A Comparison of National Weather Service Severe Weather Warned Areas under the New Polygon Warning System

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INTRODUCTION

For more than 30 years, the National Weather Service (NWS) has issued Severe Weather Warnings for Tornadoes, Hail, and Wind based on the county the severe weather was in. This caused many locations to be under a severe weather warning when there was no severe weather occurring in their area. This is especially prevalent in the Western United States, where many counties are hundreds of square miles in area (Waters, 2006). Therefore, in 2004 the National Weather Service proposed to begin issuing severe weather warnings (for hail, wind, and tornadoes) by using a polygon to represent the warned area. Many offices began to issue polygon warnings in 2005, with the polygon warnings slated to become fully operational in October 2007 (NOAA/NWS, 2007).

This project will look at the warnings issued by the Green Bay, Wisconsin National Weather Service office in 2005 and 2006. The goal of the project is to look at the individual warnings and calculate the difference in warned area with the transition from county-based warnings to polygon-based warnings. ArcGIS will be used to calculate the area of each polygon warning issued during the two given years, which will then be compared to the total area of the counties that were affected by that warning. After comparing the areas of each polygon warning and the respective county areas, statistics will be generated comparing the different types of warnings (Tornado and Severe Thunderstorm).

BACKGROUND

The National Weather Service office in Green Bay, Wisconsin serves 22 counties in Northeast Wisconsin (Figure 1). For these counties, the NWS provides routine forecasts of various meteorological parameters, as well as watches and warnings for a variety of severe weather, including thunderstorms, winter storms, flooding, and fire weather. In addition to the 22 counties, the NWS office provides forecasts and Marine Warnings for the Bay of Green Bay and the waters of Lake Michigan.

The National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS) defines a severe thunderstorm as a storm that contains at least one of the following features (National Weather Service, 1995):

- Hail that has a diameter exceeding 0.75" (3/4 inch)
- Winds at or stronger than 50 knots (58 miles per hour)
- A Tornado

The NWS issues a weather warning when a hazardous weather event is occurring or is expected to occur shortly. These weather warnings state that the expected weather conditions

pose a threat to life and/or property. A Severe Thunderstorm Warning is issued when a thunderstorm is believed to contain severe weather, hail larger than ¾ inch and/or winds stronger than 50 knots (58 mph), and is currently affecting or shortly expected to affect the area under the warning. A Tornado Warning is issued when a thunderstorm is believed to or does have a tornado associated with it.

In the past, if the NWS forecasters wanted to issue a Severe Thunderstorm or Tornado Warning for a location, they would select the county or counties the warning was for, and then using preformatted text, they would send out the warning**.** If the area was expected to only affect a portion of the county, the forecaster would manually type in the portion of the county in the text (example, NE, SW…etc.). Now, using the WarnGen software, which is normally overlaid over radar data, the forecaster will place either a point or polyline on the storm or line of storms they wish to issue the warning for. After placing the point or polyline, the forecaster will create the storm track by stepping back through the previous radar scans and adjust the point or polyline to match the speed and direction of the storm. After clicking on a button to create the polygon (Figure 2), the forecaster will adjust the polygon or its vertices to match the area that the forecaster believes are the locations that will be affected by the warning. When the forecaster is finished creating the polygon, they use the selection box on the left side of Figure 2 to create the text contained within the warning.

As previously mentioned, both county and polygon warnings are being issued by the NWS until October 2007. To show the difference between a polygon Tornado Warning and a county based Tornado Warning, two images were created using ArcGIS. As seen in Figure 3, a polygon Tornado Warning was issued by the Green Bay NWS on May 28, 2006. When the forecaster believed that there was a tornado located within this storm, he/she drew the polygon highlighting the area of greatest concern for the tornado. This polygon covers the far Southeast corner of Shawano County, the far Northeast corner of Outagamie County, and the Northern third of Brown County. Since this warning was issued while the County Based Warning system was still in place, the actual warning issued is seen in Figure 4. Looking at the two figures, one can easily notice the large difference in the warned area between the two possible types of warnings.

STEPS PERFORMED

Acquiring the Data

The first step for the project was acquiring the data needed. The base data needed for the project were County and County Warning Area (CWA) shapefiles. These shapefiles were collected from the AWIPS Map Database (NOAA/NWS, 2007). Using these shapefiles allowed the County and CWA shapefiles to be the same files used by the NWS forecasters, within the Advanced Weather Interactive Processing System (AWIPS), when issuing severe weather warnings. These shapefiles were created from USGS 1:2000000 DLG of counties in the United States. After collecting the basedata, the warning information for the years of 2005 and 2006 were collected.

The 2005 warning data was available from the NWS via the Geographic Information

Systems Resources website (NOAA/NWS, 2007). The shapefile contained the polygon warnings, along with attribute data that defined the office issuing the warning, the time that the warning was effective, the type of warning, and several additional categories. The 2006 data was a little more difficult to collect, as there wasn't a summarized 2006 warning shapefile available from the NWS. Therefore, the 2006 shapefiles were collected from an unofficial source, the Iowa Environmental Mesonet (IEM) (Iowa Environmental Mesonet, 2007). This site allowed the user to download shapefiles based on the time period requested. Due to restrictions on the website, only a maximum of two weeks worth of warnings could be downloaded at a time. Therefore, using a list of the NWS warnings in the Green Bay CWA, only the time periods that contained the Severe Thunderstorm and Tornado Warnings were downloaded. Using the official 2006 NWS Warnings document issued by the Green Bay office, the shapefiles were examined to verify all of the 2006 Green Bay warnings were included in the files. The shapefiles that were downloaded from IEM Archived NWS Watch/Warning site contained both the polygon and county warning and watch shapefiles, in addition to attribute data that defined the effective time, office that issued the warning/watch, the type of watch/warning, and the NWS county code.

Performing the Analyses

With all of the data collected, a new project was created within ArcGIS, with the CWA and County shapefiles used as the basemap. Since the basemap files were in the Geographic Coordinate System, NAD 83 and units of Decimal Degrees, the files were converted to Projected Coordinate System - NAD_1983_StatePlane_Wisconsin_North_FIPS_4801. This coordinate system conversion allowed the units to be in meters, which would make future area calculations easier.

Now that the units of the projected coordinate system were in meters, the Calculate Areas tool from within ArcToolbox was used to calculate the area of the county polygons in meters squared (m^2). The area data was added to the attribute table with the header F_AREA. With the area being fairly large in m^2, a second attribute column was added with the header F_AREA_KM2. Then, using the Calculate Values function within the attribute options, the following equation was used to convert the data to km^2: “F_AREA / 1000000”.

Out of curiosity and with an effort to best capture the actual areas of the counties in Northeast Wisconsin, the areas calculated in ArcGIS were compared to published county area sizes to make sure that the values were similar. Based on a previous homework assignment performed by the University of Colorado CE5383 class, some errors were expected in the area calculations. The comparisons of the area values confirmed that the calculated areas were different, with most sites differing by 10 to 20 km^2. Some values were off more than the average, especially in counties that contained several bends or curves along the border. For example, Marinette County differed by over 50 km^2 (3676 km^2 derived vs. 3628 km^2 actual) (U.S. Census Bureau, 2007). It is believed that the difference in the county areas is largely due to the quality of the county shapefile used, since the shapefile came from a USGS 1:2,000,000 DLG. Even though there are differences in the derived areas, it is believed that the present shapefiles should be used, since they are the same shapefiles used by the NWS forecasters when issuing warnings.

Now that the base data has been prepared for analysis, work began on the 2005 Warning Polygons (Figure 5). The first step was to limit the polygon warnings to just the Green Bay CWA. Therefore, the polygons were selected by attribute data, using the CWA field and selecting polygons with the "GRB" CWA value. With the features selected, the data was exported to a new shapefile for further editing. After a few trials and errors when trying to clip the shapefile containing the 2005 GRB Warnings, it was determined that the Check Geometry feature should be run from ArcToolbox. When this feature was run, it was discovered that the nearly all of the shapefiles had "incorrect ring ordering". Thus, the Repair Geometry feature was run to correct the errors. With the geometry corrected, the GRB 2005 shapefile was clipped by the GRB CWA shapefile. This removed any areas of the polygon from outside of the GRB CWA. The areas outside the Green Bay CWA (including locations over Lake Michigan and the Bay of Green Bay) shouldn't be included in the area calculation, since those areas are not officially warned. With the many ways that warning polygons can be created by the NWS forecasters, they are allowed to create the polygon as far outside of the CWA as they would like, without issuing the warning any counties outside of their CWA. If the areas outside of the CWA are not removed, it could affect the outcome of the warned area reduction statistics. An example of this can be seen in Figure 6, where the polygon warning for the northern tip of Door County was clipped down to the size filled in red.

With the 2005 warning polygons prepared, the area calculation from ArcToolbox was performed, which created a new attribute field named F_AREA. With the attribute field F_AREA in m^2, the Calculate Values feature was used from the Attribute Options menu. The equation, "F_AREA / 1000000", was used and added to a new field called F_AREA_KM2. This field contained the area values in km^2.

Since the 2005 Warning Polygons shapefile contained both Tornado and Severe Thunderstorm Warnings, the data was separated into two separate shapefiles. The 2005 Tornado Warning shapefile was created by selecting the "TO" values from the "PHENOM" attribute field and then exporting to a new shapefile. The same operation was performed for the 2005 Severe Thunderstorm shapefile, but "SV" was used to select values in the "PHENOM" attribute field.

With separate files containing the 2005 Tornado and Severe Thunderstorm Warnings, the attribute data was exported to a .dbf file, which was imported into Microsoft Excel. The calculations can be found in the Reduction Calculation section below.

Like the 2005 Warning shapefiles, the 2006 warning/watch shapefiles contained data from the entire United States. Therefore, the shapefiles needed to have all of the polygons removed that weren't issued by the Green Bay NWS office. In addition, since the shapefiles contained both Severe Weather Warnings and Watches, the watches and various other Severe Weather warnings (i.e. Flash Flood, Special Marine Warnings, etc) also needed to be removed from the shapefiles. Finally, with the shapefiles containing both polygon warnings and their equivalent county based warnings, these warnings needed to be divided into separate shapefiles. To perform all of this, two separate expressions were created to perform these selections, which were then exported to individual shapefiles (Table 1). After separating the polygon and county based warnings, the all of the polygon warning shapefiles were combined into one shapefile using ArcCatalog's Merge feature. The Merge feature was also performed on the county based

warnings shapefile. Finally, the number of county and polygon based warnings were compared to the 2006 official Green Bay NWS warnings issued, to verify all warnings were accounted for. The 2006 Severe Thunderstorm and Tornado Warnings can be seen in Figure 7.

Once again, both the polygon and county warning shapefiles contained incorrect geometries (Check Geometry – "incorrect ring ordering"), which was corrected by the Repair Geometry feature in ArcToolbox. After correcting the geometry errors, the polygon and county shapefiles were clipped based on the Green Bay CWA, to remove the extra data contained outside the CWA. With the shapefiles clipped, the areas of the polygons were calculated using the Calculate Area tool, which generated the area in m^2. Once again, the Area attribute data was converted from m^2 to km^2 using the Calculate Values tool in the Attribute menu. With all of the data needed to calculate the statistics, contained within ArcGIS, all of the basic statistical categories were calculated using the Statistics option in the Attribute menu. This data was recorded and listed in Table 2 below.

Reduction Calculation

To calculate the reduction in warned area, the County Area Ratio or CAR (Waters, 2006) was used. This ratio, created by Ken Waters, determines "the improvement of reducing the size of warnings by using polygons." (Waters, 2006) To calculate CAR, the following operation is performed:

$$\text{CAR} = 1 - \frac{PA}{\sum CA}$$

Where PA is the Polygon Warning Area in km^2
CA is the County Warning Area in km^2

With the area calculations from the 2005 warnings imported into Microsoft Excel, the polygon area calculations were placed in a single column. Then, several additional columns were added to the spreadsheet to place the county areas for each county within the warning. The "UGC" column contained all of the Wisconsin counties contained in the warning, based on the county UGC code. For example, Severe Thunderstorm Warning with an Event Tracking Number of 10 from May 9, 2005 affected the following counties: Outagamie (WIC087) and Winnebago (WIC139). The individual county areas calculated by ArcGIS, in the county shapefile, were placed in individual columns. These individual county areas were then added to come up with a total county area warned. This total county area warned was then placed in the CAR equation to determine the individual polygon warning CAR. After all of the individual polygon warning CAR values were calculated, the total CAR values were calculated. This was performed by adding all of the polygon warning areas and the county warning areas and then placing them in the CAR equation. The previous steps were performed for both the Severe Thunderstorm Warnings and the Tornado Warnings. The final numbers can be seen in the Results section below.

For the 2006 Warnings, the overall 2006 Tornado and Severe Thunderstorm areas had been calculated within ArcGIS. These values were entered into the CAR equation and the results are listed in the results section below. For the individual warnings, each warning has an Event

Tracking Number (ETN) which allows the warnings to be tracked by the NWS database and software. These ETN's were used to join the county warnings to the polygon warnings. With the joined attribute data, the individual warning CAR values were calculated.

Results

The 2005 and 2006 CAR values for each of the individual warning types can be seen in Table 2.

Statistic (Warning)	2005	2006
Tornado (TOR)	65.44%	65.26%
County Warnings	41	13
Polygon Warnings	33	11
Minimum Reduction	10.55%	44.62%
Maximum Reduction	86.47%	87.06%
Severe Thunderstorm (SVR)	53.73%	60.27%
County Warnings	168	206
Polygon Warnings	120	152
Minimum Reduction	2.61%	3.38%
Maximum Reduction	87.48%	92.02%
Overall	56.04%	60.55%

Table 2: County Area Ratio (CAR) values for 2005 and 2006.

Statistic (Warning)	2005 (in km^2)	2006 (in km^2)
Overall		
Average Size	1356.6	1116.2
Minimum Size	185.4	255.3
Maximum Size	5412.2	5021.8
Tornado (TOR)		
Average Size	974.8	797.8
Minimum Size	321.2	255.3
Maximum Size	2586.0	2036.0
Severe Thunderstorm (SVR)		
Average Size	1461.6	1139.2
Minimum Size	185.4	102.4
Maximum Size	5412.2	5021.8

Table 3: CAR Statistics on the Individual Severe Thunderstorm and Tornado Warnings

2005 Data Discussion

In 2005, there were a total of 209 County warnings (168 SVR and 41 TOR) issued for the Green Bay NWS CWA. Of that number, 153 polygon warnings were created, with 33 being Tornado Warnings (TOR) and 120 were Severe Thunderstorm Warnings (SVR). As seen in

Table 2 above, the CAR for the TOR warnings was 65.44%. This value is slightly lower than the 2005 National CAR Average for TOR, which was 72% (Waters, 2007). The average size of TOR and SVR warnings was 1356.6 km^2, with the individual values being 974.9 km^2 and 1461.6 km^2 respectively (Table 3).

The lowest amount of reduction for a TOR warning was 10.55%, which was for TOR ETN 35 that was issued on August 19, 2005. This warning can be seen in Figure 8. The warning that was issued is placed over the top of the radar data from the time of the warning. As you can see from the figure, the TOR warning was drawn to match the outline of Outagamie County. Even though there is widespread precipitation in the area, the chance that the whole county could receive a tornado is very slim. Looking at the other warnings for this system, there were two additional tornado warnings that were issued for counties bordering Outagamie County; Waupaca (17 minutes prior) and Winnebago (14 minutes prior) Counties. In this case, it is more than likely that the forecaster, in an effort to get the warning out and due to the widespread nature of the storms and tornado threat, just made the polygon match the county outline. At this time, the Green Bay NWS forecasters were not required to draw the polygon to an area smaller than the county.

The highest reduction in a TOR warning was 86.47%, for TOR ETN 23, which was issued on June 10, 2005. An image of this warning can be seen in Figure 9. This warning took place within Marathon County in Central Wisconsin. Looking at Figure 9, this polygon warning represents a great advantage of the polygon warning system. In this case, the forecaster used the polygon to highlight the area that they believe is under the highest risk for a tornado. The polygon only covers parts of Central and Northeast Wisconsin. In the county based warning system, the entire county would be placed under a Tornado warning, even though most of the area wouldn't experience the possible tornado. The county based warnings do use descriptors to represent the area of the county affected by the warning, but they are limited to the 9 division parts of a county (i.e. Northeast, East Central, etc.) (National Weather Service, 2005). Therefore, visual representation of the Tornado Warning will be very useful for any persons near or in the warned area.

For the SVR warnings, the 2005 CAR was 53.73%. This value is approximately 12% less than the TOR value. This difference is expected due to the differences in size between a tornado and other severe weather occurring in a thunderstorm (severe winds and hail).

The largest area reduction in a SVR warning was 87.48%, which was for SVR ETN 8 that was issued on May 06, 2005. This warning can be seen in Figure 10. This warning was issued for Marinette County, and as you can see in the figure, the warning represents a small part of the entire county. In this case, the severe thunderstorm was occurring in the southeast corner of the county. Therefore, the forecaster outlined the area the best reflected the possible severe weather. If a person living in the western or northern part of Marinette County saw the location of this polygon, they would know that they are not in harms way. Once again, this could be represented by wording in the warning, but persons near the warning area will have a better understanding of location of the possible severe weather.

The smallest area reduction for a SVR warning in 2005 was 2.61%. This warning was

issued on July 23, 2005, with ETN 83. As you can see in Figure 11, the polygon was drawn almost exactly along the county borders. This situation is unique, as even though the CAR is very low, the polygon size would probably be similar in size to the current polygon. With the size of the line of severe thunderstorms approaching the area, it is likely that the storm will affect all persons living in both of the counties. Therefore, it is possible that there will be situations were a county wide Severe Thunderstorm Warning will be warranted.

2006 Data Discussion

The overall 2006 CAR value (60.55%) improved on the 2005 CAR values by more than 4%. This improvement is likely due to the forecasters becoming more confident and understanding of the polygon warning process. In addition, the average size of all of the 2006 warnings decreased by 240 km^2 (Table 3), which also reflects a more focused polygon warning than in 2005.

Looking at the 2006 Tornado CAR values (Table 2), the overall values are very similar to the 2005 values. The similarity between the two values is expected, since the forecasters should be attempting to outline the area were the tornado is believed to be. With tornadoes occurring on a very small scale, the values should be similar. There was a marked improvement in the Minimum Reduction value, which increased by more than 34%. After looking at the individual polygon tornado warnings issued by the Green Bay NWS office, it is believed that this improvement was due to better placement of the polygons by the NWS forecasters.

As for the 2006 Severe Thunderstorm CAR values, there was an improvement of nearly 7% with the overall values, while the Minimum and Maximum Reduction values are very similar to the 2005 data. There is much improvement in the average size of the polygon, with the 2006 SVR polygon warning area averaging 322 km^2 (22%) less than the 2005 SVR warnings (Table 3). As mentioned above, the improvement is likely due to increased forecaster usage and knowledge of the polygon warning system.

Questions/Comments/Future Research

One possible problem with the polygon warning calculation is that the forecasters have some leeway when drawing the warning polygon. The forecasters are allowed to have a small slivers or parts of the polygon in a county that is not warned for. In addition, if the forecaster draws the polygon across several counties, they may remove the unwanted counties from the warning with a single mouse click. This may have created some slightly larger polygon areas, and in-turn affected the CAR percentage. It is believed that these values are usually small and occur to infrequently to have too much of an effect on the overall CAR value.

Another factor that could have an effect on the individual and overall CAR values, is the forecaster influence on the polygon. Depending on the forecaster, one may be more likely to issue smaller polygons, better reflecting the most severe part of the storm; whereas another forecaster may issue broader polygon warnings to make sure the storm doesn't move outside of the polygon or to make sure they capture all of the severe weather reports.

This leads into another concern with polygon warnings in the future. At the present time, even though the NWS issues polygon warnings, the warnings are verified based on the county-base warning. Therefore, if a severe weather report is received from outside of the polygon warning area, it still counts as a verified warning. With the end of county based warnings on October 1, 2007, it is possible that the polygon warnings may get larger than they have been in the past couple of years. That way, if a severe weather report is received along the outer edge of the storm, the report will still verify the warning. Theoretically, the polygon warning should highlight the most severe part of the storm and therefore, no severe reports should be received outside of that area. But it is always possible for new developments within the storm to cause severe weather reports to come from outside of the warned area.

Finally, there is the possibility that a storm may move outside of the polygon warning, before the warning expires. In the previous county based warning system, this wasn't too much of a concern, unless the edge of the polygon coincided with the edge of the county. Therefore, if the storm moved outside of the polygon, the storm would still be warned for, as long as it remained in the county. In October 2007, with the polygon warnings, if the storm moves outside of the polygon and it is still believed that the storm is severe, a new warning will need to be issued for the storm. This will likely increase the number of warnings issued, but should keep the CAR values nearly the same.

While this project just looked at the difference in area warned, future research could be conducted by looking at the accuracy of these warnings with associated severe weather reports. In addition, research could be performed to determine the affect the move to the polygon warning system has on the persons living in the county. For example, instead of the county area in the CAR equation, it could be the reduction in population.

Conclusion

Overall, it appears that the move to polygon based warnings will greatly reduce the falsely warned area that occurred with county based warnings. Both the 2005 and 2006 severe weather seasons showed an improvement in the falsely warned areas by 56 and 60.5% respectively. Additionally, there was a noticeable decrease in the size of the polygon warnings from 2005 to 2006. This improvement signals the acceptance and usage of the polygon warning system by the NWS forecasters to highlight the specific area of severe weather.

With more than a 4% improvement in the overall CAR from the 2005 to 2006 severe weather seasons, it is expected that the CAR will improve again in the 2007 severe weather season. But, it is not believed that the overall 2007 CAR will improve by the same percentage as in 2006, but there should be a slight increase towards the Tornado CAR values.

Tables

Warning Polygon Type	Expression
Polygon	"WFO" = 'GRB' AND "GTYPE" = 'P' AND "SIG" = 'W' AND "PHENOM" <> 'MA' AND "PHENOM" <> 'FF'
County	"WFO" = 'GRB' AND "GTYPE" = 'C' AND "SIG" = 'W' AND "PHENOM" <> 'MA' AND "PHENOM" <> 'FF'

Table 1: Expressions used to Select the appropriate polygons from the 2006 warning shapefiles.

Figures

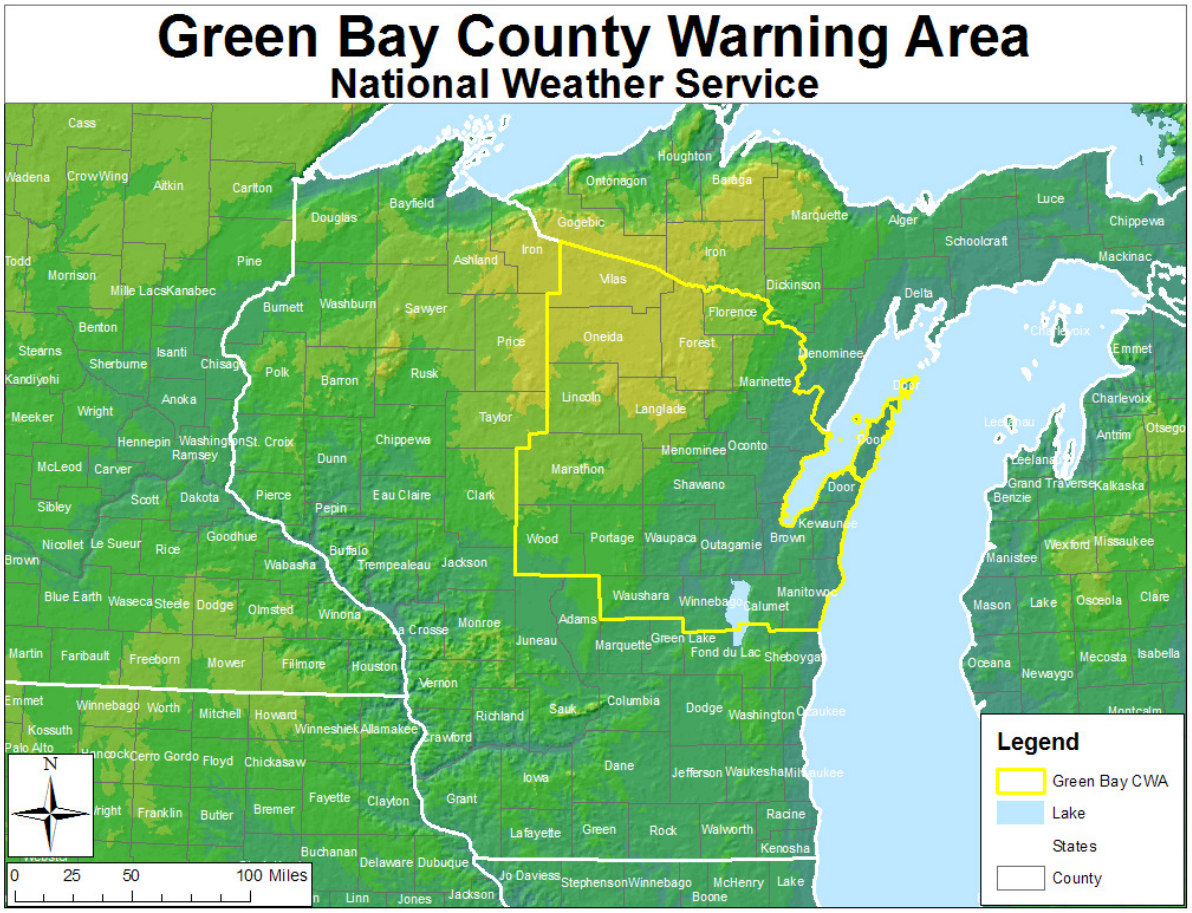

Figure 1: The County Warning Area (CWA) of the Green Bay, WI National Weather Service Office.

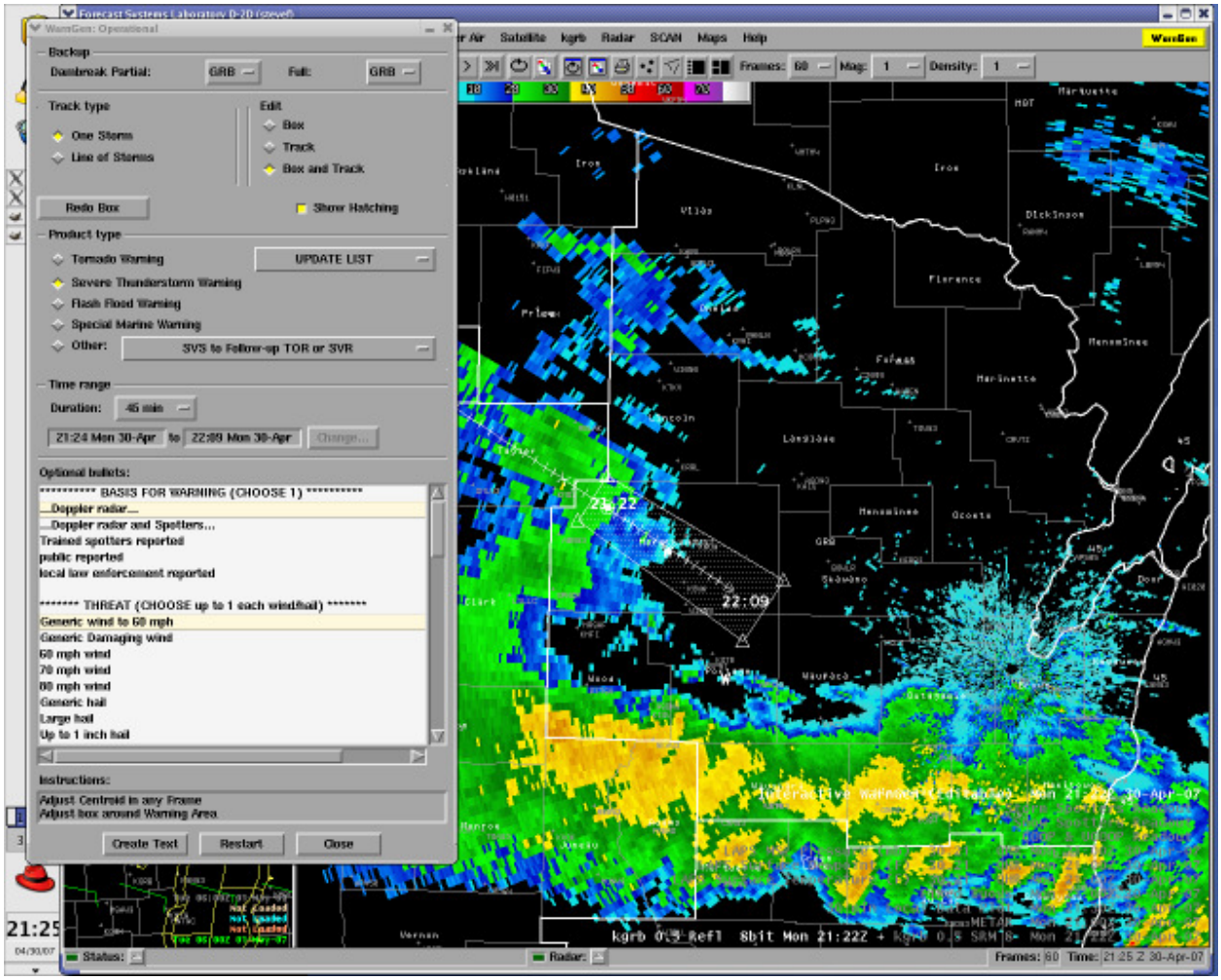

Figure 2: The WarnGen interface in AWIPS, as used by NWS Forecasters.

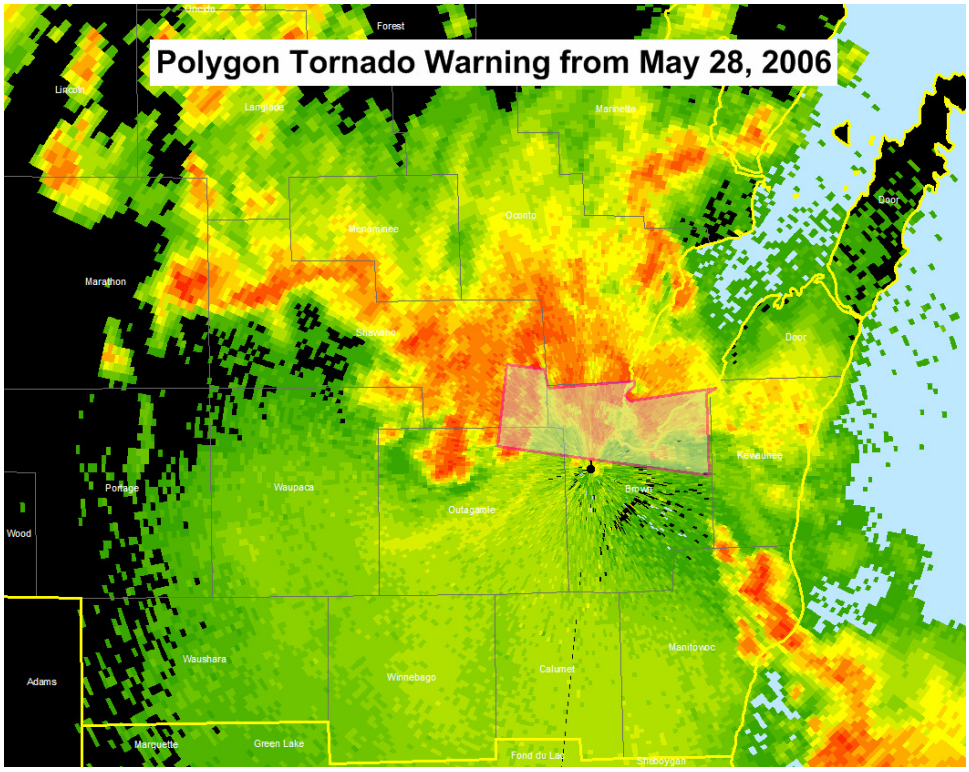

Figure 3: The Polygon Tornado Warning issued by a NWS Forecaster on May 28, 2007.

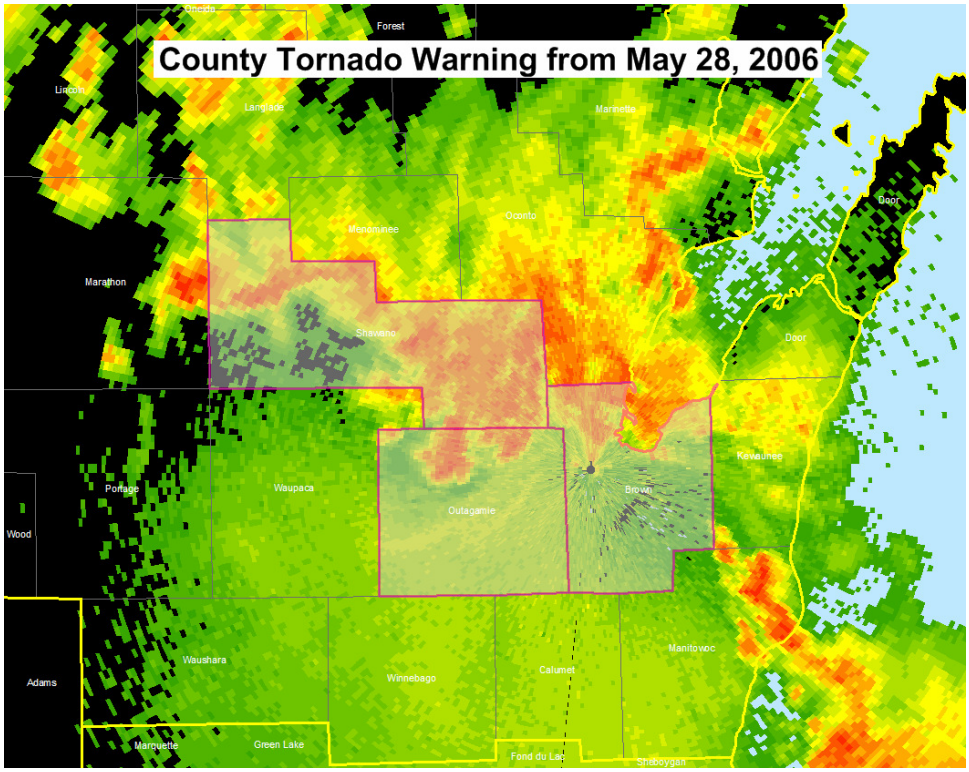

Figure 4: The "Official" County Based Tornado Warning issued by a NWS Forecaster on May 28, 2007.

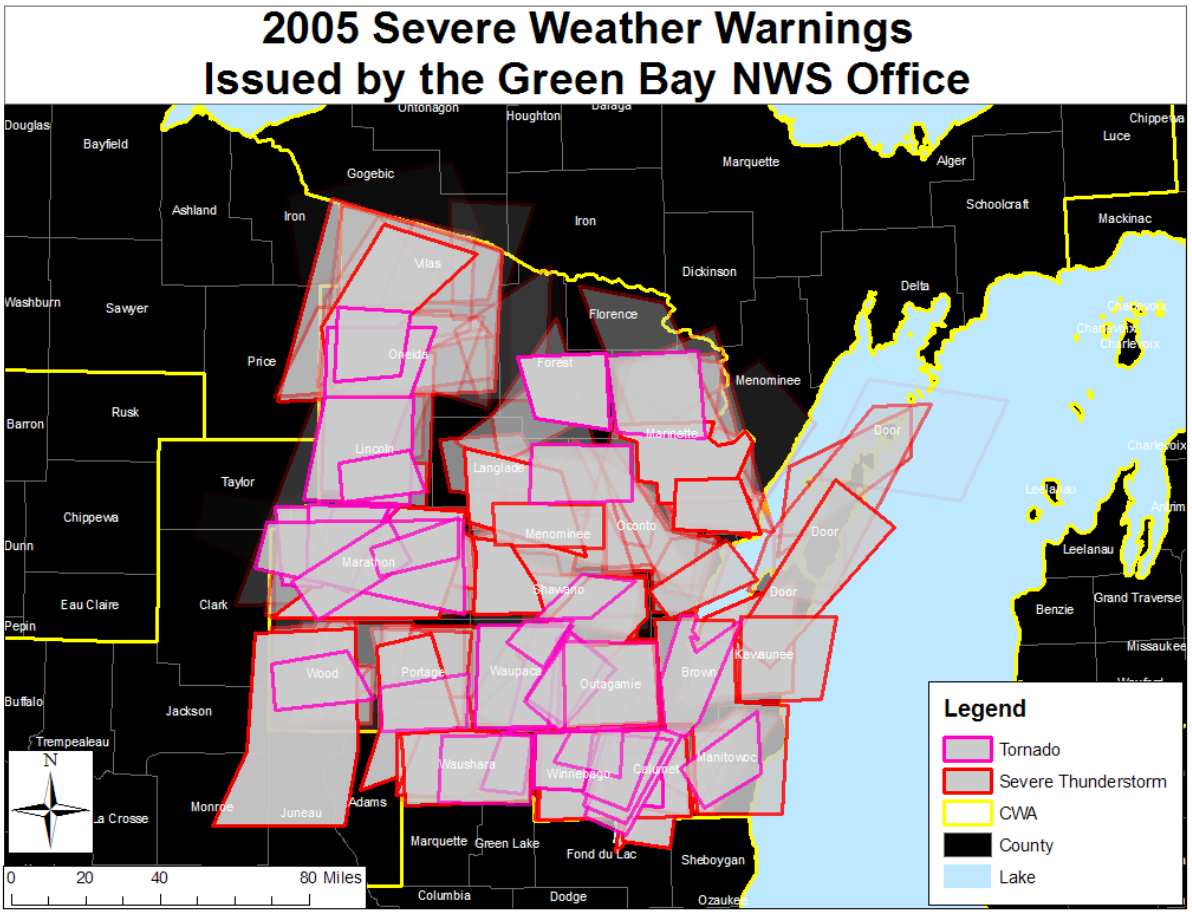

Figure 5: The 2005 Severe Thunderstorm and Tornado Warnings issued by the Green Bay NWS.

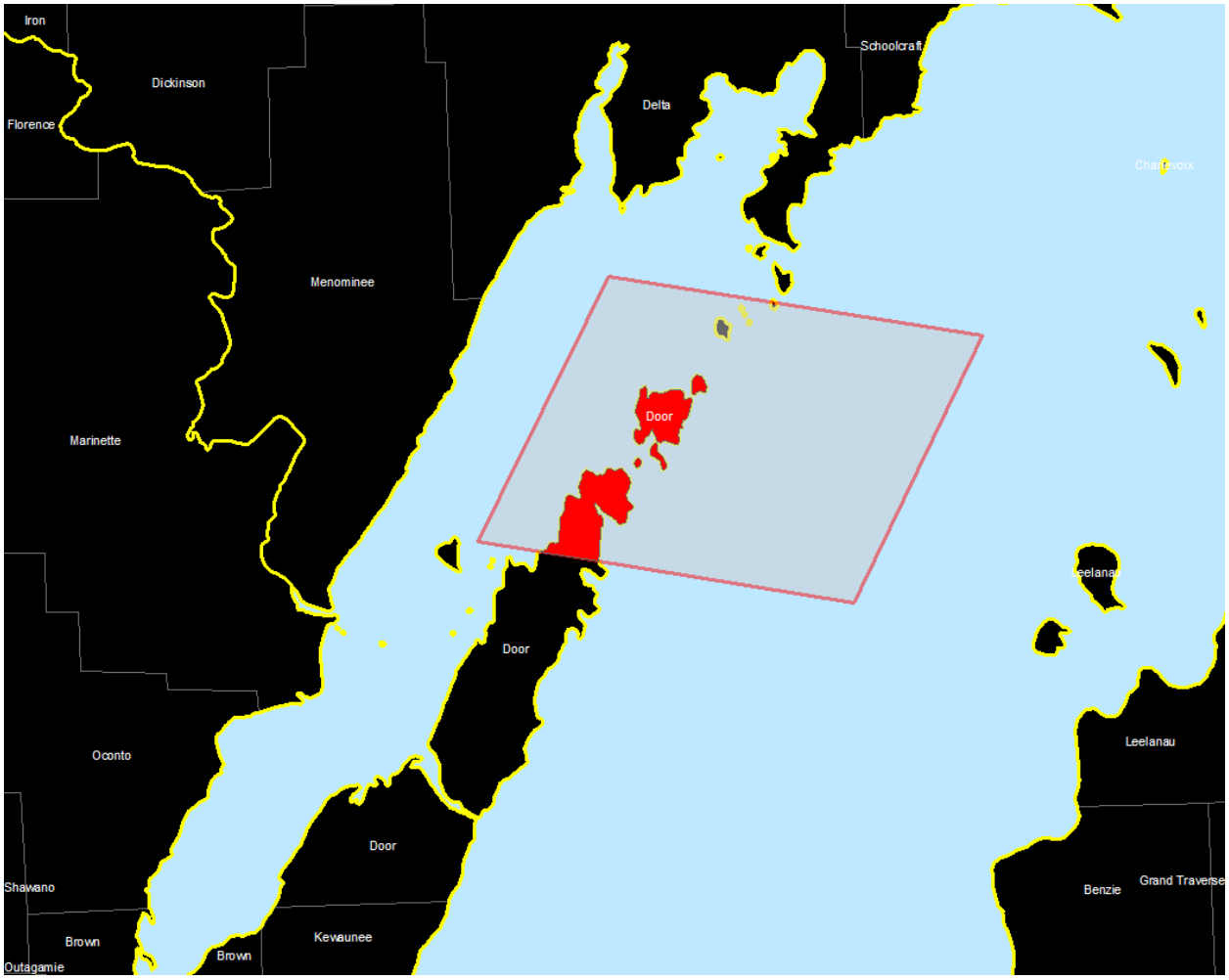

Figure 6: Initial Polygon Warning issued for Door County, Wisconsin. Since the Severe Thunderstorm Warning does not cover marine areas, the locations outside of Door County were removed. The resulting Polygon Warning for Door County is filled in red.

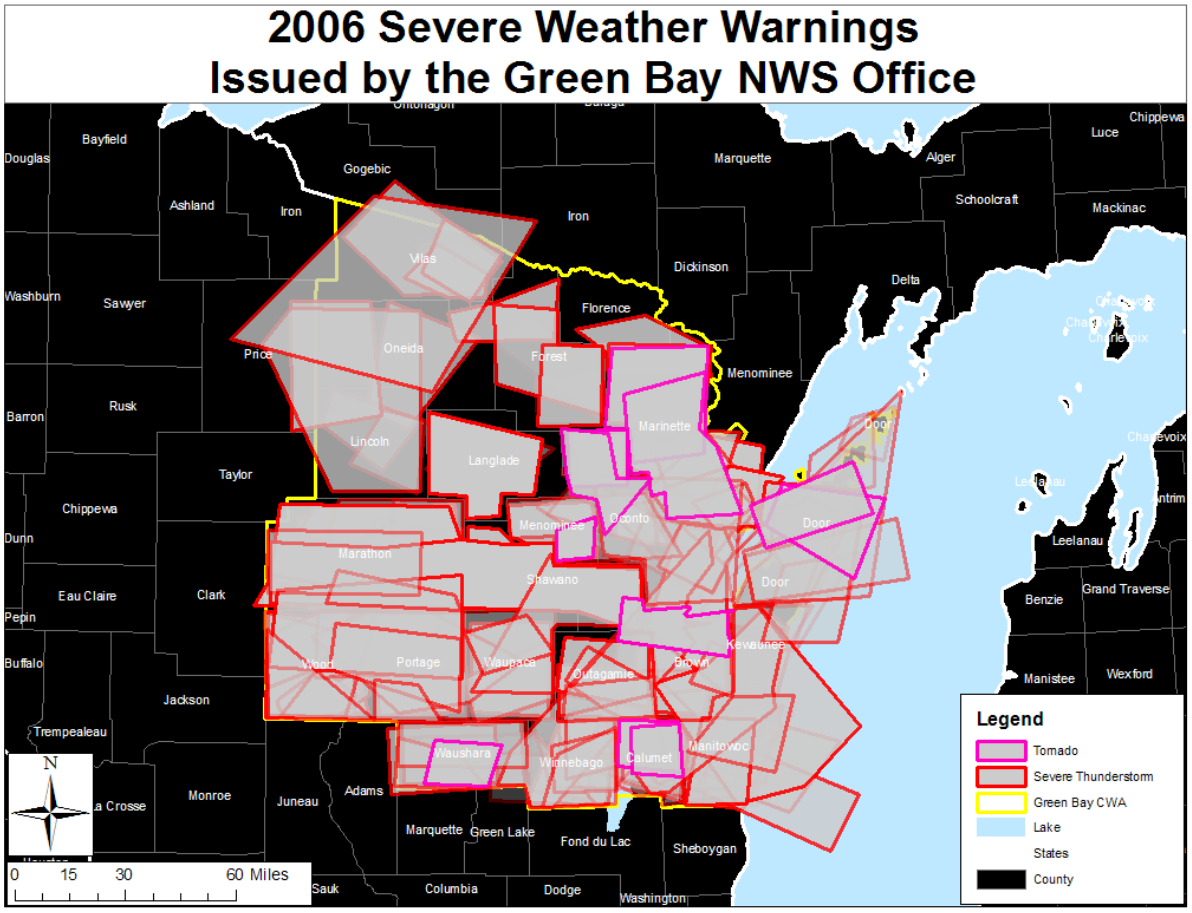

Figure 7: 2006 Polygon Severe Thunderstorm and Tornado Warnings issued by the Green Bay NWS Office.

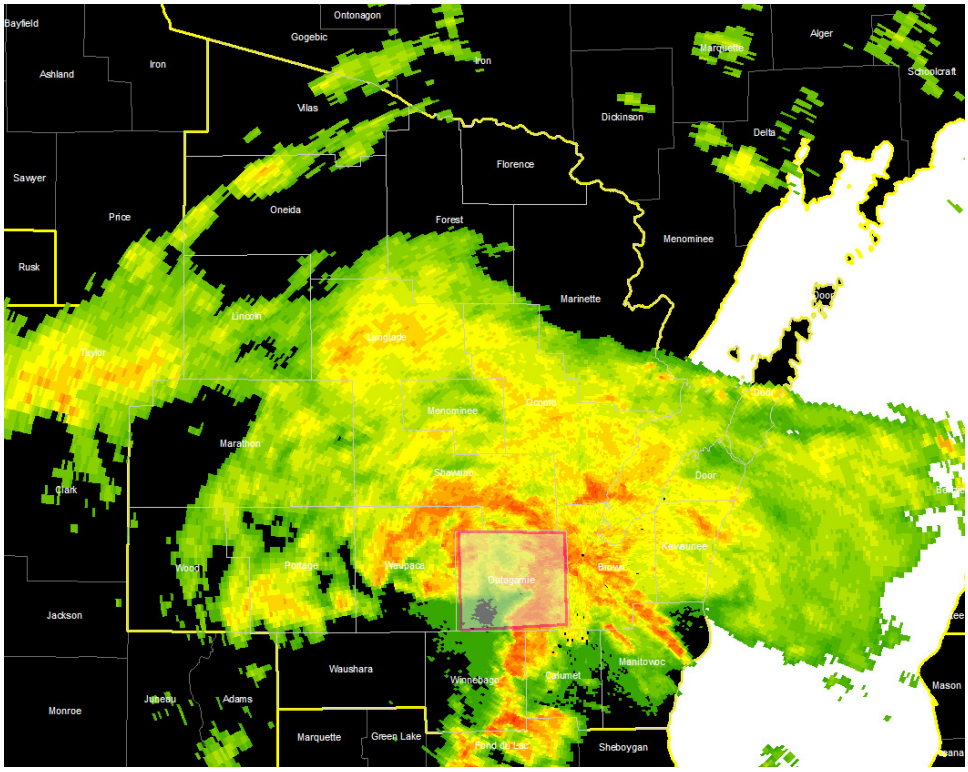

Figure 8: Polygon Tornado Warning issued for Outagamie County on August 19, 2005.

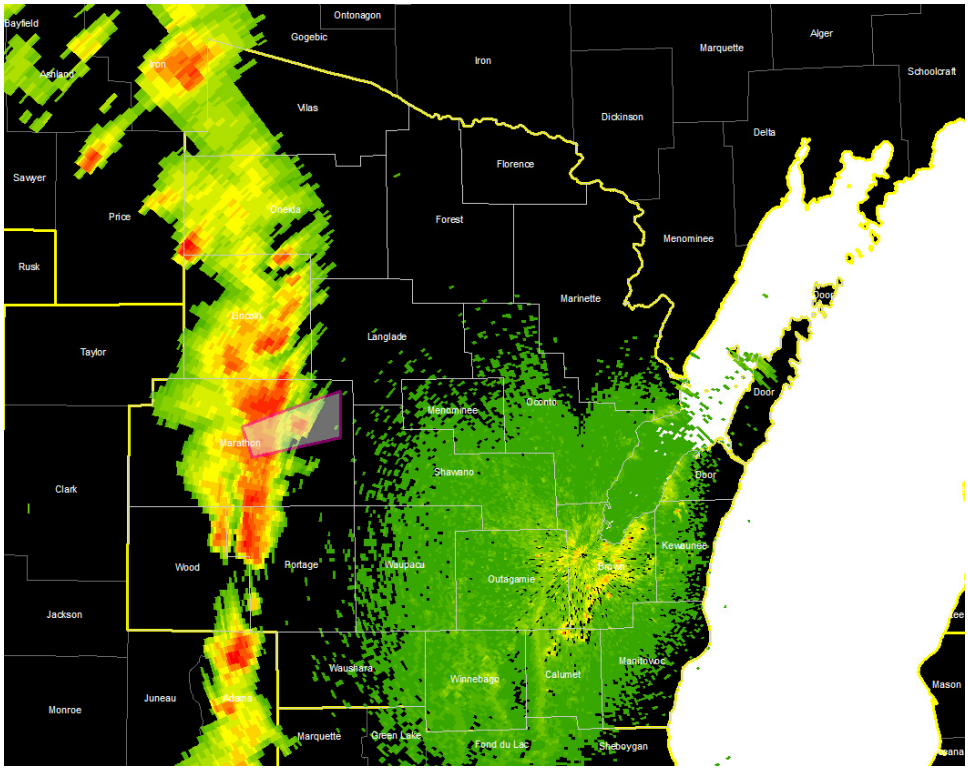

Figure 9: Polygon Tornado Warning issued by the Green Bay NWS Office on June 10, 2005.

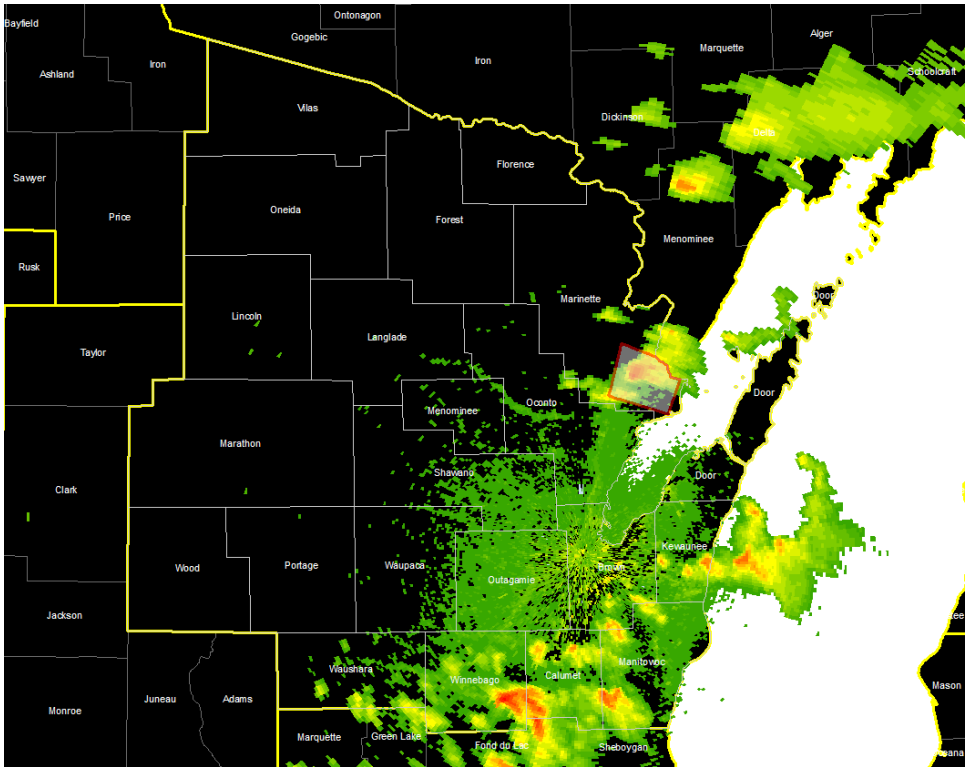

Figure 10: Polygon Severe Thunderstorm Warning issued on May 06, 2005. This polygon warning had the largest CAR value for a Severe Thunderstorm Warning.

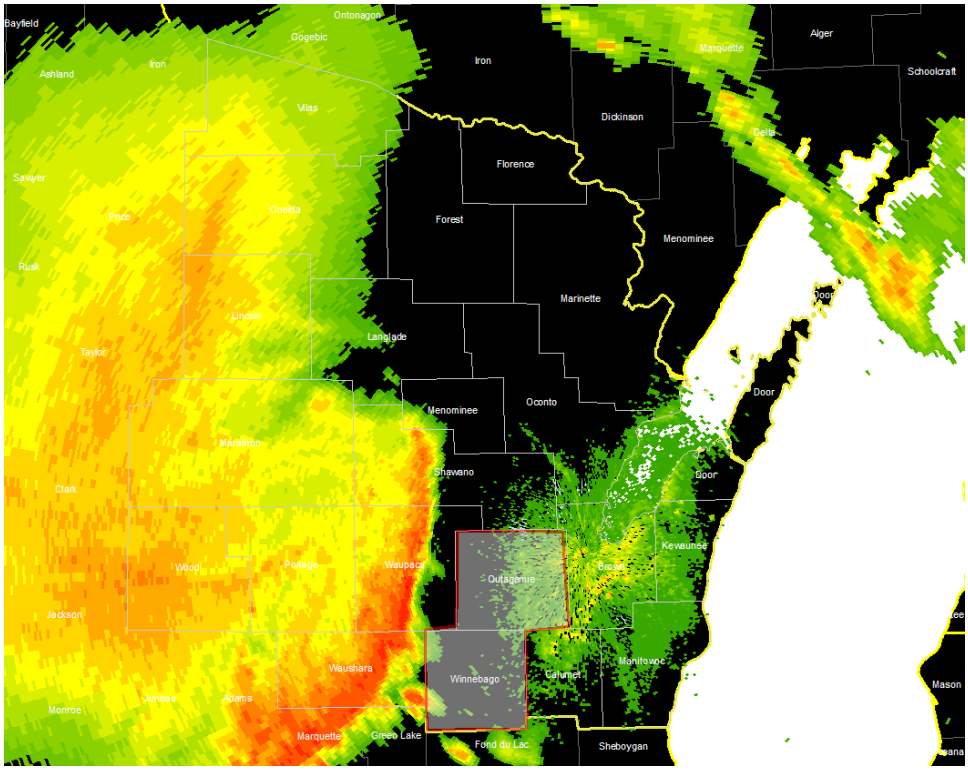

Figure 11: Polygon Severe Thunderstorm Warning issued on July 23, 2005 for Outagamie and Winnebago Counties. This polygon warning had the lowest CAR value for SVR.

REFERENCES

Iowa Environmental Mesonet. 04/02/2007. "IEM GIS – Archived NWS Warnings." http://mesonet.agron.iastate.edu/GIS/

National Climatic Data Center, 04/16/2007. "HAS Radar Data." http://has.ncdc.noaa.gov

National Weather Service, 1995: *National Weather Service Operations Manual*, Part C, Chapter 40.

National Weather Service, 2005: *WFO Severe Weather Products Specification*, NWS Instruction 10-511, NOAA. http://www.nws.noaa.gov/directives/sym/pd01005011curr.pdf

NOAA/NWS. 04/02/2007. "AWIPS Map Database." http://www.weather.gov/geodata/.

NOAA/NWS. 04/02/2007. "Geographic Information Systems Resources." http://www.weather.gov/regsci/gis/.

NOAA/NWS. 04/20/2007. "Storm-Based Warnings." http://www.weather.gov/sbwarnings/

U.S. Census Bureau. 04/04/2007. "State & County QuickFacts." http://quickfacts.census.gov

Waters, Ken, 2006: *Definition of Severe Weather Metric, "County Area Ratio."*

Waters, Ken, 2007: *Verification of National Weather Service Warnings Using Geographic Information Systems*.