Climatology of Precipitation Features within the Cyclone Comma Head and Some Comparisons with WRF

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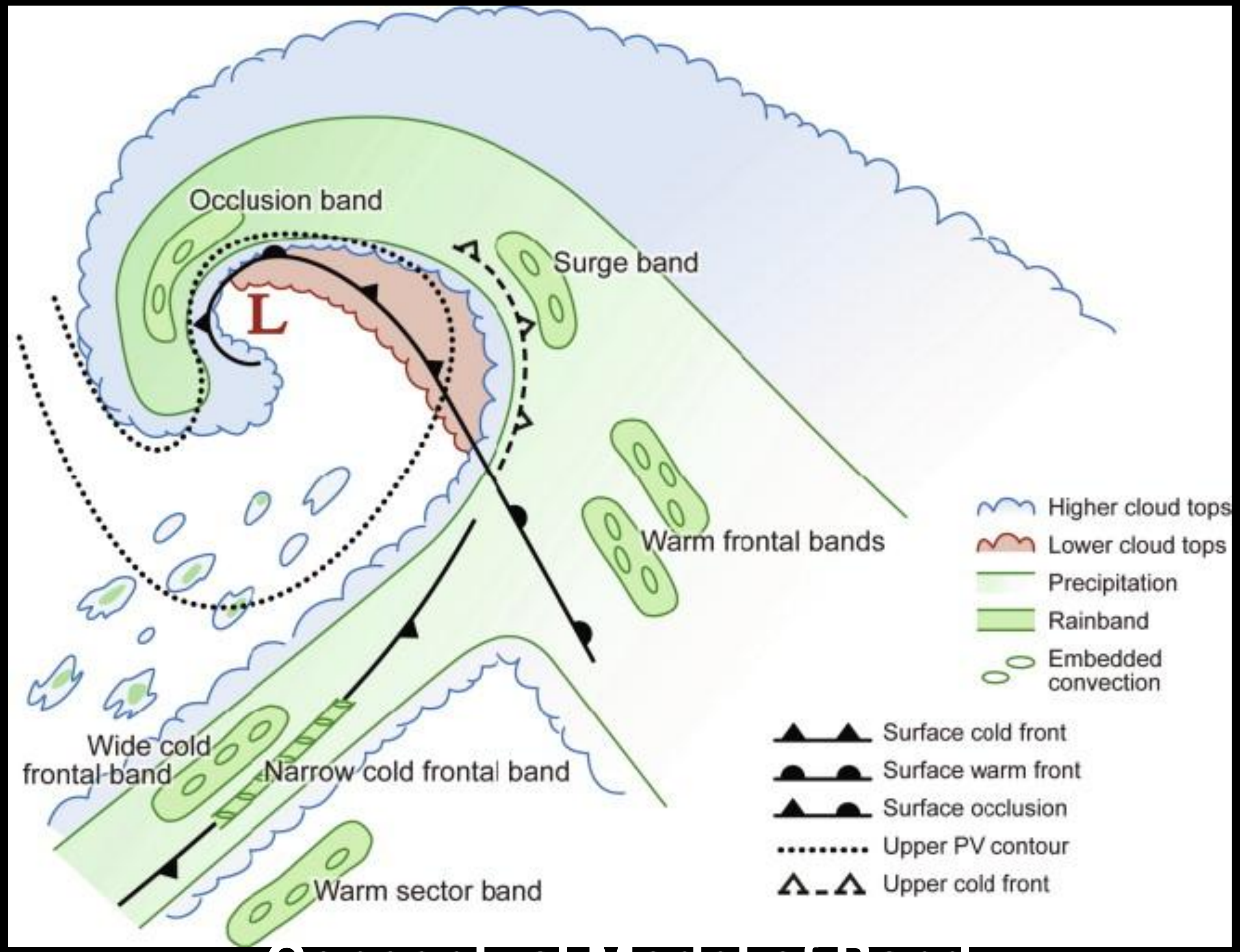
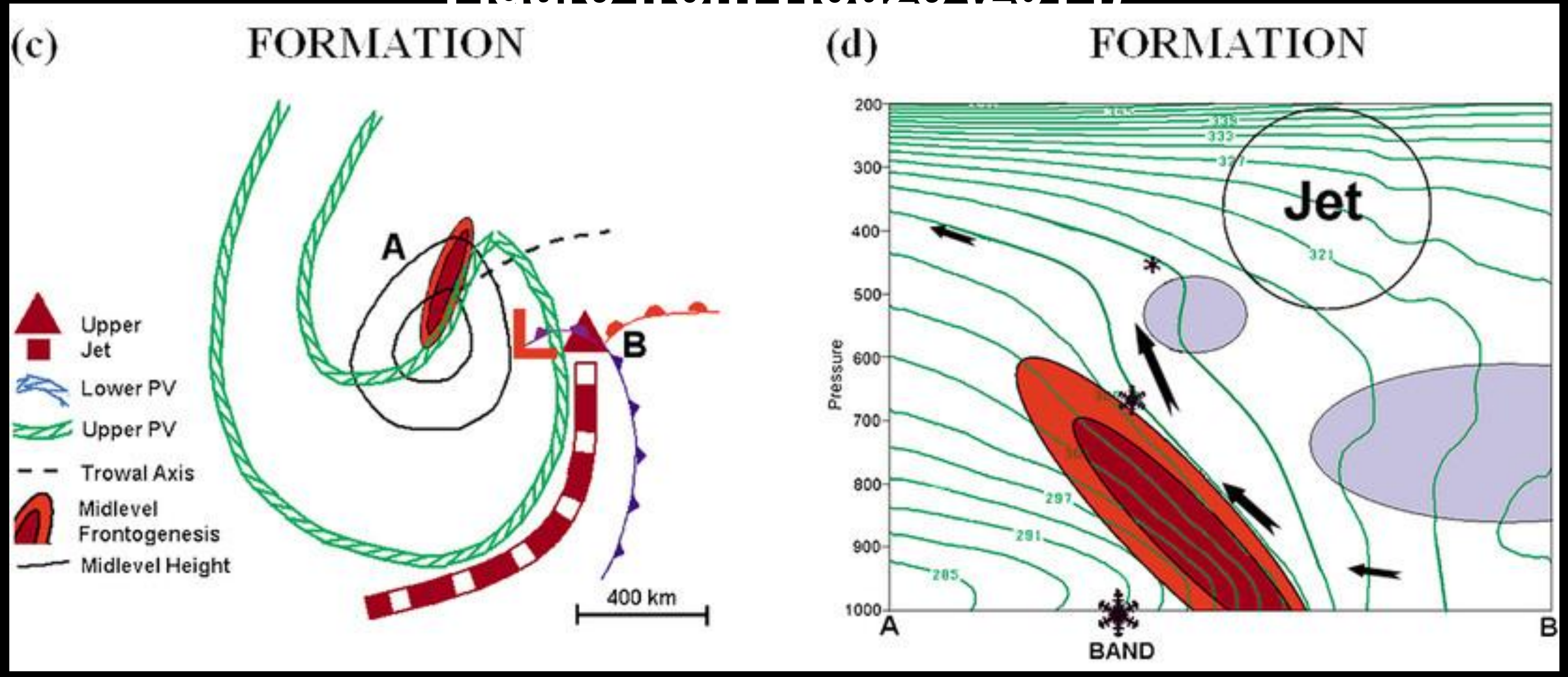
Introduction

- There are conceptional models to help forecasters anticipate bands around cyclones
- Houze et al. (1976) classified rainbands in 11 cyclones over the North Pacific
- Novak et al. (2004; 2010) documented environments typical of primary snowband-producing storms (L>200 km, AR<0.5)
- Ganetis et al. (2018; G18) found that the majority of storms with primary snowbands also contained multibands (L<200 km, AR<0.5)



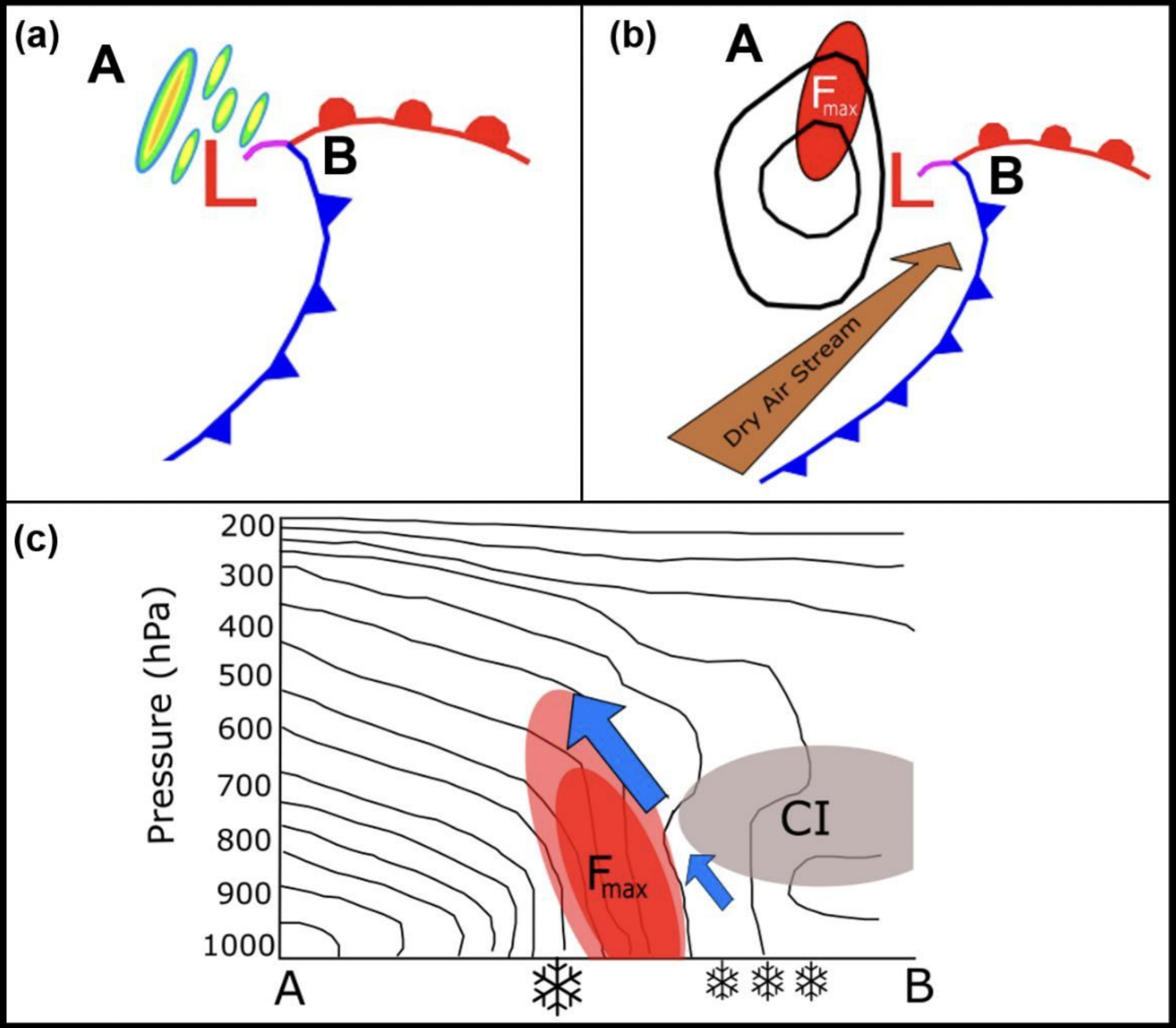
Conceptual Model of Band Types
Figure from Houze (2014)



Conceptual Model of "PV Hook" Banded Cyclone
Figure from Novak et al. (2010)

Motivation

- Much of this works was done with a limited number of case studies, done manually, or a pre-defined band size classification...
- But what is the real breakdown of precip object sizes around the cyclone, such that we can modify the conceptual model for forecasters?
- New identification schemes have been developed to address some of these issues



Conceptual Model of Banding in Mature Cyclones
Figure from Ganetis (2017)

Questions

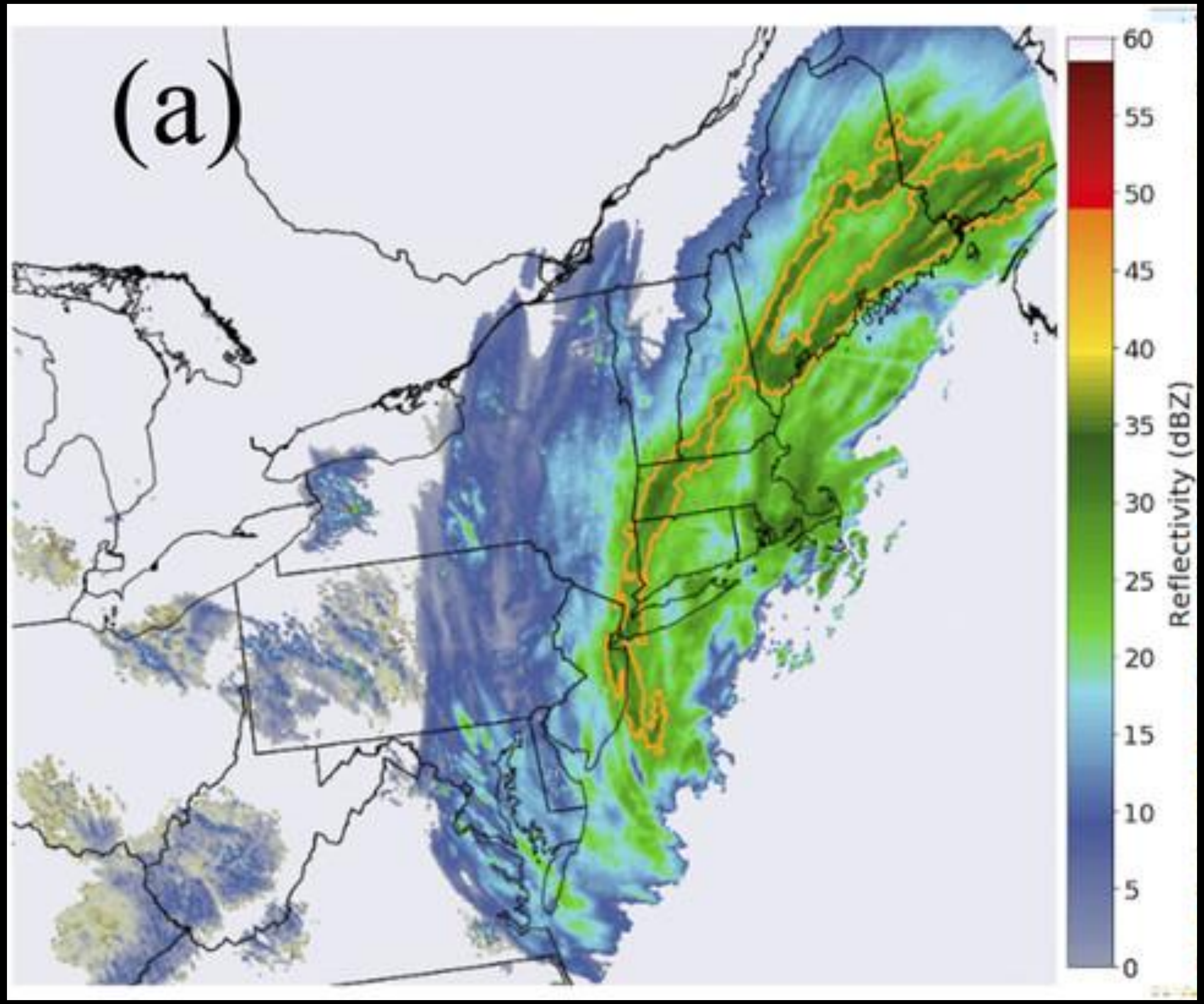
1. Using a new identification algorithm, how are precipitation objects of various shapes and sizes distributed around the cyclone comma head?

2. How do the dominant precipitation structures' sizes and shapes change for different cyclone tracks and intensity?

3. Is there any sensitivity to cyclones with different track orientations?

4. What environment is associated with different types of precipitation structures?

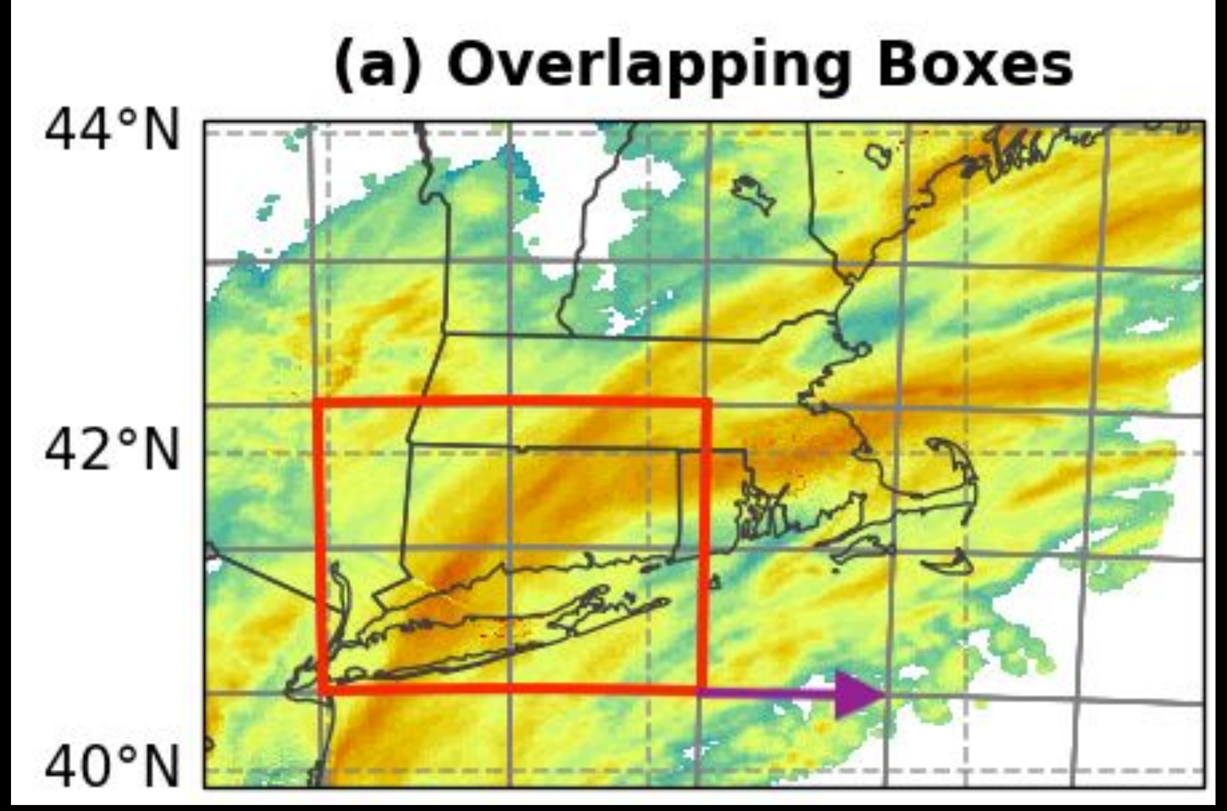
5. HRRR can produce larger bands, but how well do mesoscale models reproduce smaller precipitation structures?

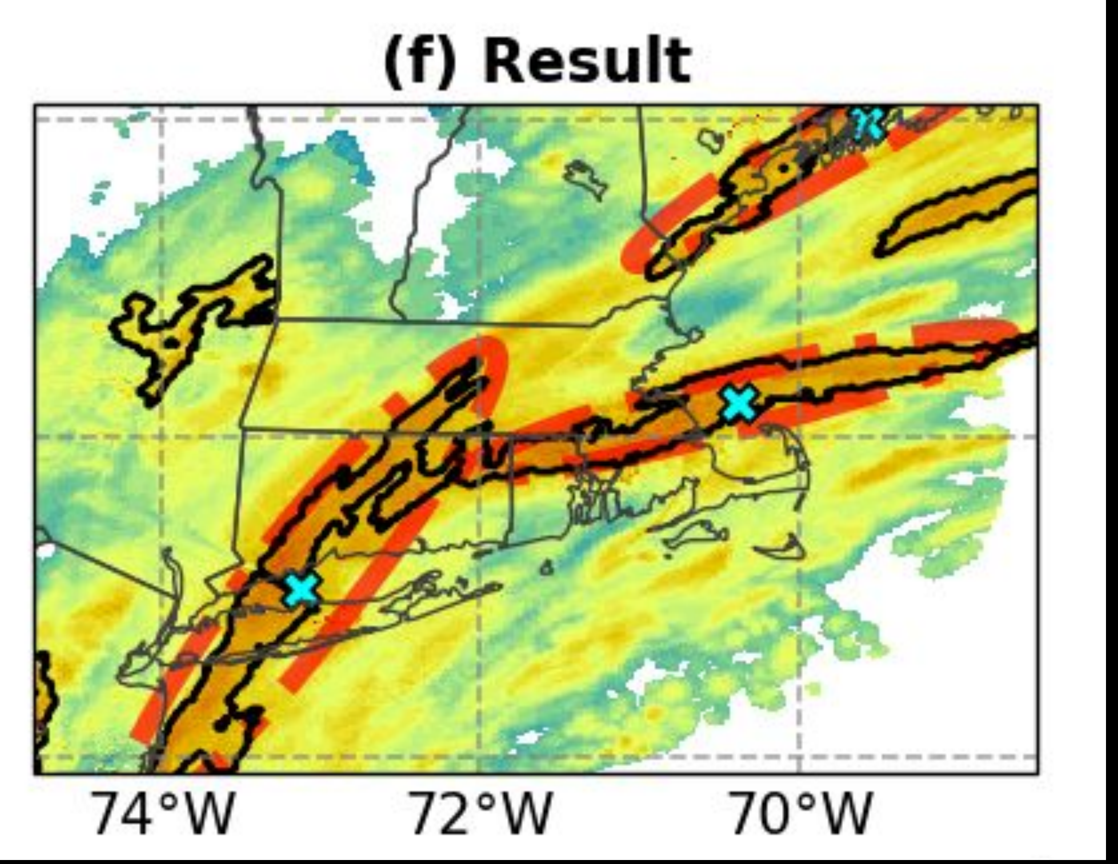


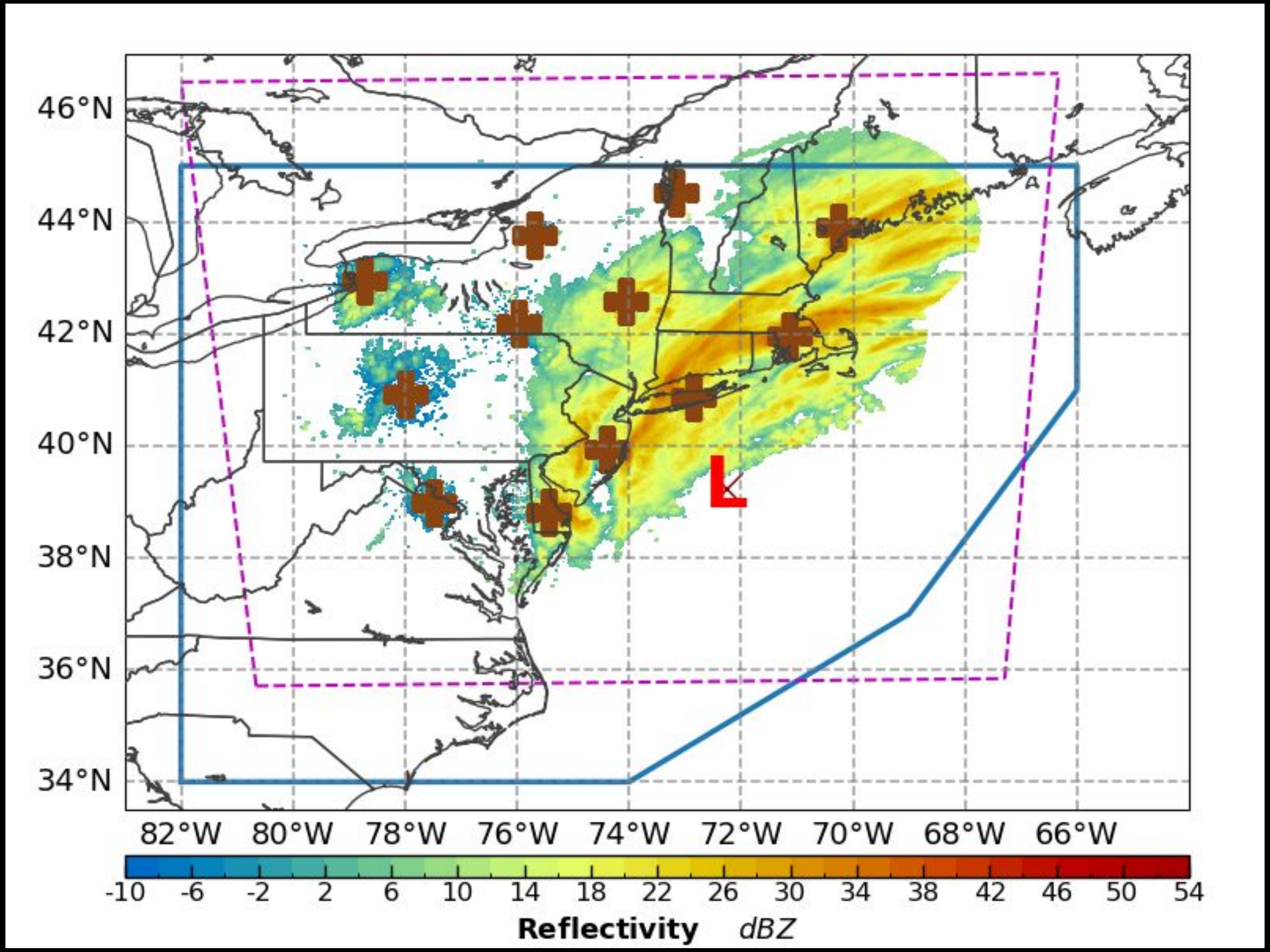
HRRR Simulated Reflectivity valid 1800 UTC 4 Jan 2018
Figure from Radford et al. (2019)

Data and Methods

- NEXRAD Level II Radar Reflectivity
  - "Stitched" composites (0.5 degree elevation angle), generated from up to 12 NEUS sites when available, using the same methodology as in Corbin (2016), Hoban (2016), and Ganetis (2017)
  - 1202x1202 km domain (dotted line)
  - Data from Nov-Mar 1996-2023
- ID-PRO Algorithm (Yeh and Colle 2024, in review)
  - Overlapping boxes of prescribed size and step
  - Used to find local enhancements from the calculated background field
- ERA-5 Reanalysis used for cyclone tracks and



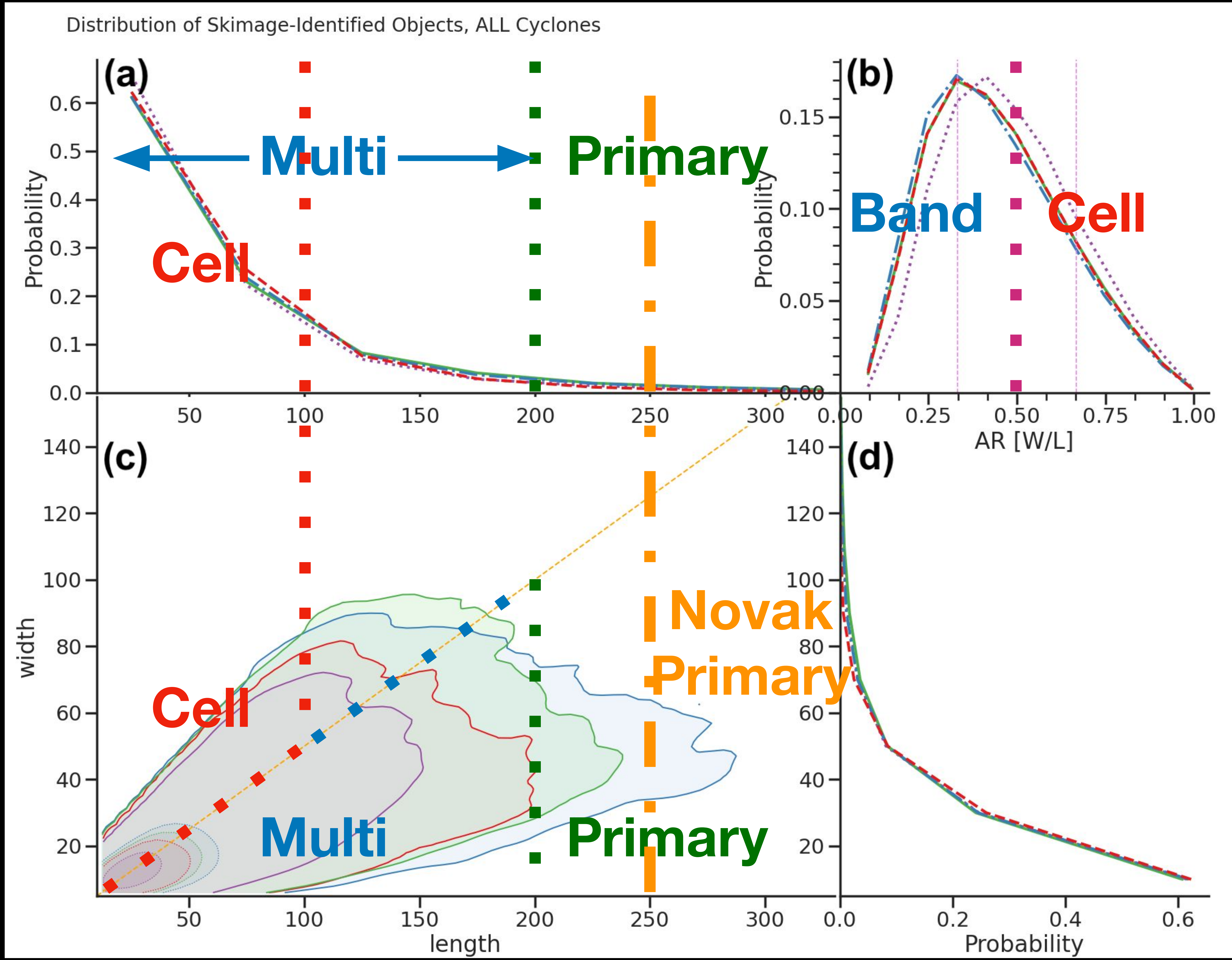




NEXRAD reflectivity (dBZ) at 0610 UTC on 12 February 2006

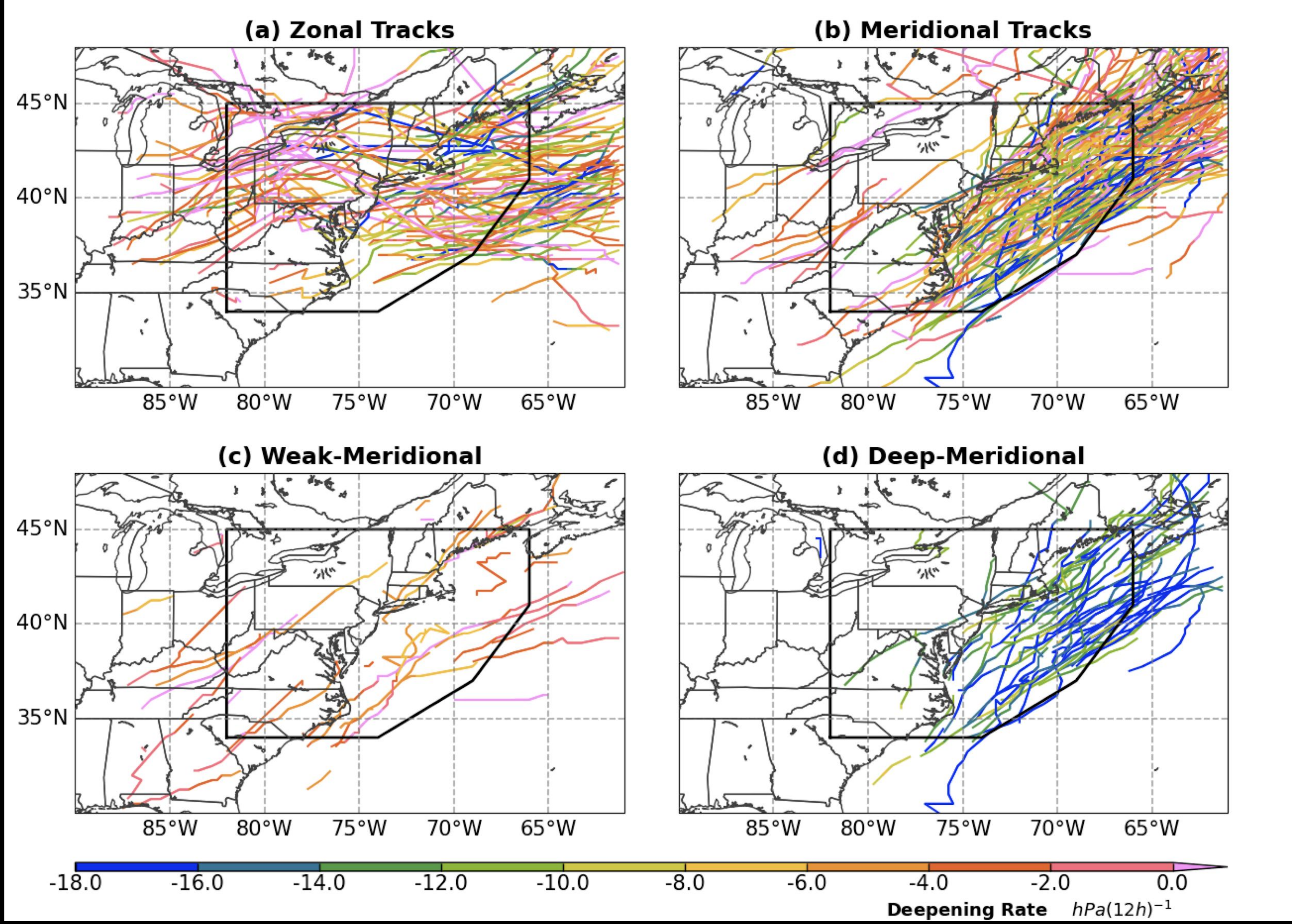
Distribution of Object Sizes and Shapes

- Primary band
  - Novak et al. (2004; 2010) definition: **L>250 km**, 20<W<100 km
  - Ganetis et al. (2018) defintion: **L>200 km**, **AR<0.5**
- Multiband (G18): **20<L<200 km**, **AR<0.5**
- Cell (G18): **L<100**, **AR>0.5**
- How does this break down for zonal and meridional cyclones?

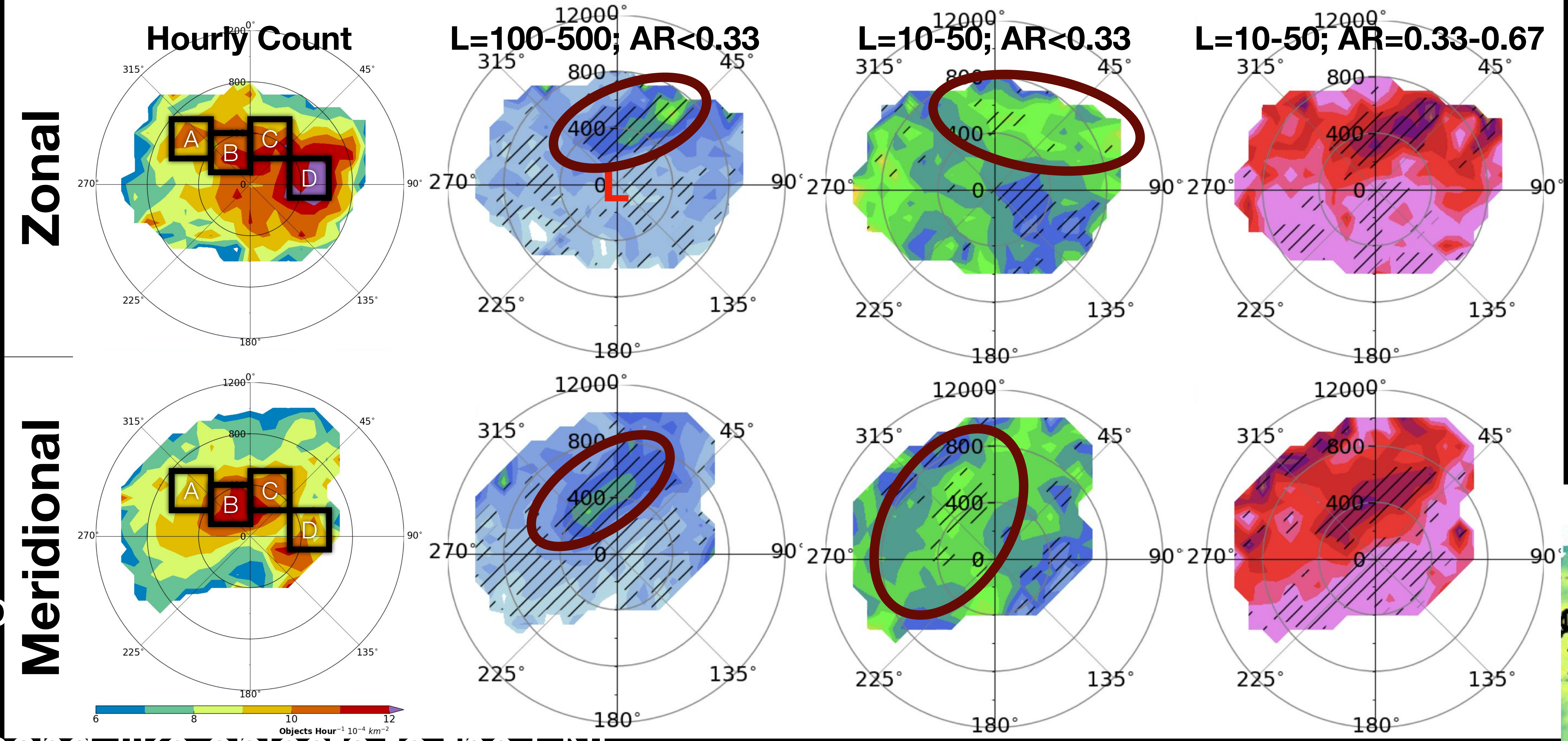


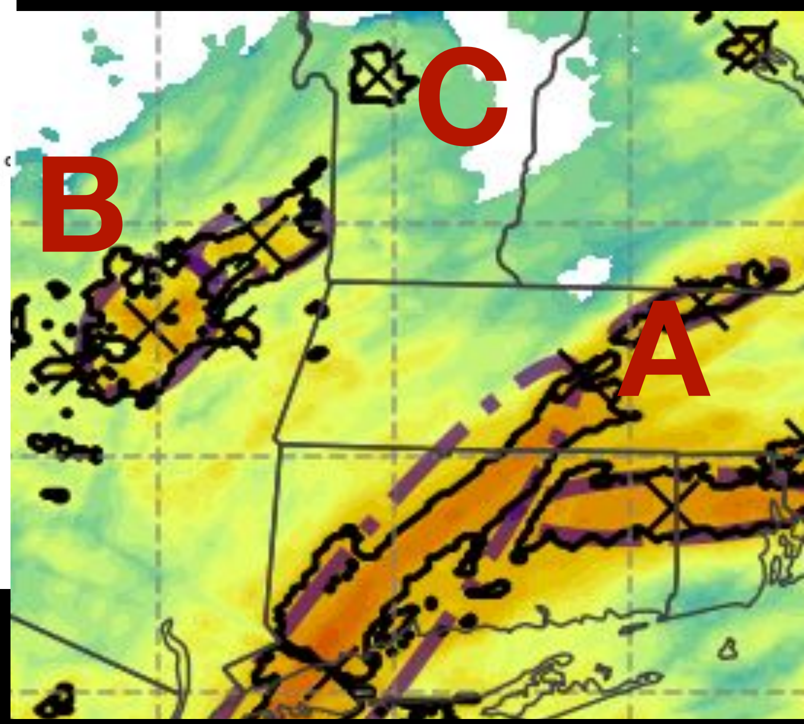
Cyclone Tracks 1996-2023

- 3-hour running mean change in latitudinal and zonal distances within the domain (black polygon)
- 12-hour deepening ratio (see Tsuji et al. 2023) used to differentiate “weak” and “deep”
- Zonal tracks may include clippers and Miller B cyclones
- Meridional tracks are mainly coastal cyclones



Spatial Distribution of Object Characteristics

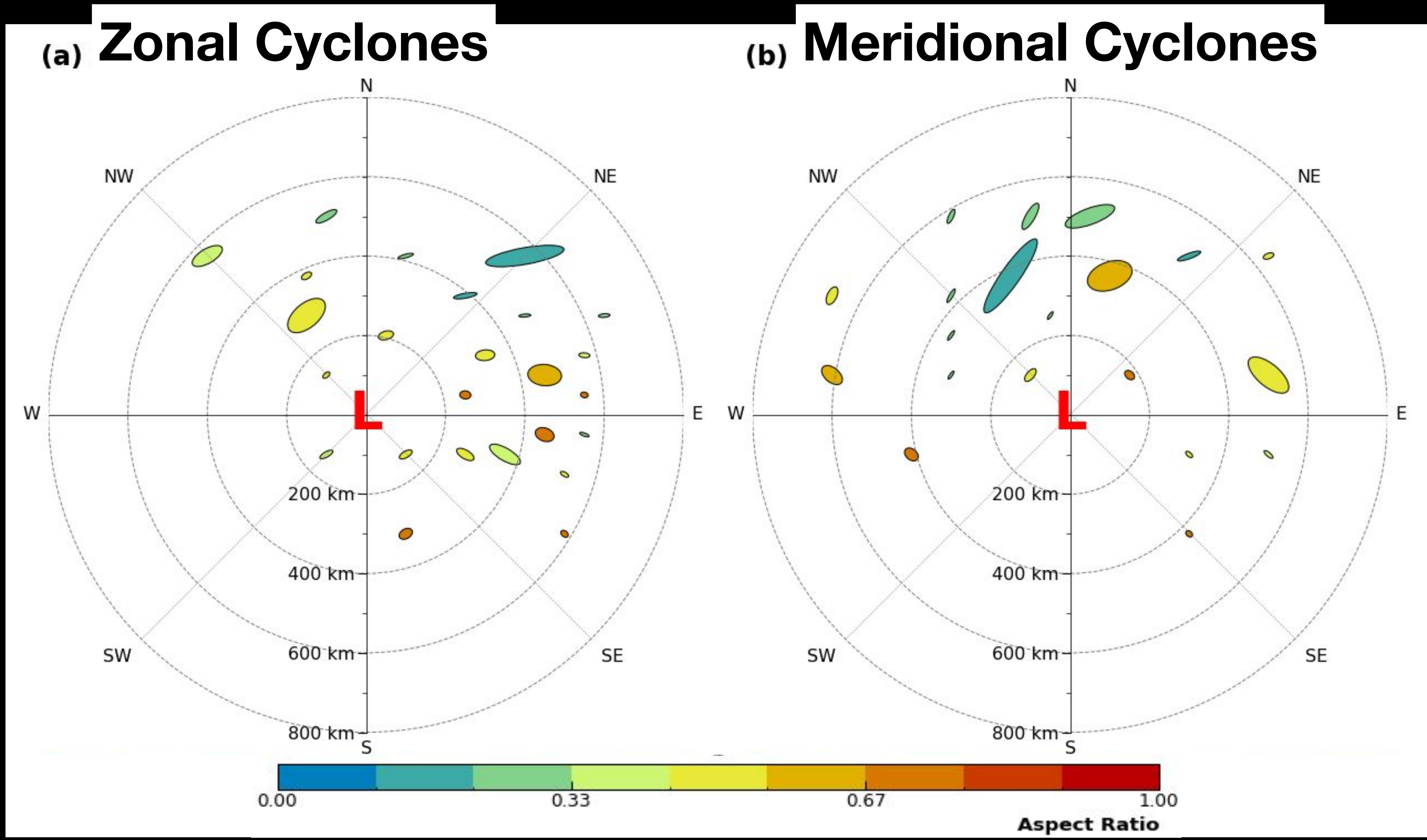




- Zonal cyclo
  - Largest band-like objects to the ENE
  - Small amorphous objects the most common object type
- Meridional cyclones

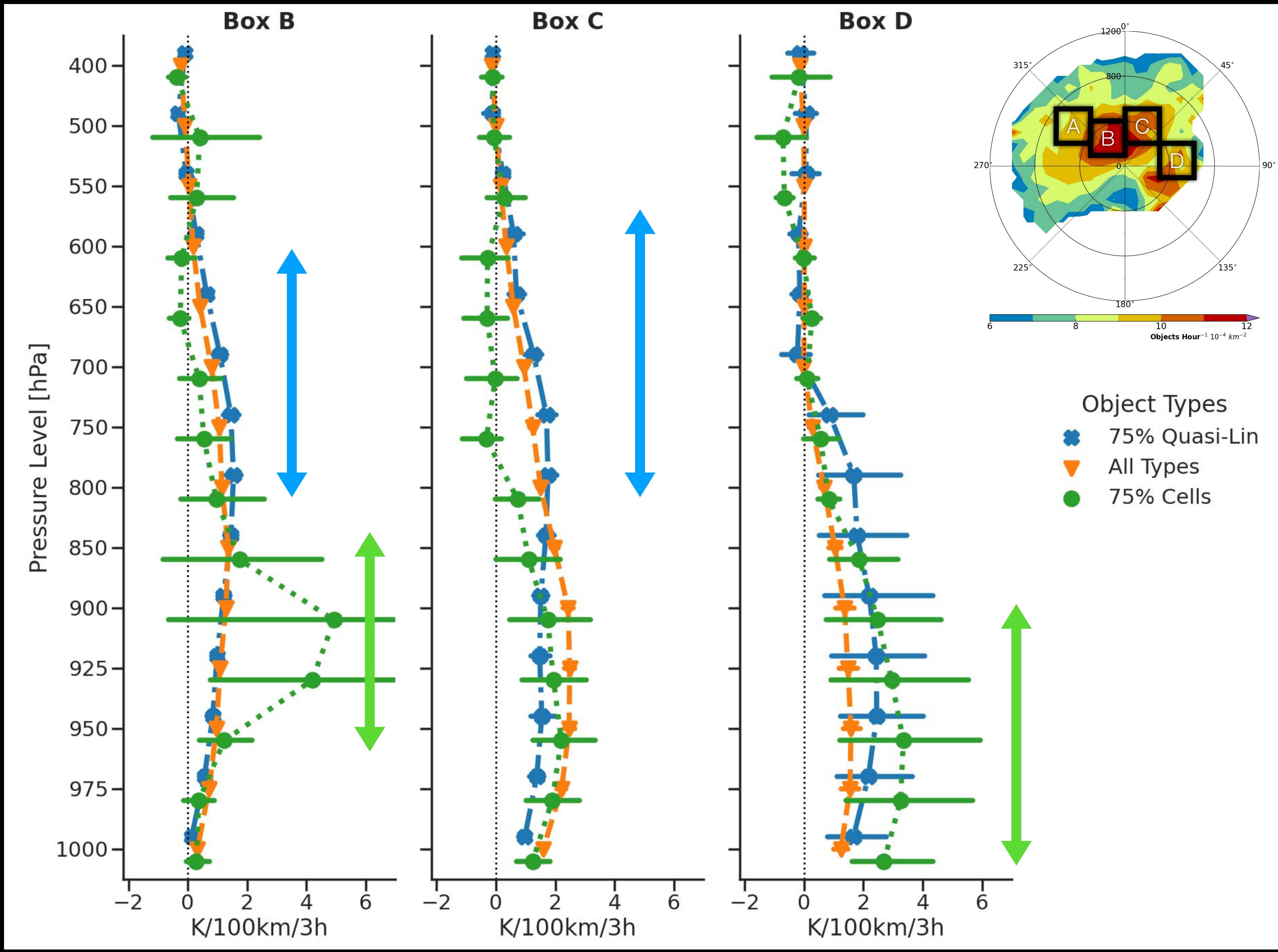
Conceptual Model of Precipitation Object Results Around Cyclone Center

- Zonal cyclones feature a greater number of objects than meridional cyclones
- Zonal cyclones have more objects oriented West-East
- Larger, band-like objects more common to NE of zonal cyclones
- Band-like objects more common to NNW of meridional cyclones
- Band-like objects coincide with regions of stronger 700 hPa



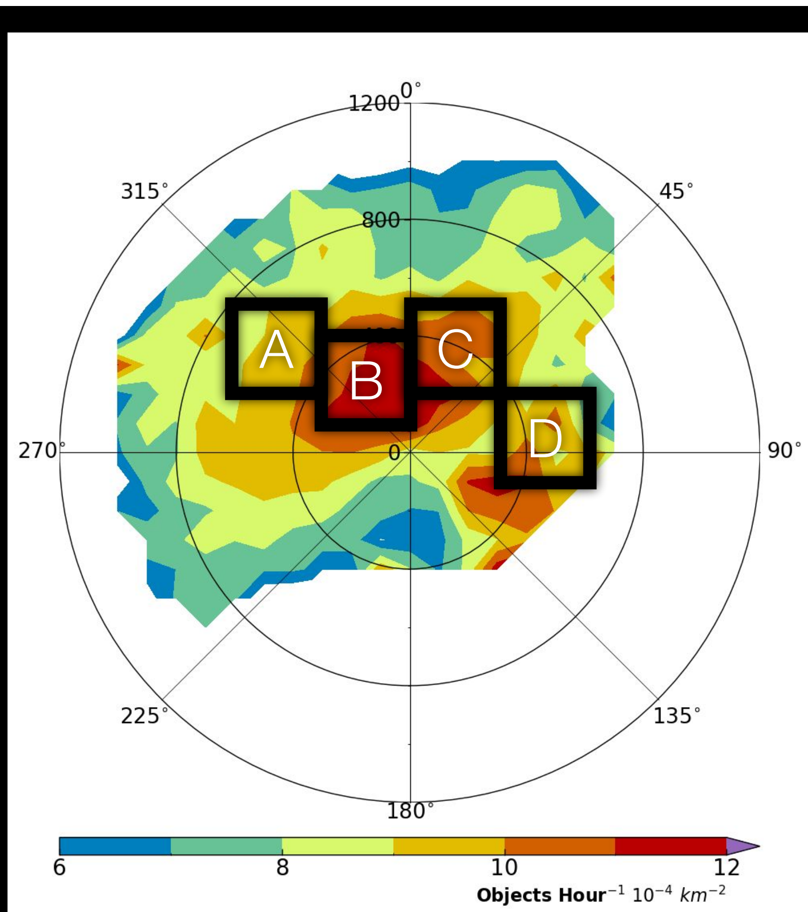
Frontogenetic Environment

- (Meridional cyclones only)
- Overall weakest in Box **A** (not shown)
- Front. above 800 hPa strongest for quasi-linear environments (Box **B** and **C**)
- Front. below 850 hPa may be stronger for cell environments



Stability Environment of Objects - Meridional Cyclones

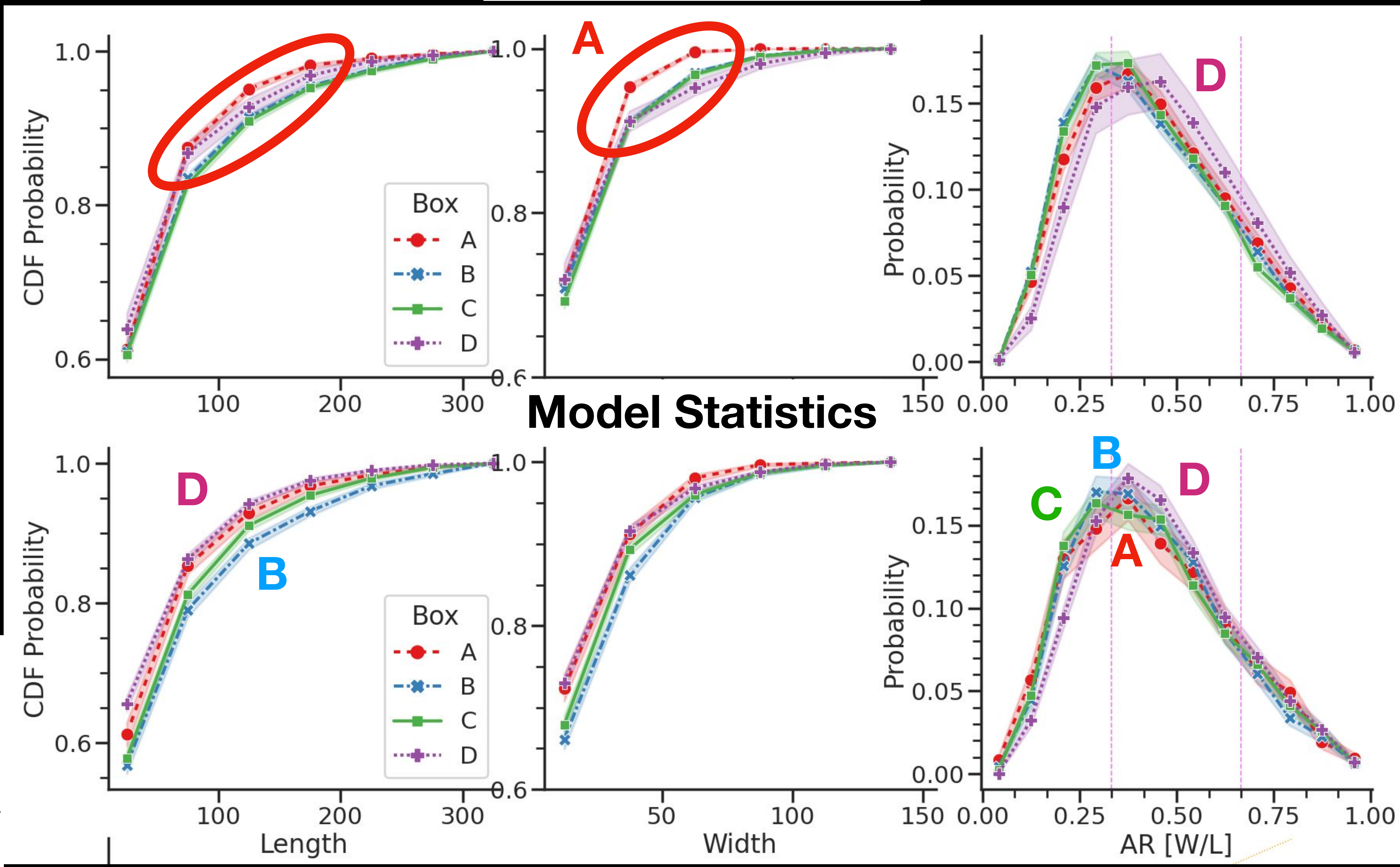
- Quasi-linear environments more likely to have CSI (20-30% of the box), especially box C
- Some mid-level CI and PI also found in boxes B-C (15-30% of the box)
- Cell environments have higher occurrences of low-level CI (high variability due to small sample size)
- Overall 45-70% of boxes A-C are stable between 850-550 hPa regardless of object type

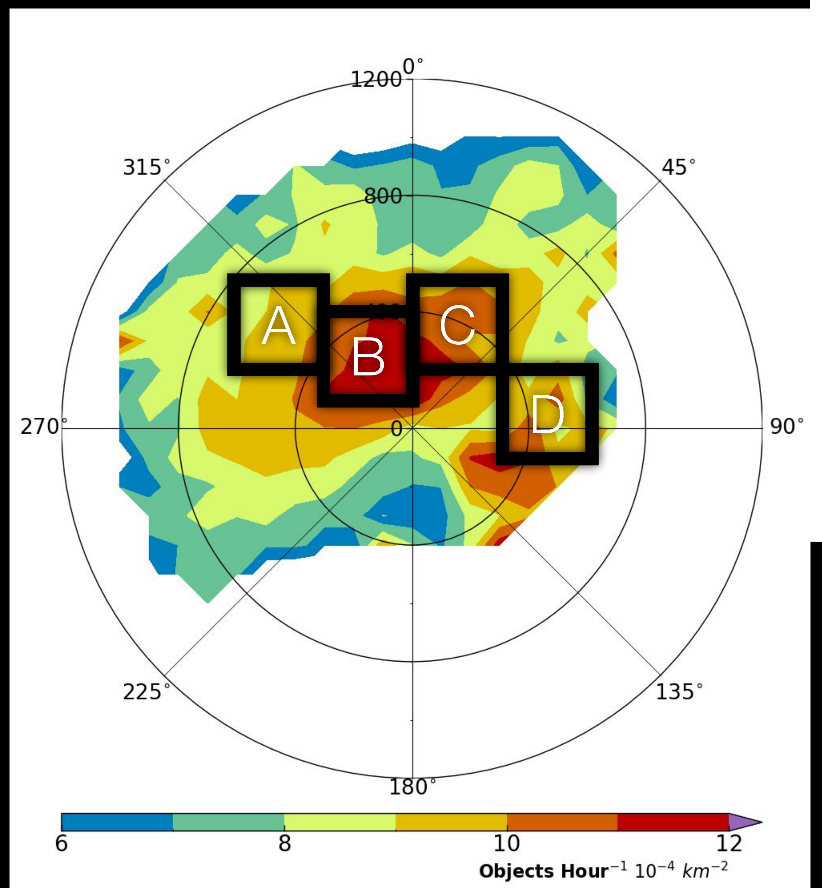


Observed vs Model-Simulated Objects

- Statistics for 21 cases (2018-2024)
- Except for box **D**, the model has lower probability of small objects (Length < 100 km)
- Model has slightly higher probability of small aspect ratio (more band-like) in box **C** but similar probability in box **D**

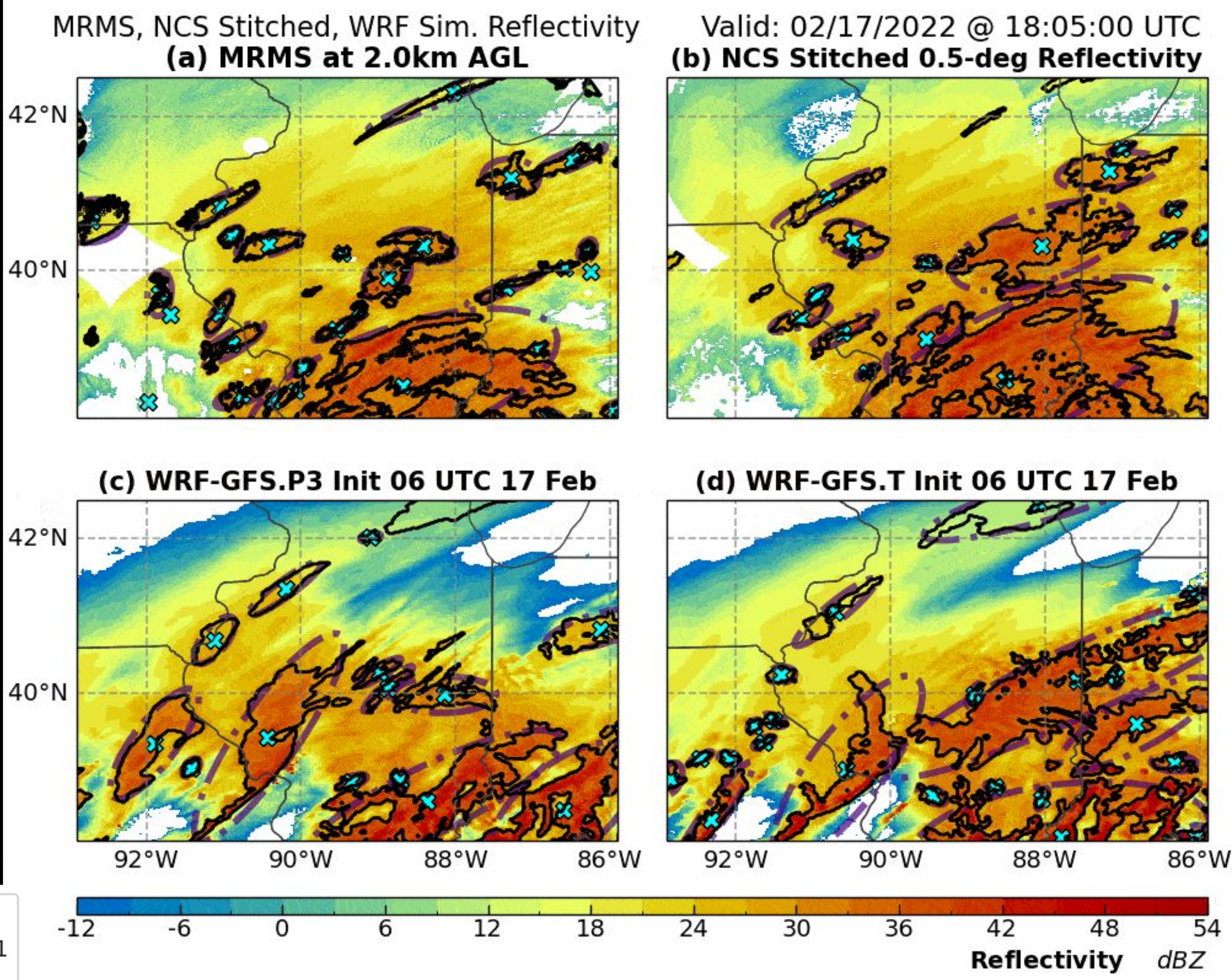
Observed Statistics

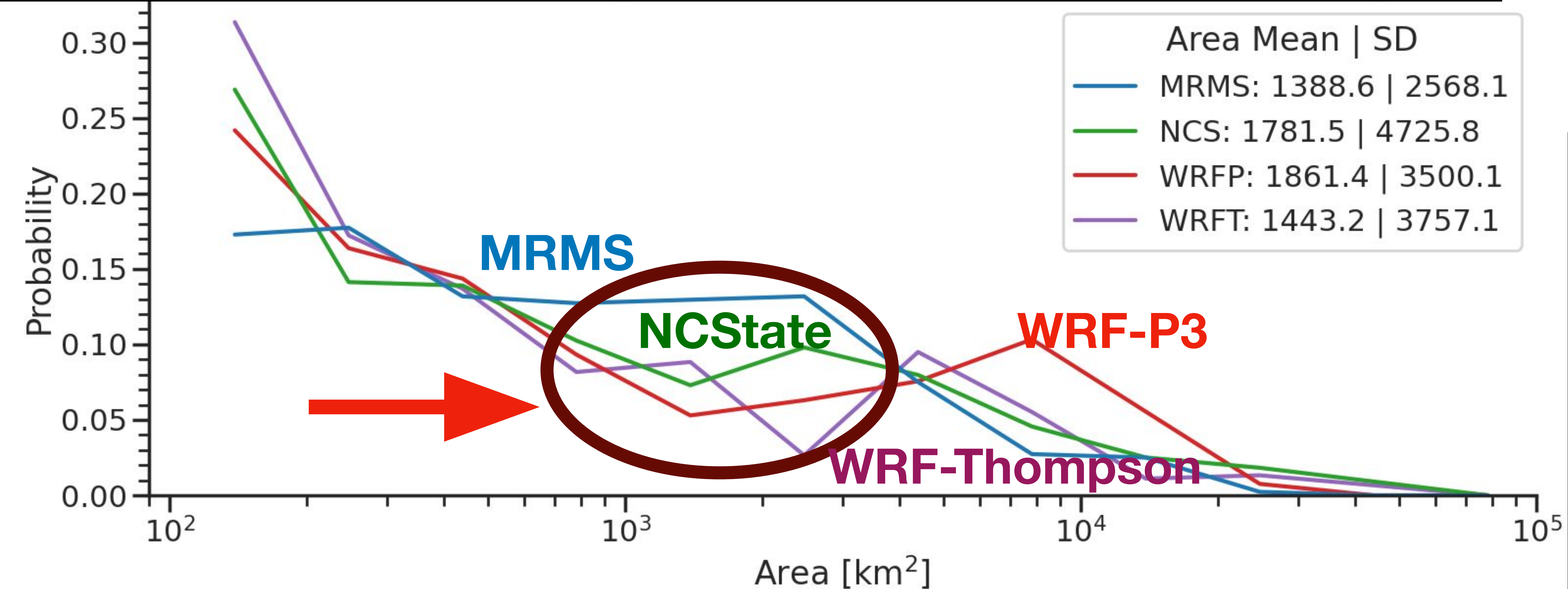




Example Case
17 Feb 2022

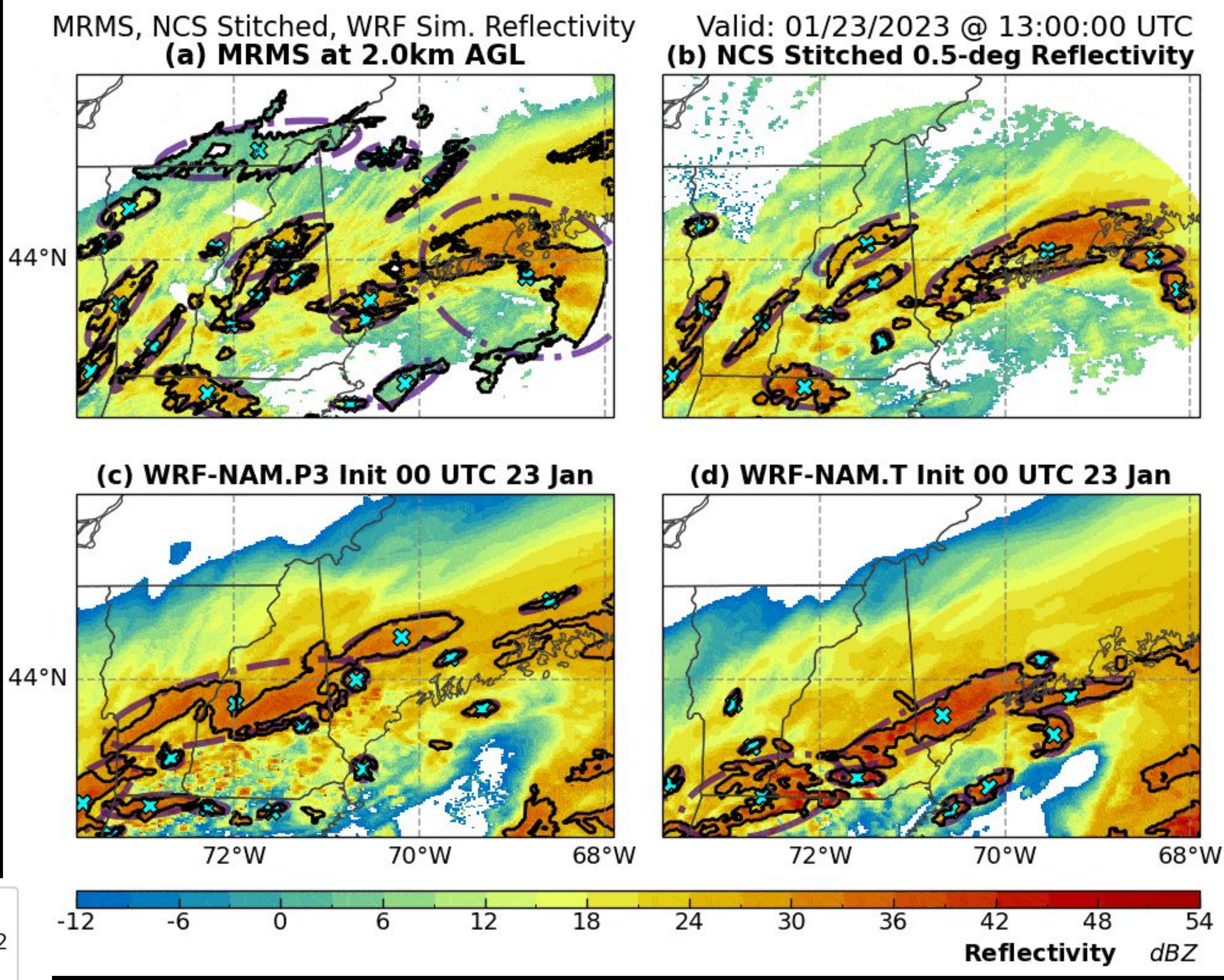
- More stratiform case with fall streaks from generating cells
- "Multibands" growing into a larger band after 2030 UTC
- WRF partially captures band structure but combines small objects into larger "amorphous" ones
  - Some medium-size structures missing
  - Thompson has greater percentage of small objects

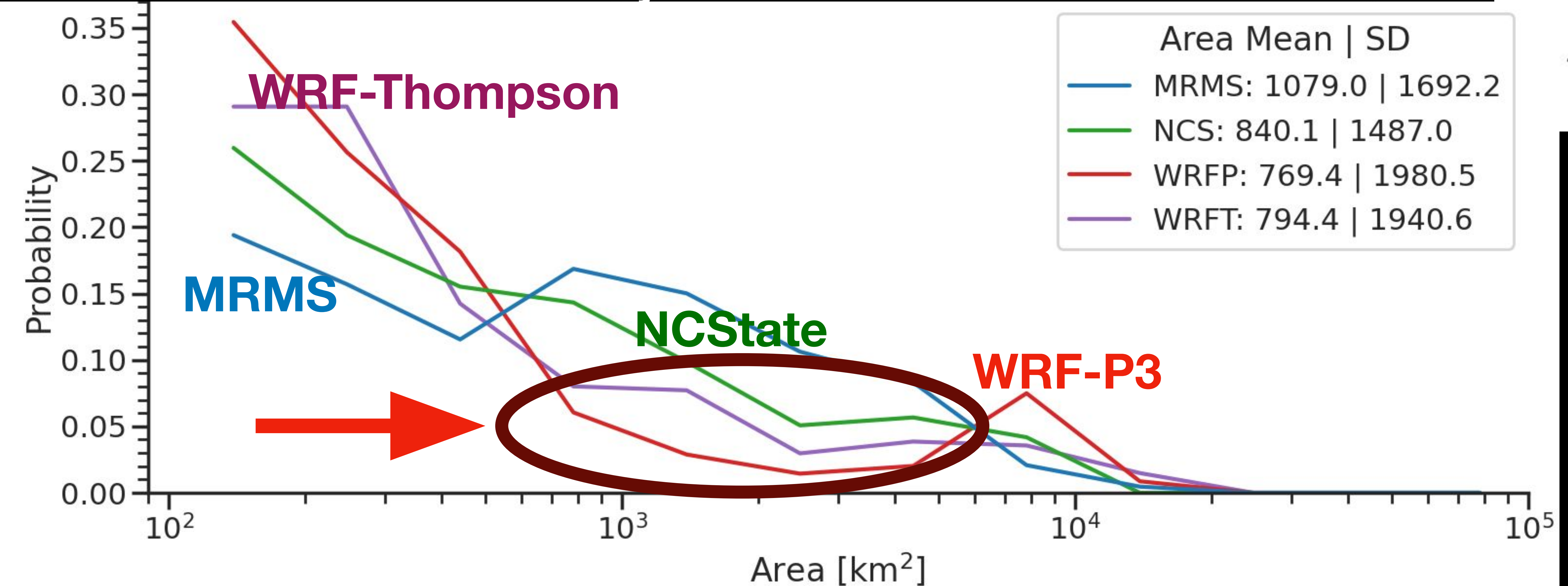




Example Case
23 Jan 2023

- Case with many convective-like plumes in the vertical
- Some variability between MRMS and NCState stitched reflectivity, with NCState objects smaller and narrower on average
- WRF is missing many of the medium-size structures and has a more bimodal distribution of object areas





Summary

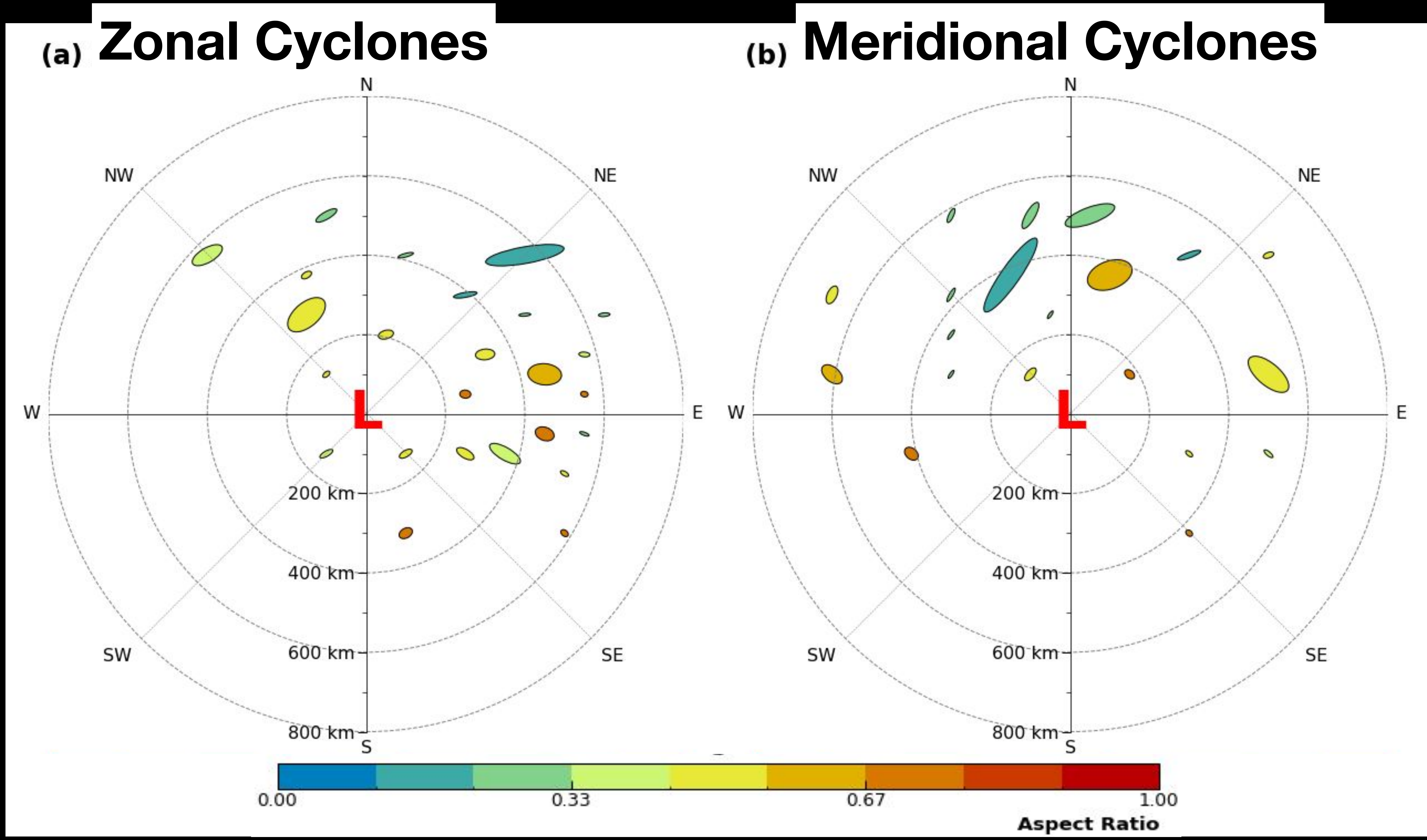
- Large, band-like objects are more common NNE of the cyclone center for zonal cyclones, or NNW of the center for meridional cyclones
- Objects to not fall in rigid categories of primary or multibands but span a wide range of sizes (lengths) and shapes (aspect ratios)
- Stronger mid-level frontogenesis to the north of the cyclone center supports the presence of more band-like objects, especially in meridional cyclones
- Although stable environments are more common than unstable environments in the comma head, low mid-level stability (especially slantwise instability) is associated with more frequent band-like objects
- WRF is able to replicate the general reflectivity structure but struggles to capture the mid-sized objects
- Future work will focus on understanding the microphysical sensitivity to WRF depiction of precipitation objects, for different types of band-producing environments

Questions?

- Contact: Phillip Yeh
  phillip.yeh@stonybrook.edu

- NEXRAD stitched reflectivity and cyclone tracks provided courtesy of Dr. Laura M. Tomkins from NC State University

- Thanks to the IMPACTS team for collecting the data



Supplementary Figures

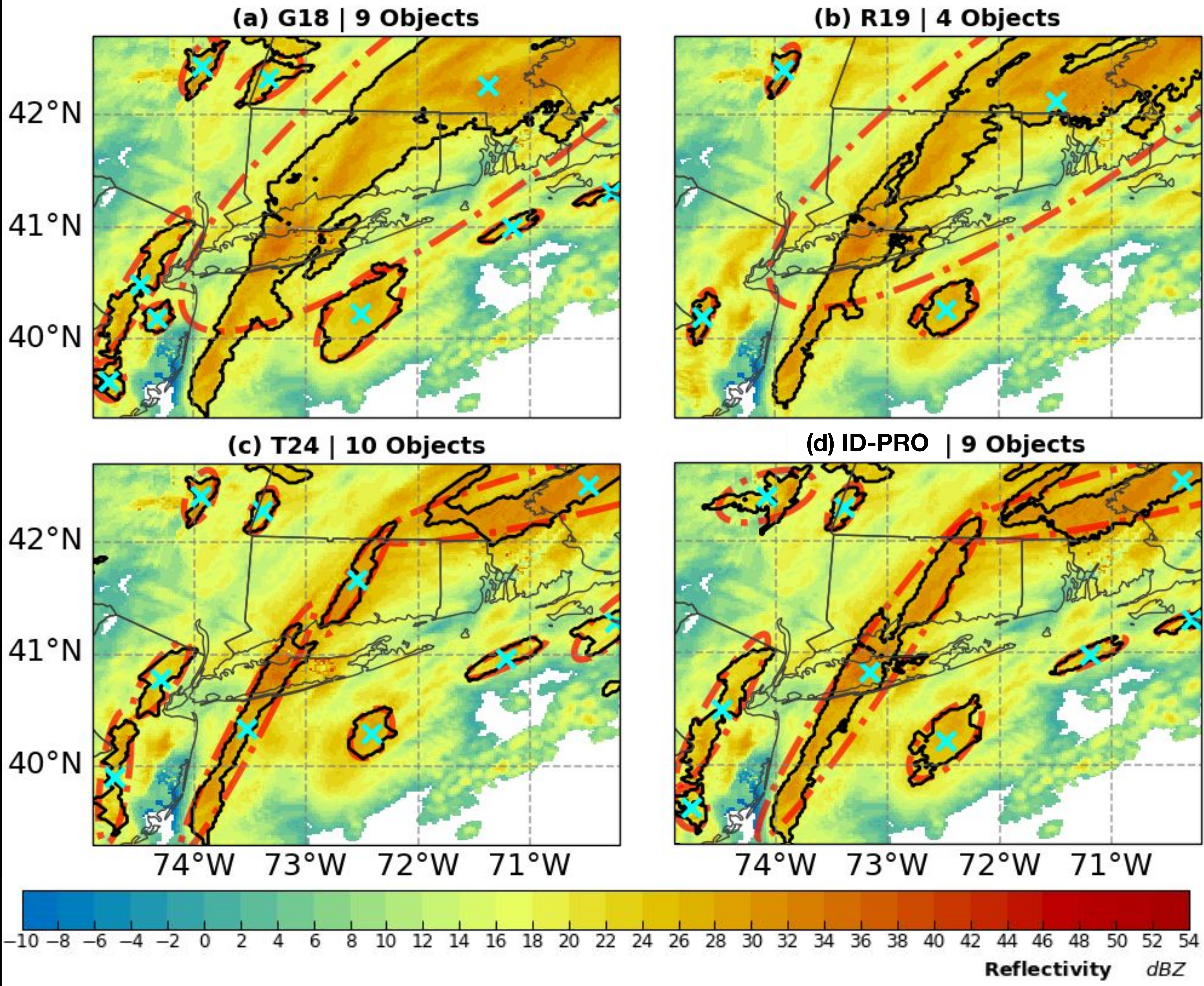
Objective ID Band Algorithms: 12 Feb 2006 Case (1701 UTC)

a) Ganetis (G18)
- Upper Sextile in domain
- Problem with large objects

b) Radford (R19)
- 0 dBZ first, then 1.25 sd above the mean
- Problem with smaller objects

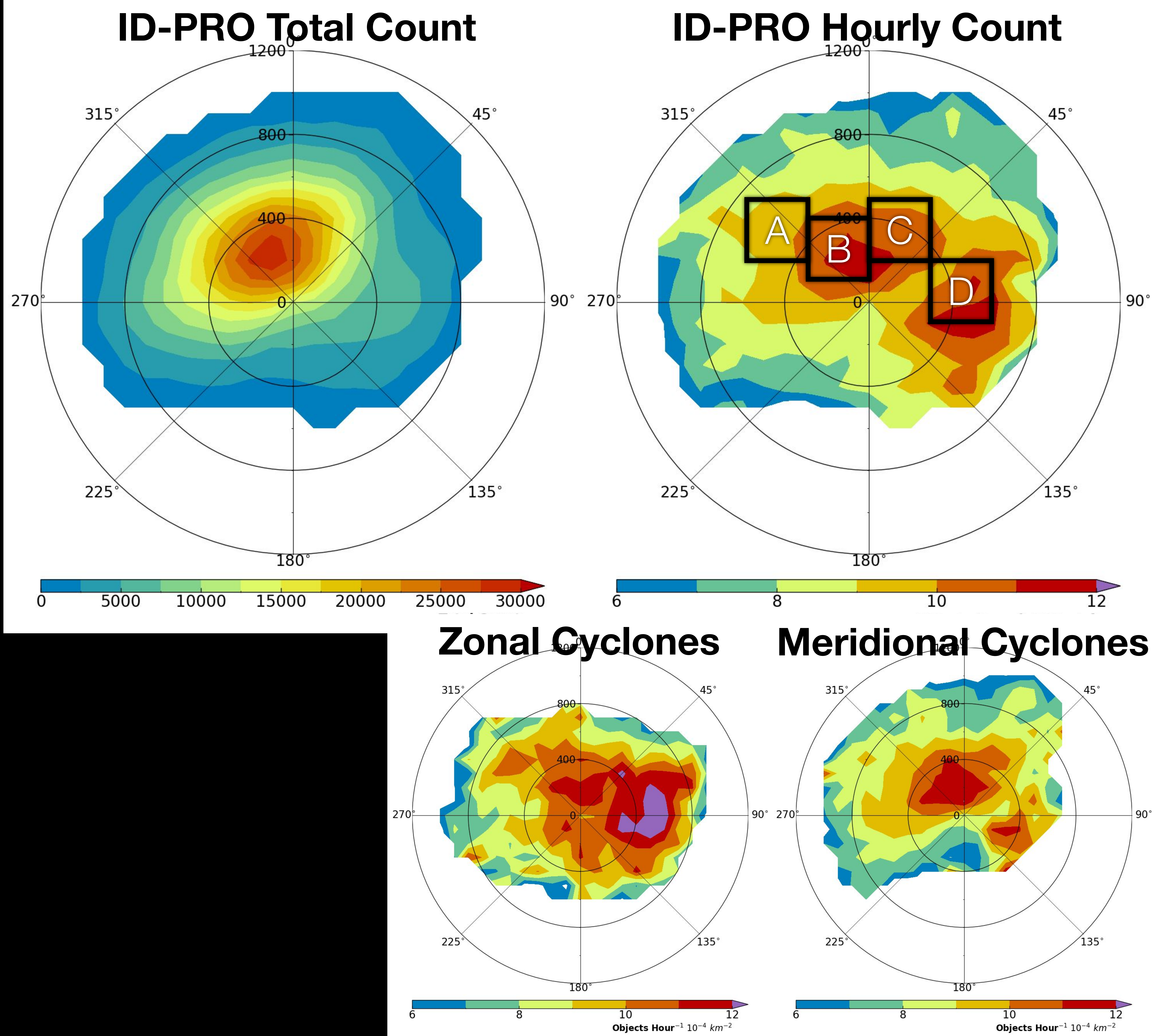
c) T24 (Feature Detection)
- Uses gradients to find locally enhanced regions
- Better separation of objects

d) ID-PRO (New Algorithm - Y24)
- Locally defined thresholds



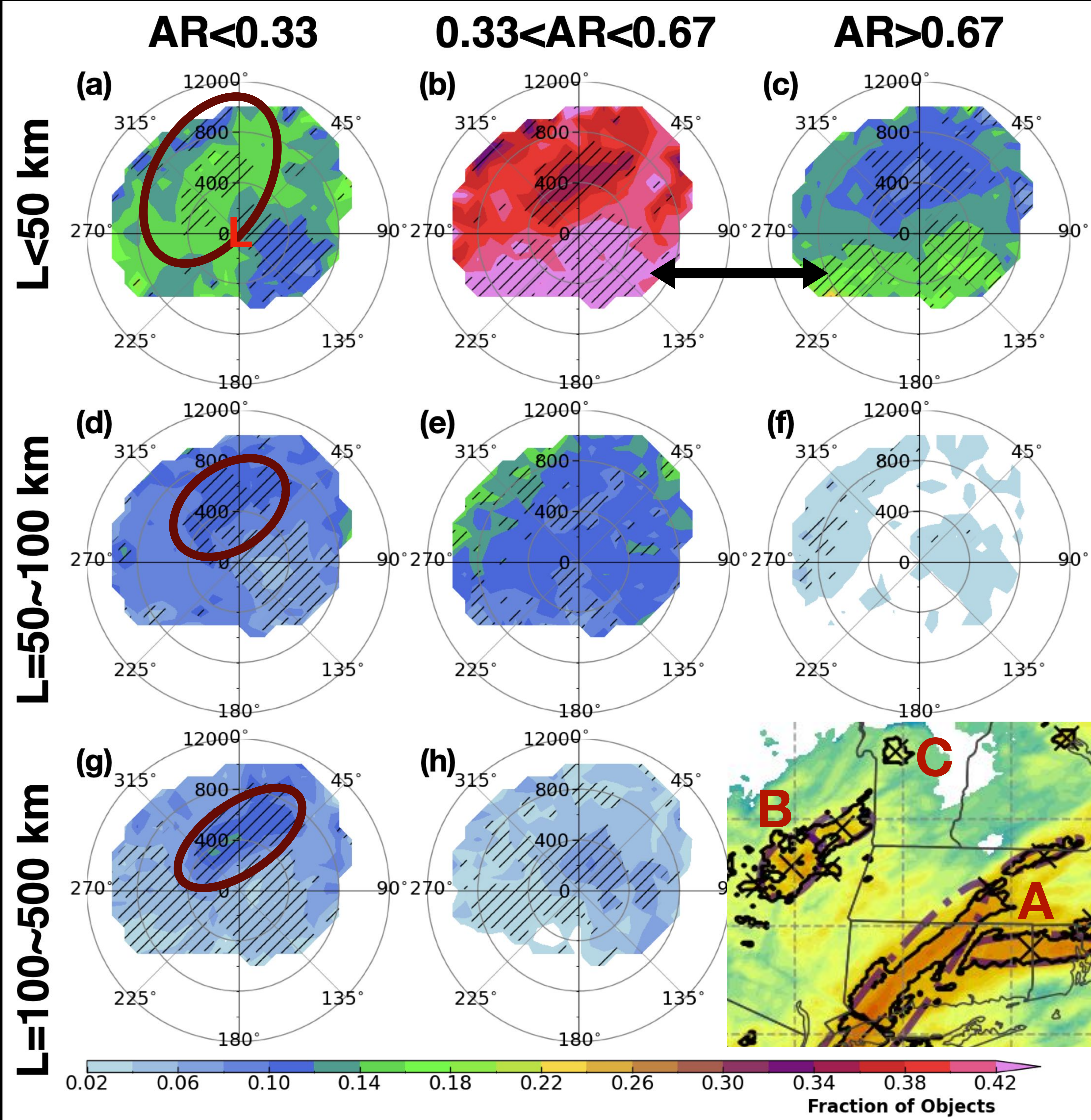
Total Objects 1996-2023

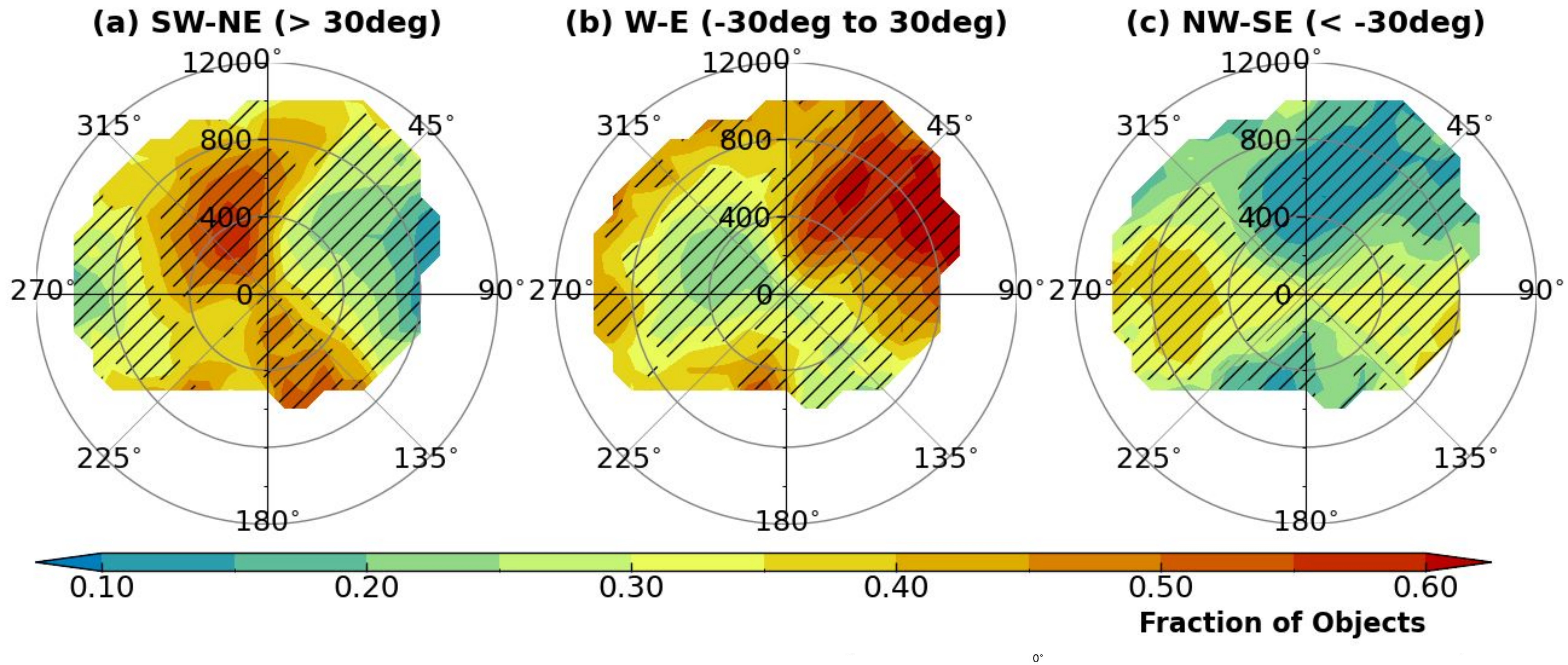
- Most objects detected within 400 km north of cyclone
- Normalized by hour, 2 maxima in object counts
- Zonal cyclones: more objects to the east
- Meridional cyclones: similar maxima to all cases

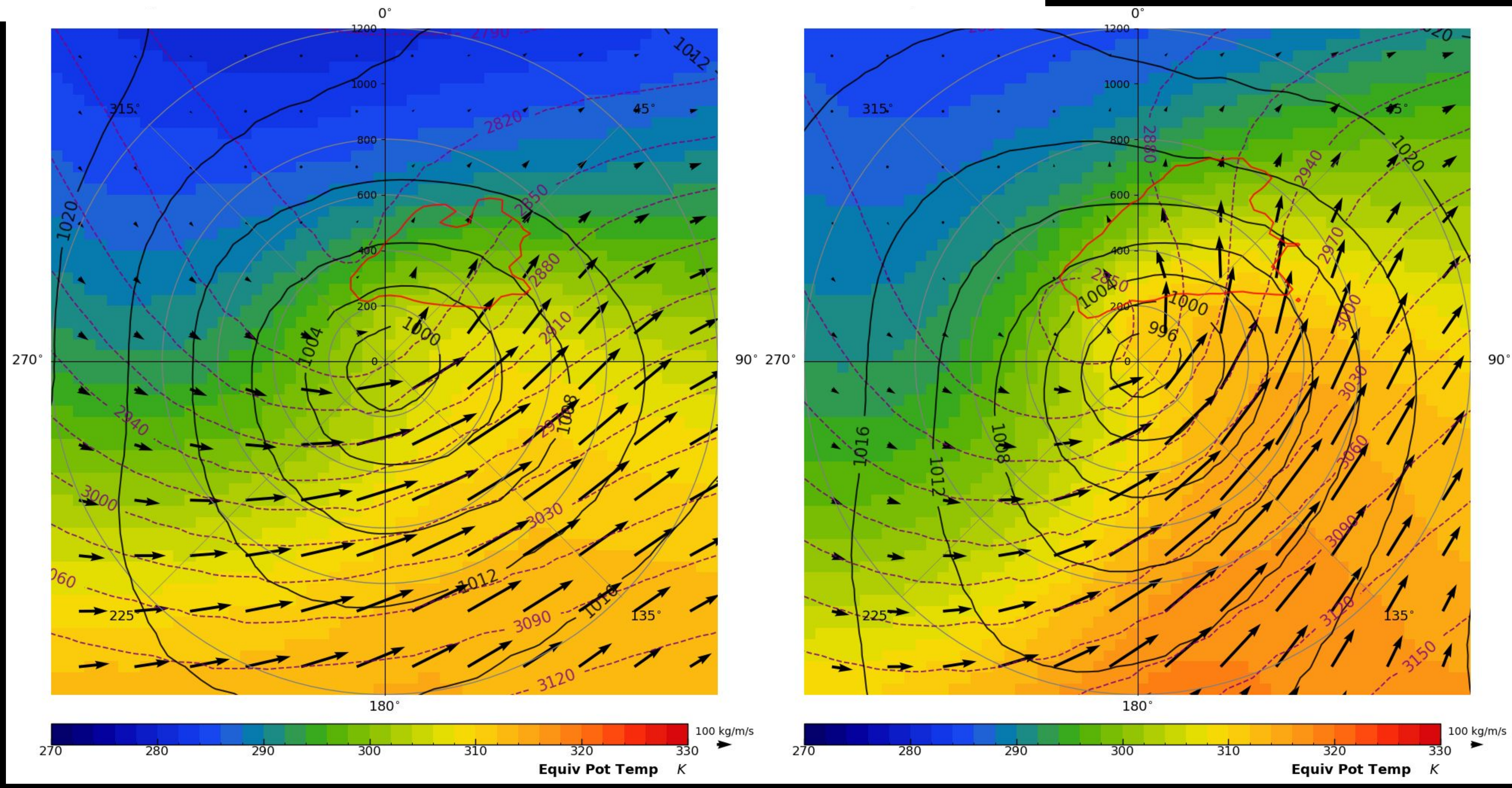


Cyclone-Relative Distributions of Object Lengths and Aspect Ratios (AR)

- < 50 km length range
  - Quasi-linear objects (A) most frequent between 300 km west to 450 km north of cyclone center
  - Amorphous objects (B) and Cells (C) more common on south side
- > 50 km length ranges
  - Lower probabilities of objects overall
  - “Primary band” signal to the north in panel G
  - Cells are rare
- “Primary bands” (L>200 km) are very rare, while

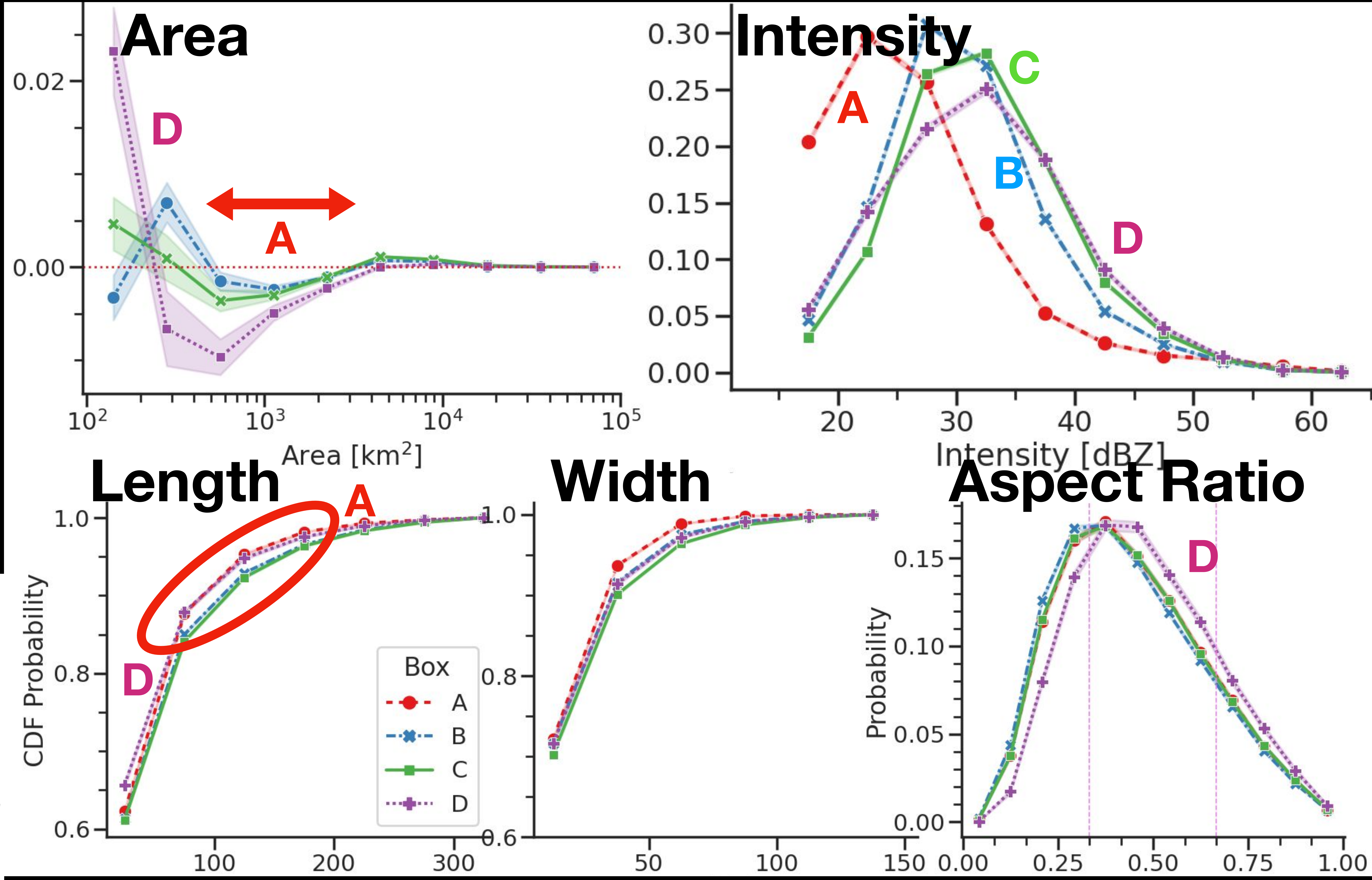


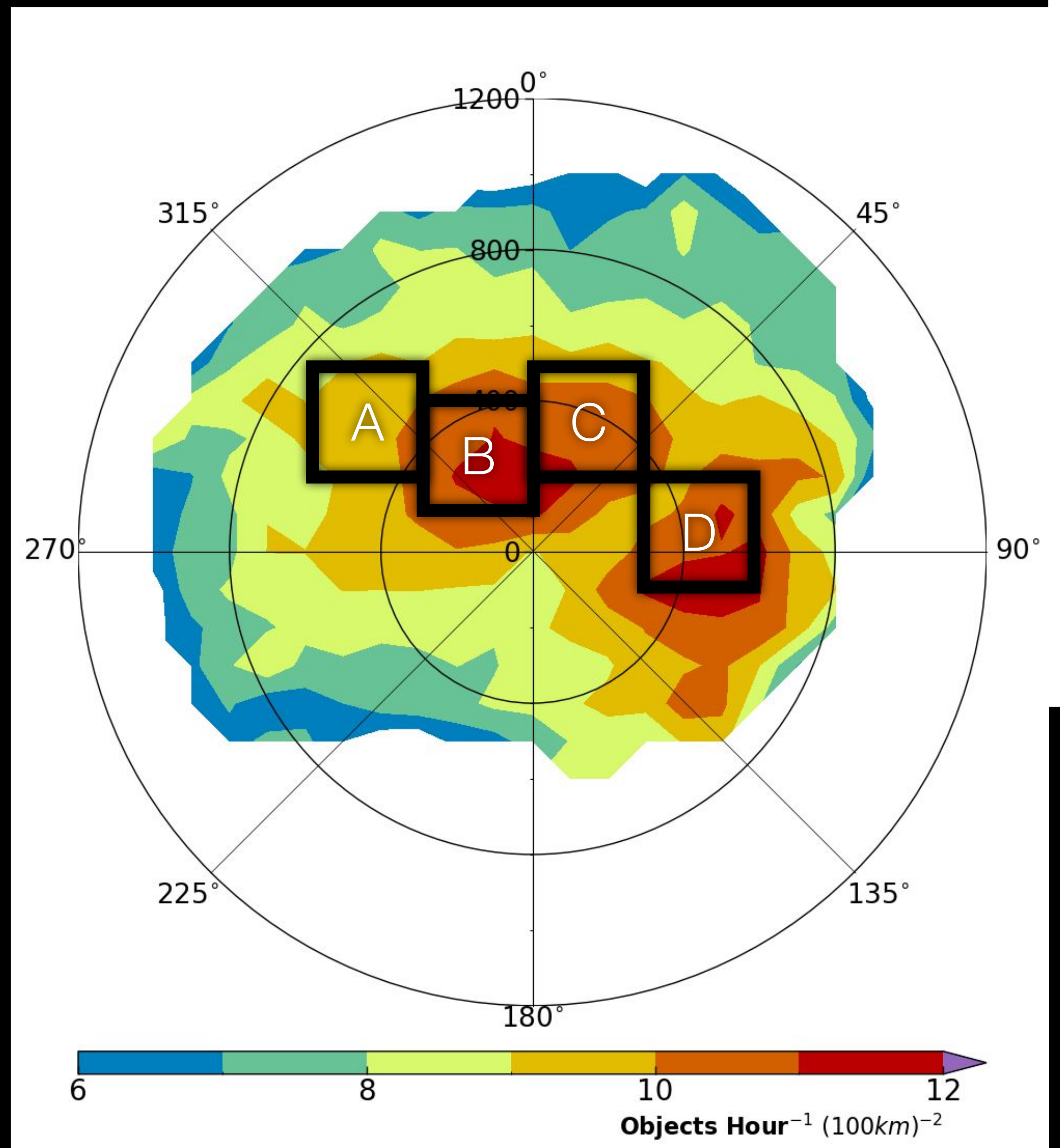

(a) SW-NE (> 30deg)
(b) W-E (-30deg to 30deg)
(c) NW-SE (< -30deg)
0°
45°
90°
135°
180°
225°
270°
315°
0
400
800
1200
0.10
0.20
0.30
0.40
0.50
0.60
Fraction of Objects


0°
90°
180°
270°
Equiv Pot Temp K
100 kg/m/s
270
280
290
300
310
320
330

Statistics of Object Characteristics

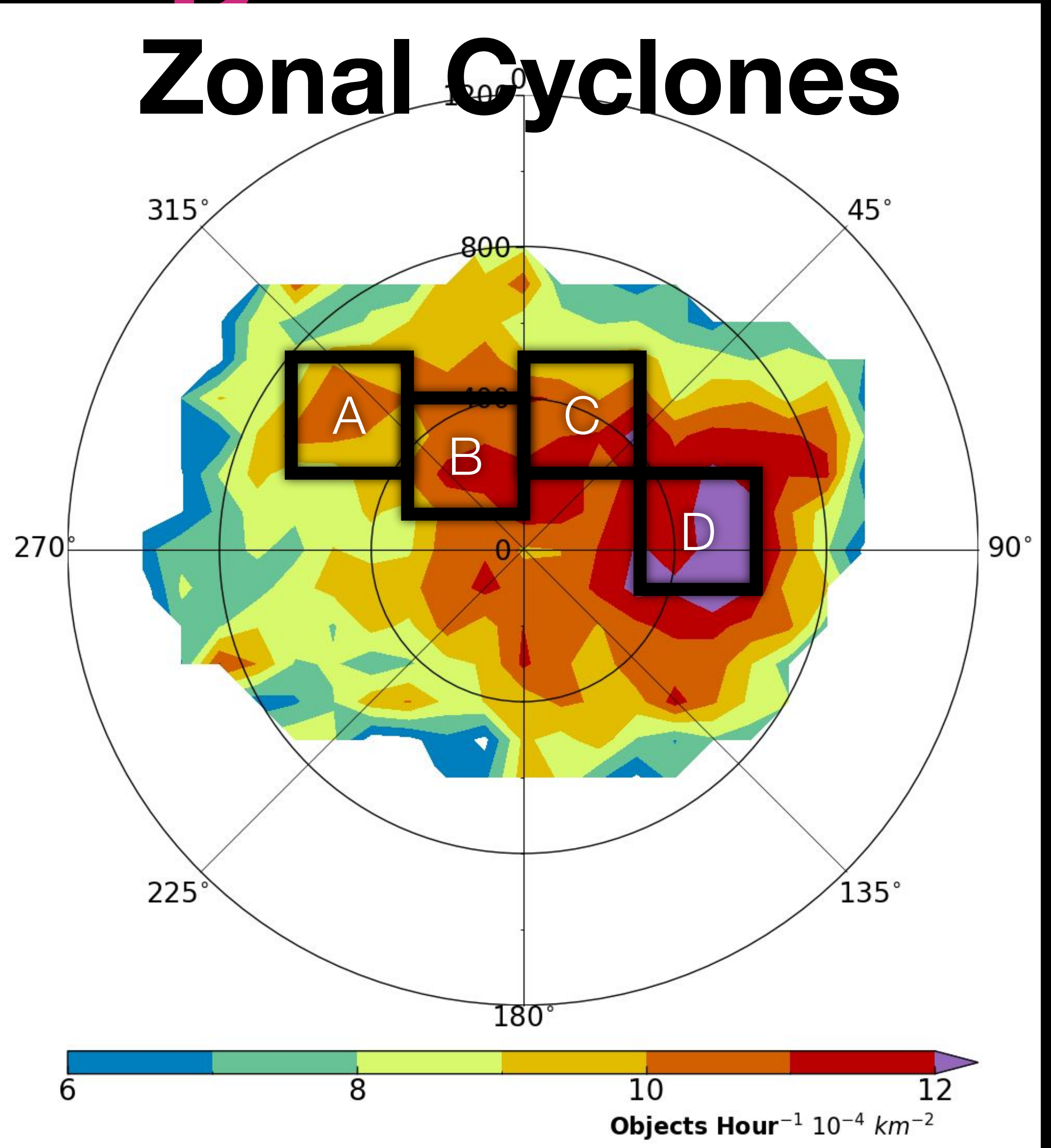
- Box D more likely to have small objects, higher aspect ratios
- Box A more likely to be less intense, medium-sized
- Boxes A and D similar in length, higher probability of L< 200 km than boxes B and C for lengths < 200 km
- No clear separation in the distribution of lengths, areas, or aspect ratios

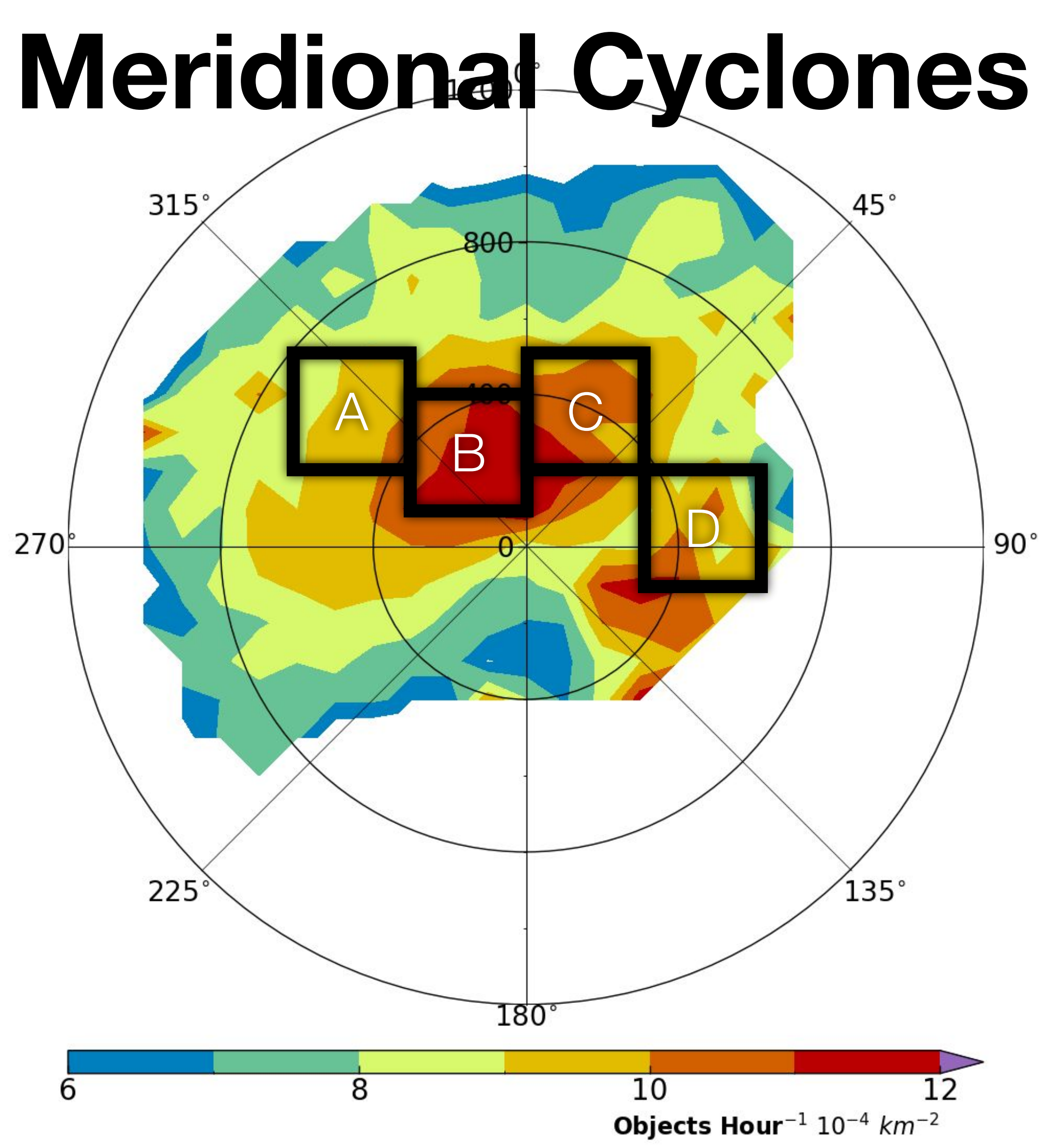


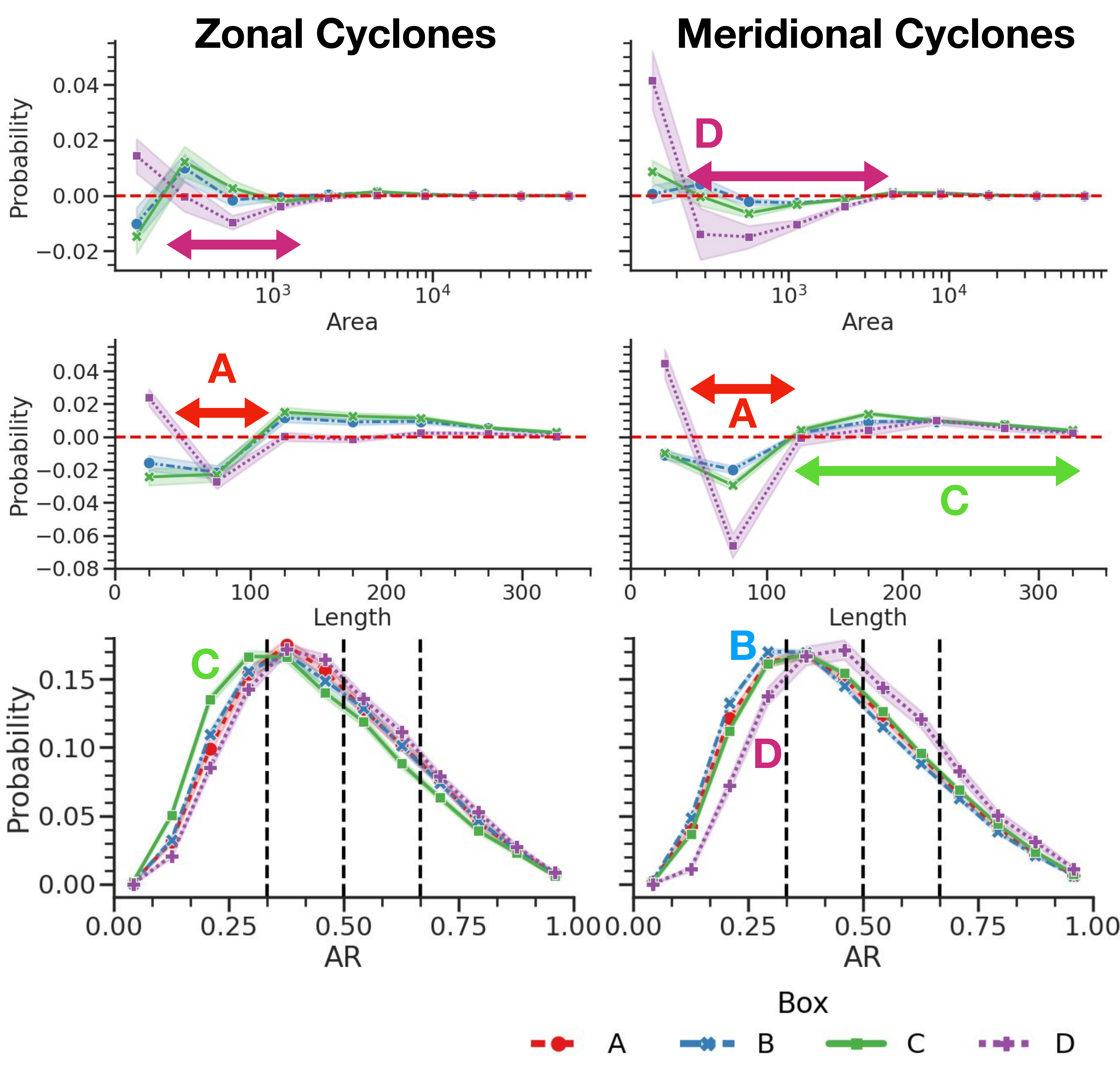


Object Sizes for Different Cyclones

- Similar area distributions for boxes **B** and **C** regardless of cyclone type, box **D** more likely smaller
- Objects are more likely longer in **B** and **C**
- Objects more band-like in box **C** (zonal) or box **B** (meridional), least band-like in box **D**







Objects Sampled 2020~2023

- Consistent number of objects/frame sampled regardless of quadrant
- Objects sampled in the NE, NW, and SW quadrants generally have SW-NE orientation (more common than mean climatology)
- NE and SW quadrant objets have the highest intensities (similar to mean climatology)
- Largest objects were sampled in NW and NE quadrants (smaller than the mean climatology)