

National Oceanic and Atmospheric Administration
U.S. Department of Commerce

Hazard-Based Workshop Series Summary

A&E Deliverable

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Introduction

The National Oceanic and Atmospheric Administration (NOAA) is working to promote climate resilience across the U.S. by partnering with key industries, including the architecture and engineering (A&E) sector. This sector plays a vital role in shaping the built environment through the design and construction of buildings, bridges, water systems, and transportation systems. Architects and engineers rely on accurate, timely, and future-facing climate and weather data to ensure buildings and infrastructure are designed to withstand not just the environmental conditions of today, but also the weather of tomorrow.

NOAA has a longstanding relationship with the sector to co-develop environmental data solutions that allow engineers to write weather-informed engineering codes and standards for resilient infrastructure. This relationship is built on an existing partnership with the American Society of Civil Engineers (ASCE), an industry leader with whom NOAA has worked since 2021. The agency's Industry Partnership program identified from a 2024 workshop that some of the A&E sector's priority hazards include: extreme rain; snow, ice, and freezing rain; temperature, and compound flooding. For additional information about the motivation and workshop design process, see Appendix A.

To better understand these needs, NOAA hosted a series of workshops, each focused on a different environmental hazard, to foster collaboration and learn the industry's specific data needs to support the development of products and services, and connect participants with resources they can use to develop a more resilient infrastructure. This document describes the needs and key products that attendees discussed during the various hazard-based data workshops with the A&E sector and highlights key takeaways that can inform NOAA's next steps with the industry.

Overview

The ASCE-NOAA Task Force for Climate Resilience in Engineering Practice (Task Force) hosts a yearly workshop for ASCE members and NOAA staff to align on new data, tools, and industry best practices to ensure that national infrastructure is ready for the climate of today and tomorrow. The breakout discussion sessions during the 2024 yearly workshop/meeting provided the basis for NOAA's ***Hazard-Based Workshop Series***, as they identified specific industry needs on a hazard-by-hazard basis.

As part of its ongoing engagement with sectors of the U.S. economy, NOAA sought to further discuss the needs identified during the Task Force workshop. The ***Hazard-Based Workshop Series*** continued the conversation to help address users' needs. This kind of continuous engagement, a key feature of NOAA's Service Delivery Model, informs the iterative development of products and services that are most useful to industry users.

Through these engagements, NOAA aimed to better understand the needs expressed by the A&E sector and to respond to participant feedback with weather and climate resources that support informed decision-making across the industry.



Figure 1. NOAA's Service Delivery Model

Workshop Contents and Timeline

Based on weather hazard needs identified in previously held Task Force workshops, the ***Hazard-Based Workshop Series*** included presentations about existing and in-progress products, recent and ongoing research, and resources for A&E professionals to help participants make informed decisions. The industry partnership program used previously gathered feedback to determine the four topic areas for the workshop series: extreme rain; snow, ice, and freezing rain; temperature, and compound flooding (Figure 2). The workshops provided opportunities for participants to ask questions regarding environmental science, and in turn, for NOAA researchers to understand how the industry can integrate environmental data into workflows and processes to guide future engagement, as well as the ongoing development of environmental data products, tools, and datasets.



Figure 2. The schedule of the Hazard Workshop Series allowed time to integrate the Hazard Workshop Development Model (Appendix A) between each event.

Key Data Needs Expressed

The Architecture and Engineering industry is looking for:

- Enhanced temporal and spatial resolution and completeness of data sources
- More accurate understanding of extreme weather and climate behavior, both historically and in terms of forward projections guided by emissions scenarios
- Bulk data downloads, with documentation or resources to lessen the technological burden of coding and processing the data
- Information regarding uncertainty, confidence intervals, data limitations, and caveats
- Integrated historical and future projection data to assist with comparison analysis
- More accessible and easy-to-use data formats (e.g. Comma-separated values (CSV), Parquet, EnergyPlus Weather (EPW))

Extreme Rain Workshop

Rain Data Usage in Architecture & Engineering

Engineers must balance resource allocations across multiple priorities while designing structures to withstand the highest relevant load demands occurring during the structures' lifetimes. Both short- and long-term conditions can affect the capacity and structural integrity of infrastructure, including water control and drainage systems. Extreme rainfall events are a critical source of such conditions, and seasonal to multidecadal conditions such as atypically heavy rain seasons or longer-term drought can destabilize earth material behavior.

The Task Force workshops in 2022 and 2024, in conjunction with input from the ASCE Environmental and Water Resources Institute (EWRI), helped identify a variety of engineering needs and use cases for rain data. These inform the development of standards such as ASCE 7-28 and manuals of practice, and more generally provide data that practitioners need for location-specific design considerations.

NOAA Rain Datasets

The 2024 ASCE-NOAA Task Force Workshop Report contained a survey from EWRI that indicates that nearly 40% of respondents use two key NOAA datasets: NOAA's Global Historical Climatology Network-hourly station data and the National Weather Service (NWS) and Office of Oceanic and Atmospheric Research's (OAR) probable maximum precipitation estimation (PMP). All survey respondents listed that they use the NOAA NWS Atlas 14 Precipitation Frequency Data Server. Industry applications can require high-resolution rainfall data as granular as a 5- to 15-minute basis, which is a focus of NWS's upcoming enhancement of Atlas 14 that it will release as Atlas 15, along with progressive changes in historical information. Users also analyze short-duration events with radar-based estimates such as the gridded Multi-Radar/Multi-Sensor (MRMS) product from the National Severe Storms Laboratory. MRMS is the basis of the U.S. Precipitation Time Series Explorer (PTE).

Rain-Related Research for New Dataset Development

MRMS

Julie Eaton Ernst, HNTB

Ms. Julie Eaton Ernst provided insight into HNTB's work with the MRMS dataset, highlighting the value of their "digital rain gauge" methodology for structural and transportation engineering. HNTB's Asset Level Rainfall Analyses Exercise allows users to get multiple years of hourly rainfall accumulation data for specific locations in seconds. This high-resolution gridded product helps provide data that point rain gauges may miss, especially when smaller, intense rainfall events occur between gauge locations.

It is important for users in the industry to be able to retrieve data at both site and watershed scales. The information informs analyses of upstream conditions that affect stream levels at particular locations, such as bridges, along with conditions at the site itself. Participants highlighted the MRMS Operational Product Viewer for users to look back at a particular event or to gather historical MRMS data for certain dates or durations. The "digital rain gauge" structure is publicly available through the NOAA Open Data Dissemination facility.

Atlas 15

Bridget Smith, Cadmus, NOAA contractor

Ms. Bridget Smith presented an overview of the forthcoming Atlas 15 precipitation product. Atlas 15 is the latest update to the precipitation frequency data presented in Atlas 14, the National Precipitation Frequency Atlas of the U.S. The statistical methodology used, the Generalized Extreme Value (GEV) distribution, provides station-specific rainfall frequency estimates under a range of Annual Exceedance Probabilities (AEP) at each location.

Atlas 15 will provide the temporal and seasonal analyses currently available with Atlas 14 at a minimum time interval of five minutes. At the time of the workshop, NOAA NWS was developing the interface for data access. Workshop participants asked whether Atlas 15 would include an application programming interface (API) format, and Ms. Smith explained that it was potentially in the works.

Projected Precipitation Intensity-Duration-Frequency (IDF) Curves

Ken Kunkel, North Carolina State University, NOAA Cooperative Institute, CISESS

Dr. Ken Kunkel presented research on adjustment factors for IDF curves, targeting the need for projected future information in Atlas 15. These factors apply modeled differences between historical values and future projections at each grid cell to corresponding recent observed data. Results for a 5° Celsius warming scenario show increases in daily maximum precipitation across the Contiguous U.S. (CONUS) at all frequencies of events, from once per two years to once per one thousand years. A notable pattern of smaller increases occurs along the Great Plains, the adjacent western High Plains, and further east into the Upper Midwest.

Participants discussed the relationship between the spatially-explicit adjustment factors and statistical downscaling, noting that statistically downscaled datasets do not capture local effects as effectively as the result of applying adjustment factors to observation stations. Dr. Kunkel expects the spatial variability of short-duration events to increase; however, he noted that, in most areas, shorter-duration events are convective in nature, which leads to larger

Breakout Sessions

The topics for this workshop's breakout sessions came from the ASCE-NOAA Task Force June 2024 Workshop report, as well as discussions with the NOAA Industry Initiative-ASCE Working Group (Working Group) on four major categories of rainfall data needs.

Stormwater Control

The discussion focused on data needs related to heavy rainfall events, hydrology as a whole, and peak discharge. Participants emphasized that they need 5-15 minute rainfall data, updates to Atlas 15 and PTE, updated design storm of record data, and soil moisture characteristics relevant to accumulation and discharge.

Reservoir Operations in Flood and Drought

The breakout discussion focused on both storage and flood control. Data needs included near real-time gridded precipitation, updated historical PMP in conjunction with projected PMP values, and precipitation for forecast-informed reservoir operations (FIRO) models, as well as seasonal outlooks and future projections of FIRO climate variables.

Extremes and Forensics

The discussion focused on evaluating failure and supporting the survival of beyond-design conditions. Data needs included fine-scale precipitation coverage that allows users to compare related cross-landscape structures (note the "digital rain gauge" capability), link precipitation intensity to damage for particular asset types, and compare extreme conditions with design standards.

Hydrologic and Hydraulic Modeling

The discussion centered on supporting design related to fluvial flooding, as this had been a primary use case that users had expressed before. Data needs included cumulative IDF curves, gridded sub-hourly precipitation, humidity, temperature, and evapotranspiration estimates.

Snow, Ice, and Freezing Rain Workshop

Snow, Ice, and Freezing Rain Data Usage and Needs in Architecture & Engineering

Engineers are concerned with loads from extreme snowfalls, icing events, and freezing rain (SIFR), or accumulated snow loads, as they can cause critical structural failure in some conditions. Engineers are also concerned with conditions that can affect the structural integrity of infrastructure, notably electric power systems, and the shedding of ice from buildings, bridges, and other structures. The 2024 ASCE-NOAA Task Force workshop and the ongoing Working Group underscored a number of SIFR considerations.

The first consideration is that snow can create highly non-uniform and dynamic load conditions. For example, wind-related drifting can create unbalanced loads leading to localized damage, and sliding snow on sloped roofs can create a significant additional load on lower roof areas.

Additionally, ice and freezing rain pose significant threats to structural integrity in a variety of ways. For example, ice can create extremely heavy loads, notably on exposed surfaces such as towers and cables. Similarly, freezing rain and sleet can lead to accretion of ice on surfaces, creating substantial additional load. Ice dams can prevent melting snow from draining, leading to structural damage from water incursion and load enhancement from saturated materials.

NOAA Snow, Ice, and Freezing Rain Datasets

NOAA data products of value to the A&E sector specific to this workshop include the Regional Snowfall Index , Snowfall Extremes, and Storm Events Database, along with the U.S. Department of Agriculture's Snopack Telemetry Station Network.

Snow, Ice, and Freezing Rain Research for ASCE Standards and New Dataset Development

The 2024 workshop and input from the Working Group helped identify three areas of product development for workshop consideration. These products are closely integrated with informing the development of standards such as ASCE 7 and manuals of practice, and with providing practitioners with data needed for specific design considerations.

Ice and Freezing Rain Product

Art DeGaetano, Cornell University, NOAA's Northeast Regional Climate Center

Dr. Art DeGaetano is developing a continuous, high-resolution gridded ice and freezing rain product to improve on spatially heterogeneous station data. This product will consider both spatial completeness and high spatial resolution for the estimation of environmental demands as needed for engineering design.

The methodology has been tested across CONUS and Alaska, and is successful at matching observations. In some areas the quality of the match is less strong, notably in Appalachia and the High Plains, which Dr. DeGaetano's team will investigate for potential improvement as product development continues. Along with these validation outcomes, the data identifies a projected decline towards less occurrence of freezing rain in the Southeast and Midwest within the next two-plus decades.

Product output will: 1) supplement observational data within design models and simulations, and estimate changes in frequency and intensity of freezing rain in the future; and 2) inform the ASCE 7-22 standard, guidance from the ASCE Structural Engineering Institute, and the ASCE Hazard Tool.

Participants extensively discussed specific technical aspects of the product's development, notably: the NOAA-NWS's Automated Surface Observing System (ASOS) observational data, an ice production model from the U.S. Army Corps of Engineers' Cold Regions Research and Engineering Laboratory (CRREL), the accuracy of ice sensors, and the machine learning model that the research employs. The CRREL model is fairly well-aligned with observations, and the precision of event timing improves with higher-resolution data, such as every one or five minutes. Researchers consider this ice production model the tried-and-true standard to access data older than 18 years, prior to the start of the ASOS record. Scientists have evaluated ice sensors for accuracy, but it is difficult to determine how accurate they truly are because Storm Data reports, the sensor data themselves, and CRREL data from researchers' measurements are the only observations available for testing. Dr. DeGaetano's team trained the machine learning model to be as close to physically relevant as possible and included training data covering as many climates as possible east of the Rocky Mountains.

Dr. DeGaetano's team evaluated statistical challenges in estimating mean recurrence intervals (MRIs) from short records and in modeling events with intensities or durations that exceed those in the training data. In both cases, a key limitation is the length of the available data record. For example, ASOS only contains 18 years of data, when reliable estimation typically requires five times the amount of data for the return period a user seeks. Two additional complications are the limited number of current observation stations and the changing nature of the climate system itself, which makes extrapolation forward from recent conditions difficult. To deal with potential output biases, the Regional Climate Center researchers applied two corrections: one that addresses cases in which freezing drizzle occurs instead of freezing rain, and another that deals with errors in the output related to the occurrence and amount of precipitation.

Participants called for ASCE to produce specific, real-world guidance regarding ice loading on open steel frame structures, which can lead to extreme potential loading. The discussion noted Dr. Kathleen Jones' and colleagues' research at CRREL as a start to understanding this issue.

Snow/Rain-on-Snow Product

Brennan Bean, Utah State University, NOAA OAR

Dr. Brennan Bean discussed the handling of ASCE7-22 on site-specific Reliability Targeted Loads (RTL) distributions, which can change depending on snow season behavior. The project has evaluated a 50-year MRI with different RTL distributions to see what kind of estimates they produced. A key finding is that the distribution curves change depending on typical snow behavior. He found that in regions with long snow seasons, the duration of the season and the snow accumulation affect load, whereas in other places, a single storm can alter the RTL distribution.

The project is additionally researching gridded (spatially complete) model simulations of snow water equivalent loads during both historical and future periods, allowing ratios of future-to-past loads to be estimated in a consistent way. This “delta” method is designed to reduce model bias that tends to be less in relative terms of load differences than in absolute terms of load amounts, and to improve the reliability of statistical analyses. Dr. Bean’s team designed the project to inform the ASCE Hazard Tool, including a key finding that the Upper Midwest (to Montana) and parts of the Northeast may need to increase snow load design considerations, while other areas of the CONUS may see a decrease in snow loads.

Rain-on-snow events can add a “surcharge” to the snow load, up to an additional twenty percent. The project team is further analyzing this phenomenon to find trends and relationships within an overall context of decreasing snow loads. One region where simulations show increased rain-on-peak snow is the Mountain West of the U.S., exclusive of California. Ground penetration from snow load changes due to freeze/thaw cycles in soil have yet to be integrated with other conditions, but Dr. Bean noted that snow load density may be a relevant factor, for which it is difficult to adjust.

Workshop discussion first targeted potential dissemination of the product by NOAA through the A&E sector website alongside the ASCE Hazards Tool, also including the possibility for public release of NetCDF files of grids.

The discussion also addressed a wide range of technical considerations. The first related to ground penetration from snow load changes that freeze/thaw cycles in the soil cause, or related changes with snow density. The product has not yet integrated ground penetration with other conditions, but snow load density may be a relevant, although difficult to account for, factor. The university research team explored using ecoregions for spatial definition in the product in relation to regionalizations in climate models. Dr. Bean indicated that ecoregion data are more reliable and accessible than those defined, for example, on a state-by-state basis, while still maintaining the level of similarity needed for comparative analyses. Dr. Bean highlighted the following resource to elaborate on the method used: Wagstaff & Bean, "remap: Regionalized Models with Spatially Smooth Predictions", The R Journal, 2023.

The presentation considered statistical issues related to parameters of estimated probability distributions, in particular how skewness and shape parameters can change when using large datasets. Dr. Bean explained that these parameters are based on ASCE extreme rain literature and added that the bounds of the parameters help keep reliability extrapolations accurate. The relationship between shape, scale, and location parameters is an area for continued research. Dr. Mari Tye (see next section) added that, as the shape parameter tends towards small absolute values (either positive or negative), resolving it accurately becomes more and more difficult because the resulting value tends towards division by zero and thus towards infinity. She also cited related work to capture changes in skew with changes in location and scale. It was noted that it is possible to capture skew in this way, but extrapolation using such estimates may be incorrect.

Finally, participants asked questions related to non-stationary climate scenarios and how the product's modeling would change if it used a nonlinear function. The maps that Dr. Bean shared assumed a linear effect, but in certain scenarios, such as the contour maps, nonlinearity was allowed for smoothing. Depending on the climate scenario, his research finds that the results could be stable for some time but then experience a drop off.

Atmospheric Icing Load: Approaches, Needs, and Future Directions

Ahmed Abdelaal, State University of New York Polytechnic Institute, and Mari Tye, University Corporation for Atmospheric Research

Dr. Ahmed Abdelaal reported research for ASCE 7 Chapter 10 on freezing rain and design for snow, in-cloud icing, and hoar frost loads, specifically targeting communications towers and power lines. He described how ice load calculations used in design require parameters can be estimated from observational data such as ASOS. ASOS, however, has issues with continuity, longevity, spatial range, and density.

To address spatial completeness, Dr. Mari Tye provided insight into the new Chapter 36 in ASCE 7, which addresses future climate modeling concepts and limitations with ice load maps. She described how integration of earth system models (ESMs) with reanalysis products is targeted to supplement ground-based weather stations and provide wider spatial coverage. An issue in this regard is that ESMs do not output precipitation subtypes. An additional important challenge is reducing barriers to data usage by engineers. The currently available model products are large and structured for use by climate scientists, but are generally not manageable for engineering applications.

Discussion targeted an expressed lack of guidance from entities like ASCE, the International Building Code, and the American Institute of Steel Construction to inform ice loading and ice shedding design, aside from power transmission applications. Both Drs. Tye and Abdelaal concurred that current guidance centers on uses of power transmission lines, along with bridges and cable-stayed structures more generally. They also remarked that most of the considerations focus on cylindrical accumulation, and do not consider other geometries, for example flat solar panels. Input is needed from the design community concerning what types of structures the ASCE guidance needs to cover.

Finally, Drs. Tye and Abdelaal added that ice shedding, such as from cables and wind electric generator blades, can be a more dangerous issue than ice loading, which is often less than the loading from wind or snow. Material degradation may also be an issue, but more analysis is likely needed for that specific context.

Snow, Ice, and Freezing Rain Workshop

Temperature Data Usage and Needs in Architecture & Engineering

Temperature is a highly important environmental condition for engineers and architects, focusing particularly on the following concerns:

- In-ground frost penetration into the ground and its impact on foundations, sub-surface systems, and materials
- Expansion, contraction, and degradation of exposed materials and structures over time
- Energy efficiency of structures and related heating and cooling demands
- Conditions that affect the capacity and structural integrity of infrastructure

NOAA Temperature Datasets

NOAA products of particular value to architects and engineers concerning temperature and historical extreme weather include: the station-based Global Historical Climatology Network Monthly, Daily, and Hourly records; the ~5 km gridded product, National Climate Grid (nClimGrid) Daily, and Monthly; the Climate at a Glance search and plotting tool; and the Storm Events Database.

Temperature-Related Research for ASCE Standards and New Dataset Development

ASCE-NOAA Task Force workshops in 2022 and 2024, and input from the ongoing Working Group, underscored the need for research and consideration of critical design variable Air Freezing Index (AFI). They also highlighted two products in development at NOAA with application to temperature in design, and shared results from a partner's focus group concerning temperature projections and data delivery summed up the workshop.

Air Freezing Index

Joseph Barsugli, University of Colorado, NOAA Cooperative Institute for Research In Environmental Sciences

Dr. Joseph Barsugli leads a project to update NOAA's AFI product, which shows the duration and intensity of below-freezing air temperatures at specific locations during the freezing season. AFI is primarily used to determine required depths for frost protected shallow foundations, which are used directly and quantitatively in ASCE standards such as ASCE32-01(R2025) to determine design parameters.

Dr. Barsugli and colleague Dr. Gaelle Hervieux are evaluating statistical distributions for estimating AFI. The GEV distribution used previously by NOAA was noted as not strictly applicable to an index like AFI, which measures cumulative values over an entire freezing season. The GEV model provides a useful starting point, however, due to its practical flexibility. The Generalized Additive Model (GAM) is also being evaluated for estimates of AFI in the context of a non-stationary (directionally changing) climate. Preliminary GAM results employing changing global mean surface temperature as a covariate lead to decreases in the 100-year MRI (or 1% probability per year) of AFI for nearly all of the CONUS, in comparison to data currently published by NOAA.

Several participants brought up matters concerning AFI observations and projections for further evaluation. The use of gridded reanalysis data was proposed by a participant as a tool to facilitate regionalized frequency analyses, which Dr. Barsugli suggested would not be required for a cumulative temperature index such as AFI. An attendee suggested that a comparison of non-stationary temperature changes for bridge design (with low temperatures increasing faster than high temperatures) indicates no need to alter existing design procedures. Dr. Barsugli noted this would not be the case for AFI in a significant set of possible contexts due to the size of the decreases involved.

An attendee noted changing demand within the A&E sector for identifying AEPs that can align with related economic analyses. Finally, an attendee asked if the environmental data needs and uses of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) were considered, which Dr. Barsugli noted include temperature and humidity, and from gridded reanalysis sources. His understanding is that ASHRAE focuses on shorter return periods, 50 years and less, compared to the A&E sector.

NOAA New and Updated Data Sets: Typical Meteorological Year and Climate Atlas

Adriana Formby-Fernandez, CSS, NOAA Contractor
Bailey Donaldson, CSS, NOAA Contractor

Ms. Adriana Formby-Fernandez presented NOAA's new Typical Meteorological Year (TMY) product, a point-and-click web interface that shows one year's worth of hourly climatological data, chosen month by month from a record of many years of data. A "typical" month is chosen to represent each calendar month from this dataset. TMY integrates historical observations from 1998-2022 with future projections to 2100.

Ms. Bailey Donaldson presented on NOAA's Climate Atlas, which is being updated to include new data, new types of variables (e.g., averages along with normals), automated monthly updates, and a new user interface with interactive maps that can be downloaded as static maps or as GeoTIFFs. The webpage will use nClimGrid data for CONUS, and European Centre for Medium-Range Weather Forecasts Reanalysis v5 (ERA5) reanalysis data will allow for global maps. AFI indices and degree day statistics were highlighted as potential future additions.

The attendees asked clarifying questions on the two products.

Temperature Projection Data and Information Delivery

Chris Anderson, EA Engineering, Science, and Technology, Inc.

Dr. Chris Anderson leads the Task Committee on Engineering Temperature Metrics Incorporating Climate Change (ETMICC) of the ASCE Committee on Adaptation to a Changing Climate. ETMICC is focused on requirements being developed to assess whether a data product provides sufficient temperature information for specific engineering design needs. Along with incorporating key data types relevant to engineering design needs–in conjunction with their descriptions and other metadata requirements–data must be delivered effectively in terms of format, disposition, compatibility, and accessibility. Dr. Anderson noted that these requirements could be used as a checksheet for the information engineers need when new resources, such as the TMY, are developed.

Examples of how these requirements are either met or are missing were evaluated by Dr. Anderson for the Government of Canada's official page on Climate-Resilient Buildings and Core Public Infrastructure, the ASCE Hazard Tool, and NOAA's Atlas 15, currently in development.

Discussion between the attendees and Dr. Anderson included the issue of data precision in relation to threshold values that determine design decisions. For example, even a small percent increase in a parameter can push a design decision over a threshold that would significantly increase cost, noting a changed requirement for a roof type with a small increment of wind speed. Relatedly, attendees acknowledged a need to focus on where model projections are and are not doing a good job, including indicating observed trends alongside projected values. Dr. Anderson agreed that this is a good recommendation. He did not present specific criteria concerning formal model verification, but noted the more general concepts of confidence and credibility: for example, the relationships of confidence interval estimates could be a subcategory of its own data type. From a spatial perspective, model reliability generally decreases at finer spatial scales. Because applied engineering applications are often site-specific, this limitation is particularly relevant (see the MRMS presentation in the Rain-Related Research for New Data Set Development portion of the Rain Workshop summary). Comparison of observed and modeled trends at finer spatial scales was again identified as important to understand where projections are credible for particular applications and where additional calibration, or specific caution, is warranted in their interpretation.

Compound Flooding Workshop

Compound Flooding Data Usage and Needs in Architecture & Engineering

The ASCE-NOAA Task Force 2024 Workshop Report lists compound flooding as a top hazard, and describes it as the combined effects of more than one flood-causing process. These processes may be induced by the same event or result from independent phenomena occurring concurrently or in relatively close succession. Potential compound flood drivers include precipitation, storm surge, tides, sea level rise, antecedent soil moisture, river discharge, ocean waves, snowmelt, and land subsidence.

For this workshop, NOAA reached out to insurance and reinsurance partners because of the overlap in weather and climate data needed to tackle concerns around compound flooding. Conversations with industry members in the insurance sector had highlighted the necessity of including the engineering perspective when discussing the solution space around compound flooding hazards.

The structure of this workshop differed slightly from previous workshops, with the inclusion of a panel and Q&A session in lieu of a more thorough discussion section.

NOAA Compound Flooding-Related Datasets

Atlas 15 Update and Overview

Sydney Luce, Cadmus, NOAA Contractor

Ms. Sydney Luce presented precipitation information from Atlas 14 and its update, Atlas 15, and the differences between the datasets provided by these products. Atlas 14 and Atlas 15 Volume 1 offer precipitation estimates based on duration and average recurrence intervals. Example applications include stormwater management, bridge and road engineering, and communicating storm severity.

The Office of Water Prediction of NOAA's NWS will offer Atlas 15 data for the U.S. and territories in two volumes that account for nonstationary and changing environmental conditions into the future. Volume 1 will include updates to Atlas 14, while Volume 2 will include projections based on several scenarios. Ms. Luce gave a demonstration of the Atlas 15 Volume 2 Pilot in Montana and compared corresponding Volume 1 and Volume 2 maps. Atlas 15 will include all of the U.S. and its territories. NOAA estimates that it will release Atlas 15 for the CONUS later in 2026 and for locations outside the CONUS in 2027. The Atlas 15 website will likely not include a way to compare the new Volume I values to previous Atlas 14 values due to differences in the methodologies used in Atlas 14 and 15.

Descriptive information concerning how Atlas 15 uncertainty bounds have been computed and, under projected future climate, how Atlas 15 will account for nonstationarity can be found in the methodology for the Atlas 15 pilot, with additional information on the main Atlas 15 website.

U.S. Precipitation Time Series Explorer

Adriana Formby-Fernandez, CSS, NOAA Contractor

Ms. Adriana Formby-Fernandez presented an overview of NOAA's forthcoming PTE product, which includes maps and time series plots whose period of coverage users can specify. PTE provides precipitation estimates from historical and near-real-time observations for the CONUS, Alaska, Hawai'i, Puerto Rico, Guam, and the U.S. Virgin Islands.

Potential applications include transportation and infrastructure design, flood risk assessment and mitigation, and post-event damage assessment and recovery planning. The tool incorporates near-real-time data with Quantitative Precipitation Estimation data from the MRMS (access here) to better understand extreme rainfall events, their exceedance potential, their frequency, and their risk for infrastructure. Ms. Formby-Fernandez demonstrated the tool under development, highlighting the map search functionality, map layers, split view of the map and time series, and the data access notebook.

PTE will be available in September 2026. Attendees were given a form to fill out to learn about upcoming PTE engagements and user testing opportunities.

NOAA's National Water Model - Overview and Application to Total Water Level Modeling

Brian Cosgrove NOAA/NWS Office of Water Prediction

Dr. Brian Cosgrove presented the existing National Water Model (NWM), the hydrologic counterpart to the CONUS weather model. NWM simulates observed and forecasted streamflow for the CONUS, southern Alaska, Hawai'i, Puerto Rico, and the U.S. Virgin Islands, and provides total water level guidance for the coastlines of these regions, except Alaska.

The core of the NWM system is the National Center for Atmospheric Research-supported community Weather Research and Forecasting Hydrologic model, which ingests forcing from a variety of observational and weather-related modelling sources. Version 3.0, added in 2023, links the NWM with the Semi-implicit Cross-scale Hydroscience Integrated System Model (SCHISM) coastal estuary model that is driven by tidal and storm forcings, with coverage over the East, Gulf and Pacific coasts of the CONUS, along with the coastlines of the Hawai'i, Puerto Rico, and U.S. Virgin Islands. Version 3.0 provides enhanced guidance to emergency responders and improves the prediction, assessment, and analysis of water level and compound flooding at the coasts. It is spatially represented at a very high resolution: 75 meters along the Atlantic coast, 50 meters along the Pacific coast, and 30 meters in Puerto Rico. NWM runs 24/7, to issue near-real time total water level analyses, along with 18-hour and 10-day flooding forecasts. It captures whatever activity occurs on the coast, including tropical cyclones, and produces a total water level forecast associated with streams and tides.

Future updates in 2026 and 2028 will include Version 4.0 coverage for the Great Lakes, Lake Champlain, and South Central Alaska, and will incorporate the Super-Fast Inundation of Coasts (SFINCS) Model in addition to SCHISM. An upcoming addition is real time operations providing analyses and forecasts. Next will be a joint effort of the National Ocean Service (NOS), NWS's Office of Water Prediction, and Lynker Technologies to provide a multi-decade continuous retrospective simulation, similar to a climate or weather reanalysis. NWM will include total water output and translate coastal inundation maps in the future.

There is not currently an option to add a factor of safety or separate storm surge estimate. Storm surge is taken externally from the probabilistic tropical cyclone surge model; it is not generated internally to the NWM. Dr. Cosgrove noted that the bathymetry of the river channels for SCHISM total water level predictions is a blend of the Storm Surge and Tide Operational Forecast System topobathy, and also draws on more than 50 digital elevation models.

When It Rains It Pours: The Importance of Modernizing NOAA Extreme Precipitation Data

Kelly Mahoney, NOAA Physical Sciences Laboratory

Dr. Kelly Mahoney explained that PMP is currently defined as the maximum depth of precipitation over a given area and duration that is meteorologically possible. NOAA's issued PMP guidance has become outdated, and precipitation has been affecting aging infrastructure to its limits in recent years. To protect high-risk infrastructure from failure and to prevent the design of projects according to incorrect estimates (either too high, adding expense, or too low, endangering the structure), NOAA is employing models, data, and understandings of PMP that have all improved over the past decade.

NOAA is seeking a fully comprehensive and inclusive set of opinions to inform the modernization of PMP. The team is implementing recommendations according to a roadmap from a 2024 National Academies of Science, Engineering, and Medicine report to modernize and improve the long-term vision, while also balancing near-term needs. One of these is to evaluate a new definition: the depth of precipitation for a particular duration, location, and area extent, such as a drainage basin, with an extremely low annual probability of being exceeded, for a specified climate period. Recommendations also include defining PMP estimates from high-resolution model datasets that incorporate nonstationarity. Progress to date includes a webpage on the Physical Sciences Laboratory project site, which is a first installment that the team plans to grow. A workshop and webinar was held in February 2026. Materials will be shared via the webpage.

Sea Level Rise Science and Tools Update

William Sweet, NOAA NOS

Dr. William Sweet presented on the inter-agency collaboration that provides a suite of data tools on sea level rise. Dr. Sweet noted that sea level is not rising at a linear rate across the U.S. coastline. Warmer waters in the East Coast are expanding faster than cooler waters on the West Coast. Areas along the U.S. coastline have experienced approximately a foot of rise over the last century. The causes are ocean heating and ice melt driven by climate shifts.

NOAA and other agencies' sea level rise resources aim to provide an observational trajectory to give users guidance on how water levels are changing, characterizing changes and then extrapolating forward multiple decades. The tool also aims to establish goalposts for the end of the century and beyond so that users have data for risk planning and contextualization.

In-depth access to the inter-agency information is available at earth.gov/sealevel. Plots show data for the last 50 years and five future scenarios, low to high, showing 0.3m to 1m global rise by the end of the 21st century. The interface shows both the distribution of estimates and what the rising sea levels actually look like; they tend to be higher along the East and Gulf Coasts than in Alaska and the West Coast.

Dr. Sweet further described issues with minor floods and sea level rise making them a significant problem in coastal communities. The distributions of sea level are shifting to higher values, while currently developed structures and infrastructure are fixed in place. Flood levels higher than docks can cause major impacts, including water reaching storefronts, traffic disruption, and storm drainage back up. NOS develops maps for potential areas in danger as the number of days of flooding exponentially increases. Additions underway include improvements to vertical land motion with radar. Finer resolution allows counties and cities to be able to use the data at smaller spatial scales and to better account for human-constructed and other nonlinearities in inundation potential, such as threshold behavior from overtopping of levees, berms and other control structures.

From a modeling perspective, Dr. Sweet noted the challenge of blending probability distributions developed by generating synthetic storms with the observational record. There are synthetic storms that are estimated to occur, but are not seen in the observational record. The goal is to enhance the engineering curve to include where these floods fall in terms of their likelihood. Dr. Doug Marcy more thoroughly presented the tools introduced during this talk later in the workshop.

Paleo-Hurricane Perspective

Eugene Wahl, NOAA Contractor

Dr. Eugene Wahl presented modern, historical, and pre-historical information on North Atlantic hurricane activity from paleoclimatology studies of tropical cyclones. These are based on geological indicators from storm-driven coastal overwash events that accumulate and are preserved in specific kinds of coastal ponds and lagoons. Research at specific sites indicates that there have been hurricanes in the past two millennia that far exceed the intensity of documented historical and modern storms since 1600 CE, and also that large hurricane frequency has been much greater in the pre-historical past.

Evidence for the North Atlantic basin more broadly indicates that, while frequency is less variable over time at the basin-wide level, the current frequency appears to be lower than it has been at times earlier in the past millennium. Non-forced (or internal) variability has dominated hurricane frequency in the last millennium. This result is consistent with the lack of a clear trend over the instrumental period, despite strong greenhouse gas forcing, which model simulations including all external forcings suggest would lead to reduced frequency. Because of these outcomes, the prospects for understanding hurricane activity in the 21st century appear limited from considerations of external forcing alone, but the joint paleoclimate, historical, and modern record does suggest there is important natural variability, including the likelihood of rare, but extremely intense events.

Sea Level Rise Calculator and Viewer

Doug Marcy, NOAA Office for Coastal Management

Dr. Doug Marcy demonstrated the Sea Level Calculator and Sea Level Rise Viewer tools available through NOAA Digital Coast. The Sea Level Rise Viewer can increase inundation layers by increments, takes into account existing surfaces, and shows specific landmarks to highlight sea level rise effects. The tool also includes marsh migration and high tide flooding, with minor, moderate, and major flood layers.

The Sea Level Calculator is specifically oriented to the A&E sector. It incorporates flood data from the 2022 Technical Report, Global and Regional Sea Level Rise Scenarios for the United States, specifies the period of record incorporated, and provides an interface of tailored dashboards. Users can view regional observations with thresholds for comparative analysis, such as the levels for average high tide and average exceedance. Extreme water levels with return periods, observed sea level trends, seasonal variation, and flood frequency are also available. The reference datum for sea level can be changed and vertical land motion is included. Similar to NASA products (the National Sea Level Explorer and the Interagency Sea Level Rise Scenario Tool), the Sea Level Calculator shows how sea level would change in the future with important ice sheet contributions.

The Sea Level Calculator will include more NOAA datasets and reanalysis information in the coming months of 2026. Users can download the available data in CSV-type files for further analysis. The tools show geographic context along with the data necessary to aid with vulnerability assessments, and there are opportunities for users to cross-reference the sea level scenarios in these tools with the precipitation data from Atlas 15.

A Compound Flooding Manual of Practice for Engineers

Rolf Olsen, ASCE Committee on Technical Advancement: Task Committee on a Compound Flooding Manual of Practice; Félix Luis Santiago-Collazo, University of Georgia; Hamed Moftakhari, University of Alabama; Jayantha Obeysekera, Florida International University

The ASCE Compound Flooding Manual of Practice for Engineers (MOP) aims to help practicing engineers apply the best possible science to their work. It approaches hydrodynamic and statistical models as well as future changes. This MOP is under development with publication expected in late 2026.

Dr. Rolf Olsen explained that compound flooding poses an engineering challenge due to multiple drivers that are correlated and independent, with some drivers changing with the climate. Generally, manuals of practice may take varied approaches for inland flooding, storm surge, and coastal flooding, but these methods may not demonstrate how the components interact, which can underestimate flood risk. Typical manuals of practice may also assume stationarity in datasets, similar to NOAA Atlas 14; however, drivers like sea level and precipitation may change over time. Mechanisms that generate compound flooding include severe storms, preexisting conditions, high river discharge, tidal coastal processes, storm surge, and sea level rise.

Dr. Félix Luis Santiago-Collazo provided an overview of hydrodynamic process-based models of compound flooding and how they incorporate a mix of inland processes. There are various ways to quantify how much water from precipitation will result in overland flood, including the use of rainfall and runoff models, riverine models, and coastal dynamics. Modeling compound flooding requires coupling different process-based models for these factors using various techniques. Among these coupling techniques, the MOP aims to encourage users to employ simple approaches and to promote higher-quality science. Simple coupling approaches take models that develop and run separately, pass the first model results to a hydrologic model as a boundary condition, and then run the hydrologic model with the outputs to get the total result. Dr. Santiago-Collazo also described a hierarchy of more complex coupling approaches: from partly coupled, in which models run at same time and information exchanges across them; to tightly coupled, in which there is a single model for everything but with different codes for coastal versus hydrological processes; to fully coupled versions in which everything is in the same code and solved simultaneously.

Dr. Hamed Moftakhari explained that there is a complementary statistical approach to modeling compound flooding, for insights into multiple variables in bulk. First, determining the association between the elements is important, as it indicates if there is a statistically significant driver, or drivers, within these systems and whether the mathematical approach can consider the elements as independent or dependent. Tools for joint probability analysis, such as copula models are helpful when considering multivariate drivers. The next step is to determine the best tool to help identify the hazard scenario for design, and then to look at clustering for compounds in spatial domains (such as neighboring watersheds) or temporal domains (the sequence of events). The section of the MOP on statistical modeling includes examples for coastal and lake flooding to assist engineers who will use this methodology.

Different drivers can reflect nonstationarity differently, and how these then interact may create additional challenges for statistical modeling. Linking statistical and process-based models has functional limitations, but also hybrid applications. There are three categories of models for linking that lead to hybrid approaches: sequential, with one-way interaction from one model to another such as setting boundary conditions; feedback, with two-way interactions with exchanges of information, sequentially updating each other; and ensemble hybrid models, with well-trusted models combined to create an output ensemble of probabilistically meaningful results. Dr. Moftakhari also introduced the Joint Probability Method as a probabilistic approach used for tropical cyclone storm surge and flood frequency analysis.

Dr. Obeysekera cited the Intergovernmental Panel on Climate Change's guidance on increasingly intense tropical cyclones and changing land use as two reasons for why engineers expect increased exposure to risk and runoff capabilities. In order to help users navigate this complex landscape, the MOP will also include case studies of the complex methods described: coupling versus statistical models, urban flooding, storm surge design with joint rainfall in Texas, and studies in the Netherlands and Miami.

Interdisciplinary Panel Discussion – A&E and Insurance/Reinsurance

Moderator: Cera Schrems, NOAA Contractor

Panelists: Dr. Shirley Clark, ASCE and Penn State Harrisburg, works in urban flood planning. Clark has served on and led various committees in ASCE's Environmental and Water Resources Institute.

Dr. Trevor Qi, Guy Carpenter, comes from a water resources engineering background and now leads a flood peril advisory team that translates flood science into practical risk decisions for insurance and reinsurance.

Mr. Charlie Sidoti, InnSure, is the executive director of InnSure, a nonprofit organization that works with communities and their planners to foster the integration of insurability planning with economic planning. Sidoti has 35 years of experience in and around the insurance industry.

Panelists explained that compound flooding is not only a multi-driver system, but also involves multiple systems. Landscapes that have changed over time experience flooding patterns that people often do not expect, especially when an area or system is already saturated and there is no outlet for additional water. Reliable engineering analysis is the basis for risk reduction. Insurance then works to "translate engineering scenarios into dollar scenarios" and a total-cost-of-risk perspective in the long term. Insurance also fuels resilience with near-real-time event response and short term awareness.

Important resources for users in this space include temperature IDF curves, annual meteorological year data, evapotranspiration information, the status of flood protection systems, coastal gauge data, flood and hydrological models, and some of the resources covered earlier in the workshop.

Two major themes emerged from the panel discussion: current gaps in compound flooding research and what the future landscape and solutions may require.

Dr. Clark highlighted a critical blind spot: underground infrastructure. These systems are often poorly documented, yet they can significantly shape urban flooding outcomes. In many cases, regulators must rely on incomplete or inaccurate data, prompting Dr. Clark's team to fill gaps using radar and supplemental sources.

Expanding on data challenges, Dr. Qi emphasized the need to better connect hazard datasets at a broader scale. Rainfall, soil conditions, coastal water levels, and insurance claims are often siloed, making it difficult to fully quantify compound flooding events, an essential step for risk analysis and insurance applications. Stronger cross-sector collaboration, he noted, is necessary to understand how these factors interact, especially as aging flood defenses introduce additional uncertainty.

Looking ahead, panelists pointed to the importance of higher-resolution data and more integrated modeling. Dr. Qi explained that high temporal resolution data are critical for understanding when different flooding drivers occur, since synchronization can significantly worsen impacts. Dr. Clark added that even 15-minute interval data can miss peak flood conditions. While her team uses hydrographs to reconstruct storm events, gaps remain in capturing highly localized flooding.

Data accessibility also emerged as a defining challenge for the future. Mr. Sidoti emphasized that even the most advanced models and datasets must be usable beyond technical audiences. As risks evolve, so must communication, especially for communities and decision-makers who need clear, actionable insights. Dr. Clark reinforced this point, noting that both engineers and local leaders need tools that make complex data easier to access and interpret.

The discussion ultimately returned to the importance of pairing data with storytelling. As Mr. Sidoti put it, "No data is allowed without stories, and no stories are allowed without data." Dr. Clark agreed, emphasizing that clear, apolitical communication can strengthen public understanding and build support for future flood protection efforts.

Key Outcomes and Next Steps

This workshop series pulled together over 170 unique participants, with industry stakeholders accounting for approximately 50% of total attendees. The interactions and discussions between NOAA and the A&E sector demonstrate the strong, ongoing relationship between the groups and fulfills a key objective to enhance NOAA/A&E interaction to a wider audience, specifically oriented towards "on the ground" practitioners. Participants provided detailed feedback, enriching discussion, and shared their excitement about the wide range of current NOAA tools and products in development across the hazard areas, serving the sector's fundamental mission to develop a more socially beneficial, resilient, and sustainable built environment. NOAA expresses deep gratitude to all the participants, and in particular to the Working Group members and the ASCE-NOAA Taskforce who helped throughout to guide the workshop focuses and structure.

The workshops connected A&E users to current NOAA tools and additional products in late stages of development prior to deployment. Nineteen tools were presented in detail, which are listed in Appendix B. Throughout the workshop presentations, participants validated and reiterated the need for higher resolution and completeness of data sources (both temporally and spatially) and the need for the most accurate understanding of extreme weather and climate behavior possible, both historically and in terms of forward projections guided by simulation scenarios.

The participants emphasized the need to incorporate future projections into their codes and standards, as the climate continues to rapidly change and because all engineering projects involve considerations that are specific to the site and its interaction with regional and local climate. As practitioners, they strive to design more resilient structures; having this information integrated into codes and standards continues to be an important goal to ensure that buildings built today will last and be useful for the future.

Feedback from the workshop attendees' was collected and disseminated to NOAA staff and partners to improve existing and new data tools and products. The specific presentations that focused on these needs are highlighted and summarized in Appendix C. The NOAA team collected 85 actionable user needs that centered on the following:

- Incorporation of additional datasets beyond those of the workshop foci, to provide a more complete meteorological picture, such as solar radiation, wind, etc.
- Coverage for Alaska, Hawai'i, and other regions outside of CONUS
- Bulk data downloads, with accompanying documentation or resources to lessen the technological burden of coding and processing the data
- Identification of data limitations and caveats
- Supplementary documentation on uncertainty estimates and data methodology

This feedback gives us confidence that the products we develop are, and will be, useful, usable, and used.

Finally, the ASCE-NOAA Taskforce used the momentum from this workshop series to bring together authors of their MOPs on compound flooding and coastal inundation in focused meetings to discuss the integration of NOAA data into those MOPs.

The key outcomes and information from this workshop series was integrated into a Meeting Summary article for the Bulletin of the American Meteorological Society. Additionally, the information shared, user needs collected, and input from the A&E sector will be used in developing further resources available for the sector on the NOAA Our Impact page. The information will also be used directly to inform the hazard-data products reference list, which will be a collection of links to applications shared through this workshop series and other relevant applications for the sector.

These workshops serve as an example of a way to continue dialogue between sectors and practitioners to increase awareness of the work being done in the climate and weather data field. Other governmental entities trying to connect to industry partners can use this workshop model as a way to facilitate discussion across sectors and user communities.

Appendices

Appendix A. Workshop Motivation and Development

NOAA's Hazard-Based Workshop Series continued NOAA's ongoing conversations with members of the A&E industry. These events built on the information collected from an existing collaboration with the American Society of Civil Engineers (ASCE), an industry leader with whom NOAA has worked since 2021. NOAA's Climate Program Office, ASCE, and the University of Maryland Center for Technology and Systems Management formed the joint ASCE-NOAA Task Force for Climate Resilience in Engineering Practice (Task Force) to collaborate and facilitate the implementation of climate adaptation into the engineering industry. The signing of the 2023 Memorandum of Understanding (MOU) continued this work to connect climate information to infrastructure codes and standards.

The ASCE-NOAA Taskforce Memorandum of Understanding

The Memorandum of Understanding (MOU) supports collaboration to strengthen the Nation's infrastructure resilience against current and future climate risks. This MOU improves cooperation in developing and delivering climate information as well as facilitating ASCE's efforts to update its published content. NOAA's role involves advising ASCE on engagement opportunities; facilitating access to observations, projections, and scientific information; and promoting coordination between NOAA climate scientists and ASCE engineers.

The NOAA team followed a consistent approach to develop each workshop (see Figure 3). They began by identifying and collecting hazard-specific information from the 2024 ASCE-NOAA Task Force Workshop Report, selecting the most relevant content for each workshop. They mapped identified needs by aligning industry gaps and questions with information, products, datasets, services, and resources from NOAA. The NOAA team then identified potential NOAA speakers to represent the areas. Key researchers joined meetings with the NOAA Industry Initiative-ASCE Working Group (Working Group) for a preview of their presentations. Working Group membership includes ASCE leadership, University of Maryland faculty, civil engineers, and architects.

NOAA then validated its findings and ideas with the Working Group to ensure that the plan for the workshop appealed to an industry audience. With the Working Group's review and suggestions for presentations and discussion topics, the NOAA team reached out to additional potential speakers from NOAA, ASCE, and other industry partners to round out the representation at the workshop.

ASCE conducted outreach to potential participants for the workshops via newsletter. NOAA also invited additional participants from previous product user tests and conferences. For the Compound Flooding Workshop, NOAA engaged insurance and reinsurance partners due to overlapping data needs. The insurance and reinsurance sector highlighted the need to incorporate engineering perspectives into potential solutions. This workshop collaboration allowed for cross-sector discussions on similar challenges faced.

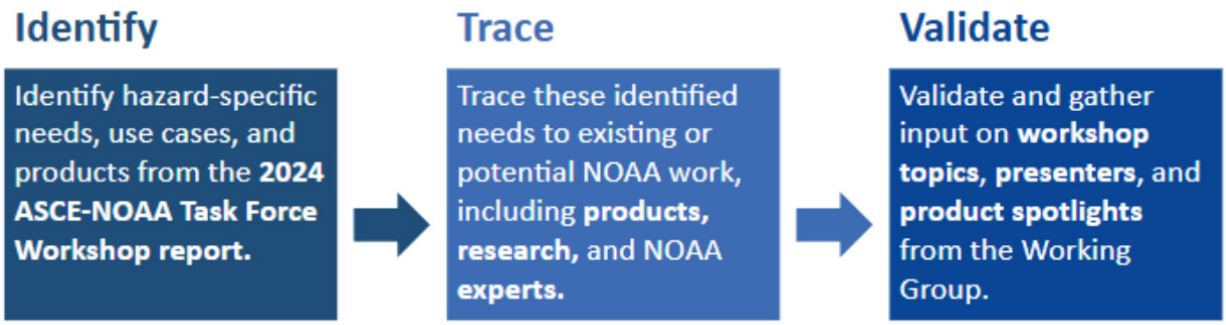


Figure 3. The Hazard Workshop Development Model outlines the process of planning and preparing for the workshop series in conjunction with the Working Group.

Appendix B. Data Sets Highlighted

Air Freezing Index

Atlas 14

Atlas 15

Climate at a Glance

Climate Atlas

Global Historical Climatology Network hourly/daily/monthly

Ice and Freezing Rain

Multi-Radar Multi-Sensor

National Climate Grid (nClimGrid) daily/monthly

National Water Model

U.S. Precipitation Time Series Explorer

Probable Maximum Precipitation Estimation Modernization

Regional Snowfall Index

Sea Level Rise Calculator

Sea Level Rise Viewer

Snowfall Extremes

Snow/Rain-on-Snow

Storm Events Database

Typical Meteorological Year

Appendix C. List and description of presentations focused on priority data needs

- Very high-resolution rainfall data are needed on even a 5- to 15-minute basis, which is one of the targets of the enhancement of Atlas 14 to Atlas 15. This update will include progressive changes in historical information along with projection information based on several simulation scenarios. Stormwater control and emergency management was highlighted as just one key example of this need, in light of the capacity of storm surges to rise rapidly.

- HNTB Inc. is working with the MRMS dataset to develop, in effect, a "digital rain gauge" for structural and transportation engineering. HNTB's Asset Level Rainfall Analyses Exercise allows users to retrieve high-resolution gridded data that point rain gauges may miss, especially when smaller-scale extreme events occur between gauge locations. The importance of this information was highlighted for comparative forensic analysis across space: for both the case when structures fail under extreme conditions and the case when structures withstand extreme conditions beyond their design criteria. This tool is available to the public through the NOAA Open Data Dissemination facility.

- Similarly, an important capability is that an analyst can retrieve precipitation data at both site and watershed scales, enabling upstream conditions that affect stream levels at particular locations, such as bridges along a floodway, to be evaluated along with conditions at a gauge site itself. This capacity depends to a degree on the size of the watershed targeted for analysis. The MRMS Operational Product Viewer was highlighted as a great way to look back at a particular event or to gather historical MRMS data for certain dates or durations.

- The NWM is a critical resource to understand the nature of streamflow behavior throughout the CONUS, along with coverage for the CONUS's East, Gulf and Pacific coasts and the coastlines of the Hawai'i, Puerto Rico, and U.S. Virgin Islands. By simulating observed and forecasted levels and operating on a 24/7 basis, the NWM provides high-spatial resolution analyses, at the scale of 30–75 meters, and forecasts ranging from 18 hours to 10 days. Real time analyses and forecasts are planned. Future updates in 2026 and 2028 will incorporate the SFINCS model to improve coastal inundation estimates.

- NOAA developed the PMP dataset to help determine and understand design considerations at the extreme high end of possible precipitation distributions. PMP guidance has become outdated over time, and precipitation has been significantly affecting aging infrastructure. To protect high-risk infrastructure from failure and prevent the design of projects according to incorrect estimates (either too high, adding expense, or too low, endangering the structure), NOAA is employing models, data, and understandings of PMP that have all been improved over the past decade. More fundamentally, and following a 2024 National Academies roadmap, NOAA is now evaluating a change in the definition: from maximum precipitation meteorologically possible for an area and duration to ultra-low AEPs within specified periods and utilizing high-resolution models that include non-stationarity. This updating of PMP's fundamental definition is important for resilience-based design amidst changing conditions.

- Icing can produce extreme loads and lead to catastrophic infrastructure failures, notably affecting electricity distribution and communications facilities. At the same time, icing is a difficult meteorological process to measure and model, in part because the nature of the surface on which icing occurs directly affects the ice accumulation itself. A high-resolution gridded icing product for the CONUS is now in development by NOAA's Northeast Regional Climate Center at Cornell University. It will inform the ASCE 7-22 standard, guidance from the ASCE Structural Engineering Institute, and the ASCE Hazard Tool.

- Similarly, complete-grid snow and rain-on-snow information is important, especially in regions where station data are sparse. NOAA OAR is sponsoring product development at Utah State University that include spatially-complete model simulations of snow water equivalent loads during both historical and future periods. This methodology allows ratios of future-to-past loads to be estimated in a consistent way, and is designed to reduce model bias that tends to be less in relative terms of load differences than in absolute terms of load amounts. The project is designed to inform the ASCE Hazard Tool, and it includes a key initial finding that the Upper Midwest (to Montana) and parts of the Northeast may need to increase snow load design considerations, while other areas of the CONUS may see a decrease in snow loads.

- NOAA's AFI product takes into account the duration and intensity of below-freezing air temperatures at specific locations during the freezing season. A key use for AFI is to determine required depths for frost protected shallow foundations, which are used directly and quantitatively to determine design parameters in ASCE standards such as ASCE32-01(R2025). NOAA's Cooperative Institute for Research In Environmental Sciences at the University of Colorado is updating NOAA's AFI product in terms of its fundamental mathematical methodology and in the context of a non-stationary climate. Preliminary results looking forward lead to decreases in the 100-year MRI (or 1% probability per year) of AFI for nearly all of the CONUS, in comparison to NOAA's current published estimates.

- NOAA and other agencies' Sea Level Rise resources provide users guidance on how water levels are changing and extrapolate forward multiple decades. In-depth access to the inter-agency information is available at earth.gov/sealevel and is aimed to enhance risk planning and design considerations in the context of rising levels. Plots show data for the last 50 years and five future scenarios, low to high, showing 0.3m to 1m global rise by the end of the 21st century. The interface shows both the distribution of estimates and what the rising sea levels actually look like; they tend to be higher along the East and Gulf Coasts than in Alaska and the West Coast.

- NOAA's Office for Coastal Management provides companion tools in the form of its Sea Level Rise Viewer and Sea Level Calculator. The Viewer visualizes inundation, taking into account existing surfaces, marsh migration, and high tide flooding. The Calculator is tailored for the A&E sector. It offers dashboards for regional observations such as: thresholds for comparative analysis; extreme water levels; flood frequency; and accounting for vertical land motion and contributions from melting ice sheets. Updates in 2026 will include reanalysis information and cross-referencing with Atlas 15.
- To address spatial completeness in a more general way, the University Corporation for Atmospheric Research is focusing on climate modeling concepts in the context of addressing limitations with ice load maps and simulations of future climate. Integration of ESMs with reanalysis products is targeted to supplement ground-based weather stations and provide wider, more complete spatial coverage, and also to deal with the limitation that ESMs do not output precipitation subtypes. An additional important, and undervalued challenge is to reduce barriers to data usage by engineers. The currently available model products are large and structured for use by climate scientists, but are generally not practical for engineering applications.

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Appendix E. Acronyms

A&E	Architecture and Engineering
AEP	Annual Exceedance Probabilities
AFI	Air Freezing Index
AK	Alaska
API	Application programming interface
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
ASOS	Automated Surface Observing System
CONUS	Contiguous U.S.
CRREL	Cold Regions Research and Engineering Laboratory
CSV	Comma-separated values
EPW	EnergyPlus Weather
ERA5	European Centre for Medium-Range Weather Forecasts Reanalysis v5
ESMs	Earth system models
ETMICC	Engineering Temperature Metrics Incorporating Climate Change
EWRI	Environmental and Water Resources Institute
FIRO	Forecast-Informed Reservoir Operations
GAM	Generalized Additive Model
GEV	Generalized Extreme Value
IDF	Intensity-Duration-Frequency
MOP	Manual of Practice
MOU	U.S. Historical Climatology Network

MRIs	Mean recurrence intervals
MRMS	Multi-Radar/Multi-Sensor
nClimGrid	National Climate Grid
netCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NWM	National Water Model
NWS	National Weather Service
OAR	Oceanic and Atmospheric Research
PMP	Probable Maximum Precipitation Estimation
PTE	U.S. Precipitation TIme Series Explorer
RTL	Reliability Targeted Loads
SCHISM	Semi-implicit Cross-scale Hydroscience Integrated System Model
SFINCS	Super-Fast Inundation of Coasts
SIFR	Snowfalls, icing events, and freezing rain
Task Force	ASCE-NOAA Task Force for Climate Resilience in Engineering Practice
TMY	Typical Meteorological Year
Working Group	NOAA Industry Initiative-ASCE Working Group

Working Together to Improve Resilience

NOAA collaborates with industry leaders to update and develop new data and observation products, including maps, interactive tools, and other datasets. By improving access to environmental data, NOAA connects decision makers with accurate, timely, and future-facing data products and services to support improved risk assessments and economic, community, and environmental resilience.

Together, we can empower safe, resilient, and cost-efficient decisions for short and long-term planning, which safeguards communities and the U.S. economy.



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