Toward the Long-range Prediction of Severe Convective Windstorms

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Objectives

• Present background and results of literature review pertaining to severe convective windstorm (SCW) structure and evolution.

• Identify potential signatures for (SCW) forecasting using satellite, radar, and NWP resources.

• Apply SCW signatures to case studies of recent significant events.

• The results of this study will serve as a basis for the development of a long-range SCW prediction technique.
Background

- Severe windstorms resulting from mesoscale convective systems (MCS) cause major disruption to society, including widespread power outages, tree and structural damage, and transportation accidents that affect multi-state regions and metropolitan areas along their track.

- A derecho is defined as a long-lived, widespread severe convective windstorm (SCW) composed of numerous downbursts (intense localized storm downdrafts) that are organized into clusters and/or families of clusters (Fujita and Wakimoto 1981; Johns and Hirt 1987).
Background

- A convective downburst is the nucleus, or fundamental element, of a severe convective windstorm. Typically, SCWs are associated with deep, moist convective storms in which dry mid-tropospheric air interacts with elevated cores of heavy precipitation.

- Past studies of significant derecho events have employed Geostationary Operational Environmental Satellites (GOES), Doppler radar reflectivity and velocity imagery, and mesoscale numerical weather prediction model output to demonstrate the development and evolution of derecho-generated winds.
Fujita and Wakimoto Damaging Winds Scale

- Family of downburst clusters (derecho)
  - 1000 km (620 mi)
- Downburst cluster
  - 100 km (62 mi)
- Downburst
  - 10 km (6.2 mi)
- Microburst
  - 1 km (0.62 mi)

From Fujita and Wakimoto (1981)
Convective Downburst Process

- Upon initiation of the storm downdraft by precipitation loading, lateral entrainment and channeling of drier mid-tropospheric air into the precipitation core often results in the following downburst process:
  - 1) sublimation and evaporation,
  - 2) cooling of the volume of precipitation-filled air,
  - 3) generation of negative buoyancy, and
  - 4) resultant acceleration of the downdraft.

- Melting of graupel and hail add an additional source of negative buoyancy.

- When the intense downdraft impinges on the surface, downward vertical momentum is converted to horizontal momentum, resulting in strong outflow winds.
Bow Echo/Derecho Conceptual Models

From Fujita (1978)

From Johns and Hirt (1987)
Squall Line Conceptual Model

From Smull and Houze (1987)
Candidate SCW Predictors

• Upper and lower-tropospheric vertical velocity (VV) and the vertical velocity difference (∆VV) between these fields:
  – Found to correspond to the presence of elevated rearward ascending flow and the presence of a cold pool, respectively.

• Theta-e advection (V · ∇θ_e):
  – Shows effectiveness as a prognostic parameter for SCW generation based on the premise that mid-tropospheric negative theta-e advection, where cooler and drier air aloft is being transported into an MCS environment and is interacting with the trailing stratiform precipitation and leading convective storms, serves as a major forcing mechanism for intense downdrafts.

• Incorporated into a numerical weather prediction (NWP) model or a satellite hyperspectral sounder profile, the combined use of these parameters could serve to indicate the presence of a mature convective system with a rear inflow jet that has the potential to generate widespread severe winds.
Vertical Velocity Difference ($\Delta VV$)

RAP model-derived 850-300-mb vertical velocity difference with overlying radar reflectivity at 2000 UTC 17 November 2013

Vertical velocity profile in maximum difference region over northeastern Illinois
GOES-East Imager Product

- Enhanced band 3 – 4 BTD image showing well-defined dry air notches.

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\text{WV BT} - \text{IR BT} = \text{BTD}
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http://www.star.nesdis.noaa.gov/smcd/opdb/kpryor/mburst/mbimg.html
Theta-e advection ($\mathbf{V} \cdot \nabla \theta_e$)

Great Lakes regional WV-IR BTD image
1945 UTC 17 November 2013

Rapid Refresh (RAP) model-derived 500-mb ($\mathbf{V} \cdot \nabla \theta_e$) at 2000 UTC (bottom) 17 November 2013
Case 1: The June 2012 North American Derecho

• During the morning of 29 June 2012, an area of convective storms over Iowa organized into a quasi-linear convective system (QLCS) as it tracked into northern Illinois. The system then evolved into a bow echo (Fujita 1978; Przybylinski 1995) during the afternoon and tracked southeastward over the Ohio Valley to the Mid-Atlantic coast by late evening.

• What would eventually become the 29 June 2012 “North American” Derecho, this QLCS produced its first significant severe downburst, with winds measured over 65 knots, at Michigan City, Indiana during the early afternoon.
Case 1: The June 2012 North American Derecho

- This extraordinary derecho-producing convective system (DCS) event resulted in 22 deaths and nearly a thousand severe wind reports from northern Illinois to the Atlantic Coast.

- This system was more typical of a warm-season progressive derecho, associated with a major heat wave and an elevated mixed layer (EML) (Banacos and Ekster 2010, Corfidi et al. 2014).
RAP model sounding profiles echo the favorable environment for severe downbursts with very large convective available potential energy (CAPE) and a prominent EML between the 500 and 700-mb levels.
June 2012 Derecho Overview

Expansive

Affected millions of people

Broke many records for highest winds

Left five million without power

Traveled 700 miles in 12 hours

Photo: NASA
Derecho Initiation
Derecho Initiation
Derecho Initiation
Derecho Initiation

- Ascending front-rear flow
- Cold pool
- Leading convective storm line
Derecho Initiation

- Ascending front-rear flow
- Heavy stratiform precipitation
- Leading convective storm line
- Cold pool
Theta-e Advection
Theta-e Advection
June 2012 Derecho: Mature Phase
Mature Phase: VV Difference
Mature Phase: VV Difference
Mature Phase: VV Difference
Mature Phase: Theta-e Advection
Mature Phase: Theta-e Advection
Case 2: 17-18 November 2013 Midwest-Ohio Valley Squall Line

- During the morning of 17 November 2013, an area of thunderstorms organized into a squall line over Illinois ahead of an intense upper-level disturbance and strong cold front.
- The squall line tracked rapidly eastward at an average speed of 40 knots through the lower Great Lakes and Ohio Valley during the afternoon and evening.
- More typical of a cool-season severe MCS.
This squall line produced nearly 100 tornado and over 400 severe wind reports.

Great Lakes Environmental Research Lab (GLERL) observing stations recorded on southern Lake Michigan recorded downburst wind gusts in excess of 65 knots with the passage of the squall line between 1300 and 1500 EST on 17 November.

PORTS station on the Baltimore Key Bridge recorded a wind gust of 62 knots near 0230 EST 18 November.
GOES-13 17 November
Mature Phase: VV Difference
Mature Phase: VV Difference
Mature Phase: Theta-e Advection
Mature Phase: Theta-e Advection
Discussion

• For both cases, SCW occurrence was associated with the development of a distinct upper tropospheric upward/lower tropospheric downward vertical velocity couplets to the rear of leading convective storm lines of the mature MCSs.

• Regions of significant mid-tropospheric negative theta-e advection on the rear flanks of MCSs signified the presence of a strong RIJ and channeling of mid-tropospheric dry (low theta-e) air into the stratiform precipitation region and leading convective storm line.
Discussion

• Ascending front-rear flow overlying strong, deep cold pools rearward of the leading convective storm lines:
  – induces the development of horizontal vorticity cells on the storm’s rear flank that channel drier mid-tropospheric air forward toward leading edge of the MCS.
  – results in the development of an elevated RIJ that interacts with the leading line storms of the MCS to produce widespread downburst activity.

• Highest wind gusts were associated either with embedded supercell storms, or the apex of bow echoes where rear inflow was strongest.
Future Work

• Further observational data analysis in which temporal and spatial patterns, both horizontal and vertical, of NWP model-simulated VV and theta-e advection fields will be compared to patterns of satellite and radar observed severe wind-producing convective storm systems.

• Historical simulation of 30-km resolution Climate Weather Research and Forecasting (CWRF) model (Liang et al. 2012) data in comparison with 32-km North American Regional Reanalysis (NARR) and 13-km Rapid Refresh (RAP) model data will be conducted to infer any signals of SCW occurrence.
Future Work

• A relationship between VV and theta-e advection magnitudes and SCW occurrence can be applied to high-resolution geostationary satellite imager and sounder profile data, as well as to the CWRF model for the purpose of long range prediction. This step can be accomplished as a weather-scale run for each selected SCW case, where numerical instability occurrence in the CWRF model could serve as an additional signal.
Conclusions

- The lower-upper tropospheric vertical velocity difference and mid-tropospheric theta-e advection have been found to effectively indicate the favorability of an MCS to evolve into a SCW.

- The combined use of $\Delta VV$ and $\mathbf{V} \cdot \nabla \theta_e$ parameters, and GOES WV-IR BTD imagery shows potential as a short term SCW prediction technique, while incorporation into the CWRF model should improve long-range prediction of SCW development.
References


References


