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Research Paper

Determining State Needs and Gaps in Weather and Climate Services: An Example from Kentucky

Jerald Brotzge[1], Steven Eddy[2], Zachary Suriano[1]

[1] Kentucky Climate Center, Western Kentucky University, [2] National Weather Service, Paducah

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Weather and climate impact every locale uniquely. Local weather hazards, climate extremes, socioeconomic vulnerability, and the sensitivity of local economic activities vary widely from one location to the next. As such, the weather-sensitive decisions that need to be made, and the subsequent need for local weather and climate information to support those decisions, vary as a function of local threat hazards and vulnerability. To better understand the decision-making, needs and gaps in weather and climate services across Kentucky, the Kentucky Climate Center hosted a 1.5-day workshop to better quantify these needs and gaps. The workshop was organized around six specific weather-sensitive sectors: (1) energy and transportation; (2) water and agriculture; (3) environment and conservation; (4) industry and commerce; (5) media and forecast providers; and (6) hazard mitigation and emergency management. The primary needs expressed by all sectors included more local, more frequent observations and more precise, longer-range forecasts. In addition, much greater organization of all available data and products would enable much broader adoption of these tools. This paper summarizes the findings from this workshop in the hope of providing an example and template for others to follow.

1. INTRODUCTION

The volume of environmental data now produced and the derived, value-added products and climatologies created from these data have increased exponentially over the last few decades. As examples, a plethora of commercial satellites, state mesonets, and autonomous vessels have exploded onto the scene, making real-time monitoring of the earth's surface, sub-surface, oceans, and atmosphere more readily available than ever before. Nevertheless, many of these data and products remain underutilized, largely out of ignorance of their existence or an inability to access them adequately. Historically, the environmental sciences have suffered from a deficiency in data; now, the significant challenges are how to find, parse, and make use of the particular data streams and products that best attend to an organization's needs. As a first step to help address this issue, the state climate office of Kentucky, the Kentucky Climate Center (KCC), held a statewide meeting to better understand user needs and gaps in monitoring and climate services.

The KCC hosted an intensive one-and-a-half-day "Kentucky Climate Services Summit" in Frankfort, Kentucky on July 16 and 17, 2024, with the primary goal to better understand and document the need for climate services by state organizations. Sponsored by the National Centers for Environmental Information (NCEI), American Association of State Climatologists (AASC), Climavision, and the KCC, approximately 50 participants attended daily, including representatives from a wide variety of federal, state, and local governments, as well as industry, academic and non-profit organizations. State organizations represented included the Kentucky State Energy & Environmental Cabinet (EEC), including the Divisions of Forestry and Air Quality; Kentucky Transportation Cabinet (KYTC), Kentucky Department of Public Health (DPH); and Kentucky Division of Water (DOW). Federal organizations represented included three regional National Weather Service (NWS) Weather Forecast Offices (ILN, LMK, and PAH); the Ohio River Forecast Center (OHRFC); the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, the U.S. Geological Survey (USGS), and NOAA/National Centers for Environmental Information (NCEI). Additional attendees represented included academia (Western Kentucky University, University of Kentucky, Centre College, Purdue University); private sector firms (Climavision, Ott Hydromet, Kentucky Farm Bureau Insurance, Kentucky Educational Television (KET/PBS), NBC (LEX18)); and non-profit groups (Resilient Boyle, Kentucky Climate Consortium).

The Summit agenda was structured to facilitate information gathering and networking. The meeting commenced with an introduction by Kentucky Deputy Commissioner Amanda LeFevre with the Kentucky Department for Environmental Protection. This was followed by a series of speakers providing general background information on Kentucky climate, area observing networks, and regional climate services. The remainder of the two-day workshop facilitated six panel discussions, each focused on climate-sensitive sectors important to the state: (1) energy and transportation; (2) water and agriculture; (3) environment

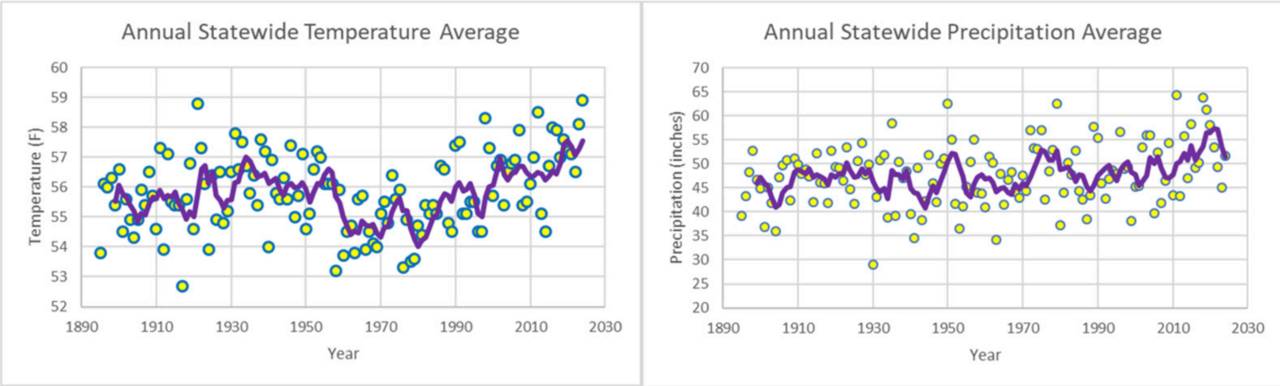

Fig. 1. Annual state mean temperatures (left) and precipitation totals (right), 1895-2024, as shown by the yellow dots. Running five-year means are shown in purple. Data provided by MRCC (2025).

and conservation; (4) industry and commerce; (5) media and forecast providers; and (6) hazard mitigation and emergency management. Two breakout sessions facilitated additional information sharing. What follows is a summary of the information gathered from this workshop, together with additional information and links provided by workshop attendees.

2. GENERAL CLIMATOLOGY

Kentucky is a southeastern state classified as humid subtropical by the Koppen climate classification scheme; it has an annual temperature of 13.5° C (56.3° F) and an annual precipitation of 1283 mm (50.5 inches) (NCEI 2025a). In general, the state experiences adequate rainfall year-round and mostly mild temperatures. Kentucky has four distinct seasons of nearly equal length where winter temperatures rarely dip below -17° C (0° F) and summer temperatures above 38° C (100° F) are uncommon. Nevertheless, Kentucky's mid-latitude location makes for highly variable conditions, from day-to-day and year-to-year.

Kentucky's climate reflects its volatile weather history. Its coldest year is 1917 at 11.4° C (52.6° F); its hottest year is 2024 at 14.9° C (58.8° F) (NCEI 2025a). In broad terms, annual temperatures increased through the 1930s, then decreased through the mid-1950s, when annual temperatures remained below the 130-year record average through the 1970s. Annual temperatures have warmed precipitously since with seven of the top eleven warmest years on record observed since 2007 (Fig. 1a). A recent rise in annual precipitation is equally notable (Fig. 1b; Tekoe and Suriano 2025). Annual precipitation has varied between 1634.5 mm (64.35 inches) in 2011 and 736.6 mm (29.00 inches) in 1930; however, recent years have been significantly wetter than average with five of the top ten wettest years observed since 2011 (NCEI 2025a). Overall, the state has observed significantly wetter, warmer conditions over the last few decades (Fig. 2).

The Commonwealth is vulnerable to a wide array of high-impact weather hazards. The state is susceptible to tornadoes, hail, severe thunderstorm winds, floods, extreme heat and cold, heavy snow, freezing rain, and

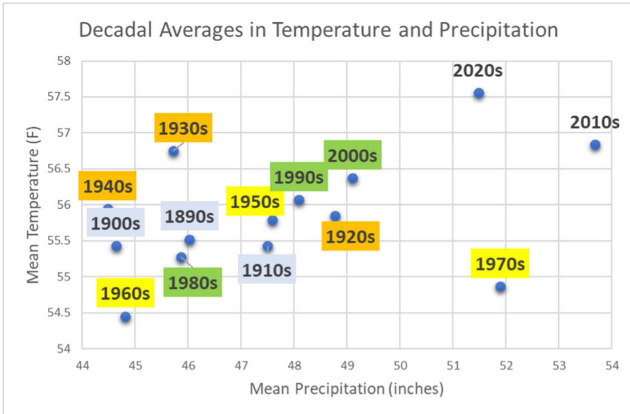

Fig. 2. Decadal state mean values plotted as a function of temperature and precipitation for the years 1895-2024. Data provided by MRCC (2025).

drought. Seven eastern Kentucky counties are among the top twelve counties in the nation in the number of FEMA major disaster declarations between 1990 and 2022, each with 26 or more declarations during the period (Crowe 2023). Despite the multiple hazard threats across the state, annual direct fatalities typically number less than ten per year (Fig. 3). However, a review of state archives shows that a once-in-a-generation hazard event with tens of fatalities is common in Kentucky history. Several notable weather events in state history include the January 1937 flood; the 4 April 1974 tornado outbreak; the winters of 1976-77 and 1977-78; the December 2021 tornado outbreak; the July 2022 eastern Kentucky floods; and the February and April 2025 floods (KCC 2025).

3. REGIONAL WEATHER DATA AND CLIMATE SERVICES

A mix of federal, state, and local entities service Kentucky with historical and near real-time weather data and climate services. The NWS is the primary provider of most weather and climate data providing near real-time in situ (COOP, ASOS), radar, and satellite information as well as model

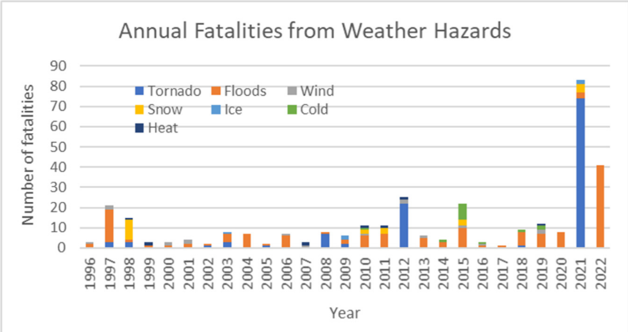

Fig. 3. Annual direct fatalities from natural hazards across Kentucky, 1996-2022. Data provided by Storm Events Database, NCEI (2025b).

forecast output and prognostic outlooks on a variety of time scales (e.g., Fig. 4). Five NWS Weather Forecast Offices (WFOs) serve the Commonwealth; those WFOs are located in Paducah (PAH); Louisville (LMK); Jackson (JKL); Wilmington, OH (ILN); and Charleston, WV (RLX). Historical data are stored and made available by NCEI. The US Geological Survey (USGS) provides water monitoring of state rivers. The Midwest Regional Climate Center (MRCC; https://mrcc.purdue.edu/) provides regional climate information and value-added products for state use. In general, federal agencies provide baseline historical and current weather and climate information.

Several state agencies supplement these efforts. The KCC houses the State Climate Office (SCO) and Kentucky Mesonet (KYMN; Mahmood et al. 2019). Founded in 1978 at Western Kentucky University (WKU), the SCO (https://kyclimate.org) provides a single point clearinghouse for providing city and county-level records and access to various federal products. The KYMN (https://kymesonet.org) operates 86 mesonet weather stations across the state, collecting, archiving and disseminating environmental data every 5 minutes (Fig. 5). The Ag Weather Center (https://weather.uky.edu/), operated at the University of Kentucky (UK), delivers value-added products and information to agricultural partners statewide. Some state agencies provide additional monitoring capabilities. The KY Division of Water (https://eec.ky.gov/Environmental-Protection/Water/Pages/default.aspx) aids in the monitoring of state river, lake, and groundwater levels, and the KY Division of Air Quality (https://eec.ky.gov/Environmental-Protection/Air/Pages/default.aspx) monitors air quality (Fig. 6a). The KY Division of Forestry (https://eec.ky.gov/Natural-Resources/Forestry/Pages/default.aspx) operates a network of Remote Automatic Weather Stations (RAWS) to aid forest fire operations, and the KY Transportation Cabinet (https://transportation.ky.gov/Pages/Home.aspx) operates a network of 38 Roadway Weather Information System (RWIS) sites to aid highway operations (Fig. 6b).

In addition to government agencies, numerous commercial firms and non-profit groups contribute to climate services through the availability of supplemental data, targeted forecasts, and value-added climate products. For example, a commercial firm based in Louisville, KY, Climavision, deploys X-band radars to fill in spatial gaps in coverage; data from these radars supplement company forecasts which are then sold to stakeholders nationwide. CoCoRaHS (Reges et al. 2016) is a citizen-based precipitation network operated by Colorado State University; precipitation type and amount are reported daily by volunteers and made available via an online database.

4. WEATHER AND CLIMATE SERVICE NEEDS AND GAPS

Despite the plethora of networks and services now available to the general public and designated stakeholders, a number of gaps remain in the state's weather data and climate services. These gaps are evaluated across nine sectors vital to Kentucky's economy: agriculture, water management, transportation, energy, public health, conservation, emergency management, industry, and media, as discussed in detail below. A summary of service needs and gaps are provided in the report Appendix.

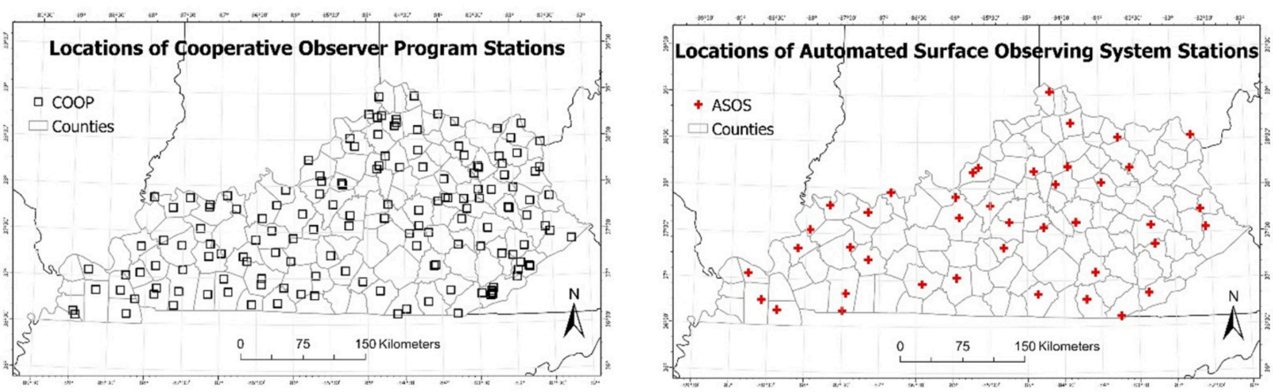

Fig. 4. Current (March 2025) state maps showing the location of the 154 Cooperative Observer Program (COOP) and 43 Automated Surface Observing System (ASOS) federal weather stations deployed across Kentucky.

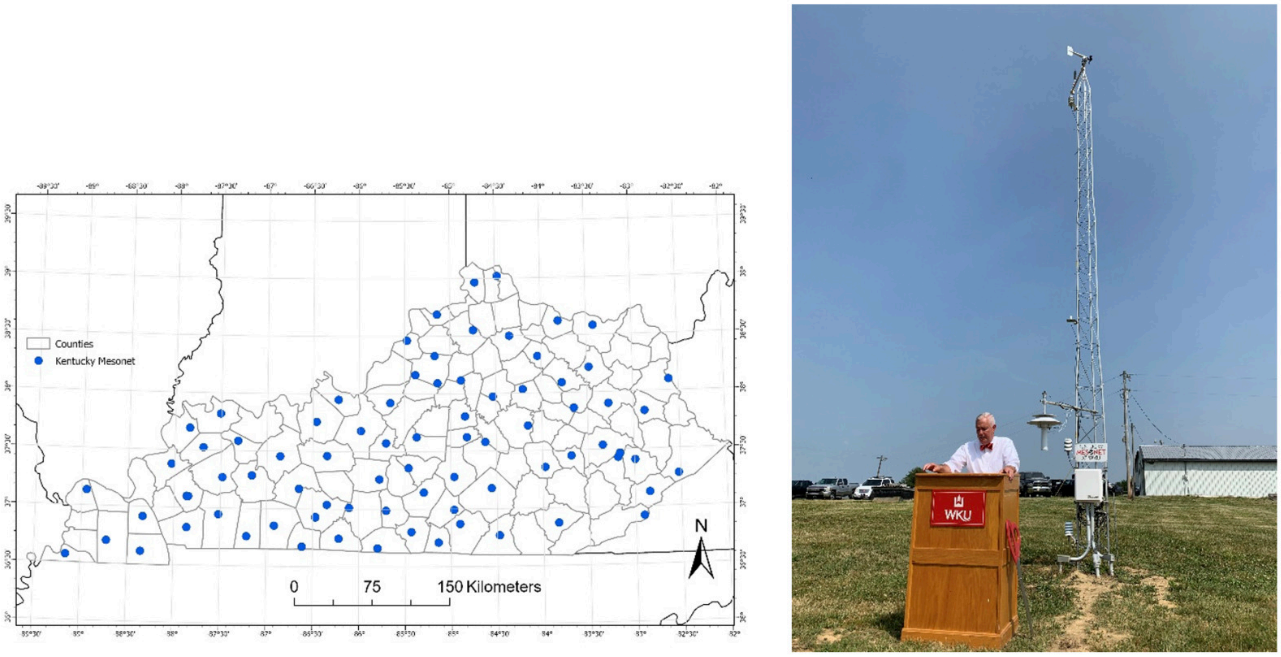

Fig. 5. (Left) March 2025 map showing the location of the 83 Mesonet stations deployed across Kentucky at that time. (Right) WKU President Timothy Caboni at the ribbon cutting ceremony of a new Mesonet station at UK Farm Spindletop on 2 August 2023.

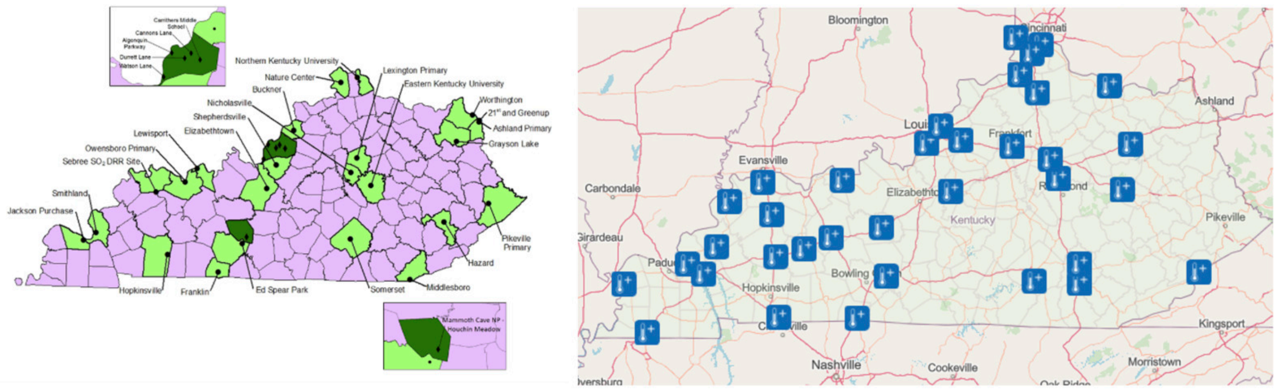

Fig. 6. Maps showing the location of the 30 state- and municipal-operated air quality stations across Kentucky. Map courtesy of the Kentucky Division of Air Quality. (b) Map showing the location of the 38 RWIS roadway weather stations. Map courtesy of the Kentucky Transportation Cabinet.

A. AGRICULTURE

I. SERVICE NEEDS

Agriculture is a major economic sector for the state. USDA figures from 2024 listed Kentucky as 9th in the nation in poultry production with over \$1.3 billion in sales, and first in the eastern US in beef production with \$1.3 billion in sales (Farm Flavor 2025). The combined production of corn and soybeans across Kentucky totals over \$2.5 billion, and which supports the distilling industry, generating over \$9 billion in state economic activity annually (Kentucky Bourbon 2025). The equine industry of Kentucky is a world leader, generating over \$1 billion annually (Farm Flavor 2025). These sectors require specialized weather data and climate services to remain economically competitive.

Farmers face a number of weather-sensitive decisions that directly impact farm productivity and safety at immediate and short-term scales. Decisions of when to plant, to fertilize, and to harvest to optimize yields are informed by the availability of common climatological parameters such as temperature and precipitation. Knowledge of atmospheric humidity values informs decisions if and when hay and tobacco production are possible. Farmers further need to decide if and when the winds and near-surface stability will allow for spray applications, thereby limiting drift potential while also needing to determine how best to optimize spraying for certain weather-sensitive pests and disease. Livestock and water management decisions are routinely informed by the understanding of meteorological conditions where farmers need to determine how best to keep livestock warm, cool and well-watered during extreme temperatures. Farmers also need to decide when to irrigate during dry conditions and how to limit losses during flood conditions. Local, real-time weather data can aid these immediate, short-term decisions.

Long-term trends and variability in climate can pose additional challenges to agriculture. For example, warmer, wetter conditions can lead to increased disease and pest pressures, along with challenges in accessing fields with the necessary equipment. Warmer years can lead to advanced growth early in the year, but with greater opportunities for frost loss. Longer growing seasons provide some benefits but with additional risk. Risk management is needed as potentially more frequent, more intense extreme weather events could incur greater agricultural losses.

II. GAPS IN SERVICES

Several gaps exist in climate services for the agricultural sector. Microclimate data are important for field applications, and localized data are needed at spatial scales much greater than even a dense statewide mesonet can provide. Denser, localized environmental data are essential, and data from these networks must be easier and more convenient to access than is currently available. As a next step, these data must be integrated with information from other platforms to yield optimized decision support tools. Early warning systems still are needed to alert farm communities of evolving hazards from heat, frosts, and pest and disease threats among others. Decision-support tools should consider language accessibility and ease of use as these can limit their effectiveness and adoption. Accurate, long-term outlooks and predictions can aid seasonal planning decisions.

B. WATER MANAGEMENT

I. SERVICE NEEDS

Kentucky's waterways shaped much of its historical development and are an essential element of its character. Ranked fourth in the nation in the number of commercially navigable inland waterway miles, Kentucky owes the expansion of much of its agriculture, energy production, and transportation sectors to its rich hydrology and careful water management (Kentucky Transportation Cabinet (KYTC) 2025). With few natural lakes, several very large, dammed lakes have been created, which now serve as major tourist destinations for recreation (e.g., Lake Cumberland, Kentucky Lake, Lake Barkley). In collaboration with the NWS and USGS, the KY Division of Water monitors river and lake levels and groundwater supplies routinely. Collectively, these agencies monitor real-time precipitation for flood monitoring, and soil moisture and groundwater for drought monitoring and response. Water quality is monitored for public water supplies, and water resource planning and permitting ensures adequate and reliable water availability. State agencies must utilize these data to make critical decisions across a variety of time scales regarding dam operation and safety, public water supply access, conservation efforts, and drought and flood response and mitigation.

II. GAPS IN SERVICES

New challenges in water management require new observations, new products, and new ways of communication. Dense, high-quality water observations are needed, but such networks vary by state with significant gaps in space and time. Quality data are usually not available at high density, which makes gridded data questionable at times. Groundwater measurements are sparse generally. Best practice recommendations are needed for how federal, state, and local partners can coordinate on the drought monitor. In general, there's an inability to maintain consistent and accurate warning messaging and to maintain consistency across political boundaries. Easily accessible records of river and lake levels are needed for contextual understanding of ongoing wet/dry conditions. Likewise, updated rainfall rate frequencies are needed in response to climate change. For short-term drought monitoring, accurate 0 to 60-day outlooks are vital, and > 60-day outlooks are essential for monthly to seasonal planning. Sub-seasonal-to-seasonal (S2S) and long-term climate projections can guide long-term planning.

C. TRANSPORTATION

I. SERVICE NEEDS

The Kentucky Transportation Cabinet (KYTC) is responsible for the care and maintenance of 27,695 centerline miles; 64,026 lane miles, and 9,069 bridges (KYTC 2025). This charge includes short-term operations and response (e.g., winter weather maintenance, decision-support, and communication messaging) and long-term planning (e.g., utilizing forecast information, performance measures, and climate projections). Weather and climate are a major factor in many short- and long-term decisions. Short-term work is often in response to anticipated, high-impact weather. For example, in the days before an expected severe weather event, SPC outlooks are used to begin planning. As confidence increases, communication increases with staff, and some crew shifts may be moved in preparation. Once an event is underway, situational awareness becomes critical as transportation crews begin clearing road blockages and deploying signage. Long-term planning is used for seasonal salt purchases (purchased at a discount when bought in the preceding spring), infrastructure maintenance, and seasonal training and signage (e.g., Matthews et al. 2017).

II. GAPS IN SERVICES

To monitor the state's highways, the KYTC utilize a variety of data. Foremost, KYTC operates a network of 38 RWIS deployed statewide, with these data supplemented with truck

AVL/GPS data such as material usage, temperature, and OBD port information. Additional external in situ and remote observations used include NWS radar, Kentucky Mesonet, CoCoRaHS, Waze, and HERE speed data. A private weather vendor (DTN) is used for pavement forecasting and specific event support. Generic forecast information is used from the NWS (e.g., NWS winter precipitation probabilities; NWS Chat, FHWA Pathfinder, SPC storm probabilities, and NWS conference calls).

While a comprehensive suite of environmental data is utilized by the KYTC, some gaps in monitoring remain. While RWIS are deployed statewide, additional mini-RWIS and/or mobile RWIS stations are being considered to fill in some gaps. An expansion in the use of truck AVL/GPS data continue to be explored. For example, KYTC is evaluating the ability to gain remote access to on-board temperature data and to add outward-facing cameras to the truck suite.

Medium to long-term planning activities are aided by use of S2S to annual climate outlooks and projections. Accurate projections can significantly enhance the cost-effectiveness of construction schedule contracts, roadway design, and highway investment decisions.

D. ENERGY

I. SERVICE NEEDS

The Commonwealth of Kentucky is a major manufacturing hub, making it the 12th most energy-intensive state in the US (Ritchie 2021). To meet this power demand cost-effectively, the energy sector in Kentucky employs over 43,000, operating 52 power plants using fossil and renewable resources to support the fourth-lowest industrial electrical prices in the country (U. S. Energy and Employment Report 2019; KEEC 2025). Kentucky is also home to one major oil refinery and several terminals, as well as two wholesale energy markets. To support this industry, the Kentucky Energy and Environment Cabinet (EEC) oversees 13,000 miles of electric lines, 6,769 miles of natural gas transmission, 18,834 miles of distribution pipelines, and over 800 miles of crude and petroleum product pipelines.

The state government has adopted the "Kentucky Energy Strategy (KYE3)". This entails a simultaneous focus on energy, the environment, and economic development to "anticipate, prepare, mitigate, respond, and recover quickly from threats or disruptions to our energy infrastructure (KEEC 2025). This strategy involves a significant amount of data acquisition and information management, utilizing a variety of meteorological and climatological data and predictive tools to inform decisions. For example, weather causes fluctuations in energy demand, current loss in extreme temperatures, outages due to storms, and wide variations in renewable power generation; these emergencies undergird the need for real-time decision-support and response.

II. GAPS IN SERVICES

The power industry, both in Kentucky and nationally, faces several challenges. First, energy production is undergoing a rapid diversification. Long-term, historical wind and solar data are needed to support the growth of renewable energies in the state. Much of Kentucky is not suitable for wind or solar, but some local areas offer adequate resources of wind and/or solar; local climatologies are needed to confirm these assumptions. A second challenge is the recent, rapid rise in energy demand, caused by a growing population, expanding domestic industrial base, and new demands from electric vehicles and especially AI/ML data centers (Koomey 2008). This is placing greater demand on regional communities to build more generating power plants and to consider nuclear power as an option. Third, climatic change poses the threat of increased volatility in high-impact weather, such as extreme heat and cold, fire weather conditions, and severe storms, which can pose hazards to electric grids and networks (Allen et al. 2016).

Environmental observations and forecasts, such as those provided by the NWS, are essential for power operations and planning. Real-time data are needed to support situational awareness and to maintain the resiliency of power generating and distribution systems. Accurate predictions are helpful for meeting real-time energy demand when drawing from a mix of energy sources. Accurate data and forecasts at high spatial and temporal resolutions are the primary services needed by the power industry to meet these evolving challenges. Accurate climate projections aid long-term planning efforts; climate will play an increasingly significant role in determining the location and type of power generation options available for any given area.

E. PUBLIC HEALTH

I. SERVICE NEEDS

A variety of weather and climate hazards pose a health risk to Kentuckians. Many common public health concerns across the state relate to weather conditions; for example, the impacts of winter snow and ice, extreme temperatures, severe winds, and flooding rains. Kentucky is susceptible to a variety of high-impact weather, and these pose a significant health threat when they occur. However, climate can also pose an indirect yet significant health hazard to Kentucky through its indirect impacts on allergies, air pollution and vector-borne disease (VBD). VBD is a disease transmitted by a vector such as a tick or mosquito. The most common VBDs in Kentucky are Ehrlichiosis, Spotted Fever Rickettsiosis, and Lyme disease, and these cases are increasing rapidly annually statewide. The Kentucky Department for Public Health (https://www.chfs.ky.gov/agencies/dph/Pages/default.aspx) operates the "KY Environmental Public Health Tracking" website for improved monitoring and communication of some of these threats (https://healthtracking.ky.gov/Pages/index.aspx). Government agencies are responsible for monitoring, predicting and warning on these threats.

Historically, air quality has posed a significant health hazard to much of Kentucky. The Kentucky Energy and Environment Cabinet Division of Air Quality is responsible for monitoring air quality across the state (https://eec.ky.gov/Environmental-Protection/Air/Pages/default.aspx). The Division of Air Quality combines their own monitoring data with real-time weather and climate data from federal and state networks to track air quality changes with time. Temperature, relative humidity, wind speed and direction, and solar radiation are used to determine pollutant flow and behavior which inform safety decisions for a variety of recreational and industry operations. Wind observations and model flow trajectories (e.g., HY-SPLIT) are used to identify pollutant sources (e.g., Koracin et al. 2011). Federal, state, and local sources of information are integrated into pollution models to optimize flow results. Agencies are responsible for warning the public when unhealthy conditions arise.

II. GAPS IN SERVICES

Improvements in the density of weather and climate observations and the development of related value-added products could aid public health. For example, development of a wet bulb globe temperature for monitoring extreme heat is needed as various stakeholders are routinely tasked with providing guidance and decisions with respect to the safety of outdoor workers, student athletes, and other potentially vulnerable populations (Morris et al. 2018). With the rapid rise in VBDs across the state, there is a subsequent rise in the need for environmental data and information to better monitor and understand the development, life cycles, and spread of disease vectors. VBD outbreaks are difficult to predict, and a notable gap remains in understanding how environmental factors and a changing climate impact VBDs. The state works with such groups as the Center for Forecasting and Outbreak Analytics (CFA) to address such gaps. Historical data are needed for retrospective study to inform future decision-making efforts.

Air quality has improved markedly across Kentucky since the 1960s, but significant challenges remain. While the current air quality network is adequate to monitor air quality as needed, a significant gap exists in the integration and organization of data as pulled from multiple sources. Climate projections are needed to understand future health impacts and plan appropriate responses.

F. ENVIRONMENT AND CONSERVATION

I. SERVICE NEEDS

State conservation services include monitoring wildlife, food supplies, fisheries, and public health across short- and long-term time scales. Critical, weather-sensitive decisions must be made regarding water resources, river and lake levels, and wildlife management, and the outcome of decisions rely on local weather and climate information. The Kentucky Department of Fish and Wildlife Resources (https://fw.ky.gov) is the lead agency in monitoring the state's fish and animal species. The state hosts over 1,000 animal species, including 34 federally-listed as endangered or threatened. The USDA's Natural Resource Conservation Service (NRCS, https://www.nrcs.usda.gov/conservation-basics/conservation-by-state/kentucky) Kentucky office leads local communities in educating and implementing many of the state's ongoing conservation efforts. Such programs provide funding and technical expertise to incentivize environmental quality, preserve wetlands and watersheds, and conserve areas for wildlife habitats. In addition to weather and climate data, communication and capacity development are essential elements for reaching non-climate experts and the general populace.

II. GAPS IN SERVICES

Several gaps significantly impede conservation services. Historical data sets of local climatologies and biomarkers are needed but are few in number. Data collection standardization is essential. For many applications, balanced surveillance resources are needed across the state (e.g., county-by-county results) for improved results and performance. Finally, much improved K-12 education about weather and climate is needed for greater understanding of all conservation issues. Data access (e.g., broadband coverage) is needed for both the collection of data and the dissemination of information.

G. EMERGENCY MANAGEMENT

I. SERVICE NEEDS

The Kentucky Division of Emergency Management (https://kyem.ky.gov) provides preparation, response, and recovery from high-impact weather hazards. Long-term planning is needed in the development and deployment of mitigation and response strategies, and rapid warning decisions are needed during emergency situations. In preparation, emergency managers develop mutual aid agreements, preposition resources, and contribute to situational awareness. In response, the Emergency Operations Center (EOC) in Frankfort coordinates Emergency Support Functions (ESFs) via the National Incident Management System / Incident Command System (NIMS/ICS) and monitors ongoing threats. In recovery, emergency management supports disaster declarations with damage assessment and hazard mitigation. The Kentucky Association of Mitigation Managers (KAMM; https://www.kymitigation.org/) and state chapter of the American Society of Flood Plain Managers provide additional support. Members in these groups comprise a diverse mix of planners and responders in the private sector and government at the local and state levels, all of whom draw from a wide mix of weather and climate resources. Additional services are provided at the federal level, primarily by the NWS through the five WFOs that cover Kentucky (ILN, JKL, LMK, PAH, and RLX).

Emergency management requires a wide array of service needs to inform their decision-making. For example, EMs must decide when to activate warning systems, and this requires ready access to real-time data and information, ideally easily accessible from a single source. In situ data, stream gauges, weather radar, satellite, lightning detection, GIS layers, and short-range models are essential for short-range activities.

The NWS applies an Impact-Based Decision Support Services (IDSS) continuum when preparing, planning and warning on high-impact events, and a variety of climate information is needed to support IDSS. For example, long-term planning requires a knowledge of the local effects of El Nino/La Nina; drought planning; wildfire outlooks; context for current weather events in comparison to records and normal hazardous weather climatology; and accurate historical climate records for monitoring changes in patterns or frequencies of extreme events and normalities.

II. GAPS IN SERVICES

Several gaps in climate services inhibit emergency management operations. Among the greatest challenges is finding specific climate information among the many climate-related websites now available. One access source portal for different scales is needed (county, state, etc.) with universal data storage (DGI/KYGeoNET). Resources are limited for developing new climate products in-house; more staff resources are needed in the climate industry focused on workload. For example, NWS WFOs do not have dedicated climatologists, and many states do not have funded climate offices. There also is a need for greater public education of climate to better discern fact from fiction; a lack of climate knowledge impedes communication and proper decision-making. Video training on available tools and services would be helpful.

Additional weather and climate tools could aid emergency management operations. For example, high-resolution inputs for flood inundation mapping and more dense hydrology monitoring for city and rural areas would aid flood monitoring and prediction. Additional radiosondes and/or drones would improve upper-air monitoring. Opportunities abound for new technologies to be applied to public safety, determination of climate risk, and the design of regulation and infrastructure. More accurate forecasts, month to S2S outlooks, and climate projections provide valuable guidance in developing preparations and long-term planning.

H. INDUSTRY AND COMMERCE

I. SERVICE NEEDS

A widely diverse community, industry is comprised of: (1) environmentally-focused companies that collect weather data and/or create value-added information; and (2) weather-sensitive companies that utilize weather data to optimize decision-making. The commercial weather sector provides environmental solutions for specific needs. Climavision is one example of a Kentucky-based company providing data and forecast services. Collectively, the "weather enterprise" delivers a variety of applications including, for example, forecasts for garden irrigation; river flow forecasts for barges; and the allocation of resources in advance of hazardous weather events. A few climate-sensitive sectors across Kentucky include many of its most profitable industries: the equine industry, distilling, metal works, forestry, tourism, organic and specialty farming, beef/livestock, and the high-tech industry (e.g., aerospace, electric batteries).

For most commercial applications, raw weather observations are translated into something meaningful to address a problem or decision, many of which have a human dimension. Commercial firms operate at short-term and long-term time scales. Observations, NWS alerts, and weather radar drive near-real-time decisions, whereas climate variability and trends impact long-term assessments. Value-added products are critical for commercial activity, both as input and as a deliverable.

One uniquely weather-sensitive commercial sector is the insurance industry. While mostly reactive after an event, insurers harness a wide variety of climate information to assess risk and weather information to properly assess post-event damage. For example, local in situ, weather radar, satellite, and social media can be used to reconstruct the life cycle of each hazard event. These data are used to verify claims and to adjust post-storm resource allocations when necessary.

II. GAPS IN SERVICES

While commercial firms make do with what is available, several gaps in service impede more effective work. The diversity of data at the local level requires significant time and effort assembling and packaging such information into value-added products. Working across disciplines requires building closer relationships and connections with those disciplines. Above all, more extensive and thorough metadata are needed to define which tools and products can or should be used for specific applications. Some data are created with a specific purpose that may or may not be appropriate for use elsewhere. More extensive climate data enable much-improved context for understanding event severity, frequency, and rate of change with time.

I. MEDIA

I. SERVICE NEEDS

Kentucky's media endures as a central tenant in the education and dissemination of weather information to the general public. Through television, radio and the internet, media provides customers with daily weather observations and forecasts, public warnings of approaching hazards, and educational information on environmental topics of interest. Media remains an essential piece of the value chain, collecting observations and information from the meteorological community and then shaping that information for easier, more effective, more pleasurable consumer consumption.

As a critical link in the warning process, media are trusted sources of information. As such, they rely heavily on NWS products, local weather observations, and public information. Regarding the dissemination of storm data and warnings, the statewide Kentucky Educational Television (KET) Public Broadcasting Service (PBS) is also a vital part of the state's Emergency Alert System (EAS). KET hosts 15 tower transmitters, a key element of EAS.

II. GAPS IN SERVICES

Media have found that news items need a local connection to generate interest. To make that connection with climate, regional interest stories often focus on how climate impacts us indirectly; recent news stories have focused on invasive species (e.g., expansion of fire ants, armadillos, and tick species in KY); the urban heat island; allergy season; and the expansion of tornado alley. In addition, discussions of climate are useful for providing historical context for periodic heat and cold waves and other weather extremes. Among the greatest challenges for the broadcast meteorologist is finding these base-level data (e.g., historical weather data, extraneous information) needed to pull these stories together.

A related challenge (i.e., gap) is finding data at the local (neighborhood) level. To complement regional and state networks, some stations will deploy their own volunteer 'neighborhood' in situ networks. Others may purchase their own weather radars, which can be used to fill gaps in space and time.

A third challenge is the fragmentation of media today, in part due to the changing economic landscape in media. Such fragmentation complicates warning dissemination as audiences are dispersed across more and varied platforms. To combat this diminishing role of TV news, media are expanding their visibility on the internet and other outlets. Environmental information in the form of visible imagery (e.g., photos, maps) are especially helpful for media in capturing viewer interest and spurring safety precautions.

5. CONCLUSIONS

On 10-11 December 2021, Kentucky withstood one of the state's most extreme tornado outbreaks, enduring four of the state's top five deadliest tornadoes of recent history in a single night. Over 80 fatalities were recorded statewide. One of these tornadoes hit a Kentucky Mesonet station, setting a new state wind gust record of 120.1 mph. During 26-30 July, 2022, several counties across southeastern Kentucky received over 350 mm (14") of rainfall within a five-day period, much of it falling within a 24-hr period. This led to catastrophic flooding across 13 counties, with a total 45 deaths and nearly $1 billion in damages. On 18-19 July 2023, an area of western Kentucky received over 280 mm (11") of rainfall within 24 hours, setting a new state 24-hr record rainfall of 286 mm (11.28") at the Kentucky Mesonet Mayfield station. Collectively, these extreme events raised the sensitivity of state citizenry to the impacts of high-impact weather and the need for heightened preparation and mitigation of such events in the future.

Funded by NCEI and in collaboration with the AASC and with additional funding from sponsor Climavision, in August 2024 the KCC hosted a 1.5-day workshop to collectively review the needs and gaps in weather and climate services as required by stakeholders across the Commonwealth. The input from workshop participants were compiled into this report. While not inclusive of the needs for all users statewide, the wide variety of workshop participants represented a broad cross-section of users and can be considered representative of the state as a whole.

A review of workshop attendee suggestions, as compiled in the Appendix, yielded several overarching recommendations. These are summarized below.

- **More local, higher-resolution observations.** Even with a Mesonet station in every county, microclimates are often not well-represented. Higher density observations support agriculture, emergency management, transportation, and more. While the WSR-88D network and gap-fill X-band radars provide excellent radar coverage across much of the state, Kentucky has no upper-air sounding stations and few groundwater observations. High-water level records and extreme weather event records need to be organized with more complete metadata. Historical climate records (COOP) need to be made more accessible with clear, easily downloadable metadata.
- **More accurate forecasts, outlooks and projections.** While observations are essential to many sectors, most applications require accurate local, high-resolution forecasts. Such predictions are needed at a variety of time scales. Long-term outlooks support hydrologic and fire weather monitoring; medium-term outlooks support hydrological and transportation applications. Short-term prediction and decision-support tools save lives and property and ensure the most optimal solutions in weather-sensitive industries. Indeed, deployment of more high-quality, denser observations will facilitate more accurate forecasts.
- **Adoption of common data formatting, protocols, and metadata.** Many participants stated that they had enough observations and support tools to do their job well. Indeed, some participants stated that new products are being made available faster than they can be adopted. However, the key element slowing further progress was the inability to merge or integrate disparate data sets together. Data formats are unnecessarily complicated, and users struggle with how to pull data from different sources into a singular platform.
- **Widespread data organization.** Many participants decried the challenge at keeping up with the 'firehose' of information. They stated that what is needed is not new information per se, but an organization of the data, products and services that are available. There is a collective cry for a "Yellow Pages" to organize the various weather and climate data and tools now available. Current platforms, such as NCEI, were not meeting the needs of users, in large part due to their navigation complexity.

Recent catastrophic events have spurred Kentuckians to invest more into weather preparedness and climate mitigation activities. Following the NCEI/AASC grant for hosting this workshop, the KCC was awarded a two-year grant from NCEI/AASC to expand on the goal to better understand and address the climate service needs of state organizations.

This new grant will allow the KCC, for the first time, to hire a dedicated staff member to organize and build climate product services to address state-level needs. On a much larger scale, a multidisciplinary, multi-university team led by the University of Kentucky (UK), that includes KCC personnel, was recently awarded a 5-year, $24M NSF EPSCoR grant focused on hazard mitigation. Referred to as "Climate Resilience through Multidisciplinary Big Data Learning, Prediction & Building Response Systems (CLIMBS)", this project will focus on climate observations and modeling, the inclusion of AI/ML, and engagement of stakeholders in the creation and implementation of hazard mitigation strategies. An independent activity hosted at UK, again with multi-university involvement including WKU and the KCC, was led by the academic-based, non-profit Kentucky Climate Consortium. The Consortium hosted a statewide "Kentucky Climate Symposium" on 26 September 2024 focused on climate change mitigation and advocacy. Collectively, these programs are bringing significant resources and awareness to establishing much-improved weather and climate services to the state of Kentucky.

Building upon the above momentum, the KCC now is coordinating with state agencies to create operational services, tools and products to address these identified gaps. As observational technologies and networks continue to proliferate at higher frequency, more localized scales, such products enable greater optimization in decision-making and service applications. For example, tools are now being developed in partnership with state agencies to monitor extreme temperatures for public health, dam safety, impact of downed power lines on wildfire, and animal welfare. Collectively, these tools and services lead to much-improved decision-making, thereby saving lives, resources, time and money to the benefit of all.

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APPENDIX

Table 1. Summary of Service Needs

Economic Sector	Service Needs
Agriculture	Climate information for planting, fertilizing, harvesting dates (T, P)
	Understanding of drying cycles for hay, tobacco production (RH)
	Spray applications of pesticides (U speed, direction)
	Limiting drift potential of pesticides (T, Td at multiple levels)
	High-res data for irrigation, drought, flood mitigation (T, P)
	High-res data, predictions for disease, pest mitigation (T, Td, P)
	High-res data for monitoring extreme temperature for livestock (T)
Water Management	Routine monitoring of lake, river levels
	High-res precipitation data for flood monitoring (P)
	High-res precipitation, soil moisture for drought monitoring (P, SM)
	Water quality data for monitoring public water supplies
	Climate record of lake, river high-water levels
Transportation	Seasonal climate outlooks for winter planning
	7-10 day outlooks for winter weather planning, preparation
	Situational awareness of developing hazards (all data, alerts, etc.)
	Real-time weather data, information for ensuring safety of staff
	Roadway information (e.g., pavement T, Tair) for winter monitoring
Energy	Historical & real-time wind data for wind energy (U speed, direction)
	Historical & real-time solar data for solar energy farms (SRAD)
	Real-time weather, climate data for energy peak supply-demand
	Situational awareness of developing hazards (all data, alerts, etc.)
	Real-time weather data, information for ensuring safety of staff
Public Health	Real-time data, forecasts for extreme heat, cold (T, RH, SRAD, U)
	Historical, real-time data for tracking vector-borne disease (T, RH, P)
	Situational awareness of developing hazards (all data, alerts, etc.)
	Historical, real-time weather, air quality information

Table 1 (Continued). Summary of Service Needs

Economic Sector	Service Needs
Environment & Conservation	Historical climate information and weather data for monitoring species' health (T, P, RH, SRAD)
	Historical climate, high-res weather data for tracking invasive species
	Need adequate broadband coverage for accessing remote areas
Emergency Management	Long-term, spatial and temporal climatologies of hazards to provide event context
	An understanding of the impacts of teleconnections (e.g., local impact of ENSO)
	Seasonal outlooks for drought, wildfire planning
	Real-time observations to aid situational awareness during evolving hazardous events (e.g., in situ, radar, satellite, cameras, stream gauge, media, public information, lightning detection).
	Short-term forecasts (0-3hr) for aiding EM operations
	Real-time observations to aid recovery work during/after events.
	GIS layers for overlaying public databases, relevant information
Industry & Commerce	Real-time data for situational awareness (e.g., in situ, radar, satellite, cameras, stream gauge, lightning detection).
	Real-time data for model initialization and assimilation for numerical weather prediction forecasting.
	NWS alerts, outlooks, value-added information
	Local climatologies at high-resolutions to drive local decision-making
	Understanding of teleconnection impacts on local hazards
	Storm data for post-event reconstruction (e.g., in situ, radar, satellite, social media)
Media	Local, real-time weather observations (in situ, radar, satellite)
	Camera, video in real-time
	Public information of hazards (social media)
	High-resolution model forecasts

Table 2. Summary of gaps in services

Economic Sector	Gaps in Services
Agriculture	Microclimate data are important for field applications, and localized data are needed at spatial scales much greater than even a dense statewide mesonet can provide.
	Localized data are difficult and often not convenient to access.
	Difficult to integrate, merge data from different platforms. Improvements in integration will aid decision-support development.
	Early warning systems needed for evolving weather hazards, and for agriculture, warnings on emerging crop diseases and pests. (Examples: Notify strawberry growers when blooms are susceptible; send alerts to scout for alfalfa weevil.)
	Multilingual decision-support tools.
	Decision-support tools that are easier to use; greater attention to the social sciences in the development of such tools.
	Accurate monthly, S2S, annual climate forecasts and projections.
Water Management	Significant gaps in observations in space and time (e.g., precipitation, water levels, water quality).
	Quality data usually not available at high density, making gridded data questionable at times.
	Groundwater measurements are sparse.
	Enhanced monitoring for algal blooms.
	Best practices instructions on how government sectors, state partners should coordinate to update the weekly drought monitor.
	Need consistent, accurate warning messaging across political boundaries.
	Monthly to decadal water budget projections
Transportation	More highway-centric data, such as pavement temperature.
	Additional mini-RWIS, mobile RWIS stations to fill spatial gaps.
	Expansion of truck AVL/GPS data during winter operations.
	Additional camera data to aid winter operations.
	Long-term, historical wind and solar data for renewables development
	Dense, high-quality, high-resolution observations to support peak demand power generation.
	Greater understanding of the threat posed by extreme heat, hazards to power generation (e.g., nuclear power) and grid.
	Accurate data and forecasts at high spatial and temporal resolutions.
	Seasonal forecasts for annual planning (e.g., salt purchases).

Table 2 (Continued). Summary of gaps in services

Economic Sector	Gaps in Services
Public Health	Further improvements in the density of weather, climate observations.
	Possible development of a wet bulb globe temperature.
	Improved monitoring of disease vectors and related environmental factors.
	Much improved integration and organization of extraneous data sets to aid air quality monitoring and prediction.
Environment & Conservation	Historical data sets of local climatologies and biomarkers are needed for species monitoring.
	Data collection standardization is needed to more easily integrate data from multiple sources.
	Balanced surveillance resources are needed across the state (e.g., county-by-county results) for more comprehensive study results.
	Much improved K-12 education about weather and climate is needed for greater understanding of all conservation issues
	Enhanced data access (e.g., broadband coverage) is needed for both the collection and dissemination of data.
Emergency Management	Much-improved data portals for finding and retrieving climate information.
	Need a single access source portal for different scales (county, state, etc.) with universal data storage.
	More staff resources are needed in the climate industry focused on workload (more direct hires focused on climate).
	A need for greater public education of climate and climate processes.
	Video training on how to access and use available tools and services.
	High-resolution inputs for flood inundation mapping.
	high-resolution, dense hydrology monitoring for city and rural areas.
	Additional radiosondes and/or drones to improve upper-air monitoring
Industry & Commerce	Need more uniform data structure, formatting to enable integration of data sets.
	More extensive, more thorough metadata to better define which tools and products can or should be useful for specific applications.
	Monthly to decadal climate projections highlighting high-impact weather/climate.
Media	More local, dense high-quality observations
	Need for high-quality weather archives to provide historical context
	Need for a well-maintained severe storms database