2nd National Flash Drought Workshop Report

Building On Progress and Looking Forward

LEAD AUTHORS

Molly Woloszyn
Cooperative Institute for Research in Environmental Sciences (University of Colorado Boulder), NOAA National Integrated Drought Information System
Sylvia Reeves
Cooperative Institute for Research in Environmental Sciences (University of Colorado Boulder), NOAA National Integrated Drought Information System
Marina Skumanich
University Corporation for Atmospheric Research, NOAA National Integrated Drought Information System

CONTRIBUTING AUTHORS

Eleanor Hasenbeck
Cooperative Institute for Research in Environmental Sciences (University of Colorado Boulder), NOAA National Integrated Drought Information System
Adam Lang
Cooperative Institute for Research in Environmental Sciences (University of Colorado Boulder), NOAA National Integrated Drought Information System
Ronald D. Leeper
North Carolina Institute for Climate Studies/NOAA National Centers for Environmental Information
Joel Lisonbee
Cooperative Institute for Research in Environmental Sciences (University of Colorado Boulder), NOAA National Integrated Drought Information System
Meredith Muth
NOAA Climate Program Office, National Integrated Drought Information System
Elizabeth Ossowski
NOAA Climate Program Office, National Integrated Drought Information System
Jason Otkin
Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison
Hailan Wang
NOAA Climate Prediction Center

ACKNOWLEDGEMENTS

We greatly appreciate the many partners on the Flash Drought Technical Working Group who contributed their time and efforts to coordinate, inform, and participate in the workshop, which provided the rich material for the development of this report.

We would like to thank the University Corporation for Atmospheric Research (UCAR)'s Cooperative Programs for the Advancement of Earth System Science (CPAESS) for their help with logistical efforts in convening the 2nd National Flash Drought Workshop.

The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of NOAA or the U.S. Department of Commerce.

SUGGESTED CITATION

Woloszyn, M., S. Reeves, M. Skumanich, E. Hasenbeck, A. Lang, J. Lisonbee, R.D. Leeper, M. Muth, E. Ossowski, J. Otkin, H. Wang, 2024. 2nd National Flash Drought Workshop Report: Building on Progress and Looking Forward. *NOAA National Integrated Drought Information System.*

Table of Contents

Executive Summary

> *The defining characteristic of **flash drought is rapid intensification** leading to new or worsening drought conditions.*

Flash droughts have been recognized within the last few decades as a unique phenomenon with significant impacts that require a different approach to monitoring, prediction, and planning. While there have been efforts to improve flash drought early warning over the last few years, a collaboration amongst researchers and practitioners[1] was needed to ensure a holistic and user-driven approach to improve the country's understanding and preparedness for flash drought. In response to this need, NOAA's National Integrated Drought Information System (NIDIS) and key partners began a Flash Drought Initiative in 2020 to build a community of practice to identify and advance outstanding research and information needs related to flash drought. This Initiative began through a collaborative workshop, the 1st National Flash Drought Workshop, which was held virtually in December 2020.

To continue building upon the work and priority needs established at the first workshop, the 2nd National Flash Drought Workshop took place in Boulder, Colorado from May 2-4, 2023. This workshop was also organized by NOAA's NIDIS with the assistance of a technical working group composed of leading practitioners and researchers from across the country who monitor, respond to, and plan for flash drought at the local, state, and/or regional level. The workshop gathered 80 other researchers and practitioners from federal, tribal, state, and local agencies, as well as academia and international institutions to address the topic of flash drought from national, regional, and sectoral perspectives.

> *Technical Working Group members are listed in **Appendix A**.*

The 2023 workshop objectives were:

1. **Convene** flash drought researchers and practitioners to learn from one another, build stronger connections, and increase coordination.
2. **Establish the state of the science** of flash drought research, monitoring, prediction, planning, and communication, and share new and emerging areas of flash drought research.
3. **Build a better understanding of practitioner needs** for improved flash drought preparedness, response, and communication.
4. **Share research, tools, case studies, and regional/seasonal characteristics** of flash drought to improve management and response.
5. **Develop an updated list of outstanding research and information needs** since the 2020 workshop for flash drought monitoring, prediction, planning, and response.

---

[1] In this report we are defining "practitioners" as those that are responding to and/or planning for flash drought like state drought leads or state climatologists.

This report captures the key takeaways from the sessions at the workshop; the gaps, needs, and opportunities identified at the workshop; and a list of priorities moving forward for flash drought research and decision making. The identified priorities also serve as a focal point for the flash drought community to effectively respond to and mitigate drought impacts. This report and the identified priorities reflect the dialogue and discussion of the workshop attendees and do not represent official Administration policy or position, or the official policy or position of the individual organizations and agencies participating.

The table below summarizes the key recommendations identified at the workshop. **To read more details about each of these recommendations, review the "Looking Forward: Gaps, Needs, and Opportunities" section of the report.**

Overarching Need	Key Recommendations	
Contextualize Flash Drought by Region and Sector	Regional Recommendations	Develop region-specific education materials, such as information sheets, on flash drought.
		Partner with existing regional programs for future regional work.
		Conduct regional climatology studies to identify typical drought intensification rates.
	Sectoral Recommendations	Conduct historical assessments of flash drought by sector to identify economic impacts and effective management strategies.
		Identify key variables needed to monitor flash drought by sector.
		Develop sector-specific information sheets on flash drought.
		Target future engagement with flash drought-prone sectors beyond row-crop agriculture.
		Explore the co-funding of flash drought research and tool development with industry partners.
Raise the Level of Condition Monitoring and Impact Collection	Partner with federal agencies to contribute to reporting impacts (e.g. Condition Monitoring Observer Reports) on a regular basis.	
	Share examples of successful efforts to collect more on-the-ground reports.	
	Engage with public water supply agencies to provide reports of flash drought impacts to water supply.	

Develop Pathways for Effective Research to Action	*Convene:* Continue in-person meetings and workshops that bring together practitioners and researchers to present the most recent flash drought science.
	Learn and share: Develop case studies of successful "research to action."
	Learn and share: Create virtual spaces for interaction among researchers and practitioners (e.g., Basecamp, Slack).
	Learn and share: Increase international collaboration to learn from one another.
	Communicate: Develop a resource webpage or newsletter focused on flash drought for practitioners.
	Operationalize Products: Develop a framework for analyzing flash drought product performance before becoming operational.
Increase Access to Flash Drought Monitoring Data and Tools	Continue training on existing flash drought monitoring tools.
	Utilize Climate Engine as a source for additional flash drought monitoring capabilities.
	Develop products in collaboration with social scientists and user design specialists.
	Expand the Upper Missouri River Basin Soil Moisture and Snowpack Monitoring pilot study to other basins across the United States.
	Continue to expand the number of flash drought indicators.
	Develop products that show recent changes in monitoring variables through time series or change maps.
	Validate existing flash drought-specific monitoring tools.
Improve Flash Drought Prediction on Multiple Timescales	Analyze which meteorological and/or radiative variables are most important to improve flash drought prediction, and explore predictability of those variables.
	Validate existing flash drought prediction tools.
	Study the "false positives" of flash drought prediction tools.
	Develop real-time monitoring tools that include trends and short-term forecasts. Continue to explore machine learning for improved flash drought prediction.
	Continue to improve dynamic vegetation processes in land-surface models and statistical prediction models for flash drought.
Improve Flash Drought	Develop drought plans that are better suited for a faster response. Test those plans in table top and scenario based exercises.

Communication, Response and Planning through Coordination and Sharing	Share success stories showcasing various scales of coordination (e.g., state, multi-state, regional) to effectively respond to a flash drought event.
	Develop template communication materials and/or guidelines to assist practitioners with flash drought response.
	Develop effective pathways to convey the risk of flash drought to the general public.
Accelerate Research and Understanding of Flash Drought	Conduct post-flash drought assessments at various scales (e.g., regional, state, local) and/or sectors.
	Study the role of antecedent conditions in flash drought development.
	Study the relationship between wildfire and flash drought.
	Study flash drought in semi-arid climates.
	Study cases where the environmental indicators pointed to the existence of flash drought conditions, but flash drought impacts did not occur.

Introduction & Background

Flash drought, or a rapid intensification drought event that leads to significant impacts, has prompted a collaboration amongst researchers and practitioners. This holistic and user-driven approach aims to improve the country's understanding and preparedness for flash drought. The 2nd National Flash Drought Workshop took place in Boulder, Colorado from May 2-4, 2023, organized by NOAA's National Integrated Drought Information System (NIDIS) with the assistance of a technical working group composed of leading practitioners and researchers from across the country who monitor, respond to, and plan for flash drought at the local, state, and/or regional level. The workshop gathered 80 other researchers and practitioners from federal, tribal, state, and local agencies, as well as academia and international institutions to address the topic of flash drought from national, regional, and sectoral perspectives. This workshop followed the 1st National Flash Drought Workshop, which was held virtually in December 2020 and identified six priority actions in its summary report - clarification of the concept of flash drought, practitioner engagement, monitoring, prediction, planning/response and building a network to enhance research coordination and applications.

What is the National Integrated Drought Information System?
The National Oceanic and Atmospheric Administration's (NOAA's) National Integrated Drought Information System (NIDIS) program was authorized by Congress in 2006 (Public Law 109-430) and reauthorized in 2014 and 2019 with an interagency mandate to coordinate and integrate drought research, building upon existing federal, tribal, state and local partnerships in support of creating a national drought early warning information system.

MISSION
To maximize the nation's ability to proactively manage drought-related risks, by providing those affected with the best available information and resources to assess the potential for drought and to better prepare for, mitigate, and respond to the effects of drought. Toward that end, NIDIS will create a drought early warning system for the nation using a comprehensive, interagency approach.

NIDIS is led by the National Oceanic and Atmospheric Administration (NOAA), and is housed within the Office of Oceanic and Atmospheric Research's Climate Program Office.

As called for in the December 2020 workshop report, NIDIS formed a technical working group of flash drought researchers and practitioners from federal, state, local, academic, and other institutions to execute the priority actions from the 2020 workshop report (Appendix A). There has been much progress made since the December 2020 virtual workshop (see Table 1), and the time was right to take stock and look forward.

The 2nd National Flash Drought Workshop in 2023 was held to provide updates on progress towards the six priority actions from the 2020 workshop, and to evaluate and potentially re-target these priorities. In particular, the second workshop built stronger connections with practitioners to ensure flash drought research and tools are meeting the needs of practitioners.

This report captures the key takeaways from the sessions at the workshop; the gaps, needs, and opportunities identified at the workshop; and the priorities moving forward for flash drought researchers and decision makers. The intended audience for this report includes those who attended the workshop, those who were unable to attend but interested in the workshop content, and those agencies, programs, and other institutions working to advance flash drought science, response, and/or preparedness.

Table 1. A list of key accomplishments based on the priority action items from the 2020 workshop report.

2020 Flash Drought Workshop Priority Action Items	Key Accomplishments Since 2020
Clarifying the Concept of Flash Drought	● Flash drought literature review - Lisonbee et al. 2021 ● Bulletin of American Meteorology Society (BAMS) article - Otkin et al. 2022 ● Numerous other publications from researchers
Practitioner Engagement	● Regional practitioner discussions: Southeast, Northeast, Southern Plains
Flash Drought Monitoring	● Continued flash drought tool development ● Key soil moisture network expansions in Upper Missouri River Basin, Southeastern U.S., and individual states
Flash Drought Prediction	● Continued flash drought tool development (see above) ● NOAA Climate Prediction Center land-surface model improvements ● Flash drought priority research list developed and shared across the federal landscape
Planning/Response for Flash Drought	● Regional practitioner discussions (see above) ● 2021 NIDIS flash drought webinar series ● Flash drought tools - advantages and disadvantages resource ● NIDIS Climate-Adaptive Drought Planning (CADP) Platform
Network Building and Coordination	● Formation of a flash drought technical working group ● Major conference sessions (e.g., American Meteorological Society, American and European Geophysical Union)

2023 Workshop Overview

Workshop Objectives

The 2nd National Flash Drought Workshop brought together flash drought researchers and practitioners to build stronger connections and increase coordination in order to ensure that flash drought research and tools are meeting the needs of practitioners who are responding to and planning for flash drought. Participants identified the following objectives for the workshop:

1. **Convene flash drought researchers and practitioners** to learn from one another, build stronger connections, and increase coordination.
2. **Establish the state of the science** on flash drought research, monitoring, prediction, planning, and communication, and share new and emerging areas of flash drought research.
3. **Build a better understanding of practitioner needs** for improved flash drought preparedness, response, and communication.
4. **Share research, tools, case studies, and regional/seasonal characteristics** of flash drought to improve management and response.
5. **Develop an updated list of essential research and information needs** since the 2020 workshop for flash drought monitoring, prediction, planning, and response.

Overview of Sessions

The workshop's seven sessions promoted discussions between researchers and practitioners to address priority actions from 2020, while identifying next steps to ensure future progress in mitigating the impacts of flash drought. The full agenda is included in Appendix B; here is a snapshot of the sessions:

Session 1: **State of the Science** addressed the current understanding of and practices related to flash drought in the following topic areas: Monitoring; Prediction; Impacts; Policy, Planning, and Decision Making; and Flash Drought in a Changing Climate.

Session 2: **Practitioners Perspectives** focused on the actual experiences and needs of decision makers and was a forum for questions from researchers.

Session 3: **Poster presentations** and an interactive **Tools Cafe** provided one-on-one engagement and learning.

Session 4: **Case Studies** showcased the various experiences in responding to flash drought, with a brainstorming session intended to draw out successes, challenges, and lessons learned.

Session 5: **Regional Breakouts** allowed for deeper discussion about flash drought science, impacts, applications, and gaps/needs to provide improved responses to flash droughts on a regional basis.

Session 6: **Emerging Science** explored new areas of research and included discussions to direct future efforts.

Session 7: **Moving Forward** identified near- and long-term work needed to further characterize, monitor, predict, respond to and communicate about flash drought based on enhanced coordination and networks forged during this workshop.

The program included 24 presentations, 12 interactive tools tables, and 4 posters from NIDIS partners representing a broad range of Federal, State, local and academic interests. The flash drought prediction and monitoring tools showcased during the Tools Cafe during Session 3 of the workshop are listed in Appendix C.

Presentations and additional resources can be found on the [NIDIS Flash Drought Workshop 2023 web page](). Recordings of plenary presentations are available on the [NIDIS YouTube page]() for each individual session.

Workshop Participants

Eighty two 82 people attended the workshop in person, including a mix of researchers and practitioners. Figure 1 shows 55% of attendees were researchers, 33% were practitioners, and 12% served in both roles—as a researcher, but also a practitioner responding and/or planning for drought in their area.

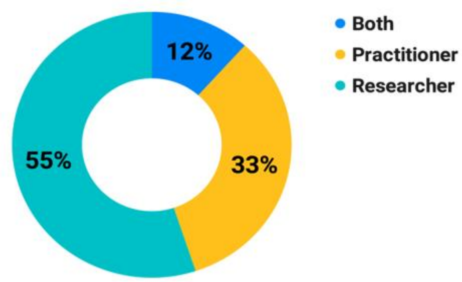


Figure 1. In-person workshop attendees by job role as either a practitioner (yellow), researcher (teal), or someone that serves in both capacities (blue).

While a majority of attendees represented universities (54%), there was a mix of representation from other entities including federal agencies (20%), state agencies (14%), private sector (7%), international entities (3%) and tribal nations (1%) (Figure 2). Workshop attendees came to Boulder, Colorado for the workshop from 24 different states spanning the entire continental U.S., with 3 international participants representing Argentina and Turkey (Figure 3).

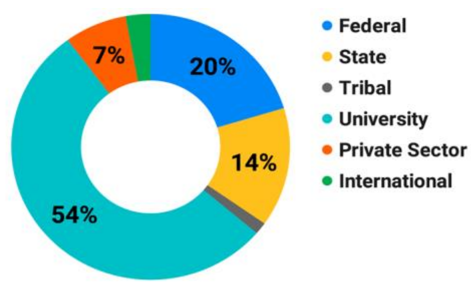


Figure 2. In-person workshop attendees by type of entity including federal (blue), state (yellow), tribal (gray), university (teal),

Based on feedback collected through a workshop evaluation form, 100% of respondents indicated that the workshop was "extremely effective" or "very effective" at providing partners with an opportunity to network and learn from one another.

An additional 112 people registered for the virtual component of the workshop. Figure 4 shows the range of geographic areas of virtual participation, with virtual registrations from 34 states, 2 U.S. territories, and 11 non-U.S. countries. Organizers shared all workshop materials, including recordings, with all registered participants. As of February 2024, the workshop session recordings have over 675 total views on YouTube.

Figure 3. In-person attendees by state and country.

Figure 4. Registered virtual attendees by state, territory and country.

2023 Workshop Key Takeaways

State of the Science

The workshop began with a session focused on the state of the science of flash drought to establish a baseline level of knowledge among the workshop participants. This session provided a framing context for the workshop by reviewing the latest research on physical science, social science, and policy components of flash drought in five presentations. A brief summary of each presentation is given below. Each presentation can be viewed in its entirety through the workshop recordings page.

Framing Flash Drought and Monitoring

Jason Otkin, from the University of Wisconsin-Madison, delivered the first presentation focused on the appropriate framing and monitoring for flash drought. In this presentation, Otkin enumerated the five topics that constitute the pillars of a robust flash drought early warning system, which are enumerated in Otkin et al. 2022. To develop this robust system, engagement is required between physical scientists, social scientists, operational monitoring and forecast centers, practitioners, and policy makers to be successful.

The five pillars are:

1. Physically-based identification framework
2. Comprehensive flash drought monitoring capabilities
3. Improved prediction of flash drought
4. Flash drought impact assessments
5. Decision-making and policy

As part of the identification framework, Otkin defined flash drought as a drought event that rapidly intensifies over the course of a few weeks and leads to new or worsening drought impacts. Flash drought can occur at the onset of drought or during an ongoing drought (Figure 5). In addition, flash drought definitions should account for the rapid rate of intensification and moisture limitation leading to impacts (Otkin et al., 2018).

***Flash drought* is a drought event that rapidly intensifies over the course of a few weeks and leads to new or worsening drought impacts. Flash drought can occur at the onset of drought or during an ongoing drought.**

Otkin emphasized existing operational drought monitoring tools may not sufficiently respond to flash drought, because they were designed for slower-developing droughts. Flash drought monitoring requires multiple datasets and tools, including (but not limited to) precipitation, evaporative demand, soil moisture, evapotranspiration, vegetation indices, and the U.S. Drought Monitor. Otkin highlighted that it is crucial to look at the rapid changes in these datasets using approaches like standardized change anomalies (e.g., rapid change index) or percentiles.

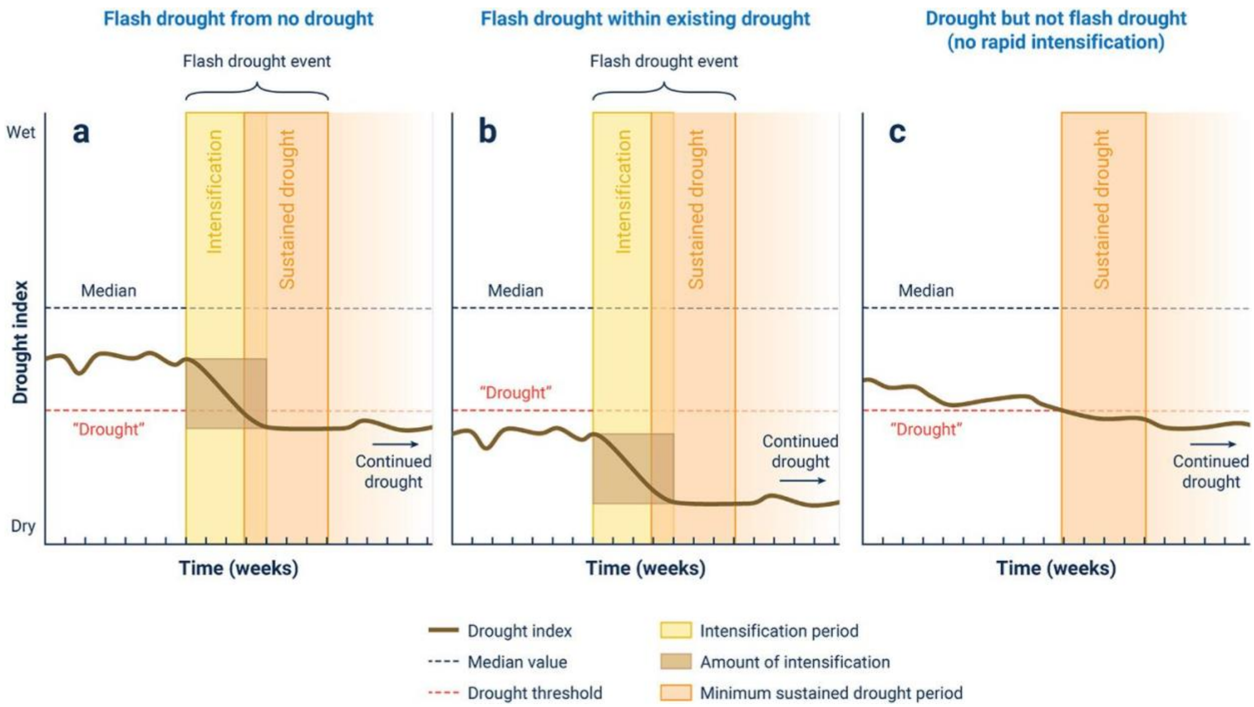


Figure 5. Reprinted with permission from Otkin et al. 2022 - Idealized time series showing the evolution of a generic drought monitoring index for (a) flash drought development from a drought-free initial state, (b) flash drought development during an ongoing drought, and (c) slow intensification during conventional drought. Time increments along the x axis are notional, with agricultural flash drought used in this example to demonstrate the flash drought identification framework. Yellow shading depicts the period of rapid intensification whereas the orange shading denotes the minimum length of time that drought must persist for an event to be considered flash drought. Note that the lengths of the intensification and minimum drought periods shown here are for illustrative purposes and can be adjusted to accommodate the emergence of different impacts or the needs of different practitioners.

Flash Drought Prediction and Predictability

Andrew Hoell, with NOAA's Physical Sciences Laboratory, and Hailan Wang, with the NOAA Climate Prediction Center (CPC), addressed flash drought prediction and predictability. Flash drought is a difficult phenomenon to predict because it involves complex moisture and energy fluxes, and dynamic vegetation response.

"Researchers must gain a better understanding of the physical mechanisms and processes driving flash drought, and models must accurately represent these mechanisms and processes as well."

Looking at past flash drought events, the 2012 Central U.S. flash drought was not predicted on the Seasonal Drought Outlook, nor was the 2017 Northern Great Plains flash drought. Researchers must gain a better understanding of the physical mechanisms and processes driving flash drought, and models must accurately represent these mechanisms and processes as well.

Hoell emphasized that identifying sources of predictability (defined as the ability to accurately predict deviations from average) is important to improving the prediction of flash drought. Examples of current predictability include: (1) a positive Indian Ocean Dipole related to below-average precipitation in the southeastern U.S., which was seen during the 2019 flash drought; and (2) La Nina conditions increasing flash drought risk in the Northern Great Plains. Moving forward, new predictability sources for flash drought need to be identified, including models of natural climate variability and non-stationary climate change. Improving statistical models by adopting and applying novel prediction techniques could help identify additional sources of predictability. For dynamical modeling, improvements are needed to model physics and data assimilation, particularly over land. In land surface models, improvements are needed to better represent dynamical vegetation processes.

Wang noted that the recommended properties for flash drought forecast products include: (1) products that specifically target flash drought, predicting on the shorter-time scale; (2) products that are probabilistic and issued weekly or more frequently; and (3) products that are aligned with flash drought impacts (e.g., soil moisture, vegetation stress). NOAA CPC is continuing to improve flash drought prediction products through a partnership with NIDIS to develop a new probabilistic flash drought outlook driven by user and stakeholder needs.

Flash Drought Impacts

Amanda Cravens, with the U.S. Geological Survey (USGS), spoke about the uniqueness of flash drought impacts. Flash drought impacts are different or of different magnitude than conventional drought because of how quickly drought intensifies and/or because of when drought intensifies. For example, if drought intensifies quickly, many calls for irrigation water at the same time may push a system beyond its ability to meet demand. Or, if flash drought occurs during crucial points of the growing season, it may push vegetation past its ability to cope compared to a flash drought that occurred during a different part of the growing season. If not monitored properly, flash drought impacts may catch people off guard as more abrupt changes are different and potentially more damaging than those that people have more time to prepare for.

"It is possible that flash drought impacts may catch people off guard as more abrupt changes are different and potentially more damaging than those that people have more time to prepare for."

Cravens highlighted that flash drought impacts are likely best understood across the agricultural sector. However, less is known about flash drought impacts to other areas or sectors, like hydrological or ecological impacts, and social and/or human health impacts outside of agriculture. In addition, less is known about how flash drought impacts vary by region within the U.S. and across the world.

Cravens also noted that an increase in drought impact collection is a crucial component of an improved understanding of flash drought. Another key difference between flash drought and slower onset drought is that impact assessments may need to use newer methods to differentiate the impacts of flash drought during the period of rapid intensification from slower onset drought impacts that precede or follow it. Unique impacts or different magnitudes of impacts will likely emerge during the period of rapid intensification. Such new methods could include social media, crowdsourcing, or other rapid assessment methods.

Incorporating Flash Drought into Planning, Policy and Decision Making

Mark Svoboda from the National Drought Mitigation Center presented a perspective on incorporating flash drought into planning, policy and decision-making. Svoboda emphasized that to improve preparedness for flash drought, it is not just about changing our “tool set”, but rather our “mindset” regarding planning and decision making. Flash drought demonstrates that drought is not always a slow-moving disaster. In addition to a comprehensive approach, facilitated through a Drought Early Warning System (DEWS), research is key to increasing resilience to drought. Flash drought demonstrates the need for a DEWS even more.

Svoboda spoke about Figure 6 below, which shows the collaboration and communication channels across scales within a DEWS, and noted that policy and planning response is most effective when informed by knowledge from within the system. Flash drought emphasizes the need for these channels to function not just during a drought, but proactively, ahead of drought and ahead of forecasts. The short time scale of flash drought requires even more efficient coordination and flow of information to anticipate and reduce negative impacts. We must bridge drought early warning systems into planning and policy.

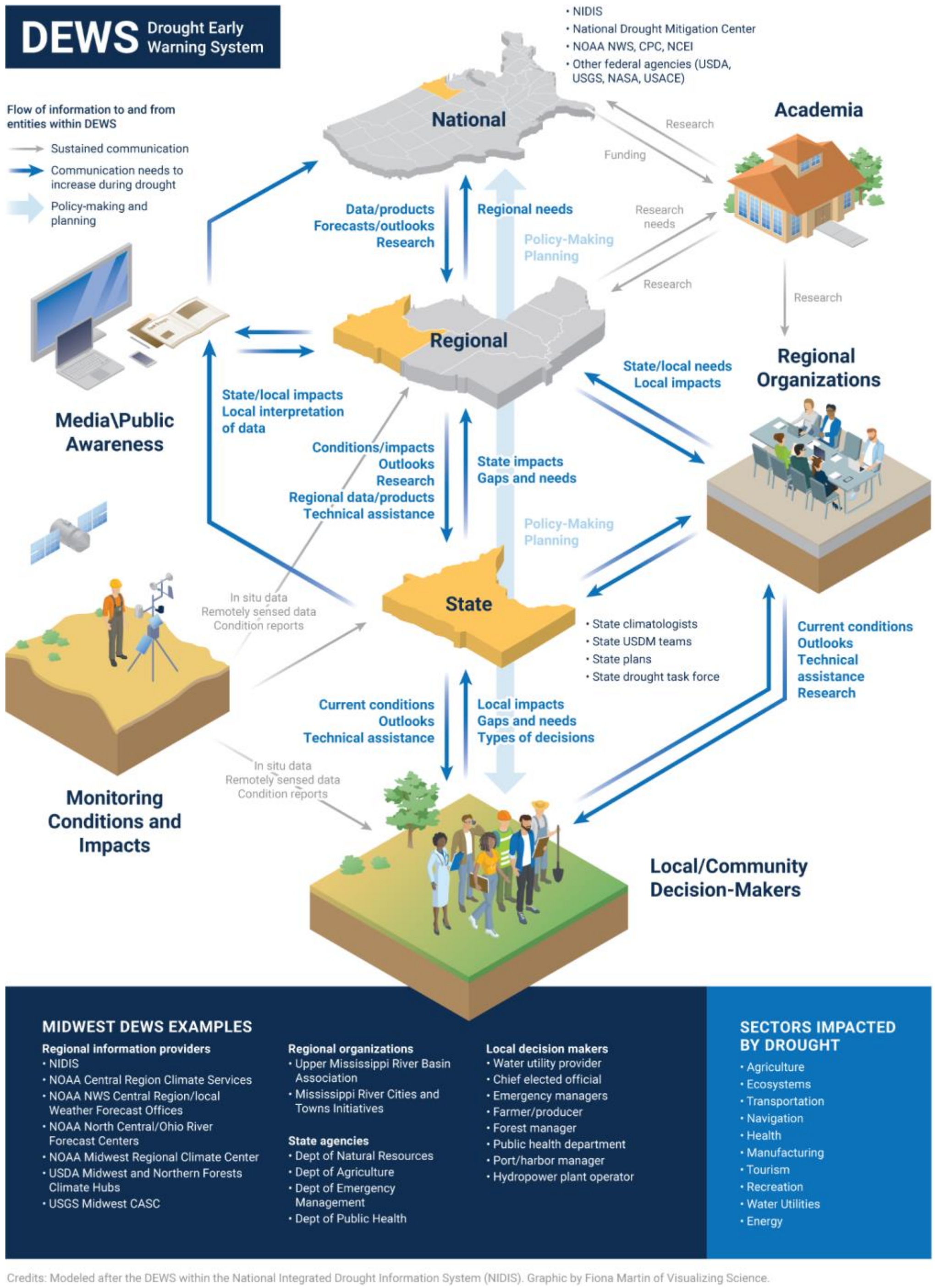


Figure 6. Reprinted with permission from Otkin et al. 2022. Simplified visualization of a DEWS, modeled after the NIDIS Midwest DEWS. The arrows represent the flow of information to and from the entities within the region, with the thicker blue arrows representing the flow of information that needs to increase during flash drought. The thick light blue arrow represents the policy and planning that happens at all levels within the DEWS. The type of information exchanged by the various pathways is shown in the text adjacent to the arrows. Specific examples of entities and drought-impacted sectors in the Midwest DEWS are in the blue box.

Projections of Flash Drought in a Warming Climate Across the United States
Jordan Christian from the University of Oklahoma made the final presentation in this session. He provided an overview of findings around future projections of flash drought in a warming climate from Christian et al. 2023. Christian noted that it is important to ensure the climate model can capture historical events. In this case, the climate model used in this study was able to capture trends including the hot spot for flash drought development in the central U.S. and the seasonal cycle of flash drought of a higher frequency in the summer months.

Looking into the future, all model scenarios (low-, medium-, high-emissions) show a 5-15% increase in flash drought frequency across the western and central U.S., with the frequency of occurrence in the eastern U.S. about the same as it is today. This study found that the increase in flash drought frequency is mainly driven by expected increases in evaporative demand, rather than precipitation. This was a global study, and the expected increase in flash drought in the U.S. was modest compared to the increase in other parts of the world, such as Europe and South America.

"All model scenarios show a 5-15% increase in flash drought frequency across the western and central U.S."

With agricultural demand expected to double by the middle of the 21st century due to an increase in global population, Christian highlighted that this study also looked specifically at how flash drought may affect cropland in the future. Cropland risk in the U.S. from flash drought is projected to moderately increase under the low- and medium-emission scenarios, but a significant increase in cropland risk from flash drought is projected under the high-emissions scenario.

Practitioner Perspectives

Practitioners from a variety of sectors (e.g., agriculture, water supply/policy, energy) shared how they assess, respond to, and guide the public on flash drought. For researchers, understanding this perspective ensures flash drought research and tools provide effective decision support.

Practitioners provided their perspectives on monitoring, responding to, and preparing for flash drought. Some of the main questions on practitioners' minds include:

- How do we know if this is a flash drought, or just a dry spell?
- How will we know if it's going to lead to impacts?
- If it is a flash drought, what can we do about it and who will this flash drought affect?

View full presentations from practitioners on the following workshop recordings pages: Session 2 (Practitioner Perspectives), the Morning Coffee Chat on Day 2, and Session 4 (Case Studies of Flash Drought).

Key takeaways from these practitioner presentations and discussions are described below. Takeaways are organized by region, by sector, and in overarching themes, which generally apply to all locations and sectors.

Overarching Key Takeaways

Some key takeaways from practitioner discussions were relevant regardless of location or sector; these are listed below.

Characteristics of Flash Drought

- The timing of the flash drought event determines the impacts (e.g., at the start of the growing season vs. the end of the growing season).
- Sectors and regions are affected differently, so identifying flash drought impacts and information needs by sector and region is important.

Planning and Response

- Across many sectors, the rapid acceleration of drought has different impacts and therefore requires different responses.
- For practitioners, there are three important time scales to look at in terms of the likelihood of flash drought:
    1. the next few weeks,
    2. the next season or two, and
    3. in the future in a changing climate (i.e., will they increase or decrease in frequency due to changes in precipitation trends).
- Even in conventional/slow-moving drought, it is difficult to motivate response actions. Flash drought exacerbates this difficulty at a time when decisions need to be made quickly.
- Land-grant extension programs play a key role in helping farmers prepare for and respond to flash drought. They also facilitate information sharing about the knowledge gaps related to drought/flash drought.
- Some examples of actions in Massachusetts to address flash drought (and drought more broadly) include: garnering support for the installation of additional monitoring stations, increasing the frequency of water-based measurements of ground water levels, and creating a state-based drought dashboard and water impact reporter.

Monitoring

- Additional soil moisture data is needed to adequately monitor flash drought. Encouraging first-hand impact and condition reports from local experts and the general public is also important.
- Many practitioners are involved in weekly state drought assessment for the U.S. Drought Monitor.

- Many states utilize Condition Monitoring Observer Reports (CMOR), through the National Drought Mitigation Center, to gather information from people on-the-ground to help assess conditions and impacts (e.g., North Dakota, South Carolina, Missouri).
- Having a system in place to monitor conditions (e.g., a drought task force) is beneficial to maintain a continuous assessment of the situation and being prepared to take action as needed.
- Assessing the situation in real-time is a challenge for practitioners, whereas researchers study flash drought in hindsight.

Communication

- There is a clear opportunity to improve communication around flash drought by focusing on the impacts of the event (similar to what the National Weather Service has done in their impact-based warnings).
- Methods used by practitioners to communicate about flash drought include sharing information coordinated with state climate offices, insurance companies, and state agencies via press releases, social media campaigns, blogs, one-on-one conversations, webinars, extension program exchanges, workshops, and media interviews.
- There are cases in which it is not beneficial (and potentially more confusing) to differentiate flash drought from conventional drought in communications. The communications approach should change with the intended audience. Many stakeholders make decisions based on the severity and impacts of drought, not based on what it is called.
- Practitioners can play a key role in communicating what flash drought is and what it isn't. This is particularly important when it comes to the misconception that a flash drought will always be short in duration.

Key Takeaways by Region and Sector

Flash drought characteristics and impacts vary by geographic regions, watersheds, land use categories, and even soil types. In some locations, flash drought is more easily identified at the beginning of a drought event. It may be more difficult to identify after the drought is in progress (e.g., a rapid change from long term D2 to D4). While agriculture is typically the first sector to see drought impacts, it is not the only sector. Rapid intensification of drought must be defined in terms of its influence on ecosystems, energy production, human health, and the response capabilities of water utilities and transportation management systems. While not an exhaustive list, **the table in Appendix D captures key regional and sectoral characteristics of flash drought discussed at the 2023 workshop**.

Table 2. List of practitioners that presented during the workshop.

Person	Title	Organization	Session
Klaus Albertin	Water Supply Engineer, Division of Water Resources	North Carolina Department of Environmental Quality	Session 2 Presentation
Miranda Meehan	Extension Disaster Education Coordinator and Livestock Environmental Specialist	North Dakota State University Extension	Session 2 Presentation
Sumit Sharma	Extension Specialist for High Plains Irrigation and Water Management	Oklahoma State University	Session 2 Presentation
Beckie Maddox	Senior Environmental Specialist	Constellation Nuclear	Session 2 Presentation
Pam Knox	Agricultural Climatologist	University of Georgia Extension	Morning Coffee Chat Recorded Discussion
Dannele Peck	Director	USDA Northern Plains Climate Hub	
Art DeGaetano	Director	Northeast Regional Climate Center	
Trent Ford	Illinois State Climatologist	University of Illinois/Illinois State Water Survey	
Vandana Rao	Director of Water Policy	Massachusetts Executive Office of Energy and Environmental Affairs	Session 4 Presentation
	Massachusetts State Resources Shared: ● Drought Management Website ● State Drought Dashboard ● Massachusetts Water Impact Reporter ● Water Conservation Toolkit (including links to infographics)		
Elliot Wickham	Water Resources Climatologist	South Carolina State Climatology Office	Session 4 Presentation
	South Carolina Resource Shared: South Carolina Drought Dashboard		
Karin Bumbaco	Assistant State Climatologist	Washington State Climate Office	Session 4 Presentation
Pablo Spennemann	Researcher	Servicio Meteorológico Nacional-CONICET, Argentina	Session 4 Presentation

Emerging Physical Science

A session about emerging science provided an overview of new and novel research in the physical science of flash drought. This session provided practitioners an indication of where future tools and resources might be found.

Each of the four presenters in this session (see Table 3 below) explored a different research area with an identified need for more investigation:

- **Defining a new conceptual model for flash drought** distinct from the more traditional, slow-developing drought. The objective was to provide practitioners a framework that can clearly describe flash drought dynamics. (Jeff Basara, University of Oklahoma)
- **Developing better techniques for applying soil moisture information to existing forecasts**. Even as soil moisture is widely recognized as an important indicator of flash drought, there remain questions on how it can be effectively harnessed to support prediction. (Kyle Lesinger, Auburn University)
- **Exploring the opportunity for new indicators of flash drought**, such as satellite data sources for vegetation-based indicators. Since flash drought often expresses as significant damage to plants, research is needed to understand how satellite and other markers of plant condition might be used as flash drought indicators. (Koushan Mohammadi, University of Connecticut)
- **Examining how teleconnections such as the El Nino Southern Oscillation can affect the potential for flash drought.** While much of the focus on flash drought has been on more localized atmospheric and soil moisture indicators, more distant dynamics might also provide some indication of flash drought potential. (Emma Scott, North Carolina Institute for Climate Studies)

Table 3: List of presenters and presentation titles/links to recordings for the "Emerging Science" session

Person	Presentation Title
Jeff Basara, University of Oklahoma	A Framework for Flash Drought Development and Progression
Kyle Lesinger, Auburn University	Subseasonal Flash Drought Prediction Skill in the Contiguous United States
Koushan Mohammadi, University of Connecticut	Assessing the performance of Sub-Seasonal Solar-Induced Fluorescence trajectory as an early warning system for flash droughts in the US regions and Ecosystems
Emma Scott, North Carolina Institute for Climate Studies	Using the El Niño-Southern Oscillation and Madden Julian Oscillation Modes of Variability to Predict Rapid Drought Change

Looking Forward: Gaps, Needs and Opportunities

The workshop provided an opportunity for researchers and practitioners to identify key recommendations that advance understanding and preparedness for flash drought. No one organization or program can address all of the recommendations identified. This report is meant to inform advancements and investments that address flash drought across multiple sectors and levels of government. Through shared understanding and dedicated resources, our nation can make real progress to increase our nation's ability to advance flash drought understanding and preparedness.

Contextualize Flash Drought by Region and Sector

There was a strong consensus at the workshop that future work should focus on contextualizing flash drought at the regional and sectoral scale, rather than the national or broad-sector approach due to important regional and sectoral nuances of flash drought. Contextualizing flash drought at the regional or sectoral scale will likely lead to more effective communication with decision-makers and the general public, which in turn will produce more successful response and preparedness. This may include identifying flash drought characteristics and nuances, impacts, critical indicators, data and information needs, and effective response and management actions.

Regional Highlights & Key Recommendations

Workshop participants shared that they valued the time spent in regional breakouts, which provided them the opportunity to discuss regional issues, meet regional partners, and identify potential solutions to improve flash drought preparedness in their region. Many participants also found the regional scenario exercise in the second breakout session helpful to brainstorm potential regional issues and response actions.

*A **full list of recommendations by region** (Northeast, Southeast, Midwest, Southern Plains, Missouri River Basin, Pacific Northwest, Intermountain West, and California-Nevada) is available in **Appendix E**.*

Recommendations of future work at the regional level include:

- **Develop region-specific documents on flash drought.** These documents could highlight what flash drought typically "looks like" in their region, including impacts and seasonal nuances of when flash drought is most impactful, critical indicators to monitor, case studies from the region, and effective flash drought management actions.
- **Utilize regional flash drought "table top" or scenario exercises.** These exercises could provide the opportunity to identify potential issues that could arise during a flash drought, "test" flash drought plans and response/mitigation actions, and bring new partners to the table that are critical in flash drought response and management.
- **Partner with the existing regional programs for future regional work**. Existing regional programs, like the Regional Climate Centers, regional drought early warning systems (DEWS),

and USDA Climate Hubs, are well suited to explore flash drought at the regional level and facilitate regional partnership. The regional DEWS networks within NIDIS can be used to share regional information and resources around flash drought.

- **Conduct regional climatology studies to identify typical drought intensification rates**. This study would establish a baseline for how fast drought typically intensifies within a region, which could be used in real-time monitoring to identify when a drought is intensifying more quickly than normal.

Sectoral Highlights & Key Recommendations

Agriculture is often the first known sector to be affected by flash drought. Many discussions and research around flash drought have focused on this sector. However, past flash droughts have shown that other sectors can be impacted as well, such as municipal water, ecosystems, and wildfire management. These other sectoral and cascading impacts are less known and/or documented.

Recommendations of future work at the sectoral scale include:

- **Conduct historical assessments of flash drought by sector to identify economic impacts and effective management strategies**. Studying past flash drought events can provide the opportunity to identify sectoral impacts of flash drought (particularly those beyond agriculture), with a particular focus on studying the economic impact. These assessments could also help identify effective flash drought response and/or management actions for particular sectors.
- **Identify key variables needed to monitor flash drought by sector**. For instance, water temperature and streamflow are important for power plants within the energy sector, while soil moisture is important for agriculture. Once identified, it is important to assess how well these variables can be monitored and predicted.

> ***A full list of recommendations*** *by sector (crop agriculture, livestock agriculture ecosystems) is available in* ***Appendix E.***

- **Develop sector-specific documents on flash drought.** These documents could highlight how flash drought typically impacts the sector, including an economic evaluation, seasonal nuances of when flash drought is most impactful, critical indicators to monitor, case studies from the sector, and effective flash drought management actions.
- **Target future engagement with sectors beyond row-crop agriculture**. Once row crops are planted, few management actions can be taken if a flash drought occurs. Also, financial systems are in place to combat the impacts (i.e., crop insurance). Future engagement should focus on sectors and/or communities beyond row-crop agriculture that might benefit from flash drought information, such as monitoring techniques, data and indicators, flash drought tools and resources, and the regional network of partners.
- **Explore the co-funding of flash drought research and tool development with industry partners**. There are opportunities to use public-private partnerships to co-fund sectoral-based research and the development of sector-specific flash drought tools.

Raise the Level of Condition Monitoring and Impact Collection

An increased understanding of regional and sectoral flash drought impacts is needed to improve monitoring, response, and preparedness to flash drought. Citizen science mechanisms, such as the Condition Monitoring Observer Reports (CMOR), collect information about conditions and impacts across the country. However, throughout the country, these mechanisms need more observers to convey what they are seeing on the ground in their region and sector.

More on-the-ground reports of conditions and impacts across the country would benefit:

- Use in coordination with existing data sources to ground-truth indicators. In the case of flash drought, impacts may happen more quickly and current datasets might not capture the rapidly-changing conditions.
- Communicate the current and/or potential impacts and risk of flash drought for a particular region or sector.
- Tie potential response and management strategies to primary impacts.

Key Recommendations

To increase the number of citizens providing condition monitoring and impact reports, key recommendations from the workshop include:

- **Partner with federal agencies that have land management staff across the country to contribute to CMOR on a regular basis**. Primary agencies to explore collaboration with include the U.S. Forest Service, National Park Service, Bureau of Land Management, U.S. Fish and Wildlife Service, and the Bureau of Reclamation.
- **Share examples of successful efforts to collect more on-the-ground reports**. For example, highlight how North Dakota utilizes their Extension agent network to collect CMOR reports from across the state. Or, share how the Southeast DEWS is documenting and exchanging best practices for expanding the use of drought impact reporting from the agricultural sector.
- **Engage with public water supply agencies to provide reports of flash drought impacts to water supply**. While some water systems are more resilient to drought (e.g., groundwater systems), other water systems (e.g., surface water supply) may be impacted by rapidly intensifying drought. Researchers and practitioners should conduct outreach to public water supply agencies to share insights into flash drought and encourage utility staff to report impacts to public water systems through CMOR and other reporting avenues.

Develop Pathways for Effective Research to Action

The intended value of flash drought research is to improve our understanding of the hazard so our nation can become more resilient and lessen the negative impacts from flash drought. To ensure this intended value, flash drought research needs to get in the hands of practitioners that are making decisions when faced with flash drought and other hazards. Developing a pathway for this "research to action" is crucial, but not straightforward.

Some of the biggest barriers for effective research to action include:

- There is a lack of operational funding for drought products in general, let alone flash drought products. There are often funds to develop and research products, but there is no clear pathway or funding mechanism to transition products from the research phase to the operational phase.
- There is no standard way to rigorously analyze drought product performance before becoming operational.
- Scientific research is most commonly published in peer-reviewed journal articles, which are limited in their reach to diverse practitioner audiences. Determining the most effective way to reach and communicate to various audiences of practitioners is difficult.

Key Recommendations

Workshop discussions resulted in several key recommendations to improve the pathways for more effective research to action around four broader topics - convening, learning and sharing, communicating, and bringing products to operation:

- ***Convene:* Continue in-person meetings and workshops that bring together practitioners and researchers to present the most recent flash drought science.** These in-person engagements also provide the opportunity to continually hear practitioner needs. There was an identified need to convene a meeting specifically for state drought managers around flash drought. Also, researchers and boundary organizations could share flash drought science at practitioners' meetings.
- ***Convene:* Include social scientists in future workshops to enhance the design of actionable products for practitioners and the public.**
- ***Learn and share*: Develop case studies of successful "research to action"**, which could showcase how practitioners take scientific information and incorporate it into their decision-making to more effectively respond to or manage flash drought.
- ***Learn and share*: Create virtual spaces for interaction amongst researchers and practitioners (e.g., Basecamp, Slack)**. These virtual spaces could provide the opportunity to continually interact with one another to ask questions, share ideas and research, and showcase flash drought products and resources.
- ***Learn and share*: Increase international collaboration to learn from one another.** Flash drought is a global issue, and working with international partners could be mutually beneficial.
- ***Communicate*: Develop a resource webpage or newsletter focused on flash drought for practitioners.** This product could be produced and/or potentially hosted by NIDIS/Drought.gov and could highlight new flash drought research and products to share with practitioners. It could also be an avenue for practitioners to share case studies and other management examples.
- ***Bring products to operation*: Develop a framework for analyzing drought product performance before becoming operational.** Researchers and practitioners should work

together to develop this framework for rigorously assessing drought product performance before a product becomes operational, or is showcased to a broader audience.

Increase Access to Flash Drought Monitoring Data and Tools

There are a wide range of datasets and products available for drought monitoring, including datasets and products suited for monitoring flash drought. However, there are still many gaps and outstanding needs across sectors and regions related to flash drought monitoring including the following:

- Additional data for soil moisture, evapotranspiration, streamflow and stream temperature at a high spatial and temporal resolution.
- Increased understanding of how rapidly soil moisture depletes under specific temperatures, wind speeds, and environments (e.g., open grasslands, forests, etc.).
- Long-term funding for more in situ monitoring, including the continued operations and maintenance of all stations.
- There is no operational entity or base funding for drought monitoring, which limits continued improvement and availability of monitoring products.
- Data latency is still an issue with many monitoring products. Products that lag by 4-5 days are not adequate to capture a rapidly-developing event. Similarly, products need to be updated at least at the weekly scale if not the daily scale to adequately capture flash drought events.
- While many of the tools and data needed for effective flash drought monitoring exist, what is missing is an understanding of how to use these tools in conjunction with one another. Tool sharing and training opportunities could help fill this gap.

Key Recommendations

With these gaps and need in mind, some key recommendations from the workshop include:

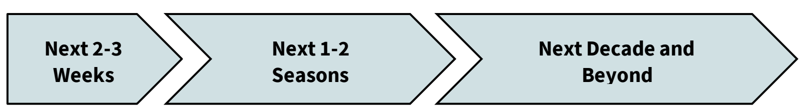
- **Continue training on existing flash drought monitoring tools.** There have been efforts to increase knowledge on existing flash drought monitoring tools since the 2020 workshop, including a tools café session at the 2023 workshop. Continued education and training on these tools is needed, and as new products are available. In particular, training on how to use them in conjunction with one another would improve monitoring.
- **Utilize Climate Engine as a source for additional flash drought monitoring capabilities.** Climate Engine tools use Google Earth Engine for on-demand processing of satellite and climate data on a web browser and features on-demand mapping of environmental monitoring datasets. Workshop participants saw value in the tool and want to explore what flash drought monitoring tools are available on Climate Engine.
- **Develop products in collaboration with social scientists and user design specialists.** To ensure that products meet the needs of end users/practitioners on the ground, new products should be developed and existing products improved in close collaboration with social scientists and user design specialists.

- **Expand the Upper Missouri River Basin Soil Moisture and Snowpack Monitoring pilot study to other basins across the United States.** With a goal to support improvements to water resource models, drought monitoring capabilities and other applications, the U.S. Army Corps of Engineers is currently supporting the buildout of over 500 soil moisture and snowpack monitoring stations across five states in the Upper Missouri River Basin. The second phase of this project is to transition the data access and operations and maintenance to NOAA's National Mesonet Program. This pilot should be used as a model in other regions to increase the availability of observational data to improve monitoring and forecasting.
- **Continue to expand the set of flash drought indicators,** including exploring further opportunities to use resources such as satellite-based plant conditions monitoring, and derived or combined indicators to provide a more integrated picture of flash drought potential.
- **Develop products that show recent changes in monitoring variables through time series or change maps.** For instance, a specific need is a map showing areas of rapid soil moisture depletion (e.g., change over last week, two weeks). Or, a station-based dashboard where you can select a station and get a recent time series of a variable (e.g., soil moisture, precipitation, Standardized Precipitation Evapotranspiration Index) to monitor recent trends and rapid changes.
- **Validate existing flash drought-specific monitoring tools.** For instance, the National Drought Mitigation Center's Flash Drought Blend and Texas A&M University's FLASH platform.

Improve Flash Drought Prediction on Multiple Timescales

The timescales of relevance for practitioners to improve flash drought response and planning include:

Flash Drought Prediction: Timescales of Relevance for Practitioners



- the near-term (i.e., the likelihood in the next few weeks),
- the seasonal to sub-seasonal scale (i.e., the likelihood over the next season or two) and
- the long-term (i.e., the likelihood in the future in a changing climate).

Once in a flash drought, practitioners need to know how long the flash drought event is expected to last. Will these conditions improve in the short-term? Or do we expect this flash drought to transition to a longer-term drought?

Other prediction needs identified at the workshop included:

- Improved prediction of flash drought-relevant variables (e.g., precipitation, temperature, soil moisture, etc.) at all of the timescales listed above, including the prediction for the intensification rate of drought.
- Access to sub-seasonal forecasts of potential evapotranspiration anomalies and/or Vapor Pressure Deficit (VPD) anomalies.

- Improved access to extreme heat forecasts, which are very relevant for potential flash drought development.

Key Recommendations

The following is a list of key recommendations identified at the workshop that work towards improving flash drought prediction at multiple scales:

- **Analyze which meteorological and/or radiative variables are most important to improve flash drought prediction, and explore predictability of those variables.** This work could include the rigorous attribution of fluxes that contribute to the development of flash drought and subsequent analysis of predictability of those fluxes.
- **Validate existing flash drought prediction tools.** For instance, the CPC Rapid Onset Drought Risk product and the Flash Drought Risk Tool from the Midwestern Regional Climate Center.
- **Study "false positives" of flash drought prediction tools**. There should be more focus on understanding why a false positive (e.g., a flash drought is predicted but does not happen) occurred in a flash drought prediction tool to reduce the number of false positives.
- **Develop real-time monitoring tools that include trends and short-term forecasts.** There are real-time monitoring tools and short-term prediction tools, but there are not many tools that integrate the two. There is a need for a daily-resolution tool that shows the recent trend of relevant variables (e.g., precipitation, soil moisture) and what the forecast is in the short-term (e.g., the next 7 or 14 days). This information could significantly improve real-time flash drought response.
- **Explore machine learning for improved flash drought prediction.** There is an opportunity to build upon and learn from existing research and products using machine learning for flash drought prediction.
- **Improve dynamic vegetation processes in land-surface models and statistical prediction models for flash drought.** These goals were also identified in the 2020 Flash Drought Workshop report. Some progress has been made, but continued attention and improvements are needed.

Improve Flash Drought Response and Planning through Coordination and Sharing

Across many sectors, the rapid acceleration of drought can have different impacts and therefore requires different responses and management actions to adequately address flash drought. The workshop provided the opportunity for practitioners to provide their perspective on flash drought, including the challenges and opportunities to improve flash drought response and planning. Some of the challenges expressed by practitioners around flash drought response and planning included:

- the inability to respond as quickly as needed due to policies in place, and/or plans that were developed for slow-evolving droughts

- the inability to take the needed actions due to lack of authority
- managing flash drought in coordination with private landowners who manage land and/or resources (for instance, working with landowners who manage forested areas to decrease wildfire risk, or working with private well-owners to monitor water levels)
- effectively coordinating with neighboring states or jurisdictions during flash drought, and
- communicating the current conditions and potential impacts of flash drought to key audiences.

Key Recommendations

The key recommendations suggested by workshop participants, including practitioners, to improve response and planning for flash drought include:

- **Develop drought plans that are better suited for a faster response.** Practitioners expressed a need to incorporate flash drought-based indicators and actions into their existing and/or future drought plans. Conducting a tabletop exercise for a drought plan is a way to identify if the plan adequately responds to a flash drought. Also, since flash droughts have a rapid onset, emergency management tools similar to emergency operation centers should be integrated into drought plans. There was also a recommendation to develop a national response framework for flash drought.
- **Share success stories showcasing various scales of coordination (e.g., state, multi-state, regional) to effectively respond to a flash drought event.** Practitioners find value in learning from others about coordinated response during flash drought events, whether this is at the state level (e.g., Massachusetts, South Carolina) or regional level (e.g., regional Drought Early Warning System, sub-state, watershed).
- **Develop template communication materials and/or guidelines to assist practitioners with flash drought response.** Pre-developed materials would help practitioners communicate about flash drought, its potential risks, and need for a quick response to constituents. Materials could include example messages that convey the potential for conditions to deteriorate rapidly or infographics and fact sheets that succinctly explain flash drought and its potential impacts for a particular region and/or sector. These materials should be made available widely to practitioners and developed in coordination with social scientists or risk communication specialists.
- **Develop effective pathways to convey the risk of flash drought to the general public.** When there are actions for the public to take during flash drought, drought managers must develop more effective pathways to reach the general public. Workshop participants recommend exploring the idea of flash drought watches or advisories, using similar communication pathways and strategies as Red Flag Warnings.

Continue to Advance Research and Understanding of Flash Drought

There has been significant advancement in the understanding of flash drought over the last several years. However, there are topics that remain understudied, and this workshop provided the opportunity for researchers and practitioners to identify what some of the most relevant, current flash drought research needs across regions and sectors. Incorporating researchers from other scientific disciplines such as ecology, policy, biology, and social science could support more effective flash drought research.

Key Recommendations

This section provides key recommendations for research topics that are currently understudied related to flash drought:

- **Conduct post-flash drought assessments at various scales (e.g., regional, state, local) and/or sectors.** Conducting post-flash drought assessments provides the opportunity to reflect upon a past flash drought event from a variety of lenses (e.g., monitoring, impacts, response) with the goal to improve response and planning for future events. A post-flash drought assessment could:
    - Identify the tools and/or datasets that were most useful to monitor the evolving flash drought conditions. Also, an assessment could identify missing tools and/or datasets that would have been helpful.
    - Document the cascading impacts of flash drought across multiple sectors. In particular, teasing out those that happened or were unique to the rapid intensification period, or those that were not expected.
    - Correlate impacts to indicators to identify the most appropriate indicators to monitor flash drought events in the future.
    - Reflect on the response actions taken. Assess whether these actions were effective, or if there are other actions that would have been more effective.
    - Identify if the right partners were involved in response, and if additional partners should be included when planning for future events.
- **Study the role of antecedent conditions in flash drought development.** Antecedent conditions seem to be more consequential during the development of flash drought than in a slow-evolving drought. Research should examine the relationship between antecedent conditions and their impact on the development of flash drought. For example, what role does rapid spring snowmelt and early-season runoff have on the rapid onset of drought later in the season?
- **Study the relationship between wildfire and flash drought.** Wildfire is often an issue during flash drought in many areas of the country. More research is needed about this relationship, particularly by region, to improve monitoring and preparedness. Workshop

participants stressed the importance of working with fire managers on this topic in order to ensure integration into their monitoring and outlook products, including Red Flag Warnings. An index focused on identifying the combination of hot, dry, and windy conditions could be particularly helpful in identifying the risk of wildfire during flash droughts.

- **Study flash drought in semi-arid climates.** Because much of the flash drought research in the last decade has focused on areas with more moist climates and/or agricultural areas, there is a need to study flash drought in more arid locations, like the western U.S, to ensure that monitoring tools capture flash drought development in these areas as well. As longer-term indicators are often most relevant when assessing drought in the western U.S. (e.g., 12-month timescales), flash drought indicators may also be different as well. This could mean exploring topics such as hydrological flash drought, which might be most relevant for semi-arid/western areas.
- **Study cases where the environmental indicators pointed to the existence of flash drought conditions, but flash drought impacts did not occur.** For instance, analyzing why some rapid decreases in soil moisture may lead to impacts but others do not, and analyzing the difference between these two events. This analysis could help improve prediction of flash drought events. This could offer an opportunity for researchers to work closely with practitioners to look at specific events and document what happened.

References

2022-2026 National Integrated Drought Information System (NIDIS) Strategic Plan. Produced by NIDIS, Released October 4, 2022.

Otkin, J. A., Svoboda, M., Hunt, E. D., Ford, T. W., Anderson, M. C., Hain, C., and Basara, J. B., 01 May 2018. Flash Droughts: A Review and Assessment of the Challenges Imposed by Rapid-Onset Droughts in the United States. BAMS, 911-919. https://doi.org/10.1175/BAMS-D-17-0149.1

Lisonbee, J., M. Woloszyn, and M. Skumanich, 2021. Making sense of flash drought: Definitions, indicators and where we go from here, 2021. Journal of Applied Service Climatology, 1-19. https://doi.org/10.46275/JOASC.2021.02.001.

Otkin, J. A., M. Woloszyn, H. Wang, M. Svoboda, M. Skumanich, R. Pulwarty, J. Lisonbee, A. Hoell, M. Hobbins, T. Haigh, and A. Cravens, October 1, 2022. Getting Ahead of Flash Drought: From Early Warning to Action. BAMS, 103 (10):E2188-E2202. https://doi.org/10.1175/BAMS-D-21-0288.1

Woloszyn, M., M. Skumanich, J. Lisonbee, V. Deheza, M. Hobbins, A. Hoell, J. Otkin, M. Svoboda, H. Wang. 2021. Flash Drought: Current Understanding and Future Priorities; Report of the 2020 NIDIS Flash Drought Virtual Workshop. *NOAA National Integrated Drought Information System.*

Christian, J.I., Martin, E.R., Basara, J. B., Furtado, J.C., Otkin, J. A., Lowman, Lauren E.L., Hunt, E. D., Mishra, V., Xiao, X. Global Projections of Flash Drought Show Increased Risk in a Warming Climate. *Commun Earth Environ 4, 165 (2023). https://www.nature.com/articles/s43247-023-00826-1#Abs1*

Appendices

Appendix A: Technical Working Group

The National Integrated Drought Information System (NIDIS) would like to thank the following partners for their participation on the Flash Drought Technical Working Group, which contributed to planning this workshop and reviewed this workshop report:

Person	Organization
Jordan Christian	University of Oklahoma
Art DeGaetano	Cornell University, Northeast Regional Climate Center
Michael Downey	Montana Department of Natural Resources and Conservation
Nelun Fernando	Texas Water Development Board
Trent Ford	University of Illinois
Peter Goble	Colorado State University
Mike Hobbins	University of Colorado-Boulder/NOAA Physical Sciences Laboratory
Andrew Hoell	NOAA Physical Sciences Laboratory
Eric Hunt	University of Nebraska-Lincoln
Pam Knox	University of Georgia
Ronald D. Leeper	North Carolina Institute for Climate Studies/NOAA National Centers for Environmental Information
Kyle Lesinger	Auburn University
Carson MacPherson-Krutsky	University of Colorado-Boulder/Natural Hazards Center
Dan McEvoy	Desert Research Institute/University of Nevada
Jamie McEvoy	Montana State University
Larry O'Neill	Oregon State University
Jason Otkin	Cooperative Institute for University of Wisconsin-Madison
Dannele Peck	USDA Northern Plains Climate Hub

Brad Rippey	USDA Office of the Chief Economist
Mark Svoboda	National Drought Mitigation Center/University of Nebraska-Lincoln
Hailan Wang	NOAA Climate Prediction Center
Viki Zoltay	Massachusetts Department of Conservation and Recreation
Jessica Martinez	University Corporation for Atmospheric Research/Cooperative Programs for the Advancement of Earth System Science

Appendix B: Workshop Agenda

2nd National Flash Drought Workshop AGENDA
May 2-4, 2023 | Boulder, Colorado (UCAR Center Green)

DAY 1: Tuesday, May 2, 2023		
Time (MT)	**Topic**	**Speaker/Moderator**
8:30 AM	Welcome & Introductions	Sylvia Reeves, NOAA/NIDIS
9:00 AM	Progress since 2020 Virtual Workshop	Marina Skumanich, NOAA/NIDIS
Session 1: State of the Science *This session will provide a framing context for the workshop, by reviewing the latest research on the physical science, social science, and policy components of flash drought.* ***Moderator: Dan McEvoy, Western Regional Climate Center***		
9:20 AM	Framing Flash Drought and Monitoring	Jason Otkin, University of Wisconsin Madison
9:40 AM	Flash Drought Prediction and Predictability	Hailan Wang, NOAA Climate Prediction Center Andy Hoell, NOAA Physical Sciences Laboratory
10:00 AM	Flash Drought Impacts	Amanda Cravens, USGS Forest and Rangeland Ecosystem Science Center - *VIRTUAL*
10:20 AM	Break	
10:40 AM	Incorporating Flash Drought into Planning, Policy, and Decision Making	Mark Svoboda, National Drought Mitigation Center
11:00 AM	Projections of Flash Drought in a Warming Climate Across the United States	Jordan Christian, University of Oklahoma
11:20 AM	Group Discussion	Moderator: Dan McEvoy, Desert Research Institute
12:00 PM	Lunch (Provided)	
Session 2: Practitioner Perspective *This session will provide an in-depth discussion of how practitioners assess, respond to, and provide*		

<table>
<tr><td colspan="3">guidance to the public on flash drought.
Moderator: Pam Knox, University of Georgia Extension</td></tr>
<tr><td>1:00 PM</td><td>Practitioner Presentations & Panel Discussion</td><td>Panelists:
● Klaus Albertin, Water Supply Planning Engineer - North Carolina Department of Environmental Quality, Division of Water Resources
● Miranda Meehan, Extension Disaster Education Coordinator and Livestock Environmental Specialist - North Dakota State University Extension
● Sumit Sharma, Extension Specialist for High Plains Irrigation and Water Management - Oklahoma State University Extension
● Beckie Maddox, Senior Environmental Specialist - Constellation Nuclear</td></tr>
<tr><td>2:30 PM</td><td>Group Discussion</td><td>Moderator: Pam Knox, University of Georgia Extension</td></tr>
<tr><td>3:00 PM</td><td>Introduction to Tools Cafe and Poster Session</td><td>Sylvia Reeves, NOAA/NIDIS</td></tr>
<tr><td>3:05 PM</td><td colspan="2">Break</td></tr>
<tr><td colspan="3">Session 3: Flash Drought Tools Cafe and Poster Session
This session will provide a hands-on opportunity for participants to explore current flash drought web-based maps and other tools, and to discuss emerging research with poster presenters.</td></tr>
<tr><td>3:20 PM</td><td colspan="2">Flash Drought Tools Cafe and Poster Session

Confirmed Tools:
● Climate Engine
● Climate Smart Farming
● CPC Week-2 Hazards, Including Rapid Onset Drought
● Evaporative Drought Demand Index (EDDI)
● Evaporative Stress Index (ESI)
● FLASH: FLash drought Assessment using SMAP Hydrology
● High Plains Regional Climate Center Water Deficit Trends & Other Tools
● Midwestern Regional Climate Center Flash Drought Risk Tool (Flash-DRT)
● National Drought Mitigation Center Flash Drought Monitor & QuickDRI
● Standardized Evaporative Stress Ratio (SESR)</td></tr>
</table>

	• U.S. Drought Portal: Resources • U.S. Drought Portal: Soil Moisture Product Dashboard ***Confirmed Posters:*** • Quantifying the Frequency of Flash Drought in the Southeastern United States and Estimating Its Effects on Corn and Cotton Yields (Jasia Jannat, University of Georgia) • Understanding Sub-seasonal Predictability of Soil Moisture Flash Drought in the SE US Based on Causal Analysis of Large-Scale Climate Patterns (Sudhanshu Kumar, Auburn University) • Characterization of Rapid Drought Change Across the United States (Ronald Leeper, Cooperative Institute for Satellite Earth System Studies (CISESS)) • A Climatology of High Reference Evapotranspiration Events in Colorado (Peter Goble, Colorado State University)	
4:45 PM	Day 1 Adjourn	Sylvia Reeves, NOAA/NIDIS
5:00-7:00 PM	Optional Social Event	Location: Rayback Collective 2775 Valmont Rd, Boulder, CO 80304

DAY 2: Wednesday, May 3, 2023		
Time (MT)	**Topic**	**Speaker/Moderator**
8:30 AM	Welcome Back & Overview of Day 2	Sylvia Reeves, NOAA/NIDIS
8:35 AM	Morning Coffee Panel Chat *This session will provide an opportunity for flash drought researchers and practitioners to have a back-and-forth discussion on how best to work together to deliver early warning and effective management of flash drought.*	Panelists: • Pam Knox, Agricultural Climatologist - University of Georgia Extension • Dannele Peck, Director - Northern Plains Climate Hub • Art DaGaetano, Professor - Cornell University and Director - Northeast Regional Climate Center • Trent Ford, Illinois State Climatologist - University of Illinois/ Illinois State Water Survey Moderator: Sylvia Reeves, NOAA/NIDIS
Session 4: Case Studies of Flash Drought *This session will showcase regional responses to flash drought events, and the successes, challenges, and/or lessons learned from the experience.* ***Moderator: Carson MacPherson-Krutsky, Boise State and University of Colorado***		

9:30 AM	Massachusetts – On a Path to Better Drought Preparedness	Vandana Rao, Massachusetts Executive Office of Energy & Environmental Affairs
9:45 AM	Flash Drought in South Carolina: Overcoming Barriers through Investments in Relationships, Collaboration, and Communication	Elliot Wickham, South Carolina State Climatology Office
10:00 AM	Break	
10:20 AM	2021 Drought in the Pacific Northwest: A Different Flavor	Karin Bumbaco, WA State Climatologist, *VIRTUAL*
10:35 AM	2017-2018 Flash Drought Event in Argentina: Characteristics, Impacts and Lessons Learned	Pablo Spennemann, Servicio Meteorologico Nacional-CONICET, Argentina
10:50 AM	Table Brainstorm & Group Discussion	
12:00 PM	Lunch (Provided)	
Session 5: Break Out Group Sessions *This session will explore opportunities to better integrate and apply what we have discussed so far in a regional place based context, to strengthen the regional flash drought community, and to identify opportunities to strengthen flash drought understanding and response at the regional level.* ***Moderators: Meredith Muth and Joel Lisonbee, NIDIS***		
1:00 PM	Regional Case Study: Flash Drought Science to Action at the Regional Level	Lee Ellenberg, University of Alabama Huntsville and Meredith Muth, NOAA/NIDIS
1:20 PM	Introduction to Breakout Groups	Meredith Muth, NOAA/NIDIS
1:30 PM	Breakout 1: Flash Drought in a Regional Context	
2:30 PM	Break	
2:50 PM	Brief Plenary Report-out Breakout 1	
3:10 PM	Breakout 2: Table-top Exercise by Region	Joel Lisonbee, NOAA/NIDIS
4:25 PM	Plenary Close Out - Day 2	Sylvia Reeves, NOAA/NIDIS
4:30 PM	Adjourn for the Day	

Day 3: Thursday, May 4, 2023		
Time (MT)	**Topic**	**Speaker/Moderator**
8:30 AM	Welcome Back & Overview of Day 3	Sylvia Reeves, NOAA/NIDIS
Session 6: Emerging Flash Drought Science *This session will highlight current research and provide an opportunity for discussions of new research directions.* ***Moderator: Ronnald Leeper, Cooperative Institute for Satellite Earth System Studies (CISESS)***		
8:40 AM	A Framework for Flash Drought Development and Progression	Jeff Basara, University of Oklahoma
8:55 AM	Subseasonal Flash Drought Prediction Skill in the Contiguous United States	Kyle Lesinger, Auburn University
9:10 AM	Assessing the performance of Sub-Seasonal Solar-Induced Fluorescence trajectory as an early warning system for flash droughts in the US regions and Ecosystems	Koushan Mohammadi, University of Connecticut
9:25 AM	Using the El Niño-Southern Oscillation and Madden Julian Oscillation Modes of Variability to Predict Rapid Drought Change	Emma Scott, North Carolina Institute for Climate Studies
9:40 AM	Table Brainstorm & Group Discussion	
10:30 AM	Break	
Session 7: Reflection + Forward Thinking *This session will synthesize our progress in meeting the priority actions identified from the 2020 Flash Drought Workshop, incorporate additional gaps and needs, and identify tangible opportunities for making progress in addressing those needs.* ***Moderators: Meredith Muth and Sylvia Reeves, NOAA/NIDIS***		
10:50 AM	Synthesizing and Addressing Outstanding Needs	Meredith Muth, NOAA/NIDIS
11:50 AM	Reflections	Sylvia Reeves, NOAA/NIDIS
12:00 PM	Workshop Adjourns	

Appendix C: Tools Cafe Handout - Flash Drought Prediction & Monitoring Tools

<table>
<tr><th>Name</th><th>Type</th><th>URL</th><th>Contact info</th><th>Source</th></tr>
<tr><td rowspan="2">Climate Engine</td><td>Monitoring, Prediction</td><td>https://app.climateengine.com/climateEngine</td><td>Dan McEvoy
mcevoyd@dri.edu</td><td>Desert Research Institute</td></tr>
<tr><td colspan="4">Climate Engine uses Google Earth Engine for on-demand processing of satellite and climate data on a web browser and features on-demand mapping of environmental monitoring datasets, such as remote sensing and gridded meteorological observations. With fully customizable analyses, the Climate Engine App enables the user to produce maps and time series summaries from these datasets. There are many drought indices, satellite data vegetation metrics, and sub-seasonal forecast products available in Climate Engine that are useful for flash drought monitoring and prediction.</td></tr>
<tr><td rowspan="2">Climate Smart Farming Water Deficit Calculator</td><td>Monitoring</td><td>http://climatesmartfarming.org/tools/csf-water-deficit-calculator/</td><td>Art DeGaetano
atd2@cornell.edu</td><td>Northeast RCC</td></tr>
<tr><td colspan="4">The CSF Water Deficit Calculator estimates soil water content within a crop’s effective root zone to inform decision makers about current and forecasted water deficits. This information is used by farmers and irrigation system managers to determine the optimum frequency and duration of watering that is necessary to avoid plant stress. The tool uses historical climatological data; forecasted rainfall and evapotranspiration and user-provided site-specific data to estimate current and forecasted water deficits. With this information, water balance calculations are performed for a soil depth of one foot (the assumed effective root zone of your crop). Water deficit is defined as the amount of water necessary to raise the soil water content to field capacity. Daily forecasted data are also used to forecast water deficits over subsequent days for planning purposes. Water deficit probabilities over the next 30 days are calculated from historical data (2002-present).</td></tr>
<tr><td rowspan="2">CPC Week-2 Hazards</td><td>Prediction, Communication</td><td>https://www.cpc.ncep.noaa.gov/products/predictions/threats/threats.php</td><td>Brad Pugh
brad.pugh@noaa.gov</td><td>NOAA Climate Prediction Center</td></tr>
<tr><td colspan="4">Beginning in May 2022, rapid onset drought (ROD) risk was added to the Climate Prediction Center's week-2 hazards. Forecasters base this forecast on an internal tool that uses initial conditions, such as antecedent dryness, and skillful temperature and precipitation outlooks during the next two weeks to identify areas at an increased risk of rapid onset drought. The inclusion of the ROD risk to CPC's week-2 hazards will improve communication and supplement the Monthly Drought Outlook.</td></tr>
</table>

Name	Type	URL	Contact info	Source
Evaporative Demand Drought Index (EDDI)	Monitoring, Communication	https://psl.noaa.gov/eddi/	Mike Hobbins mike.hobbins@noaa.gov	CU-CIRES and NOAA-Physical Sciences Laboratory
	EDDI is a drought monitoring and early warning guidance tool. It examines how anomalous the atmospheric evaporative demand (or the " thirst of the atmosphere") is for a given location and across different timescales. We generate EDDI at 1-week through 12-month timescales. As a multi-scalar index, it captures drying dynamics that operate at different timescales. EDDI can offer early warning of agricultural drought, hydrologic drought, and fire-weather risk by providing near-real-time information on the emergence or persistence of anomalous evaporative demand in a region. A particular strength of EDDI is in capturing the precursor signals of water stress at weekly to monthly timescales, which makes EDDI a strong tool for preparedness for both flash droughts and ongoing droughts. Currently, EDDI is generated daily—though with a 5-day lag-time—by analyzing a near-real-time atmospheric dataset.			
Evaporative Stress Index	Monitoring	https://www.drought.gov/data-maps-tools/evaporative-stress-index-esi	Christopher Hain christopher.hain@nasa.gov	NASA Marshall Space Flight Center / SPoRT
	The Evaporative Stress Index (ESI) describes temporal anomalies in evapotranspiration (ET), highlighting areas with anomalously high or low rates of water use across the land surface. Here, ET is retrieved via energy balance using remotely sensed land-surface temperature (LST) time-change signals. LST is a fast-response variable, providing proxy information regarding rapidly evolving surface soil moisture and crop stress conditions at relatively high spatial resolution. The ESI also demonstrates capability for capturing early signals of "flash drought," brought on by extended periods of hot, dry, and windy conditions leading to rapid soil moisture depletion.			
Flash Drought Blends	Monitoring	https://ndmcblends.unl.edu/Home.aspx	Curtis Riganti criganti2@unl.edu	National Drought Mitigation Center
	The flash drought blends are one of three gridded drought blends tools being developed at NDMC, alongside our short- and long-term blends. The tool is a weighted combination of several short-term drought indicators that are tuned towards detecting flash drought conditions. This tool is still under development; please see https://ndmcblends.unl.edu/Metadata.aspx for further information.			

<table>
<tr><th>Name</th><th>Type</th><th>URL</th><th>Contact info</th><th>Source</th></tr>
<tr><td rowspan="2">FLASH: FLash drought Assessment using SMAP Hydrology</td><td>Monitoring</td><td>http://vadosezone.tamu.edu/flash/</td><td>Vinit Sehgal vinit@tamu.edu</td><td>Texas A&M University</td></tr>
<tr><td colspan="4">FLASH (FLash drought Assessment using SMAP Hydrology) is an open-source tool for near-real-time global flash drought monitoring using NASA’s SMAP soil moisture, operating at low latency (2 days) and 1-day temporal resolution. Two complementary indices are defined based on SMAP soil moisture for measuring the severity and the rate of intensification of drought, namely, Soil Moisture Stress (SMS) and Relative Rate of Drydown (RRD), respectively. SMS and RRD are non-linearly combined to provide FDSI (Flash Drought Stress Index) — a composite indicator used for global flash drought monitoring. FLASH relies on the footprint-scale (36-KM) thresholds of soil hydrologic regimes (energy-limited wet phase, moisture limited transitional, and dry phase) and land-atmospheric coupling strength to estimate flash drought severity. Several advantages of FDSI include non-reliance on long-term soil moisture records, sensitivity to changing land-surface heterogeneity, land-atmospheric interactions, and evolving meteorological anomalies. FDSI is extensively validated globally across multiple timescales (daily, weekly, and monthly) using a suite of vegetation and meteorological drought indices. Since its operationalization in 2021, FLASH has captured major drought events across the globe and provides freely available public data access for effective drought mitigation.</td></tr>
<tr><td rowspan="2">QuickDRI</td><td>Monitoring</td><td>quickdri.unl.edu</td><td>Curtis Riganti criganti2@unl.edu</td><td>National Drought Mitigation Center</td></tr>
<tr><td colspan="4">QuickDRI is a geospatial tool that characterizes the intensification of short-term drought condition patterns on a weekly basis across the continental United States (CONUS) at a 1-km gridded spatial resolution. The primary goal of QuickDRI is to serve as an "alarm" indicator of rapidly emerging events such as "flash drought" that manifest rapidly on the order of a few days to weeks, are often difficult to detect using traditional drought indicators, and can have devastating negative impacts on agriculture and natural resources.</td></tr>
<tr><td>Rapid Drought Intensification Risk Tool</td><td>Prediction</td><td>https://mrcc.purdue.edu/MWDEWS/flashdroughttool.html</td><td>JonathanWeaver weaverjc@purdue.edu</td><td>Midwestern Regional Climate Center</td></tr>
</table>

Name	Type	URL	Contact info	Source
	Flash droughts can be devastating to communities and ecosystems. The Rapid Drought Intensification Risk Tool, developed by the Midwestern Regional Climate Center, represents a significant advance in predicting these events. By utilizing advanced artificial intelligence techniques to analyze millions of atmospheric data points, the tool can forecast the likelihood of rapid drought intensification over the next two weeks. Its intuitive and interactive interface allows users to assess the risk of such intensification for any location in the central and eastern United States from April 1 - October 31. The tool provides decision-support information without requiring personal knowledge of weather conditions or whether such conditions would lead to rapid drought intensification, making it accessible to a wide range of users. By utilizing this tool, individuals and organizations can make informed decisions, prepare for potential flash droughts, and minimize the harm caused by these disruptive events.			
Standardized Evaporative Stress Ratio (SESR)	Monitoring	N/A (still in development)	Jordan Christian jchristian@ou.edu	University of Oklahoma
	The Standardized Evaporative Stress Ratio (SESR) is a metric used to capture flash drought development by quantifying the evaporative stress on the environment. SESR is the ratio of evapotranspiration (used as a general indicator of the available moisture at the land surface) and potential evapotranspiration (the demand for land-surface moisture given the atmospheric conditions). Near real-time monitoring of flash drought is provided by computing SESR from NLDAS-2 at pentad (5-day) resolution. Areas are identified with flash drought development after a minimum set of criteria are satisfied: 1) change in SESR between pentads at the 25th percentile or lower for at least four consecutive weeks (i.e., a rapid and persistent decline in SESR values) and 2) a SEAR value at the 20th percentile or lower (i.e., drought conditions are reached).			
U.S. Drought Portal (Drought.gov)	Monitoring, Prediction, Planning, Communication	https://www.drought.gov	Kelsey Satalino kelsey.satalino@noaa.gov	NOAA/NIDIS, CIRES/CU Boulder
	The U.S. Drought Portal (drought.gov) is an interagency federal website that provides a one-stop shop for drought data, maps, and resources from across the federal government, academia, and the private sector—including tools for flash drought monitoring, prediction, and communication. On Drought.gov, users can explore up-to-date interactive maps showing current, future, and historical conditions from the national to the city/county level. This includes measures of evaporative demand (EDDI), soil moisture, temperature, precipitation, and vegetative stress. These maps are customizable, allowing users to zoom in on a region of interest, adjust the map appearance, display state/tribal/county boundary lines, and download high-quality images to use in communications, research, or reports. The website also contains educational resources on flash drought, summaries of relevant research, and targeted resources developed from the previous National Flash Drought Workshop. Finally, users can browse the Drought.gov Data Catalog to search for an even wider range of tools and resources, filtering by indicator type, file format, period of record, and more.			
U.S. Drought Portal - Soil	Monitoring	https://www.drought.gov/testing/soil-moisture-indicators	Marina Skumanich marina.skumanich@noaa.gov	NOAA/NIDIS

Name	Type	URL	Contact info	Source
Moisture Product Dashboard	The Soil Moisture Product Dashboard provides easy, side-by-side access to several root-zone soil moisture mapping products, including NASA's SPoRT-LIS, GRACE, NationalSoilMoisture.com, and NLDAS NOAH. These maps are customizable, allowing users to zoom in on a region of interest, adjust the map appearance, display state/tribal/county boundary lines, and download high-quality images to use in communications, research, or reports. The aim is to facilitate the review and intercomparison of different soil moisture estimates to support convergence of evidence assessment of drought conditions.			
Water Deficit Trends	Monitoring	https://hprcc.unl.edu/wdt/#	Gannon Rush grush2@unl.edu	High Plains Regional Climate Center
	The Water Deficit Trends tool allows for quick overviews of how SPI/SPEI has trended between weeks on a nationwide map, and overlays of the latest drought monitor, USGS stream gages, and other data layers. Clicking any station on the map opens the Trend Analysis Panel, which shows a week-by-week overview of precipitation and drought indices at the station. A short, printable report is also available, which includes information about the closest 5 USGS stream gages over the weeks analyzed.			

Appendix D: Flash Drought Characteristics and Impacts by Region and/or Sector

Caption: Table of key regional and sectoral characteristics and impacts from flash drought as heard during the 2023 workshop.

NORTHEAST	
Regional Characteristic or Impact	**Sector**
If crops have fared well most of the season, the onset of flash drought during the fall harvest might actually be welcomed as it brings dry field conditions.	Agriculture (All Crops)
Crops like corn, grapes, apples and potatoes can have reduced yields.	Agriculture (All Crops)
Wild blueberries can take a hit quickly because they are not irrigated.	Agriculture (Specialty Crops)
Christmas trees, especially those newly planted or less than 5 yrs old, can be wiped out in just weeks.	Agriculture (Specialty Crops)
Cranberry harvests are often water facilitated. Fall harvest season often runs concurrently with the peak of flash drought events in this region.	Agriculture (Specialty Crops)
Livestock feed crops like hay have a reduced number of cuttings. Dairy farmers incur higher costs for water provisioning and feed.	Agriculture (Livestock)
Ecological impacts come with low streamflow and warm streams that impact migrating fish populations.	Ecosystems
Hydropower production drops can occur but the energy mix (source production has been able to adapt with most recent droughts. Rapid onset or intensification of drought has little impact on total regional power supply.	Energy
Nuclear plants require cooling water intake within specific temperatures. If drought combined with extended extreme heat periods occur, cooling water temperature variances may be needed from the Nuclear Regulatory Commission (NRC). Repeated flash drought episodes may demand longer-term investment in power plant infrastructure to pipe cool water from other sources. The impact is on economic investment requirements.	Energy
Recreation impacts vary with hunting and fishing seasons. A low or no snow winter impacts recreation and tourism.	Recreation and Tourism
There is a prevalence of private wells in this region, which can cause issues during drought. There are few back-up resources for towns, homes, etc. Repeated episodes of flash drought influence infrastructure investment decisions	Water Utilities/Infrastructure

impacting taxes and bond funding requirements.	
Flash drought is most impactful during the summer months for water utilities. A period of lower dew points triggers monitoring. Reservoir levels are monitored weekly when there is drought; water utility managers increase vigilance along with preparation for the issuance of advisories and restriction information.	Water Utilities/Infrastructure
Municipal water managers have a hard time with an increase in heat and a rapid intensification of drought conditions. Summer brings increased water usage - incl. pool fills and landscape watering. This “tap” on the water supply does not help and mandatory restrictions may be needed.	Water Utilities/Infrastructure
A recent example of a flash drought impact occurred in early 2023 - there were very sudden hot, dry, windy conditions that caused record-breaking spring fires. A contributing factor is the management of forested areas/private land. When populations are unaware of rapid onset of drought conditions, unexpected and rapidly moving brush fires near human populated areas are dangerous (New Jersey pine barrens fire near suburbia - homes and gas stations threatened).	Wildfire Management
Flash drought caused extensive wildfires in fall 2016. These fires were also associated with low stream flows. These low streams and ponds could not be relied upon as fire fighting water resources.	Wildfire Management
Seasonal characteristics: flash drought in the spring can bring wildfire threats and planting concerns. Summer heat can fuel intensification, which can impact crop yields.	All sectors
Massachusetts uses 6 indicators to monitor drought in the state: 1) precipitation, 2) streamflow, 3) groundwater, 4) lakes and impoundments, 5) Keetch-Byram Drought Index, 6) crop moisture/Evaporative Demand Drought Index (EDDI). Trends in these categories can characterize flash drought.	All sectors
Massachusetts’ primary impacts during flash drought: streamflow and groundwater record lows, wildfire due to dry topsoil and ground cover vegetation.	All sectors
In coastal streams, gauges - which reflect tidal changes - may not be reliable flash drought drought indicators.	All sectors
SOUTHEAST	
Regional Characteristic or Impact	**Sector**
Seasonal characteristics: September is a month for some droughts to rapidly intensify. Just a few weeks of below-normal rainfall can impact crops and pasture.	Agriculture (All Crops, Livestock)

Early growing season flash drought can wipe out crops. It is more impactful in March/April versus later in September/October.	Agriculture (All Crops)
In Georgia, one week without rain generates agriculture impacts, but making a determination of whether it is a flash drought is difficult.	Agriculture (All Crops)
Florida agriculture is year round, so monitoring for all signs of drought and rapid changes in drought character is helpful.	Agriculture (All Crops)
Forested areas vary in their response to flash drought. Small streams are obviously more at risk during flash events - and are an indicator.	Ecosystems
A good example of a monitoring system is from Duke Power. They monitor reservoir levels, along with the USDM and streamflow to determine protocols that municipalities need to follow for conservation.	Energy
The 2016 flash drought in Georgia was an example of two flash droughts within a longer-term drought. Early in 2016 there was a flash drought driven by precipitation deficits. The drought continued, but intensified once again in the fall when there was a temperature-driven flash drought.	All sectors
MIDWEST	
Regional Characteristic or Impact	**Sector**
Once corn/soybean crops are planted, there is not much that can be done if a flash drought occurs. Other sectors are more vulnerable.	Agriculture (All Crops)
With late season heat, disease stress becomes an issue (tar spot - fungal disease).	Agriculture (All Crops)
High evaporative demand, over time, is often reported as “no morning dew”. This could be a flash drought indicator.	Agriculture (All Crops)
Specialty crops like apples, cherries and pumpkins show signs of stress during flash drought.	Agriculture (Specialty Crops)
Stock ponds and other surface water sources run low.	Agriculture (Livestock)
DNR reports on streamflow and water resources can be helpful information sources. When creek and stream levels drop rapidly, fish kills are common.	Ecosystems
Animals, suddenly seeking alternative water sources, may migrate into areas of human habitation.	Ecosystems

Nuclear power plants have cooling ponds. Primary impact from flash drought is when the ponds get too low, they have to decouple from the river, which can be done quickly, but shuts down the plant.	Energy
The water discharge temperatures are regulated by the state environmental protection agency and those discharge activities can be impacted by drought and river temperatures. A March 2012 drought with high river temperatures required NRC regulation (temperature allowances) changes.	Energy
Sediment buildup during low flow is a problem, too.	Energy
Sudden increased reporting of West Nile/Lyme disease/tick problems come with flash drought.	Public Health
Major rivers with transportation delays are a symptom of drought intensification.	Navigation/Transportation
There is potential to have water supply issues in the Midwest during flash drought, especially systems that rely upon surface water.	Water Utilities/Infrastructure
Increases in grassland and wildland fire activity are key to monitoring rapid onset drought.	Wildfire Management
Urban and suburban lawns may go brown and crunchy quickly.	All sectors
MISSOURI RIVER BASIN/NORTHERN GREAT PLAINS	
Regional Characteristic or Impact	**Sector**
Calf loss from water toxicity when water sources dried up quickly.	Agriculture (Livestock)
2017 was the “worst case” scenario of flash drought for livestock producers. Producers did not make decisions fast enough in 2017.	Agriculture (Livestock)
In Nebraska, drought impacts to water quality and quantity can be significant to livestock operations (forage growth monitoring required). State level water assistance programs may go into effect to supplement federal funding.	Agriculture (Livestock)
Grazing impacts show up early. Forecasts for the upcoming season are needed in early May, when grazing begins.	Agriculture (Livestock)
Soil moisture changes usually signal flash drought.	All sectors

SOUTHERN PLAINS	
Regional Characteristic or Impact	**Sector**
The biggest impact of flash drought is on dryland crops (versus irrigated crops).	Agriculture (All Crops)
February-April is a key time to know if drought will be an issue during the growing season.	Agriculture (All Crops)
Key crop reproductive stages are between July-August; this is when flash drought is most harmful to crops and most likely to occur.	Agriculture (All Crops)
Oklahoma flash droughts in 2015, 2019 and 2021: Planting decisions may go on hold in relation to reimbursement deadlines and impact which crops get planted in which order.	Agriculture (All Crops)
Decisions are also made based on which crops will require less water to grow. The cost of irrigation is considered.	Agriculture (All Crops)
Soil health and management are key. Dust storms can reduce soil depths if there is drought. Building a reserve of water for irrigation and in the soil must be planned.	Agriculture (All Crops)
Timing is critical. For instance, wheat planted in October and harvested in May has a critical growth period in April-May. Flash drought during this time can impact the crop.	Agriculture (All Crops)
Drought during expected corn tasseling periods will impact the plant negatively.	Agriculture (Row Crops)
Milo and other crop planting timing decisions are flash drought dependent. Feb - March is seed purchase time and it is good to know if drought will happen.	Agriculture (All Crops)
Pest management problems can come on suddenly with flash drought.	Agriculture (All Crops)
Flash drought can be ended by heavy rains. Southern Texas flash droughts can be impacted by tropical systems.	All sectors

Fall flash droughts often persist. Spring flash droughts often end in the fall.	All sectors
WESTERN U.S.	
Regional Characteristic or Impact	**Sector**
In arid or semi arid regions, agricultural impacts of flash drought are difficult to identify. Routine irrigation practices can mask flash drought impacts - especially at onset.	Agriculture (All Crops)
Monitoring and quantifying increased water needs for irrigation may be a proxy for tracking rapid onset/intensification.	Agriculture (All Crops)
Monitoring impacts during extreme heat episodes might reveal flash drought that is embedded in more arid regions.	Agriculture (All Crops)
The combination of drought and heat waves can exacerbate impacts (e.g. in 2021 even irrigated crops like potatoes, berries and tree fruit were impacted in Washington State).	Agriculture (All Crops)
Monitoring non-irrigated rangelands can provide needed data to track the rapid onset of flash drought.	Agriculture (Livestock)
The combination of drought and heat waves can exacerbate impacts (e.g. in 2021 livestock producers saw increased animal stress in Washington State).	Agriculture (Livestock)
Accelerated tree stand die-off, often prompted by infection from pests or rapid decline in tree health.	Ecosystems
Flash drought time scales (as compared to a slower-evolving drought) can cause rapid declines to reservoir levels and water supply availability.	Water Utilities/Infrastructure
Rapid drying of forested areas and increases in fuel loads (as compared to slower-evolving drought conditions impacts) could be a flash drought characteristic.	Wildfire Management
Wildfire risk (watches and warnings) increases in a short span of time (12 hrs).	Wildfire Management

Variations in seasonal wildfire periods, shifting to typically low fire occurrence periods, or changes in the duration of fire season may be a proxy for flash drought intensification.	Wildfire Management
Timescales and antecedent conditions are important indicators for wildfire related flash drought impacts.	Wildfire Management
Broad tree health declines over the span of several years, coupled with increased fuels from rapid spring growth, summer heat and low-to-no precipitation (drying out duff and increasing fuels) can then lead to a rapid increase in fire activity.	Wildfire Management
There is a need for a better understanding of how to manage flash drought in the West. There are concerns about using the term flash drought and communicating with the media, general public and impacted communities/sectors.	All Sectors
The term flash drought is not used as much in the west - “rapidly deteriorating conditions” is more common. This points to the need for further research on defining the characteristics of flash drought in arid and aridifying areas.	All Sectors
Example: The 2021 drought in Washington was a different “flavor” of drought. It was driven by both below-normal spring and summer precipitation, as well as an unprecedented heat wave in the summer. This event has not been referred to as “flash drought” by state agencies or producers.	All Sectors
Further understanding of the variations of flash drought impacts in the west is needed. Rapid and out-of-season changes need better classification during extreme heat events.	All Sectors
ALL REGIONS	
Flash Drought Characteristics or Impacts	**Sector**
Drought, including flash drought, during the reproductive stage is most harmful (this varies by region and crop).	Agriculture (All Crops)
Southern areas plant earlier than northern areas, this means growing season forecasts are needed earlier, comparatively.	Agriculture (All Crops)
Once the plant is in the ground, your management options reduce unless you have irrigation.	Agriculture (All Crops)

Flash drought impacts in agriculture will likely vary by crop type (some crops are more resilient), type of soil, the amount of water available, etc. Variations in impacts may be apparent within the same region.	Agriculture (All Crops)
Grazing begins earlier in the south. Seasonal forecasts are needed earlier in the year for southern herds compared to northern herds.	Agriculture (Livestock)
Ranching decisions can be more emotional than other agricultural responses because it involves livestock. Herds take years to build.	Agriculture (Livestock)
The worst case scenario is shutting down energy plants/production due to flash drought in the summer.	Energy
Unusual increases in water demand may signal rapid onset/intensification.	Water Utilities/Infrastructure
Rapid decreases in surface or groundwater supplies may signal flash drought.	Water Utilities/Infrastructure
An early indicator of flash drought may be infrastructure damage from rapidly drying soils or shifts in ground and surface water.	Water Utilities/Infrastructure
Fuel loads increase or change rapidly during flash drought.	Wildfire Management
Antecedent conditions like a dry cold snap (and its impacts) might be linked to subsequent flash drought. Collection of these conditions and impacts might be helpful (e.g. in South Dakota in 2017).	All Sectors
The psychology of abrupt changes like flash drought can magnify impacts because they are “unexpected”.	All Sectors
Flash drought impacts sometimes seem to hit harder than impacts from slower onset droughts. This may be a psychological reaction to rapid and unexpected onset or intensification. It may also be a characteristic that needs further assessment.	All Sectors
Soil moisture is a good indicator for flash drought across all sectors and locations.	All Sectors

Appendix E: Regional and Sectoral Gaps, Needs, and Opportunities

Caption: This table was assembled from discussion during the 5th session of the 2023 workshop.

Northeast
Monitoring of streams and groundwater could be improved with state/regional mesonets leading to faster recognition of flash drought.
Forest health during drought needs additional study.
Determining whether rapid onset/intensification needs to be addressed differently or just on a faster timeline will help with decision making.
Continuing education on rapid onset/intensification (and drought in general) is needed for the public and for sectors other than agriculture.
Continue to bring together researchers (especially early career researchers) and practitioners to improve the selection of research projects and products, and to provide a better understanding of practitioner challenges and decision-support needs.
Continue to share regional response strategies with explanations of why drought status often varies by state.
Train state agencies on drought plans, test plans through exercises and improve plans based on after action reports and improvement plans.
One opportunity to mitigate the impacts of flash drought may come with routine reminders about water conservation during the months when flash drought is most likely to occur.

Southeast
Hold conversations with specific sectors, at the DEWS level, to understand the nature of their decisions (decision calendar) and when they are most sensitive and impacted by rapid-onset drought conditions.
Improve our collection of economic impacts in water supply, energy, industry, and other sectors. Work to predict economic losses.
Incorporate outcomes of sector conversations to develop a flash drought impact matrix by month/season/sector. Then, identify appropriate indicators and decision calendars for sector-specific decisions, and use this exercise to define flash drought in the Southeast by its impacts.
Incorporate rapid-onset drought into scenario/table-top exercises with multiple sectors, building on the impact matrix.
Use the above knowledge to provide training and overviews on new and existing tools and models for flash drought early warning based on sectors and decision requirements. Determine whether these tools can expand the dialog between sectors.

Identify role of antecedent conditions on flash drought development and impacts (e.g. late freeze, rain followed by high temperatures that lead to soil crusting). Ask the question, "Is there a convergence of indicators?"
Soil moisture monitoring is lacking in some Southeastern states (e.g. South Carolina, North Carolina). It is needed to help monitor and characterize rapidly changing conditions.
Increase investments and understanding of soil moisture networks to better validate models.
Increased communications around water conservation throughout the year, including infographics (a Massachusetts example was mentioned).
Develop a decision calendar with useful indicators for rapid onset/intensification.
Consider flash drought in the Southeast DEWS at the sub-regional scale: (e.g. Coastal, Piedmont, Mountain regions) and determine what indicators work best for flash drought in these sub-regions.

Midwest, Missouri River Basin and Pacific Northwest
Ensure that two-way lines of communication exist between service providers and users/practitioners to increase responsiveness to rapid onset/intensification.
Document impacts for analysis and ensure information on insurance and federal assistance programs is available.
Monitor streamflow and water temperatures.
Better monitoring of evaporative demand is needed, given this is a key component of flash drought.
Improved monitoring of remote areas is needed.
Monitoring and focused alerts for observed and forecasted overnight low temperatures that stay above a certain threshold (e.g., 75 or 80 degrees) are needed.
Automate the daily reporting of reservoir levels.
Monitor and share information on animal migrations, illness/disease prevalence and fish kills.
Explore how NASA Surface Water and Ocean Topography (SWOT) data resolution of 250 square meters for lakes and reservoirs and its coverage of 50 - 100 meter wide rivers support drought or flash drought monitoring needs.
Develop a better understanding of how wind contributes to rapid soil moisture degradation. Provide better wind forecasts.
Work to provide better pre-impact early warning with better vegetation monitoring and ground truthing of vegetation indices (e.g., use of phenocams).
Monitor and make use of forecasts and outlooks for high impact precipitation events including tropical storms that might provide relief.

Gather private well data - include water quality and quantity.
Monitor cool-season grasses and other crops for yield information that will help assess cool weather water availability.
Learn more about forest health and future potential for flash drought.
Quantify drought and flash drought impacts to recovery over burned areas and how that impacts post-fire debris flows.
Identify whether there are impacts for flash drought that only occur with flash drought.
Determine the relationship between low water levels and the formation of ice jams (i.e. ice jams as a winter season flash drought indicator).
Information on timelines for forecasts for drought and heat events is needed. Who (by sector) needs to know what and at what time?
Guidance for the avoidance of "false alarms" would be helpful. How long should we wait before advising on flash drought potential? What level of forecast confidence is needed?
Determine whether rapid onset is the new normal for specific regions.
Conduct post drought surveys or assessments in conjunction with other natural hazard events like floods, fires, etc. to better understand the connections.
Track mitigation and adaptation actions (and their effectiveness).
Identify characteristics for the end of rapid onset/intensification phases when they are a part of longer term drought events.
Link notifications on the potential for wildfire with drought monitoring tools (e.g., evapotranspiration, soil moisture).
Use impact assessments/summaries to support legislative efforts and funding requests.
Link communications channels for public and private land management.
Link notifications for extreme heat and drought potential (include human health impacts).
Test drought response plans with flash drought scenario exercises.
Utilize social science to support a better understanding of why some sectors report "This drought caught me off-guard". Convene focus groups, by sector, to understand the psychology of "not being ready".
Improve communication guidance on flash drought to motivate preparation.
Northern Plains: Additional drought planning is needed amongst livestock producers in this region. (This was a lesson learned during the 2021 flash drought webinar series.)

Southern Plains
Promote awareness that remote sensing of soil moisture and many flash drought tools work well in this region.
Communicate better about the shortcomings of some soil moisture products.
Increase the speed of research to operations (R2O) efforts, and promote more R2O pathways.

Intermountain West and California/Nevada
What role does wind play in flash drought in the west?
Connect flash drought examples to a regional definition of flash drought.
Assess large scale wildfire activities in connection to indicators (like EDDI).
Promote multi-sector and cross jurisdictional workgroups on downstream flash drought effects.
Determine whether impact-based forecasting is possible.
Determine whether there are monitoring/planning parallels for drought/heat potential and events.
Understand the differences in the pace of communications and response for drought versus flash drought.
List all antecedent conditions and impacts from previous flash drought events.
Develop a Red Flag Warning criteria comparison to flash drought analysis.
Create an analysis of this situation: Flash drought in a monsoon area - Atmospheric set-up looks like you'll have a monsoon, but then it breaks down. High pressure sets in, temps go up, humidity down, more winds - does this lead to flash drought?
Connect evaporative demand to rangeland decision making.
Continue collaboration and coordination to support funding, analysis and for operational tools.

Sectors
Agriculture (crops)
Crop calendars are needed by region. They are a way to understand when flash drought might have the biggest impact. Real-time adjustments on deviations from typical crop calendar would be to track the USDA crop progress reports.
Increase the opportunities to identify soil management and conservation practices that are beneficial to not only flash drought, but drought in general.
Diversify cropping in flash drought prone regions.

Innovate repurposing of impacted crops.
Identify resources to facilitate adaptive regeneration of farming.
Identify financial strategies for agricultural producers that decrease their vulnerability to extreme weather and events like flash droughts.
Agriculture (livestock)
Expand GrassCast to other parts of the country beyond the Northern Plains.
Develop forage calendars to understand the timing of impacts.
Natural Resources Conservation Service (NRCS) ecological site descriptions have a growth curve as a starting point for forage calendars.
Ecosystems
Further investigations on how ecosystems are impacted by flash drought.
We need to rapidly improve our drought monitoring systems for ecological impacts.
NRCS ecological site descriptions can be exploited for drought monitoring.
Energy
Early warning on low flow episodes and high water temperatures on rivers supplying water for cooling nuclear power plants.
Health
Flash drought monitoring and detection may be aided by syndromic health monitoring of respiratory and other diseases.

Appendix F: Workshop Attendees

Last Name	First Name	Affiliation
Albertin	Klaus	North Carolina Department of Water Resources
Aumann	Ethan	American Property Casualty Insurance Association
Basara	Jeffrey	University of Oklahoma
Bash	Rachel	Lynker
Blaha	Frank	The Water Research Foundation
Bolinger	Becky	Colorado State University
Boza	Burcu	Istanbul Technical University /NCAR
Carbone	Emily	Northern Water
Casola	Joe	NOAA National Centers for Environmental Information (NCEI)
Christian	Jordan	University of Oklahoma
DeGaetano	Art	Cornell University/Northeast Regional Climate Center
Dunbar	Jamie	State Government
Ellenburg	Lee	University of Alabama in Huntsville
Erger	Patrick	Bureau of Reclamation
Figueroa	Mendi	Colorado Division of Water Resources
Foley	Kevin	Bureau of Reclamation
Follingstad	Gretel	NOAA NIDIS/University of Colorado-CIRES
Ford	Trent	University of Illinois
Fuchs	Brian	National Drought Mitigation Center
Gedefaw	Melakeneh	New Mexico State University
Geli	Hatim	New Mexico State University
Goble	Peter	Colorado State University
Goff	Katie	Kansas Water Office
Granger	Stephanie	NASA/JPL-Caltech
Green	Luther	University of Colorado Boulder, Natural Hazards Center
Hain	Christopher	NASA Marshall Space Flight Center
He	Siwei	University of Colorado Boulder and NOAA GSL
Hobbins	Mike	University of Colorado-CIRES / NOAA
Hoell	Andrew	NOAA Physical Sciences Laboratory

Last Name	First Name	Affiliation
Hudgens	Bradley	U.S. Army Corps of Engineers
Hurwitz	Maggie	NOAA National Weather Service
Jannat	Jasia	University of Georgia
Jensen	Eric	Desert Research Institute
Kaushik	Aleya	CU CIRES/NOAA GML
Knox	Pam	University of Georgia
Krichels	Alexander	USDA Forest Service
Kumar	Sudhanshu	Auburn University
Leeper	Ronald	North Carolina State University and NOAA/NCEI
Lesinger	Kyle	Auburn University
Lindquist	Eric	State of Connecticut
Lisonbee	Joel	NOAA NIDIS/University of Colorado-CIRES
Luebbert	Phil	JEO
Lundt	Steve	Metro Water Recovery
MacPherson-Krutsky	Carson	University of Colorado Boulder, Natural Hazards Center
Maddox	Beckie	Constellation Nuclear
McEvoy	Dan	Desert Research Institute
McInerney	Joe	NCAR
McKenzie	Shane	Texas Division of Emergency Management (TDEM)
McWilliams	Chuck	U.S. Army Corps of Engineers
Meehan	Miranda	North Dakota State University
Mishra	Vikalp	SPoRT/University of Alabama at Huntsville
Mohammadi	Kosuhan	Department of Civil and Environmental Engineering
Muth	Meredith	NOAA/NIDIS
O'Callaghan	Ariel	Duke University Masters Student
Osman	Mahmoud	Johns Hopkins University
Ossowski	Elizabeth	NOAA NIDIS/University of Colorado-CIRES
Otkin	Jason	University of Wisconsin-Madison
Parker	Britt	NOAA NIDIS/University of Colorado-CIRES

Last Name	First Name	Affiliation
Peck	Dannele	USDA Agricultural Research Service
Qu	John	George Mason University
Rao	Vandana	Massachusetts Executive Office of Energy and Environmental Affairs
Reeves	Sylvia	NOAA NIDIS/University of Colorado-CIRES
Riganti	Curtis	National Drought Mitigation Center (University of Nebraska-Lincoln)
Rush	Gannon	High Plains Regional Climate Center
Salvinelli	Carlo	University of Colorado Boulder
Scott	Emma	North Carolina State University
Sehgal	Vinit	Texas A&M University
Sharma	Sumit	Oklahoma State University
Sheffield	Amanda	NOAA NIDIS/University of Colorado-CIRES
Skelly	Dana	U.S. Forest Service/Oregon State
Skumanich	Marina	NOAA/NIDIS
Spennemann	Pablo	Servicio Meteorológico Nacional-CONICET
Stiffarm	Kyle	Fort Belknap Indian Community
Strautins	Aldis	NOAA
Svoboda	Mark	National Drought Mitigation Center
Tian	Di	Auburn University
Toker	Emir	Istanbul Technical University
Unruh	Matt	State of Kansas
Waid	Natalie	WA Department of Natural Resources
Wang	Hailan	NOAA/NWS Climate Prediction Center
Weaver	Jonathan	Purdue University
Wickham	Elliot	South Carolina State Climatology Office