National Aeronautics and
Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

## Hurricane observations with HAMSR in the GRIP and HS3 field campaigns

# An RI Case Study: Hurricane Karl (2010)

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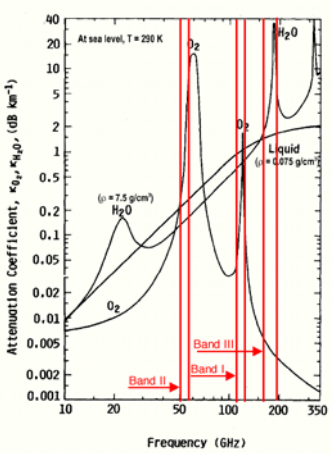
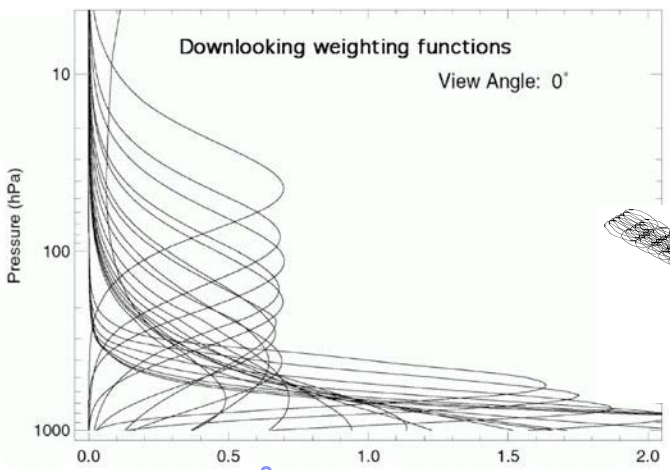
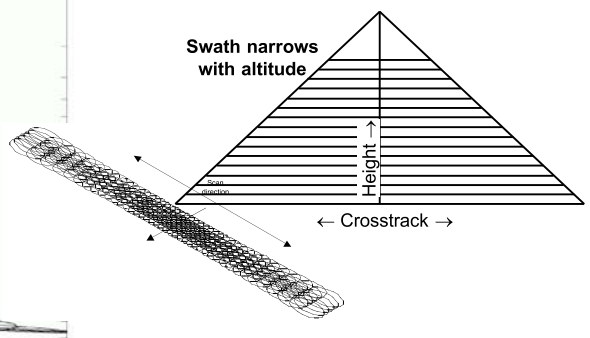
# The High Altitude MMIC Sounding Radiometer

## HAMSR




| Chan # | Center freq. [GHz] | Offset [GHz] | Bandwidth [MHz] | Wt func. Peak [mb or mm] |
|---|---|---|---|---|
| I-1 | 118.75 | -5.500 | 1500 | Sfcr/30 mm |
| I-2 | " | -3.500 | 1000 | Surface |
| I-3 | " | -2.550 | 500 | Surface |
| I-4 | " | -2.050 | 500 | 1000 mb |
| I-5 | " | -1.600 | 400 | 750 mb |
| I-6 | " | -1.200 | 400 | 400 mb |
| I-7 | " | ±0.800 | 2x400 | 250 mb |
| I-8 | " | ±0.450 | 2x300 | 150 mb |
| I-9 | " | ±0.235 | 2x130 | 80 mb |
| I-10 | " | ±0.120 | 2x100 | 40 mb |
| II-1 | 50.30 | 0 | 180 | Sfcr/100 mm |
| II-2 | 51.76 | 0 | 400 | Surface |
| II-3 | 52.80 | 0 | 400 | 1000 mb |
| II-4 | 53.596 | ±0.115 | 2x170 | 750 mb |
| II-5 | 54.40 | 0 | 400 | 400 mb |
| II-6 | 54.94 | 0 | 400 | 250 mb |
| II-7 | 55.50 | 0 | 330 | 150 mb |
| II-8 | 56.02<br>56.67 | 0 | 270<br>330 | 90 mb |
| III-1 | 183.31 | -17.0 | 4000 | [11 mm] |
| III-2 | " | ±10.0 | 2x3000 | [6.8 mm] |
| III-3 | " | ±7.0 | 2x2000 | [4.2 mm] |
| III-4 | " | ±4.5 | 2x2000 | [2.4 mm] |
| III-5 | " | ±3.0 | 2x1000 | [1.2 mm] |
| III-6 | " | ±1.8 | 2x1000 | [0.6 mm] |
| III-7 | " | ±1.0 | 2x500 | [0.3 mm] |



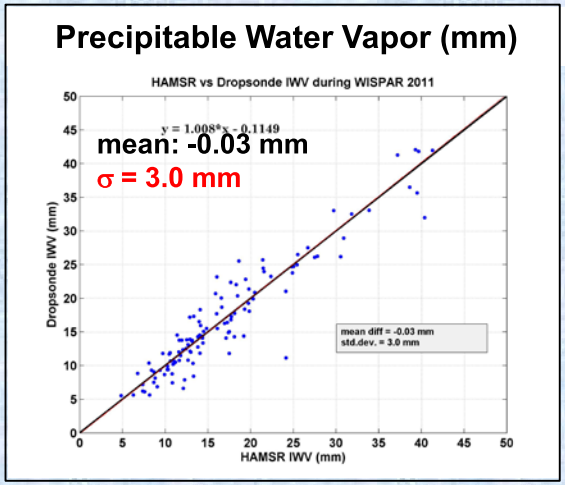



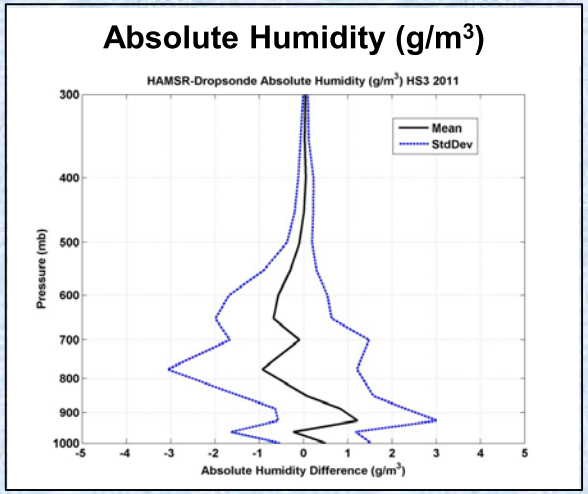
# Thermodynamics: HAMSR is an accurate sounder

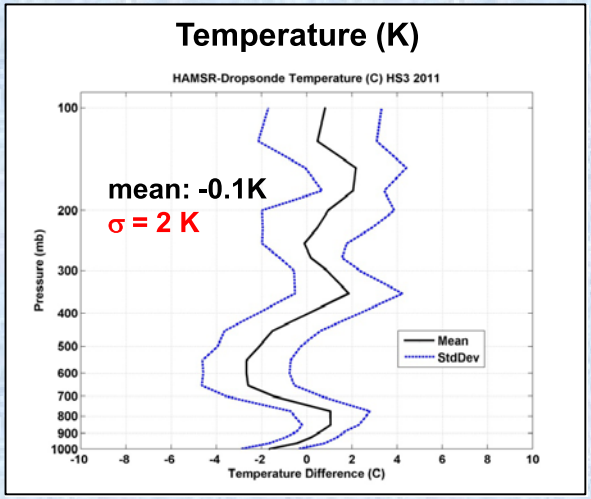
**Sounders are normally used to determine thermodynamic structure:**

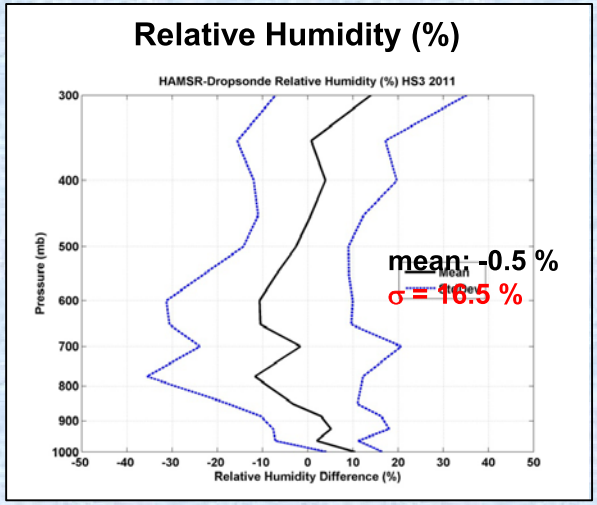
- Retrieval of 3-D atmospheric temperature, water vapor and cloud liquid water profiles using optimal estimation inversion approach
- Good agreement with dropsonde observations
- Vertical resolution (averaging kernels) is 2-3 km

- 50 dropsonde comparisons during HS3 over a wide variety of atmospheric conditions
- Dropsonde profiles smoothed vertically to match HAMSR vertical resolution
- HAMSR website contains validation reports for each flight
- Reports include comparison to MERRA and dropsondes T,q,RH



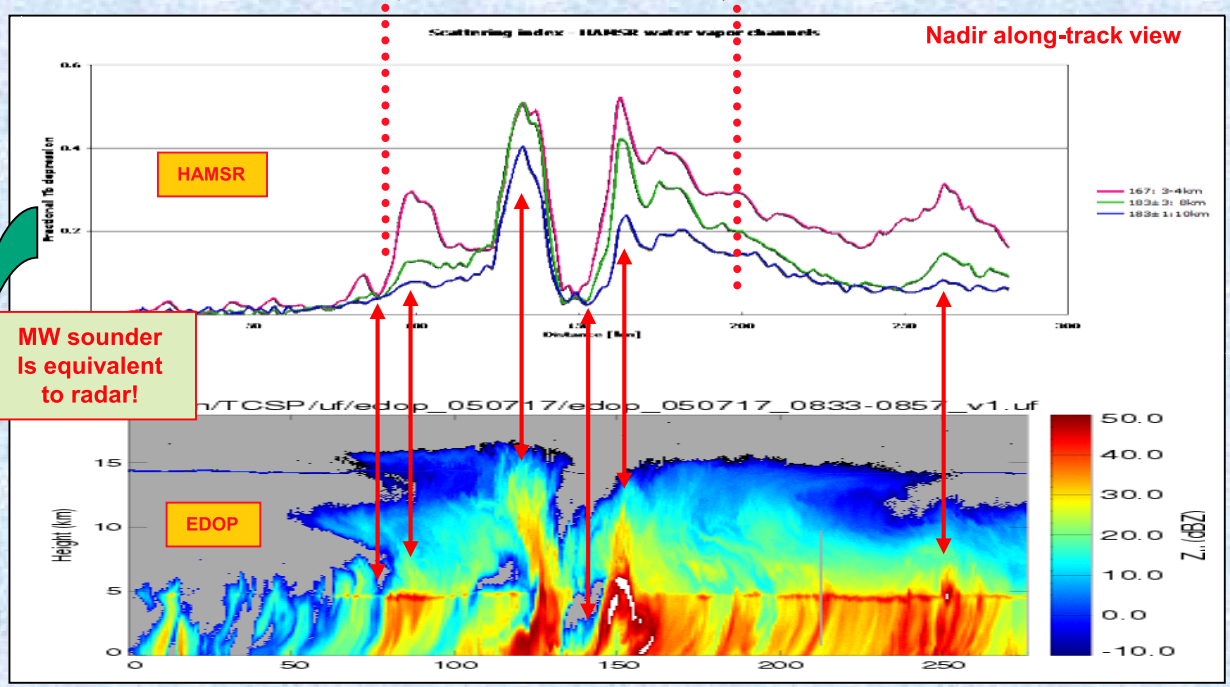
# NEW: Scattering profiling ⇒ Reflectivity algorithm

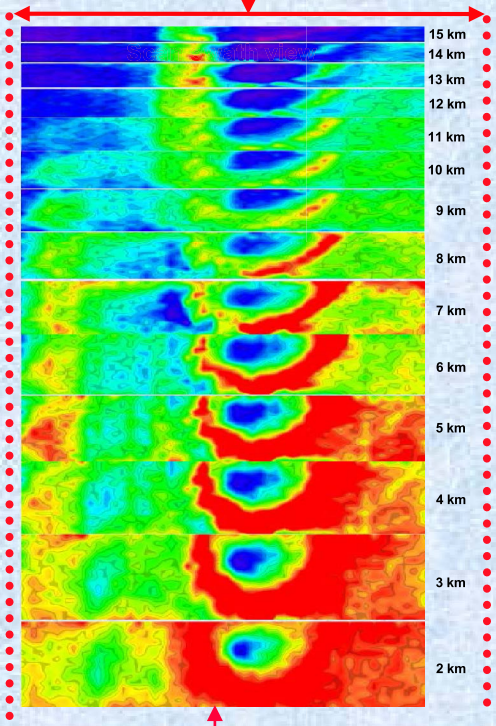
## Based on comparison of microwave sounder (HAMSR) with doppler radar (EDOP) during TCSP/2005

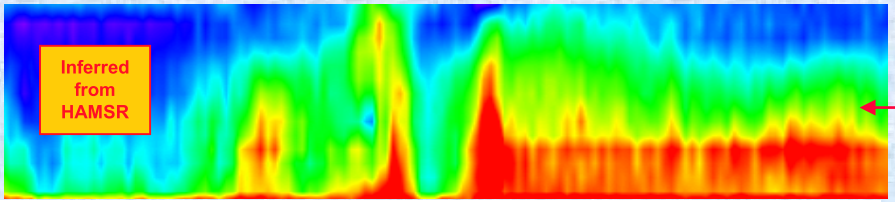
### Hurricane observations with MW sounder (HAMSR) compared with doppler radar (EDOP)

Observations from NASA TCSP campaign, Costa Rica, 2005

Vertical slicing through hurricane Emily - July 17, 2005



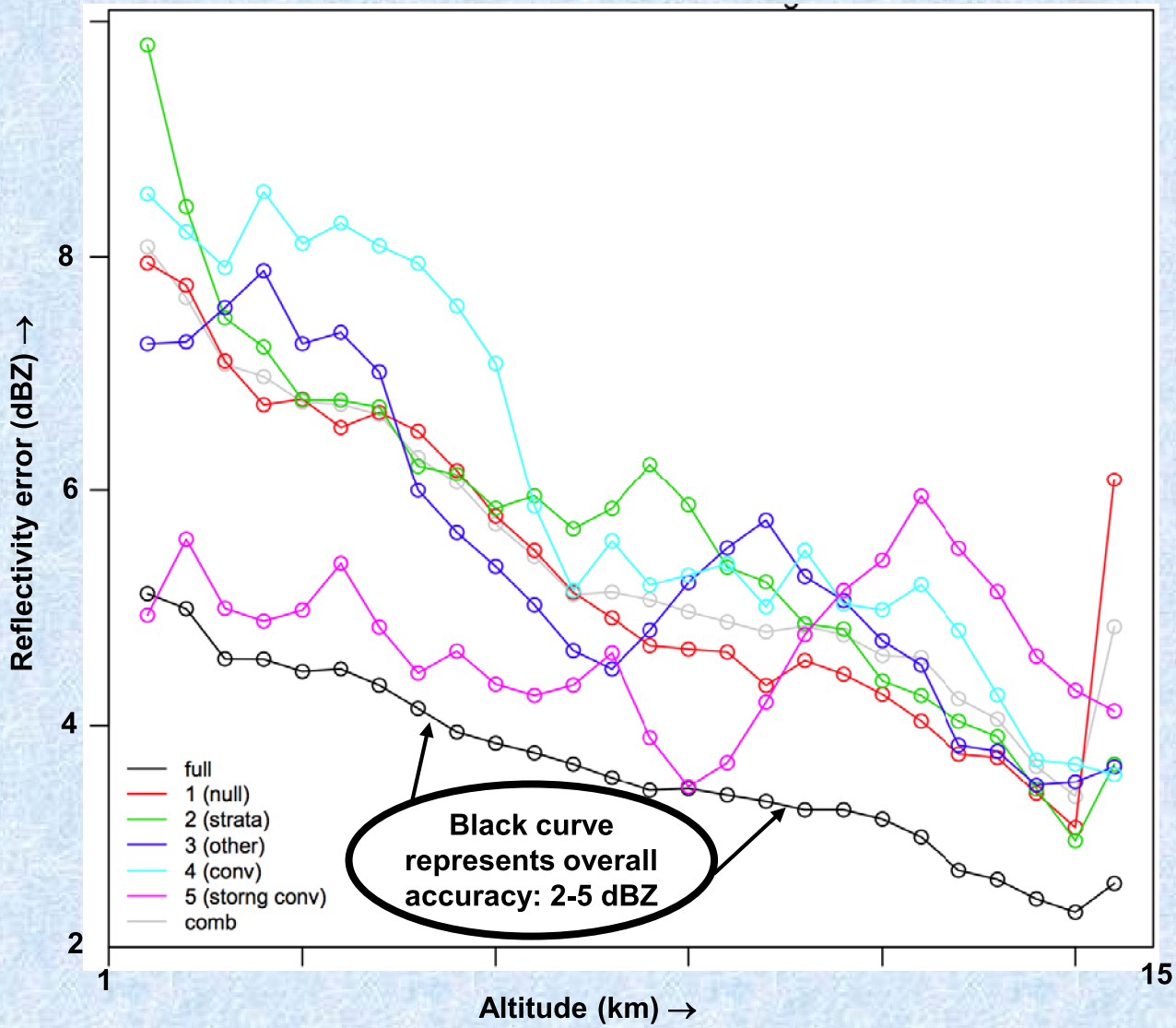

Correlation between MW-sounder ΔTb and radar reflectivity exceeds 90% at all levels except near surface

**Height resolved "Radar reflectivity"**

**⇒ Use radar algorithms to derive**

- Precipitation rate
- Ice water path
- Convective intensity
- Vertical structure

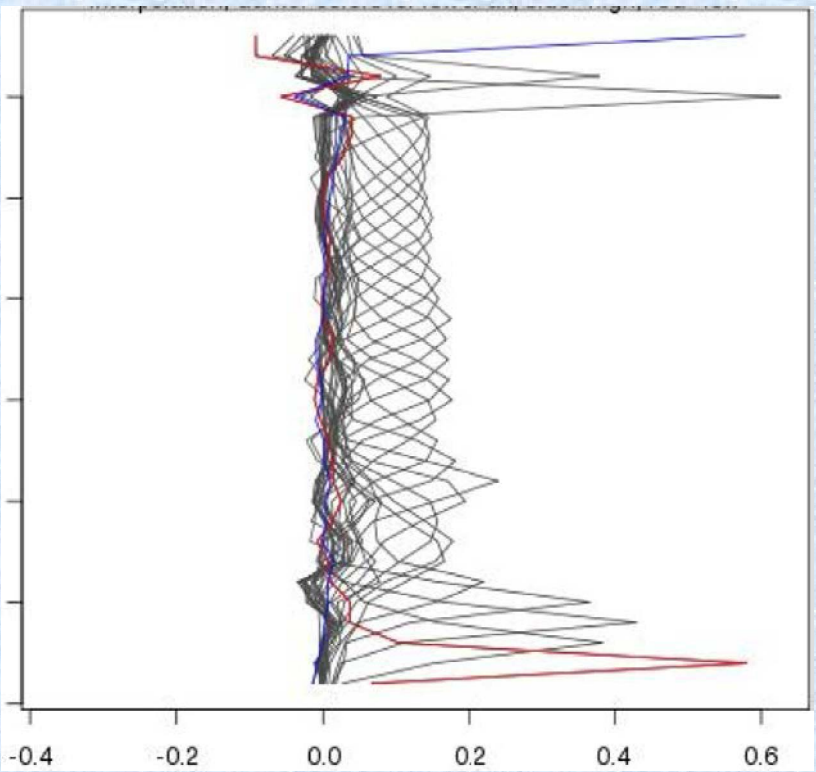
# Reflectivity retrieval accuracy: 2-5 dBZ



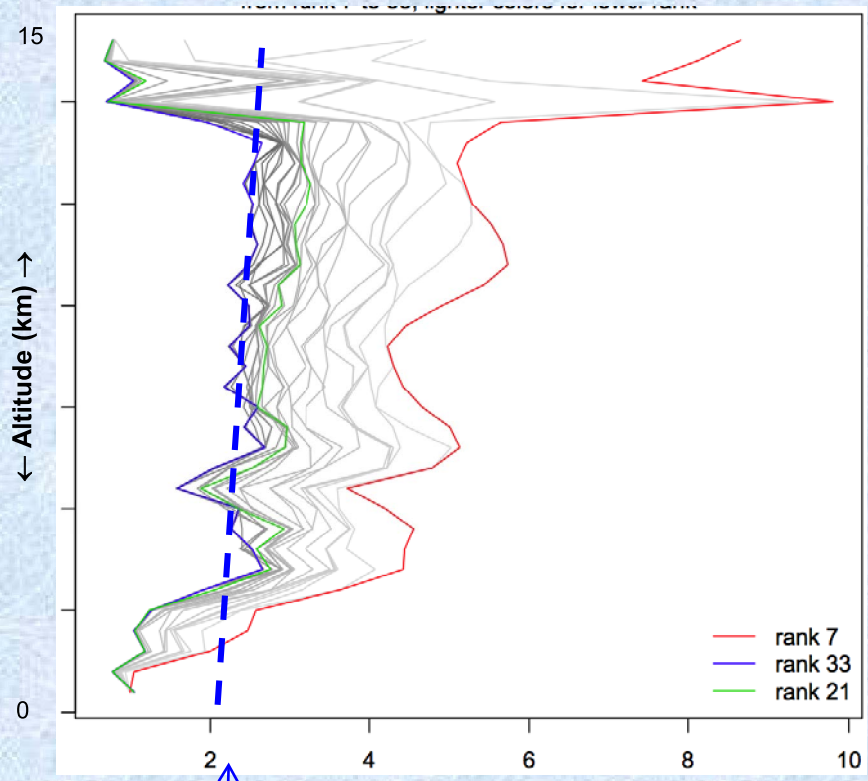

Colored curves represent category clusters and reflect clustering uncertainty and not retrieval uncertainty

# Averaging kernels and vertical resolution

**Averaging kernels:**




**Vertical resolution:**



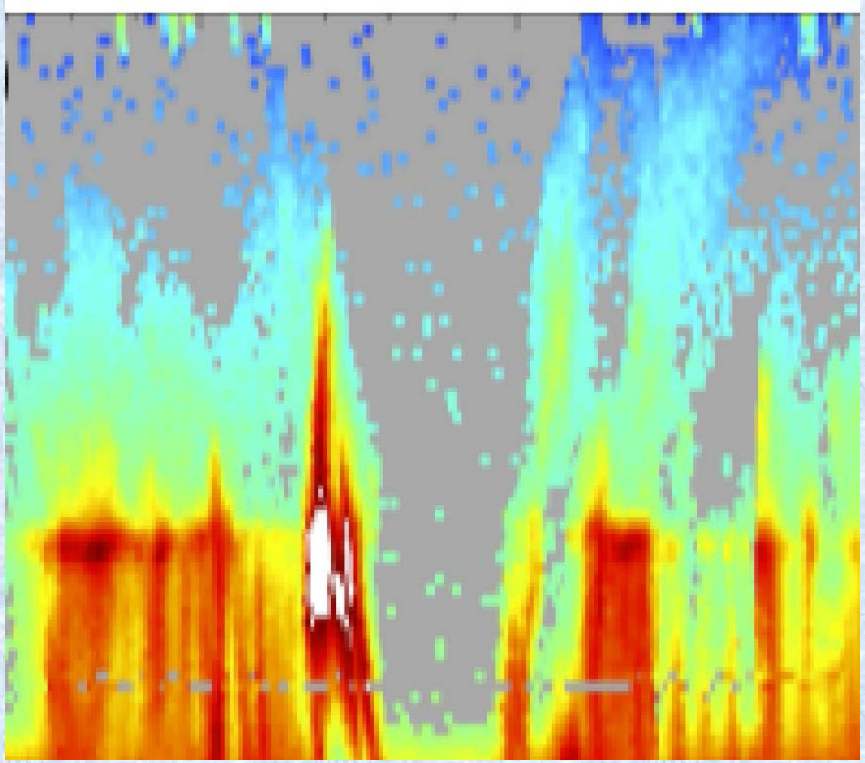

**2-3 km true vertical resolution**

Hurricane Karl (2010)

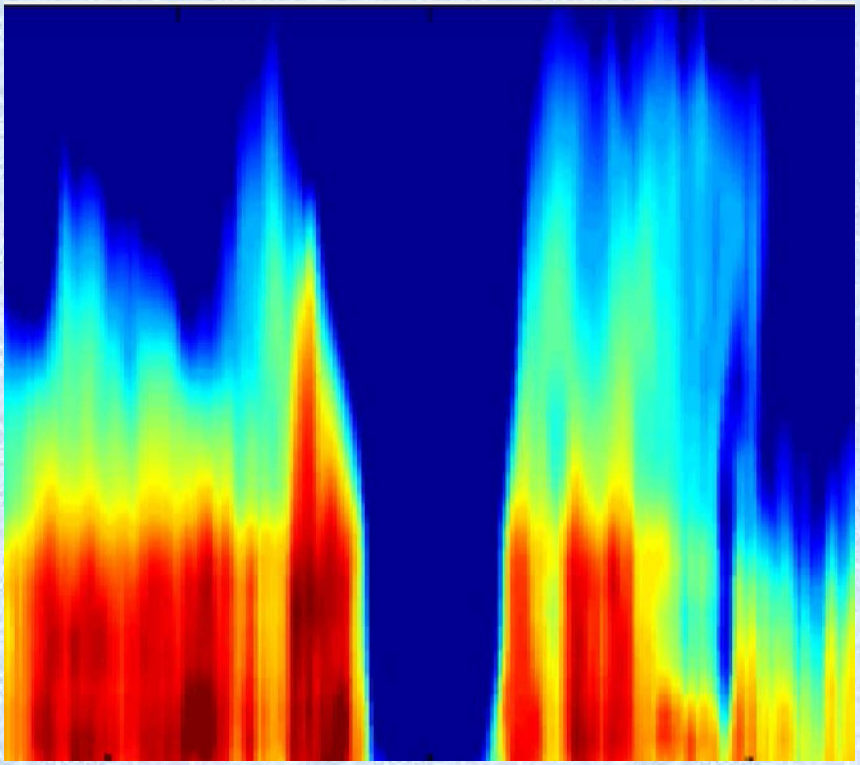
# Comparison with radar (HIWRAP)

**H. Karl, 0644 UTC 9/17/2010**

**Note: Perfect space-time match since both sensors are on same aircraft**



**HIWRAP**



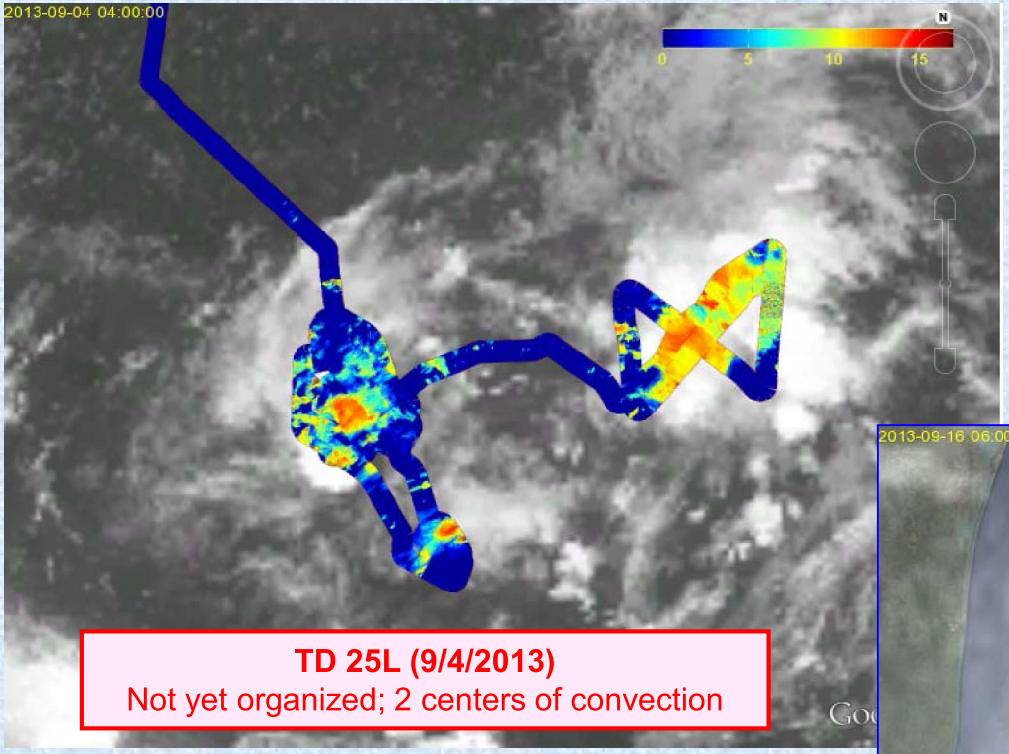
**HAMSR**

**HAMSR reproduces all major structures, but at lower spatial resolution**
- **including cloud top structure**
- **including eye/eyewall structure**

**HAMSR has reduced sensitivity near surface**

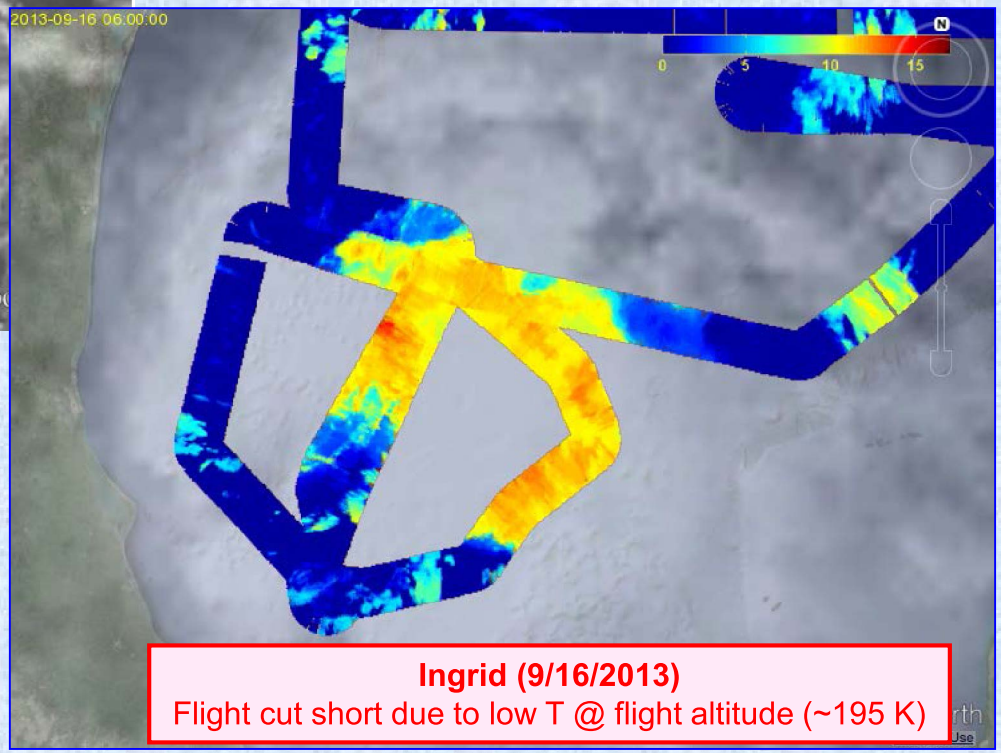
**HAMSR has reduced sensitivity through stratiform structures**

# Not much happening in the 2013 HS3 campaign




**TD 25L (9/4/2013)**
Not yet organized; 2 centers of convection

**Height of convection from HAMSR reflectivity (real-time display)**

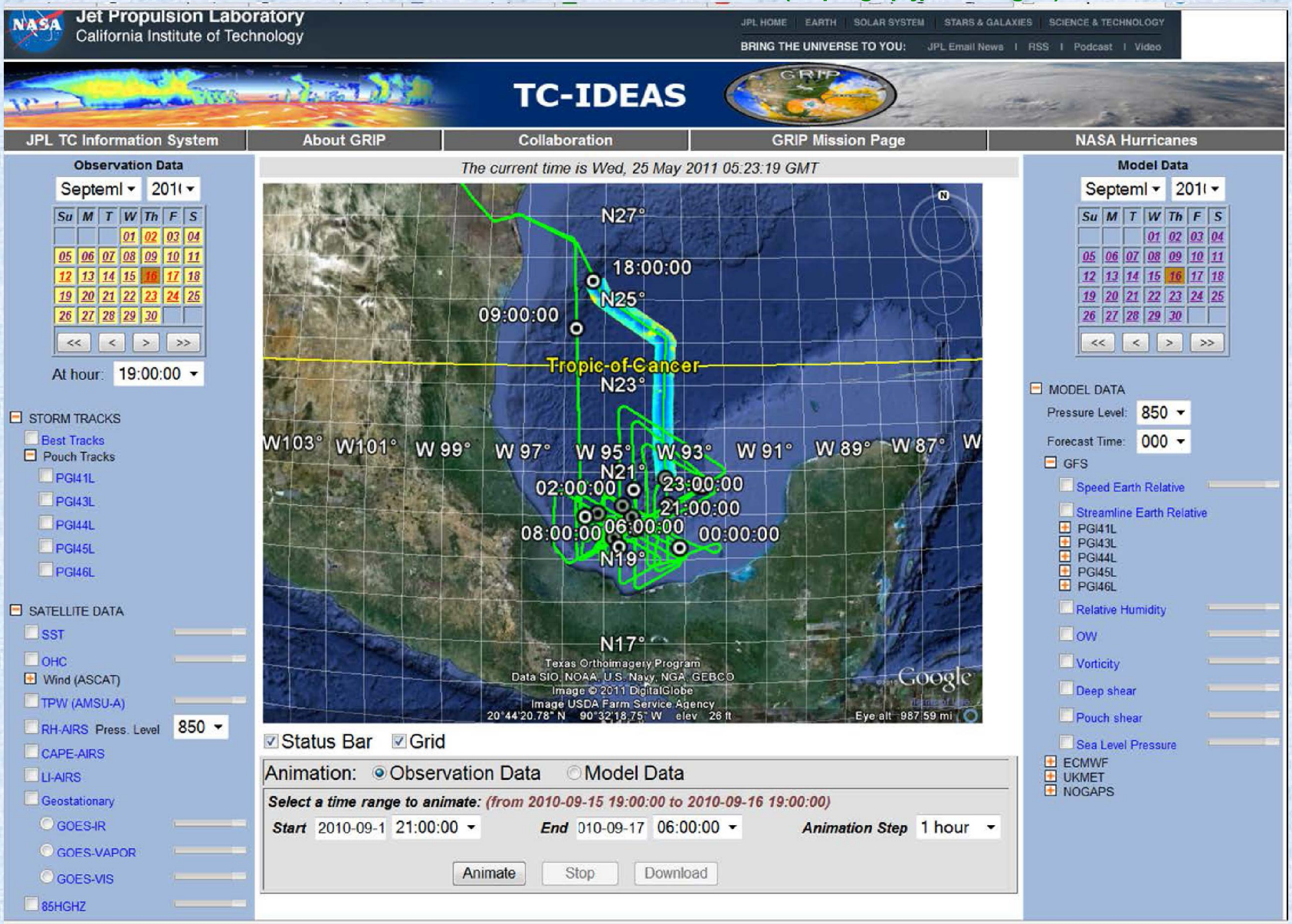



**Ingrid (9/16/2013)**
Flight cut short due to low T @ flight altitude (~195 K)

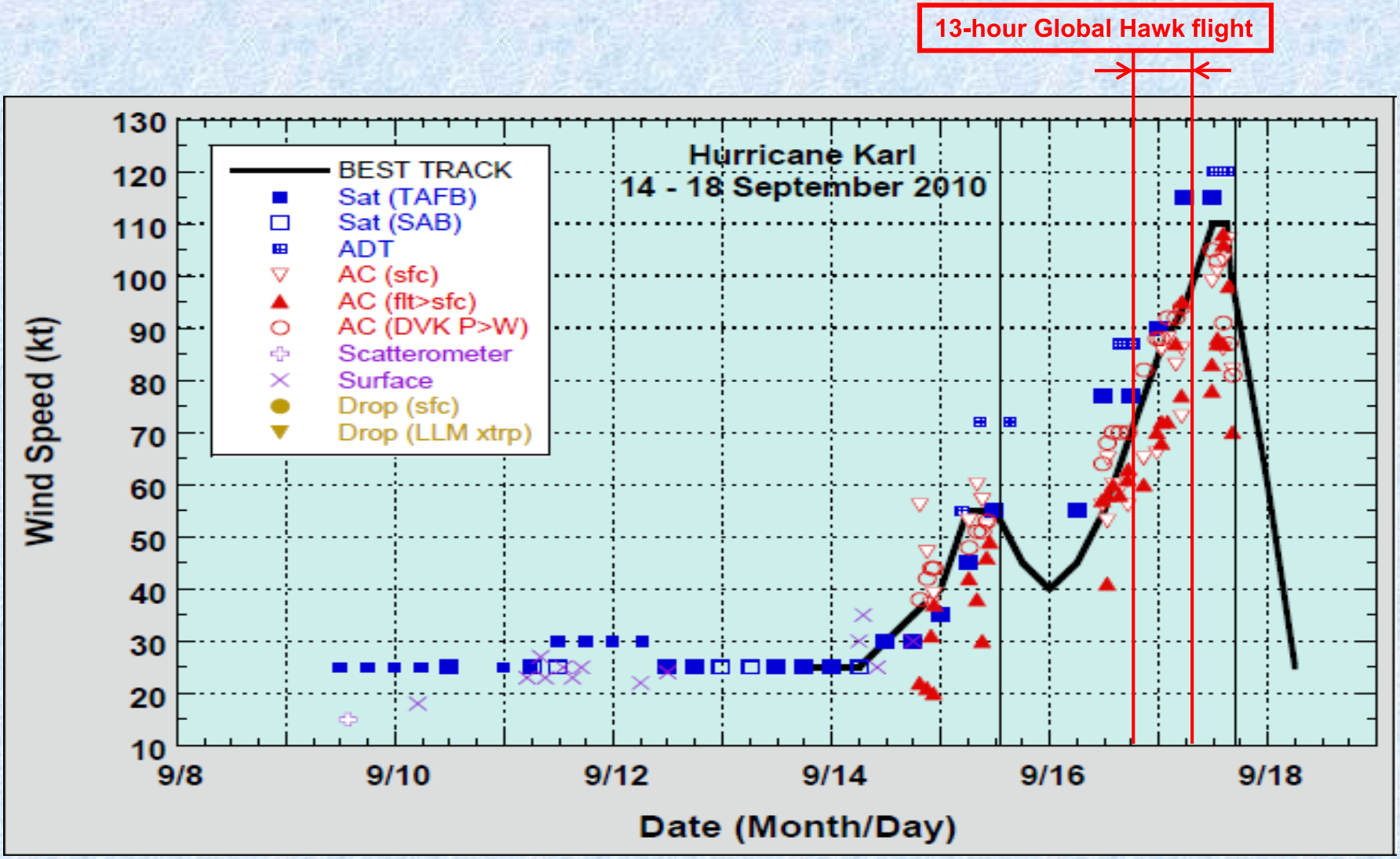
**Gabrielle (9/10/2013)**
Flight aborted
due to problems with the aircraft

# Back to GRIP: Hurricane Karl flight (9/16-17, 2010)

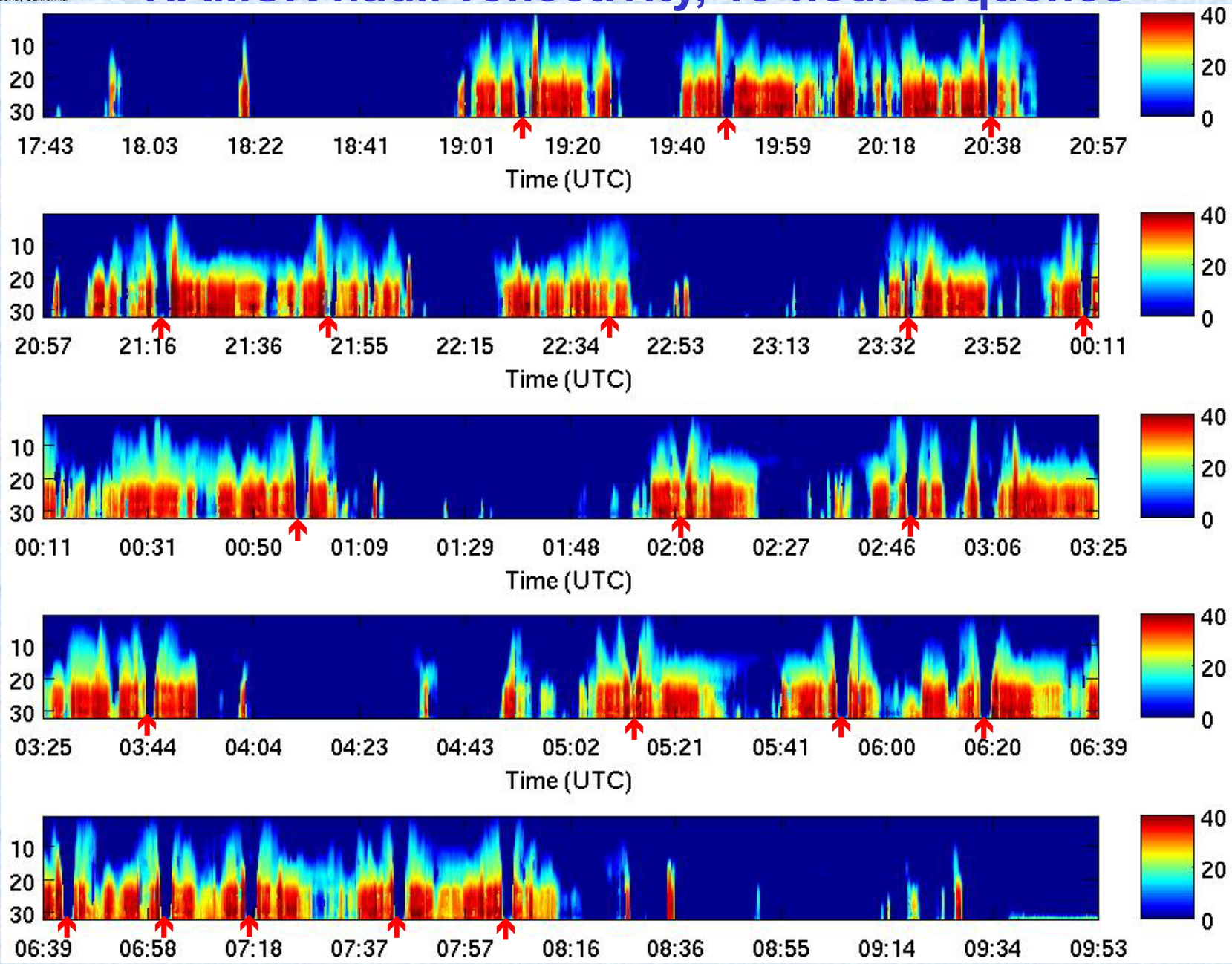
**Data viewable at the JPL Hurricane Portal (http://grip.jpl.nasa.gov):**



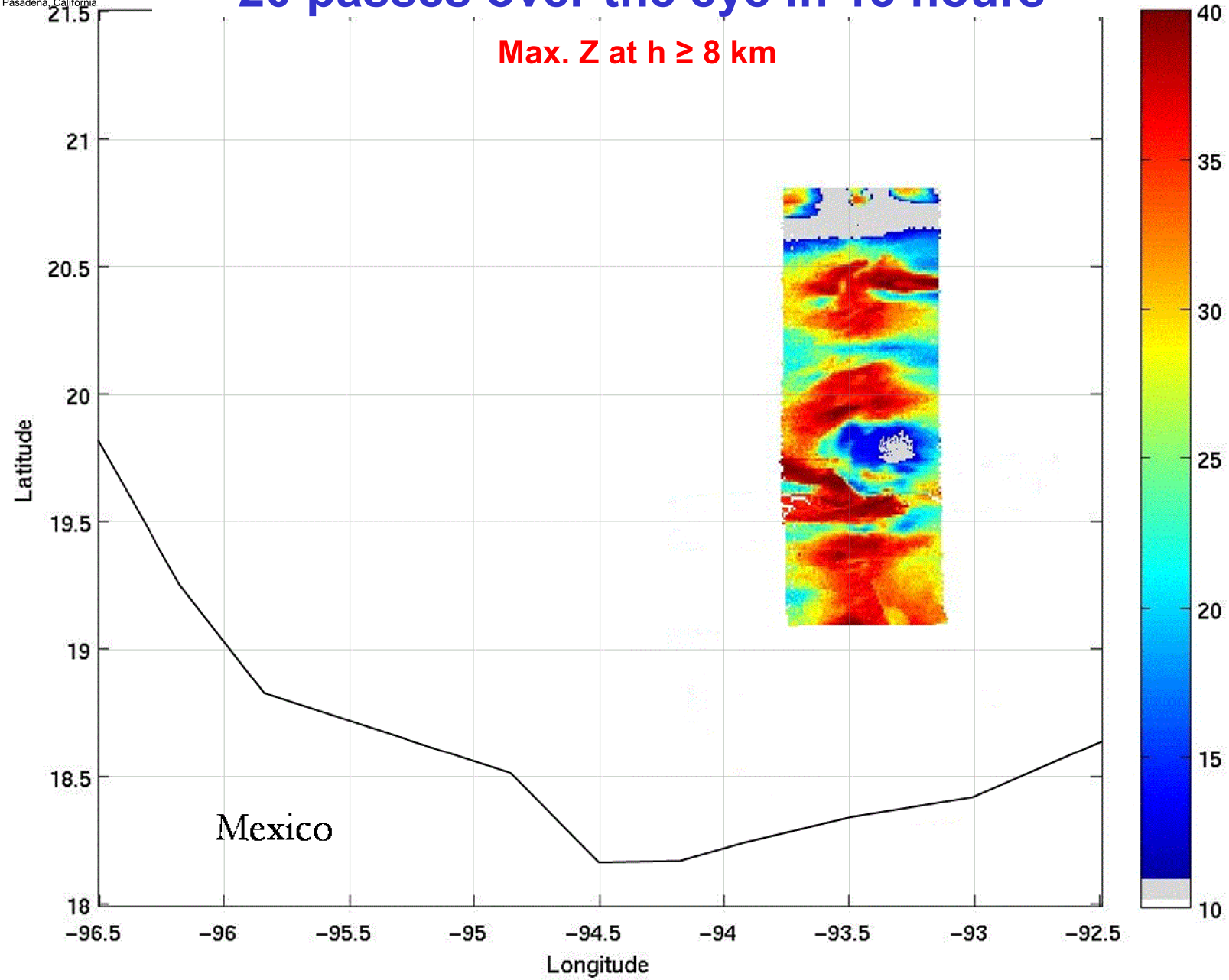
# Rapid Intensification period



# HAMSR nadir reflectivity, 13-hour sequence

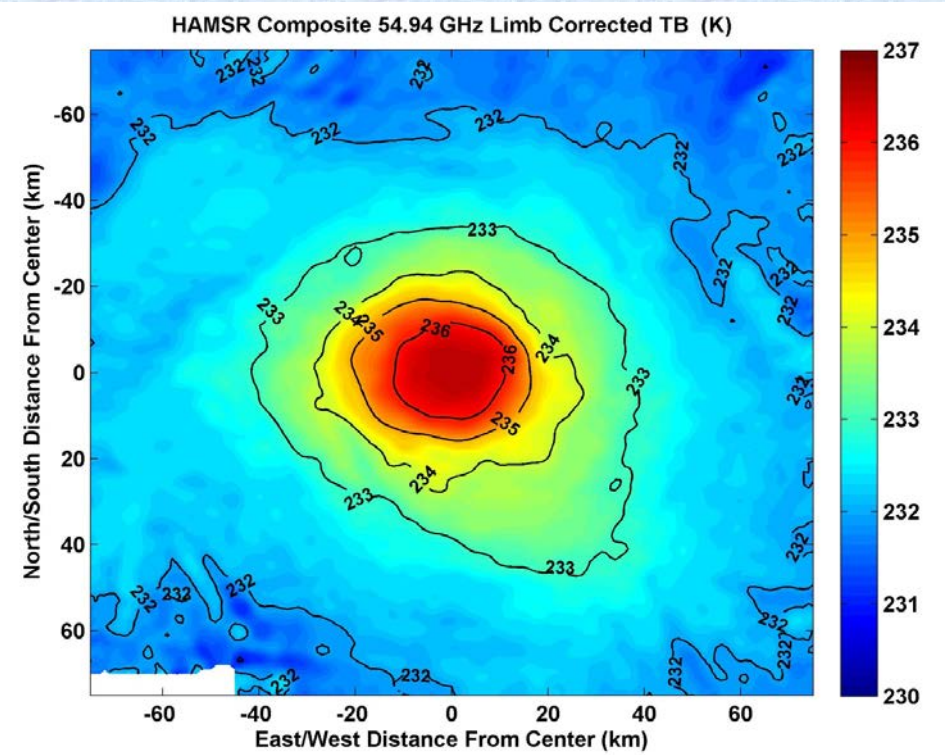


# 20 passes over the eye in 13 hours

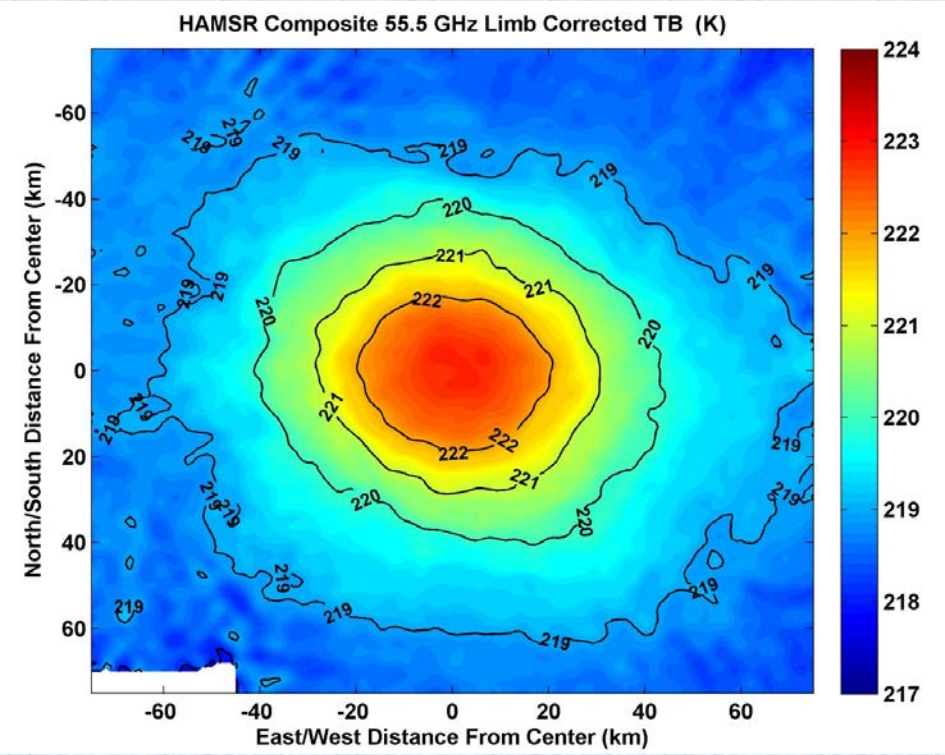


# Warm core anomaly

**Tb-anomaly at 54.94 GHz (HAMSR ch. 6 = AMSU ch. 7) ~ 250 mb**

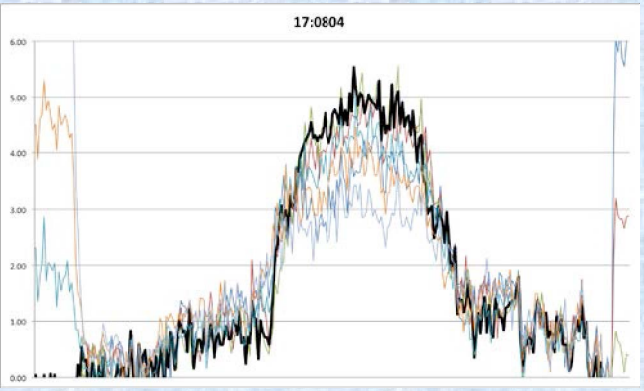



**Tb-anomaly at 55.5 GHz (HAMSR ch. 7 = AMSU ch. 8) ~ 150 mb**

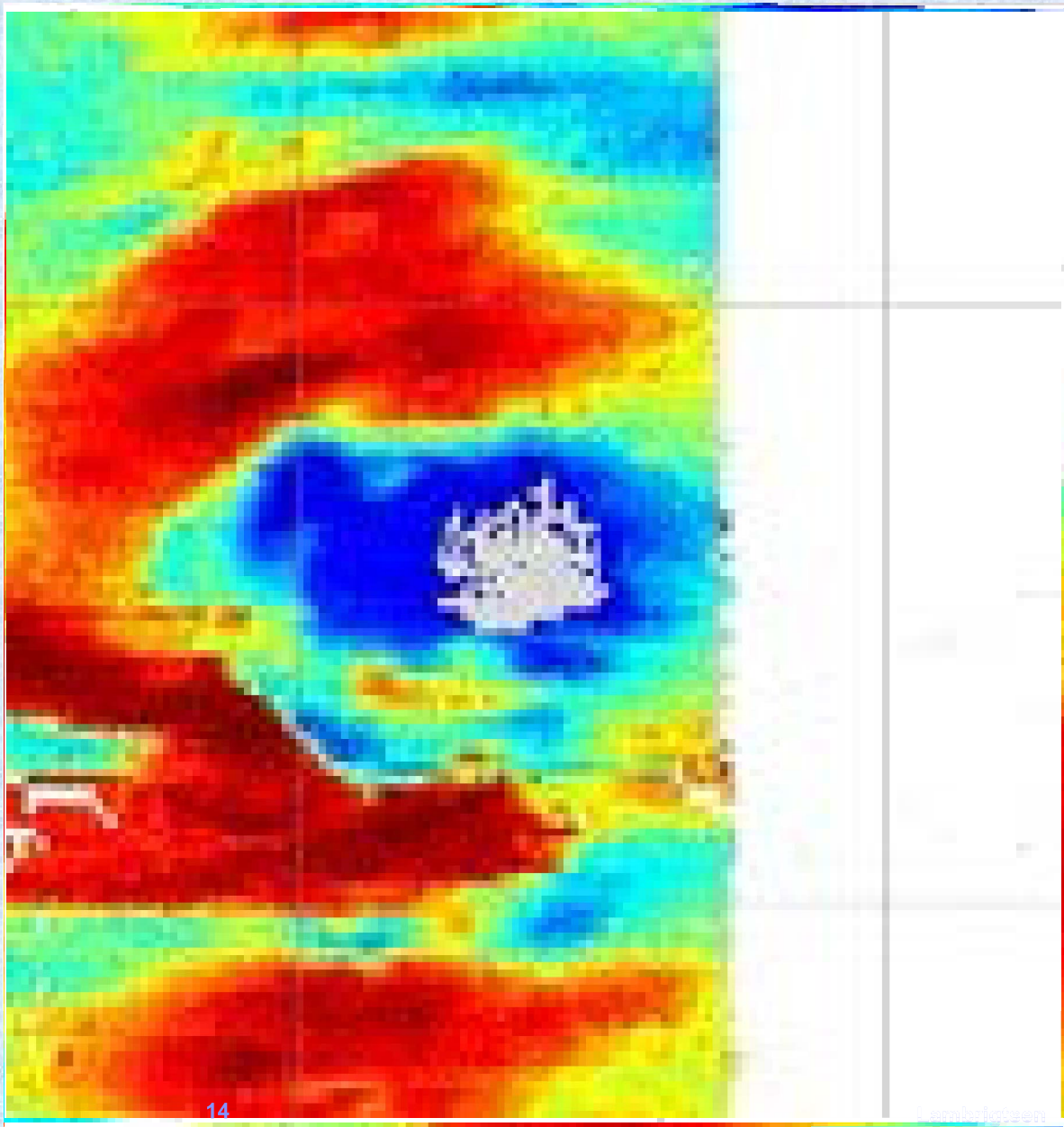


# Closeup views of the inner core

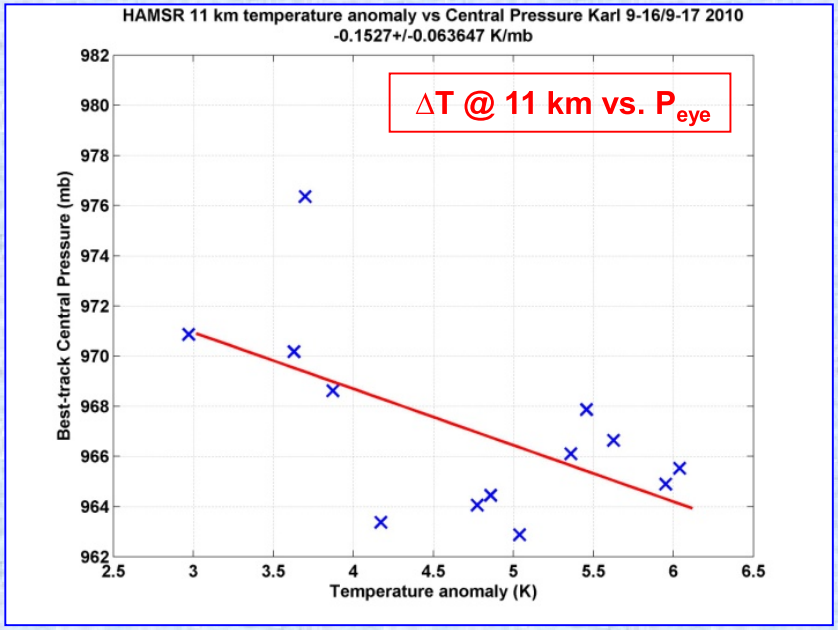
**Warm core anomaly**
**HAMSR ch. 6 = AMSU ch. 7**

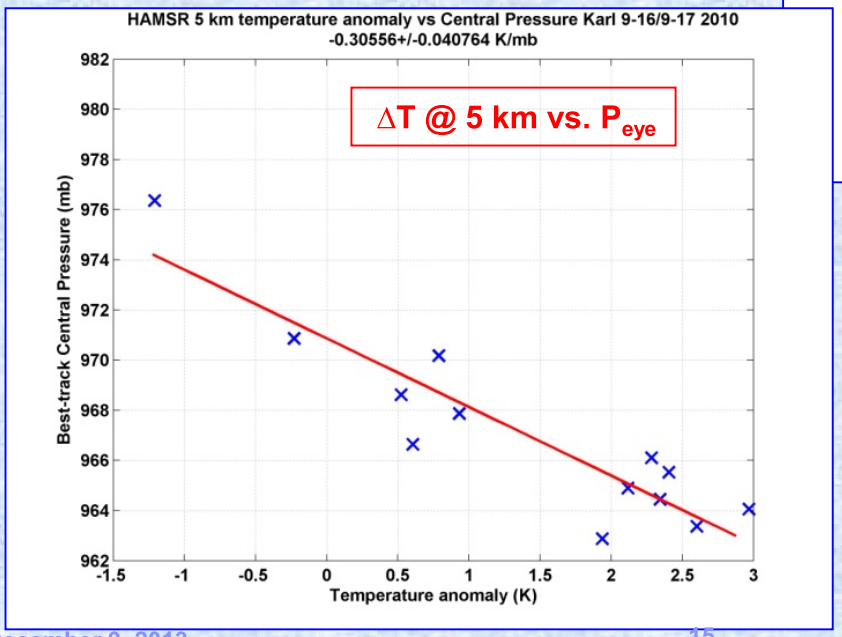


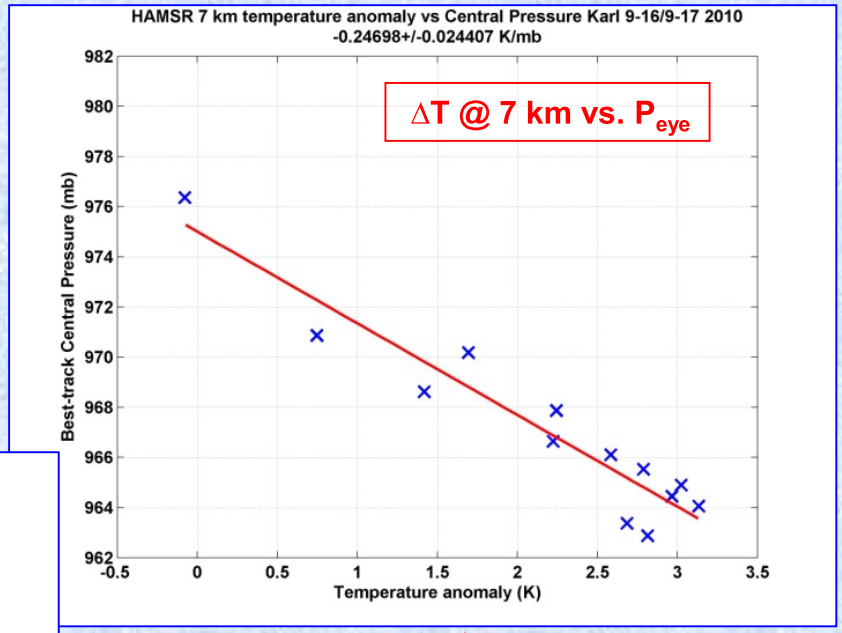

**10 minutes**



# Warm core temperature anomaly correlations



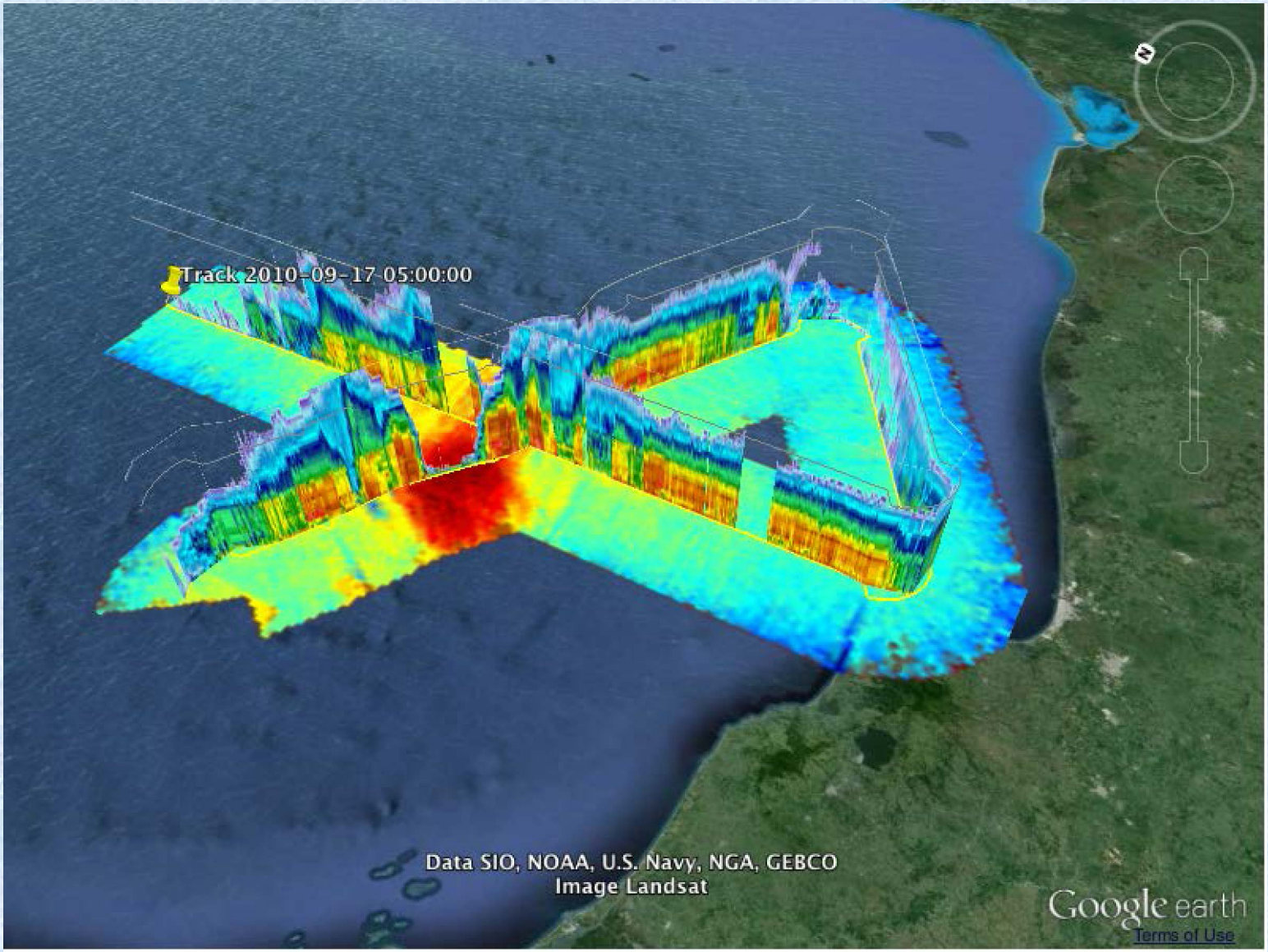



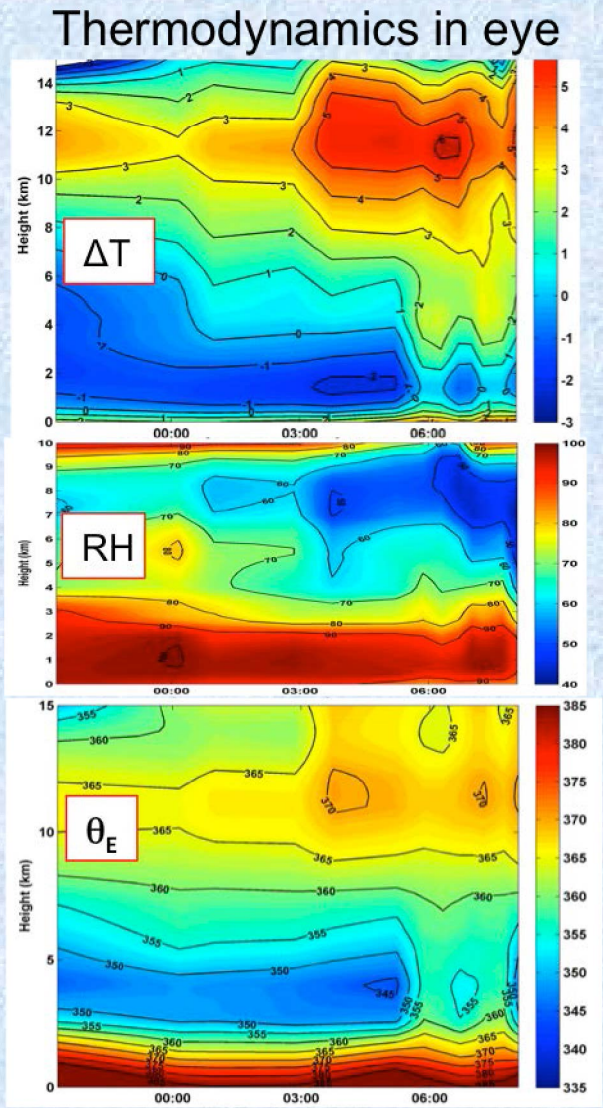

**Strongest correlation at 7 km**
**-0.3 K/mb**

# Closeup view of warm anomaly & reflectivity

**Nadir reflectivity and 250-mb Tb anomaly during two eye passes (06-07Z, 9/17/10)**



# Thermodynamic structure of the warm core



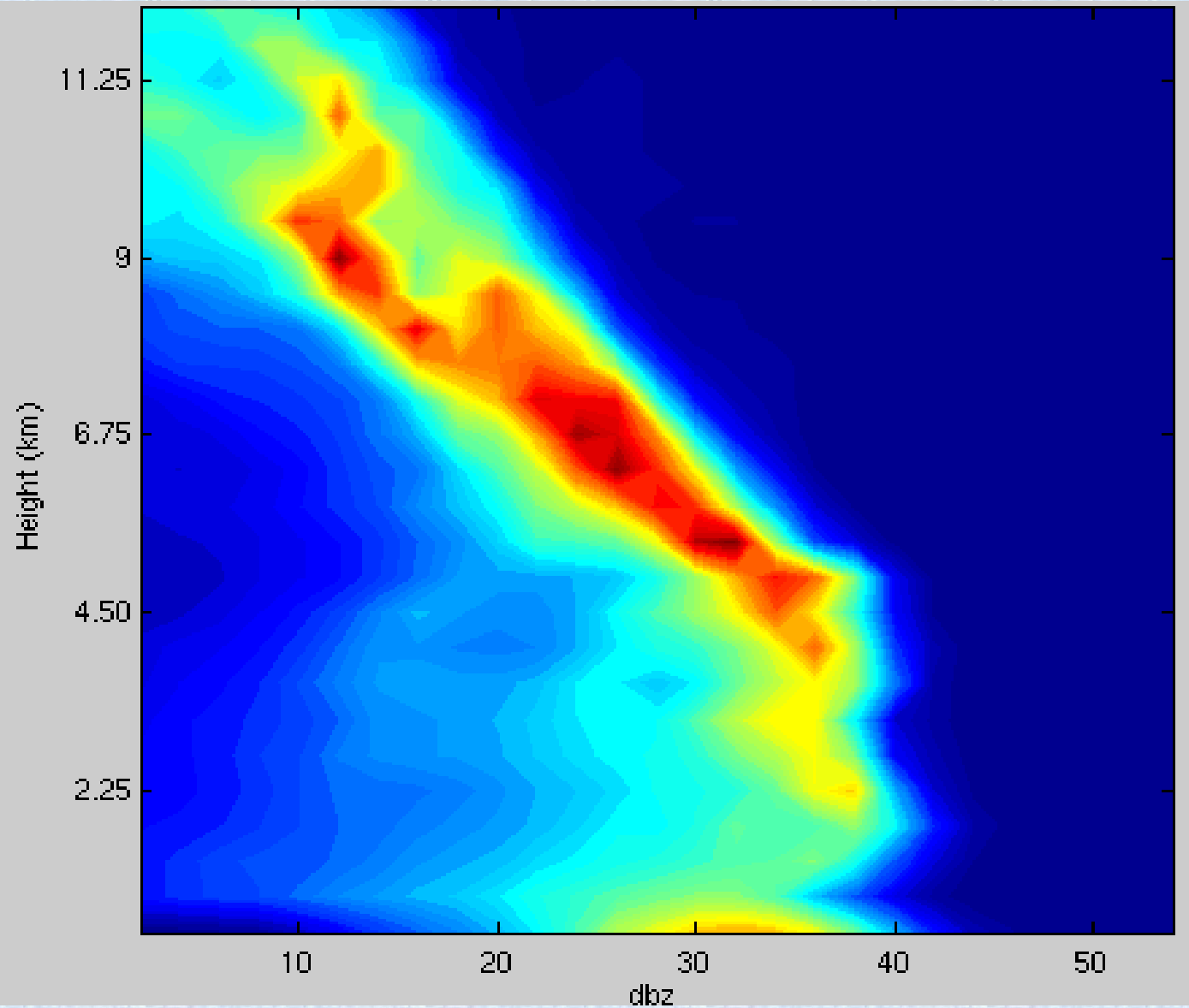

Warm anomaly propagates to lower levels as the storm intensifies with the peak warm anomaly increasing by ~2-3C

Decreasing RH in upper troposphere while air below the inversion layer remained near saturation

Evolution near the end of the flight may be influenced by proximity of land

# Evolution of thermodynamics & convective structure

# Average CFAD

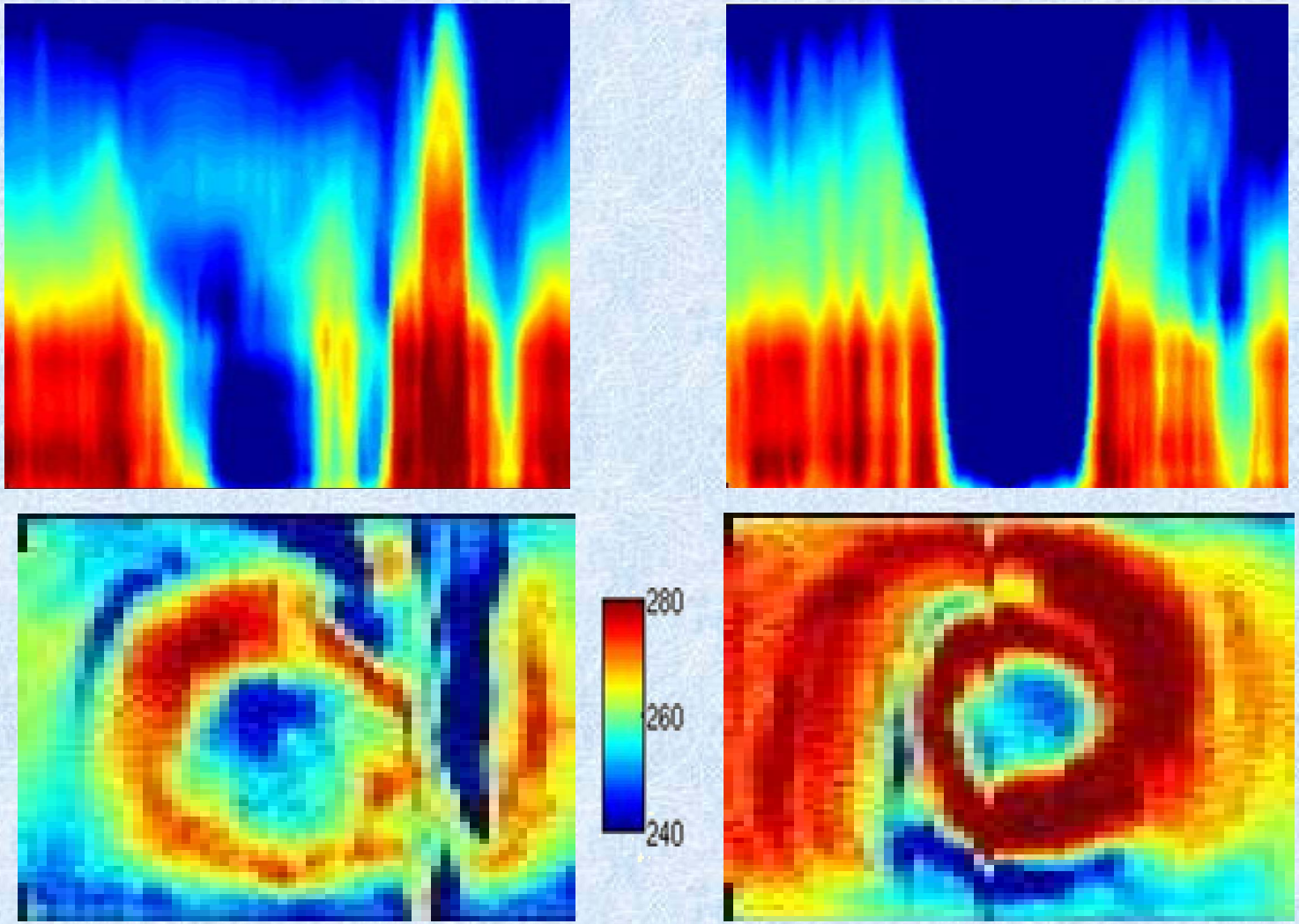


# Inner core structure change in 12 hours of RI

**9/16/1949Z (75 kt)** | **9/17/0745Z (88 kt)**

Reflectivity (surface to 15 km)

50.3 GHz brightness temperature




**Eye is cloudy**
**Deep convective structures**
**Large asymmetric nonuniform inner 50-GHz ring**

**Eye is clear and smaller**
**Deep convection has weakened**
**Ring is uniform, symmetric, lower & smaller**

***Is this related to the 37-GHz ring hypothesis?***

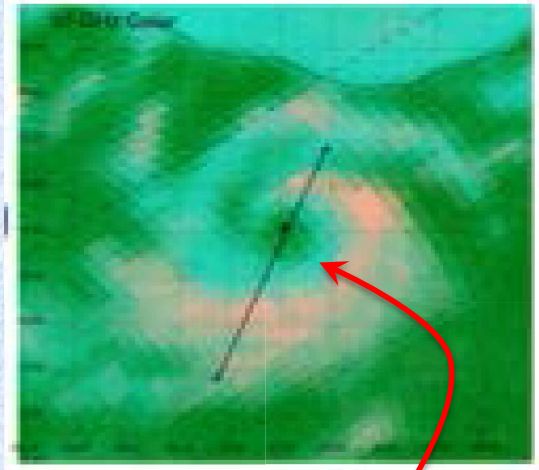
# Rapid Intensification and the 37 GHz ring

Kieper, M. E., H. Jiang, and J. P. Zagrodnik, 2012: Using the 37 Color Composite PMW for Rapid Intensification Forecasts of Tropical Cyclones, 2012 Fall AGU

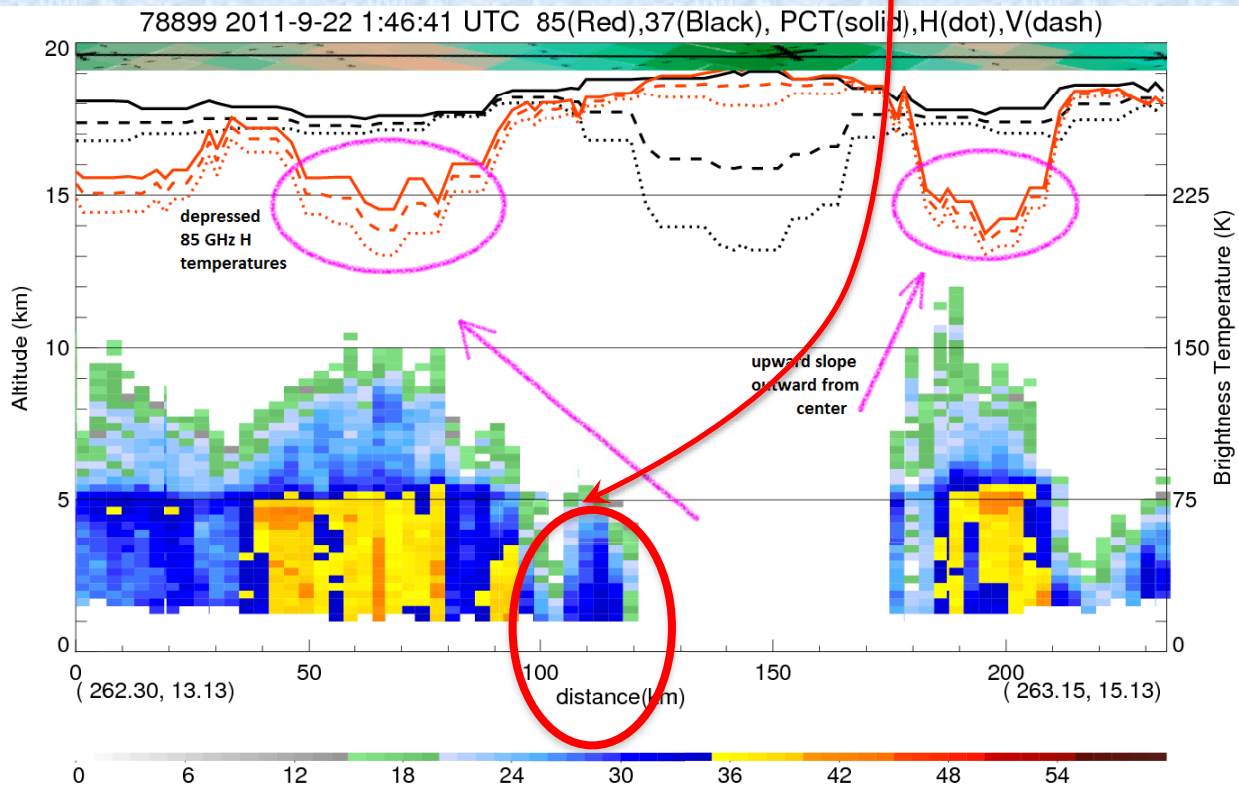
Kieper, M. E., and H. Jiang, 2012: Predicting tropical cyclone rapid intensification using the 37 GHz ring pattern identified from passive microwave measurements. Geophys. Res. Lett., 39, L13804, doi:10.1029/2012GL052115.

*From simultaneous radar vertical cross sections, the inner edge portion of the ring is nearly 100% closed surrounding the TC center and mainly consists of* ***shallow precipitation from near or below the freezing level to the surface*** *(Kieper and Jiang, 2012) . The outer edge portion of the ring could have asymmetric intense convection (i.e., hot towers) embedded within the ring. This outer edge portion of intense convection (the pink color) is highly asymmetric.*

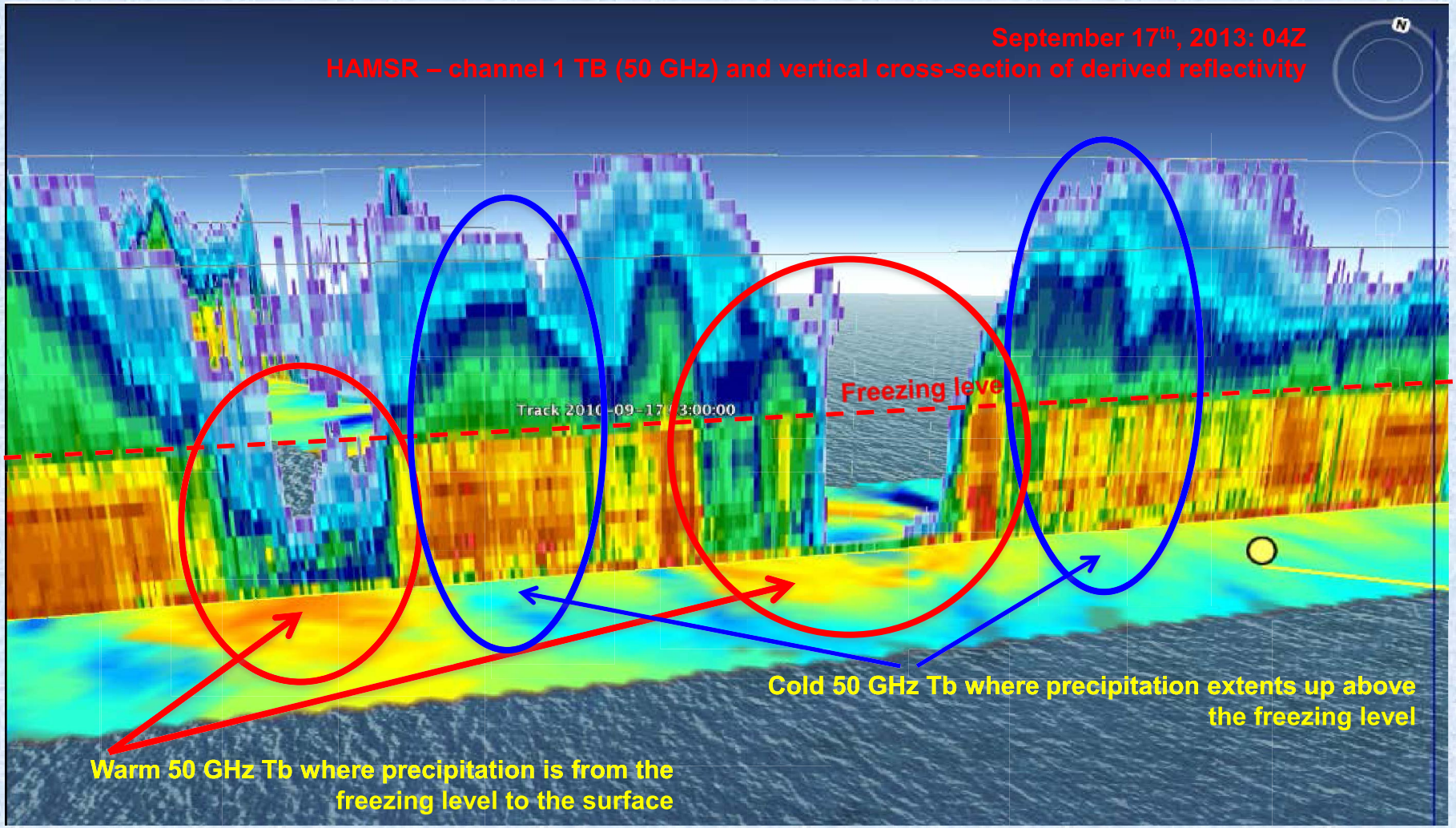
**2011 EPAC Hilary at 50kt Intensity**



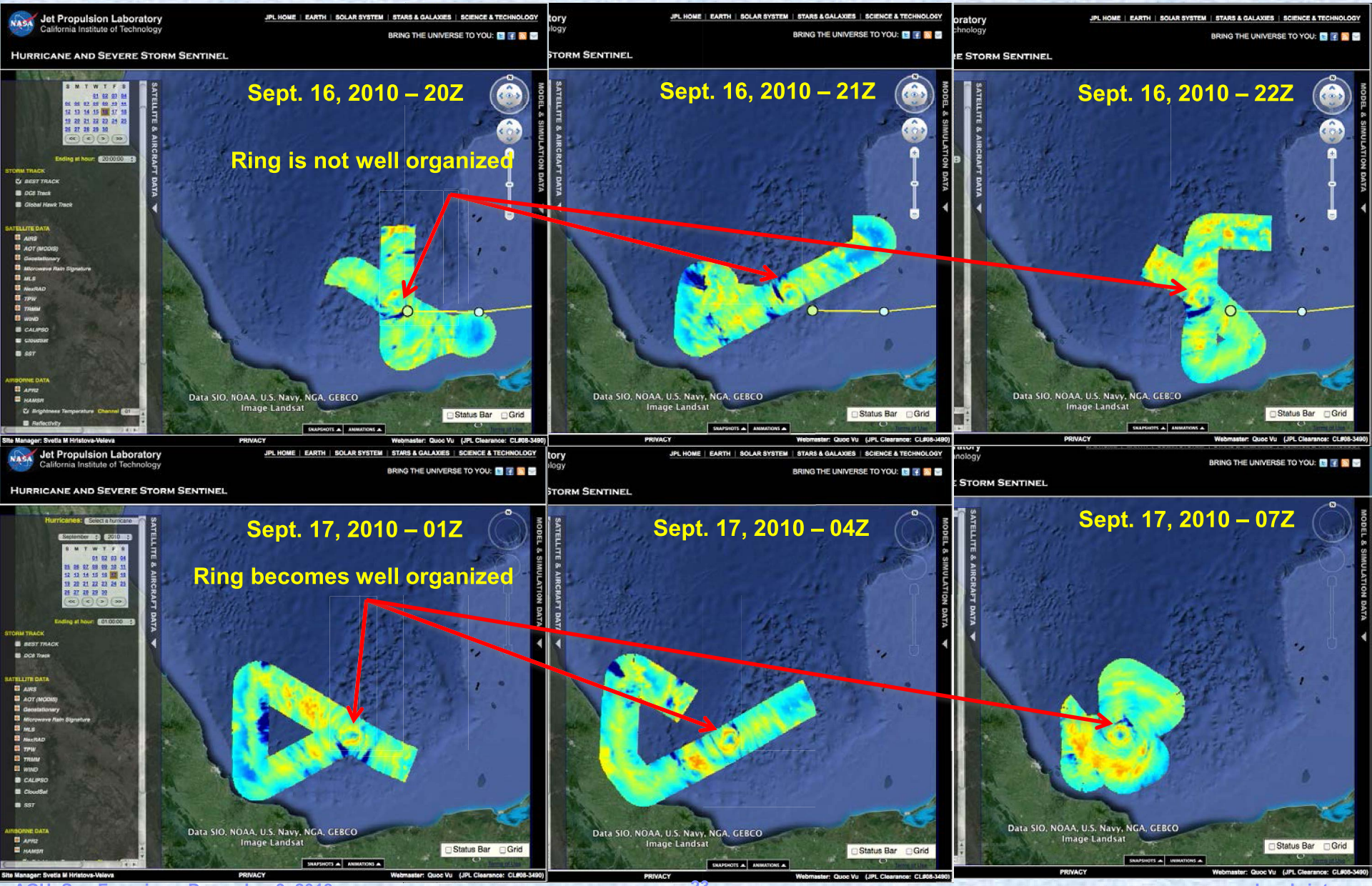
*"A cyan ring feature on the 37 color composite image has been observed to forecast rapid intensification of tropical cyclones under favorable environmental conditions."*



# HAMSR 50 GHz view similar to 37 GHz view

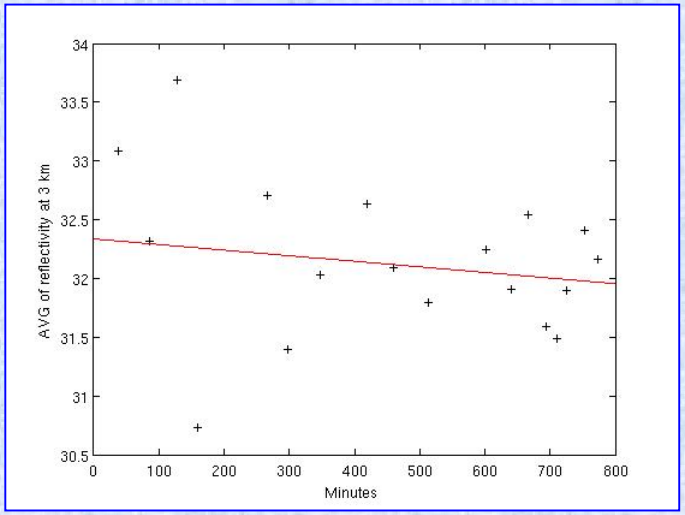


# Evolution of the 50 GHZ HAMSR ring

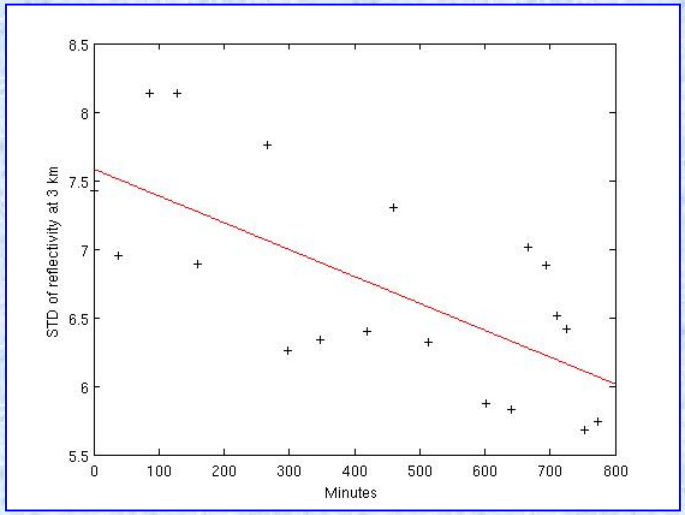


# Trends in convective structure during RI

## Inner core (eye wall) reflectivity

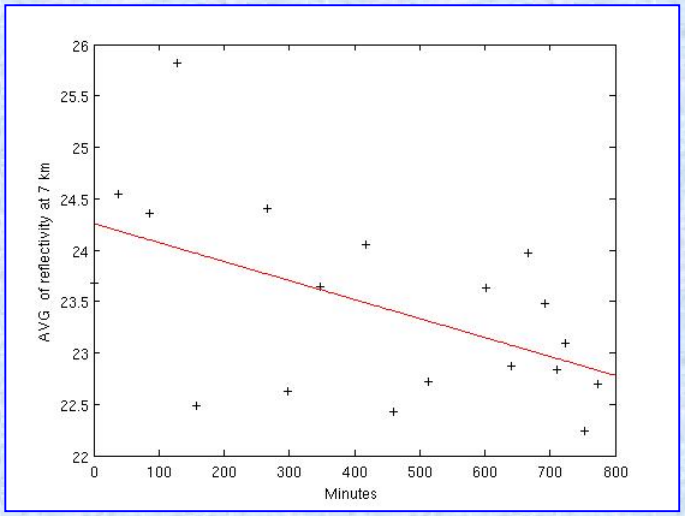



3 km

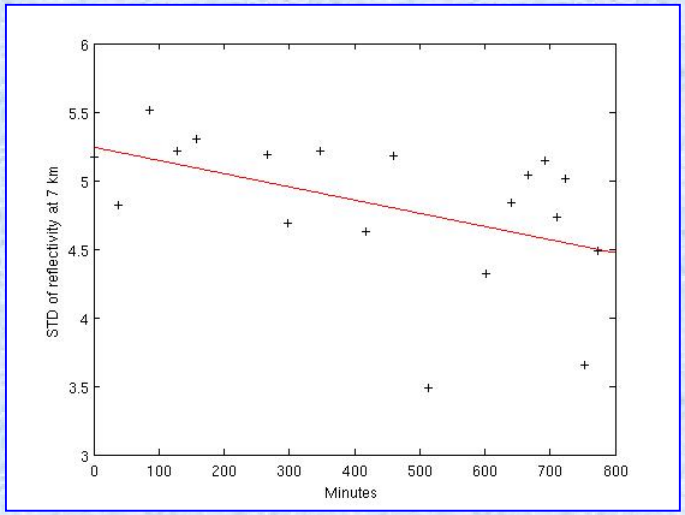



Mean

Standard deviation

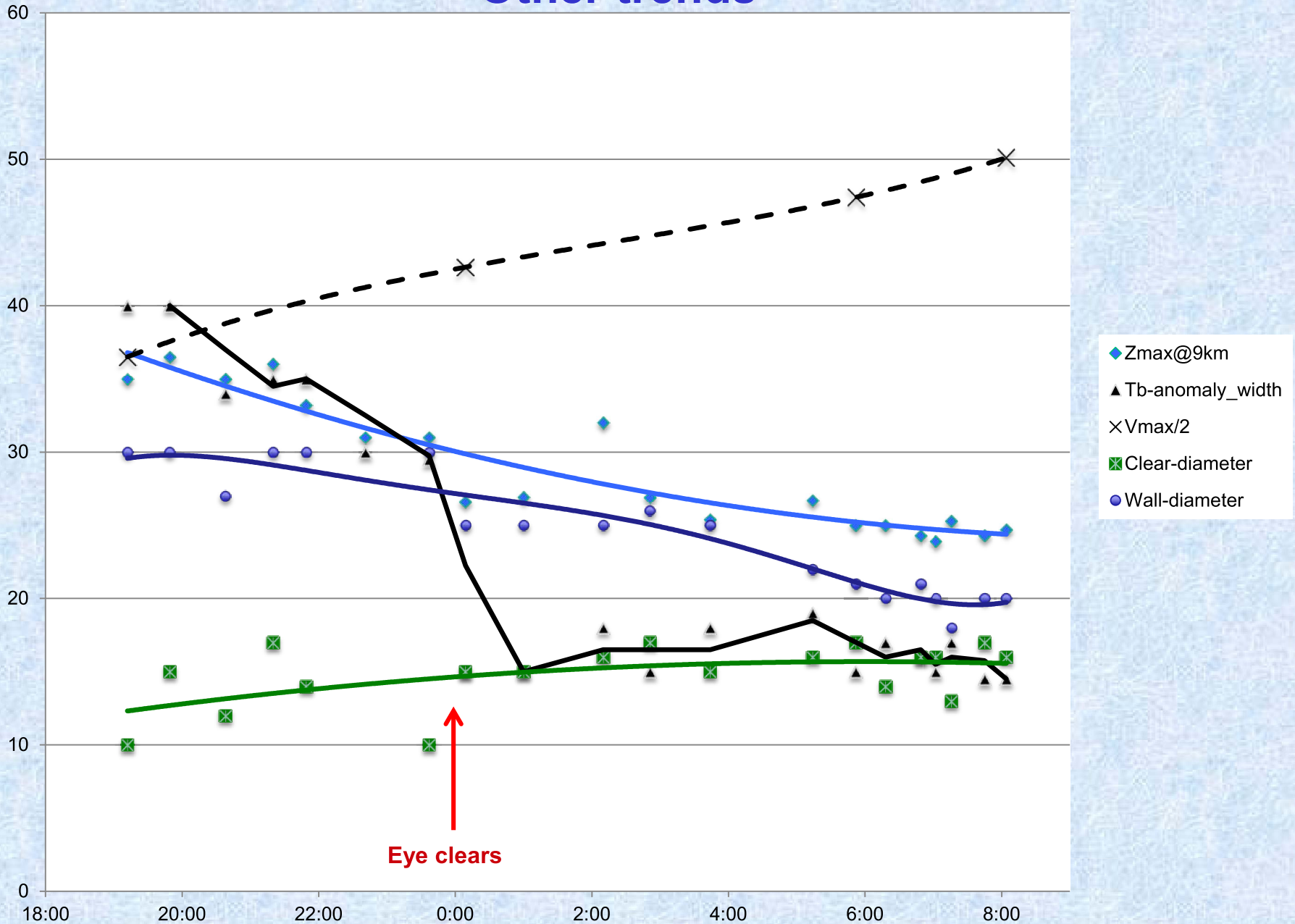



7 km



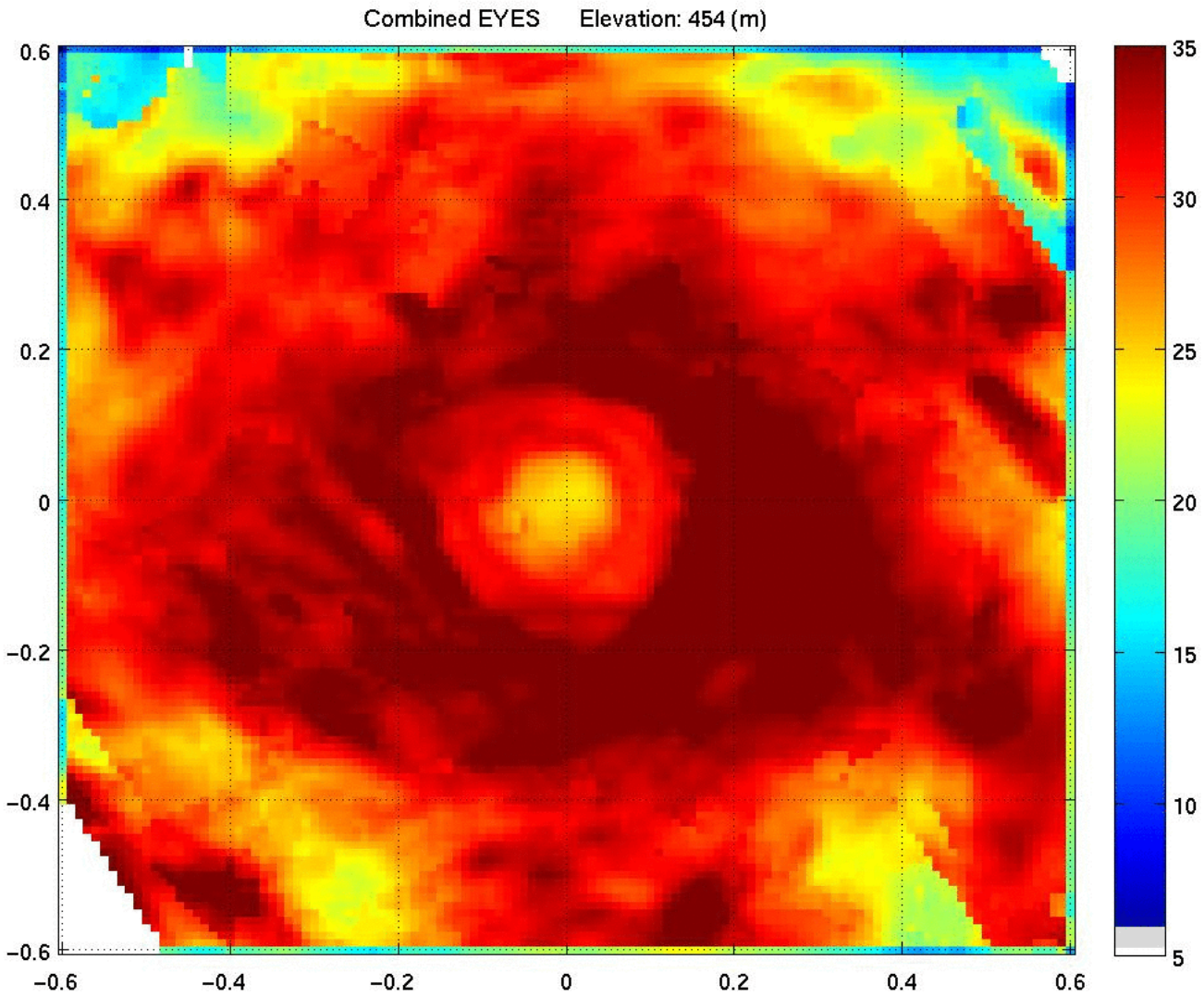

**Eye wall convection is becoming more uniform**

# Other trends

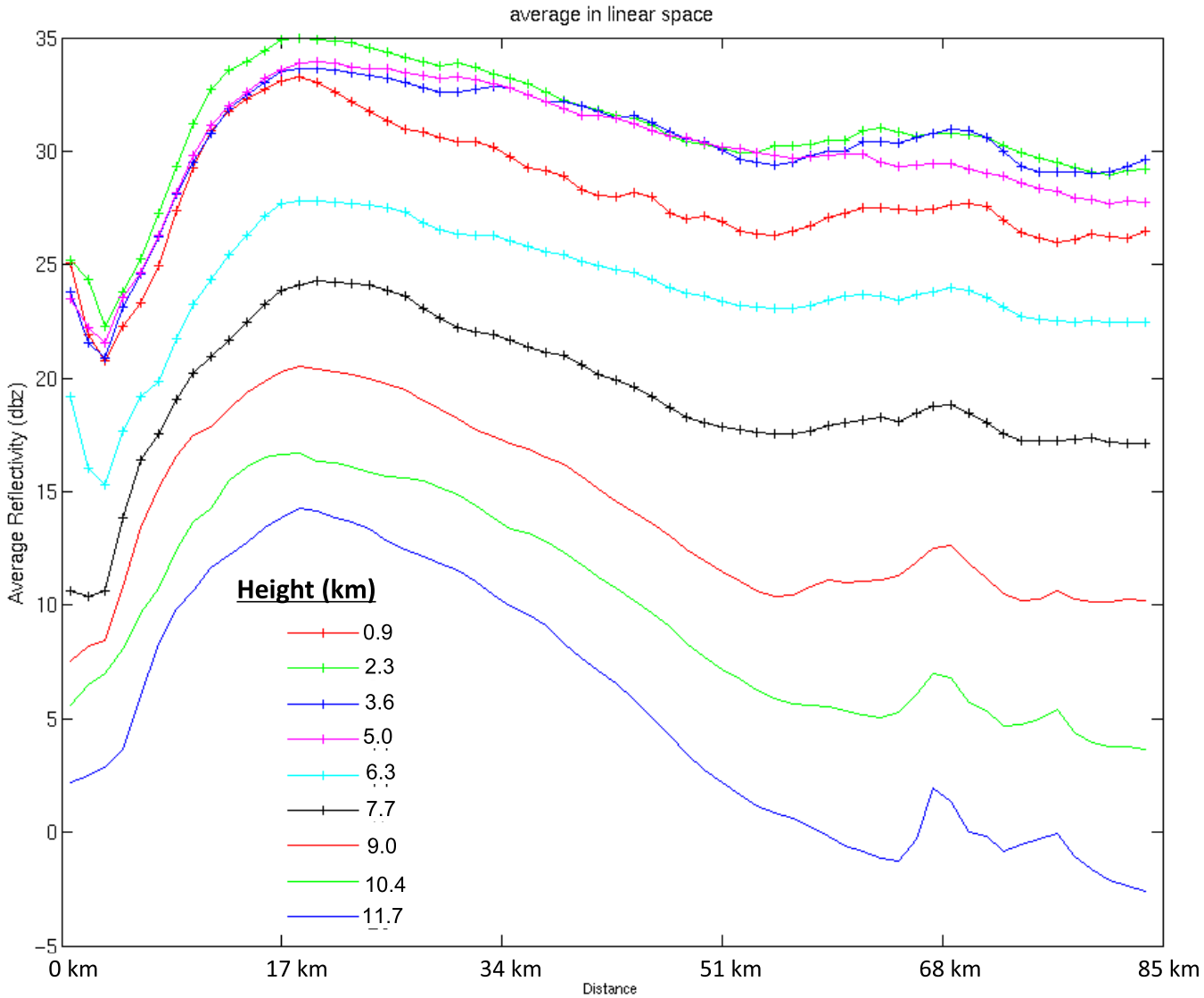


# Mean 3-D structure

## All 20 eye passes



# Radial distribution of reflectivity



# Summary (no conclusions yet)

Some preliminary observations from 13 hours of RI:

- Warm core develops at 200 mb and spreads down to surface
- Inner core drying starts at 300 mb and spreads to top of BL
- There is a slow compression of the BL (from 3 km to 2 km)
- Warm core extends well beyond the inner eye wall
- Warm core contracts when the eye becomes cloud free
- Eye wall convective structure changes significantly
    - Deep convective cells disappear
    - Inner-core convection becomes symmetric, uniform, shallower
    - Eye clears and changes in diameter:
        - Clear and low-reflectivity area expands
        - Eye walls contract and narrow
- Convective structure may be exhibiting oscillatory behavior (TBD)

HAMSR is a valuable tool for hurricane research

- Brightness temperatures → Warm core anomaly
- Sounding products → Thermodynamics
- Reflectivity products → Convective structure

The analysis will continue