Severe Weather on 11 June, 2008

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Abstract

On the 11th of June, 2008 there were at total of 341 severe weather reports across the western edge of the corn belt, starting in central Kansas, and extending northeast into central Minnesota. This paper examines the causes for why the severe weather outbreak occurred, both from a synoptic and mesoscale perspective. There was abundant low level moisture from both nocturnal thunderstorms the night before, as well as the strong advection of Gulf moisture into the region. An area of convergence associated with a surface front provided a lifting mechanism at the surface. There was diffluent flow above 500mb, which aided in the upward vertical motion at lower levels. There was also a dry elevated mixed layer above 500mb which led to large CAPE values. Southerly winds at the surface, and westerly winds aloft meant that there was veering with height, creating an environment favorable for tornadoes. Special attention was given to an F3 tornado, and it was determined that the tornado was most intense while the storm made its right turns. Finally, another possible contribution strong southerly winds, by means of the Sawer-Eliasson Circulation in the jet exit region, was analyzed and left up for debate.

1. Introduction

Every year dry air from the Great Basin gets ejected out over the High Plains, meanwhile low level moisture from the Gulf of Mexico is advected northward into the Midwest. During the spring and summer months, the combination of the two sets the stage for severe weather. The dry elevated mixed layer can have steep lapse rates (on the order of 8-9^{o}C), and together with the warm moist air at lower levels, leads to a very potentially unstable air mass. However, unless there is a forcing mechanism to release the convective available potential energy (CAPE), the atmosphere will remain just that, *potentially* unstable.

June 11th, 2008 had both of the two ingredients mentioned earlier, as well as several others, which caused that day to be favorable for severe weather to develop. As will be shown shortly, both upper level dynamics and veering winds with height, contributed to the development of supercell thunderstorms. The byproducts of these storms were over a hundred hail and wind reports, as well as several tornadoes (Fig 1).

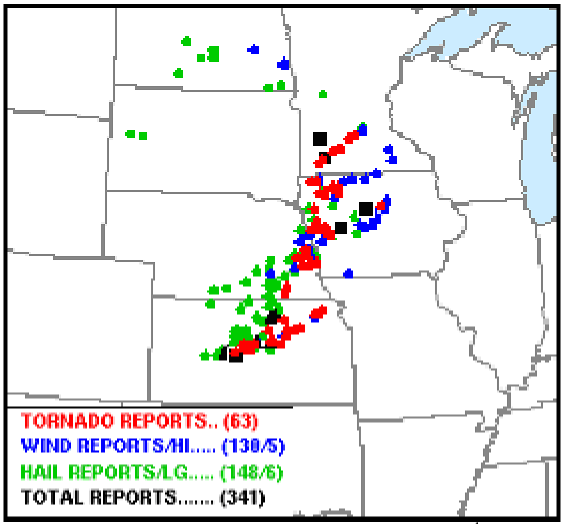

Figure 1: Storm reports from June 11th, 2008 courtesy of the Storm Prediction Center (SPC). The blue, green, and red marks represent wind, hail, and tornadoes. The black triangles indicate reports of hail larger than 1.5 inches, while the black boxes are reports of wind greater than 65kts.

Before sunrise, during the early morning hours of June 11th, a complex of thunderstorms moved across virtually this same area of the upper Midwest. There were some minor storm reports, but mostly just heavy rain. The reason for pointing that out is because now there was abundant surface moisture for the June 11th storms to work with, as will be shown later in more detail. Also, as shown in Fig 2, the environmental air around a thunderstorm sinks and slightly warms. The atmosphere wants stay in equilibrium, so a small area of upward vertical motion, such as in a storm updraft, is offset by a large broad area of subsidence. This acted to stabilize the air on the following day, which was responsible for clear skies on June 11th (Fig 3a). Since this severe storm event

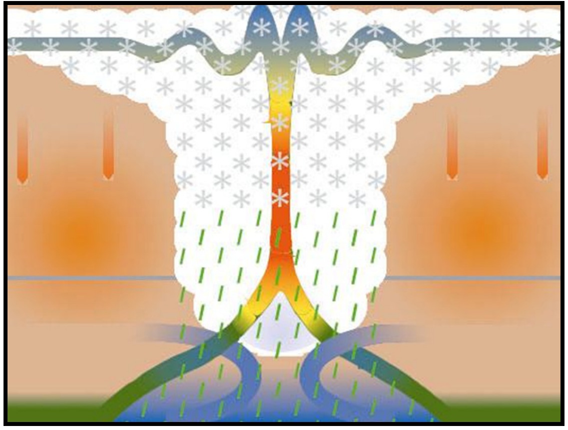

Figure 2: Conceptual Model of how during the mature stage of a thunderstorm, the environmental air around the storm is gradually sinking, thus becoming more stable. (Tripoli)

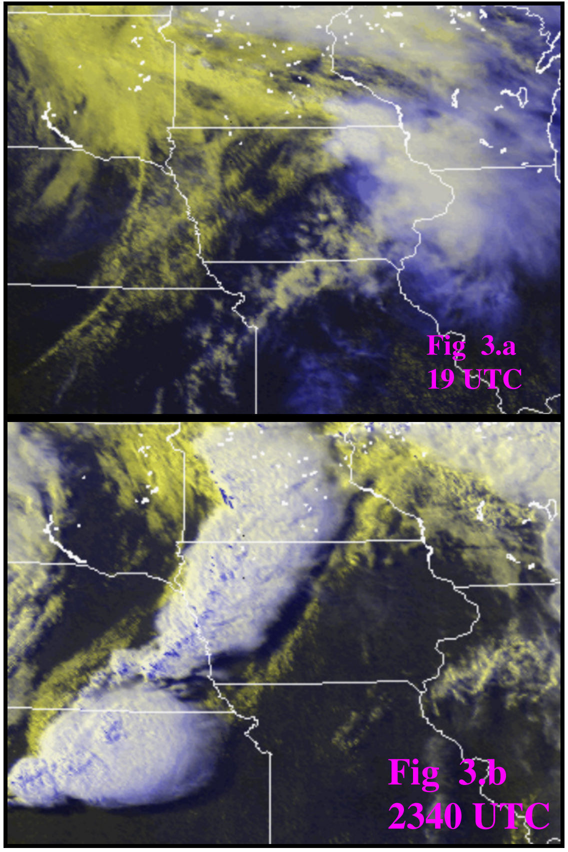

Figure 3: Satellite images using the .65 and 11μm wavelength show that throughout the afternoon, (a) the sky was clear over much of western Iowa, eastern Nebraska, and northern Kansas. The white clouds over southwestern Wisconsin are remnants of the overnight convection. The yellow clouds indicate warmer temperatures, thus lower cloud tops. These clouds were most likely caused by the surface heating and evaporation of the available water from the previous night's rain. Notice the cold front made visible by the arc of clouds over southeastern South Dakota, extending down into north central Kansas. (b) During the evening hours there is an explosion of thunderstorms along and ahead of the cold front, as indicated by the bright white clouds. It is even possible to distinguish the over-shooting tops. The subsidence modeled in Fig 2 is very clear both east and west of the severe storm. This image was taken just five minutes after an F3 tornado ripped through Iowa. (Pavolonis)

occurred in mid-June, the sun's direct rays were almost at their highest latitude in the northern hemisphere. Therefore, clear sky allowed the incoming solar radiation to both evaporate the rain water that had recently fallen, and warm up the temperatures at the surface. However, as the same time, cool and dry air at upper levels was advected over this region. Therefore, by the late afternoon, the combination of this elevated mixed layer together with the warm moist surface air created a potentially unstable environment. A surface cold front (Fig 3a) was enough to lift this unstable surface air up to the level of free convection, and the diffluent flow at upper levels created favorable conditions for the anvil outflow. Rapid thunderstorm development quickly followed (Fig 3b).

This set up could be generically summed up as a *Type D/E* synoptic pattern. As Fig 4 shows, there was a 500mb upper level diffluent jet (brown) associated with an upper level low (purple arrows) spinning over Wyoming. There was also a strong cold front (blue), associated with a surface cyclone (L), which is oriented north/south across eastern Kansas and Nebraska. There was considerable surface convergence due to the wind shift along the cold front. A tongue of warm moist air (green) existed out ahead of this westward propagating cold front, and was being advected into the region (teal) by both the circulation associated with the surface low, as well as an area of high pressure over the eastern US (not shown). The warm moist air from the gulf was capped by a dry elevated mixed layer at the middle levels (tan dashed). The area most favorable for the development of thunderstorms was out ahead of the cold front (pink). Unlike the classic Type E synoptic pattern, the warm front (red) is further north, and the surface cyclone is nearly occluded.

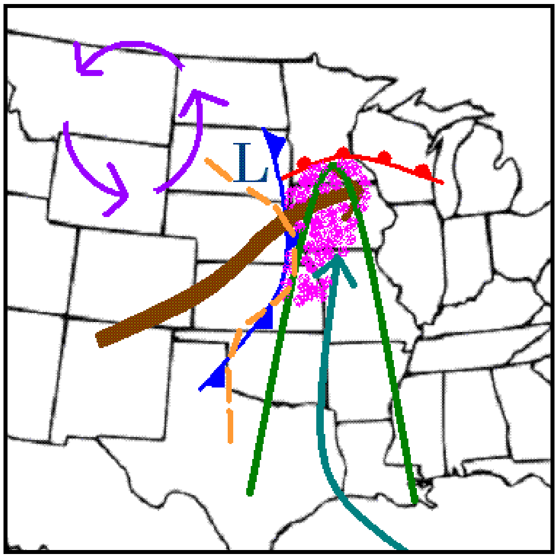

Figure 4: Miller diagram showing a simple representation of the set up that took place over the central plains during the afternoon hours of June 11th 2009. See text for explanation. (Fitzgerald, 11)

2. Data

Data was gathered from the Storm Prediction Center, ETA model, RUC model, SSEC, the University of Wyoming, as well as AOS453 lecture material. The SPC webpage was referenced in regards to storm reports. Both ETA and RUC model data was analyzed using GEMPAK. Different variables were plotted to show the forcings for the severe weather that day. Satellite images were courtesy of SSEC, and soundings were obtained from the University of Wyoming.

3. Synoptic Set-up

One can make a strong argument that no matter how potentially unstable an environment may be, no significant weather will occur unless there is a forcing mechanism to realize the instability. On June 11th there were several forcing mechanisms that united to produce the severe weather outbreak. First of all, there was a broad area of upper level diffluence both at 200 and 300mb (Fig 5). Upper level diffluence is important, because if mass (air) is being evacuated over a

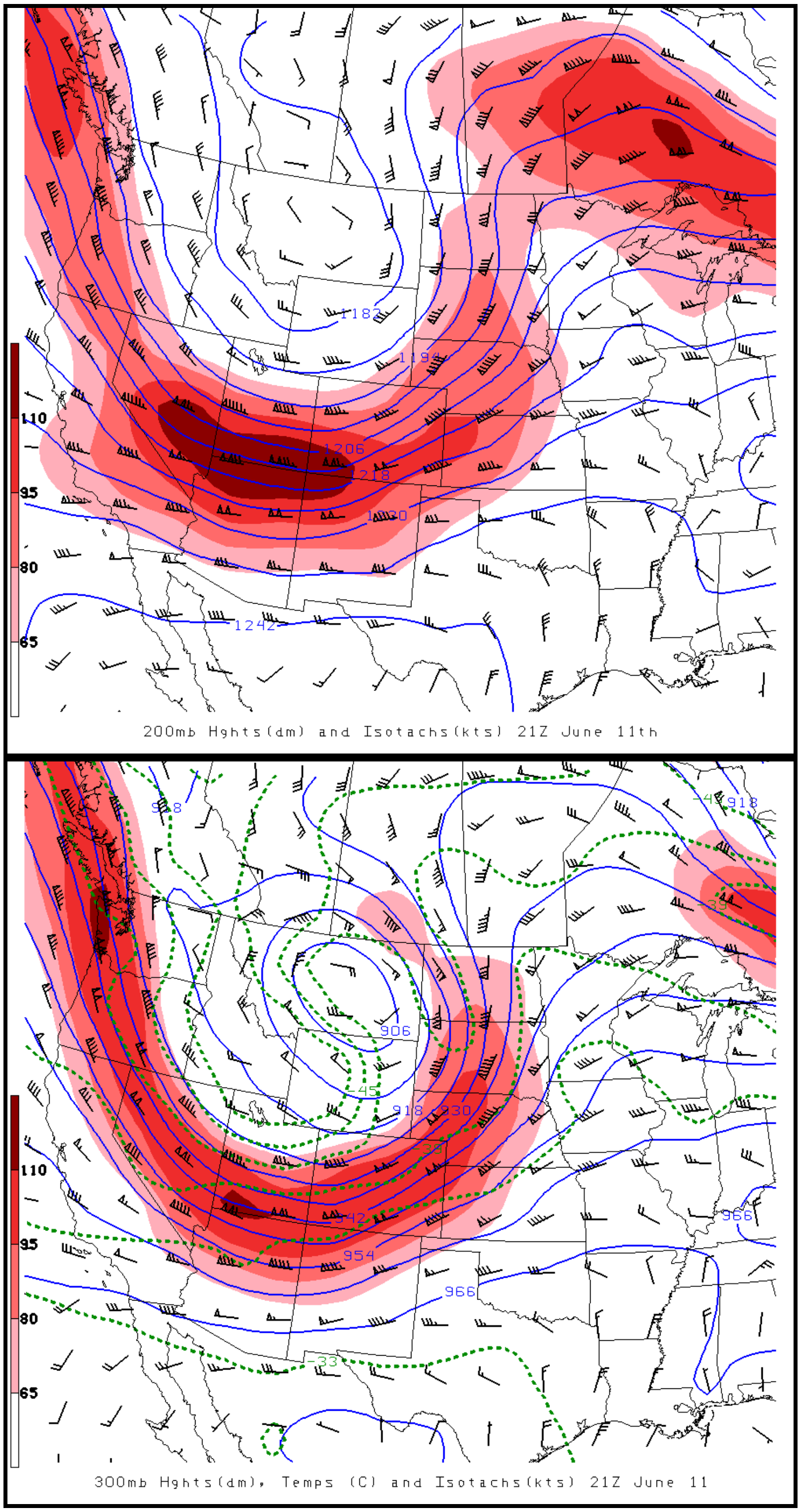

Figure 5: This two-panel plot to the left shows both the 200mb (top) and 300mb (bottom) map at 21Z on June 11th 2008 according to the RUC analysis. The red fills indicate regions of winds in excess of 65kts. The blue lines are geopotential (dm) and the black wind barbs are plotted to help illustrate the extensiveness of the diffluent flow downstream of the upper level trough. The 200mb map is shown, because it is interesting to note that at this level the winds are strongest, but not hard to believe considering this case was from the summer when the tropopause is at its highest elevation in the northern hemisphere. At 300mb there is a closed geopotential height minimum, indicative of cold air at lower levels. The green dashed lines are temperature (C) plotted to illustrate the warm advection in the exit region of the jet streak.

certain area at that level, then by continuity there must be some air at lower levels replacing it. There in lies one cause for vertical motion. Also, there was a negatively tilted ridge axis located over International Falls MN. Since a ridge is a location of super-geostrophy, there was going to be divergence upstream of the ridge, mainly over the upper Midwest. Using the jet entrance/exit region as a way to distinguish vertical motion, especially with regards to the 300mb map, would put an area of upper level convergence over Iowa and Minnesota. That would imply that there should be sinking air in this region, which obviously was not the case. Therefore with confidence, one can make the statement that the both the curvature and the diffluence at upper level are the dominant catalysts for the vertical motion at lower levels.

At 500mb there was a negatively tilted trough with a closed low over Wyoming and Montana (Fig 6). There was also a shortwave associated with the overnight convection mentioned earlier. As the day progressed, this spinning low slowly nudged eastward, and with it, an area of positive vorticity advection. By the time evening rolled around, there was positive vorticity inducing rising motions over the region where convection broke out. As 12Z, the 500mb flow nearly mirrored the miller diagram (Fig 4), but by 00Z June 12th, there was a region of diffluence even at 500mb. It seems rather straight forward that the diffluent flow in the column of are at 500mb up to the tropopause had the largest contribution to the upward vertical motion.

The last level to look at from a synoptic perspective was the surface. The motivation behind this being a smooth transition to the mesoscale. Fig 7 shows that there was a surface low over the South Dakota/Nebraska. By geostrophy the winds blow in a counterclockwise direction parallel to the isobars. However, the winds appeared slightly ageostrophic. Due to the effects of friction, the winds tend to converge toward the center of low pressure. Following the wind barbs along the stream lines shows that air from the Gulf of Mexico was traveling all the way up to Iowa and southern Minnesota, but that is not the whole story. Recall from the foreshadowing earlier in the introduction of the surface high pressure in the eastern third of the country. Its role was also important to this event.

During the summer months, the Bermuda High sets up off the Atlantic coast. This establishes clockwise flow that “opens up the Gulf”. What this means is that flow on the back side of this high pressure causes low level southerly winds off the Gulf of Mexico to advect warm moist air up into the southern plains. Often this moisture gets caught up in the westerly winds and doesn’t make it further north than Missouri. However, the presence of the high pressure over West Virginia not only blocked this westerly flow, but enhanced the return flow of the Bermuda High. This allowed for the tropical summer air usually found in Louisiana, to flow undisturbed up to Iowa. Had the surface high pressure not been located where it was, the scenario probably would have played out much differently. One other thing to take away was the surface convergence over eastern Kansas and Nebraska at 12Z (Fig 7). This surface convergence is related to the wind shift along the cold front extending southward form the low pressure. In the end the three main synoptic scale forcing were 1) upper level diffluence, 2) positive vorticity advection at 500mb, and 3) the surface convergence associated with the low pressure over South Dakota. The next section looks at the mesoscale features.

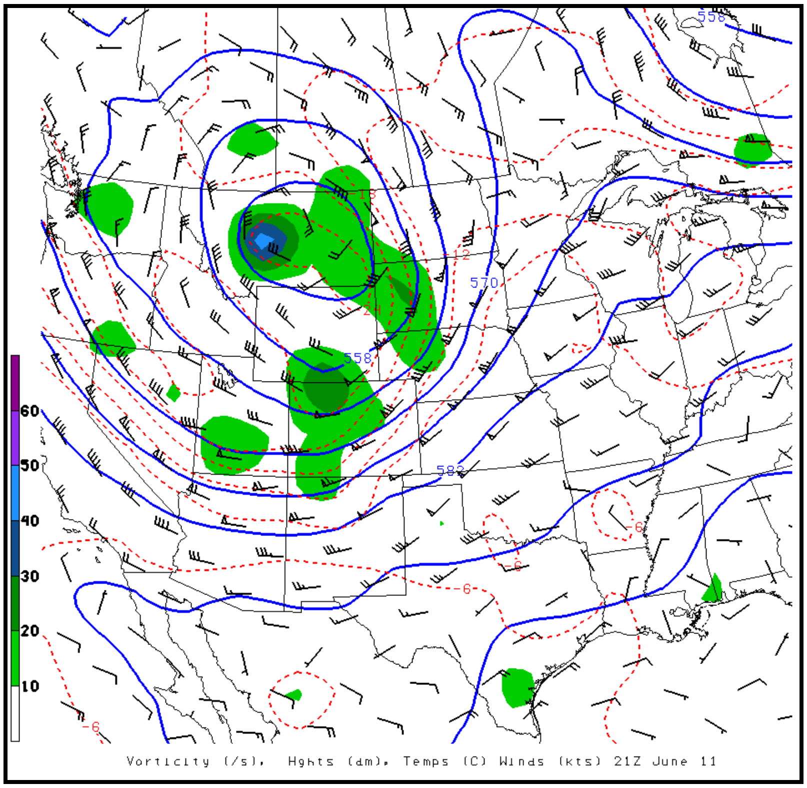

Figure 6: The figure to the left shows 500mb positive vorticity (color fills), temperatures in Celsius (red dashed) and geopotential heights (blue), as well as the wind barbs from the zero hour forecast of the 21Z RUC analysis from June 11th. The negatively tilted trough and diffluent flow both favor thunderstorm development over the upper Midwest. One would expect positive vorticity advection over eastern South Dakota, which is downstream of the area of positive vorticity.

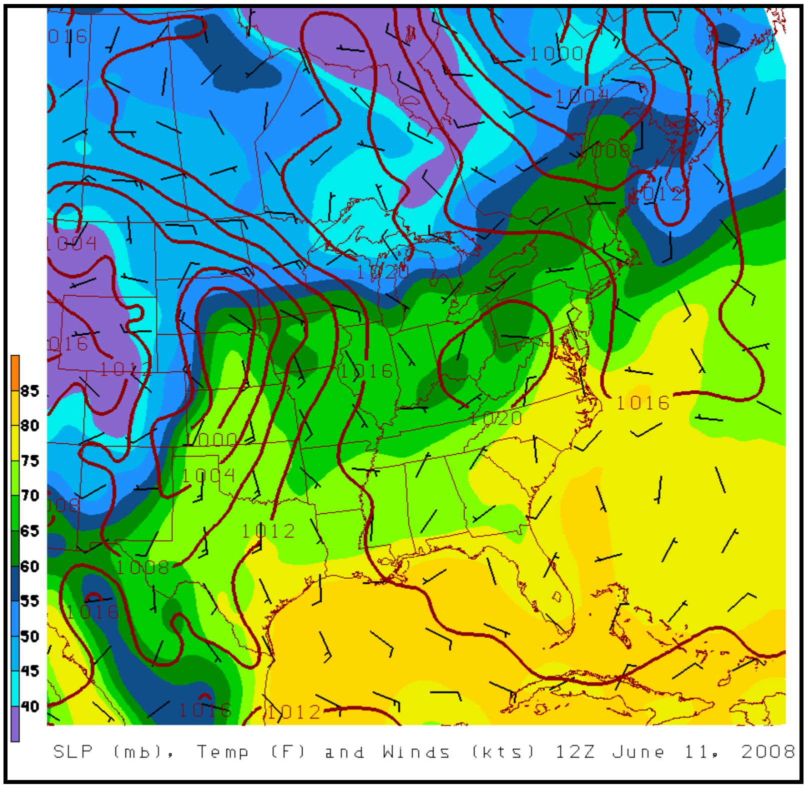

Figure 7: Surface analysis from zero hour forecast of the 12Z ETA model analysis of June 11th. Temperatures are the filled contours (°C), maroon lines are mean sea level pressure (mb), and winds are the black barbs (kts). Notice the low pressure over South Dakota and Nebraska, as well as the high pressure over the Appalachians. This set-up favors strong advection of Gulf moisture into the Missouri River Valley, as indicated by the black wind barbs.

4. Mesoscale Analysis

To build off of the thorough synoptic analysis given in the prior section, the surface dewpoints, temperature, and soundings are going to be examined. These mesoscale features play just as important of role in the severe weather as the synoptic scale forcing.

The next page (Fig 9) shows the RUC analysis at three different times in six hour increments, starting at 12Z on the 11th and ending at 00Z on the 12th. Notice the warm advection to the east of the cold front over the Nebraska/Iowa and Kansas/Missouri borders. At 7:00AM local time, temperatures were still in the upper 70s, with a few scattered 80s. Also, the dewpoints were in the upper 60s. These readings would be high for any time of day in the summer, but that fact that this was just a couple hours after sunrise is quite impressive. There was also a strong gradient of dewpoints, especially heading west along the Nebraska/Kansas border. Over just a few hundred kilometers, the dewpoint changed over 20°F. And lastly, the wind shift was almost 180°, from southerly ahead of the front, so north northwesterly behind it. This higher resolution illustrates the surface convergence along the front.

Just six hours later, at 1:00PM local time, temperatures rose into the upper 80s in parts of Kansas, and dewpoints were in the low 70s. Also noteworthy is the fact that the winds had not subsided. Often times a low level jet will form over the southern plains as the nocturnal boundary layer gets decoupled from the surface. The wind undergoes an inertial oscillation, and becomes super-geostrophic in the early morning hours. However, after the sun comes up and heats the ground, the low level jet subsides as it once again feels the affects of friction at the surface from mixing that occurs in the convective boundary layer. The fact that the winds were still 20-25kts at 18Z over eastern Kansas, is evidence that they were not simply associated with the low level jet. Instead a better diagnosis yields the cause to be from the circulation of both the surface low pressure over South Dakota, as well as the high pressure centered over West Virginia. A secondary cause may be the ageostrophic circulation associated with the upper level jet streak, which will be explained later in the paper. Referring back to figure 9, by 00Z June 12th, dewpoints had climbed into the 70s over much of Iowa, and eastern Nebraska and Kansas, and temperatures were in the 80s. By this time thunderstorms had broken through the cap and were intensifying as the moved across this rich environment.

A sounding was launched at 18Z (Fig 8) from Omaha NE, which showed high values of CAPE and minimal CIN.

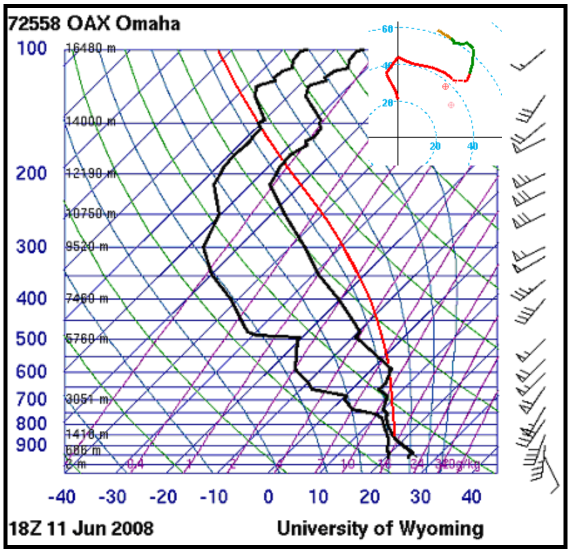

Figure 8: An 18Z sounding and 00Z hodograph from Omaha. The red line in the sounding is the SALR of a parcel lifted from the surface to its lifting condensation level (LCL). The hodograph shows veering winds at the low levels. There is extensive CAPE (2006 J/kg) and little CIN (-9.6 J/kg). Several other severe parameters; LI = -4.86, SHOW = -3.39, SWET = 420.6, BRN = 15.6, and TT = 49.9, indicate that severe thunderstorm development was very likely.

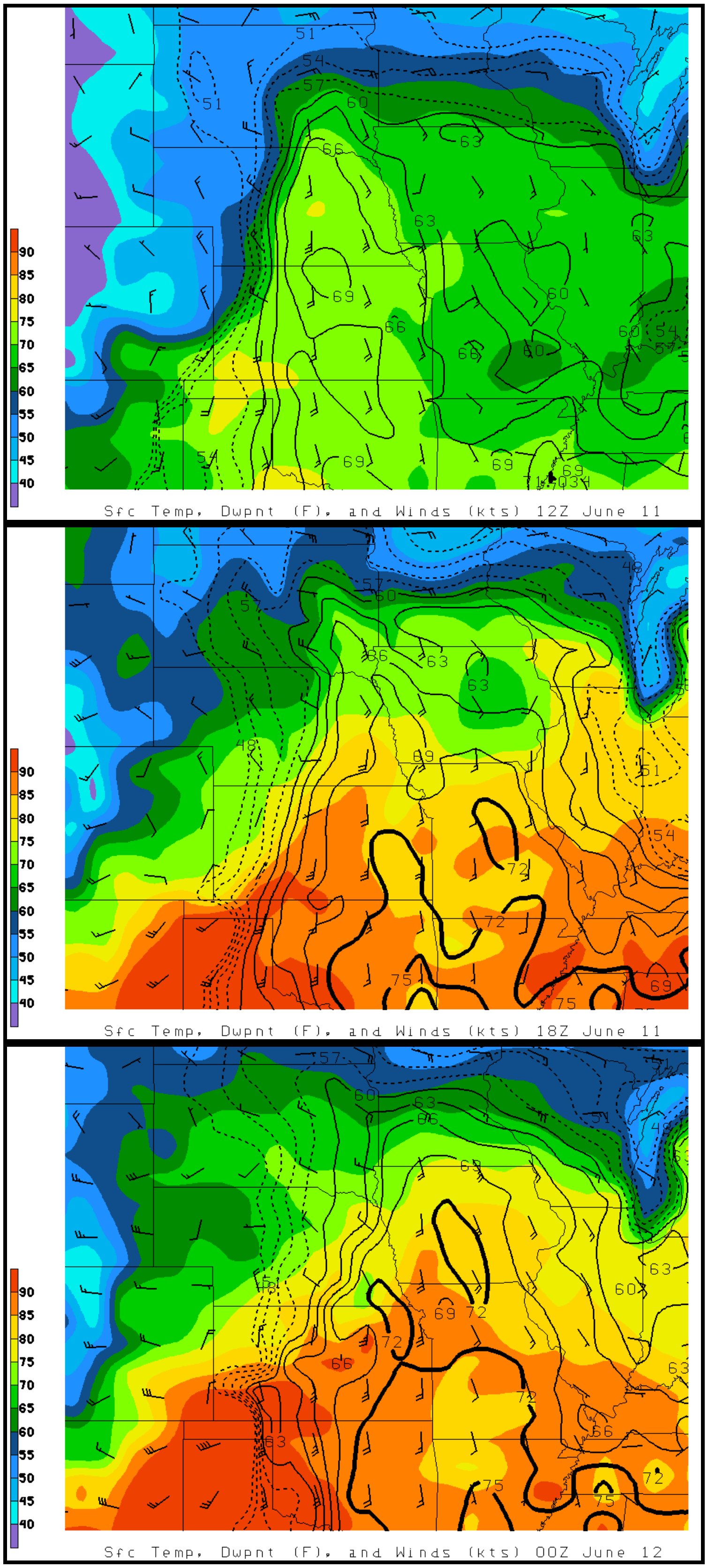

Figure 9: This three-panel plot is a six-hour snap shot from the RUC analysis at 12Z and 18Z, and the 3hr forecast from the 21Z model run. It shows wind (barbs) in knots, temperature (fills), and dewpoint (black contours) in degrees Fahrenheit. The dewpoint is plotted every three degrees so that intervals from 48-57 are dashed, 60-69 are solid, and > 72 are thick solid. This draws attention to the area of warm moist air over the region coincident with the storm reports from Fig 1. Notice the sharp wind shift that maintains itself throughout the time period. Ahead of the front, the winds are southerly at 20kts, and behind the front they shift to northwesterly at about 5kts. One other thing to point out is the strong gradient of dewpoints to the west of the warm tongue. At 21Z, there were even higher dewpoint readings than the ones shown at 18 and 00Z. From these plots it is clear that high Theta_e values, from both the surface temperature and moisture, were in place for storm to quickly grow.

The hodograph, though taken six hours after the special 18Z sounding was launched, still shows veering winds at the lower levels. Recall from Fig 9b, that at 18Z temperatures were in the low 70s and dewpoints were in the upper 60s over eastern Nebraska (74 and 67 to be exact). One way to reduce the CIN and break through the cap of warm dry air located slightly above 600mb (Fig 8), would be to either warm the surface, or increase the low level moisture. Both of these happened over the next few hours, as the temperature rose to 86 degrees, and the dewpoint was in the low 70s.

The sounding also shows a well mixed layer between 600 and 500mb. The lapse at in this column was nearly dry adiabatic. Just above this layer was a small inversion, where the mixing ratio decreased sharply. From this level, all the way up to the tropopause, were two elevated mixed layers. The lapse rates were conditionally unstable, so that a saturated parcel would be positively buoyant compared to the environment.

At 18Z, the SPC put out a mesoscale discussion concerning this event (Fig 10). It confirms the prior statements regarding the high CAPE values. However, it also shows how there was ample effective bulk shear, which would favor supercell development. This parameter is similar to the 0-6km bulk shear, in that it denotes that change in wind with height. The difference is that the EBF accounts for the storm depth, and is designed to identify both the surface based and elevated supercell environments. Supercells are probable for values of 25-40kts or greater, and as the figure shows, the values in this case were around 50kts. It was for this reason that the National Weather Service issued a tornado watch including counties in western Iowa and eastern Nebraska

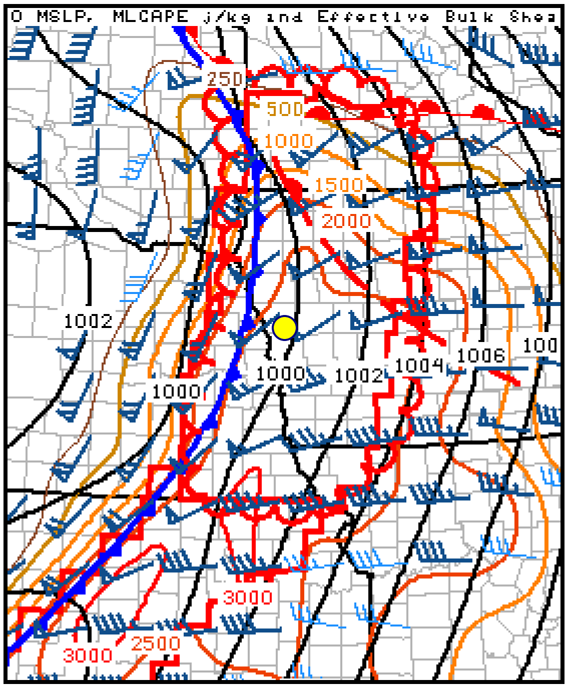

Figure 10: This is from a mesoscale discussion off the SCP webpage on June 11th, 2008. Effective Bulk Shear is denoted with the blue wind barbs, MLCAPE is the brownish colored lines in 500 J/kg intervals, and the black contours are MSLP drawn every 2mb. The yellow dot in western Iowa indicates where the Boy Scout tornado occurred.

5. Boy scout tornado

One storm of particular interest produced an F3 tornado that tracked from eastern Nebraska, into western Iowa just before 7:00PM local time. This cell formed just after 23Z, in the region of the highest windshear, and largest CAPE values (Fig 10), just north of Omaha. Therefore, the environment was probably very similar to the one depicted in the sounding (Fig 8). It moved northeast across the Missouri River into Monona County Iowa, before taking a mild right turn and heading more easterly. This change in direction, or winds backing with time, enhanced the storms development due to the generation of cyclonic vorticity relative to the storm. This can be seen by following the source website from Fig 11. According to the damage, the tornado was strongest when it moved to the right.

This storm was not a discrete supercell with the classic hook echo on the radar reflectivity (Fig 11). Rather, it was a particularly strong rotating heavy precipitating supercell imbedded within a line of storms. According to the nationwide radar from the SPC archive, the individual cells began to merge together and take on more of a linear appearance. However, the radial velocity (not shown) from 6:24 to 6:42PM depicted a distinct inbound/outbound couplet in the winds. So it is clear of some these storms were indeed rotating, which one would expect given the high-shear environment described earlier. However, because of the surplus of low level moisture to work with, these storms were heavy precipitating. Any tornado that would have formed was most likely rain-wrapped, making it very difficult to see from the ground.

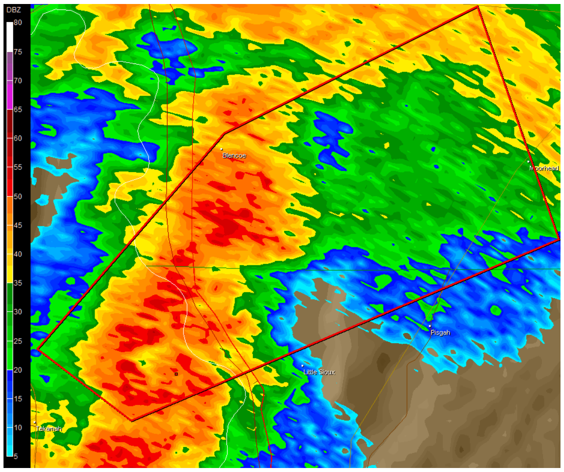

Figure 11: Base Reflectivity at roughly 6:30 PM local time from the cell that produced the Boy Scout tornado in western Iowa, courtesy of the NWS Omaha. The red polygon indicates the area that is under the tornado warning. This image shows how hook echoes are not always present in rotating storms, especially when they are heavy precipitating. (Omaha)

The fact that this storm had so much precipitation could help to explain why the tornado was so strong. A tornado is a violently rotating column of air at the surface. A couple of ways this can happen is by tilting the horizontal vorticity associated with the mean winds, or advecting vorticity from the rotating updraft down to the surface. Tilting alone can not accomplish this, because in a supercell, the air from the surface is being taken from the surface up into the storm. This happens both 1)thermodynamically, where the air at the surface is warmer and therefore positively buoyant, so it rises into the storm, and 2)dynamically, where the fast moving air of the rotating updraft creates a lower pressure gradient at the surface, thereby acting as a vacuum that sucks up the air near the surface. So tilting alone can not produce tornadogenesis. However, a downdraft can advect the vertical vorticity toward the surface, stretch it, and form a tornado. This can be thought of as a rotating downdraft turret superimposed under a rotating updraft mesocyclone. This reasoning supports the argument that a downdraft is needed for tornadogenesis, when pre-existing rotation in absent near the ground. This downdraft is created by both precipitation drag and evaporative cooling. During precipitation drag, as the hydrometeors fall to the surface, there is friction between them and the environmental air, which can pull the air towards the surface. Also, as hydrometeors fall through a dry layer, they evaporate and cool the air. In this way, low θ_e reaches its low θ value. This evaporatively cooled air is negatively buoyant and crashes to the surface. So in a heavy precipitating supercell, there is by definition, more precipitation, so a better chance for the downdraft to create vorticity at the surface and spin up a strong tornado. Aside from the Boy Scout tornado, another supporting example would be the Parkersburg Iowa tornado, which also was a strong tornado produced from a heavy precipitating supercell.

6. Jet Circulation

So far all the hypotheses presented in this paper have been supported by the given data, and been fairly straight forward. However, there is one element yet to be discussed, which may help explain the persistence of the strong moisture advection from the south at lower levels. The analysis of Fig 7 gives irrefutable evidence that the strong southerly winds were primarily governed by the surface low pressure over South Dakota. A secondary influence was almost undoubtedly the high pressure located over West Virginia. However, there could possibly be a third cause that is not quite so obvious at first glance. Throughout the day at the 300mb level, there was warm air advection in the jet exit region. This can be verified by looking at the second plot of Fig 5. The warm air advection shifted the area of ageostrophic divergence from the left exit region , more towards the center of the jet. (Martin 217) So there was upward vertical motion (rising air) in the center of the jet, and downward vertical motion (sinking air) further removed from the right jet exit region.

This set-up can lead to a secondary ageostrophic circulation, most often referred to as the Sawyer-Eliasson Circulation. The Sawyer-Eliasson Circulation is often noted in the jet entrance region of the jet streak. Here there is rising motion in the right entrance region. Generally this upper level jet feature is north of the low level southerly jet. So a circulation is easily set up by the upper level winds acting to expel the outflow from the storms that are fed by the moisture associated with the low level winds. The storms are enhanced by the vertical motion generated in the right entrance region. In response, latent heating released in the convection will warm the column of air, expand it, and create a tropopause fold that will end up increasing the jet streak. This is known as the Dynamic Flywheel, and it is a means by which the upper level jet can couple with the lower level jet to for a positive loop.

To some degree, this paper poses that the same coupling can occur in the exit region of the upper level jet (Fig 12). Rising air north of the center of the jet had to be replaced by continuity. A jet exit region in isolation would have low level return flow from the south acting to replace the rising air in the left exit region. With that idea in mind, this circulation was in an environment that already had strong southerly flow at the surface. By this reasoning, this paper makes the claim the this circulation of southerly winds a lower levels of the jet exit region was another forcing mechanism that contributed to the strong advection of warm moist air for the south. Since there was warm air advection, thermally indirect circulation of sinking warm air in the right exit region would have been weaker. Therefore, there wouldn't be as strong of an opposing flow that would hinder the southerly low level winds from making their way to the left exit region.

The cross section (Fig 12) is from 12Z on June 11th, so throughout the entire day as the jet propagated towards the northeast with time, this circulation could have enhanced the southerly flow from the gulf. It is difficult to explicitly prove without directly modeling the situation, but the logic is accurate, and the wind arrows make a strong case that this Sawyer-Eliasson Circulation could have increased the southerly winds. This effect would have been to increase the low level moisture, as well as the helicity, which eventually enhanced the severity of the storms.

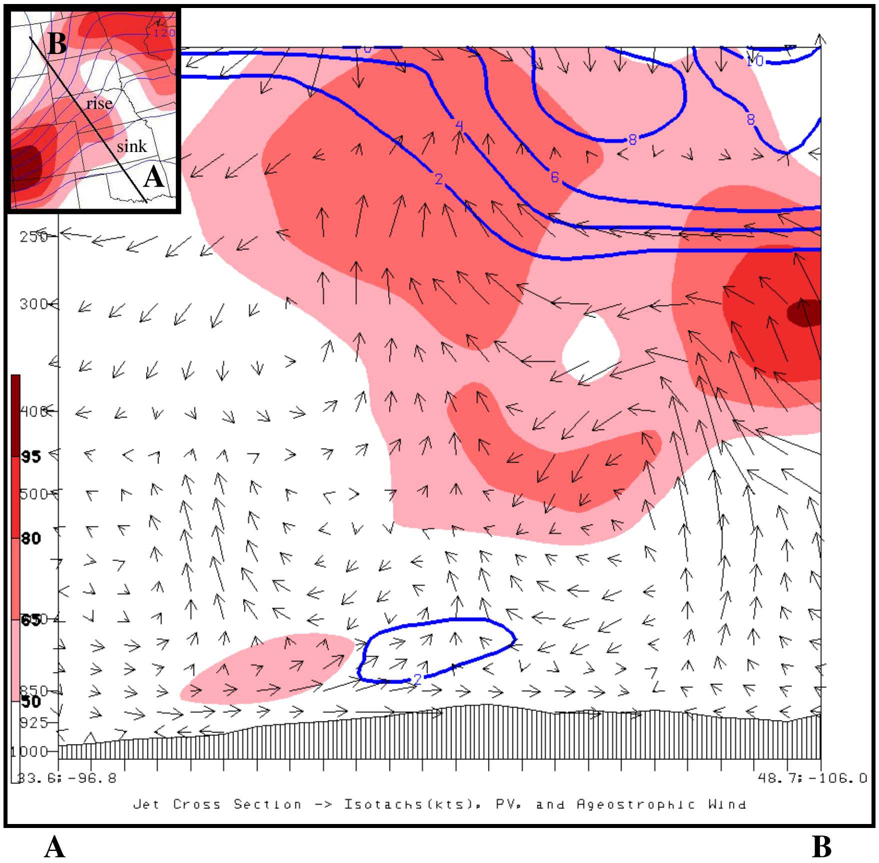

Figure 12: This cross section is from the 0hr analysis of the 12Z ETA run on June 11th 2008. It is taken from the North/South Dakota and Montana border (right, B), through the jet exit region down to the Oklahoma/ Texas border (left, A). The blue lines are PV, arrows are ageostrophic circulation, and red fills are winds (knt). The 12Z ETA was used to show how early in the day the strong southerly winds from the nocturnal low level jet could have persisted due to the secondary ageostrophic circulation of the jet exit region. One can definitely get a sense of southerly winds (left to right) in the cross section. As the day progressed, and the jet streak shifted to the northeast (Fig 5), so too would this circulation, enhancing the warm moist advection from the south at the lower levels.

7. Conclusion

On the 11th of June, 2008 there were at total of 341 severe weather reports across the western edge of the corn belt, starting in central Kansas, and extending northeast into central Minnesota. Of these 341 reports, 63 were tornadoes, and six were large hail. This event was during the middle of an active period of weather across the plain states in the month of June. Several different ingredients came together, which contributed to the thunderstorm development.

First of all, from a synoptic stand point, there was a broad area of diffluent flow in the upper levels. Diffluent flow at 200 and 300mb led to rising air at lower levels to compensate the export of mass at upper levels. This allowed the storms that did initially fire to have little resistance in developing vertically, and it gave them an avenue by which they could expel their outflow. At 500mb there was an upper level low spinning over Wyoming. As it slowly trudged eastward, rising air and height falls accompanied the positive vorticity advection downstream. A sounding from 18Z indicates that there were two distinct elevated mixing layers separated by a small inversion. One was found from 600 to 500mb, and the other slightly above 500mb all the way up to the tropopause. Both were well mixed with regards to mixing ratio, and they also had lapse rates that were conditionally unstable, meaning that a saturated parcel with a moist adiabatic lapse rate would cool slower than the environment, and therefore be positively buoyant. At the surface there was a developing low pressure system in response to the 500mb upper low moving in and ejecting mass, therefore lowering the pressure at the surface. The southerly winds on the western side of low pressure system helped to draw warm moist air up from the Gulf of Mexico. Also, the climatological Bermuda high, together with the localized high pressure over West Virginia, allowed the gulf moisture to reach northward up into Iowa and southern Minnesota. And the last synoptic feature was a surface cold front. This created a narrow line of convergence, with northwesterly winds behind the front, and strong southerly winds ahead of the front. The cold front focused the rising air along a single point, which in return helped to overcome the little CIN.

Secondly, from a mesoscale perspective, there were several features that contributed to the severe weather outbreak. As mentioned earlier, the dry elevated mixed layer allowed for a large amount of CAPE to be present. Once a parcel from the surface was lifted it its LCL, it would cool at a lesser moist adiabatic rate than that of the environment. Related to this, the low level moisture was another major factor to the severity of the event. Dewpoint temperatures in the lower 70s, coupled with surface temperatures in the mid 80s meant low LCLs. The low cloud base made it easier for any circulation associated with the rotating mesocyclone, to have a fairly good chance of combining with the surface vorticity and forming a tornado. These high dewpoints were in place partly because of the synoptically forced advection of Gulf moisture northward, and also the abundance of surface moisture made available from the previous night's rainfall. One other contribution not alluded to was the evapotranspiration from the cornfields. The reason being, this event took place on June 11th, and there was no significant data source that could confirm whether or not the fields had reached canopy. Had this been the end of May, there would not have been any contribution. Parallel to this reasoning, if this event would have taken place in late June or early July, then there most certainly would have been some contribution from the cornfields to the high dewpoint temperatures.

Moving from a qualitative description of the mesoscale environment to a more quantitative approach, the severe indices from a sounding in Omaha launched at 18Z were used to help determine if severe weather was imminent. It is important to point out that while looking at these, one must be careful to understand that they do not tell the full story. The dynamic forcing of the atmosphere must be in place. Otherwise the end result could be incredible "loaded gun soundings", but nothing to pull the trigger. Since it was made clear throughout the paper that there were several synoptic features in place, this was not a concern.

The surface based CAPE was over 2000 Joules/kg, so an air parcel lifted from the surface had plenty of kinetic energy simply from thermodynamic buoyancy. The Lifted Index, which is the temperature difference between the environmental air at 500mb to an air parcel lifted adiabatically from the surface, was in the category of the highest chance for severe weather. The value of -4.88 indicated that severe thunderstorms were probable, and tornadoes were possible. The Showalter Index was -3.39, which, by definition, meant that in this environment, severe thunderstorms were possible. The Severe Weather Threat Index was calculated at an astounding 420.6, which said that in this environment, severe weather, including tornadoes were possible. One of the parameters that include shear, the Bulk Richardson Number, which is the ratio of CAPE to shear, was calculated to be 15.6. This parameter predicted that the environment would favor supercell development.

Finally, looking more closely as to why tornadic cells formed on this day. A hodograph from 00Z, which was roughly 30 minutes after the Boy Scout Tornado occurred to the north of Omaha, shows veering winds with height. This sounding did not make it past the 400mb level, but it still proved useful when analyzing the shear in the low levels. The helicity at both 1 and 3 km was 225 and 239m^2s^{-2}. There were two main reasons why an 18Z hodograph was not shown. First of all, the SPC page did not have the sounding data from the specially launched 18Z sounding. Secondly, the University of Wyoming's website did not calculate the helicity, and their hodographs were not in color. So for the reader's benefit, a 00Z hodograph was overlaid on the 18Z sounding to show the helicity of the environment at the nearest time of thunderstorm development. All these parameters, combined with other mesoscale and synoptic features, help explain why the severe weather outbreak occurred on June 11, 2008.

8. References/Acknowledgements

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