3.1 Generating Probabilistic Severe Timing Information from SPC Outlooks using the HREF

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1. INTRODUCTION

Storm Prediction Center (SPC) forecasters have demonstrated skill over the past decade in generating probabilistic Convective Outlooks for the entire convective day (i.e., valid from 12 UTC to 12 UTC on the following day). Although adding timing information on the expected severe weather threat to the SPC Outlooks would be a desirable feature, generating this information is challenging without requiring a significant increase in workload for the forecaster or increasing the number of forecast staff.

The operational implementation of a convection-allowing model (CAM) ensemble in the NWS, the High-Resolution Ensemble Forecast (HREF) system, has enabled the development of a prototype system at SPC that uses explicit convective timing and evolution details from the HREF in conjunction with SPC Convective Outlooks to generate probabilistic severe timing information. The advantage of this type of system is that it combines the strengths of the human forecast (i.e., location and magnitude of the daily severe weather threat) with the strengths of a CAM ensemble (i.e., explicit hourly probabilistic information on the convective evolution) while maintaining overall consistency with the operational SPC Convective Outlooks.

This paper will focus on the inputs and algorithm used to generate the SPC Severe Timing Guidance and provide examples of the output and performance of this real-time prototype system.

2. SPC SEVERE TIMING GUIDANCE INPUTS

The ***SPC Severe Timing Guidance*** leverages the HREF to add hourly probabilistic information regarding the temporal evolution of the severe weather threat that is consistent with the SPC forecaster outlook. There are two primary inputs to generate the probabilistic severe timing guidance:

1. Operational or experimental event-driven SPC Day 1 Convective Outlook in continuous-probability form
2. Hourly 4-h calibrated probabilistic hazard guidance from the HREF/SREF (Jirak et al. 2014)

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An important aspect of this process involves generating a continuous probability representation of the traditional stair-step outlooks to provide additional probabilistic resolution (e.g., Fig. 1). SPC Day 1 Convective Outlooks are converted to continuous probability grids using the following steps:

- Close outlook lines to an expanded version of the CONUS bounds using a 1-degree buffer
- Top-hat fill the expanded outlooks on the NDFD grid
- Generate continuous probabilities on the NDFD grid using a method that leverages Euclidean Distance Transform to interpolate between standard probability contours while treating them independently (to preserve topology)

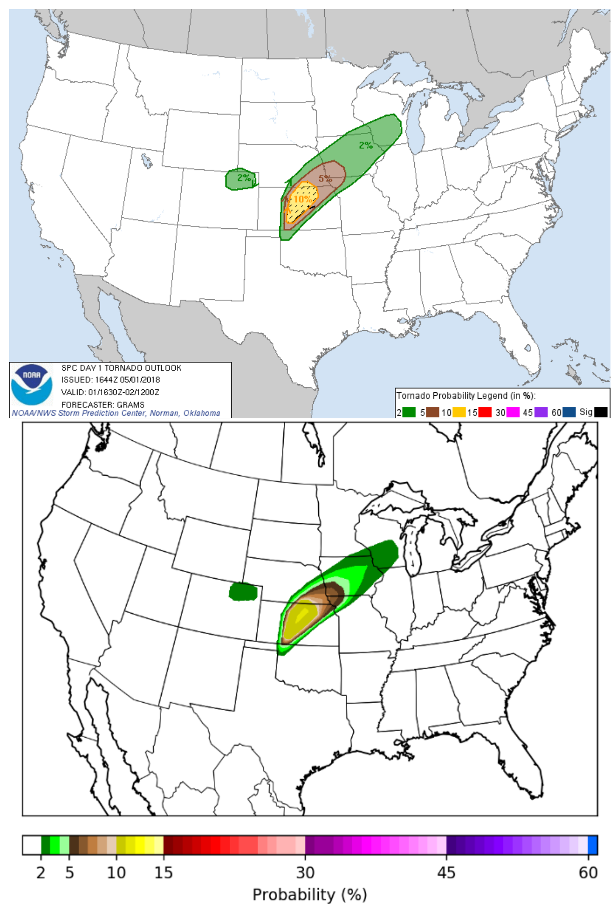

Figure 1. SPC 1630 UTC Day 1 Tornado Outlook for 1 May 2018 (top panel) with corresponding continuous probability representation (bottom panel).

With a continuous probability field from SPC Outlooks available as input to set the spatial and probabilistic bounds for severe weather on a convective day, the HREF is used to provide the timing information. The HREF is the operational CAM ensemble in the NWS, which was implemented based on favorable results from the SPC Storm-Scale Ensemble of Opportunity (Jirak et al. 2012) during several Hazardous Weather Testbed (HWT) Spring Forecasting Experiments (Jirak et al. 2016). The HREF (v2.1) consists of ten (10) members with half of the members being time-lagged runs. The models are run at ~3-km grid spacing, using a multi-model (WRF-ARW & NMMB), multi-initial condition (NAM & RAP), and multi-physics approach to diversify forecast solutions (Table 1).

Table 1. HREFv2.1 member configuration showing initial conditions (ICs)/lateral boundary conditions (LBCs), planetary boundary layer (PBL) schemes, and microphysics schemes. *SPC uses the 12-h time-lagged NAM Nest while NCO uses the 6-h time-lagged NAM Nest in HREFv2 products.

Member	**ICs/LBCs**	**PBL**	Micro
HRW NSSL	NAM/NAM	MYJ	WSM6
HRW NSSL -12h	NAM/NAM	MYJ	WSM6
HRW ARW	RAP/GFS	YSU	WSM6
HRW ARW -12h	RAP/GFS	YSU	WSM6
HRW NMMB	RAP/GFS	MYJ	F-A
HRW NMMB-12h	RAP/GFS	MYJ	F-A
NAM Nest	NAM/NAM	MYJ	F-A
NAM Nest -12h*	NAM/NAM	MYJ	F-A
HRRR	RAP/RAP	MYNN	Thompson
HRRR -6h	RAP/RAP	MYNN	Thompson

The convection-allowing aspect of the HREF inherently provides probabilistic information on thunderstorm timing, mode, coverage, and intensity. This explicit storm-attribute information from the HREF is combined with environmental information from the larger-member Short-Range Ensemble Forecast (SREF) system to produce calibrated hazard probabilities for tornadoes, large hail, and damaging winds (Jirak et al. 2014). Specifically, at every grid point for the valid forecast hour, two probabilities are paired:

1. Neighborhood maximum probability (Roberts et al. 2019) of UH ≥ 75 m2/s2 over the previous 4 hours from the HREF
2. Probability of environmental field(s) exceeding a threshold over the previous 4 h from the SREF (see Table 2)

The historical frequency of a hazard report occurring within 25 miles of that grid point and within the 4-h period for that forecast pair of probabilities is the resultant 4-h calibrated hazard probability.

Table 2. Probabilistic inputs from the HREF and SREF to the calibrated hazard guidance.

Hazard	**HREF**	**SREF**
Tornado	UH ≥75 m^2s^{-2}	STP ≥1
Hail	UH ≥75 m^2s^{-2}	MUCAPE ≥1000 & Eff. Shear ≥20 kts
Wind	UH ≥75 m^2s^{-2}	MUCAPE ≥250 & Eff. Shear ≥20 kts

This calibration approach attempts to mimic the process that a forecaster might use to assess the expected severe weather hazard: Given a storm of a certain mode/intensity in a given environment, what is the probability of a severe hazard? An example of this calibrated probabilistic guidance is provided in Fig. 2.

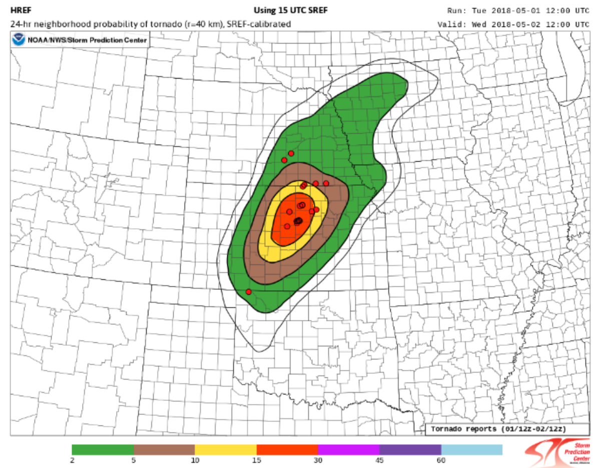

Figure 2. HREF/SREF 24-h calibrated tornado probability valid for the convective day of 1 May 2018. The preliminary tornado reports for that period are overlaid as red circles.

3. SPC SEVERE TIMING GUIDANCE ALGORITHM

The SPC Severe Timing Guidance is based on an algorithm that uses the HREF/SREF calibrated probabilistic guidance to temporally disaggregate the continuous-probability version of the SPC Day 1 Convective Outlook into hourly overlapping 4-h probabilities. There are three primary steps to this process to ensure consistency with the SPC Day 1 Convective Outlook:

1. The full-period calibrated HREF/SREF probabilistic hazard guidance is scaled to the SPC Day 1 Convective Outlook to ensure that the guidance is consistent with the SPC Day 1 Convective Outlook in terms of magnitude and location.
2. The full-period, grid-point-dependent scaling factor is applied to each 4-h calibrated hazard probability to more closely resemble the magnitude and spatial distribution of the SPC Day 1 Convective Outlook.
3. Finally, a series of smoothing and probabilistic checks are applied to the scaled 4-h probabilities to arrive at the final product of hourly overlapping 4-h spatial probabilities through the remainder of the convective day for each hazard.

As an example for 1 May 2018, the calibrated tornado guidance had a scaling factor >1 across much of Iowa into southern Wisconsin (Fig. 3), where the SPC Outlook probabilities were higher than the calibrated guidance. Across north-central Kansas, the scaling factor was <1, where the calibrated tornado probabilities were higher than the SPC Outlook probabilities (Fig. 3). Then, those location-dependent scaling factors were applied to the 4-

h calibrated guidance to bring them into alignment with the SPC Outlook probabilities. A final automated quality-control step was then applied to generate the SPC Severe Timing Guidance based on the SPC 1630 UTC Day 1 Outlook.

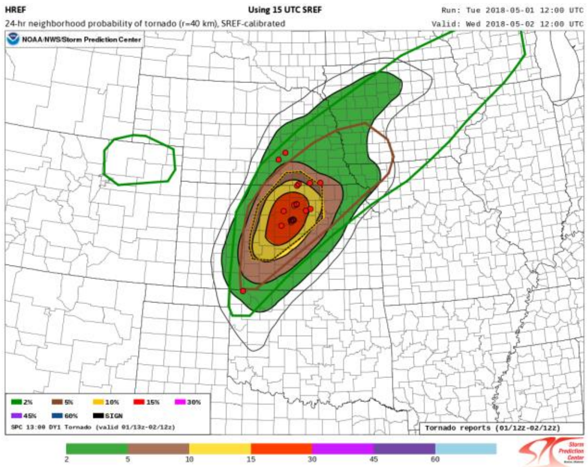

Figure 3. Same as Fig. 2, except for the addition of the SPC 1630 UTC Day 1 Tornado Outlook as a contour overlay (green – 2%; brown – 5%; yellow – 10%).

4. PERFORMANCE EXAMPLES

The SPC Severe Timing Guidance has been produced as a prototype demonstration in real-time since May 2019. In addition, an archive was generated to provide data back through 1 April 2018, so the SPC Severe Timing Guidance could be evaluated for many diverse severe weather events spanning multiple seasons. Overall, the SPC Severe Timing Guidance seems to perform well for many of the active severe weather days during the warm season. Not surprisingly, the timing guidance performs better with SPC Day 1 Outlooks that verify well and when the HREF has a good handle on convective timing and evolution. Some issues can occur when there is a large discrepancy between the calibrated guidance and SPC Day 1 Outlooks, which is more likely in high-shear, low CAPE severe weather environments.

An example of the type of output available from the SPC Timing Guidance is shown for the Moderate Risk across north-central Kansas on 1 May 2018 (Fig. 4). The time series showing the hourly 4-hour probabilities for tornado (red line), wind (blue line), and hail (green line) during the convective day reveals a peak in severe weather probabilities between 4 p.m. and 9 p.m. local time near Tescott in north-central Kansas. A tornadic supercell produced an EF-3 tornado near Tescott around 8 p.m., within the time of peak probabilities from the SPC Severe Timing Guidance. An animation of spatial probability maps (not shown) for this event reveals a southwest-to-northeast progression of higher probabilities from the afternoon through the evening hours, accurately capturing the temporal evolution of the severe weather event. Many other products (e.g., onset time of maximum probabilities; Fig. 5) can also be generated from the SPC Severe Timing Guidance.

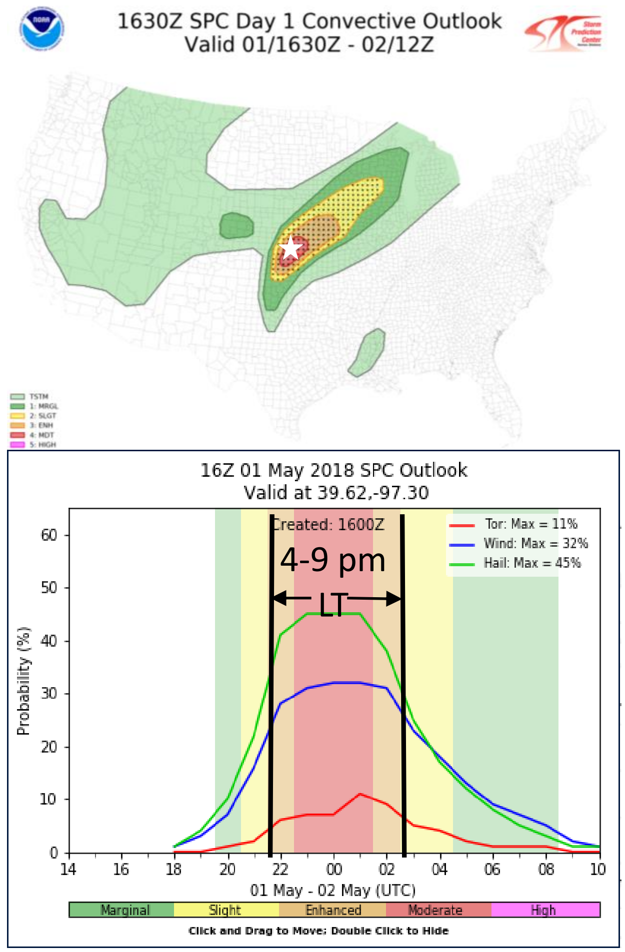

Figure 4. SPC 1630 UTC Day 1 Categorical Outlook for 1 May 2018 (top panel), with the white star indicating the location of the probability time series in the bottom panel. The 4-h tornado (red line), wind (blue line), and hail (green line) probabilities (bottom panel) shown every hour during the convective day of 1 May 2018 for Tescott, Kansas, derived from the SPC Severe Timing Guidance.

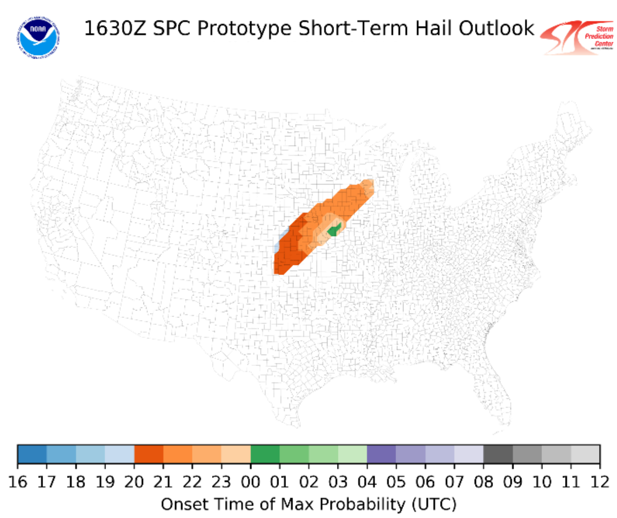

Figure 5. Onset time of maximum hail probabilities (in UTC) on 1 May 2018 derived from the SPC Severe Timing Guidance.

To demonstrate the performance characteristics of the SPC Severe Timing Guidance for an event with a complex convective evolution, a couple of examples are shown for the 19 July 2019 convective day (Fig. 6). On this day, multiple derechos evolved across the north-central CONUS. The first derecho moved across northern Wisconsin during the evening hours of 19 July 2019 with severe wind probabilities from the SPC Severe Timing Guidance peaking during the 0000-0400 UTC window (top panel of Fig. 6). Later on in the convective day toward the morning of 20 July 2019, another derecho was developing back to the west across South Dakota. The severe wind probabilities peak across central South Dakota in the SPC Severe Timing Guidance during the 0600-1000 UTC period (bottom panel of Fig. 6). Despite the complex nature of the convective evolution on this day, the SPC Severe Timing Guidance provides useful temporal information on the severe weather threat that is otherwise not available graphically from any SPC products.

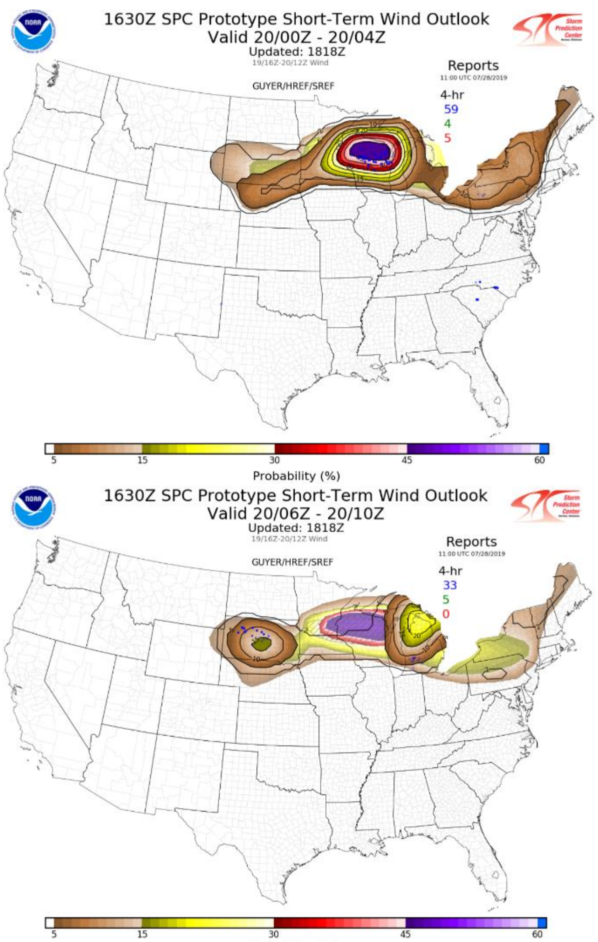

Figure 6. 4-h severe wind probabilities from the SPC Severe Timing Guidance at two different times during the convective day of 19 July 2019: 0000-0400 UTC (top panel) and 0600-1000 UTC (bottom panel). The preliminary wind reports for the respective 4-h periods are overlaid as blue circles. The SPC 1630 UTC Day 1 Wind Outlook is shown as an underlay in lighter shading beneath the 4-h probabilities.

5. SUMMARY AND CONCLUSIONS

Through evaluation in the HWT and SPC operations, the HREF has proven to be a very useful and skillful CAM ensemble for forecasting convective and severe weather. With the HREF now operational in the NWS, the convection-allowing resolution of the HREF can be leveraged to provide explicit temporal information on the convective evolution for most severe weather events. As a result, a prototype system, the SPC Severe Timing Guidance, has been developed to add temporal resolution to SPC Outlooks. The SPC Severe Timing Guidance combines the strengths of the human forecast (i.e., location and magnitude of the daily severe weather threat) with the strengths of the HREF (i.e., explicit hourly probabilistic information on the convective evolution) while maintaining overall consistency with the operational SPC Convective Outlooks. Early subjective evaluation of the SPC Severe Timing Guidance for numerous severe weather events across multiple seasons suggests that the guidance provides useful timing information on the severe weather threat for the majority of events.

Acknowledgements. The SPC Severe Timing Guidance has benefitted from evaluation by participants during several HWT Spring Forecasting Experiments and from the support and assistance of numerous individuals at SPC, NSSL, and the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS) at the University of Oklahoma.

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