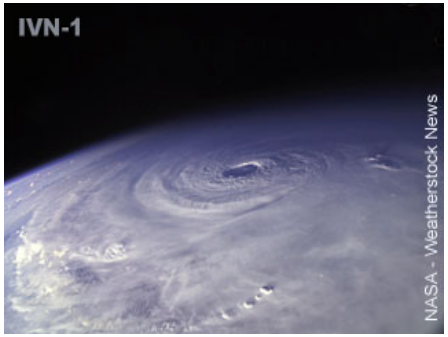
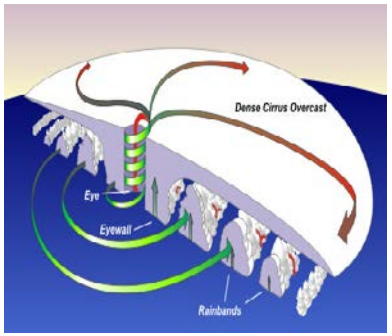
NASA'S Exploration of Hurricanes The Genesis and Rapid Intensification Processes (GRIP) experiment

Ed Zipser, University of Utah, on behalf of
Scott Braun, NASA GSFC, and the GRIP Science Team
(similar to overview talk given at April 2012 AMS Hurricane Conference)





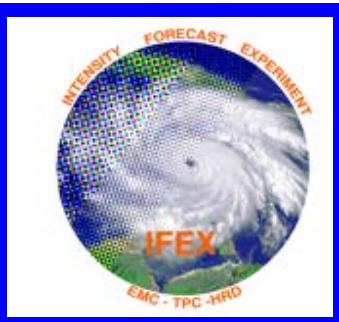
Funded by Dr. Ramesh Kakar, NASA HQ

What did we do during hurricane season 2010?

- NSF/NCAR PREDICT (PRE-Depression Investigation of Cloud Systems of the Tropics)

- NASA GRIP (Genesis and Rapid Intensification Processes)

- NOAA IFEX (Intensity Forecasting Experiment)



GOALS: Remarkably Similar…..*Not a coincidence!*

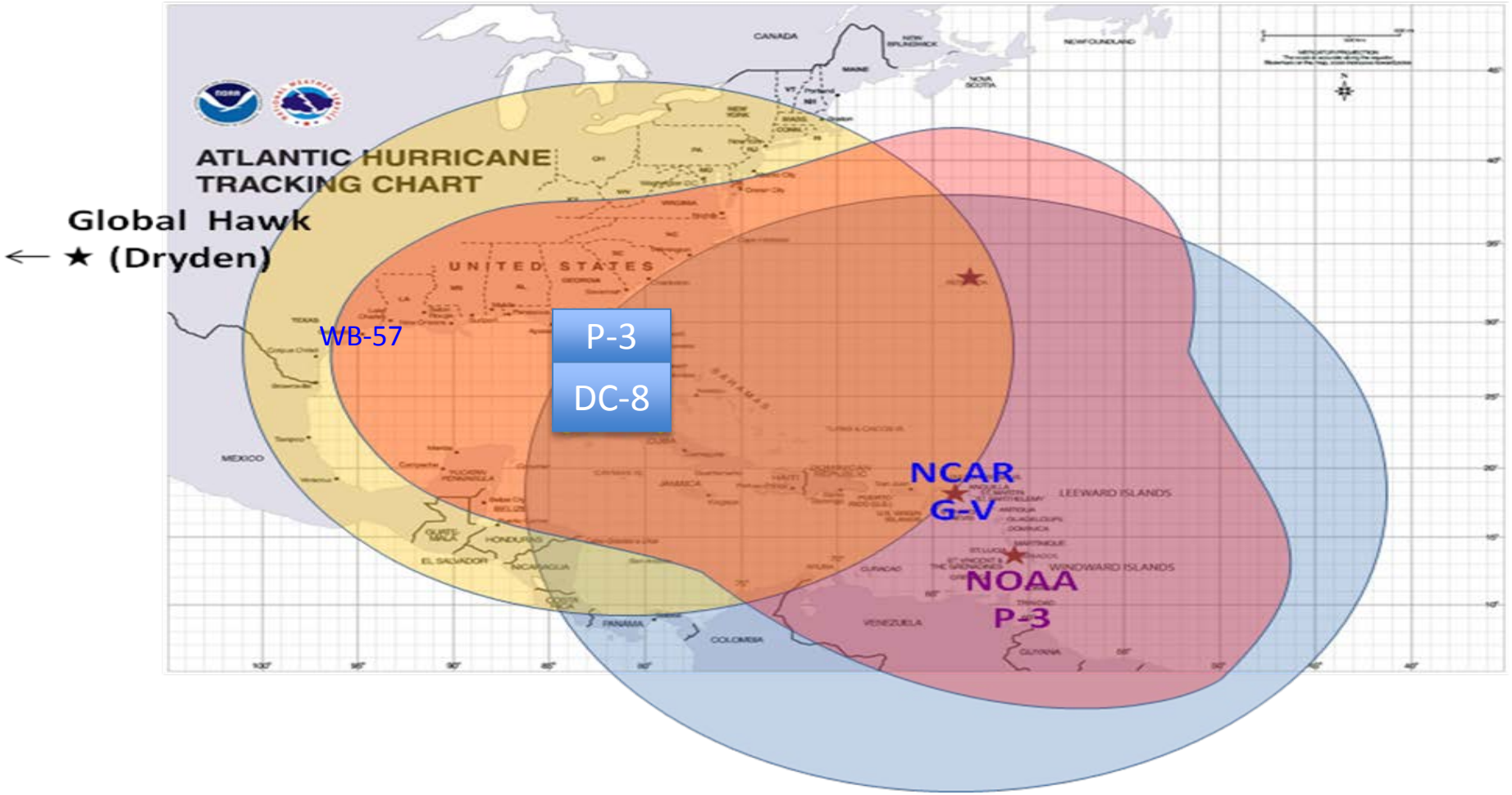
Mission and Science Overview: Summary of GRIP Science Objectives

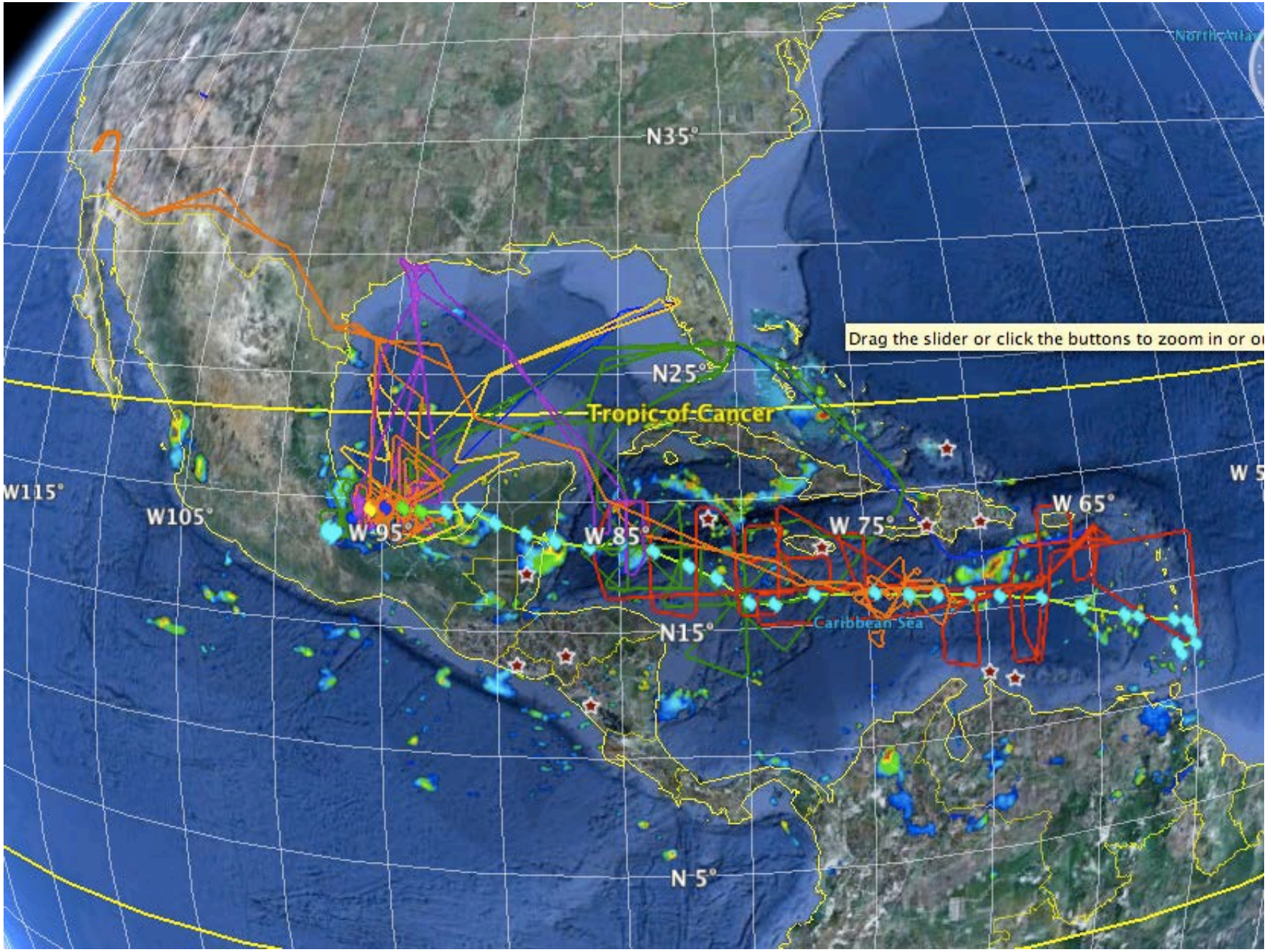
- Genesis: Role of the larger-scale environment vs. meso-convective processes near the putative developing center. Is genesis predictable?

- Rapid Intensification: Relative role of environmental vs. inner core processes? Role of dust, aerosols, Saharan Air Layer? Is RI predictable?

- Test-bed: Evaluate candidate technologies for remote sensing from aircraft and from satellites. Wind lidar, high frequency passive microwave, dual-frequency radars, Global Hawk itself.

PREDICT/GRIP/IFEX Domains





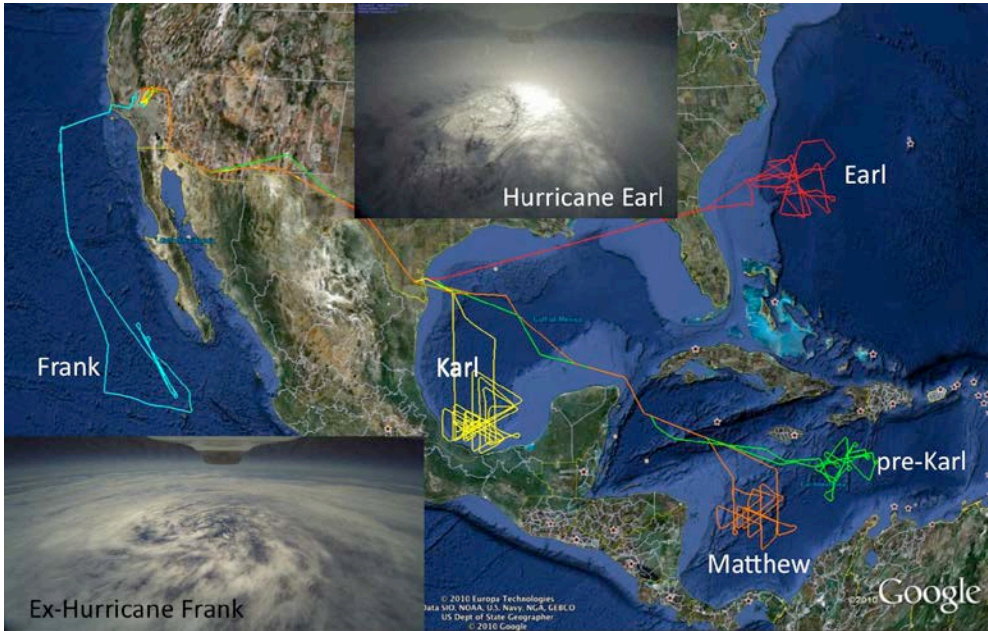
This made all the planning worthwhile! Karl 2010: All Flight tracks (almost) Sept 11-17 *Courtesy Scott Braun*

DC8: Up to 40 kft, 8-10 h duration

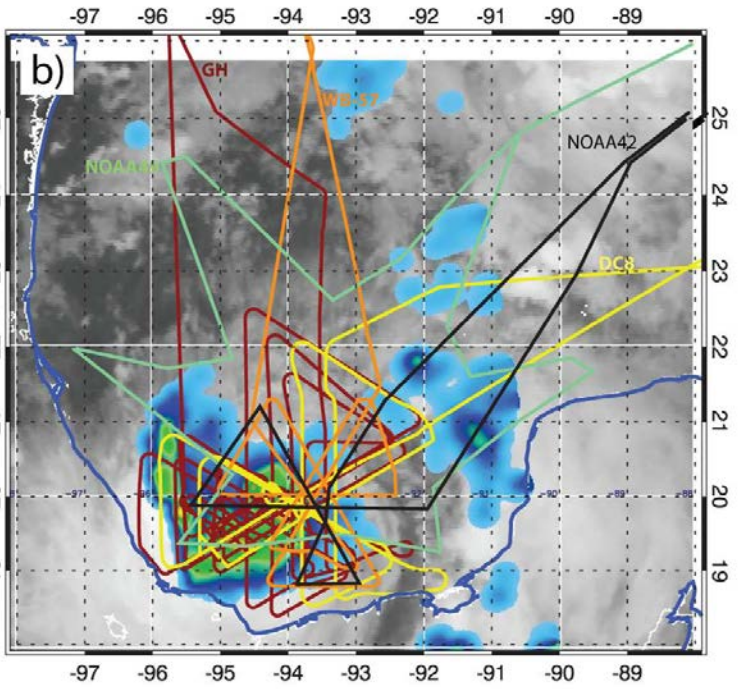
DC8 Instruments include LASE, APR2, DAWN, and dropsondes

GRIP Accomplishments

- Major cases
  - Multi-day flights of covering the genesis of Karl, Matthew, and non re-genesis of Gaston
  - DC-8 flights for RI of Earl (from Cat1 to Cat4)
  - DC-8 & GH flights of RI of Karl (from Cat1 to Cat3)
- Technical Achievements
  - First GH flight over a hurricane
  - 20 GH eye crossings in one flight over Karl



Hurricane Karl Flights



Rapid Intensification Stage

September 16

DC-8 (yellow), WB-57 (orange), Global Hawk (red), NOAA P-3 (black), NOAA G-IV (green)

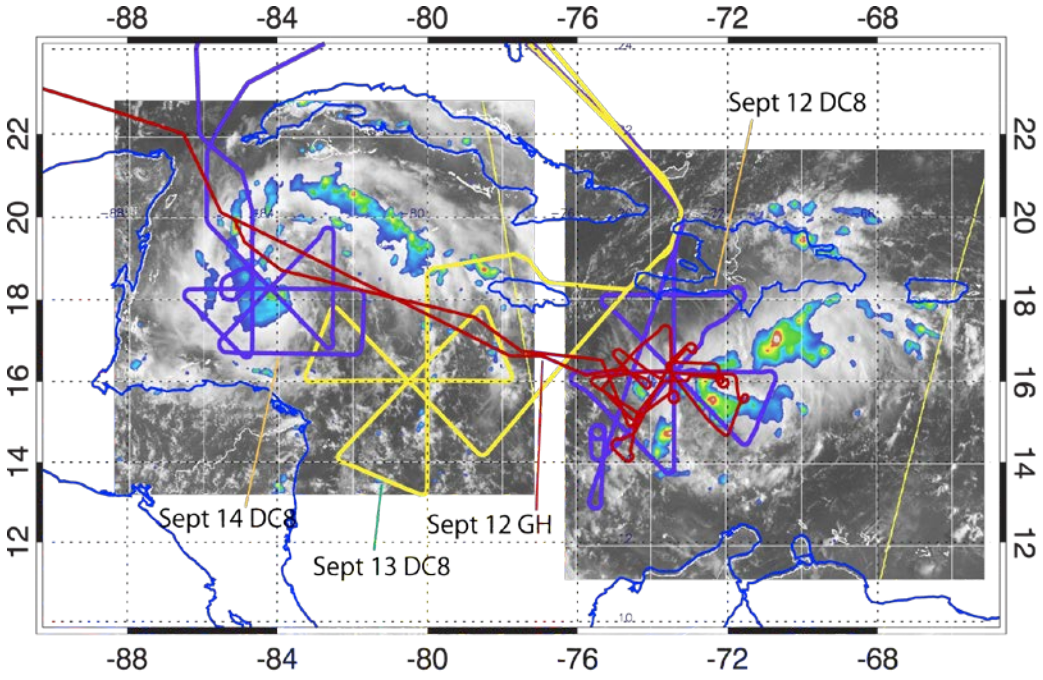
September 17 (Karl's Landfall)

DC-8 over ocean/land; WB-57 offshore

Genesis Stage

DC-8 on Sept. 12-14

Global Hawk on Sept. 12



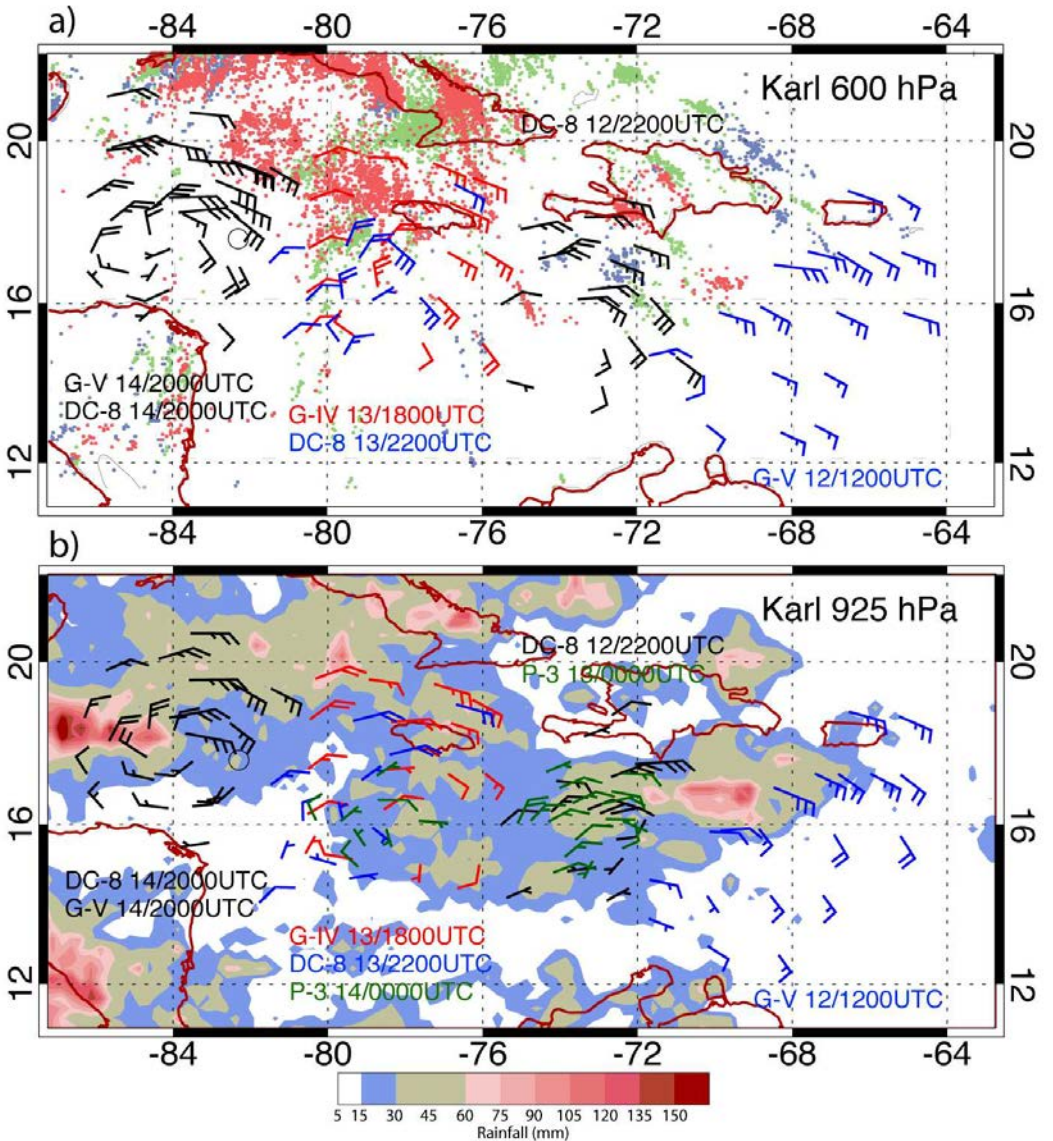
Karl's Genesis

(see Jon Zawislak's talk and poster, and several other talks, for details)

- Gradual intensification to TS
- Lightning primarily on NE side
- Rainfall episodic until increase late on Sept. 15

Upper panel:
Dropsonde wind barbs @ 600 hPa
Lightning flash locations:
Blue: Sept. 12
Green: Sept. 13
Red: Sept. 14

Lower panel:
Dropsonde wind barbs @ 925 hPa
Shading: TRMM Multi-satellite precipitation accumulation, Sept. 12-15.



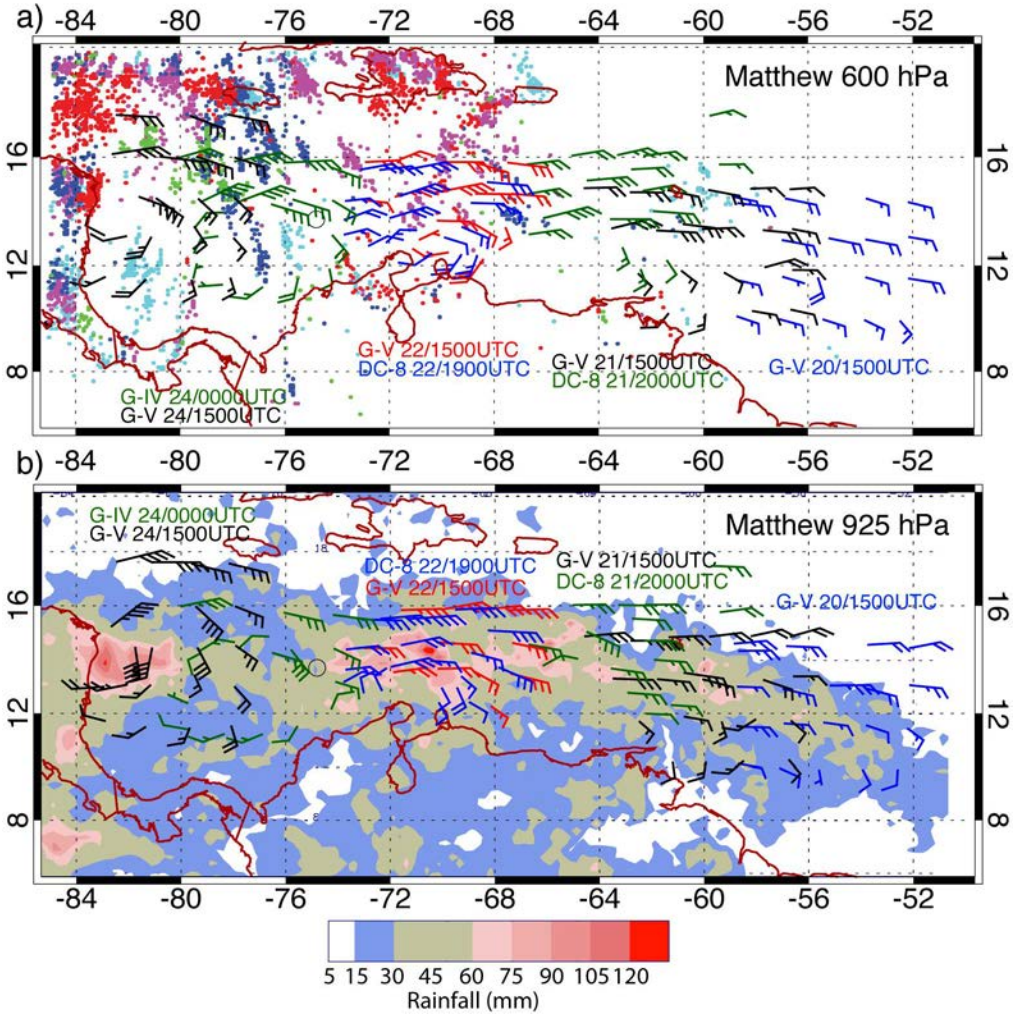
Matthew's Genesis

- Gradual intensification to TS
- Lightning primarily west of disturbance
- Rainfall: Significant bursts on Sept 22 and 24

Upper panel:
Dropsonde wind barbs @ 600 hPa
Lightning flash locations:

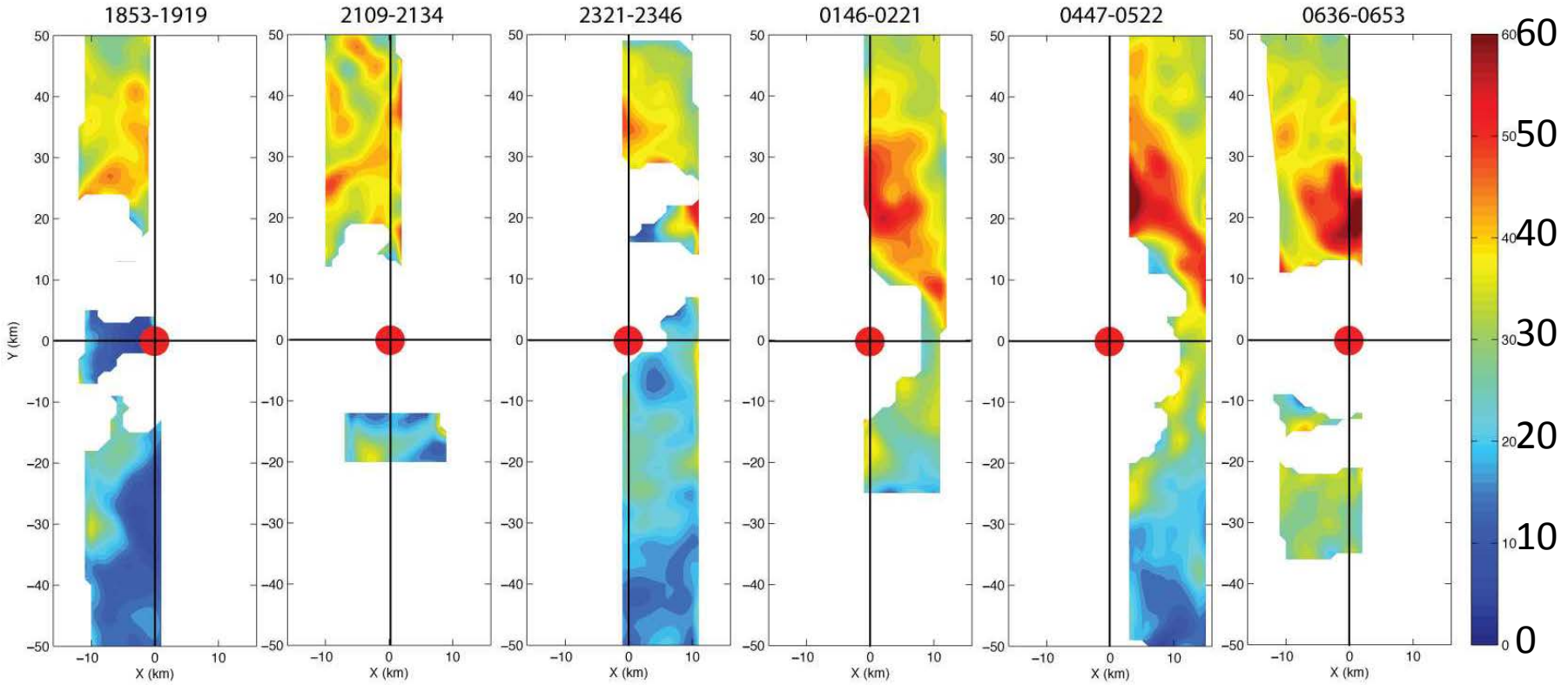
Cyan: Sept 20
Violet: Sept 21
Blue: Sept. 22
Green: Sept. 23
Red: Sept. 24

Lower panel:
Dropsonde wind barbs @ 925 hPa
Shading: TRMM Multi-satellite precipitation accumulation, Sept. 20-24.



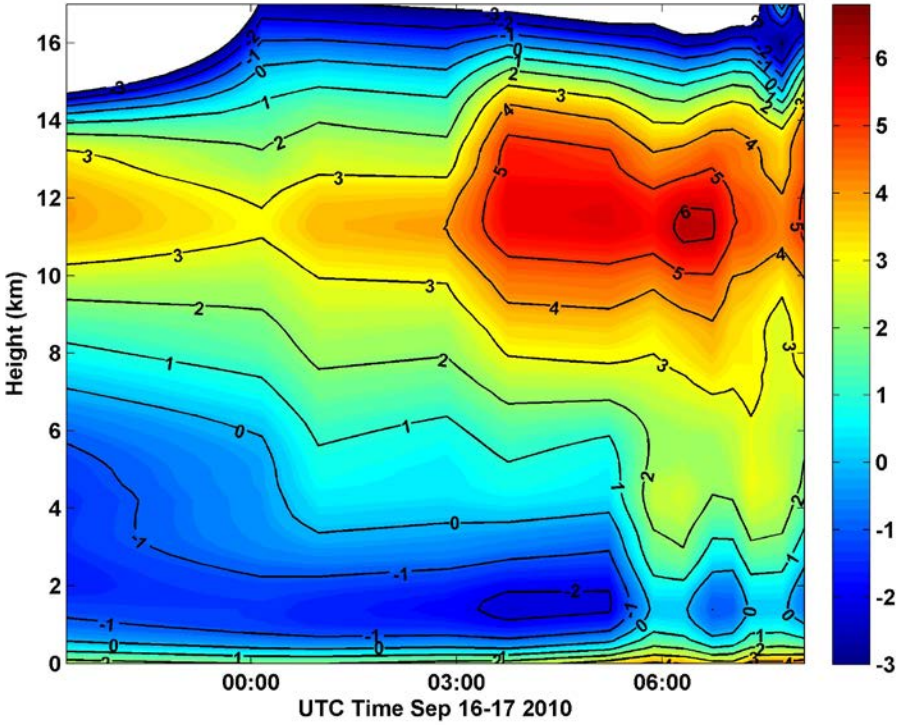
HIWRAP View of Intensification

3-km Wind Speed from HIWRAP

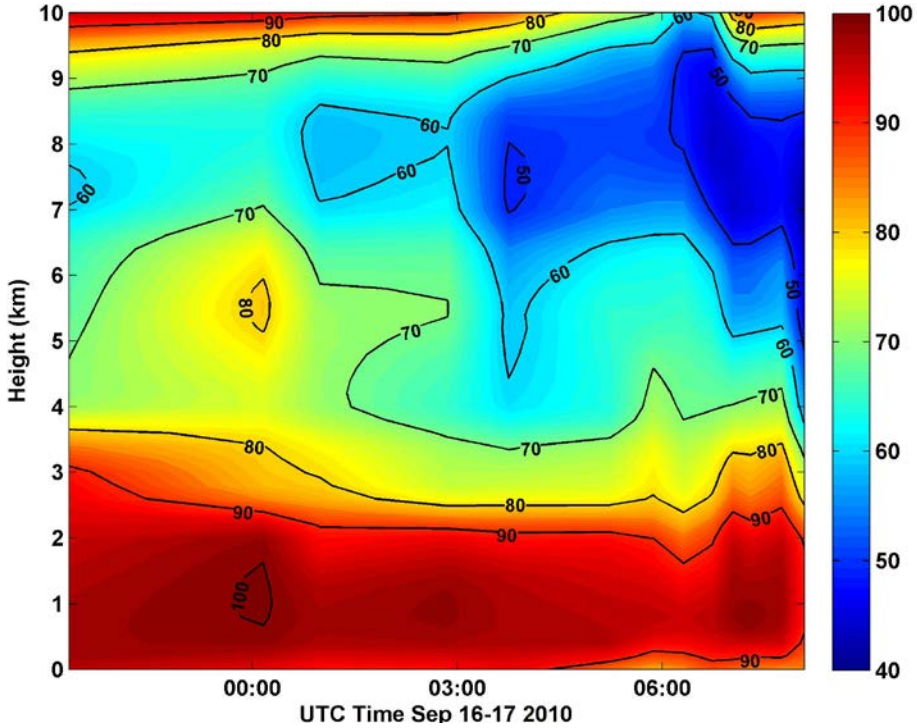


Time Evolution of the Inner Core Vertical Thermodynamic Structure (HAMSR retrievals)

T(z) vs Time



RH (z) vs Time

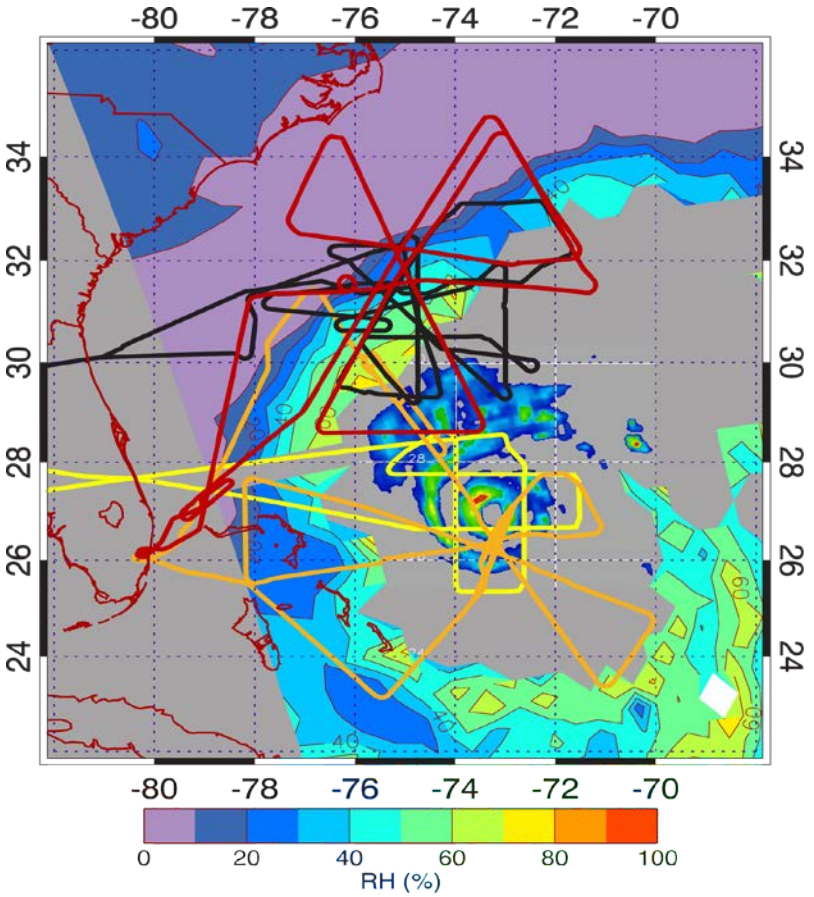


Warm anomaly propagated to lower levels as the storm intensified with the peak warm anomaly increasing by ~2-3C

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

Courtesy of S. Brown, B. Lambrigtsen, JPL

Hurricane Earl Flights



Mature Stage

September 1: DC-8 (orange) and WB-57 (yellow)

September 2: DC-8 (red) and Global Hawk (black)

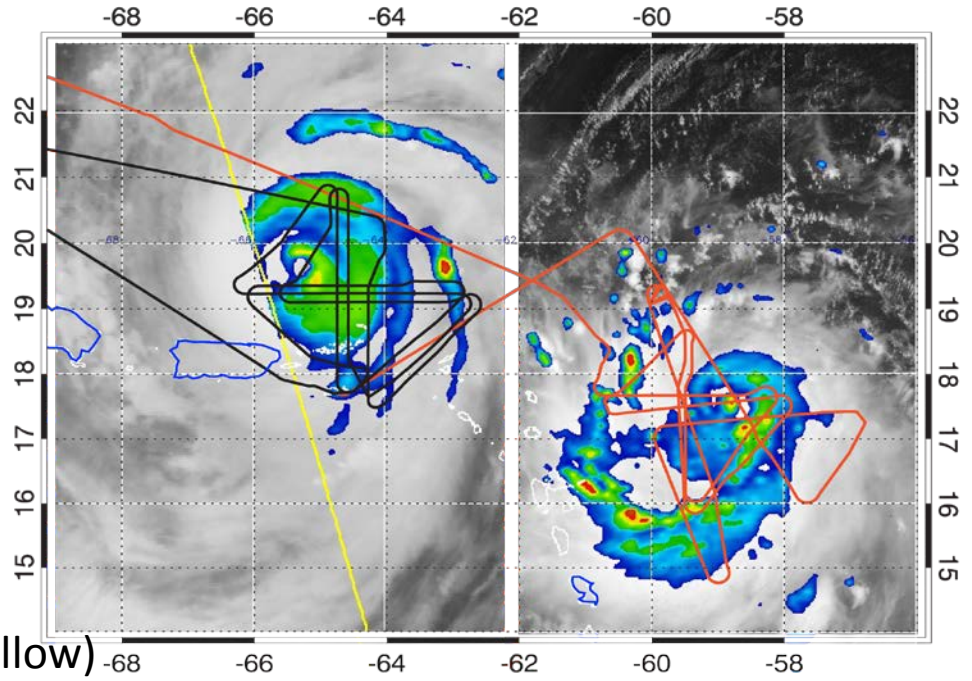
Background: AIRS 700-600 Relative Humidity, AMSR-E precipitation structure

Rapid Intensification Stage

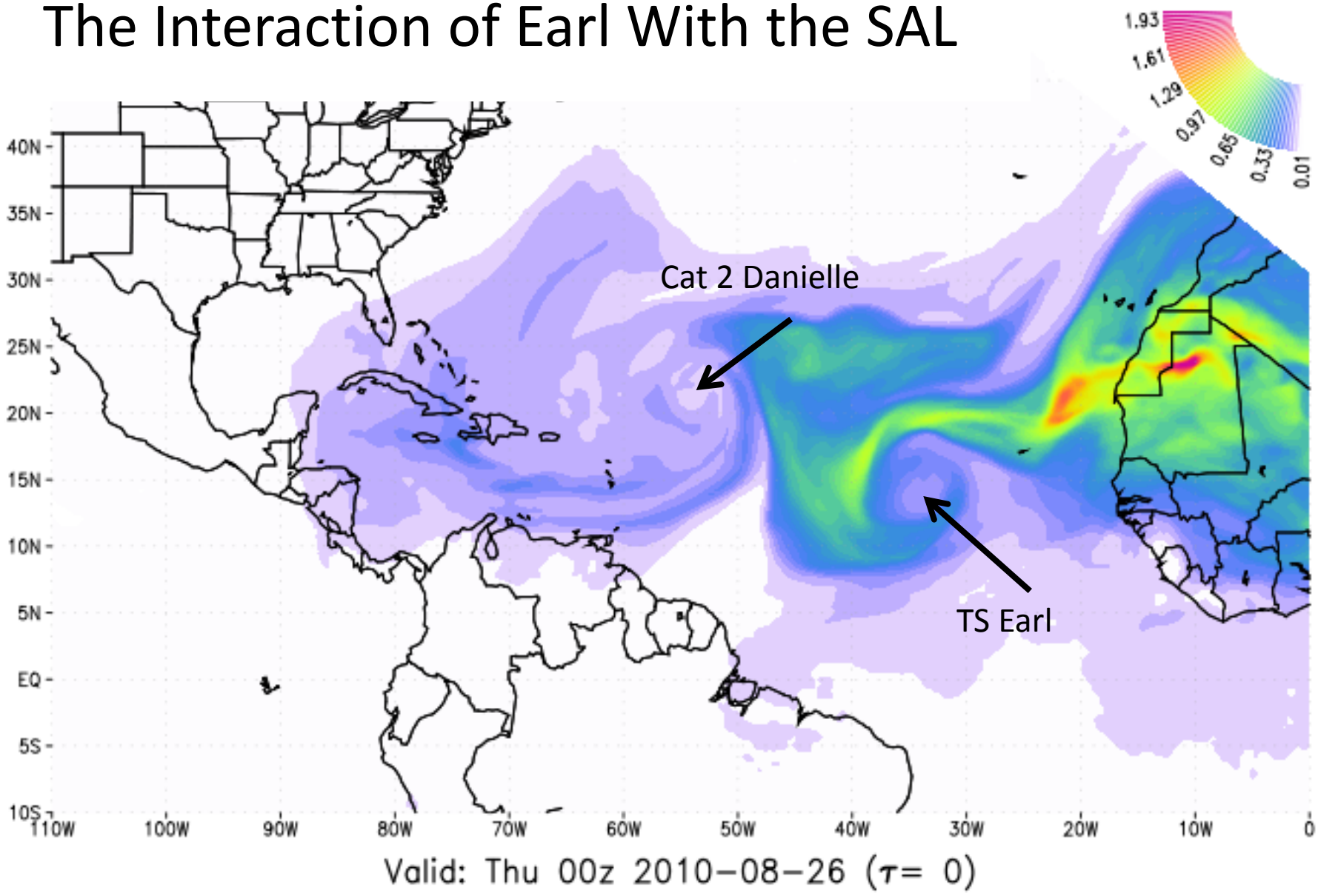
DC-8 on August 29-30

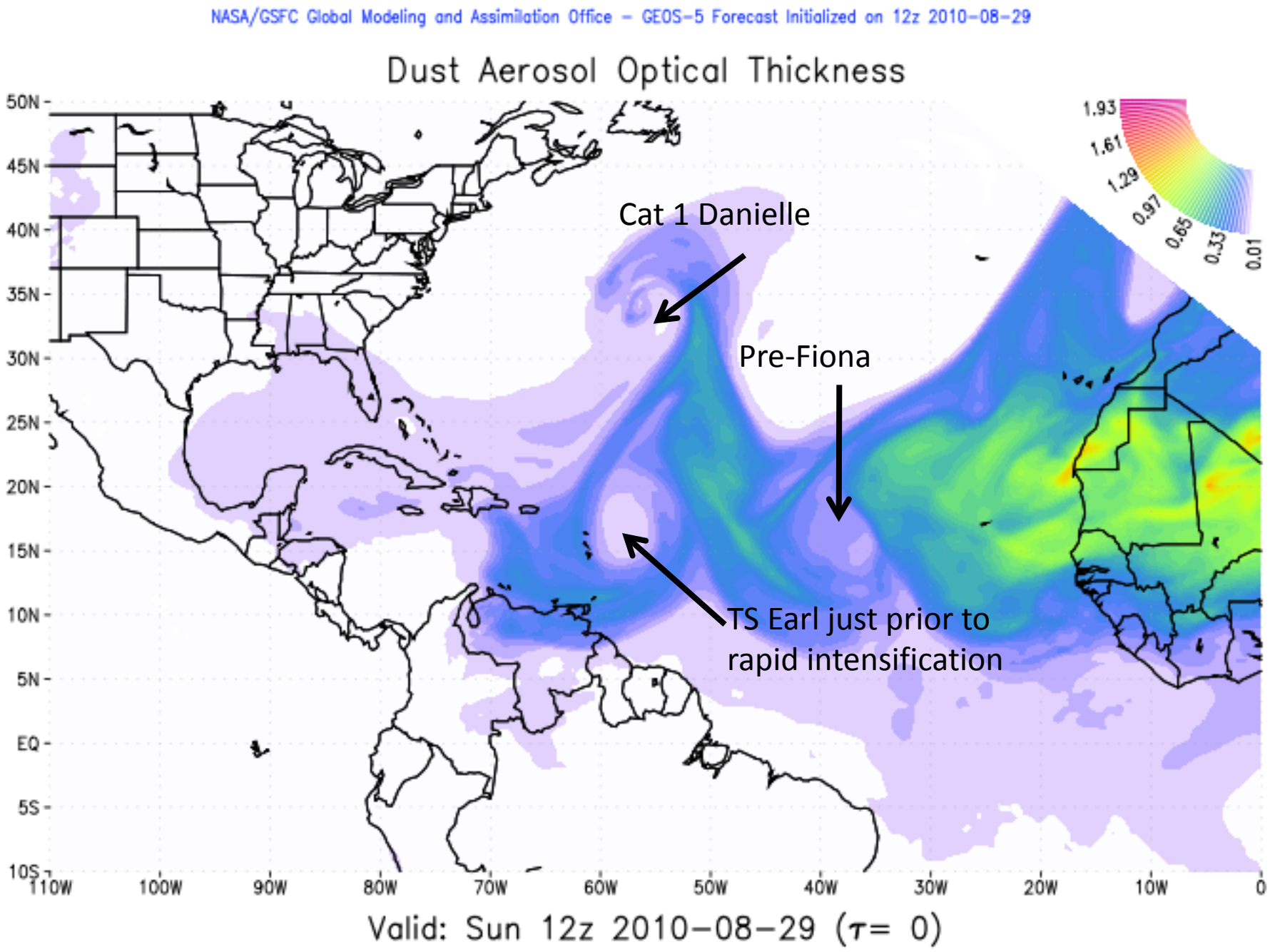
Aug 30:
Cat3-Cat4

Aug 29:
Cat1-Cat2



The Interaction of Earl With the SAL



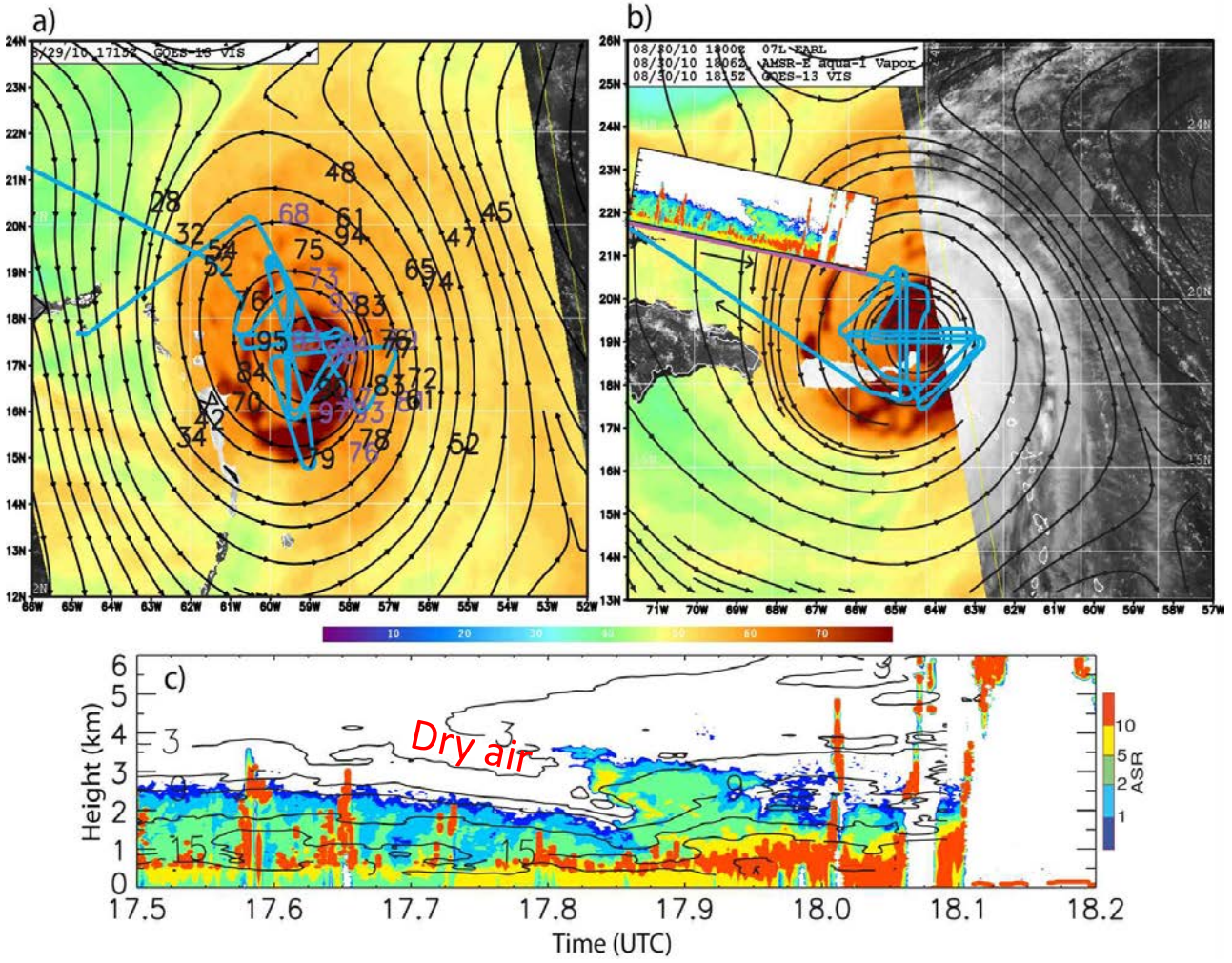

NASA/GSFC Global Modeling and Assimilation Office – GEOS-5 Forecast Initialized on 12z 2010-08-29
Dust Aerosol Optical Thickness
1.93
1.61
1.29
0.97
0.65
0.33
0.01
Cat 1 Danielle
Pre-Fiona
TS Earl just prior to rapid intensification
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
5S
10S
110W
100W
90W
80W
70W
60W
50W
40W
30W
20W
10W
0
Valid: Sun 12z 2010-08-29 (τ= 0)

Interaction of Earl with the SAL

- GFS 700 hPa storm-relative streamlines suggest **slow** pathway for dry SAL air to get into Earl (too slow to have effect?)

- Dust and low RH observed in near environment of Earl

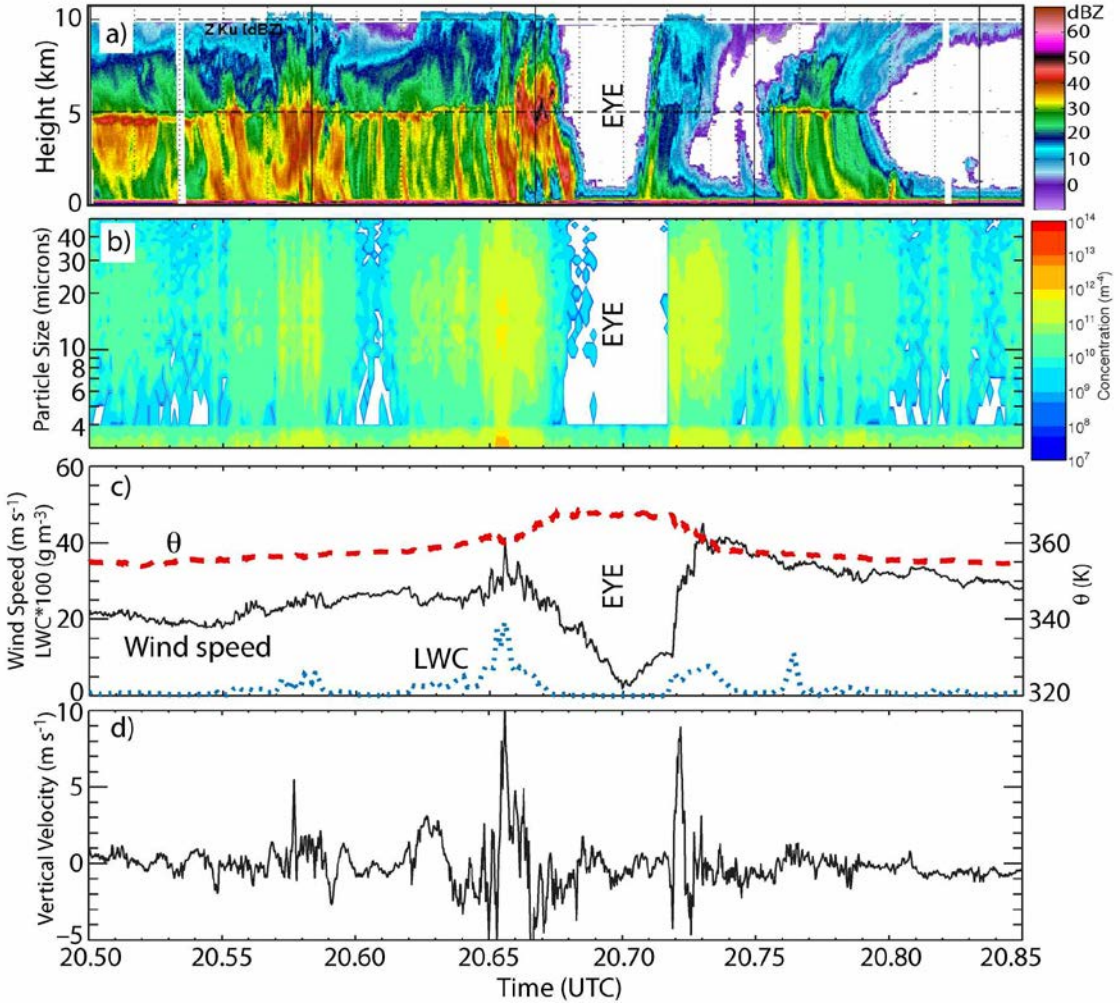
- Dry tongue of air in LASE data between SAL layers—suggests non-SAL source of dry air



Microphysical Impacts of Dust?

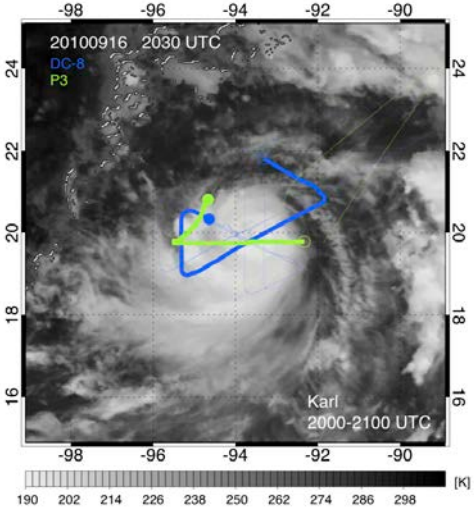
- Microphysical impact of dust should be seen in CDP data as high concentration of small (3-10 microns) drops
- Shown here is one of the 5 passes during an east-to-west (left-to-right in figure) pass
- But bottom line: There is much work that we GRIP PIs need to get together and accomplish to extract the best information from these outstanding missions.

(see pointed finger)



Red dashed line: θ-320K
Blue dotted line: LWC*100

Potential Opportunities for in situ microphysics data from the NASA DC-8, coincident with NOAA P-3 radar coverage and data from other aircraft



Karl, Sept. 16: Beginning rapid intensification

DC-8: SW-NE through the eye, 2020 – 2038 (all times UTC)

NOAA 42: W-E through the eye, 2020 – 2100

Earl, Sept. 02: Strong but weakening, possible double eyewall

DC-8: NE-SW through the eye, 2132-2200

NOAA 43: SW-NE through the eye, 2139-2220

Earl, Aug 30: Rapidly intensifying

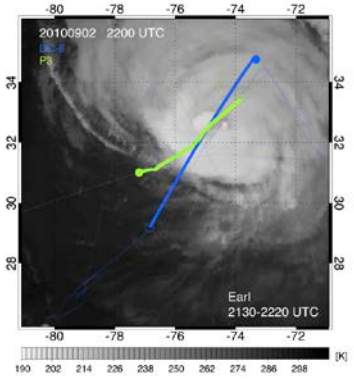
DC-8: N-S through the eye, 2113-2132; E-W through the eye, 2156-2218

NOAA 43: SE-NW through the eye, 2100-2140; SW-NE through the eye, 2200-2250

Earl, Aug 29: Beginning rapid intensification

DC-8: N-S through the eye, 2055-2114

NOAA 43: SE-NW through the eye, 2040-2120



Microphysics/dynamics interactions: *Why do we care*?

- Retrievals require knowledge of particle phase, habit, density, size distribution
- Evolution of convection depends *to first order* on the difference between particle fall speed and updraft speed
- To know particle fall speed: (See first bullet!)

Short and very incomplete list of interesting unanswered questions

• If aerosols are suspected in the eye or eyewall of Earl, what is the pathway for them to reach DC-8 altitudes? Do they somehow survive passage through the rain area outside the eyewall? Are they products of evaporation in the mid-upper troposphere?

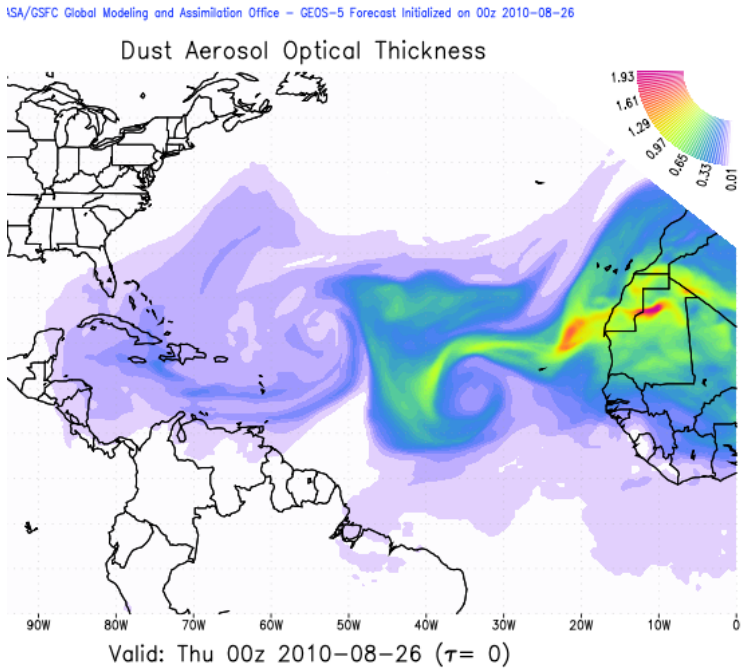
• High concentrations of cloud droplets in the 3-10 micrometer range are observed on occasion by the DC-8 microphysics package at temperatures of -30 to -40 C in the eyewall. What is the pathway for their appearance in this location? If they first form in the low troposphere, how do they avoid growing to larger drops?

• (Add several dozen others here – see next 2 days of talks!)

• We have much to look forward to! Let's get to it.

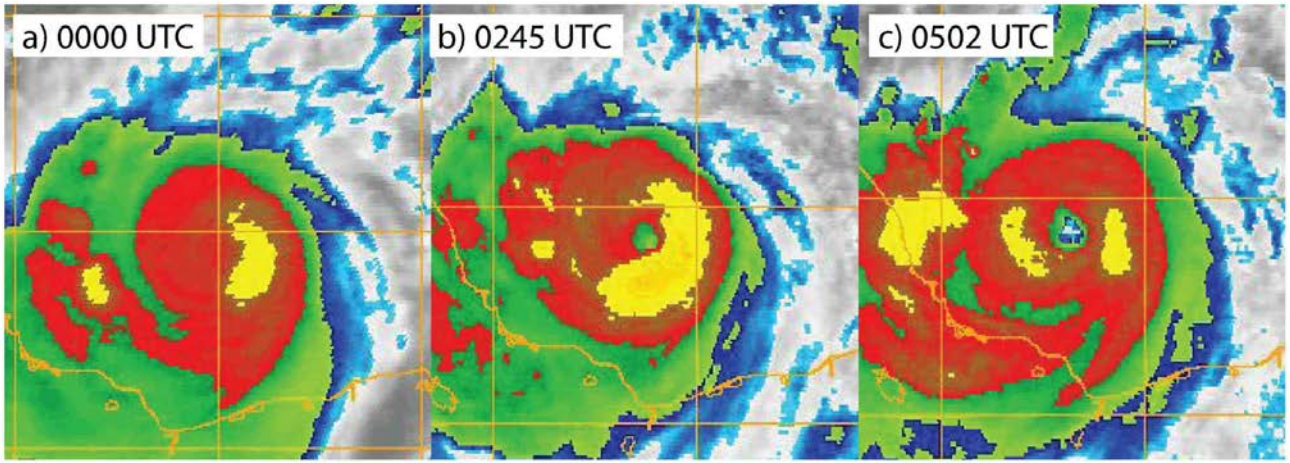
Summary of GRIP

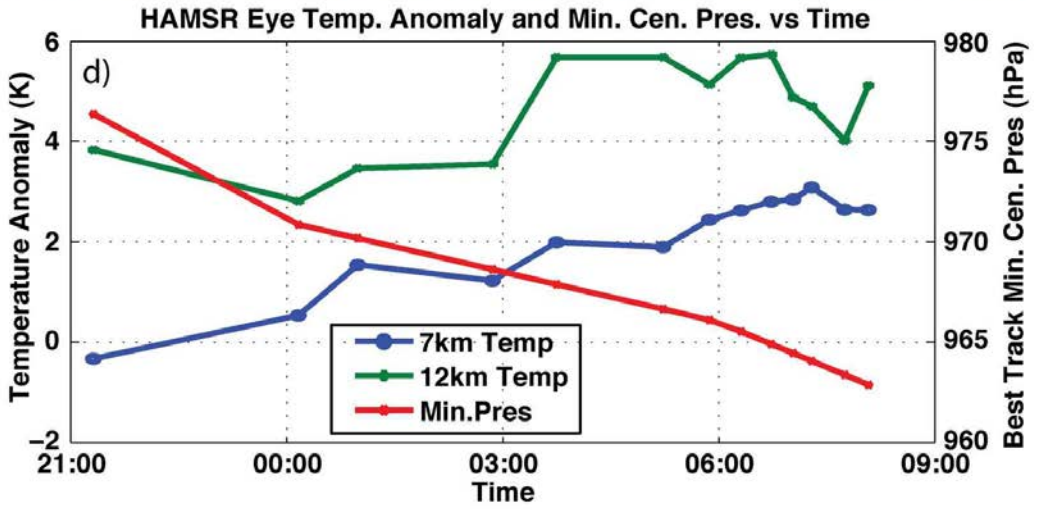
- The GH was demonstrated to be a unique and valuable tool for long-duration, high-altitude observations of the hurricane inner core
- GRIP will provide valuable information on the formation and rapid intensification of hurricanes
- The 2010 season included three storms that underwent rapid intensification while surrounded by, or adjacent to, dusty Saharan air

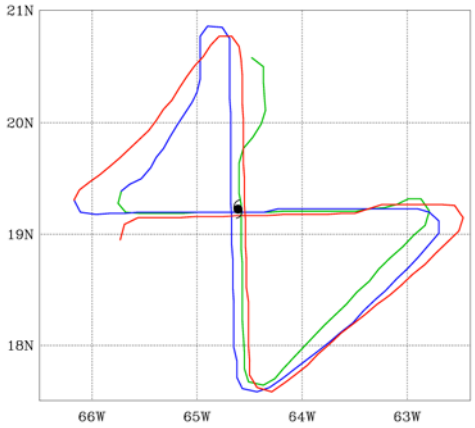


Upper Warm Core Intensification and Clear-Eye Formation

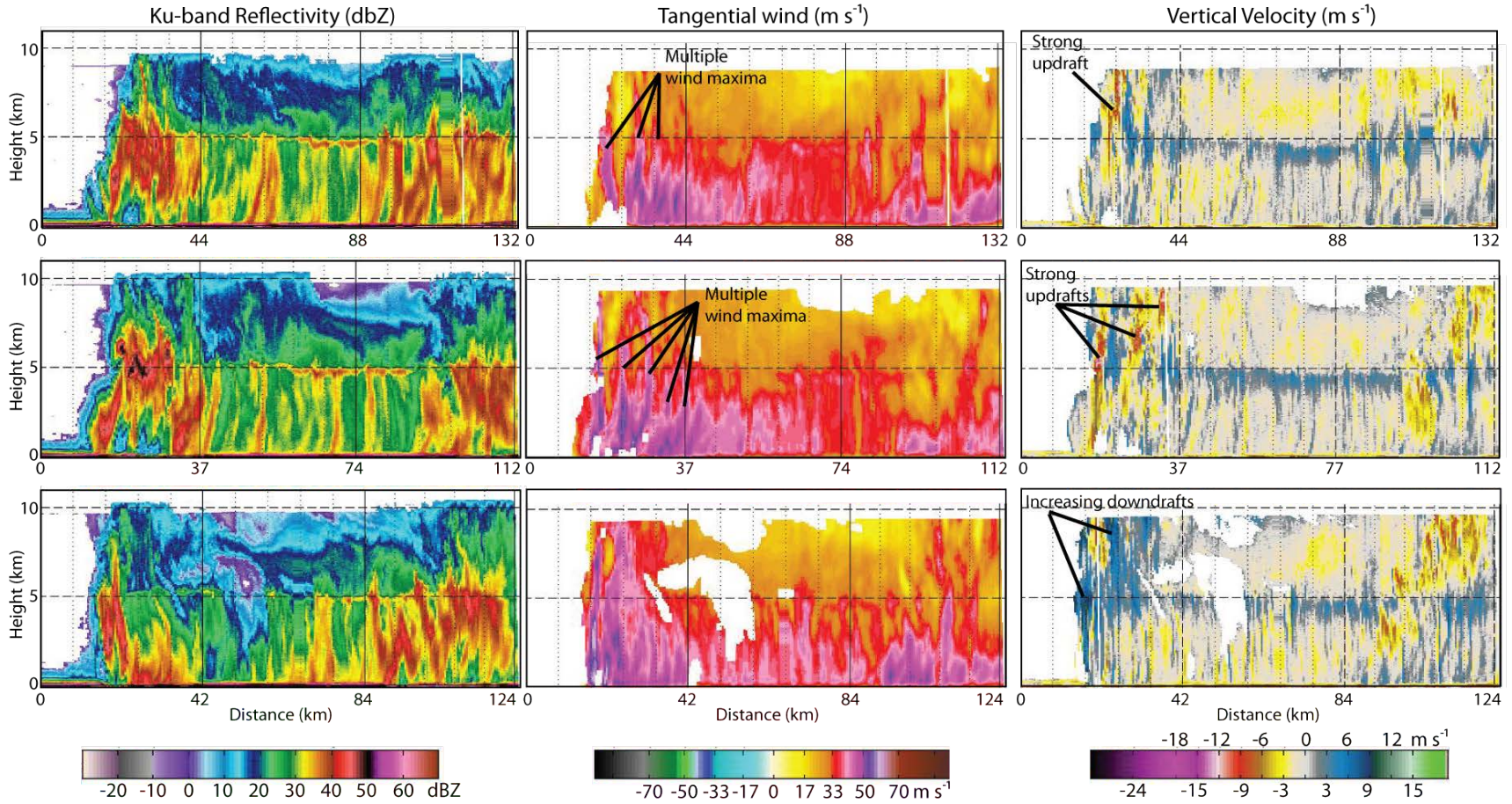
- HAMSR data monitored warm core intensification
- 7-km warming steadily increasing with drop in SLP
- 12-km warming increases suddenly after formation of clear eye in IR





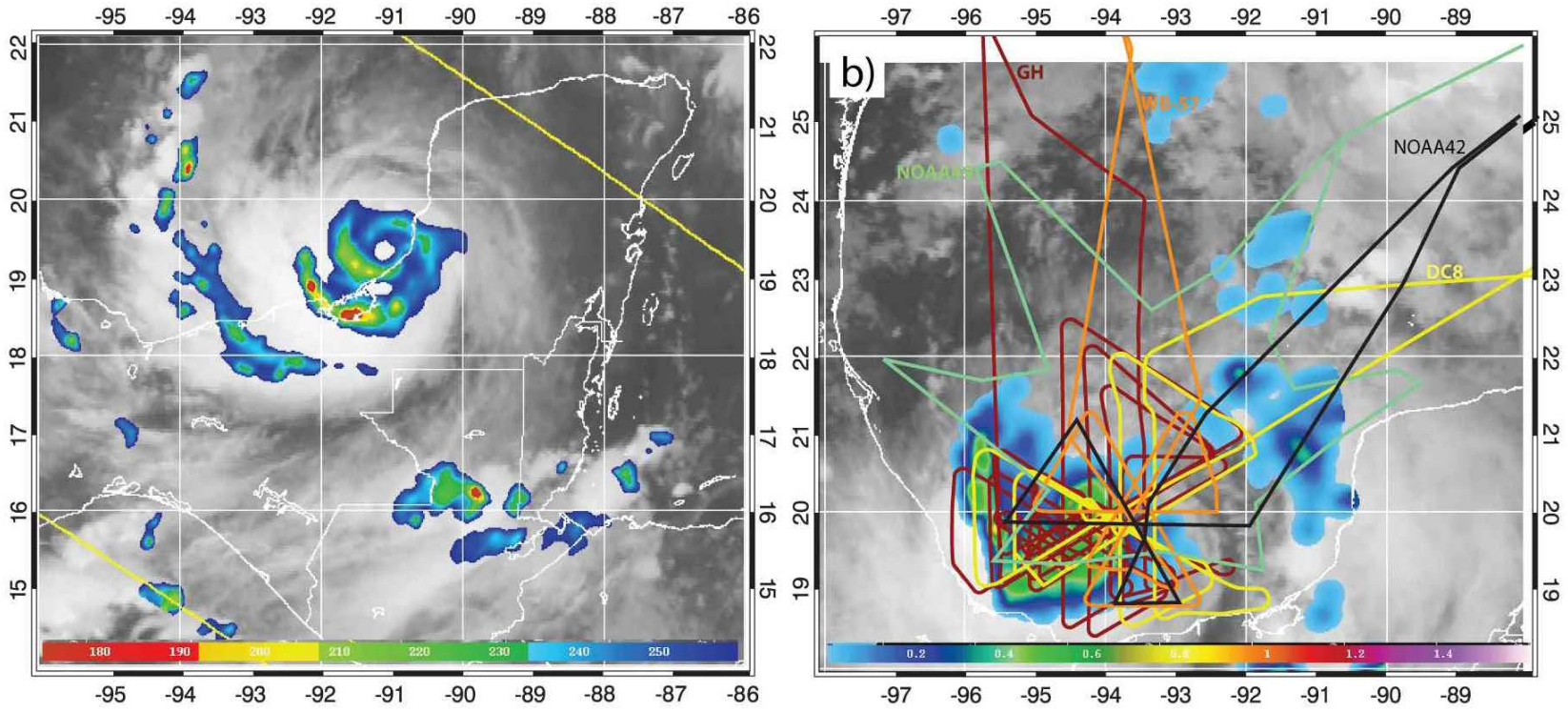


Eastern Eyewall Cross Sections During Repeated Passes on Aug 30



Coordination of NASA and NOAA aircraft in Hurricane Karl

A new record: 6 aircraft simultaneously



NASA: DC8, WB57, GH

NOAA: P3, G-IV

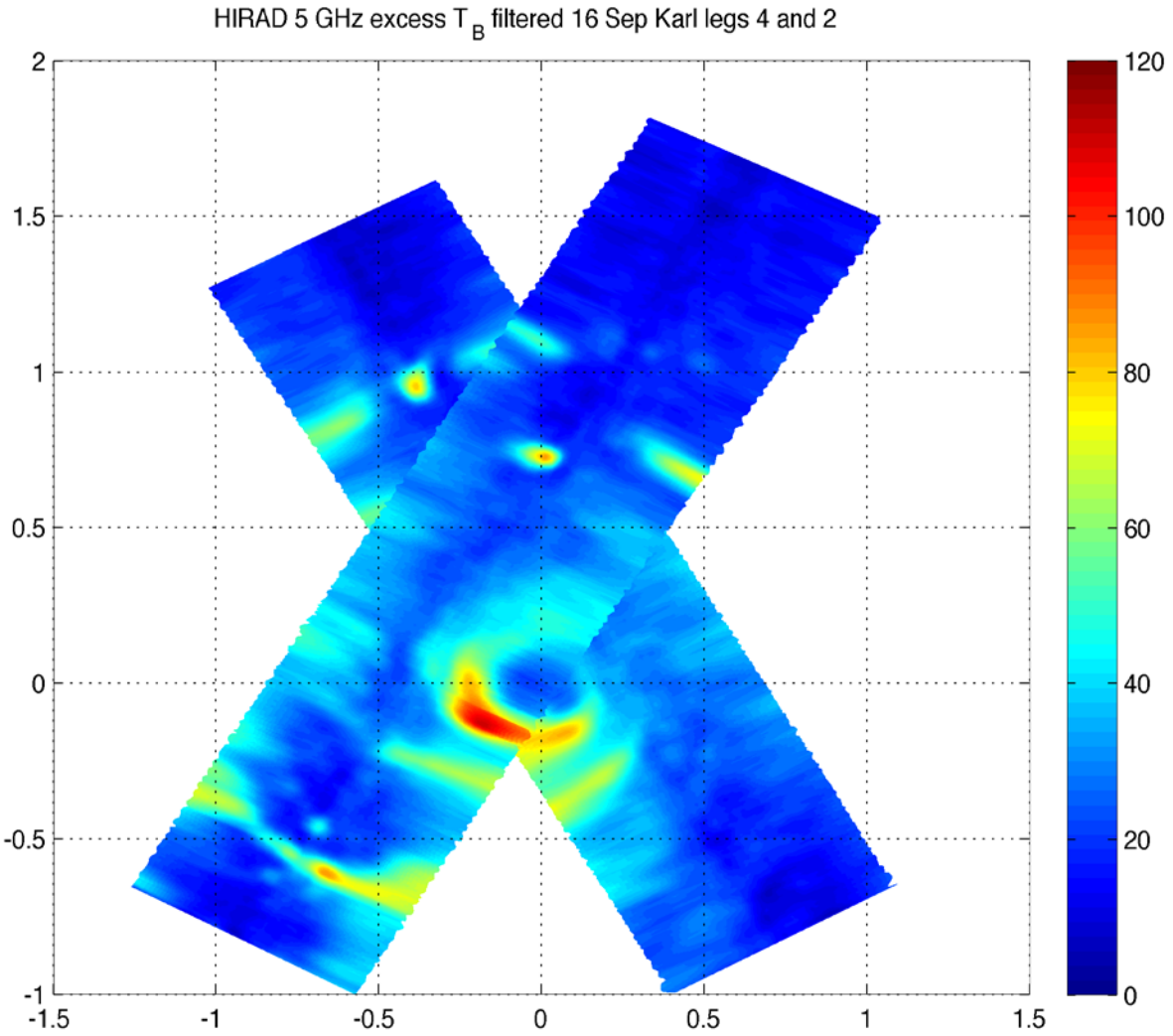
Air Force: C130

HIRAD Measurements in Karl

- HIRAD measures surface wind & rain
  - –similar to SFMR, but with cross-track scanning

- HIRAD captures the key structures of the eyewall and rainbands

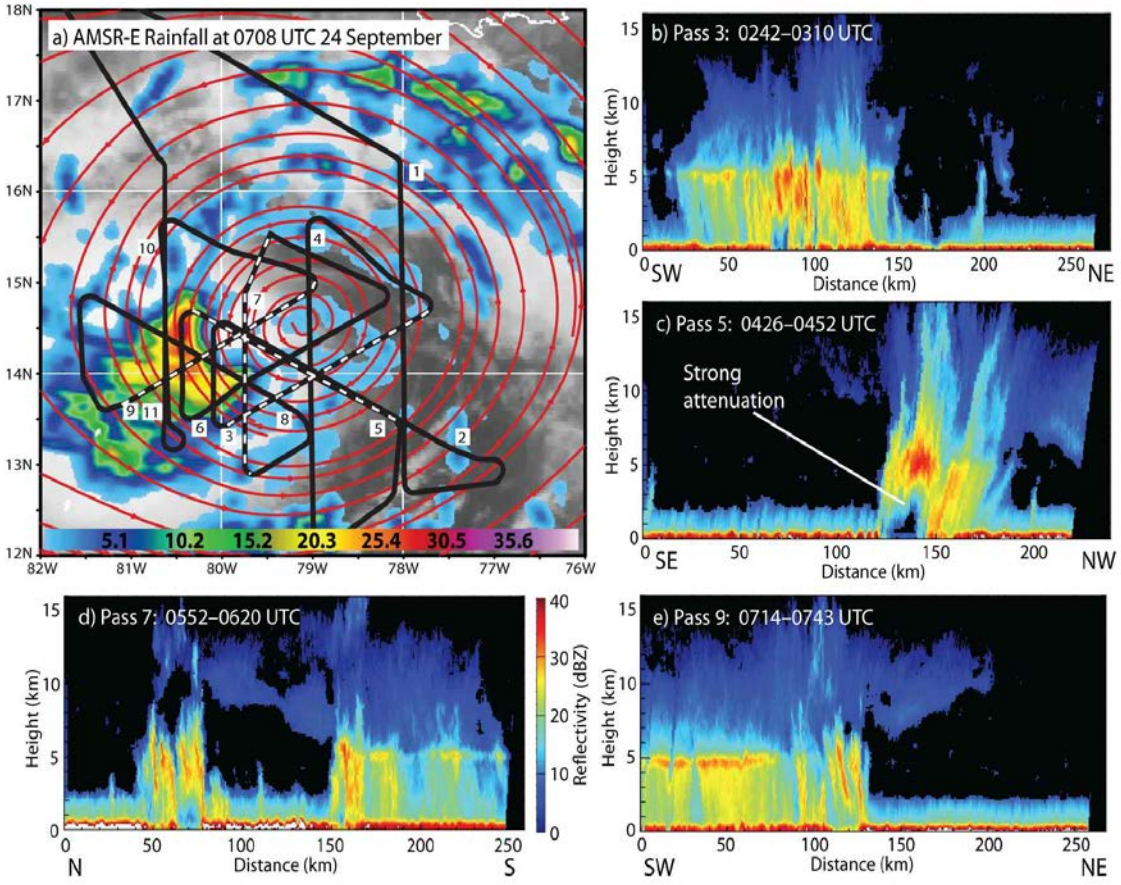
- Will fly on the GH during the Hurricane and Severe Storm Sentinel (HS3) EV-1 project



Radar Structure in TS Matthew

- NCEP storm-relative 700 hPa streamlines, AMSR-E rainfall show strong asymmetry of precipi-tation on SW side

- HIWRAP cross sections of radar reflectivity



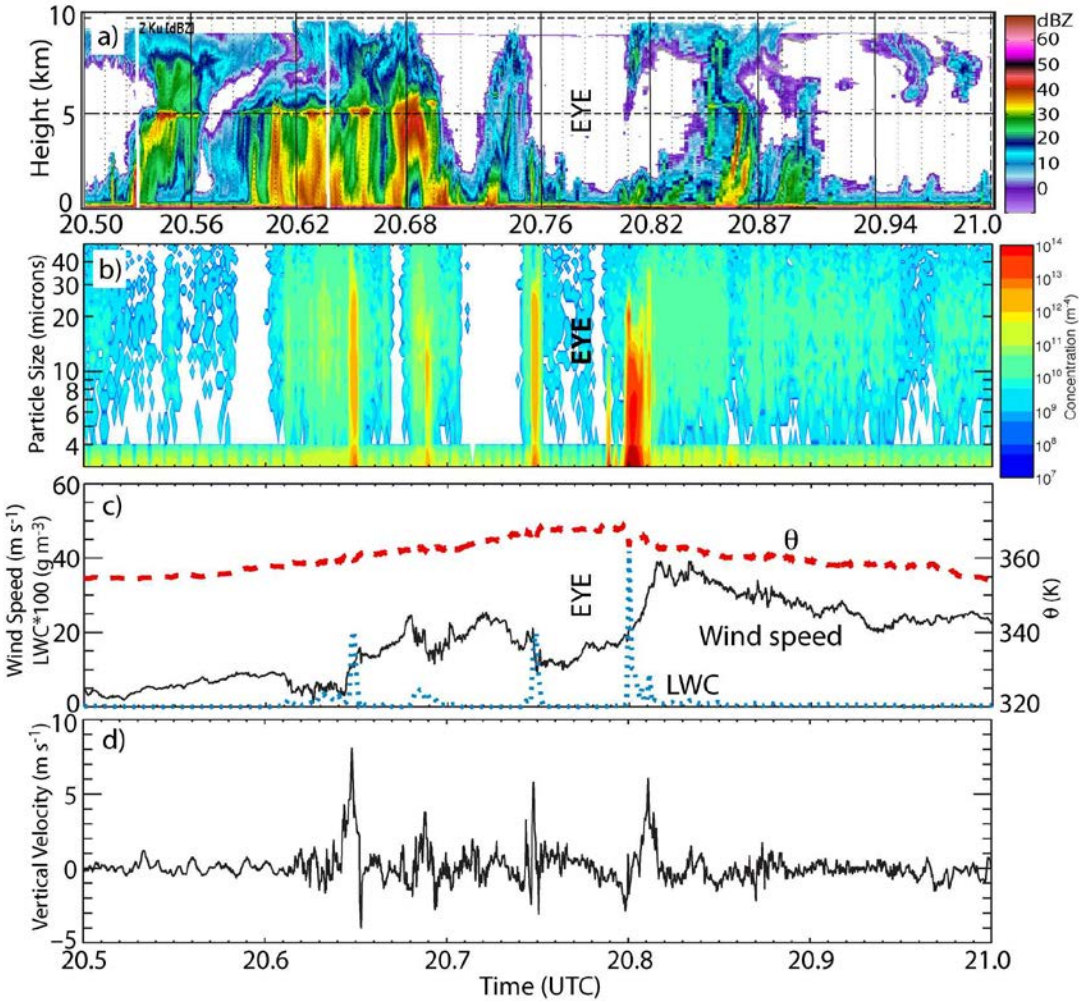
Microphysical Impacts of Dust on Sept 2?

- Microphysical impact of dust should be seen in CDP data as high concentration of small (3-10 microns) drops

- 3 of 4 passes on 9/1 and 4 of 5 on 9/2 **do** show enhanced concentrations of small drops

- Shown here is one of the passes with enhanced drops during an west-to-east (left-to-right in figure) pass

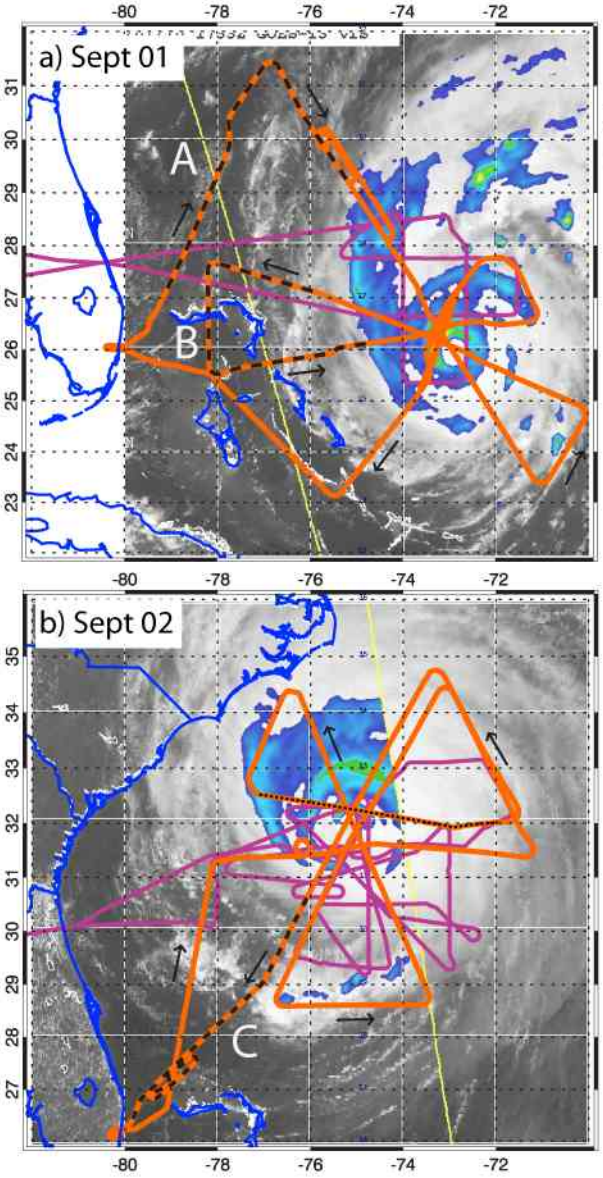
- Eastern eyewall echo only at upper levels, and has very large concentration of small drops, 5 m/s vertical velocity

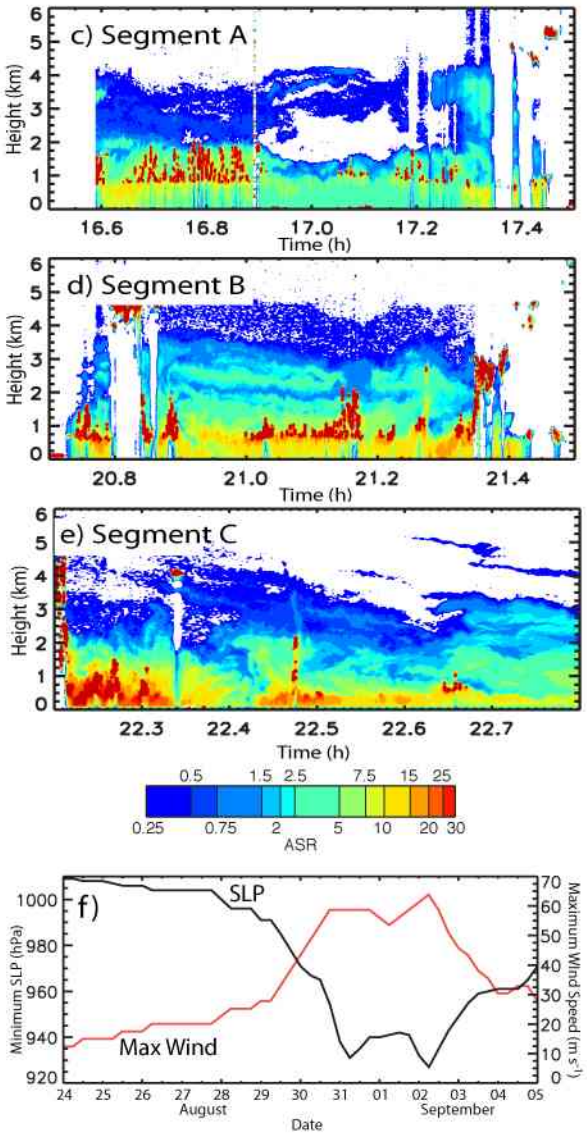


Red dashed line: θ-320K
Blue dotted line: LWC*100

Earl Flights—September 1 & 2

- Earl underwent eyewall replacement cycle on Aug 31 and weakened
- Earl reintensified Sept 1, then weakened Sept 2 due to increasing westerly shear
- LASE cross sections show plentiful dust on western side of storm on both Sept 1 and 2

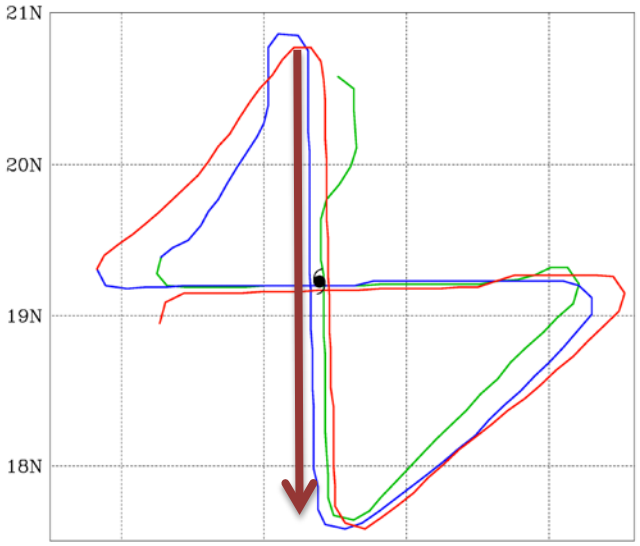


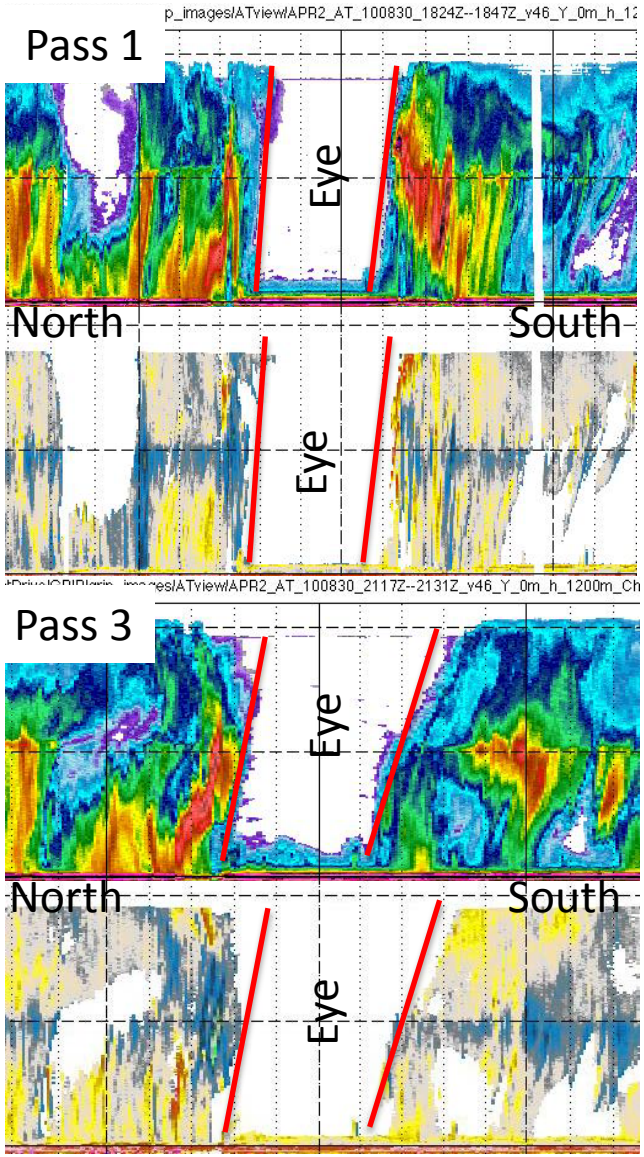


Tilt of the Hurricane Eyewall

(courtesy JPL's APR-2 team)

Modest vertical wind shear (NNW @ 6 m s^{-1}) produces southward tilt of Cat 4 hurricane



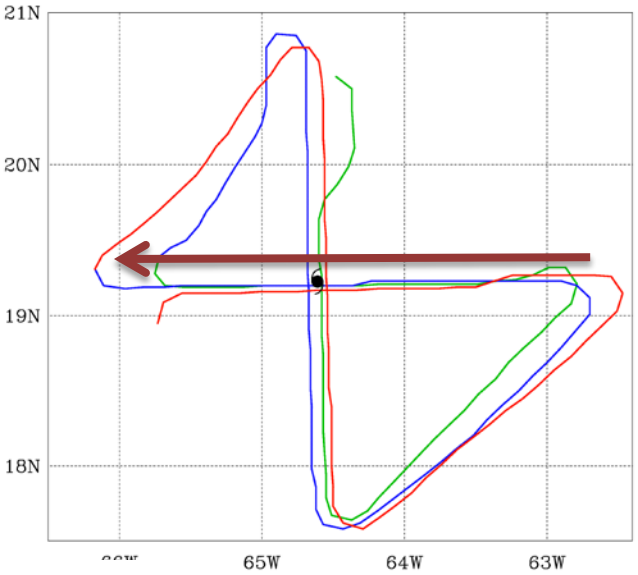


Radar reflectivity (dBZ)

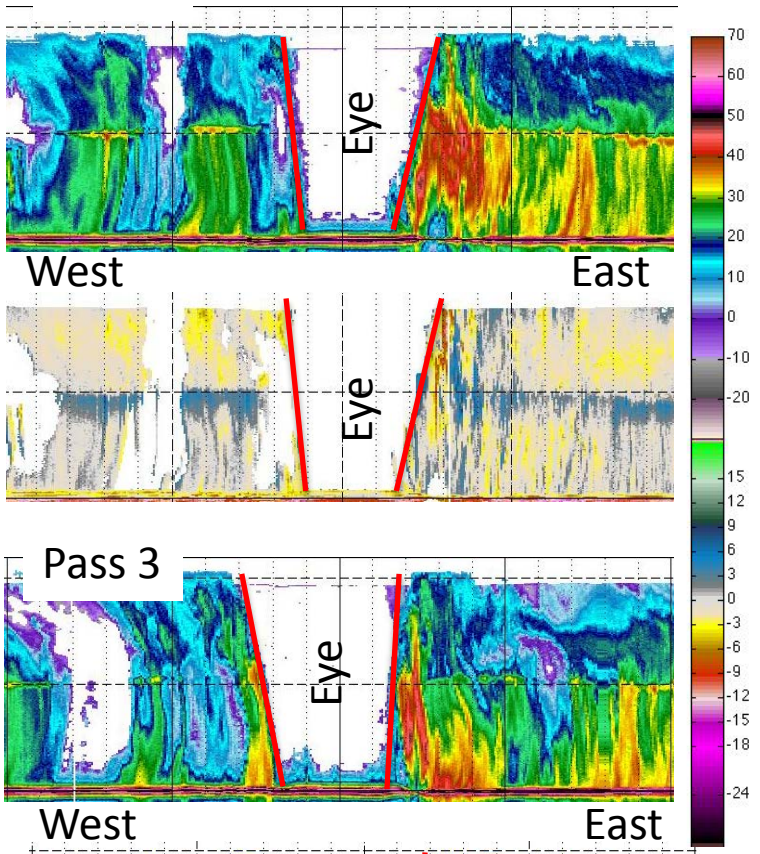
Estimated vertical velocity (m s^{-1})

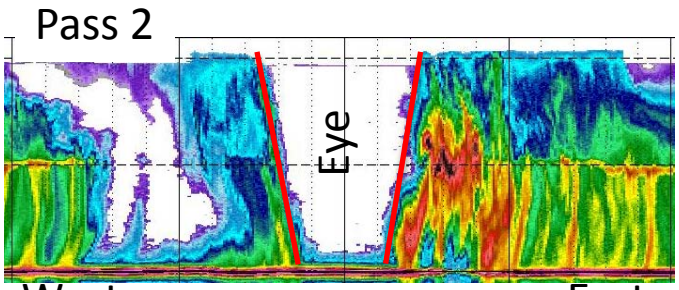
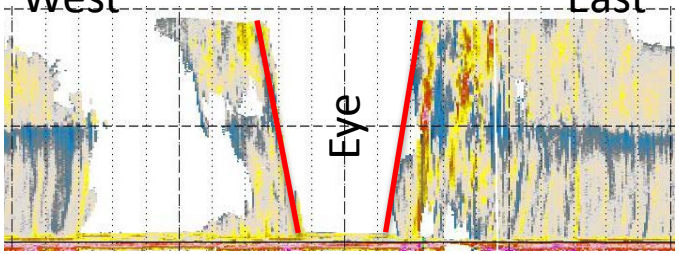
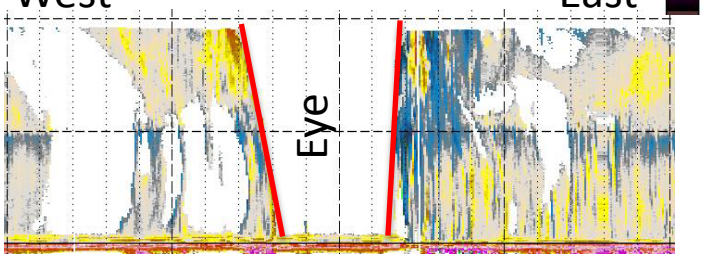
Tilt of the Hurricane Eyewall

Shear (NNW @ 6 m s^{-1}) produces little tilt in E-W direction



Radar reflectivity (dBZ)





Estimated vertical velocity (m s^{-1})