Central Region Technical Attachment
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Basic Blizzard Ingredients Unmasked and a Review of the 5 April 2009 Non-Blizzard through the Eyes of the Short-Range Ensemble Forecast

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1.0 Introduction

Blizzards are the most extreme and dangerous winter weather event that affects the people of Iowa and surrounding states. Emergency agencies must have credible advance notice to plan for and maximize their resources when it comes to preparing for a blizzard. A climatological study by Schwartz and Schmidlin (2002) indicates that Iowa has a probability between 25 percent (southeast) to 76 percent (northwest) of experiencing a blizzard in any given year. Before the blizzard of 8-9 December 2009, the winter storm of 5 April 2009 was the sixth case in the preceding 3 years in which Blizzard Warnings were posted for parts of central Iowa. Of those six events, only three of them realized true blizzard conditions according to the National Weather Service definition (combination of sustained wind or frequent gusts equal to or greater than 35 mph and visibility reduced to less than one quarter mile in snow and/or blowing snow lasting at least 3 hours). The purpose of this research is to study basic elements of all six of these storms, plus ones that occurred in January 2005 and December 2009, to see if any baseline set of meteorological thresholds can be established to help guide the forecaster when it comes to deciding whether or not to issue a Blizzard Warning. In addition, an analysis of output from the Short-Range Ensemble Forecast (SREF) for the 5 April 2009 winter storm leading up to the time of the forecaster decision to issue a Blizzard Warning is shared, in hopes of showing how data from this model are useful to the decision process.

2.0 Method

The eight cases reviewed are listed in Table 1 along with whether or not Blizzard Warning criteria were met. This study was completed before the 9 December 2009 blizzard, but data from this event have been included and used to validate the results of the initial research. A full suite of data was loaded onto the local office Weather Event Simulator, and the author studied the Global Forecast System (GFS), North American Model, and SREF model forecasts for the time the forecaster on duty would have been making his/her warning decision. The observational data including radar, surface observations, and Rapid Update Cycle (RUC) model initializations were used to compare the reliability of the various model forecasts, and to see if the forecaster may have been led astray. National Climatic Data Center *Storm Data* publications were reviewed for determining the character, intensity and impact of each event. A review of previous research on the subject of blizzards was conducted from the NWS Central Region Technical Attachments, American Meteorological Society Bulletins and National Weather Association publications. Surprisingly, the author did not find any similar studies on this subject that looked at key elements forecasters could use to make warning decisions. Published research by Salmon and Smith (1980) touched on a couple key parameters such as surface low pressure magnitude and change of surface low pressure magnitude specific to an extreme case in January 1978. It is believed that other studies or papers on this topic are not formally published.

Event Date	Blizzard Warning Criteria Met
22 January 2005	Yes
1-2 March 2007	Yes
29 January 2008	Yes
20-21 December 2008	Partially
17 February 2008	No
12 January 2009	No
5 April 2009	No
9 December 2009	Yes

Table 1. The eight events studied for this research and their corresponding verification.

Table 2 shows the model forecast data the author analyzed at 6-hour intervals through the duration of the blizzard warnings issued by the National Weather Service office in Des Moines, Iowa.

Surface	**850 mb**	**500 mb**
Low pressure magnitude	Low height magnitude	Low height magnitude or character of the wave
6-hr low pressure magnitude change	6-hr height magnitude change	6-hr height magnitude change
Absolute difference between the minimum and maximum 6-hr surface pressure rise and fall couplet in the vicinity of the low pressure system	Maximum wind over central Iowa	Trough tilt over the Upper Midwest (Positive or Negative)
Maximum surface pressure gradient across the state of Iowa during event	Maximum temperature change over central Iowa during event	

Table 2. Model forecast data studied at 6-hour intervals.

3.0 Analysis

Only three of the cases (1-2 Mar 2007, 29 Jan 2008, and 9 Dec 2009) were blizzards involving falling snow, and of those, the 1-2 Mar 2007 and 9 Dec 2009 cases were the only ones with heavy falling snow. The 20-21 Dec 2008 event was a ground blizzard and the 22 Jan 2005 event was mostly a ground blizzard. The other three cases were events that came close to blizzard, but lacked either the wind or duration criterion. While there were some similarities in the observed data for all eight events, there were some striking similarities between the events that verified as blizzard. Conversely, there were some definitive differences between those that verified and those that did not.

Beginning at the surface, the blizzards involving falling snow were associated with low pressure centers that were sub-990 mb, deepening to less than 985 mb and had a minimum 6-hour intensification of 5 mb. The maximum pressure gradient across Iowa (a distance of 500-550 kilometers or 310-340 miles) was at least 20 mb at some point during each blizzard (Figure 1). At 850 mb, the low height center was deepening and preferably less than 1300 meters, the maximum winds were at least 45 knots, and cold advection occurred at the rate of at least 10 degrees Celsius per 12 hours. At 500 mb, the low height centers were deepening as one would expect, but blizzard conditions also occurred with an open wave. Regardless, the upper-level trough being or becoming negatively tilted appeared to be a good signature for aiding the intensity of any system for which this was the case. It was noted though that the 22 January 2005 blizzard event occurred with a positive-tilt 500-mb trough.

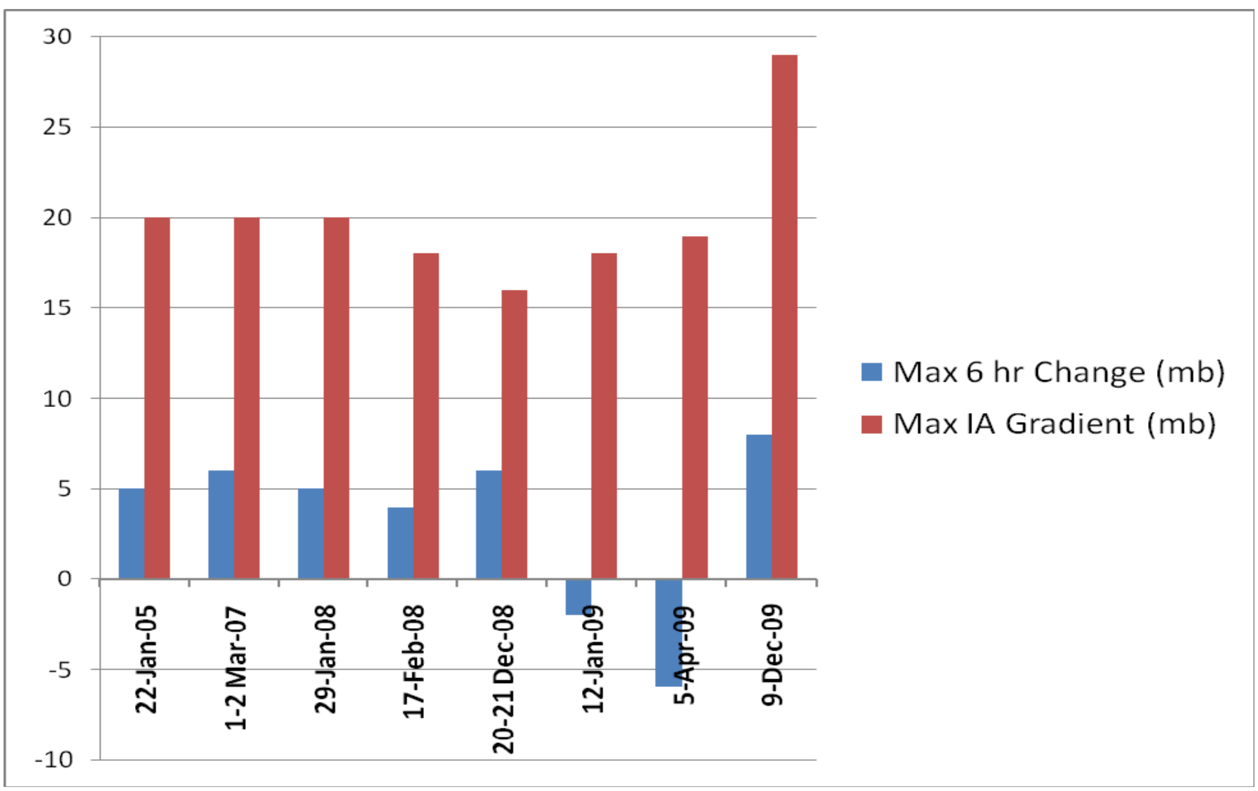


Figure 1. Bar graph of maximum 6-hour surface pressure change and maximum pressure gradient across the state of Iowa. Positive 6-hr change indicates strengthening (deepening) low pressure.

The cases which *did not* verify blizzard conditions involved surface low pressure centers that were either weakening with time or not deepening quickly enough. Some of these cases still contained pressure gradients close to 20 mb across Iowa. For example, the 5 Apr 2009 event had a maximum pressure gradient of 19 mb across Iowa, but the surface low underwent considerable weakening over the first 12 hours of the blizzard warning valid time before intensifying slightly over the last 12 hours (Figure 2). Therefore, it is clear that the only reasonably dependable thresholds found at the surface in this study are the intensity and deepening nature of the cyclone (to less than 985 mb with 6-hour changes of at least 5 mb) coupled with a maximum pressure gradient across Iowa of 20 mb, as with the 1-2 Mar 2007, 29 Jan 2008, and 9 Dec 2009 events (Figure 3). One has to wonder if the magnitude of the wind is driven in part by the absolute intensity of the low pressure system and some acceleration component of the air converging into the center of a deepening/strengthening low pressure system.

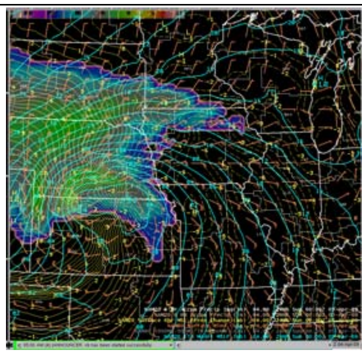
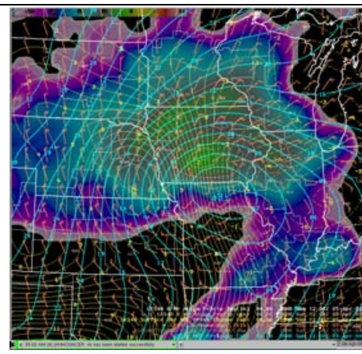
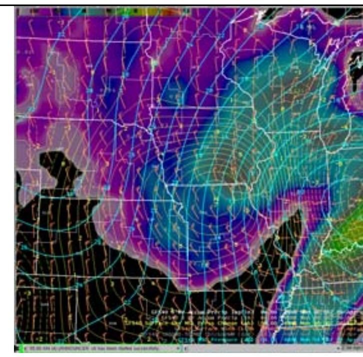
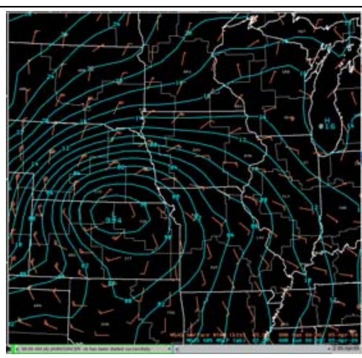
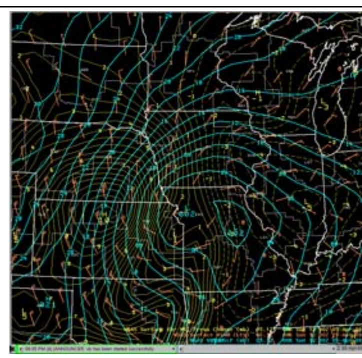
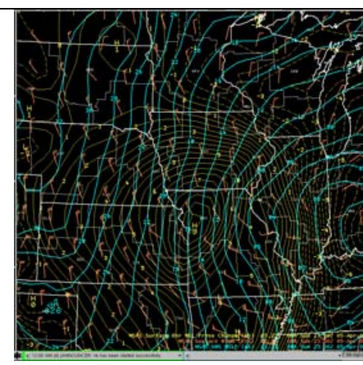
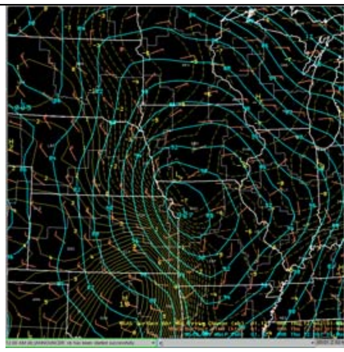
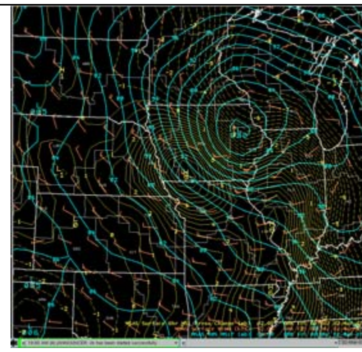
 GFS 24-hour forecast valid 0000 UTC 5 April 2009	 GFS 36-hour forecast valid 1200 UTC 5 April 2009	 GFS 48-hour forecast valid 0000 UTC 6 April 2009
 MSAS valid 0000 UTC 5 April 2009	 MSAS valid 1200 UTC 5 April 2009	 MSAS valid 2300 UTC 5 April 2009

Figure 2. (Top) 0000 UTC 4 April 2009 GFS model mean sea level pressure (cyan; contour interval 2 mb), surface wind (orange; standard notation in kts), 6-hour mean sea level pressure change (yellow; contour interval 1 mb), and 6-hour QPF forecast (image) valid at 24-hour, 36-hour and 48-hour time steps. (Bottom) Mesoscale Analysis and Prediction System Surface Assimilation System (MSAS) analyzed mean sea level pressure (cyan; contour interval 2 mb), surface wind (orange; standard notation in kts), and 6-hour mean sea level pressure change (yellow; contour interval 1 mb). Click on images to enlarge.



MSAS
valid 1200 UTC 1 March 2007



MSAS
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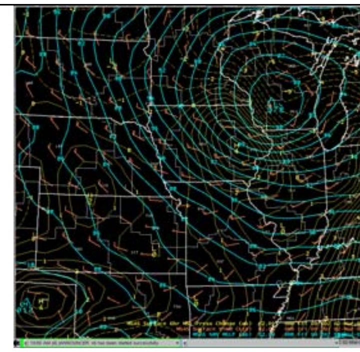

MSAS
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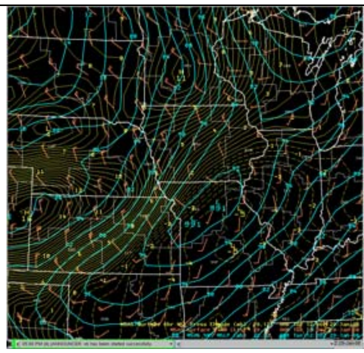
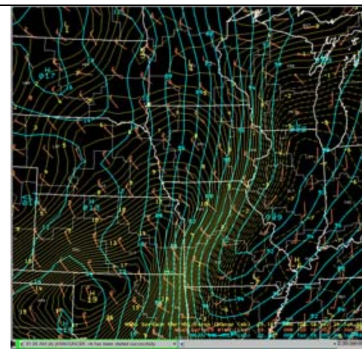


MSAS
valid 1200 UTC 29 January 2008



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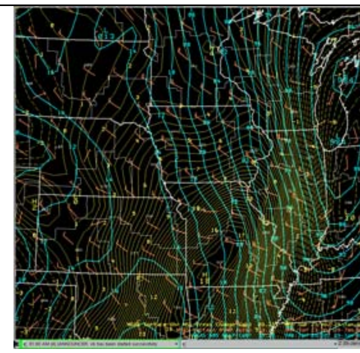

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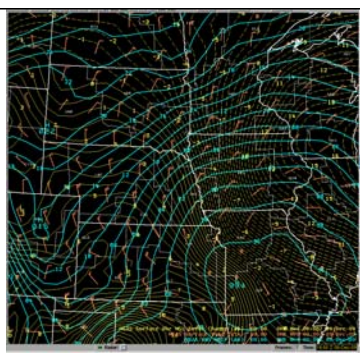
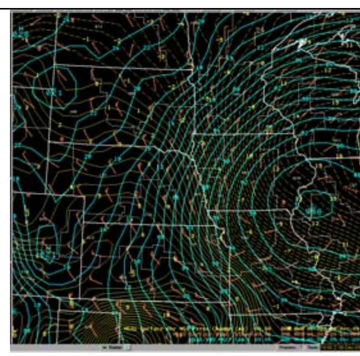
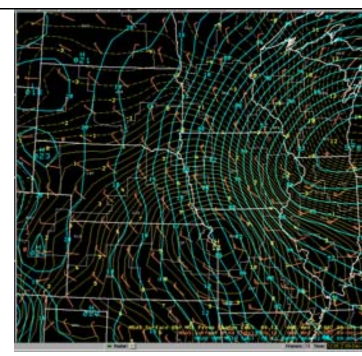


MSAS
valid 0000 UTC 9 December 2009



MSAS
valid 0600 UTC 9 December 2009



MSAS
valid 1200 UTC 9 December 2009

Figure 3. MSAS plots of mean sea level pressure (cyan; contour interval 2 mb), surface wind (orange; standard notation in kts) and 6-hour mean sea level pressure change (yellow; contour interval 1 mb) for the 1-2 March 2007 (top), 29 January 2008 (middle), and 9 December 2009 (bottom) blizzard events. Note the difference in intensity of the surface lows between Figure 2 and Figure 3, despite having similar surface pressure gradients over Iowa. Click on images to enlarge.

Thresholds found at 850 mb and 500 mb were not as clearly defined. However, it appears that a deepening 850-mb cyclone with a maximum height of 1300 m and a 6-hour rate of intensification of at least 40 m is required, along with winds of at least 45 kts and cold advection at the rate of 10 degrees Celsius in 12 hours (Figure 4).

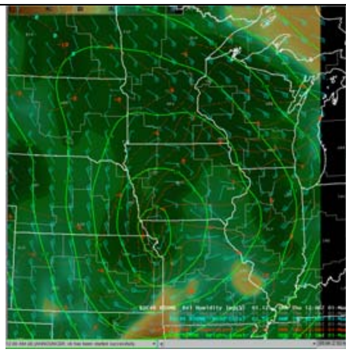
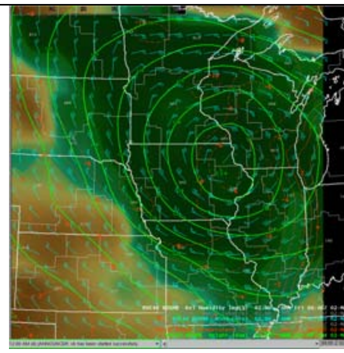
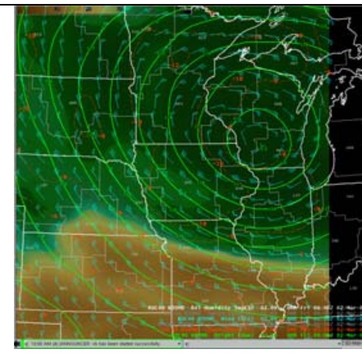
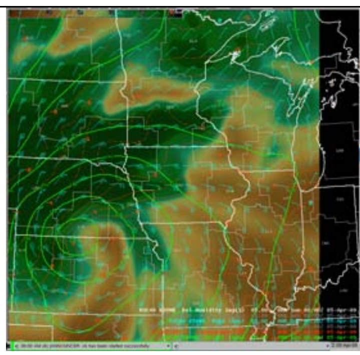
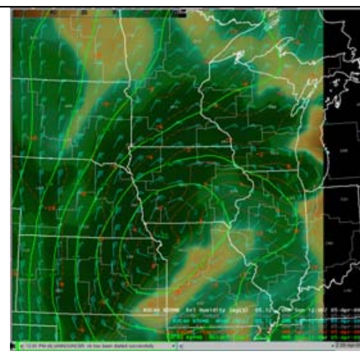
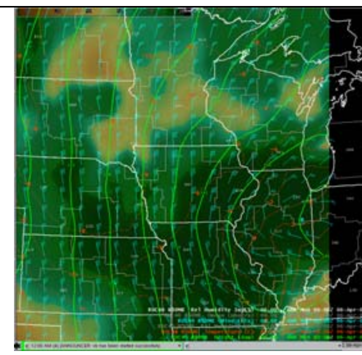
 RUC Initialization valid 1200 UTC 1 March 2007	 RUC Initialization valid 0000 UTC 2 March 2007	 RUC Initialization valid 0900 UTC 2 March 2008
 RUC Initialization valid 0000 UTC 5 April 2009	 RUC Initialization valid 1200 UTC 5 April 2009	 RUC Initialization valid 0000 UTC 6 April 2009

Figure 4. Contrasting RUC 850-mb initializations at generally 12-hour time steps during the blizzard of 1-2 March 2007 (top) and the non-blizzard of 5 April 2009 (bottom) events. Geopotential heights are in green (contour interval 30 m), wind in cyan (standard notation in kts), temperature in red (contour interval 2 degrees Celsius), and relative humidity as image (dark green greater than 90 percent relative humidity). Click on images to enlarge.

Similarly, at 500 mb a rapidly deepening negatively tilted cyclone is a good indicator (1-2 Mar 2007), but blizzard conditions occurred with open waves and waves characterized by a positive tilt (22 Jan 2005, 29 Jan 2008).

There are certainly other variables that have an impact on the creation of blizzard conditions. Some of those include mixed layer wind (for gust potential), character of the falling snow or antecedent snow cover, and depth of snow already on the ground. While these were not studied comprehensively for this work, maximum mixed layer winds were studied for the 9 December 2009 blizzard. During this storm, maximum mixed layer winds were 45 to 50 knots. Peak surface wind speeds measured by area Automated Surface Observation Stations (ASOS) equipment during the blizzard were within the range expected given such mixed layer wind speeds (Table 3). Further study of past and future events' mixed layer winds should be conducted, but the author hypothesizes that one would need at least 35 knots of wind in the mixed layer to result in peak surface winds of at least 35 mph.

Table 3. 9 December 2009 Peak Wind Gusts in Central Iowa
Measured by ASOS equipment

Site	Peak Wind Speed (mph)
KEST – Estherville	61
KMCW – Mason City	52
KALO – Waterloo	49
KMIW – Marshalltown	51
KAMW – Ames	54
KDSM – Des Moines	53
KLWD – Lamoni	48
KOTM – Ottumwa	49

An operational tool that was developed from the results of this study was a "blizzard checklist" (Appendix A). The checklist was provided to the DMX operational staff prior to the onset of severe winter weather in December 2009. Forecasters found the checklist useful in helping them determine the validity of issuing Blizzard Warnings for the 9 December 2009 blizzard event and subsequent events during the busy winter weather period extending into early 2010.

4.0 5 April 2009 SREF Analysis

There were some interesting and useful forecasting parameters found on SREF charts produced by the Storm Prediction Center leading up to the 5 April 2009 early spring winter storm. This study shows that at the time of deciding whether or not to issue a Blizzard Warning for central Iowa, there were plenty of factors that did not support blizzard conditions. While the information from each chart considered by itself does not necessarily reveal whether or not blizzard conditions are likely, collectively, the information can be used to help support or not support the issuance of blizzard warnings. The particular times of each chart shown in this study were when specific parameters were maximized over the blizzard warning area.

10-Meter Maximum Wind: 25 to 30 knots. This was not quite at blizzard level (35 mph) (Figure 5).

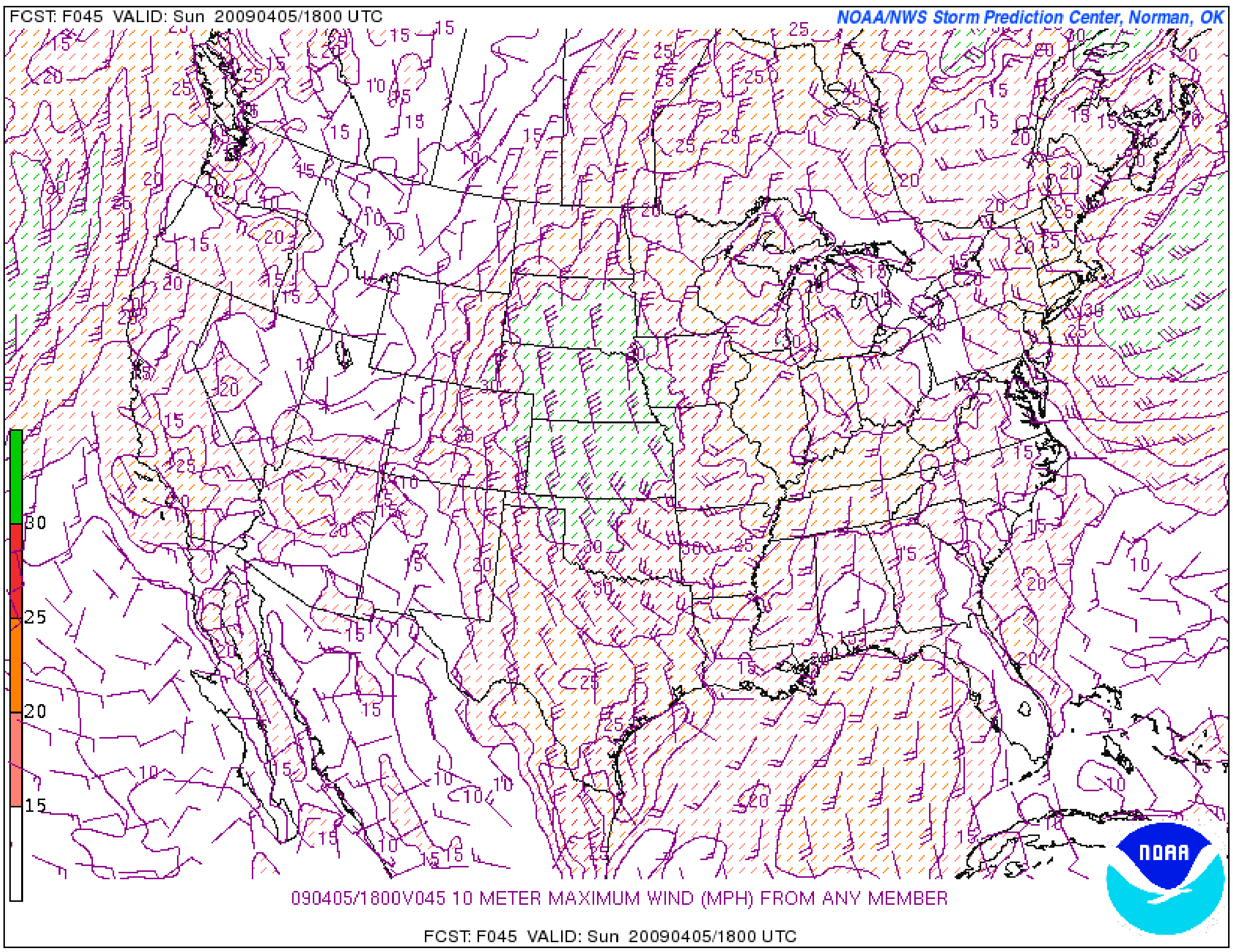


Figure 5. 45-hour SREF forecast 10-Meter Maximum Wind from Any Member valid 1800 UTC 5 Apr 2009.

Likely Precipitation Type: Snow did not start to become the likely precipitation type until 0900-1200 UTC on 5 Apr 2009 (Figure 6). This was 9 to 12 hours into the valid time of the Blizzard Warning.

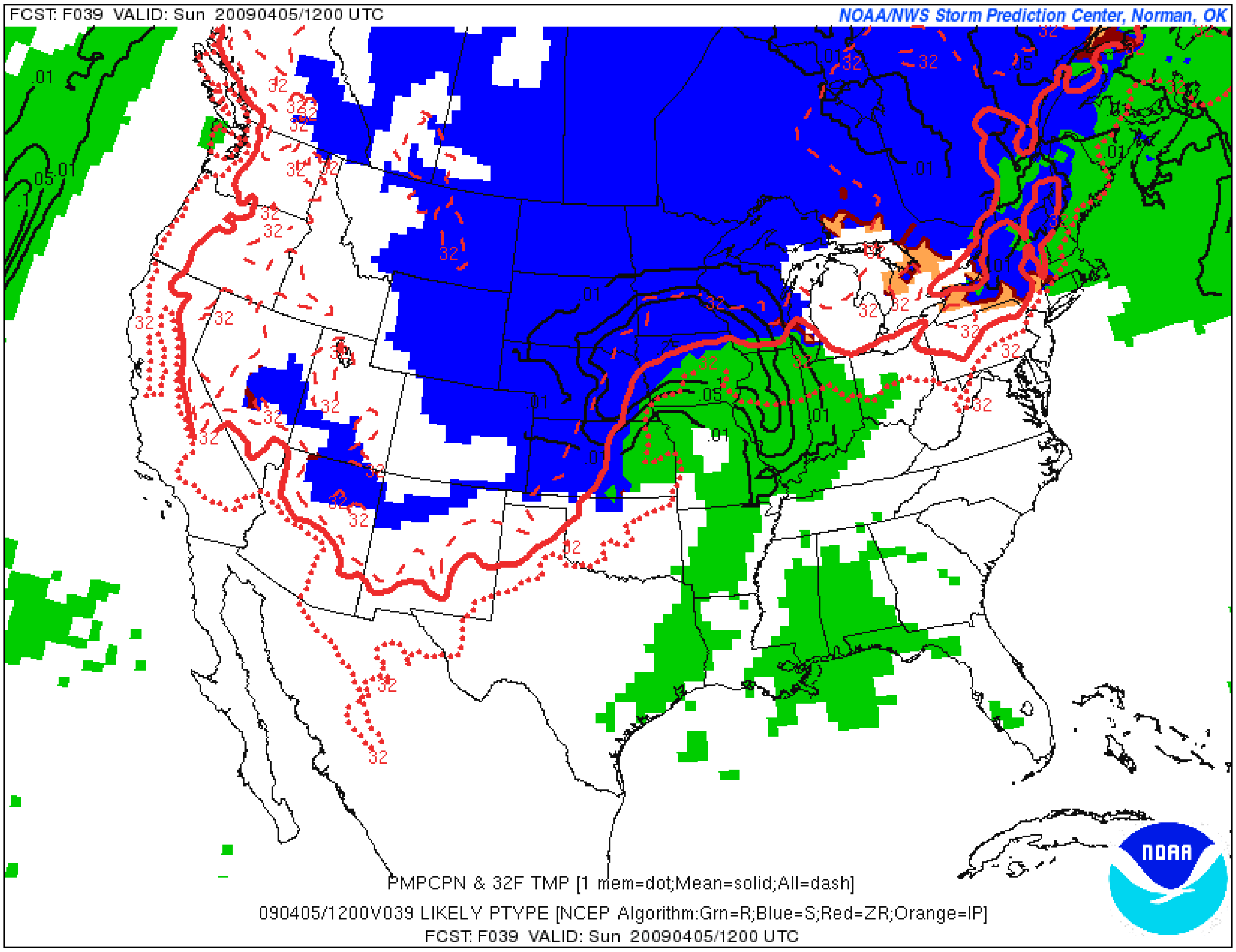


Figure 6. 39-hour SREF forecast Likely Precipitation Type valid 1200 UTC 5 Apr 2009

Mean Depth of the Dendrite Growth Zone = 50mb: Thirty hours before the event begin time, the forecast probability of this occurrence 3 hours into the valid time of the blizzard warning was highest along the Minnesota border and in the 50 to 70 percent range over the expected blizzard area, but also before the probability of snow became likely (Figure 7).

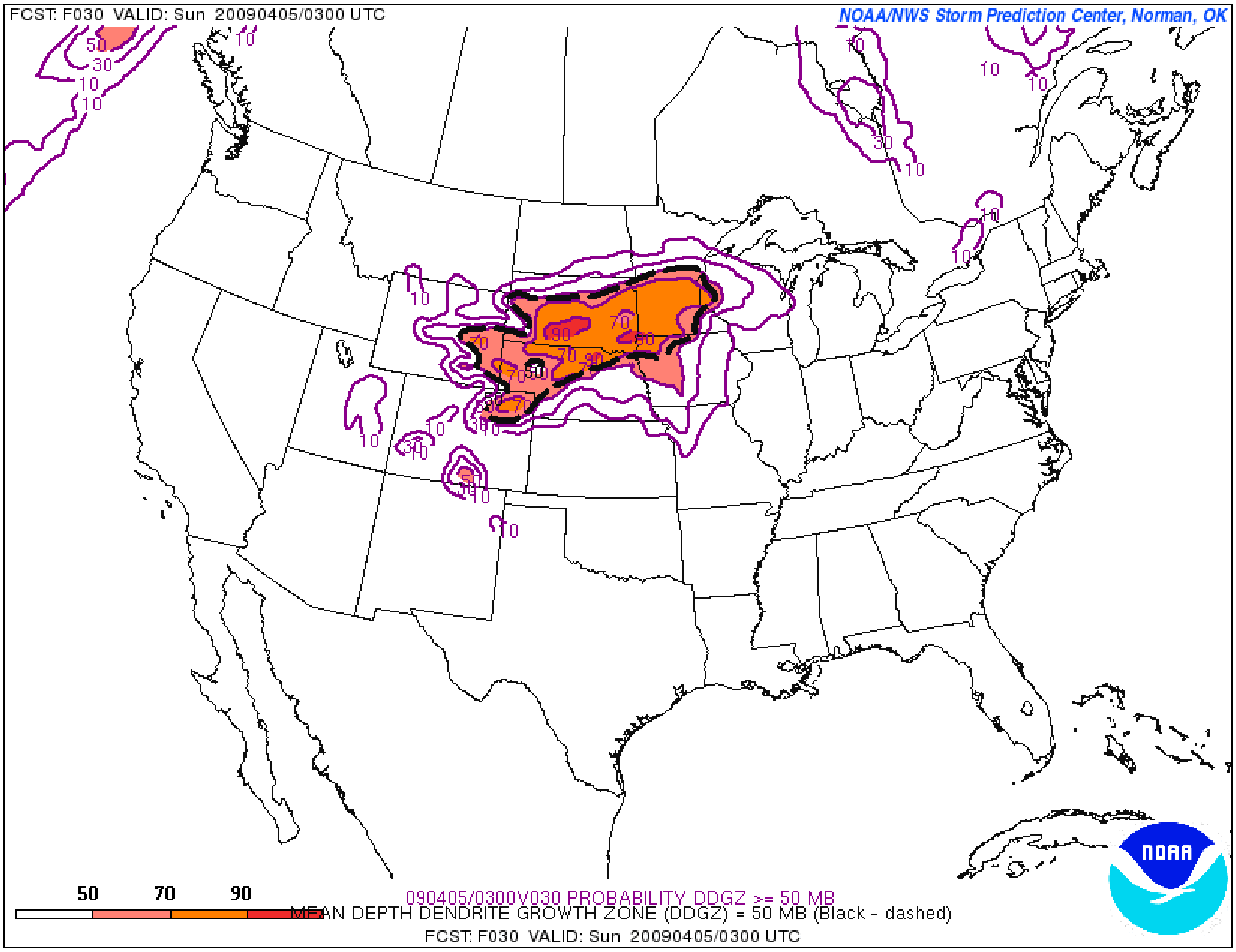


Figure 7. 30-hour SREF forecast of probability that the Mean Depth Dendrite Growth Zone >= 50 mb valid 0300 UTC 5 Apr 2009.

Twelve hours later, the maximum probability of a 50-mb deep dendritic growth zone had shifted east and decreased (Figure 8). Northern Iowa was still had the best chances of any in the DMX county warning area. This maximum turned out to be misplaced as the corridor of best dendritic growth occurred farther south in a narrow band between Highways 20 and 30 across central Iowa.

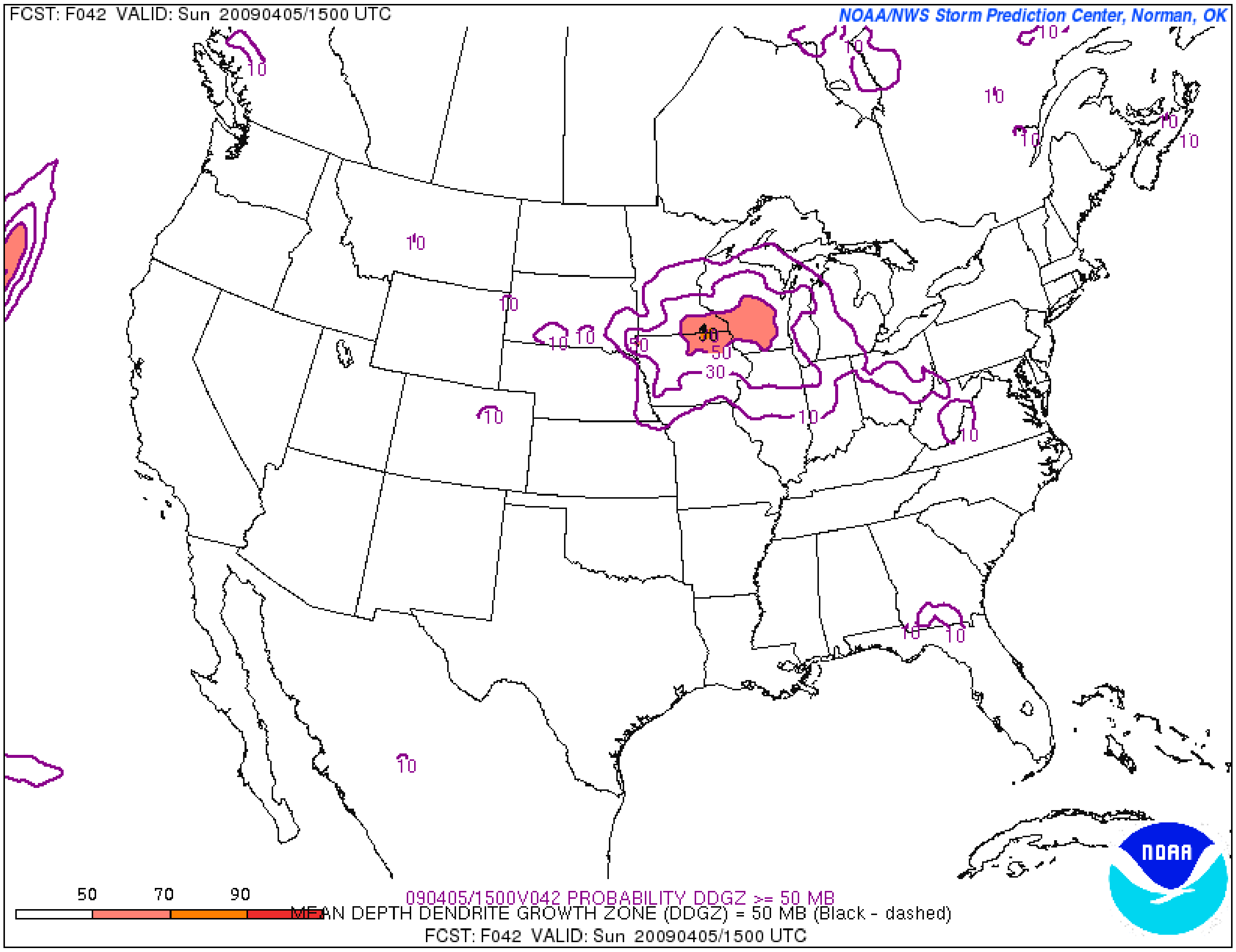


Figure 8. 42-hour SREF forecast of probability that the Mean Depth Dendrite Growth Zone >= 50 mb valid 1500 UTC 5 Apr 2009.

Mean Depth of the Dendrite Growth Zone = 100mb: This never gained a probability greater than 10 to 30 percent, but this was before the snow precipitation type became likely (Figure 9). Therefore, between the relatively low probability of the dendritic growth zone being greater than 50 mb and the very low probability of it being greater than 100 mb, it can be inferred that an abundance of heavy snowfall was unlikely.

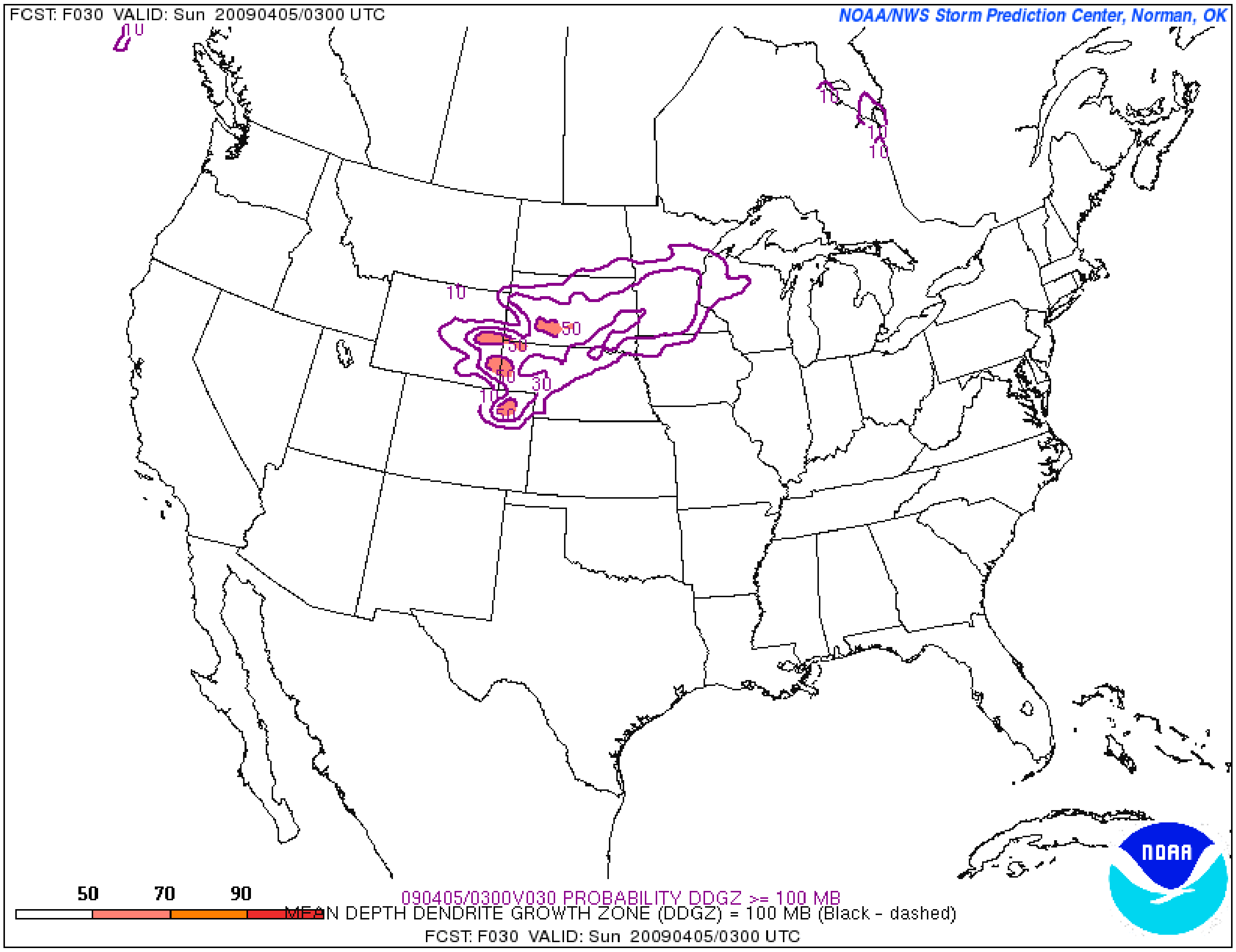


Figure 9. 30-hour SREF forecast of probability that the Mean Depth Dendrite Growth Zone = 100 mb valid 0300 UTC 5 Apr 2009.

Calibrated 6-hour Probability of New Snow or Ice on Roads: The mean contour of ground temperatures equal to 32°F from the ensemble members did not even move into central Iowa until 1200 UTC 5 Apr 2009 – 12 hours into the valid time of the Blizzard Warning (Figure 10). After 1200 UTC, the 32-degree line moved only slightly farther southeast, and then it retreated back to the northwest during the day (Figure 11). The probability of new snow on the roads never even reached 25 percent and got even lower during the day time hours. The model was picking up on the ground and air temperature at or above 32 degrees F, an indication that the snow would be very wet and not susceptible to blowing around once on the ground.

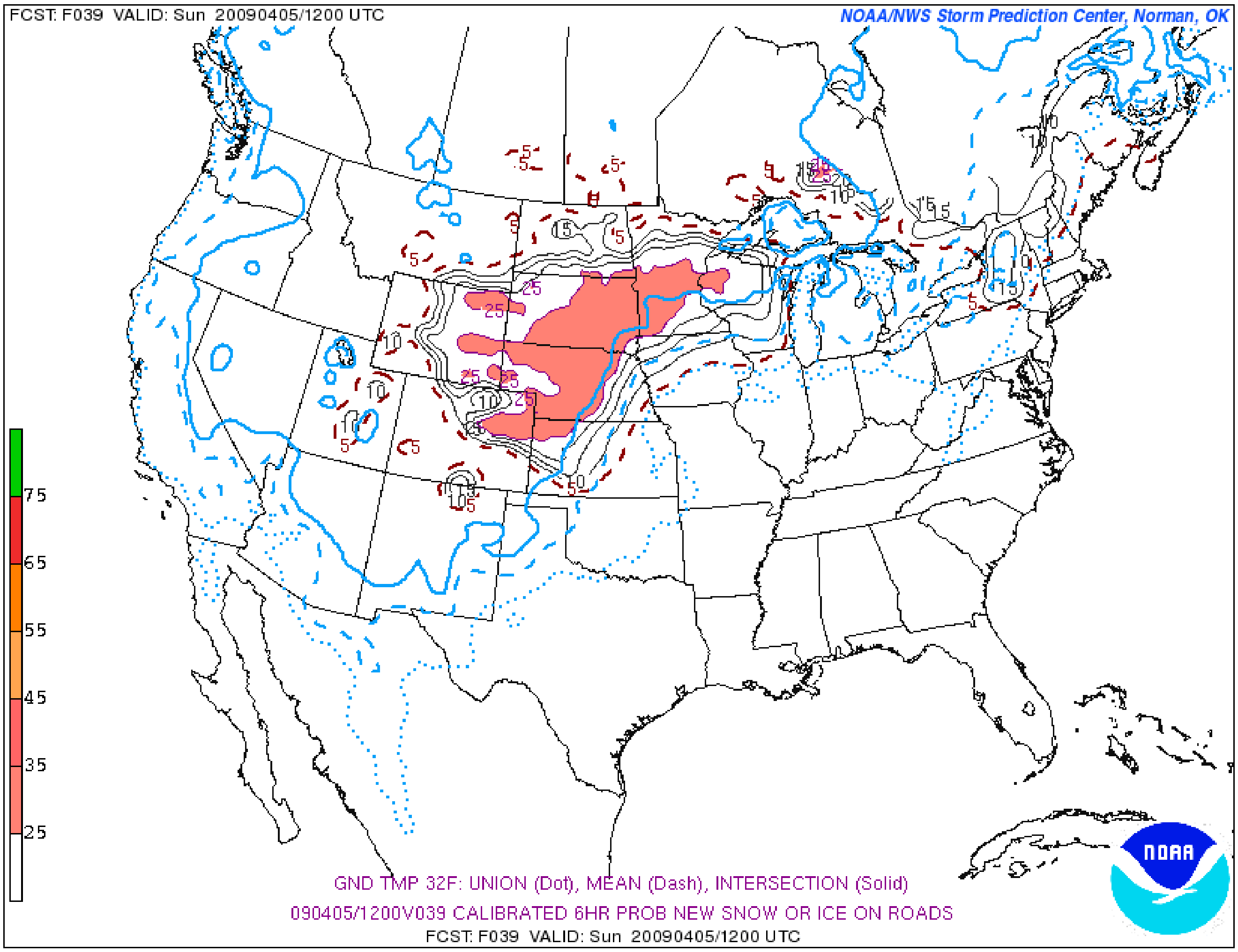


Figure 10. 39-hour SREF forecast Calibrated 6-hour Probability of New Snow or Ice on Roads valid 1200 UTC 5 Apr 2009.

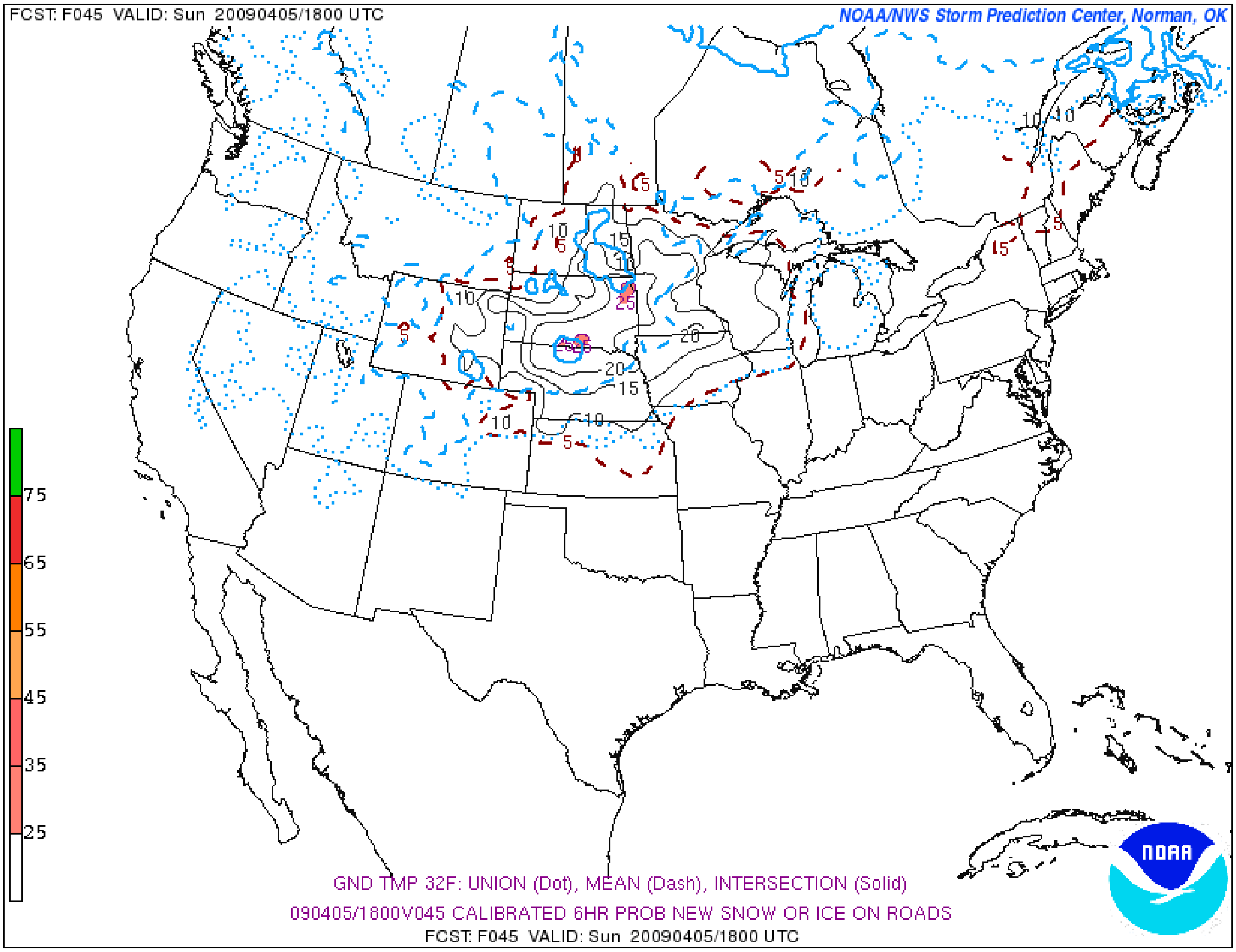


Figure 11. 45-hour SREF forecast Calibrated 6-hour Probability of New Snow or Ice on Roads valid 1800 UTC 5 Apr 2009.

Chance of Snow/Sleet/Freezing Rain Detection on Road Relative to Normal: These charts did indicate equal to above normal probabilities of snow accumulating on the roads (Figure 12). However, remember that it was early April, so relative to normal, this would be expected since the mere fact that the atmosphere was going to produce snow was already an anomalous condition.

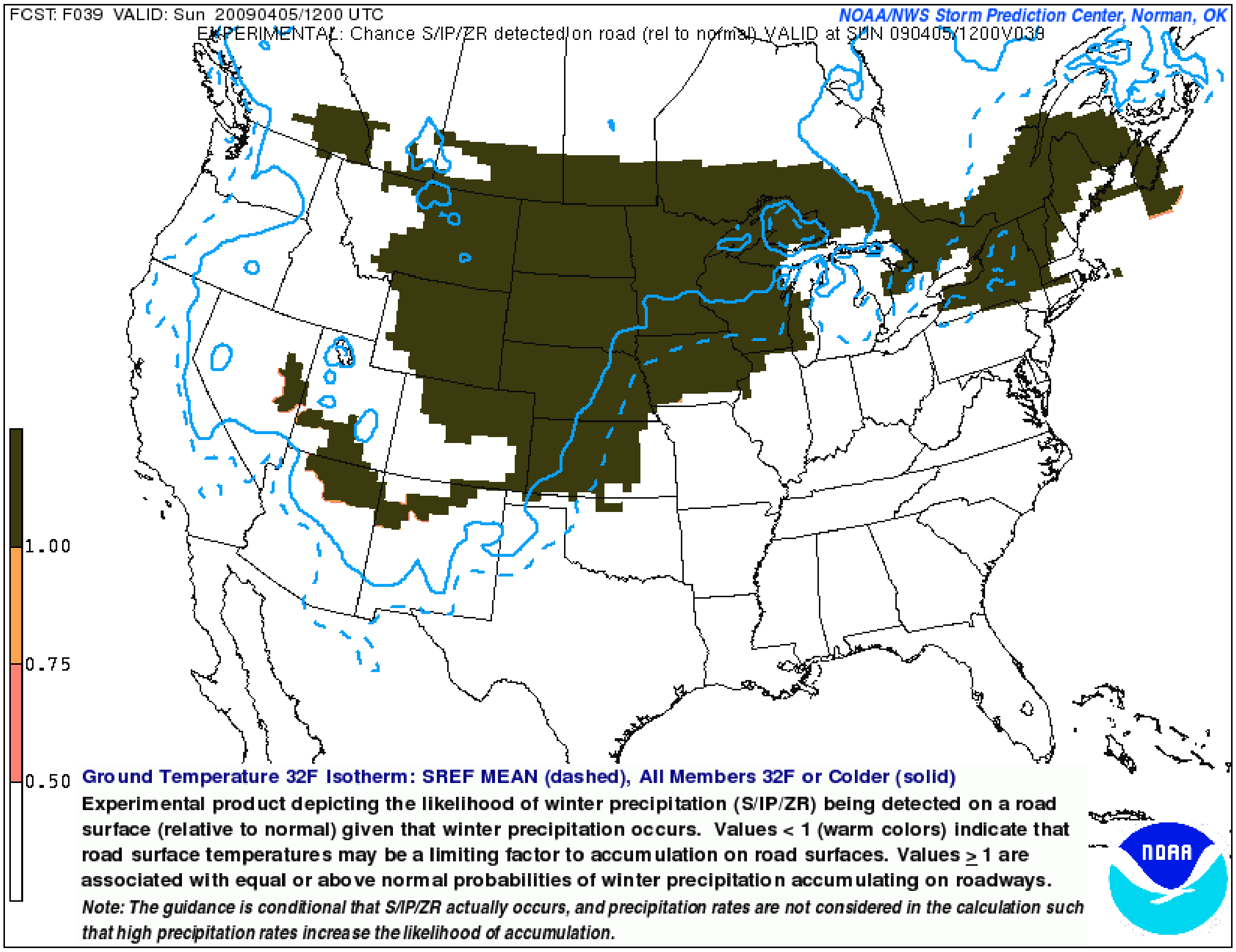


Figure 12. 39-hour SREF forecast Chance of Snow/Sleet/Freezing Rain Detection on Road Relative to Normal valid 1200 UTC 5 Apr 2009.

Mean Estimated Snow-to-Liquid-Equivalent Ratio: This ratio barely got to 10 and only after 1200 UTC (Figure 13). This is yet another indication of wetter than normal snow not likely to blow around much.

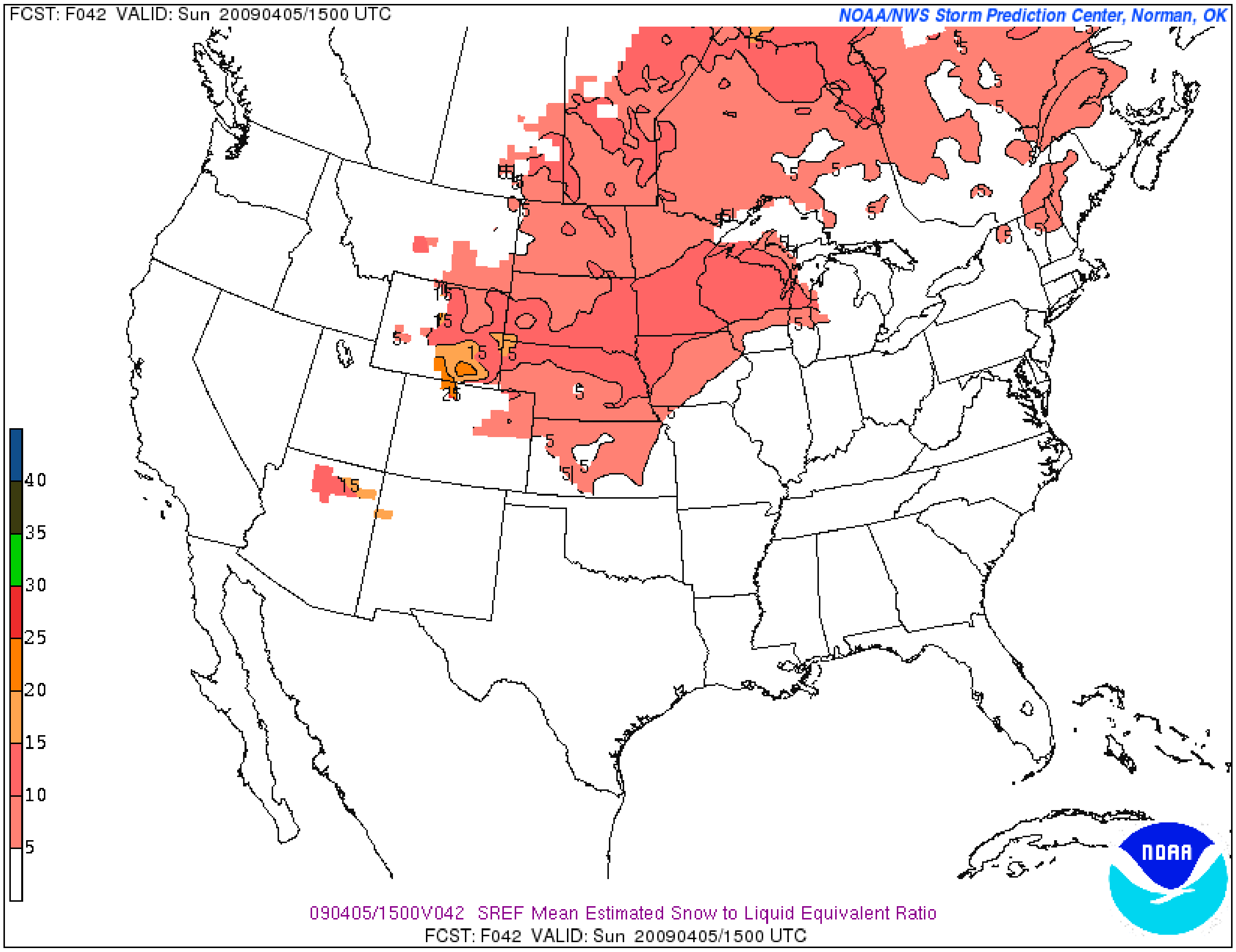


Figure 13. 42-hour SREF forecast Mean Estimated Snow-to-Liquid-Equivalent Ratio valid 1500 UTC 5 Apr 2009.

Probability of Snowfall Rates >= 1 inch/hour: This probability only reached 10 to 30 percent over northern Iowa and really only before snow became the likely precipitation type (Figure 14). So, heavy snowfall seemed unlikely, at least in the blizzard warning area.

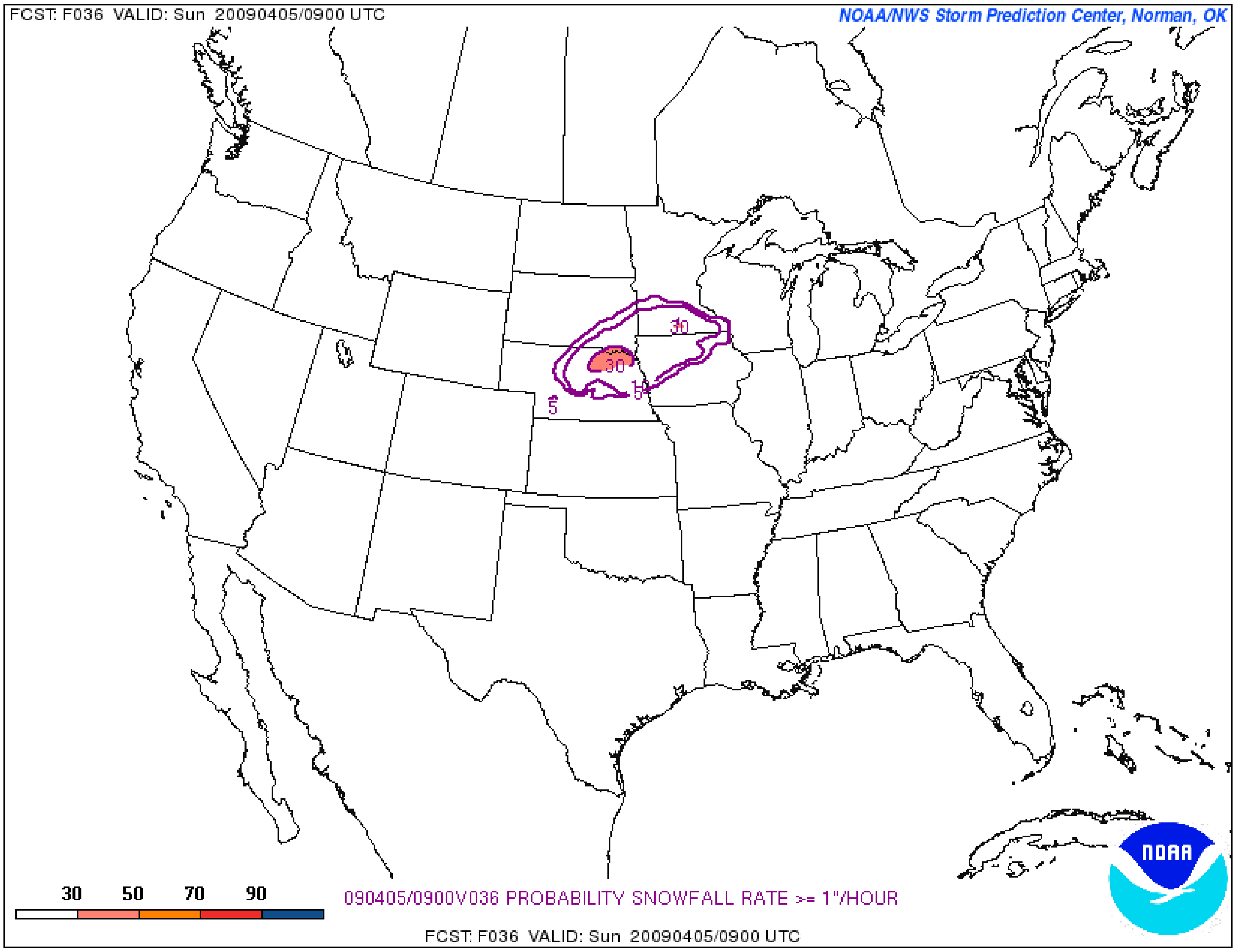


Figure 14. 36-hour SREF forecast Probability of Snowfall Rate >= 1 inch/hour valid 0900 UTC 5 Apr 2009.

Despite several signs offered by the SREF output that attaining true blizzard conditions would be difficult (warm ground and air temperatures, wetness of snow, unlikelihood of sustained heavy snowfall, 10-m winds of less than 35 mph), other non-meteorological factors may have led to the issuance of the Blizzard Warning. First, a significant blizzard affected parts of the Northern Plains two weeks prior, so it is possible that forecasters in the adjacent region were unconsciously swayed toward a higher-end forecast for 5 Apr 2009. Second, once the Blizzard Watches were issued – up to 48 hours in advance, it may have been hard to back down from a Blizzard Watch or Warning.

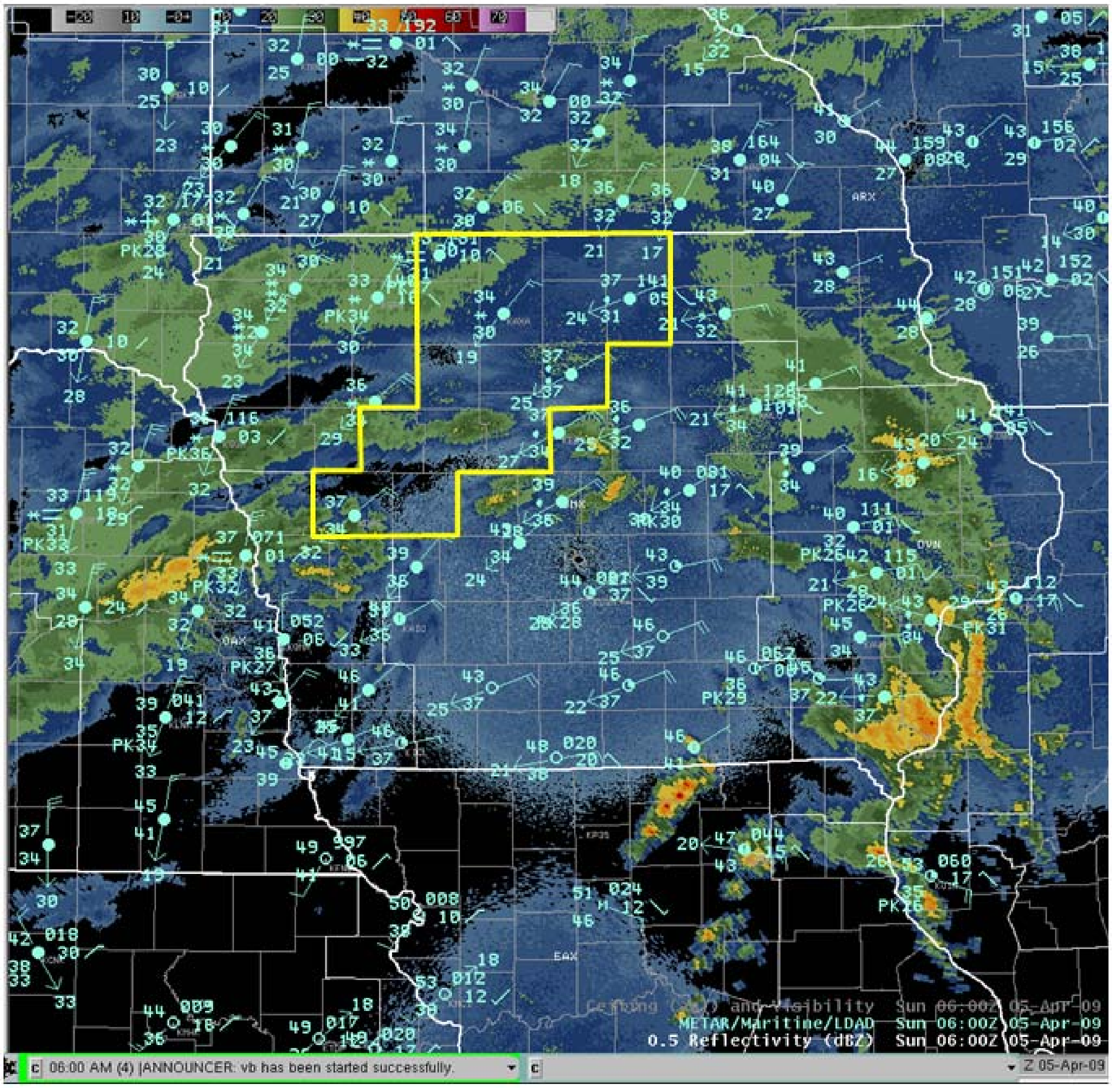


Figure 15. Regional radar mosaic, surface observations (standard notation), and DMX Blizzard Warning area (yellow boundary) valid 0600 UTC 5 Apr 2009.

Figure 15 is from 6 hours into the valid time of the Blizzard Warning. Note temperatures above freezing and winds well below 35 mph in Blizzard Warning area.

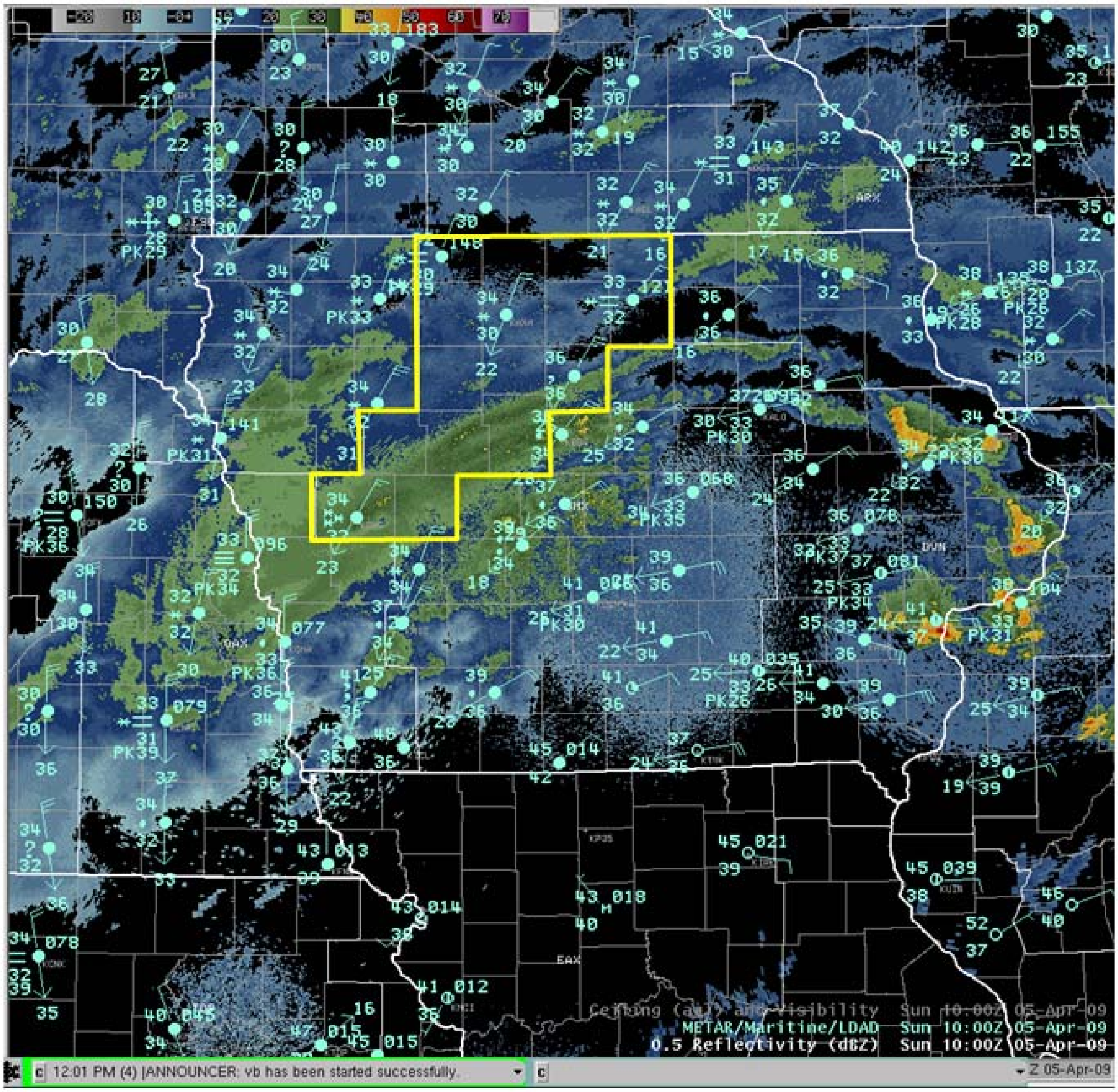


Figure 16. Same as Fig. 16, but valid 1000 UTC 5 Apr 2009.

Figure 16 is at the time of maximum blizzard potential in the Blizzard Warning area. A significant portion of the warned area barely saw any snowflakes, and those that did fall did not have much chance to even accumulate due to the warm surface temperature. The SREF was on to something all along. Note the center of low pressure somewhere between Kansas City, Missouri and Clarinda, Iowa with mean sea level pressure of around 1001 mb – a far cry from the threshold suggested in this study of sub-990 mb. The heavy band of snow did have a short duration of 35 mph wind gusts associated with it, but certainly not three consecutive hours worth.

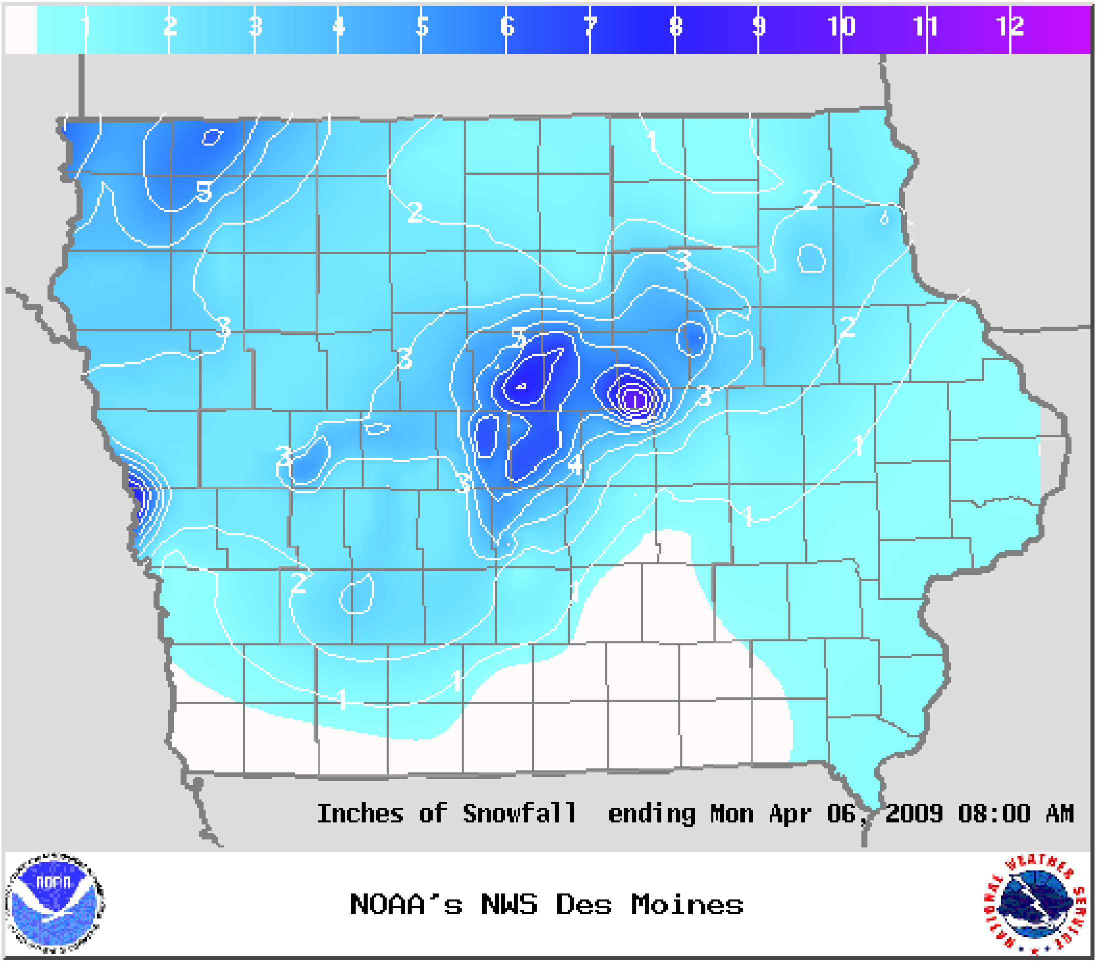


Figure 17. Final analysis of Iowa storm-total snowfall for the 5 Apr 2009 winter storm based on reports collected by the National Weather Service.

5.0 Conclusion

While six of the eight potential or actual blizzard events used in this study had their own set of circumstances which made the blizzard warning decision difficult, the forecast models upon which the forecast was based were in fairly good agreement. While some of the magnitudes were off slightly, their trends verified well. By using a combination of basic meteorological parameter thresholds in conjunction with trends in the SREF winter weather fields and impact graphics, forecasters should be able to make a higher-confidence winter-storm forecast and more easily discern the validity of issuing a Blizzard Warning.

6.0 Acknowledgements

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Manion, NWS Central Region Headquarters Scientific Services Division provided additional feedback during the review process.

7.0 References

Salmon, E.M., and Philip J. Smith, 1980: A Synoptic Analysis of the 25-26 January 1978 Blizzard Cyclone in the Central United States. *Bulletin American Meteorological Society*, **61**, 453-460.

Schwartz, R.M., and Thomas W. Schmidlin, 2002: Climatology of Blizzards in the Conterminous United States, 1959-2000. *Journal of Climate*, **15**, 1765-1772.

Appendix A - Operational Blizzard Checklist

A simple guide for determining the likelihood of a blizzard passing through central Iowa

	Write down values during potential Blizzard Warning duration		Circle Y or N
Surface			
SFC Low pressure		Sub-990 mb?	Y / N
		Deepening to less than 985 mb?	Y / N
6-hr pressure change		6-hr intensification at least 5 mb?	Y / N
Pressure gradient across IA		Max at least 20 mb?	Y / N
850 mb			
Low center height magnitude		< 1300 m?	Y / N
6-hr height change		6-hr intensification at least 40 m?	Y / N
Max wind (DMX CWA)		Max >/= 45kts?	Y / N
Cold advection 10 C/12 hr (DMX CWA)		10 C/12 hr?	Y / N
500 mb *This level is not as well-correlated, but answering "Yes" to the two questions below certainly helps the cause*			
Low center height magnitude		Rapidly deepening?	Y / N
Trough orientation		Negative tilt?	Y / N

Other parameters to consider:
Mixed Layer wind ______________________________
Character of falling snow ________________________ wet (SLR < 10), dry (SLR 12-18), very dry (SLR > 20)
Character of antecedent snow on ground ___________ (packed, crusted, loose, powdery)
Depth of snow on ground ________________________