# Development of the Door County Supercell on 23 August 1998

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ABSTRACT

Analyzes a supercell the produced a tornado over northeast Wisconsin on 23 August 1998. A shortwave passing over Wisconsin provided upward vertical motion while a combination of daytime heating and low-level moisture provided sufficient instability. The supercell developed first as a small storm cell along the shortwave, restricted by a weak cap. A lake breeze provided the lifting mechanism to break through the cap, enhancing the storm cell, as well as changing the path of the storm. The tornado was estimated to be an F3 on the Fujita scale and caused millions of dollars in damage. Analysis provides radar images throughout the development of the supercell.

## 1. Introduction

The Door County supercell that developed on 23 August 1998 was one of three supercells to develop that day over Wisconsin and produced damaging hail and tornadoes. Conditions for supercell development were weak and the Storm Prediction Center downgraded the severe weather threat from moderate to a slight risk during the day. The supercell that moved over Door County developed a tornado over the bay of Green Bay before reaching the Door Peninsula and hitting a county park. The tornado was an estimated half-mile wide and created a path just over five miles long, ending a few miles short of the east coast. The tornado was rated an F3 and caused an estimated $4.7 million in property damage, $1.8 million in crop damage and two injuries. Although synoptic conditions were unfavorable for supercell development over northeast Wisconsin, analysis of model data and surface conditions shows mesoscale events that allowed a supercell to develop and produce a tornado.

## 2. Data

In this paper, the Door County supercell is examined using Doppler radar data from Green Bay, surface and upper air observations and model data taken from the ETA 211 model. The ETA 211 model will be referred to as the ETA model from this point on. The model data was taken from the 23 August 1998 run at 1200 UTC.

## 3. Synoptic Overview

A weak low pressure trough was located over the upper Midwest at 1800 UTC on 23 August (Fig. 1). The trough helped bring in an overall west-southwesterly flow at the surface and a zonal flow aloft. A jet streak at 300 hPa was located over the northern United States (Fig. 2), extending from northern California, through the northern plains, to western Wisconsin, over which the exit region of the jet was located. With further analysis of the vertical motion at 700 hPa (Fig. 3), it did not appear that the jet had any influence on the development of the supercell.

The vertical motion at 700 hPa shows a large amount of synoptic descent over most of Wisconsin and the convective inhibition (CIN) provided a weak cap near the surface (Fig. 4). The combination of synoptic descent and CIN prevented upward vertical motion. Much of the Midwest saw temperatures

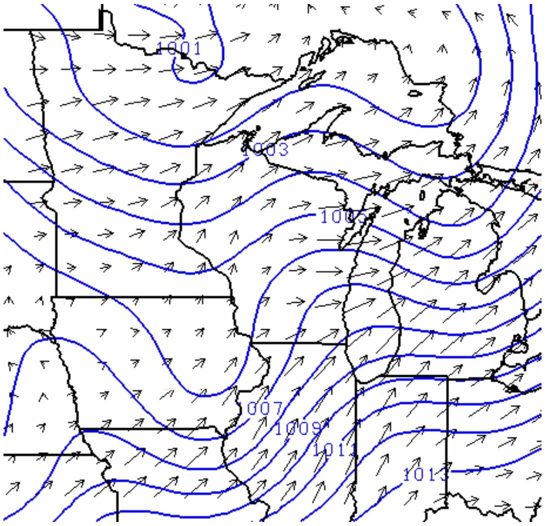

Fig. 1. Surface pressure (blue lines) and wind (arrows). Valid for 18Z on 23 August 1998.

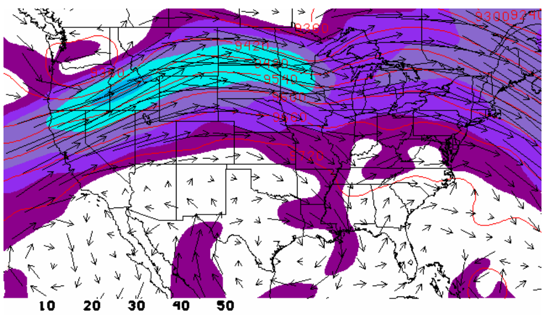


Fig. 2. 300 hPa winds (arrows), wind speed (filled contours) and geopotential heights (red lines). Wind speed measured in knots and geopotential heights measured in m. Valid for 18Z on 23 August 1998.

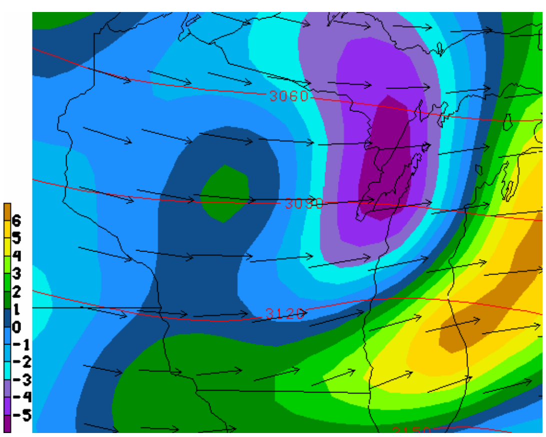


Fig. 3. 700 hPa vertical motion (filled contours), geopotential height (red lines) and wind (arrows). Vertical motion measured in cm/s and geopotential height measured in m. Valid for 18Z on 23 August 1998.

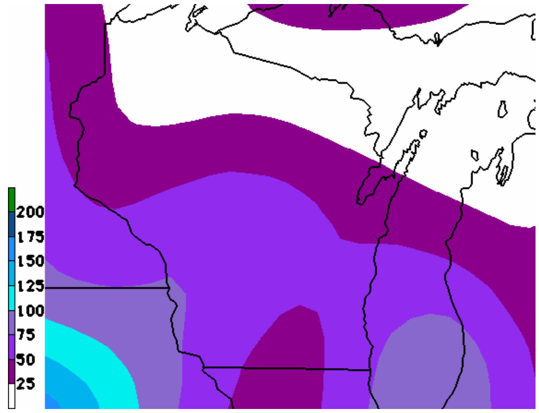


Fig. 4. Surface convective inhibition (CIN), measured in J/kg. Valid for 18Z on 23 August 1998.

in the upper-70s Fahrenheit to lower-90s (25 to 35ºC) (Fig. 5).

## 4. Mesoscale Analysis

A cross section (Fig. 6) taken through the Door County supercell provides insight to the driving mechanisms of the storm. The cross section is parallel to the path of the supercell. Higher values of equivalent potential temperature (theta-e) are located near the surface and to the southeast of the supercell due to large amounts of available moisture. Behind the supercell, theta-e values are lower from cooler temperatures, produced by precipitation evaporating in the rear flanking downdraft. Above 600 hPa, theta-e values are low from a dry layer that extends to the tropopause. The updraft of the supercell is visible with high values of theta-e extending from the surface to the tropopause. Potential temperature (theta) values are shown expanding at mid levels due to latent heating and increasing the temperature within the supercell.

### *A. Shortwaves within Low Pressure Trough*

There were several shortwaves within the low pressure trough that

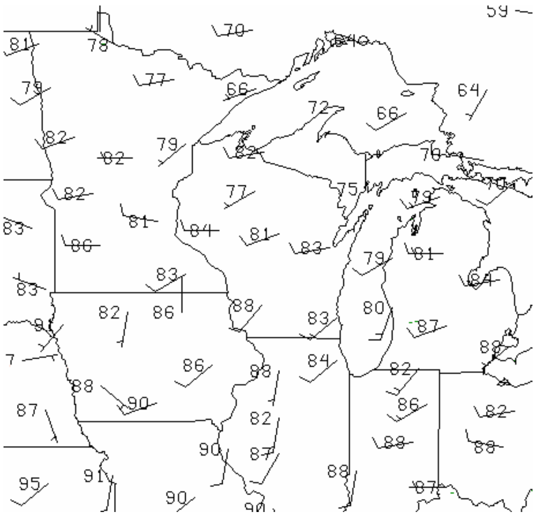

Fig. 5. Observed surface temperatures (ºF) and winds (knots). Valid for 18Z on 23 August 1998.

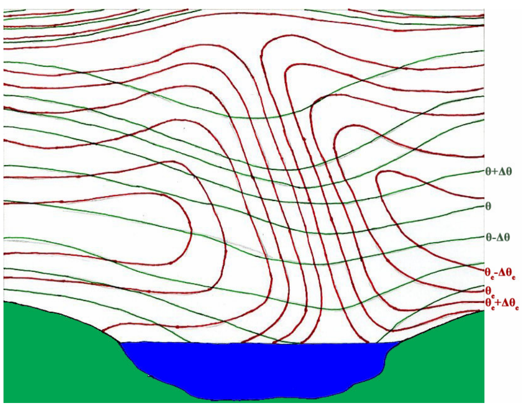


Fig. 6. Cross section of supercell passing over the bay of Green Bay. Oriented in a northwest to southeast direction and taken parallel to the storm path.

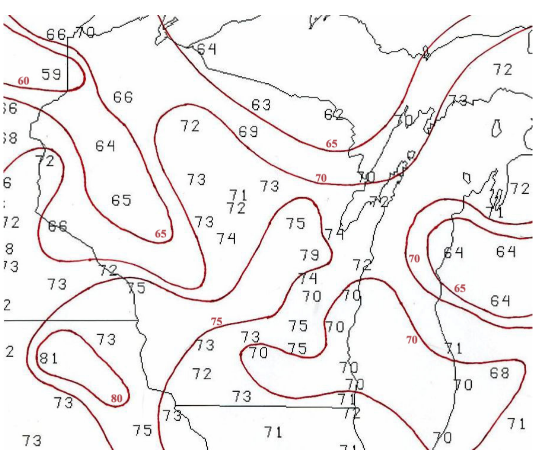

Fig. 7. Observed surface dew points (ºF). Contours are for every 5ºF. Valid at 18Z on 23 August 1998.

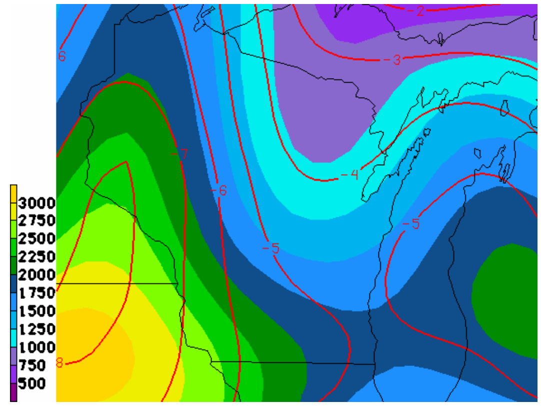


Fig. 8. CAPE (filled contours) and Lifted Index (red lines). Valid for 18Z on 23 August 1998.

extended into the upper Midwest (Fig. 1). The first shortwave that passed over Wisconsin helped set off precipitation that later would provide the low-level moisture the next day. By 1800 UTC the first shortwave moved over central Michigan leaving eastern Wisconsin under a shortwave ridge. The ridge produced an area of downward vertical motion due to diverging ageostrophic winds, which discouraged cloud development over eastern Wisconsin. With clear skies, daytime heating helped to destabilize the air near the surface and create a warm, well-mixed boundary layer.

The second shortwave was located along the Wisconsin-Minnesota border at 1800 UTC. The shortwave helped to produce areas of weak upward vertical motion over central and southern Wisconsin (Fig. 3). As the shortwave propagated to the east, the upward vertical motion moved over northeast Wisconsin and provided enough lift for the unstable air near the surface to break through the weak cap.

### *B. Available Moisture*

Dew points throughout the state were influenced by the first shortwave that passed through the previous night and triggered precipitation. As the day

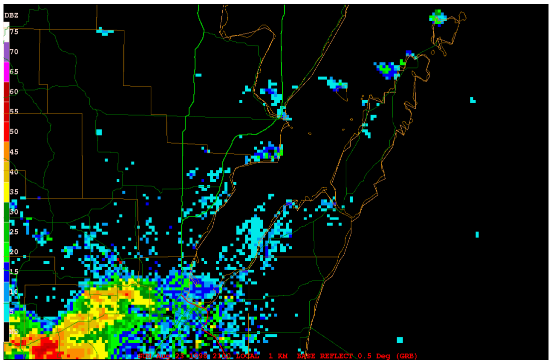

Fig. 9a. WSR-88D reflectivity from Green Bay, WI (GRB). Valid at 2100 UTC on 23 August 1998.

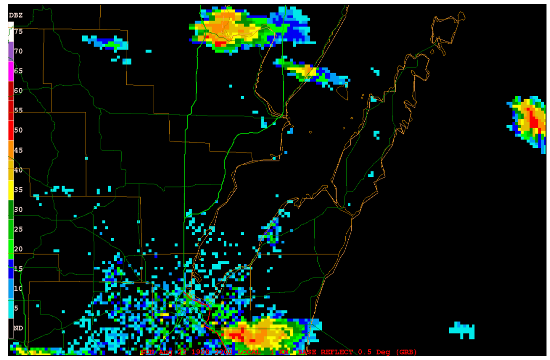

Fig. 9b. WSR-88D reflectivity from Green Bay, WI (GRB). Valid at 2200 UTC on 23 August 1998.

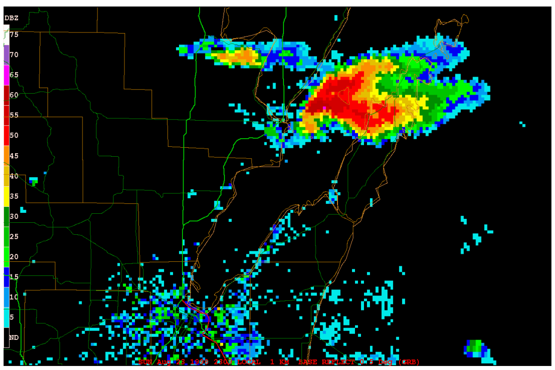

Fig. 9c. WSR-88D reflectivity from Green Bay, WI (GRB). Valid at 2310 UTC on 23 August 1998.

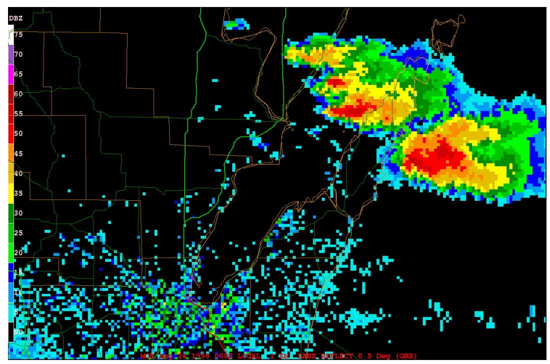

Fig. 9d. WSR-88D reflectivity from Green Bay, WI (GRB). Valid at 0000 UTC on 24 August 1998.

progressed and daytime heating destabilized the boundary layer, a weak inversion developed and sustained the high dew points near the surface. Surface observations throughout Wisconsin showed dew points above 60ºF (16ºC), with much of southern Wisconsin seeing dew points in the 70s (Fig. 7). Many convective cumulus clouds were observed to develop as the second shortwave passed over Wisconsin. Surface observations also recorded southwesterly winds at 1800 UTC (Fig. 5). Despite being relatively weak, the winds were able to advect more moisture into northeast Wisconsin.

*C. Instability and Available Energy*

The stability at the surface continued to decline throughout the day as daytime heating occurred. By 1800 UTC Wisconsin was seeing lifted index values less than -4ºC/km (Fig. 8), sufficient for supercell development. As the second shortwave over western Wisconsin moved east, the instability continued to increase, promoting stronger supercell development.

The convective available potential energy (CAPE) also increased throughout the day. The CAPE remained fairly weak at 1800 UTC (Fig. 8) over northeast Wisconsin, with values slightly above 1000 J/kg, but daytime heating near the surface helped to increase values more than twofold within a six-hour period. Just before the initial tornado reports, storm relative helicity was also recorded at 135 $m^2/s^2$.

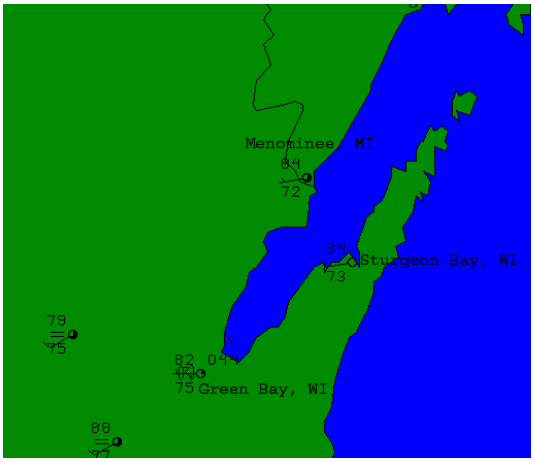


Fig. 10a. Surface observations for northeast Wisconsin. Valid at 2100 UTC on 23 August 1998.

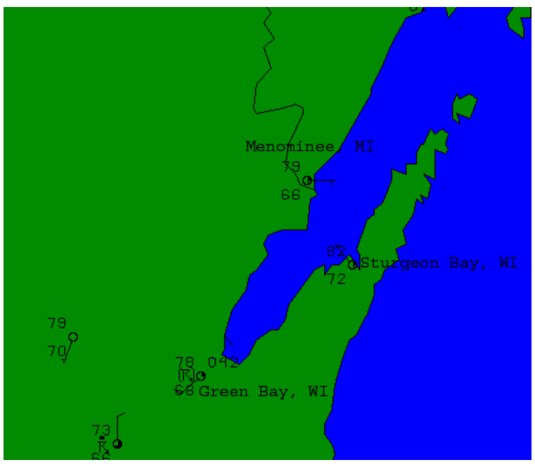


Fig. 10b. Surface observations for northeast Wisconsin. Valid at 2200 UTC on 23 August 1998.

*D. Lake Breeze Circulation and Evolution of the Storm Cell*

By 2100 UTC an isolated storm cell started to develop in northern Oconto County, near the Marinette County border (Fig. 9a). The storm cell moved toward the east, growing in size, but showed no evidence of rotation, possibly from a weak updraft. The observation station in Menominee, Michigan recorded southwesterly winds at 5 knots (2.6 m/s), with a temperature of 84ºF (29ºC) and a dew point of 72ºF (22ºC) (Fig. 10a).

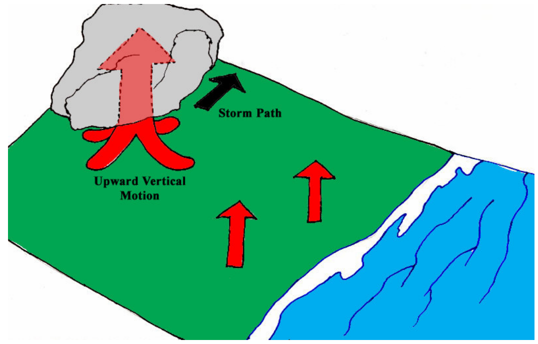


Fig. 11a. Conceptual model of storm cell before interacting with a lake breeze. The storm path is indicated with a black arrow and upward vertical motion is indicated with red arrows.

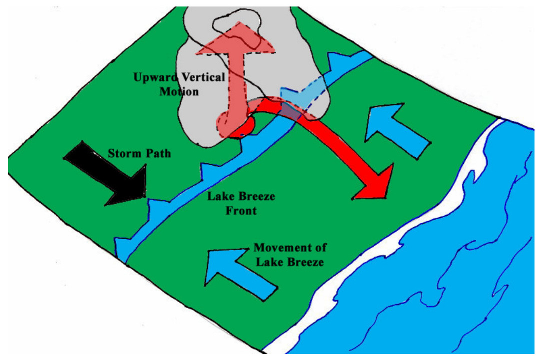


Fig. 11b. Conceptual model of storm cell interacting with a lake breeze. The storm path is indicated with a black arrow and upward vertical motion is indicated with red arrows. Lake breeze front is indicated by a cold front and the movement of the lake breeze is indicated by the blue arrows. Note the change in the storm path from Fig. 11a.

Around 2200 UTC a lake breeze developed off the bay of Green Bay, changing the wind observed in Menominee from southwesterly to easterly (Fig. 10b). The temperature dropped to 79ºF (26ºC) at the station, a decrease of 5ºF in an hour. In the next two hours the temperature would drop another 6ºF. The storm cell that developed had moved over the Wisconsin-Michigan border, approximately 22 miles (35 km) northwest of Marinette at this time (Fig. 9b). As the lake breeze pushed further inland it came into contact with the storm cell and provided extra upward vertical motion, lifting the unstable, moist air from the surface.

After coming into contact with the lake breeze, the storm cell started to develop a traditional supercell structure on the radar. The path of the storm also changed dramatically, moving southeast instead of due east. The change in direction of the storm's path came from the lake breeze front that provided stronger upward vertical motion than the potential vorticity (PV) anomaly that first started the convective storm.

The storm continued to develop and move southeast, passing just north of Menominee and out over the bay of Green Bay. By the time the supercell had reached the bay a well defined "V-notch" had developed on the east side of the storm and a strong rotation could be seen in the radar reflectivity (Fig. 9c). The supercell produced a tornado over the bay and was first observed at 2310 UTC. The storm continued to move southeast, finally reaching the Door County peninsula by 2330 UTC, with the tornado remaining on the ground for another five miles. The tornado was estimated to dissipate around 2344 UTC.

The supercell moved over Lake Michigan by 0000 UTC on 24 August (Fig. 9d). At this time the supercell had started to dissipate due to inflow from the storm cells that developed to its northwest, but still remained strong. The path of the storm cell changed as it moved over Lake Michigan, once again taking a westerly path.

**5. Conclusion**

Convective storms were able to develop due to a shortwave passing over Wisconsin while a lake breeze provided enhanced lifting for a storm cell to develop into a supercell and produce a tornado. The lake breeze also changed the path of the storm by providing a stronger upward vertical motion that the PV anomaly that first started the storm cell. A weak inversion provided a strong enough cap to sustain a moist, well-mixed boundary layer for most of the day until a lifting mechanism, such as a PV anomaly or lake breeze front.

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