An Observational Study of a Cyclic Tornadic Storm in South Dakota on 18 June 2014

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Event Overview

- Third consecutive day of severe weather and significant tornadoes across the Great Plains (Pilger 6/16, Coleridge 6/17)
- Localized conditions became very favorable for tornadoes across central South Dakota by the afternoon of the 18th, with over a dozen tornadoes documented in the state between 2300 to 0130 UTC – several of these tornadoes were visually large and intense; fortunately many remained over open fields
- The most prolific tornado-producing storm exhibited several interesting traits worthy of further examination. Specifically, the environment, storm mode and evolution, lightning activity, and its rapid cyclic mesocyclogenesis
- New operational radar advancements allowed for a higher temporal real-time analysis of the tornadic storm, but also yielded a couple new challenges

Acknowledgements:
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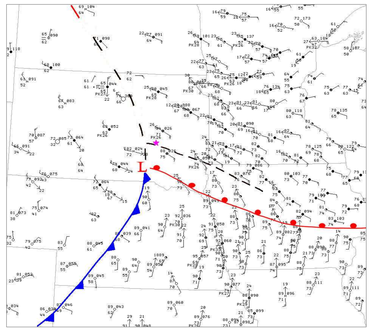
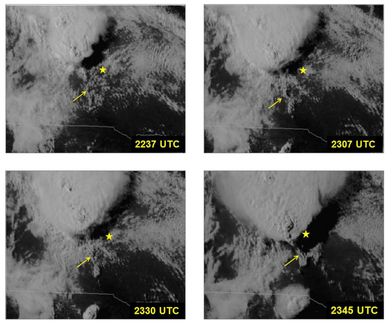
Mesoscale Environment

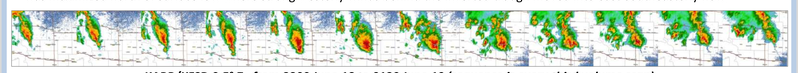


Surface analysis from 2300 UTC 18 June. Magenta star denotes the approximate location of Wessington Springs, SD.

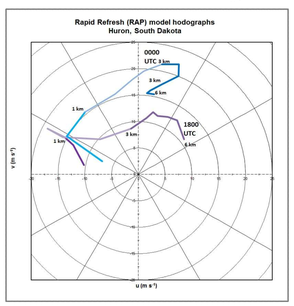


Visible satellite imagery. The yellow arrow highlights the approximate location where towering cumulus began to form. Approximate location of Wessington Springs, SD (yellow star).

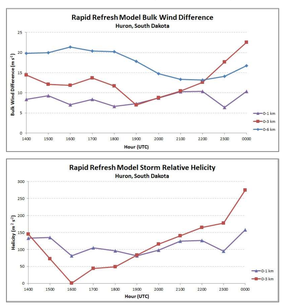
Pronounced capping inversion (700-mb temp 13-14°C; not shown) prohibited robust convective development south of the warm front. New convection developing north of the warm front had a mean storm motion at 190°. As they moved north, these cells crossed the east-to-west boundary. The developing storms would then merge with the ongoing convective cell to the north. Low-level convergence was maximized north of surface low where strong westerly winds behind the inverted trough moved into east-southeasterly flow.



KABR/KFSD 0.5° Z_H from 2300 June 18 to 0130 June 19 (sequence is every third volume scan)



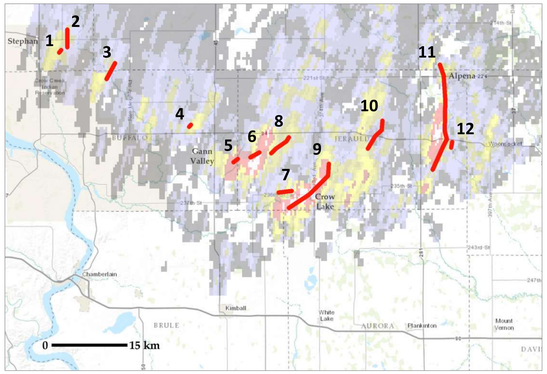
Hodograph taken from the 00 h analysis of the Rapid Refresh model for Huron, SD at 1800 UTC 18 June (purple) and 0000 UTC 19 June (blue). The observed wind was used at the surface.



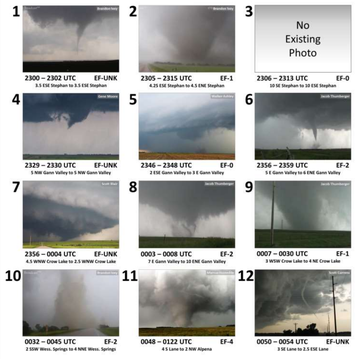
Time series of bulk wind difference (top) and storm relative helicity (bottom) from the Rapid Refresh model. The storm motion of Tornado #11, 180° at 11.8 m s^{-1}, was used to compute SRH.

The wind at 1 km and 3 km both veered and increased in strength during the afternoon resulting in an increase in 0-3 km Bulk Wind Difference and Storm Relative Helicity. At the same time, the 6 km wind backed resulting in a decrease in 0-6 km Bulk Wind Difference. The result is that the hodograph at 0000 UTC 19 June has most of the shear below 3 km.

Documented Tornadoes – 18 June 2014

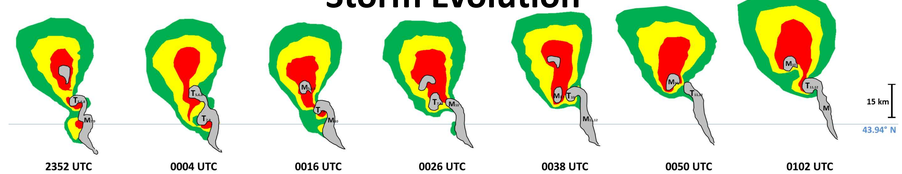


NSSL low-level (0-3 km AGL) rotation tracks (background image) and tornado paths (red)

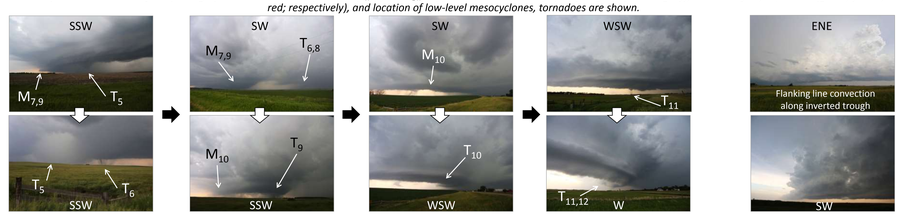


NSSL low-level (0-3 km AGL) rotation tracks (background image) and tornado paths (red)

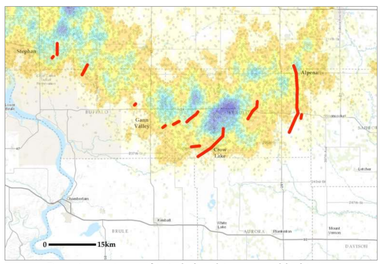
Storm Evolution



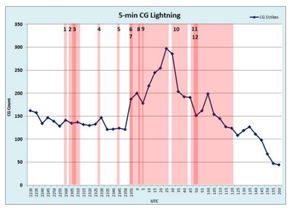
Conceptual model derived from photographs and radar-based products (Z_H, V, SW, Z_{DR}). Approximate locations of updraft regions (shaded gray), contours of 30, 40, 50 dBZ (green, yellow, red; respectively), and location of low-level mesocyclones, tornadoes are shown.



Cloud-to-Ground Lightning Characteristics



Density contour of total cloud-to-ground lightning flashes (+/-CG) during 2330 to 0200 UTC from NLDN

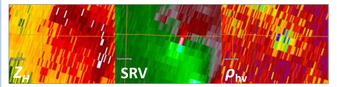


Five min lightning trend analysis examining the lightning/tornado relationship from 2330 to 0200 UTC. Lightning data (blue line) and tornado duration (red highlight) are depicted.

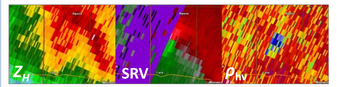
- **6972 total CG lightning flashes produced by storm** (2.7% positive polarities)
- **Maximum 68 flashes per minute; 297 flashes 5-minute maximum)**
- Substantial increase in lightning activity 2355-0100 UTC during most active period of mesocyclone and tornado development
- Event deviates from prior research (total CG lightning flash rate: local maximum prior to tornadogenesis, decrease with tornadogenesis, increase with tornado dissipation)

WSR-88D Signatures and Scanning Strategies

Tornado Debris Signature (TDS)



Tornado #8. KFSD 0.5° at 0010 UTC [178 km from RDA]



Tornado #11. KFSD 0.5° at 0107 UTC [146 km from RDA]

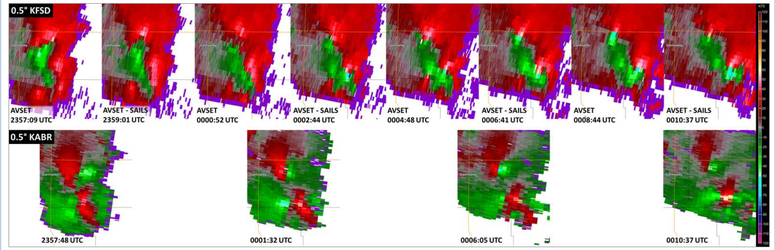
All tornadoes far from both RDAs (> 140 km); lofted debris had to reach > 2.3 km ARL to be sampled by the 0.5° elevation scan

Only 2 of 12 tornadoes had polarimetric TDS (EF2, EF4); 15 of 111 min of tornado time (13%) contained TDS during event

Potential factors contributing to the absence of TDSs during event

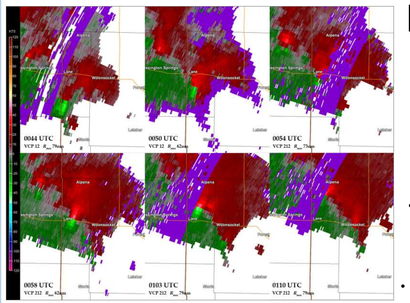
- General absence of damage targets (vegetation, engineered structures) in the area
- Short-lived TORs (≤ 5 min) in 50% of cases; limited temporal sampling may miss TDS
- Local max Z_H "debris ball" not observed with any TORs; Z_H often decreases w/ height
- Long radar distance results in broadening of beam; may be too large to resolve TDS
- Weak TORs may not loft debris to heights observable by the radar
- RFD surrounding TOR limits vertical debris transportation, reducing TDS height
- High precipitation entrainment around the TOR increases ρ_{hv} values

Automated Volume Scan Evaluation and Termination (AVSET) – Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS)



KFSD and KABR 0.5° storm relative velocity from 2357-0010 UTC over SW Jerauld County, SD

- AVSET terminates volume scan if notable returns are absent above 5°, shortening the elapsed time between data collection on low elevation angles. SAILS adds a new split cut low-level scan into the middle of the volume scan.
  - Greatly improves analysis of low-level data in real-time severe weather operations
  - **KFSD 6.4°/8.0° AVSET termination angle with SAILS enabled = 0.5° update times of ~113 s**

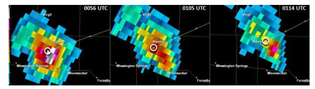


KFSD 0.5° storm relative velocity of tornado #11 from 0044-0110 UTC

Storm-Based Auto PRF

Tracks the 3 strongest storms (based on Cell-Based VIL from SCIT output) and assigns a PRF that results in the fewest range-obscured 1 km range bin for the 3 storms

Z_H data current volume scan → SCIT/VIL data previous volume scan = Determines best PRF next volume scan



- **Velocity data of EF4 tornado periodically RF, hindering real-time analysis** (storm identified Top 3 cell-based VILs)
- Small azimuth range (≤ 33°) of Top 3 storms during tornado; minimizing RF for all storms difficult to automatically determine
- Deviant track of occluding mesocyclone as parent storm moved east, yielding few RF bins within 20 km of the forecast storm centroid locations

Storm Summary

- Propagation of the storm was strongly influenced by a continuum of merging updrafts associated with the low-level convergence of the eastward moving inverted trough.
- Storm mode trended within the supercellular spectrum, yet featured an elongated/linear updraft orientation, similar to a LEWP structure at times.
- Rapid cyclic mesocyclogenesis (~20 min/per cycle) occurred during much of the event, with virtually all tornadoes originating from one of six well-defined low-level mesocyclones. Mesocyclogenesis was noted along the shear zone of the inverted trough and intersection of a W-E surface boundary, where developing updrafts merged into the ongoing convection.
- Tornadogenesis tended to occur as the low-level mesocyclone moved to the north or western-rear of a bulging updraft/gust front region, eventually updraft shedding during the occlusion process.