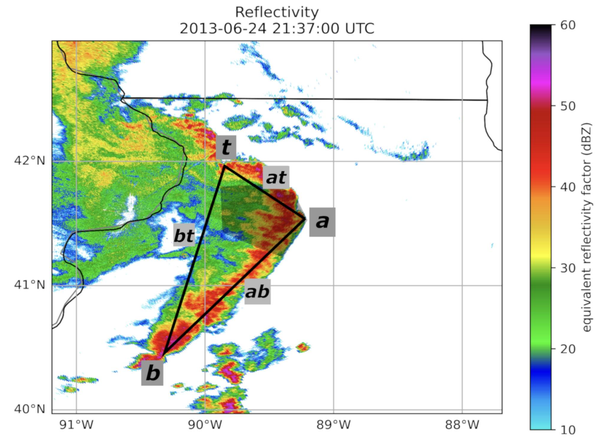
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Bow Echo Formation Mechanisms: An Analysis of 293 Events

Background

- Bow echoes can cause destructive winds, posing significant threats to communities.
- The mechanisms driving their formation remain poorly understood, reducing forecast skill.
- Formation mechanisms were compared among diurnal and nocturnal bows
- Bow echo apex curvature was calculated and compared to wind severity.



Apex curvature was calculated using radar reflectivity data and Heron's formula.

Mechanisms

Surface Boundary Intersections:
- Frontal or outflow boundaries interact with storms to enhance vertical vorticity and influence dynamics.

Individual Cell Interactions:
- Convective cell mergers alter local environments, aiding in bow echo formation.

Line-Normal Inflow:
- Environmental inflow perpendicular to the storm line supports convection and bowing structures.

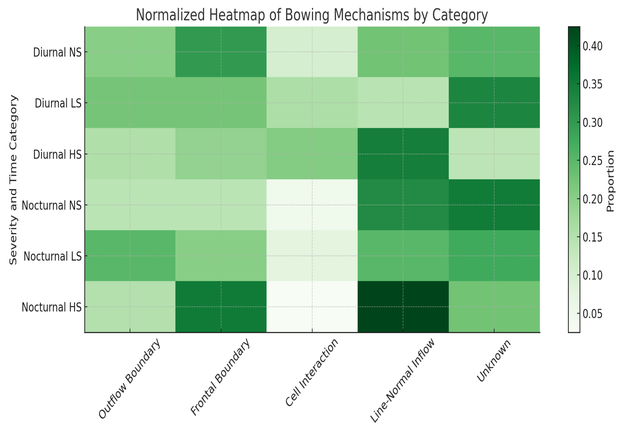
Unknown Mechanisms:
- Cases where mechanisms are not clearly identifiable suggest complex storm-scale processes.

Data Classification

Wind Level	Wind Speed (knots)	Number of Cases	$\frac{Diurnal}{Nocturnal}$
Non-Severe (NS)	<50	85	$\frac{40}{43}$
Low-Severe (LS)	50-65	125	$\frac{65}{40}$
High-Severe (HS)	>65	83	$\frac{58}{47}$

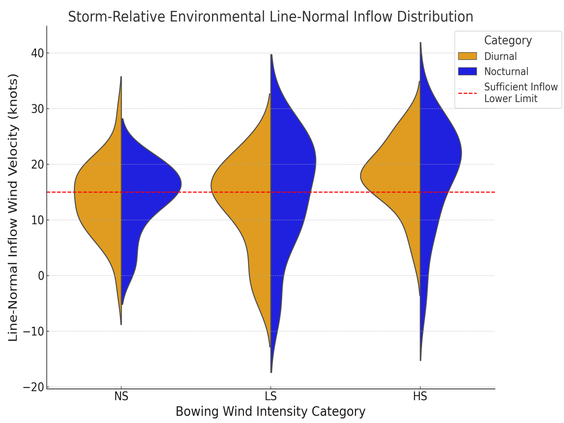
- Events analyzed from 2010 to 2018 during the warm season (April–August).
- Temporal categorization included:
  - 130 nocturnal events (2–11 UTC).
  - 163 diurnal events (14–00 UTC).
  - All events occurred east of the Rocky Mountains.

Mechanism Analysis



Proportions of bow echo formation mechanisms (outflow boundaries, fronts, cell interactions, line-normal storm-relative inflow ≥15 knots, unknown*) categorized by severity and time of day.*

- Strong line-normal inflow and fronts usually dominate among known mechanisms, especially for nocturnal HS events, but mechanisms are also often unknown.
- Outflow boundaries play a relatively greater role for LS events than NS or HS
- Cell interactions are limited, but more common for diurnal cases
- Unknown mechanisms are more prevalent in nocturnal cases, highlighting nighttime complexity.



Distribution of NS, LS, and HS bowing wind for diurnal and nocturnal cases with outliers removed (1.5x IQR).

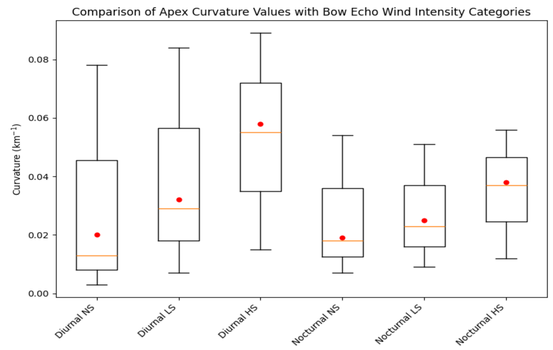
- Non-Severe (NS): Weakest inflow reflecting weaker environmental forcing.
- Low-Severity (LS): Greater variability, especially at night, when inflow is often much greater than in daytime (likely reflecting LLJ).
- High-Severity (HS): Large variability, with larger inflow at night than during day (again likely due to LLJ), for given time period (day or night), inflow is greater on average than for NS and LS events.

Apex Curvature

Non-Severe (NS):
- Average curvature: 0.020 km^{-1}
- Lowest median and variability in curvature

Low-Severity (LS):
- Average curvature: 0.032 km^{-1}
- Higher median values compared to NS

High-Severity (HS):
- Average curvature: 0.058 km^{-1}
- Greatest median and most consistent curvature values



Diurnal HS events exhibited the highest curvature values due to enhanced surface instability and vigorous outflow surges, while nocturnal HS events displayed slightly lower curvature values influenced by mesoscale inflow and low-level jet activity.

Summary

- Strong inflow and frontal boundaries dominate bow echo formation mechanisms with notable differences between day and night systems.
- Apex curvature correlates strongly with wind severity, particularly for diurnal bow echoes.
- Sufficient line-normal inflow (≥15 knots) is essential for sustaining severe bow echoes, with nocturnal events exhibiting greater variability than diurnal.

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