12.1 PRELIMINARY EVALUATION OF A PARAMETER TO FORECAST ENVIRONMENTS CONDUCIVE TO NON-MESOCYCLONE TORNADOGENESIS

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1. INTRODUCTION

Tornadoes that occur prior to the formation of radar-detected mesocyclones present many problems to the operational forecast community. This type of tornadogenesis usually occurs within minutes of, or prior to, the first detection of radar reflectivity echo (Burgess and Donaldson 1979; Roberts and Wilson 1995). Often, radar signatures of the larger tornado cyclone are quite weak during tornado time, yielding little or negative lead time for National Weather Service (NWS) warnings issued to the public. Further, modeling research (Lee and Wilhelmson 1997) and historical events show these types of tornadoes tend to occur in families providing further operational challenges. Depending on local climatology, an environment conducive to non-mesocyclone tornadoes could account for 50% or more of the tornadoes observed in a particular year. Because of this difficult sampling issue and behavior, higher situational awareness of the miso- to mesoscale environment conducive to this non-mesocyclone tornadogenesis mode can provide positive impacts to warning services by increasing information flow to the public on the range of threats.

Research continues to increase on radar and environmental aspects of the non-mesocyclone tornadogenesis process which is mainly achieved through updraft stretching of ambient vertical vorticity. Modeling and observational studies suggest non-mesocyclone tornadogenesis typically occurs with convective updrafts in weak wind shear environments characterized by steep low-level lapse rates and strong low-level instability. Further, these updrafts generate along slow-moving or stationary surface boundaries possessing strong horizontal shears with misoscale vorticies (Wakimoto and Wilson 1989; Brady and Szoke 1989; Lee and Wilhelmson 1997, 2000; and Davies 2003).

Non-mesocyclone tornadogenesis environmental diagnosis attempts have been made by Davies (2003) by parameterizing higher low-level lapse rates and higher low-level convective instability (e.g., enhanced stretching potential (ESP)). Davies (2003) suggests higher values of ESP along slow-moving or stationary boundaries suggest more support for non-mesocyclone tornadoes. In an effort to further increase situational awareness in the operational forecast environment, a parameter was designed in spring 2005 to build on work by Davies (2003) and others described above. The parameter, titled the non-supercell tornado parameter (NST), was intended to downscale the work by Davies (2003) toward the lower mesoscale. The goal is to provide differentiation, on the county level, of updrafts, or areas of updrafts, more prone to non-mesocyclone tornadogenesis. This work will define the NST, provide case study examples of its use and limitations, and summarize its operational use overall to improve NWS mission services.

2. METHODOLOGY AND PARAMETER DEFINITION

The NST parameter, is defined by the following equation:

$$=\left(\frac{LR_{0-1}}{9}\right)\left(\frac{MLCAPE_3}{100}\right)\left(\frac{(225-MLCIN)}{200}\right)\left(\frac{18-Shear_6}{5}\right)\left(\frac{\zeta_r}{8}\right)$$

where LR_{0-1} is the 0-1 km temperature lapse rate in °C km^{-1}, $MLCAPE_3$ is the convective available potential energy for a 0-1 km mixed-layer parcel lifted to 3 km in J Kg^{-1}, MLCIN is the convective inhibition for a 0-1 km mixed-layer parcel (positive for increasing CIN; J Kg^{-1}), $Shear_6$ is the 0-6 km Bulk Shear (ms^{-1}) and ζ_r is the surface relative vorticity ($1e^{-5}s^{-1}$). The NST targets high low-level lapse rates (≥ 9°C km^{-1}), higher values of MLCAPE below 3 km ($\geq$ 100 J Kg^{-1}), and low convective inhibition ($\leq$ 25 J Kg^{-1}) which act to maximize ambient misovortex vorticity stretching. The NST also targets deep wind shear not supportive of supercell and higher-end multicellular organized convection ($Shear_6 \leq 13$ ms^{-1}, 26 kts). Finally, surface relative vorticity was included in the equation to constrict the parameter to illuminate more meaningful boundaries possessing rich vertical vorticity available for vortex stretching ($\geq$ $8e^{-5}s^{-1}$). The authors acknowledge that the vorticity used here is not that of misovortex scale shown in the research and radar observational data (Pietrycha et. al., 2006) but rather a surrogate indicative of environments that could possess misovortex existence. NST values of 1 or more indicate environments that have a higher risk of non-mesocyclone tornadogenesis. In theory, the threat would increase as the NST values grow above 1.

Operationally, and in research mode, the NST is calculated using data from the National Center for Environmental Prediction (NCEP) RUC model and the Earth System Research Lab's (ESRL, formerly Forecast Systems Lab) Local Analysis and Prediction System (LAPS) in AWIPS. The RUC's native horizontal grid resolution is currently 13 km - after a change on June 28 2005 that decreased the resolution from 20 km. However, the RUC is delivered to NWS field offices on AWIPS grid 236 which has a horizontal resolution of 40 km with forecasts out to 12 hours. Locally run at each NWS Forecast Office, LAPS provides an hourly, 3-D environmental analysis grid at 10 km horizontal

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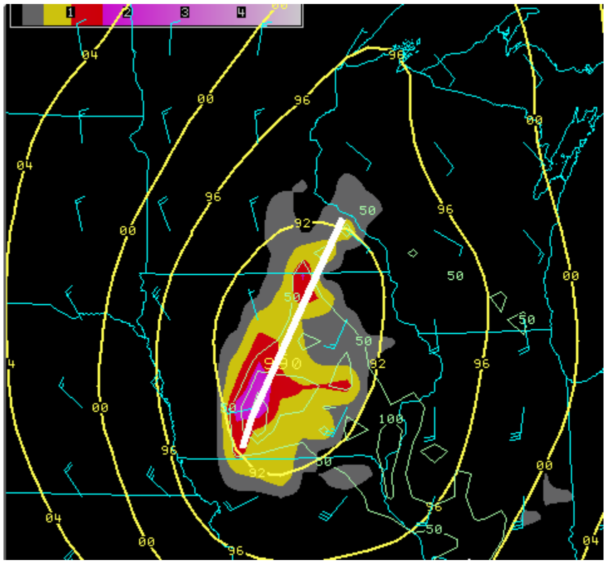

Figure 1. NCEP RUC 1500 UTC 30 March 2005 6-hour forecast of mean sea-level pressure (mb, solid yellow), NST (shaded, >1 red and pink), and ESP (beige, thin solid). White line indicates the frontal boundary in the text.

resolution at approximately 20 minutes past each hour. These two gridded data systems provide NWS forecasters with model analysis and forecast information in real-time.

The NST parameter was deployed to six NOAA/NWS Forecast Offices in 2005 and 2006 on an experimental basis. Events were gathered and archived to provide a growing database of non-mesocyclone tornadogenesis events. The authors carefully reviewed WSR-88D radar data to ensure mesocyclones were not present prior to funnel or tornado events within the dataset. Because a limited (but growing) number of non-mesocyclone tornado events with supporting AWIPS data have been gathered since early 2005 (10 environment days with over 40 funnels or tornadoes), examples and preliminary *qualitative* assessment of the NST parameter follows.

3. CASES

3.1 *30 March 2005: Iowa and Southern Minnesota*

During the day of 30 March 2005, an area of surface low pressure tracked north-northeast along a pre-existing frontal boundary extending from roughly Duluth, MN to Kansas City, MO. This system was responsible for 8 confirmed non-mesocyclone tornadoes in Iowa and southeast Minnesota. With limited cloud cover, heating and destabilization was forecast by the 1500 UTC 30 March 2005 NCEP RUC to combine with the nearly stationary front to produce 6-hour forecast NST values above 1 (Fig. 1). The NST parameter indicated a threat along the boundary as the low shifted northeast. By 1900 UTC, the surface low was located in central Iowa with a large area of southeasterly flow in the boundary layer meeting northwest flow on the front from north-central Iowa into southeast Minnesota. A pronounced clearing (Fig. 2) with steep 0-1 km lapse rates (9.5 °C km^{-1}, not shown) were found east of the boundary, and ahead of a west-east band of moderate intensity convective storms (45-55 dBZ, not shown), where MLCAPE values were near 1000 J Kg^{-1}. Although the MLCIN was <10 J Kg^{-1}, the 0-3 km MLCAPE was only positive along the boundary where values were greater than 125 J Kg^{-1}. By 1900 UTC, temperatures were 12-15°F colder west of the front with lower 70s to the east. The 0-6 km Bulk Shear in the southeast flow ahead of the convective line shifting northward was 10-15 ms^{-1}.

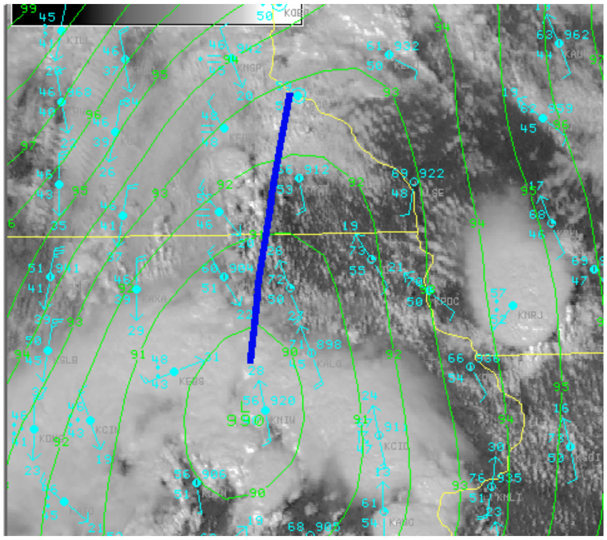

Figure 2. 1855 UTC 30 March 2005 GOES visible satellite image, 1900 UTC mean sea-level pressure (mb, solid yellow) and METAR observations. Blue line indicates the frontal boundary discussed in the text.

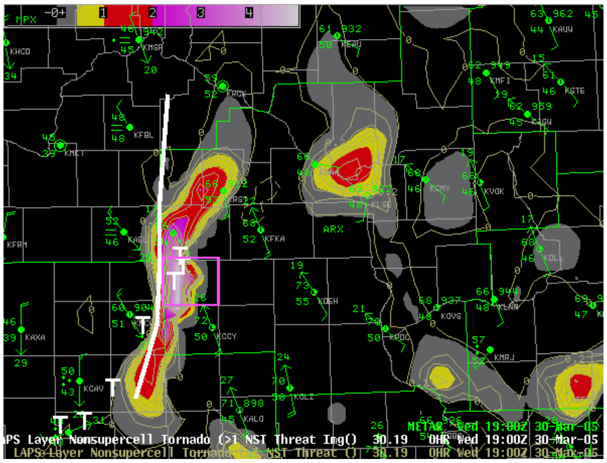

Figure 3. 1900 UTC 30 March 2005 METAR observations, LAPS NST (shaded, red 1-2, pink>2), "T" indicates a 30 March 2005 confirmed tornado and white line indicates the frontal boundary in the text.

The AWIPS LAPS depicted a narrow (< 50 km) NST threat band along the north-south oriented surface boundary at 1900 UTC (Fig. 3). Further, the LAPS NST indicated values over 4 on the boundary at 1900 UTC.

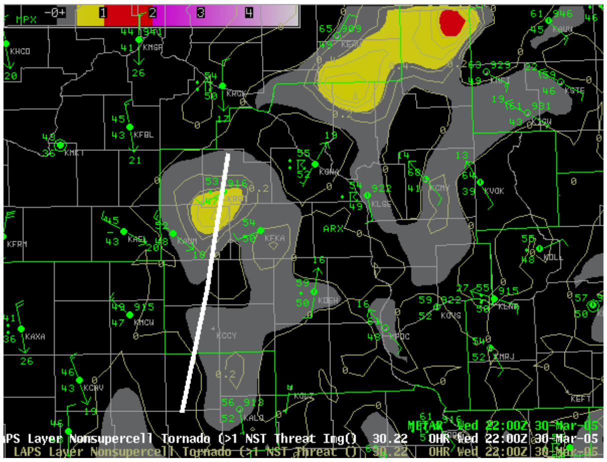

Figure 4. 2200 UTC 30 March 2005 METAR observations, LAPS NST (shaded, red 1-2, pink>2), white line indicates the frontal boundary in the text.

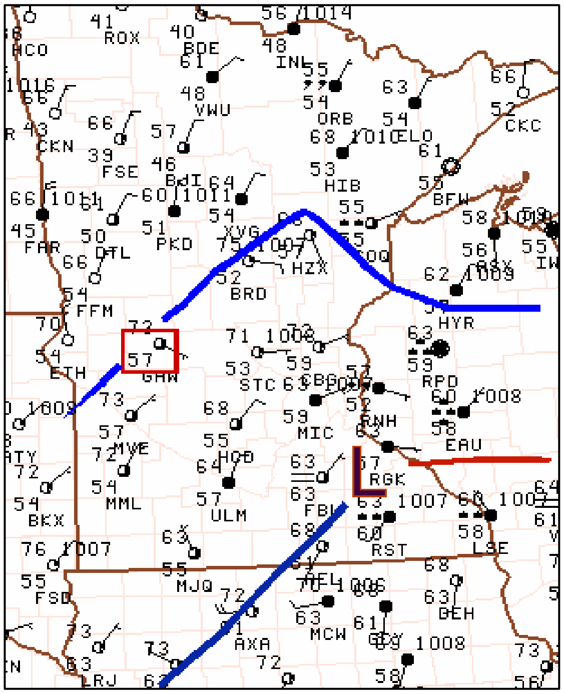

Figure 5. 2100 UTC 19 April 2005 METAR observations, frontal positions, and Pope County, Minnesota highlighted in red**.**

Three non-mesocyclone tornadoes occurred from 1825 to 1851 UTC in north-central Iowa along the boundary near the intersection of the west-east oriented line of storms. The NST also indicated a threat (NST>1) northeast along the western Wisconsin border however this turned out to be a false alarm area not associated with a boundary. From 1900-1945 UTC, brief tornadoes continued to be reported, shifting northeastward along the boundary. At 1952 UTC, the NWS La Crosse issued a tornado warning for Mitchell Co., which was located along the front in northern Iowa, that verified with 12 minutes of lead time. A warning was also issued for the county to the north (Mower Co., MN) that verified with a 3 minute lead time. As the west-east convective line continued to shift north, the LAPS NST values diminished in value with time. WFO La Crosse issued one additional tornado warning to the northeast (Olmstead Co., MN) along the non-mesocyclone tornadogenesis threat boundary at 2100 UTC. No tornadoes were confirmed for this warning although wind damage was sustained to a barn. The last confirmed tornado occurred at 2018 UTC. By 2200 UTC, NST values over the area where less than 1 (Fig. 4).

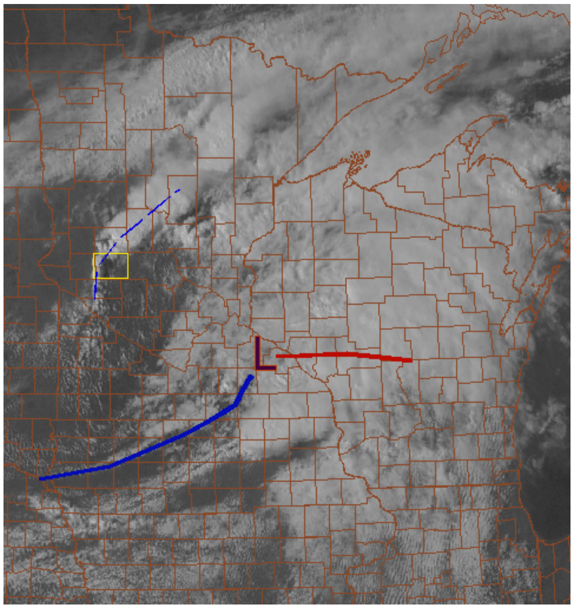

Figure 6. 2125 UTC 19 April 2005 GOES visible image with frontal positions, and Pope County, MN highlighted in yellow.

Very high environmental situation awareness, complemented by the LAPS NST parameter to understand upstream tornado occurrences in real-time, provided the integrated outcome of both positive warning lead time and NWS mission services. Having the NST parameter aligned along the boundary with a width of less than 50 km, reduced the tornado threat area to only a line of counties as the west-east convective line approached from the south.

3.2 *19 April 2005: Lake Emily, Minnesota*

On 19 April 2005, a non-mesocyclone tornado occurred in Pope County in central Minnesota (Fig. 5). This tornado occurred well to the northwest of a more "attractive" cyclone shifting through southeastern Minnesota, along a stationary frontal boundary associated with a low pressure system moving through southern Quebec. Dewpoints were in the lower 60s (°F) in the warm sector of the southern cyclone while in the middle 50s (°F) along the stalled front across central Minnesota at 2100 UTC 19 April 2005. A pronounced wind shift was visible along this boundary in central Minnesota providing a source of vertical vorticity. At

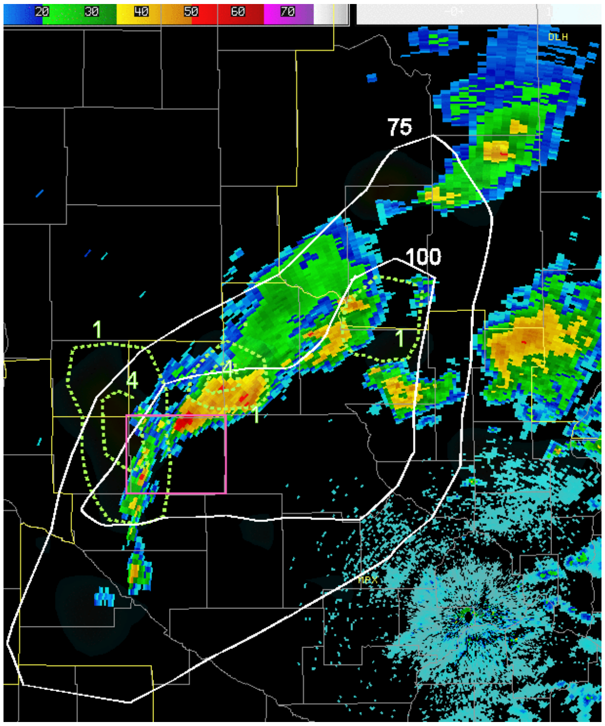

Figure 7. 2128 UTC 19 April 2005 0.5° reflectivity from the KMPX WSR-88D. Dotted contours indicate NST values, solid contours indicate ESP values from 2100 UTC LAPS. Pope County, MN highlighted in pink.

2100 UTC, LAPS analysis indicated 0-6 km Bulk Shear of 5-8 ms^{-1} and 0-3 km MLCAPE values around 75 J Kg^{-1} in western Pope County under minimal cloud cover (Fig. 6). Convection had begun to form on the convergent boundary across central Minnesota where LAPS indicated favorable ESP values (>75) and NST values over 1 along the boundary (Fig. 7). The LAPS 2100 UTC NST values over western Pope County were over 4 with another max of NST>4 located one county further northeast. The circular look to the NST at 2100 UTC is mainly due to the LAPS analysis of relative vorticity maxima at those locations. At 2128 UTC, WFO Minneapolis issued a Tornado Warning for Pope County valid through 2230 UTC because of the nearly stationary boundary and high NST and ESP diagnosed. No rotational signal was detected from the KMPX WSR-88D radar with any of the storms at that time. By 2200 UTC, LAPS had analyzed an NST threat area of 4-5 units in the western half of Pope County and at 2208 UTC law enforcement reported a tornado (F0) near Lake Emily within the NST max (Fig. 8). The NST max of 4 further northeast of Pope County was a false alarm.

Situational awareness was higher in the NWS Forecast Office in Minneapolis, MN (MPX) after some of the staff attended the NWS Northern Plains Convective Workshop a few weeks prior (personal communication) where the NST parameter was introduced. That presentation focused on historical non-mesocyclone research and application to the 16 June 2004 case in northeast Iowa (see section 3.3). The 1500 UTC 19 April 2005 NCEP RUC 6-hour forecast depicted an increased threat along the central Minnesota boundary at 2100 UTC with NST forecast values above 1 (including Pope County, Fig. 9). The 6-hour NST parameter forecast provided a more focused threat area than the broader ESP parameter. That guidance prompted the MPX forecast staff to update the Hazardous Weather Outlook (HWO) at 1528 UTC to include "*brief tornadoes possible (in) central Minnesota mainly between noon and 4 pm*" (1700-2100 UTC). Again updated at 2123 UTC, the HWO included "*a few brief tornadoes possible in Douglas, Morrison, Pope, Stearns, Stevens and Todd Counties until 630 PM*"

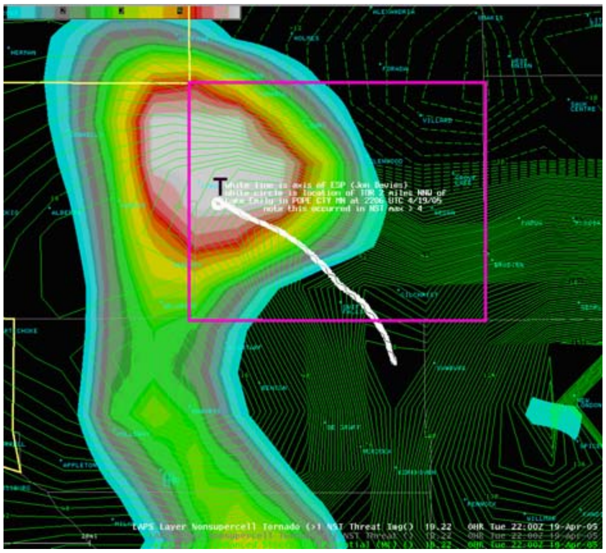

Figure 8. 2200 UTC 19 April 2005 LAPS NST image (red-pink > 4). "T" indicates the tornado report from 2208 UTC. Pope County, MN highlighted in pink.

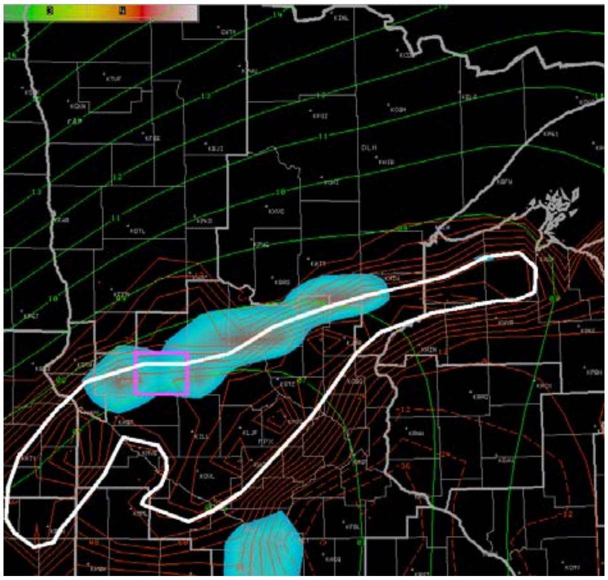

Figure 9. NCEP RUC 1500 UTC 19 April 2005 6-hour forecast valid at 2100 UTC of mean sea-level pressure (mb, solid yellow), NST (shaded, >1), and ESP (solid white =75). Pope County, MN highlighted in pink.

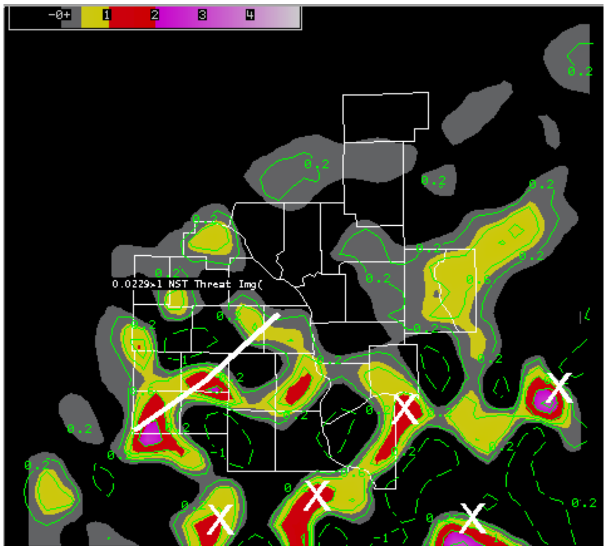

Figure 10. 1800 UTC 16 June 2004 LAPS NST image (red 1-2, magenta>2). Solid white line indicates the stationary boundary at 1800 UTC and "X" indicates NST maxima not associated with a linear boundary.

(2330 UTC). Two tornado warnings were issued: 1) Pope County (2128 UTC) with a 40 minute lead time (F0) and 2) Swift County (2228 UTC) was unverified and thus a false alarm (previous Pope Co. storm tracked southwest into Swift Co.).

3.3 *16 June 2004: Northeast Iowa*

While the previous cases were two of the more successful applications of the NST, this case provides one example of an NST parameter limitation: false alarms. This was the original case that initiated a re-training of the forecast staff at the NWS Forecast Office in La Crosse, WI on non-mesocyclone tornado modes. It also began the investigative era to improve situational awareness through environmental knowledge and diagnosis. On 16 June 2004, 6 tornadoes occurred in northeast Iowa and southeast Minnesota along a stationary boundary, which accounted for 75% of the climatological average. Many parameters came together by early afternoon to provide a heightened non-mesocyclone tornado threat (Table 1). The NST parameter indicated threats along the boundary in northeast Iowa at 1800 UTC, 30 minutes prior to the first tornado (Fig. 10). However, the NST also depicted other small areas of threat on the county scale with NST>1 east of the boundary. These were NST parameter false alarms and mainly associated with surface relative vorticity maxima generated from calm surface winds adjacent to (and west of) south winds at 5-10 kts. These relative vorticity centers were $4\text{-}7e^{-5}s^{-1}$ in magnitude versus the main maxima on the tornado-producing boundary that were 11 and $22e^{-5}s^{-1}$. In this case, forecaster training and environmental investigation would be needed to reduce the threat that NST false alarms posed for values over 1 away from the boundary.

0-6 km Bulk Shear	12-14 ms^{-1}
0-3 km ML CAPE	175-200 J Kg^{-1}
ML CAPE	1500-1800 J Kg^{-1}
ML CIN	0-20 J Kg^{-1}
0-1 km Lapse Rate	9.5 °C km^{-1}
LCL/LFC Height	1000m
Surface Relative Vorticity	7-12 ($e^{-5}s^{-1}$)

Table 1. 1800 UTC 16 June 2004 AWIPS LAPS parameters.

4. LIMITATIONS

4.1 *Numerical model limitations*

As of 2006, the main models used to diagnose and forecast the NST parameter in the NWS Forecast Office were the NCEP RUC and LAPS, with 40 km and 10 km horizontal resolution, respectively. The 40 km RUC grid does possess some value in differentiating NST threats into county-scale regions, however the ideal resolution would be the native 13 km grid. LAPS definitely provides enhanced NST environment differentiation but can also produce more false alarms (addressed in section 4.2). Because the magnitude of surface relative vorticity is dependent upon horizontal grid spacing, the differences of the vorticity between the RUC and LAPS may not necessarily be the result of differences in the wind field. Rather, it could be the result of differences in the grid spacing. The same wind field in the RUC and LAPS will result in surface relative vorticity values 4 times larger in LAPS. So, in general, LAPS tends to analyze larger NST values overall. Finally, the parameter is only a reflection of how well the model represents, or forecasts, the true atmospheric conditions. Correct boundary location and thermodynamic knowledge in the modeling system is key to a representative NST forecast. Operational use of the NST without considering the model's accuracy in representing the atmosphere correctly is ill-advised.

4.2 *False alarms*

With a more noticeable presence in the summer season (when more widespread 0-3 km CAPE is present) the NST does have a false alarm component. The false alarms appear mainly in maxima of surface relative vorticity located both along, and away from, the boundary presenting a threat for tornadogenesis. False alarms in LAPS are more prevalent owing to the resolution difference discussed in section 4.1. Those false alarm areas where the NST>1 away from the true threatening boundary do pose a limitation to the parameter's operational use. Some of these maxima are weak-moderate, isolated cyclonic shear areas not associated with boundaries and only weakly convergent with a lower probability of convective initiation. Part of this limitation can be mitigated through forecaster training on, and understanding and awareness of, the non-mesocyclone tornado process and environment. The authors feel this is the first step to improving NWS mission services in this area.

4.3 *Other limitations*

From preliminary findings, it appears the NST has higher success rates with boundaries that are somewhat more significant in their thermodynamics and wind fields and also larger in scale. This favors stationary or slow-moving synoptic frontal boundaries. These are typically better resolved by the models used to assess the environment in the NWS Forecast Office. NST parameter skill appears to decrease toward lower mesoscale boundaries such as outflow boundaries associated with single-cell or pulse-type convective storms. Mainly, these boundaries are not resolved well by 10 km horizontal resolution models and larger, and thus the NST parameter skill suffers. Most of the case assessment for the NST was accomplished in the Midwest. Sites using the NST in other geographical regions must have a good knowledge of its components and review their appropriateness. For example, application of the NST in the High Plains (e.g., western KS) may produce better results using a 0-3 km lapse rate (versus a 0-1 km measure) because of deeper boundary layers typical of that climatology.

5. SUMMARY AND OPERATIONAL USE

The non-mesocyclone tornadogenesis mode is still very difficult to forecast operationally. Even if the forecaster has confidence that the environment is likely to produce this form of tornadogenesis, he/she is still unsure of which updraft will form a tornado (without radar signals suggesting even higher confidence e.g., misovorticies). The NST parameter was created to enhance situational awareness on the lower mesoscale environment conducive to the non-mesocyclone tornadogenesis mode. Enhanced situational awareness provides a foundation for: 1) more general threat information to the public in a more timely manner (e.g., Hazardous Weather Outlooks) and 2) forecasters to act in a forecast mode, or at least react promptly (e.g., Tornado Warning), should further data increase tornado confidence (e.g., radar detection, incoming reports).

It is critical that foundational training on the NST mode, its preferred environment, and its radar sampling issues be provided to the forecaster as the first step. With this foundation, higher levels of situational awareness can be attained and the NST parameter applied correctly with its limitations well known to the user (e.g., false alarms).

The preliminary findings suggest the NST parameter has produced positive impacts on the warning program in the NWS when applied correctly. It is important that the NST not be used alone but rather compliment environmental diagnosis. The NST parameter seems to have potential to enhance forecaster confidence by narrowing the probability spectrum of possible threats and their areal extent.

6. FUTURE WORK

A more thorough quantitative assessment of the NST events gathered is planned for the future. NST parameter weighting, comparison of mixed-layer versus surface parcel use, the possible removal of the MLCIN term (redundant with the 0-3 km MLCAPE?), and inclusion of a surface moisture convergence term to decrease false alarms will also be explored.

The events also suggested the possibility that storm, or updraft, motion relative to the vertical vorticity supplying boundary may be more important to non-mesocyclone tornado formation than a slow-moving or stationary boundary. This relative motion may also have impacts on the longevity of the tornado once formed.

7. ACKNOWLEDGEMENTS

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