global Environmental Change*, *17*(1), 47–58. https://doi.org/10.1016/j.gloenvcha.2006.10.004

Najibi, N., & Steinschneider, S. (2023). A Process-Based Approach to Bottom-Up Climate Risk Assessments: Developing a Statewide, Weather-Regime based Stochastic Weather Generator for California Final Report. Retrieved from https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/All-Programs/Climate-Change-Program/Resources-for-Water-Managers/Files/WGENCalifornia_Final_Report_final_20230808.pdf

Najibi, N., Perez, A. J., Arnold, W., Schwarz, A., Maendly, R., & Steinschneider, S. (2024a). A statewide, weather-regime based stochastic weather generator for process-based bottom-up climate risk assessments in California – Part I: Model evaluation. *Climate Services*, *34*, 100489. https://doi.org/10.1016/j.cliser.2024.100489

Najibi, N., Perez, A. J., Arnold, W., Schwarz, A., Maendly, R., & Steinschneider, S. (2024b). A statewide, weather-regime based stochastic weather generator for process-based bottom-up climate risk assessments in California – Part II: Thermodynamic and dynamic climate change scenarios. *Climate Services*, *34*, 100485. https://doi.org/10.1016/j.cliser.2024.100485

Porter, K., Wein, A., Alpers, C. N., Baez, A., Barnard, P. L., Carter, J., et al. (2011). *Overview of the ARkStorm scenario* (USGS Numbered Series No. 2010–1312). *Overview of the ARkStorm scenario* (Vol. 2010–1312). U.S. Geological Survey. https://doi.org/10.3133/ofr20101312

Rahat, S. H., Steinschneider, S., Kucharski, J., Arnold, W., Olzewski, J., Walker, W., et al. (2022). Characterizing Hydrologic Vulnerability under Nonstationary Climate and Antecedent Conditions Using a Process-Informed Stochastic Weather Generator. *Journal of Water Resources Planning and Management*, *148*(6), 04022028. https://doi.org/10.1061/(ASCE)WR.1943-5452.0001557

Rhoades, A. M., Zarzycki, C. M., Inda-Diaz, H. A., Ombadi, M., Pasquier, U., Srivastava, A., et al. (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*(10), e2023MS003793. https://doi.org/10.1029/2023MS003793

Rhoades, A. M., Zarzycki, C.M., Hatchett, B.J. et al. (2024). Anticipating how rain-on-snow events will change through the 21st century. *Climate Dynamics*. https://doi.org/10.1007/s00382-024-07351-7

Rye, C. J., & Boyd, J. A. (2022). Downward Counterfactual Analysis in Insurance Tropical Cyclone Models: A Miami Case Study. In J. M. Collins & J. M. Done (Eds.), *Hurricane Risk in a Changing Climate* (pp. 207–232). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-031-08568-0_9

Sauchyn, D., & Ilich, N. (2017). Nine Hundred Years of Weekly Streamflows: Stochastic Downscaling of Ensemble Tree-Ring Reconstructions: 900 YEARS OF WEEKLY STREAMFLOWS. *Water Resources Research*, *53*(11), 9266–9283. https://doi.org/10.1002/2017WR021585

Schwarz, A., Ray, P., & Arnold, W. (2019). Decision Scaling Evaluation of Climate Change Driven Hydrologic Risk to the State Water Project: Final Report. California Dept. of Water Resources.

Skamarock, C., Klemp, B., Dudhia, J., Gill, O., Barker, D., Duda, G., et al. (2008). A Description of the Advanced Research WRF Version 3. https://doi.org/10.5065/D68S4MVH

Sorooshian, S., & Martinson, D.G. (1995). Proxy Indicators of Climate. In National Research Council, *Natural Climate Variability on Decade-to-Century Time Scales*. https://doi.org/10.17226/5142

Steinschneider, S., Ray, P., Rahat, S. H., & Kucharski, J. (2019). A Weather-Regime-Based Stochastic Weather Generator for Climate Vulnerability Assessments of Water Systems in the Western United States. *Water Resources Research*, *55*(8), 6923–6945. https://doi.org/10.1029/2018WR024446

US Dept. of Homeland Security. (2020). Homeland Security Exercise and Evaluation Program (HSEEP).

Vasileiadou, E., & Botzen, W. J. W. (2014). Communicating adaptation with emotions: the role of intense experiences in raising concern about extreme weather. *Ecology and Society*, *19*(2), art36. https://doi.org/10.5751/ES-06474-190236

Werner, A. T., & Cannon, A. J. (2016). Hydrologic extremes – an intercomparison of multiple gridded statistical downscaling methods. *Hydrology and Earth System Sciences*, *20*(4), 1483–1508. https://doi.org/10.5194/hess-20-1483-2016

Wilks, D. S., & Wilby, R. L. (1999). The weather generation game: a review of stochastic weather models. *Progress in Physical Geography: Earth and Environment*, *23*(3), 29.

STANDING DISTRIBUTION LIST

Michael Anderson
California Department of Water Resources
P.O. Box 942836
Sacramento, CA 94236
Michael.L.Anderson@water.ca.gov

Nevada State Library and Archives
State Publications
100 North Stewart Street
Carson City, NV 89701-4285
NSLstatepubs@admin.nv.gov

Archives Getchell Library
University of Nevada, Reno
1664 N. Virginia St.
Reno, NV 89557
tradniecki@unr.edu

Document Section, Library
University of Nevada, Las Vegas
4505 Maryland Parkway
Las Vegas, NV 89154
sue.wainscott@unlv.edu

†Library
Southern Nevada Science Center
Desert Research Institute
755 E. Flamingo Road
Las Vegas, NV 89119-7363

All on distribution list receive one PDF copy, unless otherwise noted.

† 2 copies; CD with pdf (from which to print)