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The Role of Topography on the 7 June 2012 Tornadic Supercell near Wheatland, WY

A Senior Honors Thesis

Submitted in Partial Fufillment of the Requirements for Graduation in the College Honors Program

By

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Abstract:

This paper discusses a case study of an EF2 tornado that occurred with a supercell thunderstorm on June 7th, 2012 near Wheatland, WY. It is hypothesized that the topography of the Rocky Mountains played a role in this storm's formation, based on another study that showed that the mountains created low-level flow channeling and banners of strong potential vorticity that enhanced another storm near Laramie, WY and made it become tornadic. This study intended to find out whether these two tornadoes occurred under similar conditions. Stability, shear, low-level and upper-level environmental conditions, and radar and satellite imagery were used to asses this storm's formation and strength using the Storm Prediction Center's Severe Weather Event Review, as well as the NCDC NEXRAD Data Inventory. The storm's path was also tracked over the terrain of the region. There were high instability values and low shear values, as well as synoptic forcing, a front at the surface and a dryline. The conditions turned out to be somewhat different from the other case, and in the case of the Wheatland storm, a synoptic scale upper-level trough and associated shortwave contributed, and banners of potential vorticity were not found, so topography did not play a role.

Introduction

This study is about a tornadic supercell thunderstorm that occurred near Wheatland in southeastern Wyoming on June 7, 2012 during a storm chasing trip. This storm produced an EF2 tornado. It touched down at 2107 UTC and lasted until 2219 UTC, moving from west of Wheatland, WY, to the southeast across Platte County, then dissipated just northeast of Chugwater, WY. Wind speeds were estimated to be between 130 – 135 mph by a NWS survey team. The most significant damage along its path was along Olson Road, which is southwest of Wheatland. At this location, a new, well-constructed barn was destroyed (Storm Events Database).

Tornadoes tend to be uncommon in this area, but when they do form, they can become intense (Geerts et al., 2009). When looking at the conditions that morning, it seemed unlikely that there would be any tornadic storms in this area. According to the Storm Prediction Center (SPC), there was only a 5% chance of tornadoes. Other parameters that can be indicative of strong storms were not predicted to have values that were sufficiently high for strong storms to occur on this particular day. CAPE values near Wheatland were not predicted to be high. The supercell and significant tornado parameters did not show anything indicating that there would be supercells or tornadoes. However, there was an upper level shortwave moving into the region, and eventually an EF2 tornado did form. This shows that something besides the typical conditions for a tornadic storm, such as topography or the synoptic scale, played a role in the formation and strengthening of this particular storm. Despite what were predicted to be less than ideal conditions, the SPC eventually put out a tornado watch, and a hook echo appeared on the radar and soon after the tornado touched down at approximately 3:07 pm local time. The purpose of this study is to do a case study on the storm that produced an EF2 tornado near Wheatland, WY. In general, it is to find out what large and small scale parameters and processes caused this storm to produce a tornado at that place and time, and how these influenced its intensity.

Tornadoes typically form under a certain set of atmospheric conditions, which include high instability and strong wind shear. A common parameter used to determine instability is convective available potential energy (CAPE), which tends to be very high (with values around 2000 J/kg, and sometimes much higher) when the atmosphere is sufficiently unstable to produce supercells and tornadoes. Storm relative helicity (SRH) is frequently used to measure wind shear, and when it is high (around 100 m^2/s^2 or higher for 0-1km SRH, and 250 m^2/s^2 for 0-3km SRH). However, sometimes tornadoes can occur under conditions that do not follow this typical pattern. Things other than weather patterns, in particular, topography, can also influence their formation. Topography clearly has been shown to influence the strength of storms (Geerts et al., 2009, Markowski and Dotzek, 2011, Markowski and Rochardson, 2009, Bosart et al., 2006). For example, Markowski and Dotzek (2011) used models to study how orography affects supercells. They focused on how mature supercells interacted with different types of idealized terrain, and found that the airflow around certain topography can create vertical velocities and mesoscale vorticity anomalies that allow spin-up to occur, which can strengthen a storm. Wesolek and Mahieu (2011) also studied an F4 tornado in France that formed under a low CAPE environment, which is not a typical situation for a tornadic storm. In this case, the storm became as intense as it did due to particularly intense wind shear, strong low level convergence and synoptic conditions that were conducive to tornado formation. This shows that even with low CAPE values, as long as other conditions are right, a tornado may still form.

Geerts et al (2009) studied a mesocyclone that also produced an EF2 tornado in southeastern Wyoming. This storm formed under relatively low values of CAPE, which is unusual, but still had relatively high values of storm relative helicity (SRH), with low-level values exceeding 500 m^2/s^2, which is more typical of a tornadic environment. In this case, the authors determined that the supercell got some of its spin from its environment. The Front Range helped create banners of strong potential vorticity that influenced the vertical vorticity of the storm, and caused it to become mesocyclonic (Geerts et al., 2009). They found that banners of high cyclonic vorticity, from 700 to 500 hPa, aligned with the Front Range, as well as with the 0-5 km shear vector. There were also potential vorticity banners at the time of convective initiation between 700-600 hPa in the area of the storm. The authors concluded that these banners were generated by friction along the Front Range, which caused southerly flow shearing, and that the storm became mesocyclonic due to these banners. So, vertical vorticity can come from orographically-induced banners of potential vorticity (Geerts et al., 2009). They observed locally high SRH values as well, from channeling of the low-level flow. An example of the banners of strong potential vorticity that they found is shown in Figure 1.

This study leads to the hypothesis that the Wheatland storm also formed due to topographical effects and had channeling of low-level flow that increased storm-relative helicity

(SRH), and the mesocyclone acquired some of its spin from banners of strong potential vorticity. Bosart et al. (2006) also found that terrain can influence storms by enhancing vertical shear profiles. The storm that produced the Wheatland tornado is predicted to have had low CAPE values, and this project will determine if it became a tornadic storm because it was influenced by the topography of the region.

Data and Methods

This study was loosely based on the study by Geerts et al. (2009), because it happened very close to the Wheatland tornado, and topography (and therefore location of the storm) was a factor. The day studied was June 7, 2012, and the data was available every hour for this entire day. The change in conditions over time for all of the data was looked at, with a focus on 2100 UTC, which was the closest time available to approximately the time that the tornado touched down (2107 UTC). The area of focus was southeastern Wyoming, but conditions surrounding this area were also assessed.

This study uses surface charts, 850, 500 and 300 hPa analyses to get an overall idea of atmospheric conditions. Then it uses radar imagery, including reflectivity (elevation angle 0.5°) and radar velocity (lowest elevation angle), which came from the National Climatic Data Center (NCDC) (NOAA Satellite and Information Service). This data is NCDC Level III NEXRAD data from Cheyenne, WY. These will show what kind of structure the storm had, what kinds of clouds were associated with it, as well as whether or not it produced a hook echo shape or a tornado vortex signature. Reflectivity is used to look for dBZ values that indicate heavy rain or hail, as well as hook echoes, which would indicate a tornado. The radar velocity is used to look for tornado vortex signatures. It also uses visible and infrared satellite imagery from the SPC Mesoscale Analysis Archive. For instability, surface-based CAPE (SBCAPE) and convective inhibition (SBCIN), potential temperature and equivalent potential temperature were studied. The sounding from Denver, CO was also used, because it was the closest available sounding to Wheatland from the SPC. SBCAPE and SBCIN both came from the SPC Mesoscale Analysis Archive as well. To analyze moisture, surface mixing ratio and dew points were studied. To analyze shear, 0-1 km SRH, 0-3 km SRH and 0-1 km shear vectors were studied. Wind shear is necessary for the formation of rotating supercells, and for tornado formation. 700-400 hPa differential vorticity advection, 500 hPa vorticity, 400-250 hPa potential vorticity advection were also studied. Potential vorticity over the 600-700 hPa layer was studied using GARP and the RUC model. Vorticity is essentially a measure of spinning motion, which, again, is necessary for storm rotation. Friction, and therefore, topography, changes potential vorticity, so if topography played a role, it would affect potential vorticity. The vorticity parameters were specifically studied to determine whether or not there were banners associated with the topography that day, and the shear vectors would be aligned with these if the potential vorticity banners affected the storm. The 300 hPa analysis with heights and winds was used to asses synoptic conditions like upper level troughs and associated shortwaves. The Energy Helicity Index (EHI) was also used, because it is a parameter that had been shown to be a very good predictor of tornadic activity. Rasmussen and Blanchard (1998) studied how well different parameters worked in predicting tornadoes and determined that EHI discriminates well between ordinary thunderstorms and supercell/tornadic thunderstorms. They also found that EHI worked well in predicting significant tornadoes (Rasmussen and Blanchard, 1998). These parameters all came from the NWS Storm Prediction Center’s Mesoscale Analysis Data Archive, which uses the 40 km Rapid Refresh (RAP) model (Archive National Sector (s4) SPC Hourly Mesoscale Analysis).

The storm was then tracked over the terrain to determine any changes in elevation height that the storm passed over. Also, the locations of any banners of potential vorticity and their locations compared to any terrain changes were determined, in order to find out whether or not they may have influenced the storm in any way.

Results

The surface analysis shows a surface low that shifts between southeastern Wyoming and northern Colorado throughout the day, with a cold front that turned to a stationary front later in the day just northwest of the Wheatland area. At 2100 UTC the low was in central Colorado, with the front analyzed as a cold front just northeast of Wheatland, with 10-20 knot surface winds out of the south southwest in the area, as shown in Figure 2 (SPC Severe Weather Event). From 1600 UTC to 2200 UTC, the sky cover shifts from clear to cloudy, then back to clear. There was also a clear dryline shown in a tight dewpoint gradient, that stretches from western New Mexico northward through Colorado and western Wyoming. On the east side of the dryline there was more moisture from the Gulf of Mexico, while the west side was the drier side. This gradient tightened throughout the day. The dryline is shown in Figure 3, where Wheatland is just east of the dewpoint gradient. The high temperature was 23° C. Over this time period, the winds shifted over time from southerly to southeasterly, then back to southerly (SPC Hourly Mesoscale Analysis). The 850 hPa analysis (Figure 4) shows dew points increasing over time, and a 22°C dew point at 2100 UTC. In Figure 5, the 500 hPa analysis shows a negatively tilted trough that weakens over time, as well as a shortwave that moves through the trough and right over southeastern Wyoming. This shortwave develops around 1800 UTC, and then propagates through the trough throughout the day. The 300 hPa analysis shows no jet streaks near southeastern Wyoming, but does show upper level divergence around 0000 UTC near this region (Figure 6).

Mixing ratio values at the surface are steady in this area throughout most of the day at 10 g/kg but it does increase to 12 g/kg around 1900 UTC. There is no significant moisture convergence at the surface during the day at all, and only a small amount at 2100 UTC, as shown in Figure 7. Equivalent potential temperature values at the surface in southeastern Wyoming decrease throughout the morning, then being to increase again around 1400 UTC with a value of 338 K at this time. By 2100 UTC (Figure 8), equivalent potential temperature had reached 344 K, but there was no significant advection of this property.

The visible satellite imagery shows cloud cover in the morning, with multiple discrete storm cells with clear anvils developing in western Wyoming around 1945 UTC. At 2045 UTC, shown in Figure 9, it shows a storm cell with a large anvil near Wheatland, without any other major cells in the area. This is the cell that was studied, and the one that produced the tornado. There also seems to be an overshooting top associated with this storm. In the infrared satellite imagery, cells with relatively cold cloud tops begin to form around 1715 UTC. Over time, the cold tops spread. In Figure 10, at 2115 UTC, the same cell as seen in Figure 9 is shown, slightly farther west, with a cold anvil top. In the base reflectivity radar, the cell develops out of a small cluster of cells around 1930 UTC, and then continues to develop while the other cells die off. It progresses east southeast, and by 2042 UTC has maximum reflectivity values of 69 dBZ. At 2051 UTC, it develops a distinct hook echo, which persists until 2114 UTC, when it develops a wedge shape, then develops a hook echo again at 2146 UTC, which it holds until 2223 UTC. At 2109 UTC, just after the tornado had touched down, it has a hook echo shape and a maximum reflectivity value of 66 dBZ, shown in Figure 11. After 2223 UTC, it begins to lose its cellular shape, but also develops higher reflectivities (71 dBZ). Radar velocities begin to indicate the formation of a tornado vortex signature (TVS) at 1956 UTC, but there is not a clear TVS until 2056 UTC. At 2109 (Figure 12) there is a clear TVS in the same location as the hook echo. It shows up on the radar until about 2205 UTC.

As far as assessing instability, surface-based CAPE increased throughout the day, while surface-based CIN decreased. At 2100 UTC, as shown in Figure 13, SBCAPE was around 3000 J/kg near Wheatland and 2000-3000 J/kg in the surrounding area, while SBCIN was less than 25 J/kg, since there is no shading. The Denver 1200 UTC sounding shows almost saturated air up to approximately 700 hPa, then a shallow inversion layer, and becomes much drier aloft. It also calculated surface-based CAPE as 1649 J/kg, while most unstable CAPE was 1803 J/kg.

At 1200 UTC, 0-1 km SRH values were fairly high north of Wheatland, with values around 150-200 m^2/s^2, however, it decreased as time went on. By 2100 UTC (Figure 15), there were no significant values of 0-1 km SRH anywhere near Wheatland. 0-3 km SRH values were similar to 0-1 km SRH values in that there was not anything significant at the time of the storm (Figure 16), however there are values of 100 m^2/s^2 to the north of Wheatland. They also increase to 200 m^2/s^2 by 0100 UTC near Wheatland. Around 1600 UTC, there were southerly 10 kt shear vectors over southeastern Wyoming; however these weaken and disappear by 2100 UTC.

A vorticity max forms just to the east of the area, in northwestern Oklahoma, by 1000 UTC, with vorticity advection to the north in northeastern Wyoming. This weakens over time, but another region of high vorticity moves into western Wyoming, with advection on the east side of the maximum around 1600 UTC. This moves over Wheatland by 2100 UTC, while there is also a stronger vorticity maximum over northeastern Wyoming, with strong vorticity advection as well, as shown in Figure 17. Over the next couple of hours, the vorticity maximum near

Wheatland moved eastward, while the stronger one to the north moved slightly southeast, with strengthening advection. Figure 18 shows potential vorticity, but there are no high values, and no clear banners like in Figure 1, at all.

The 0-1 km EHI shows values of 0.5-1 starting at 1700 UTC in the area of study, but nothing at 2100 UTC, shown in Figure 19a, then 0.5-1 again from 2200 UTC to 2300 UTC. For 0-3 km EHI, values of 1 appear at 1600 UTC and remain in the area until 2100 UTC (Figure 19b). Then they increase to 3 at 2300 UTC.

While the storm was progressing, it did not go over any significant changes in elevation. According to Figure 20a, it stayed within the region of 4500-6000 ft. Then, according to Figure 20b, it is clear that relative to other areas of Wyoming, the storm was not near any significant terrain at all. Also, according to Google Earth, the tornado started at 1533 meters, and ended at 1589 meters, which was only an approximately 60 meter change in elevation over its lifetime.

Discussion

The surface analysis showing a front in the region would help force upward motion in the area, which is necessary for storm formation. Features shown in the visible, infrared and satellite imagery all correlate well and are indicative of a strong storm and/or a tornado on the ground. High dBZ values indicate heavy rain and hail, while the hook echo shape is a typical indicator of a tornado on the ground. In the visible satellite, cloudiness was shown earlier in the day. This could have limited daytime heating and therefore limited instability in the atmosphere, although clearly this was not the case, since CAPE values were high. Therefore, any cloudiness must not have significantly limited instability. The overshooting top in the supercell shows that there were strong updrafts, which means that the storm was strong. In the radar velocity images, strong winds are clearly moving in opposite directions in the feature of a tornado vortex signature, which again indicates a tornado on the ground. All of these contribute to the idea that there should have been a tornado on the ground, and they make sense because a tornado was actually observed.

Sufficiently high equivalent potential temperature values show that temperatures and moisture was high, and the tight gradient observed agrees with the tight dewpoint gradient because of the dryline through eastern Wyoming. This is because of the moisture differences created by the dryline. The CAPE values from the observed Denver sounding are not extremely high, however they still do show sufficient instability in this area, which is relatively far from Wheatland. The SBCAPE values over Wheatland, however, are very high and show that there was a lot of instability in this area, and no SBCIN to prevent convection. Gruwald and Brooks (2011) studied how different parameters can discriminate between tornadic and non-tornadic storms, and found that CAPE is typically a good discriminator. This makes sense, because then in this case, having 3000 J/kg of SBCAPE would indicate tornado formation. However, they also concluded that CAPE does not predict the strength of the tornadoes themselves very well, so having high SBCAPE would not have predicted the tornado having EF2 strength (Grunwald and Brooks, 2011). Overall, instability looked good for the formation of supercell storms and tornadoes, even when other factors were not as good.

In the Denver, CO sounding, the winds were veering slightly in the lower atmosphere, with weak winds near the surface. Wind speeds continuously increased with height, but were not particularly strong. Veering winds have been shown to be conducive to severe storm formation (Hannesen et al., 1998). Storm relative helicity values were not very good for tornado formation, and instability alone is not good enough to form tornadoes. For 0-1 km helicity, values of 100 m^2/s^2 or higher favor tornado formation. In this study, there was no 0-1 km helicity in the area.

For 0-3 km helicity, values of 250 m^2/s^2 or greater favor tornadoes. In this case, again there was no 0-3 km helicity, and even where there was some, north of Wheatland, they still were not sufficient values for tornadoes. Since helicity is essentially a measure of the potential for spin in the atmosphere, it is a very important parameter for strong, rotating storms. Typically, wind shear tilts horizontal vorticity into vertical vorticity to get spin in a storm (Markowski and Richardson, 2009). Markowski and Richardson (2009) also concluded that strong environmental horizontal vorticity can allow for stronger vertical vorticity to happen sooner. In this case, the storm must have gotten its spin elsewhere, possibly from the environment. In Geerts et al.'s study (2009), the storm studied got its spin from banners of strong potential vorticity that formed as a result of the topography of the region. Aebischer and Schar (1997) also found that topography can help form potential vorticity banners when winds blow across the topography, and these enhance cyclogenesis. However, in the case of the Wheatland storm, there were no banners of strong potential vorticity, like Geerts et al. (2009) found, shown in Figure 1. Also, Geerts et al. (2009) found that the shear vectors aligned with the potential vorticity banners that they found, but in this case there were no shear vectors (or potential vorticity banners) to begin with. Any vorticity in the region seemed to be correlated with the upper level trough and associated shortwave in the area, which have been shown to have an effect on supercells and tornadoes (Evans and Johns, 1996). Evans and Johns (1996) studied tornadoes that formed in complex terrain, and in their cases, still found that the effects of an upper level trough dominated. In all cases they studied, there was a well-defined, negatively tilted trough with a shortwave, as there was at the time of the Wheatland tornado. Positive vorticity advection tends to form with shortwave troughs and this is seen in this case. This could potentially have enhanced the storm and give it enough spin to form a tornado.

According to the study done by Rasmussen and Blanchard (1998), the very low EHI values should have predicted that a tornado would not occur. For a strong tornado, EHI > 1 is necessary, while for a violent tornado, EHI > 2.5 is necessary (Hannesen et al., 1998), and the highest EHI value seen in this case was 1. However, EHI combines instability and wind shear into one parameter, and since there was very little wind shear, it makes sense that EHI would be low. Then, tornadoes would only occur if wind shear was supplemented in another way. Contrary to the hypothesis of this study, another case studied by Thompson and Edwards (2000) turned out to be more similar. In this case there was also a trough with a shortwave that corresponded to the high vorticity values, as well as large CAPE values. The authors of this study determined that the large scale environment was conducive to storms, and that was why there was a tornado outbreak that day (Thomson and Edwards, 2000). The Wheatland tornado seems to have formed under somewhat similar conditions, where a large scale trough and shortwave may have played a role, although not a significant one, since there was not a large outbreak in this case.

The storm did not significantly change elevations as it progressed, so this could not have impacted its formation or strength. Other storms that have been studied near complex terrain looked at areas with elevations greater that approximately 1800 meters, while this storm was only at approximately 1500 meters. Also, the Laramie Mountains are the closest to Wheatland, however, they are not even as high in elevation as the Medicine Bow Mountains, which affected the storm studied by Geerts et al. (2009).

Conclusion

Things that are not directly related to the environment surrounding storms and tornadoes have been clearly shown to affect their formation. In this case, it is not clear whether the storm was affected by the topography, as was hypothesized. This does make some sense, since it was not in the exact area as was studied by Geerts et al. (2009); it was close enough that it was a reasonable hypothesis, but this means that it was also farther away from any significant topography in southeastern Wyoming. The synoptic scale provided a good set up, in this case. This storm seems to have been affected by a shortwave trough and its associated high vorticity and potential vorticity values. This shows that it is necessary to look at all scale levels, as well as topography in some cases, when assessing the potential for severe thunderstorms and tornadoes. However, this did not dominate, because if it had, there would have been more of a tornado outbreak that day. The high instability values found make sense, since this is necessary for storms and tornadoes. The low storm relative helicity values do not make sense because storms need some kind of spin to produce tornadoes. However, low level storm relative helicity values can change dramatically over very short distances due to rough terrain. Also, no banners of strong potential vorticity were found. This leads to a rejection of the original hypothesis; topography did not influence the flow and/or potential vorticity banners that then influenced the Wheatland storm.

Despite this, further research is necessary to determine exactly what influenced the helicity in this area during the time of this storm. It may be more likely that the shortwave did affect the storm. Looking at a smaller scale could reveal better local SRH values for tornado formation as well. There were other storms in Laramie County in southeastern Wyoming during this time period that produced two tornadoes, and expanding the study to include these storms as well could enhance these conclusions or produce different ones. Also, performing a computer simulation of this storm and including topography would be useful to see if topography influenced the storm in another way. Another thing that should be expanded on is looking at the terrain that the storm traveled over. Instead of only looking at the terrain that the storm traveled over after the tornado formed, it would help to look at what terrain the storm traveled over starting as soon as the storm began to form.

Appendix

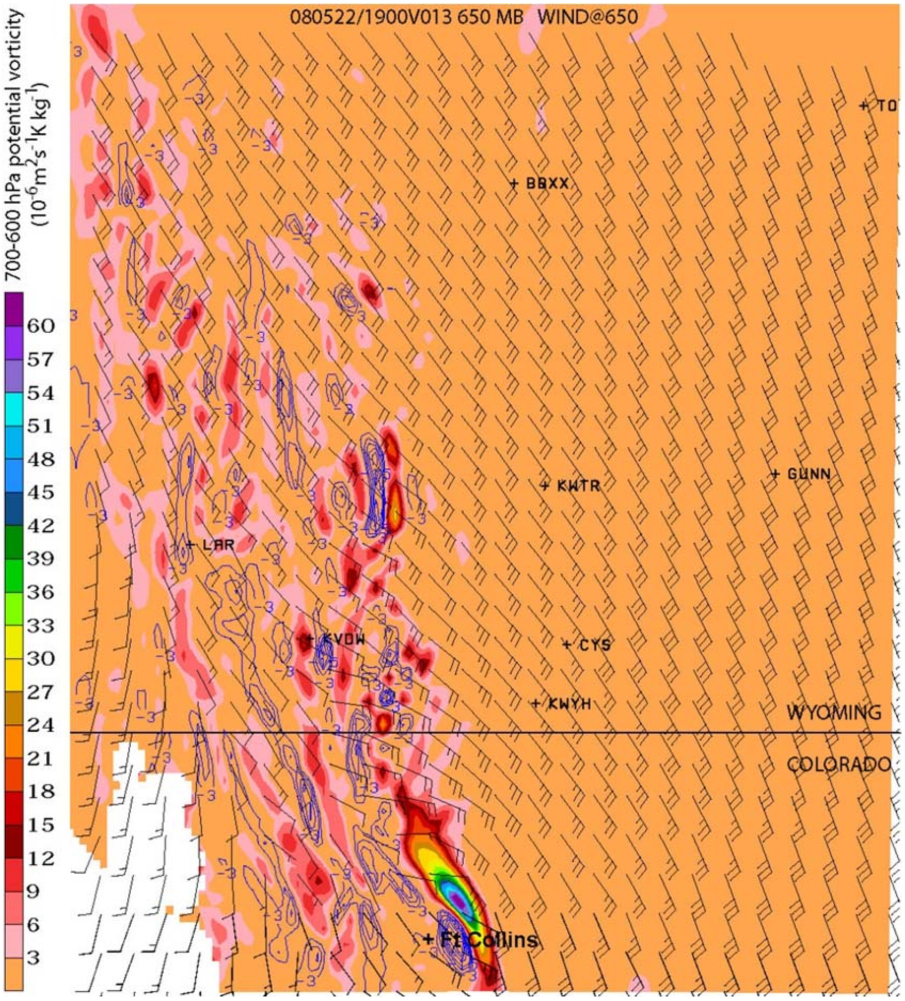


Figure 1: Wind barbs at 650 hPa, with potential vorticity over the 600-700 hPa layer for 1900 UTC on May 22nd 2008. Positive PV is shown with color fill, while negative PV is shown with blue contours (Geerts, et al., 2009).

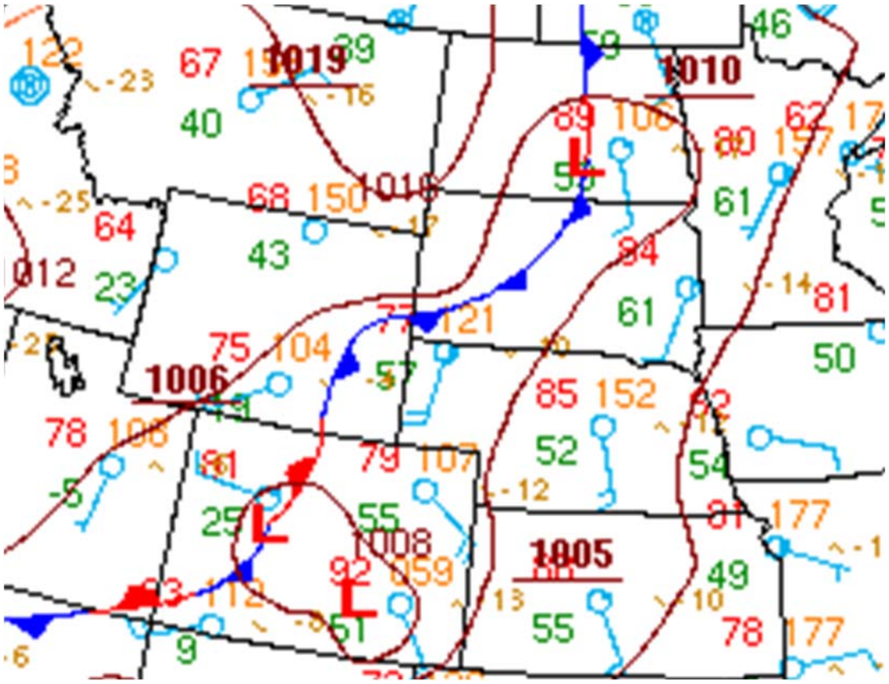


Figure 2: Storm Prediction Center analyzed fronts and pressure systems, sea level pressure (dark red lines), and metar stations at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

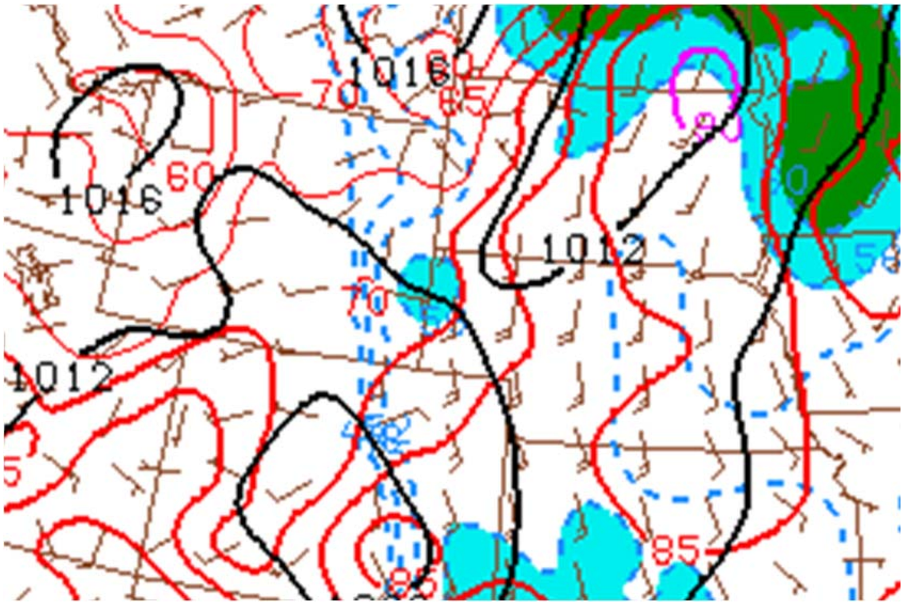


Figure 3: Surface temperature in °F (red and purple lines), dewpoints in °F (blue dotted line and color fill) and sea level pressure (black lines) at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

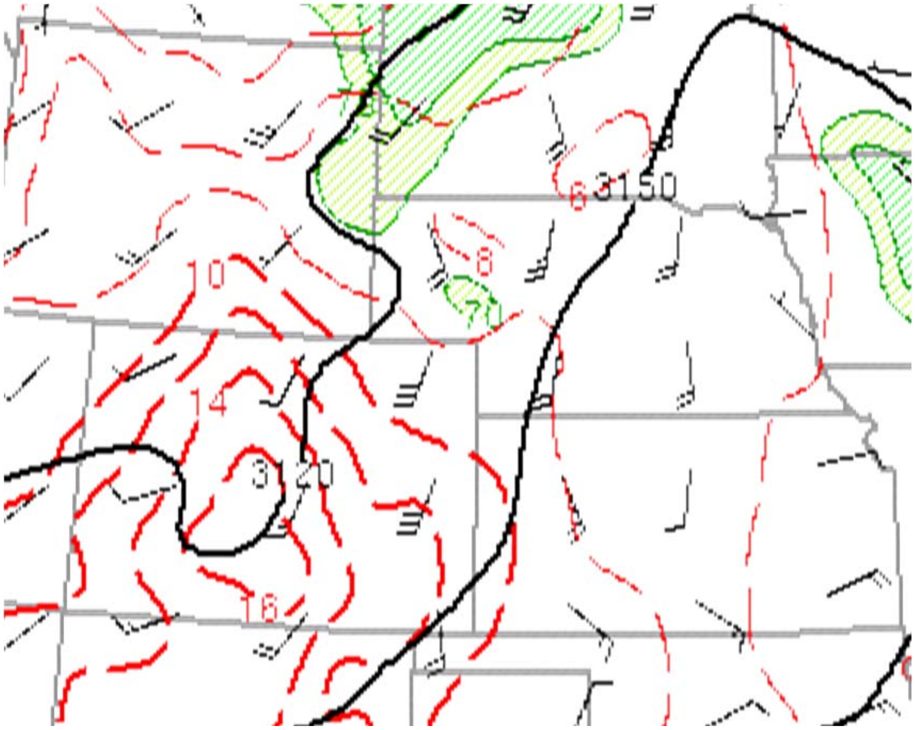


Figure 4: 850 hPa heights (black lines), temperatures in °C (red dashed lines), dew points (green lines and shading) and winds at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

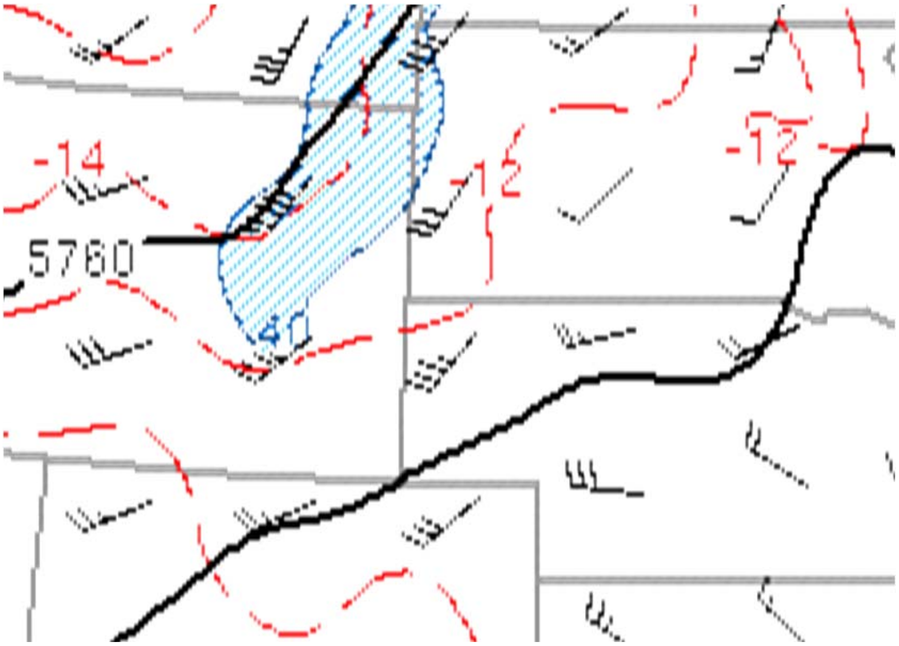


Figure 5: 500 hPa heights (black lines), temperatures in °C (red dashed lines) and winds (blue shading) at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

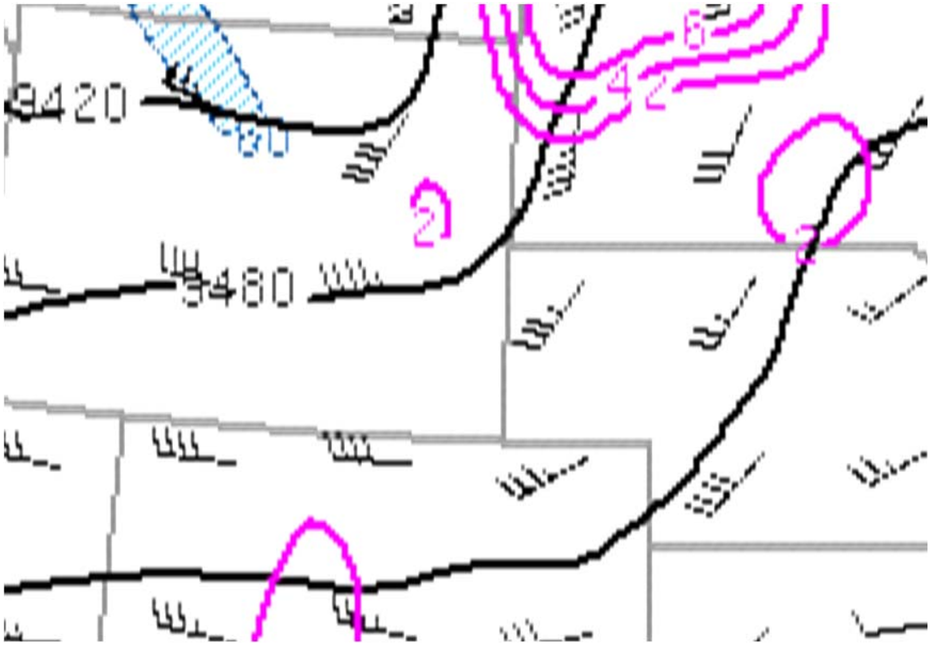


Figure 6: 300 hPa heights (black lines), divergence (purple lines), and winds (blue shading) at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

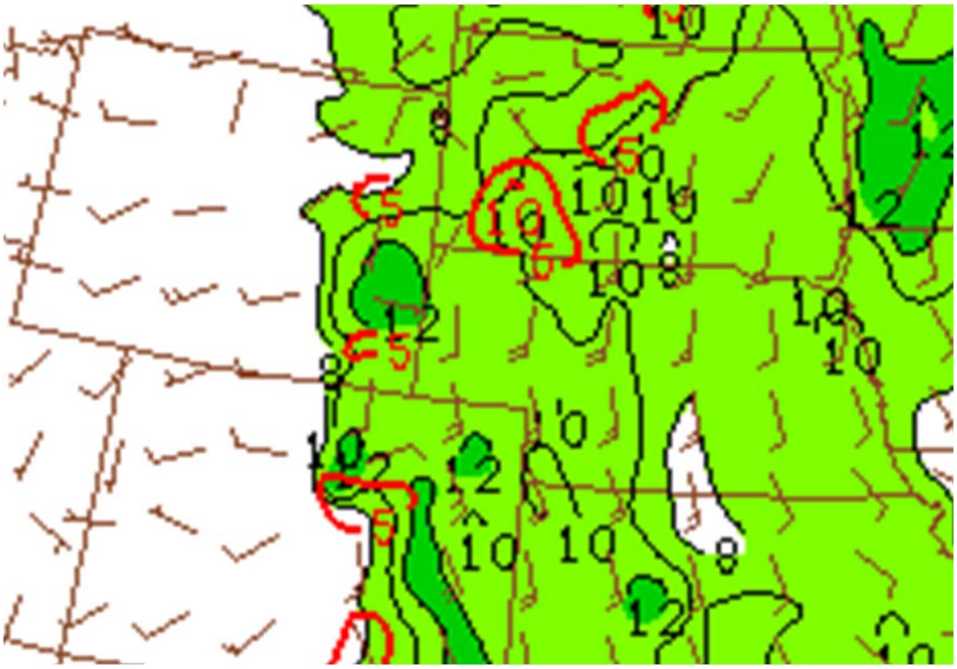


Figure 7: Moisture convergence (red lines) and mixing ratio values (green color fill) at 2100 UTC on June 7th 2012. (Archive National Sector (s4) SPC Hourly Mesoscale Analysis)

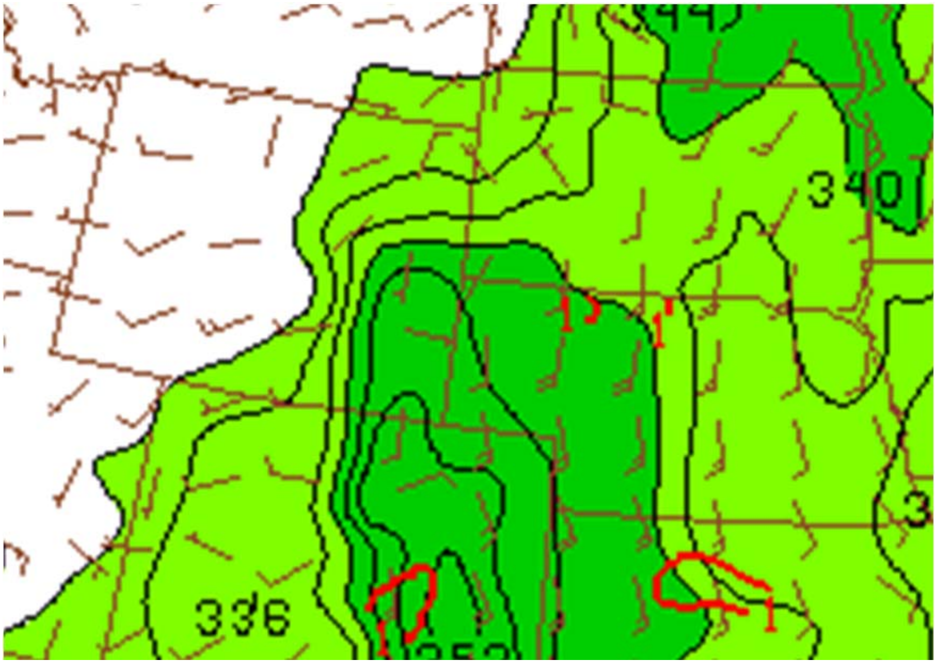


Figure 8: Surface equivalent potential temperature (thetaE) values (green color fill) and thetaE advection (red lines) at 2100 UTC on June 7th 2012. (Archive National Sector (s4) SPC Hourly Mesoscale Analysis)

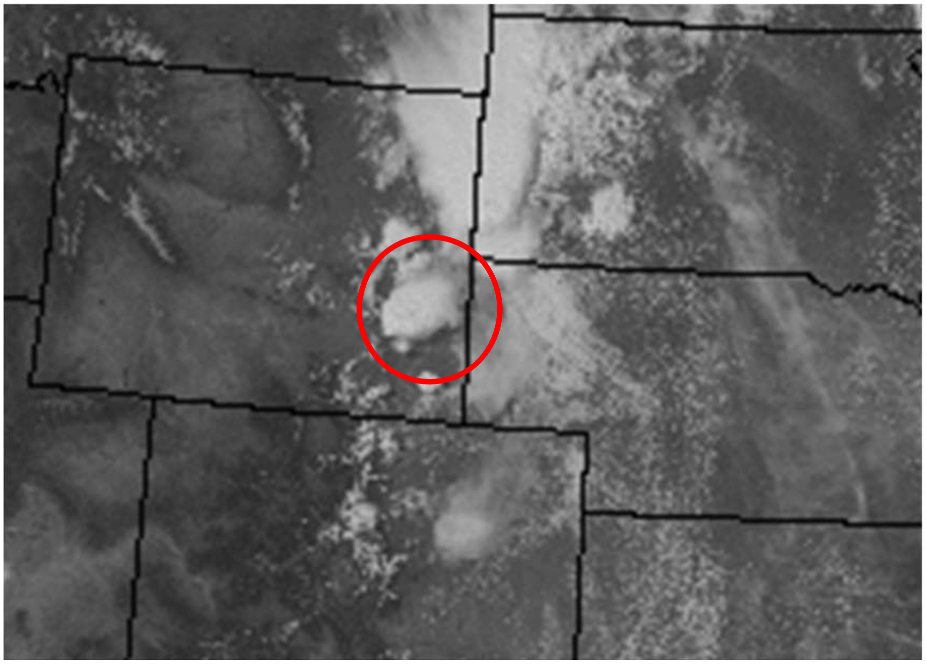


Figure 9: Visible satellite image at 2045 UTC on June 7th 2012. The red circle indicates the supercell of interest. (SPC Severe Weather Event Review for Thursday June 07, 2012)

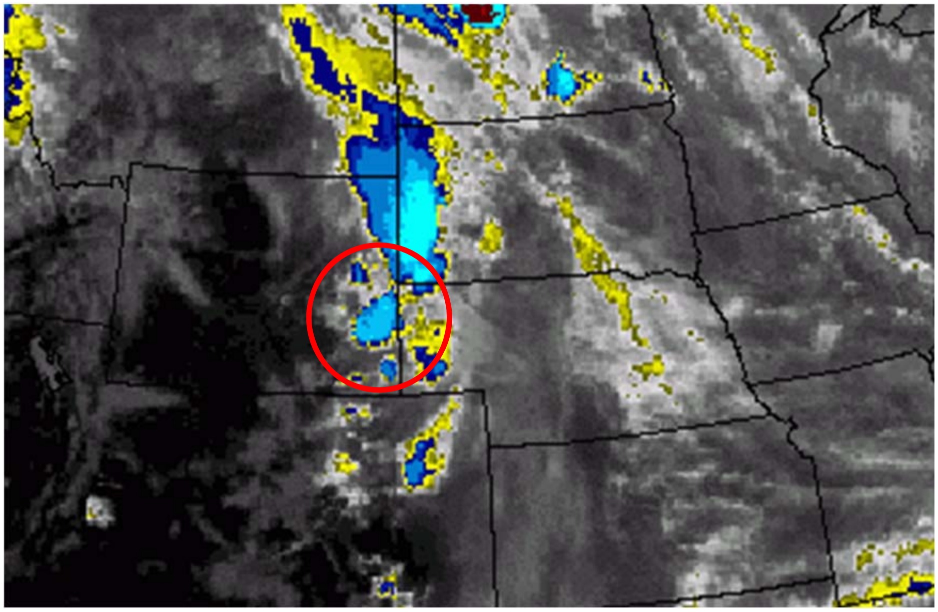


Figure 10: Infrared satellite imagery at 2115 UTC on June 7th 2012 from NOAA's NWS. The red circle indicates the supercell of interest. (SPC Severe Weather Event Review for Thursday June 07, 2012)

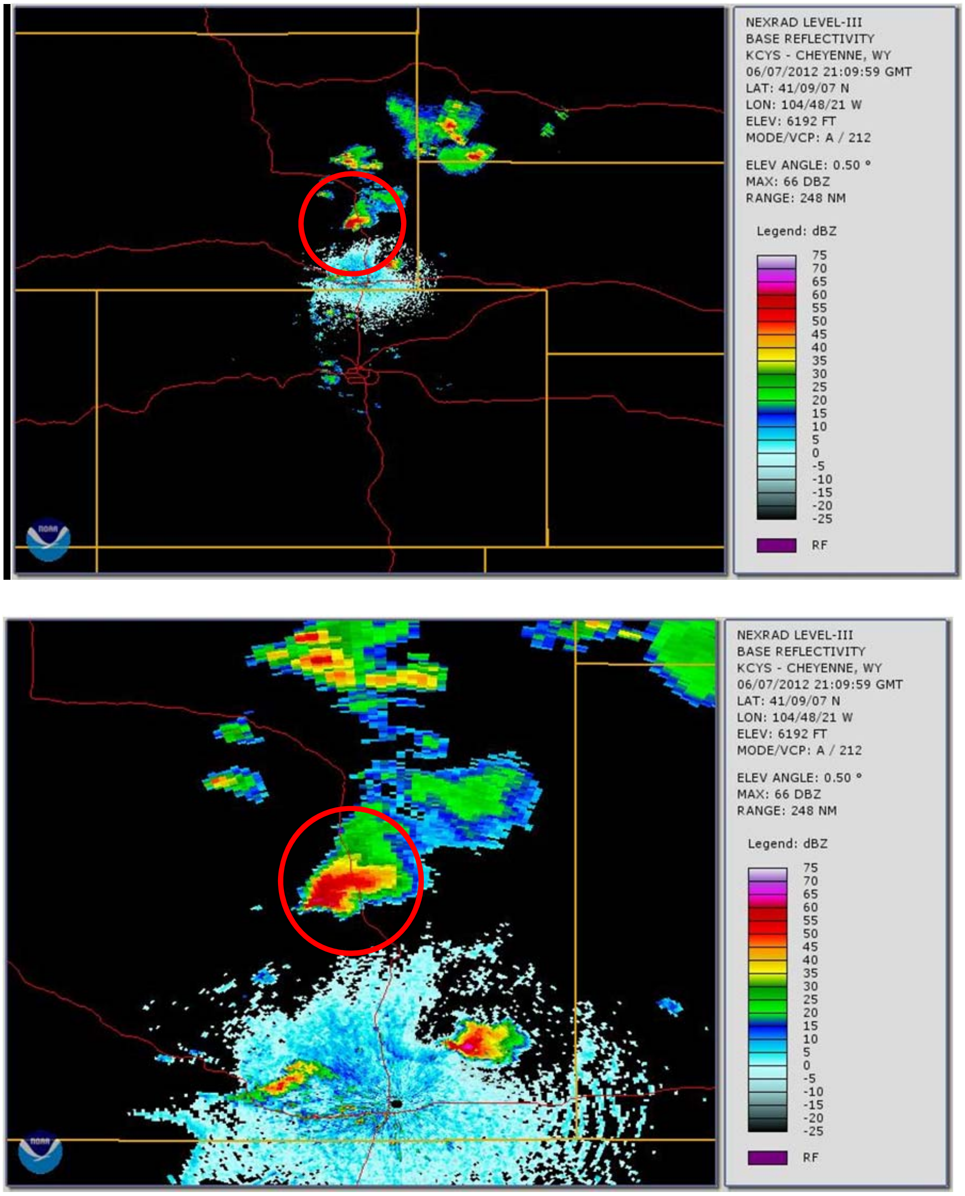


Figure 11a&b: a) Top image, base reflectivity at 2109 UTC on June 7th 2012, b) same image as a., but zoomed in to show hook echo shape. The red circles indicate the supercell of interest. (NCDC NEXRAD Data Inventory Search)

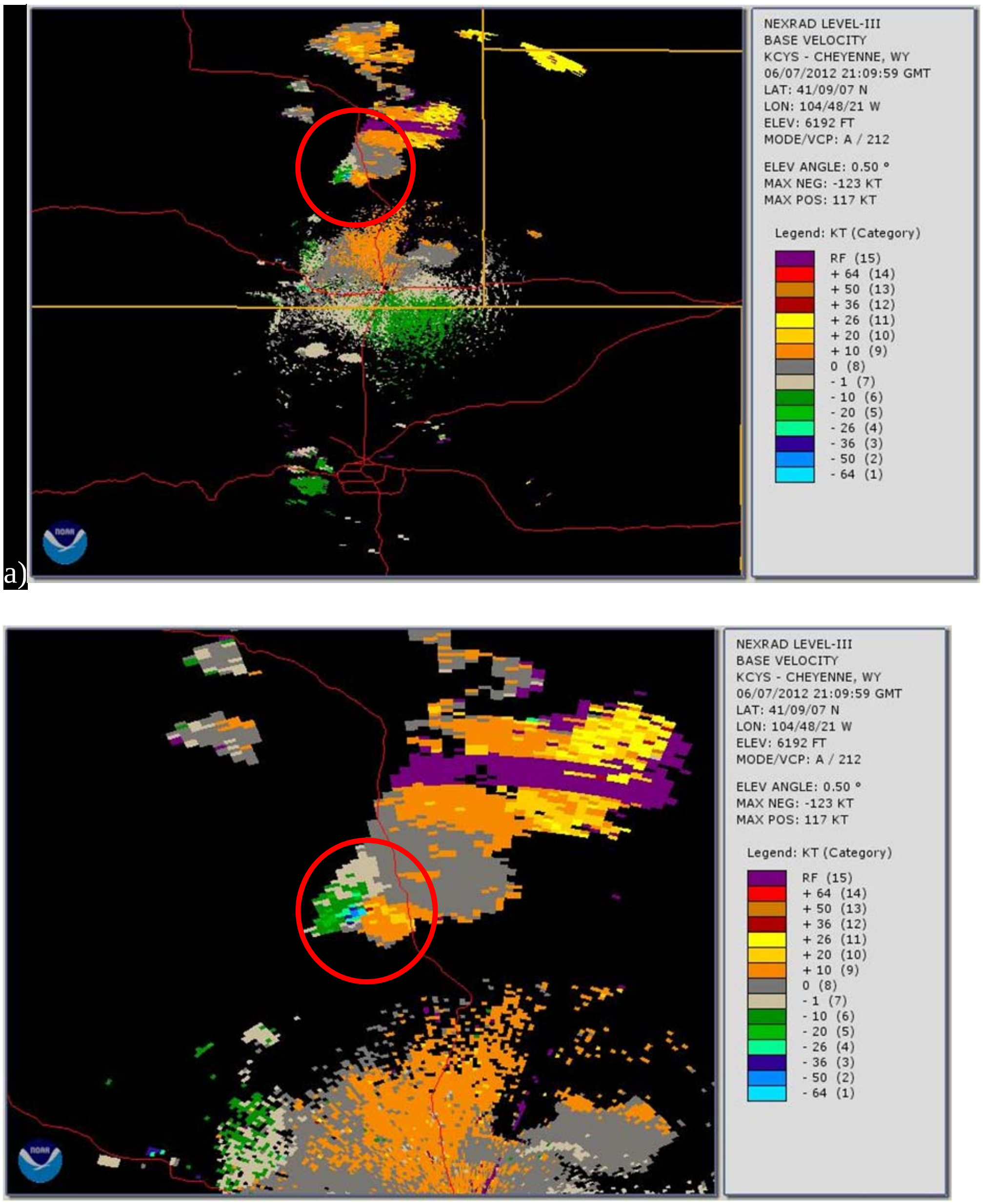


Figure 12a&b: a) Top image, base velocity at 2109 UTC on June 7th 2012, b) same image as a., but zoomed in to show tornado vortex signature. The red circles indicate the TVS. (NCDC NEXRAD Data Inventory Search)

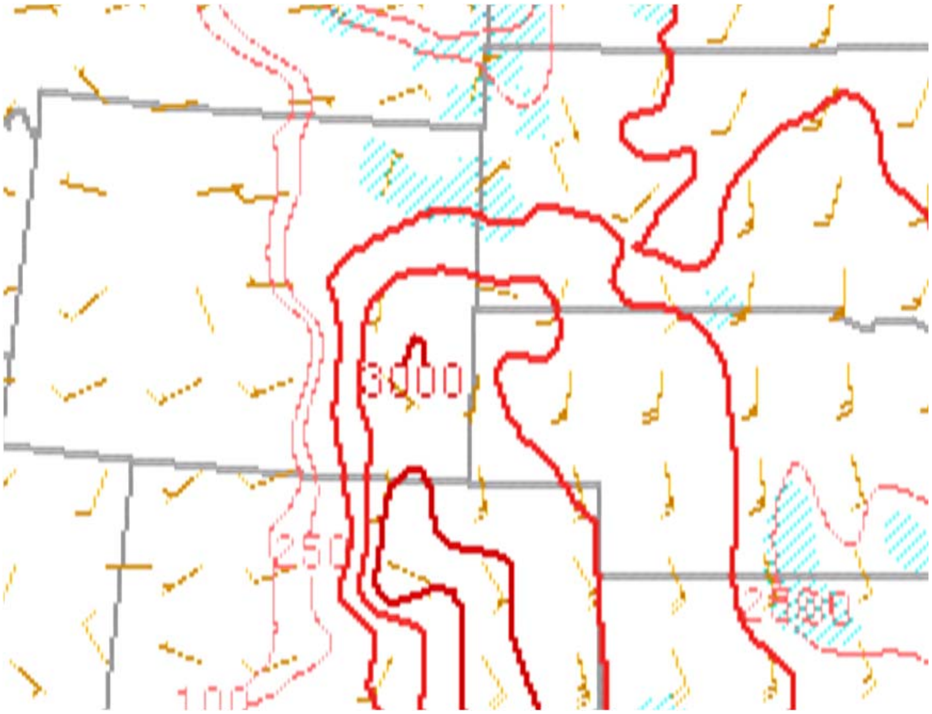
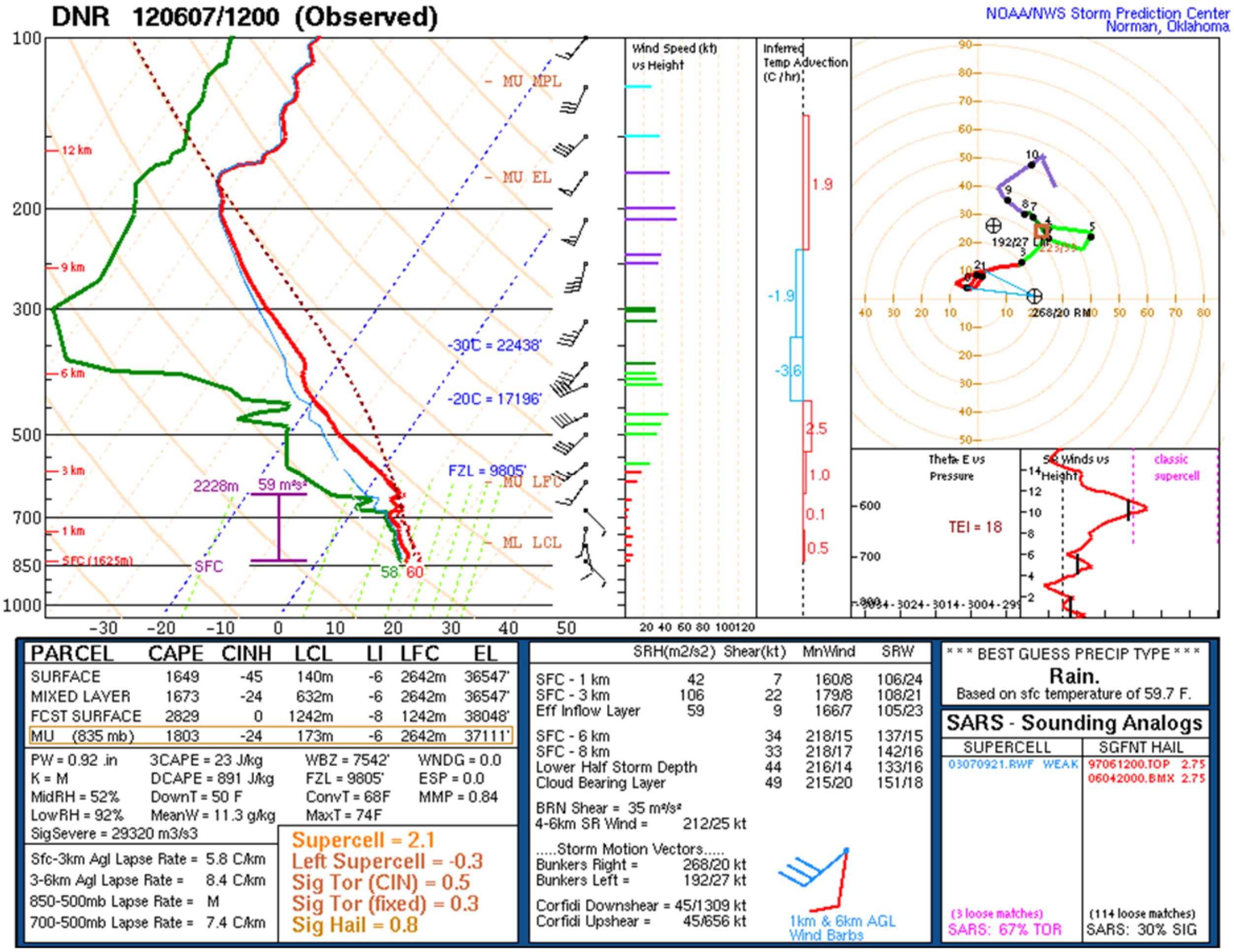


Figure 13: SBCAPE (red lines) and SBCIN (blue shaded at 25 and 100) in J/kg at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)



PARCEL	CAPE	CINH	LCL	LI	LFC	EL
SURFACE	1649	-45	140m	-6	2642m	36547'
MIXED LAYER	1673	-24	632m	-6	2642m	36547'
FCST SURFACE	2829	0	1242m	-8	1242m	38048'
MU (835 mb)	1803	-24	173m	-6	2642m	37111'

PW = 0.92 .in
K = M
MidRH = 52%
LowRH = 92%
SigSevere = 29320 m3/s3

3CAPE = 23 J/kg
DCAPE = 891 J/kg
DownT = 50 F
MeanW = 11.3 g/kg

WBZ = 7542'
FZL = 9805'
ConvT = 68F
MaxT = 74F

WNDG = 0.0
ESP = 0.0
MMP = 0.84

Sfc-3km Agl Lapse Rate = 5.8 C/km
3-6km Agl Lapse Rate = 8.4 C/km
850-500mb Lapse Rate = M
700-500mb Lapse Rate = 7.4 C/km

Supercell = 2.1
Left Supercell = -0.3
Sig Tor (CIN) = 0.5
Sig Tor (fixed) = 0.3
Sig Hail = 0.8

	SRH(m2/s2)	Shear(kt)	MnWind	SRW
SFC - 1 km	42	7	160/8	106/24
SFC - 3 km	106	22	179/8	108/21
Eff Inflow Layer	59	9	166/7	105/23
SFC - 6 km		34	218/15	137/15
SFC - 8 km		33	218/17	142/16
Lower Half Storm Depth		44	216/14	133/16
Cloud Bearing Layer		49	215/20	151/18

BRN Shear = 35 m²/s²
4-6km SR Wind = 212/25 kt

.....Storm Motion Vectors.....
Bunkers Right = 268/20 kt
Bunkers Left = 192/27 kt

Corfidi Downshear = 45/1309 kt
Corfidi Upshear = 45/656 kt

* * * BEST GUESS PRECIP TYPE * * *
Rain.
Based on sfc temperature of 59.7 F.

SARS - Sounding Analogs

SUPERCELL	SGFNT HAIL
03070921.RWF WEAK	97061200.TOP 2.75 06042000.BMX 2.75
(3 loose matches) SARS: 67% TOR	(114 loose matches) SARS: 30% SIG

Figure 14: Denver, CO 1200 UTC on June 7th 2012 upper-air sounding and related parameters.

(SPC Severe Weather Event Review for Thursday June 07, 2012)

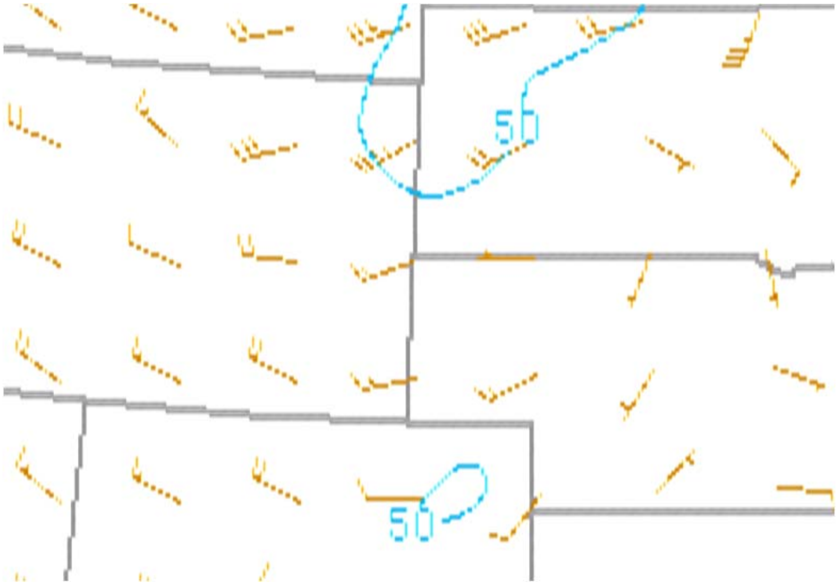


Figure 15: 0-1 km storm relative helicity in m^2/s^2 (blue lines) and storm motion in kts at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

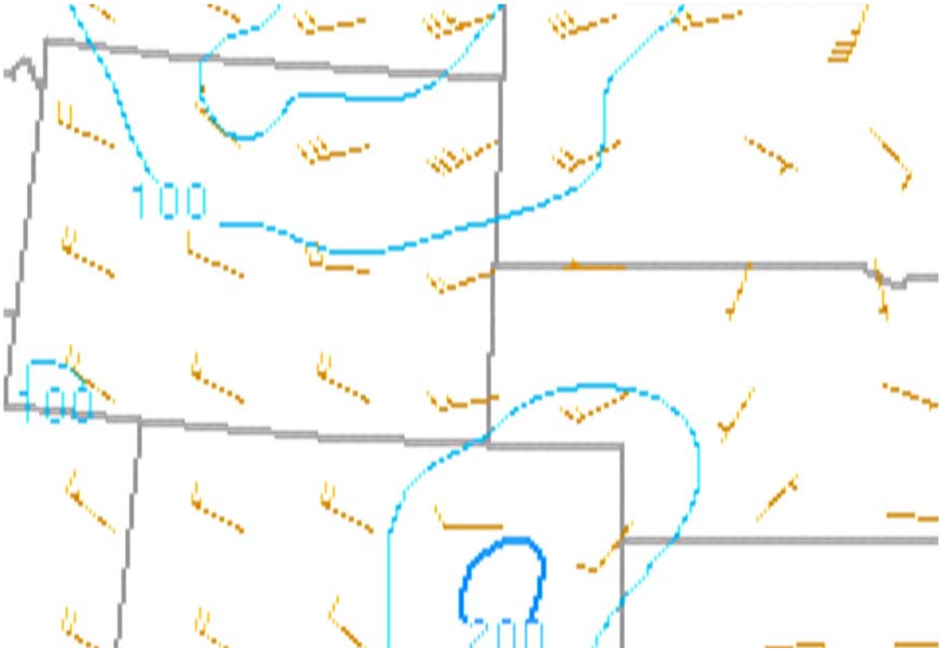


Figure 16: 0-3 km storm relative helicity in m^2/s^2 (blue lines) and storm motion in kts at 2100 UTC on June 7th 2012. (SPC Severe Weather Event Review for Thursday June 07, 2012)

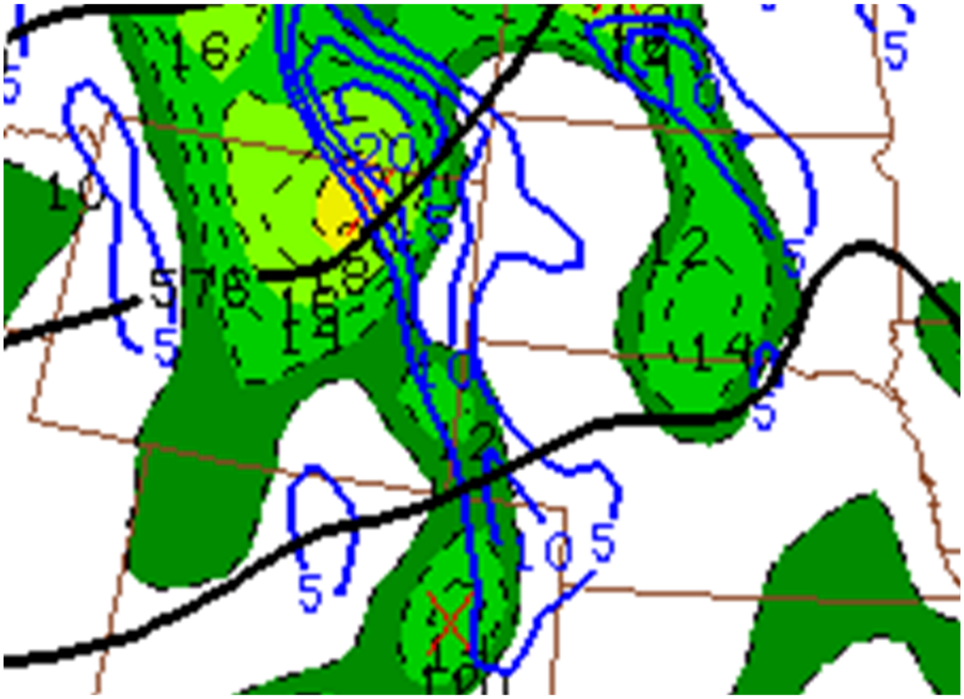


Figure 17: 500 hPa heights (black lines) and vorticity (green color fill), and 700-400 hPa differential vorticity advection (blue lines) at 2100 UTC on June 7th 2012. (Archive National Sector (s4) SPC Hourly Mesoscale Analysis.)

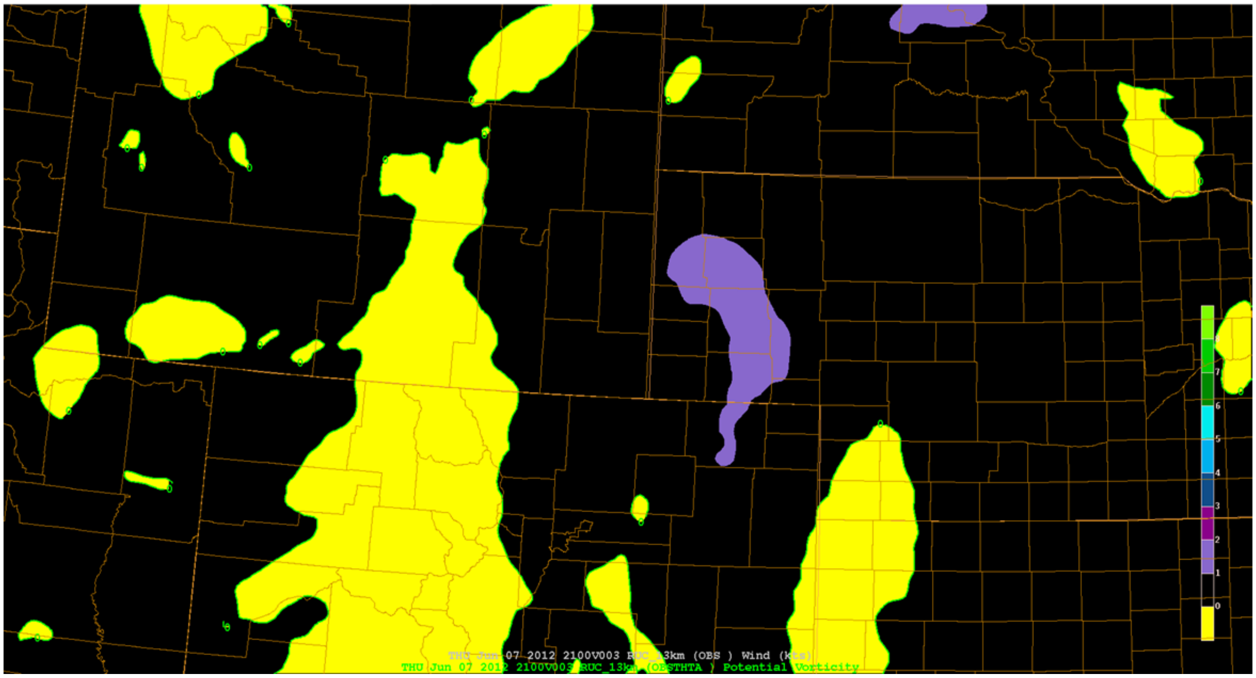


Figure 18: 600 – 700 hPa potential vorticity (color fill) at 2100 UTC on June 7th 2012. (GARP. RUC model data).

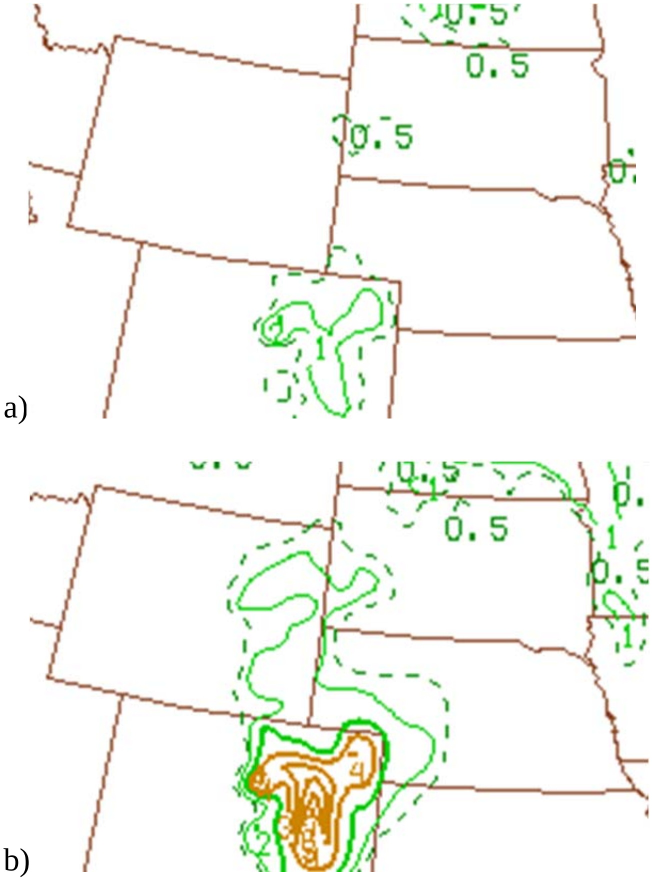


Figure 19a&b: a) (top) 1 km EHI values (dashed green line – 0.5, solid green line – 1), b) (bottom) 0-3 km EHI values (dashed green line – 0.5, solid green line – 1, thicker green line – 2, brown lines – 3+) at 2100 UTC on June 7th 2012. (Archive National Sector (s4) SPC Hourly Mesoscale Analysis.)

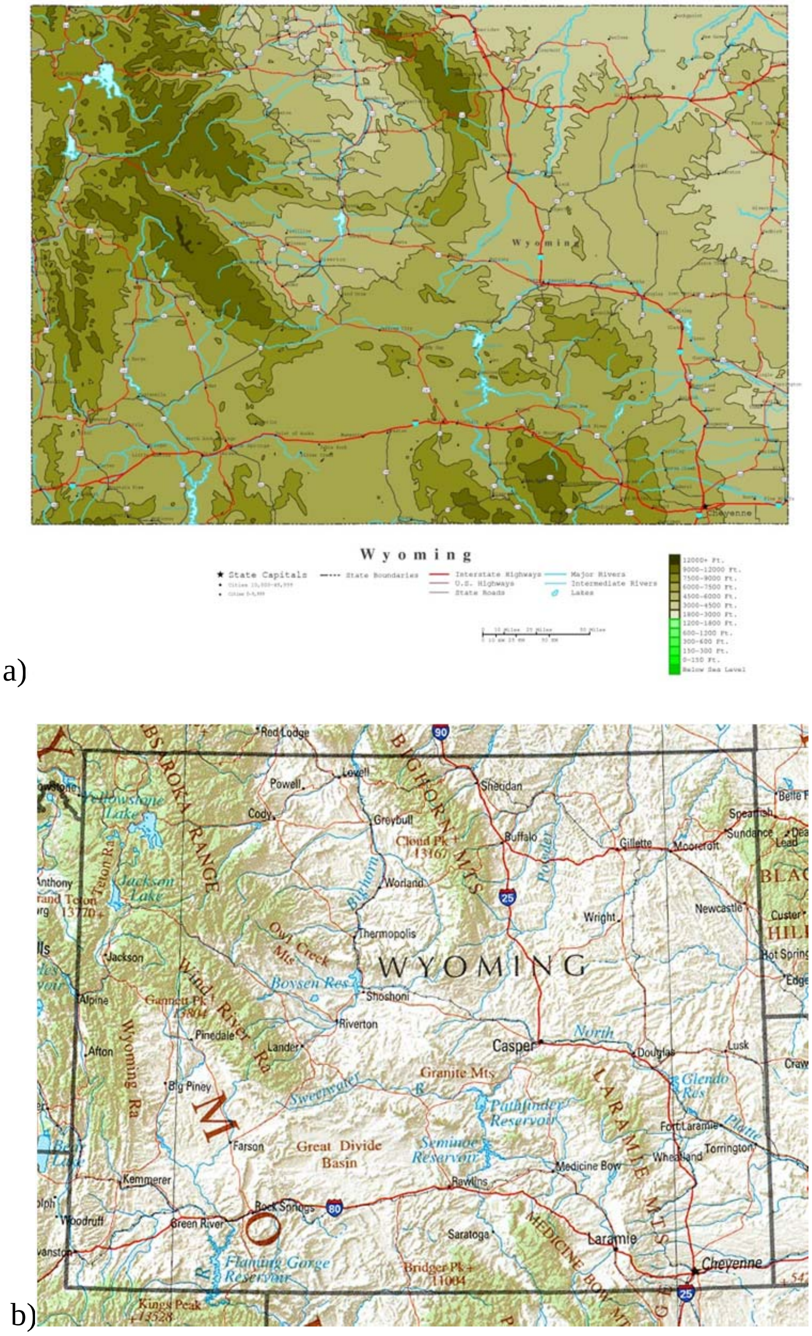


Figure 20a&b: a) topographic map of Wyoming with elevations. b) topographic map showing elevation through texture. (Yellow Maps World Atlas)

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