P2.2

Prototype Tool Development for Creating Probabilistic Hazard Information for Severe Convective Phenomena

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1. INTRODUCTION

Forecasting A Continuum of Environmental Threats (FACETs; Rothfusz et al. 2013; 2014) presents a vision for the next-generation National Weather Service (NWS) watch/warning system. A significant component to this vision is the development of scientific methodologies and tools that allow forecasters to convert guidance information (e.g., mesoscale/storm-scale models, storm-scale statistics, radar) on multiple time scales (i.e., days, hours, minutes) into Probabilistic Hazard Information (PHI). PHI may be defined as information describing the probability for a given hazardous weather phenomena within a defined spatial and temporal range.

In June of 2013, the National Severe Storms Laboratory (NSSL) was awarded a Special Early-stage Experimental or Development (SEED) grant from the National Oceanic and Atmospheric Administration's (NOAA) Office of Oceanic and Atmospheric Research (OAR) to begin addressing part of the FACETs vision. The goals of this project include:

1. Development of forecaster-enabling tools to bridge the gap between guidance sources and end-user PHI needs.
2. Establishment of a variety of guidance sources from which PHI can be automatically derived and presented to the forecaster (e.g., Warn-on-Forecast).
3. Collaborate with NOAA's Global Systems Division (GSD) Hazard Services development team for beginning the process of transitioning tool functionality into the Advanced Weather Interactive Processing System (AWIPS-II).
4. Collaborate with human factors and behavioral scientists within the University of Oklahoma (OU) School of Industrial and Systems Engineering throughout the development process.
5. Conduct joint testing and evaluation between NSSL, GSD, OU, NWS, and the Storm Prediction Center (SPC) in the 2014/15 NOAA Hazardous Weather Testbed (HWT) Spring Experiments.

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In this paper, we provide a brief overview of the historical efforts related to the inception and initial creation of PHI, a description of the activities related to and development of a new prototype PHI tool, a discussion of ongoing challenges, and a description of future work.

2. PRIOR PHI DEVELOPMENT

Brainstorming on the concept of creating PHI for severe convective phenomena began in the 1990's and early 2000's, with early developmental work beginning at NSSL in 2005 (Lakshmanan et al. 2005). In 2007, the first prototype software was developed within the WDSS-II software framework (Ortega 2008; Fig. 1). Tests with this prototype software were conducted in the NOAA HWT spring experiment in 2008 (Kuhlman et al. 2008; Stumpf et al. 2008).

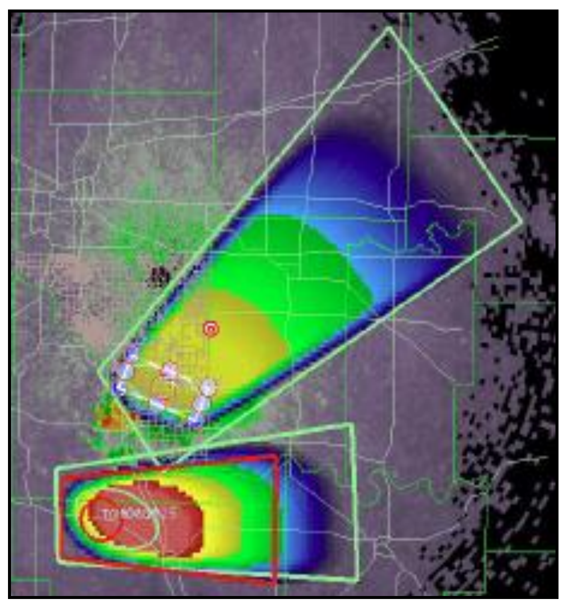

Figure 1. Screen capture of the first prototype PHI tool software for creating threat areas and PHI.

A subsequent Weather and Society Integrated Studies (WAS*IS) workshop was held in late 2008 to discuss the concept of PHI (Kuhlman et al. 2009). In 2009, collaboration with NOAA GSD began with their development of the Integrated Hazard Information Services (IHIS; now known simply as Hazard Services; Hansen et al. 2010), and continues to this day.

3. CURRENT PHI DEVELOPMENT

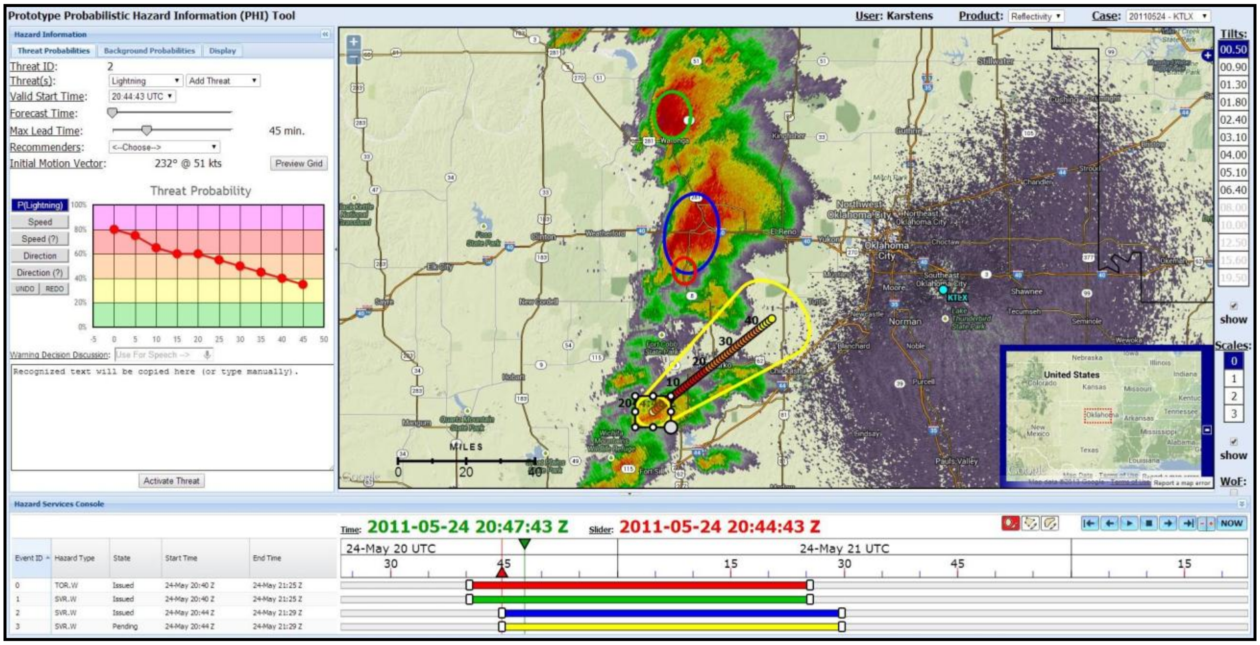

Figure 2. Screen capture of the new prototype web-based PHI tool for creating PHI.

3.1 *Background*

Ideas for how to conduct threat tracking and PHI creation have been and continue to be rigorously discussed in numerous cross-disciplinary interactions at NSSL and in the NWS Virtual Lab (https://nws.weather.gov/innovate/). These ideas extend from the aforementioned historical development and testing, as well as from new ideas emerging within the weather enterprise and members of the development team. Human factors and behavioral scientists from the OU School of Industrial and Systems Engineering, the NOAA GSD Hazard Services development team, meteorologists from NOAA NWS, SPC, the Warning Decision Training Branch (WDTB), research scientists and staff from NOAA NSSL and Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), and NWS Meteorological Development Laboratory (MDL) have all participated in these discussions by attending weekly, bi-weekly, or monthly meetings. The ideas that surface not only serve as the foundation for the creation of the new prototype PHI tool, but also serve to guide the progress of current and future development.

Specific components of the prototype PHI tool development are described in the following sections. It is important to note that the concept of PHI is divided into two main categories: PHI generated from guidance to be interpreted by the forecaster (sections 3.3, 3.4 and 3.5) and PHI generated by the forecaster to be interpreted by the end-user (section 3.6).

3.2 *Prototype Tool Development*

Initial development of a new prototype web-tool began in May 2013, with efforts bolstered upon receiving the SEED grant. This tool expands upon the original PHI tool (Ortega 2008) by including more Graphical User Interface (GUI) functionality for real-time previewing and more real-time Geographic Information Systems (GIS) functionality. Four development cycles have occurred, with more development iterations planned. In each development cycle, scientific methodologies for PHI creation/interpretation are incorporated along with recommendations from human factors and behavioral scientists. The goal of this process is to create a tool flexible enough to allow for multiple methodologies and/or guidance sources to be rapidly prototyped and tested, while maintaining core functionality, logical user-interface design, and mirrored functionality of the Hazard Services software (with some limitations).

A screen capture of the most recent version of the prototype PHI tool is shown in Fig. 2. The interface is comprised of five main panels, including an information panel (top), hazard information configuration/display panels (left), map panel (center), quick-access controls panel (right), and a hazard services console panel (bottom). To reiterate, the panels have been designed to mirror functionality present in the AWIPS-II Hazard Services software, especially the time and hazard event controls located in the hazard services console panel.

3.3 *PHI Threat Objects*

An example of a PHI threat object and its resulting PHI grid is given in Figs. 3a and 3b, respectively. Conceptually, the PHI threat object's polygon geometry is intended to denote the region that is experiencing, or is forecast to experience, a particular threat or hazard over the forecast duration of the event (Fig. 3; filled red polygon). The PHI threat object may be forecast to change location/speed/direction and/or expand using prognostic motion vectors and motion uncertainty values, respectively. This process is iteratively computed with increasing forecast times through the end of the forecast period, while temporally and spatially integrating the PHI threat object polygon geometry to create a forecast strike swath (Fig. 3; hollow red polygon). The PHI threat object and its associated forecast strike swath can be rendered at any time during the forecast period, thus giving the impression of a moving threat (i.e., Threats-in-Motion; e.g., Wolf et al. 2013).

Beyond spatially denoting the threat or hazard region (now and in the future), the purpose of the PHI threat object is to:

1. Calculate location- and grid-point-specific information such as its estimated current location, movement, time of arrival (TOA), time of departure (TOD), and duration.
2. Geospatially apply forecaster generated or approved prognostic probabilities of exceedance of a severity threshold for a particular hazard.

Consequently, the forecast strike swath represents the area that is forecast to experience the threat or hazard during the forecast period. Additionally, the forecast strike swath denotes the region of accumulated probabilities from #2 above. Thus, the forecast strike swath boundary represents boundary between the background probability fields (outer) and the enhanced, threat-based probabilities (inner).

It is important to note that the PHI threat object and its strike swath *do not* represent "the warning". Note that FACETs aims to modernize the binary product-centric watch/warning paradigm through the delivery of rapidly-updating PHI optimized for effective, user-specific decision making in the proper societal contexts. Thus, a "warning" becomes end-user specific, based on the exceedance of preset probability thresholds. An example is given in Fig. 4, which shows two probability thresholds, and thus, two different derived warnings from the same PHI.

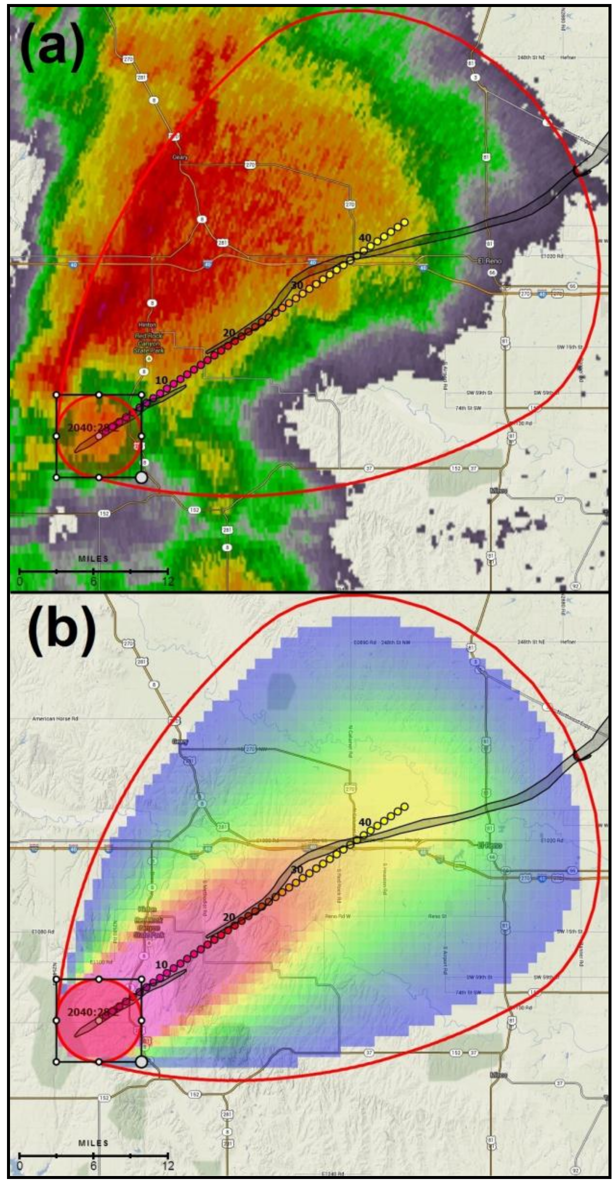

Figure 3. (a) Forecaster-initiated creation and modification of a PHI threat object (filled red polygon with bounding box that includes modification knobs) over base reflectivity data (24 May 2011, 2040:28 UTC). Large red hollow polygon is the forecast strike swath. Filled black polygon denotes the 24 May 2011 El Reno, OK tornado track. Positions of colored dots denote location of the centroid of the PHI threat object in 1-minute forecast intervals, and colors of dots denote forecast probabilities. (b) As in (a), except previewing the resulting accumulated PHI grid (filled grid cells; 1 km^2 resolution) that are generated by the PHI threat object.

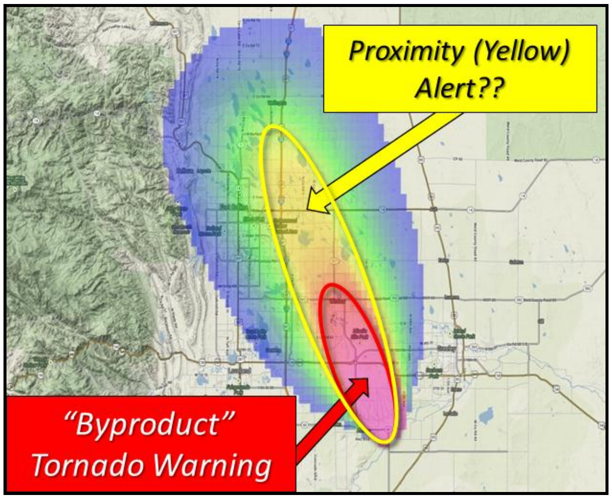

Figure 4. Example of end-user "warning" polygons (red and yellow ellipses) derived using probability thresholds from the underlying PHI grid (filled grid cells). Example is for the 22 May 2008 Windsor, CO tornado.

It is also important to consider resource limitations, specifically, bandwidth. One of the most important aspects of the PHI threat object is that it is an "object" (i.e., data). This allows it to be serialized into a data string for easy portability (typical size < 3 Kb). Much like using radar data to calculate and render a derived product (e.g., MESH), the PHI threat object relies on GIS modules to calculate its position, its forecast positions (i.e., forecast strike swath, threats in motion), and its underlying PHI. This can be produced at preset time intervals (e.g., 1 minute) and grid resolutions (e.g., 1 km), or rendered on the fly via more sophisticated real-time GIS applications.

3.4 *Background PHI*

An additional component of the prototype PHI tool is providing forecasters with the ability to generate, evaluate, and manipulate automated PHI derived from NWP model diagnostics for time and space scales beyond that of warnings (i.e., 1 h +). We refer to these probabilities as "background probabilities" because in most cases they would be issued prior to observed or near-observed threat formation and would cover relatively broad regions over which particular threats are expected to eventually develop. Under the FACETs vision of a time and space continuum, probabilities generated using PHI threat objects would blend into these background probability fields.

Development related to this aspect of the project has been limited thus far, but will be of primary focus in the near future. The ultimate goal is to build functionality that allows the forecaster to derive PHI using the following as inputs:

1. NWP model/ensemble diagnostics
2. Time period for threat guidance
3. Radius of influence (e.g., probability that threat will occur within X miles of a point)

From these inputs, the derived PHI would be presented to the forecaster for further evaluation and modification prior to public dissemination. To accomplish this task, we plan to incorporate recently developed methods that have recent been or are soon to be tested (e.g., Jirak et al. 2012; Marsh et al. 2012) in the HWT Experimental Forecast Program (EFP; e.g., Clark et al. 2012) Spring Experiments.

3.5 *Guidance PHI*

Perhaps one of the most critical components to the prototype PHI tool is the establishment and presentation of guidance PHI to the forecaster for incorporation into PHI threat objects or background PHI. Examples of PHI guidance sources include the Multi-Radar Multi-Sensor (MRMS; e.g., Cintineo et al. 2011) data stream, the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS) project that would be offered via a storm identification and tracking algorithm (Humphrey et al. 2014), and PHI derived from Warn-on-Forecast (e.g., Stensrud et al. 2009; 2013) probabilities. For background probabilities at "Day 1" time scales (i.e., 12 to 36 hour forecasts), examples of guidance sources include forecasts of storms and storm attributes (e.g., hourly maximum updraft helicity) from convection-allowing ensembles (e.g., Correia et al. 2014) and the High-Resolution Rapid Refresh (HRRR) model. For longer time scales (e.g., 2 – 8 days), guidance could be derived from environment-based severe weather parameters forecast by coarser ensemble systems like the SREF system and the GEFS global ensemble.

Efforts toward incorporating these automated PHI sources into the tool are still quite preliminary and will be the focus of near-future development, especially since that capability is at the heart of the SEED project. An example of incorporating Warn-on-Forecast probabilities (Wicker et al. 2014) into a PHI threat object is provided in Fig. 4. It is important to note that the concept of PHI guidance sources is not limited to any particular project or methodology. It is our intent to design the prototype tool with the capability of incorporating new PHI guidance sources, when such sources are developed within the broad research community. Thus, we are striving to establish a tangible research-to-operations infrastructure (following the Hazard Services "recommenders" concept).

Another important consideration is the involvement of the forecaster in monitoring and updating PHI offered from guidance sources. The prototype PHI tool is being designed to integrate the forecaster into every decision that is made. However, we could explore ways in which guidance products are used to allow PHI for some low-impact events to be automatically generated while forecaster time is freed up to concentrate on higher-impact events and enhanced decision support services.

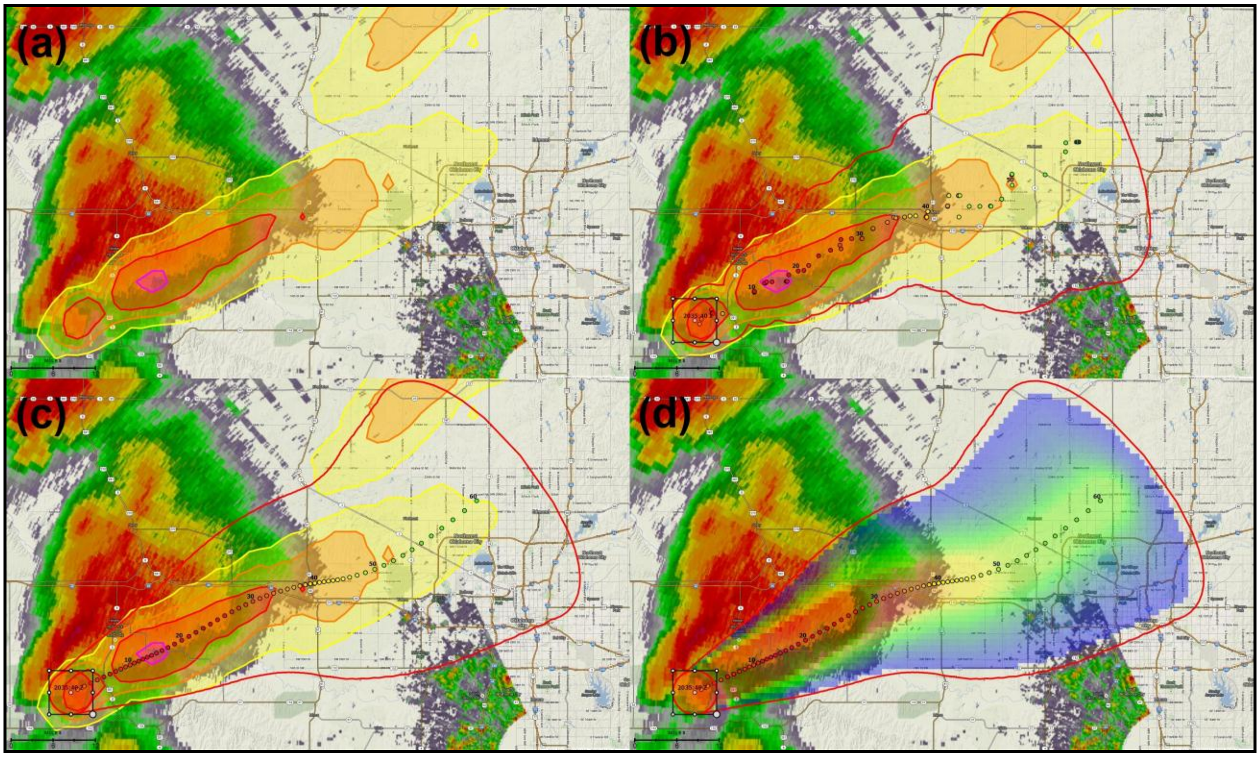

Figure 4. Mock-up Warn-on-Forecast guidance incorporated into a PHI threat object. (a) Probabilities of modeled strong rotation overlaid on Phased-Array Radar (PAR; Heinselman et al. 2009), (b) raw incorporation of probabilities into a PHI threat object, (c) cubic-spline interpolation of raw probabilities, and (d) preview of output PHI grid.

3.6 *End-User PHI*

Once PHI is generated by the forecaster for a given threat or hazard, the output information can be specifically tailored in a variety of ways to meet various end-user needs. In particular, approximations to the following example fundamental questions can derived based on location:

1. When will the hazard arrive?
2. When will the hazard be over?
3. How long will the hazard last?
4. What is the probability of the hazard occurring?
5. Where is the hazard currently?
6. What direction and how fast is the hazard moving?
7. How intense is the hazard (observations)?

An example display of this information is provided in Fig. 5. It is important to note that these questions are only examples and do not represent the full spectrum of questions that could be asked. We foresee this as an opportunity for the weather enterprise to deliver customized or personally-tailored information to meet the diversity of end-user needs.

4. DISCUSSION & FUTURE WORK

The progress we have made toward meeting the goals outlined in the SEED project thus far has spurred a number of additional key questions that will need to be addressed in later development iterations. These questions include:

1. Probability of What? Should probabilities be generated for preset severity threshold(s) for a particular threat/hazard [e.g., P(1” hail)] or should probabilities be coupled with a fluctuating prognostic severity threshold? What temporal and spatial scales should be used? Should alternative methods of generating probabilities be incorporated (e.g., Dance et al. 2011)?
2. How will legacy information and products be derived? What probability threshold should correspond with legacy warnings?
3. How will various end-users (e.g., emergency managers, first-responders, businesses, general public) react to receiving forecasts for severe convective weather that have more specificity (i.e., location-derived TOA, TOD, duration, probabilities)? How can this information be communicated in ways that strive to meet the Weather Ready Nation objectives?
4. What are the appropriate verification metrics to use for PHI (tinyurl.com/ewp-thoughts)? Ideally, verification data (e.g., Ortega et al. 2009; Elmore et al. 2013) or synthetic verification data (e.g., Cintineo et al. 2011) should match the temporal and spatial scale of PHI data.

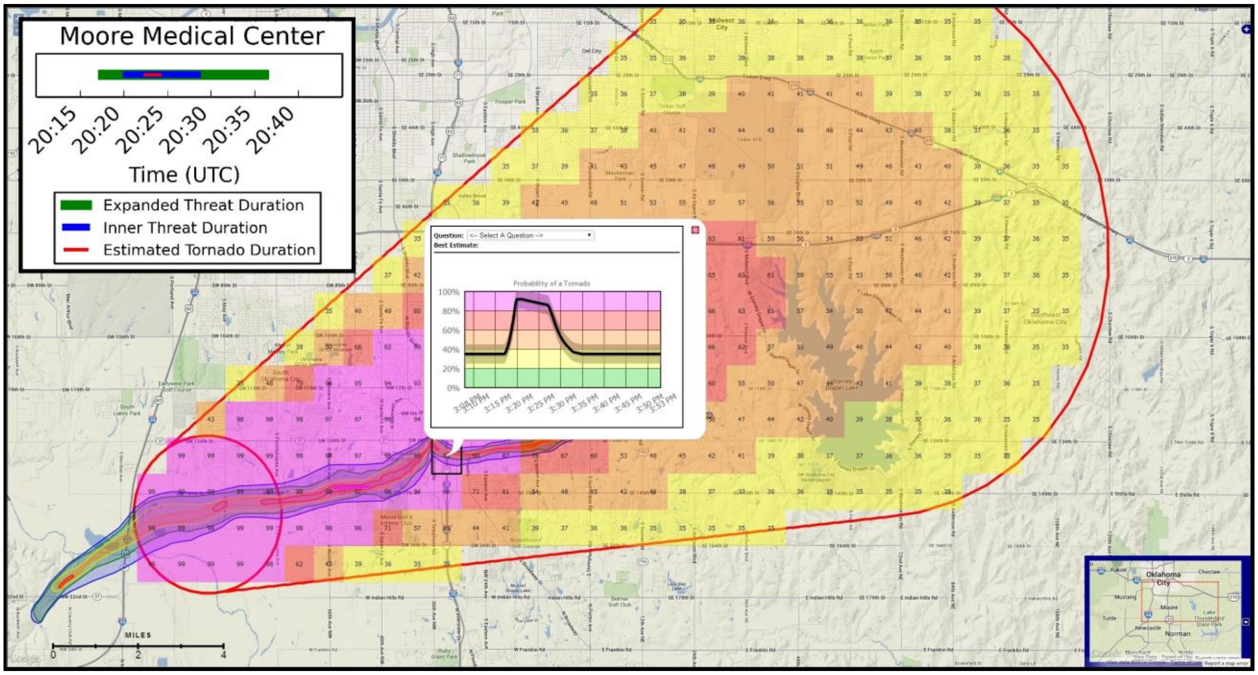

Figure 5. Mock-up of PHI that could be provided to end-users. Color-filled grid cells are the PHI grid. The popup window in the center shows the probability time series associated with this particular PHI threat object forecast. The inset in the upper-left shows the forecast TOA and TOD (35% probability threshold) for the Moore Medical Center compared to the estimated observed tornado duration (using TDWR and damage width; Ortega et al. 2014).

An internal beta-test evaluation is currently being conducted at NSSL to scrutinize the functionality and initial attempts at presenting guidance information within the prototype PHI tool. Members of his evaluation include a core group of researchers, operational meteorologists, and human factors and behavioral scientists. Recommendations from this evaluation, as well as continued development of real-time PHI guidance sources, will serve as input to the fifth iteration of development to be completed prior to formal evaluation in the 2014 HWT Spring experiment.

Testing in the HWT Spring experiment is planned through collaboration between the Experimental Warning Program (EWP; e.g., Stumpf et al. 2012) and the EFP using a variety of real-time guidance sources. Within the EWP, NWS forecasters will evaluate the functionality methodologies available in the prototype PHI tool for subsequent development iterations (with perhaps some rapid prototyping during the experiment).

Efforts will continue to build upon existing collaborations with OU human factors and behavioral scientists, the Hazard Services development team, and operational forecasters in the NWS. The long-term goal (2015+) is to fold the capabilities of this tool into the AWIPS-II Hazard Services software and to evaluate this framework jointly with GSD, NWS, SPC, and NSSL in NOAA's HWT prior to operational consideration by NWS.

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6. REFERENCES

Cintineo, J. L., T. M. Smith, V. Lakshmanan, and S. Ansari, 2011: An automated system for processing the Multi-Year Reanalysis Of Remotely Sensed Storms (MYRORSS). *27th Conf. on Interactive Information Processing Systems,* Seattle, WA, J9.3.

Clark, A. J., and Coauthors, 2012: An overview of the 2010 Hazardous Weather Testbed Experimental

Forecast Program Spring Experiment. *Bull. Amer. Meteor. Soc.,* **93,** 55–74.

Correia, J., Jr., J. S. Kain, and A. J. Clark, 2014: A four year climatology of simulated convective storms form NSSL WRF. *22nd Conf. on Numerical Weather Prediction,* Atlanta, GA, Amer. Meteor. Soc., J11.2.

Dance, S., E. Ebert, and D. Scurrah 2010: Thunderstorm strike probability nowcasting. *J. Atmos. Oceanic Technol.*, **27**, 79–93.

Elmore, K. L., Z. L. Flamig, V. Lakshmanan, B. T. Kaney, V. Farmer, and L. P. Rothfusz, 2013: mPING: Crowd-sourcing weather reports for research. *Bull. Amer. Meteor. Soc.,* In press.

Hansen, T. L., T. J. LeFebvre, C. S. Bullock, J. Wakefield, J. Ramer, S. Williams, G. J. Stumpf, K. Scharfenberg, J. T. Ferree, B. C. Motta, E. Gruntfest, S. Romano, M. K. Zappa, W. F. Roberts, 2010: Hazard Information Services Vision. *Extended Abstracts, 26th Conf. on Interactive Information and Processing Systems,* Atlanta, GA, USA, Amer. Meteor. Soc., CD-ROM, 6B.4.

Heinselman, P. L., D. L. Priegnitz, K. L. Manross, T. M. Smith, R. W. Adams, 2008: Rapid Sampling of Severe Storms by the National Weather Radar Testbed Phased Array Radar. *Wea. Forecasting*, **23**, 808–824.

Humphrey, T. W., V. Lakshmanan, T. M. Smith, K. L. Ortega, B. T. Smith, and R. L. Thompson, 2014: Automated storm classification for the development of probabilistic hazard information. *26th Conf. on Weather Analysis and Forecasting,* Atlanta, GA, Amer. Meteor. Soc., J3.4.

Jirak, I. L., C. J. Melick, A. R. Dean, S. J. Weiss and J. Correia, Jr., 2012: Investigation of an automated temporal disaggregation technique for convective outlooks during the 2012 Hazardous Weather Testbed Spring forecasting experiment. *26th Conf. on Severe Local Storms,* Nashville, TN, Amer. Meteor. Soc., 10.2.

Kuhlman, K. M., T. M. Smith, G. J. Stumpf, K. L. Ortega, and K. L. Manross, 2008: Experimental probabilistic hazard information in practice: Results from the 2008 EWP Spring Program. *Extended Abstracts, 24th Conf. on Severe Local Storms,* Savannah, GA, Amer. Meteor. Soc., 8A.2.

____, E. Gruntfest, K. A. Scharfenberg, and G. J. Stumpf, 2009: Beyond Storm-Based Warnings: An Advanced WAS*IS Workshop to study communication of probabilistic hazardous weather information. *Extended Abstracts, 4th Symp. on Policy and Socio—Economic Research,* Phoenix, AZ, Amer. Meteor. Soc., 3.5.

Lakshmanan, V., I. Adrianto, T. Smith, and G. Stumpf, 2005: A spatiotemporal approach to tornado prediction, *Int'l Joint Conf. on Neural Networks*, (Montreal), p. CDROM 1072.

Marsh, P. T., J. S. Kain, V. Lakshmanan, A. J. Clark, N. M. Hitchens, and J. Hardy, 2012: A method for calibrating deterministic forecasts of rare events. *Wea. Forecasting*, **27**, 531–538.

Ortega, K. L., 2008: Severe weather warnings and warning verification using threat areas. M.S. thesis, School of Meteorology, University of Oklahoma, 50 pp.

____, T. M. Smith, K. L. Manross, A. G. Kolodziej, K. A. Scharfenberg, A. Witt, and J. J. Gourley, 2009: The Severe Hazards Analysis and Verification Experiment. *Bull. Amer. Meteor. Soc.*, **90**, 1519–1530.

____, D. W. Burgess, G. S. Garfield, C. D. Karstens, J. G. LaDue, T. P. Marshall, T. C. Meyer, B. R. Smith, R. Smith, D. Speheger, and G. J. Stumpf, 2014: Damage survey and analysis of the 20 May 2013 Newcastle-Moore, OK, EF-5 tornado. *Special Symposium on Severe Local Storms,* Atlanta, GA, Amer. Meteor. Soc., 828.

Rothfusz, L. P., E. Jacks, J. Ferree, G. J. Stumpf, and T. M. Smith, 2013: Next-generation warning concept: Forecasting A Continuum of Environmental Threats (FACETs). *2nd Conf. on Weather Warnings and Communication,* Nashville, TN, Amer. Meteor. Soc., 3.4.

____, P. T. Schlatter, E. Jacks, and T. M. Smith, 2014: A future warning concept: Forecasting A Continuum of Environmental Threats (FACETs). *2nd Symposium on Building a Weather-Ready Nation: Enhancing Our Nation's Readiness, Responsiveness, and Resilience to High Impact Weather Events,* Atlanta, GA, Amer. Meteor. Soc., 2.1.

Stensrud, D. J., M. Xue, L. J. Wicker, K. E. Kelleher, M. P. Foster, J. T. Schaefer, R. S. Schneider, S. G. Benjamin, S. S. Weygandt, J. T. Ferree, and J. P. Tuell, 2009: Convective-scale warn on forecast: A vision for 2020, *Bull. Amer. Meteor. Soc.,* **90,** 1487-1499.

____, L. J. Wicker, M. Xue, D. T. Dawson II, N. Yussouf, D. M. Wheatley, T. E. Thompson, N. A. Snook, T. M. Smith, A. D. Schenkman, C. K. Potvin, E. R. Mansell, T. Lei, K. M. Kuhlman, Y. Jung, T. A. Jones, J. Gao, M. C. Coniglio, H. E. Brooks, and K. A. Brewster, 2013: Progress and Challenges with Warn-On-Forecast. *Atmos. Res.,* **123,** 2-16.

Stumpf, G. J., T. M. Smith, K. Manross, and D. L. Andra, 2008: The Experimental Warning Program 2008 Spring Experiment at the NOAA Hazardous Weather Testbed. *Extended Abstracts, 24th Conf. on Severe Local Storms*, Savannah, GA, Amer. Meteor. Soc., CD-ROM, 8A.1.

____, and Coauthors, 2012: The Experimental Warning Program's 2011 and 2012 spring experiments at the NOAA Hazardous Weather Testbed. *26th Conf. on Severe Local Storms,* Nashville, TN, Amer. Meteor. Soc., 3.4.

Wicker, L. J., C. K. Potvin, T. E. Thompson, D. J. Stensrud, and P. L. Heinselman, 2014: Improved convective scale prediction from the assimilation of rapid-scan phased array radar. *22nd Conf. on Numerical Weather Prediction,* Atlanta, GA, Amer. Meteor. Soc., 7.7.

Wolf, P., G. J. Stumpf, E. E. Carpenter, C. Entremont, A. P. Enyedi, G. R. Garrett, M. L. Grantham, K. B.

Laws, and S. E. Nelson, 2013: A next-generation warning concept of threats-in-motion (TIM): An operational warning decision making collaborative exercise. *2nd Conf.e on Weather Warnings and Communication,* Nashville, TN, Amer. Meteor. Soc., 3.5.