Progress in Calculating Tropical Cyclone Surface Wind Inflow from OVW Observations

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QuikSCAT Neural Net GMF for Tropical Cyclones

- Speed-only TC Geophysical Model Function
  - 10 years of data at JPL: http://tropicalcyclone.jpl.sa.gov/hurricane/gemain.jsp
  - NN trained against 2005 H*WIND
    - Stiles BW, RE. Danielson, W. Lee Poulsen, M J. Brennan, S. Hristova-Veleva, T-P.J. Shen, and A. G. Fore: 2013: Optimized Tropical Cyclone Winds from QuikSCAT: A Neural Network Approach, *TGARRS*, Doi 10.1109/TGRS.2014.2312333
  - 12.5 km pixels
  - Rain contamination reduced or removed

Find collocated research aircraft flights

↓

Map drop sondes to satellite overpass

↓

Initialize wind directions wind Zhang-Uhlhorn[1] composite

↓

Optimize wind directions for best match with drop sonde sea-level pressure (Holding NN wind speeds constant)

[1] Zhang, J. A., and E. W. Uhlhorn, 2012: Hurricane sea surface inflow angle and an observation-based parametric model. *Mon. Wea. Rev.*, **140**, 3587-3605

Navigating Aircraft to Satellite Image

- Matchups between flights and images are somewhat rare
  - Need to make best use of each matchup
  - 6 to 8 hour flight duration (multi-hour ΔT)
  - Intensity may change during these intervals
- HRD recommends using “TRAK” files
  - Cubic-Spline fit through aircraft and Best Track centers

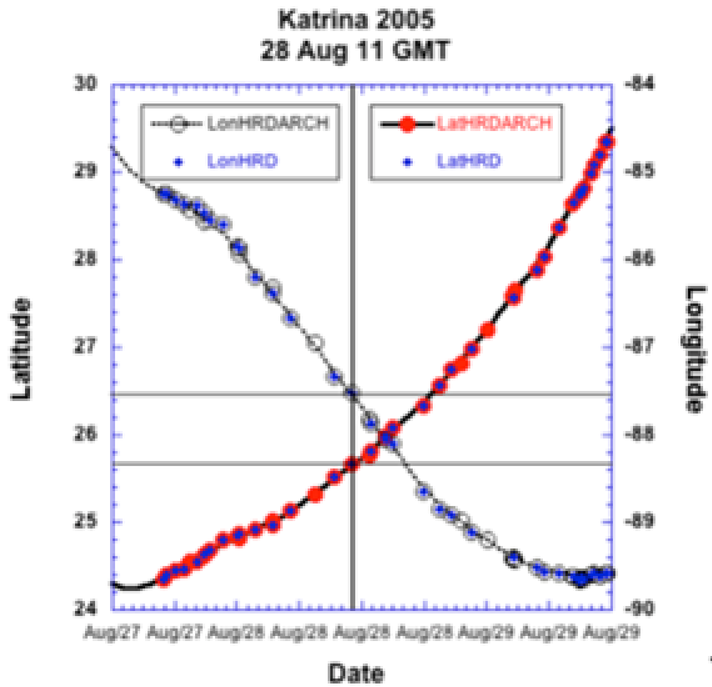
Largest Source of Error in Sonde Sea-Level Pressure Validation is …

- ***Inaccurate determination of storm track***
- Aircraft centers are not exact and may not represent surface wind circulation
- Best Track locations are not intended to represent actual storm location at specified times
- HRD TRAK files:
  - Must pass through center fixes
  - Must match slopes at center fixes
  - Results in spurious track deviations

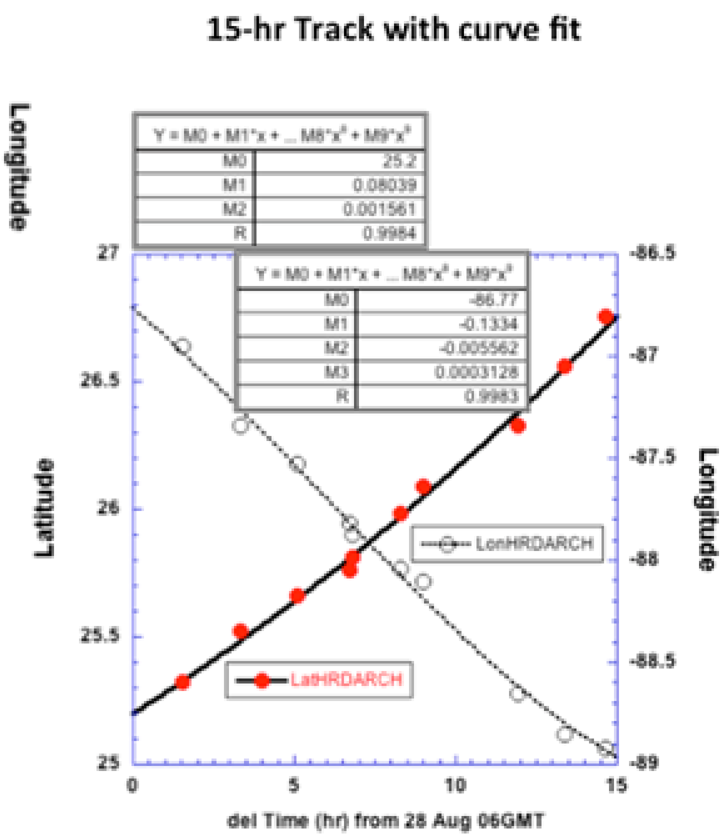
Improved Storm Track Determination

- Two competing methods
- Black: Piecewise polynomial fit
  - aircraft observations
  - ARCHER center fixes
    - Automated Rotational Center Eye Retrieval (microwave)
    - CIMSS by Wimmers and Velden (2010, 2015).
- Foster: p-splines
  - Aircraft only (ARCHER to be added)
    - p=0 → least-squares line
    - P=1 → cubic spline
  - Best collapse of pressure difference
    - observations vs. OVW-derived

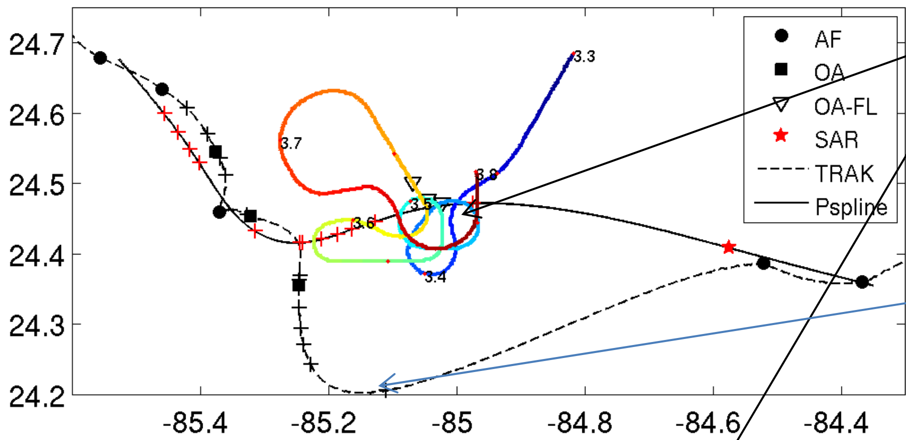
Black's Method



48-hr Track 12Z 27 Aug – 12Z 29 Aug
ARCHER/ aircraft fix (blue) combo

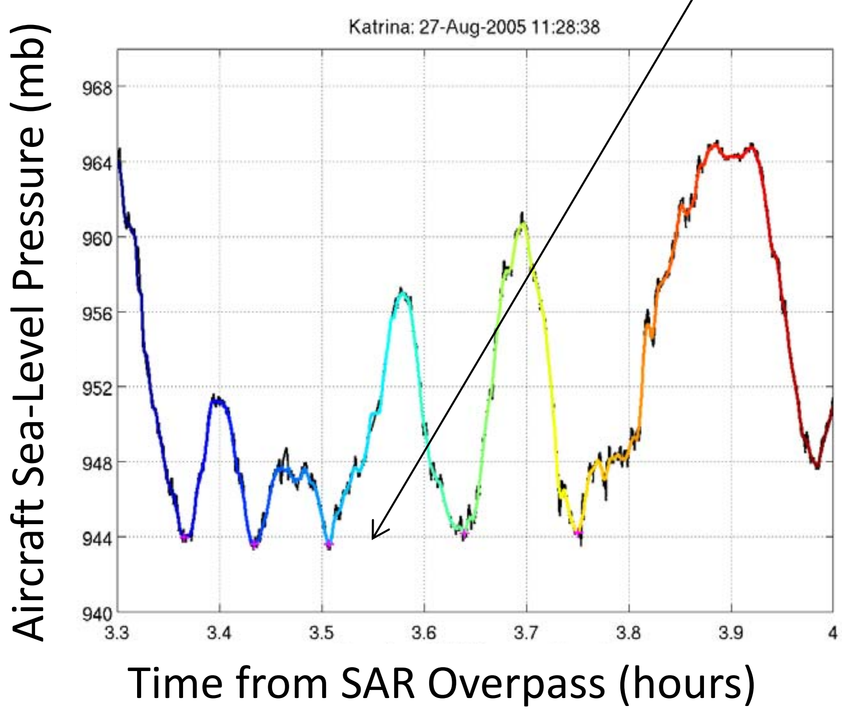


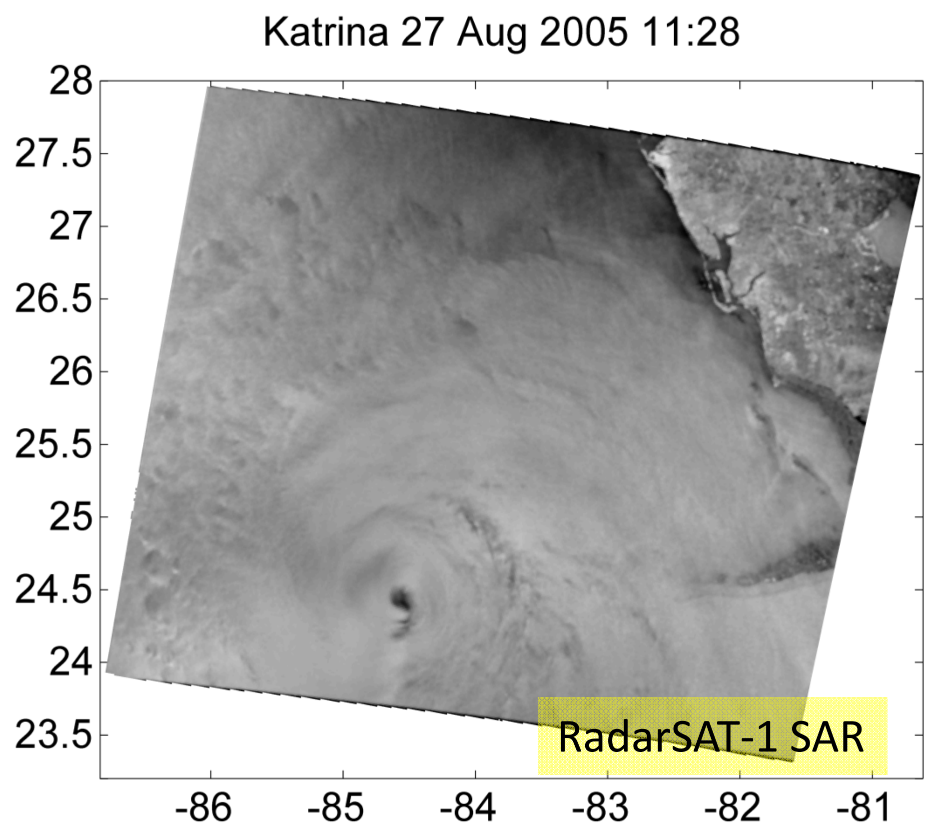
Least Squares fit to ARCHER and HRD aircraft fix data for 48-hour period bracketing 28 August, 2005, 1100 GMT. 15-hour sub-sample beginning on 28 August, 0600 GMT (right), provides a polynomial fit to both latitude surrounding the SAR overpass time.



P-3 sampling near center

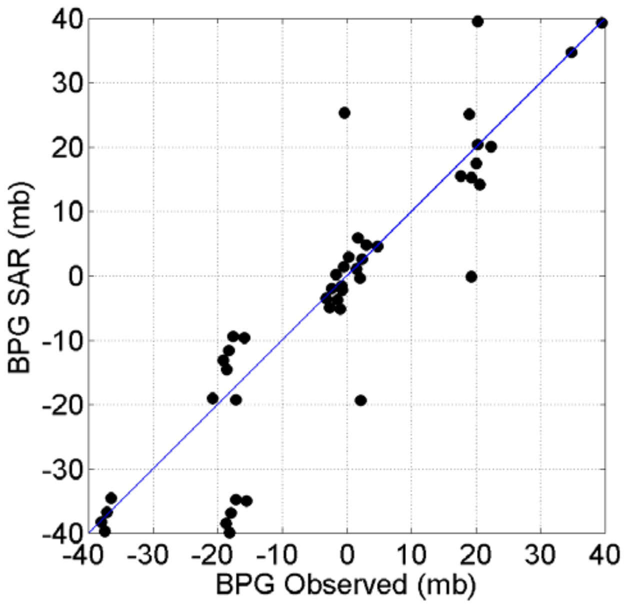
HRD TRAK locates center far to the south



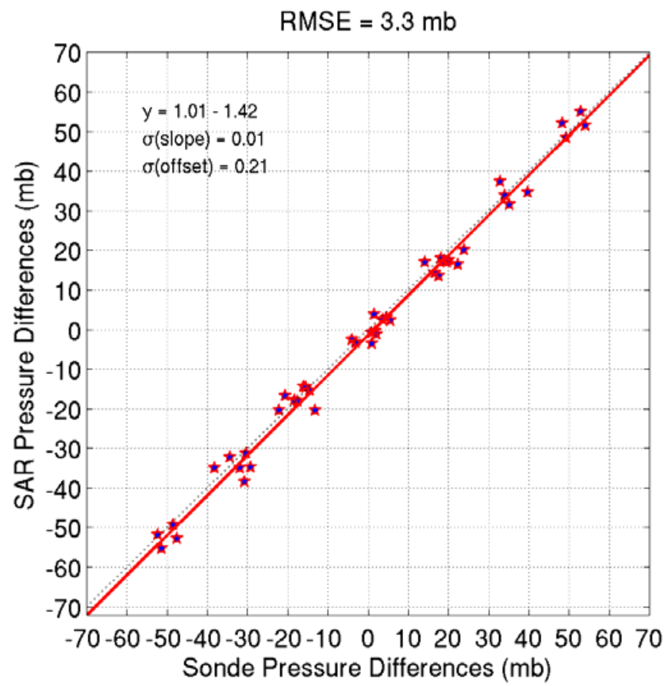


Foster Method

TRAK Storm Track

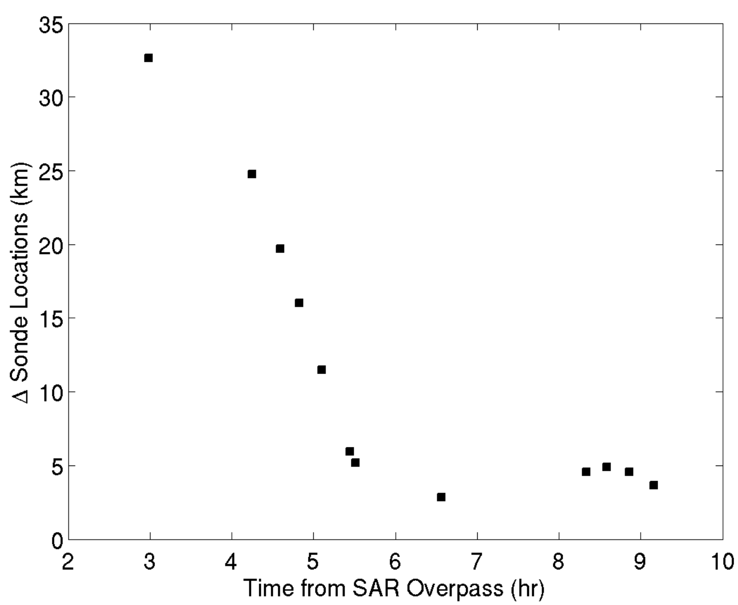


Corrected Storm Track

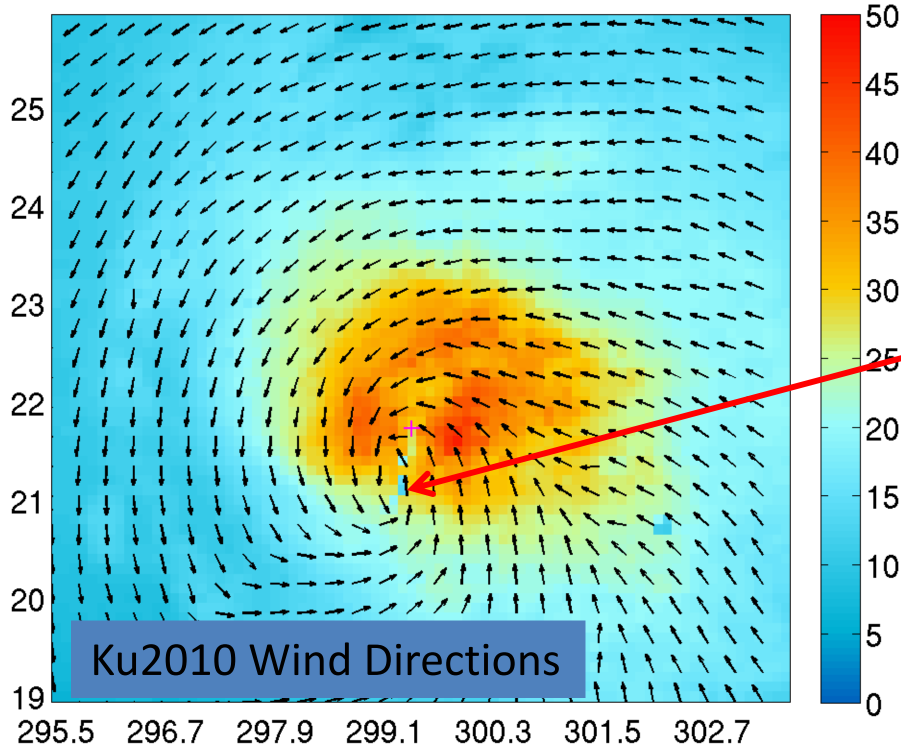


Validate against pressure difference between pairs of drop sondes

Up to 30 km change in "Storm-Relative" Drop Sonde location for this case

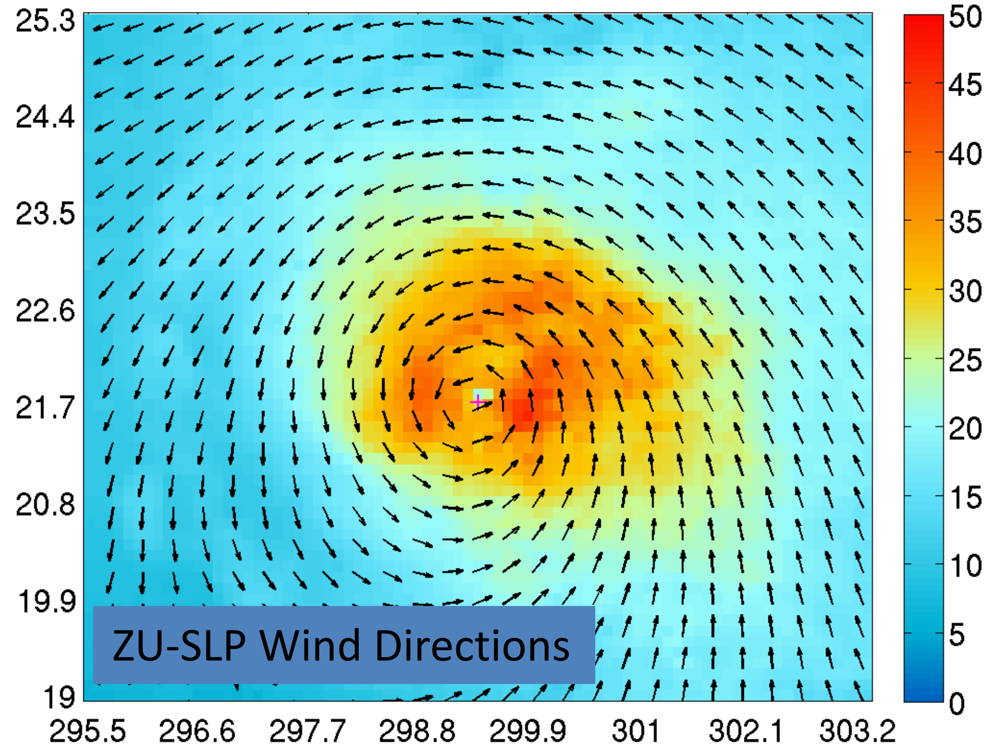


Hurricane Bill
20 Aug 2009, 09:45
QuikSCAT NN

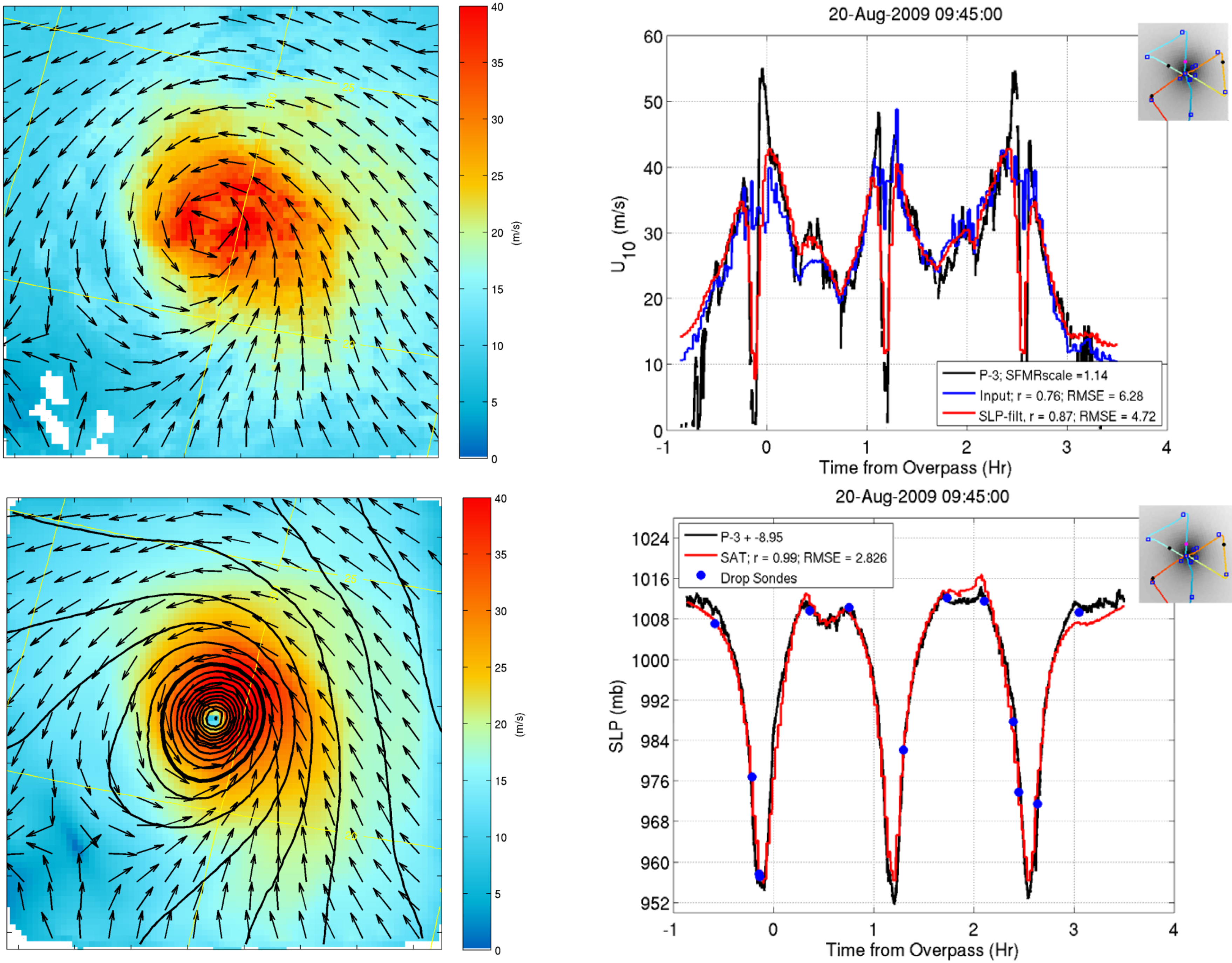


Note: “squared-off” vortex shape & misplaced storm center

“Standard” wind directions are not reliable



First-guess wind directions



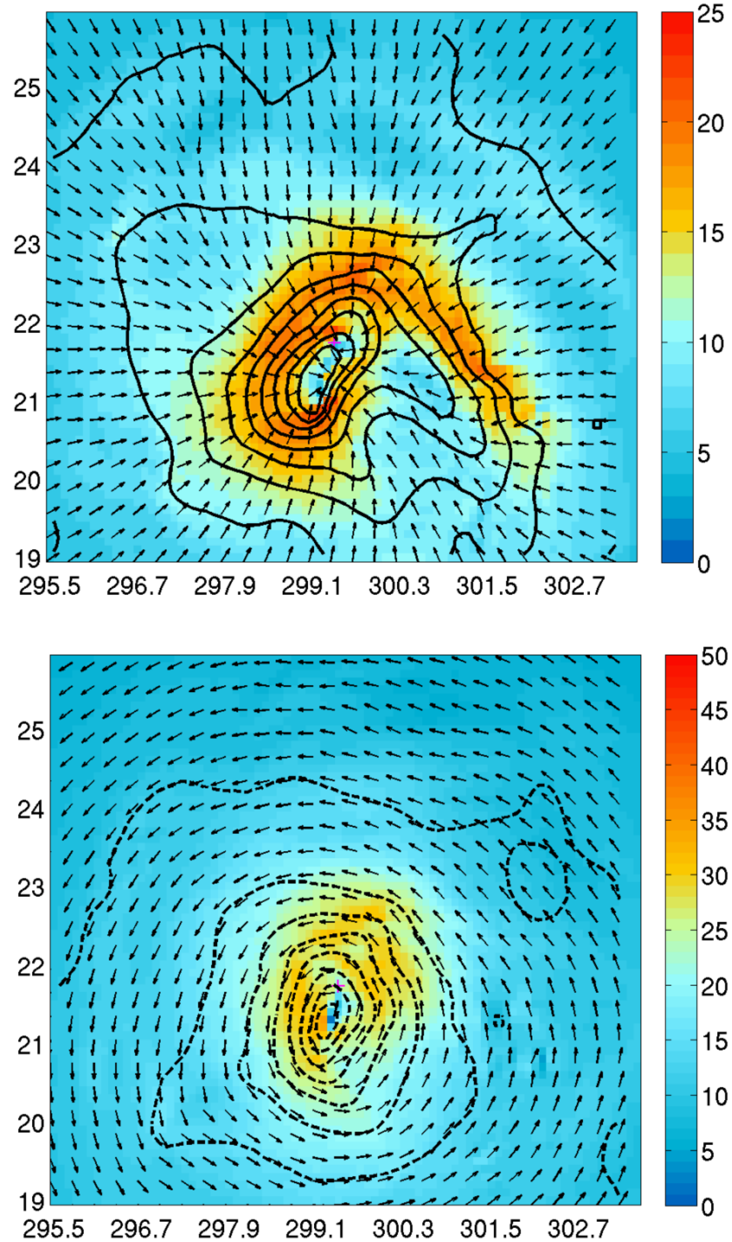
40
35
30
25
20
15
10
5
0
(m/s)
20-Aug-2009 09:45:00
U_{10} (m/s)
Time from Overpass (Hr)
P-3; SFMRscale =1.14
Input; r = 0.76; RMSE = 6.28
SLP-filt, r = 0.87; RMSE = 4.72
20-Aug-2009 09:45:00
SLP (mb)
Time from Overpass (Hr)
P-3 + -8.95
SAT; r = 0.99; RMSE = 2.826
Drop Sondes

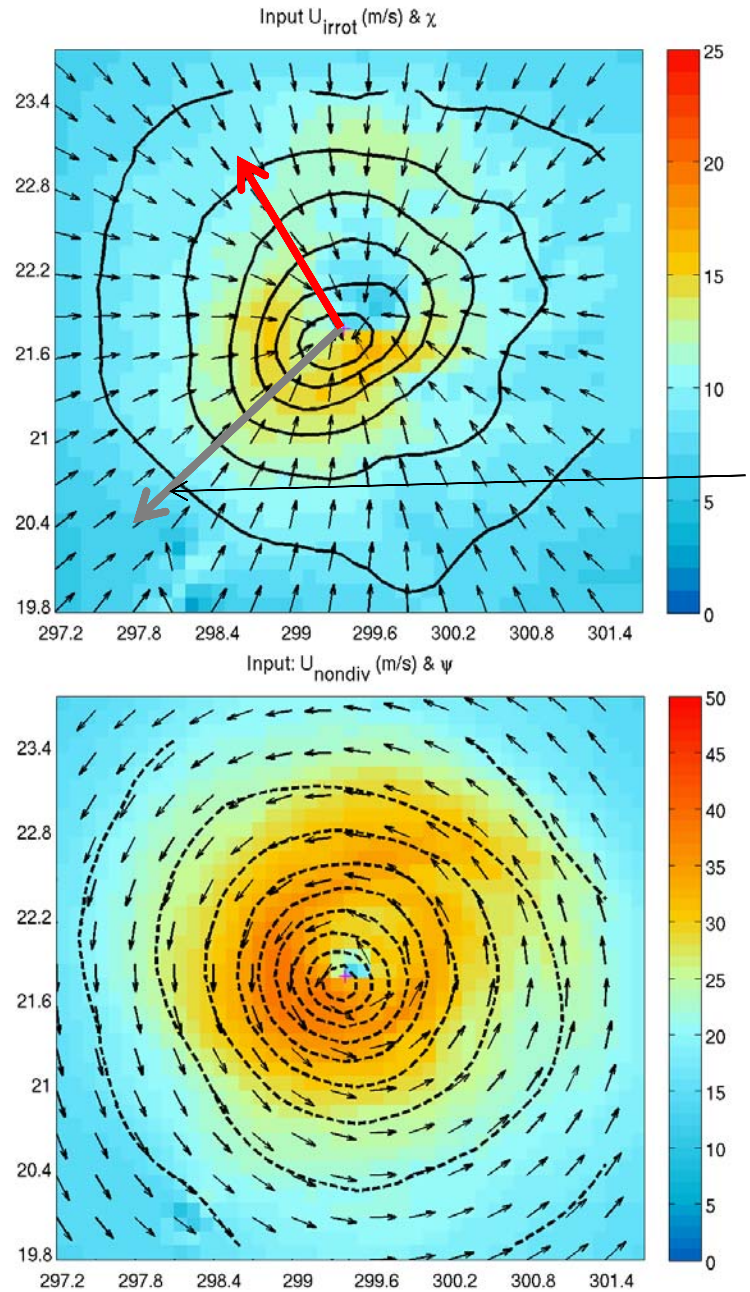
Wind Direction Assumption (All use QSNN speed)	SFMR (SLP-filtered) ($m\ s^{-1}$)	P-3 Flight-Level SLP Calculation (mb)	Sonde SLP (mb)	Sonde SLP pair-wise pressure differences (mb)
Ku2010	6.2	10.0	8.6	12.2
H*WIND	4.9	3.4	4.3	6.0
Zhang-Uhlhorn	4.9	3.1	4.7	6.7
Single Iteration	**4.7**	**2.8**	**3.5**	**3.3**

Wind Partitioning

- Estimate non-divergent & irrotational parts of flow in a limited domain
  - **Non-divergent**: surface signature of ***primary*** circulation
  - **Irrotational**: surface signature of ***secondary*** circulation
  - Potentially more informative than standard radial/azimuthal flow partitioning
- Residual is non-divergent and irrotational **deformation** flow
  - Surface signature of external influence on local flow
- Bishop, C H., 1996: Domain-Independent Attribution. Part I: Reconstructing the wind from estimates of vorticity and divergence using free space Green's functions. *J. Atmos. Sci.*, **53**, 241–252.

Ku2010 + NN



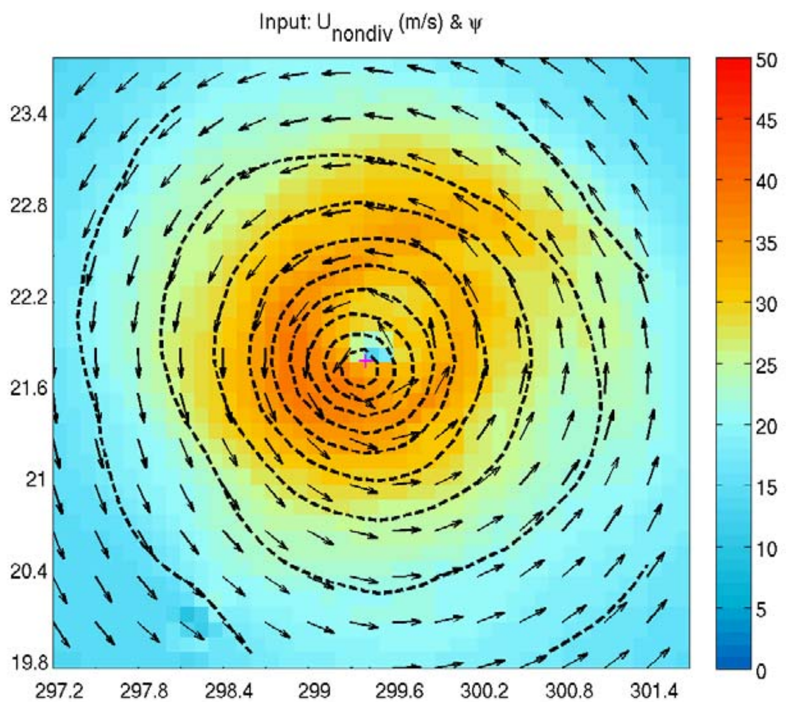


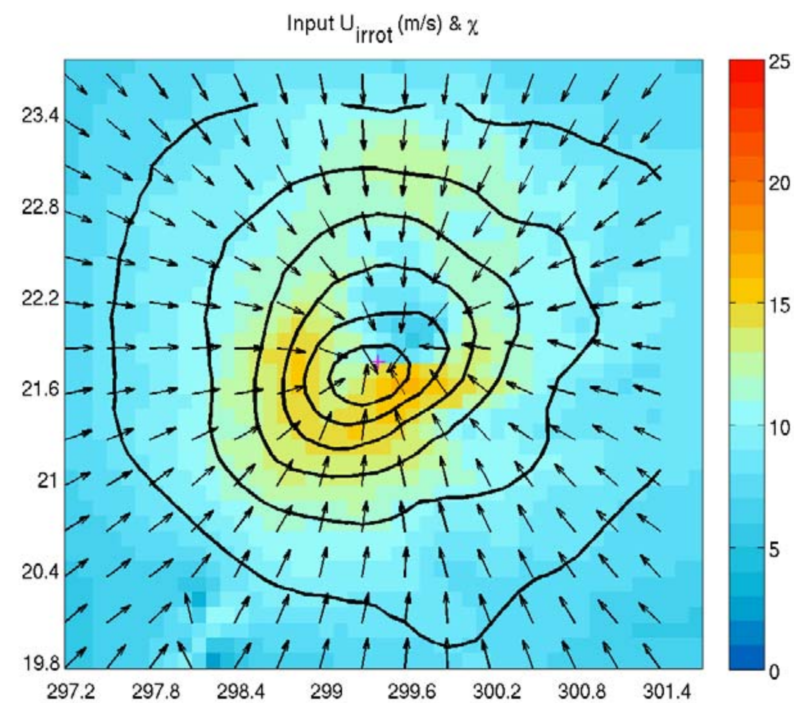
Irrotational Flow (Lower branch of the Secondary Circulation)

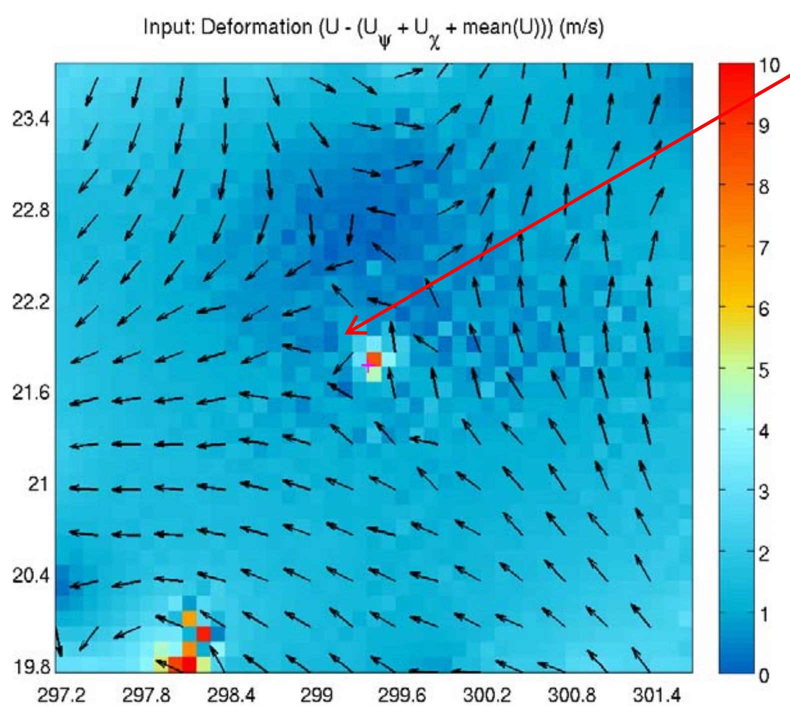
Approx. Vert. Shear from SHIPS

Nondivergent Flow (Surface imprint of the Primary circulation)

Bill (2009)







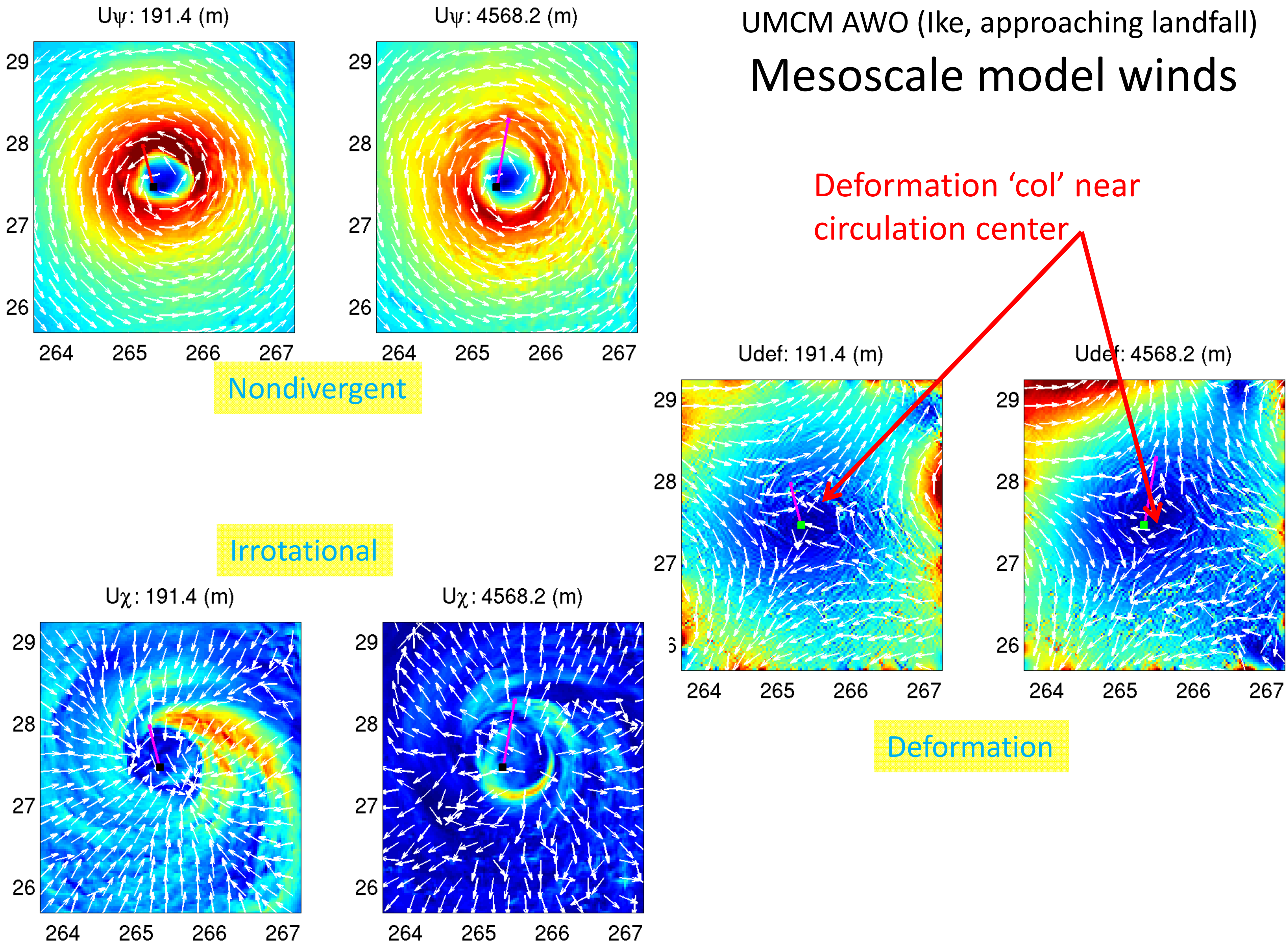
Deformation ‘col’ near circulation center

- Use flow partition analysis & SLP data to refine estimates of surface-level circulation center
- Best fit to SLP obs
- Find flow partition metrics e.g.:
  - Maximize circulation near RMW
  - Location of deformation ‘col’

Bill (2009)

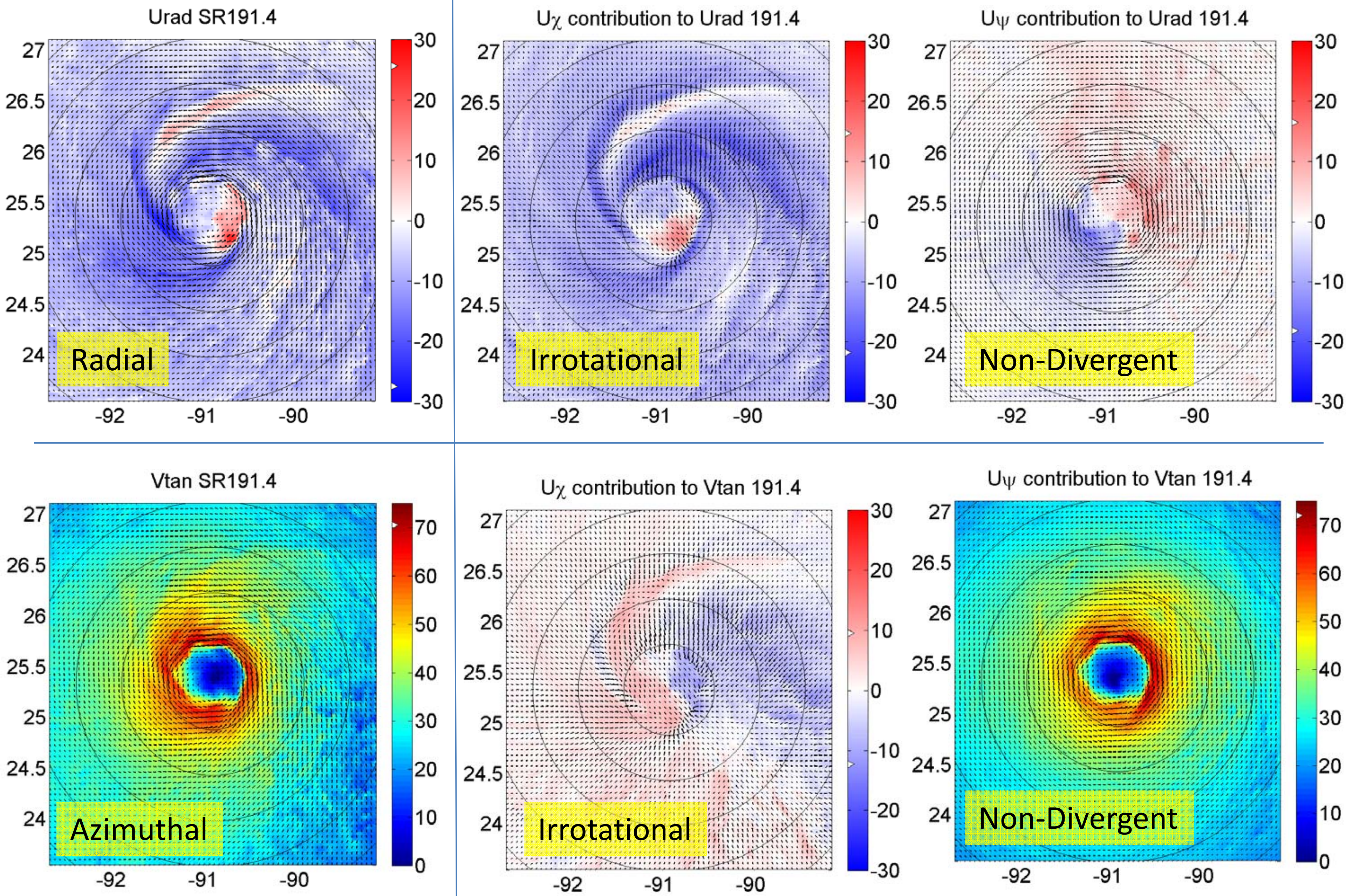
UMCM AWO (Ike, approaching landfall)

Mesoscale model winds



SR Radial/Azimuthal

Flow Partitioning



UMCM, AWO: Ike, z = 190 m

Current Work

- Developing improved storm tracks for all of our matchups
  - Best method wins!
  - Include "ARCHER" storm centers in Foster's method
- Extract ${U_{10}}^{N}$ from profiles
- Fitting surface wind directions
  - Exploit flow partitioning

Summary

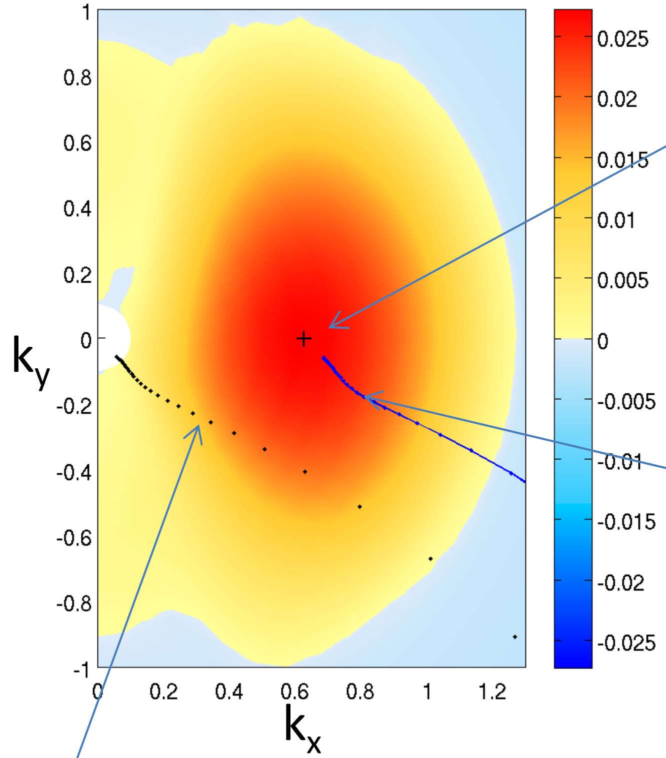
- Given accurate wind directions, accurate SLP patterns can be derived from TC NN wind speeds
  - Use collocations to develop inflow angle parameterization
- Correct location of in situ data is crucial
- Flow partitioning extracts surface signature of TC secondary circulation
- Deformation "col" location may help identify TC surface circulation center

Research supported by NASA: Ocean Vector Winds Science Team

Why do Multi-scale Rolls Form in Hurricane PBL?

- Well-observed O(300 m) wavelength rolls
  - (e.g., Wurman and Winslow, 1998)
- Interact with ‘classic’ O(2 km) wavelength rolls
  - (e.g., Morrison et al. 2005; Lorsolo et al., 2009)
- Ubiquitous SAR signature O(10 km) rolls
  - (e.g. Foster, 2013; Gall et al. 1998 (?))

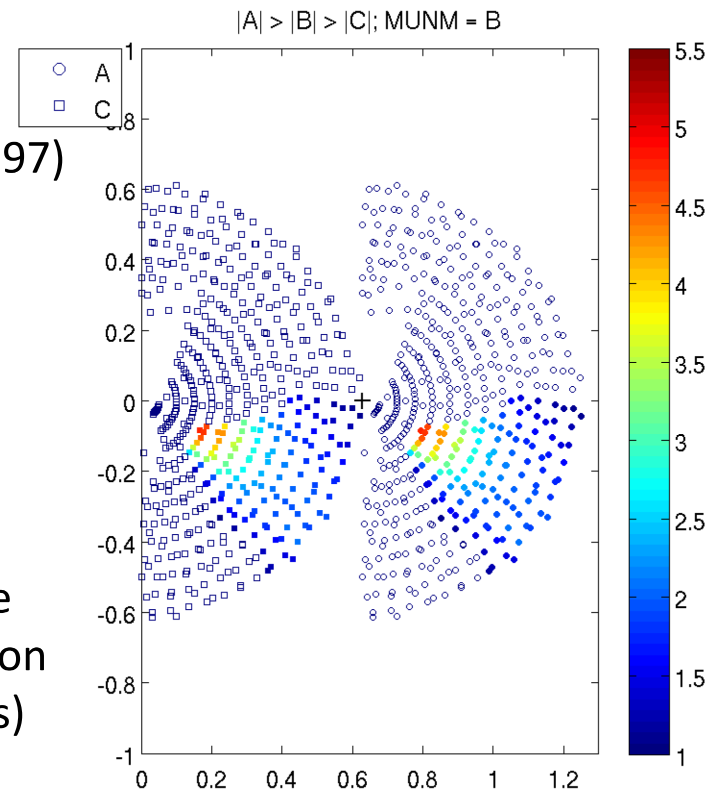
Linear instability growth rate



Dominant ('classic') fastest-growing rolls (Morrison et al 2005; Foster 2005)

Most dangerous Super-exponential ('algebraic') rolls. Small-scale, near-surface, Foster (1997) (Wurman & Winslow, 1998)

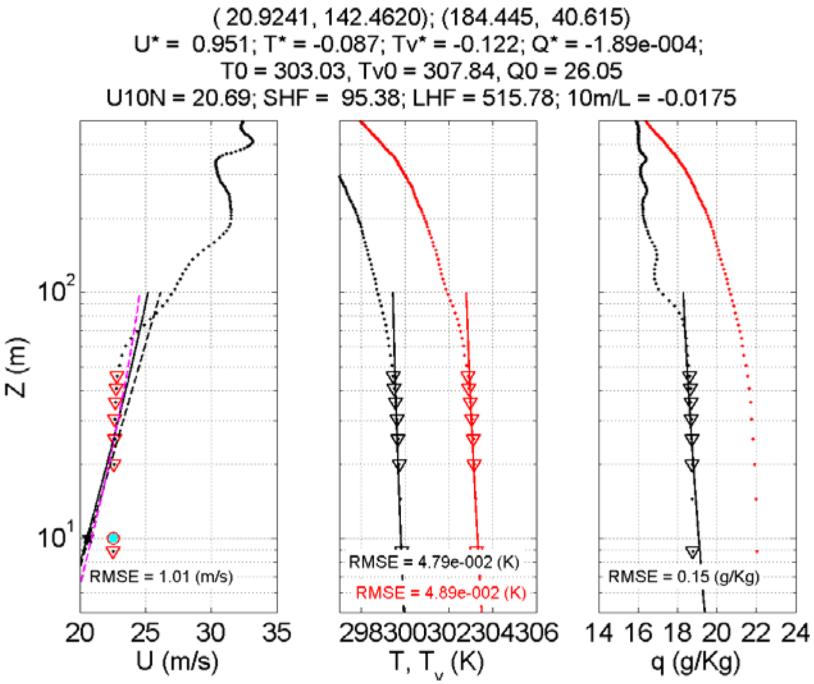
Slowly-growing Large-scale rolls (3^{rd} leg of triad) (Foster, 2013)

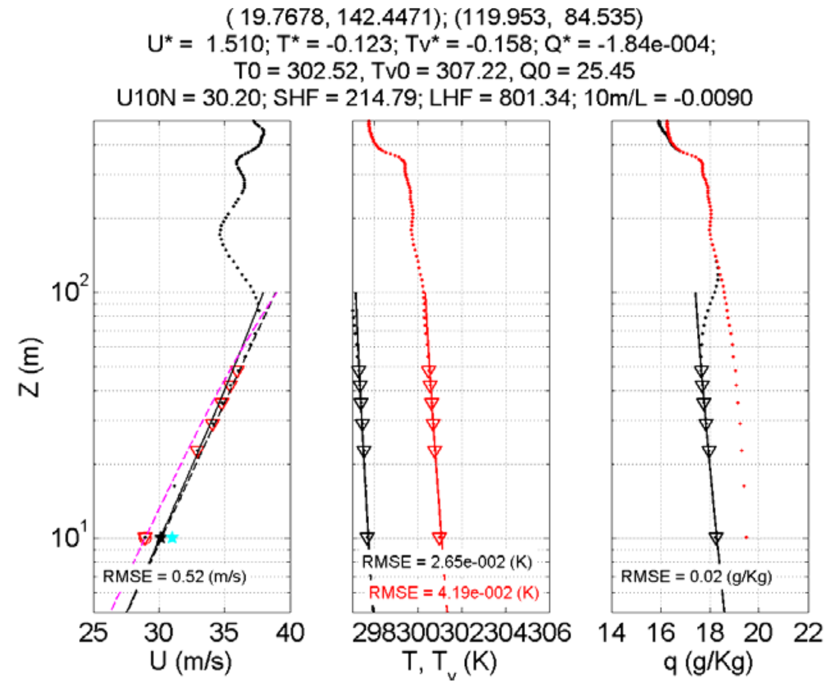


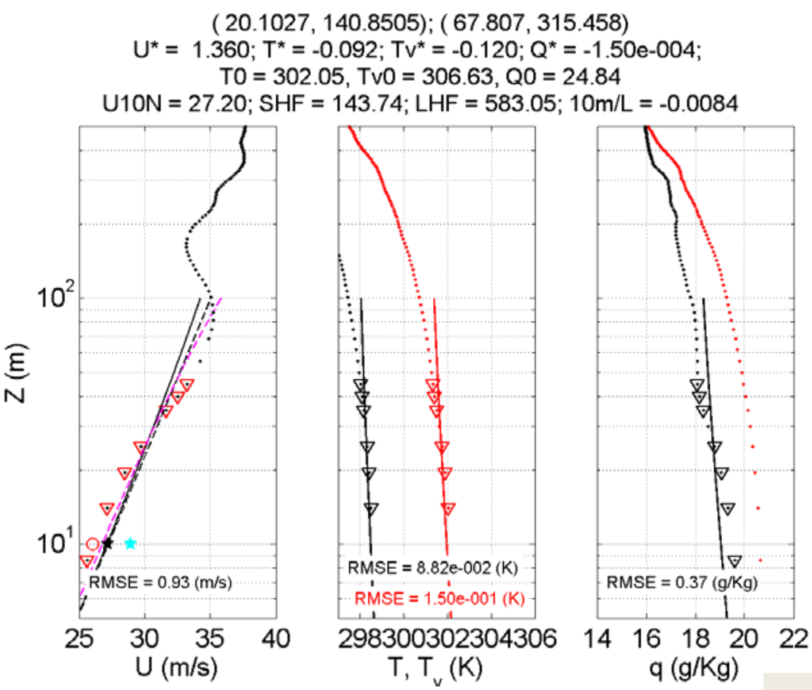
Momentum transfer to surface due to resonant triad interaction (multiple of single 'classic' rolls)

Estimating U10N from Sondes

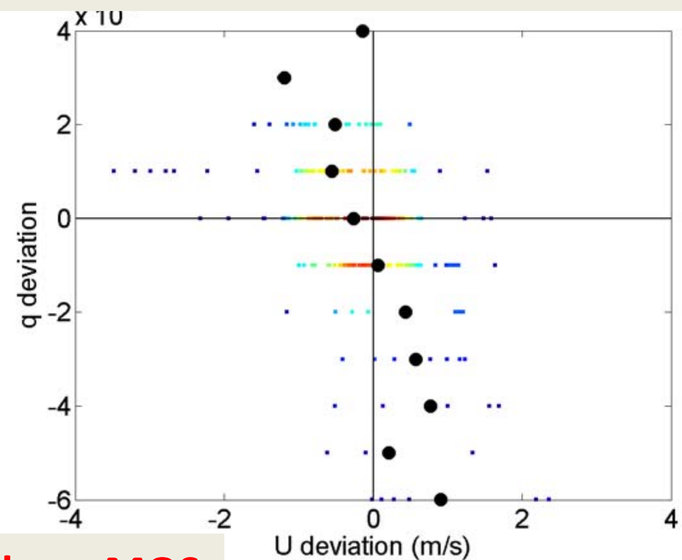
- New technique: fit Monin-Obukhov profiles to near-surface profile (new generation sondes)
  - Inherent assumption: each measurement in the sonde profile is independent
- Temperature always follows M-O
  - Buoyancy continuously adjusts
  - Wind and humidity frequently deviate from M-O
- Wind and humidity deviations anti-correlate
  - Signature of near-surface overturning flow that is coupled to surface streaks
  - Association of streaks with intermittent flux eddies
    - Ejections (sweeps) form in the updraft (downdraft) bands associated with streaks
    - Maintain the surface stress
  - Modification of estimated mean wind is real, but likely smaller scale than SAR pixels
    - Larger-scale rolls also introduce local mean wind perturbations





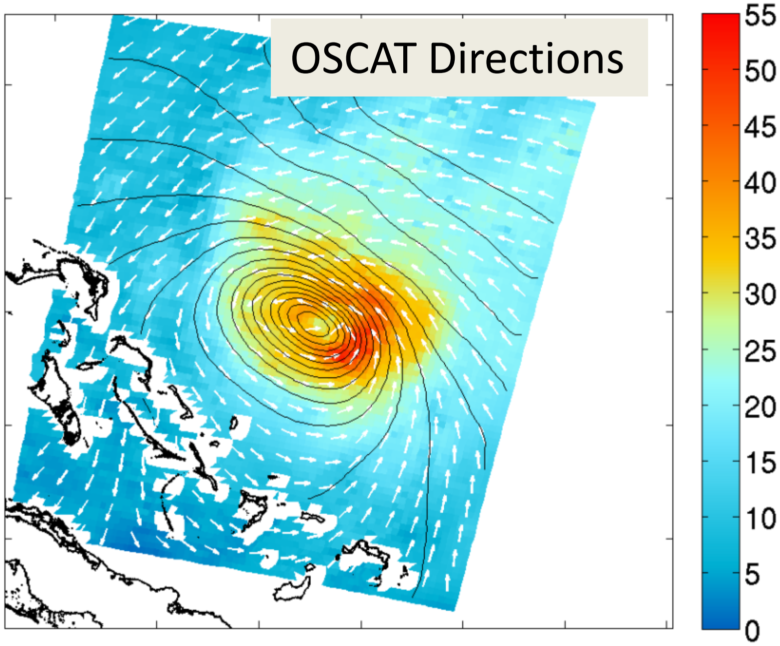


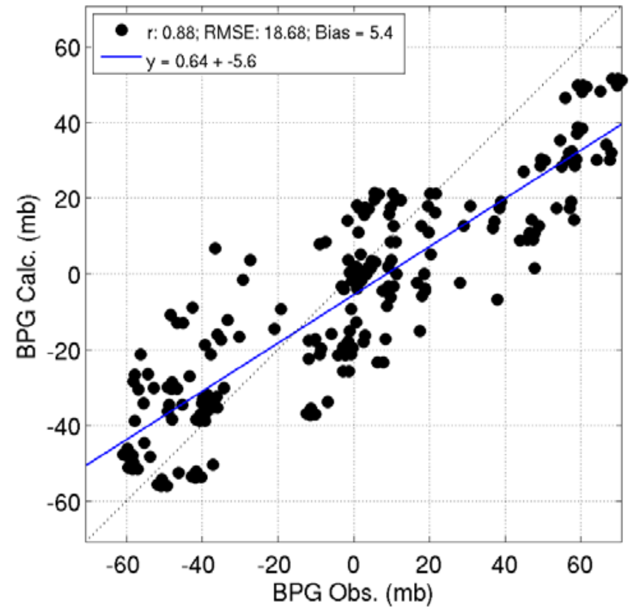
Near-surface overturning flow signature:
Higher U_{10} ↑, q ↓ or U_{10} ↓, q ↑

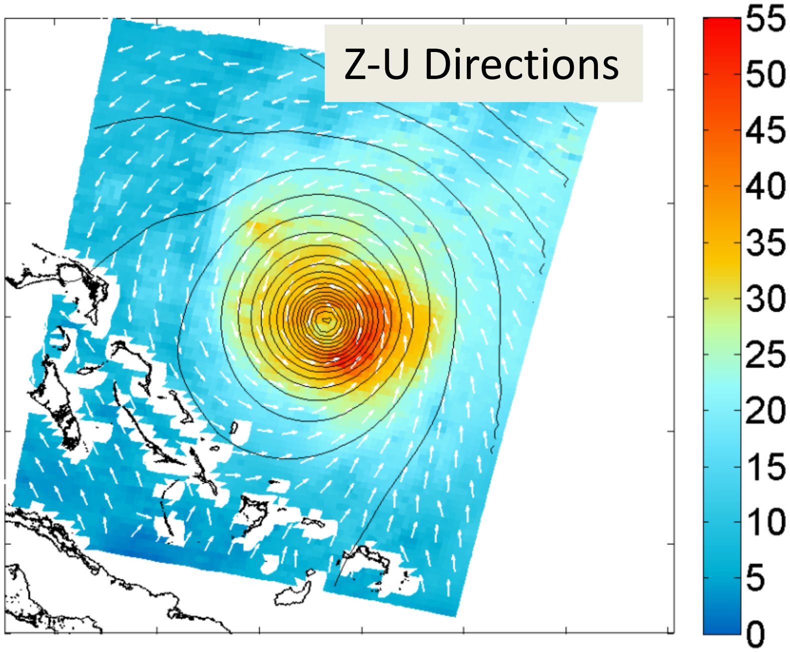


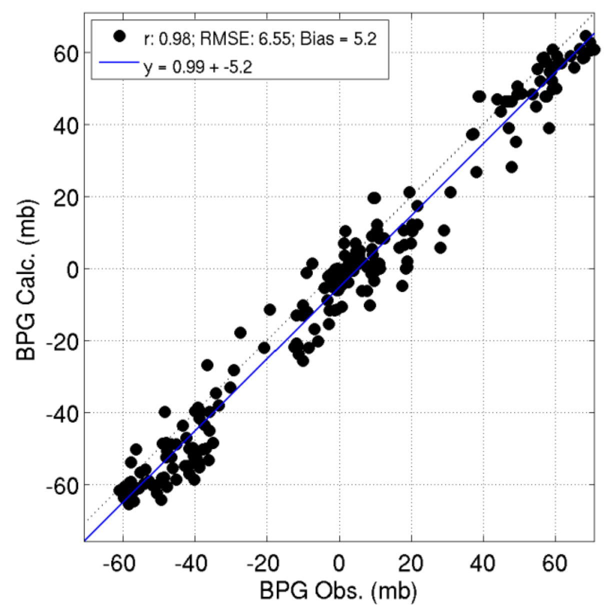
T always follows MOS

Hurricane Earl, 1 Sep, 2010







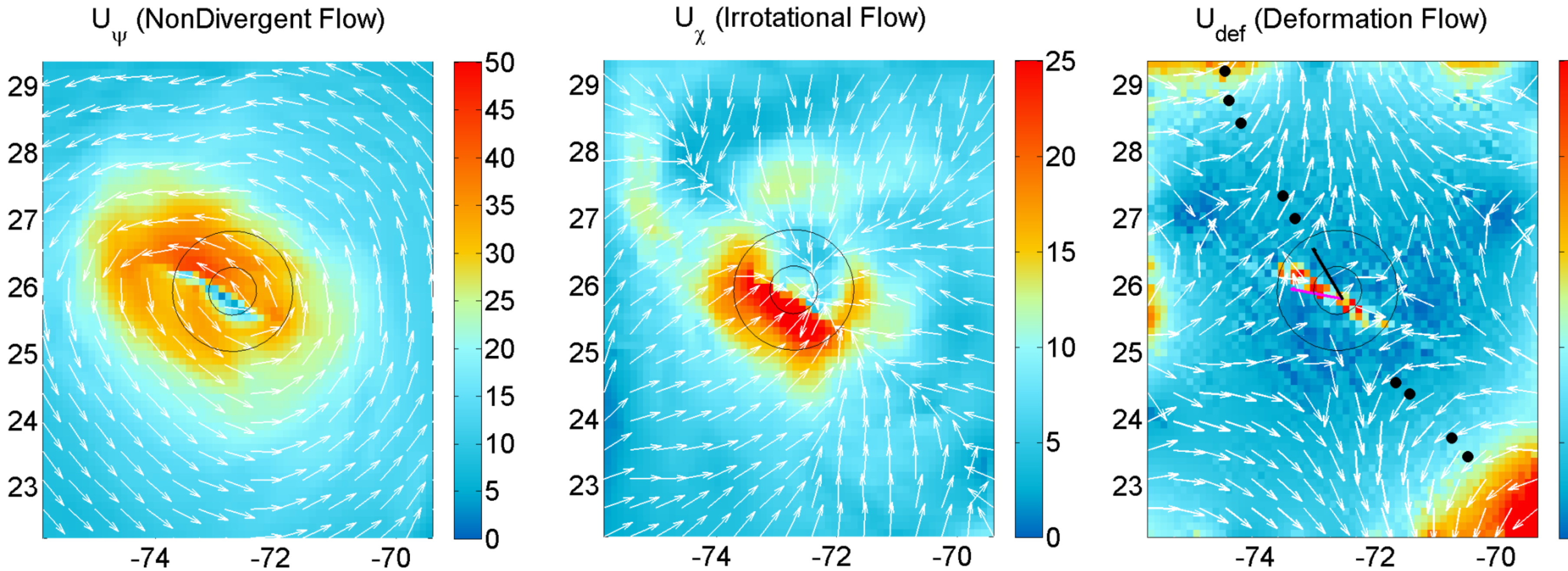


Preliminary navigation of drop sondes

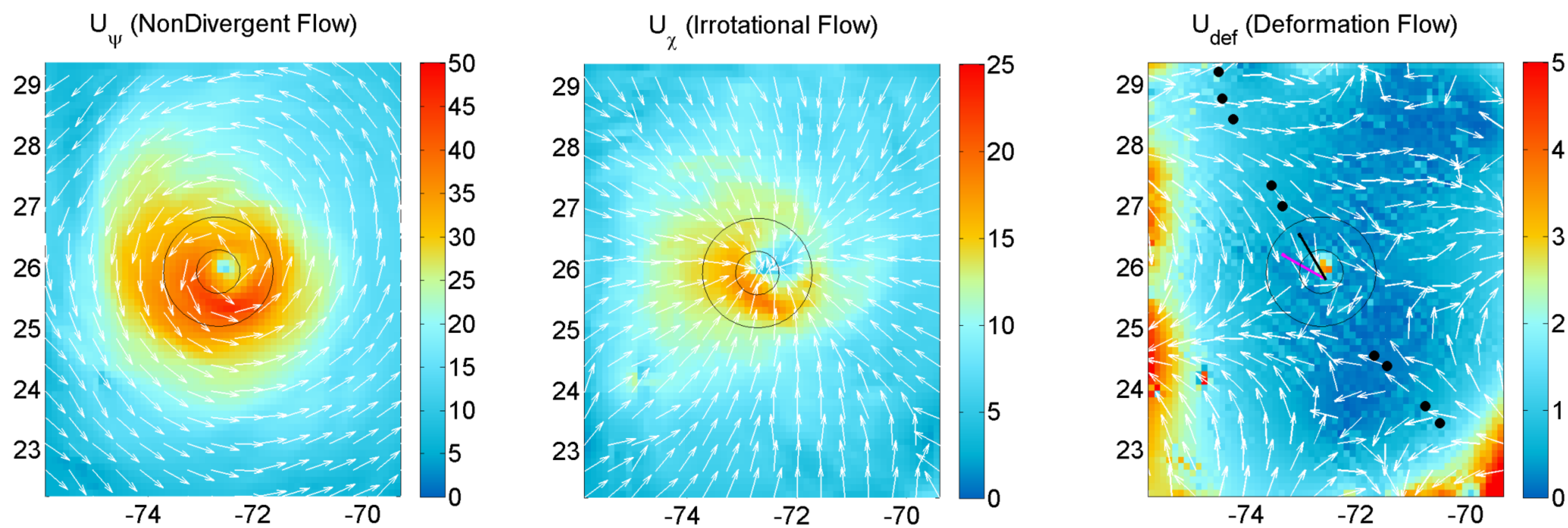
Note: OceanSAT, not QuikSCAT

OSCAT Directions

Hurricane Earl, 1 Sep, 2010



ZU Directions



Motivation

- Synthetic Aperture Radar for Tropical Cyclones
  - Pros:
    - Very high resolution (~1km)
    - Very reliable OVW retrievals
  - Cons:
    - Non-continuous retrievals
    - Need to schedule ~24 hrs in advance
- Scatterometers for Tropical Cyclones
  - Pros:
    - Wide swath
    - Continuous retrieval
    - Long data record, e.g.
      - 10-years QuikSCAT (NASA)
      - 2-years RapidSCAT (NASA)
      - 2-years OceanSCAT (India)
      - Upcoming HY-2 (China)
      - ASCAT (ESA; dual narrow swath)
  - Cons:
    - Coarser-resolution (~12 km)
    - Serious rain contamination for Ku-band