Value of Data: Natural Hazards and Disaster Risk Reduction Sector

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Purpose of Report

This report was developed in response to Task Order #1332KP19FNEEN0003 for the National Centers for Environmental Information (NCEI)[1] Science and Data Stewardship (SDS) Services Support under the Riverside contract #ST-1330-17-CQ-0058. NCEI directed the contractor to "develop case studies and success stories for user engagement that can be used to highlight its benefit across NCEI and externally for senior-level talks highlighting NCEI's growing understanding of user needs and value." This report focuses on the value that NCEI's data has on the sector of natural hazards and disaster risk reduction (DRR).

In an effort to ensure the safety, security, and well-being of our nation, significant federal resources are allocated to support hazard risk reduction and disaster management operations. This presents a unique opportunity for NOAA/NCEI to showcase the valuable role that the organization plays to support such activities. NCEI is responsible for the world's largest environmental data archive (climate, geophysical, coastal, and marine), and gaining a better understanding of how NCEI's data, products, and services are used to support risk reduction and manage disaster-related activities will help promote its mission for data stewardship.

Therefore, the purpose of this report is to provide NCEI with better insight into the types of data and information used by disaster risk reduction specialists, their needs, and improvements that can be made to help better serve this community of users. The DRR community and their data needs are particularly relevant, given that its members apply NCEI data and information to reduce lives lost and/or property lost during extreme weather events, as described by NCEI Billion-Dollar Weather and Disasters[2] product (Smith and Katz, 2013). In addition to the immense value that environmental data has on decision support for risk reduction, this report also showcases successful avenues for translating NCEI data and information into actionable plans and operational outcomes, with a particular focus on building a community of practice by leveraging opportunities for interorganizational coordination.

Methodology

The methodology used in this report entails the review of literature, case studies, and when necessary, informational interviews with organizations and professionals on the type of data and information at NCEI that are commonly used at the federal, state, and local level to reduce risk as well as effectively plan for and adapt to natural hazards.

Specifically, the methodology involves four primary activities, which include:

1) Identify data services, products, datasets, and data types that are commonly used to support disaster risk reduction activities pre- and post-event.
2) Conduct applied research in order to outline user needs.
3) Identify technologies the Sector uses to discover and explore environmental data in a decision-making context that NCEI might need to consider for future improvements.
4) Present an in-depth case study from the Sector.

[1] https://www.ncei.noaa.gov
[2] https://www.ncei.noaa.gov/access/monitoring/billions/

Executive Summary

In the sections that follow, this report highlights the depth and breadth of value derived from environmental data stored at NCEI, and how it plays a crucial role in supporting policy, planning, and decision making across the risk reduction and disaster management domain.

Section 1 introduces the necessity of data-informed decision making in the context of managing risks to natural hazards, and highlights value derived from commonly referenced tools and products that utilize NCEI data.

Section 2 captures value gained through the contributions made to long-term decision-making outcomes at the federal, state, and local levels. It references various governance initiatives informed by environmental data, products, and information archived at NCEI, including presidential executive orders related to climate action plans and financial risk disclosure, as well as FEMA's recently revised methodology for flood insurance rates. In addition, it provides examples at the state and local level of ways in which environmental data supports community planning and long-term decision making, including floodplain management efforts and disaster recovery programs aimed at building resilience to future risks.

Section 3 highlights how value of data and information can be leveraged through partnerships that promote a community of practice approach, specifically the externalities generated from the continuum of services used by a wide spectrum of users. Reducing risk and managing the impacts of hazards cannot be carried out by any sole agency or level of government. Rather, it requires support from a broad range of stakeholders that each bring their own knowledge and expertise. Such a community sheds light on the needs, capabilities, expectations, and assumptions of users across the environmental data and information, and in doing so, reveals insight needed to help bridge research to practice.

Section 4 addresses the importance of actionable data and information, including current practices that NCEI is doing to fulfill this need along with recommendations to enhance engagement and access to applications. As such, it highlights specific datasets and services commonly used by practitioners involved in managing risk to hazards, including outlining data needs and gaps in information expressed by users. In addition, this section provides examples of innovative ways in which the public sector leverages NCEI data and information to assess exposure to risk.

Section 5 focuses on innovative technology that sources environmental data archived at NCEI to support decision makers with better understanding risk exposure and avenues for improved asset management. It provides an overview of the increased demand for environmental data and technology and highlights the value that publicly accessible data from NCEI brings to the emerging sector of climate intelligence.

Finally, Section 6 presents a case study of the broad application of environmental data and information as it relates to preparedness, response, and recovery of wildfires. It addresses the use of NCEI's environmental data for modeling wildfire risk and covers innovative applications that offer improved forecasting during active incidents. By drawing on lessons learned and best management practices from 2021 California wildfire season, this section demonstrates the themes highlighted throughout this report, specifically how actionable data, innovative technology, community planning efforts, and strategic partnerships help reduce risk to wildfires and other natural hazards.

1.0 A Data-Driven Approach

> ***"At no other point in modern history has humankind faced such an array of familiar and unfamiliar risks and hazards, interacting in a hyperconnected and rapidly changing world" (UNDRR, 2022).***

Throughout the history of human settlement, natural hazards have remained a prominent threat for communities worldwide, thus requiring various management approaches ranging from regulatory policy to innovative mitigation measures, to autonomous adaptation approaches. As climate change brings increased uncertainty to future conditions, existing frameworks for managing risk to natural hazards may no longer be adequate. Therefore, assessing exposure and addressing underlying vulnerabilities will require strategic thinking, innovative technology, and improved partnerships for building resilience and adaptive capacity.

The vast amount of climate, marine, and geophysical information archived and maintained by NCEI is used by many diverse sectors of the economy. As the effects of climate change compound in the coming decades, the relevance and application of NCEI data to the field of disaster risk reduction is becoming more critical, especially for underserved, low-capacity communities who remain most vulnerable (NOAA, 2022).

Data-informed decisions improve the efficiency and success of DRR efforts through informed decision-making of policy officials, private companies, and consumers alike. NOAA and its partners have already developed numerous products and tools that utilize NCEI data to help assess exposure of potential hazards. Examples include the National Integrated Drought Information System (NIDIS)[3], Billion-Dollar Weather and Climate Disasters product[4], The Digital Coast[5], the U.S. Climate Resilience Toolkit[6], and Weather-Ready Nation[7]. In addition, NCEI data and information are used to improve forecasts and early warning systems and to improve decision-making, thus contributing to reduced losses of life and property. For example, coastal digital elevation models (DEMs) developed by NCEI are combined with historical tsunami data and used by the NOAA Tsunami Program to develop forecast models, enabling NOAA's Tsunami Warning Centers to issue timely warnings to communities that are in danger (NOAA, 2017).

And while these resources hold significant value across a wide range of users and stakeholders, such applications are well documented. Instead, this report intends to target data utilization across the field of natural hazards risk reduction that are less widely known, and in doing so, helps to identify value within NCEI that is not already accounted for. Such efforts highlight not only the many avenues in which the organization is able to serve the constituency, but also demonstrate meritable contributions to national objectives, which are crucial for budgetary considerations.

2.0 Long-term Planning & Decision Making

2.1 Various Federal Government Initiatives

Strategic policy, along with long-term planning and mitigation projects, remains a key avenue for implementing risk reduction measures. If properly executed, these initiatives not only save lives, but can

[3] https://www.drought.gov/
[4] https://www.ncei.noaa.gov/access/billions/
[5] https://coast.noaa.gov/digitalcoast/
[6] https://toolkit.climate.gov
[7] https://www.weather.gov/wrn/

also result in economic returns on investment and losses avoided over an extended period of time. For example, for every dollar expended today on flood hazard mapping, two dollars are subsequently saved (ASFM, 2020). Similarly, natural hazard mitigation measures have a six-to-one benefit ratio (FEMA, 2018). Such activities rely heavily on climate, ocean, and geophysical data, and utilizing the best science and data available is key to ensuring favorable outcomes.

Whether environmental data is being used to advocate for improved national objectives, implementing disaster recovery programs, or local floodplain management efforts, such decisions must be evidence based. The discussion below highlights various governance initiatives that are informed by environmental data and information archived at NCEI. These activities arise from federal, state, and local level planning and decision making, and in doing so, demonstrate NCEI's leadership in data stewardship as well as the value that the organization brings to our nation's security and safety of our communities.

2.1.1 4th National Climate Assessment

A number of initiatives aimed at assessing the impacts of climate change and risk to natural hazards have already been put forward. The Fourth National Climate Assessment is one of the most comprehensive and authoritative documents of its kind. It relies heavily on the science and data archived at NCEI in order to fulfill the federal mandate of analyzing "the effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity" (USGCRP, 2018). From GOES satellite imagery, to tropical cyclone tracks, to surface temperature data, and sea level rise scenarios, the observational and modeling datasets archived by NCEI are used to develop the most up-to-date assessment of climate change impacts threatening the country. In doing so, the National Climate Assessment not only informs the decision-making process across agencies at various levels of government, but it also provides additional stakeholders in the public and private sector with an accurate evaluation of climate risks so that they are equipped to take necessary actions to protect their assets. Such a report has significant value to long-term governance strategies, private investments, and economic returns; all of which shape community well-being.

2.1.2 Executive Order 14008: Tackling the Climate Crisis at Home and Abroad

Climate data sources must be continuously monitored and updated—with consideration of the operational impact—to account for the rapid rate of climate change and its impacts. All other actions in this plan are dependent on the outcomes of this effort.

On January 27, 2021, the Biden Administration announced Executive Order (E.O.) 14008 *Tackling the Climate Crisis at Home and Abroad*[8], which declared a government-wide approach to ensure that climate change considerations are reflected in all federal strategies and policies for every sector of the economy. In addition, Section 211 stipulates that all major federal agencies develop Climate Action Plans that outline respective vulnerabilities as well as efforts made to improve operational stability, bolster adaptation, and ensure climate readiness. A number of these plans highlight the importance that climate data has on the success of agency implementation.

[8] https://www.federalregister.gov/documents/2021/02/01/2021-02177/tackling-the-climate-crisis-at-home-and-abroad

For example, the Department of Defense's Climate Action Plan states, "Climate data sources must be continuously monitored and updated—with consideration of the operational impact—to account for the rapid rate of climate change and its impacts. All other actions in this plan are dependent on the outcomes of this effort" (Department of Defense, 2021). Additionally, the Army Corp of Engineers (USACE) Climate Action Plan states that the organization "relies on multimillion-dollar federal investments in science agencies to produce climate data and research for USACE to use in support of adaptation actions and investment decisions. USACE aggregates, integrates, and translates this science into actionable information for USACE decision-makers" (USACE, 2021). As environmental data continues to be used to support policies, plans, and decision-making for how we manage natural hazards and the impacts of climate change, the value of such data will continue to increasingly substantiate over time.

2.1.3 Executive Order 14030: Climate Related Financial Risk

With the signing of E.O.14030 of May 20, 2021, *Climate-Related Financial Risk*[9], the Office of Management and Budget (OMB) is now obliged to account for climate-related risks in federal financial management and reporting. In their recent assessment of federal budget exposure to climate risk, OMB (2022) determined that the federal expenditures could increase from $25 billion to $128 billion annually as a result of just six climate-related financial risks: disaster relief, flood insurance, crop insurance, healthcare expenditures, wildland fire suppression spending, and flood risk at Federal facilities. In this report, OMB repeatedly references NOAA data and NCEI's Billion Dollar Weather and Climate Disasters product and mentions OMB and NOAA's coordination efforts to assess inundation risk to federal buildings and structures located on the coast. As efforts made to disclose climate-related financial risk become more mainstream, the demand for reliable and up-to-date environmental data will only continue to grow.

2.1.4 NFIP Risk Rating 2.0

In 2021, FEMA announced that it was updating its flood insurance rating methodology in order to ensure more equitable pricing for households participating in the National Flood Insurance Program (NFIP). This new methodology claims to leverage innovative technology that will establish rates that more accurately reflect a property's flood risk (FEMA, 2022). Furthermore, it accounts for additional flood risk variables, including type of flooding, flood frequency, distance from water, structure's replacement cost value, and height of the lowest floor relative to the base flood elevation (Horn, 2022). This undertaking represents a unique data partnership between NOAA, FEMA, and USGS. Specific NCEI data included national shoreline data and NOAA's National Centers for Coastal Ocean Shoreline shapefiles (FEMA, 2021).

2.2 Community Planning and Long-term Decision Making

The value of data is inherent to its application. This includes not only how the data is utilized, but also at what scale, across what scope, and governed by what rules and conventions. The more that environmental data is able to inform the operational process of human systems, the more valuable it becomes. This is especially true at the state and local level where decision makers rely on such data to help them manage complex social-environmental systems. The examples below demonstrate a range of such applications, in addition to showcasing the important role that environmental data plays when managing risk in hazard prone areas.

[9] https://www.federalregister.gov/documents/2021/05/25/2021-11168/climate-related-financial-risk

2.2.1 Floodplain Management Efforts

The Association of State Floodplain Managers (ASFM) was established in 1977 with the intent to educate policy makers on effective floodplain management practices that include flood mapping, mitigation planning, and resilience building initiatives. ASFM has more than 20,000 national and state chapter members that work throughout the public, private, and academic sectors, and it is also responsible for implementing the national Certified Floodplain Manager (CFM) program. The CFM certification program tests the professional competency of floodplain management, including topic areas on floodplain mapping, flood hazard mitigation, and NFIP regulatory standards (ASFM, 2022). In addition, the ASFM publishes the Flood Mapping for the Nation report, which estimates the amount of funding it would cost to complete flood hazard mapping for all communities in the United States. As stated in the report, the National Flood Mapping Program relies on accurate ground elevation data, NOAA's shoreline data, and modeling that incorporates the best available climate science on coastal inundation, storm surge, land subsidence, coastal erosion hazards, changing lake levels, and other related flood hazards. Because only a third of U.S. rivers and streams are currently mapped with flood hazard information, understanding the investment needed to comprehensively update and maintain the entire Nation's flood map inventory is a vital step forward for reducing risk to future impacts (ASFM, 2020).

2.2.2 Disaster Recovery and Resiliency Programs

According to the World Bank (2017), disasters cause approximately $300 billion in economic losses every year. When accounting for the impacts on well-being, that number rises to a staggering $520 billion per year. Furthermore, approximately 25 percent of businesses do not reopen after a disaster (FEMA, 2018). Knowing that natural hazards and the impacts of climate change will continue to occur in the future, efforts focused on managing these threats and reducing future risk will require the best available data to inform decision making for individuals, communities, businesses, and governments (Shea et al., 2021). As an authoritative leader of environmental data, NOAA NCEI remains a valuable resource for decision makers performing pre-event planning, hazard mitigation, emergency response, and disaster recovery activities. The two examples below demonstrate not only the critical need for evidence-based decision making, but also the many ways in which environmental data is being used to reduce risk to natural hazards. Capturing the benefits accrued is of value considering the amount of government expenditures aimed at ensuring the safety, security, and well-being of our Nation[10]. NCEI should promote the value it can lend to these efforts (Shea et al., 2021).

2.2.3 Puerto Rico's GeoFrame Program

In 2017, Puerto Rico was devastated by Hurricane Irma and, again two weeks later, by Hurricane Maria. The Department of Housing and Urban Development (HUD) awarded them over $18 billion in 2018 to help support long term disaster recovery efforts (HUD, 2018). Of that total, $50 million has been earmarked for the Puerto Rico Geospatial Framework (GeoFrame) Program[11] with a goal of developing a comprehensive spatial data infrastructure for the island. Shortly after the disaster, it became apparent that the existing land use, land administration, and gaps in spatial data were constraining response and reconstruction efforts.

[10] According to HUD's Climate Action Plan (2021), Congress has appropriated a total of $89.8 billion for grant funding for CDBG-DR since 1993, and $16 billion for CDBG-MIT since 2019.
[11] https://cdbg-dr.pr.gov/en/puerto-rico-geospatial-framework-geoframe-program/

> Inaccurate and inaccessible spatial information in Puerto Rico crippled emergency responders during Hurricanes Irma and Maria and resulted in response teams wasting critical time trying to navigate unmapped roadways. Puerto Ricans were isolated by landslides and flooded waterways, and many homes without physical addresses, or homes that were informally constructed, unregistered, and unknown outside the immediate community, were unable to be reached. A comprehensive, secure, and interoperable spatial data infrastructure that provided accurate baseline information did not exist. (PRDOH, 2022)

With these funds, the GeoFrame program is intended to increase transparency and access to land use and geospatial data for improved evidence-based decision making (PRDOH, 2022). The program is currently in its initial development phase, offering a unique avenue to explore to establish partnerships for coordinated data stewardship efforts.

2.2.4 Louisiana Watershed Initiative

The Louisiana Watershed Initiative (LWI)[12] was launched in 2018 by Louisiana Governor John Bel Edwards. HUD allocated over $1.2 billion of Community Development Block Grant Mitigation (CDBG-MIT) funds to LWI to support a statewide flooding mitigation project. This is particularly critical in Louisiana, where 51% of the state has been designated as a Special Flood Hazard Area by FEMA[13]. LWI approaches flood mitigation at the watershed level, breaking the state into eight regions based on its major waterways rather than political parish or local-level barriers. LWI is also set apart from other statewide mitigation efforts by its data-driven approach (L. Robertson, personal communication, April 8, 2022), using computer models to assess flood risk and choose cost-effective mitigation projects. Two projects that the LWI is currently pursuing to help address the lack of reliable flood-risk data are the Statewide Data and Modeling Program and the River and Rain Gauge Network initiative. NOAA remains a collaborative partner for these efforts, along with USGS, Department of Environmental Quality, University of Louisiana at Lafayette, and Tulane University.

3.0 Community of Practice

In a March 2022 Environmental and Energy Study Institute seminar entitled “Climate Adaptation Programs Across Federal Agencies”, Mark Osler, NOAA Senior Advisor for Coastal Inundation and Resilience, said:

> “Resilience, in all senses, is local in its essence. It is a condition that individuals or organizations or systems work towards achieving. From a Federal government and agency perspective, it is an outcome achieved by others. It is not a product which can be created and then delivered by the Federal government… Our charge is not to solve these challenges on behalf of our communities, but rather for the Federal government to bring its human, fiscal, legal, and policy resources to bear in a manner designed to lift up and support our State, local, tribal, and territorial governments in understanding and engaging with these challenges on their own terms, within the context of their geography, their history, their priorities, and their own self-defined aspirations for the future.”

Promoting resiliency and influencing actions geared toward hazard risk management requires interdependent engagement that extends beyond policy officials and decision-makers. Incorporating

[12] https://watershed.la.gov/
[13] https://watershed.la.gov/faq

diverse stakeholders from various sectors and institutions provides a holistic lens for analysis, where knowledge sharing can be utilized to better manage risk reduction under conditions of uncertainty. This includes various levels of government in addition to stakeholders from the private and public entities, including local citizens, Indigenous communities, universities, and small businesses (Smith, 2011).

NOAA NCEI plays a pivotal role in providing such support to states, tribes, and local communities. NCEI data and information have value to a diverse group of researchers, practitioners, companies, and other stakeholders in the disaster risk reduction sector. These different user groups have varying capabilities and needs when it comes to working with NCEI environmental and climate data. Some user groups work with raw data downloaded directly from NCEI or other sources. Other user groups lack the data science expertise and/or computational resources, and instead, rely on data solution tools and products to tailor the information properly, both geographically and temporally, for their scope (L. Hilberg, personal communication, March 30, 2022; A. Joyner and W. Tollefson, personal communication, April 29, 2022; K. Spidalieri, personal communication, March 30, 2022; OCM, policy staff interview, April 20, 2022). Often, these products function as visualization tools to help make data more easily consumable for non-experts.

Equally important is the awareness that certain data and tools are not always accessible and/or usable for underserved communities, for a variety of reasons including lack of technical expertise, inadequate funding, staffing limitations, etc. (Glavovic and Smith, 2014; K. Spidalieri, personal communication, March 30, 2022), and that the exclusion of these communities can perpetuate injustices related to hazard risk and the ability to manage them effectively (Bullard and Wright, 2009). Ensuring that decision support data is equitable, and representative of user needs[14] strongly aligns with NOAA's recently published Strategic Plan[15]. One of the three overarching priorities identified by NOAA is the integration of equity into the organization's core operations. This includes "improving service delivery and leveraging customer experience tools to ensure that new products and services consider the needs of underserved and vulnerable communities, help build trust and are effective and user-friendly" (NOAA, 2022, p.41).

Such a community would not only foster deeper, more meaningful engagement, but also shed light on the needs, capabilities, expectations, and assumptions of users across the environmental data enterprise. Doing so would reveal the strengths, limitations, and gaps needed to help bridge research to practice.

To enhance the value of NCEI data, a comprehensive continuum of services that meet the needs of the DRR community is required. The development of these services requires engagement and shared learning beyond NOAA/NCEI staff, their partners, and data scientists. A more unified *community of practice* – involving NCEI archivists, data scientists/researchers, academia, legal/policy experts, state and local community leaders, private sector, and other stakeholders – could benefit the DRR sector and the public who rely on it. Such a community would not only foster deeper, more meaningful engagement, but also shed light on the needs, capabilities, expectations, and assumptions of users across the environmental data enterprise (WMO, 2022; Opitz-Stapleton et al., 2021). Doing so would reveal the strengths, limitations, and gaps needed to help bridge research to practice.

[14] Resources can be found through the Environmental Data & Governance Initiative at https://envirodatagov.org/. For guidance on data infrastructure and racial equity, refer to Hawn Nelson et al. (2020). A Toolkit for Centering Racial Equity Throughout Data Integration.

[15] https://www.noaa.gov/sites/default/files/2022-06/NOAA_FY2226_Strategic_Plan.pdf

"The value of NOAA's data depends on its quality, integrity, and the ability of users to access and use the data with modern, emerging, and innovative cloud-based services." – Neil Jacobs, Ph.D., former acting NOAA administrator.

The institutions, individuals, and agencies who contribute to the US National Climate Assessment, including the regular assessments of the Intergovernmental Panel on Climate Change, are an example of a community of practice that involves NCEI. Another example is the growing community of state and city resilience offices, their staff, and community partners. Hackathons, as described below, also serve as a unique opportunity to foster a community of practice approach by leveraging expertise from various disciplines to reveal a new, innovative solution to an existing challenge.

3.1 Hackathons

3.1.1 Use Case: Insights from Hackathons

Hackathons are an increasingly common example of a community of practice at work. Generally, a hackathon is an event where participants are provided with datasets, a problem, and an objective to develop code or models that will outperform a provided baseline measurement to predict or address the assigned problem. These events encourage academic and computer programming communities, who may not typically work with specific datasets or otherwise tackle certain problems, to think creatively about analyses and solutions.

The NOAA Center for Artificial Intelligence (NCAI) has hosted an AI workshop for the last several years and has included a hackathon component that is jointly organized with the Climate Informatics[16] community. Topics for these hackathons range from Colorado wildfire risk estimation, marine heatwave prediction, fire weather, and interoperable Digital Twin Earth[17,18]. Additional hackathons focused on risk reduction also take place outside NOAA. For example, the Amazon Web Services (AWS) Disaster Response Hackathon[19] took place from December 2021 through February 2022 and offered up to $54,000 in prizes to the winning teams who put forth innovative machine learning solutions that address the threat of natural hazards. Nearly 1,500 individuals participated, and topics included wildfire mitigation, thunderstorm prediction, earthquake response, and the improved allocation of relief resources. One of the winning teams developed a fire spread prediction system that utilized NOAA NCEI Visible Infrared Imaging Radiometer Suite (VIIRS) satellite data.

Hackathons hold great potential for not only improving operational decision making, but they also offer a mechanism for a broad range of data users and specialists to collaborate to solve complex challenges. Recognizing that the solutions generated from these events are of interest to practitioners in the DRR domain, the NCAI and Climate Informatics hackathon will hopefully be restructured in 2022 to incorporate end users into working groups (Y. Rao, personal communication, March 9, 2022). The goal of this change is to increase the explainability of machine learning models, which are often described as a "black box" where data goes in and results come out without much understanding about how these results were generated, particularly for end users of the models (Y. Rao, personal communication, March 9, 2022; Jain et al., 2020). As described by VanderMolen and colleagues (2019), it is also valuable to involve users in

[16] http://www.climateinformatics.org/
[17] https://2021noaaaiworkshop.sched.com/event/IVkA
[18] https://www.noaa.gov/ai/events/4th-noaa-ai-workshop
[19] https://awsdisasterresponse.devpost.com/

the development of tools because they can ensure that the final product is useful, which, in the DRR field, requires that the data and results be translatable into actions.

4.0 Actionable Data

In 2019, NCEI hosted a conference to gather user needs and feedback from the community. In the subsequent conference report, Brewer, and colleagues (2020) stated:

> The overarching requirement defined the need for a straightforward, web accessible data platform that provides all available data, globally and updated frequently, at the highest possible resolution in a standardized format. The platform should provide user-defined customization options, data layers, and analytic capabilities. Essentially, allow users to analyze NCEI's data on the fly, apply multiple data types, and select only the ranges needed, bringing the analysis to the data instead of requiring users to find, download, reformat, subset, and merge data types to perform client-side analytics.

The delivery of such a platform by NCEI would be a significant undertaking for the organization, yet, at the core of what the users want is *actionable data*. In order to translate NCEI data into usable, actionable knowledge for end users, data must be easily accessible, meaningfully scaled down, and more than likely, changed into a visually impactful format that is easily understood by specialists from diverse disciplines. This is especially true in the fields of natural hazards risk reduction and disaster management where the speed at which strategic decisions are made carries enormous weight and repercussions (Olshansky et al., 2012; Smith et al., 2018). Therefore, this transformation from data into actionable information serves as an important lifeline for decision makers, and value can be enhanced through both internal practices at NCEI and those external to the organization.

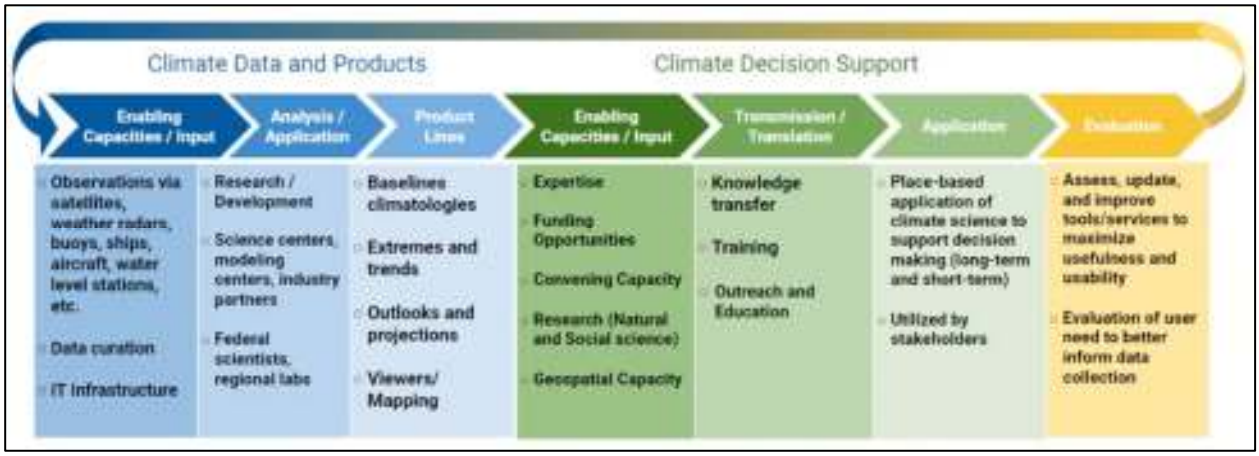

Figure 1. The flow of data from collection to curation into actionable knowledge for users. Source: Mark Osler, NOAA [EESI seminar "Climate Adaptation Programs Across Agencies" March 18, 2022

4.1 Internal Value Across NCEI, NOAA, and Other Government Levels

Several different interviewees cited the importance of cross-NOAA and interagency collaboration to develop data products and tools (OCM, policy staff interview, April 20, 2022; A. Joyner and W. Tollefson, personal communication, April 29, 2022). This allows different agencies or offices to contribute their own unique data or insights to development and eliminates the possibility of duplicating efforts to fill the same community need. In these collaborations, it is also critical to engage with end users to ensure that the

products being developed adequately address their needs. This does not entail simply sharing an end product with users for feedback, but instead, true co-development from start to finish with iterative user feedback (VanderMolen et al., 2019; A. Joyner and W. Tollefson, personal communication, April 29, 2022). While there are some hazard or community-specific tools already available from NOAA and its federal partners, further collaboration across and within agencies, as well as with stakeholders at different levels in the DRR field (academics, regional and local decision makers), could improve the breadth and scale of available resources.

For example, in the field of hazard risk reduction and disaster management, the FEMA Geospatial Resource Center[20] database may be a worthwhile partnership for facilitating information sharing and the pursuit of actionable data. The database provides access to geospatial information, services, and technologies useful for decision makers before, during, and after a disaster. As stated on their website, the goal of FEMA's Geospatial Resource Center is "to make content provided by us and our governmental, private sector and volunteer agency partners, including HHS, Census, NASA, and many others, easy to retrieve, and visible to everyone" (FEMA Geospatial Resource Center, n.d.). Value can be enhanced by coordinating with FEMA to ensure that relevant data archived at NCEI is accessible to a broader audience, thereby furthering data stewardship and interorganizational coordination.

A tiered liaison approach may also be effective in not only communicating the needs of diverse user groups, but also helping users navigate relevant datasets. State climate offices or other local, public climate entities can act as climate information brokers when researchers, private companies, or local or state agencies have data requests (A. Joyner and W. Tollefson, personal communication, April 29, 2022; S. Stapleton, personal communication, March 20, 2022). However, in cases where these state or local brokers are unsure of where to access specific datasets, a Federal liaison would be helpful in pinpointing the appropriate resources. This could be the role of Regional Climate Service Directors (RCSDs) or another position within NOAA/NCEI (e.g., SDS customer engagement team) that requires in-depth knowledge of NCEI's archive and the data and information needs of particular user groups (A. Joyner and W. Tollefson, personal communication, April 29, 2022; OCM, policy staff interview, April 20, 2022).

4.1.1 Visualizations

Based on interviews, the majority of users from the field of DRR do not go to NCEI to access datasets and run analyses. Instead, they access this information from other tools and portals, as described in SECTION 4: Actionable Data. Many platforms and services that users go to for data share a similar quality - the use of visualizations. Visualizations allow data to be more easily understood and consumed by non-technical users. Billion-Dollar Disasters, Digital Coast, Climate Explorer, and Climate.gov were all mentioned by interviewees as resources often utilized by practitioners (L. Hilberg, personal communication, March 30, 2022; K. Spidalieri, personal communication, March 30, 2022; OCM, policy staff interview, April 20, 2022). One participant explained that they prefer these resources because they can instruct local DRR practitioners on how to utilize the tool, thus empowering them to explore and analyze the data themselves. (L. Hilberg, personal communication, March 30, 2022).

[20] https://gis-fema.hub.arcgis.com/

4.1.2 Data Requested from Risk Management Practitioners

Some interviewees had specific requests for high-resolution datasets that would help with better forecasting, scenario planning, and adaptation efforts. Some of these may be possible for NCEI to provide, but others would be supplemental information that can be made available through other federal, state, local, or private partners. High-resolution spatial representations of future precipitation (<1 km spatial scale), high-resolution aerial photography for urban areas that is regularly updated (or nonurban areas, especially after disaster events), high accuracy digital elevation models that are updated with the most recent elevation data, and long-term inland, riverine flooding projections that account for climate change were all requested by users (OCM, policy staff interview, April 20, 2022; S. Fletcher, personal communication, March 25, 2022; L. Hilberg, personal communication, March 30, 2022).

Supplemental, non-environmental data were also requested by some interviewees, such as building footprints and structure specifications, national parcel data, population, and migration data. (T. Parris, personal communication, March 22, 2022; OCM, policy staff interview, April 20, 2022; K. Spidalieri, personal communication, March 30, 2022; C. Grant, personal communication, March 25, 2022). Although such data falls outside the purview of NCEI, these data are useful in the development of products or tools for users. It can also be beneficial to provide links to federal, authoritative sources for these datasets, if available, to help users who are having difficulty with data access. Again, this could be a role for information liaisons from other state or federal agencies that collect and archive data to help users locate resources.

4.2 External Value Beyond NOAA and Government Entities

For a variety of reasons, many users access NCEI-derived data through alternative sources. Academic researchers and geospatial analysts with federal, state, or private companies may choose to access NCEI data through other sources because it is served in a way that is ready to use. For example, PRISM Climate Group[21] and WorldClim[22] are commonly used because they provide gridded raster datasets (Fick and Hijmans, 2017; Daly et al., 2000). For users further downstream, they may choose to access NCEI-derived data via portals that are capable of high-resolution mapping. NC One Map, ArcGIS Living Atlas of the World, NIDIS, Climate Explorer and the U.S. Climate Resilience Toolkit, and the NOAA Digital Coast are all examples of different websites where users access data that has been more filtered (geographically, spatially, and by hazard) to cater to their needs.

Additionally, users may access NCEI-derived data via climate services provided by private companies. These companies add value to existing public environmental data by integrating supplemental data (e.g., demographic, built environment, etc.), scaling data down, producing dynamic visualizations, and providing insights into how the resulting information impacts their customers and their decisions.

For example, ISciences, a scientific consulting company, launched their Data Analytics and Tools for Ecosecurity (DANTE) platform in 2019. This platform was co-developed with the Center for International Earth Science Information Network at Columbia University and CASE Consultants International (ISciences, 2019). It combines environmental data with demographic, economic, and health data to inform users about the implications of environmental stresses on security issues, including resource conflicts, mass migration, and political instability. The DANTE platform is open-source and acts as a depository for

[21] https://prism.oregonstate.edu
[22] https://www.worldclim.org/

datasets, tools, and literature relevant for academics and practitioners of the environmental-security enterprise. Datasets accessible with DANTE tools include elevation data (DEMS), historical precipitation, and Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat data.

Temblor, Inc.[23] is a catastrophe modeling company that assesses seismic risk. Their website and phone app allow the public to visualize the projected seismic risk based on one's location, estimated damage costs in the event of an earthquake, and lists insurance companies that provide earthquake coverage. First Street Foundation developed Flood Factor[24], another free, online tool that assesses property flood risk over time and estimates the costs of damage in the event of flooding. This tool, in addition to their recently released Fire Factor tool that assesses wildfire risk for homeowners, makes use of NCEI data to better inform property owners of their exposure.

These examples demonstrate value derived from external entities that utilize data archived at NCEI to educate individuals of their exposure to potential hazards and are therefore important for the data ecosystem in DRR and other sectors. Compared to government agencies, the private sector is better equipped to respond quickly and agilely to the needs of the public and businesses. These companies meet the needs of a variety of different user groups without reliance on one entity (NOAA) to create every product. At the same time, gaps in the private sector exist around data access and inclusion, thus highlighting the importance of organizations like NCEI who are better equipped to democratize climate data through free tools and platforms. Collaboration and the exchange of knowledge between these groups can provide greater insight into addressing issues of data equity and the needs of underserved communities.

4.3 Mesoscale Data Gap Improvements

Finer grain data provide more thorough insight into extreme weather events by providing information about small scale variability. In the field of risk reduction and disaster management, smaller scale resolution improves models that feed into risk assessments and hazard mitigation plans (A. Joyner and W. Tollefson, personal communication, April 29, 2022). For example, The Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)[25], a community science effort to record precipitation data, was prompted after the Spring Creek flood in Fort Collins, Colorado in 1997 (Colorado Climate Center, 2022). During this storm, the rainfall variability across the local area was approximately 12.5 inches, with 14.5 inches total on the hardest-hit area over 30 hours (Grigg et al., 1999). This is roughly the equivalent of the yearly rainfall average for this area, and yet, no warnings were issued because minimal data was reported to the NWS during the event. This resulted in the loss of five lives, the destruction of 200 homes, and damages to 1,500 structures in the town (Grigg et al., 1999).

The August 21, 2021 flooding in Tennessee further highlighted the importance of mesoscale observational data in improving climate services for communities. In this storm, approximately 21 inches of rain fell in 24 hours, resulting in the death of 20 people (Eggers & Bruggers, 2022). Tennessee is one of fifteen states in the country without a mesoscale observation network, but the 2021 flooding event illustrated the need for such funding and the value that an automated, real-time weather station brings (Eggers & Bruggers, 2022; A. Joyner and W. Tollefson, personal communication, April 29, 2022). The Tennessee State Climatologist and Assistant State Climatologist, Dr. Andrew Joyner, and Dr. Wil Tollefson, are leading an

[23] https://temblor.net/
[24] https://floodfactor.com/
[25] https://cocorahs.org/

effort to establish a mesonet, which would support the NWS with creating more targeted, timely warnings for the state.

While the primary function of mesoscale data is to help provide more specific, timely warnings prior to and during extreme weather events, they also serve another valuable purpose for climate scientists. They can also play a fundamental role in ground truthing data when evaluating the accuracy of downscaled datasets. For example, the Oklahoma Mesonet assessed the accuracy of satellite-derived Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) by comparing these estimates to their mesoscale soil moisture observations (Gu et al., 2008). These measures are commonly used for drought and wildfire monitoring, but they are also used for a myriad of other scientific research applications, thus demonstrating why actionable data holds such value for hazard risk reduction specialists.

5.0 Innovative Technology and the Future of Risk Intelligence

5.1 Increased Demand for Environmental Data and Technology

> ***"Where there is data smoke, there is business fire."***
> ***– Thomas Redman, president of Data Quality Solutions***

As the impacts of extreme weather continue to manifest, the reliance on and utilization of environmental data for policy and operational decision making will only expand over time, thus substantiating the value of organizations like NCEI who archive and steward such information. The ability to manage and provide this valuable service will require innovative approaches to ensure accessibility and sufficient storage capabilities. The recently released NOAA Cloud Strategy report (2020) states that "the volume and velocity of our data are expected to increase exponentially…[and] modernizing our infrastructure requires leveraging cloud services as a solution to meet future demand." The decision to partner with cloud service providers was driven not only by the expectation of reduced costs associated with storage, computation, and data distribution, but also the increase in IT provisioning speed, scalability, and necessity of high-level security (NOAA Central Library, 2021).

The shift to cloud-based data and services is unfolding at a time when the demand for environmental data has never been higher. Investments in climate technology represented 6% of global annual venture capital funding in 2019, which is not only an increase of 3750% in absolute terms since 2013, but this growth rate is three times that of venture capital investment into artificial intelligence (PwC, 2021). This presents a unique opportunity for organizations such as NCEI to leverage their expertise and services so as to improve environmental data stewardship through the application of emerging technology and analytical methodologies. Providing strategic guidance as well as promoting meaningful partnerships that aim to equip governments, businesses, and consumers in asset protection and risk management will extend value to not only NCEI's data, but to the organization itself.

5.2 Climate Intelligence

Technological advancements are capable of not only capturing risk exposure across an area, but certain methods are now better suited to account for uncertainty, and as a result, can be extremely valuable for decision making purposes. This is especially true with private sector innovations that center on managing financial assets as they relate to climate uncertainty and risks posed by natural hazards. According to a study published in *Nature Climate Change*, up to $24.2 trillion (or 16.9%) of global financial assets could

be at risk due to climate change (Dietz et al., 2016). Better understanding of the nuances of exposure and vulnerability can aid in the logistical and operational management of both the public and private sector.

As the demand for climate-related data and information continues to grow, so too does the climate service industry, which in 2015 was valued at $2.6 billion worldwide and growing between a rate of 6-10% per year (Environmental Business International, 2020 as per Dembicki and Ensia, 2019). While governments have been at the forefront of providing tools and necessary services, the private sector is emerging as a key player within the industry where they are able to leverage existing data and financial capital in an effort to fulfill an identified gap in service. In their 2020 report on managing climate risk in the financial system, the U.S. Commodity Futures Trading Commission argued,

> At the heart of efforts to make climate-related data more accessible are two objectives, which can at times be in tension with each other: the expansion of public open access to climate data on one hand, and the development of proprietary intellectual property related to climate data and services, on the other. … [Proprietary intellectual property] technologies and services are necessary to facilitate the data underlying climate risk management and disclosure. In recent years, increased investment in climate data technologies has been a positive sign for the commercialization of underlying intellectual property and the recognition in the private sector of its value. The challenge ahead will be to balance both the public and private objectives in the interests of both transparency and innovation. (p.60)

Climate intelligence is an emerging service that analyzes large-scale environmental datasets for informed decision making. With the aim of making weather data actionable, climate intelligence utilizes the science and technology of artificial intelligence and machine learning to process and scale down climate risk data to the local and asset level. In doing so, businesses are more equipped to monitor their exposure to climate hazards, and if necessary, manage such risks through appropriate mitigation or adaptation measures (Yeoh et al., 2021).

Companies such as Tomorrow.io, Jupiter Intelligence, Cervest, Everbridge Inc., and the Climate Service are emerging players in the climate intelligence industry. Their analytics platforms analyze billions of environmental data points to help governments and businesses identify early warning signs of extreme weather and predict operational impact. These groups rely on publicly accessible datasets from NOAA, NASA, ECMWF, and CMIP6 to help inform their analysis. In a report published by the Institute for Global Environmental Strategies, "Federal geospatial data and satellite images are integrated into the organization's products and services… [as well as] supplemental mission specific data from other free sources when appropriate, such as traffic data, insurance reports, citizen science, and other government-sponsored and commercial satellite images. Without the magnitude of freely-available data, these companies would not be as successful (Colleton and Plescha, 2021).

Within the magnitude of freely-available data, these companies would not be as successful.

5.2.1 Use Case: Pacific Disaster Center

One unique partnership in the disaster intelligence enterprise exists between the University of Hawaii's Pacific Disaster Center (PDC Global) and Tenefit, a software development company that specializes in

cloud-based infrastructure and scalability. Their risk and intelligence platform, DisasterAWARE[26], is used by decision makers and professionals around the world to provide global early warning and decision support tools in the event of a natural hazard emergency. Not only does DisasterAWARE provide real-time data analytics to potential disruptions, but it is free for disaster management practitioners and the humanitarian assistance community (PDC Global, 2022). Similar to other risk intelligence platforms, DisasterAWARE utilizes a wide range of environmental and social datasets and products, including those stored at NCEI. According to Cassie Stelow, PDC Global's acting Director of Information Technology, specific NOAA NCEI datasets and products include global recent earthquake locations, historical earthquakes, historical tornado and storm statistics, global surface anomalies, sea ice and snow cover extent, and US historical wildfires (personal communication, June 14, 2022).

6.0 Reducing Wildfire Risk: A Case Study Exploring the 2021 California Wildfire Season

The area where habitable structures are intermixed with undeveloped lands of natural vegetation is regarded as the wildland-urban interface (WUI), and as these areas continue to grow, so does wildfire risk (Radeloff et al., 2015). This proliferation of humans living in previously undeveloped areas, combined with climatic changes that make fire weather more likely, will result in increased occurrences of extreme wildfire in the coming decades (Parks and Abatzoglou, 2020; Joseph et al., 2019; Coogan et al., 2019; Turco et al., 2018; USGCRP, 2018).

Using historical climate data archived by NCEI (e.g., monthly average daily maximum temperature and monthly average daily vapor pressure deficits), along with different general circulation models (GCMs) under different emissions scenarios, researchers from the USDA Forest Service estimated acres burned and the cost of wildland fire suppression on Federal lands in the coming century. Their analysis found that by mid-century (2041-2059), the median result was a $1.67 billion annual increase in wildland fire suppression expenses. For late-century (2081-2099), the median increase was $3.71 billion per year (OMB, 2022). The analysis performed was only for expenditures to the Forest Service and the Department of the Interior and does not include State or private lands. Wildfires are an ongoing, severe threat that will only worsen with climate change, resulting in higher fire suppression costs for land managers at all levels. However, the application of NCEI data and products are a key defense that can be leveraged to help inform plans aimed at mitigating wildfire risks.

6.1 Data Uses and Improvements in Managing Wildfire Risk

Modeling wildfire risk and forecasting the spread of active fires are critical measures that can reduce the loss of lives and property by enabling emergency managers to strategically plan how to use their often limited resources, in addition to assisting land managers with planning for and targeting fuel treatment efforts (Ager et al., 2006; Singla et al., 2020). Prior work in wildfire modeling generally used physics-based modeling approaches (Andrews, 2007; Finney, 1998; Rothermel, 1972). Newer developments in wildfire risk modeling rely on more data-driven approaches, incorporating machine learning algorithms that use environmental data from different sources as predictors (Jain et al., 2020).

Remotely sensed data from satellites – such as NASA TERRA, NASA AQUA, NOAA GOES, and NASA/NOAA Suomi NPP – play a key role in new wildfire risk modeling techniques (NASA, 2019; Jain et al., 2020; Singla

[26] https://disasteraware.com/

et al., 2020). These remotely sensed data include the Normalized Difference Vegetation Index (NDVI), thermal anomalies from Visible Infrared Imaging Radiometer Suite sensors (VIIRS), and outputs from other radiometers (e.g., Advanced Very High Resolution Radiometer (AVHRR)) and spectroradiometers aboard satellites (e.g., Moderate Resolution Imaging Spectroradiometer (MODIS), which are all archived at NCEI. Remotely sensed data can be combined with observations from surface weather stations and retrospective weather data, which is also archived by NCEI. Commonly used climate and weather variables include precipitation, temperature, soil moisture, drought severity, wind, and even lightning strikes (NASA, 2019; Jain et al., 2020; Singla et al., 2020).

Fire weather warnings alert the public when weather conditions are conducive to fire and prompt preventative measures to be taken. NIFC Predictive Services produces Significant Wildland Fire Potential Outlooks[27] for the wildfire season using NCEI data, and the National Weather Service (NWS) issues Red Flag Warnings when temperature, wind, and humidity conditions create increased fire risk[28].

Wildfire modeling can also integrate data from external sources, making it more actionable. For example, historical occurrence data for wildfires are available through fire management agencies, such as the National Interagency Fire Center (NIFC)[29]. WIFIRE[30], which was developed in a project led by the San Diego Supercomputer Center at the University of California at San Diego, incorporates data extracted from satellites[31] as well as data from the High Performance Wireless Research and Education Network (HPWREN)[32], which is a high-speed fiber optic and wireless network that produces granular environmental observations and imagery from across the southern California region. WIFIRE is an example of a successful academic-public partnership utilized by the Los Angeles Fire Department, Los Angeles County Fire Department, Ventura County Fire Department, and the Orange County Fire Authority. As of January 2019, 120 other agencies in California were also testing the use of WIFIRE (de la Garza, 2019).

6.1.1 Use Case: Lessons Learned from the Caldor Fire

The California Department of Forestry & Fire Protection (CAL FIRE) reports that, in 2021 alone, more than 2.5 million acres burned throughout the state during the 8,835 incidents of documented wildfire. Those most notable include the Dixie Fire, the Caldor Fire, McFarland Fire, and Monument Fire. The 2021 wildfire season resulted in three fatalities along with damage or destruction to 3,629 structures. Additionally, such events spanned the entire year from January to December, which is not typical even when compared to past wildfire seasons in 2020 and 2019 (CAL FIRE, 2022).

The Caldor Fire began on August 14, 2021 near Little Mountain in El Dorado County, California. It burned over 221,000 acres across three counties in California until it was contained on October 21, 2021. No fatalities were documented, yet the fire destroyed 1,003 structures and damaged 81 others (CAL FIRE, 2021). Although the Caldor Fire was not the largest or longest-running fire in 2021, several unique factors contributed to its containment by CAL FIRE.

For example, fuel treatment activities, such as prescribed burn projects, helped firefighters save the town of South Lake Tahoe, California. The Caples Restoration Project, located in the Eldorado National Forest,

[27] https://www.predictiveservices.nifc.gov/outlooks/7-Day_Product_Description.pdf
[28] https://droughtmonitor.unl.edu/About/AbouttheData/DroughtClassification.aspx
[29] https://www.nifc.gov/
[30] https://wifire.ucsd.edu/
[31] https://wifire.ucsd.edu/modeling-workflows
[32] http://hpwren.ucsd.edu/

completed 3,600 acres of treatment prior to the fire, which in doing so ultimately suppressed the expansion of the fire (Jung and Friedrich, 2021). Furthermore, planning and mitigation measures also proved effective at containing the fire. After the 2007 Angola fire, the communities of Meyers and Christmas Valley, along with twenty other local, state, and federal agencies, came together to develop an interagency response plan to be used in future events, including the Caldor Fire. In addition, Meyers and Christmas Valley implemented fuel treatment projects that ultimately reduced the fuel amount available during the Caldor Fire (Jung and Friedrich, 2021). The use of innovative technology also proved helpful during the Caldor Fire. Researchers from San Jose State University's Wildfire Interdisciplinary Research Center were on-the-ground running fire progression models to help inform CAL FIRE where it might spread next, including downwind smoke dispersion paths (Bigler, 2021; Mayeda, 2021).

6.1.2 Wildfire Risk Case Study Conclusion

The Caldor Fire experience and the 2021 wildfire season demonstrate the themes highlighted across this report, specifically how innovative technology, actionable data, community planning efforts, and strategic partnerships help reduce risk to hazards. New predictive technology that uses real-time forecast models is providing insight into fire behavior and aiding the decision making of risk practitioners and disaster management personnel. Additionally, long term planning measures proved valuable for timely decision making for emergency response efforts taken during the Caldor Fire. Not only were proactive steps taken by two communities to mitigate risk by fireproofing their surrounding area, but they were also able to apply lessons learned from a past fire to develop a response plan that proved vital for the strategic decision making of emergency response personnel. Such a plan required interorganizational coordination and unique partnerships that may otherwise not have occurred.

Identifying best management practices and applying lessons learned from past events remains just as valuable today. According to NCEI, a total of 33,926 wildfires were documented in the United States between January and June of this year (2022). This resulted in 3,922,641 acres burned, which is the second most on record. Coupled with the implications of unprecedented drought and heatwaves[33] occurring throughout the world this year, such events illustrate the complexity across socio-ecological systems and the tremendous efforts taken to address these hazards and the risks they pose to our community's safety and wellbeing. Effectively managing such risks requires a nuanced, strategic approach to decision making. Such decisions must be informed by accurate and reliable data. NCEI remains a valuable source for such necessary data.

[33] https://abcnews.go.com/US/texas-residents-asked-immediately-conserve-water-amid-drought/story?id=87010305 https://www.reuters.com/business/environment/dire-italian-drought-worsening-breaking-records-water-authority-2022-06-23/; https://earthobservatory.nasa.gov/images/150083/heatwaves-and-fires-scorch-europe-africa-and-asia; https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2022/record-temperatures-2022-a-review; https://public.wmo.int/en/media/news/climate-change-made-heatwaves-india-and-pakistan-30-times-more-likely; Opitz-Stapleton, S., Sabbag, L., Hawley, K., Tran, P., Hoang, L., & Nguyen, P. H. (2016). Heat index trends and climate change implications for occupational heat exposure in Da Nang, Vietnam. *Climate Services*, *2–3*, 41–51. https://doi.org/10.1016/j.cliser.2016.08.001

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8.0 Interviews and Conversations

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