17A.2 Conditional Intensity Estimation of Severe Hail and Wind using Environmental Parameters

Israel L. Jirak[1*], Jacob Vancil[1,2], Joey Picca[1,2], Russell S. Schneider[1], and Patrick T. Marsh[1]
[1]NOAA/NWS/NCEP/Storm Prediction Center, Norman, OK
[2]Cooperative Institute for Severe and High-Impact Weather Research and Operations, Norman, OK

1. INTRODUCTION

The majority of societal impacts from severe weather typically come from the most intense storms despite being rare events. The current operational intensity forecasts for hail and wind are issued as part of the NOAA/NWS/Storm Prediction Center (SPC) Convective Outlooks. These hail and wind intensity forecasts currently consist of one probabilistic contour representing the unconditional 10% probability of a significant hail report (i.e., 2+ inch diameter) and significant wind report (i.e., 65+ knot gusts) within 25 miles of a point, respectively. To allow for more flexibility and specificity in hail and wind intensity forecasts, SPC is proposing to move toward a conditional intensity framework.

This paper provides the motivation for moving toward a conditional intensity framework at SPC, methodology and initial results of using environmental parameters to estimate the conditional intensity of severe hail and wind, and a discussion of the operational implications at SPC.

2. MOTIVATION AND PROPOSED FRAMEWORK

SPC issues Hail and Wind Outlooks for Days 1 & 2 for the probability of severe hail/wind (1"+/50+ kts: 5/15/30/45/60%) and the probability of significant hail/wind (2"+/65+ kts: 10%) within 25 miles of a point. Both of these probabilities (i.e., severe and significant severe) are currently unconditional, which means that the 10% significant severe probability can only be drawn where the severe probabilities are ≥10%. This is a limiting factor on expressing low confidence/coverage, yet high intensity/impact events (e.g., strongly capped, but otherwise favorable environments). In addition, a single probabilistic threshold (i.e., 10%) for significant severe limits the ability to communicate higher impact events, like a derecho. A more flexible framework for forecasting high-impact events will enable better estimation and communication of societal impact from severe weather.

Given these factors, SPC is proposing to move toward a ***conditional intensity*** forecast framework that separates expected severe-hazard intensity from the underlying probability (i.e., likelihood and coverage) of severe weather. In this framework, the forecast hail size or wind gust magnitude is *conditional* on the occurrence of severe hail or wind. This framework allows more forecast flexibility in communicating all types of events: high coverage, low intensity; low coverage, high intensity, and high coverage, high intensity (e.g., Fig. 1).

* *Corresponding author address*: Dr. Israel L. Jirak, NOAA/NWS/NCEP/Storm Prediction Center, 120 David L. Boren Blvd., Norman, OK 73072; e-mail: Israel.Jirak@noaa.gov

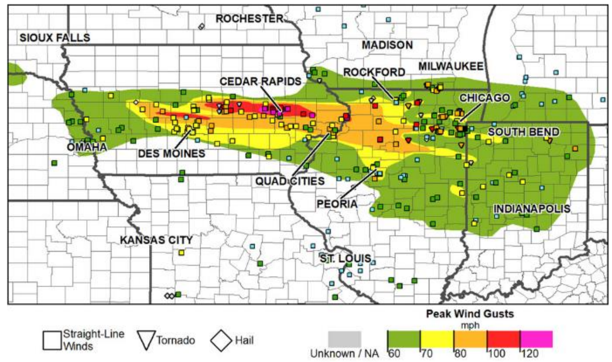

Figure 1. The 10 August 2020 derecho is an example of a high coverage, high intensity severe-wind event. Figure taken from Bell et al. (2022).

3. METHODOLOGY

During the initial stages of developing a conditional intensity forecast framework, environmental baselines are useful in determining reference intensity distributions and setting forecast targets. In this study, the SPC Environment Database (Dean and Schneider 2012) was used to extract environmental information for each severe hail and severe wind grid hour (i.e., maximum intensity report on a 40-km grid) from 2003-2020. This resulted in over 120,000 severe hail grid hours and over 260,000 severe wind grid hours with associated environmental information derived from the SPC RUC/RAP-based mesoanalysis (Bothwell et al. 2002).

Owing to reporting biases and issues, the reports are binned to minimize the secular influence and maximize the environmental signal. Convective wind reports reveal estimated reporting biases that are especially evident at 5 mph and knot increments (Edwards et al. 2018; Fig. 2). In an attempt to remove these artifacts, the wind reports are binned into five broader ranges in this study to better represent an expected distribution in nature (Fig.3).

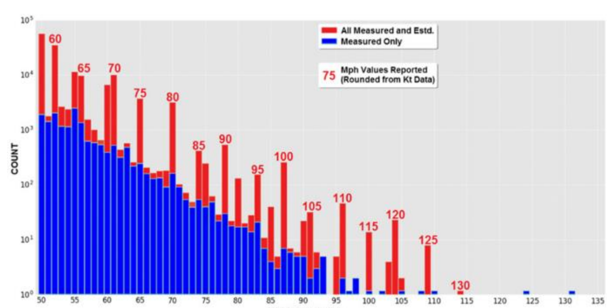

Figure 2. Histogram of convective wind-report distributions from Edwards et al. (2018). The estimated wind gust reports are in red and highlight the issue with estimated gusts in the database.

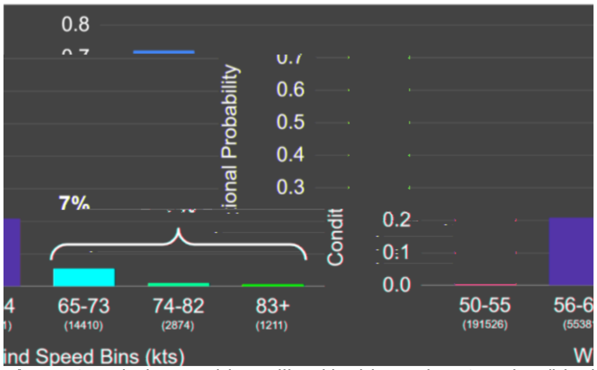

Figure 3. Wind report bins utilized in this study: 50-55 kts (blue), 56-64 kts (green), 65-73 kts (yellow), 74-82 kts (orange), and 83+ kts (red). The conditional probability of a severe report falling into each of these bins is provided on the y-axis, and the sample size per bin is denoted in parentheses. Note that only 7% of all severe wind grid hours from 2003-2020 were significant severe (i.e., 65+ kts).

Similar to severe wind reports, severe hail reports also have some reporting biases and issues. The distribution of severe hail report sizes (Fig. 4) reveals some clear reporting biases. Namely, the frequency of hail reporting spikes at common ball sizes, especially for golf balls (i.e., 1.75") and baseballs (i.e., 2.75").

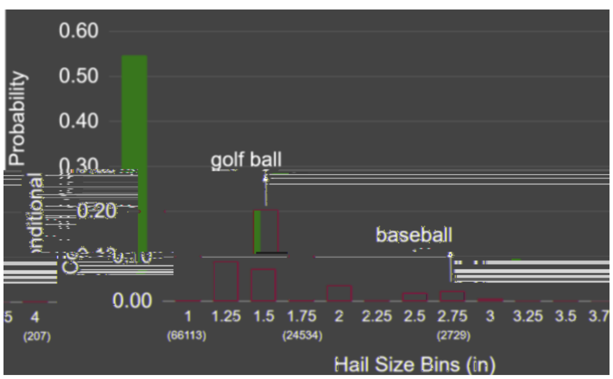

Figure 4. Distribution of hail report sizes (diameter in inches) from 2003-2020 provided as the conditional probability of a specific size given a severe hail report. The sample sizes of select hail diameters are provided below the bar graph in parentheses.

To minimize the effect of these hail reporting biases on the results, the hail sizes were binned into four size categories (Fig. 5), following Johnson and Sugden (2014). As a result, the hail-size distribution looks more physically reasonable with an exponential decrease in frequency when moving from smaller hailstones to larger hailstones (Fig. 5). Similar to the severe wind reports, which had less than 10% of grid hours at or above the significant severe threshold (65 kts), severe hail reports also had less than 10% of grid hours larger than 2".

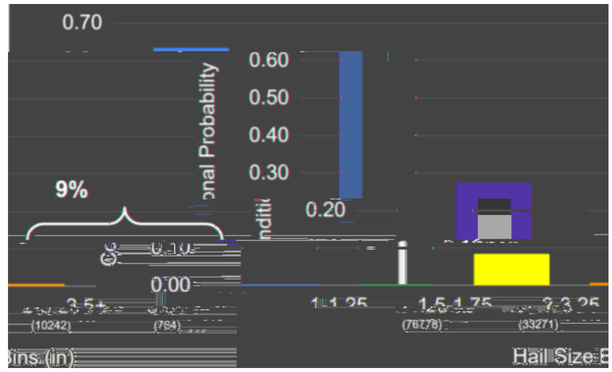

Figure 5. Hail report bins utilized in this study: 1-1.25" (blue), 1.5-1.75" (green), 2-3.25" (yellow), and 3.5"+ (orange). The conditional probability of a severe report falling into each of these bins is provided on the y-axis, and the sample size per bin is denoted in parentheses. Note that only 9% of all severe hail grid hours from 2003-2020 were significant severe (i.e., 2"+).

4. RESULTS

The goal of this initial exploration is to determine if there is a quantifiable relationship between the environment and hazard intensity (i.e., convective wind speed gust and hail size). If there is a relationship between environmental parameters and hazard intensity, can it be leveraged practically in a forecast system framework? This type of information is critical to establishing environmental baselines and potential forecast targets, which have been beneficial to SPC forecasters doing experimental conditional intensity forecasts. The results in the next two subsections provide some initial findings when exploring some basic and derived parameters commonly used in severe-weather forecasting. This is not an exhaustive analysis of all environmental parameters and parameter combinations. Rather, this is a preliminary investigation into the environmental relationships to hazard intensity.

4.1 Environmental Relationships to Wind Speed

Because significant-severe winds can occur in a variety of environments with different convective modes (Smith et al. 2012), a strong environmental signal was not expected when examining convective wind gusts. The first environmental parameter examined was 100-mb mixed-layer convective available potential energy (MLCAPE). As expected, there is not a very strong relationship between MLCAPE and the conditional probability of significant-severe wind (Fig. 6). The conditional probabilities for 65+ kt gusts only slightly increase for MLCAPE values over 2000 J/kg. Even so, the conditional probability of significant-severe gusts is only slightly higher than climatology for large values of MLCAPE (i.e., ~9% for values of MLCAPE ≥3000 J/kg compared to 7% in climatology).

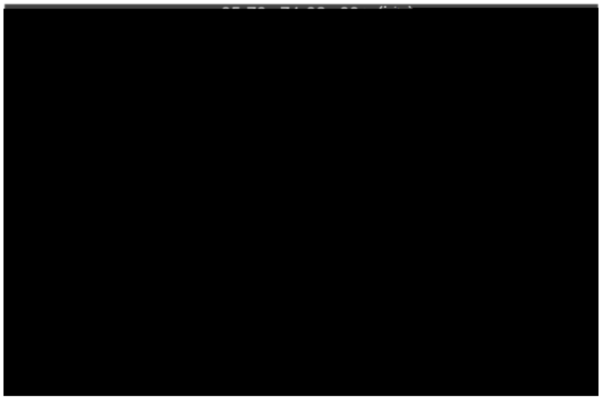

Figure 6. Conditional probability of the three significant-severe wind bins (64-73 kts in yellow; 74-82 kts in orange; 83+ kts in red) by MLCAPE (J/kg) value. Some sample sizes are indicated below select MLCAPE values in parentheses.

Downdraft CAPE (DCAPE) is occasionally considered in the forecast process to estimate severe-wind potential, so this parameter was also examined. Compared to MLCAPE, DCAPE appears to be a slightly better predictor of significant-severe winds (Fig. 7) though the signal is still relatively weak. At DCAPE values of 1500 J/kg, the conditional probability of significant-severe winds is ~12%.

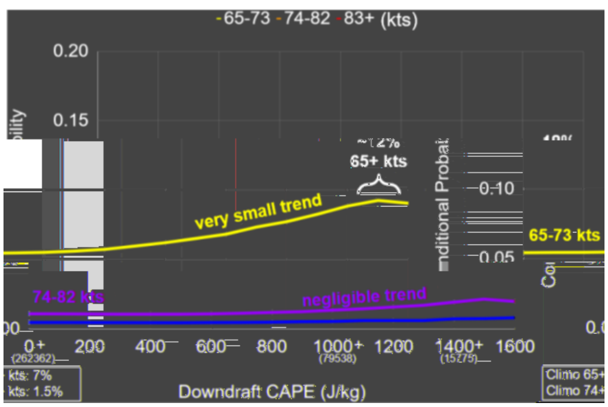

Figure 7. Same as Fig. 6, except for downdraft CAPE.

In addition to thermodynamic variables, some kinematic variables were also examined with regard to significant-severe wind potential. For example, 0-6 km shear is shown in Fig. 8. For this variable, there appears to be an optimal threshold around 45 knots where the conditional probability is maximized. Nevertheless, the relationship is relatively weak with a peak conditional probability of 10% for significant-severe winds. Overall, these were some of the best individual kinematic and thermodynamic variables examined in this initial exploration, and as expected, the relationship between the environment and convective wind-gust magnitude was relatively weak.

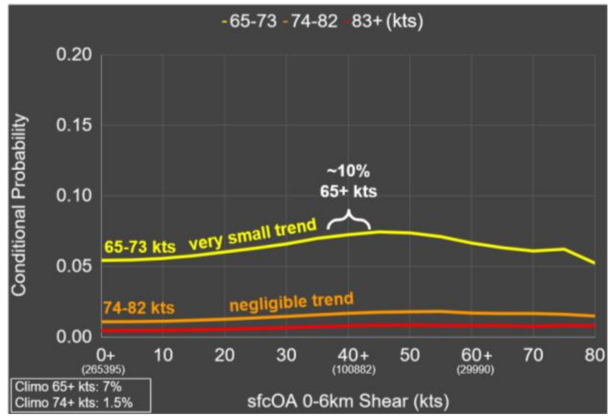

Figure 8. Same as Fig. 6, except for 0-6 km shear.

One might expect a better relationship when considering multiple variables, so some basic exploration was done in this regard. The best bivariate combination for significant-severe winds explored was DCAPE with 0-6 km shear. When DCAPE and 0-6 km shear are multiplied, the product results in an increasing conditional probability of significant-severe winds up to about 20%. In fact, this relationship is stronger than anticipated and nearly triples the climatology of significant-severe wind occurrence. Physically, this seems reasonable because as the 0-6 km shear increases, the environment becomes supportive of organized storm modes, and as the DCAPE increases, the thermodynamic environment will support strong evaporative cooling and downdrafts. More comprehensive and/or elaborate multivariate environmental parameters may show an even stronger relationship to convective wind-gust intensity.

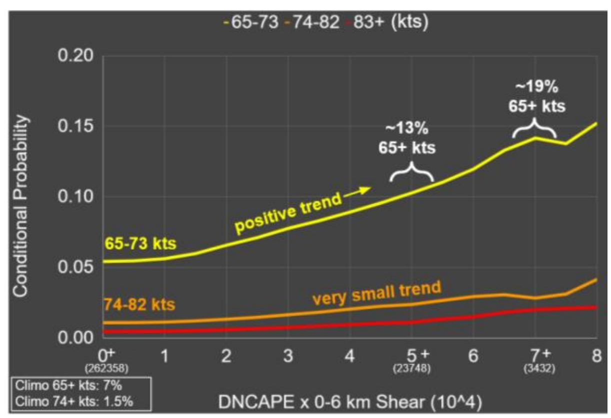

Figure 9. Same as Fig. 6, except for the product of DCAPE and 0-6 km shear.

4.2 Environmental Relationships to Hail Size

As was done with severe wind, several individual environmental variables were examined for their relationship to hail size. While there were modest relationships between hail size and some kinematic and thermodynamic variables, the best relationship was found with the multivariate parameter, significant hail parameter (SHiP). SHiP is a function of most-unstable

(MU) CAPE, mixing ratio of the MU parcel, 700-500 mb lapse rates, 500 mb temperature, and 0-6 km shear. The conditional probability of significant hail increases monotonically up to values of SHiP of 2. In fact, the climatological probability of significant hail nearly doubles for severe hail that falls in environments with a SHiP value of 2 or greater.

Figure 10. Conditional probability of the two significant-severe hail bins (2-3.25" in yellow; 3"+ in orange) by SHiP value. Sample sizes are indicated below the SHiP values in parentheses.

5. OPERATIONAL IMPLICATIONS AT SPC

Using these relationships between the environment and hazard intensity, some basic reference intensity distributions can be developed as forecast targets or baselines. For example, we can define conditional intensity groups (CIGs) that describe the conditional probabilities for each of the bins. For severe wind, the product of DCAPE and 0-6 km shear can be used to define a **CIG 0** conditional-intensity distribution for values below 5×10^4 and a **CIG 1** conditional-intensity distribution for values $\geq 5 \times 10^4$ (Fig. 11). Based on this work and operational experience, it appears that the environment alone can only describe a CIG 1 conditional-intensity distribution. A **CIG 2** conditional-intensity distribution (not shown) would shift conditional probabilities from the lower intensity bins to the stronger intensity bins and is strongly dependent on convective mode (i.e., severe MCS).

For severe hail, SHiP can be used to define a **CIG 0** conditional-intensity distribution for values below 2 and a **CIG 1** conditional-intensity distribution for values ≥2 (Fig. 12). The conditional probability of significant-severe hail (i.e., 2"+ diameter) doubles between these CIGs. As with wind, the environment can only provide enough information to define a CIG 1 conditional-intensity distribution for severe hail. A **CIG 2** conditional intensity distribution for severe hail (not shown) would require additional information about storm mode, where long-track discrete supercells would favor a shift in the hail-size distribution toward the larger bins (given a favorable environment).

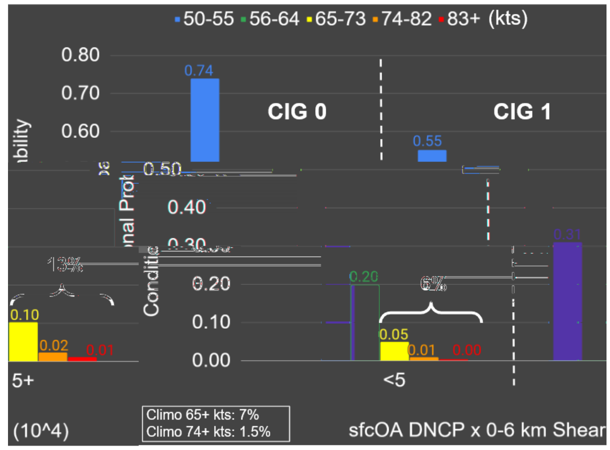

Figure 11. Conditional probability distributions for each of the severe wind bins based on DCAPE x 0-6 km shear for two CIGs: **CIG 0**, where the product of DCAPE and 0-6 km shear is $<5 \times 10^4$, and **CIG 1**, where the product of DCAPE and 0-6 km shear is $\geq 5 \times 10^4$.

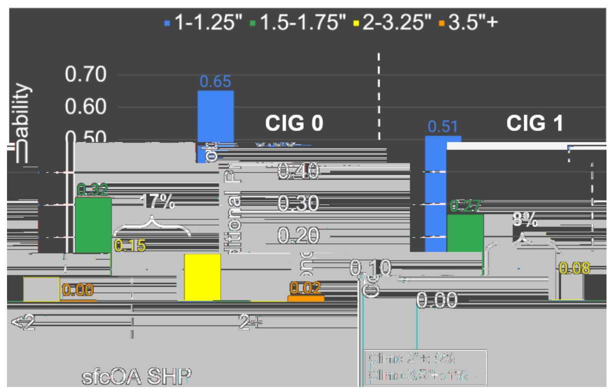

Figure 12. Conditional probability distributions for each of the severe hail bins based on SHiP for two CIGS: **CIG 0** for SHiP <2, and **CIG 1** for SHiP ≥2.

This study provides evidence that the environment has some ability in discriminating the conditional-intensity distribution of severe hail and wind reports. Previous work has shown an even better relationship between tornado intensity and the significant tornado parameter. All of this information supports the move by SPC toward a conditional-intensity framework to replace the existing unconditional significant severe 10% probability line. The conditional intensity framework offers more flexibility to forecasters in communicating different forecast scenarios (e.g., Fig. 13). Ultimately, improved severe-hazard intensity forecasting will lead to improved estimates of societal impacts through statistical modeling efforts, which are underway at SPC as quantitative Impact Decision Support Services (qIDSS).

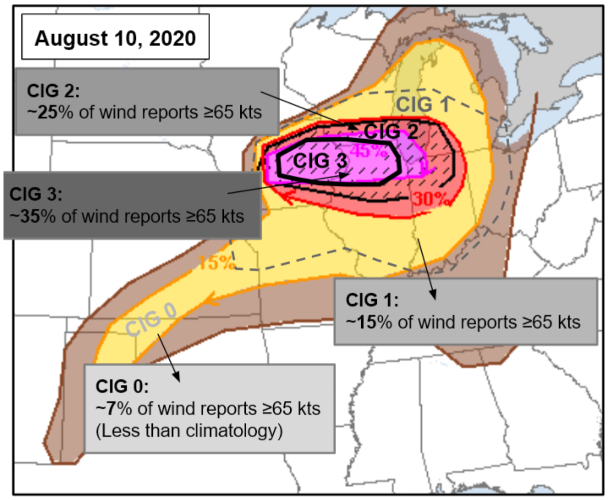

Figure 13. Prototype conditional-intensity hindcast for 10 August 2020 derecho. Underlying shaded probabilities indicate the likelihood/coverage of severe wind while the CIGs indicate the underlying intensity distribution of wind reports (e.g., Fig. 11).

REFERENCES

Bell J.R. and coauthors, 2022: Satellite-based characterization of convection and impacts from the catastrophic 10 August 2020 Midwest U.S. derecho. *Bull. Amer. Meteor. Soc.*, **100**, 1172–1196, https://doi.org/10.1175/BAMS-D-21-0023.1.

Bothwell, P. D., J. A. Hart, and R. L. Thompson, 2002: An integrated three dimensional objective analysis scheme in use at the Storm Prediction Center. *Preprints*, 21st Conf. on Severe Local Storms, San Antonio, TX, Amer. Meteor. Soc., J117–J120.

Dean, A.R. and R.S. Schneider, 2012: An examination of tornado environments, events, and impacts from 2003-2012. *Preprints*, 26th Conf. Severe Local Storms, Nashville, TN. Amer. Meteor. Soc., P60.

Edwards, R., J. T. Allen, and G. W. Carbin, 2018: Reliability and climatological impacts of convective wind estimations. *J. Appl. Meteor. Climatol.*, **57**, 1825–1845, https://doi.org/10.1175/JAMC-D-17-0306.1.

Johnson, A., and K. E. Sugden, 2014: Evaluation of sounding-derived thermodynamic and wind-related parameters associated with large hail events. *Electron. J. Severe Storms Meteor.,* **9** (5), https://ejssm.com/ojs/index.php/site/article/view/57.

Smith, B. T., R. L. Thompson, J. S. Grams, C. Broyles, and H. E. Brooks, 2012: Convective modes for significant severe thunderstorms in the contiguous United States. Part I: Storm classification and climatology. *Wea. Forecasting*, **27**, 1114–1135, https://doi.org/10.1175/WAF-D-11-00115.1.