Quasi-Stationary Convective Systems Forming Perpendicular to, and Above the Cold Pools of, Strong Bow Echoes

Kelly M. Keene and Russ S. Schumacher

Department of Atmospheric Sciences, Texas A&M University, College Station, TX

Introduction

◆ **Corfidi (2003) examined cold-pool-induced convection behind bow echoes, and showed that the convection typically forms along the periphery of the outflow boundary.**

◆ **This study looks at a circumstance in which back-building convection forms perpendicular to, and above the cold pool region of, strong bow echoes (i.e. not along the outflow boundary).**

◆ **We refer to this phenomenon as a "bow and arrow" because, on radar imagery, the two convective lines resemble an archer's bow and arrow.**

◆ **Cases were found using Hovmoller diagrams and archived radar observation**

◆ **A total of 10 cases have been found, but only 3 are being used for this study.**

◆ **15 September 2010 Case:**
- Used NCEP's NAM analyses as initial and boundary conditions
- Created simulations using the Advanced Research version of the Weather Research and Forecasting (WRF) model, version 3.2
- Nested grids with horizontal grid spacing of 27 km, 9 km, and 3 km

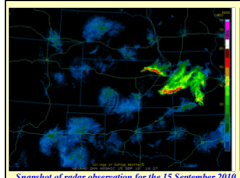
◆ **8 May 2009 and 18 June 2006 Cases:**
- Used NCAR's real-time high-resolution forecast data
- Horizontal grid spacing: 3 km (8 May 2009) and 4 km (18 June 2006)

◆ **All 3 Cases:** Used the Read/Interpolate/Plot (RIP) program to display and analyze results

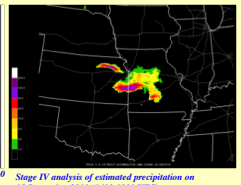
◆ **Simulations of several cases are analyzed in an attempt to identify common environmental conditions prior to the development of the back-building convection, in addition to understanding the mechanisms responsible for initiating and maintaining the convective line.**

Why is This Important?

- To get an accurate forecast, a numerical model needs to correctly predict multiple environmental conditions and resulting convective processes that take place before and throughout the duration of the Bow and Arrow phenomenon.
- The "arrow" is usually an area of strong convection that is capable of creating a vast amount of additional precipitation to an area, after the area most likely already received a decent amount from the bow region that passed over in the recent past.
- In addition to heavy precipitation and flooding, the arrow is capable of producing severe winds and hail.

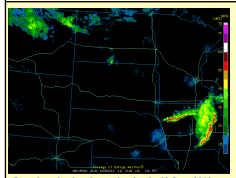


Snapshot of radar observation for the 15 September 2010 case (1827 UTC).

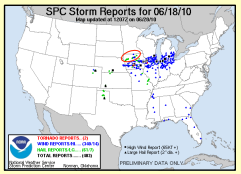


Stage IV analysis of estimated precipitation on 15 September 2010 (1600-1900 UTC)

- The arrow produces up to 50 mm of precipitation in a 3 hour time period.



Snapshot of radar observation for the 18 June 2010 case (1657 UTC).

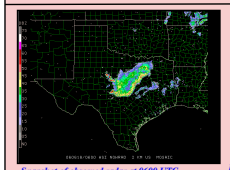


Storm Prediction Center Storm Reports from 18 June 2010, DOC/NOAA/SPC

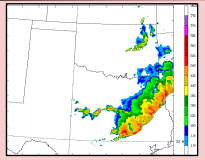
- A convective arrow formed behind this bow echo on 18 June 2010, resulting in 9 hail reports in northwestern Iowa, at the same time the arrow was over that region. Reports estimated golf-ball-sized hail, causing damage to trees and roofs.

Results

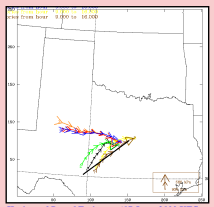
18 June 2006



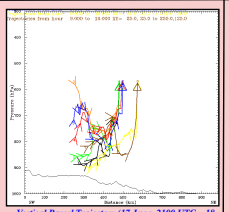
Snapshot of observed radar at 0600 UTC



Radar image created, using the WRF model output, for 0400 UTC

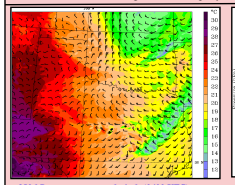


Horizontal Parcel Trajectory (17 June, 2100 UTC – 18 June, 0400 UTC). Straight black line is cross-section for theta plot (below)

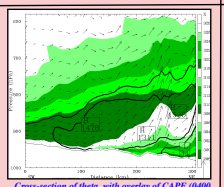


Vertical Parcel Trajectory (17 June, 2100 UTC – 18 June, 0400 UTC)

- A 575 hPa vertical motion plot is used to locate areas of greatest updraft within the arrow, then backward trajectory plots are created to show the air parcels' horizontal and vertical motion over the indicated 7-hour time period.
- Parcels originate out of both the southwest, and the west-northwest before rising in the "arrow" updrafts.
- Parcels fluctuate with height and then rapidly rise in the last hours.



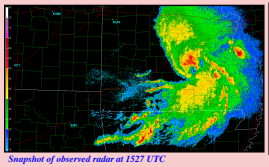
850 hPa temperature and winds (0400 UTC) Bullets indicate exact locations of updraft



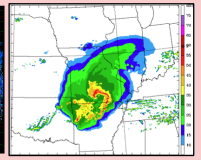
Cross-section of theta, with overlay of CAPE (0400 UTC)

- Convergence of south-southwesterly & north-northwesterly winds in the area where the arrow forms.
- Gradual isentropic lifting just above the surface, then strong vertical motion as air approaches the near-surface cold pool.
- Evidence of surface-based CAPE for air approaching from the southwest.

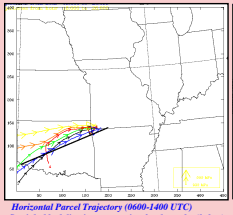
8 May 2009



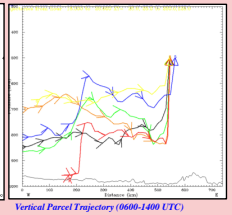
Snapshot of observed radar at 1527 UTC



Radar image created, using the WRF model output, for 1400 UTC

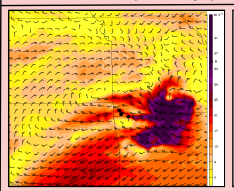


Horizontal Parcel Trajectory (0600-1400 UTC) Straight black line is cross-section for theta plot (below)

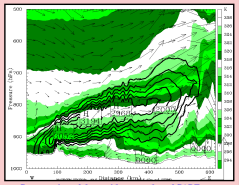


Vertical Parcel Trajectory (0600-1400 UTC)

- Same process used, as with the 18 June 2006 case, but the 500 hPa level is chosen because this level showed the strongest updrafts
- Parcels originate out of the west, southwest, and south
- Parcels fluctuate vertically, then rise rapidly in the last hours



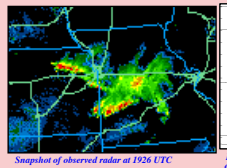
850 hPa isotachs (1400 UTC)



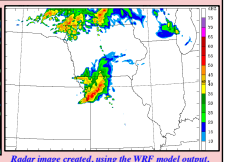
Cross section of theta with an overlay of CAPE (1400 UTC)

- Convergence of winds out of the southwest & west,
- Evidence of a strong Low-Level Jet.
- Slower wind speeds on either side of the arrow region, causing horizontal speed shear, & possibly the orientation of the arrow.
- Gradual isentropic lifting, and then a sharp lift in the area of strong updraft (shown in the vertical trajectory above).
- No CAPE for surface-based parcels, but a great amount of instability (>3000 J/kg) for elevated parcels (where the lifting begins).

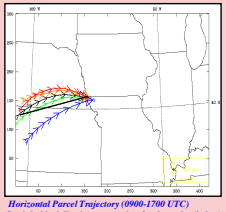
15 September 2010



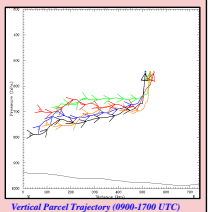
Snapshot of observed radar at 1926 UTC



Radar image created, using the WRF model output, for 1700 UTC

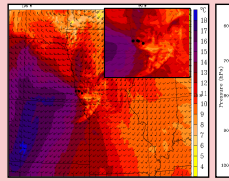


Horizontal Parcel Trajectory (0900-1700 UTC) Straight black line is cross-section for theta plot (below)

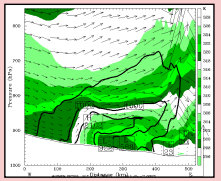


Vertical Parcel Trajectory (0900-1700 UTC)

- Same process used, as with the 18 June 2006 case, but the 550 hPa level is chosen because this level showed the strongest updrafts
- Parcels all originate out of the southwest.
- Parcels gradually rise between 800 hPa and 700 hPa, and rapidly rise near the 700 hPa level.



700 hPa temperature and winds (1700 UTC) (Top right): magnified plot of area of interest Bullets indicate exact locations of updraft



Cross-Section of theta with an overlay of CAPE (1700 UTC)

- Strong convergence of winds out of the southwest & northwest along the arrow region.
- Strong warm air advection across the region, into the region where the arrow is formed.
- Air gradually moves vertically upward above the cold pool, & then enters a sharp updraft when it approaches a region of stronger isentropic lifting.
- Surface stabilization within the cold pool, while elevated instability remains.

Conclusions

◆ Some common environmental characteristics of the bow and arrow phenomenon include:

- **Convergence of winds from the south-southwest and the north-northeast in the location of the arrow**
- **Horizontal speed shear along the arrow, which may explain its orientation perpendicular to the bow**
- **South-southwesterly flow inducing gradual isentropic lifting in unstable environments, then strong, forced updrafts**
- **Enhancement of wind speed in the arrow region due to rear-inflow into the bow echo**

◆ It seems as though, when all of the above characteristics are in place, after the passage of a strong bow echo, there is a greater chance of convection to form behind the bow echo, and above the cold pool region. Additionally, the horizontal wind shear could lead to the linear orientation of the arrow. There are still several things that are not well-understood; for instance, the cause of the sharp isentropic lift just below the strong updraft. This, along with many other questionable aspects of this project will be examined in the future, with hope for a greater understanding of the cause of this phenomenon.

Future Work

- Create images with greater temporal resolution to analyze plots between the hours
- Use ensemble runs to determine differences in model initial conditions between model runs that detect the bow and arrow, and those that do not
- Attempt to determine the exact cause(s) for the updrafts in the arrow region, possibly using idealized simulations
- Compare bow and arrow cases with cases that only create the bow echo, without the arrow, to determine environmental differences

- ***This material is based upon work supported by the National Science Foundation under Grant No. AGS-0954908.***
- ***Computing resources were provided by the National Center for Atmospheric Research, and a special thanks to Morris Weisman and Clark Evans for providing forecast data.***