WES Case Facilitator's Guide:
WFO FSD - July 5, 2022

Warning Operations Course: Severe Curriculum

NWS Warning Decision Training Division

Released August 2024

Introduction

Welcome to the national WES case for WOC Severe from 5 July 2022. On 5 July, a cluster of supercells evolved into a derecho that moved from north central South Dakota into southwestern Minnesota and northwestern Iowa. For this simulation, we will focus on the mature stage of the derecho as it moved across southeastern South Dakota and impacted the Sioux Falls metropolitan area around the evening rush hour. During this scenario, numerous wind gusts of greater than 80 mph were observed. What makes this case unique from past WES cases is that these gusts occurred more than 30 minutes after the gust front had moved through and wind gusts over 60 mph persisted for over an hour. During the simulation the student will be challenged to figure out the best warning strategy for warning the public of long-duration destructive winds.

The Sioux Falls CWA consists of 45 counties in 4 states (Fig. 1). Twenty-four of the counties are located in southeastern South Dakota with 8 counties in southwestern Minnesota, 11 in northwestern Iowa and 2 in far northeastern Nebraska. The two largest cities in the forecast area are Sioux Falls, South Dakota, with a population just over 208,000, and Sioux City, Iowa, with a population of around 100,000. Two interstate highways bisect the CWA with I-90 running from Brule County through Sioux Falls and to Jackson County, Minnesota. The second interstate, I-29, runs east and west from Sioux City, Iowa (eastern Woodbury County, Iowa) through Sioux Falls and to Brookings County, South Dakota. Landcover is primarily cropland with corn and soybeans. There are some grasslands in south-central South Dakota. There are few trees in the CWA except for near rivers, farms, and in cities. So strong winds are common in this area.

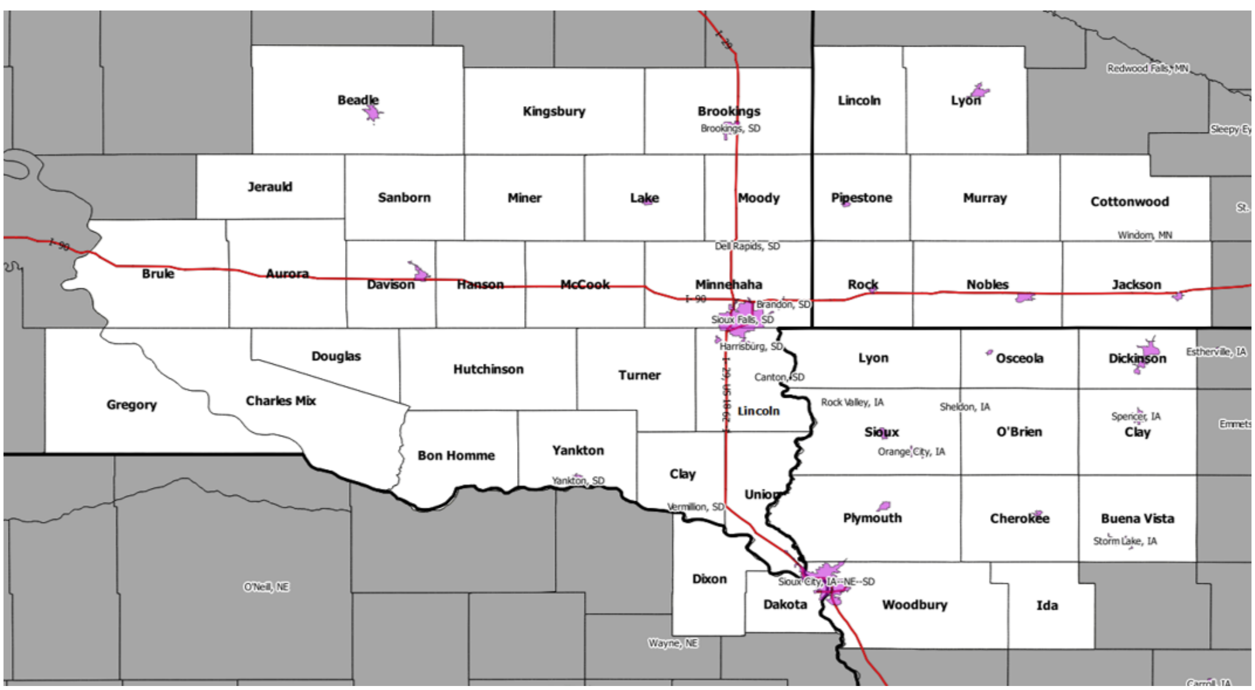


Fig. 1. Map of the WFO Sioux Falls County Warning Area.

Severe weather typically occurs between 4 pm and 11 pm with overnight convection fairly common as storms develop in the western High Plains during the afternoon and move across the Sioux Falls CWA in the overnight - especially if a low-level jet can develop and provide additional moisture and shear to keep storms organized. In this scenario, severe weather will be ongoing at 2 pm CDT (1900 UTC) which is uncommon and could require additional messaging to alert the public to the danger of destructive winds through the afternoon.

Taking the Simulation

Part 1: Prerequisites

WOC Severe students, prior to taking the WES simulation, should complete all of the following:

1. Hand analysis homework (via the How to Hand Analyze Maps module)
2. WOC Severe Instructor-Led Webinar
3. Recommended modules:
    a. The I-SPIDA Warning Workflow
    b. Advanced Warning Methodology: Wind from Linear Storm Modes
    c. Anticipating Severe Winds
    d. Introduction to Derechos
    e. Derecho Warning Strategies and Operations

Non-WOC Severe students, prior to taking the WES simulation, should complete the following:

1. "Mesoanalysis Walk-Through Worksheet" at the back of this student guide.
2. Recommended modules:
    a. The I-SPIDA Warning Workflow
    b. Advanced Warning Methodology: Wind from Linear Storm Modes
    c. Anticipating Severe Winds
    d. Introduction to Derechos
    e. Derecho Warning Strategies and Operations

Then, all those taking the WES simulation should complete the following steps:

1. Take the introduction module, WES Case Introduction: FSD July 2022, which provides an overview of the case.
2. Based on the student's threat assessment and convective expectations, discuss their warning strategy with the facilitator. Include all facets of the I-SPIDA Warning Methodology in their discussion.

WES in the Cloud Case Instructions:

Instructions students will follow to access the simulation in the cloud:

1. Contact your office's WES point of contact (SOO or WES focal point) to turn on WES in the Cloud instance
2. Log into instance
3. Open WES2Bridge
4. Start the EDEX for the WES case
5. (If case is not loaded to an EDEX, load it to an open EDEX first)
6. Select the case *"2022Jul5FSD"* from the available cases window
7. Right click on the case and select "Simulation"
    a. If you would like to issue warnings during the regular warning simulation period from 1902 - 2135 UTC, load the macro *"WOC Severe Macro"*

b. If you would like to issue warnings during the regular warning simulation period from 1902 - 2135 UTC AND the bonus period from 2135 - 2300 UTC, load the macro *"WOC Severe (With Bonus Time)"*

8. Press "Simulate" (simulation will be paused at 1902Z)
9. Follow the instructions in Part 2 for steps to complete before you hit "Start" and let the simulation run.

Part 2: Simulation

Set-up: Simulation Paused at 1902 UTC

Take this time to load your warning procedures. Then, while paused, work through your first I-SPIDA cycle.

Warning Simulation Period: 1902 - 2135 UTC

As the warning forecaster, you are responsible for issuing warnings along the line of storms moving through the FSD CWA. As the warning meteorologist, your goals include:

1. Follow the I-SPIDA warning workflow in your warning process.
2. In the "Act" step of the I-SPIDA warning workflow, follow the 10 Steps to Issue a Warning or Statement to issue timely warnings for the convective hazards associated with this event.

Warning Simulation Period (BONUS): 2135 - 2300 UTC

Those who wish to continue with the case can run it up to an hour longer, providing an opportunity to warn across a metro area and as the system moves through the FSD CWA.

Part 3: Debrief

Watch the debriefing module, WES Case Summary: FSD July 2022, and take its quiz in the CLC module for course completion credit (mandatory for those in WOC Severe). If proctored, your SOO or facilitator will review the case with you, focusing on how you performed regarding the stated objectives.

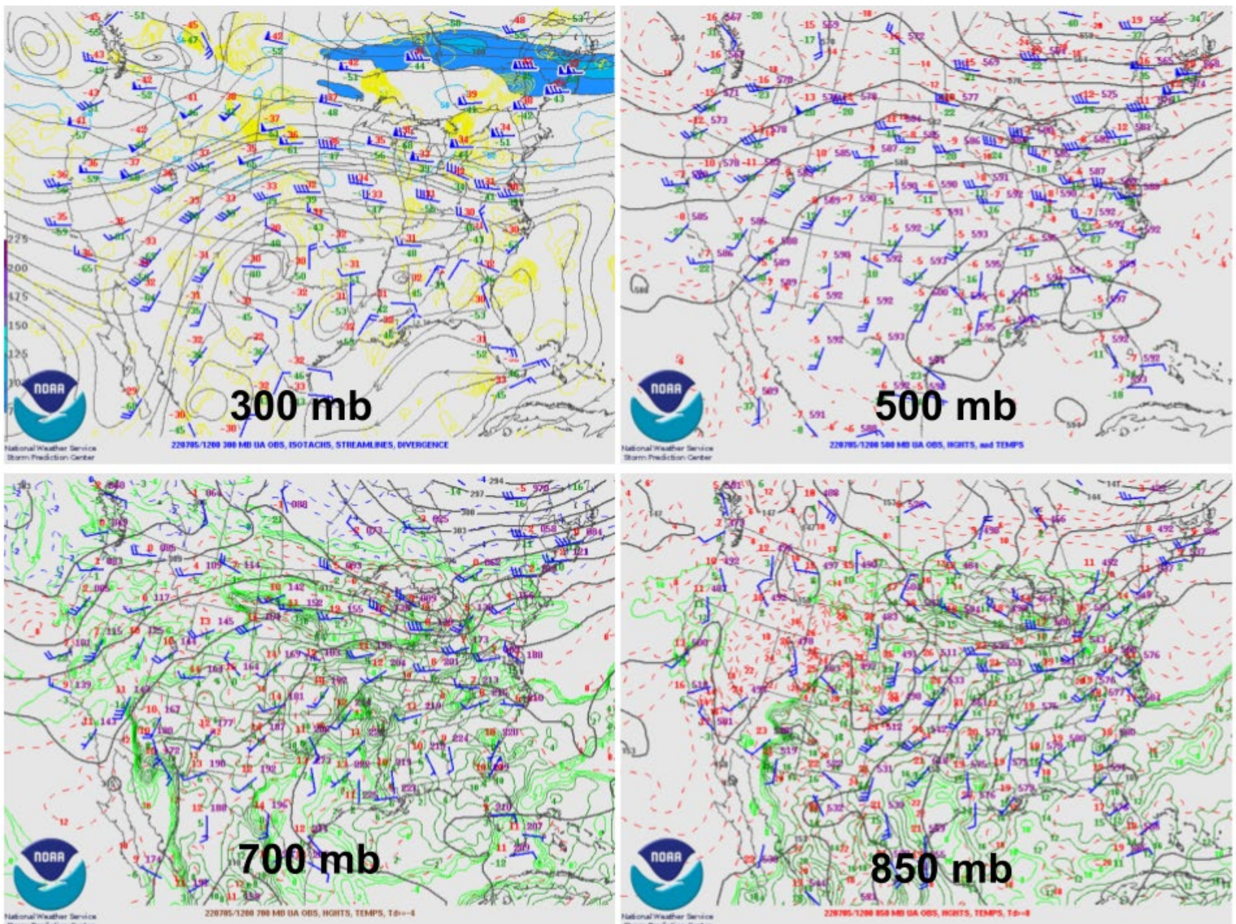


Fig. 2. Four-panel of 1200 UTC upper air plots on the morning of July 5th, 2022.

Pre-event Mesoanalysis

Initial Setup

Referencing the four-panel objective analysis (Fig. 2) above, at 1200 UTC on the morning of July 5th, 2022, a broad subtropical mid- and upper-level ridge was positioned over the southern United States, with a zone of seasonably zonal to slightly anticyclonically curved, strong flow (70 kts at 250 mb) atop the ridge across the Dakotas and Minnesota. The apex of the mid-level ridge (500 mb - upper right panel) was centered along the Missouri River in the Dakotas, with 1200 UTC RAOBS from across the area indicating around 20-30 kts of westerly flow at this level. A weak low-level shortwave trough was pushing east through the Great Lakes, leaving a trailing zone of convergence and moisture at 700 mb/850 mb (lower panels) oriented WNW-ESE across South Dakota and southern Minnesota. A subtle shortwave trough was evident over eastern Montana, as well, and would prove instrumental for incipient thunderstorm development during the early morning hours of July 5th. A southerly low-level jet was feeding into southern and central South Dakota, with 15 kts (KUNR) and 30kts (KLBF) respectively at 850mb impinging on the gradient.

At the surface at 1500 UTC (Fig. 3, Fig.4), a stationary front extended west to east across southern South Dakota and had begun to slowly shift north with warm frontal characteristics (weak warm advection) on the southerly low-level jet across southern South Dakota.

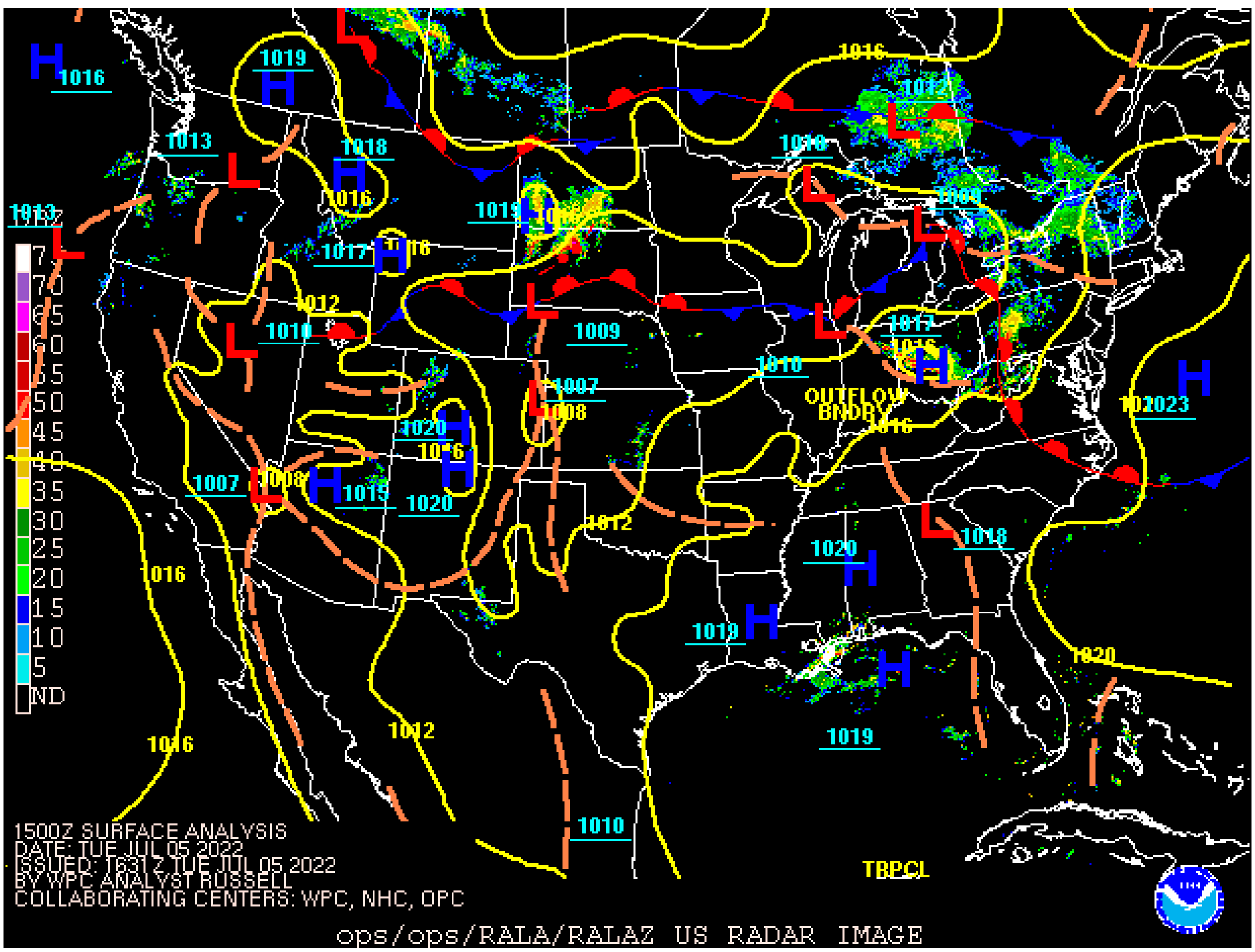


Fig. 3. WPC surface frontal analysis as of 1500 UTC on July 5th, 2022.

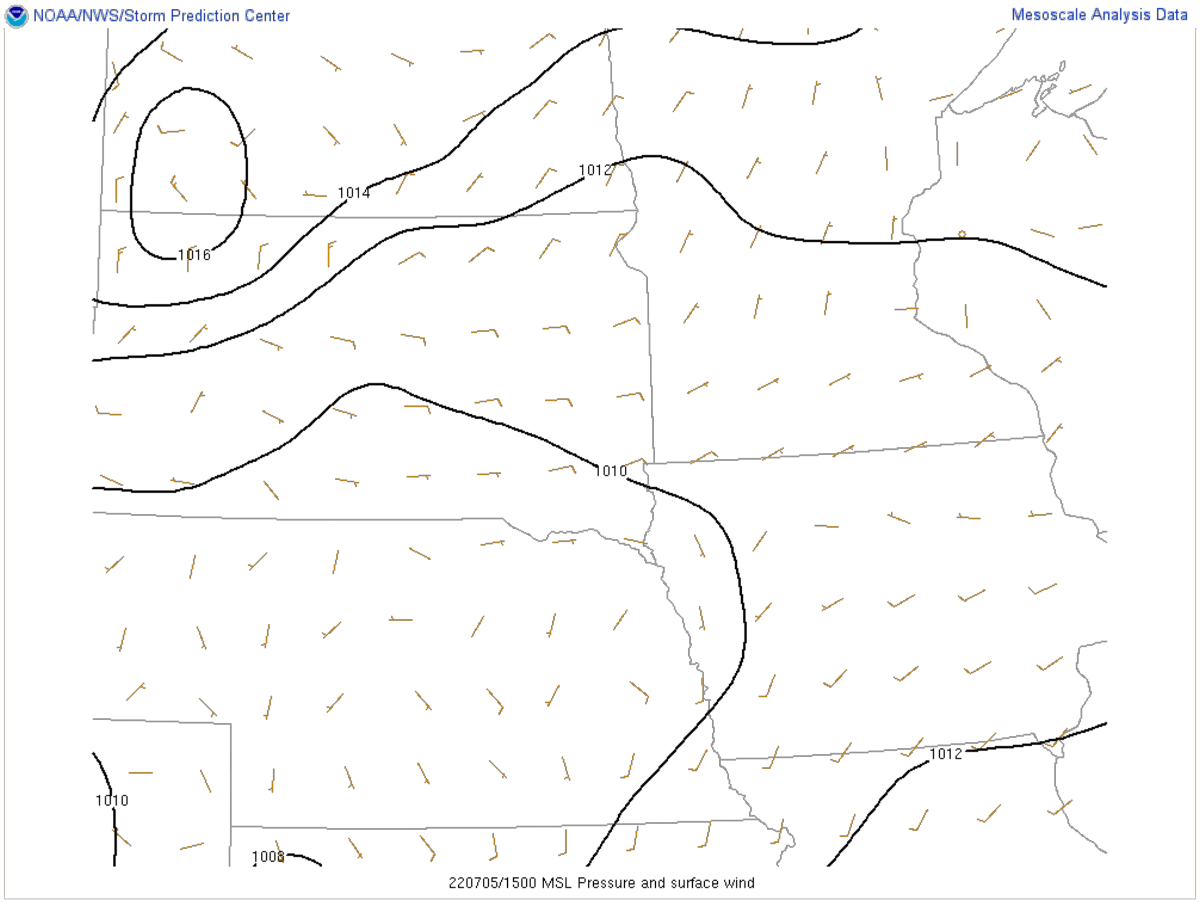


Fig. 4. SPC Mesoanalysis sector zoomed in over the FSD CWA at 1500 UTC.

1200 UTC

The 1200 UTC KABR (Aberdeen) sounding in northeastern South Dakota (Fig. 5) on the morning of July 5th sampled the airmass north of the surface stationary front / warm front effectively, showing weak northerly low-level flow and low-level cold advection, underneath a residual elevated mixed layer (EML) with 700-500-mb lapse rates near 8 ºC/km. The upstream air mass feeding northward into the FSD CWA on the low-level jet is appropriately measured by the 1200 UTC sounding from KLBF (North Platte) (Fig. 6), indicating >25 ºC warmth at 85 0mb, adding considerable potential instability once daytime heating commences. Surface dew points (not shown) just north of the boundary in southeastern South Dakota were in the lower 70s at 1200 UTC. As the EML moved north of the boundary, a very unstable airmass existed. A cluster of elevated, severe thunderstorms was moving across northern South Dakota through the morning hours on the nose of the weakening and veering low-level jet, dropping slowly southeast with time into the feed of higher theta-e air being transported atop the surface frontal zone.

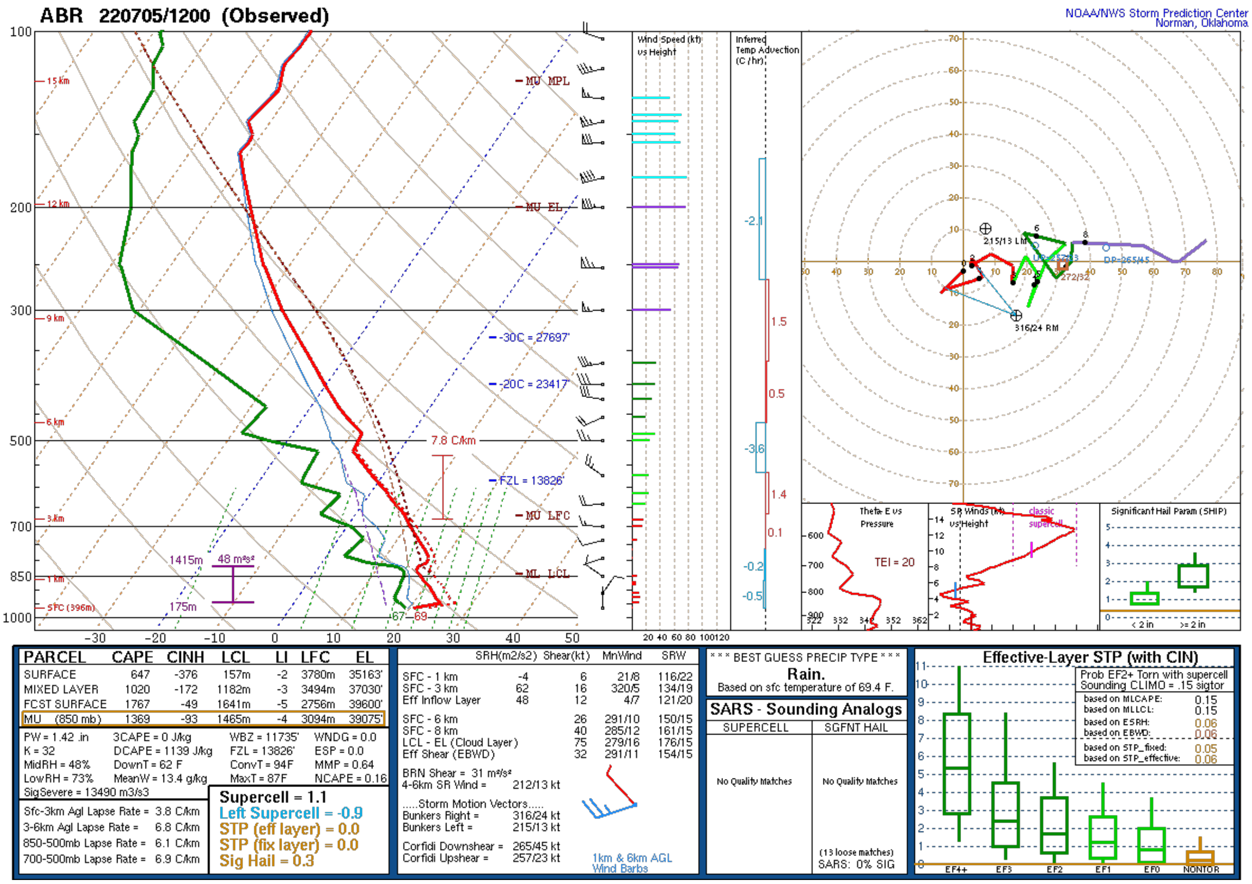


Fig. 5. SPC sounding from KABR at 1200 UTC on July 5th, 2022.

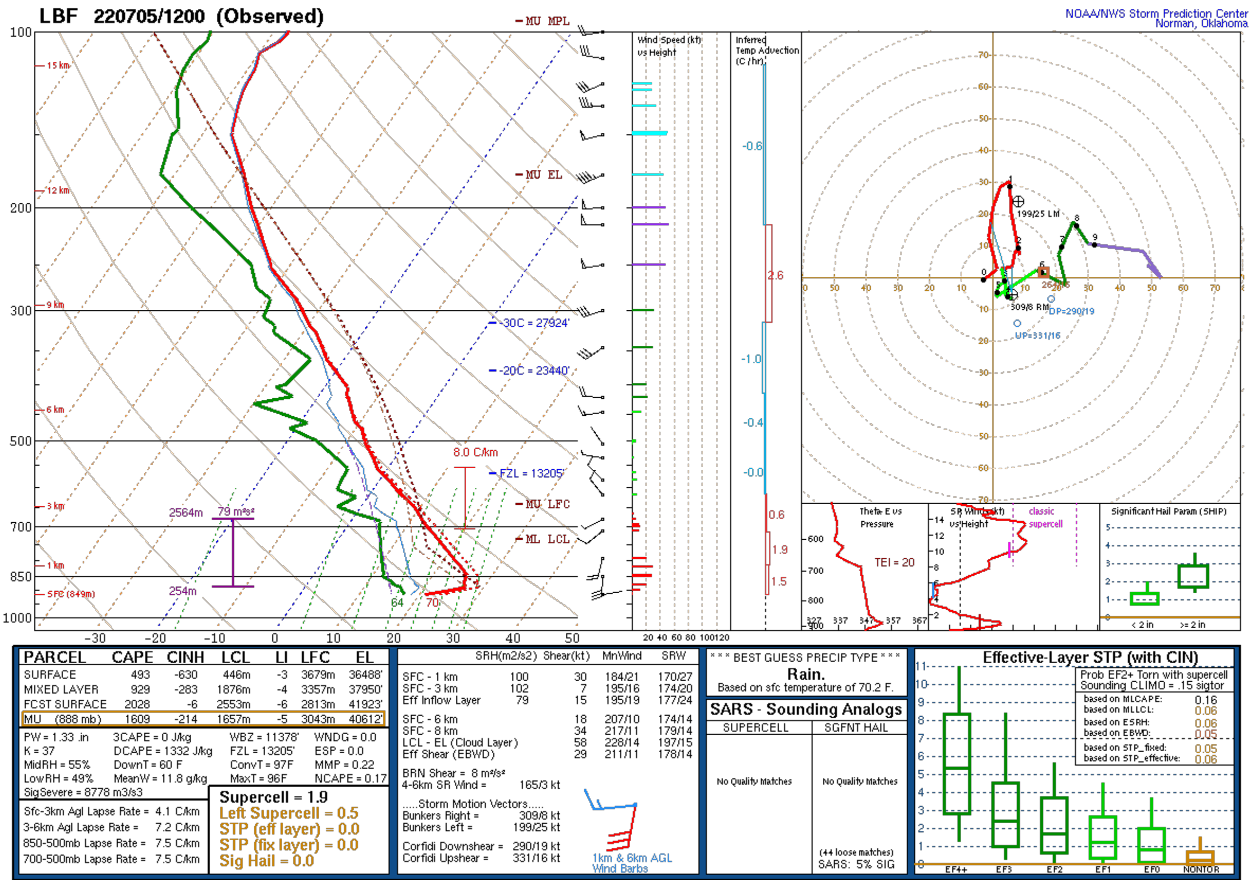


Fig. 6. SPC sounding from KLBF at 1200 UTC on July 5th, 2022.

1500 UTC

At 1500 UTC, the KFSD radar vertical wind profile (VWP) (Fig. 7) captured the weak easterly flow at low levels north of the advancing warm front, with maximum flow around 15-20 kts around 4-5 kft MSL (3-4 kft AGL). Above the frontal inversion at 8 kft MSL (7 ft AGL), winds switch to southwest.

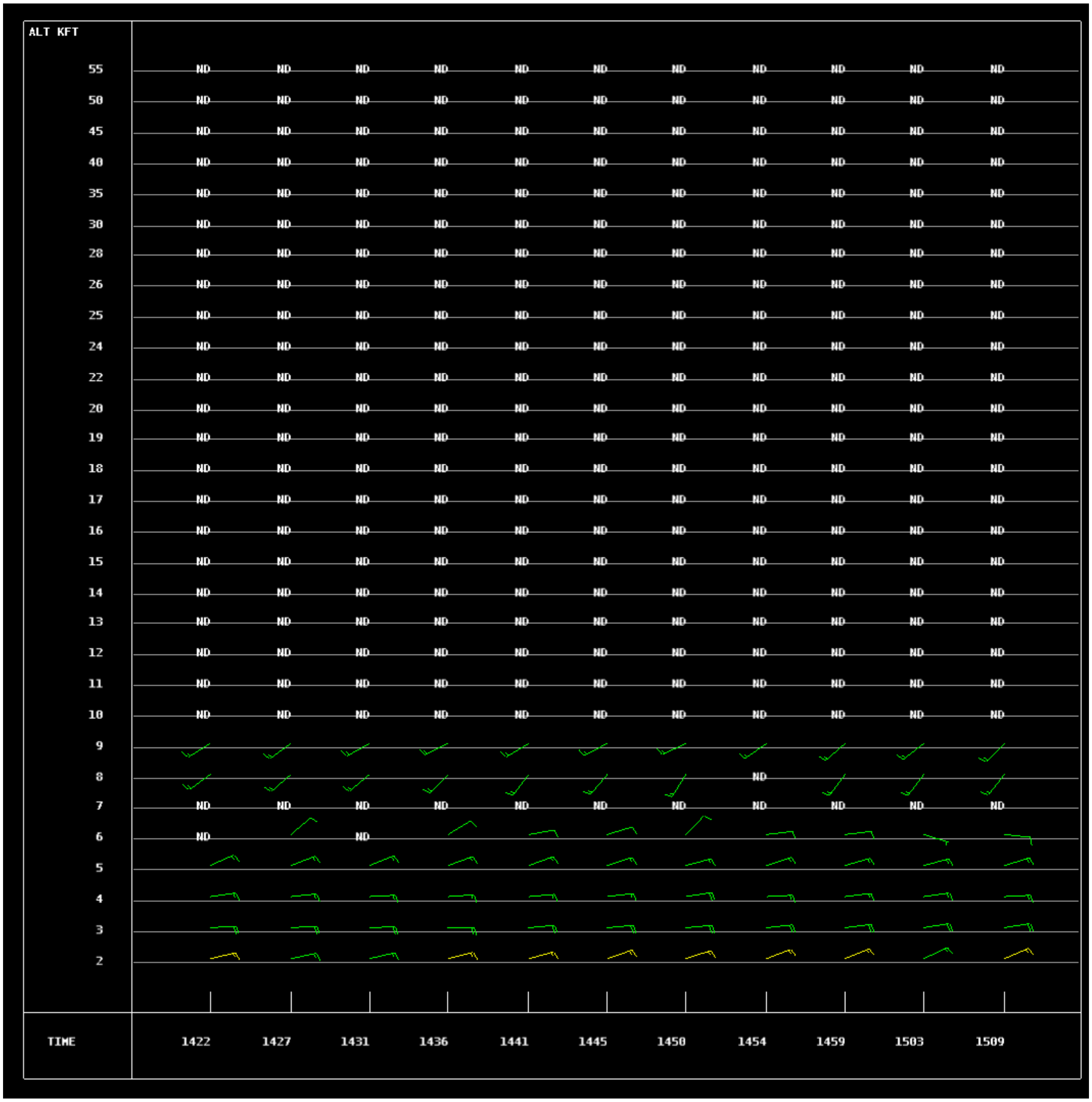


Fig. 7. KFSD VWP valid at 1500 UTC.

1800 UTC

By 1800 UTC, a mesoscale area of low pressure had begun to form along the stalled surface boundary across southern South Dakota, with a meso-high formation owing to a deepening cold pool associated with the upscale growth of the thunderstorm cluster which was slowly becoming surface based over central South Dakota (Fig. 8).

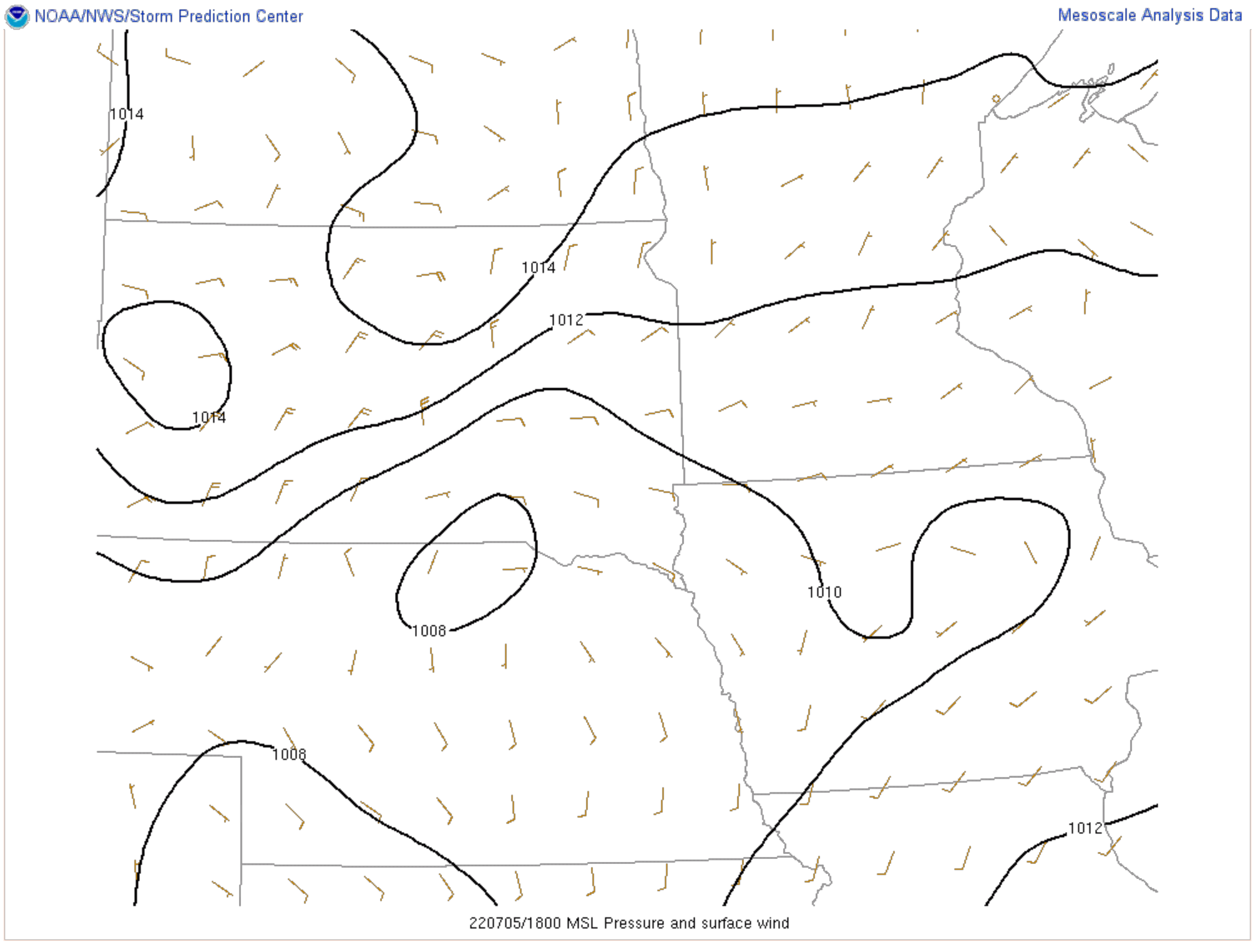


Fig. 8. SPC mesoanalysis of surface pressure and winds valid 1800 UTC.

Daytime heating south of the boundary had steepened lapse rates considerably across the Nebraska/South Dakota border area, and this was being transported quickly northeast into the FSD CWA (Fig. 9).

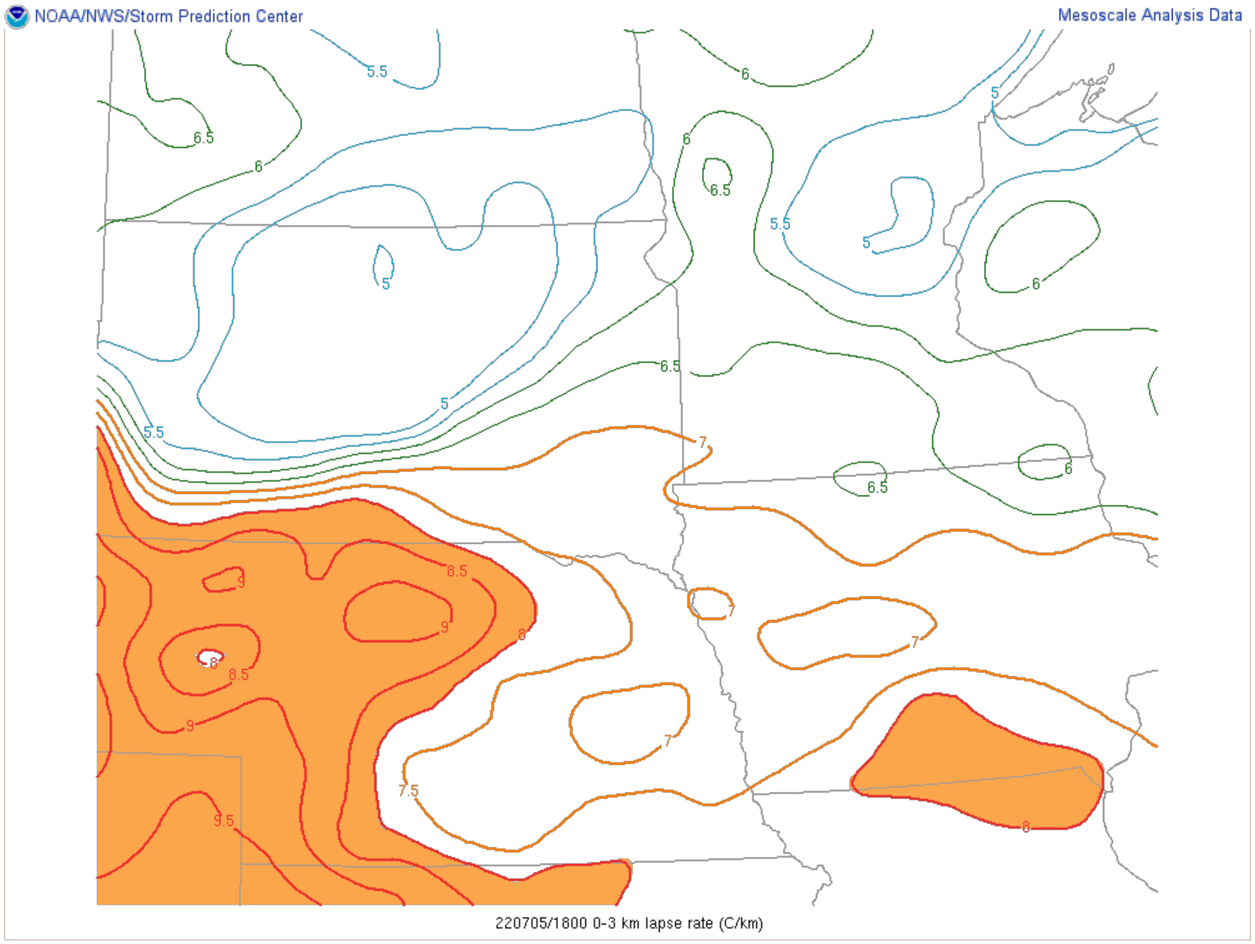


Fig. 9. SPC mesoanalysis of low level lapse rates valid at 1800 UTC.

Due to the degree of diabatic heating and warm advection along and south of the northward retreating frontal zone, and in combination with pooling of very high dew points, a narrow corridor of strong to extreme surface based instability (MLCAPE axis in Fig. 10) had developed out in front of the inbound thunderstorm cluster and continued to lift north with each hour as MLCINH decreased.

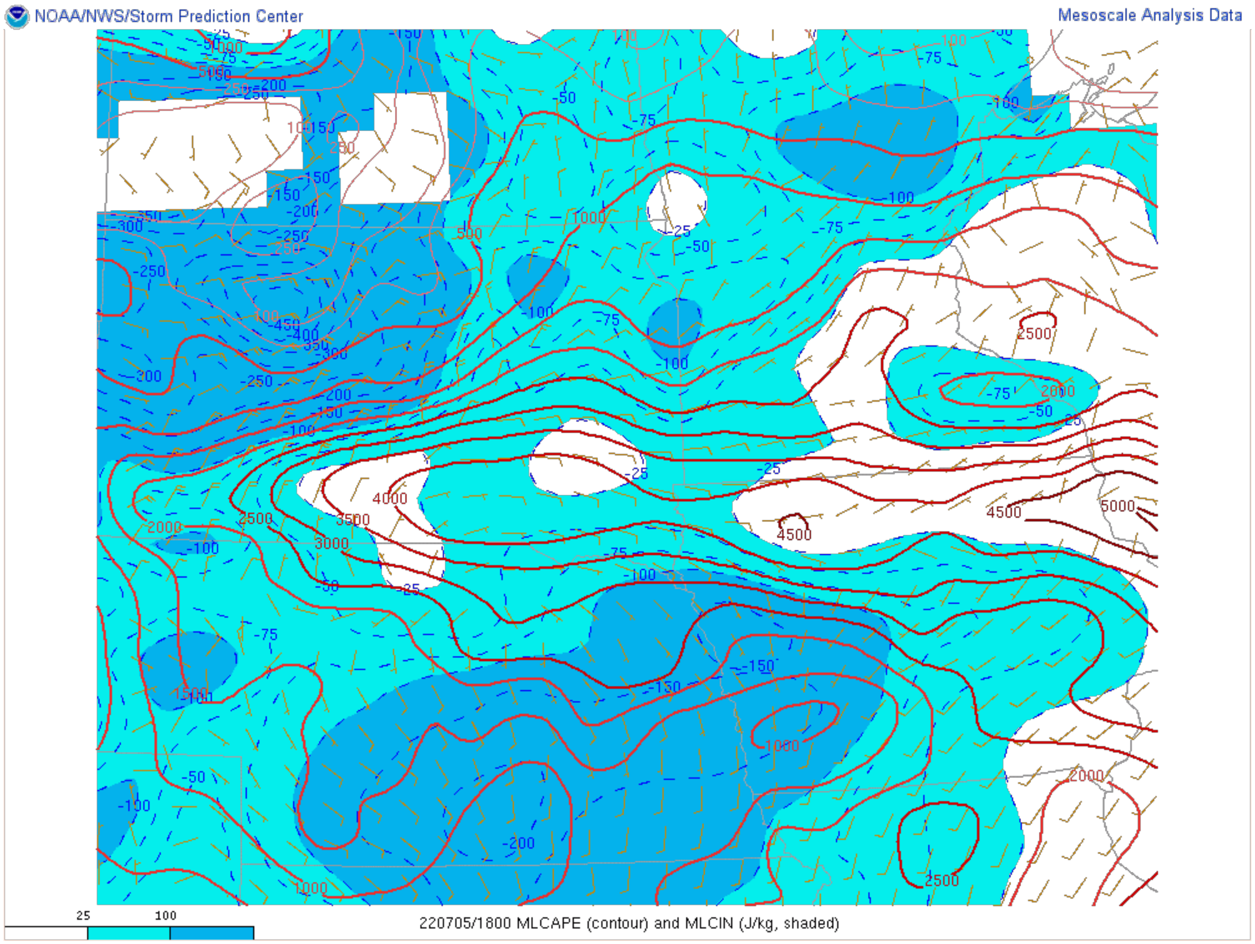


Fig. 10. SPC mesoanalysis of MLCAPE (red contours) and MLCINH (blue contours, shaded fill) valid 1800 UTC.

At 1800 UTC, the KFSD VWP (Fig. 11) showed the depth of easterly flow becoming more shallow as the warm frontal structure aloft shifted north (with southeasterly flow now showing up at 4-5 kft MSL (3-4 kft AGL) in comparison to easterly flow back at 1500 UTC). Flow magnitude continued to be in the 10-15-kt range immediately above the surface.

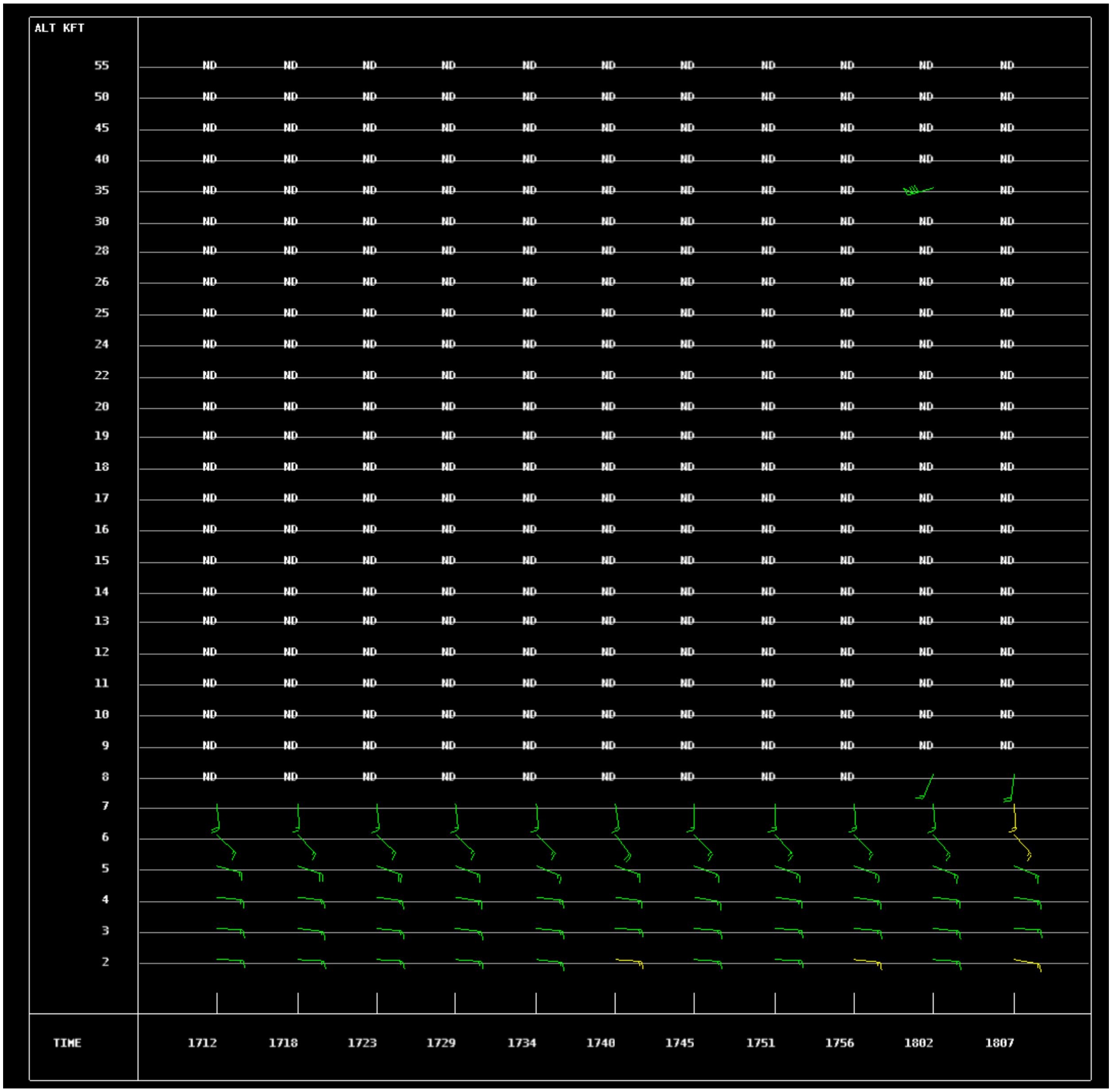


Fig. 11. KFSD VWP valid at 1800 UTC

Given the seasonably strong mid and upper tropospheric flow across South Dakota, effective shear of ~50 kts was common (Fig. 12) across much of the area along and north of the surface frontal zone, overlapping the extreme instability.

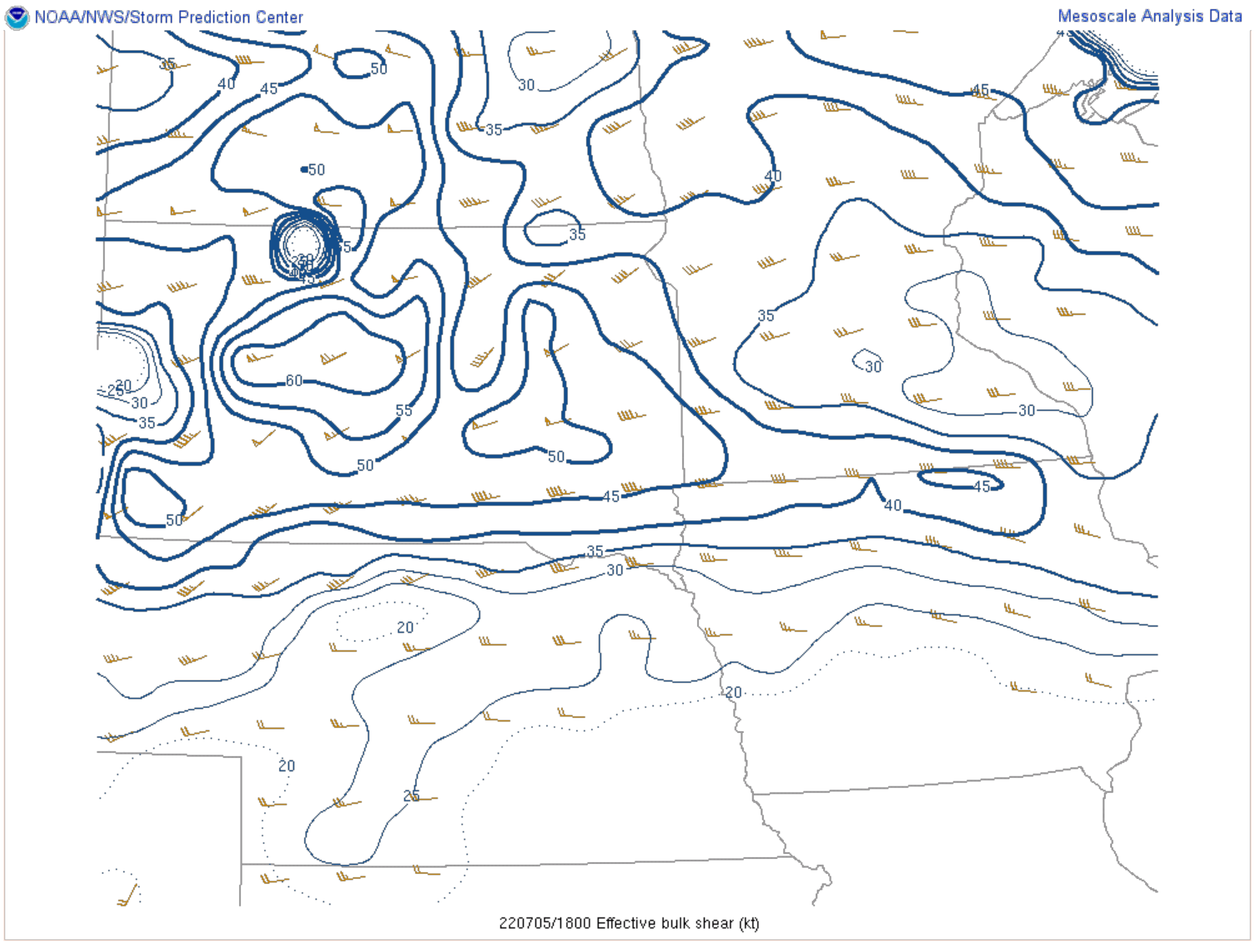


Fig. 12. SPC mesoanalysis of effective shear valid 1800 UTC.

Low-level (0-1 km) shear was weak in the vicinity of the surface frontal zone (Fig. 13) with values generally less than 10 kts.

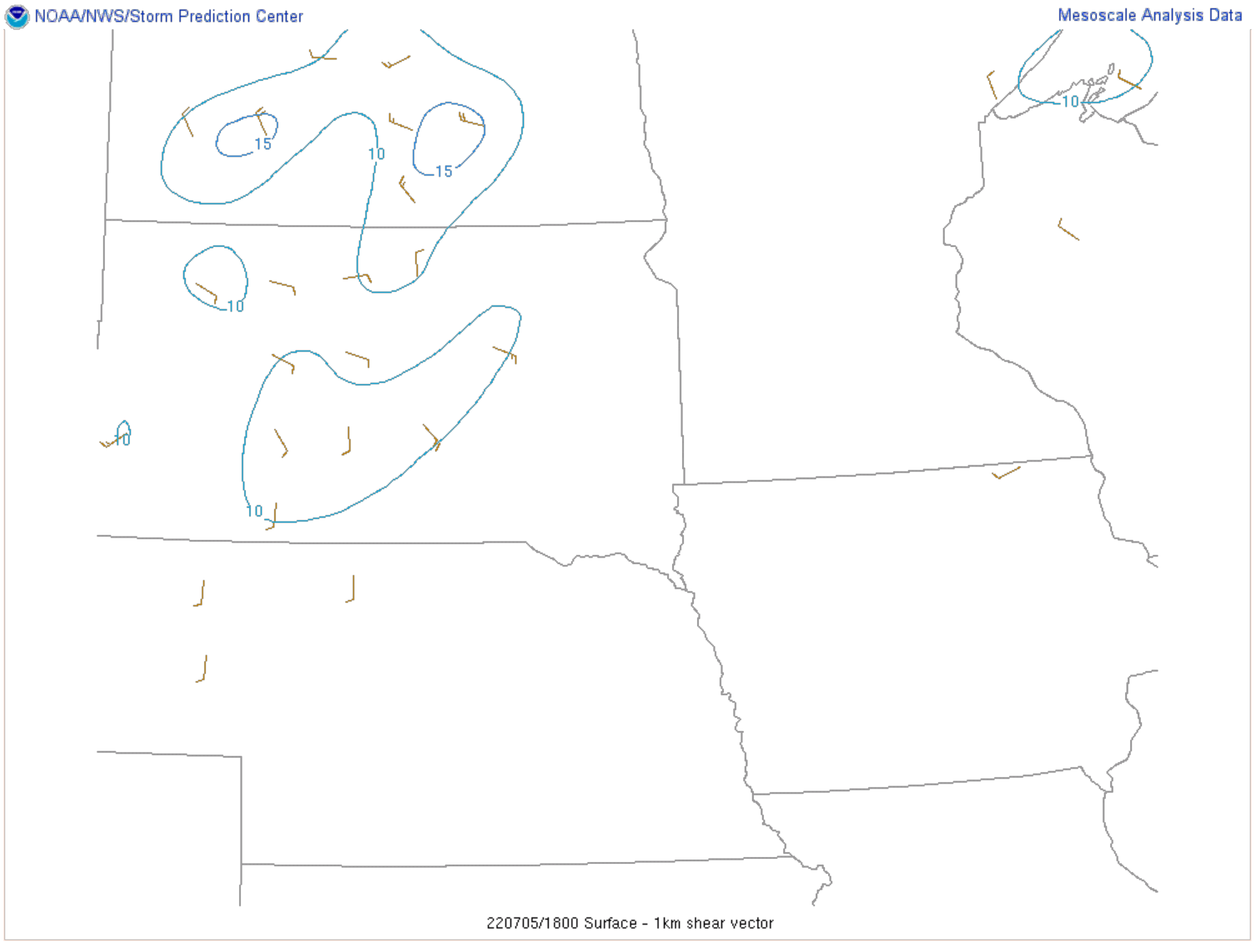


Fig. 13. SPC mesoanalysis of 0-1km shear valid 1800 UTC.

During the Event

Evolution of severe weather: 1500 - 1900 UTC

A strong thunderstorm developed ahead of shortwave trough in southeastern Montana between between 0730 - 0740 UTC 5 July and took on supercell characteristics as it approached the South Dakota border northwest of Buffalo, South Dakota (Fig. 14 upper left). Through 1200 UTC 5 July up to 1.75 in. hail was reported with this storm. New storms began to form ahead of this supercell (hereafter S1) in northwestern South Dakota near the North Dakota border. Around 1140 UTC, a cell formed east of S1 and became supercellular after 1200 UTC and will be denoted as S2 (Fig. 14 upper right).

The storm motion through 1200 UTC was primarily easterly. However, as the supercells continued to move east and maintained a strong meso, the storm motion turned to the east-southeast by 1400 UTC and then southeast by 1600 UTC. This storm motion was also along a MUCAPE gradient with MUCAPE between 2000 and 3000 J kg^{-1} (Fig. 16

left image) and also followed the Bunkers predicted motion for a right-moving supercell (Fig. 15 upper left and right images). Effective shear was also increasing to over 40 kts by 1500 UTC so the supercell remained in a favorable environment. While many of the multicells storms weakened by 1400 UTC, the two supercells maintained strong updrafts and produced severe hail (Fig. 15 lower left). The largest hail was in Dewey County, South Dakota, in north central South Dakota around 1500 UTC, with 4 inch diameter hail reported. The storms also began to form into a line around 1400 UTC and new multicellular storms developed southwest of S1 by 1500 UTC (Fig. 15 lower right). With storms gradually forming into a line, damaging winds became more prevalent with the storms. Multiple reports of 60 to 75 mph were reported as the storms moved across the Missouri River between 1500 and 1630 UTC. Even as the storms formed into the QLCS, the storm motion continued to follow the supercell motion to the southeast and not that predicted by the Corfidi (2006) forward propagation vectors which had an ENE MCS motion (Fig. 15 lower left and lower right). This is because the Corfidi propagation vectors assumed the cell motion would be the 850 to 300 mb mean wind. Since the S1 and S2 were supercells, their motion continued to be to the right of the 850 mb to 300 mb mean wind similar to the predicted right-moving supercell motion from Bunker et al. (2001).

The supercells moved to the east of the Missouri River by 1600 UTC (Fig. 17). Both supercells maintained a strong reflectivity core with 60 dBz over 30 kft and 50 dBZ to 40 kft. Strong mid-level mesocyclones were also observed with the supercells at this time. In addition, bowing segments associated with the rear flank downdraft were becoming evident with both supercells. Wind gusts became more frequent with several gusts of 70 to 90 mph reported in north central South Dakota. These winds produced damage to outbuildings. At the same time, no severe hail was reported from 1600 to 1700 UTC.

At 1700 UTC, the storms moved into Hyde County, South Dakota (Fig. 18). S2 (northern supercell) had begun to weaken, with 60 dBZ now to 20 kft and 50 dBz to 33 kft, although a mesocyclone was still present above 10 kft. The RFD also remained evident with this storm in the reflectivity field. However, there were no severe gusts reported in northern Hyde County associated with this RFD. S1 (southern supercell) continued to be very strong, with a reflectivity core that had 60 dBZ over 40 kft and 50 dBZ approaching 50 kft. Despite the high reflectivity core, only one hail report, golf ball size hail, was reported between 1700 and 1800 UTC in northern Hyde and Hand Counties. Similar to S2, S1 had a well-defined RFD signature on radar. Significant severe wind gusts were measured with this RFD, including an 87 mph wind gust at the Road Weather Information System (RWIS) near Ree Heights, South Dakota, at 1714 UTC. Numerous measured wind gusts of 60-70 mph were reported across Hyde and Hand county. As the line of storms continued to develop southeast of S1 between 1600 and

1800 UTC, these storms also became severe. Wind reports of 50 to 70 mph were reported in parts of Hughes and Lyman county.

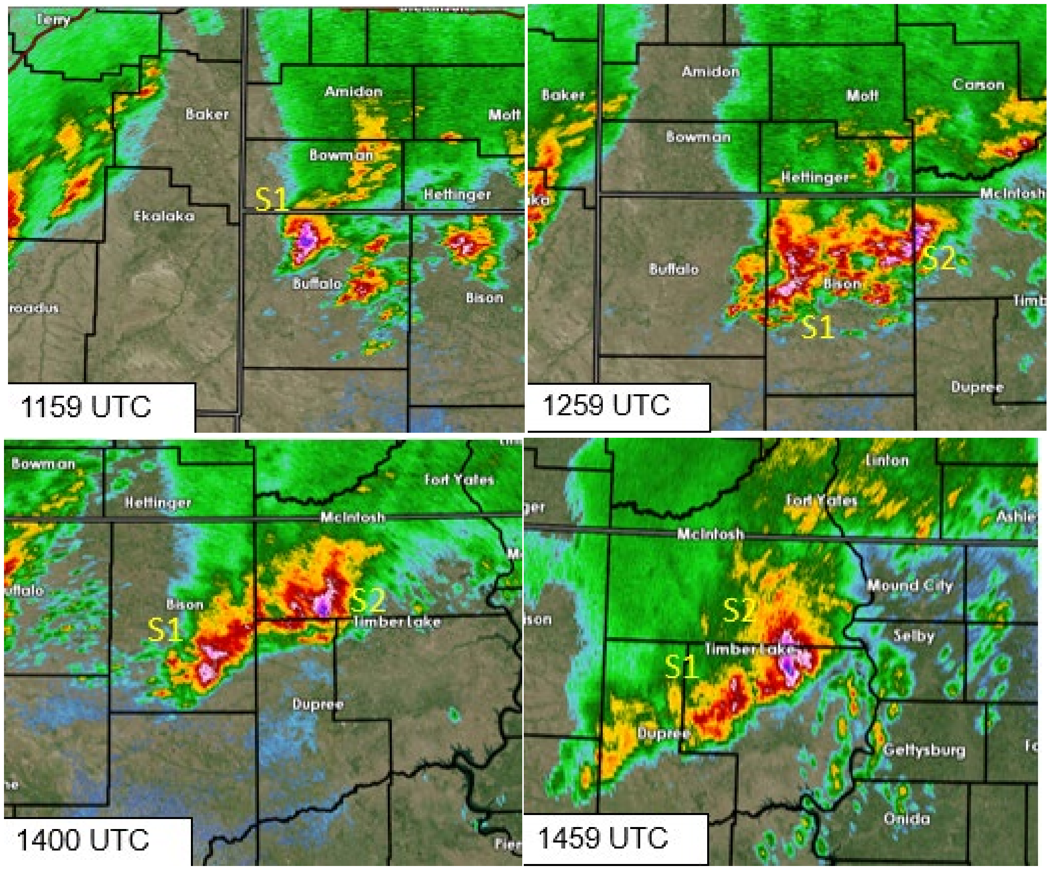


Fig. 14. 0.5º base reflectivity at a) KUDX radar at 1159 UTC, b) KUDX radar at 1259 UTC, c) KUDX radar at 1400 UTC, and d) KABR radar at 1459 UTC. S1 indicates the first supercell that formed at 0740 UTC and S2 is the second supercell that formed around 1140 UTC.

By 1800 UTC, the line of storms was approaching the Sioux Falls (FSD) CWA with the RFD associated with S1 moving into Jerauld County, South Dakota, and the outflow from S2 moving into Beadle County, South Dakota (Fig. 19). S1 continued to have supercell characteristics, with a strong mid-level mesocyclone, an elevated reflectivity core (60 dBZ to 35 kft), and prominent RFD. S2 had weakened markedly over the last hour and no longer had supercell characteristics. However, the line began to organize as a rear inflow jet was now evident where storms associated with the RFD of S1 had formed a few hours earlier.

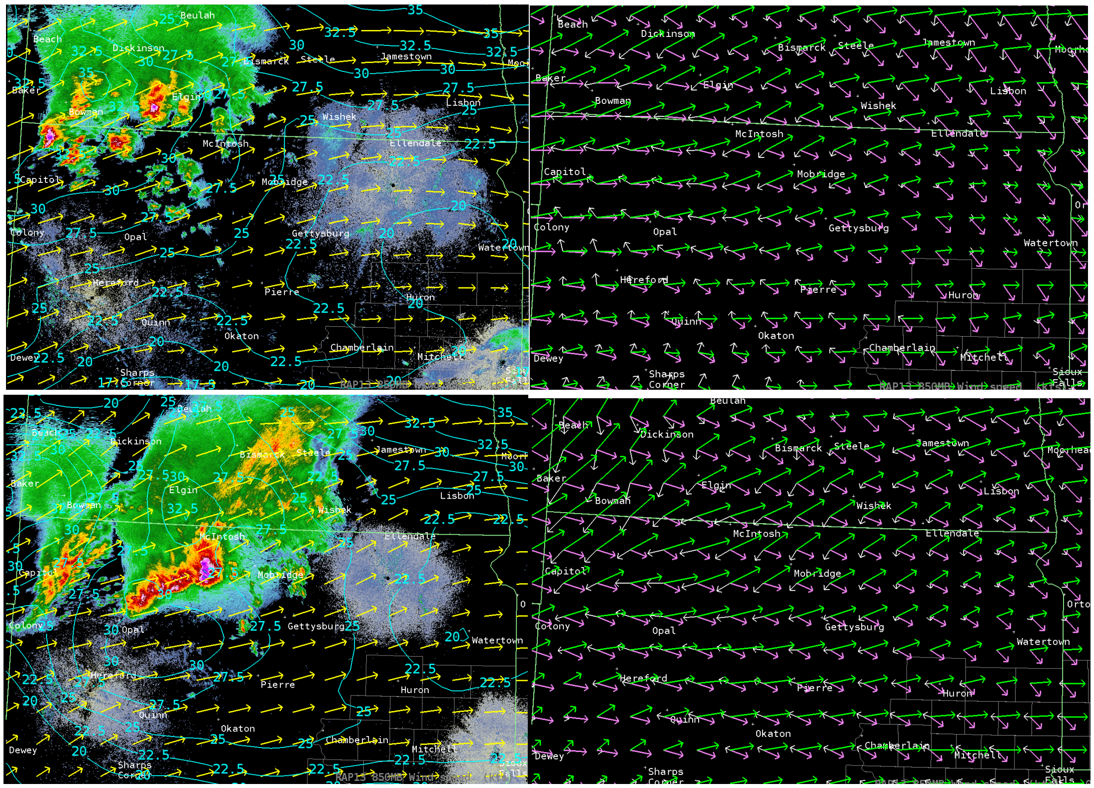


Fig. 15. Top left: 0.5º base reflectivity at 1210 UTC with the forward propagating Corfidi vectors (yellow arrows) and magnitude (cyan line) from the 00 h forecast of the 1200 UTC 5 July 2022 RAP. Top Right: 800-300 mb mean wind (green vectors, 850 mb wind (white vectors) and Bunkers et al. (2001) right-moving supercell motion vector (magenta) from the 00 h forecast of the 1200 UTC 5 July 2022 RAP. Bottom left: Same as the top left image except at 1510 UTC 5 July 2022 with 00 h forecast of the 1500 UTC 5 July 2022 RAP. Bottom right: Same as the top right image except using data from the 00 h forecast of the 1500 UTC 5 July 2022 RAP.

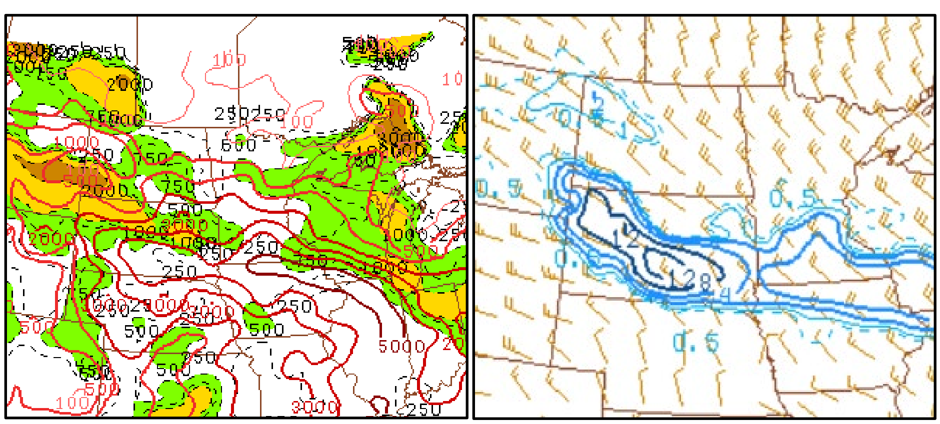


Fig. 16. 1500 UTC effective bulk shear (upper left) and MUCAPE (contoured red), lifted parcel level (shaded and dashed lines) (upper right), Supercell composite parameter (contoured) and Bunkers right-moving supercell motion (lower left).

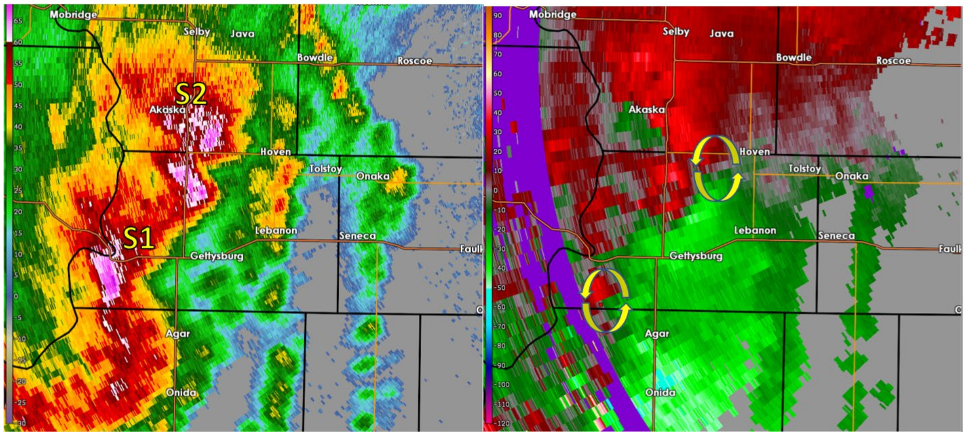


Fig. 17. a) KABR 0.5º base reflectivity and b) KABR 2.4º storm-relative velocity at 1605 UTC. The arrows indicate the approximate location of the mid-level mesocyclone associated with each supercell.

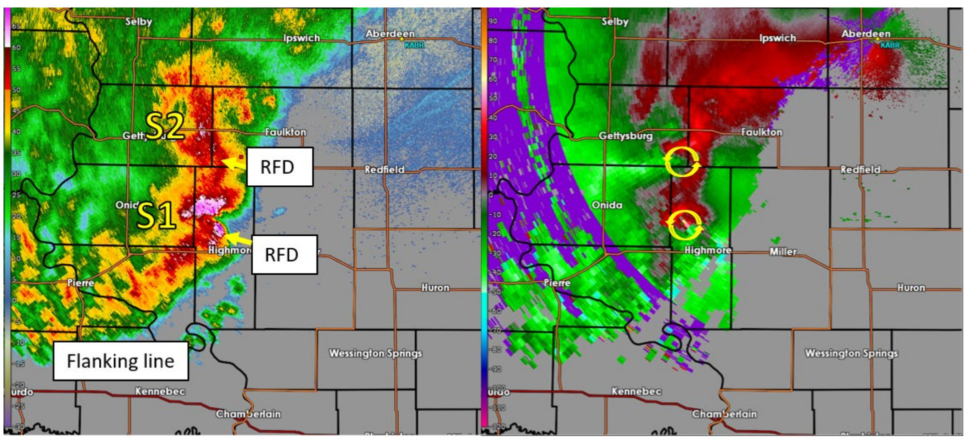


Fig. 18. a) KABR 0.5º base reflectivity and b) KABR 1.8º base velocity at 1700 UTC. The arrows indicate the approximate location of the mid-level mesocyclone associated with each supercell. Text indicates locations of the RFD and flanking line at 0.5º.

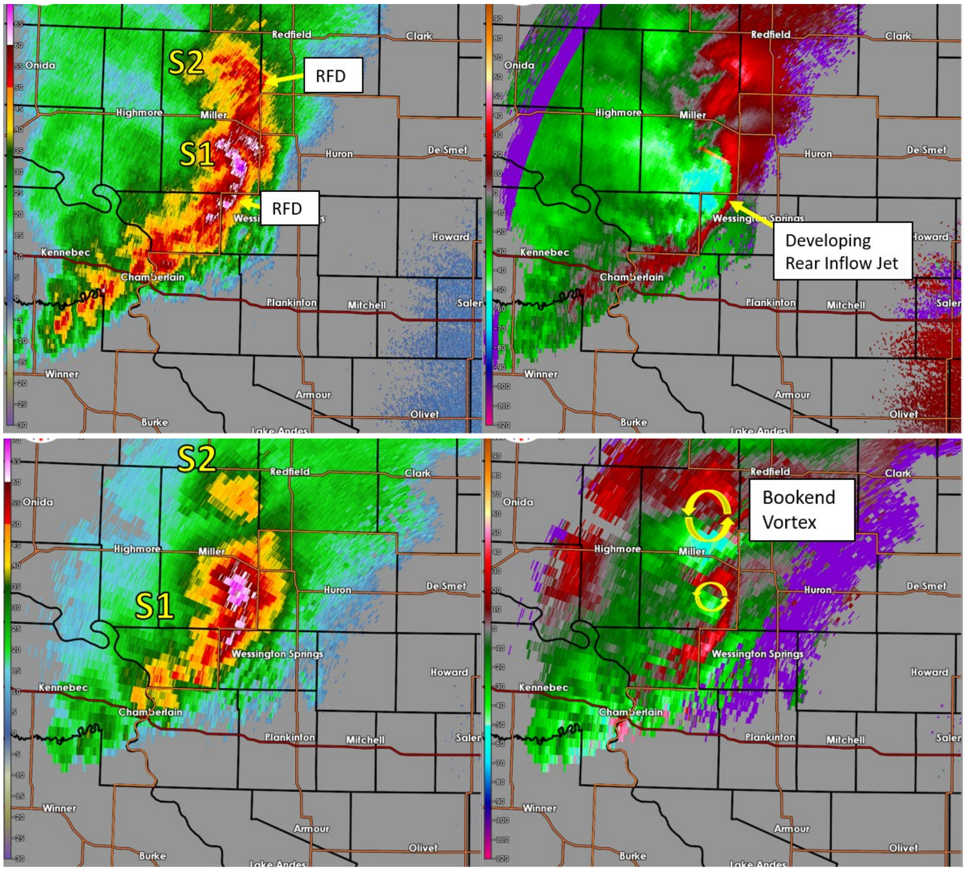


Fig. 19. a) KFSD 0.5º base reflectivity, b) KFSD 0.5º base velocity, c) KFSD 1.8º base reflectivity, and d.) KFSD 1.8º base velocity at 1805 UTC. The arrows indicate the approximate location of the mid-level mesocyclone associated with S1 and the developing bookend vortex near S2. Text indicates locations of the RFD at 0.5º.

Current radar analysis and location of supercell and bookend vortex and large hail indicators: 1830 - 1900 UTC

Between 1845 UTC - 1900 UTC, a mature and severe-warned squall line had entered the FSD County Warning Area (CWA) (Fig. 20). KFSD and KABR radars indicate three particular features of note within this squall line during this timeframe:

1) an expanding and broadening bookend vortex over southern Beadle and northern Jerauld counties

2) a strengthening rear inflow jet immediately south of the bookend vortex centered on Jerauld and Aurora counties, moving into Sanborn and Davison counties (Fig. 20).

3) a line-embedded and long-lived supercellular structure centered on central and northern Sanborn County

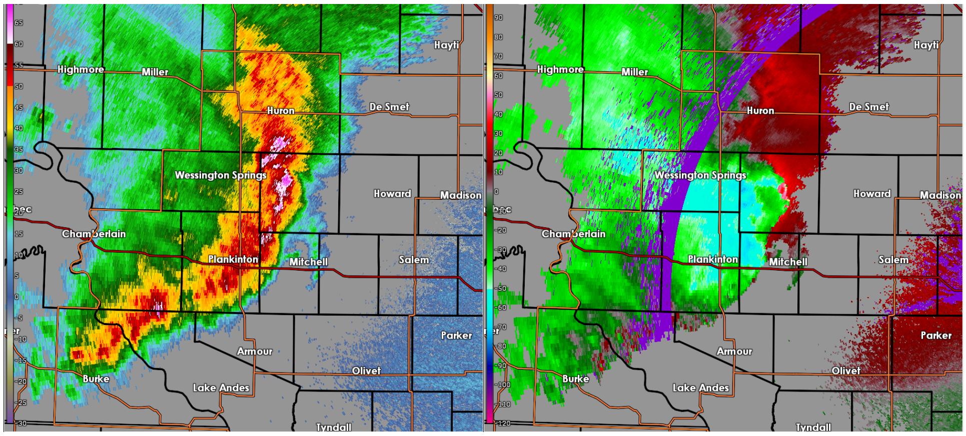


Fig. 20. a) KFSD 0.5º base reflectivity and b) KFSD 0.5º base velocity at 1858 UTC. The arrows indicate the approximate location of the mid-level mesocyclone associated with S1 and the developing bookend vortex near S2. Text indicates locations of the RFD at 0.5º.

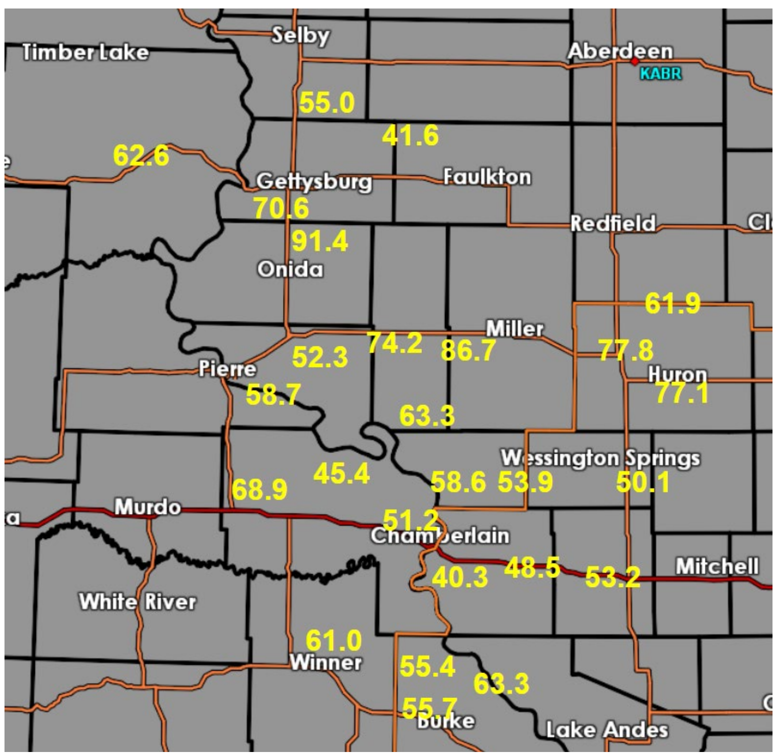


Fig. 21. Peak gusts at South Dakota Road Weather Information System (RWIS) sensors and ASOS and AWOS sensors from 1500-1900 UTC 5 July 2022. Note that all gusts shown occurred within 30 minutes of the passage of the gust front.

While the squall line and updraft-downdraft convergence zone are fairly curvilinear up to about 1830 UTC, important transformations begin to occur between 1830 UTC and 1900 UTC across Jerauld and Sanborn counties as prominent bowing of the line begins to develop as the rear inflow jet descends and broadens. There were measured wind gusts of 50 to 60 mph reported near the gust front in this portion of the line of storms (Fig. 21). This is immediately south of persistent, deep, and broad cyclonic rotation attendant to the bookend vortex. The bookend vortex was also expanding as the diameter went from ~18 miles at 1800 UTC to ~23 miles by 1900 UTC. Volumetric data from the KFSD/KABR radars indicate 55-60 dbZ to 45 kft with a likelihood of at least some hail in association with the northern portion of the line of thunderstorms immediately along and ahead of the bookend vortex.

The reflectivity cross-section at 1900 UTC shows that the convective towers tilt downshear within the flanking line south of the embedded supercell (Fig. 22). This would indicate that either the line of storms is balanced or even slightly shear dominant at this time. While tornadoes were not anticipated with this line due to the very weak 0-1-km shear, the balanced nature of the line indicates that the cold outflow was unlikely to move out ahead of the updrafts. With 4000+ J kg^{-1} MUCAPE available and very little convective inhibition, the line of storms is expected to continue to propagate southeast and maintain strength over the next couple of hours as it moves across eastern South Dakota and toward the Sioux Falls metropolitan area.

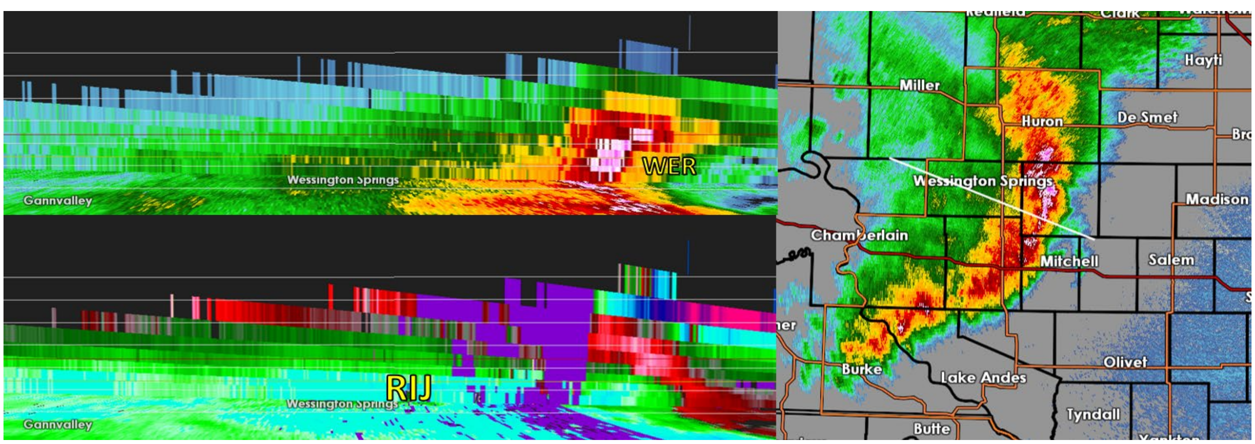


Fig. 22. Cross-section of base reflectivity (top) and base velocity (bottom) at 1900 UTC. KFSD 0.5º base Reflectivity with the white line denoting the location of the cross-section (right).

At 1853 UTC, a closer look at the Sanborn County supercellular structure indicates a potential for large hail. Per Fig. 23 below, a 4-panel from the KFSD radar shows high values of MESH (maximum expected hail size), with a large clustering of pixels > 2” and localized pockets of >3” hail. Corresponding dual pol moments (CC and ZDR) from the FSD radar at 3.1 degrees (about 25,000 feet AGL) in the area of high reflectivity (65 dBZ) confirm the presence of hail at this level, but values of CC remain mostly above 85% amid ZDR values of 0 to -1 (Fig. 25). While this certainly confirms the presence of hail well aloft in the storm, the values of CC do not suggest giant hail (as depicted by MESH values) are present in the storm. Although hail was not reported in real time, satellite imagery and photographs later showed evidence of wind-blown hail damage in parts of Sanborn County, with corn stripped due to wind and hail (Fig. 24). So, large hail is a continued threat attendant to the supercellular structure moving across much of Sanborn into Miner counties.

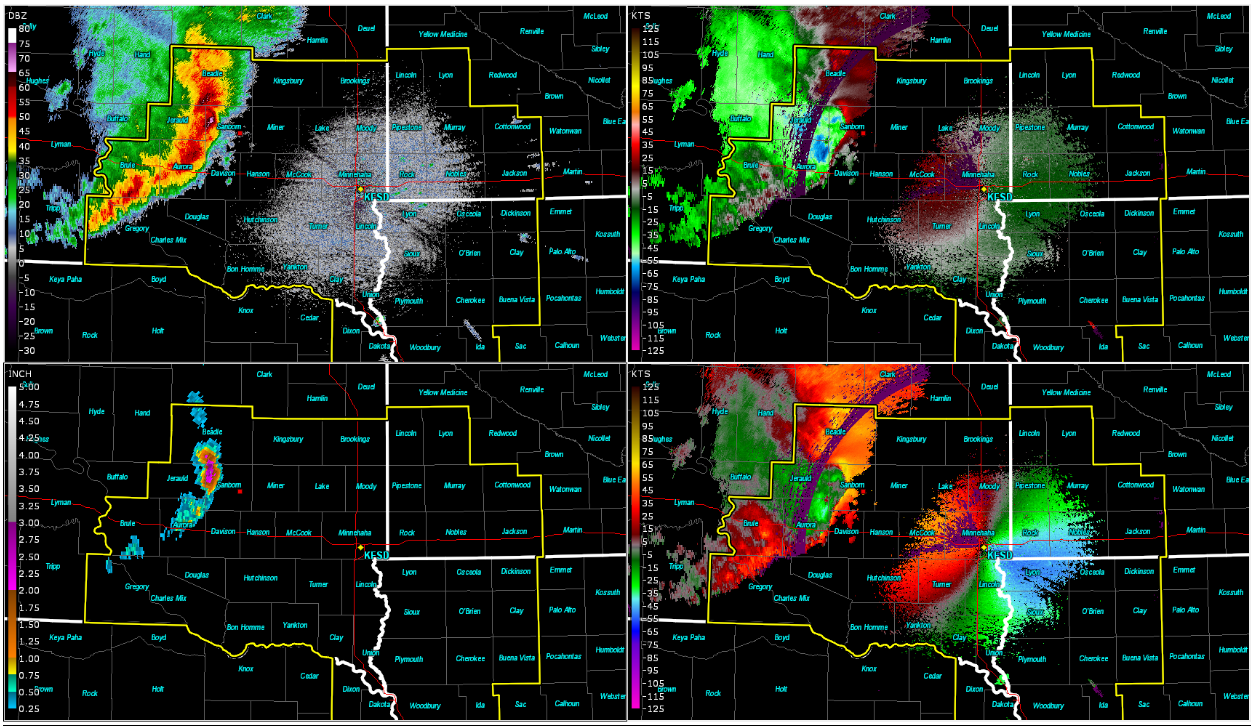


Fig. 23. KFSD 4-panel valid 1847 UTC via GR2 Analyst showing: **Top Left:** 0.5 reflectivity, **Top Right:** 0.5 base velocity, **Bottom Right:** 0.5 storm-relative velocity, **Bottom Left:** MESH.

Fig. 24. Photo of corn damaged by wind and hail near Woonsocket, SD. Damage is estimated to have occurred around 1900 UTC.

The flanking line of storms southwest of the supercell reached Brule County around 1800 UTC and Gregory County by 1825 UTC. Severe wind reports of 50 to 70 mph continued to be reported with this line as it moved into Charles Mix and Douglas Counties. As these storms continue to move east, they will continue to pose a damaging wind threat, although wind gusts would be expected to remain below 70 mph.

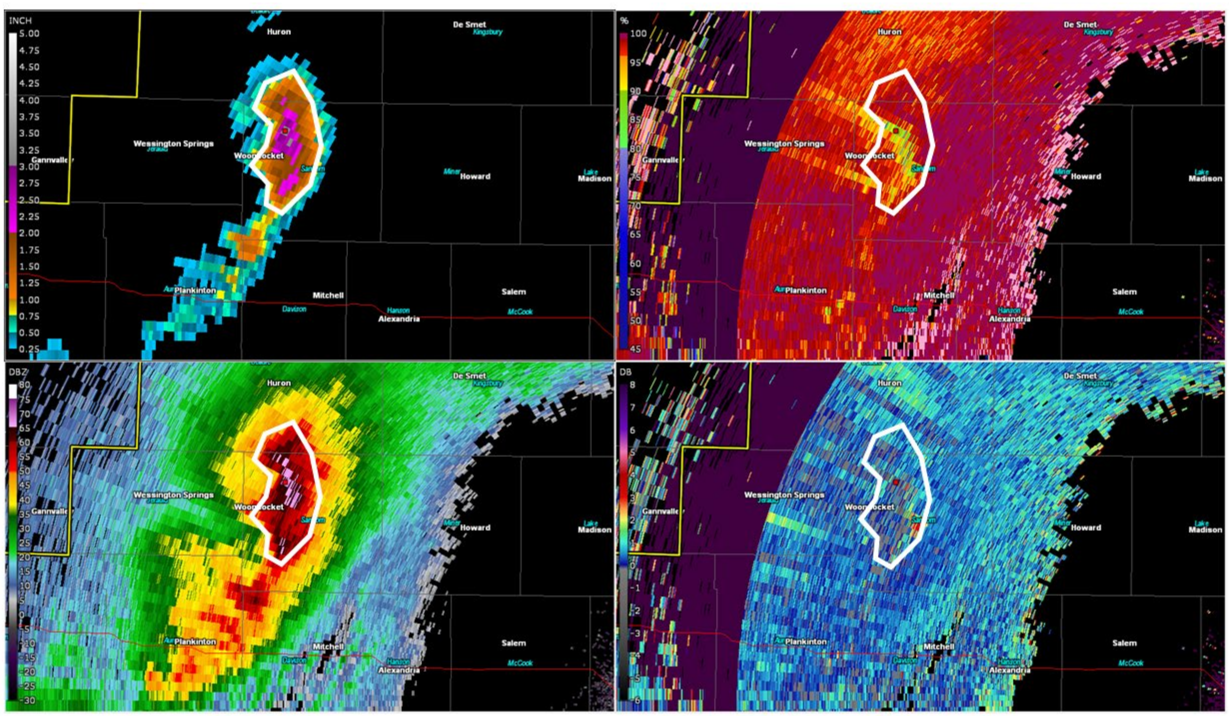


Fig. 25. KFSD 4-panel valid 1853 UTC via GR2 Analyst showing: **Top Left:** MESH, **Top Right:** 3.1 degree correlation coefficient, **Bottom Right:** 3.1 degree differential reflectivity, **Bottom Left:** 3.1 degree reflectivity.

A look at the 3 ingredients: 1900 UTC

At around 1900 UTC, the KFSD radar showed a mature QLCS with bowing segments across the western FSD CWA (Fig. 26). A 3-ingredients approach suggested that the system was well balanced across Davison and Sanborn counties, where several storm-scale velocity surges were located, becoming slightly shear dominant into Huron County where a maturing bookend vortex was located. On the southern flank of the system, the UDCZ slightly outpacing convective towers suggests the convective system across Douglas, Charles Mix, and Gregory counties was slightly cold pool dominant, but becoming more so with time.

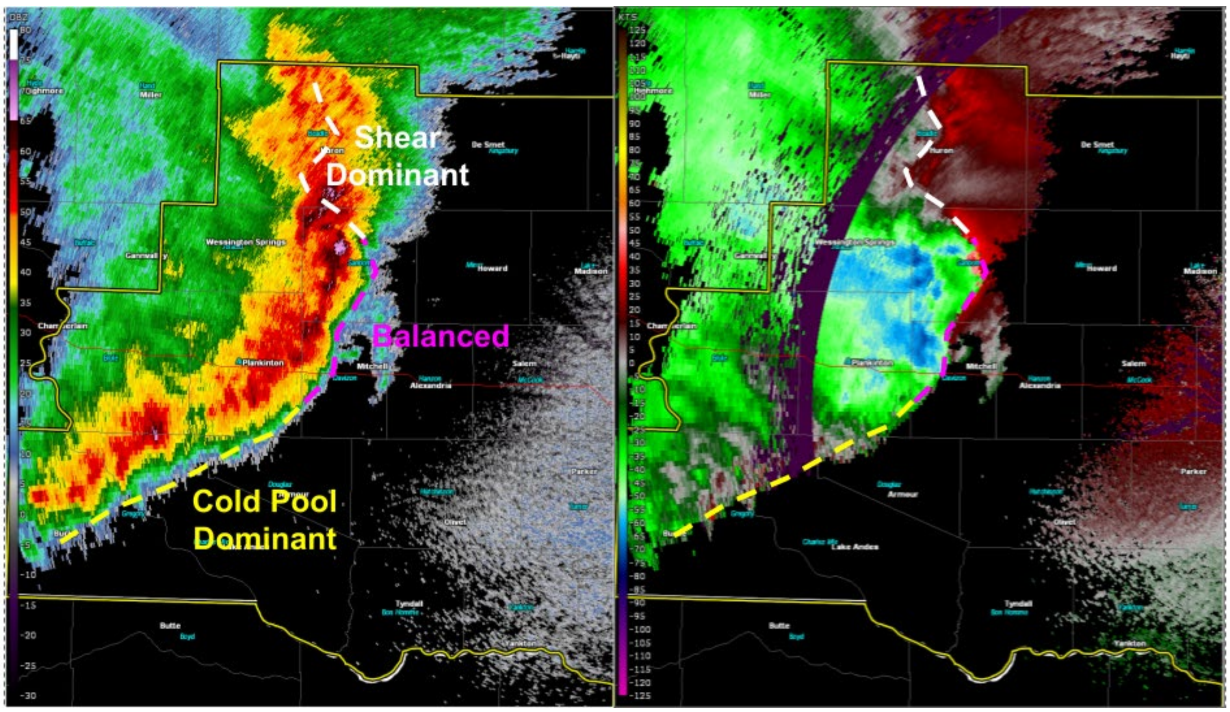


Fig. 26. KFSD 2-panel valid 1858 UTC via GR2 Analyst showing: **Left:** 0.5 degree reflectivity, **Right:** 0.5 degree base velocity. Annotations of the UDCZ indicate a shear dominant convective system (white dashed line) across the northern FSD CWA, a balanced convective system (purple dashed line) across the central FSD CWA, and a slightly cold pool dominant convective system (yellow dashed line) across the southern FSD CWA.

The velocity image above also indicates a considerable rear inflow jet (RIJ) extending behind the convective system with some increasing low level reflectivity erosion, which confirms two necessary components of 3-ingredients method are being met (balanced or slightly shear dominant QLCS with RIJ). The third requirement for the 3-ingredients method is 30 kts of line-normal 0-3-km shear, and 1900 UTC SPC mesoscale analysis (Fig. 27) shows that due to the weak low level flow across southeast South Dakota, this requirement is not being met, with 0-3-km shear values around 20 kts to the southeast of the advancing convective line. Thus, it can be concluded that QLCS mesovortex generation will be more difficult to obtain with this convection despite the presence of a considerable number of nudgers and confidence builders seen in the radar data.

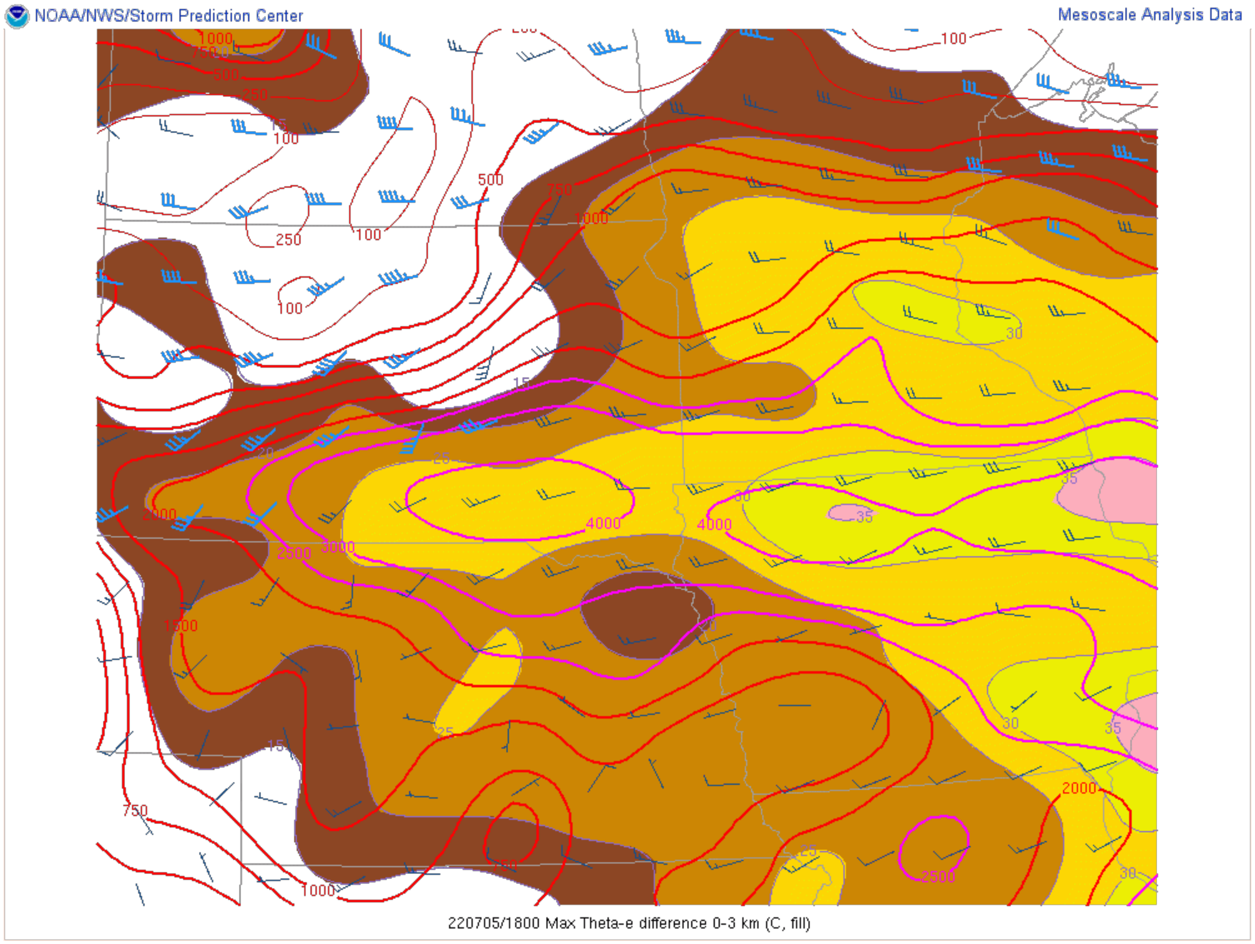


Fig. 27. SPC mesoanalysis valid 1800 UTC showing 0-3-km shear (vectors) and MLCAPE (contours), as well as MaxThetaE difference in the 0-3-km layer.

Rear Inflow Jet (Re)Orientation

A peculiar and important evolution of this event lies with a “reorientation” of the rear-inflow jet (RIJ) as the thunderstorm complex reaches maturity as it crosses the FSD CWA after 1900 UTC, and the RIJ itself broadens and begins to rotate through the southwestern and then southern quadrants of the bookend vortex as it moves directly over the Sioux Falls metropolitan area.

This is best depicted by looking at the evolution WFO FSD severe thunderstorm warning polygons and the RIJ itself during the first hour (1900 UTC - western FSD forecast area) and last hour (eastern FSD forecast area) of the event (Fig. 28). Early on in the mature life cycle of the thunderstorm complex, while the bookend vortex was still strengthening across Beadle County, the RIJ and associated severe thunderstorm warning polygons were aligned on a decidedly northwest orientation – about 320 degrees.

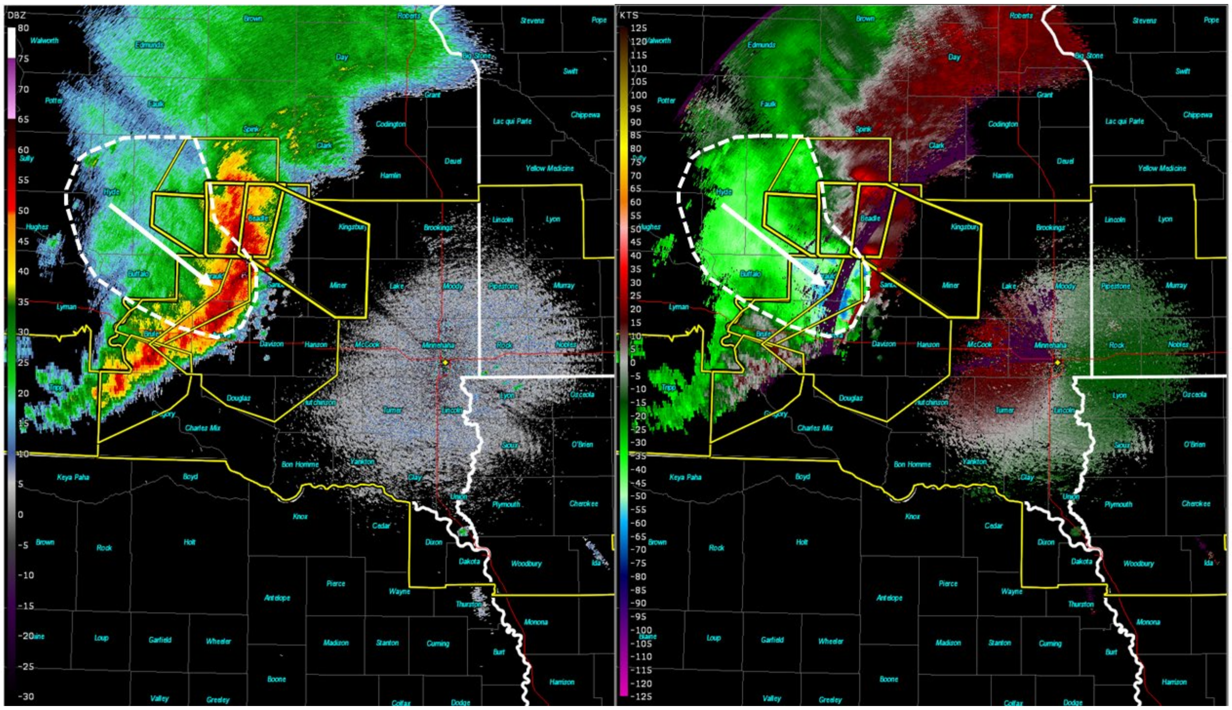


Fig. 28. KFSD 2-panel valid 1841 UTC via GR2 Analyst showing: **Left:** 0.5 degree reflectivity, **Right:** 0.5 degree velocity. Annotations of the RIJ (white dashed line) are included, on the southwest quadrant of the evolving bookend vortex over Beadle County.

By 2200 UTC, as the bookend vortex has broadened and bow echo approaches the eastern side of the FSD forecast area, a reorientation and enlargement of the severe thunderstorm warning polygons is needed to not only capture a still southeast-spreading cold pool, but strong winds also now wrapping east-northeast cyclonically on the southeast side of the larger scale booked vortex (Fig. 29). This forces polygons to be - at a minimum - oriented on a west-to-east axis, with consideration needed that some parts on the northern end of the line be oriented southwest to northeast to effectively capture the spreading cold pool and RIJ wrapping cyclonically around the bookend vortex.

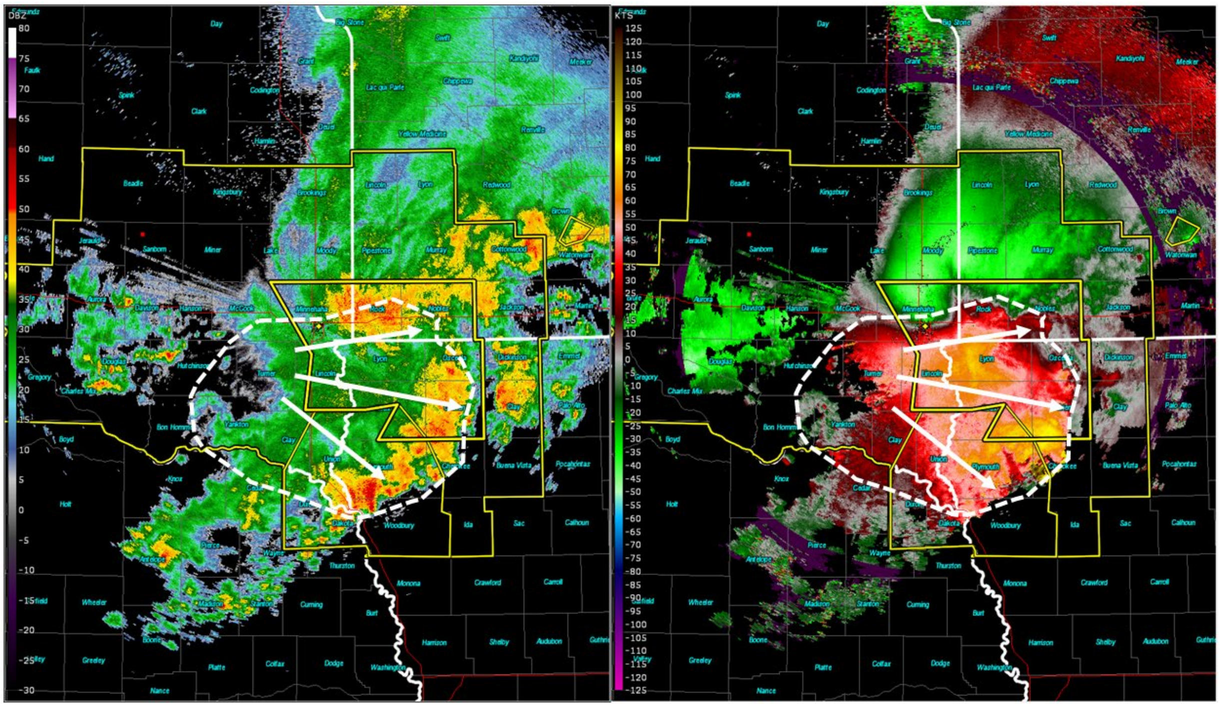


Fig. 29. KFSD 2-panel valid 2158 UTC via GR2 Analyst showing: **Left:** 0.5 degree reflectivity, **Right:** 0.5 degree velocity. Annotations of the RIJ (white dashed line) are included, which has now spread cyclonically around the bookend vortex located very near FSD in Minnehaha county, and beginning to spread northeast into adjacent areas of southwest Minnesota on the southeast flank of the vortex.

Wind graph analysis: 2004 UTC

At 2004 UTC, there will be a WESSL prompt which will reveal graphs of wind speed and wind gusts from 5 locations in the Sioux Falls CWA - Lane, Forestburg, Mitchell, Tripp, and Alexandria (Fig. 30). All but Mitchell are RWIS sites from the South Dakota Department of Transportation. This data are displayed in a station plot format on AWIPS using the Surface Plot display within D2D. The data are also available as a map plot and as a time series from Mesowest. The data are not alarmed or available in a text format within AWIPS for this simulation. The observation from Mitchell is from the ASOS. Any METAR or SPECI transmitted by the Mitchell ASOS with a wind gust over 45 kts is automatically alarmed on the Text Workstation, and any gust over 50 kts appears in NWSChat as well.

During this event, forecasters at WFO Sioux Falls monitored wind gusts at all RWIS and ASOS locations as the gust front moved through an area. The forecasters assumed that the strongest winds would be at the gust front or just behind the gust front. Once the wind peaked and began to decrease at either an RWIS or ASOS, the forecasters would note the gusts and, when appropriate, send out a Local Storm Report (LSR). Subsequent observations were not monitored as it was expected that there would not be stronger winds well behind the gust front.

At 1938 UTC, an ASOS special was issued by the Mitchell ASOS with a gust of 67 mph. This was higher than the maximum gust of 47 mph immediately behind the gust front around 1910 UTC. In addition, this gust occurred ~25 miles behind the gust front and also well behind the updrafts. A pressure fall was not observed, so the gust was not associated with a wake low. For simulation purposes, we assume the arrival of this gust would result in the mesoanalyst or another support staff person examining observations well behind the gust front to ascertain whether this gust was atypical or if other locations had also observed these wind gusts. The graphs shown below are the result of this investigation of the staff and are now being shared with the warning meteorologist. Additional wind graphics covering the entire event are shown in Appendix A. These graphics include annotation of winds associated with the initial surge of winds and, where appropriate, the secondary surge of damaging winds.

The graphs show that at several locations north of I-90 there was a second peak in wind speed that was much stronger than the initial gust behind the gust front. Lane, South Dakota, had a peak gust of 70 mph over 70 minutes after the gust front moved through and 40 miles behind the gust front. We see a similar evolution at Forestburg and Mitchell and are beginning to see winds increase at Alexandria approximately 30 minutes after the gust front went through. At all four of these locations, the initial gust front brought wind gusts of 45 to 65 mph. And with the exception of Alexandria, wind gusts and wind speeds decreased ~10 minutes after the initial surge from the outflow, with gusts falling to 30-40 mph. This was followed by a second surge of winds beginning approximately 30 minutes after the gust front and reaching a peak 45-70 minutes after the gust front went through. At all four of these sites, the winds were stronger with this second surge of wind than with the initial outflow. Further, Mitchell, Lane, and Forestburg have had winds over 58 mph for at least 30 minutes with severe wind gusts continuing at Lane for almost 1 hour. In contrast, at Tripp, South Dakota, which is south of I-90 and farther down the line, the wind also increased, with the outflow peaking at 60 mph at 1930 UTC. There is no evidence at this time of a second surge of strong winds at Tripp. Farther west at Dixon, Dallas, and Corsica, South Dakota (see Appendix A), no additional severe gusts were reported following the surge. The wind time series was similar to what is expected with a squall line, a quick increase in wind speeds followed by a decrease in wind gusts 20-30 minus following the initial severe gust. Later in this document, we will discuss our hypothesis for why this second surge of damaging winds occurred and why it persisted for tens of minutes.

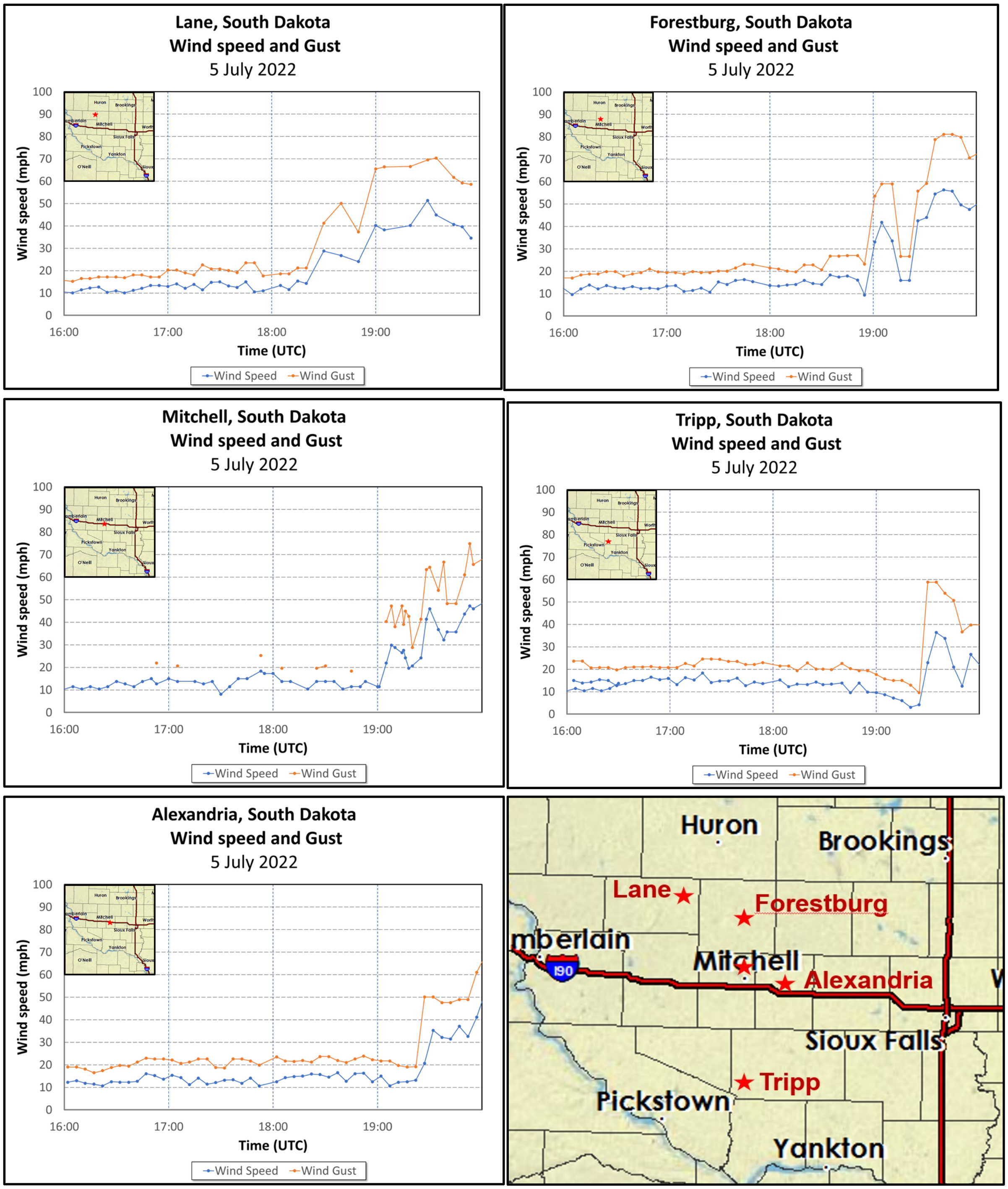


Fig. 30. Plots of wind speed and wind gust from 1600 - 2000 UTC at Lane, SD (top left), Forestburg, SD (top right), Mitchell, SD (middle left), Tripp, SD (middle right), and Alexandria, SD (bottom left). A map of the location of each observation is shown in the bottom right corner.

The challenge for the remainder of this simulation will be for the student to develop a warning strategy that accounts for these damaging winds well behind

the outflow boundary. As can be seen in these graphs, the second period of damaging winds is long-lived and is occurring at multiple locations. Note that heavy rain and lightning was observed at most locations with the second surge of winds and, as noted above, no pressure fall was observed. So these winds are not the result of a wake low. The warning forecaster will need to determine how best to provide severe convective warnings for both areas near the outflow boundary which are experiencing 50-70 mph wind gusts for up to 15 minutes. They will then need to determine what type of warning strategy they will follow for areas experiencing 60-90 mph wind gusts well behind the outflow boundary and persisting for at least an hour. These decisions will have to be made as the severe storms are approaching the Sioux Falls metropolitan area. The outflow boundary is expected to reach Sioux Falls around 4 pm CDT which coincides with the evening rush hour. Later in the document we will propose a warning strategy for these types of events. This warning strategy will be shared with the student in a post-mortem video. The strategy is also discussed in the WOC Severe module "Derecho Warning Strategies and Operations."

Lightning analysis: 2034 UTC

Lightning jumps (statistically significant increase in total lightning) can be indicative of a growing updraft and often precede severe weather (tornadogenesis and large hail) reports by 5-10 minutes. For the time period of this simulation, the storm is well developed and has already formed a bow structure, which results in very noisy lighting data, making it very difficult to identify a lightning jump. Lighting jumps are usually easiest to identify on discrete cell storms. Although this case may not be a great teaching moment for identifying lighting jumps, it does have a good IDSS teaching moment that illustrates the importance of pairing both the ground-based and satellite lightning products.

An IDSS scenario can be simulated at 2034Z for Watertown Regional Airport (KATY) in Codington County. A good question for the student is: "At this time, using just reflectivity, would you tell the airport manager that the severe weather threat has cleared the area?" Have the student pull up the Flash Extent Density (5 minute -1 minute update) product from the GLM East Full Disk and overlay it with the NLDN (5 minute plot -1 minute update) product from the lightning observations tab.

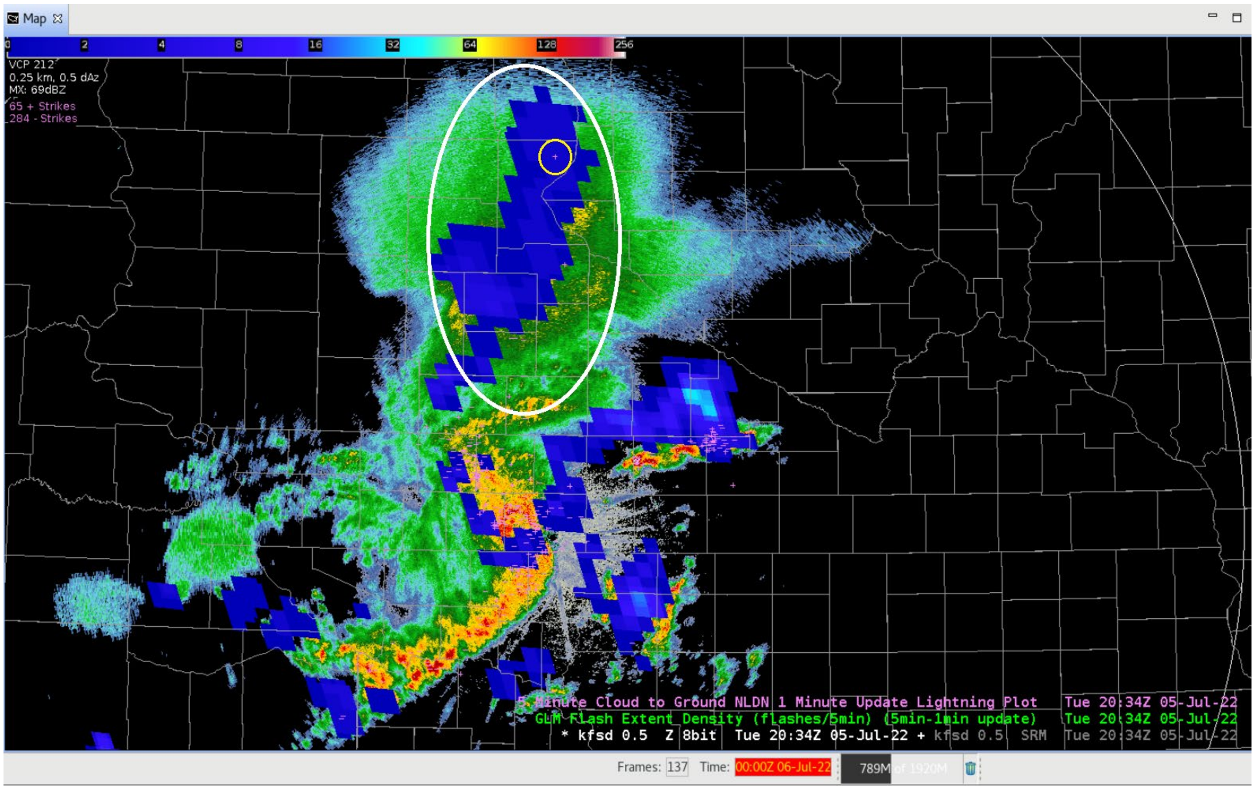


Fig. 31. KFSD 0.5º base Reflectivity, GLM Flash Extent Density (5 minute - 1 minute update; blues), and NLDN Cloud to Ground flashes(5 minute plot -1 minute update; pink) at 2034 UTC. The white oval indicates spatial extent of large stratiform flash and the yellow oval indicates location of a positive ground strike.

At 2034Z, the GLM FED displayed a long lightning flash reaching out into the stratiform portion north of the main convective line (white oval) and resulted in a positive ground strike to the far north as seen with the NLDN 5-min 1-minute product (yellow oval; Fig. 31). Figure 31 illustrates the utility of the GLM and its products for showcasing the spatial extent for lighting activity aloft, as well as the importance of pairing ground-based products to identify the precise locations of recent ground strikes.

This scenario illustrates how using reflectivity alone cannot provide a clear answer on whether or not the severe thunderstorm threat has ended. In this example, the GLM and NLDN products show that lightning activity is still prevalent for the Watertown Regional Airport (KATY) and the student should alert the airport manager of this ongoing threat.

Event Summary

The evolution of the QLCS event was similar to those bow echoes that are initiated by HP supercells as described by Klimowski et al. (2004). In this case, two HP supercells developed in the early morning in southeastern Montana and northwestern South Dakota. Over time the two storms formed a cluster. As the RFDs developed within the storms, a flanking line of storms developed to the south of the supercells forming an MCS as it crossed the Missouri River into eastern South Dakota. This line of storms continued to build southeast into the unstable air. Damaging winds also became more prevalent with the developing derecho with numerous gusts of 60-90 mph reported across central South Dakota.

As the line approached the Sioux Falls forecast area, the first supercell (S2) had weakened while the second supercell (S1) was evident in the northern end of the line. A rear inflow jet (RIJ) developed south of S1 and approached the line. The diameter of the bookend began to slowly increase as the storm continued to move southeastward. In addition, a second maximum in wind speeds began to occur south of the cyclonic bookend vortex. Several locations between the Missouri River and the Sioux Falls CWA reported wind gusts of 50-75 mph more than 30 minutes after the gust front went through (Fig. 32). Winds gusting over 58 mph persisted for more than 30 minutes in several locations such that locations had damaging winds occurring an hour or longer after the gust front had moved through the area.

These strong winds between the rear inflow jet and the cyclonic bookend vortex increased in strength and duration as the storms moved into the Sioux Falls CWA and toward the city of Sioux Falls. Wind gusts were commonly peaking between 70 and 100 mph causing damage to buildings and knocking down trees. The wind graphs from Parker and Sioux Falls, South Dakota, show that the wind gusts with the outflow boundary were marginally severe - between 50 and 60 mph. After a lull in the winds for 15-30 minutes, wind rapidly increased above 58 mph and gusted between 80 and 90 mph at their peak. At both locations, wind gusts of at least 58 mph occurred for over one hour. The highest wind gust recorded with the event, 99 mph, at Howard, South Dakota, occurred 35-45 minutes after the gust front moved through the area. At Parker, the peak wind gust was 65 minutes after the gust front moved through. South of the apex of the bow echo, the strongest winds occurred with the gust front and were generally 55-70 mph. The winds decreased to less than 50 mph within 30 minutes after the gust front moved through.

The challenge of this event focuses on drawing polygons for different portions of the line. Equally important is communicating to the public and partners that the strongest winds would come up to an hour after the gust front moved through and that damaging winds would last over an hour. Below we discuss a warning strategy for this type of derecho and how forecasters will want to communicate the unique threat associated with this type of derecho to the public.

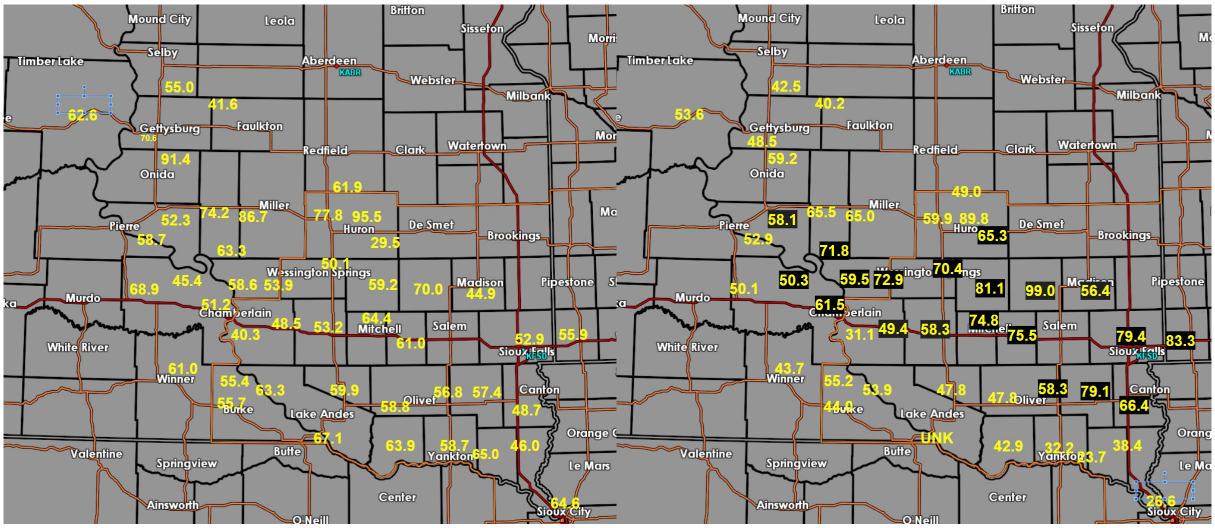
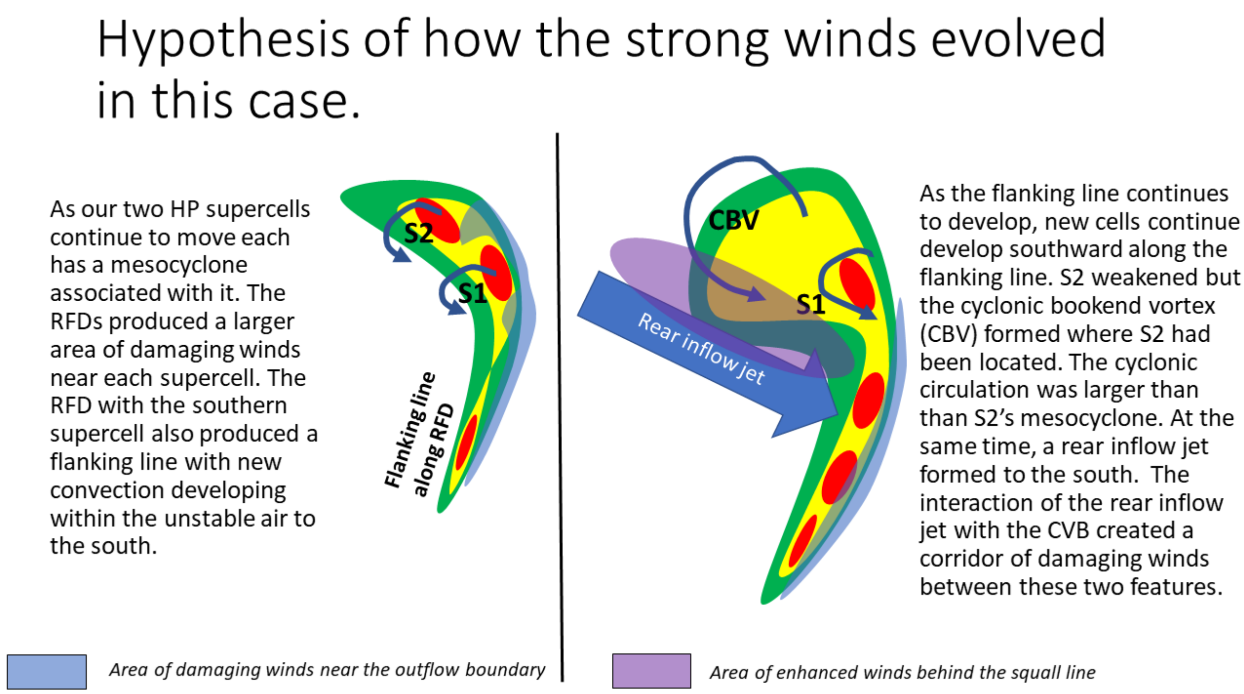


Fig. 32. A map of peak wind gusts (mph) with 30 minutes of the passage of the outflow boundary (left) and a map of the peak wind gust 31 or more minutes after the passage of the outflow boundary (right). Locations where the gust peaked 31 or more minutes after the outflow boundary have a black outline.



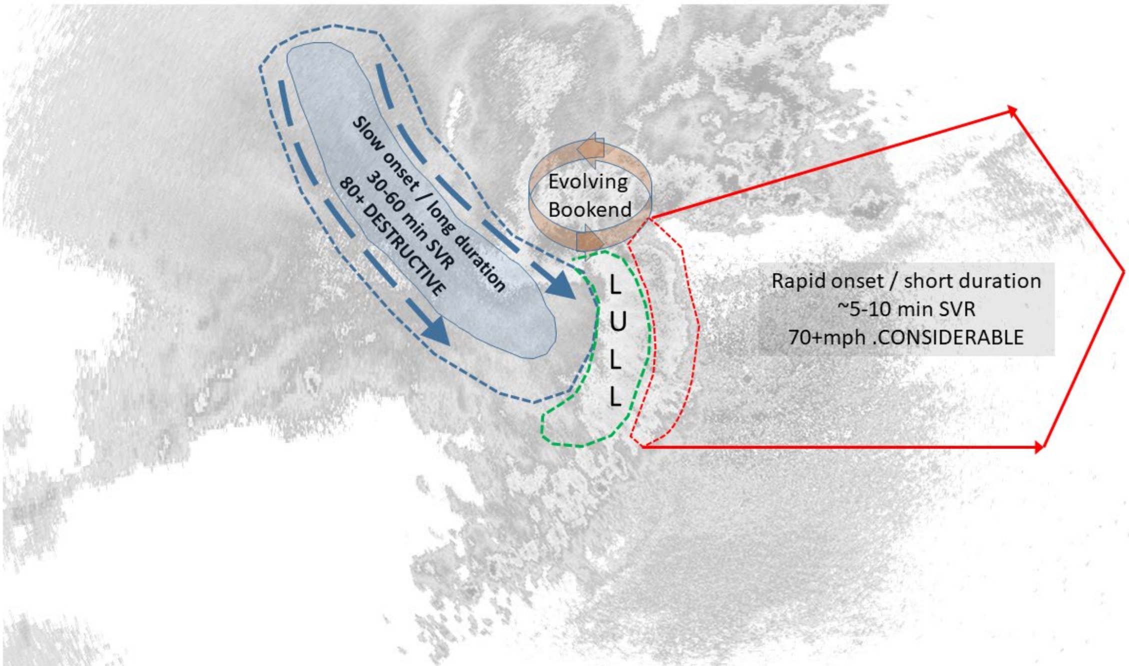


Fig. 33. A depiction of how the bow echo evolved for a cluster of supercells with a developing flanking line to a long duration damaging wind event.

Post-event Analysis

Updated Conceptual Model for (Some) Derechos

The complexities for warning decisions, polygon orientation and duration, and messaging threat levels in *some* derechos owing to the development and longevity and exceptionally strong and lengthened RIJ calls for a renewed look at the conceptual model of some derechos, especially in a warning and messaging sense.

A cursory review of peer-reviewed literature on strong/long-lived bow echoes tends to focus on mechanisms tied to the gust front, or mesovortices forming as the RIJ impinges on the UDCZ. While there is certainly some literature on the role(s) of bookend vortices and RIJ interaction, it is not a concept that has received much attention, especially in terms of tangible severe weather hazards and particularly in the NWS warning decision paradigm.

We offer up the following conceptual model for what is happening in a large number of mature derechos, where the overlap of bookend vortex low to mid-level flow interacts with a RIJ, inducing a prolonged period of *channeled* significant or sometimes catastrophic wind events that last more than 30 minutes in duration, well behind the derecho gust front.

Warning Strategy for Long-Lived Severe Wind Events

For most squall lines and many derechos, the warning strategy has been to issue warnings from near the heavy precipitation cores within the line to 30-60 minutes downstream of the gust front as discussed in the ***Advanced Warning Methodology: Winds from Linear Storm Modes.*** Forecasters also need to consider the location of bowing segments, the development of the rear inflow jets, the development of mesovortices, and observations in order to create segments in which the threat is similar while also being cognizant of the number of counties in the warnings so that it does not exceed the mandated limit of 12 counties per warning.

As discussed above and shown in the plots of wind speed below, this derecho had long duration winds that had severe gusts for 30-90 minutes located tens of miles behind the outflow boundary. The development and persistence of severe wind gusts provides a unique challenge to forecasters who have to warn on both winds near the gust front and winds associated with the cyclonic bookend vortex of the derecho. Is a pathcast with times of arrival appropriate for a hazard that lasts more than an hour? Should the same polygon be used to highlight a threat along the gust front as one associated with a cyclonic bookend vortex?

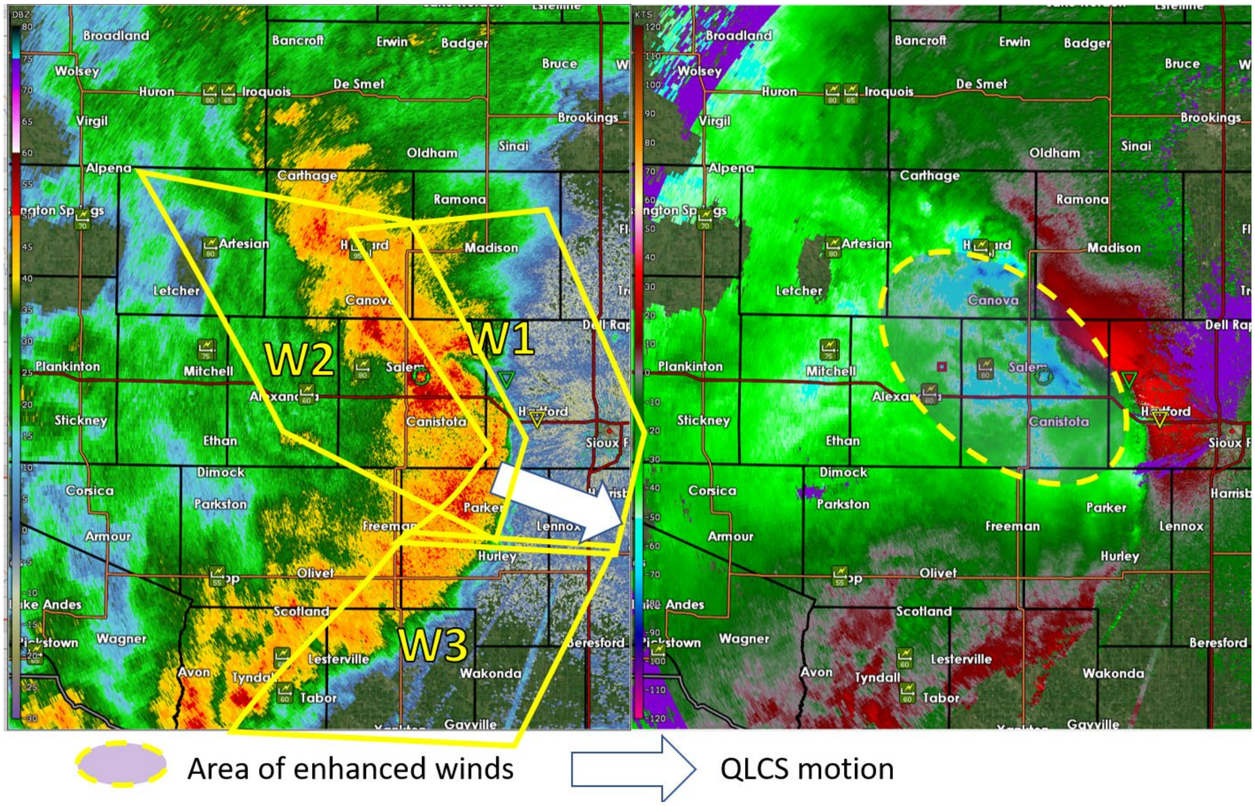


Fig. 34. A radar image of 0.5º reflectivity (left) and radial velocity (right) from the KFSD WSR-88D at 2013 UTC 5 July 2022. Solid yellow lines are the proposed polygon strategy for the derecho after long-duration high winds have developed. The dashed yellow line is the approximate area where long duration severe winds had developed and the white arrow is the approximate motion of the derecho.

In Fig. 34, we show the derecho as it approaches the Sioux Falls metropolitan area. Because we are close to the radar, the 0.5º velocity data does show a large area of radial winds exceeding 50 kts. For echoes near and south of I-90 (red line in the graphic), total wind speeds are likely being underestimated due to the angle of the wind to the radar beam. Also of note is that the motion of the derecho is nearly parallel to the major axis of our channel of high winds associated with the cyclonic bookend vortex. This is one reason that damaging winds were recorded for as long as 90 minutes near the cyclonic bookend vortex.

For issuing warnings for this derecho, we divide the derecho into 3 parts. W1 is the area from the high reflectivity core within the derecho to 30-60 minutes downstream from the outflow boundary. The polygon also extends from near the cyclonic bookend vortex to just south of the apex of the bow. W2 is the area south of the apex of the bow to the southern extent of the damaging wind threat. And W3 is the “post-outflow boundary” area that extends from near the outflow boundary to 30-50 miles behind the line between the center of circulation associated with the cyclonic vortex to the north edge of the highest wind speeds within the rear inflow jet.

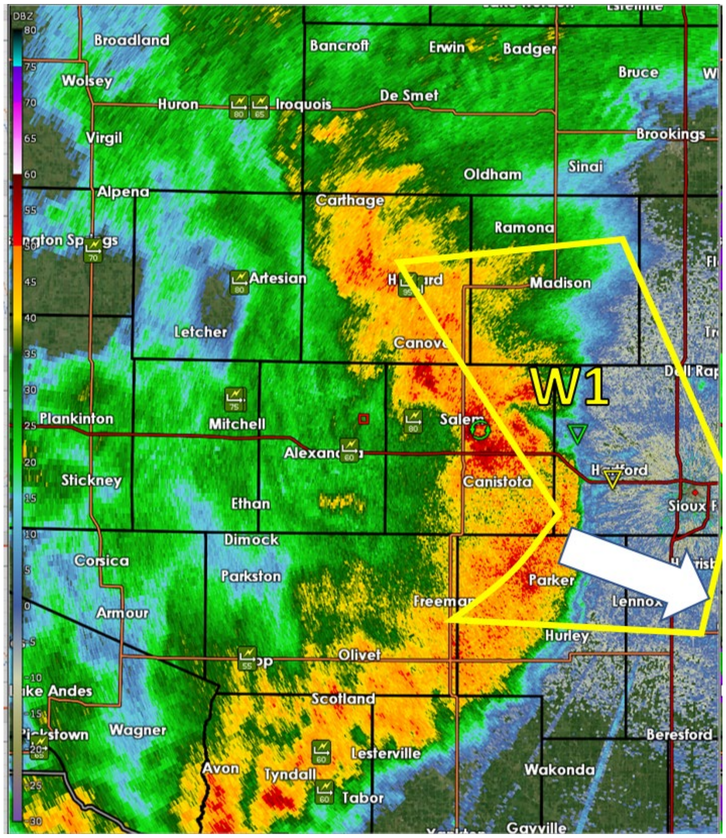


Fig. 35. A radar image of 0.5º reflectivity (left) from the KFSD WSR-88D at 2013 UTC 5 July 2022. The solid yellow line is the proposed warning polygon associated with damaging winds along and just behind the outflow boundary.

The first warning would be issued from south of the apex of the bow to near the cyclonic vortex (Fig. 35). The expectation is that winds with this warning would primarily be associated with the initial surge of the cold pool located between the outflow boundary and high-reflectivity cores within the derecho. In the 5 July 2022 case, winds within this portion of the squall line were 50-70 mph and severe gusts lasted for less than 15 minutes before decreasing. Each case is different, so it is critical to monitor observations near the gust front to ascertain the wind threat. In our case, we would recommend a duration of 45 minutes since a longer warning may result in too many counties in the warning. We would also recommend a 60 mph wind tag because gusts over 70 mph were rare, so a CONSIDERABLE tag is not warranted. Finally, we recommend using the full pathcast so that partners and the public are aware of how much time they have before severe winds reach their location.

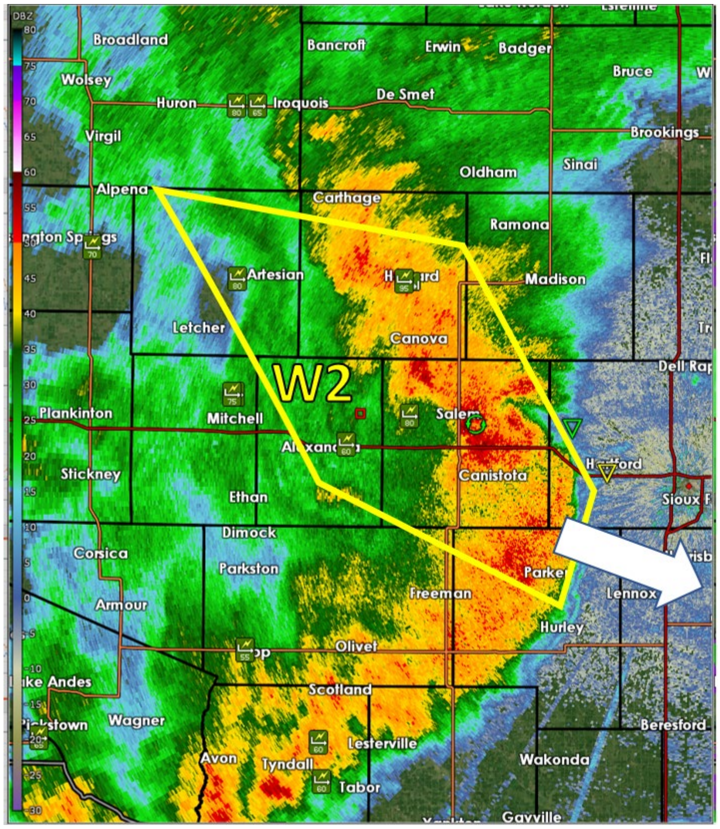


Fig. 36. A radar image of 0.5º reflectivity (left) from the KFSD WSR-88D at 2013 UTC 5 July 2022. The solid yellow line is the proposed warning polygon associated with damaging winds associated with the cyclonic bookend vortex.

The second warning we will discuss is the warning for the long-duration winds that are located well behind the outflow boundary, between the core of the rear inflow jet and center of the cyclonic bookend vortex circulation. As noted above, winds within this warning will last tens of minutes and perhaps over an hour depending upon the size and strength of both the bookend vortex and rear inflow jet. This should not be confused with winds near a wake low which will typically have a component opposite the direction of the outflow and be accompanied by rapid pressure falls on the order of 3-5+ mb per hour. Within this warning, winds will pick up 10-30 minutes after the peak winds associated with the outflow boundary. Once winds increase, they will continue to produce severe gusts for tens of minutes and may not peak until 15-30+ minutes after they reach severe criteria for a second time. Severe wind gusts may also persist another 15-30+ minutes after reaching the second peak. In the case of 5 July 2022, peak wind gusts within this channel of severe winds were 10 to 30 mph higher than those within the immediate outflow, but it is not known if this is the case with every event where strong winds occur south of the cyclonic vortex. Damaging wind gusts also lasted 60-90 minutes after the gust front moved through. So for a warning, we recommend a duration of 45-60 minutes depending upon how many counties are within the polygon and how long wind gusts are observed to persist. It is possible warnings will need to be reissued for a significant portion of this area if gusts last well over an hour, as they did on 5 July 2022. Also, it is likely there will be overlap between this warning and the one above. For wind speed, we recommend using 80 mph and a destructive tag unless observations suggest winds are lighter and there is no need for WEA activation. The biggest change is that we recommend that the **List of Cities** is used for the locations impacted statement. This is an update to what is suggested in the ***Advanced Warning Methodology: Winds from Linear Storm Modes***, which focuses more on the leading gust front (as in Warning 1). The reason for the difference is due to the long duration of the winds. Using the full pathcast or shortened pathcast would result in a time of arrival within the warnings, which is not optimal for the long-duration nature of the winds.

There are two options that WarnGen would use to find the pathcast based upon storm motion, and here are reasons why both are not optimal:

1.) You can draw the polygon so that the line segment is at the back edge of the damaging winds. As a result, the time of arrival for places on the eastern edge of your polygon will be 45-60 minutes into the future! Yet severe winds will be ongoing for tens of minutes before that time of arrival.
2.) You can draw the polygon at the leading edge of the damaging winds - say near the reflectivity gradient upstream from the highest reflectivity cores. Once you have a speed, then you alter the location of the vertices such that the polygon extends well behind the polygon as shown in Figure 36. In this case, you may get a correct time of arrival for places where the winds pick up, but places behind where your "line of storms" are not be listed in the pathcast at all!

By drawing your polygon using either method above and then selecting **List of Cities**, all towns and locations of interest (i.e. state parks) will be mentioned in the Locations Impacted. There will be no erroneous data such as places being impacted not being listed or having the wrong time of arrival. ***Be aware that this method alone will not be sufficient to convey the unique threat of long-duration damaging winds to the public and partners.*** In the next section we will discuss additional actions that the office should take to alert core partners and the public of the threat these storms produce.

The final warning is for the area south of the apex of the bow (Fig. 37). The warning strategy for this segment is similar to that for damaging winds along the outflow boundary along and north of the apex of the bow. You will use the line tool to determine the speed of this portion of the line and then determine the polygon shape based upon the track of the storm. As above, you will want to extend the polygon behind the outflow boundary to the core of the high reflectivity associated with the strongest updrafts. In this case, the damaging wind threat is only associated with the leading edge of the cold pool between the outflow boundary and strong updrafts. Duration will be 45-60 minutes depending on the number of counties within the polygon. The wind tag will likely be 60 or 70 mph depending upon past reports and radar estimated wind speeds - if available. Because the threat will last only a short time and will be near the outflow boundary, the full pathcast should be used to provide location and timing information on the threat.

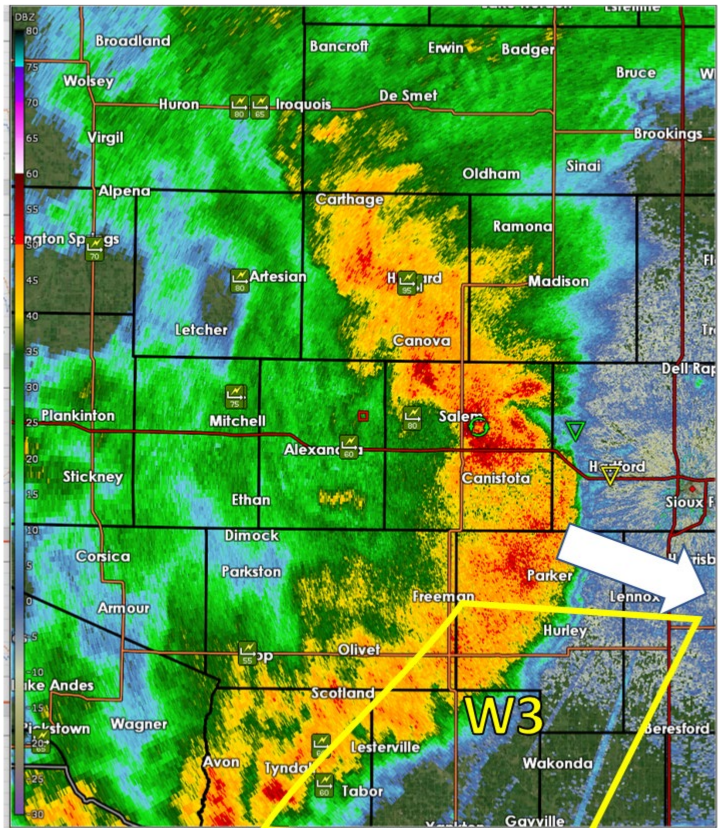


Fig. 37. A radar image of 0.5º reflectivity (left) from the KFSD WSR-88D at 2013 UTC 5 July 2022. The solid yellow line is the proposed warning polygon associated with damaging winds south of the apex of the bowing segment.

Messaging Long-Duration Damaging Winds within a Derecho

These types of long-duration severe events are rare for any one location. Both forecasters and the public expect that winds will be at or within a few miles of the outflow boundary and that severe winds will only last a few minutes. Because of this, many people will leave their place of shelter after the first surge of winds pass. This may include doctors and nurses who may begin to bring hospitalized patients back into rooms with windows or schools resuming normal activities as the first round of winds decrease. In addition, the media may focus only on the strong winds near the gust front and not warn people that damaging winds will resume and persist over a long period of time. The result is that people may be unprepared for damaging winds restarting and put themselves and others they are responsible for at greater risk of injury. To make people aware of this unique threat, enhanced messaging is critical to highlight the threat.

- **NWSChat 2.0:** Once NWS forecasters realize that long duration damaging winds are expected well behind the line of storms, partners must be made aware. Issuance of a severe thunderstorm warning behind the line as described above is not enough. NWSChat 2.0 is a great way to reach out to both emergency managers as well as the media. As the warning is being issued or after it is issued, forecasters should write up a post within NWSChat 2.0 to explain why a warning has been issued well behind the line. Include not just expected wind speeds but how long you expect winds to remain severe in any location. Putting together a map to show the current location of the strongest winds behind the line overlaid with a radar image similar to what was shown in Fig. 34 can be a powerful way to highlight the threat. You could also show a time series of wind speeds from MesoWest or the NWS Western Region Times Series Viewer. Don't just emphasize the strong winds but also note there will be a brief lull between the two periods of high winds. If the media understands the unique threat posed by these storms, they can relay that message to viewers, increasing the possibility that more people will stay in shelter during the entire event.

- **Contact Emergency Managers:** If time permits, contact the emergency managers in impacted counties before the storms arrive. This would be most important in areas with lots of people who may be outdoors (i.e. state or national parks or cities). Ideally we would want to do this 30-60 minutes before the storm reaches an impacted county or city. They can help make sure that people not only take shelter but take shelter in a place they may need to stay over an hour.

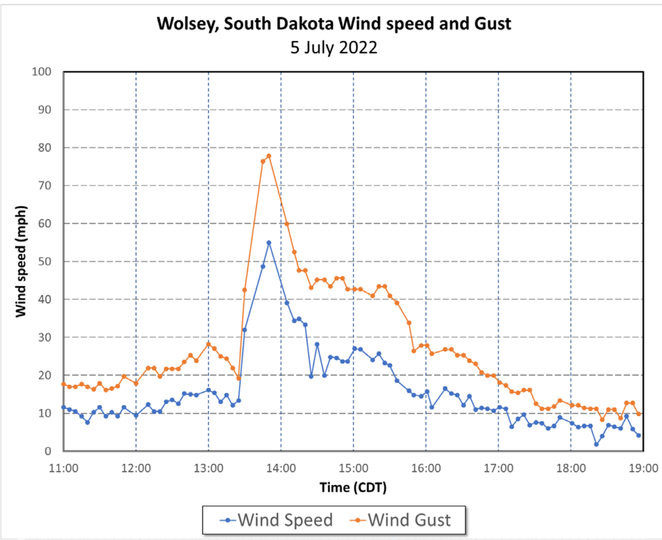
- **Social Media:** In order to reach the public and to also have information core partners can quickly share, create a post within social media that succinctly highlights the threat. Remember having a long period of damaging winds is outside the experience of most people. They expect that once winds decrease, they will not increase again. Emphasizing how the event will evolve - "Winds will gust to 60 mph initially as the storms approach. The winds will briefly decrease before picking back up with gusts as high as 80 mph." As with NWSChat, emphasize both the strength of the winds within the long-duration event and the fact that there will be a brief lull between the initial gust of winds and the long duration winds. Remain in shelter is necessary to keep one safe during the entire event. And don’t be afraid to state that this is a rare event. Emphasizing the unique nature of the threat may result in people paying more attention.

Because of the enhanced messaging and the rarity of this type of event, we recommend having a person available who can answer questions from the public. This person may also need to do interviews with local media who want to use an expert to explain the threat to their listeners/viewers.

Appendix A – Wind Observations

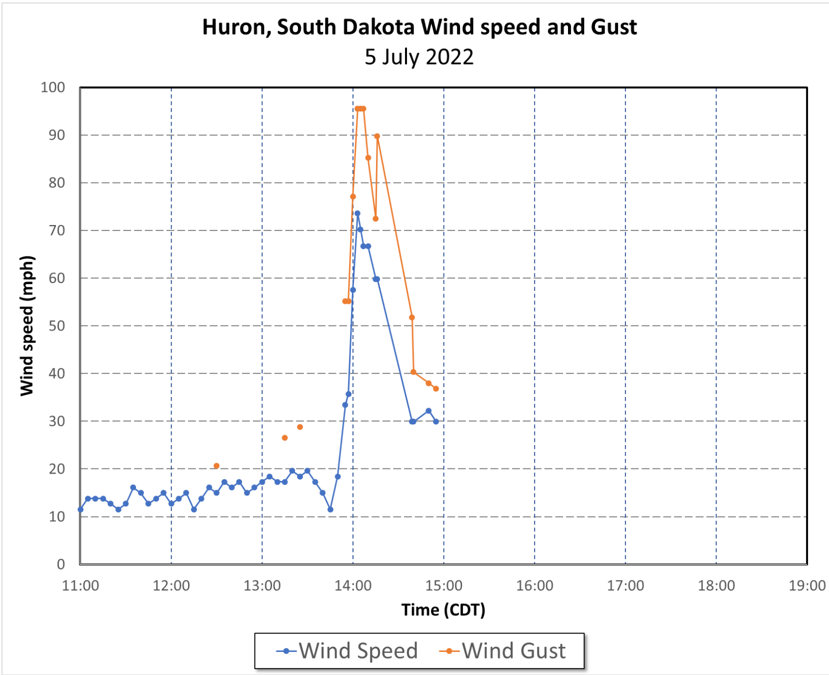
Here is a listing of wind observations from near and inside the WFO Sioux Falls County Warning Area between 1 PM and 4:30 PM CDT (1800 – 2130 UTC). Only stations with severe winds are included. All wind speeds are in mph.

Wolsey, South Dakota



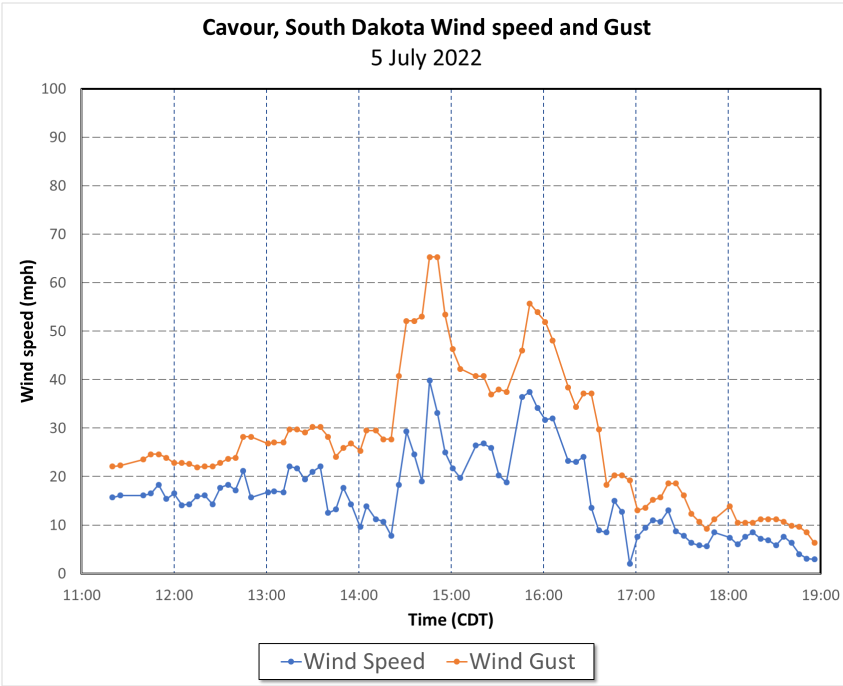
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	ENE	16.1	28.2	1951	NNE	23.7	45.6
1805	NE	15.4	27.0	1955	NE	23.7	42.7
1810	NE	13.0	25.0	2001	ENE	27.0	42.7
1815	NE	14.8	24.4	2006	ENE	26.8	42.7
1820	NNE	12.1	21.9	2016	ENE	24.1	40.9
1825	NW	13.4	19.2	2021	ENE	25.7	43.4
1830	WNW	32.0	42.5	2026	ENE	23.2	43.4
1845	NNW	48.7	76.4	2030	ENE	22.6	40.9
1850	NNW	55.0	77.8	2036	ENE	18.6	39.1
1905	NNW	39.1	59.9	2046	ENE	15.9	33.8
1911	NNW	34.4	52.5	2050	ENE	14.8	26.4
1915	NNW	34.9	47.6	2056	NE	14.5	27.9
1920	N	33.3	47.6	1601	ENE	15.7	27.9
1925	N	19.7	43.1	1605	ENE	11.6	25.7
1930	NNE	28.2	45.2	1616	ENE	16.5	26.8
1936	NE	19.9	45.2	1621	ENE	15.2	26.8
1941	NNE	24.8	43.4	1626	ENE	14.8	25.3
1946	NNE	24.6	45.6	1631	ENE	12.1	25.3

Huron, South Dakota



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	ENE	17.3		1415	NW	59.8	72.5
1805	ENE	18.4		1416	NW	59.8	89.8
1810	ENE	17.3		1439	N	29.9	51.8
1815	ENE	17.3	26.5	1440	N	29.9	40.3
1820	ENE	19.6		1450	N	32.2	38.0
1825	ENE	18.4	28.8	1455	NNE	29.9	36.8
1830	NE	19.6					
1835	NE	17.3					
1840	NE	15					
1845	NE	11.5					
1850	NNW	18.4					
1855	NW	33.4	55.2				
1857	NW	35.7	55.2				
1400	NW	54.5	77.1				
1403	NW	73.6	95.5				
1405	NW	70.2	95.5				
1407	NW	66.7	95.5				
1410	NW	66.7	85.2				

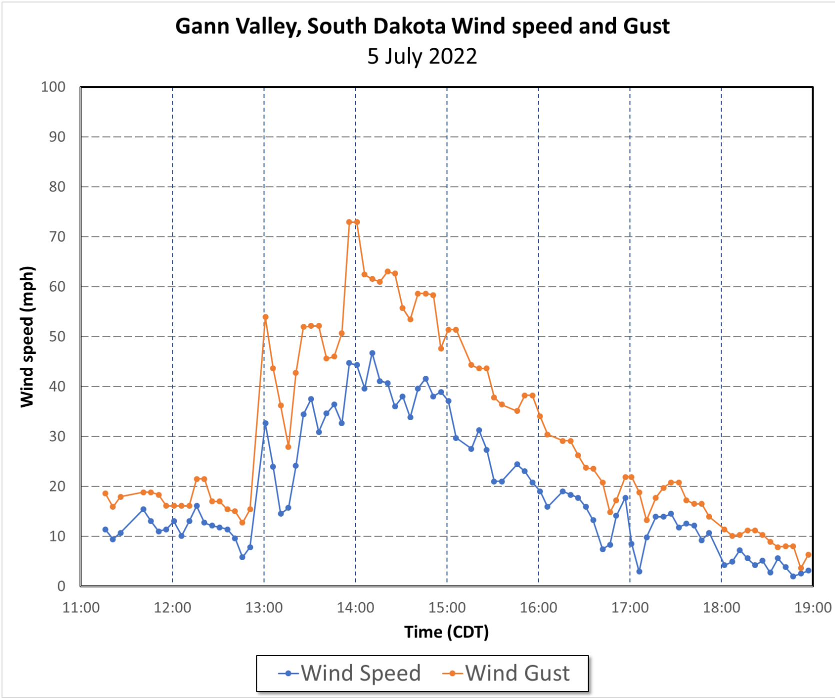
Cavour, South Dakota



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1801	ESE	16.8	26.8	1941	N	19.0	53.0
1805	ESE	17.0	27.0	1946	NNE	39.8	65.3
1811	ESE	16.8	27.0	1951	NNW	33.1	65.3
1815	ESE	22.1	29.7	1956	N	25.0	53.4
1820	ESE	21.7	29.7	2001	N	21.7	46.3
1825	ESE	19.4	29.1	2006	NNE	19.7	42.2
1830	ESE	21.0	30.2	2016	ENE	26.4	40.7
1835	ESE	22.1	30.2	2021	ENE	26.8	40.7
1840	E	12.5	28.2	2026	ENE	25.9	36.9
1845	E	13.2	24.1	2031	E	20.3	38.0
1850	E	17.7	25.9	2036	E	18.8	37.5
1855	E	14.3	26.8	2046	ESE	36.4	46.0
1901	E	9.6	25.3	2051	SE	37.5	55.7
1905	E	13.9	29.5	2056	ESE	34.2	53.9
1911	E	11.2	29.5	2001	SE	31.7	51.9
1916	ENE	10.7	27.7	2006	SE	32.0	48.1
1921	N	7.8	27.7	2016	ESE	23.2	38.4
1926	N	18.3	40.7	2021	ESE	23.0	38.4
1931	NNE	29.3	52.1	2026	ESE	24.1	37.1
1936	N	24.6	52.1	2031	E	13.6	37.1

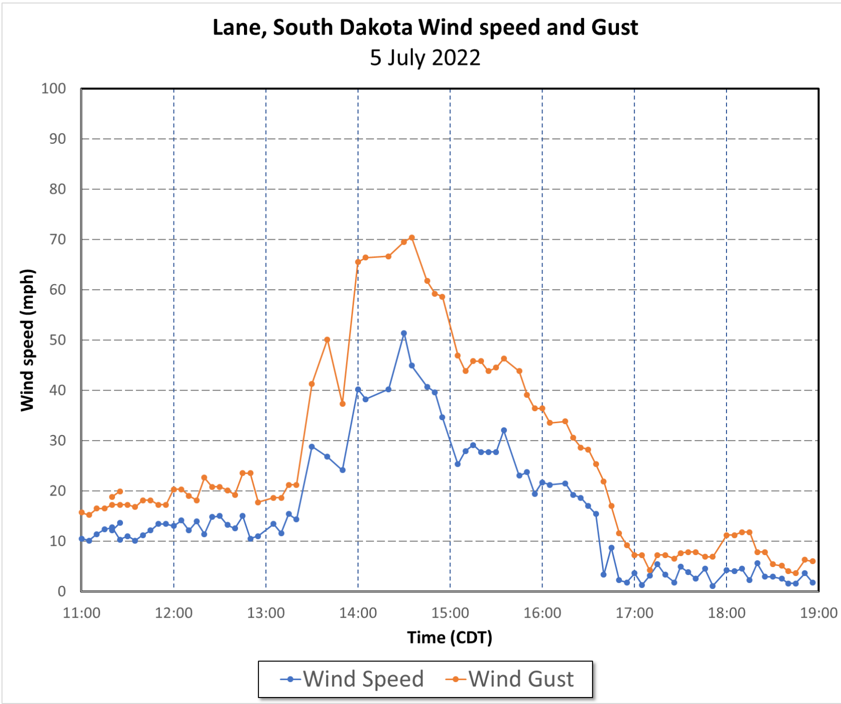
*Note: Strong gusts after 1940 UTC were due to a wake low.

Gann Valley, South Dakota



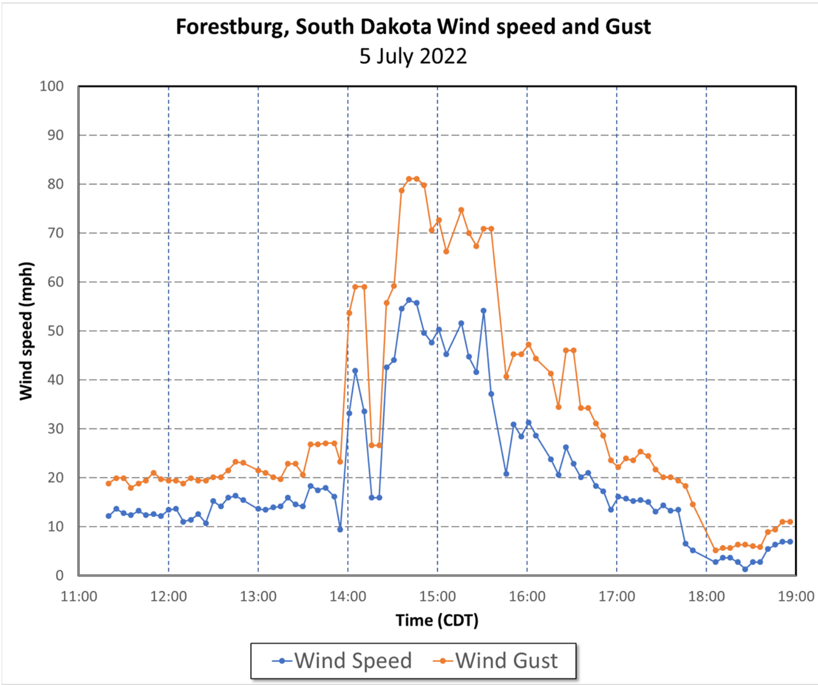
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1801	WNW	32.6	53.9	1941	ENE	39.6	58.6
1806	NNW	23.9	43.6	1946	ENE	41.6	58.6
1811	N	14.5	36.2	1951	E	38.0	58.3
1816	N	15.7	27.9	1956	E	38.9	47.6
1821	NNE	24.1	42.7	2001	E	37.1	51.4
1826	NNE	34.4	51.9	2006	E	29.7	51.4
1831	NNE	37.5	52.1	2016	ESE	27.5	44.3
1836	NNE	30.9	52.1	2021	ESE	31.3	43.6
1841	NNE	64.6	45.6	2026	ESE	27.3	43.6
1846	NNE	36.4	46.0	2031	ESE	21.0	37.8
1851	NNE	32.6	50.7	2036	ESE	21.0	36.4
1856	NE	44.7	72.9	2046	ESE	64.4	35.1
1901	NE	44.3	72.9	2051	ESE	23.0	38.2
1906	NE	39.6	62.4	2056	ESE	20.8	38.2
1911	ENE	46.7	61.5	2001	ESE	19.0	34.0
1916	ENE	41.1	61.0	2006	ESE	15.9	30.4
1921	ENE	40.7	63.0	2016	ESE	19.0	29.1
1926	ENE	36.0	62.6	2021	SE	18.3	29.1
1931	ENE	38.0	55.7	2026	SE	17.7	26.2
1936	ENE	33.8	53.4	2031	SE	15.9	26.7

Lane, South Dakota



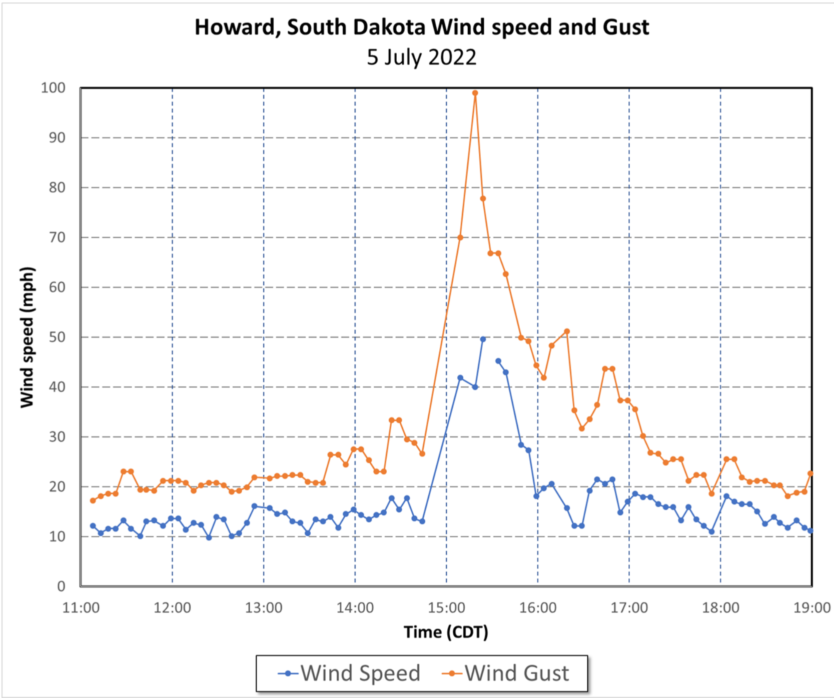
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1805	ESE	13.4	18.6	2030	ENE	27.7	44.5
1810	ESE	11.6	18.6	2035	ENE	32.0	46.3
1815	ESE	15.4	21.2	2045	ENE	23.0	43.8
1820	ESE	14.3	21.2	2050	E	23.7	39.1
1830	WNW	28.8	41.3	2055	E	19.4	36.4
1840	NNW	26.8	50.1	2100	E	21.7	36.4
1850	NNW	24.1	37.3	2105	E	21.2	33.5
1900	NNW	40.2	65.5	2115	E	21.5	33.8
1905	N	38.2	66.4	2120	E	19.2	30.6
1920	N	41.2	66.6	2125	E	18.6	28.6
1930	NNE	51.4	69.5	2130	E	17.0	28.2
1935	NNE	44.9	71.4				
1945	NE	401.7	61.7				
1950	NE	39.6	59.2				
1955	NNE	34.6	58.6				
2005	NNE	25.3	46.9				
2010	NNE	27.9	43.8				
2015	NE	29.1	45.8				
2020	NE	27.7	45.8				
2025	NE	27.7	43.8				

Forestburg, South Dakota



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	ENE	13.6	21.5	1941	NW	56.3	81.1
1805	ENE	13.4	21.0	1946	NNW	55.7	81.1
1810	ENE	13.9	20.1	1951	NNW	49.6	79.8
1815	ENE	14.1	19.7	1956	NNW	47.6	70.6
1820	NE	15.9	22.8	2001	NNW	50.3	72.6
1825	NE	14.5	22.8	2006	NNW	45.2	66.2
1830	NE	14.1	20.6	2016	N	51.6	74.7
1835	NE	18.3	26.8	2021	N	44.7	70.0
1840	ENE	17.4	26.8	2026	N	41.6	67.3
1845	ENE	17.9	27.0	2031	NNE	54.1	70.9
1851	ENE	16.1	27.0	2036	NNE	37.1	70.9
1855	ENE	9.4	23.2	2046	NNE	20.8	40.7
1901	WNW	33.1	53.6	2051	NNE	30.9	45.2
1905	WNW	41.8	59.0	2056	NNE	28.4	45.2
1911	W	33.5	59.0	2101	NE	31.3	47.2
1916	W	15.9	26.6	2106	NE	28.6	44.3
1921	WSW	15.9	26.6	2016	ENE	23.7	41.3
1926	NW	42.5	55.7	2021	ENE	20.6	34.4
1931	NW	44.0	59.2	2026	NE	26.2	46.0
1936	NW	54.5	78.7	2031	NE	22.8	46.0

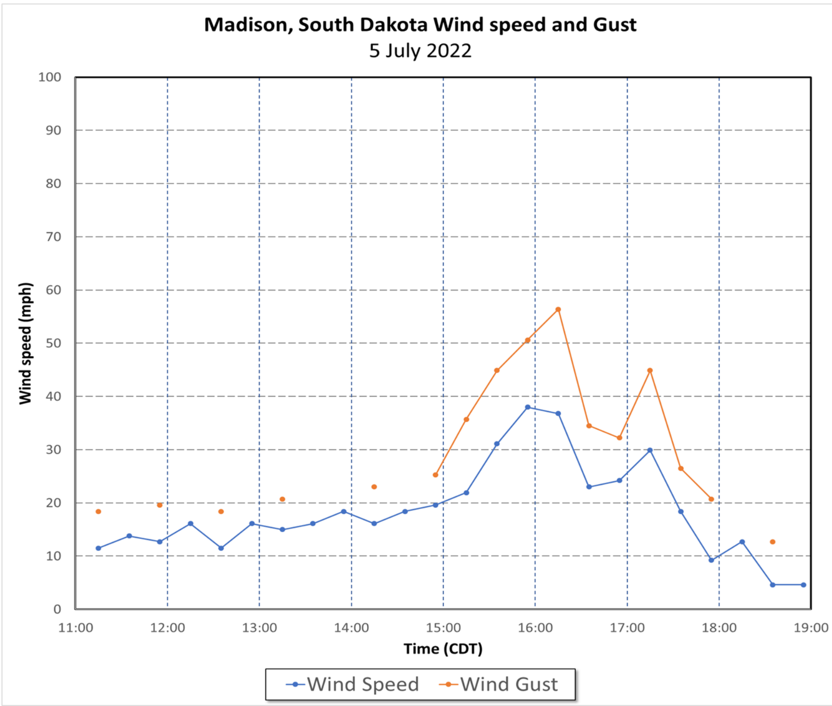
Howard, South Dakota



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1804	ENE	15.7	21.7	1944	NE	13.0	26.6
1809	ENE	14.5	22.1	2009	WSW	14.8	70.0
1814	ENE	14.8	22.1	2019	W	40.0	99.0
1819	NE	13.0	22.3	2024	W	19.6	77.8
1824	ENE	12.7	22.3	2029	Missing	Missing	66.8
1829	NE	10.7	21.0	2034	WNW	45.2	66.8
1834	NE	13.4	20.8	2039	NW	42.9	62.6
1839	NE	13.0	20.8	2049	NNW	28.4	49.9
1844	ENE	13.9	26.4	2054	NNW	27.3	49.2
1849	NE	11.8	26.4	2059	NNW	18.1	44.3
1854	ENE	14.5	24.4	2104	N	19.7	41.8
1859	NE	15.4	27.5	2109	N	20.6	48.3
1904	NE	14.3	27.5	2119	NNE	15.7	51.2
1909	NE	13.4	25.3	2124	NNE	12.1	35.3
1914	NE	14.3	23.0	2129	NNE	12.1	31.7
1919	NE	14.8	23.0				
1924	NE	17.7	33.3				
1929	NE	15.4	33.3				
1934	NE	17.7	29.5				
1939	NE	13.6	28.8				

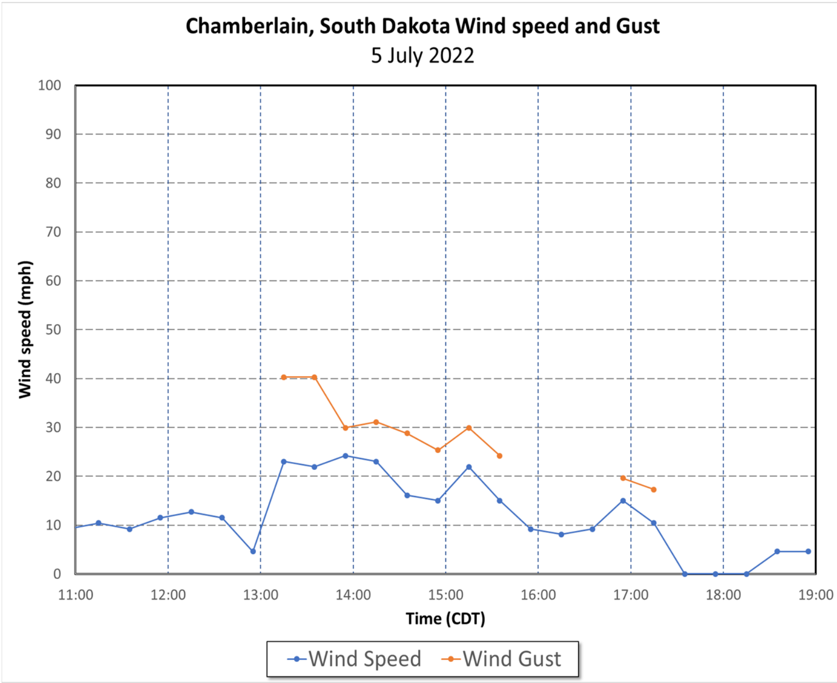
A unique aspect of the Howard, SD RWIS site wind data - the bookend vortex passes right overtop the observation site (which explains the persistent ENE flow until a rather violent switch to the west as the vortex passes). In addition, there is a 25 minute gap in the observation data that may have revealed a subtle outflow boundary passage just moments before the cyclonic bookend vortex and rear inflow jet overlap arrives. Per radar analysis (not shown), this may have occurred during the data gap around 1956 UTC.

Madison, South Dakota



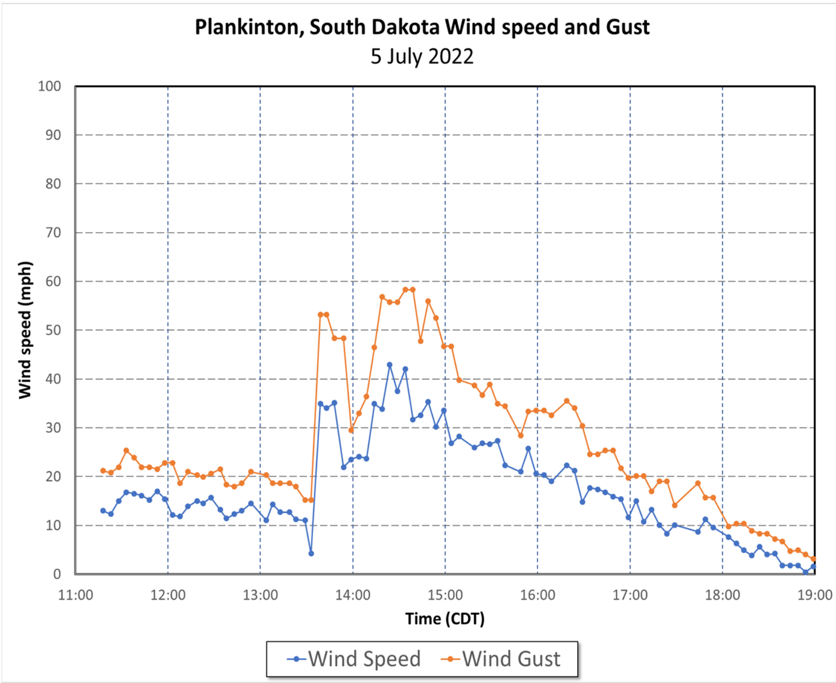
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1755	E	16.1					
1815	E	15.0	20.7				
1835	E	16.1					
1855	ENE	18.4					
1915	ENE	16.1	23.0				
1935	NE	18.4					
1955	NE	19.6	25.3				
2015	NNE	21.9	35.7				
2035	NNE	31.1	44.9				
2055	N	38.0	50.6				
2115	NW	16.8	56.4				
2135	N	23.0	34.5				

Chamberlain, South Dakota



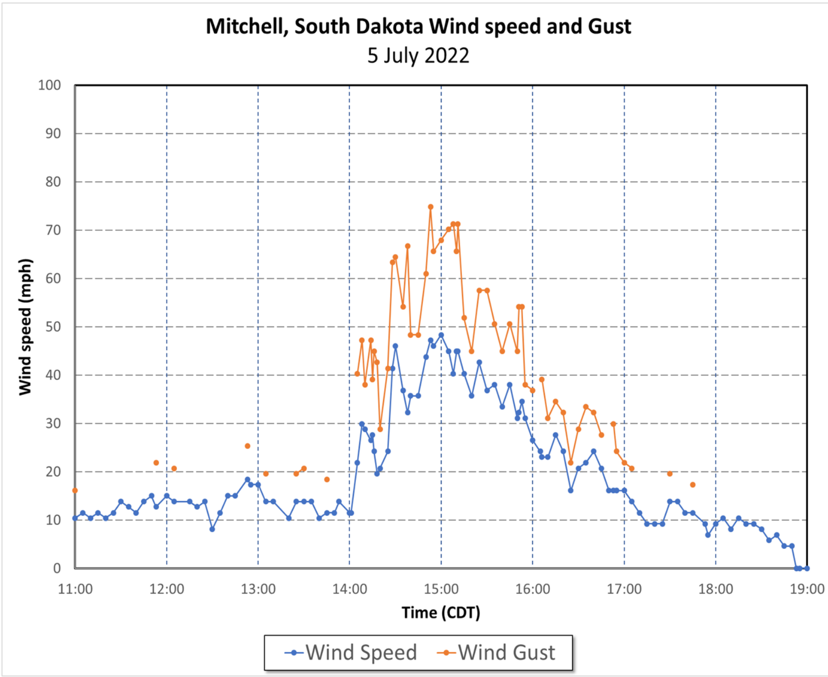
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1755	NNW	4.6					
1815	N	23.0	40.3				
1835	NNW	21.9	40.3				
1855	NNE	24.2	29.9				
1915	N	23.0	31.1				
1935	NNE	16.1	28.8				
1955	NNE	15.0	25.3				
2015	ENE	21.9	29.9				
2035	ENE	15.0	24.2				
2055	E	9.2					
2115	ESE	8.1					
2135	E	9.2					

Plankinton, South Dakota



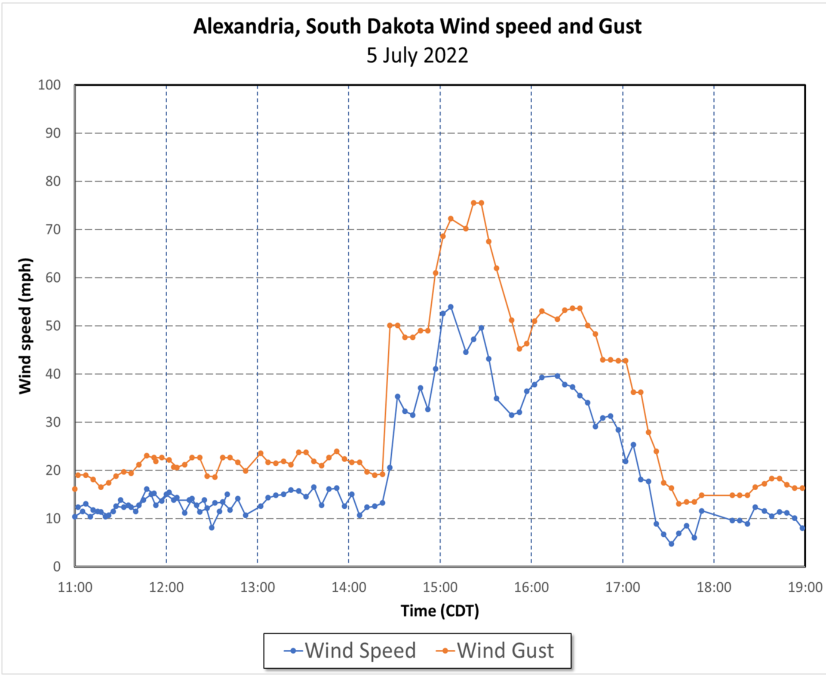
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1804	ESE	11.0	20.3	1944	N	32.	47.8
1808	SE	14.3	18.6	1949	N	35.3	55.9
1813	SE	12.7	18.6	1954	NNE	30.2	52.5
1819	SE	12.7	18.6	1959	NNE	33.5	46.7
1823	SE	11.2	17.9	2004	NNE	26.8	46.7
1829	SSE	11.0	15.2	2009	NNE	28.2	36.8
1833	SSW	4.2	15.2	2019	NNE	25.9	38.7
1839	NW	34.9	53.2	2024	NE	26.8	36.7
1843	NW	34.0	53.2	2029	NE	26.6	38.9
1848	NNW	35.1	48.3	2034	NE	27.3	34.9
1854	NNW	21.9	48.3	2039	NE	22.3	34.4
1859	NNW	23.5	29.5	2049	NE	21.0	28.4
1904	NNW	24.1	32.9	2054	NE	25.7	33.3
1909	NNW	23.7	36.4	2059	NE	20.6	33.5
1914	NNW	34.9	46.5	2104	NE	20.3	33.5
1919	N	33.8	46.8	2109	ENE	19.0	32.6
1924	N	42.9	55.7	2119	ENE	22.3	35.5
1929	N	37.5	55.7	2124	ENE	21.2	34.0
1934	N	42.0	58.3	2129	ENE	14.8	30.4
1939	N	31.7	58.3				

Mitchell, South Dakota



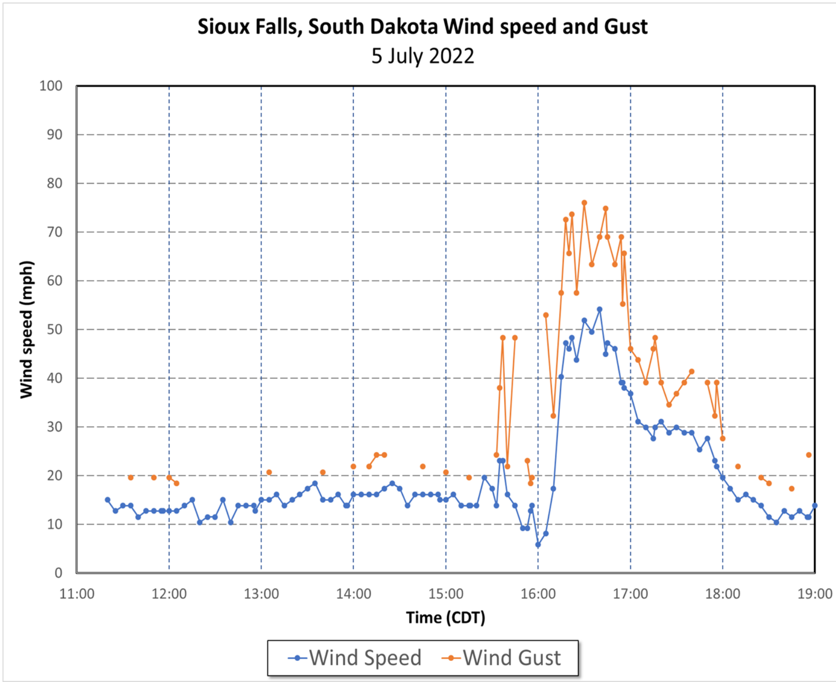
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	ESE	17.3		1940	N	35.7	48.3
1805	ESE	13.8	19.6	1945	N	35.7	48.3
1810	ESE	13.8		1950	N	43.7	61.0
1820	ESE	10.4		1953	N	47.2	74.8
1825	E	13.8	19.6	1955	N	46.0	65.6
1830	ESE	13.8	20.7	2000	N	28.3	67.9
1835	ESE	13.8		2005	N	44.9	70.2
1840	ESE	10.4		2008	N	40.3	71.3
1845	SE	11.5	18.4	2010	N	44.9	65.6
1850	SE	11.5		2011	N	44.9	71.3
1853	SE	13.8		2015	NNE	40.3	51.8
1900	SSE	11.5		2020	N	35.7	44.9
1901	SSE	11.5		2025	NNE	42.6	57.5
1905	W	21.9	40.3	2030	NNE	36.8	57.5
1908	WNW	29.9	47.2	2035	NNE	38.0	50.6
1910	WNW	28.8	38.0	2040	NE	33.4	44.9
1914	WNW	26.5	47.2	2045	NE	38.0	50.6
1915	WNW	27.6	39.1	2050	NE	31.1	44.9
1916	WNW	24.2	44.9	2051	NE	32.2	54.1
1918	W	19.6	42.6	2053	NE	34.5	54.1
1920	W	20.7	28.8	2055	NNE	31.1	38.0
1925	W	24.2	41.4	2100	NNE	26.5	36.8
1928	WNW	41.4	63.3	2105	NE	24.2	
1930	NW	46.0	64.4	2106	NE	23.0	39.1
1935	NNW	36.8	54.1	2110	NNE	23.0	31.1
1938	N	32.2	66.7	2115	NE	27.6	34.5

Alexandria, South Dakota



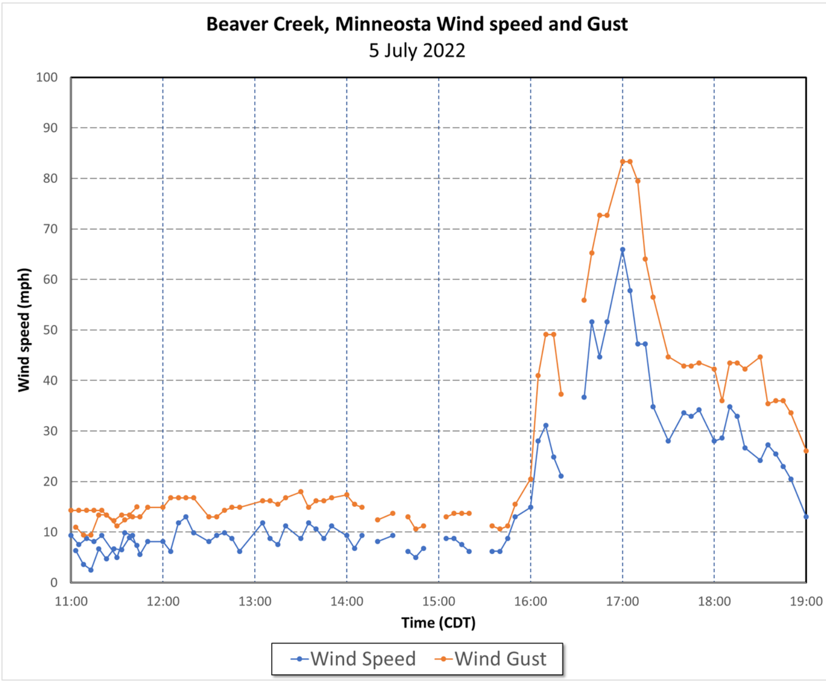
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	12.5	23.5	2017	NW	44.5	70.2
1807	ENE	14.3	21.7	2022	NNW	47.2	75.5
1812	ENE	14.8	21.5	2027	NNW	49.6	75.5
1817	E	15.0	21.9	2032	NNW	43.1	67.5
1822	E	15.9	21.2	2037	NNW	34.9	61.9
1827	E	15.7	23.7	2047	NNW	31.5	51.2
1832	E	14.5	23.7	2052	NNW	32.0	45.2
1837	ENE	16.5	21.9	2057	NNW	36.4	46.3
1842	E	12.7	21.0	2102	N	37.8	51.0
1847	E	16.1	22.6	2107	N	39.3	53.0
1852	E	16.3	23.9	2117	N	39.6	51.4
1857	E	12.5	22.3	2122	NNE	37.8	53.2
1902	E	15.0	21.7	2127	N	37.3	53.6
1907	E	0.7	21.7	2132	NNE	37.3	53.6
1912	E	12.3	19.7				
1917	ESE	12.5	19.0				
1922	ESE	13.2	19.2				
1927	SW	20.6	50.1				
1932	WSW	35.3	50.1				
1937	WNW	32.2	47.6				
1942	NW	31.5	47.6				
1947	WNW	37.1	49.0				
1952	W	32.6	49.0				
1957	WNW	41.1	61.0				
2002	NW	52.5	68.6				
2007	NW	53.9	72.2				

Sioux Falls, South Dakota



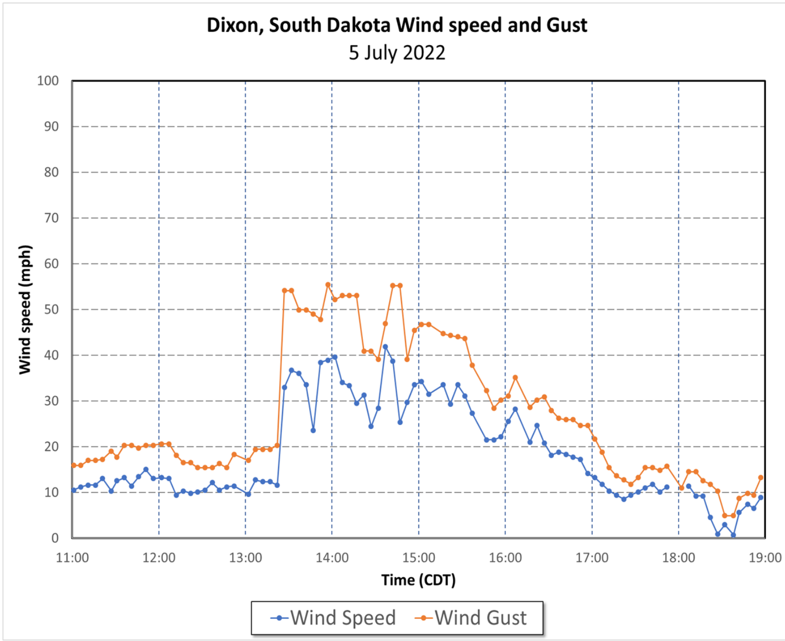
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	E	15.0		2000	E	15.0	
1805	E	15.0	20.7	2005	E	16.1	
1810	E	16.1		2010	E	13.8	
1815	E	13.8		2015	E	13.8	19.6
1820	E	15.0		2016	E	13.8	
1825	ESE	16.1		2020	E	13.8	
1830	ESE	17.3		2025	E	19.6	
1835	ESE	18.4		2030	E	17.3	
1840	ESE	15.0	20.7	2033	SSE	13.8	24.2
1845	E	15.0		2035	SW	23.0	38.0
1850	E	16.1		2037	WSW	23.0	48.3
1855	E	13.8		2040	WSW	16.1	21.9
1856	E	13.8		2045	WSW	13.8	48.3
1900	E	16.1	21.9	2050	SW	9.2	
1905	E	16.1		2053	SW	9.2	23.0
1910	E	16.1	21.9	2055	SSW	12.7	18.4
1915	E	16.1	24.2	2056	SSW	13.8	19.6
1920	ESE	17.3	24.2	2100	SSE	5.8	
1925	ESE	18.4		2105	NNW	8.1	52.9
1930	ESE	17.3		2110	N	17.3	32.2
1935	E	13.8		2115	NW	40.3	57.5
1940	E	16.1	21.9	2118	NNW	47.2	72.5
1945	E	16.1		2120	NNW	46.0	65.6
1950	E	16.1		2122	NNW	48.3	73.6
1955	E	16.1		2125	NW	43.7	57.5
1956	E	15.0	20.7	2130	NNW	51.8	76.0

Beaver Creek, MN



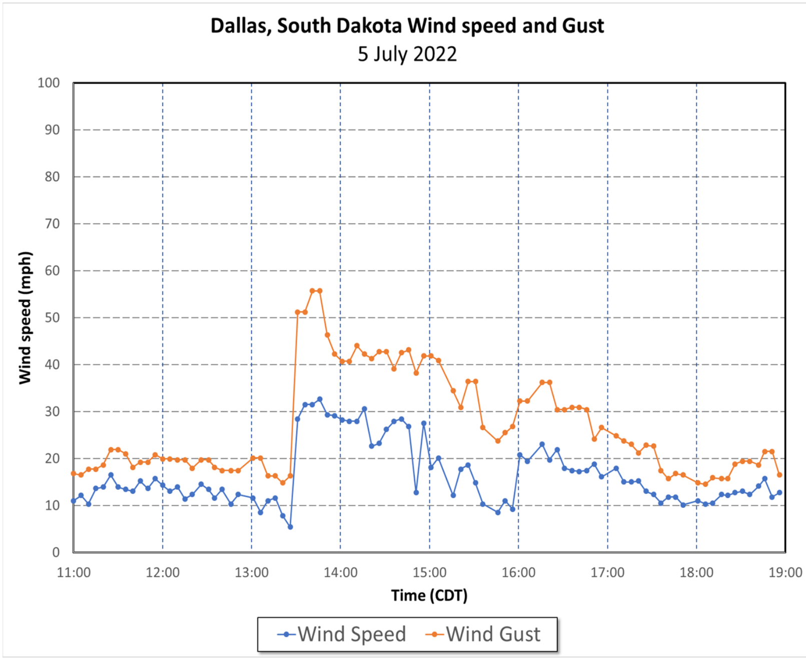
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1805	ESE	11.8	16.2	2105	SE	28.0	41.0
1810	ESE	8.7	16.2	2110	SW	31.1	49.1
1815	ESE	7.5	16.8	2115	SW	24.9	49.1
1820	ESE	11.2	17.4	2120	S	21.1	37.3
1830	ESE	8.7	15.5				
1835	ESE	11.8	14.9				
1840	ESE	10.6	16.2				
1845	E	8.7	16.2				
1850	ESE	11.2	16.8				
1900	ESE	9.3	17.4				
1905	ESE	6.8	15.5				
1910	ESE	9.3	14.9				
1920	ESE	8.1	12.4				
1930	ENE	9.3	13.7				
1940	ENE	6.2	13.0				
1945	E	5.0	10.6				
1950	ENE	6.8	11.2				
2005	E	8.7	13.0				
2010	ESE	8.7	13.7				
2015	ESE	7.5	13.7				
2020	E	6.2	13.7				
2035	E	6.2	11.2				
2040	E	6.2	10.6				
2045	E	8.7	11.2				
2050	E	13.0	15.5				
2100	E	14.9	20.5				

Dixon, SD



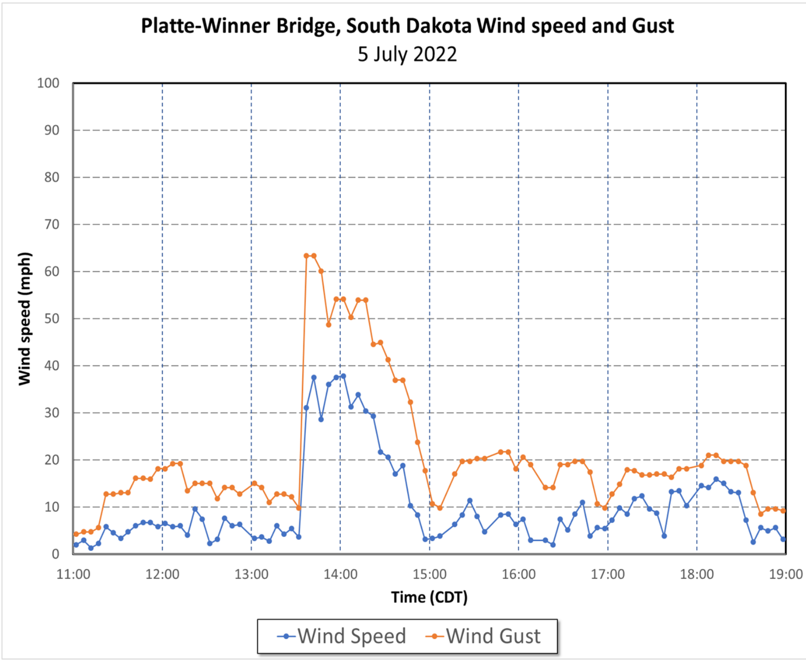
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	9.6	17.0	2017	NNE	33.5	44.7
1807	E	12.7	19.4	2022	NE	29.3	44.3
1812	E	12.3	19.4	2027	NE	33.5	44.0
1817	E	12.3	19.4	2032	NE	31.1	43.6
1822	N	11.6	20.3	2037	NE	27.3	37.8
1827	NNW	32.9	54.1	2047	NE	21.5	32.2
1832	NW	36.7	54.1	2052	NE	21.5	28.4
1837	NNW	36.0	49.9	2057	NE	22.1	30.2
1842	NNW	33.5	49.9	2102	ENE	25.5	31.1
1847	N	23.5	49.0	2107	ENE	28.2	35.1
1852	N	38.4	47.8	2117	ENE	21.0	28.6
1857	N	38.9	55.4	2122	ENE	24.6	30.2
1902	N	39.6	52.1	2127	ENE	20.8	30.9
1907	NNE	34.0	53.0	2132	ENE	18.1	27.9
1912	NNE	33.3	53.0				
1917	NNE	29.5	53.0				
1922	NNE	31.3	40.9				
1927	NNE	24.4	10.9				
1932	NNE	28.4	39.1				
1937	N	41.8	46.9				
1942	NNE	38.7	55.2				
1947	NNE	25.3	55.2				
1952	NNE	29.7	39.1				
1957	NNE	33.5	45.4				
2002	NNE	34.2	46.7				
2007	NNE	31.5	46.7				

Dallas, SD



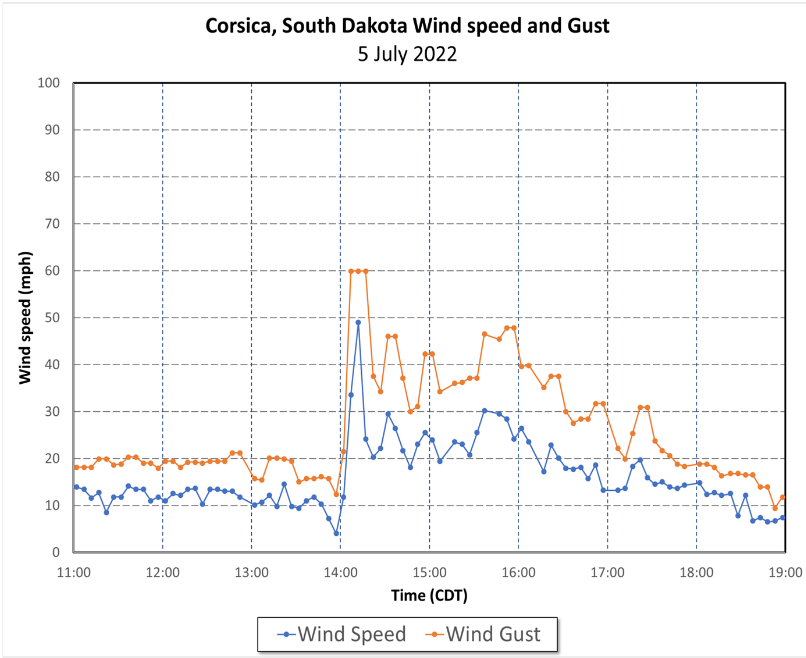
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1801	E	11.6	20.1	2016	NNE	12.1	34.4
1806	E	8.5	20.1	2021	NNE	17.7	30.9
1811	E	11.0	16.3	2026	NNE	18.6	36.4
1816	ENE	11.6	16.3	2031	NNE	14.8	36.4
1821	ENE	7.8	14.8	2036	NNE	10.3	26.6
1826	ENE	5.4	16.3	2046	NNE	8.5	23.7
1831	NNW	28.4	51.2	2051	NE	11.0	25.5
1836	NNW	31.5	51.2	2056	NE	9.2	26.8
1841	NNW	31.5	55.7	2101	ENE	20.8	32.2
1846	N	32.6	55.7	2106	ENE	19.4	32.2
1851	N	29.3	46.3	2116	ENE	23.0	26.2
1856	N	29.1	42.2	2121	ENE	19.7	36.2
1901	N	28.2	40.7	2126	ENE	21.9	30.4
1906	N	27.9	10.7	2131	ENE	17.9	30.4
1911	N	27.9	44.0				
1916	N	30.6	42.2				
1921	N	22.6	41.3				
1926	NNE	23.2	42.7				
1931	N	26.2	42.7				
1936	N	27.9	39.1				
1941	N	28.4	42.5				
1946	N	26.8	43.1				
1951	NNE	12.7	38.2				
1956	N	27.5	41.8				
2001	NNE	18.1	41.8				
2006	NNE	20.1	40.9				

Platte-Winnter Bridge, SD



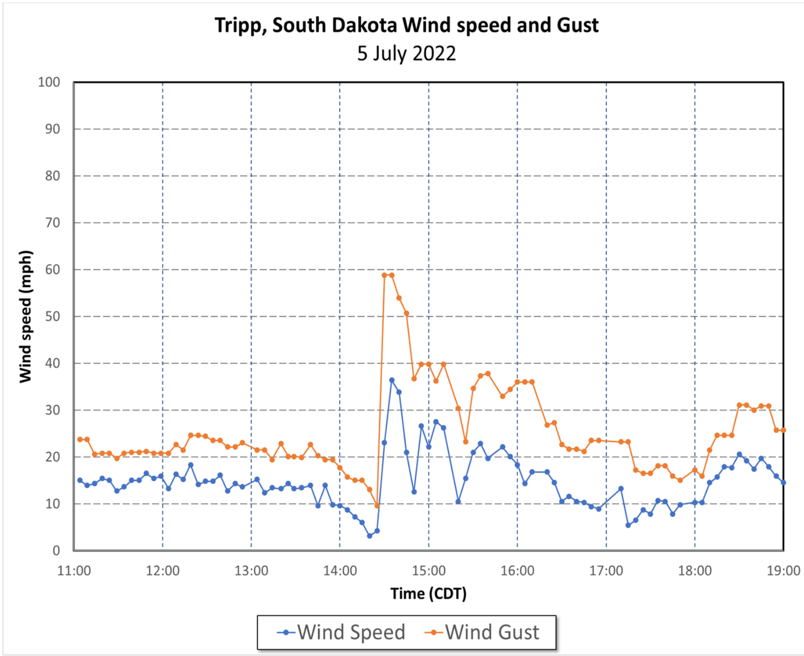
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	ENE	3.3	15.0	2017	N	6.3	17.0
1807	ENE	3.6	14.1	2022	NNW	8.3	19.7
1812	E	2.7	11.0	2027	N	11.4	19.7
1817	E	6.0	12.7	2032	N	8.0	20.3
1822	ENE	4.2	12.7	2037	NNE	4.7	20.3
1827	E	5.4	12.1	2048	NNE	8.3	21.7
1832	NNE	3.6	9.8	2053	NE	8.5	21.7
1837	NNW	31.1	63.3	2058	NE	6.3	18.1
1842	NNW	37.5	63.3	2103	NNE	7.4	20.6
1847	NNW	28.6	60.1	2108	ENE	2.9	19.0
1852	NNW	36.0	48.7	2113	SE	2.9	14.1
1857	NNW	27.5	54.1	2128	NNW	2.0	14.1
1902	NNW	37.8	54.1	2123	E	7.4	19.0
1907	NNW	31.3	50.3	2138	ENE	5.1	19.0
1912	N	33.8	53.9				
1917	N	30.4	53.9				
1922	N	29.3	44.5				
1927	N	21.7	44.9				
1932	NNE	20.6	41.3				
1937	NNE	17.0	36.9				
1942	N	18.8	36.9				
1947	N	10.3	32.2				
1952	NW	8.3	23.7				
1957	SW	3.1	17.7				
2002	SE	3.3	10.7				
2007	NE	3.8	9.8				

Corsica, SD



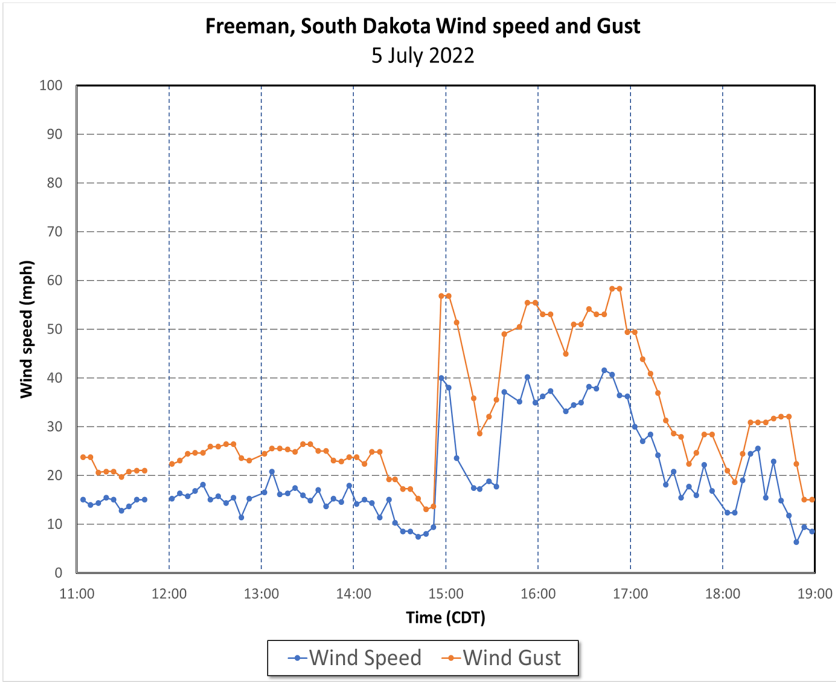
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	10.1	15.7	2017	N	23.5	36.0
1807	ESE	10.7	15.4	2022	NNE	23.0	36.2
1812	ESE	12.1	20.1	2027	N	20.8	37.1
1817	E	9.8	20.1	2032	N	25.5	37.1
1822	ESE	14.5	19.9	2037	NNE	30.2	46.5
1827	ESE	9.8	19.4	2047	NNE	29.5	45.4
1832	SE	9.4	15.0	2052	NNE	28.4	47.8
1837	ESE	11.0	15.7	2057	NNE	24.1	47.8
1842	ESE	11.8	15.7	2102	NNE	26.4	39.6
1847	E	10.3	16.1	2107	NNE	23.5	39.8
1852	ESE	7.2	15.7	2117	NE	17.2	35.1
1857	E	4.0	12.3	2122	NE	22.8	37.5
1902	N	11.8	21.5	2127	NE	20.1	37.5
1907	NNW	33.5	59.9	2132	NE	17.9	30.0
1912	NNW	49.0	59.9				
1917	NNW	24.1	59.9				
1922	NNW	20.3	37.5				
1927	N	22.1	34.2				
1932	N	29.5	46.0				
1937	NNW	26.4	46.0				
1942	NW	21.7	37.1				
1947	NNW	18.1	30.0				
1952	NNW	23.0	31.1				
1957	N	25.5	42.2				
2002	N	23.9	42.2				
2007	N	19.4	34.2				

Tripp, SD



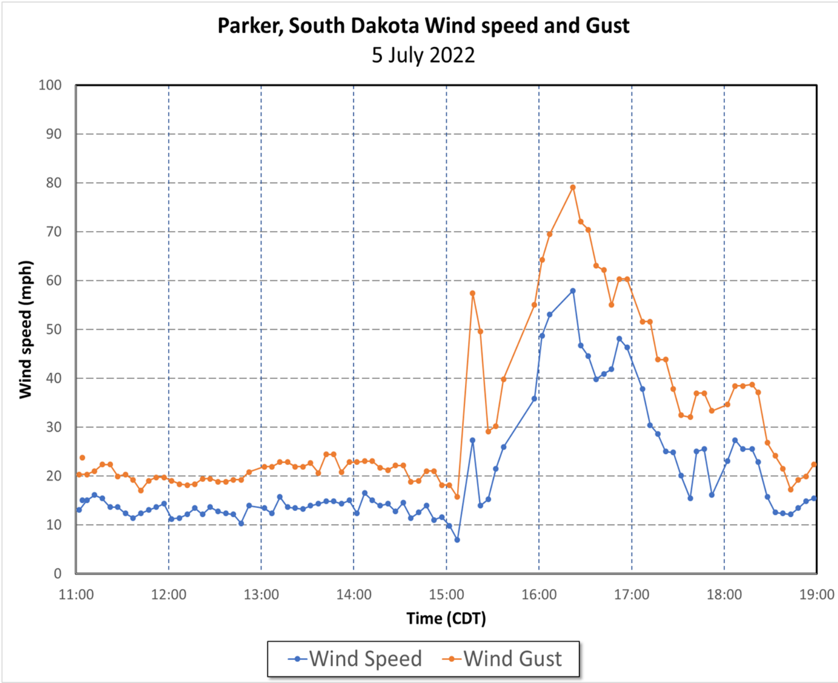
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1804	ESE	15.2	21.5	2020	NW	10.5	30.4
1809	ENE	12.3	21.5	2025	NNW	15.4	23.2
1814	ESE	13.4	19.4	2030	NNW	21.0	34.6
1820	E	13.2	22.8	2035	N	22.8	37.3
1825	ENE	14.3	20.1	2040	N	19.7	37.8
1829	ESE	13.2	20.1	2050	N	22.1	32.9
1834	ESE	13.4	19.9	2055	N	20.1	34.4
1840	E	13.9	22.6	2100	N	18.3	36.0
1845	SE	9.6	20.3	2105	N	14.3	36.0
1850	E	13.9	19.4	2110	N	16.8	36.0
1855	ENE	9.8	19.4	2120	N	16.8	26.8
1400	ESE	9.6	17.7	2125	N	14.5	27.3
1905	ESE	8.7	15.7	2130	N	10.5	22.6
1910	E	7.2	15.0				
1915	E	6.0	15.0				
1920	ENE	3.1	13.0				
1925	NE	4.2	9.6				
1930	NNW	23.0	58.8				
1935	NW	36.4	58.8				
1940	NW	33.8	53.9				
1945	NNW	21.0	50.7				
1950	N	12.5	36.7				
1955	NNW	26.6	36.8				
2000	NW	22.1	36.8				
2005	NW	27.5	36.2				
2010	NW	26.2	39.8				

Freeman, SD



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	16.5	24.4	2018	NNW	17.4	35.8
1807	E	20.8	25.5	2022	NNW	17.2	28.6
1812	ESE	16.1	25.5	2028	NW	18.8	32.0
1817	E	16.3	25.3	2033	NW	17.7	35.5
1822	E	17.4	24.8	2038	NNW	37.1	49.0
1827	E	15.9	26.4	2048	NNW	35.1	50.5
1832	E	14.8	26.4	2053	NNW	40.2	55.4
1837	ESE	17.0	25.0	2058	NNW	34.9	55.4
1842	ESE	13.6	25.0	2103	NNW	36.2	53.0
1847	E	15.2	23.0	2108	N	37.3	53.0
1852	ESE	14.5	22.8	2118	N	33.1	44.9
1857	E	17.9	23.7	2123	N	34.4	51.0
1902	ESE	14.1	23.7	2128	N	34.9	51.0
1907	ESE	15.0	22.3	2133	N	38.2	54.1
1912	ESE	14.3	24.8				
1917	ESE	11.4	24.8				
1922	SE	15.0	19.2				
1927	ESE	10.3	19.2				
1932	ESE	8.5	17.2				
1937	SE	8.5	17.2				
1942	ESE	7.4	15.2				
1947	ESE	8.0	13.0				
1952	SW	9.4	13.6				
1957	WNW	40.0	56.8				
2002	NW	38.0	56.8				
2007	NW	23.5	51.4				

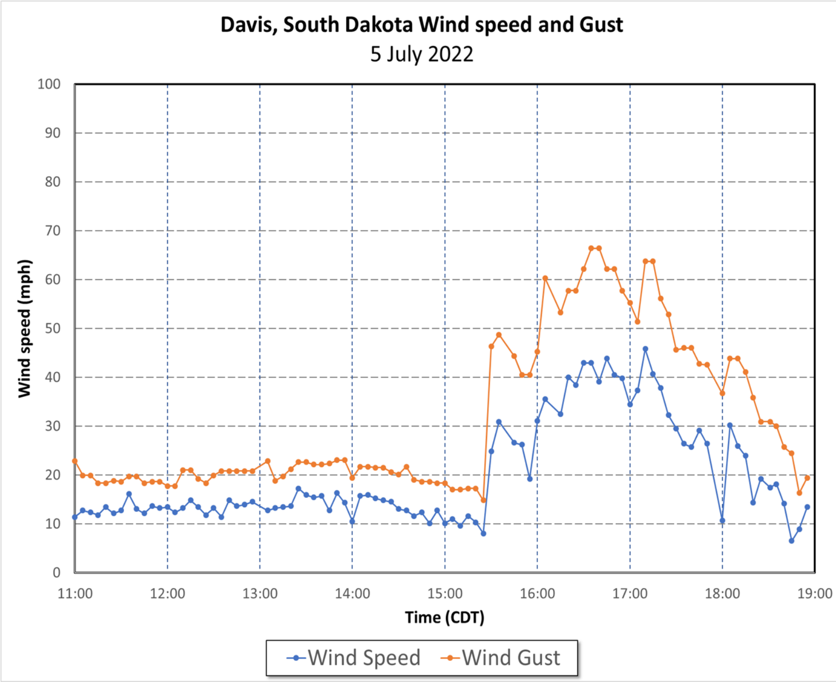
Parker, SD



★

Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	13.4	21.9	2017	WNW	27.3	57.4
1807	ESE	12.3	21.9	2022	NW	13.9	49.6
1812	ESE	15.7	22.8	2027	WNW	15.2	29.1
1817	ESE	13.6	22.8	2032	WNW	21.5	30.2
1822	ESE	13.4	21.9	2037	WNW	25.9	39.8
1827	E	13.2	21.9	2057	NNW	35.8	55.0
1832	ESE	13.9	22.6	2102	NNW	48.7	64.2
1837	ESE	14.3	20.6	2107	NNW	23.0	69.5
1842	ESE	14.8	24.4	2122	N	57.9	79.1
1847	ESE	14.8	24.4	2127	N	46.7	72.0
1852	E	14.3	20.8	2132	N	44.5	70.4
1857	E	15.0	22.8				
1902	ESE	12.3	22.8				
1907	ESE	16.5	23.0				
1912	ESE	15.0	23.0				
1917	ESE	13.9	21.7				
1922	ESE	14.3	21.2				
1927	ESE	12.7	22.1				
1932	ESE	14.5	22.1				
1937	ESE	11.4	18.8				
1942	ESE	12.5	19.0				
1947	ESE	13.9	21.0				
1952	ESE	11.0	21.0				
1957	ESE	11.6	18.1				
2002	SE	9.8	18.1				
2007	SSE	6.9	15.7				

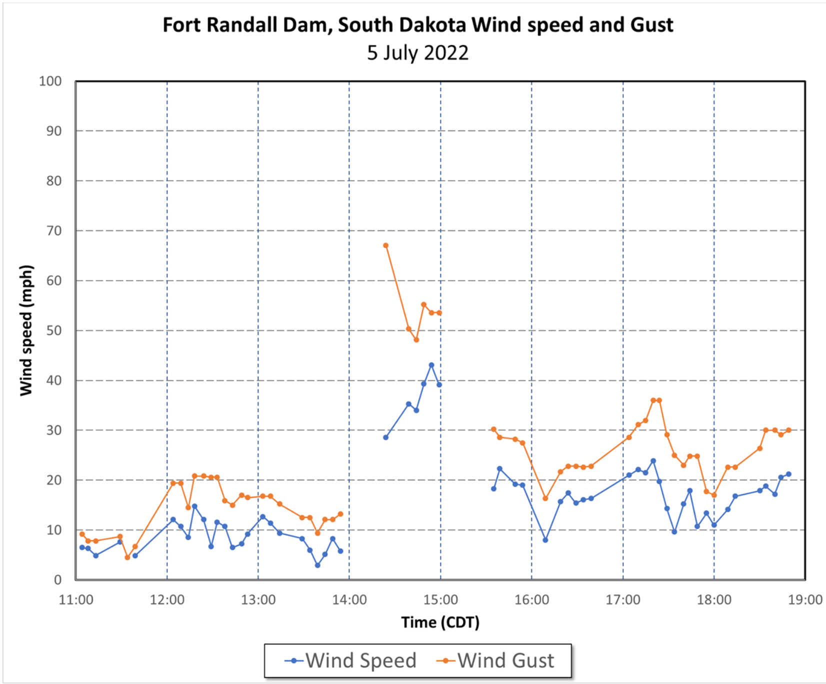
Davis, SD



★

Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1805	ESE	12.7	22.8	2015	SSE	11.6	17.2
1810	E	13.2	18.8	2020	S	10.3	17.2
1815	E	13.4	19.7	2025	S	8.0	14.8
1820	ESE	13.6	21.2	2030	WNW	24.8	46.3
1825	ESE	17.2	22.6	2035	NW	30.9	48.7
1830	E	15.9	22.6	2045	NW	26.6	44.3
1835	ESE	15.4	22.1	2050	NW	26.2	40.5
1840	ESE	15.7	22.1	2055	NW	19.2	40.5
1845	ESE	12.7	22.3	2100	NW	31.1	45.2
1850	ESE	16.3	23.0	2105	NW	35.5	60.3
1855	E	14.3	23.0	2115	NNW	32.4	53.2
1900	ESE	10.5	19.4	2120	NNW	40.0	57.7
1905	ESE	15.7	21.7	2125	NNW	38.4	57.7
1910	ESE	15.9	21.7	2130	N	42.9	62.1
1915	SE	15.2	21.5				
1920	SE	14.8	21.5				
1925	ESE	14.5	20.6				
1930	ESE	13.0	20.1				
1935	ESE	12.7	21.7				
1940	SE	11.6	19.0				
1945	SE	12.3	18.6				
1950	SE	10.1	18.6				
1955	SE	12.7	18.3				
2000	SE	10.1	18.3				
2005	SE	11.0	17.0				
2010	SSE	9.6	17.0				

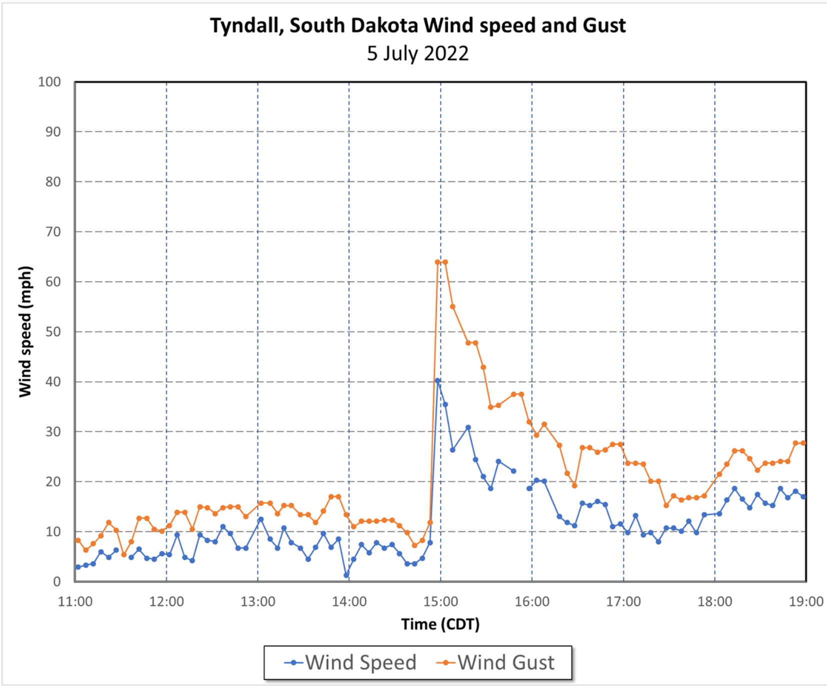
Fort Randall Dam, SD



★

Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1803	ESE	12.7	16.8				
1808	ESE	11.4	16.8				
1814	E	9.4	15.2				
1829	E	8.3	12.5				
1834	E	6.0	12.5				
1839	ESE	2.9	9.4				
1844	ESE	5.1	12.1				
1849	ENE	8.3	12.1				
1854	SE	5.8	13.2				
1924	NW	28.6	67.1				
1936	NNW	35.3	50.3				
1944	N	34.0	48.1				
1949	N	39.3	55.2				
1954	N	43.1	53.6				
1959	N	39.1	53.6				
2035	NNE	18.3	30.2				
2039	NNE	22.3	28.6				
2049	NNE	19.2	28.2				
2054	NNE	19.0	27.5				
2109	ESE	8.0	16.3				
2119	E	15.7	21.7				
2124	NE	17.4	22.8				
2129	NNE	15.4	22.8				

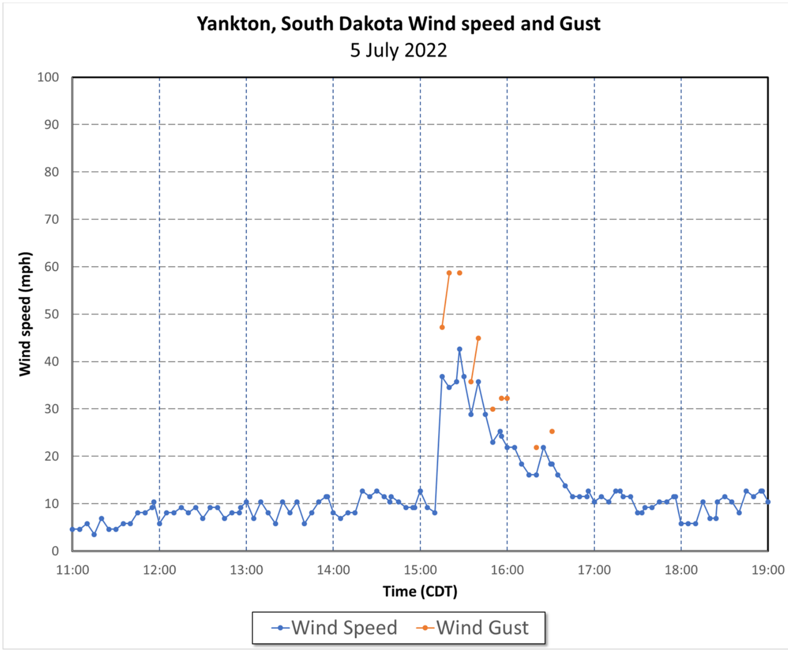
Tyndall, SD



★

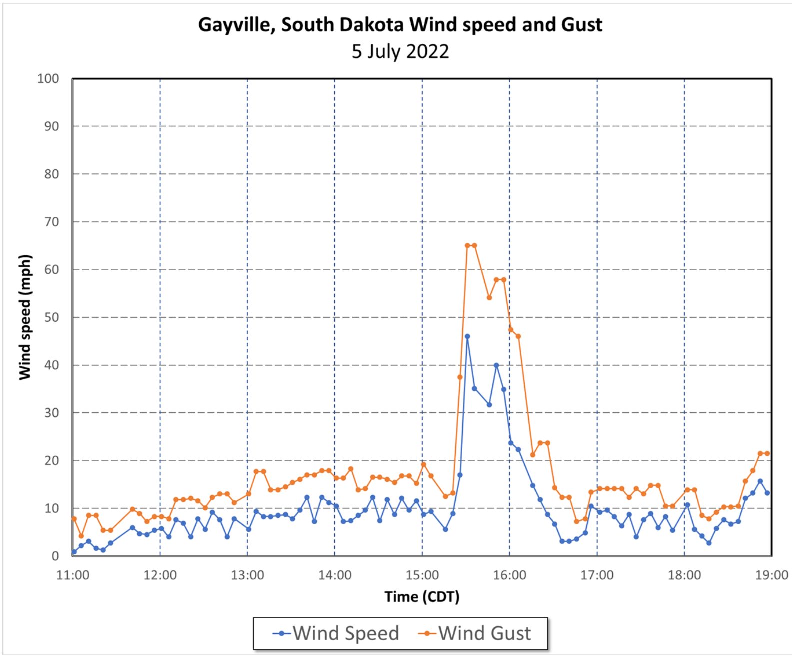
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1802	E	12.5	15.7	2018	NW	30.9	47.8
1808	E	8.5	15.7	2023	NNW	24.4	47.8
1813	E	6.7	13.6	2028	NNW	21.0	42.9
1817	ESE	10.7	15.2	2033	NNW	18.6	34.9
1822	E	7.8	15.2	2038	NNW	24.1	35.3
1828	E	6.7	13.4	2048	NNW	22.1	37.5
1833	ESE	4.5	13.4	2053	NNW	M	37.5
1838	ESE	6.9	11.8	2058	NNW	18.6	32.0
1843	ESE	9.6	14.1	2103	NNW	20.3	29.3
1848	SE	6.9	17.0	2108	NNW	20.1	34.5
1853	E	8.5	17.0	2118	NNW	13.0	27.3
1858	NNE	1.3	13.4	2123	NW	11.8	21.7
1903	ENE	4.5	11.0	2128	N	11.2	19.2
1908	SE	7.4	12.1	2133	NNW	15.7	26.8
1913	SSE	5.8	12.1				
1918	S	7.8	12.1				
1923	S	6.7	12.3				
1928	S	7.4	12.3				
1933	S	5.6	11.2				
1938	SW	3.6	9.8				
1943	WSW	3.6	7.2				
1948	W	4.7	8.3				
1953	WNW	7.8	11.8				
1958	NNW	40.2	63.9				
2003	NW	35.5	63.9				
2008	NNW	26.4	55.0				

Yankton, SD



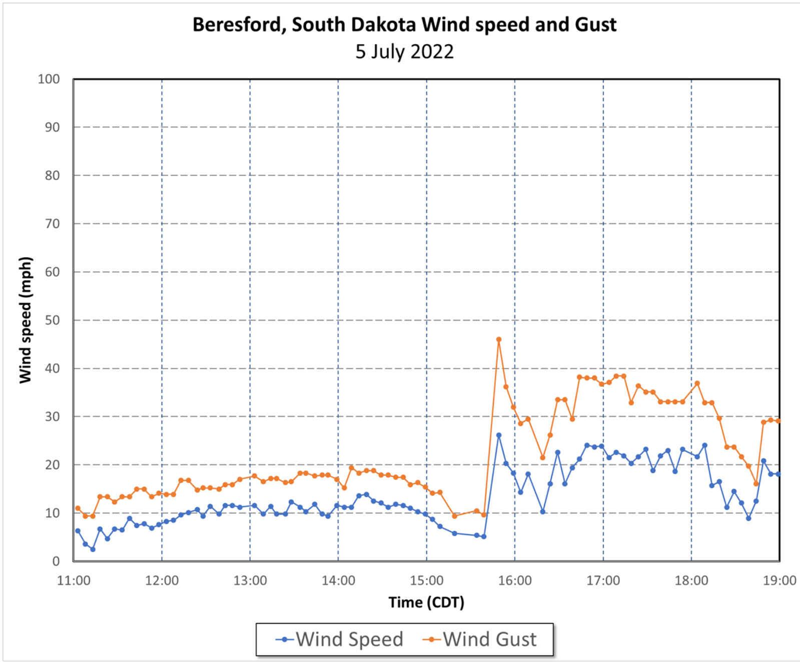
Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1800	ESE	10.4		1956	S	9.2	
1805	ESE	6.9		2000	S	12.7	
1810	ENE	10.4		2005	SSE	9.2	
1815	E	8.1		2010	S	8.1	
1820	SE	5.8		2015	WNW	36.8	47.2
1825	ESE	10.4		2020	NW	34.5	58.7
1830	SSE	8.1		2025	NNW	35.7	
1835	ESE	10.4		2027	NNW	42.6	58.7
1840	SE	5.8		2030	NNW	36.8	
1845	ESE	8.1		2035	NNW	28.8	35.7
1850	E	10.4		2040	NNW	35.7	44.9
1855	ESE	11.5		2045	NNW	28.8	
1856	ESE	11.5		2050	NNW	23.0	29.9
1900	E	8.1		2055	NNW	25.3	
1905	E	6.9		2056	NNW	24.2	32.2
1910	ENE	8.1		2100	NNW	21.9	32.2
1915	SE	8.1		2105	NW	21.9	
1920	E	12.7		2110	NW	18.4	
1925	ESE	11.5		2115	NW	16.1	
1930	SE	12.7		2120	NW	16.1	21.9
1935	S	11.5		2125	NNW	21.9	
1939	S	10.4		2130	NNW	18.4	
1940	S	11.5					
1945	S	10.4					
1950	S	9.2					
1955	S	9.2					

Gayville, SD



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1801	ENE	5.6	13.0	2016	SSE	5.6	12.5
1806	ESE	9.4	17.7	2021	SSE	8.9	13.2
1811	ESE	8.3	17.7	2026	SW	17.0	37.5
1816	E	8.3	13.9	2031	NW	46.0	65.0
1821	E	8.5	13.9	2036	NW	35.1	65.0
1826	E	8.7	14.5	2046	NW	31.7	54.1
1831	ESE	7.8	15.4	2051	NW	40.0	57.9
1836	E	9.6	16.1	2056	NNW	34.9	57.9
1841	ESE	12.3	17.0	2101	NNW	23.7	47.4
1846	ESE	7.2	17.0	2106	NW	22.3	46.0
1851	E	12.3	17.9	2116	NW	14.8	21.2
1856	E	11.2	17.9	2121	WNW	11.8	23.7
1901	E	10.5	16.3	2126	WNW	8.7	23.7
1906	ENE	7.2	16.3	2131	W	6.7	14.3
1911	E	7.4	18.3				
1916	ESE	8.5	13.9				
1921	E	9.6	14.1				
1926	E	12.3	16.5				
1931	E	7.4	16.5				
1936	SE	11.8	16.4				
1941	SE	8.7	15.4				
1946	SSE	12.1	16.8				
1951	SSE	9.6	16.8				
1956	SE	11.6	15.2				
2001	SE	8.7	19.2				
2006	SE	9.4	16.8				

Beresford, SD



Time (UTC)	Wind Direction	Wind Speed	Wind Gust	Time (UTC)	Wind Direction	Wind Speed	Wind Gust
1803	ESE	11.6	17.7	2019	SE	5.8	9.4
1809	E	9.8	16.5	2034	S	5.4	10.5
1814	ESE	11.4	17.2	2039	WSW	5.1	9.6
1818	E	9.8	17.2	2049	WNW	26.2	46.0
1824	ESE	9.8	16.3	2054	NW	20.3	36.2
1828	ESE	12.3	16.5	2059	WNW	18.3	32.0
1834	E	11.2	18.3	2104	WNW	14.3	28.6
1838	ESE	10.3	18.3	2109	NW	18.1	29.5
1844	ESE	11.8	17.7	2119	NW	10.3	21.5
1849	ESE	9.8	17.9	2124	NW	16.1	26.2
1853	ESE	9.4	17.9	2129	NW	22.6	33.5
1859	ESE	11.6	17.0	2134	WNW	16.1	33.5
1904	ESE	11.2	15.2				
1909	ESE	11.2	19.4				
1914	ESE	13.6	18.3				
1919	SE	13.9	18.8				
1924	ESE	12.5	18.8				
1929	ESE	12.1	17.9				
1934	SE	11.2	17.9				
1939	SE	11.8	17.4				
1944	ESE	11.6	17.4				
1949	ESE	11.0	15.9				
1954	ESE	10.3	16.3				
1959	ESE	9.8	15.4				
2004	ESE	8.7	14.1				
2009	ESE	7.2	14.3				