Assessment of NOAA National Weather Service Methods to Warn for Extreme Heat Events

MICHELLE D. HAWKINS, VANKITA BROWN, AND JANNIE FERRELL

NOAA/National Weather Service, Silver Spring, Maryland

(Manuscript received 27 May 2015, in final form 8 August 2016)

ABSTRACT

Recent climate studies have predicted a future with longer, more intense, and more frequent heat events. Evolving challenges presented by this paradigm necessitate an assessment of current efforts to warn for extreme heat events. NOAA's National Weather Service (NWS) Weather Forecast Offices (WFOs) issue Excessive Heat Watch, Excessive Heat Warning, and Heat Advisory products as conditions warrant. In the fall of 2013 the NWS conducted an internal assessment with its WFOs to 1) document variations in the usage of heat-based watch, warning, and advisory hazard messages (products) across the country; 2) learn about the degree to which locally developed criteria are applied to forecaster decision-making processes in issuing these products; and 3) gather ideas for enhancing communication of expected excessive heat events in general. Survey responses indicate that WFOs selectively use one or a combination of products, and that various methodologies are used to develop criteria for issuing heat products. Given that forecasters use meteorological and nonmeteorological factors when deciding to issue heat products, forecaster judgment is a crucial element of the warning process. Results also revealed partner confusion due to inconsistent heat product issuance criteria. Suggestions were made for eliminating or revising existing products and policies, or creating new products, policies, or issuance criteria. Results of the survey led the NWS to investigate approaches for achieving higher levels of consistency in heat product issuance criteria, and to engage health partners to examine how heat product issuance criteria could incorporate the known health impacts of heat exposure.

1. Introduction

The National Oceanic and Atmospheric and Administration's (NOAA) National Weather Service (NWS) adopted the heat index (HI) into its operations in 1979. The HI was based on the work of Robert G. Steadman, a textiles and materials professor at Colorado State University, who published his temperature–humidity index (THI) table in 1979 (Steadman 1979). Steadman's THI equations require variables that are not readily accessible for calculation from meteorological parameters. Therefore, Lans Rothfusz, an NWS forecaster at the time, developed a simplified NWS HI later in 1979 by performing multiple regression analysis on data from Steadman's THI table, resulting in the current NWS equation, which uses only air temperature and relative humidity as inputs (Rothfusz 1990).

The HI parameter and guidance on its usage was introduced in an NWS policy document in 1984 (NWS 1984) and remains the primary NWS parameter for expressing the combined effects of temperature and humidity on the human body (NWS 2011a). Shown in Table 1 are definitions of NWS's heat-related watch, warning, and advisory (WWA) products, and general national criteria for issuing these products, as described in the NWS Instruction 10-515 (NWS 2011a). This document communicates NWS policies, procedures, and guidance for issuing nonprecipitation weather products. The NWS excessive heat product policy and criteria were developed through collaboration between NWS national and regional level officials, local forecasters, and researchers across various parts of the United States. Excessive heat products are issued mutually exclusive. For example, a Weather Forecast Office (WFO) may issue either an Excessive Heat Watch or Excessive Heat Warning but not both at the same time. Since heat

Denotes Open Access content.

Corresponding author address: Michelle D. Hawkins, Ph.D., Climate Services Branch, Analyze, Forecast and Support Office, NOAA National Weather Service, 1325 East-West Highway, Room 13352, Silver Spring, MD 20910.
E-mail: michelle.hawkins@noaa.gov

DOI: 10.1175/WCAS-D-15-0037.1

TABLE 1. NWS heat products and criteria for issuing products as described in NWS Instruction 10-515. The Excessive Heat Warning/Heat Advisory criteria are highly variable in different parts of the country because of climate variability and the effect of excessive heat on the local population. WFOs are strongly encouraged to develop local criteria in cooperation with local emergency and health officials and/or utilize detailed heat/health warning systems based on scientific research.

Excessive Heat Watch	Conditions favorable for an excessive heat event/meet or exceed local heat warning criteria in the next 24–72 h
Heat Advisory	HI values forecast to meet/exceed local heat advisory criteria for one to two days Typical values: North: HI ≥ 100°F; south: HI ≥ 105°F Minimum nighttime lows ≥ 75°F
Excessive Heat Warning	HI values forecast to meet or exceed locally defined warning criteria for at least two days Typical values: North: HI ≥ 105°F; south: HI ≥ 110°F Minimum nighttime lows ≥ 75°F

impacts are highly variable in different parts of the country because of climate variability and the effect of excessive heat on the local population, the national policy provides baseline guidance for the 122 local WFOs. Additionally, WFOs are strongly encouraged to develop local criteria in cooperation with local emergency and health officials and/or utilize localized heat health warning systems based on scientific research.

NWS was presented with research in the mid-1990s that showed temperature and humidity alone may not adequately determine the impact of excessive heat on human health, which resulted in an exploration of impact-based guidance tools beyond HI. Subsequently, the NWS provided forecasters at some of its WFOs customized heat health warning systems (HHWSs) as decision support for heat product issuance (Kalkstein et al. 1996). The HHWS is a synoptic classification system that evaluates the negative health impact of oppressive air masses based on several parameters including local wind, pressure, cloud cover, temperature, and humidity (Sheridan and Kalkstein 2004); 28 WFOs, mostly in urban areas, now utilize a HHWS.

Severe weather can lead to degradation of essential infrastructure and services, causing a series of cascading impacts that contribute to the burden of weather-related mortality and morbidity (IPCC 2012). An NWS Service Assessment identified 13 deaths directly attributed to a 2012 historic derecho that occurred during the midst of a heat wave, and 34 heat-related deaths due to widespread power outages caused by the storm (NWS 2012a). One study found that nearly one-third of weather-related deaths during 2006–10 were attributed to excessive natural heat (Berko et al. 2014). Studies have indicated that heat waves have become more frequent across the United States (Peterson et al. 2013). As the probability of severe heat waves increases, significant increases in the risk of illness and death related to extreme heat exposure are very likely (Luber et al. 2014). Even small differences from seasonal average temperatures are associated with increased illness and death (Sarofim et al. 2016). Weather and health communities joining together to leverage each other's data and expertise can foster the development of information and services that support a shared interest in protecting life.

However, predictions of longer and more frequent heat waves necessitate a review of current heat warning methods and identification of future needs. Each WFO issues heat WWAs as conditions warrant within their county warning area (CWA)—the group of counties for which they are responsible for issuing warnings. Although there is no single definition of a heat wave, several studies have examined national or local criteria used by the NWS to issue heat WWAs (Sullivan 1995; Kalkstein et al. 1996; Dixon 1999; Robinson 2001, Basu and Samet 2002; Ebi et al. 2004; Smith et al. 2013). Those studies have suggested NWS criteria should be enhanced to better capture heat impacts on health outcomes. One such study identified 19 heat waves that had a significant impact on health in California, and only six of these events were accompanied by an NWS advisory or warning (Guirguis et al. 2014). Another study explored heat-related mortality in Detroit, Michigan, based on forecast and observed weather data to examine the performance of forecast products for predicting heat and heat waves (Zhang et al. 2014). They found variation in the accuracy of heat predictions, and associations between mortality and forecast heat and heat waves to be overestimated and underestimated, respectively. Zhang et al. (2014) suggest that local knowledge of weather and population health, as well as collaboration among the weather, health, and social service communities, is critical input in issuing heat warnings and alerts. However, prior to the present study, nothing has been published in peer-reviewed literature describing the

national variation in WFO criteria for issuing heat products, along with input from NWS forecasters on the development of local criteria and their decision-making process for issuing heat products.

In the fall of 2013, the NWS conducted an internal assessment with the objective of 1) documenting variations in the usage of heat WWAs across the country, 2) assessing the degree to which locally developed criteria are applied to forecaster decision-making processes in issuing heat products, and 3) gathering ideas for enhancing communication of expected excessive heat events in general. This paper summarizes results of the assessment and resulting NWS heat-related initiatives.

2. Methods

To address the assessment objectives, a survey methodology was employed for its effectiveness in its ability to solicit and examine feedback for specific programs and products (Frey et al. 2000). The survey instrument consisted of 13 questions: six closed ended and seven open ended. Survey questions asked about policy and criteria used to issue heat products, the use of the HHWS, partner feedback, and ideas for communicating heat impacts. NWS partners are government and nongovernment entities that are directly involved in the preparation, dissemination, and discussions involving hazardous weather or other emergency information disseminated by the National Weather Service. To explore local criteria WFOs were asked, ''Please describe your local criteria and how it was developed.'' To examine partner feedback and WFO suggestions on the NWS heat warning program, WFOs were asked questions such as the following: ''From your perspective, do you have any suggestions for how to alter the current suite of NWS Excessive Heat Watch, Warning, and Advisory products; or ideas for communicating heat impacts in general,'' and ''Please share any feedback you have received on NWS heat products.'' In May 2013, the survey was distributed from NWS headquarters via e-mail to staff at the six NWS regional headquarters offices, who then disseminated the survey to all 122 WFOs. The survey was open for two months. Information from all WFOs was collected; however, not all WFOs provided comments to the open-ended questions.

Google Forms was used to collect and analyze survey responses. Data from open-ended questions were assessed using a thematic analysis, which is an evaluative approach used to assess qualitative data and focuses on identifiable patterns and consistencies that emerge from data (Braun and Clarke 2006). One data coder evaluated 320 comments to identify initial salient concepts. After the first data sort, it was decided that comments such as ''No feedback,'' ''N/A,'' and ''None'' would be eliminated from analysis, resulting in a total of 263 comments analyzed to arrive at salient themes and subthemes.

To facilitate a visual comparison between WFOs, survey responses were exported to Microsoft Excel and then imported into Environmental Systems Research Institute's (ESRI) geographical information system (GIS) ArcMap 10.0 software (ESRI 1998). Shapefiles for NWS CWA boundaries, NWS regions, and WFOs were imported from the NWS GIS data portal (NWS 2012b). To prepare the raw data for study, survey results were converted to a dBASE table and joined with NWS shapefiles by linking identical WFO site identifiers. Alaska and Hawaii have never issued heat watches, warnings, or advisories, and thus are not shown on the maps in order to increase the size of the continental U.S. maps for ease of viewing.

3. Discussion

a. WFO issuance of heat products

Survey responses indicated that WFOs selectively use one or a combination of products. For example, some WFOs issue Excessive Heat Watches and Excessive Heat Warnings ($n = 85$), while others use only one product such as Heat Advisory ($n = 12$) or Excessive Heat Warnings ($n = 19$). WFOs noted various reasons for their choices, but the most common explanation was partner confusion over one or more product definitions. WFO partners, such as state and local emergency management agencies, public health agencies, and broadcast meteorologists, indicated the desire for simpler definitions and a clear connection to the protective actions that should be taken. For example, during excessive heat events when WFO products are issued, some partners may decide to open cooling shelters, modify schedules for light rail, activate county emergency operation centers, or open water stations.

1) WFO CRITERIA FOR ISSUING HEAT PRODUCTS

Figure 1 shows the policy used by WFOs to issue heat products; 55 WFOs (45%) adhere to guidance in the NWS Procedural Directive for issuing heat products, and 60 WFOs (49%) have developed their own revised policy with unique local criteria for issuing heat products. These unique criteria may use maximum temperature instead of HI, or include other factors such as sunlight, elevation, time duration, nighttime temperatures, delineation between rural and urban temperatures, and knowledge of historical weather. Six WFOs stated that they revised their criteria based on outcomes of a local climate study. A visual comparison reveals that

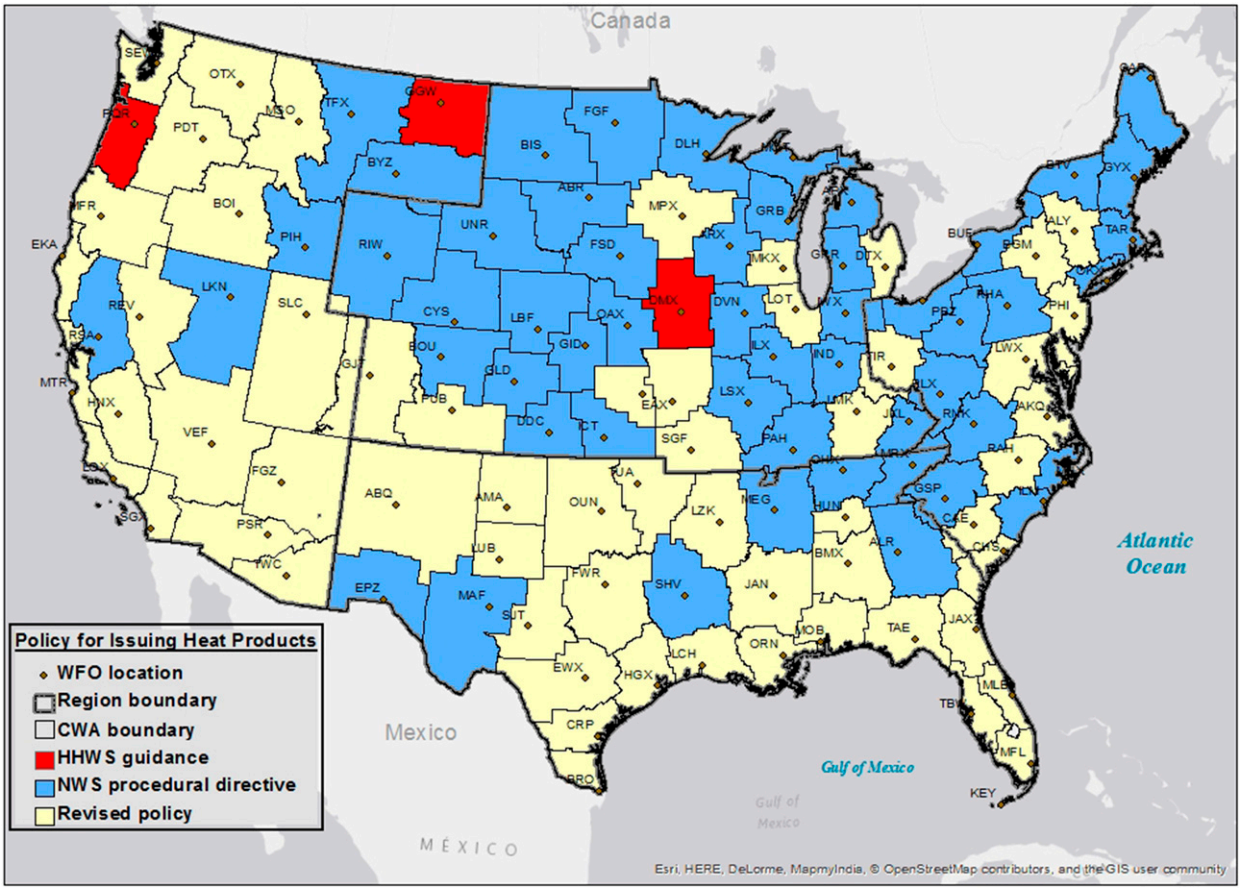

FIG. 1. Policy used by WFOs to issue heat products.

most WFOs in the NWS Central Region adhere to policy guidance, while most WFOs in the NWS Western and Southern Regions have developed unique criteria. Figure 2 shows that 29 WFOs collaborated with health officials to develop their revised criteria. Often state or county health department officials, hospital epidemiologists, or researchers from a university school of public health were identified as collaborators. Nineteen WFOs stated that they worked with surrounding WFOs to address consistency issues. Figure 3 shows HI values at which warnings are issued. A visual comparison reveals that there is only a 3°–5°F difference in some areas where a warning might or might not be issued.

2) WFO USE OF THE HHWS

While 28 WFOs have a HHWS, Fig. 1 also shows that three WFOs primarily consider guidance from NWS policy and the HHWS in their decision-making process to issue heat products. Eighteen WFOs stated that the HHWS benefits their heat warning program. Positive feedback focused on the system's ability to provide insight into the impact of a heat event, capture out-of-season heat events, and provide additional guidance beyond use of the NWS criteria alone. However, some WFOs were concerned about their inability to control or tailor the system's settings, and others noted that the system recommended too many warnings for their CWA. Many WFOs who have the HHWS stated that they use the system as one tool of many that informs their decision to issue a heat product (n = 13). When asked ''How much does the HHWS guidance influence forecaster decision to issue a heat product?'' responses were equally divided between ''often'' and ''rarely.''

Given that forecasters use meteorological and nonmeteorological factors when deciding to issue heat WWAs, forecaster judgment is a crucial element of the warning process. The survey revealed that factors such as duration of heat, nighttime temperature, HHWS guidance, potential for cooling lake breeze, dry desert heat, terrain, time of year, mass outdoor gatherings, recent power outages, and agreements with emergency operation centers can influence a forecaster's decision to issue a heat product.

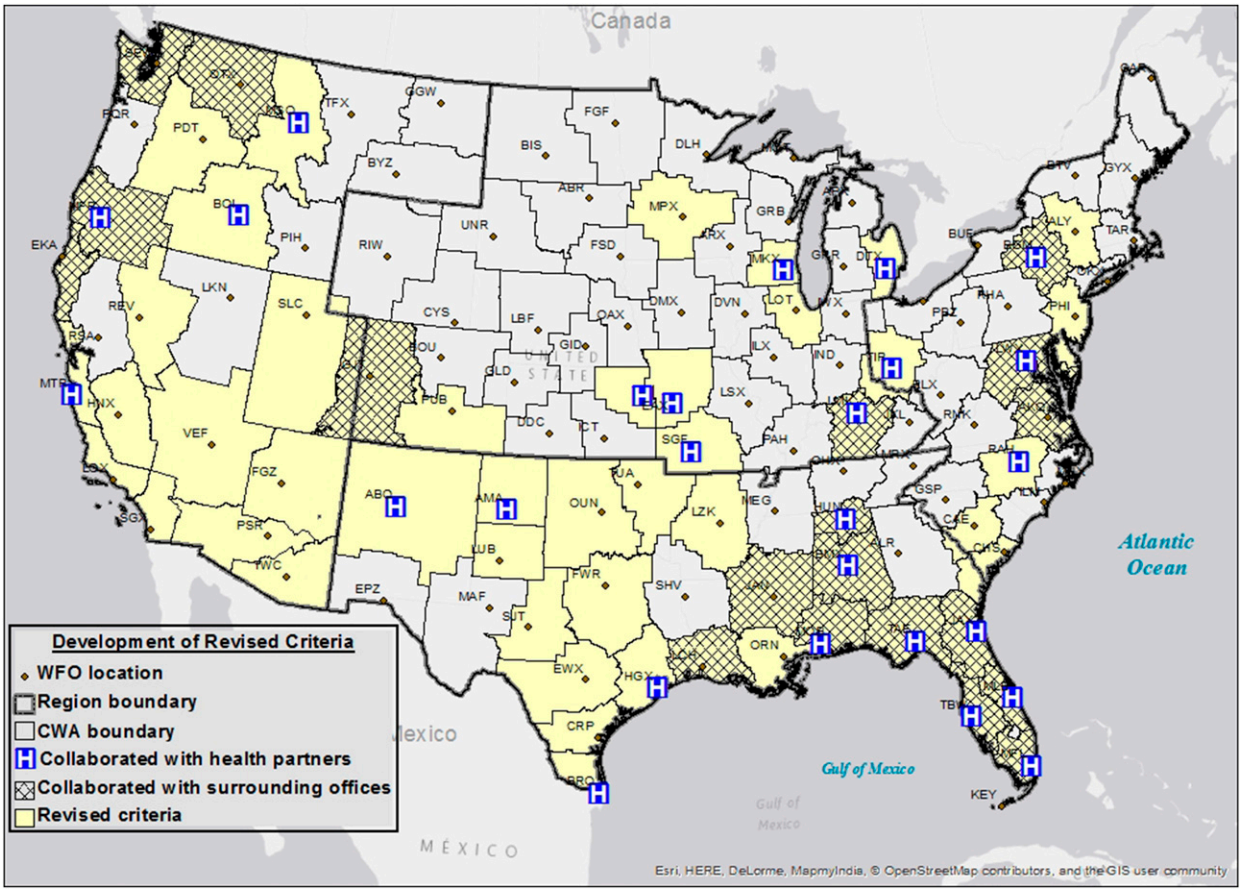

FIG. 2. Methods used to develop revised local criteria.

b. WFO suggestions and partner feedback

Questions that examined partner feedback and WFO suggestions for the NWS heat warning program revealed five salient themes: 1) confusion and frustration from inconsistency, 2) elimination of existing products/services, 3) creation of new products/services, 4) revising existing policies/criteria, and 5) creating new policies/criteria. Table 2 shows the frequency occurrence of these themes.

1) CONFUSION AND FRUSTRATION FROM INCONSISTENCY

One of the most prominent issues identified on the behalf of partners was confusion from the inconsistency that resulted from a lack of uniformity of warning criteria. For example, Fig. 3 shows that varying criteria can create a patchwork of heat products, often within the same state. Media partners, in particular, expressed their frustration to WFOs with this inconsistency as their broadcast areas often encompass several CWAs. This presents a challenge when attempting to interpret and communicate what appears to be a conflict with warnings and watches adjacent to each other. The following quotes illustrate this dilemma: "Media partners DMA's [Designated Market Area] are not confined within a WFO's CWA . . . and sometimes the differing criteria from CWA to CWA can give a mixed message. This has come up in our local IWT [Integrated Warning Team] meetings with partners here." "I have heard concerns from local media regarding the differing criteria. We border a CWA which has a large metro area, and their criteria are quite different from ours."

2) ELIMINATION OF EXISTING PRODUCTS/SERVICES

The second topic, also notable, was the suggestion to eliminate current products in order to reduce the number of products and streamline their use. Many comments specifically recommended terminating watch and/or advisory: "In our area, excessive heat is rare. Do we need advisories? I would like to have heat warnings issued at 100°F and eliminate advisories for simplicity. Even heat advisories are rarely issued this far north." "I

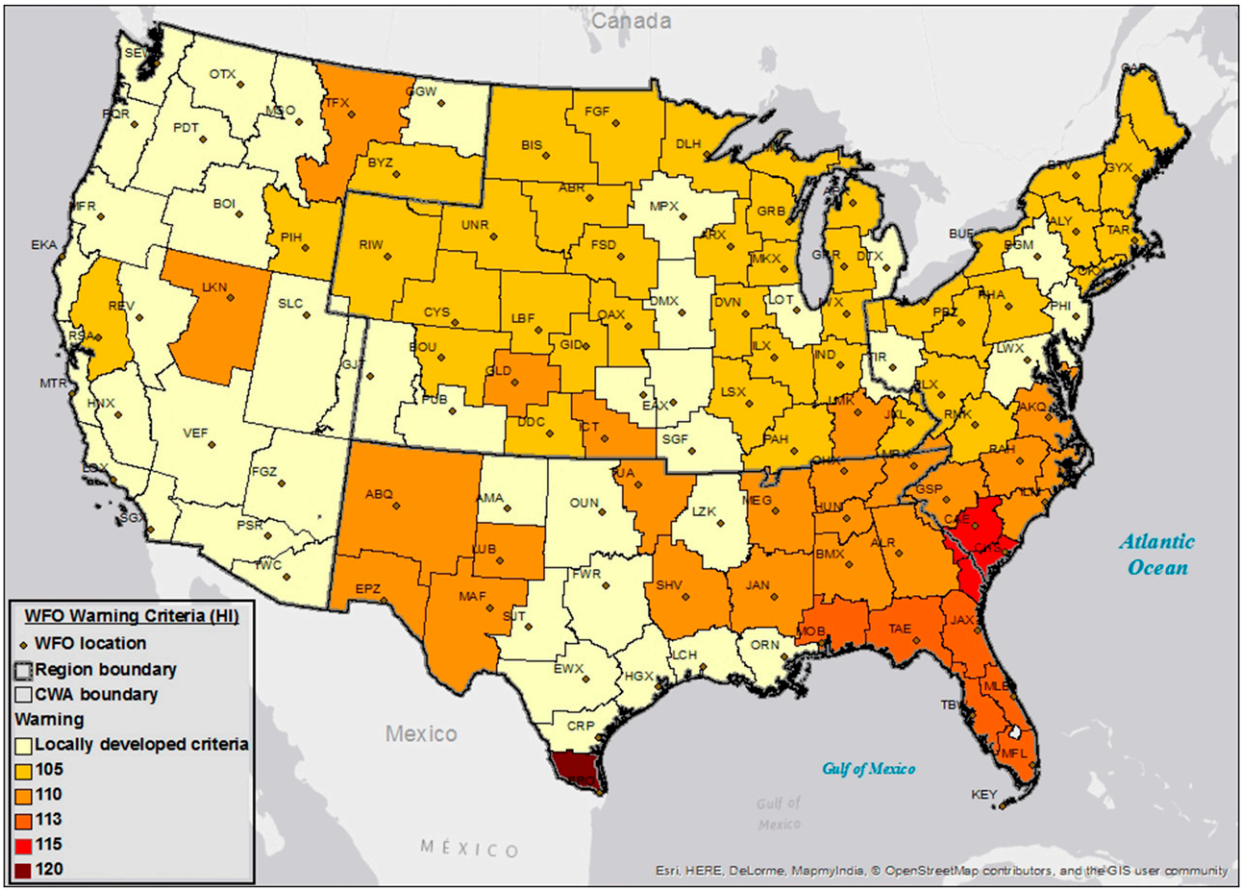

FIG. 3. HI values at which NWS WFOs issue Excessive Heat Warnings. Locally developed criteria may use max temp instead of HI, or include other factors such as sunlight, elevation, time duration, nighttime temperatures, or delineation between rural and urban temperatures.

would opt for dropping the heat watch and just have a warning and advisory for simplicity and better understanding by the general public.'' ''Our office used to issue advisories but stopped a few years ago because our primary partners advised us that they weren't using them and didn't find them that useful. This has worked well for us and does appear to be a trend that some of our neighbors have picked up on as well.''

3) CREATION OF NEW PRODUCTS/SERVICES

Some WFOs suggested the development of new products that could have more utility for their partners. For example, one quote illustrates the need for a collaborative product: ''What if we came up with a new product in cooperation with local health departments along the lines of a 'heat statement'? . . . Perhaps we should issue some sort of 'routine' heat impact product between Memorial Day and Labor Day. . . like air quality index.''

Other comments in this same regard focused on enhancing existing products with wording, and utilizing social media: ''Many people died in the heat that followed the 2012 mid-Atlantic derecho where power was lost. We need to develop some kind of warning in our heat products to warn people to abandon homes that lose power in heat waves.'' ''Move TOWARD concise, attention-grabbing social media. Limit the messaging to the essentials: check on the kids, elderly, and other vulnerable populations. Filter out the rest.'' ''Promote the use of social media to increase the delivery of heat awareness information that can be easily shared through graphics, videos and links.''

4) REVISING EXISTING POLICIES/CRITERIA

Although the NWS policy encourages WFOs to develop local criteria in coordination with local officials, the need for criteria flexibility was illuminated in the comments. Some WFOs suggested a change in criteria that excludes the time duration component. For example, they indicated they would like the flexibility to issue a warning in cases where the 2-day criteria described in the directive will not be met. The following comment serves to explicate this point: ''time element

TABLE 2. Frequency of which themes appear in the open-ended comments.

Theme	Frequency
Confusion from inconsistency	$n = 78$
Revising existing policies/criteria	$n = 37$
Creating new policies/criteria	$n = 52$
Elimination of existing products/services	$n = 41$
Creation of new products/services	$n = 55$
Total	$n = 263$

[should] be eliminated from NWS heat warning (and advisory) products. If HI values will exceed 105 for even ONE day . . . in the interest of public health . . . a warning should be issued.''

Some comments also advocated revising the current policy so it is more adaptable to the needs of partners:

> ''Make the limits a bit less absolute and rigid and a tad more flexible so if an EM [Emergency Manager] or the Health Dept. thinks the situation may warrant an advisory or warning . . . it can be done at their request. For example if the forecast is shy by 1 degree of the rigid criterion but a huge outdoor event is planned . . . the flexibility to issue say an advisory may be a good idea to promote situational awareness and safety.''

''Adjustments from criteria should be allowed when health officials request . . . Criteria ha[ve] been developed based upon input from our partners and we need to respect the value of their knowledge and expertise.''

5) CREATING NEW POLICIES/CRITERIA

Among the suggestions for new policies and criteria was the recommendation to develop very distinct criteria for urban areas, which tend to be warmer than surrounding rural areas because of the urban heat island effect. Several public health studies indicate the heat island effect, in which land cover characteristics and poor air quality combine to enhance the impacts of heat for city dwellers, further increases the health burden on vulnerable populations within cities (Anderson and Bell 2009; Uejio et al. 2011; Berko et al. 2014). ''Special heat warning criteria should be established for large metro areas.'' ''Heat impacts obviously are much greater in urban areas, and local criteria for such locations must be developed in coordination with local officials.''

4. Conclusions

This paper provides some background on the history of heat products in NWS, examines the variability in which heat products are developed and issued, and provides ideas for enhancing communication of expected excessive heat events. The survey revealed that WFOs selectively use one or a combination of heat products, as well as various methodologies for developing and issuing heat products. Results also revealed partner confusion due to inconsistent heat product issuance criteria. Suggestions were made for revising or eliminating existing products and policies, and creating new products, policies, and issuance criteria. NWS regularly examines the needs and requirements for products and services, as well as internal capacity to provide a consistent level of service. Officially proposed new services are reviewed prior to implementation, per NOAA's Policy on Partnerships in the Provision of Environmental Information (NOAA 2007).

The survey revealed that forecasters issue heat WWAs based on heat index forecasts and several other meteorological and nonmeteorological parameters. In addition to heat index forecasts and guidance from the HHWS, other factors can influence a forecaster's decision to issue a heat product. These factors include duration of heat, nighttime temperature, potential for cooling lake breeze, dry desert heat, terrain, time of year, mass outdoor gatherings, recent power outages, and agreements with emergency operations centers. Overall, forecaster knowledge of both weather and their CWA is a critical component of issuing Excessive Heat Watches, Excessive Heat Warnings, and Heat Advisories.

Although NWS policy encourages WFOs to develop local criteria in coordination with local officials, the need for criteria flexibility was illuminated in the survey responses. The strong recommendations to make criteria more nimble, in spite of the guidance, may suggest that some forecasters are uncomfortable with making criteria adjustments, or that they are unaware of how far this discretion extends.

While criteria are variable across the country, leading to observed inconsistencies by partners and other stakeholders, the need for coordination among WFOs is important, in particular neighboring WFOs that border rural and urban areas. However, because of climate variability and the effect of excessive heat on the local population, a national standardization of criteria will likely be unfeasible and inappropriate.

NWS is working to build a Weather-Ready Nation (NWS 2011b) to improve the nation's readiness, responsiveness, and overall resilience to extreme weather, water, and climate events—including extreme heat. As heat has profound impacts on human health, the NWS is collaborating with federal, state, and local health partners to better understand how the NWS forecasts, data, and information are used for health-related decisions. Collaboration between the weather and health

communities can accelerate understanding of the direct and indirect impacts of weather and environment on health and advance preparedness and response efforts that lead to reduced harm from weather, water, air quality, and climate events.

Results of this study have already led the NWS to investigate approaches for achieving more consistency in excessive heat products and to engage the Centers for Disease Control and Prevention (CDC) and local health partners to examine how health impacts of heat can be considered in criteria for issuing heat products. In October 2014, the NWS collaborated with CDC to host a NOAA–CDC Heat Health Summit that brought together WFOs, state health departments, social scientists, and other interested partners to further discuss issues identified in this study and opportunities for future collaborations. Topics discussed included understanding heat-related health decisions on preparedness and response, health data availability and compatibility with meteorological data, and the need for consistent methodologies for issuing heat forecasts that are balanced with flexibility for local context.

The NWS is also evaluating options for simplifying and clarifying hazard products for all weather and water events through a Hazards Simplification (Haz Simp) Project. Results from service assessments, public opinion surveys, and feedback from partners indicate many people may not fully understand what WWA terms mean or how to properly respond to stay safe and protect property. Through the Haz Simp Project, the NWS is working with social scientists to develop alternative methods of conveying hazards with the goal of simplifying and clarifying messages for the general public and for those responsible for making key decisions to protect the public. Outcomes of the Haz Simp Project will be discussed in a future publication.

5. Limitations

There are several limitations of this study. In some WFOs the survey may have been completed by one individual without input from colleagues. Thus, responses may not be representative of the entire WFO. The number of WFOs that performed local climate studies, worked with surrounding WFOs, or collaborated with local partners to revise local criteria could be higher since this was not directly asked in the survey, and the numbers presented here represent WFOs that provided this information in open-ended questions. Finally, partner needs and input represented here are expressed by WFO staff instead of directly from partners and might not precisely represent partner issues or perceptions. To address these limitations, future studies could include an independent assessment of the use of HHWSs in WFO operations and engagement with partners directly to identify collaborative efforts and requirements for heat products. Future research could also include targeted studies of regional or locally appropriate thresholds for issuing heat products.

Acknowledgments. The authors acknowledge the many helpful discussions with NWS forecasters, NWS regional headquarters directors for encouraging participation of all WFOs in this study and subsequent efforts, and Elliott (Eli) Jacks and Fiona Horsfall for supporting this effort and providing helpful input on the development of the survey and reviews of this article. Funding for this work was provided by NOAA/National Weather Service. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the authors and individuals who provided comments and do not necessarily reflect the views and policies of NWS, NOAA, or the U.S. Department of Commerce.

REFERENCES

Anderson, B. G., and M. L. Bell, 2009: Weather-related mortality: How heat, cold, and heat waves affect mortality in the United States. *Epidemiology*, **20**, 205–213, doi:10.1097/EDE.0b013e318190ee08.

Basu, R., and J. M. Samet, 2002: Relation between elevated ambient temperature and mortality: A review of the epidemiologic evidence. *Epidemiol. Rev.*, **24**, 190–202, doi:10.1093/epirev/mxf007.

Berko, J., D. D. Ingram, S. Saha, and J. D. Parker, 2014: Deaths attributed to heat, cold, and other weather events in the United States, 2006–2010. National Health Statistics Rep. 76, National Center for Health Statistics, 16 pp. [Available online at http://www.cdc.gov/nchs/data/nhsr/nhsr076.pdf.]

Braun, V., and V. Clarke, 2006: Using thematic analysis in psychology. *Qual. Res. Psychol.*, **3**, 77–101, doi:10.1191/1478088706qp063oa.

Dixon, R., 1999: A benefit/cost index for evaluating threshold temperatures for excessive heat advisories. *Natl. Wea. Dig.*, **23** (3), 3–6.

Ebi, K. L., T. J. Teisberg, L. S. Kalkstein, L. Robinson, and R. F. Weiher, 2004: Heat watch/warning systems save lives: Estimated costs and benefits for Philadelphia 1995–98. *Bull. Amer. Meteor. Soc.*, **85**, 1067–1073, doi:10.1175/BAMS-85-8-1067.

Environmental Systems Resource Institute, 1998: ESRI shapefile technical description. ESRI White Paper J-7855, 34 pp. [Available online at https://www.esri.com/library/whitepapers/pdfs/shapefile.pdf.]

Frey, L. R., C. H. Botan, and G. L. Kreps, 2000: *Investigating Communication: An Introduction to Research Methods.* Allyn & Bacon, 514 pp.

Guirguis, K., A. Gershunov, A. Tardy, and R. Basu, 2014: The impact of recent heat waves on human health in California. *J. Appl. Meteor. Climatol.*, **53**, 3–19, doi:10.1175/JAMC-D-13-0130.1.

IPCC, 2012: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation.* C. B. Field et al., Eds., Cambridge University Press, 582 pp. [Available online at http://www.ipcc-wg2.gov/SREX/images/uploads/SREX-All_FINAL.pdf.]

Kalkstein, L. S., P. F. Jamason, J. S. Greene, J. Libby, and L. Robinson, 1996: The Philadelphia hot weather-health watch/warning system: Development and application, summer 1995. *Bull. Amer. Meteor. Soc.*, **77**, 1519–1528, doi:10.1175/1520-0477(1996)077<1519:TPHWHW>2.0.CO;2.

Luber, G., and Coauthors, 2014: Human health. *Climate Change Impacts in the United States: The Third National Climate Assessment*, J. M. Melillo, T. C. Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 220–256, doi:10.7930/J0PN93H5.

NOAA, 2007: Policy on Partnerships in the Provision of Environmental Information. Accessed 25 July 2016. [Available online at http://www.corporateservices.noaa.gov/ames/administrative_orders/chapter_216/216-112.html.]

NWS, 1984: Zone and local forecast. Weather Service Operations Manual, NOAA. [Available online at http://www.nws.noaa.gov/wsom/manual/archives/NC118411.HTML.]

——, 2011a: WFO non-precipitation weather products specification. National Weather Service Instruction 10-515, 27 pp. [Available online at http://www.nws.noaa.gov/directives/sym/pd01005015curr.pdf.]

——, 2011b: Weather-Ready Nation. NOAA, 46 pp. [Available online at http://www.nws.noaa.gov/com/weatherreadynation/files/strategic_plan.pdf.]

——, 2012a: National Weather Service GIS data portal. Accessed 27 September 2013. [Available online at http://www.nws.noaa.gov/gis/.]

——, 2012b: The historic derecho of June 29, 2012. NOAA, 61 pp. [Available online at http://www.nws.noaa.gov/om/assessments/pdfs/derecho12.pdf.]

Peterson, T. C., and Coauthors, 2013: Monitoring and understanding changes in heat waves, cold waves, floods and droughts in the United States: State of knowledge. *Bull. Amer. Meteor. Soc.*, **94**, 821–834, doi:10.1175/BAMS-D-12-00066.1.

Robinson, P., 2001: On the definition of a heat wave. *J. Appl. Meteor.*, **40**, 762–775, doi:10.1175/1520-0450(2001)040<0762:OTDOAH>2.0.CO;2.

Rothfusz, L. P., 1990: The heat index ''equation'' (or, more than you ever wanted to know about heat index). NWS Southern Region Tech. Attachment SR-9023, 2 pp. [Available online at http://www.srh.noaa.gov/images/ffc/pdf/ta_htindx.PDF.]

Sarofim, M. C., and Coauthors, 2016: Temperature-related death and illness. *The Impacts of Climate Change on Human Health in the United States: A Scientific Assessment.* U.S. Global Change Research Program, 43–68.

Sheridan, S., and L. S. Kalkstein, 2004: Progress in heat watch–warning system technology. *Bull. Amer. Meteor. Soc.*, **85**, 1931–1941, doi:10.1175/BAMS-85-12-1931.

Smith, T. T., B. F. Zaitchik, and J. M. Gohlke, 2013: Heat waves in the United States: Definitions, patterns and trends. *Climatic Change*, **118**, 811–825, doi:10.1007/s10584-012-0659-2.

Steadman, R. G., 1979: The assessment of sultriness. Part I: A temperature-humidity index based on human physiology and clothing science. *J. Appl. Meteor.*, **18**, 861–873, doi:10.1175/1520-0450(1979)018<0861:TAOSPI>2.0.CO;2.

Sullivan, K. D., 1995: July 1995 heat wave. NWS Natural Disaster Survey Rep., 74 pp. [Available online at http://www.nws.noaa.gov/om/assessments/pdfs/heat95.pdf.]

Uejio, C. K., O. V. Wilhelmi, J. S. Golden, D. M. Mills, S. P. Gulino, and J. P. Samenow, 2011: Intra-urban societal vulnerability to extreme heat: The role of heat exposure and the built environment, socioeconomics, and neighborhood stability. *Health Place*, **17**, 498–507, doi:10.1016/j.healthplace.2010.12.005.

Zhang, K., Y. H. Chen, J. D. Schwartz, R. B. Rood, and M. S. O'Neill, 2014: Using forecast and observed weather data to assess performance of forecast products in identifying heat waves and estimating heat wave effects on mortality. *Environ. Health Perspect.*, **122**, 912–918, doi:10.1289/ehp.1306858.