The Relationship Between Turbulent Shear Layers and Precipitation Structures Within Northeast United States Coastal Winter Storms

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Background

- The origins of multiband development are still unknown (Ganetis et al. 2018)
- Recent work has suggested that vertical wind shear may be related to the production and/or organization of multibands within winter storms (Ganetis et al. 2018). The authors found increased vertical wind shear to be associated with storms characterized by multibands using a 108-storm climatology
- Case studies (Medina and Houze (2005), Houze and Medina (2015), Barnes et al. 2018, Grasmick et al. 2021) have investigated the role of vertical wind shear within winter storms, but a climatological based approach has yet to be done
- The Ka-Band Scanning Polarimetric Radar (KASPR) at Stony Brook University (SBU) in Long Island, NY, with high spatial and temporal resolution, observes layers of enhanced spectrum width (SW) not seen by the WSR-88D network

Science Questions

1. What are the typical values of vertical wind shear observed within coastal winter storms?
2. Are all SWLs associated with increased vertical wind shear, or may there be other origins?
3. Do we see an increase in precipitation object occurrence or precipitation object size in environments characterized by increased vertical wind shear?

Data & Methods

KASPR PPI, VPT, and Velocity Azimuth Display (VAD) Data

Scan Type	PPI (15 deg elevation) & VAD	VPT
Vertical Resolution	35m	15m
Total # of SWL	> 83,000	> 56,000
Total # of Hours	79	178
Number of Storms from 2017-2021	41	41

- KASPR PPI measurements of doppler velocity were used to estimate wind direction and speed following the technique of Browning and Wexler (1968)
- VAD measurements extend to 7.8km (max altitude of the PPI dataset)

Spectrum Width Layer (SWL) Detection

1a

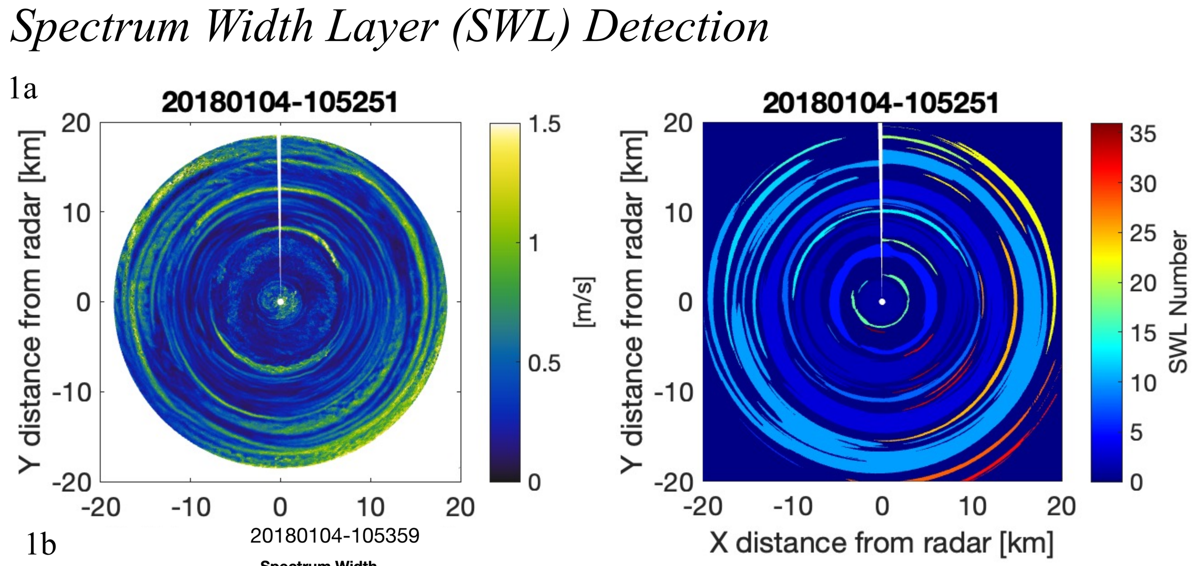
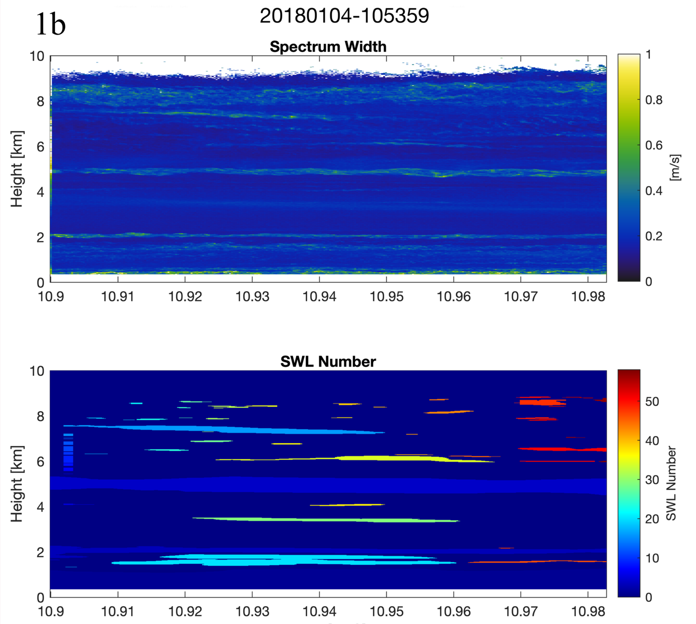


Fig 1a. Example of the SW field and resulting convolution output, colored by SWL number, from a KASPR PPI scan. Fig 1b. Example of a SW field and resulting convolution output, colored by convolution type, from a KASPR VPT profile.

1b



- 2D convolution-based algorithm is used to objectively identify horizontally linear SWLs of varying thicknesses within the KASPR PPI scans and VPT profiles
- A SW value must exceed its surroundings by 0.25 m/s (0.20 m/s) to be considered a SWL in the PPI scans (VPT profiles)
- A binary image processor connects pixels of equal convolution output into the same SWL

Precipitation Object (PO) Detection

- Objectively-identified precipitation structures from gridded NEXRAD composites (See presentation 15.A5 by Phillip Yeh 15.A5 on Thursday Feb 1)

Vertical Wind Shear in Winter Storms

2

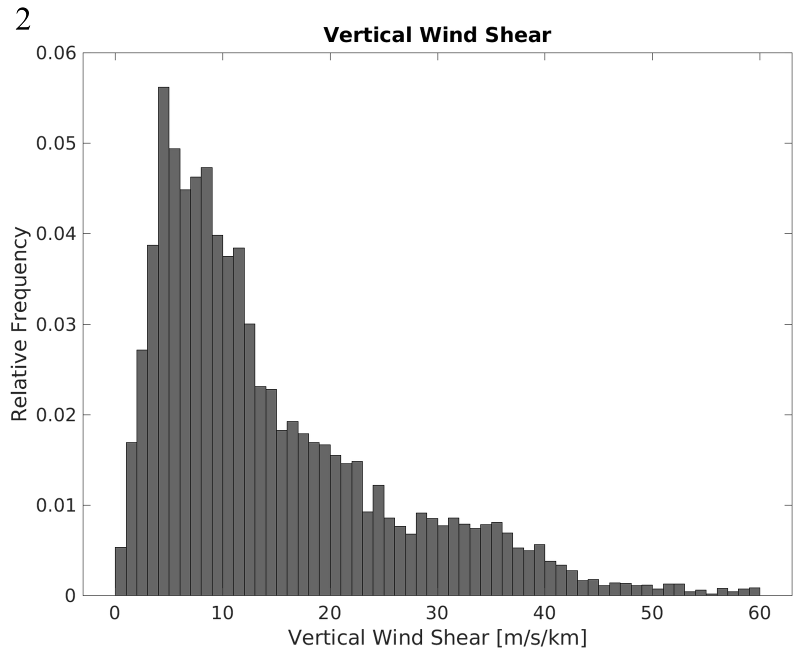


Fig 2. Distribution of vertical wind shear within all KASPR cases.

- Logarithmic distribution
- Majority of vertical wind shear < 11.2 m/s/km
- < 6% of observed vertical wind shear exceeds 40 m/s/km

3a 3b

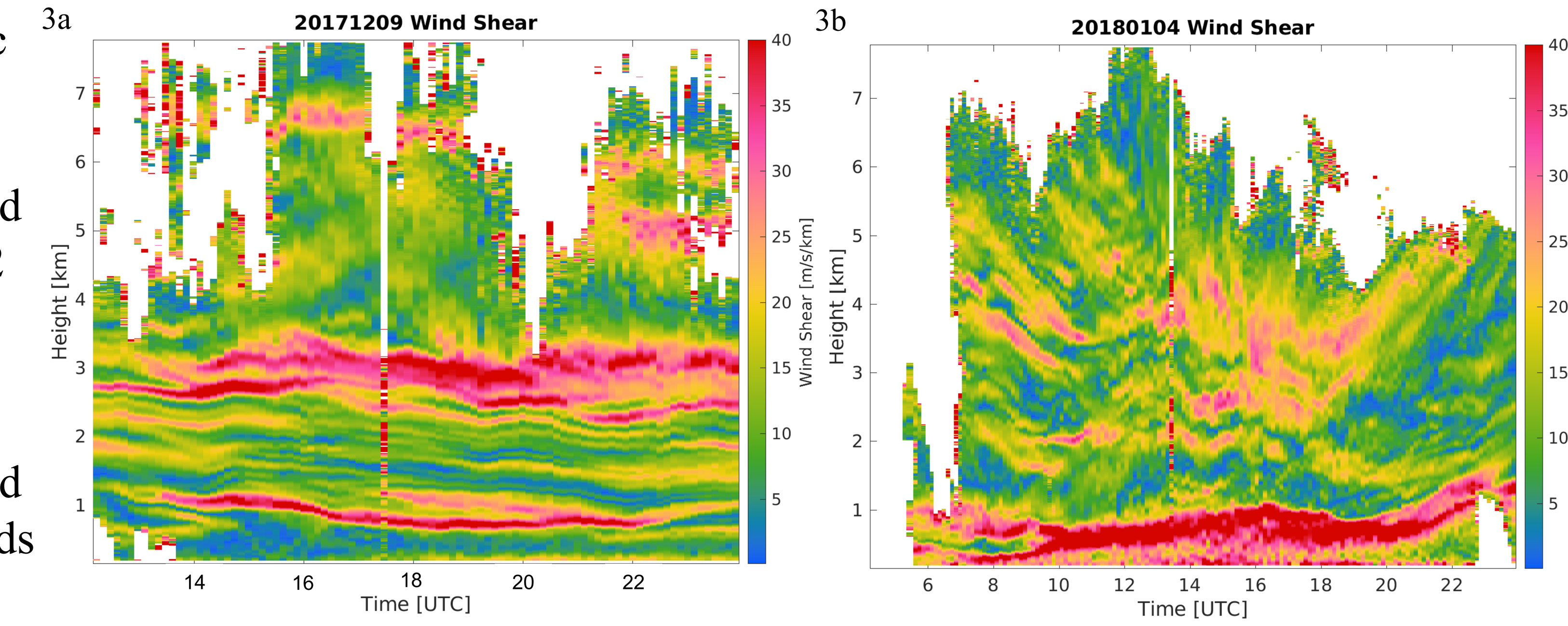


Fig 3. a) Vertical wind shear profile from 20171209. This case was an overrunning event, characterized by a stationary front 300 km southeast of KASPR. b) Vertical wind shear profile from 20180104. This case was a major coastal cyclone, where the comma head passed over KASPR before progressing towards the Canadian Maritimes.

- Vertical wind shear structure varies between storms of different types
- 3a is an overrunning event with horizontally linear, well-defined shear layers
- 3b is comma head/occluded passage with sloping, transient shear layers

Vertical Wind Shear and SWLs

4

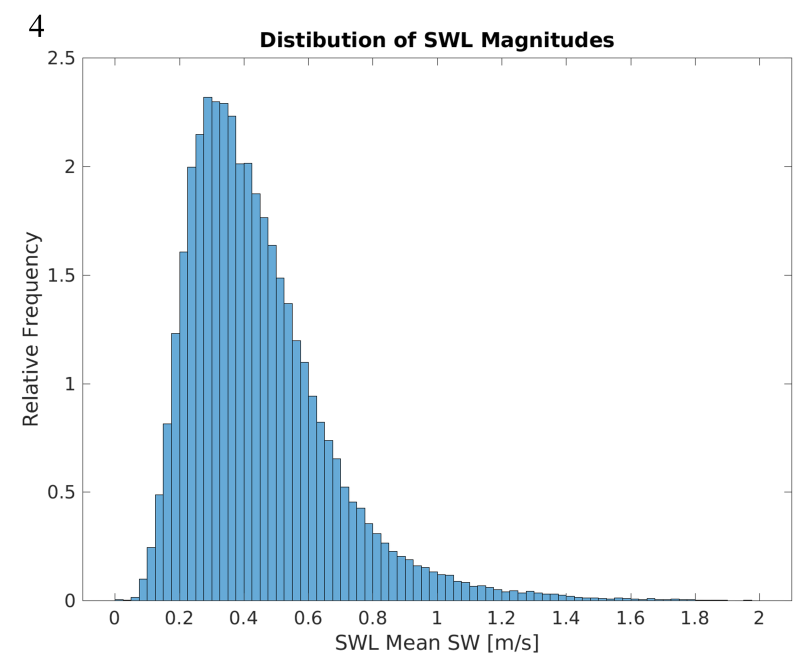


Fig 4. Distribution of layer mean SW magnitude from all PPI SWLs, totaling >83,000 SWLs.

- Similar distribution to vertical wind shear (Fig. 2)
- Majority of SWLs are <150m thick (not shown) with magnitudes < 0.4 m/s

5

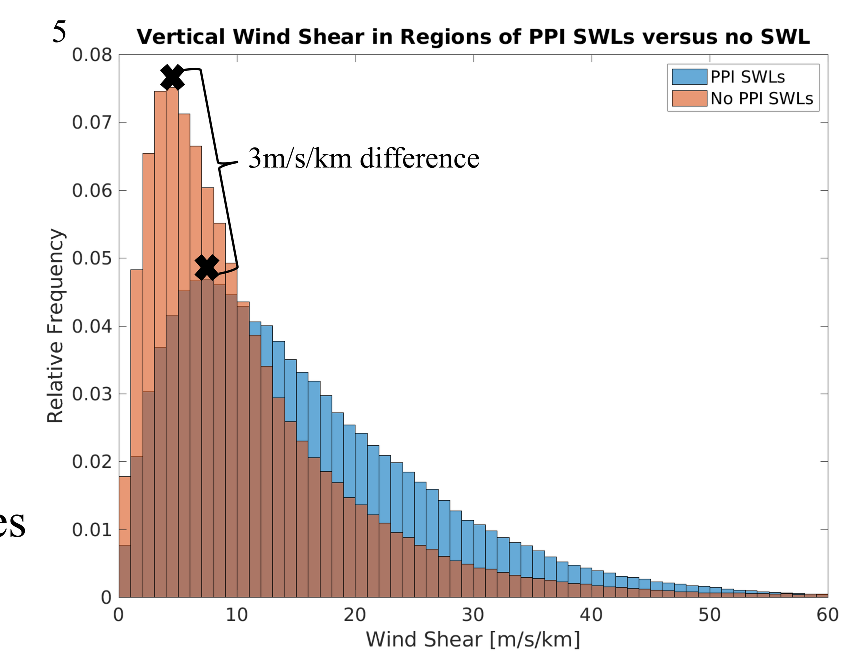


Fig 5. Distribution of vertical wind shear values observed at altitudes where a SWL was (blue) or was not (orange) present.

6

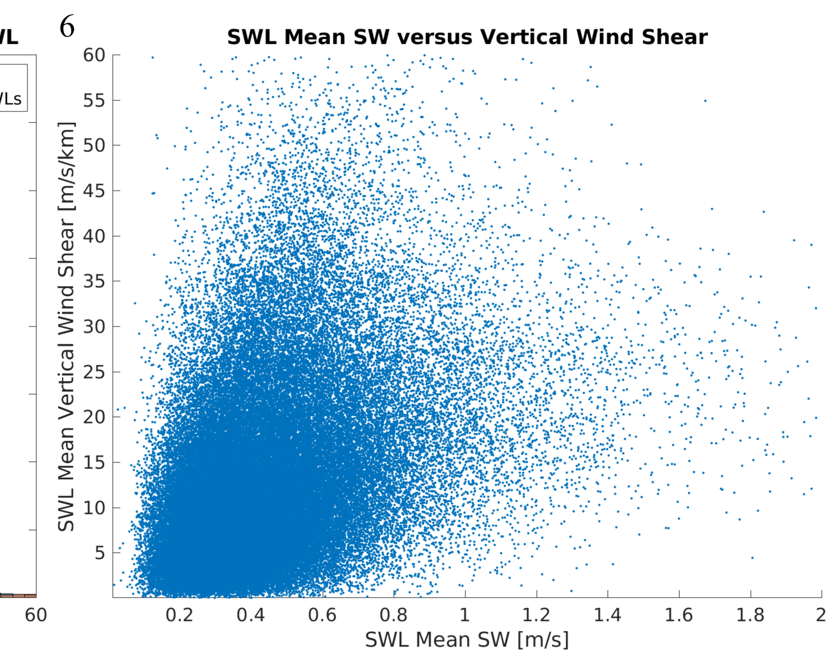


Fig 6. Scatter plot showing the average SW and average vertical wind shear of each SWL.

- SWLs are found in regions of enhanced vertical wind shear compared to regions of weaker vertical wind shear (Fig. 5)
- High wind shear outside of SWLs likely due to chaotic, non-stratified, turbulence (Fig. 5)
- No easily identifiable relationship between SWL magnitude and vertical wind shear (Fig. 6)

Vertical Wind Shear and Precipitation Objects (POs)

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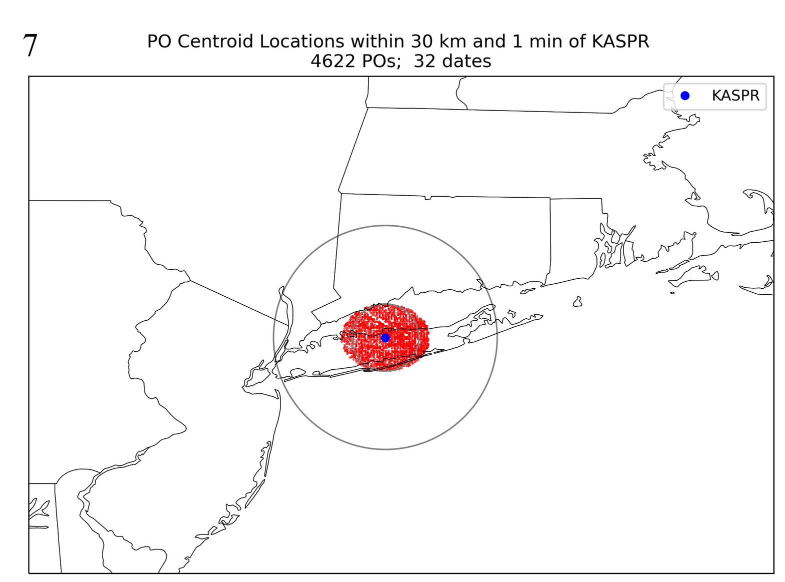

Fig 7. Map of the coastal northeast with the location of KASPR (blue), KASPR's 30km domain (inner gray), the centroid location of POs within KASPR's domain (red), and 100km range ring for spatial reference (outer gray)

- POs observed within KASPR's 30km domain, constrained within 1 minute of a KASPR PPI
- 4,622 POs from 32 unique dates

8a 8b

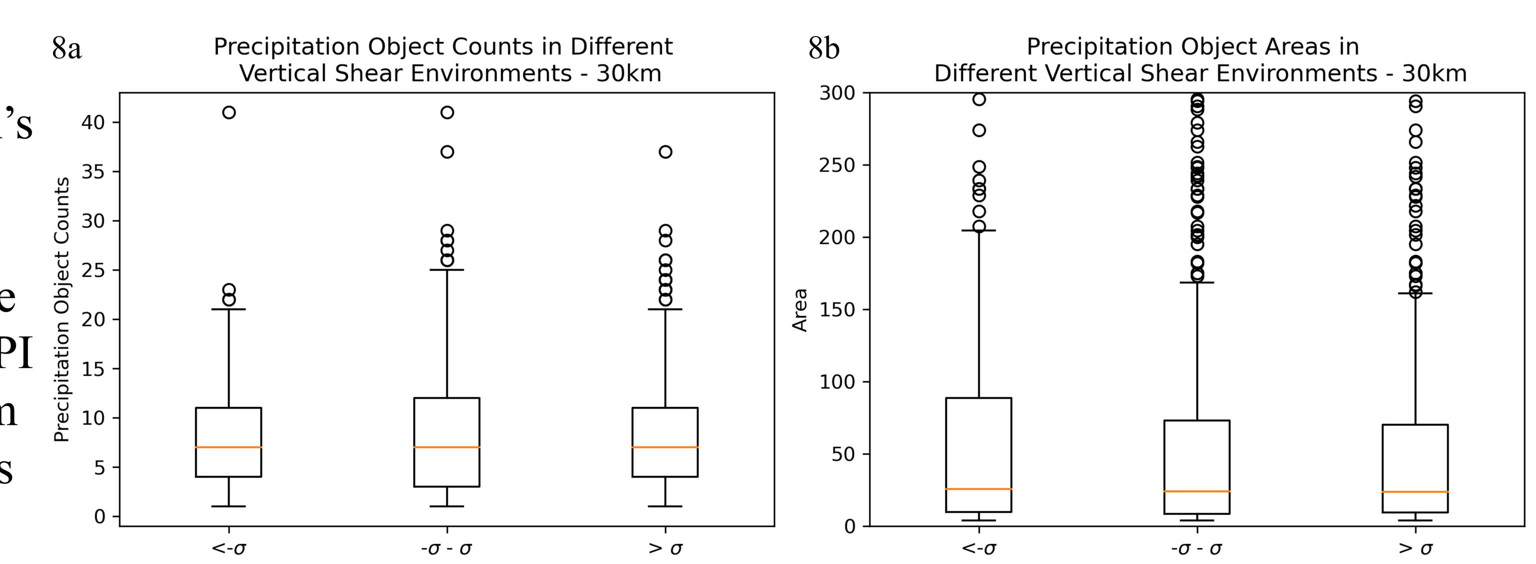

Fig 8. The PPI SWL dataset was separated into categories based on observed vertical wind shear: lower (< -σ; < 2.0 m/s/km), middle (- σ - +σ; 2.0 – 24.3 m/k/km), and upper (> σ ; > 24.3 m/s/km). All PO centroids are within KASPR's 30km domain. a) PO counts within different vertical wind shear environments, b) PO area within different vertical wind shear environments.

- The relationship between precipitation object occurrence and vertical wind shear is not clear
- Bulk of precipitation objects appear to be smaller as vertical wind shear increases

Conclusions

- Vertical wind shear within winter storms ranges from 0 – 60 m/s/km, with the majority of vertical wind shear not exceeding 11.2 m/s/km
- The structure and transience of vertical wind shear changes between storm types
- Enhanced vertical wind shear is more commonly observed within SWLs than in regions void of SWLs, but there is not a one-to-one relationship between SWL magnitude and vertical wind shear
- PO area appears to decrease as vertical wind shear increases

Future Work

- Investigate the differences in vertical wind shear between different storm types, and utilize sounding data to assess the roles of stability and the Moist Richardson Number on vertical wind shear transience, structure, and magnitude
- Constrain the analysis of POs to only investigate vertical wind shear within the 800 – 600 mb (~2-4 km) layer, as that region is often associated with mid-level lifting processes

References

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