4A.14 A FORECASTER'S PERSPECTIVE OF, AND POST ANALYSIS SUMMARY ON, THE APRIL 2, 2006 SEVERE WEATHER OUTBREAK

Phillip A. Zuzolo*, The Boeing Company, Mission Systems Division, Springfield, Virginia 22153

ABSTRACT

The severe weather events of April 2, 2006, resulted in 27 tornado-related deaths and $193 million in damages across the central United States in the Mississippi and Ohio Valley areas[1]. A classic severe weather scenario led to this tornadic outbreak.

This paper examines the Geostationary Operational Environmental Satellite (GOES)-12 satellite imagery and the Global Forecast System (GFS) forecast data associated with the April 2 severe weather event. A discussion of the pre-severe event weather forecast conditions along with the progression of the severe weather satellite signatures is provided. In addition, a number of graphic images are discussed that relate to the ability to use weather forecast tools to accurately identify areas where tornados were confirmed by the National Weather Service (NWS). The tornado watch areas and the actual tornado paths for several key damage areas are highlighted to help focus the severe weather factors on areas where tornados were confirmed.

Post analysis discussions of the severe weather scenario focus on the general weather situation, the severe weather dynamics, and the use of visual analysis graphics to relate severe weather potential to the scale and location of the severe weather watch boxes.

I. Introduction

On April 2, 2006 a severe weather event developed over the central Mississippi and lower Ohio River valleys. The low pressure causing this severe weather event had many classic severe weather characteristics. This paper examines, from a forecaster's perspective, the development of this low pressure system, the resulting severe weather, and some of the products available from the National Weather Service to forecast the severe events. A focus of this analysis is the timing of the products and the potential impact of the weather events on aviation routing. In addition, a discussion is also provided regarding the repetitive nature of this event in succeeding weeks and a concept for breaking these types of events in to phases. The phases provide a breakdown of the storm in a context of severe weather recognition and issuance of warnings or advisories. Analysis and visual summary products used to support the analysis and the discussions are produced using the heritage Boeing EDGE^{TM} visualization engine. Data and products used in the visualizations are from the NOAA GFS gridded forecast data and the GOES-12 imagery products.

II. April 2, 2006 Weather Discussion

The April 2, 2006 weather situation produced widespread severe weather over the central Mississippi and lower Ohio River valleys. Figure 1 shows the low pressure and associated fronts with the weather situation at 12Z on April 2. A mature low was present over eastern Nebraska with a well defined warm sector. Surface streamlines from the 12Z National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) numerical weather prediction (NWP) model show maritime tropical air from the Gulf of Mexico flowing into the warm sector out of the High pressure over western Florida. The streamlines also show a secondary cold push out of Canada developing north and west behind the Low pressure system. The yellow box shows where most of the severe weather events occurred.

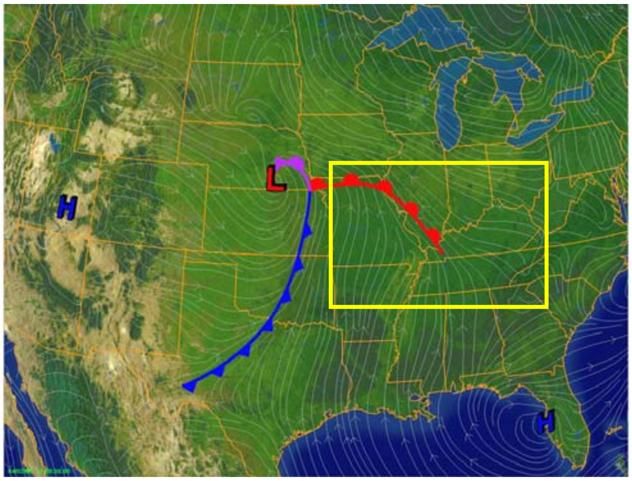

Figure 1. Frontal positions on April 2, 2006 as defined by the 12Z GFS surface streamline analysis and the Region of Interest (ROI) for this paper.

Convective activity began early in the day on April 2. Figure 2 shows a GOES East satellite visible image overlaid with the frontal positions. The visible satellite image at 14Z shows several bright spots resulting from developing convective towers reflecting light from the early morning sun position. Convective cloud signatures already present at this time of day indicated the presence of significant instability in the warm sector. A detailed discussion of the stability conditions for the April 2 event are provided in Grumm (1). This analysis provides an in-depth review of the convective available potential energy (CAPE) and helicity taken from the short-term ensemble (SREF) forecast data from NCEP. The severe weather

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**Corresponding author address:* Phllip A. Zuzolo, The Boeing Company, 7700 Boston Blvd, Springfield, VA 22153. email: phillip.a.zuzolo@boeing.com

discussion here focuses on April 2, 2006 GOES satellite and GFS data.

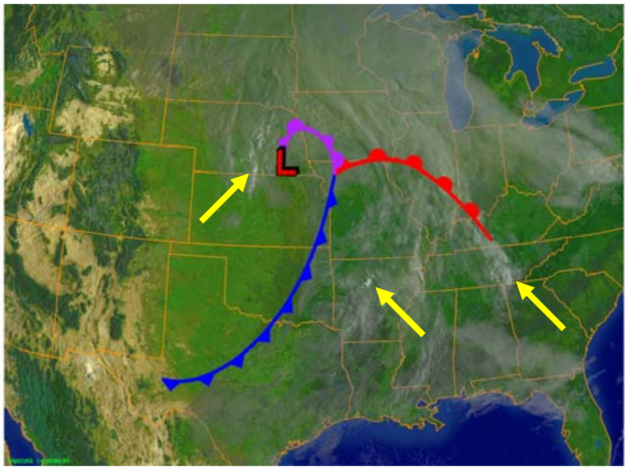

Figure 2. Frontal positions on April 2, 2006 at 14Z with the 1355Z GOES East visible imagery. Yellow arrows show areas of convection reflecting the morning sunlight.

III. Classic Severe Weather Case Study

Several classic factors contributed to the explosive development of severe weather on April 2, 2006. These factors are summarized in this section. Of particular note in this discussion is the fact that these contributors were present very early in the day. The first was the available moisture already in place ahead of the cold front. An analysis of the surface relative humidity field is presented in Figure 3. At 15Z relative humidity values exceeded 75% in nearly the entire area ahead of the cold front. The relative humidity values in Missouri, Illinois, and Arkansas were well above 75% as indicated by the red shading in the analysis.

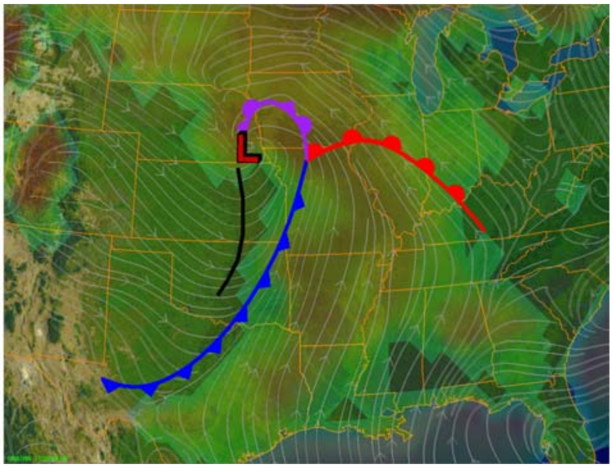

Figure 3. Frontal positions on April 2, 2006 at 15Z with the 15Z GFS surface relative humidity at 75%of greater. Trough line (black) shows secondary cold push supporting dry slot behind cold front.

The second key factor was the cold front. With moisture in place, the only thing needed was the surface cold front to initiate convection. Once this convective process started, the moving cold front and the advecting moisture from the Gulf of Mexico would sustain convective activity for an extended period of time over the central United States.

A third factor in this severe outbreak was a developing dry slot at the middle levels in the atmosphere. Figure 4 shows the 3000 meter level in the atmosphere with relative humidity values less than 50%. This dense dry air at the middle levels provides the capping mechanism to trap the moisture at the lower levels. The dry slot generally allows a cloud-free zone with higher surface temperatures due to intense daytime solar heating process. In addition, the result of this capped moisture in the warm sector contributes directly to the large CAPE values highlighted in Grumm (1). Much of the severe convection occurred within this dry slot as a secondary cold push developed behind the surface cold front.

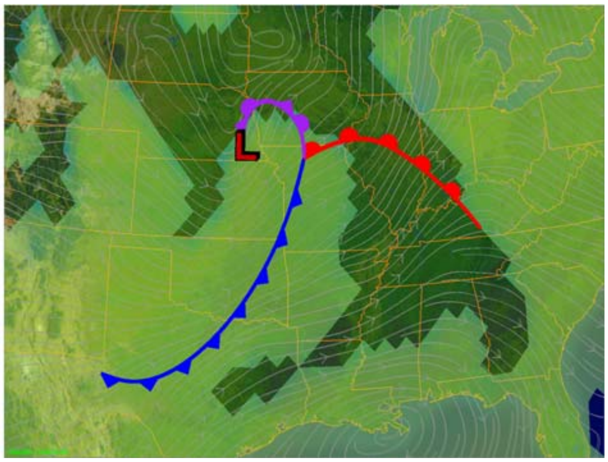

Figure 4. Frontal positions on April 2, 2006 at 15Z with 3000 meter streamlines and relative humidity values 50% or less.

The upper-level support at 300mb provided the fourth factor. In Figure 5, the 300mb wind pattern shows a strong area of divergence with the left, forward quadrant of a 100kt (50 meter per second (m/s)) jet stream wind speed maximum entering the region over the panhandle of OK. An area of diffluence ahead of the cold front is also shown. These upper-level factors, present at 15Z, are well positioned to support the explosive convection that occurred later in the day. In fact, the position of the 300mb trough and the rotation through this trough put the speed maximum in an ideal position to support severe weather later in the day. This position would coincide with the area of maximum surface relative humidity at 15Z shown in Figure 5. The upper-level support shown in Figure 5 is already helping with the convective cells shown on the GOES East water vapor imagery. These are the same areas highlighted in Figure 2 that were developing at 14Z.

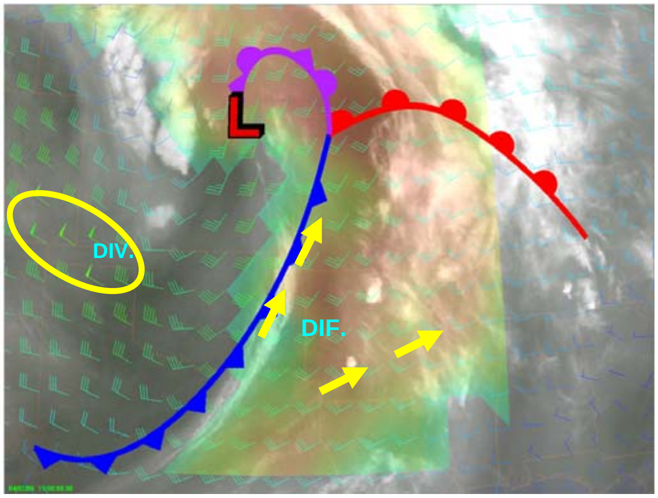

Figure 5. Frontal positions on April 2, 2006 at 15Z overlaid with the GOES East water vapor, the 300mb wind barb (m/s), and the 15Z GFS surface relative humidity at 75%of greater. The area of divergence associated with a 100kt (50m/s) jet core (yellow ellipse) and the area of diffluence ahead of the cold front are also shown.

The final factor is shown in Figure 6. A strong area of cold are is advecting into region at the 500mb level. This will do two things. One, as this cold pocket of air with central values of 252^{o}K (-21^{o}C) or less advects through the severe region identified in Figure 1, the region will continually destabilize. Additionally, a 500mb thermal trough is often associated with a developing vorticity maximum and as the thermal trough moves closer the the region, the positive vorticity advection (PVA) will provide another lifting mechanism.

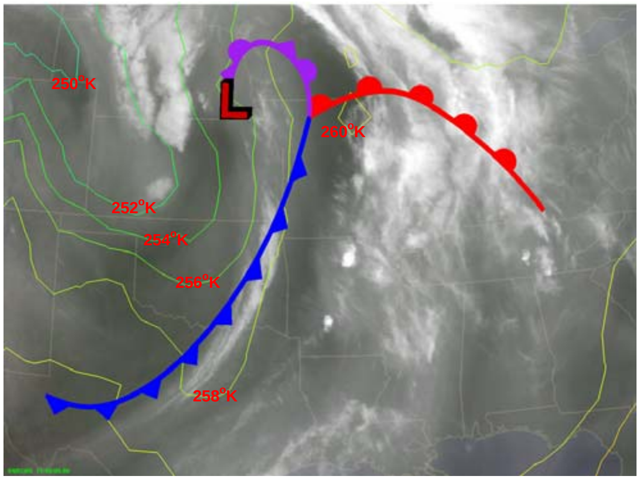

Figure 6. Frontal positions on April 2, 2006 at 15Z overlaid with the GOES East water vapor and 500mb isotherms at 2^o intervals.

These key, classic factors taken from the April 2, 2006 12Z GFS model and the GOES East visible and water vapor imagery, provide a clear indication at 15z a severe weather event is likely to develop later in the day. Not only are the factors present, they are temporally and spatially coincident over the ROI. Additional analysis of enhanced infrared imagery (nighttime data), surface dew point and temperature, surface pressure change, specific severe weather indices, etc., would also add to the severe weather picture. However, for this paper only those factors observed from the GFS forecast fields and the daytime GOES visible and water vapor were used. The decision to limit the analysis data was made to simplify the discussion of recognizing severe weather indicators when using NWP tools such as the GFS model data and GOES imagery. If NWP models are initialized, they are excellent tools to prepare forecasters for identifying the development factors and the timing for the actual severe weather events. The next section discusses a concept for breaking a severe weather event into four phases. The GFS model data and the GOES East imagery are used as supporting analyses to identify the four phases.

IV. Phasing of a Severe Weather Event

A severe weather event presents forecasters with many challenges. The National Weather Service (NWS) has a specific instruction (2) defining the policy for the management and use of NWS products for events including “a widespread severe thunderstorm or tornado outbreak”. There are three other specific significant weather events listed in the instruction. When these events occur a Critical Weather Day (CWD) is declared to ensure procedures are followed to generate and disseminate weather products for the protection of life and property. The severe events of April 2, 2006 met the event criteria as listed in the instruction for the declaration of a CWD. This section looks at April 2 as a CWD and provides a concept for breaking the event evolution into four phases to help forecasters manage the challenges of rapidly developing severe weather.

The four phases of the severe event evolution are defined as the ***preparation phase, discovery phase, development phase, and the severe phase***. During the ***preparation phase*** a forecaster recognizes the ingredients are present for severe weather and makes the necessary preparations to manage the task load well ahead of the first occurrence of severe weather. This is also the phase when the forecaster identifies the likely area and time for the severe event to take place. The next phase is the ***discovery phase***. This phase begins when the forecaster identifies rapidly developing convective cloud signatures, decreasing stability indices, and recognizes the environment is ideal for imminent severe weather. Severe and tornado watch boxes are issued during this phase. The third phase is the ***development phase***. Conditions during this phase result in the actual development and identification of severe signatures either by cloud imagery or radar imagery. This phase continues until the first warnings are issued. The final phase is the ***severe phase***. During this phase, severe weather continues until the severe potential ends. Boundaries between these phases are very subjective. The April 2 weather situation was broken into these four phases using the subjective boundary definitions and the timeline of tornadic events within the ROI.

On April 2, the ***preparation phase*** was defined between 12Z, or shift start, until around 18Z when convective cloud lines began to develop. During this period the low pressure system highlighted in Sections II and III, had all the classic factors to produce a severe event. In addition, based on the cloud signatures identified in Figure 2, the possibility existed for severe weather to occur well ahead of the time of maximum afternoon heating.

A severe weather and a tornado watch box were issued at 1730Z and 1815Z, respectively, within the ROI. At this point, the transition occurred to the ***discovery phase***. The period of this phase, 18Z to 1930Z, was limited primarily due to the rapidly changing weather conditions. Within that 90-minute period severe weather began to develop. Figure 7 provides a view of the visible cloud features at 19Z. Of particular note in this figure are the lines of convection developing in the western side of the tornado watch box (3).

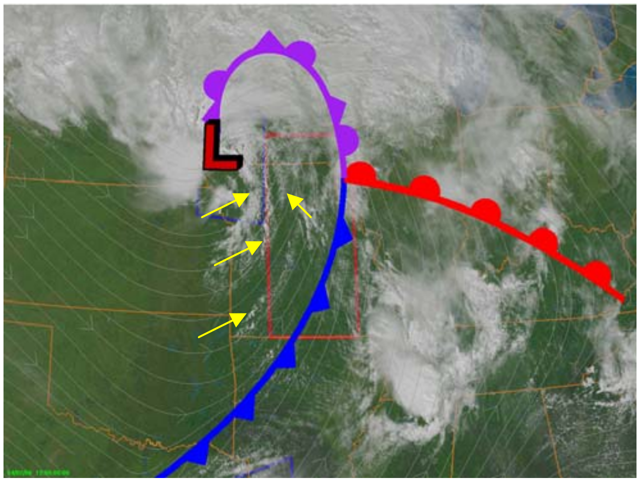

Figure 7. April 2, 2006 19Z frontal positions with surface streamlines, tornado watch boxes (red), severe thunderstorm (blue), and visible cloud imagery. Lines of convection are highlighted with the yellow arrows.

The ***development phase*** on April 2 was defined as the period between 1930Z and 21Z. Numerous watch boxes were issued during this period and at 2047Z, the first tornado was reported in Davis County IA (golfball-sized hail was reported at 12Z in Cass County IL) (4). Severe weather developed rapidly during this phase and the visible cloud imagery in Figure 8 provides a good example of these rapidly developing severe conditions. Several overshooting cloud tops within the lines of convection are clearly present in the figure. From this point on, tornadic events developed explosively.

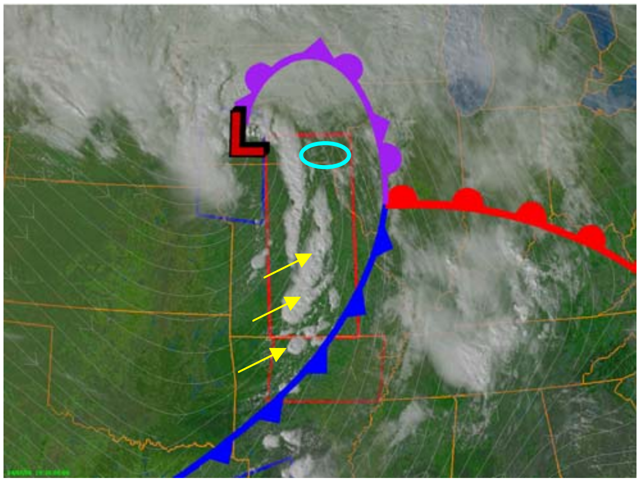

Figure 8. April 2, 2006 2030Z frontal positions with surface streamlines, tornado watch boxes (red), severe thunderstorm (blue), and visible cloud imagery. Severe convective towers in the dry slot convective area are highlighted with the yellow arrows. The blue ellipse indicates the general location where the first tornado occurred at 2047Z.

At 21Z two tornados were already on the ground in Davis County IA and by 2115Z three additional touchdowns were reported in Van Buren and Jefferson counties in IA. These repetitive tornadic events were used to define the start of the *severe phase* for April 2. Severe and tornadic events occurred nearly continuously from 21Z until 12Z on April 3. Figures 9 shows severe cells in the visible imagery around 21Z with the 3000 meter wind (m/s) field. Figure 10 provides the same imagery overlaid with the tornado watch boxes at 2130Z and where F2 tornados occurred. Note the movement of the cloud areas between 21Z and 2130Z. The wind field shows winds between 25 and 30 m/s and provides a rough estimate of the speed of movement. Figure 11 shows the NWS Storm Prediction Center (SPC) map of storm reports for April 2, 2006 (4). Nearly all these reports occurred in the severe phase.

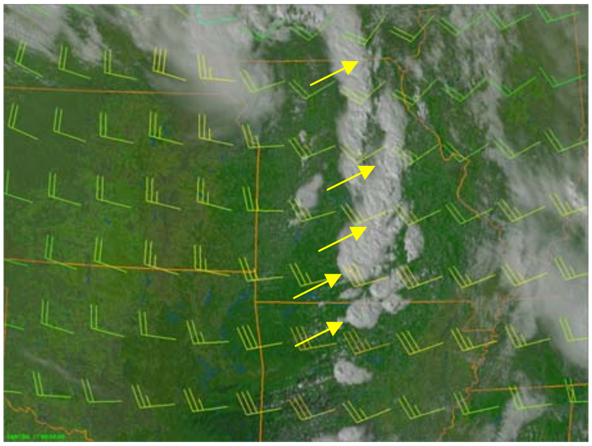

Figure 8. April 2, 2006 21Z 3000 meter wind field (m/s) and visible GOES imagery. Severe cells are highlighted with the yellow arrows.

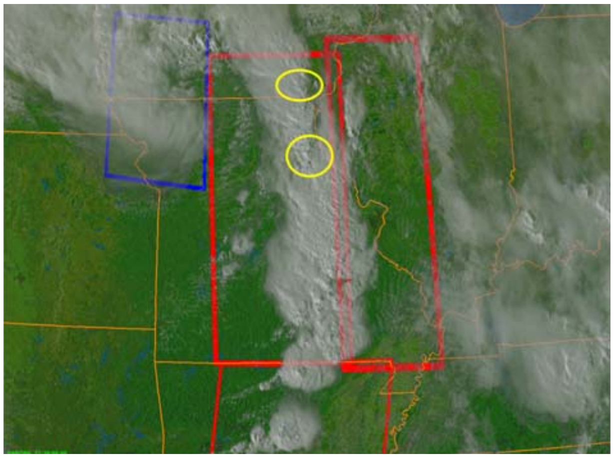

Figure 10. April 2, 2006 2130Z tornado watch boxes (red), severe thunderstorm (blue), and visible cloud imagery. Areas where F2 tornados touched down are shown with the yellow ellipses.

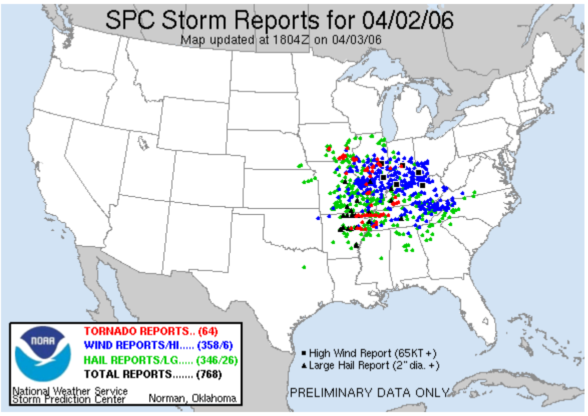

Figure 11. April 2, 2006 SPC storm reports over the Continental United States.

The phasing concept defined in this paper is presented to identify the complexity of the severe weather situation and the challenges imposed on a forecaster. In the author's view, the development and severe phases present the most challenges. Not only does the forecaster continue to issue watch boxes, but products are disseminated for warnings and notifications to the appropriate emergency agencies. The "forecaster" in this situation includes both the centralized and the local NWS office forecaster. Close collaboration as defined by the procedures in the NWS CWD instruction (2) is the key to successful support to these agencies.

V. The Value of High-Resolution GOES Imagery

There is no substitute for high-resolution GOES imagery when forecasting, monitoring, and managing severe weather events. High resolution radar imagery is also extremely important but was not included as part of this discussion. A good summary of the high-resolution Next Generation Radar (NEXRAD) imagery for St. Louis, MO on April 2, 2006 is presented on the St. Louis NOAA NWS Weather Forecast Office web site in (5). This paper focuses on the visible and water vapor imagery available from GOES East.

Figure 12 provides a view of the GOES East visible cloud imagery around 2215Z. Note the frequency of over-shooting tops in this imagery. A forecaster using frequent visible imagery updates at this time of day has a very high likelihood of identifying these severe signatures. This is due to the earth-sun geometry and the resulting shadowing effect. Figure 13 provides a close-in view of the visible satellite over the lower half of Figure 12 30 minutes later at 2245Z. During this 30-minute period eight tornados were reported in IL and two in AR. Of those ten, two F2s and one F3 (Tri-State Supercell) were reported (4). Imagery with high temporal resolution improves the forecasters' capability to monitor the location and development of severe convective cells.

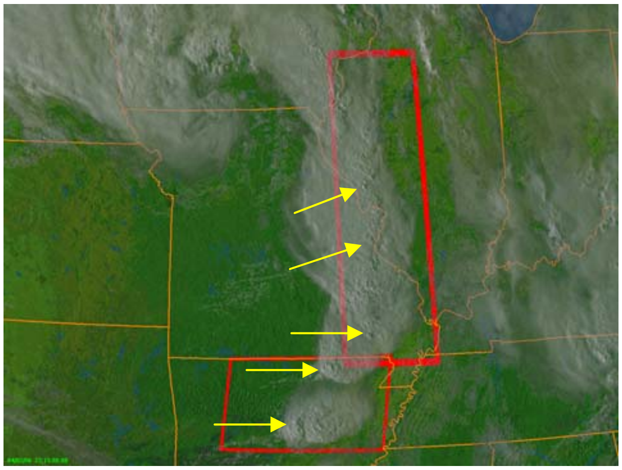

Figure 12. GOES East visible imagery with tornado watch boxes (red) at 2215Z on April 2, 2006. Severe cells are highlighted with yellow arrows.

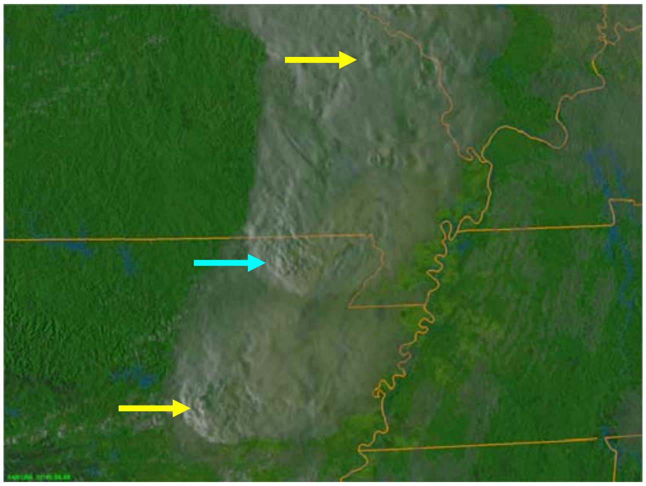

Figure 13. GOES East visible imagery with severe cells highlighted with yellow arrows. The Tri-State Supercell is highlighted with the blue arrow.

The visible imagery is complemented with infrared imagery such as the water vapor channel. This imagery highlights the location of the most concentrated moisture areas in the atmosphere. Figure 14 shows the water vapor imagery overlaid with the 300mb wind field. Strong winds aloft and diffluent flow continue to support the moisture plume from the severe convective cells. In addition, the 50 m/s wind maxima will sustain the convective activity for an extended period of time. The forward wind maximum moving through southern MO likely was a supporting mechanism for the tornadic activity that moved through the St. Louis metropolitan area. Severe activity at this time was widespread and as noted in Figure 11 this activity continued eastward into the Carolinas and Virginia.

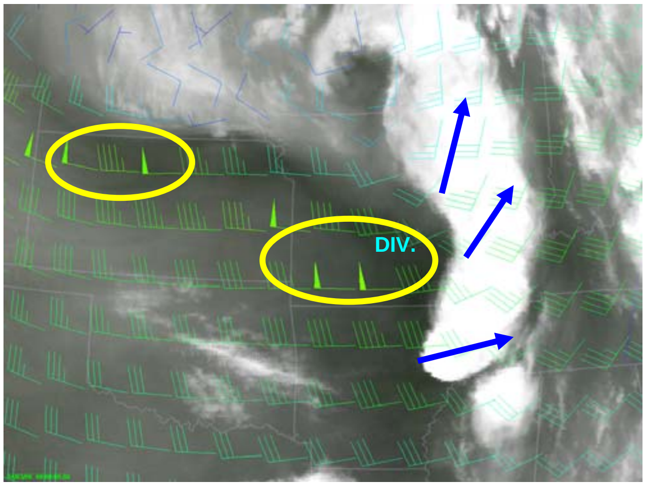

Figure 14. April 3, 00Z water vapor imagery with 00Z 300mb winds (12-hour forecast winds from 12Z April 2 GFS NWP model). Note the blue arrows showing the diffluent areas and the yellow ellipses showing the 50 m/s wind maxima.

The use of high-resolution cloud imagery allows forecasters to monitor storm development and when combined with other data such as NEXRAD radar a forecaster may categorize radar information with the cloud signatures. By using this information together with NWP or analysis data such as middle-level winds, forecasters are able to adjust the timing to issue more accurate watches and warnings. In addition, these watch and warning products provide better guidance for support to such operations as commercial aviation route planning and adjustment. An overview of the methods commercial aviation uses these data is provided in the next section.

VI. An Overview of the Relationship between Severe Weather Events and Commercial Aviation

Severe weather events affect commercial aviation traffic in several ways. Ground traffic, departure and arrival routes, as well as en route traffic management are just some of the key operational considerations for adjustments due to severe weather. In addition to the actual changes in operations, air traffic control (ATC), NWS personnel, and other operations staff work together to issue the Collaborative Convective Forecast Product (CCFP) (6) for traffic management (7). This collaborative effort defines the Federal Aviation Administration products and activities for programs such as the Severe Weather Avoidance Plan (SWAP) and Airspace Flow Programs (AFPs). The FAA issues and AFP for viewing at the following web site: http://www.fly.faa.gov/adv/advAdvisoryForm.jsp.

Once convective activity begins the FAA looks at the extent and severity of the activity relative to the impact regarding the disruption of overall flight operations within the National Airspace System (NAS). The FAA Air Traffic Control System Command Center (ATCSCC) has specific guidelines and associated procedures to account for Severe Weather and Route Management (8). These guidelines provide pre-established routes to account for convective activity in specifically impacted areas within the NAS. There are established guidelines for both “Proactive Outcomes” and “Reactive Outcomes” as well as other specific procedures. Figures 15 and 16 present examples the more extreme route change guidelines outlined by ATCSCC. Additional guidelines are provided within the ATCSCC Severe Weather and Route Management document (8).

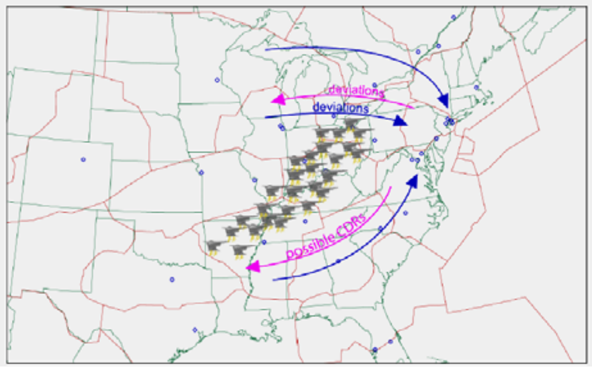

Figure 15. Example of pre-established routes for “Proactive Outcomes” resulting from extreme severe weather routing. Possible Coded Departure Routes (CDRs) are shown with alternates.

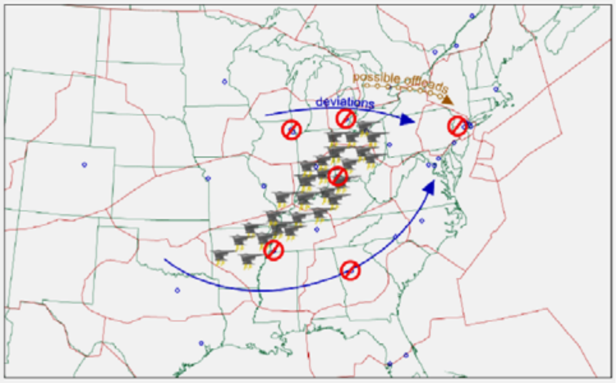

Figure 16. Example of routing changes due to a less extreme severe weather event.

The weather event of April 2, 2006 also affected arrival routing. Figure 17 shows the possible alternate routes for arrival routes into Chicago's O'Hare Airport overlaid on the visible cloud imagery around 2125Z. The impact to the "BDF Star" arrival route was clearly evident in this graphic. Monitoring the development and movement of the severe area is critical in this type of situation to ensure the proper alternate arrival route is chosen and is a key part of the SWAP. The high-resolution visible imagery and radar products provide this critical data during the daylight hours. At night forecasters rely on the enhanced infrared imagery data and products with the radar data to identify locations and track movement of severe cells. For an event such as April 2, forecasters and mission support staff use a variety of products to minimize the impact of weather to mission operations.

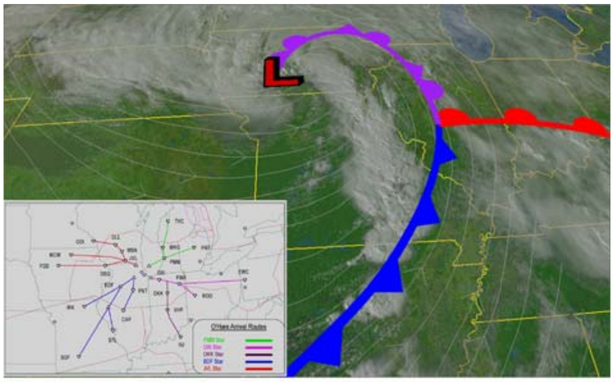

Figure 17. April 2, 2006, 2125Z surface fronts, streamlines, and visible cloud imagery. The inset map shows O'Hare arrival routes and the BDF route is shown in blue.

VII. Summary.

The severe weather events of April 2, 2006, a Critical Weather Day by NWS definition, impacted the lives, activities, and property over a wide area. Over 800 severe weather events were recorded. This paper provided a discussion of some of the tools available to forecast and monitor these types of events. Visible satellite imagery from GOES East and the GFS analysis and forecast fields from the 12Z, 2 April NWP model were used to identify key severe weather factors. These data products and the analysis discussion were limited to a daytime perspective. An obvious addition to these data products would be the enhanced infrared imagery to identify the occurrence and development of enhanced V-notch signatures. This author realizes a forecaster uses all available products to identify, monitor, and forecast intensity and movement of severe storms. A discussion regarding additional products such as the enhanced infrared, or other imagery products, may be accomplished in a succeeding paper.

The visible satellite imagery and GFS data products discussed here provided a good picture of the potential severe weather environment. Classic signatures on the imagery and actual severe weather and tornadic reports occurred where the key factors identified by the GFS model were located. In addition, the coincident location of these factors in both space and time provided a good indication the central Mississippi and lower Ohio Valley region had a high likelihood of widespread severe weather formation. The key point to take away from this discussion is that NWP models, used properly with other data products like visible and water vapor satellite imagery, can provide valuable, complementary information to the analysis of near real-time observational data. In the case of April 2, the GFS model data was a highly accurate tool for identifying the timing of key factors affecting the developing severe weather situation.

These NWP model products are also valuable when severe weather occurs in a repetitive pattern. Widespread severe weather outbreaks over this ROI occurred again during the periods 5-7 April, 13-18 April, and 1-3 May (4). Using the model data, a forecaster can observe and subjectively, and in some cases objectively, calibrate the accuracy of the models in forecasting the intensity of the key factors identified in this paper. Adjustments to timing of severe events based on this calibration process can sometimes make the difference between meeting or not meeting the lead-times required to save lives and protect property or resources. The satellite data used in conjunction with these NWP products is also valuable as a comparison of intensity between severe weather signatures. Note that there were additional less widespread outbreaks that occurred on other dates during the same period from early April to May.

This forecaster's perspective on the tools used to forecast these events attempted to identify not only the weather impacts and the evolution of the severe weather situation, but also the impacts to a key mission such as commercial aviation. As discussed above, it is imperative to collaborate between key agencies to ensure the proper flight routing including the generation and dissemination of critical products in support of the SWAP. Using or considering a concept such as the four phases of a severe event outlined in this paper, a rapidly developing severe weather situation may be managed more efficiently. The focus of the concept is to look at when task management becomes a challenge and to prepare early for this intense effort. To mitigate the impact of events such as April 2, forecasters need to manage tasks efficiently in support of missions such as issuing severe weather warning for the protection of lives and property or for routing aviation traffic to maximize safety of flight.

Prevention of damage similar to that pictured in Figure 18 (9), and due to the image in Figure 19 (9), is not possible. However, forecasters must use all available tools to issue warnings with maximum lead-time to avoid the potential loss of lives with these events.

Figure 18. Aerial photograph of damage in Christian, Todd County KY from the F3 Hopkinsville, KY tornado recorded at 0150Z on 3 April 2006.

Figure 19. Hopkinsville, KY web camera capture at 9:10 P.M. CDT April 2, 2006 (0210Z 3 April 2006) from Jennie Stuart Hospital Webcam.

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