BAMS Article

NWS Regional and Local Climate Services: Past 20 Years, Present, and Future

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Decision making;
History;
Societal impacts

ABSTRACT: The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) has been providing national, regional, and local climate services for more than 20 years. The NWS climate services building blocks consist of service provision infrastructure, partnership and outreach, discovery of user needs and requirements, and service delivery at national, regional, local, and tribal levels. To improve services, the NWS climate services program accelerated user engagement through customer surveys, workshops, and collaborations. Since 2002, the annual Climate Prediction Applications Science Workshop has developed a community of climate information producers and users through sharing of climate science applications, decision support tools, and effective communication practices. Although NWS had been producing operational climate monitoring and prediction products for several decades, the Weather Research and Forecasting Innovation Act of 2017 (U.S. Public Law 115-25) specifically mandated that NWS deliver services at subseasonal to seasonal time scales, including periods from two weeks to two years. Looking ahead, both the Department of Commerce (DOC) and NOAA have included climate services in their new 2022–26 strategic plans, including DOC's goal to address the climate crisis through mitigation, adaptation, and resilience efforts and NOAA's initiatives to build a Climate Ready Nation (CRN). The NWS Climate Services Program supports these strategic goals and CRN initiatives through integrating climate information into Impact-based Decision Support Services, the most critical element for implementation of the NWS strategy for a Weather-Ready Nation. This includes application of state-of-the-art climate monitoring and prediction products to the most societally relevant impacts while empowering regional and local climate delivery of enhanced services.

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1. History of the NWS regional and local climate services

The year 2023 marked the twentieth anniversary of the regional and local climate services infrastructure established in the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS). Western Region Headquarters spearheaded the effort by appointing the first Climate Services Program Manager (CSPM) in 2001, who worked with a team of six local NWS office representatives to formally develop a climate services plan for the regional and local offices. By 2003, all six NWS regional headquarters adopted this model, in which a newly appointed CSPM led the regional climate services program and a Climate Services Leader (CSL), originally called Climate Services Focal Point (CSFP), and provided climate services within all local offices, including Weather Forecast Offices (WFOs), River Forecast Centers (RFCs), and Weather Service Offices (WSOs).

NWS and predecessor agencies have been providing climate services for the nation since the creation of an organized observation network in the late 1800s. The U.S. Weather Bureau issued the first experimental monthly prediction in 1947, followed 37 years later by seasonal predictions in 1994 (Reeves and Gemmill 2004). The passage of the National Climate Program Act led to the formation of the Climate Analysis Center in 1979, presently called the Climate Prediction Center (CPC). CPC is an integral part of the NWS's climate services, providing national and global operational climate prediction, monitoring, and assessment products for subseasonal to seasonal (S2S) time scales. CPC provides critical climate expertise and operational service delivery support to NWS regional and local offices. Together with CPC, the national, regional, and local offices have established a more streamlined approach for delivering climate services to partners and stakeholders.

Although the formal regional and local climate services infrastructure was established in 2003 (Fig. 1), there were several climate services initiatives driven by local user needs previous to that time. The most prominent one was the Pacific El Niño–Southern Oscillation (ENSO) Applications Climate (PEAC) Center, established in 1994 in the NWS Pacific Region as a multi-institutional partnership, to conduct research and produce informational products on climate variability related to the ENSO climate cycle in the U.S.-Affiliated Pacific Islands (USAPI) including the Republic of Micronesia, the Federated States of Micronesia (Pohnpei, Chuuk, and Yap), the Republic of Palau and American Samoa. PEAC's formation was a result of advances in research and operations made in the CPC's climate predictions and in understanding ENSO impacts on local temperature and precipitation. PEAC's legacy included unprecedented local-level climate service delivery activity—for the first time, NWS Warning Coordination Meteorologists (WCMs) and Water and Environmental Research Institute at the University of Guam informed the public about ENSO impacts, expectations for ENSO development, and unseasonal changes in temperature and precipitation.

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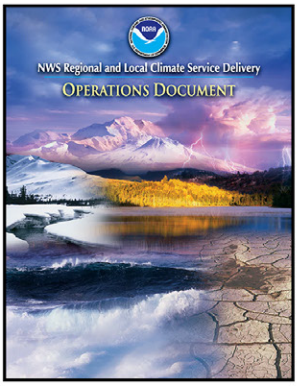
1994
PEAC created in Pacific Region

2000
CSB established at NWS Headquarters

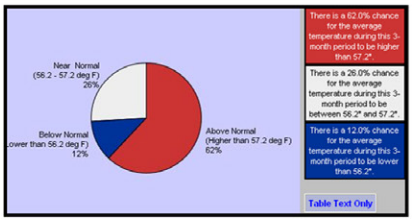
2001
NWS WR appoints a Regional CSPM

2002
Climate Services policy directives developed; 1st resident climate training course introduced, 1st annual CPASW event



2003
Climate Services Regional and Local Implementation Program released; climate staff appointed at regional and local offices

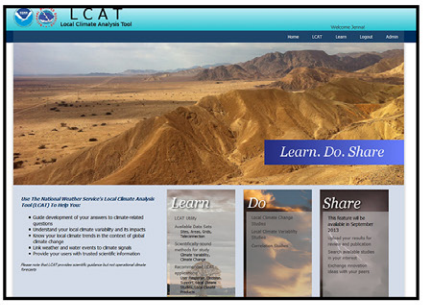
2004
1st local climate services tool developed - xmACIS, 1st customer satisfaction survey completed



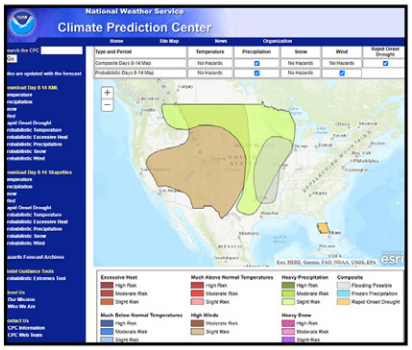
2005
1st Climate Services Ops Document released, standard webpages deployed, NIDIS strategey developed

2006
Local 3-Month Temperature Outlook (L3MTO) produced

2008
NWS develops policy directives on drought services



2010
CPC appoints regional liaisons for supporting climate services in regional and local offices



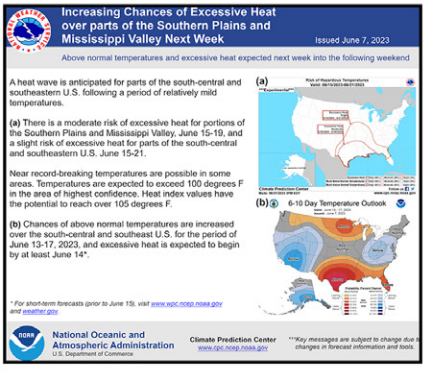
2013
LCAT becomes operational, WFO Pendleton develops CPC Outlooks interactive display

2014
CPC Week-2 Probabilistic Hazards Outlook operational

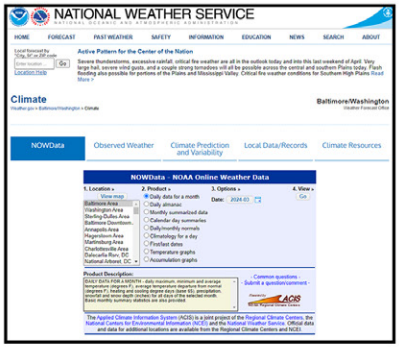
2016
1st NWS National Climate Services meeting

2017
Weather Act mandated S2S services and IDSS in NWS

2019
NWS hydroclimatologist position established



2021
Update to local climate web pages



2022
NOAA identified strategic goal for building a Climate Ready Nation (CRN), CPC key messages, update to climate training modules, new S2S IDSS course

2023
Local office focus on CRN support, update to LCAT, DGT modernization

Fig. 1. Timeline of major milestones in NWS Climate Services Program, including images for various products, tools, and documents developed by NWS over the years.

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Public warnings on ongoing El Niño events and their impacts, such as freshwater shortages at the Pacific Islands, provided actionable information for building communities resilient to weather and water elements. Climate services at local offices across the contiguous United States began to emerge in the late 1990s, largely due to the emergence of the Internet to relay information to users, as well as a surge of inquiries on the impacts of the two strong ENSO events in the 1990s.

In 2000, NWS established the Climate Services Division (CSD), which was renamed the Climate Services Branch (CSB) in 2015, to provide policy, planning, and training support for operational climate services at national, regional, and local NWS offices. CSD introduced NWS Policy Directive and Instructions in the 10–10 series on Climate Services of the NWS Directives System (2002), providing governing roles and responsibilities for NWS climate services operations as well as climate products delivery process, schedules, and formats. At the same time, NWS started the development of the climate services training program to build capacity for service delivery at local offices. This included several online distance learning modules and the first residence training course on NWS Climate Services Operations targeting Science and Operations Officers (SOOs). The climate variability and change course from the Cooperative Program for Operational Meteorology, Education and Training (COMET) (offered from 2002 through 2017) built knowledge in climate variability and change as well as understanding of NWS climate monitoring and outlook products. In 2008, this course was converted into a virtual format, and in 2013, much of it was recorded for asynchronous learning (COMET 2013). In addition, NWS produced various outreach materials including fact sheets, brochures, and standard presentations on climate topics and products, including ENSO, drought, and climate change and variability.

CSD launched the first Climate Prediction Applications Science Workshop (CPASW) in 2002 to build a community of climate information users, producers, and researchers working in the area of climate extension to share developments in research and applications of climate predictions for societal decision-making. Earlier user engagement included surveys of NWS climate products conducted by the Claes Fornell International (CFI) Group using the American Customer Satisfaction Index (ACSI). These efforts helped to identify user needs for NWS product and service improvements.

In August 2003, CSD led the development of programmatic support for NWS climate services operations with the release of the NWS Regional and Local Climate Services Implementation Plan, which defined five climate services pillars as the following:

- Partnership with NWS service programs, NOAA operational centers, and other climate services providers such as State Climatologists (SCs), Regional Climate Centers (RCCs), etc.
- Guidance and tools for effective and efficient climate services delivery
- Observations and data stewardship
- Climate monitoring and prediction products at regional and local levels
- Education and outreach to local users and the public

Partnership between CSD and NWS regional offices with CPC, Oceanic and Atmospheric Research (OAR) offices, the National Centers for Environmental Information [NCEI, under the National Environmental Satellite, Data, and Information Service (NESDIS)], and NCEI-affiliated RCCs played an important role in building regional and local climate services capacity. The outcomes of these partnerships included significant progress made in NWS climate data observations and stewardship, local climate outlook products, and climate data mining and analysis tools. Working within these partnerships also infused expertise and guidance in ensuring that high-quality data and the appropriate products were used in creating tools and information for decision-makers.

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The importance of climate data stewardship became significant in the 2000s and included the development of tools for the collection, archive, and quality control of climate data (Leffler et al. 2007). One of these tools is used for data mining based on the Applied Climate Information System (ACIS; DeGaetano et al. 2015). This tool, xmACIS (released in 2004), is an NWS internal tool with a public interface called NOAA Online Weather Data (NOWData). Additionally, the development of standardized NWS climate web pages in 2005 provided users an easier way to find information and allowed the NWS to provide information in a consistent manner, while still allowing each office to maintain localized climate and data information.

To add local value to CPC's suite of national climate products, NWS developed the Local Three-Month Temperature Outlooks (L3MTO; NWS Directives System 2007a) as an early example of a local climate outlook product. L3MTO, collaboratively developed among CPC, NCEI, CSD, and the NWS regional offices, was a site-specific 3-month temperature outlook that was statistically downscaled from the CPC's official Three-Month Temperature Outlooks. The outlooks were provided in many formats (Fig. 2) such as pie charts, temperature range for different probabilities, and probability of exceedance and nonexceedance for different average temperature thresholds. These formats, together with dynamic interpretation statements, were a novelty in NWS operations at that time and intended to mitigate barriers for climate forecast use (Hartmann et al. 2002). CPC operationally produced the L3MTO during 2006–21. NWS also developed the Local Climate Analysis Tool (LCAT; Timofeyeva-Livezey et al. 2015) to help office staff perform local climate studies. LCAT is an analytical tool for assessing impacts of climate variability and climate change on regional and local environmental variables. It was released in July 2013, and version 2 will be deployed experimentally in 2024 with a new user interface, additional datasets, and updated capabilities.

The NWS Climate Services Program also played a significant role in developing local and regional drought services in the 2000s. NWS assisted in developing the National Integrated Drought Information System (NIDIS; Leffler et al. 2007), which has since fostered regional drought early warning systems and supported critical drought research. In 2005, the Drought Information Statement (DGT) product was created for the use of drought messaging by NWS local offices. DGTs draw on NWS and partner-provided drought indicators and tools, including the U.S. Drought Monitor and CPC's U.S. Monthly and Seasonal Drought Outlooks. DGTs deliver localized messaging to key partners, such as state climate offices, agriculture and water resources managers, and the media. "The DGT" was the first impact-based NWS product that targeted the impacts of drought on various sectors. In 2007, NWS introduced policy directive series 10–12 (NWS Directives System 2007b) describing roles and responsibilities of NWS offices and national centers in producing drought monitoring and predicting products. Recognizing the strong linkages between climate and water resources, a hydroclimatologist joined the CSB staff in 2019 to provide strategic direction for the development of NWS drought products and services, identify requirements for longer-range hydrologic outlooks, and foster drought services partnerships across NOAA.

The NWS Regional and Local Climate Services Delivery Operations Document, published in 2005, outlined the NWS climate services program's governance structure. The document described roles and responsibilities of NWS national, regional, and local office staff in providing climate services and detailed available resources such as climate data, products, tools, and partnership engagement. Several updates to the document have been published since the original to reflect programmatic changes. Version 2, published in 2007, described NWS local offices' roles in delivering local climate outlook products and growing training resources to build professional competence. Version 3, published in 2012, reflected NOAA's growing footprint in climate services and NWS's role within it, as well as incorporating examples of

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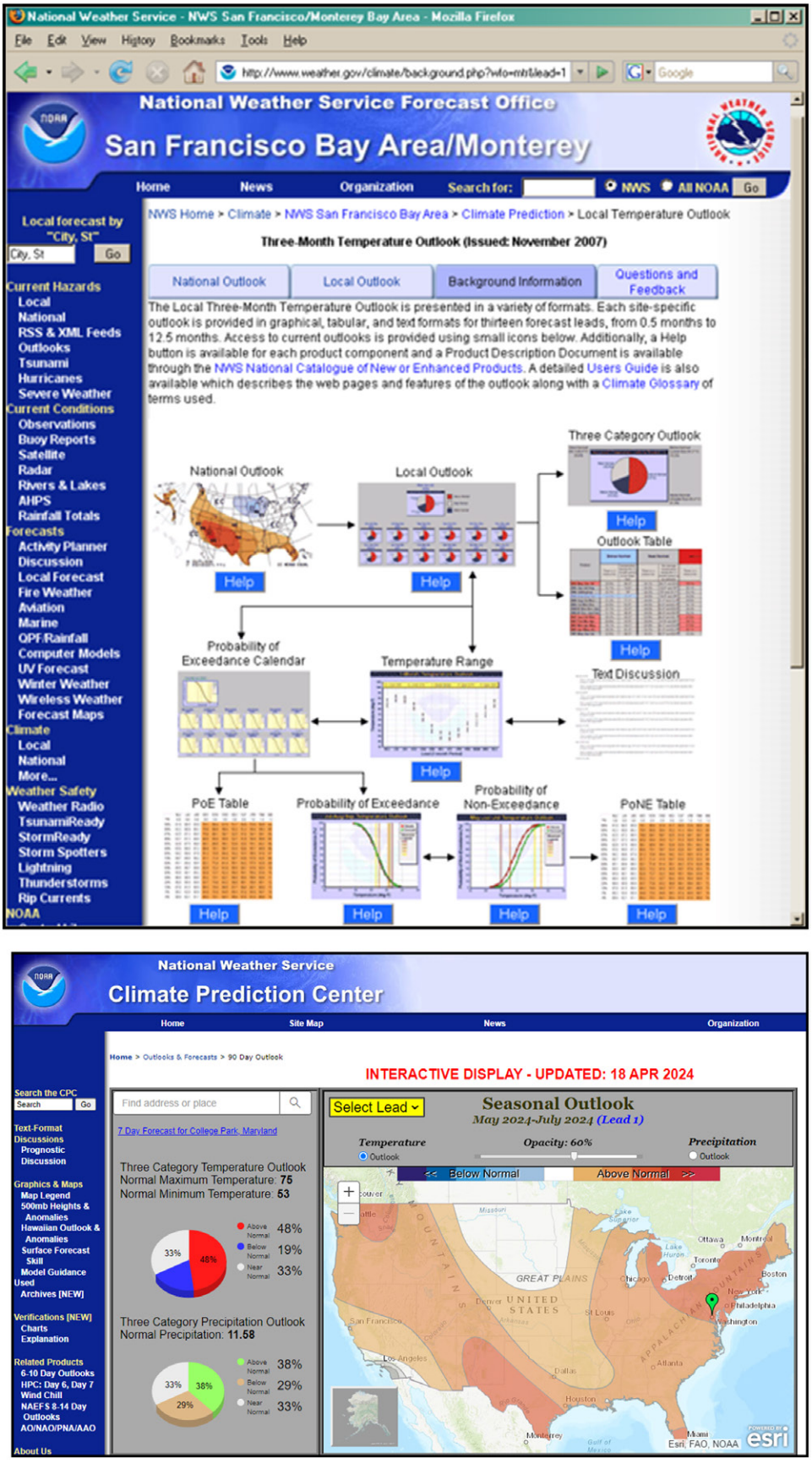

FIG. 2. (top) The L3MTO was a site-specific seasonal temperature outlook that was statistically downscaled from the CPC's official 3-month outlooks. (bottom) CPC's Interactive Display showcases an example of field-led innovation scaled up to the national level to dynamically display outlook information for a selected site.

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local climate studies submitted by CSLs. Version 4 (NWS 2020) focused on the role of climate services within Impact-Based Decision Support Services (IDSS), which is the NWS principal mechanism for building a Weather-Ready Nation (WRN; Uccellini and Ten Hoeve 2019).

2. Current state of NWS climate services building blocks

a. Regional and local climate services programs. NWS is unique among the other NOAA line offices as its geographically distributed infrastructure of 122 WFOs, six WSOs, 13 RFCs, 21 Center Weather Service Units, six regional offices, and nine national centers allows for direct engagement with local customers and partners at national, regional, local, and tribal levels.

Roles of the regional and local climate services programs within the NWS have expanded and evolved over the last 20 years. Main responsibilities, such as data stewardship, have always been foundational to NWS climate services. However, the NWS has made massive strides in many other aspects of climate services, including service delivery and user engagement. These improvements consist of building stronger relationships with core partners and learning about their specific climate interests and needs; more routinely engaging and collaborating with local, state, regional, tribal, and national partners on climate-related interests; and providing expertise on proper interpretation of climate products to ensure core partners can make better informed decisions. One recent example of improved support for climate services at the regional level is the Central Region Monthly Climate Outlook. This product uses a collaborative approach to provide a two-page summary of relevant S2S climate information to inform local office service delivery.

The need for the expanded climate services also has been driven by the steadily increasing demand for more climate information and interpretative climate services by members of the media, emergency management community, and the general public. To effectively meet these growing needs, local and regional climate services within the NWS have prioritized partner relationship building with climate-focused state, regional, and federal entities so that the various areas of expertise can be better leveraged. Examples of such partnerships include state climatologists, various state departments (i.e., water resources, forestry, health and human services, and transportation), NCEI (and its six Regional Climate Services Directors aligned with NWS regions), RCCs, and NOAA's Climate Adaptation Partnerships Program (CAPs), NIDIS, regional Drought Early Warning Systems, and United States Department of Agriculture Climate Hubs. NWS offices have created local climate studies and publications to share with their partners that include not only extreme records and climate normals, but also climate narratives and graphics providing weather facts by day, first/last freeze dates, severe weather statistics, ENSO, and flood/snowfall climatologies. In the last decade, social media channels have also provided a pathway to distribute climate information graphically, further increasing its reach. Information from national and regional climate centers can be shared to local users and allow tailoring of national-scale products to local impacts to better message key points.

b. NWS regional and local climate products, tools, and services. NWS local and regional climate services programs are supported by two key NWS national offices: CSB and CPC. CSB provides programmatic and capacity development support, while CPC serves as NWS's authoritative source of climate monitoring and prediction products. There are several developments and innovations from these national offices that serve as building blocks not only for the observed 20 years of progress, but also for the future evolution of NWS climate services.

In 2021, L3MTO was phased out of operations, and users were referred to interactive map displays of CPC 8–14-day, 1-month, and 3-month outlooks (Fig. 2), first developed by NWS WFO Pendleton, Oregon. Comparison between these two products is not direct because the

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interactive display provides spatially interpolated values rather than L3MTO's downscaled information. The interactive map provides users with a high-resolution climate and a point-and-click interface to obtain a pie chart of forecast probabilities for below-, normal-, and above-tercile outcomes that resembled L3MTO output. Ported to CPC in 2012, implemented operationally in 2013, and extended for CPC's 1-month and 3-month outlooks in 2017, the tool was an example of successful local office innovation that was scaled up to provide a national solution.

To supplement NWS climate predictions and provide more actionable and easily accessible information, NWS launched LCAT (https://lcat.nws.noaa.gov/) in 2013 (Timofeyeva-Livezey et al. 2015). Harmonic International (in 2016) and the National Environmental Modeling and Analysis Center at the University of North Carolina at Asheville (in 2018) conducted LCAT usability studies using different methods and evaluation criteria. Both studies found that LCAT users favor the tool for its power and ability to identify and qualify climatic signals at the local level, unique statistical sophistication, ability to focus on specific geographic locations, added insight to other resources and conclusions, and being a timesaver for conducting climate analyses. The studies also provided user recommendations for 1) correcting some usability issues; 2) enabling studies of severe weather signals, snowpack and ice pack, sea ice, flooding, and agricultural applications; 3) improving LCAT graphical outputs; and 4) providing case studies and application examples. Working with NWS's Meteorological Development Laboratory, the next generation LCAT is scheduled to be implemented in 2024, addressing many of user recommendations including temperature and precipitation extremes, severe convective weather, coastal data, water resources, and critical datasets for the Arctic. It also provides new navigation options, dynamic graphics, interpretations of the analysis results, and templates of applications to improve user experience and LCAT utility as a decision support tool (Fig. 3).

To meet the growing demand for climate services in a changing world, efforts to provide information beyond average temperature and total precipitation have accelerated during the past decade. LCAT is a critical tool on this front at monthly and seasonal time scales. At the subseasonal time scale, the development of the CPC 8–14-day (week 2) probabilistic hazards outlook was a milestone in national climate services delivery. This outlook leverages hindcast-calibrated extremes guidance from multiple ensemble modeling systems (Ou et al. 2016) to provide advanced lead time for potentially impactful events, including low-probability, high-impact events, such as extreme temperatures, heavy precipitation, snow blizzards, high winds, and rapid onset drought. This outlook product serves as a cornerstone for coordinated and collaborated national, regional, and local impact-based messaging.

Building on the success of Key Messages issued by the National Hurricane Center and the Weather Prediction Center (WPC) in association with forecasts of high-impact weather, CPC began issuing Climate Key Messages in 2022 (Fig. 1). This collaborated product consists of a few figures and clear and concise text bullets in a single document. Climate Key Messages are initiated when the weeks 2–4 outlooks highlight particularly impactful climate anomalies or a high-amplitude pattern change. In the case of long-duration hazards that extend from week 1 to week 2 and beyond, CPC and WPC issue Key Messages jointly to ensure that NWS stakeholders receive a clear, unified message from an authoritative source.

c. Advancing NWS drought services. The strength and efficacy of NWS drought services comes from combining national drought monitoring and prediction products with local expertise. Since 1999, NWS has been a key partner in the weekly U.S. Drought Monitor (USDM) process, with CPC staff serving as authors and CSPMs and local offices contributing regional and local input on drought conditions and impacts to the weekly map identifying areas of the United States currently in drought.

The accessibility of DGTs was greatly improved in 2021 when NWS partnered with NIDIS to develop a centralized national web page (Drought.gov 2023). In the following year, NWS

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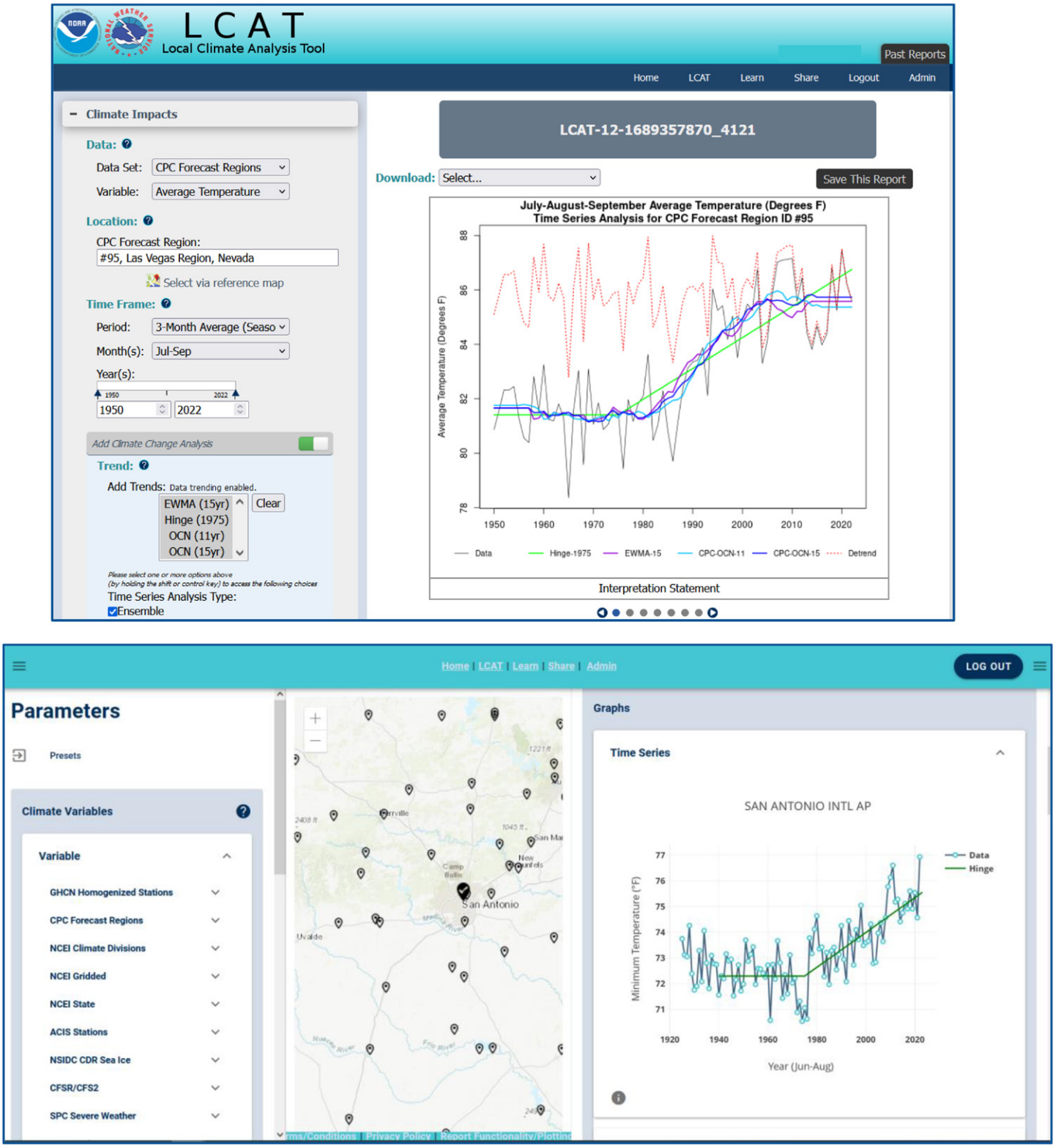

FIG. 3. LCAT (top) version 1 (2013) and (bottom) version 2 (2024) with an active multiwindow interface, dynamic interactive graphics, navigation map, interpretation statements, and catalog for application templates.

led an effort to gather the drought messaging needs of NWS local office staff and state- and regional-scale NWS partners. Extensive regional engagement through the 2021 NWS Western States Drought Workshop and subsequent focus groups, ensured that the resulting drought messaging recommendations reflected the unique nature of drought events and drought messaging needs across the country. In response, CSB worked with CSPMs, local offices, and regional partners to develop a modernized DGT that reduces the burden for forecasters, with

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a prepopulated template, incorporating graphics and enabling collaboration among offices. NWS implemented the modernized DGT into operations in April 2024.

d. Capacity development. NWS's workforce, consisting predominantly of meteorologists, physical scientists, and hydrologists, very often lack formal training or education in climate science and services. The training program is organized as the Climate Services Professional Development Series (PDS) consisting of six Professional Competency Units (PCUs; NWS 2001): 1) climate services infrastructure, 2) climate variability and change, 3) CPC products, 4) local climate studies, 5) climate outreach and IDSS, and 6) climate data. The training delivery uses any combination of in-residence, asynchronous, recorded, or document-based training.

The audience for climate training events has evolved over the last two decades. In 2002, the training targeted SOOs, but quickly shifted toward NWS climate services infrastructure development. Starting in 2020 with WRN initiatives featuring IDSS for service areas, the climate services training program began targeting the entire NWS workforce dealing with IDSS and other climate services activities.

The climate training program consists of residence training courses and several hours of online distance learning modules. The current resident training program consists of the following courses:

- Operational climate services course: offered from 2005 to the present, this 3-day course provides operational skills in climate customer services, climate observing system stewardship, and the ability to communicate local climate variability and change products and services.
- S2S IDSS course: this newly offered course, from 2022 to the present, includes five days of highly interactive scenario-based activities focusing on fundamentals of climate data, observations, forecast, and application products. The course emphasizes operational application and communication of NWS climate services in IDSS and other customer-related services. Participants work in teams to role-play a range of S2S IDSS scenarios, from answering brief partner questions to simulating multiday events with climate components.

Both residence training courses use online learning modules as prerequisites. Since 2021, the NWS training team has created nearly a dozen new online modules to replace the original and outdated materials. The content of the modules covers a wide range of topics, including interpreting CPC outlooks, data tools, drought, climate-weather interactions, ENSO, and climate change. Four of the new lessons on "Communicating Subseasonal to Seasonal Impacts," which were codeveloped with COMET, showcase interactive and engaging scenarios that take the learner through a series of recent real-life events to help build their IDSS and messaging skills on the topics.

The modules are accessible to NWS's workforce and other external users, allowing widespread access to baseline climate competency. Additionally, CSB and the CSPMs coordinate a monthly Climate Services Seminar Series (NWS 2023a; https://www.weather.gov/climateservices/seminars), where internal and external climate experts share important climate research, best practices, and product and tool demonstrations on various climate topics that are relevant to local office climate staff and partners.

e. Observation data stewardship. Collecting and preserving the best possible climate data are crucial for the provision of high-quality climate services, including climate products, data inquiries, media interviews, and social media interactions. Observations and data stewardship are key aspects of the NWS's Climate Services Program and having a top-tier quality

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assurance/quality control (QA/QC) process is imperative for building premier datasets for reference, research, and policy making. Data management tools (e.g., Datzilla, ThreadEx, xmACIS) are vital for these QA/QC processes. After local offices perform the initial QA/QC, additional checks are performed by state climate offices, RCCs, and NCEI prior to being archived and added to a station's dataset. When suspect data are identified in the historical record, local offices utilize an online resource called Datzilla, provided by NCEI and the RCCs, to address the discrepancies, correcting or removing errors as needed.

NWS and its partners have developed a plethora of data analysis and visualization tools for climate datasets, for both internal and external use. One of the most widely used is xmACIS, developed by the Northeast RCC, as a querying mechanism for weather and climate observation statistics that help NWS staff address questions from the media or other partners, provide IDSS, and develop content for social media. The public NOWData interface, available on each NWS WFO web page, allows users to create their own queries. Although this database currently contains only daily temperature, precipitation, and snowfall/snow depth data, efforts are underway to include hourly datasets and additional weather elements such as winds and dewpoint.

The Climate Extremes Committees are another example of the NWS working closely with climate data partners. In 1997, the National Climate Extremes Committee (NCEC) was established after a significant snow event prompted the need for better coordination on investigating the validity of national records. This initiative was taken a step further in 2006 with the creation of State Climate Extremes Committees for investigating the validity of records at the state level.

f. Outreach activities. CSB maintains and updates numerous materials (https://www.weather.gov/climateservices/print) that can be used to support local and regional NWS offices in their outreach activities within their communities. NWS offices provide information to users on climate products and services, participate on regional and national external climate teams as a local expert, support climate literacy with local educators through the NWS Education Program and NOAA Office of Education, and educate local users on the science of climate variability and change. NWS local offices also use social media to convey climate-related information to customers and partners. For example, offices may provide local climate context, comparisons to extreme or historical events, or interpretations of national center outlooks.

Community outreach example: Indigenous communities in Western Alaska face many challenges related to rapid climate change. The changing environment amplifies many threats, such as coastal flooding, high winds, erosion, icing, and permafrost thawing. To provide Indigenous communities with actionable climate information and predictions, the NWS Alaska Region Office, the Alaska Institute for Justice (AIJ), and the Alaska Division of Geological and Geophysical Surveys formed a partnership (Fig. 4) to assist communities in evaluating environmental trends, preparing them for threats, and advocating for their rights. NWS Alaska Region Headquarters and the Alaska Center for Climate Assessment and Policy provide seasonal and subseasonal climate information that is helping native communities adapt to rapidly changing environmental conditions, such as coastal flooding, coastal erosion, and sea ice extent.

g. User engagement and service requirements. Information about user needs is the major driving force for NWS climate services development. Three main avenues of engagement to identify user needs are: 1) NWS regional and local staff engagement, 2) the annual CPASW events, and 3) customer satisfaction surveys. Examples of regional and local staff engagement include the Partnership Exchange Program (PEP), training courses, and periodic formal engagement with CSLs.

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Fig. 4. AIJ hosts meetings at Chevak, Alaska, to ensure strong community engagement occurs with all environmental monitoring practices. Photo credit: Annauk Denise Olinm (AIJ).

PEP, which initially began as an orientation program in 2003, allowed local staff and partners to visit NWS Headquarters or other NOAA national centers and offices, such as CPC, Climate Program Office, and NCEI, to become familiar with NOAA's national climate data, monitoring, and outlook products and research development. It evolved over the years (2010–13) to encourage mutually beneficial collaborations by participants to work together on future projects or climate-related activities. PEP participants provided insight on unique user needs for their geographic area to the national office/center staff, helping to improve national guidance for regional and local climate services.

The National Climate Services Meetings held in May 2016 and February 2023 brought together local, regional, and national NWS staff in addition to NOAA and non-NOAA partners. Key user needs that emerged from these meetings included improved probabilistic information mapped to decision-making thresholds, improved graphics and templates for S2S IDSS delivery, and improved communication and collaboration practices to ensure users get consistent, actionable messages from NWS.

The annual CPASW event, cohosted by CSB with various climate partners since 2002, plays a vital role in the NWS's climate services program for not only user engagement activities and partnership building, but also for fostering the service requirements process. Many of the meeting outcomes helped to formulate needs assessments, new program initiatives, and product development. CPASW provides a unique opportunity for direct interaction with local stakeholders including farmers, water managers, agrobusinesses, local governments, retail sustainability officers, and many others. These stakeholders share their current applications of climate information and needs for the types of services they require to produce crops, raise livestock, and address hazards including flooding, extreme heat, drought, and extreme rainfall in urban and rural areas. CPASW opens other avenues for collaboration, including social, behavioral, and economic science (SBES), to improve NWS climate services through understanding of user needs, developing a better format for service delivery, and working with core partners from the bottom up to coproduce and codeliver sector-specific decision support services.

Periodic customer satisfaction surveys conducted by external organizations provide an engagement with the broad U.S. public and yield a robust evaluation of NWS regional and local

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services. The surveys in 2004 and 2009 uncovered a relatively high rating of NWS climate services that was comparable with other federal government products. The surveys yielded higher ratings for regional and local services, especially the climate data products. Starting in 2011, NWS continuously conducted surveys with periodic focus on climate products to monitor user satisfaction.

3. Lessons learned and next steps

NWS regional and local climate services have evolved from what science can offer to what users need to know to make informed decisions. Initially, the main criteria for climate services were scientific credibility, skill, and timeliness, which is understandable as the new products needed to earn users' trust. Improved user engagement identified clarity in product communication, interpretive services connecting science and users, and intuitive product formats as necessary components in service delivery, in addition to baseline metrics of forecast skill. Climate services is an ever-evolving iterative process that balances science development, technological advances, and user needs for information.

User engagement continues to be a critical part of regional and local climate services, which is the scale at which most climate-related decisions are made. With its distributed workforce, the NWS is well positioned to serve as a key component of NOAA's service outlet for climate products and information to mitigate against climate-related hazards. NWS climate services infrastructure has improved substantially through its 20 years of development. Due to the development of climate services tools, training activities, outreach support, and seminars sharing best practices available now for all offices, NWS climate staff can convey important information about climate, conduct IDSS activities at S2S time scales, and work toward the broad incorporation of climate information in weather and water forecasts and warnings.

Engagement with underserved communities will allow NWS products and services to reach new and diverse core partners and stakeholders, empowering them to improve their decision-making across time scales. Helping communities and stakeholders become more resilient to the impacts of climate variability and change also supports their preparedness for extreme weather events in the process. Infusion of SBES into NWS's climate services and product development will improve how climate information is delivered and communicated to different types of users.

Regional and local climate services partnerships have expanded climate services and improved their efficiency. Local offices often make referrals to SCs and RCCs for climate data needs and scientific expertise, such as assessing drought conditions and impacts. Partnerships between academic institutions and NWS operational offices expedite transitions from research to operations (R2O), and ultimately supports the NWS's goal to advance climate services codevelopment and coproduction with core partners.

Climate is a cross-cutting theme between all NWS service programs including aviation, severe weather, public weather, winter weather, tropical, fire weather, marine services, tsunami, and water resources. Users may not differentiate between weather and climate time scales as their decisions deal with temperature, precipitation, and other environmental elements. Therefore, a comprehensive "knowledge-based approach in addition to product-based approach" (D. Arndt 2023, NCEI, personal communication) including weather, water, and climate information at different time scales should be employed in future climate services development.

Incorporating climate change information into service delivery is continuously growing in demand. Delivering IDSS, NWS staff frequently encounter questions on the attribution of extreme weather and water events to climate change. Although science on regional environmental trends is widely available, local event attribution studies are limited and do not make

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a quick transition from research to operational use. Local attribution studies remain a service gap.

The continued evolution of NWS climate services is critical to the NWS identity and its weather, water, and climate mission, as well as achieving the NOAA strategic goal of building a Climate Ready Nation (CRN; NOAA 2022). CRN may help improve existing climate services and close existing service gaps. This initiative will integrate climate into a seamless suite of services to support flood, drought, water resources, fire, heat, and coastal hazards, among other societal challenges. CRN does not change the NWS mission, but rather emphasizes the climate role. NWS is uniquely positioned to place observations, weather and water forecasts, and S2S outlooks in the context of a changing climate. NWS partners need information to make decisions at longer time scales from subseasonal to seasonal and beyond. The demands for receiving and understanding clear and actionable weather, water, and climate information are growing. In response, NWS is transforming to be more nimble, flexible, and mobile to better engage with partners to deliver IDSS (NWS 2023b).

Fig. 5. NWS Climate Services vision graphic. Four key working themes (colored wedges) are surrounded by four methods to ensure success: building partnerships, achieving service equity, training and capacity building, and coproduction with end users. The cross bars (white background) highlight four high-level outcomes of executing this vision.

The NWS climate services future vision (Fig. 5) is organized around key working themes, overarching methods, and desired outcomes:

Improving climate observations, monitoring, and prediction means building on the current foundations of the program through continuous reevaluation of existing products and services and integration of promising research results (i.e., R2O).

Incorporating multi-timescale climate information into NWS products and services is needed to better contextualize weather, water, and climate events. Advances in climate change research and social, behavioral, and economic sciences will be leveraged to communicate current trends in drought, temperature, heat, fire weather, and hazard outlooks in a changing climate, and for climate attribution of extreme events.

Applying climate information to NWS service areas and societal challenges recognizes that climate is fundamentally a cross-cutting program among all NWS service program areas. Incorporating climatological risks to fire weather, heat, marine, severe weather, tropical weather, drought, and water resources will improve NWS messaging and, in turn, preparedness in these areas. Quantitative tools that allow decision-makers to tailor products to their risk thresholds are in development.

Providing collaborated climate messages and decision support builds on the early success of Climate Key Messages through sharing best practices and IDSS templates with local and regional staff.

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NWS climate services will succeed in these areas through coproducing services with NOAA's internal and external partners, working toward service equity, building partnerships, and continuing to advance training, tools, and capacity development. CRN will bring together the suite of weather, water, and climate products and services provided by the NWS local, regional, and national offices to enable useful and actionable messaging to NWS partners.

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References

COMET MetEd, 2013: Climate variability and change lectures, July 2013. Accessed 9 July 2023, https://www.meted.ucar.edu/education_training/lesson/1034.

DeGaetano, A. T., W. Noon, and K. L. Eggleston, 2015: Efficient access to climate products using ACIS web services. *Bull. Amer. Meteor. Soc.*, **96**, 173–180, https://doi.org/10.1175/BAMS-D-13-00032.1.

Drought.gov, 2023: National Weather Service drought information statements. Accessed 12 July 2023, https://www.drought.gov/drought-information-statements.

Hartmann, H. C., T. C. Pagano, S. Sorooshian, and R. Bales, 2002: Confidence Builders: Evaluating seasonal climate forecasts from user perspectives. *Bull. Amer. Meteor. Soc.*, **83**, 683–698, https://doi.org/10.1175/1520-0477(2002)083<0683:CBESCF>2.3.CO;2.

Leffler, R., M. J. Brewer, R. E. Livezey, T. W. Owen, and K. Shein, 2007: NOAA climate data stewardship: Progress through partnerships. *J. Appl. Serv. Climatol.*, **1** (3), 1–14, https://doi.org/10.46275/JoASC.2007.06.003.

NOAA, 2022: NOAA fiscal year 2022–2026 strategic plan on building a climate ready nation. 73 pp., https://www.noaa.gov/sites/default/files/2022-06/NOAA_FY2226_Strategic_Plan.pdf.

NWS, 2001: National Weather Service's Climate Services Professional Development Series. Accessed 9 July 2023, https://training.weather.gov/pds/climate/.

——, 2020: The National Weather Service regional and local climate services operations document. 48 pp., https://www.weather.gov/media/climateservices/NWS-Climate-Services-Operations-Doc-4th-Edition-web.pdf.

——, 2023a: NWS Climate Services Seminar Series. Accessed 14 November 2023, https://www.weather.gov/climateservices/seminars.

——, 2023b: 2023-2033 Strategic plan. Accessed 25 April 2024, https://www.weather.gov/media/wrn/NWS-2023-Strategic-Plan.pdf.

NWS Directives System, 2002: National Weather Service Policy Instruction 10-10, climate services. NOAA, 4 pp., https://www.nws.noaa.gov/directives/010/archive/pd01010a.pdf.

——, 2007a: National Weather Service Policy Instruction 10-1005, climate services. NOAA, 11 pp., https://www.nws.noaa.gov/directives/010/archive/pd01010005a.pdf.

——, 2007b: National Weather Service policy directive drought services. NOAA, 4 pp., https://www.nws.noaa.gov/directives/010/archive/pd01012a.pdf.

Ou, M. H., M. Charles, and D. C. Collins, 2016: Sensitivity of calibrated week-2 probabilistic forecast skill to reforecast sampling of the NCEP Global Ensemble Forecast System. *Wea. Forecasting*, **31**, 1093–1107, https://doi.org/10.1175/WAF-D-15-0166.1.

Reeves, R. W., and D. J. Gemmill, 2004: *Reflections on 25 Years of Analysis, Diagnosis, and Prediction 1979-2004.* U.S. Government Printing Office, 106 pp.

Timofeyeva-Livezey, M., F. Horsfall, A. Hollingshead, J. Meyers, and L.-A. Dupigny-Giroux, 2015: NOAA Local Climate Analysis Tool (LCAT): Data, methods, and usability. *Bull. Amer. Meteor. Soc.*, **96**, 537–545, https://doi.org/10.1175/BAMS-D-13-00187.1.

Uccellini, L. W., and J. E. Ten Hoeve, 2019: Evolving the National Weather Service to build a weather-ready nation: Connecting observations, forecasts, and warnings to decision-makers through impact-based decision support services. *Bull. Amer. Meteor. Soc.*, **100**, 1923–1942, https://doi.org/10.1175/BAMS-D-18-0159.1.

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