

Using SAR to Diagnose the Boundary Layer Structure of Hurricane Larry, 7 Sep 2021

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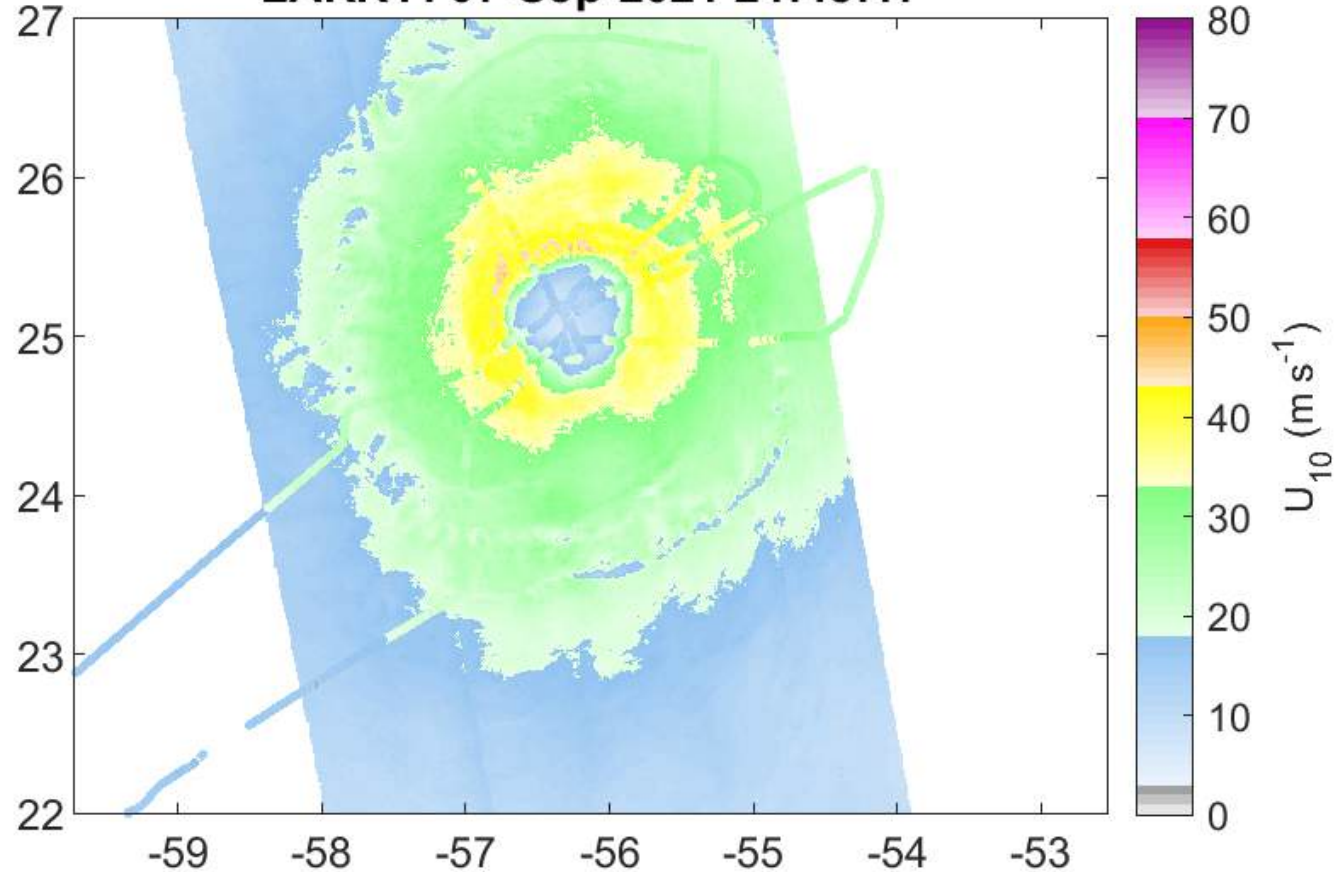
Take-Home Messages

- ***Using only SAR images of TCs, derive:***
 - Reasonable mean wind profiles in the TC PBL
 - TC PBL roll characteristics (scale, orientation & magnitude)
- TC PBL characteristics are *sensitive & independent* test of $K(z)$ formulations used in numerical models
- Validation against IWRAP horizontal winds
 - ~150 x 30 m “pixels”
 - IWRAP detects TC PBL rolls
 - Confirms they are ***Shear-Driven*** and ***NOT CONVECTIVE***
 - First observational test of Foster (2005)

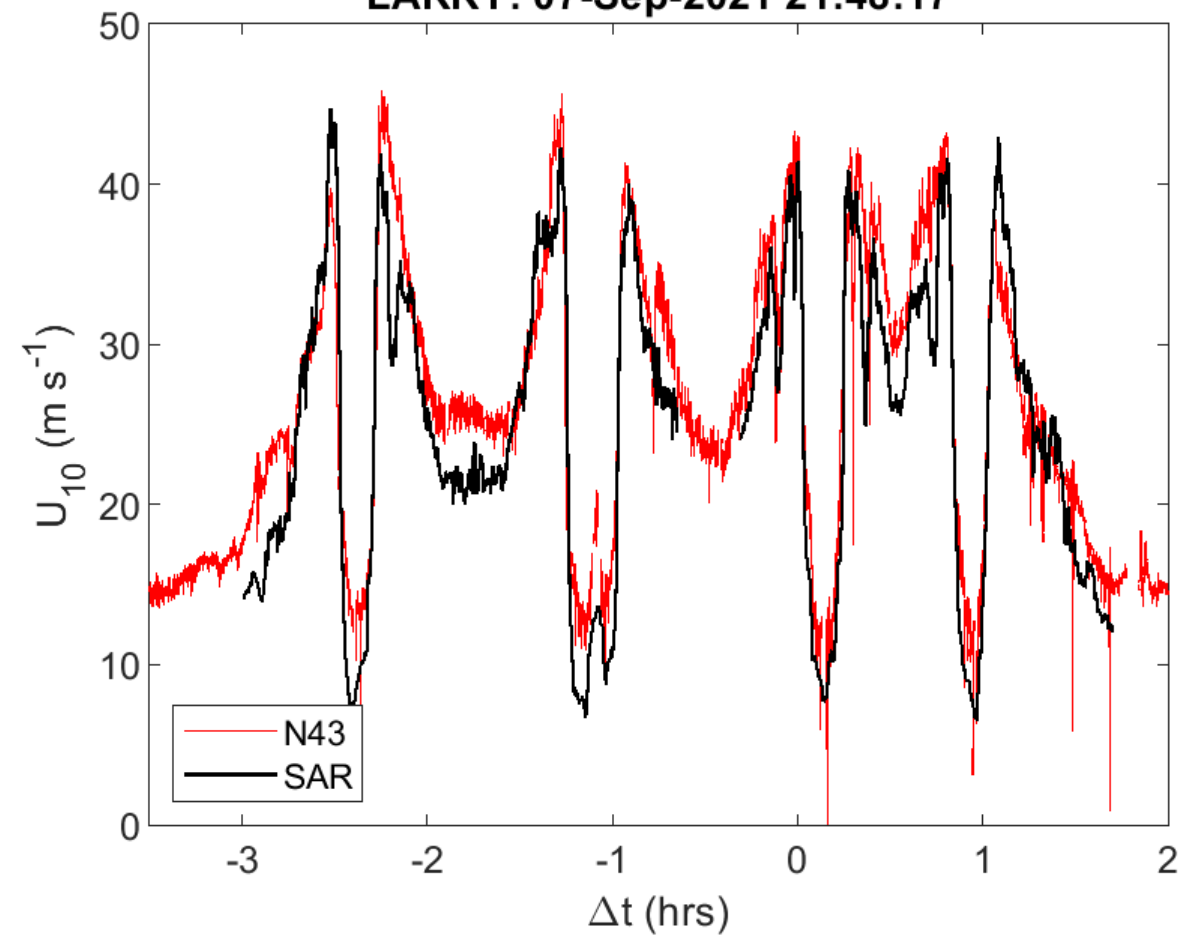
Larry 7 Sep, 2021

- S-1 Ascending (~18:00 local) Overpass at 21:46 UTC
- NOAA N43 P-3 flight with:
 - IWRAP
 - SFMR
 - TDR
 - 4 drop sondes (near storm center)
 - $\Delta t = -3$ to $+1.5$ hours of S-1 (21:46)
- NOAA G-IV flight
 - 7 drop sondes in-image within P-3 time window
 - Environment soundings, far from center

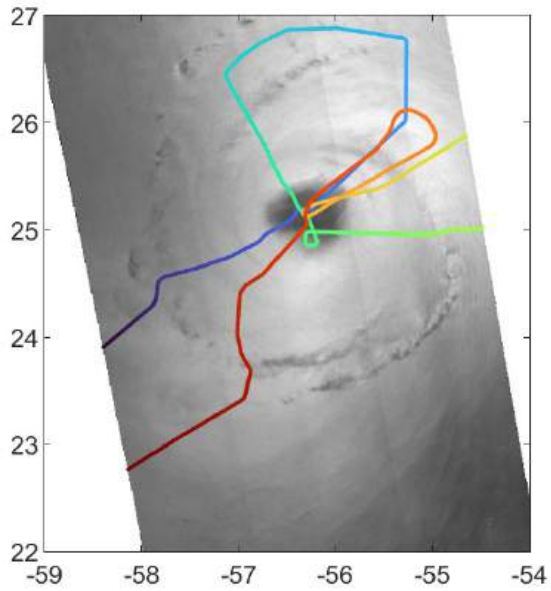
LARRY: 07-Sep-2021 21:48:17



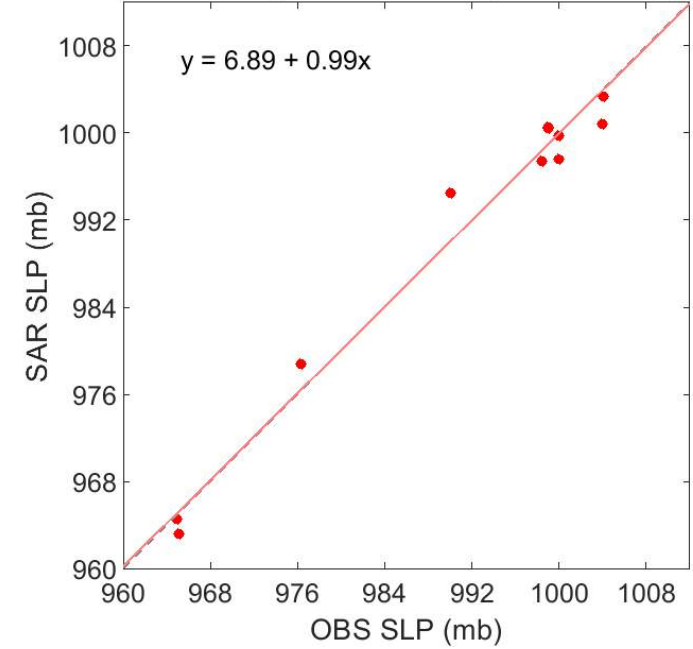
LARRY: 07-Sep-2021 21:48:17



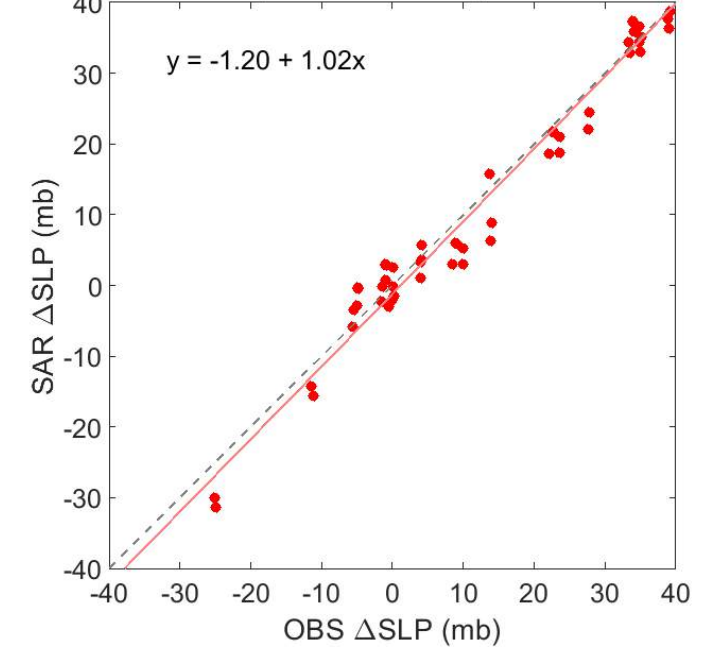
Storm track (P-3 navigation to SAR image) determined by matching SFMR & SAR U10
RMS ~ 4 (m/s) (within 150 km)
S-1 GMF trained against SFMR



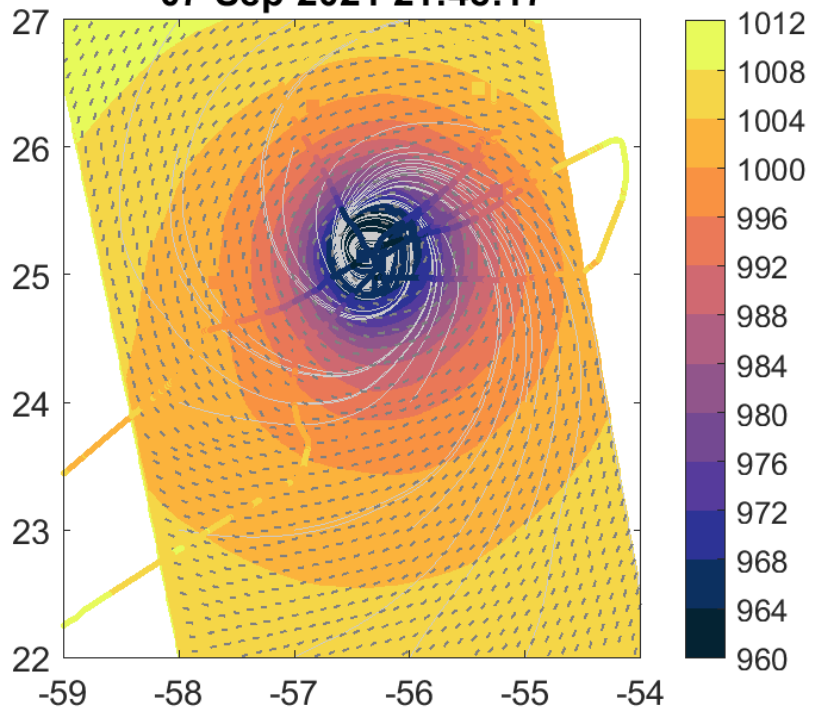
LARRY: 07-Sep-2021 21:48:17; RMS = 1.52 (mb)



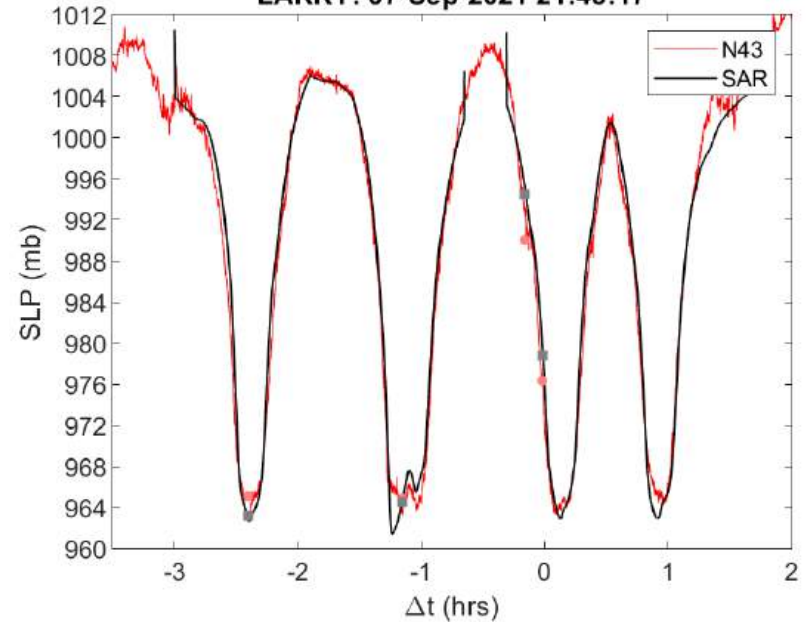
LARRY: 07-Sep-2021 21:48:17; RMS = 2.15 (mb)



07-Sep-2021 21:48:17



LARRY: 07-Sep-2021 21:48:17

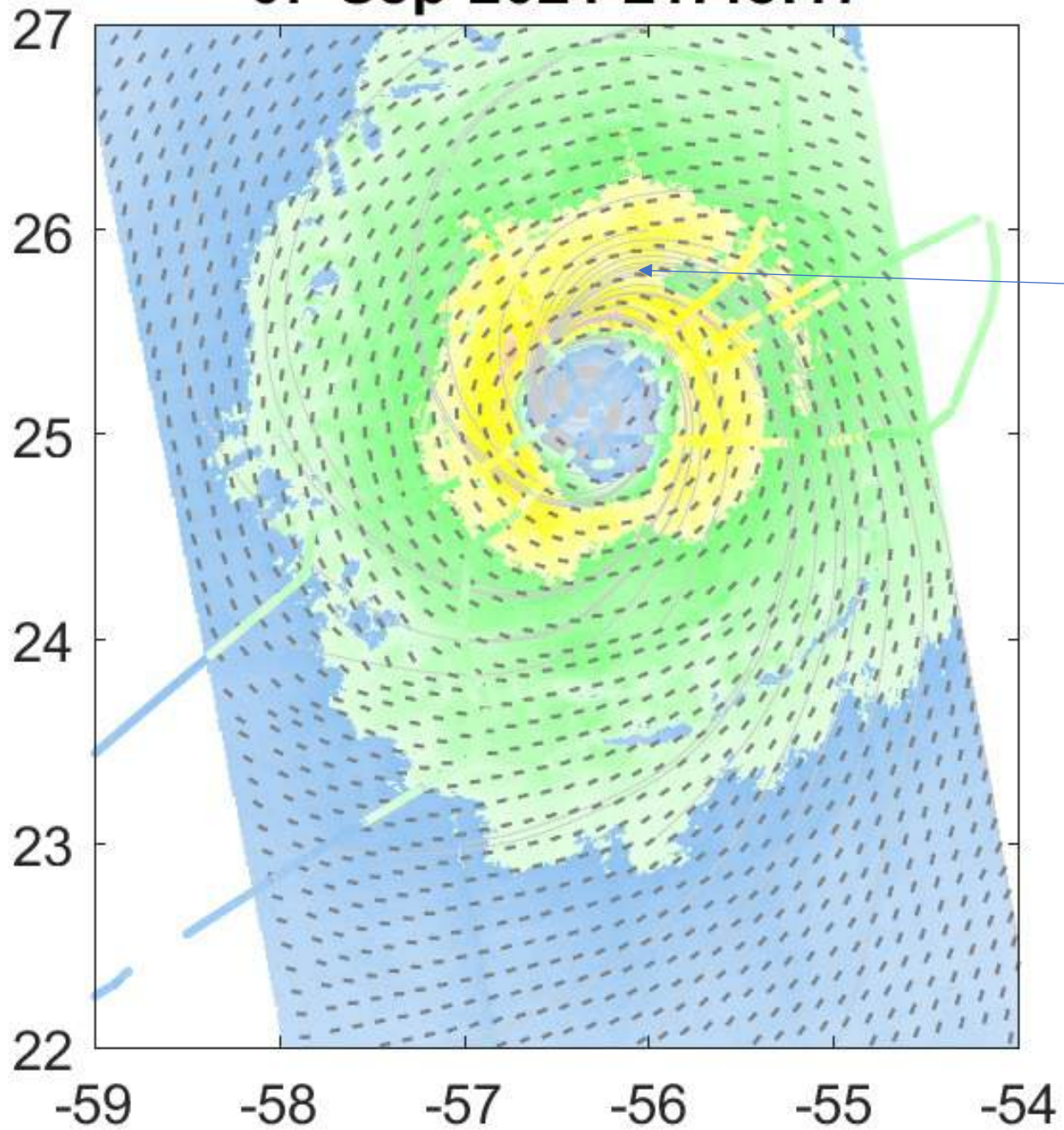


SLP Retrieval

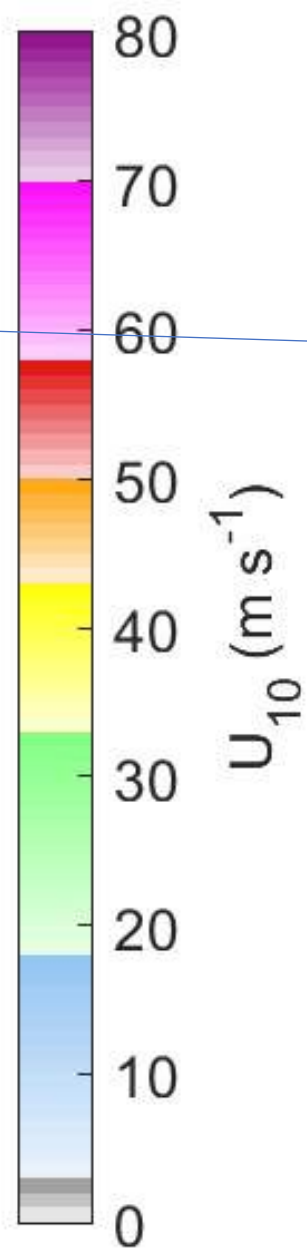
- Scatterplots ~along 1:1 line
 - Total-least-squares
 - 4 sondes from P-3
 - 7 sondes from G-IV
- $\frac{N(N-1)}{2} \Delta P$ from Sondes
 - RMS 2.2 mb
- Good agreement with P3 SLP

Ref: Foster, 2017

07-Sep-2021 21:48:17



PBL rolls throughout storm



Surface wind streamlines (light gray)

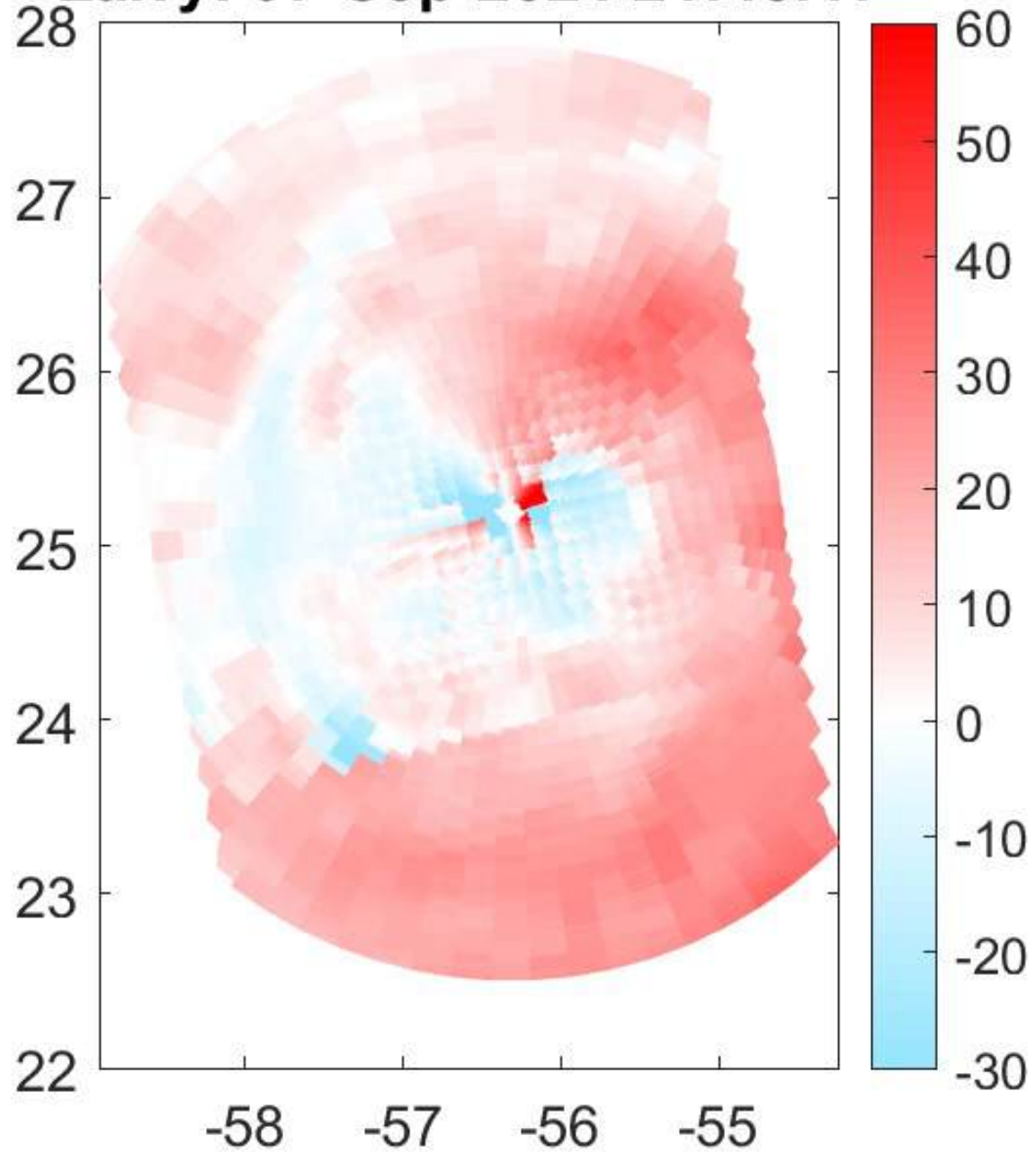
Roll orientations (thick gray bars)

- Note: rolls detected throughout SAR image
- Agrees with prediction of Foster (2005)

PBL Roll Direction

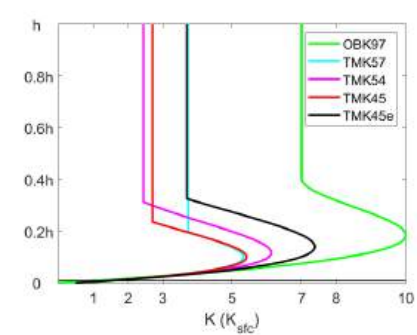
- Spectral analysis 20 km NRCS blocks
- Rolls are close to wind direction
- Roll signature throughout images

Larry: 07-Sep-2021 21:48:17

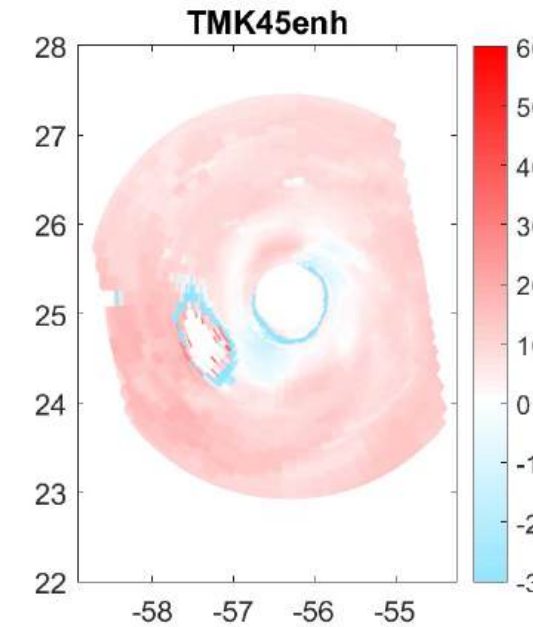
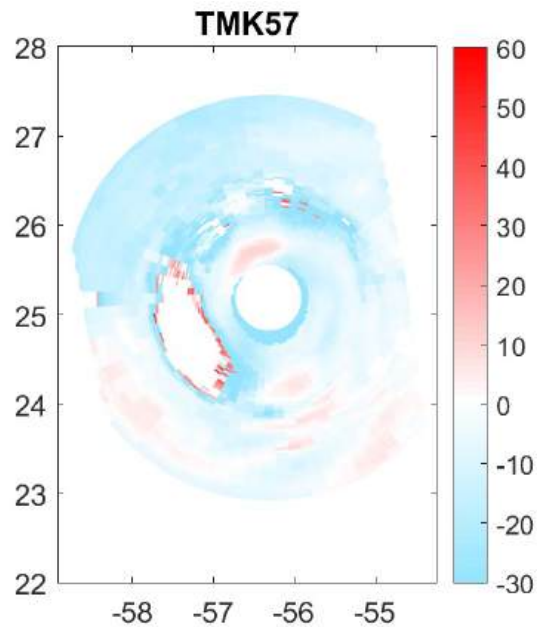
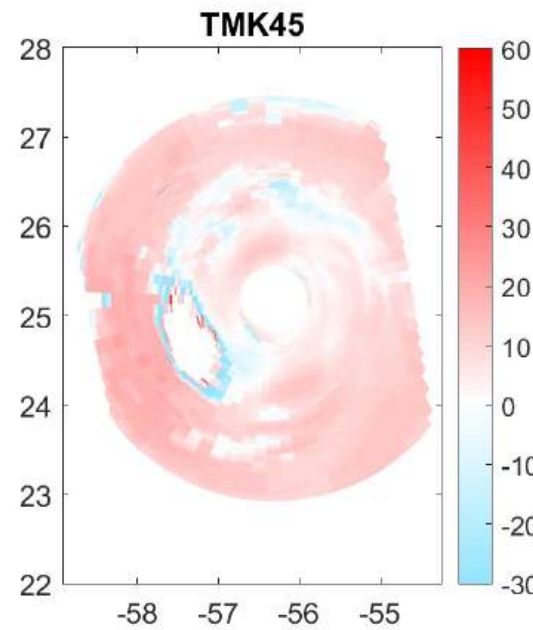
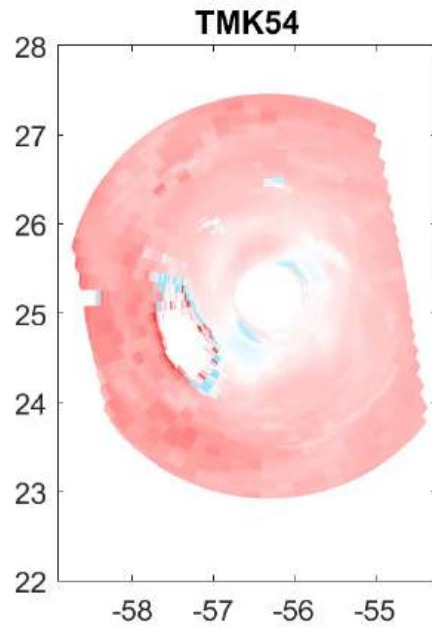
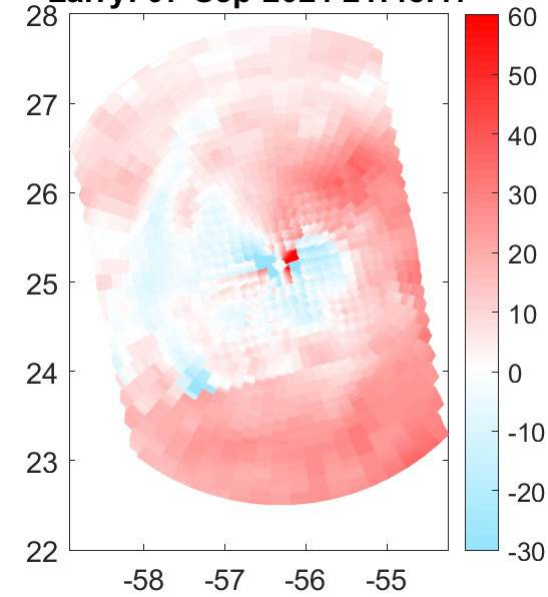


TCBL rolls "Inflow" Angle

Positive Angle: rolls point toward low pressure



Larry: 07-Sep-2021 21:48:17



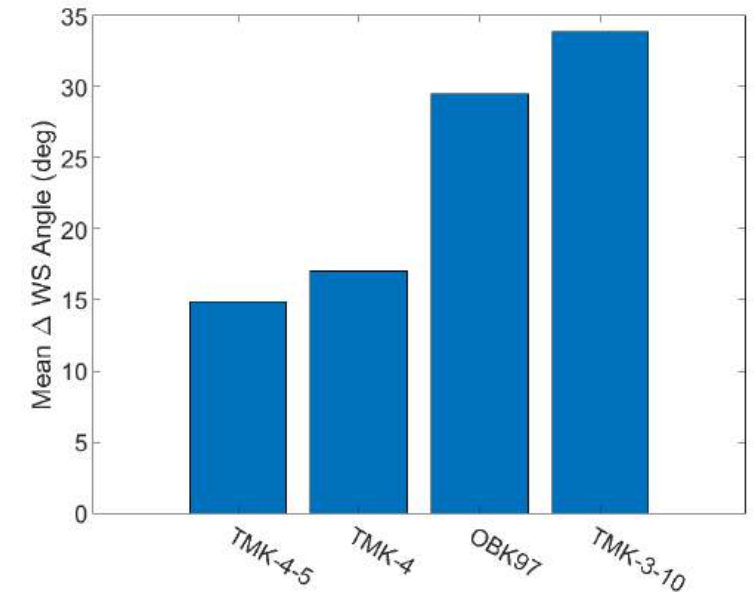
Orientation of TCBL rolls

Assumptions:

- Roll orientation primarily determined by TCBL mean shear profiles
- SAR-estimated mean shear profiles primarily determined by assumed $K(z)$

Seek best agreement with OBS

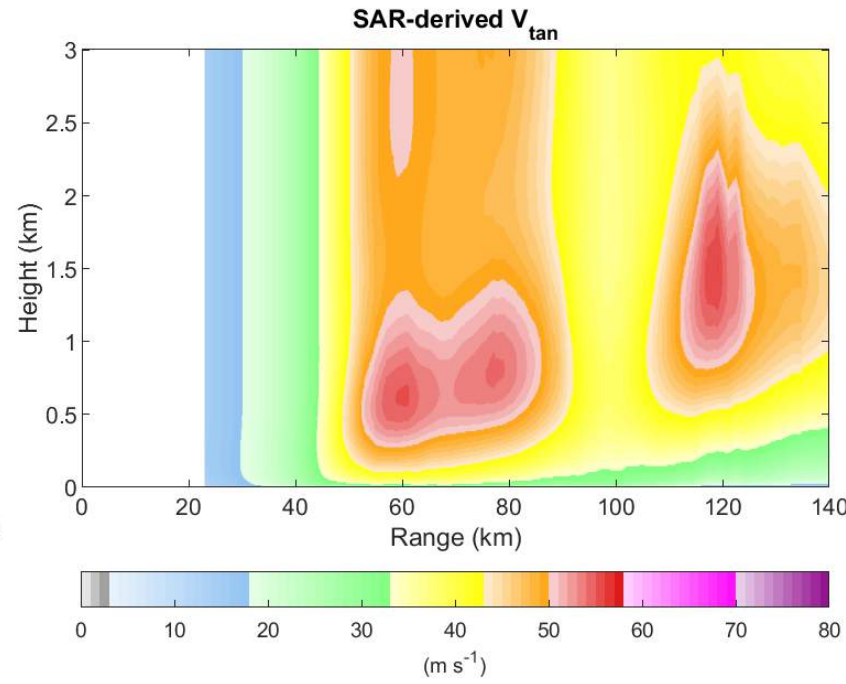
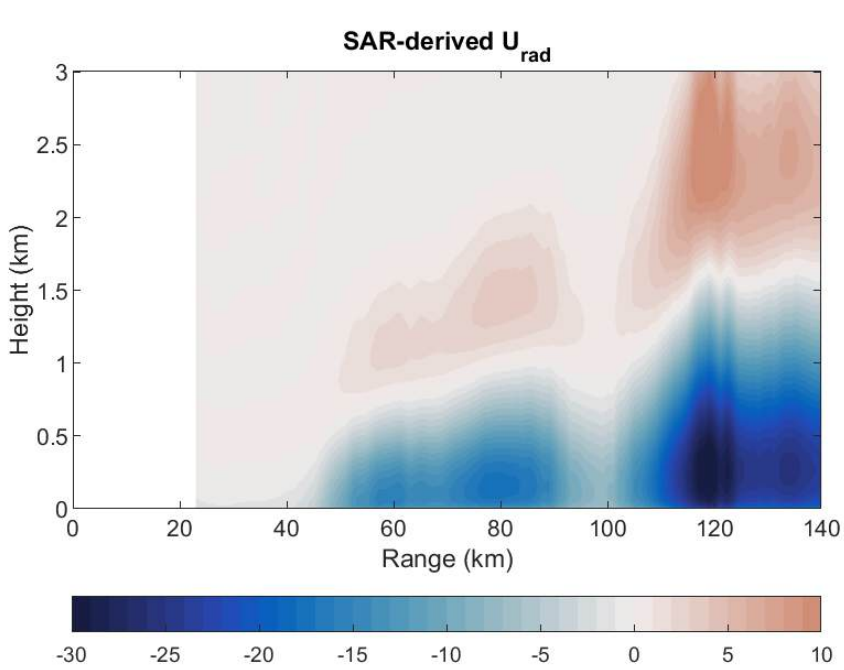
- Insight into TCBL roll dynamics
- Insight into $K(z)$ distributions (small-scale turbulence)



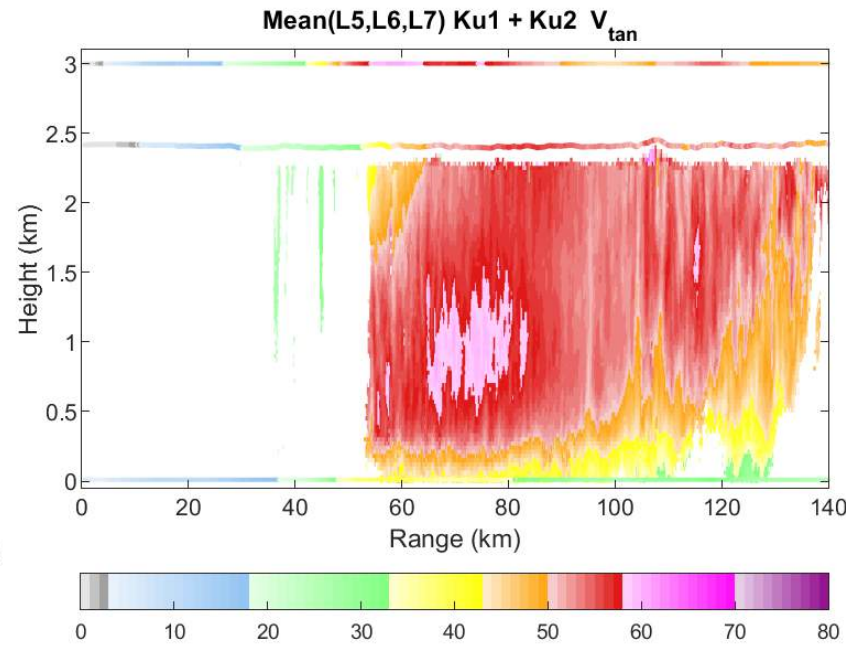
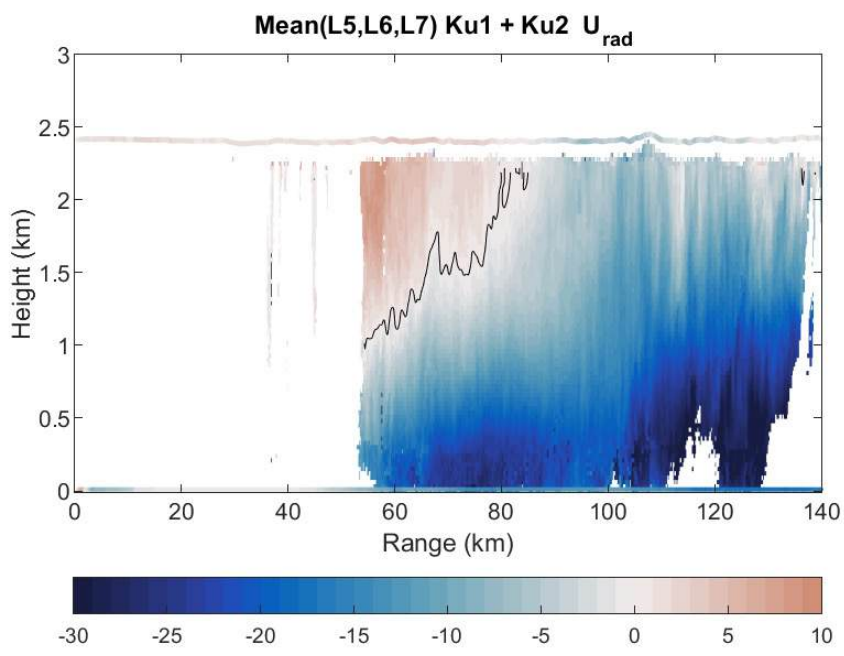
Calculated using Foster (2005; 2009)

IWRAP Winds

- Repeat legs near SAR Overpass time

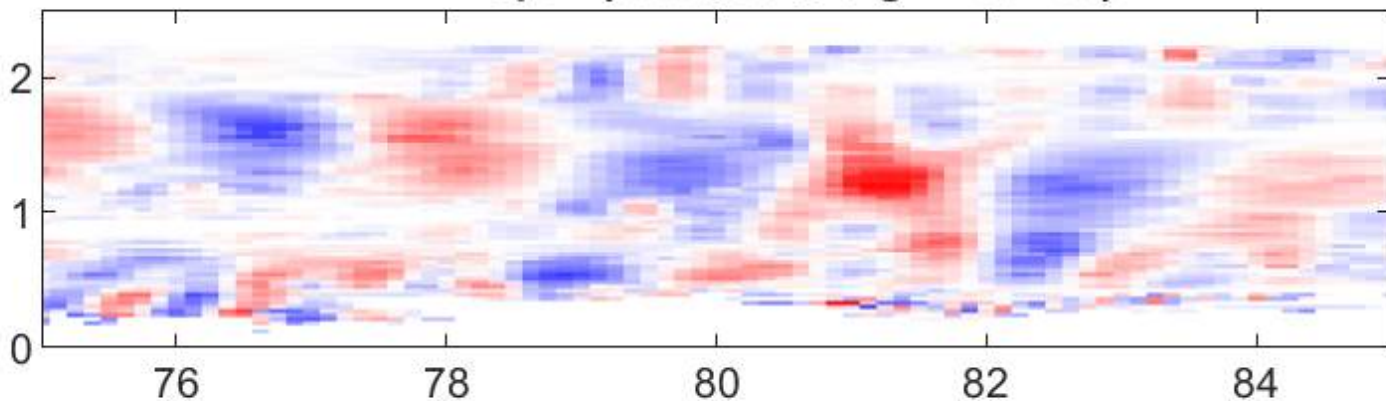


- SAR-derived wind profiles have no additional data input
 - PBL depth a bit shallow
 - $K(z)$ a bit diffusive
 - Circulation a bit weak.

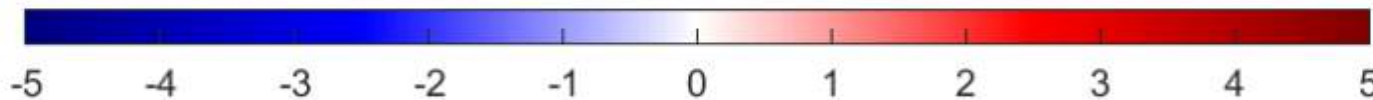
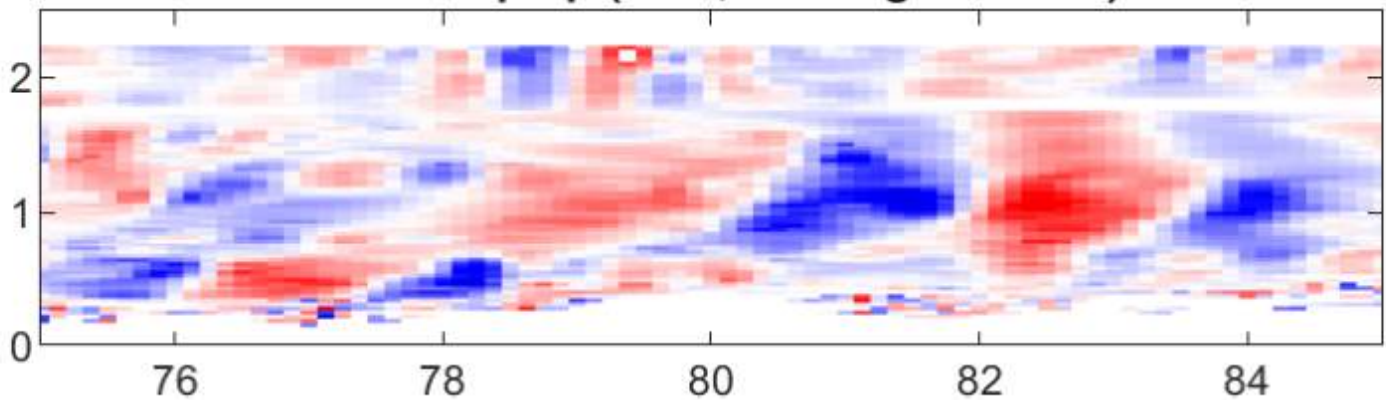


Note the periodic modulation in IWRAP winds

IWRAP Upar (total, 95% significance)



IWRAP Uperp (total, 95% significance)



Wavelet-filtered IWRAP winds

- $r = 65 - 95$ km (RMW = 65)
- Use SAR to rotate into local roll frame
- Perturbation from 5-km running mean
- Wavelet spectra for each z
- Reconstruct input:
 - 95% Confidence spectral peaks
- Spectra: broad peaks $1.5 < \lambda < 4$ km

Figure 15: Hurricane Larry (2021) (a) Upar perturbation wind reconstructed using only significant spectral peaks (b) As in (a), but for Uperp

Upper: Upar: horizontal component of overturning flow (nearly radial)
Lower: Uperp: horizontal along-roll flow (in/out of page; nearly azimuthal)

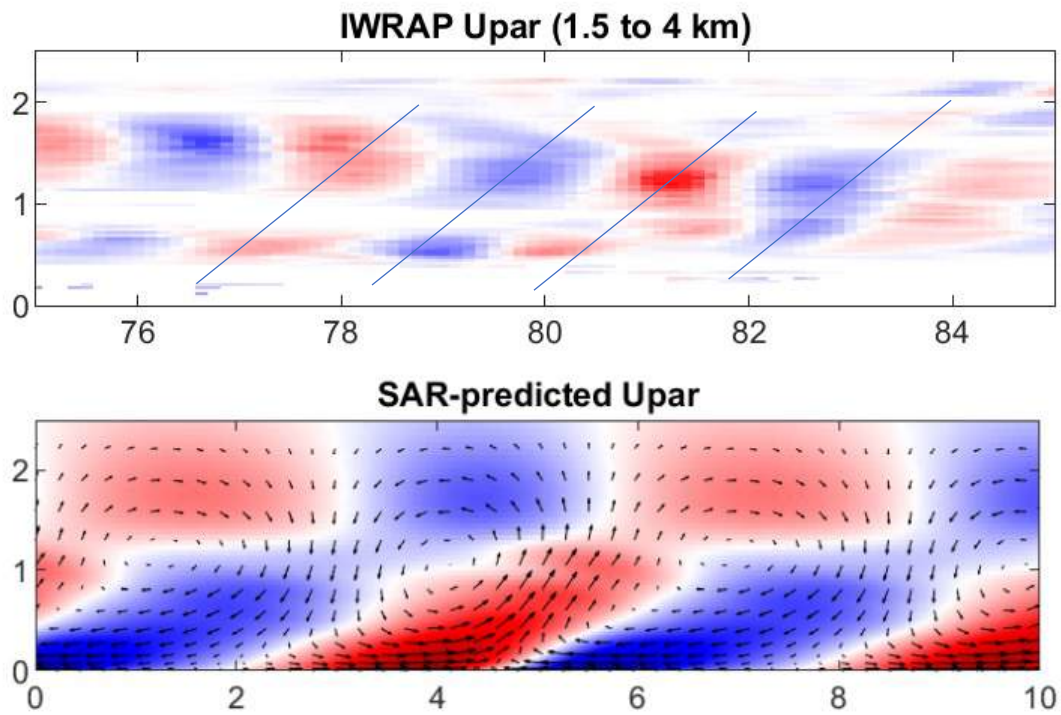


Figure 16: Hurricane Larry (2021) (a) IWRAP Upar reconstructed using only significant peaks between 1.5 and 4 km scale (b) SAR-Predicted Upar

Upper: IWRAP filtered to $1.5 < \lambda < 4km$
 Lower: SAR-predicted (nonlinear) roll circulation

These are NOT convective rolls!

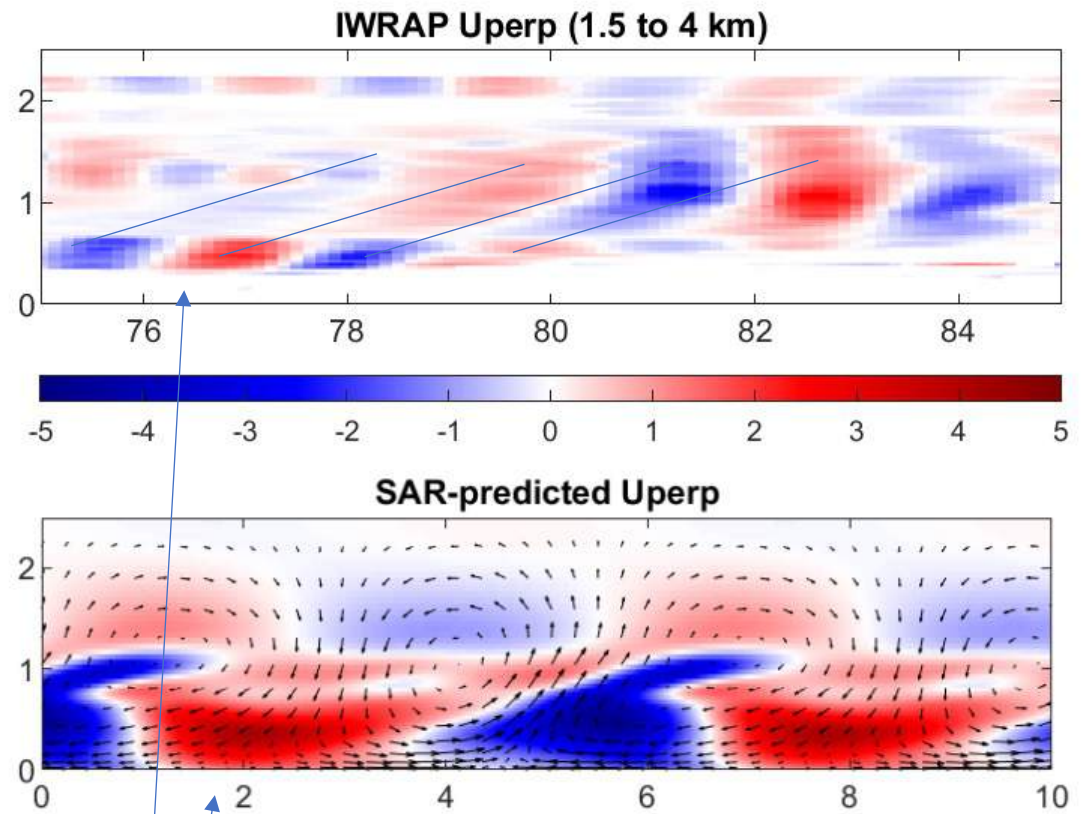
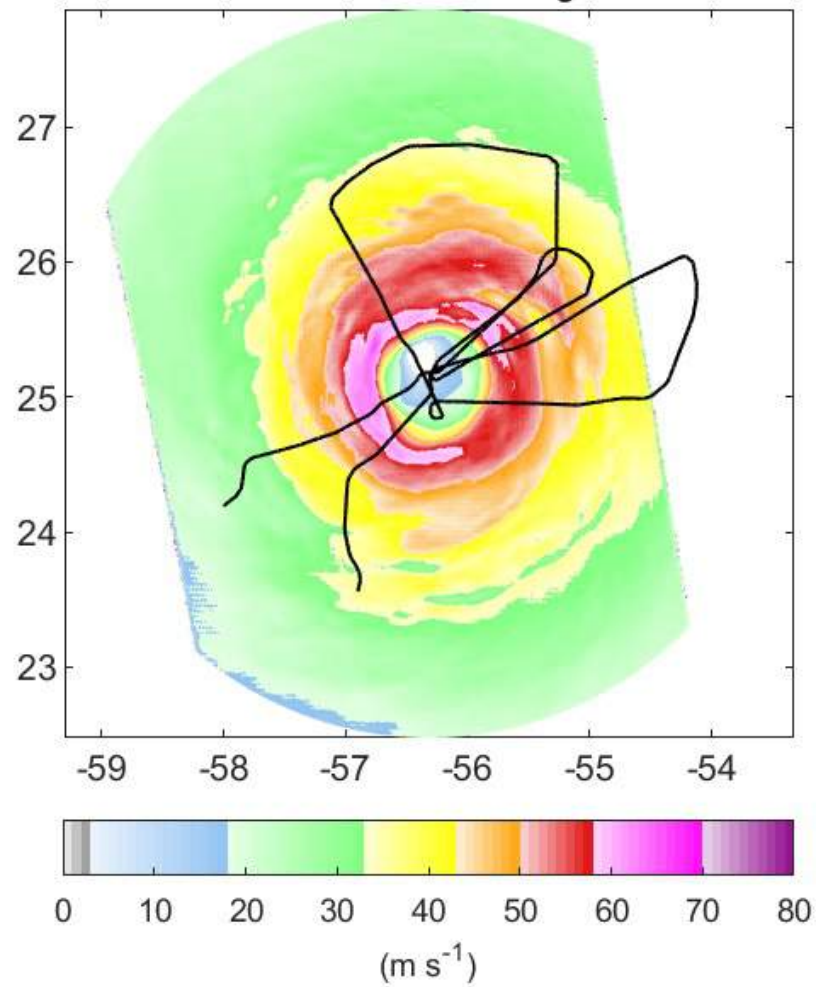
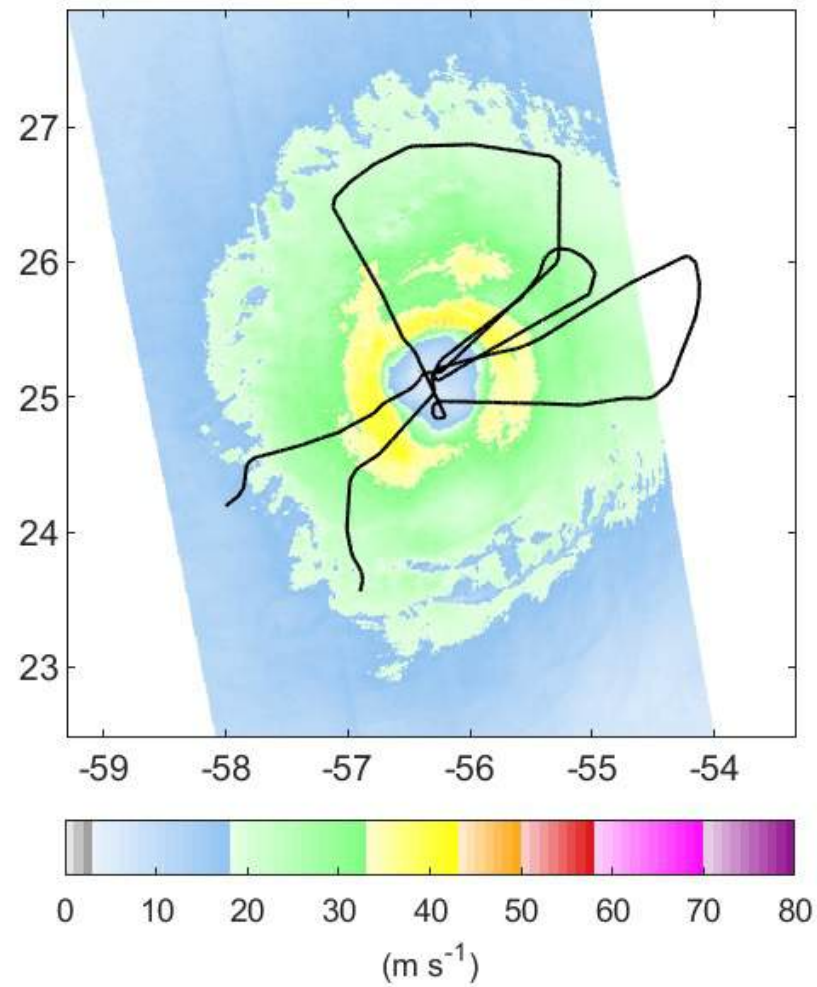
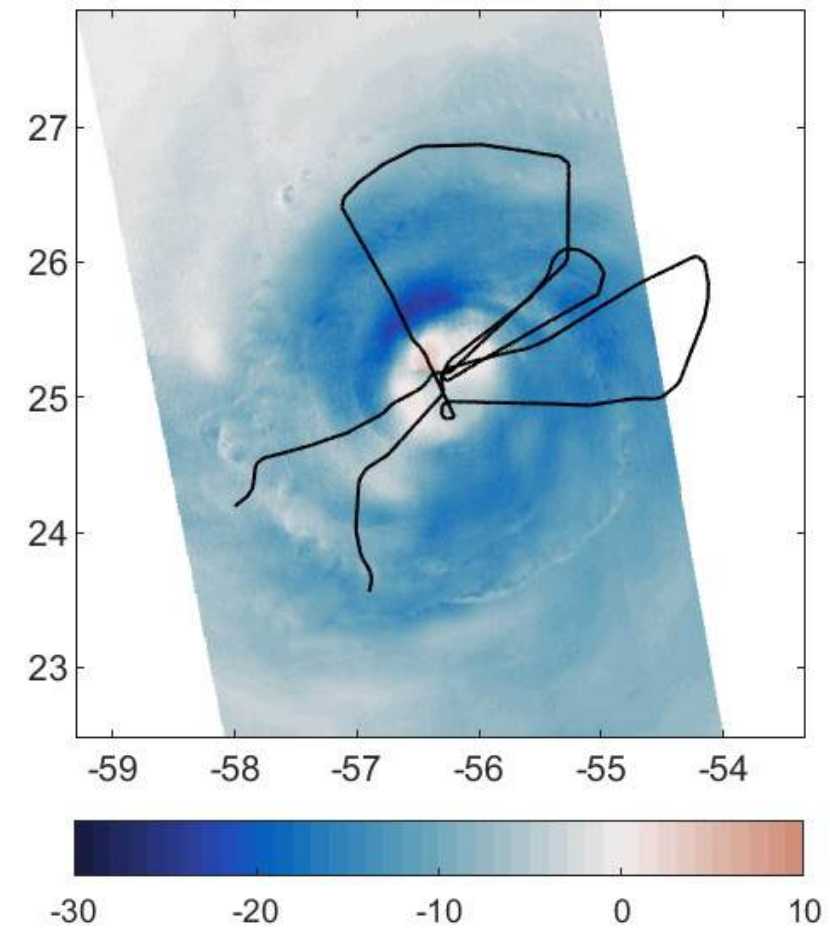


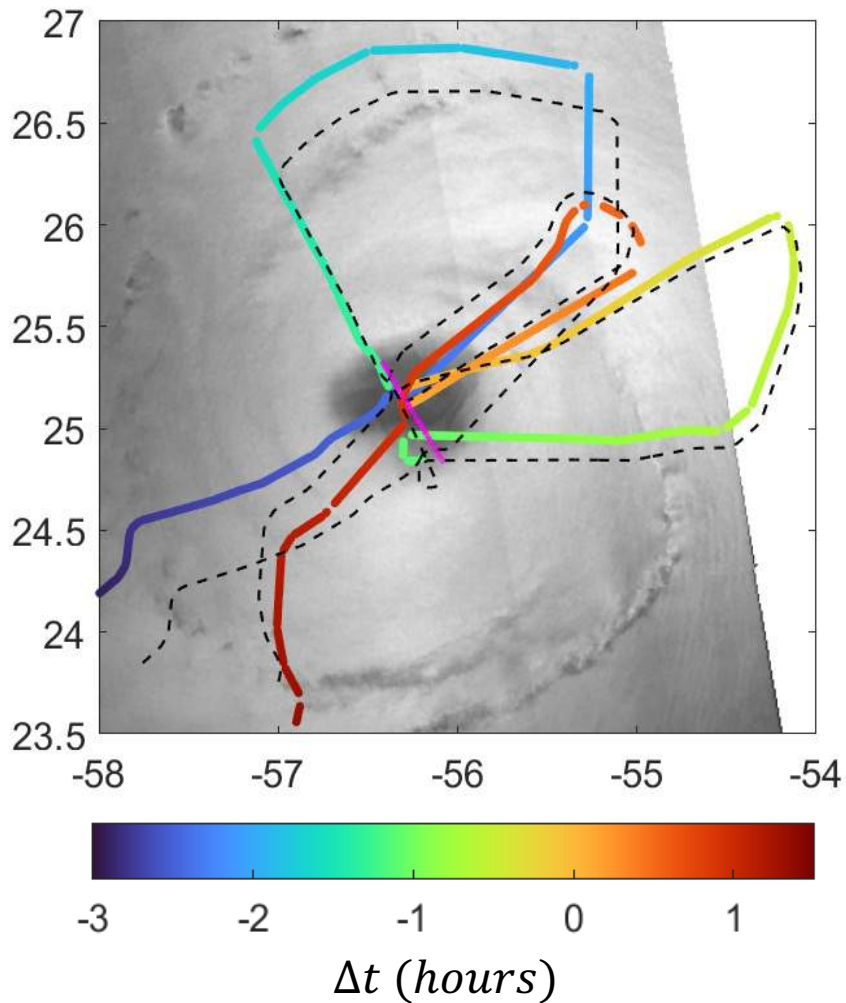
Figure 17: As in Fig. 16, but for Uperp

- Roll circulations “lean into mean shear” (neutral stratification)
- **Uperp largest in lower PBL**, “stretches-around” above
- Similar phasing in theory and IWRAP
- Structures are asymmetric → enhance fluxes

Extra Slides

SAR-derived V_g **SAR V_{tan}** **SAR U_{rad}** 

Boundary conditions for Foster (2009) TCBL similarity model for mean wind profiles



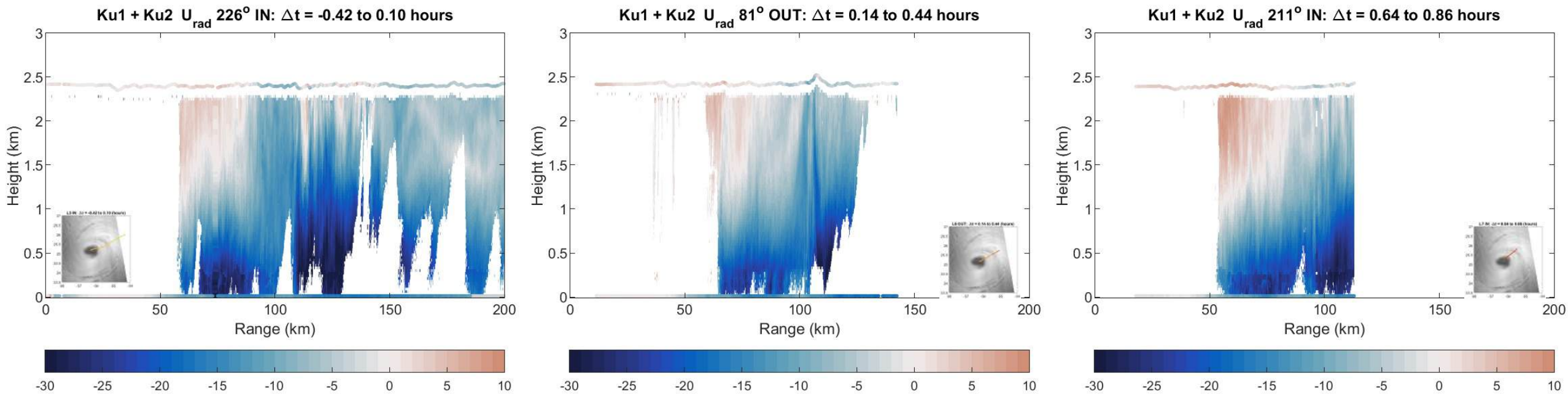
Dashed: Actual P-3 flight track

Colored: P-3 adjusted to SAR overpass time

Magenta: Storm track

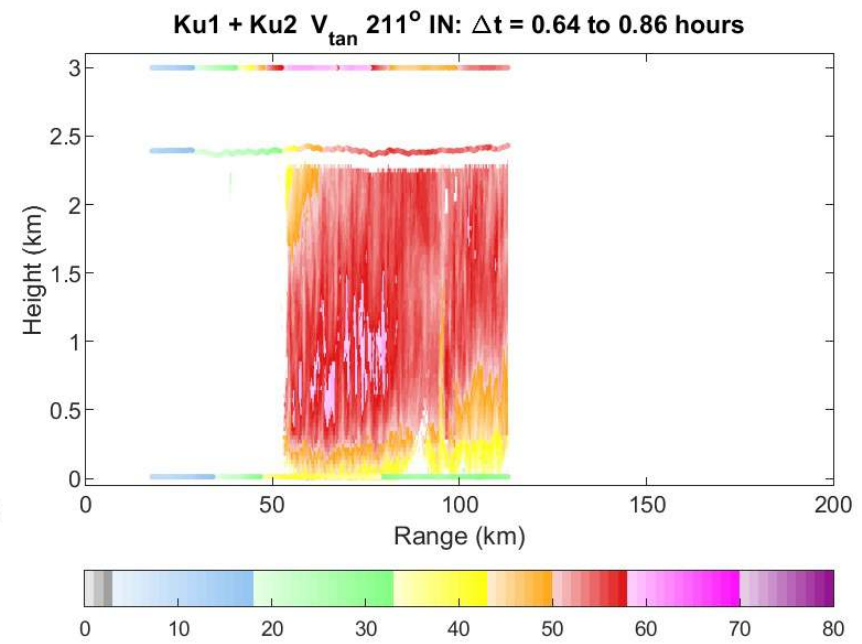
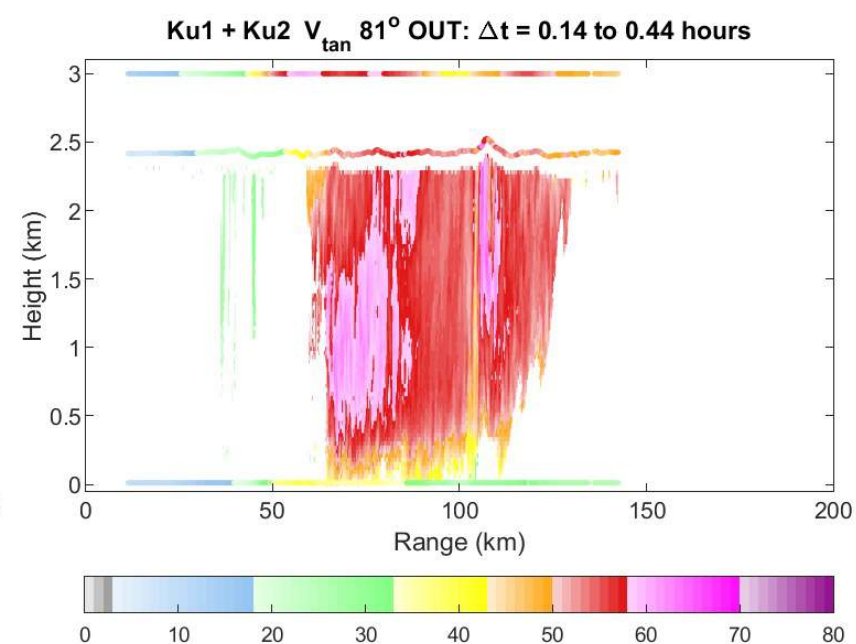
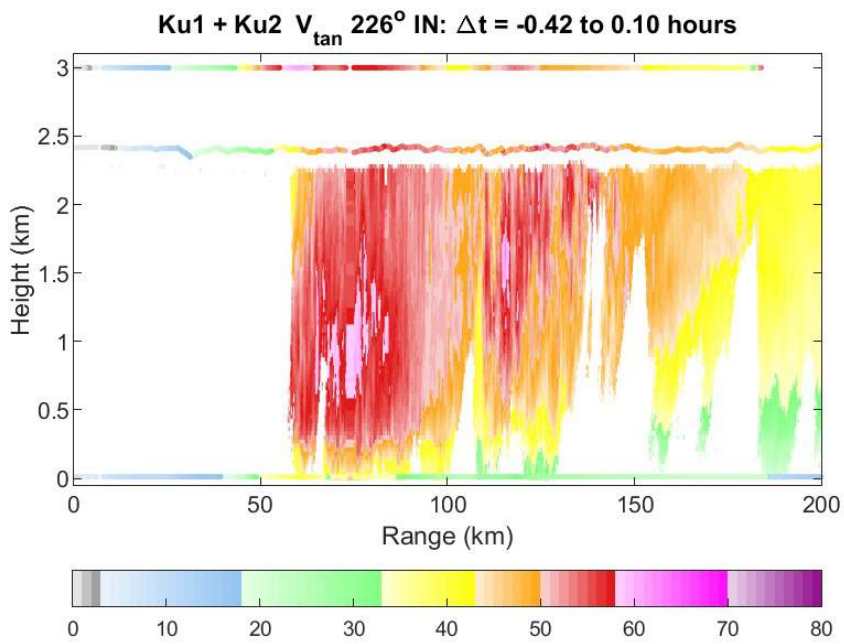
- Approximate center fixes
 - Four NHC 6-hourly locations
 - First-guess SAR surface wind circulation center
- Minimize RMS between SAR - SFMR U_{10}
 - Do not require track to match any of the center fixes
 - Smooth path, keep within 10 km of NHC and 4 km of SAR
 - Optimization cost function restricted to ~150 km of storm center
 - RMS:
 - Initial ~6.5 m/s
 - Final ~4 m/s

This is the most difficult aspect of analyzing SAR data and contributes the most to RMS!



Note inflow/outflow transition clear & consistent in IWRAP and FL
 Similar to Leg 2 ($\Delta t = -2.41$ to -2.1)

Repeat tracks near S-1 overpass



Deep layer of strong azimuthal winds
Similar to Leg 2 ($\Delta t = -2.41$ to -2.1)
FL & V_G are comparable

Repeat tracks near S-1 overpass

SAR-observed TCBL Roll Orientation

- Each TC image is divided into ~ 20 km² roll detection blocks
- Within each block, σ_0 is analyzed for WS signature
 - Typically 2 to 4 km-scale wavelengths
 - Orientation is close to wind direction
- SAR Roll signatures are ubiquitous
- Foster (2005) conclusions:
 - TCBL rolls are essentially normal PBL rolls
 - Stronger because scaling wind speed is stronger
 - TCBL is ***paradigm environment for rolls***
 - Neutral to stable stratification \leftrightarrow Shear production dominates
 - Closely aligned to wind direction, but
 - Orientation is sensitive to TCBL mean shear profiles, especially radial component
 - Large-scale cross-stream instabilities tend to equilibrate
 - Streamwise instabilities tend to generate turbulence
- TCBL results consistent with global WV analysis