Coherent Turbulence in the Boundary Layer of Intense Hurricanes

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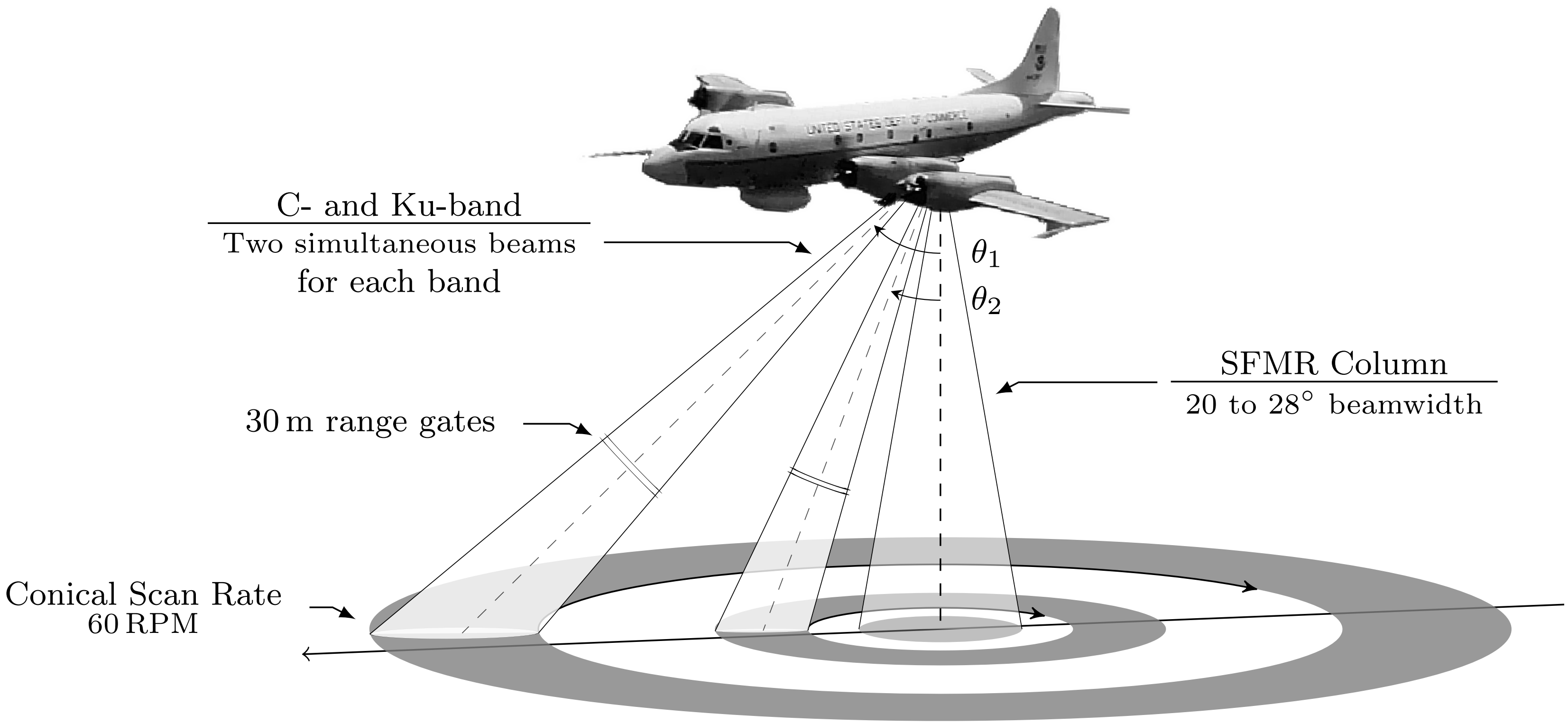
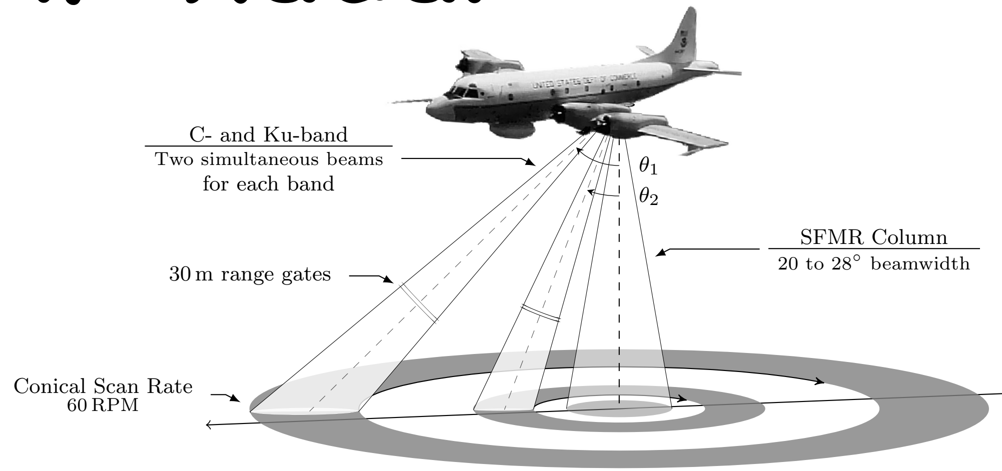
The IWRAP Radar



3DVAR Wind Retrieval Algorithm

Guimond et al. (2014) in JTECH; Guimond et al. (2018a) in JAS

The IWRAP Radar



Novel features of IWRAP

- Very high-resolution wind/reflectivity data
  - ~ 100 – 150 m along-track and 30 m range sampling
  - 3D winds/reflectivity/derivatives on ~ 200 m/30 m grid
- Quality data down to ~ 200 m height
  - Deep into boundary layer, swath width 1 – 2 km
- Extensive TC database (starting with 2003 season)
  - Many Cat. 4/5 storms sampled, focus on high wind regions
  - Continues to collect data

Understanding Sampling Characteristics: Large Eddy Simulation of a Rapidly Intensifying Hurricane

Guimond et al. (2018b)

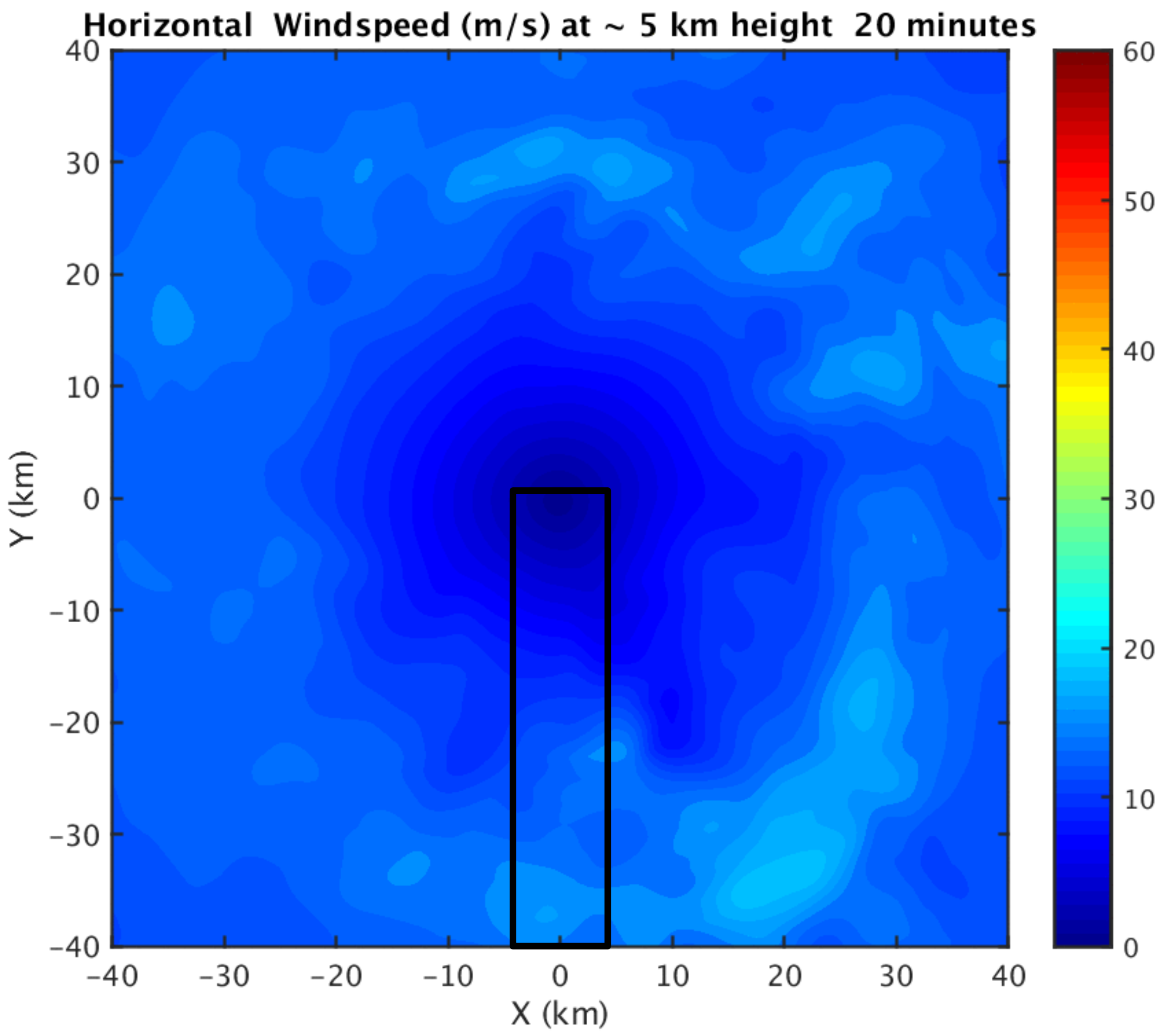
- Idealized numerical simulation of the rapid intensification of Hurricane Guillermo (1997) in East Pacific was conducted.

Initial conditions…

- Latent heat retrievals (Guimond et al. 2011) used as forcing, vortex based on Guimond et al. (2016).
- Dry dynamics, simple sub-grid model.

1) Grid spacing of 60 meters in x/y/z with arrays of size 2100x2100x210, time step of 0.1 – 0.2 seconds.
2) Up to ~ 20,000 compute cores at one time used on NASA Pleiades system.

- Data being used for Observing System Experiments (OSE) to test sampling strategies of various airborne radars.



Effective Resolution of IWRAP Wind Retrievals

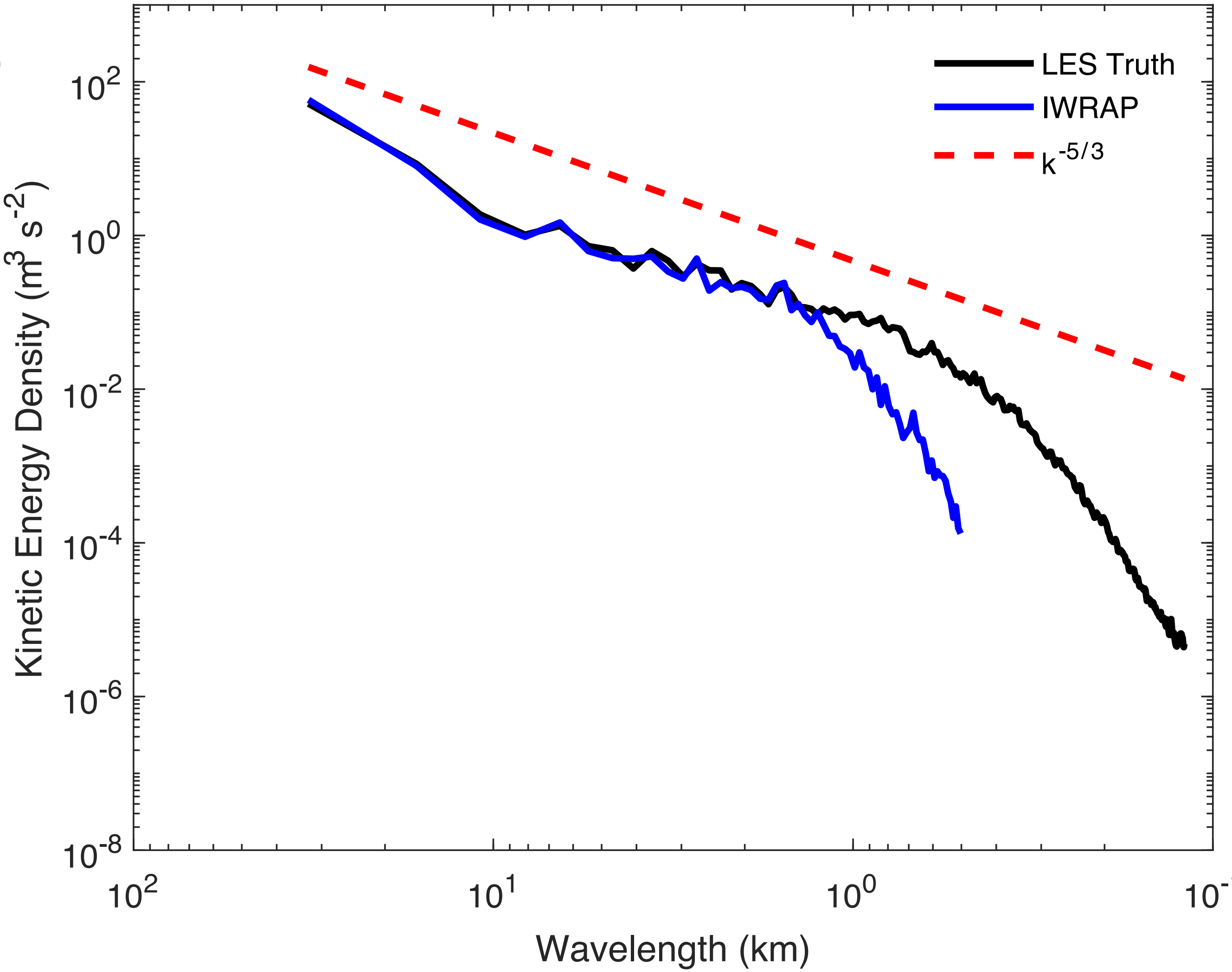
Guimond et al. (2018b)

Antenna Pattern

$$\bar{V}_r = (\bar{u}x + \bar{v}y + \bar{w}z)r^{-1}$$

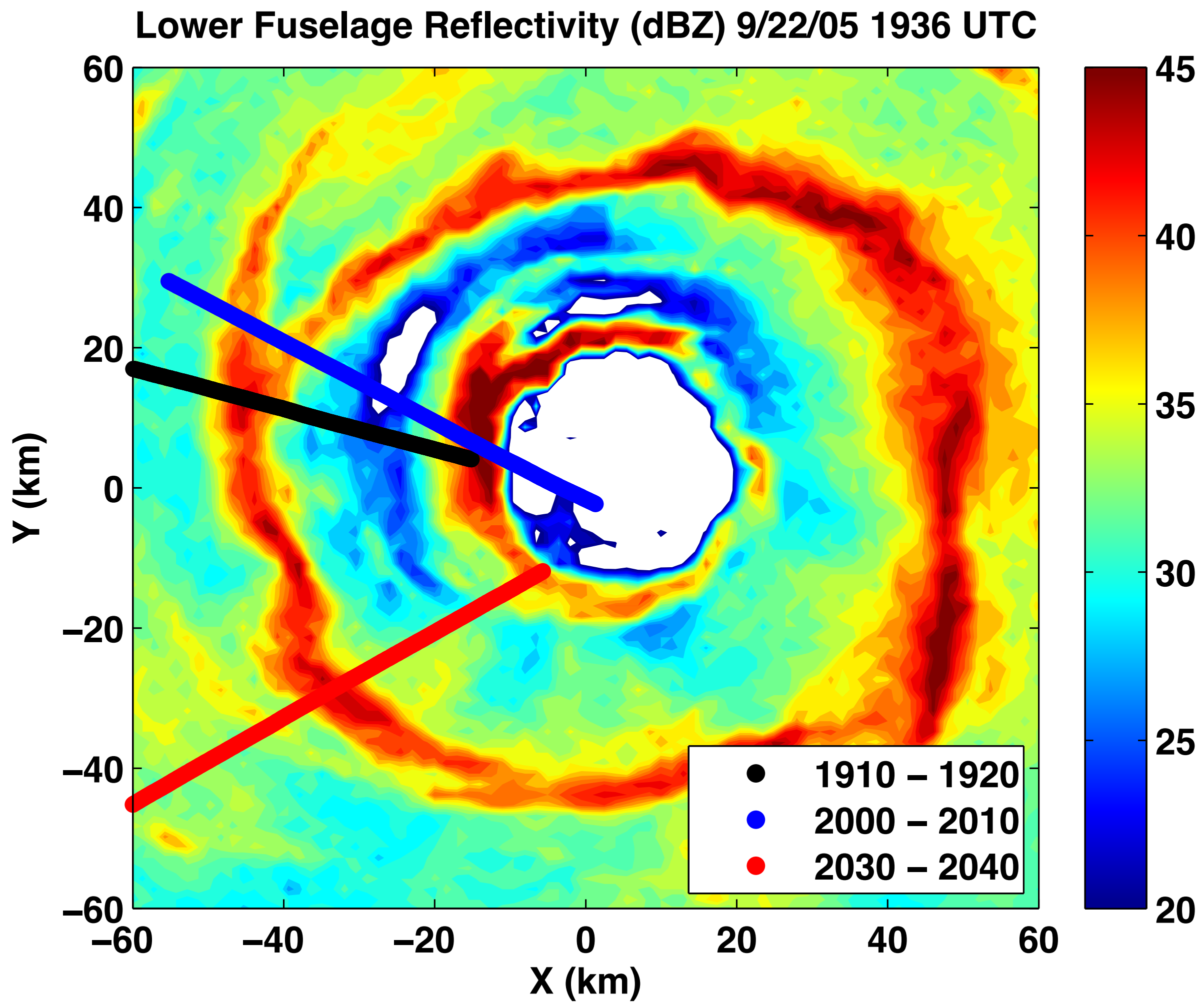
$$\overline{(f)} = \frac{\sum_{i=1}^{n} f_i w_i}{\sum_{i=1}^{n} w_i}$$

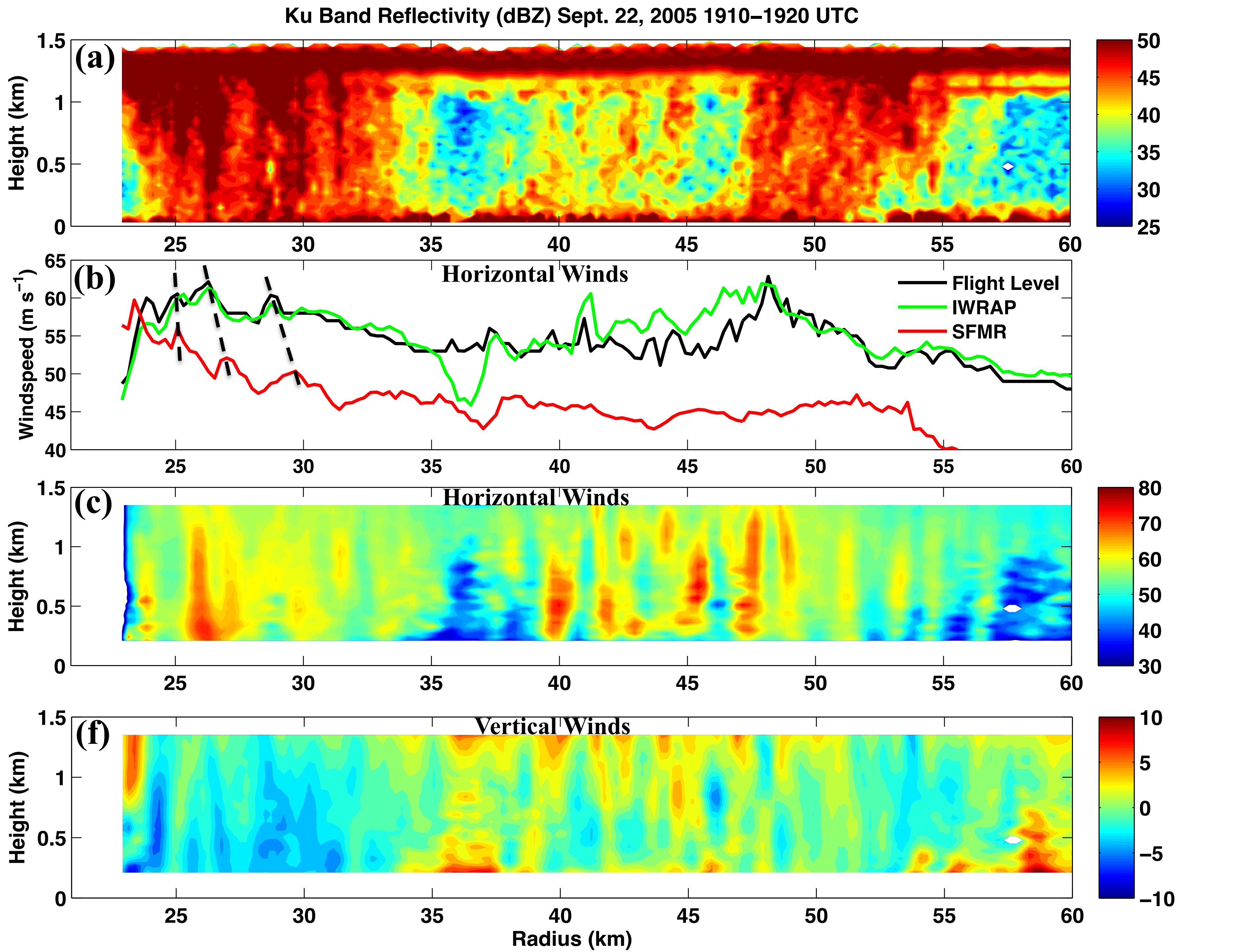
$$w_i = e^{-(r_i/R_k \tan(BW/2))}$$



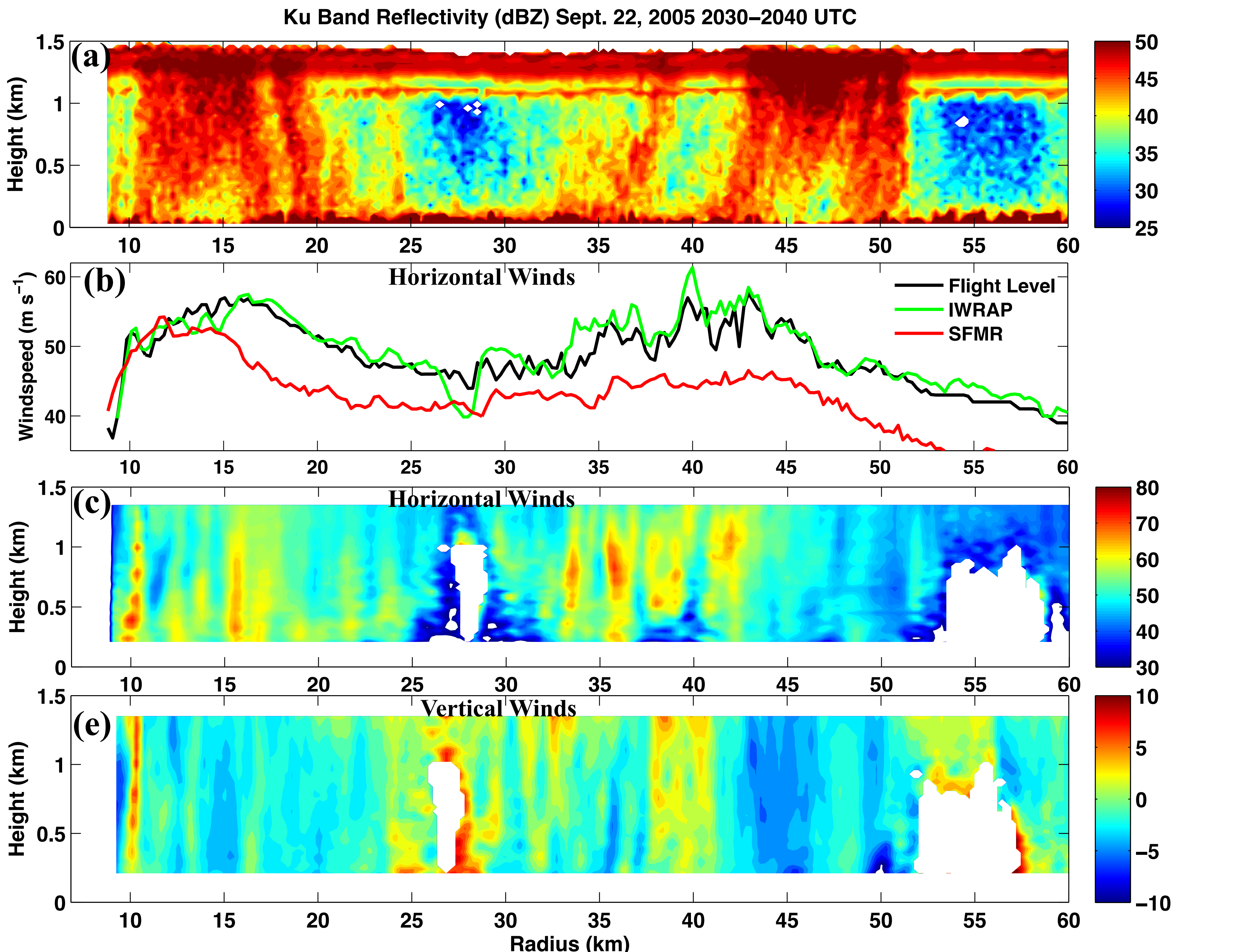
Hurricane Rita (2005)
Sept. 22 ~ 1700 – 2200 UTC

- Peak intensity on 9/22 at 06 UTC, slow weakening during sampling, intensity of 914 hPa
- Concentric eyewall formation at ~ 9/22 00 UTC
- Didlake et al. (2011)… focus on asymmetric structure (pert. vorticity)
- Bell et al. (2012)… axisymmetric structure of concentric eyewalls





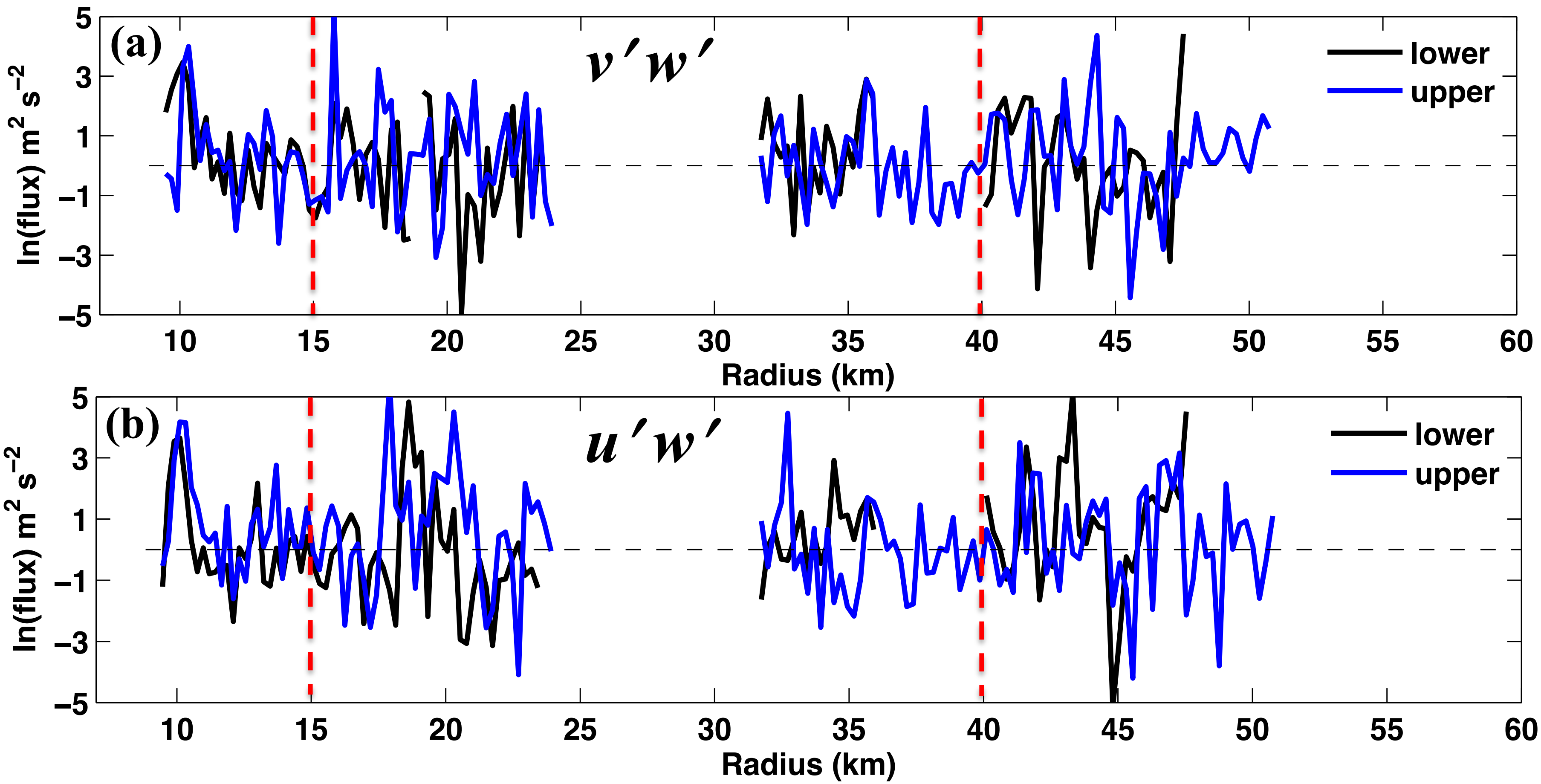
Ku Band Reflectivity (dBZ) Sept. 22, 2005 1910–1920 UTC
(a)
Height (km)
(b)
Horizontal Winds
Windspeed (m s⁻¹)
Flight Level
IWRAP
SFMR
(c)
Horizontal Winds
Height (km)
(f)
Vertical Winds
Height (km)
Radius (km)



Ku Band Reflectivity (dBZ) Sept. 22, 2005 2030–2040 UTC
(a)
Height (km)
(b)
Horizontal Winds
Windspeed (m s^{-1})
Flight Level
IWRAP
SFMR
(c)
Horizontal Winds
Height (km)
(e)
Vertical Winds
Height (km)
Radius (km)

Eddy Momentum Fluxes 2030–2040 UTC Leg

- **Lower = 0.20 – 0.50 km mean, Upper = 0.50 – 1.00 km mean**
- Peak $v'w'$ = 55 $m^2 s^{-2}$, Mean (eyewalls) $v'w'$ = ~ 1.0 – 1.5 $m^2 s^{-2}$
- Peak $u'w'$ = 150 $m^2 s^{-2}$, Mean (eyewalls) $u'w'$ = ~ 0.0 – 3.0 $m^2 s^{-2}$



Typical Boundary Layer Roll Structure

$$v'w' \text{ and } u'w' < 0$$

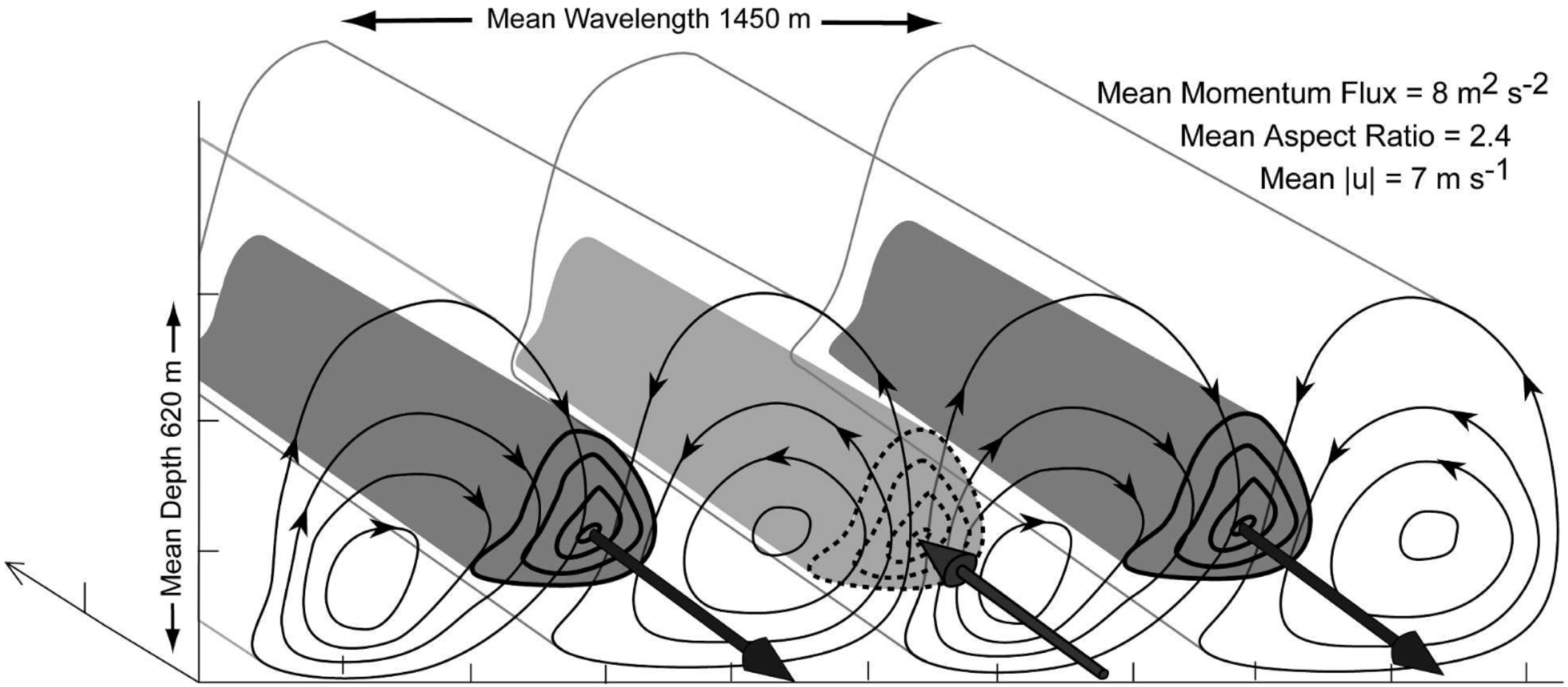
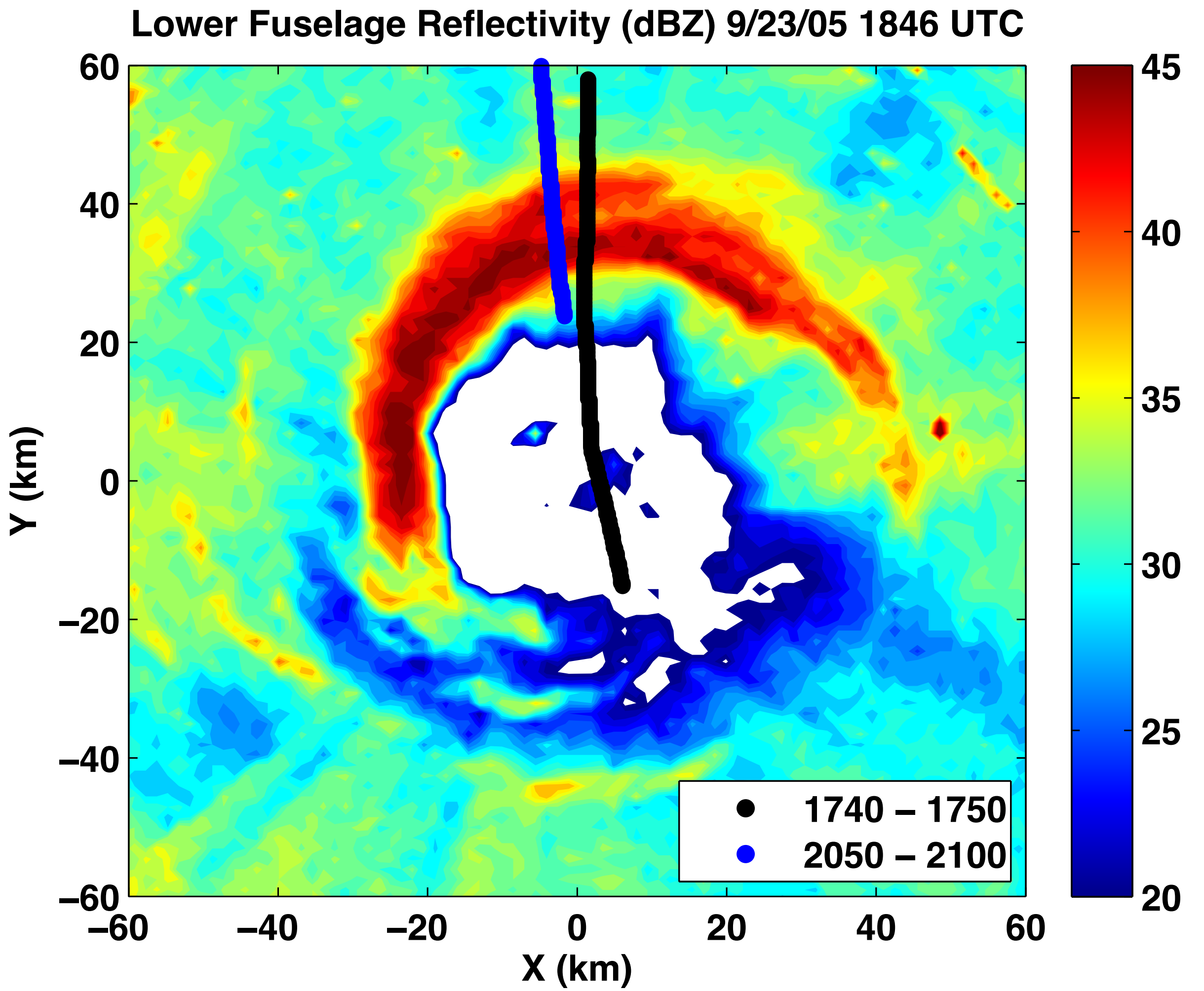


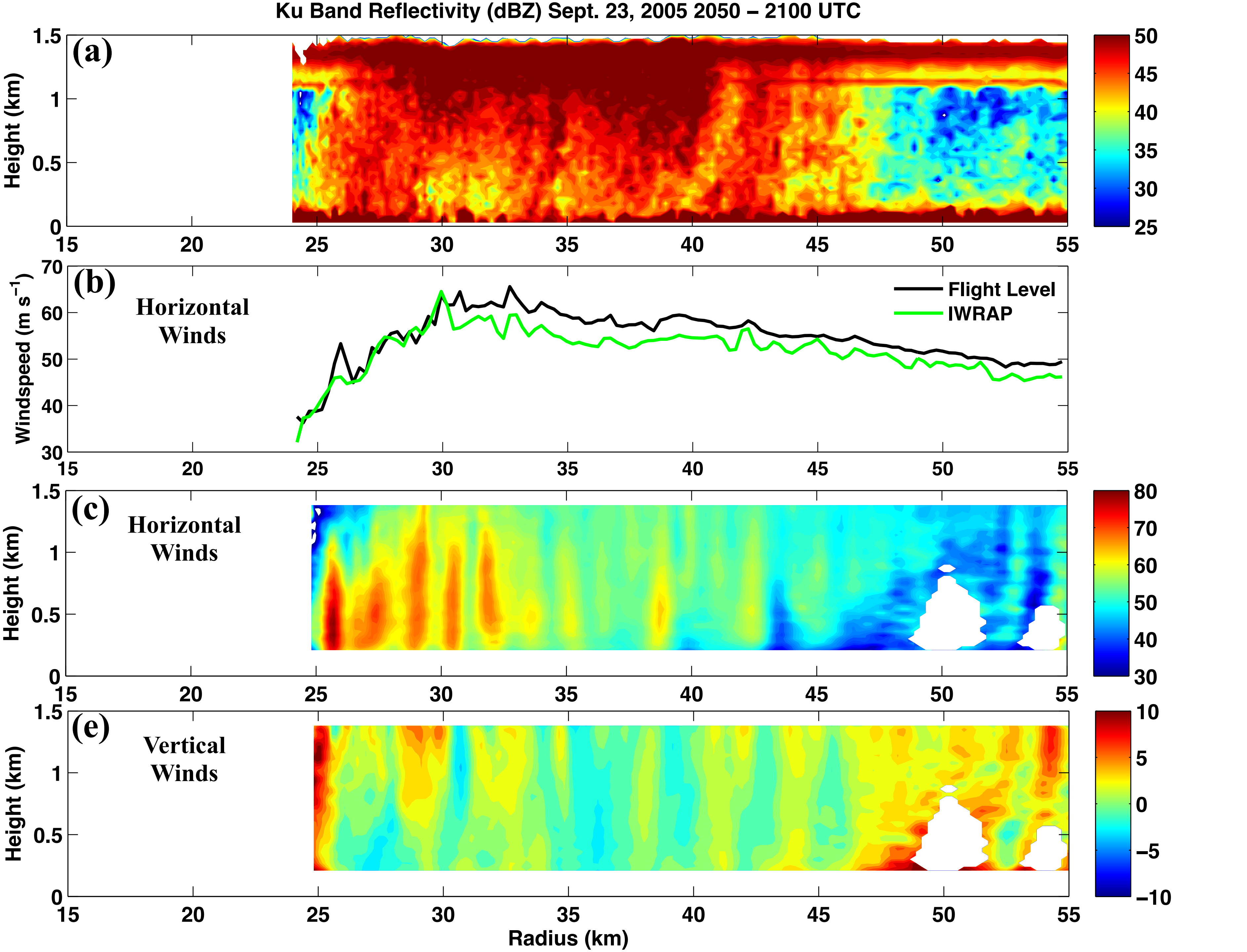
FIG. 8. Schematic depicting hurricane boundary layer rolls observed during four hurricane landfalls. Streamline arrows indicate transverse flow, with high (low) momentum air being transported downward (upward). Shaded arrows and bold contours indicate the positive (red) and negative (blue) residual velocities [R. Foster 2004, personal communication; after Brown (1974) and WW98].

Morrison et al. (2005)

IWRAP Rita Data
Sept. 23, 2005 ~ 1700 – 2200 UTC

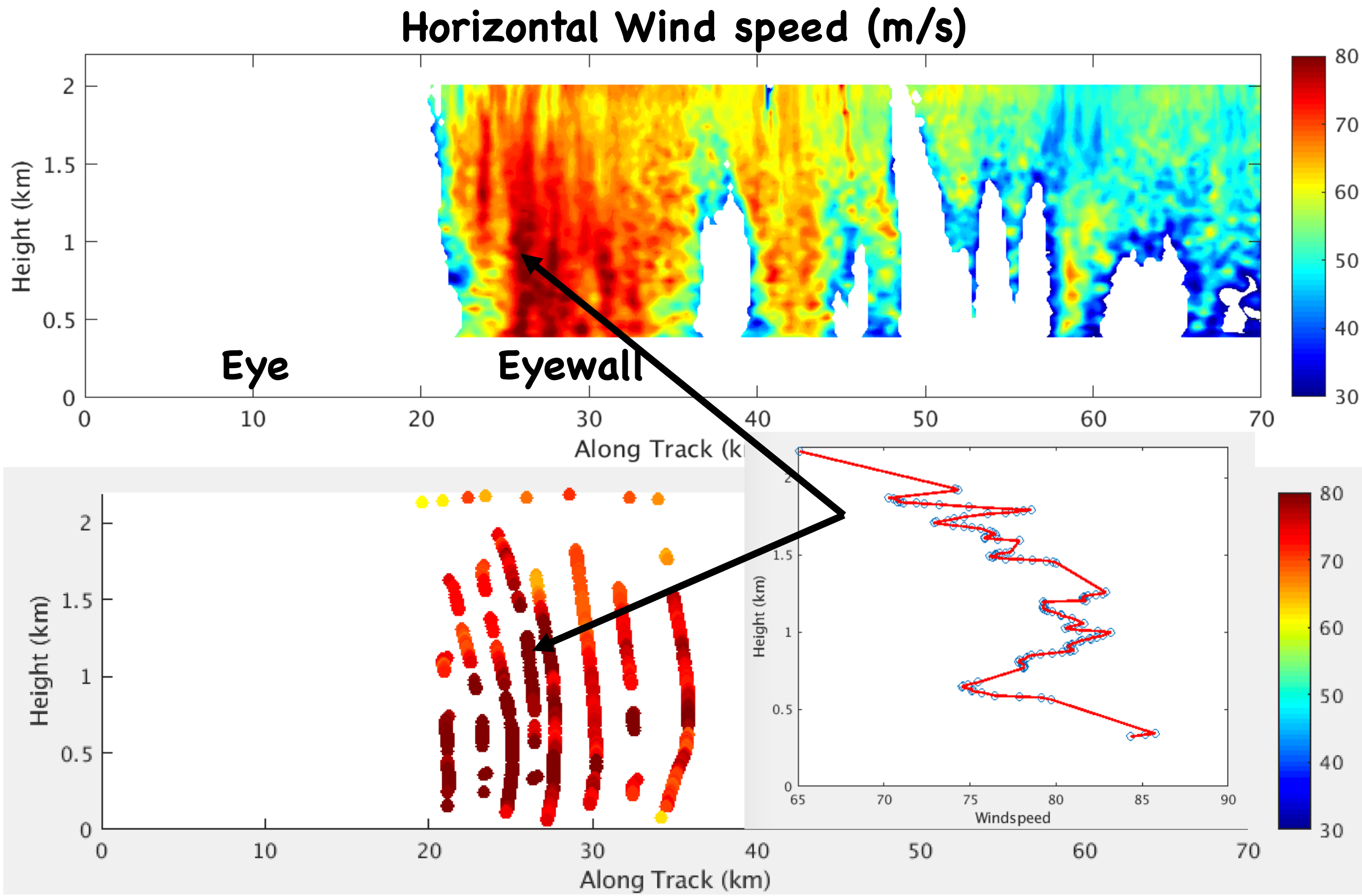
- Continued slow weakening during sampling, intensity of 930 hPa
- Merged eyewalls





Ku Band Reflectivity (dBZ) Sept. 23, 2005 2050 – 2100 UTC
(a)
Height (km)
(b)
Horizontal Winds
Windspeed (m s^{-1})
Flight Level
IWRAP
(c)
Horizontal Winds
Height (km)
(e)
Vertical Winds
Height (km)
Radius (km)

Hurricane Isabel (2003) - Sept. 12
1720 - 1730 UTC C-Band vs. Dropsonde



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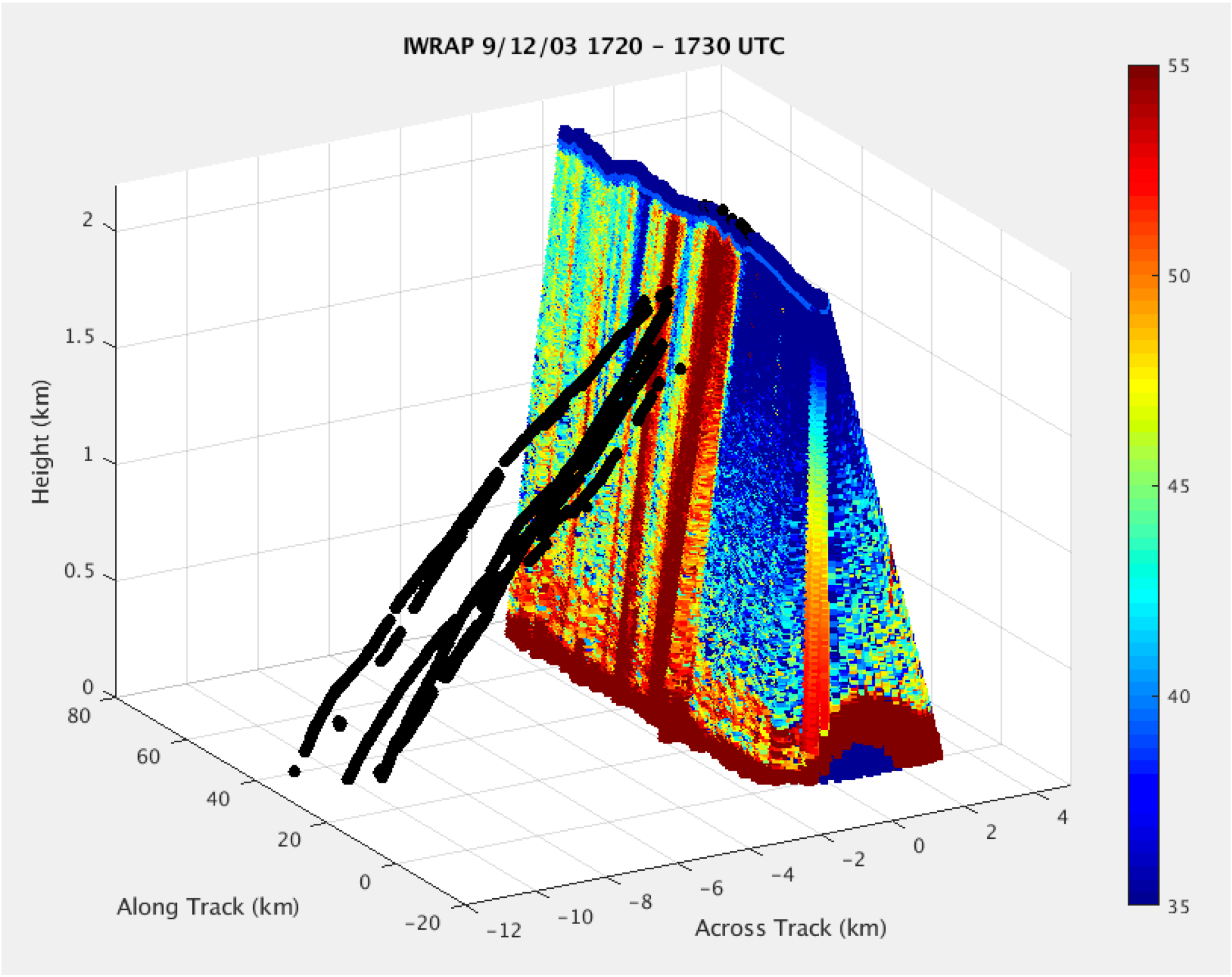

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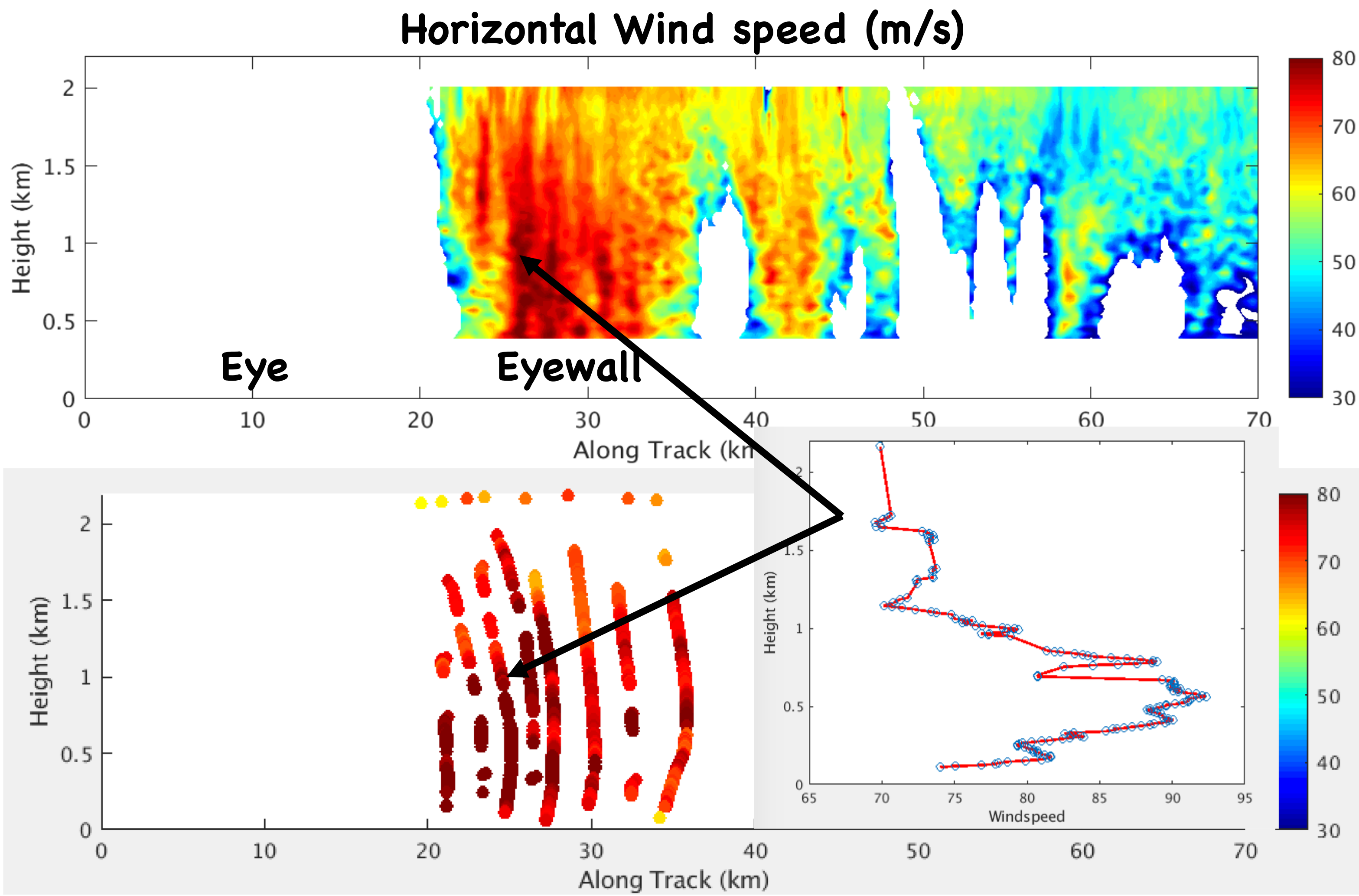

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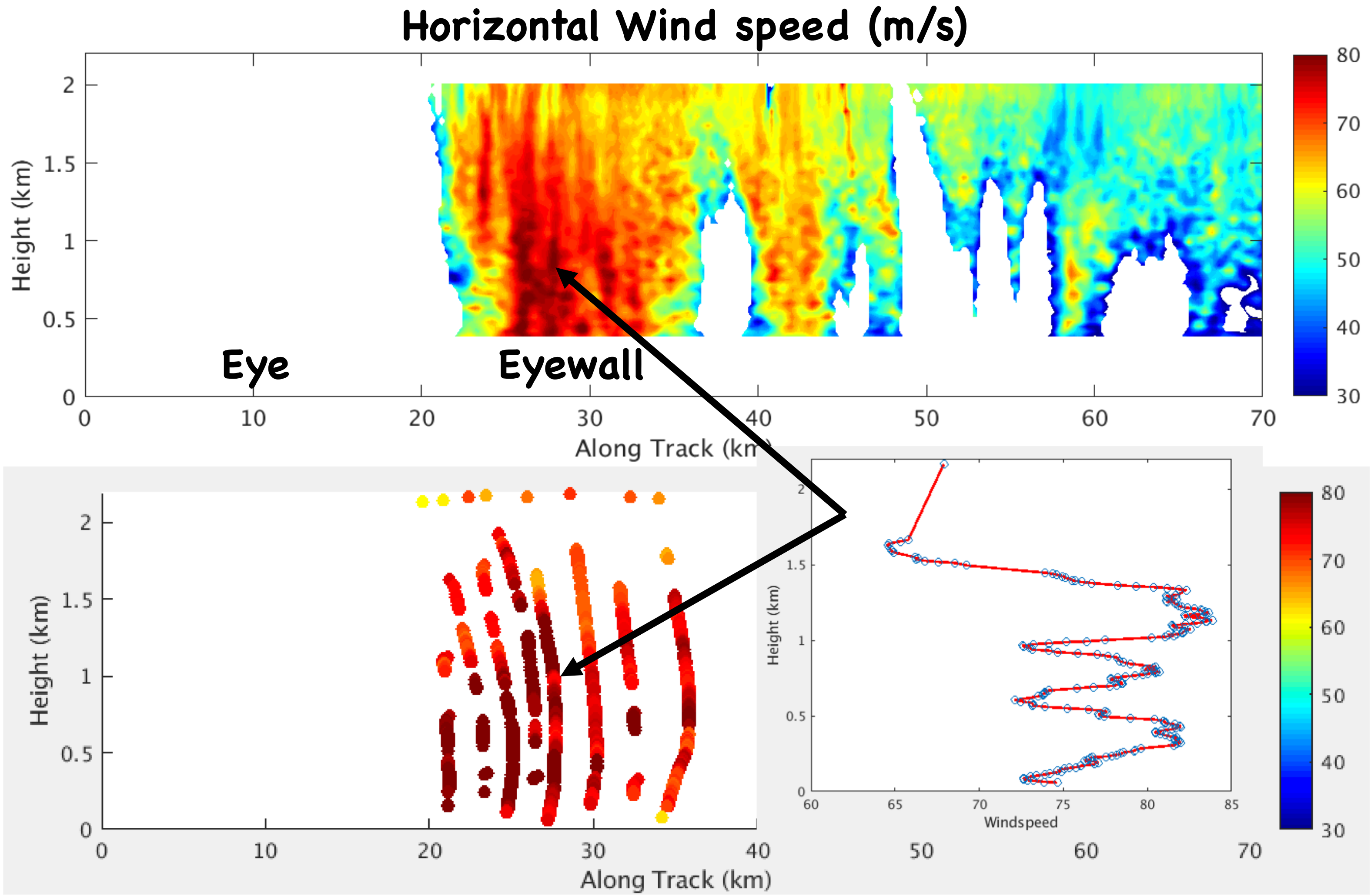

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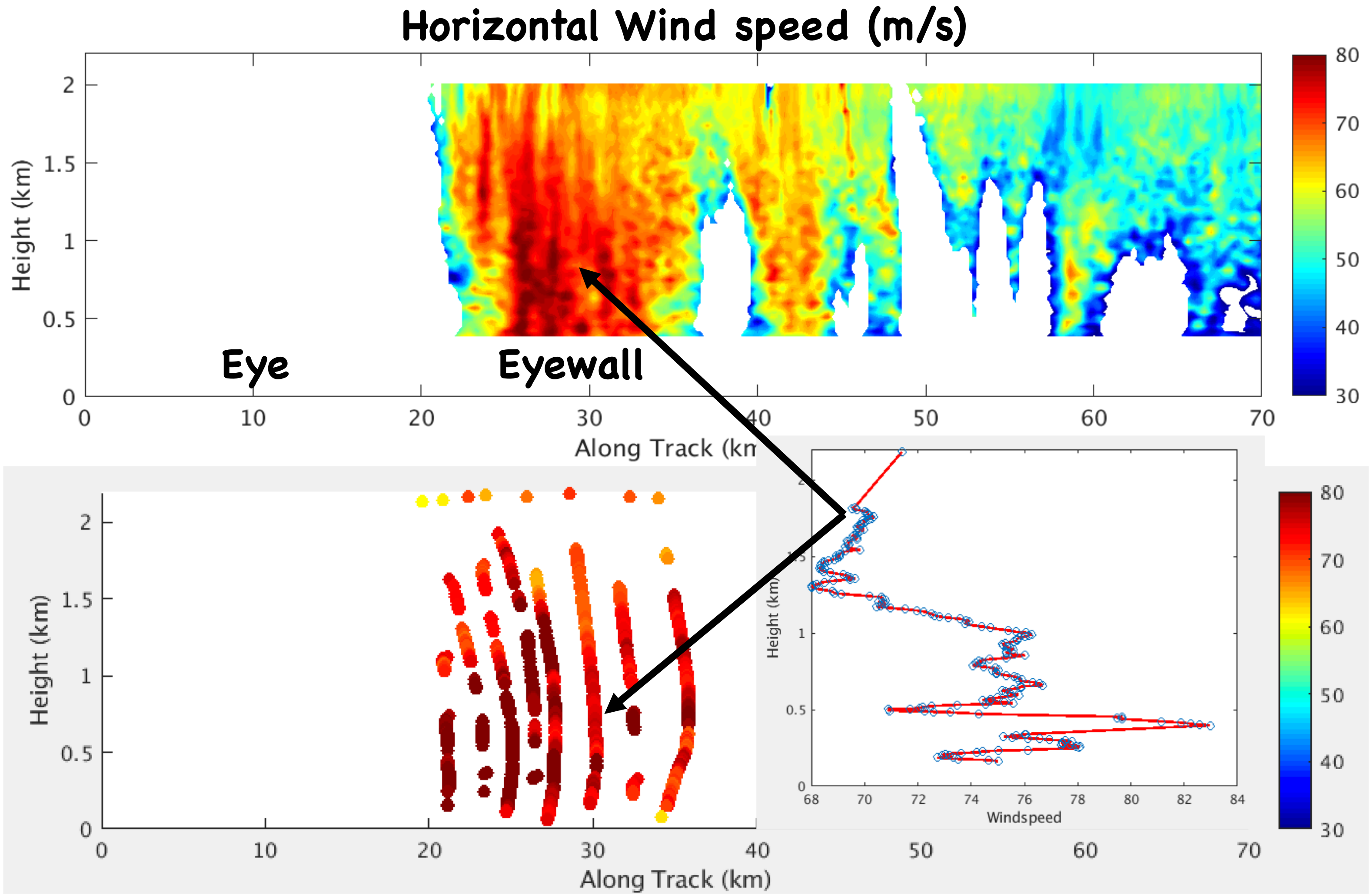

Summary/Conclusions

Guimond et al. (2018a), JAS – remote sensing work

- Effective resolution of IWRAP wind retrievals
  - ~ 1 km or 4-5Δx with Δx = 200 – 250 meters
  - Fully capable of resolving "large turbulent eddies" with scales on order of 1 km

- Rich spectrum of turbulent eddies ubiquitous in IWRAP data
  - Both inner, outer eyewall and transition region
  - Typical characteristics of coherent eddies
    - Radial wavelengths of ~ 1 – 3 km (mean of 2 km)
      - SFMR wavelengths (mean of 2.65 km), SAR wavelengths (2 – 3 km)
    - Depths from ocean surface to flight level (at least ~ 2 km deep)
    - Aligned with mean tangential wind, tilt consistent with radial flow structure
    - Maximum winds located in eddies (up to 90+ m/s), perturbations of 10 – 20 m/s

- Impacts for IOVWST community
  - Understanding (physics & measurement) of dropsonde and SFMR obs
  - Feedback to satellite scales (e.g. how to up-scale SFMR)

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