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AN ANALYSIS OF THE INCORPORATION OF LIGHTNING INTO THE NOWCASTING OF ENHANCED FROZEN PRECIPITATION

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1. INTRODUCTION

The primary purpose of this research is to investigate if and how lightning data can enhance the prediction of heavy snow and ice, over a short 6-hour and 500-km time and space scale. Lightning does occur in winter storms, even near the area of frozen precipitation; however, little research has been accomplished in the field of winter lightning, especially regarding how lightning relates to current meteorological conditions (Holle and Watson, 1996; Pfost and Burse, 1996). Lightning (at least cloud-to-ground (CG) lightning) should be examined alongside satellite imagery, radar fields and model output to determine its ability to predict enhanced frozen precipitation bands, especially with its connection to features of other data sources via various mechanisms. The 3 major linkages between lightning and other data include lift, instability and moisture (top contributors to heavy snow/ice).

2. OBJECTIVES

There are four major objectives of this paper, with a focus on storms over four major regions of the country, to include the Western Plains, Central and Northern Plains, the Deep South, and the Northeast. The first three objectives are an analysis of the intercomparison of lightning data to convective signatures on satellite imagery, in radar fields, and in model output parameters. The final objective involves the compilation of the results in such a way that forecasters in NWS, USAF or Navy offices can determine if/when CG lightning data can be used in conjunction with other data sources to accurately forecast enhanced frozen precipitation. The ultimate goal is to provide forecasters with techniques that can help in borderline winter weather events and nail down the exact time/location of large bands.

3. OVERVIEW OF DATA AND ANALYSIS

Data from satellite, radar, lighting, surface, upper air and forecast models were collected for 110 cases from 1987 to 1998. Heavy bands of ice and snow for each storm were identified with climatological reports from the National Climatic Data Center, from Storm Report bulletins, and newspaper articles. In 27% of the cases no lightning activity occurred within 500 km and 6 hours of enhanced snow/ice, and 9 cases had lightning but no enhanced snow/ice. This research did not examine intracloud lightning and winter precipitation, nor did it look at false alarms.

3.1 *Case Selection Procedure*

Two criteria were used to identify cases, one being the availability of lightning, radar, and satellite data, as well as model output; focus was on tools used on Advanced Weather Information Processing System. The other was that some amount of CG lightning had to be upstream of well-defined bands of snow/ice. Twenty-six of the 110 cases met the criteria above, and they were divided up into those occurring on the Western Plains (6), those on North/Central Plains (6), those in Southern Plains/Southeast (6), and those in NE U.S (8).

3.2 *Process Used to Analyze Data*

The initial step in analyzing the cases was an examination of model output, mainly Eta, within mesoscale range of potential bands. During this step one would carefully evaluate potential convection and enhanced snow/ice about 1200 km and 12 hours into the future. The second part consisted of a look at satellite imagery (GOES, mostly obtained at CIRA), radar data (obtained from National Climatic Data Center), and lightning data (obtained from NASA), on a regional, nowcasting scale. The last step involved a detailed, localized evaluation of the data used in Step 2. The analysis data and model output parameters were directly compared to the lightning data for each of the 26 cases, and statistics were drawn on a case by case basis and regional basis to help develop forecaster methodologies.

4. SAMPLE CASE ANALYSIS

Obviously, not all storms could be described in this paper. One Southeast U.S. storm was selected to portray the analysis of lightning data in the nowcasting of heavy snow/ice bands. This storm, the third major storm to hit the Atlantic Coast in 1995-96, occurred 1-3 Feb 1996, dropping more than 12” of snow from Tennessee to the Del Marva Peninsula.

4.1 *Synoptic Situation for Feb 1996 Event*

As a strong Arctic air mass continued its control over the Central Plains, an 850 mb low progressed

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along a zone of strong frontogenesis stretching from eastern Texas to central Virginia. Forecasters, not expecting heavy snow along the mid-Atlantic coast, had to use Eta model output and experience to determine the storm's future. Unfortunately, the model could not define the intensity of vertical motion and instability that would lead to heavy snow over the mid-Atlantic region. Forecasters had to use other tools to correctly forecast the bands of snow.

4.2 *Correlation of Lightning to Other Data*

The Eta model 6 and 12-hour forecasts depicted a fairly strong low-level conveyor belt that extended from the Gulf to southern Virginia. Visible, as well as enhanced IR satellite imagery, were used to track this conveyor belt as it interacted with the area of strong frontogenesis. The NEXRAD data depicted strong cells with DBz returns of > 35 moving up the conveyor belt. The lightning data depicted two occurrences of cells moving along the conveyor belt, within 500 km and 6 hours of the heavy snow in Virginia. This data, at half intervals and in 10-km grids, showed packets of lightning progressing northeastward and then fading out in North Carolina. The snow in Virginia, downstream of the lightning activity in North Carolina, would intensify over the next 3-4 hours.

4.3 *Final Analysis of Feb 1996 Event*

Overall, the model handled this case fairly well; its only problem was that it insinuated that the system would be much weaker than it actually turned out to be. In the lower levels it had predicted a strong zone of frontogenesis with a strong conveyor belt (defined by a 45-50 kt jet and a $\theta_E > 321$K tongue) that extended from the Gulf of Mexico to southern Virginia. In the upper levels, the entrance of a jet streak pattern should have provided moderate divergence along the mid-Atlantic coast. On the contrary the Eta model predicted vertical velocities were too weak to explain the heavy snow band from Tennessee to Delaware (-5 to –6 μbar^{-1} at best). Moisture convergence (70 to 80 $\text{gkg}^{-1}\text{hr}^{-1}$) and Q-vector convergence (8 to 10 s^{-1}) were fairly strong upstream of the snow but not far north enough (and widespread) to explain the heavy snow in the Piedmont region (moisture convergence fel 150 km upstream of the lightning). Lightning activity was unusually frequent for this case and there were two occurrences where packets of lightning moved off the main area of convection (in southern Georgia and Alabama) and proceeded northeastward into the mid-Atlantic region (could see with progression of NEXRAD cells of >35 dBz. Satellite imagery also depicted this activity; the overall gradation of cloud top temperatures on IR imagery enabled forecasters to pick out/detect storm movement and intensification.

5. RESULTS AND FORECAST METHODOLOGY

To develop recommendations for how forecasters can best use lightning data in the nowcasting of enhanced frozen precipitation, the results of the regional analyses contained in the research had to be organized so that the comparison of certain important features could be ascertained. Typical ranges were determined for those specific parameters that were compared to ongoing lightning activity.

5.1 *Quantitative Comparison of Regions*

A sample of the data analysis is in Table 1. Specific model features are discussed (850 mb jet, 700 mb vertical velocities, etc.), as well as satellite imagery (changes in texture on visible imagery, concentration of cold IR cloud tops, etc.), radar reflectivity patterns (peak returns, etc.), and lightning rates (given in ranges of number per hour per region). The left-hand column of the table represents the region of the country studied (i.e., Western Plains, Northern and Central Plains, etc.). Numbers represent average ranges ascertained in the analyses by region while other identifiers represent the most common feature found (e.g., UL for upper left of upper level jet maximum in association with enhanced frozen precipitation and lightning activity).

For the model products the regions differ somewhat in the lower levels. At the lower levels, the Western Plains (700 mb level for this area, 850 mb for the others) consistently had lower vertical velocities (-2.0 to –4.5 μbars^{-1} versus –6.0 to –11.0 μbars^{-1}) and weaker jets (10-20 kt vs. 50-60 kt) than the other regions did. The strongest vertical velocities occurred in the Northeast (-10.0 to –17.0 μbars^{-1}) while the higher lightning rates existed in the Southern Plains and Southeast (upwards of 90-120 flashes per hour (0.036 to 0.048 (bin)). The greatest variability as to the poleward extent of lightning up to the 850 mb θ_E tongue occurred in the Southern Plains and Southeast. The extent and character of lightning within the 850 mb tongue gives a forecaster an idea as to how the model is picking up the strength of moisture flow, a basic determinant of how far north heavy snow or ice will fall. The strongest 850 mb gradient occurred in the Southern Plains and Southeast (0.55 to 0.70 K/km) with the lowest in the Northeast (0.30 to 0.55 K/km); isentropic lifting and frontogenesis play a big role in convective snow over the Deep South. In the upper levels, lightning and enhanced snow and ice often occurred in areas of weak or non-existent 500 mb positive vorticity advection and within the main thermal ridge where temperatures are accommodating to both large amounts of supercooled water and ice crystal growth. Lightning and heavy snow tended to occur more within the upper portion of strong 300 mb jet streaks in the Western Plains, the lower right portion of jet streaks in the South and in the lower portion of jet streaks in the Northeast; no consistency existed in the remaining region. Development of lightning in areas where the model had predicted downward motion would signal a large adjustment needed to the way the model was handling the storm.

Conditional symmetric instability (CSI) tended to occur higher up in the atmosphere as one progressed eastward. The most important finding here was that lightning activity nearest the frozen precipitation would rarely extend beyond the poleward extent of CSI bands. Moisture convergence in the lower levels was much stronger in the east than in the west (by as much as –50 $gkg^{-1}hr^{-1}$ over Northeast and Southern U.S.), and Q-vector convergence played a dominant role in the Western Plains, as well as in the Northern and Central Plains.

As for the radar-lightning relationship, lightning activity occurred on the reflectivity gradient, upstream of the heaviest snow and ice (reflectivity values were 3-5 dBZ higher in areas of lightning near enhanced snow/ice than in regions of the enhanced snow/ice themselves). The comparison between satellite imagery and lightning data revealed a few interesting features. In general the lightning activity took place under cloud tops that were 4-6 ^{o}C warmer in temperature than the clouds under which heavy snow and ice fell. In three of the regions the texture on the visible satellite imagery could be used in conjunction with lightning activity to determine areas of heavy snow or ice. The relationship of 3.9 mm reflectivities to lightning activity and heavy snow/ice could not be ascertained.

5.2 *Forecast Methodologies*

Forecast methodologies were developed based on experiences with the 26 cases used in this work. They first address the model's handling of the systems, then a first look at observations (satellite, radar, lightning and surface observations), an examination of the progression of convection into winter storms (with a cross comparison between the observations and model output), and, finally, a local (within 3 hours and 250 km) glance at oncoming convection and enhanced snow/ice.

The overall process brings a forecaster from the initial look at model output to the final "short-term" forecast based on his/her examination and comparison of model output and observations available (as shown in Figure 2). In the first step the forecaster examines model output to determine potential for enhanced snow and ice; figure xx shows the primary and secondary model tools used for this study and how they did for the four regions of the country. In the second step the forecaster would look at observational tools within 500 km and 6 hours of a potential enhanced frozen precipitation band; these observations would be compared with each other on a static basis. If there are no lightning flashes within nowcasting range of the heavy snow or ice, the forecaster would utilize strong mesoscale features to nail down locations of bands. In the second to last step the forecaster would examine the developing band regions via all three sets of observational data, comparing them with analyzed model output. The final piece of the puzzle involves the forecaster arriving at his/her predicted location of the bands.

6. CONCLUSION

The specific intent of this research was to investigate the potential of incorporating lightning data into the nowcasting of enhanced frozen precipitation in winter storms. "Incorporation" entailed the cross-analysis between lightning data and data/output from other platforms just as a forecaster would via a modern weather interactive processing system (e.g., AWIPS) as a storm approached their area of responsibility.

6.1 *Major Conclusions*

Overall, using lightning to nowcast enhanced frozen precipitation helps in an increasing fashion as one proceeds from the East Coast to the Rocky Mountains. It is over the Western Plains where lightning activity provides the most benefit for nowcasting in winter storms, predominantly because vertical velocities forecast by models there are too low to explain convective conditions. The most interesting finding was that in 11 of the 26 cases lightning activity represented packets (i.e., small areas of maxima) of moisture and enhanced stability that would break off the main area of convection within the warm sector of the storm or in the deformation zone and progress into the snow or ice sector; within hours and 400 km downstream, frozen precipitation rates would increase due to these packets of enhanced moisture, lift, and instability. Lightning activity, especially over the Plains and the Southeast, occurred mainly (20 out of the 26 cases) along the main axis of the conveyor belt just upstream of the heavy snow or ice sector of the storm. There were seven cases, however, where lightning activity occurred along the strong low-level θ_E gradient, adjacent to the path of heavy snow or ice; in some of these cases the conveyor belt was either weak or non-existent. This suggested a link between isentropic lift on the equatorward edge of the cold air dome and lightning activity. There were several instances where the CG lightning activity would extend into the model-predicted cold sector of the storm, suggesting that the Eta model was underestimating the strength of the moisture feed into the storm, and the northern extent of the low-level θ_E gradient and frontogenesis. In analyses of satellite-derived cloud top temperature fields versus lightning activity it was found that lightning activity occurred on the upstream side of the coldest clouds in areas where a large gradient of cloud top temperature existed. With regard to the analysis of radar data versus lightning activity, lightning tended to occur in areas where the radar depicted weak reflectivity returns and surface observations depicted moderate to heavy frozen precipitation. In ten of the storms, mostly in the Western and Central Plains, lightning activity occurred 1-2 hours before the radars would depict reflectivities indicating upstream convection. In seven of the storms the lightning activity helped to identify areas of the storm system within or near the cold sector where bright bands would likely exist. Finally, twenty-three of the twenty-six cases studied had substantial lightning upstream of enhanced snow or ice (within the nowcasting timeframe); the other three had minimal activity upstream of the enhanced snow or ice. Fifteen cases had lightning bands that were parallel in orientation to the frozen precipitation bands; the other eleven lightning bands were almost perpendicular (and upstream of) to the frozen precipitation bands.

6.2 *Potential Future Efforts*

There are five tentative efforts that could evolve from this research. They include an analysis of sea-surface temperature patterns and lightning activity for east coast storms. A second endeavor could involve an extensive analysis of CG lightning climatology for winter months. A third could be the detailed analysis of multi-parameter radar data versus CG lightning activity to ascertain the physical reasons for convective, heavy snow/ice. The fourth possible effort would be a more extensive effort to further populate and refine the table depicting the ability of data to help forecasters in winter storm situations. Finally, the results of this work need to be assimilated into forecast methodologies, and forecasters will need to compare lightning to snow/ice and offer up any suggestions for other model output or observational that could be used.

REFERENCES

Holle R.L. and A.I. Watson, 1996: Lightning during two central U.S. winter precipitation events. *Weather and Forecasting*, **11(4)**, 599-614.

Pfost, R.L. and O.G. Burse, 1996: Disastrous Mississippi ice storm of 1994. *Nat. Wea. Dig.*, **20**, 15-33.

ACKNOWLEDGMENTS

This research was conducted at Colorado State University while Maj Roohr was a student under the civilian institution program of AF Institute of Technology. The DoD Center for Geosciences provided computer and data resources to make the research possible.

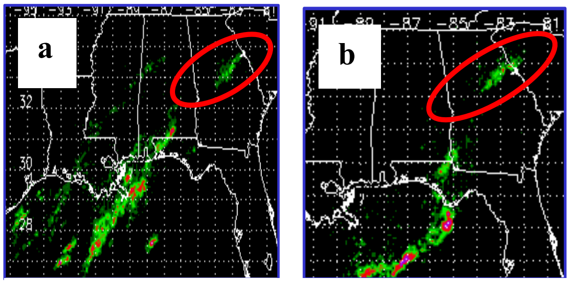

Figure 1: Lightning activity (10-km grid) on 2 Feb 96, (a) 13-14 GMT, and (b) 18-19 GMT

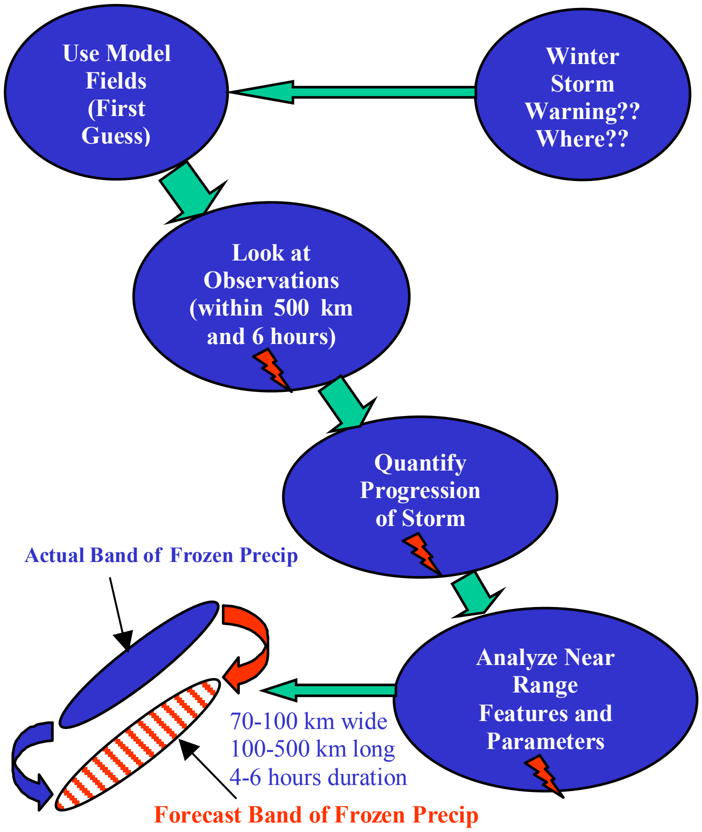

Figure 2: Overall process (enhanced frozen prcepitation forecasting)

TABLE 1 (Sample of Data Analysis)

	850mb Vert Vel μbar/s	*850mb Jet kt/dir*	*850mb θ_E ext. K*	*850mb θ_E grad K/km*	*850mb Frtgen C/km*
West* Plains	-1.5 -3.0	10-20 North	300 314	0.040 0.070	0.020 0.040
N-C Plains	-5.0 -8.0	50 S	300 312	0.035 0.065	0.020 0.036
S Plns South	-4.0 -6.0	50 SW	304 320	0.055 0.070	0.022 0.030
North East	-7.5 -14.0	60 SW	297 310	0.030 0.055	0.020 0.030
	300mb JetStrk Max	*Diverg $10^{-5}s^{-1}$*	*Stblty Total Totals*	*Stblty Lifted Index*	*Stblty K-Index*
West* Plains	UL 80	+1.0 +3.0	49.0 53.0	-2.0 0.0	25.0 31.0
N-C Plains	None	+0.5 +3.0	40.0 44.0	+2.0 +7.0	18.0 23.0