Using SAR Imagery to Diagnose TCBL Structure

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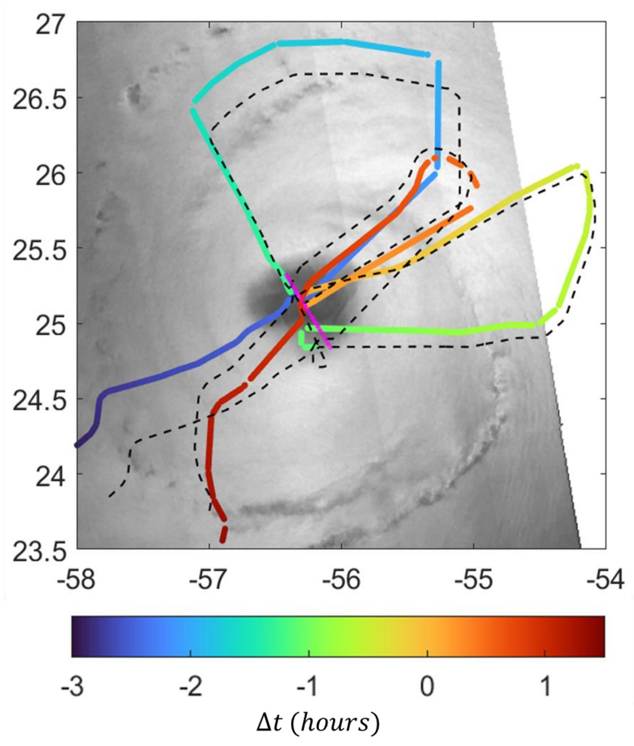
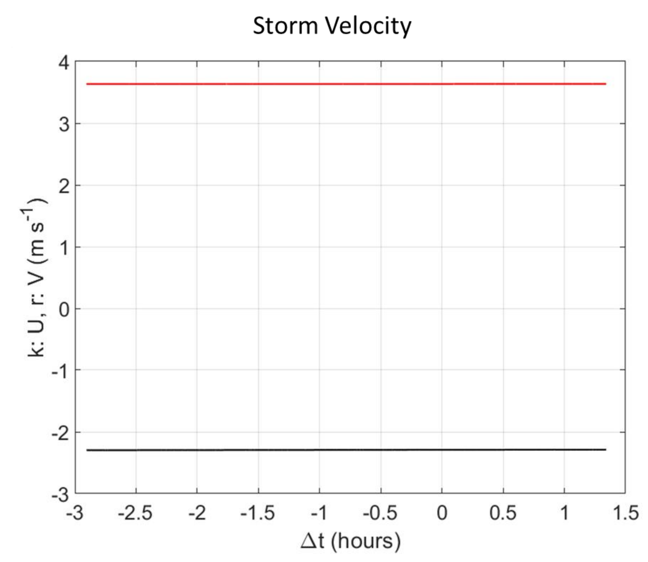
SAR Surface winds in TCs

- Older SAR: only co-Pol (VV)
  - Saturation ~40 m s^{-1} (depending on incidence angle)
- New SAR: dual-pol (Sentinel-1) and full-pol (RadarSAT2 & RCM)
  - VH weaker than VV, but
    - Does not saturate
    - Lower sensitivity to radar beam direction
  - Calibrated against SFMR surface winds
  - Model function useful to ~80 m s^{-1}
  - Currently, S-1 and RSAT are different enough that Ifremer's GMF does not work on RSAT2 or RCM
  - RMS vs. SFMR ~4 m s^{-1}
- Directions: minimize misfit between retrieved and ECMWF forecasts
  - I correct for gross errors in ECMWF storm tracks. (Not needed for Larry.)
- ~1 km pixel
  - 250 to 400 km image width for Sentinel-1
  - 300 to 500 km image width for RadarSAT-2

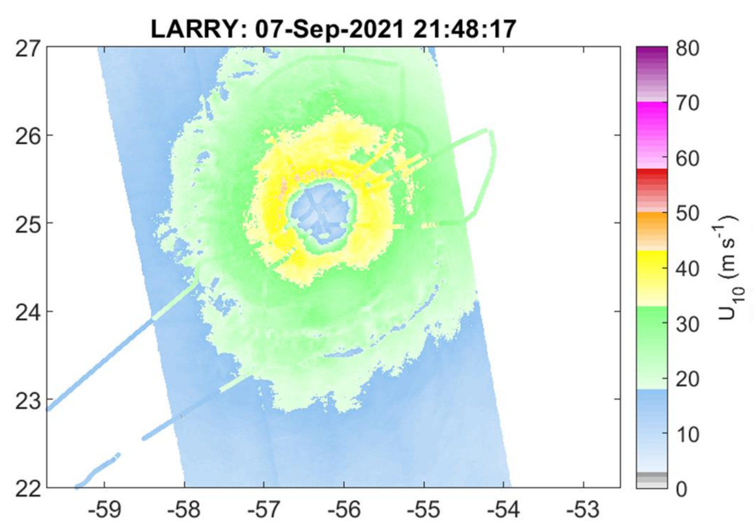
Calculate Storm Track

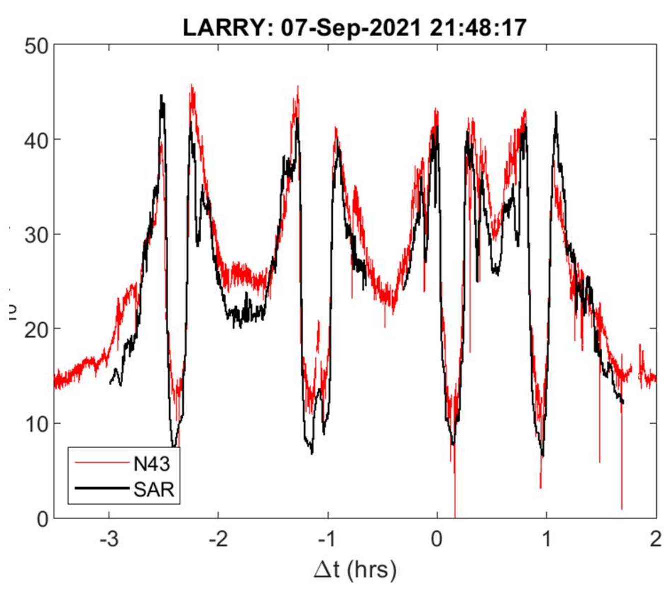
- Approximate center fixes
  - Four NHC 6-hourly locations
  - First-guess SAR surface wind circulation center
- Optimization to minimize the RMS difference between SAR and SFMR U_{10}
  - Initialize with linear interpolation
  - Do not require track to match any of the center fixes
  - Smooth path, keep within 10 km of NHC and 4 km of SAR
  - Operational SFMR U_{10},
    - Possible rain issues?
      - Should re-do with NESDIS SFMR winds
    - Optimization cost function restricted to ~150 km of storm center
  - Initial RMS ~6.5 m/s, final ~4 m/s





Dashed: Actual flight track
Colored: Adjusted to SAR overpass
Magenta: Storm track





Operational SFMR winds. RMS ~ 4 (m/s) (within 150 km)
S-1 GMF trained against SFMR

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)
  - Δt= -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

Outline

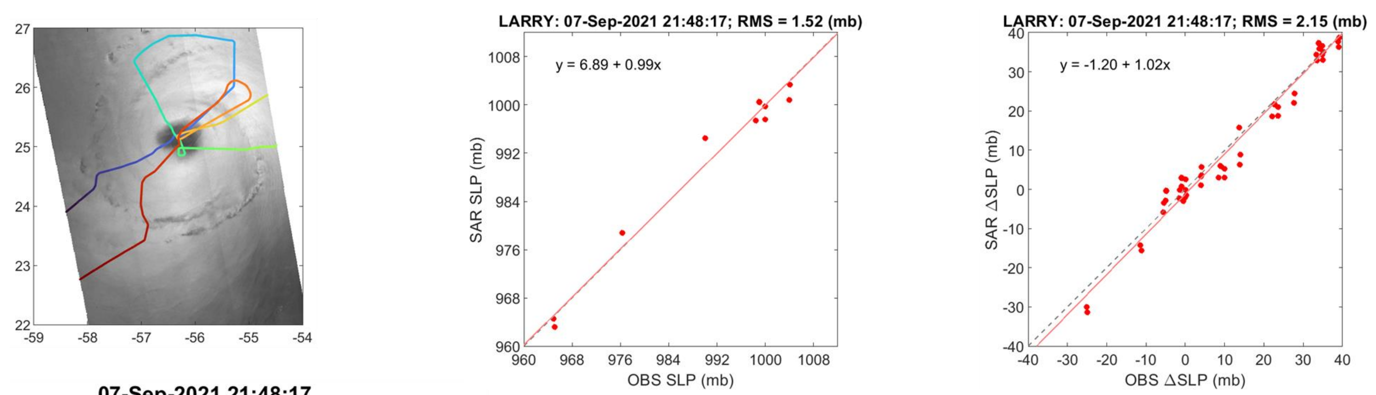
- Ocean SAR analysis
  - Coherent structures & connection to air-sea stratification
  - SAR-TC Ocean Vector Winds
- SLP retrieval
- Observed TCBL roll orientation
- TCBL mean wind profiles retrieval
  - Predict orientation
  - Qualitative assessment vs TDR png files

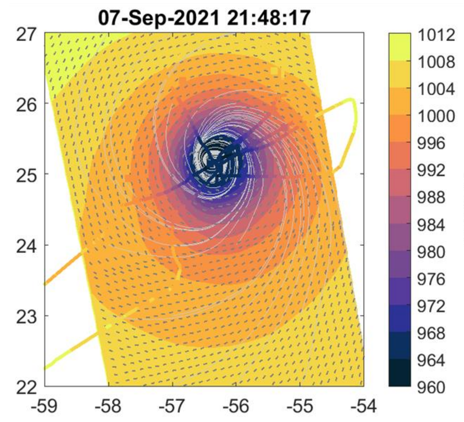
Take-Home Messages

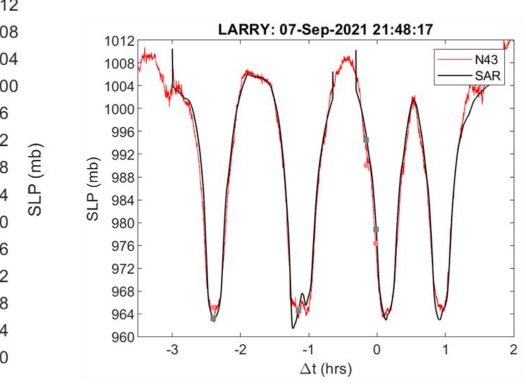
- Ocean SAR images are *Swiss Army Knife* for TCBL analysis
  - All-Weather; Sees through cloud cover; Day & Night
- Surface wind vectors (U_{10}^N, V_{10}^N)
  - ~1 km wind vector cells (WVC) up to ~80 m/s (Mouche et al., 2019)
    - 4 to 5 m/s RMS vs. SFMR
  - Ocean surface stress vector
- Retrieve Sea-Level Pressure (SLP) (Foster, 2017)
  - ~4 mb RMS vs. drop sondes
  - Defines P_r (hence V_g) at top of TCBL
- Routine extraction of TCBL roll vortices
  - ~wind-aligned, ~1 to 4 km wavelength
- Given V_g and (U_{10}^N, V_{10}^N), retrieve TCBL $\left(U_{rad}(z), V_{tan}(z)\right)$, (Foster, 2009)
  - $U_{rad}(z), V_{tan}(z)$ depend sensitively on $K(z)$
  - Roll orientation sensitive to TCBL shear, especially $U_{rad}(z)$, (Foster, 2005)
    - Investigate relationship between roll orientation and $K(z)$
  - Insight into TCBL parameterization schemes

Sea-Level Pressure (SLP) from Ocean Vector Winds OVW)

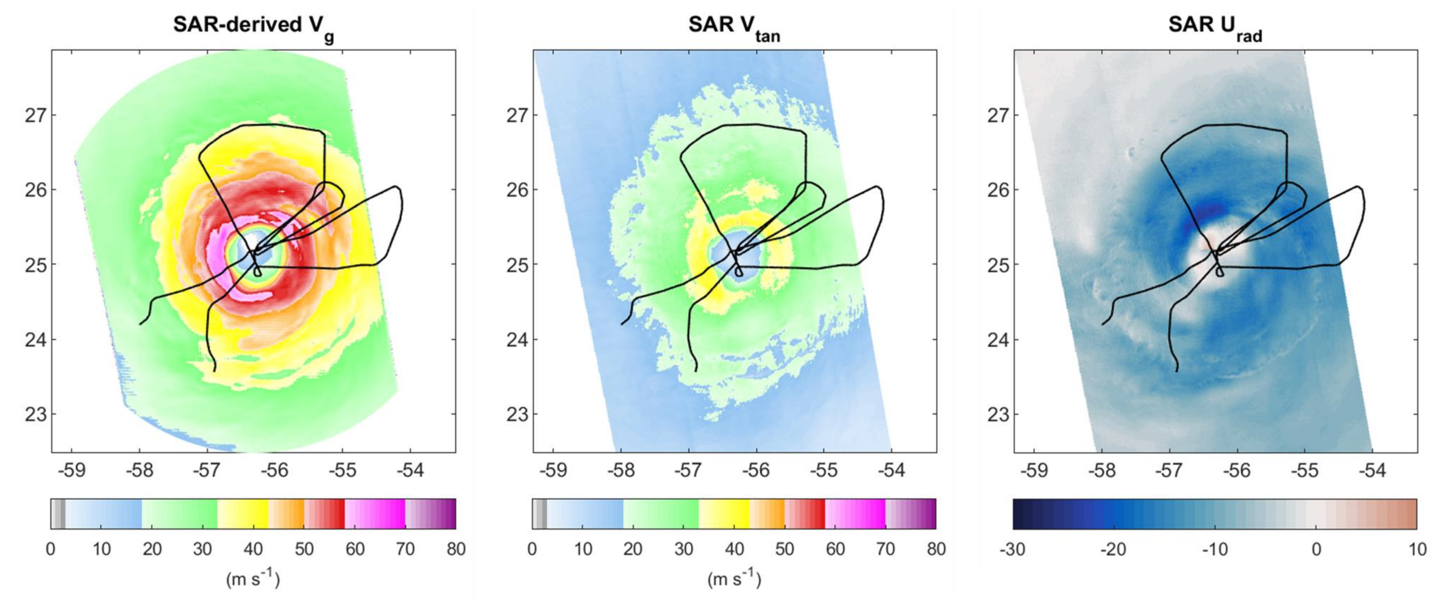
- Foster (2017): Based on Patoux and Foster (2012)
  - Replaced PBL model with simplified version of Foster (2009)
  - Calculate ∇P corresponding to surface wind vector
  - Setup sparse gradient matrices
  - Seek least-squares SLP; no direct integration
- Results compare well with drop sondes & A/C flight level P_{sfc}
- Gradient wind calculated from SAR-derived SLP
  - Used $\rho = 0.86$ (Kg m^{-3})
  - Calculated for z = 3 km using G-IV drop sondes

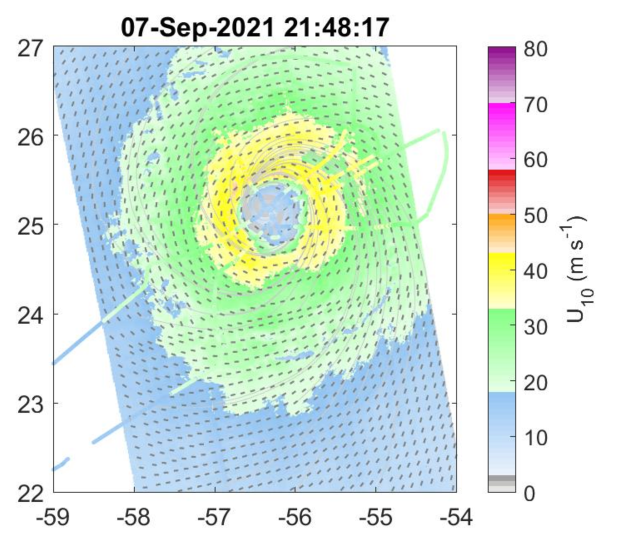




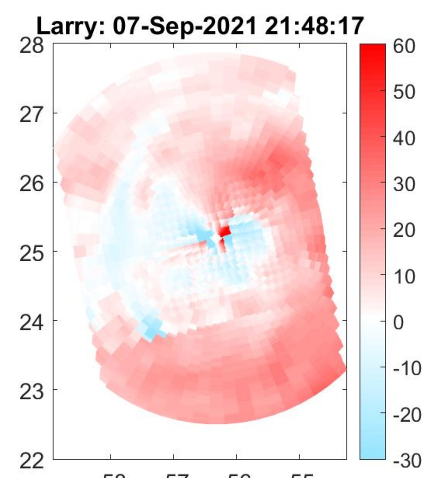


Typical SLP Retrieval
- Scatterplots ~along 1:1 line
  - 4 sondes from P-3
  - 7 sondes from G-IV
- $\frac{N(N-1)}{2}$ ΔP from Sondes
  - RMS 2.2 mb
- Good agreement with P3 SLP

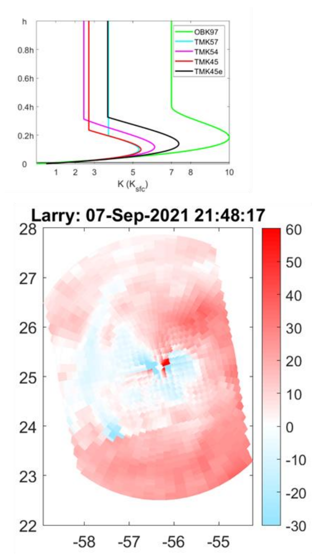


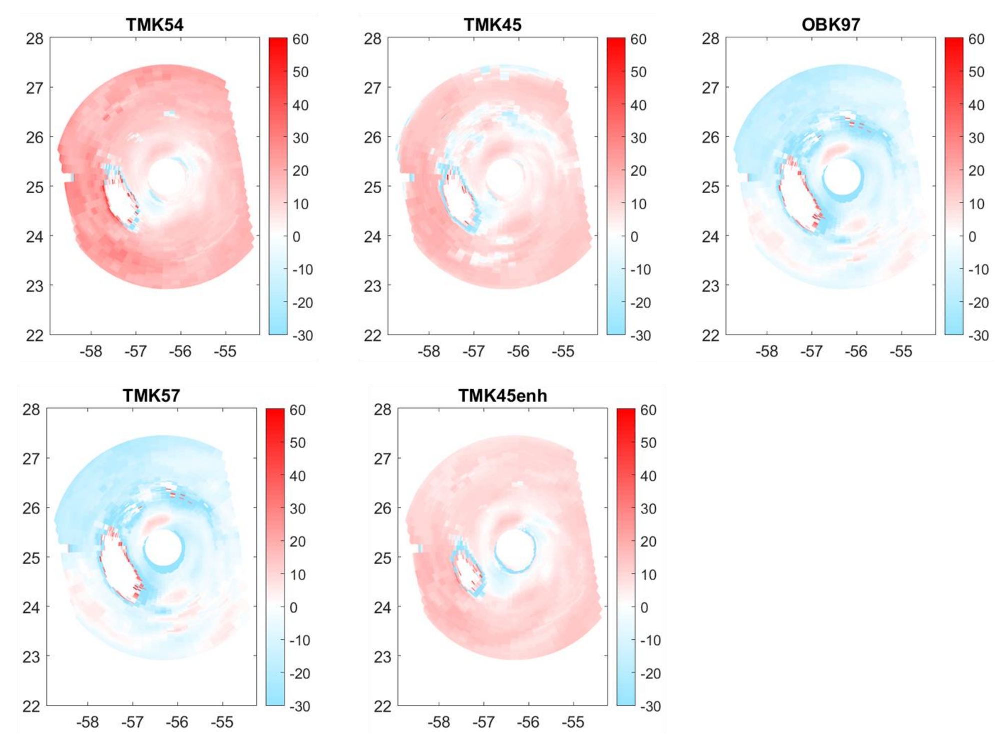


Typical Roll Orientations
- Light gray lines are surface wind streamlines
- Heavy gray dashes are roll orientations in each roll detection block
  - Rolls are close, but not exactly aligned with wind direction
- Roll signature throughout images

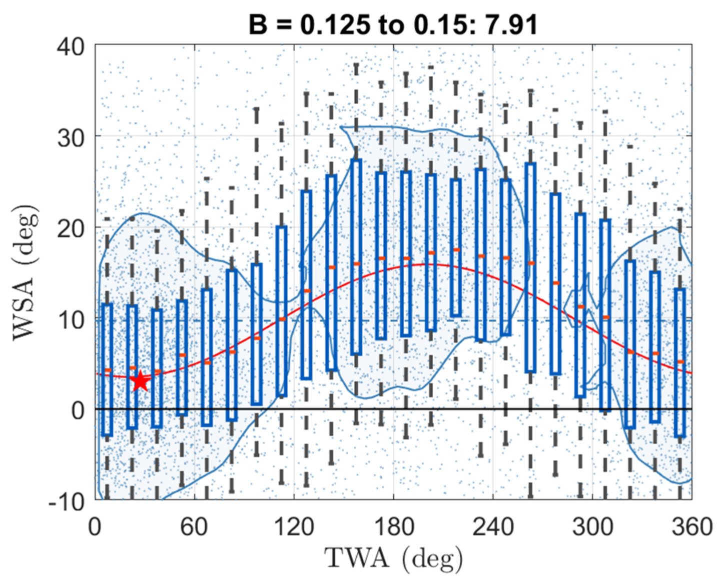


TCBL rolls "Inflow" Angle
Positive Angle: rolls point toward low pressure

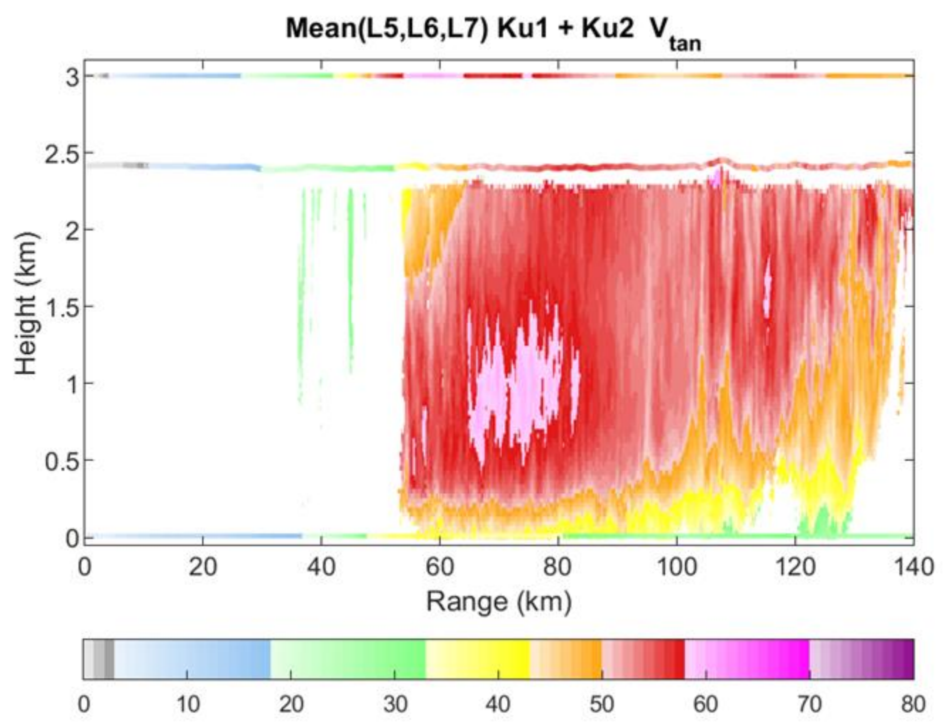


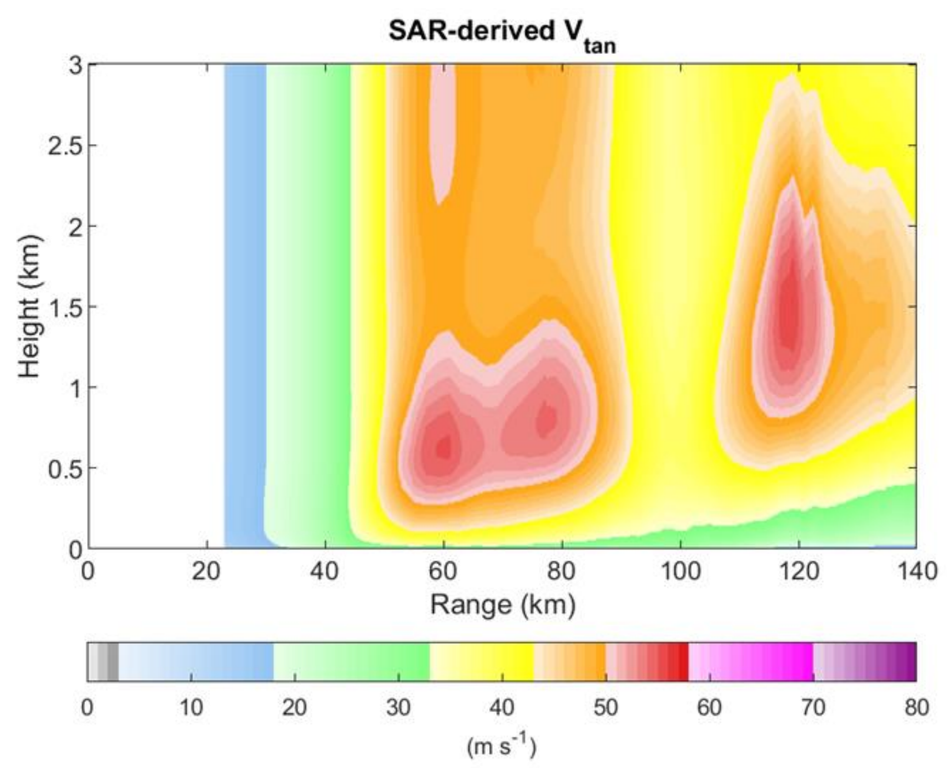


Roll Orientation Sensitive to PBL Shear Profile



- PBL rolls caused by PBL-scale mean flow instabilities
  - Faller (1965), Lily (1968), Brown (1970)
- Foster (1996) predicted:
  - Baroclinicity in PBL can significantly modify rolls
  - Sinusoidal variations of
    - Wavelength
    - Intensity
    - Orientation to surface isobars (WSA) w/rt orientation of the thermal wind (TWA)
  - Observations too sparse to test prediction
- Finally confirmed by global WV data 24 years later!
  - Relatively small shear variations induce ~8° turning compared to barotropic value of ~10°





Still refining estimates of mean U, V in TCBL
Preliminary results