Paper review

mainly refer to

Doppler Radar Analysis of the Eyewall Replacement Cycle of Hurricane Matthew (2016) in Vertical Wind Shear

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Introduction(1/2)

- The radar observations indicate that Matthew underwent an ERC process where the primary eyewall was replaced with a weaker outer eyewall, but unlike a classic ERC (Willoughby 1982; Black and Willoughby 1992; Sitkowski et al. 2011), Matthew did not reintensify.
- The observations also show the presence of significant asymmetries due to increased vertical wind shear and possible land interactions throughout the process.
- A key element of the structural changes of the storm during a canonical ERC is the replacement of an older, weakening inner eyewall by a newer, intensifying outer eyewall. The paradigm of a classic ERC in an axisymmetric framework in terms of the intensity change is associated with three phases: intensification (Shapiro and Willoughby 1982; Smith et al. 2009; Bell et al. 2012b), weakening (Hoose and Colón 1970; Houze et al. 2007; Rozoff et al. 2008; Bell et al. 2012b; Didlake et al. 2017) and reintensification (Sitkowski et al. 2011, 2012).

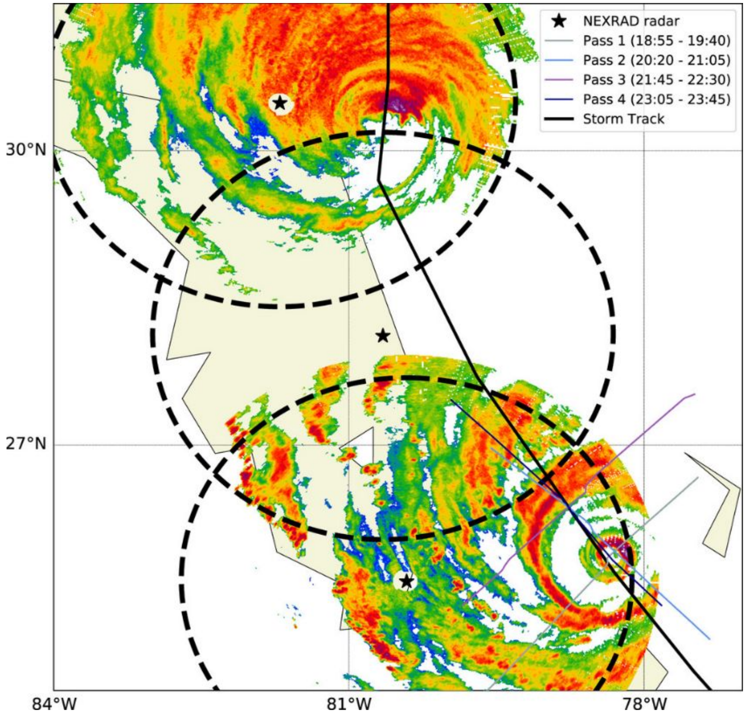
Introduction(2/2)

- Vertical wind shear (VWS) results in the strongest convection on the downshear left, with a transition to stratiform precipitation occurring when the cells reach the upshear side of the eyewall (Black et al. 2002; Hence and Houze 2012; DeHart et al. 2014; Foerster et al. 2014; Boehm and Bell 2021).
- Guimond et al. (2020) suggested that vortex Rossby waves (VRWs) contributed to Hurricane Matthew's (2016) secondary eyewall formation by spinning up the outer core tangential wind.
- Reasor et al. (2009) and Reasor and Eastin (2012) further supported the reduction of vortex tilt by the VRW damping mechanism in response to the shear forcing using observations of Hurricane Guillermo (1997).
- In this study, we investigate the interaction between environmental VWS and internal vortex dynamics in Matthew's ERC, and document the axisymmetric and low-wavenumber evolution with the triple-Doppler and single-Doppler analyses.

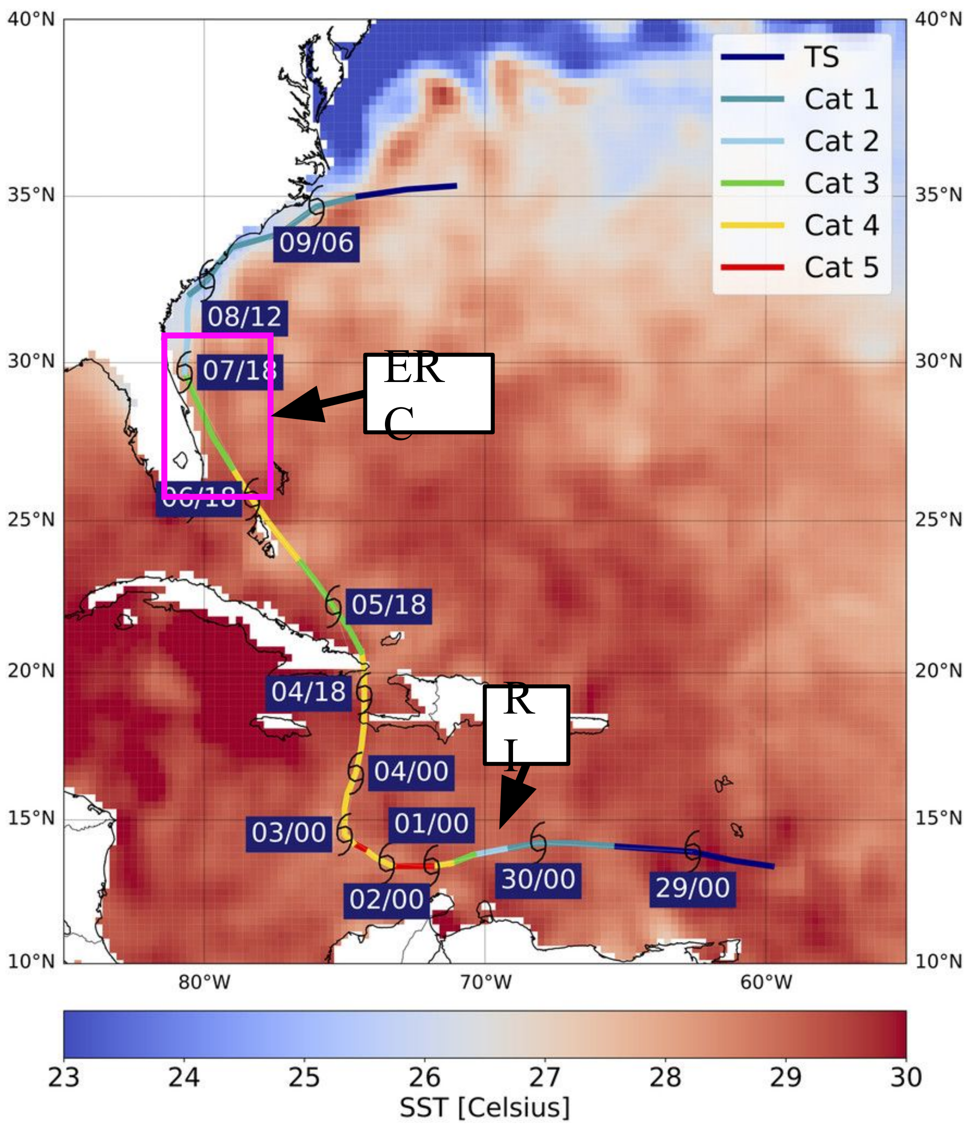
Dataset and analysis methodology

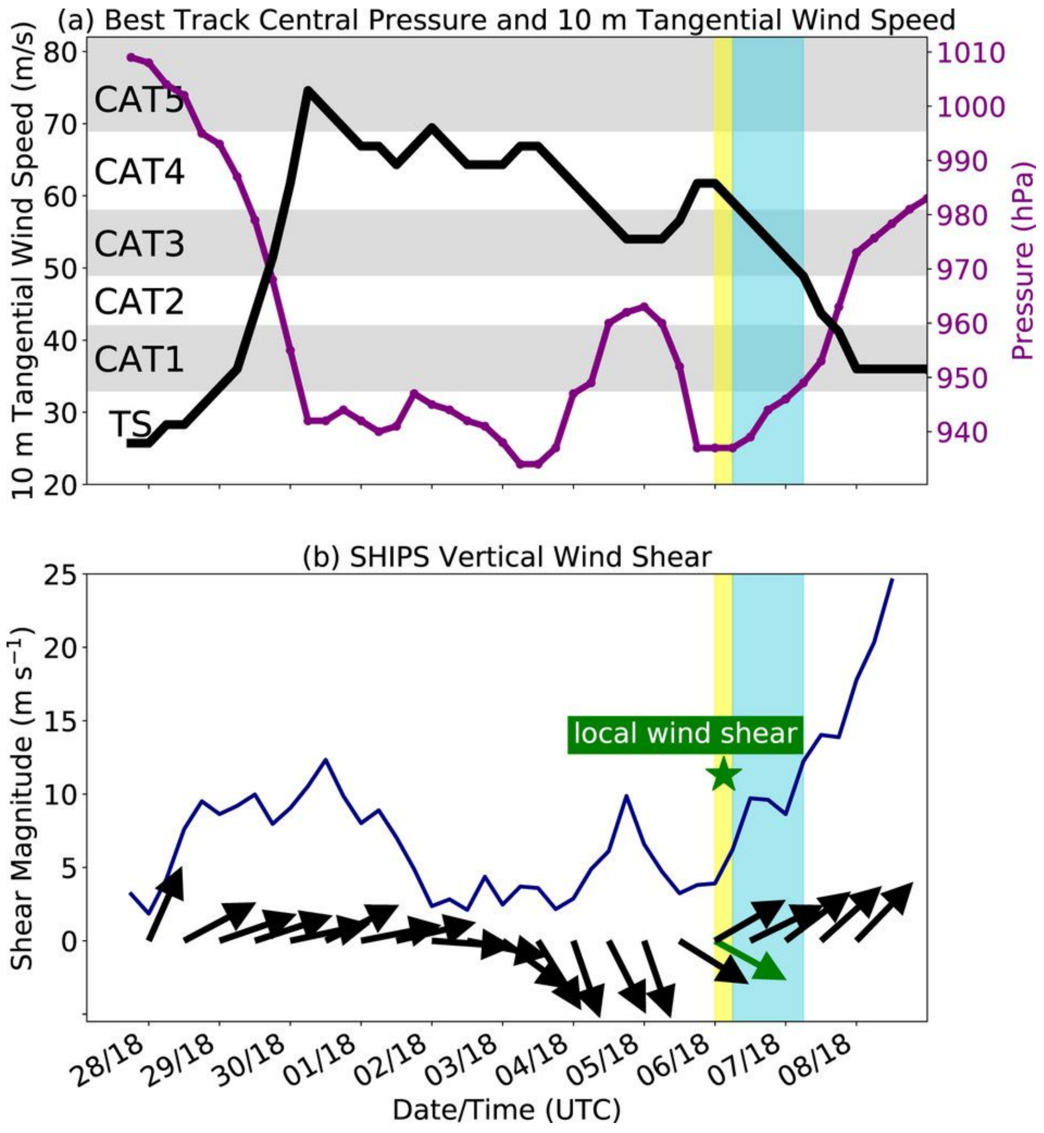
- Full radar volumes were available from each radar at approximately 5-min intervals and were processed with lidar Radar Open Software Environment (LROSE) software (Bell 2019) and were quality controlled to remove nonmeteorological echoes and correct velocity aliasing (Bell et al. 2013).
- The edited data were analyzed by the Vortex Objective Radar Tracking and Circulation (VORTRAC) software using the GVTD technique with an improved algorithm to retrieve the kinematic structure (Jou et al. 2008; Cha and Bell 2021).
- Aircraft-derived dynamic centers (Willoughby and Chelmow 1982) from the Hurricane Research Division (HRD) were utilized as stable, reference centers to perform the GVTD technique.
- Each pass and one volume of KAMX data were synthesized at 1-km horizontal nodal spacing and 0.5-km vertical nodal spacing with Spline Analysis at Mesoscale Utilizing Radar and Aircraft Instrumentation (SAMURAI) software (Bell et al. 2012a; Foerster et al. 2014; Foerster and Bell 2017) in LROSE.
- Additional datasets:
  - Best track and intensity from the National Hurricane Center (NHC)
  - Environmental vertical shear from the Statistical Hurricane Intensity Prediction Scheme dataset (SHIPS; DeMaria et al. (2005)).
  - The measurements of surface wind during the four passes are obtained from the Stepped Frequency Microwave Radiometer (SFMR; Uhlhorn et al. (2007)).

Radar analysis	Duration
Pass 1	P3: 1855–1940 UTC 6 Oct KAMX: 1920 UTC 6 Oct
Pass 2	P3: 2020–2105 UTC 6 Oct KAMX: 2039 UTC 6 Oct
Pass 3	P3: 2145–2230 UTC 6 Oct KAMX: 2211 UTC 6 Oct
Pass 4	P3: 2305–2340 UTC 6 Oct KAMX: 2323 UTC 6 Oct
KAMX radar	1907 UTC 6 Oct–0550 UTC 7 Oct
KMLB radar	0125–1800 UTC 7 Oct
KJAX radar	1307 UTC 7 Oct–0009 UTC 8 Oct

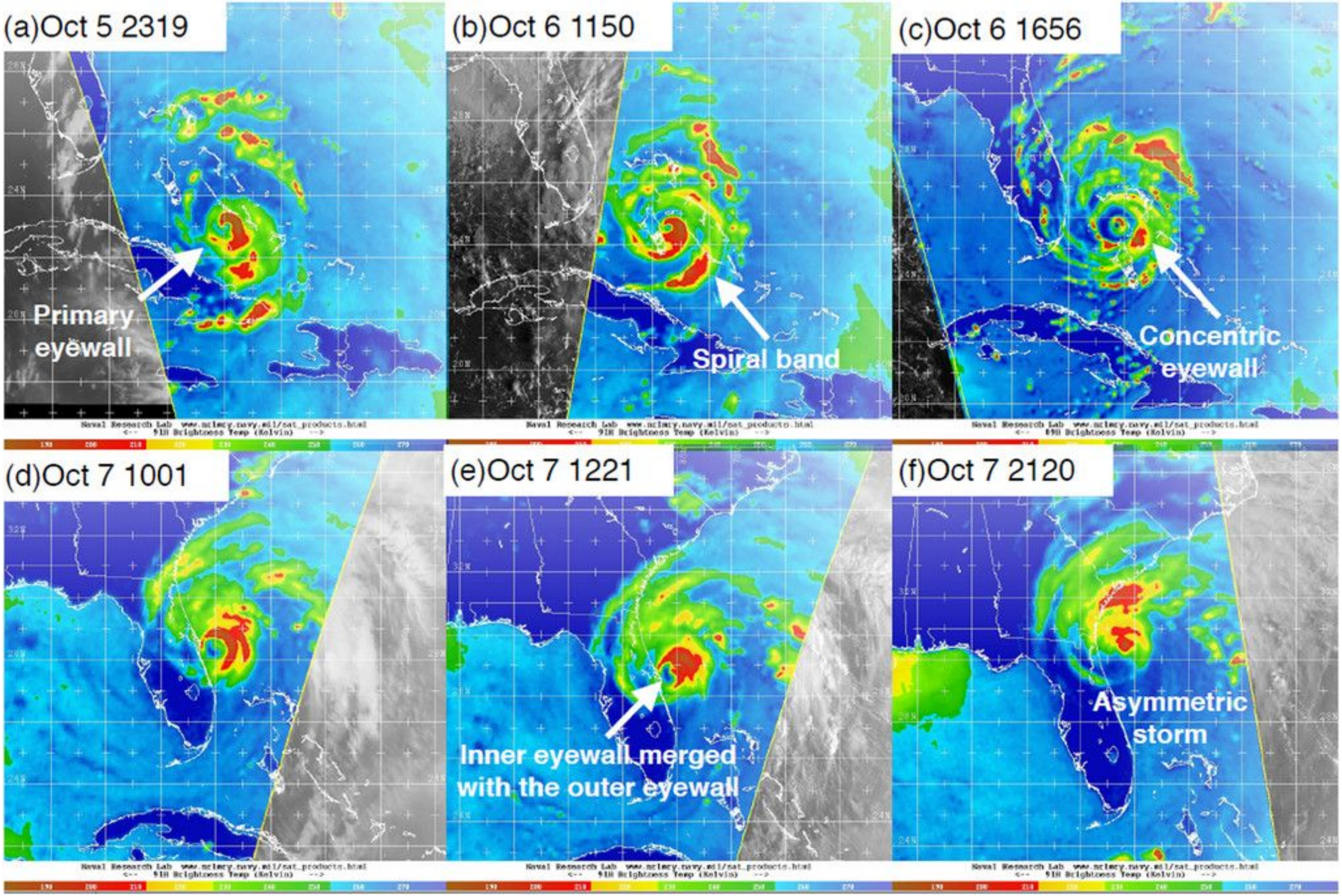


Hurricane Matthew (2016)



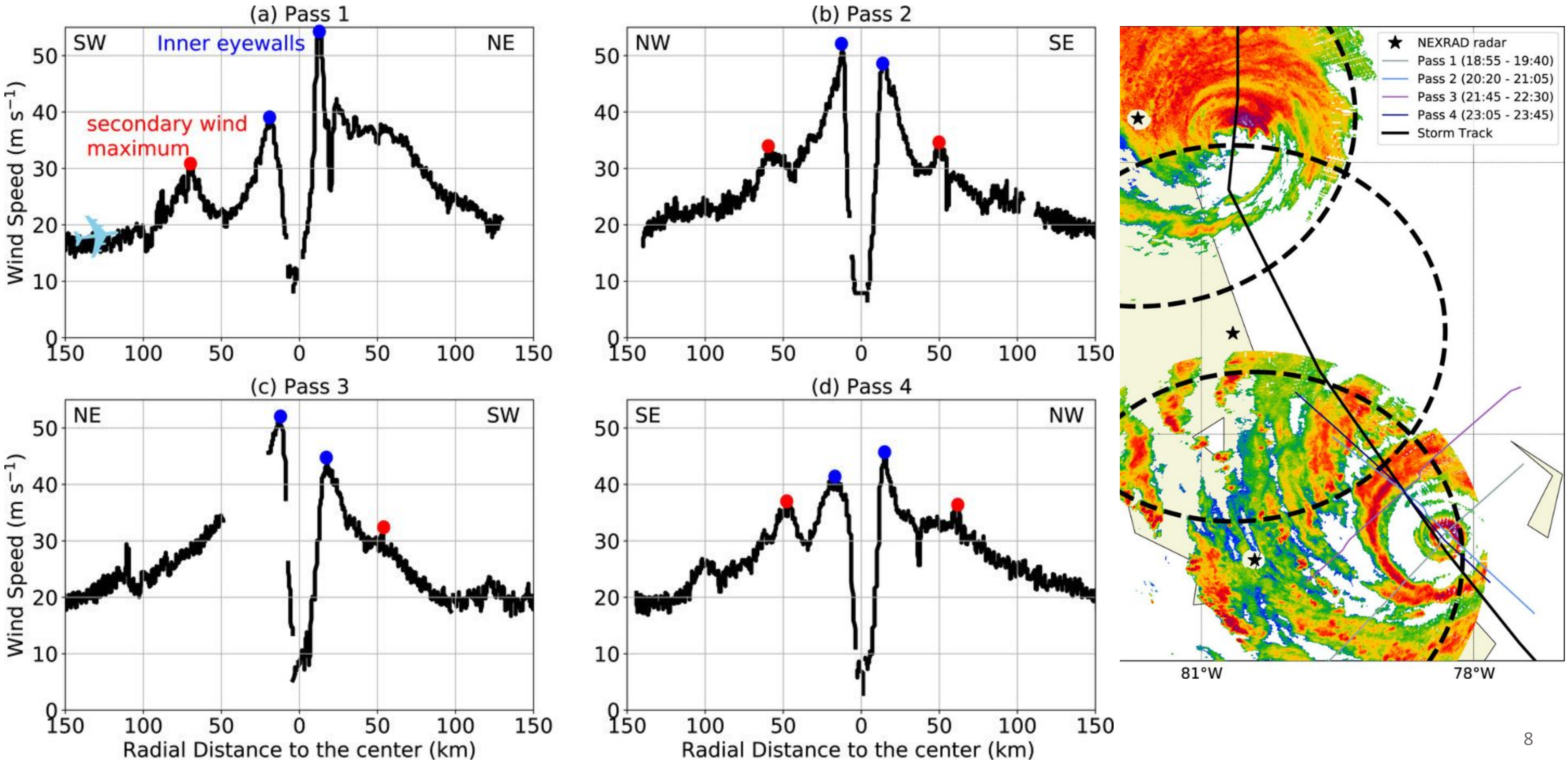


The 89- and 91-GHz microwave satellite imagery



P3 SFMR observations

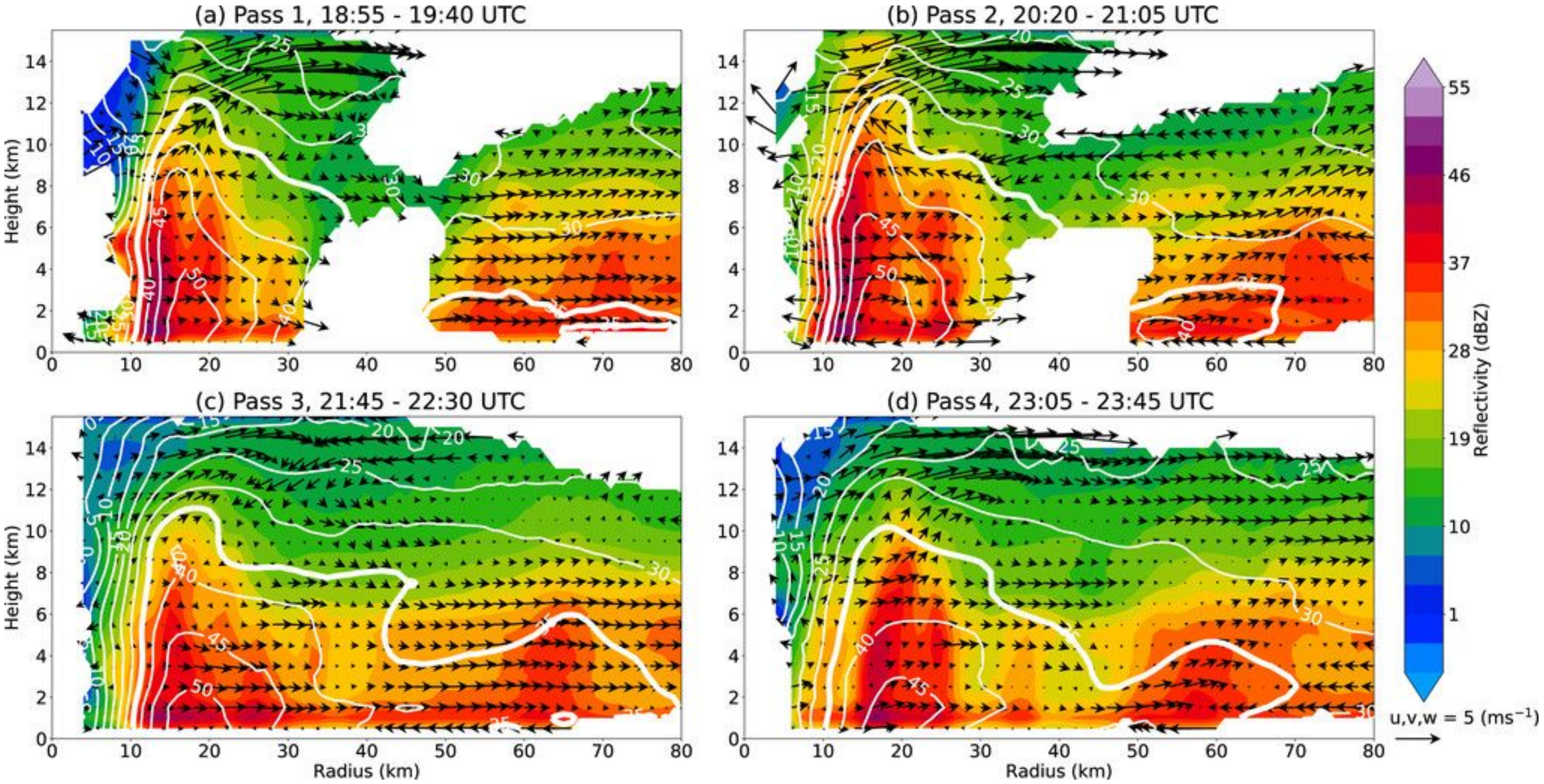
Stepped Frequency Microwave Radiometer (Uhlhorn et al. (2007))



Axisymmetric structure

Triple-Doppler analysis

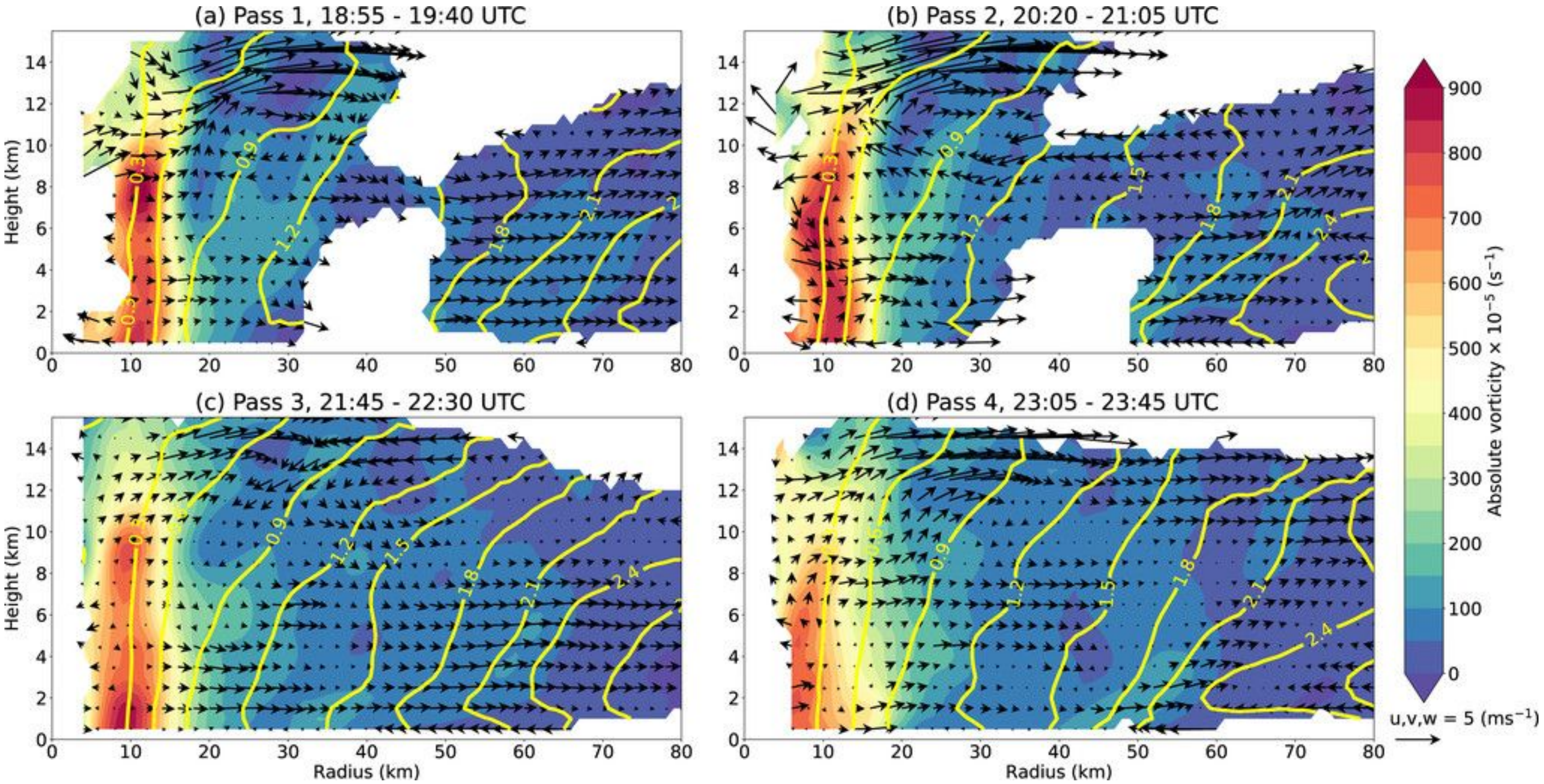
- Azimuthally averaged reflectivity (shaded)
- Primary circulation (white contours, m s^{-1})
- Secondary circulation (vectors)



Axisymmetric structure

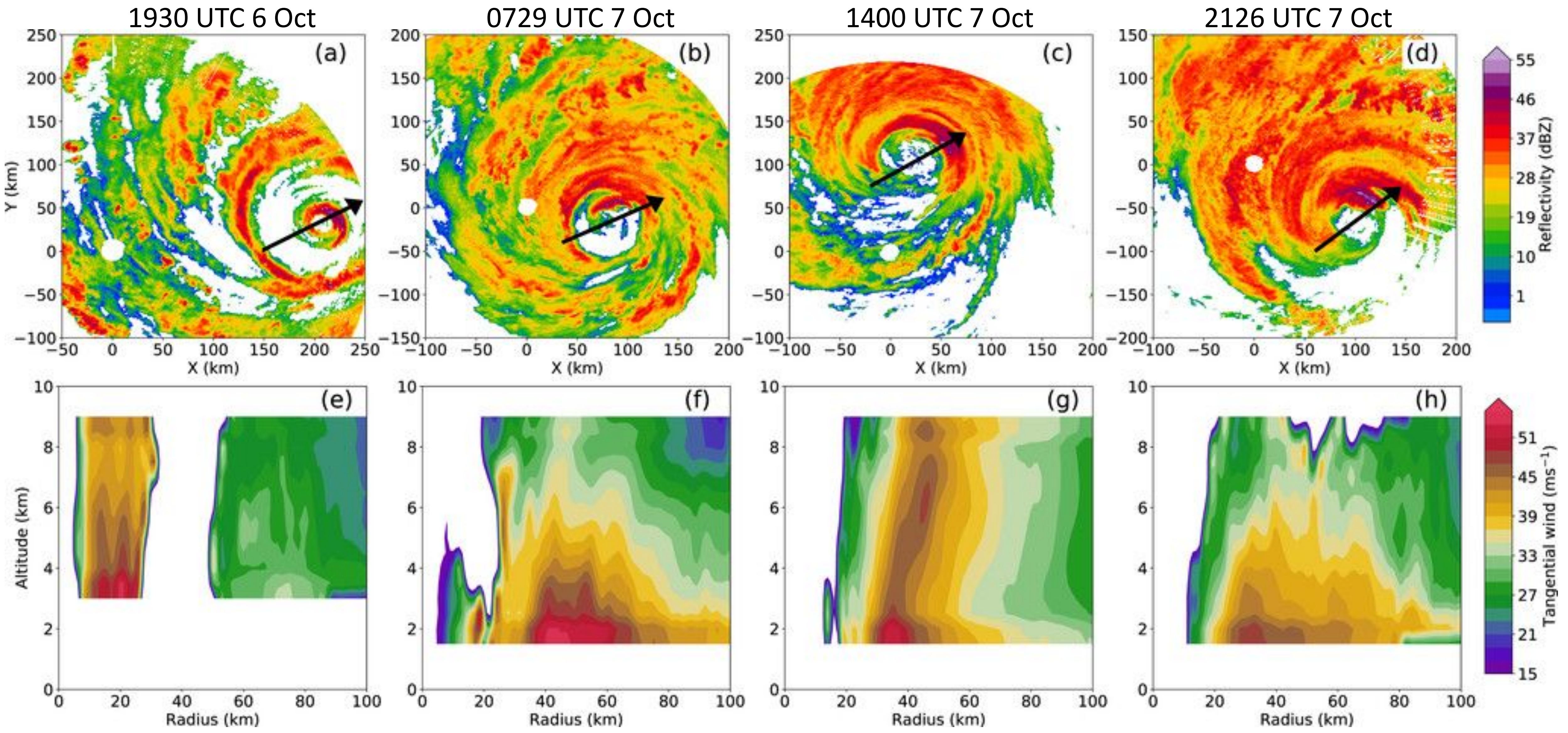
Triple-Doppler analysis

- Azimuthally averaged absolute vorticity (shaded, 10^{-5} s^{-1})
- Absolute angular momentum (yellow contours, 10^{-6} m^2 s^{-1})
- Secondary circulation (vectors)



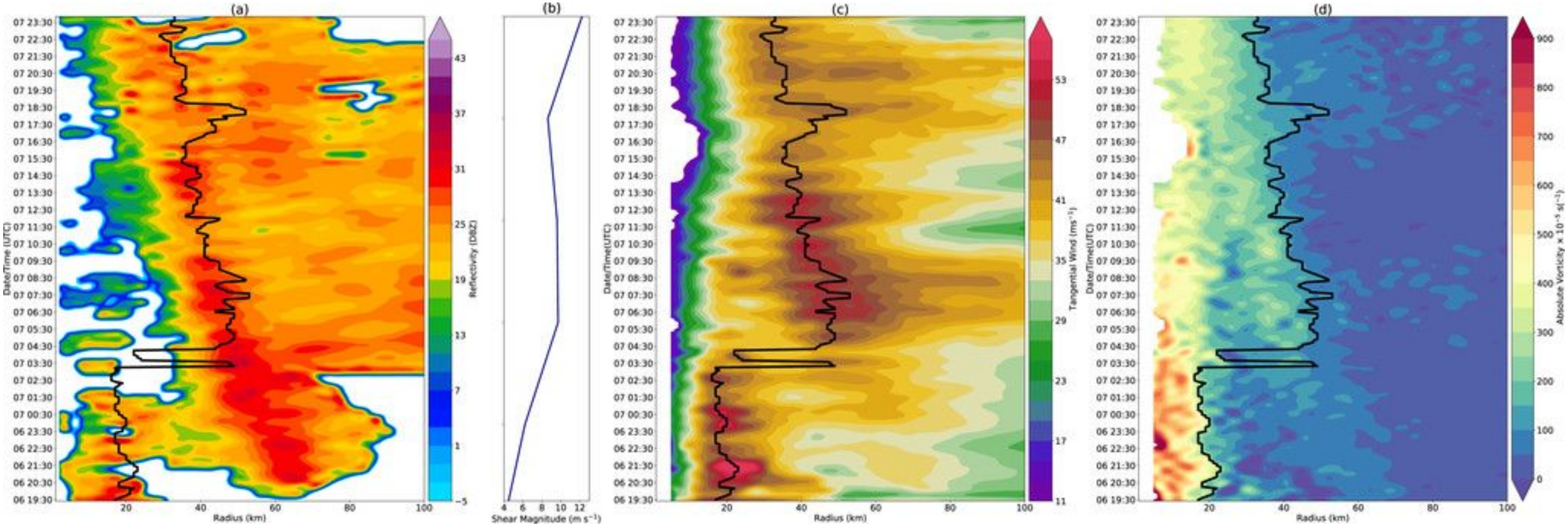
Axisymmetric structure

Single-Doppler analysis



Axisymmetric structure

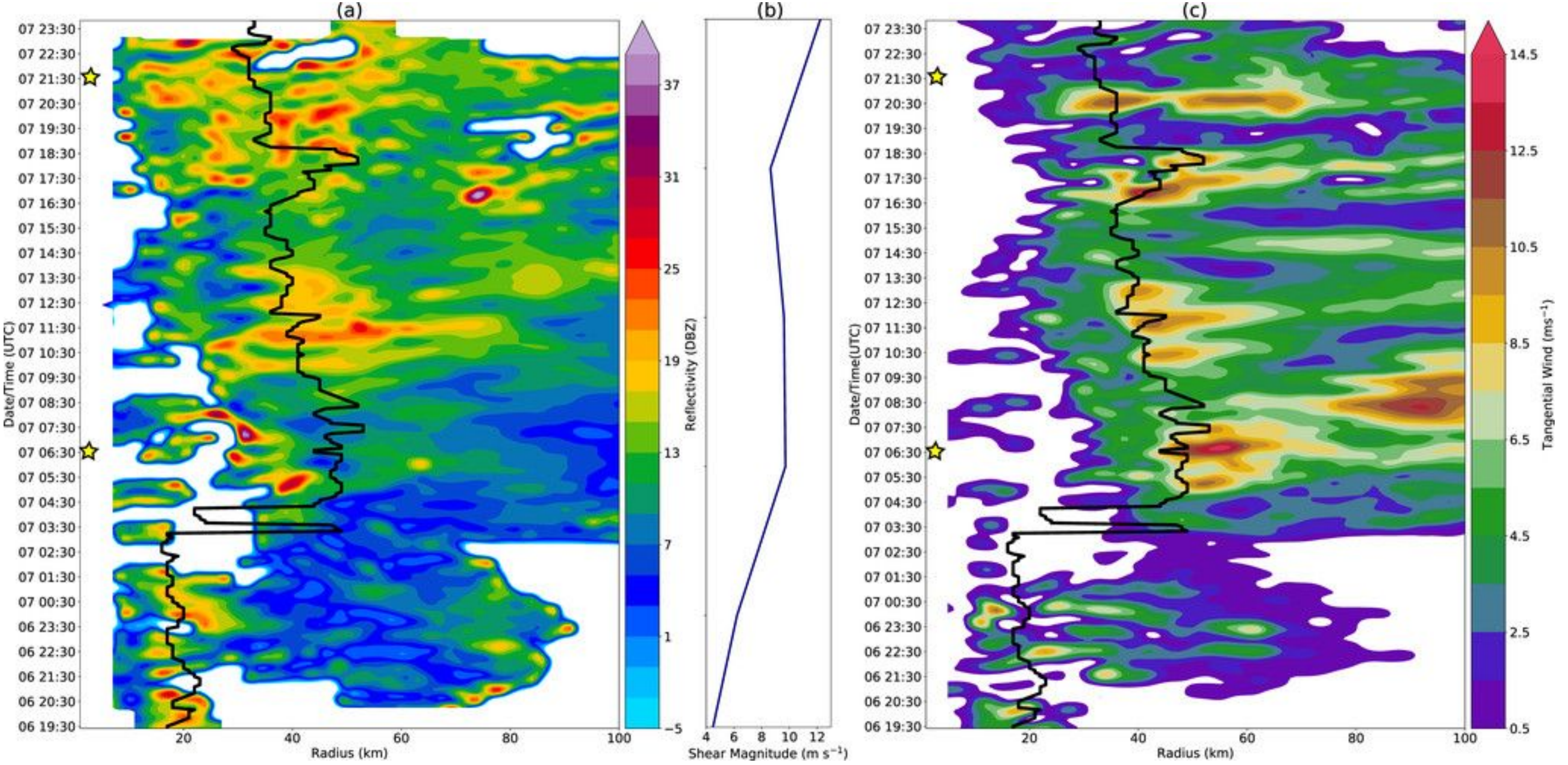
Time–radius diagram



The contraction rate of the outer eyewall is 1.5 km h^{-1}, which is similar to the composite value of 1.75 km h^{-1} in Sitkowski et al. (2011).

Asymmetric structure

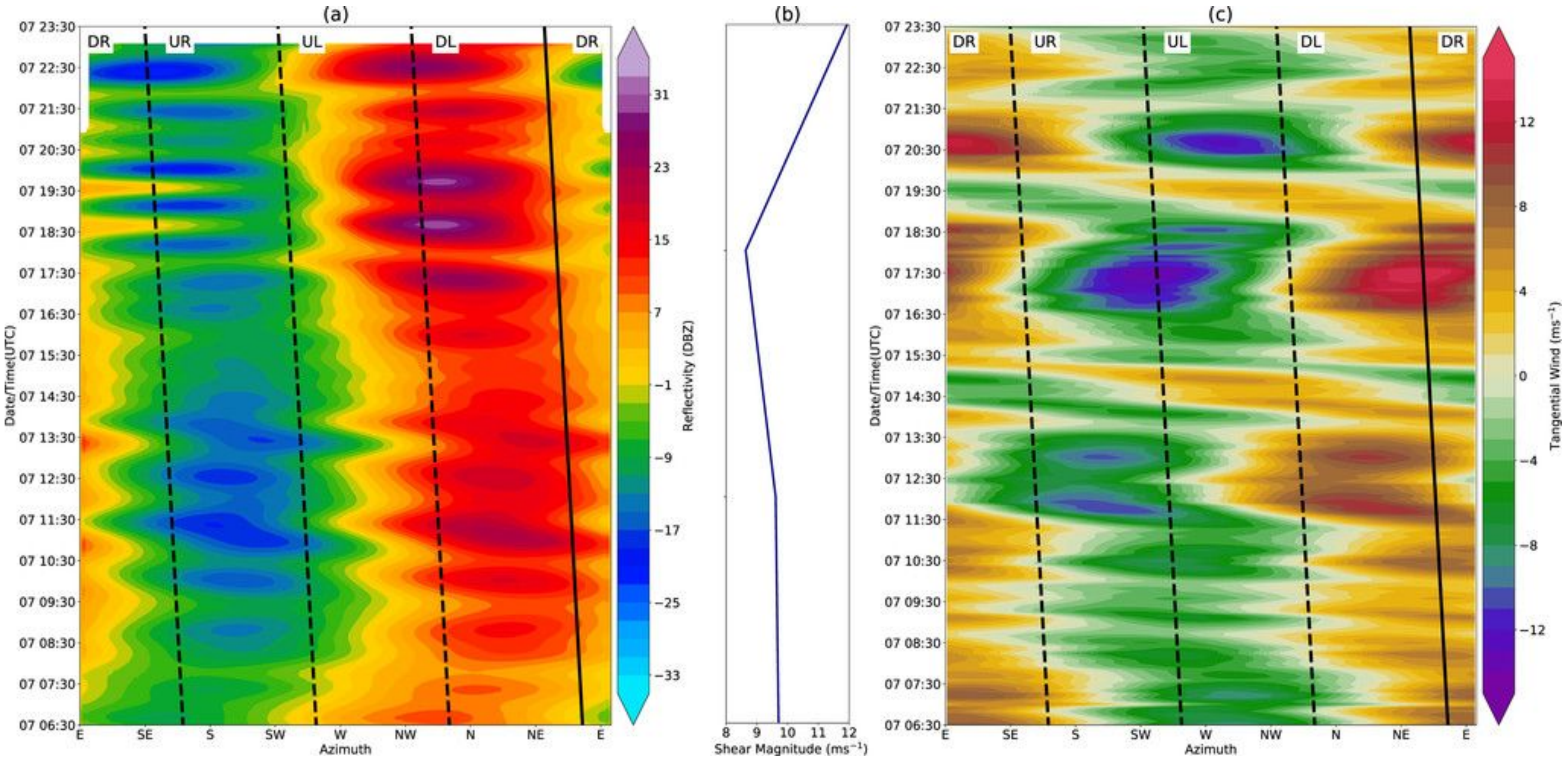
Wavenumber-1 evolution



Asymmetric structure

RMW – 2 km and RMW + 2 km

The combination of the internal vortex dynamics, environmental properties, land interaction, and shear direction may have played a role in the azimuthal distribution of wavenumber-1 reflectivity and tangential wind.

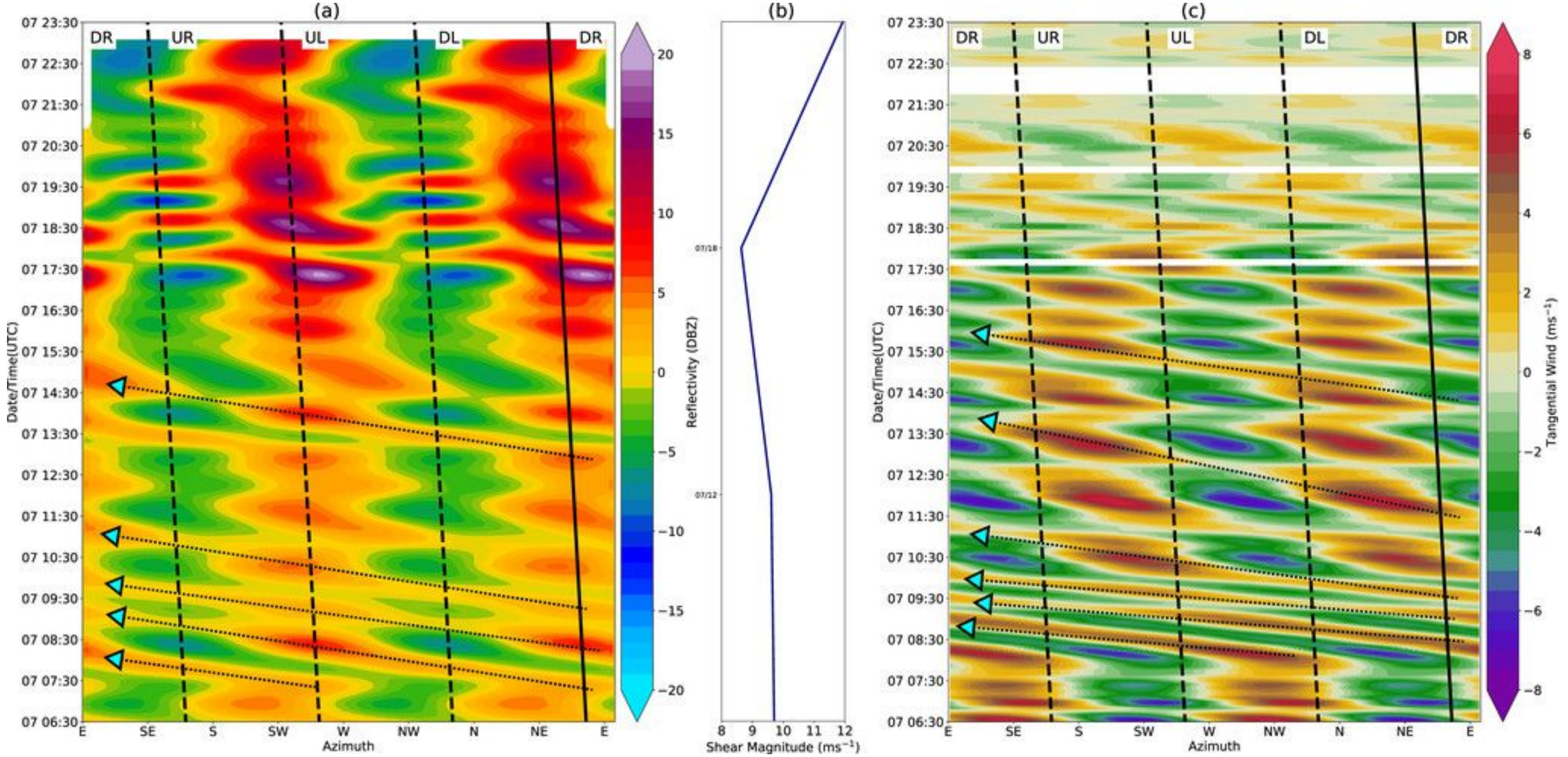


Asymmetric structure

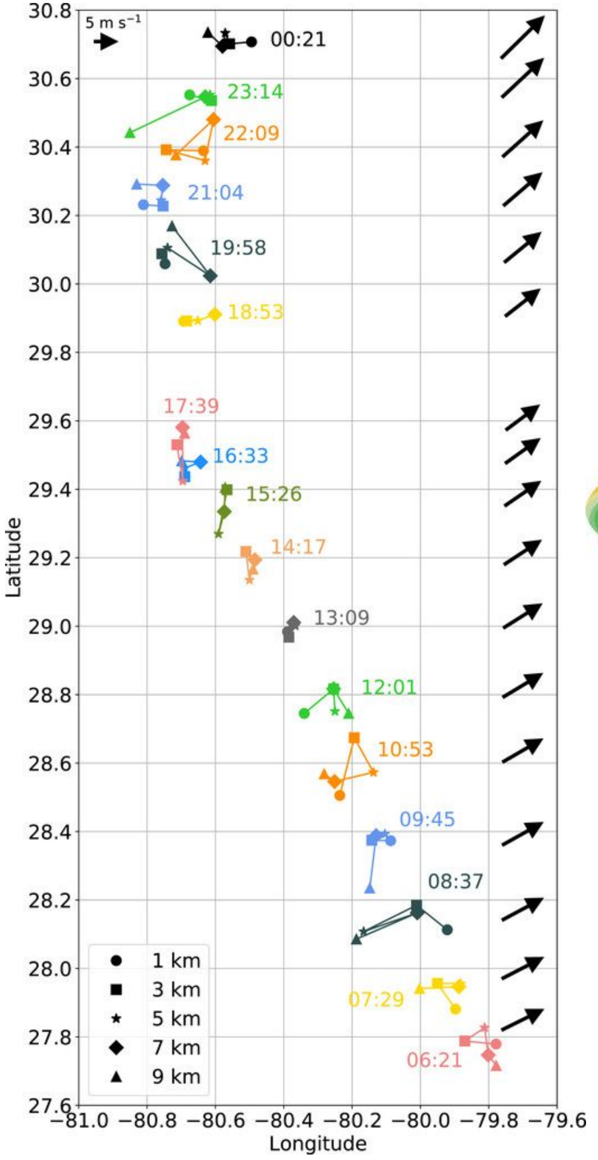
Wavenumber-2 evolution

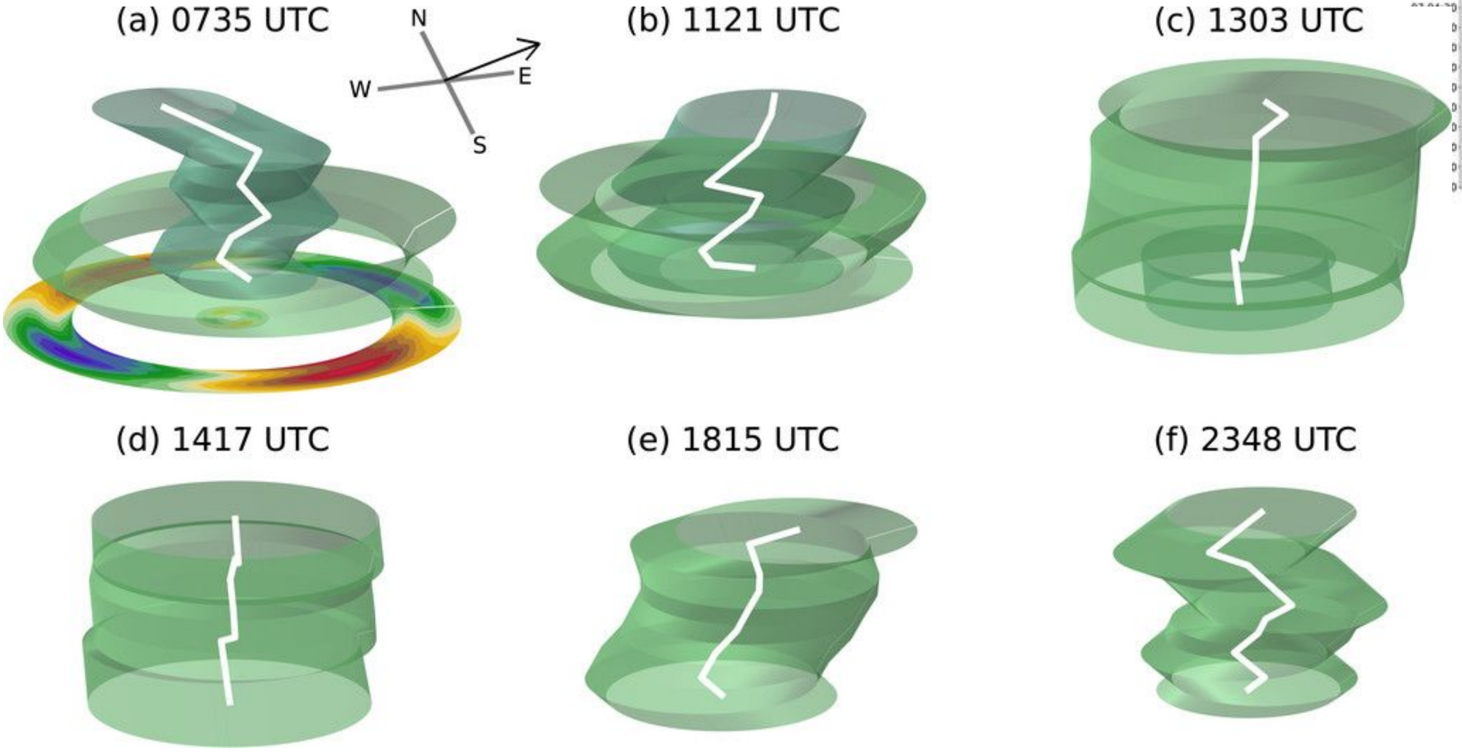
$$C_\lambda = V_{max}(1 - 1/n)$$

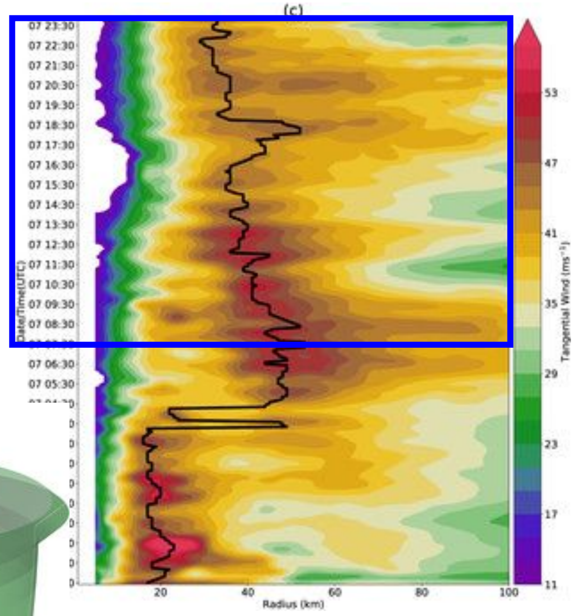
The retrieved phase speed is about 58% of the maximum tangential speed of the mean flow, consistent with the linear wave theory.



Vortex realignment process







Conclusions

- Matthew's ERC process was a complex combination of both internal axisymmetric and asymmetric dynamics that were impacted by external factors of environmental shear and land interaction.
- The canonical ERC process can be interrupted by strong shear, and in Matthew's case was not able to enter the reintensification stage found in other ERCs.
- The reduction of vortex tilt despite increasing shear and presence of VRW activity suggests that the VRW damping mechanism and vortex resiliency conceptual model proposed by Reasor et al. (2004) may be applicable to the ERC process.