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From Science to Solutions

HIRAD

12A.1 Observations of C-band brightness temperatures from the Hurricane Imaging Radiometer (HIRAD) during GRIP

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(with special acknowlegment to Robbie Hood, NOAA UAV Office

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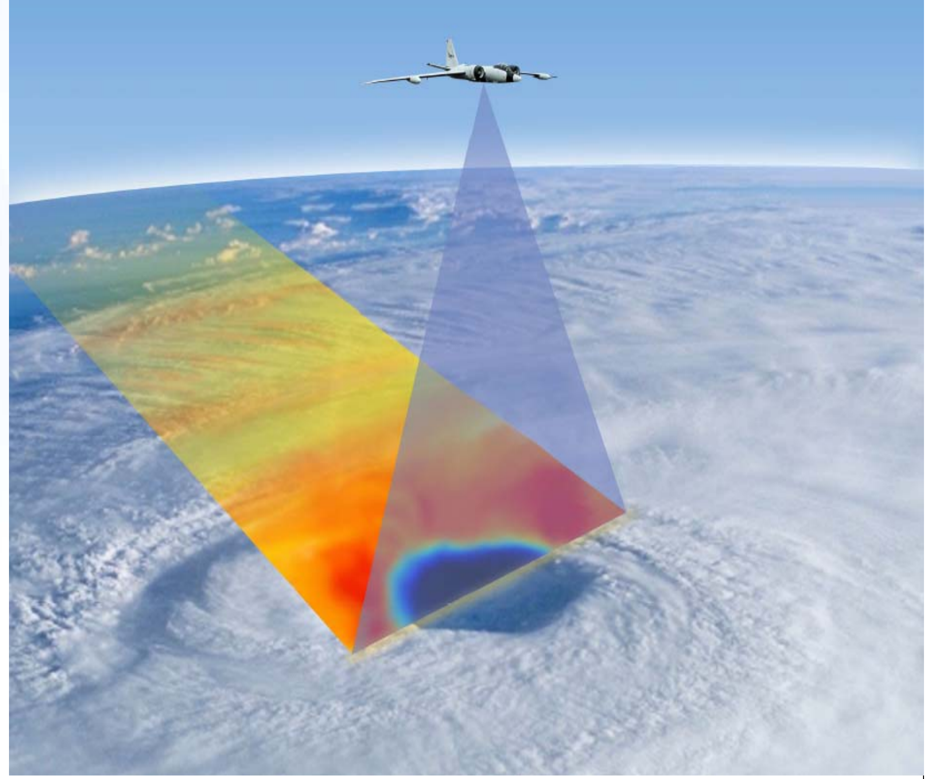
Hurricane Imaging Radiometer (HIRAD)

- Passive microwave radiometer (C-band, 4 frequencies), similar to SFMR: Measures emissivity and retrieves hurricane surface wind speeds and rain rates over a wide-swath:
  - Swath Width ~ 80 km
  - Resolution ~ 1- 5 km
  - Wind speed ~10 – 85 m/s
  - Rain rate ~ 5 – 100 mm/hr
- Key Feature: Near-instantaneous mapping of entire inner-core hurricane surface wind field and rain structure.
- Operational advantages: Surface wind and rain swath will complement SFMR and airborne Doppler radar mapping of inner-core structure for improved short-term advisories and numerical model simulations.

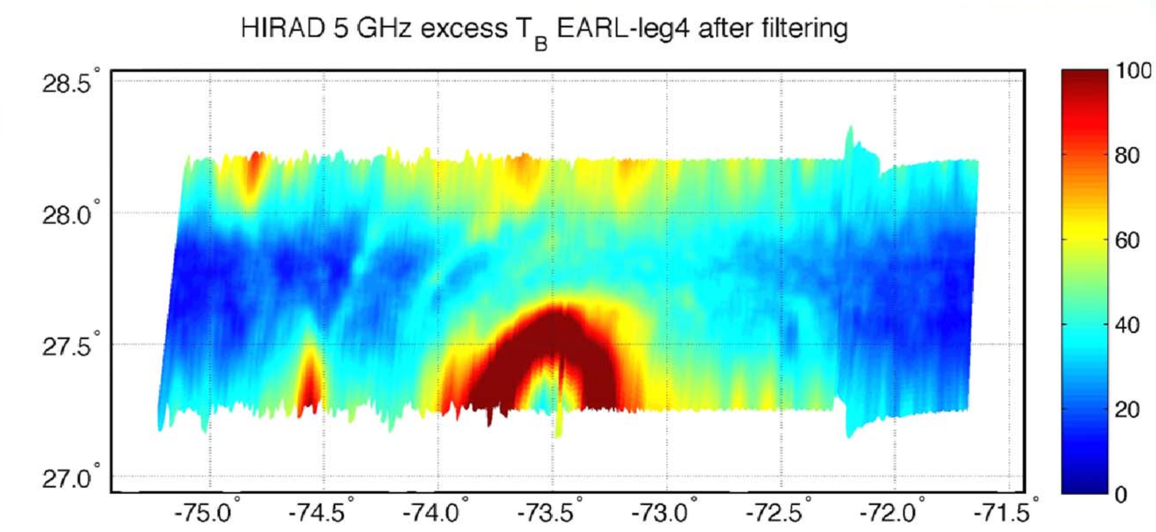
NASA GRIP (2010) RB-57F HIRAD Swath Geometry

- **Similar to NASA HS3 Global Hawk configuration for 2012-2014**



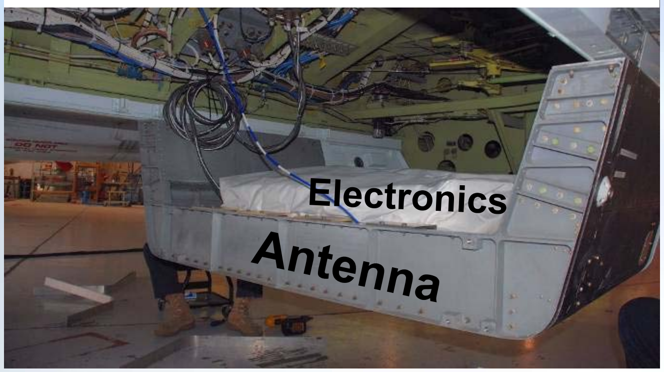
HIRAD's Heritage

- Currently, NOAA/AOC and the 53rd WRS use the SFMR instrument on their WP-3D and WC-130J hurricane reconnaissance aircraft to measure ocean surface wind speed. HIRAD uses the same physical principles as SFMR.
- Both of these instruments use multiple C-band frequencies to retrieve surface wind speed and rain rate simultaneously.
- HIRAD's new contribution is that it obtains a swath of measurements, as shown below, rather than a single line under the aircraft.

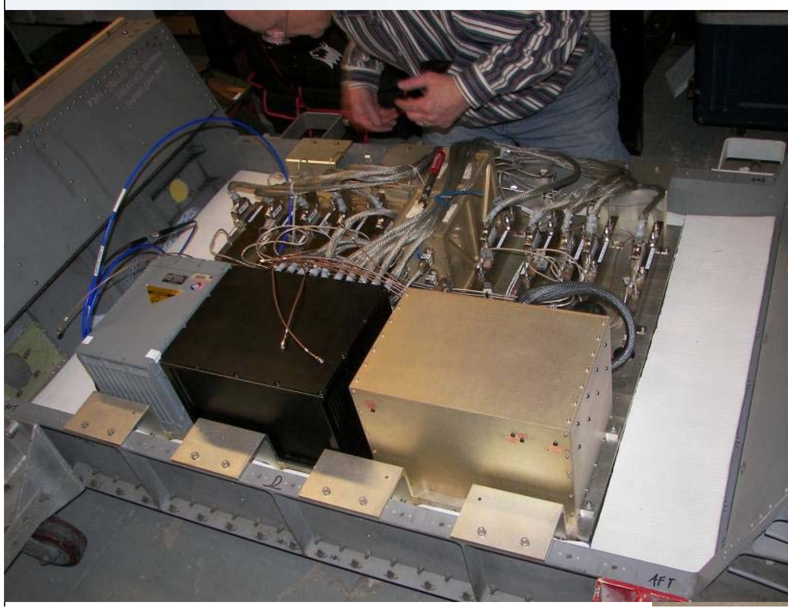


HIRAD integration on WB-57

HIRAD installation pallet



Antenna Radome



Receivers and Supporting Electronics

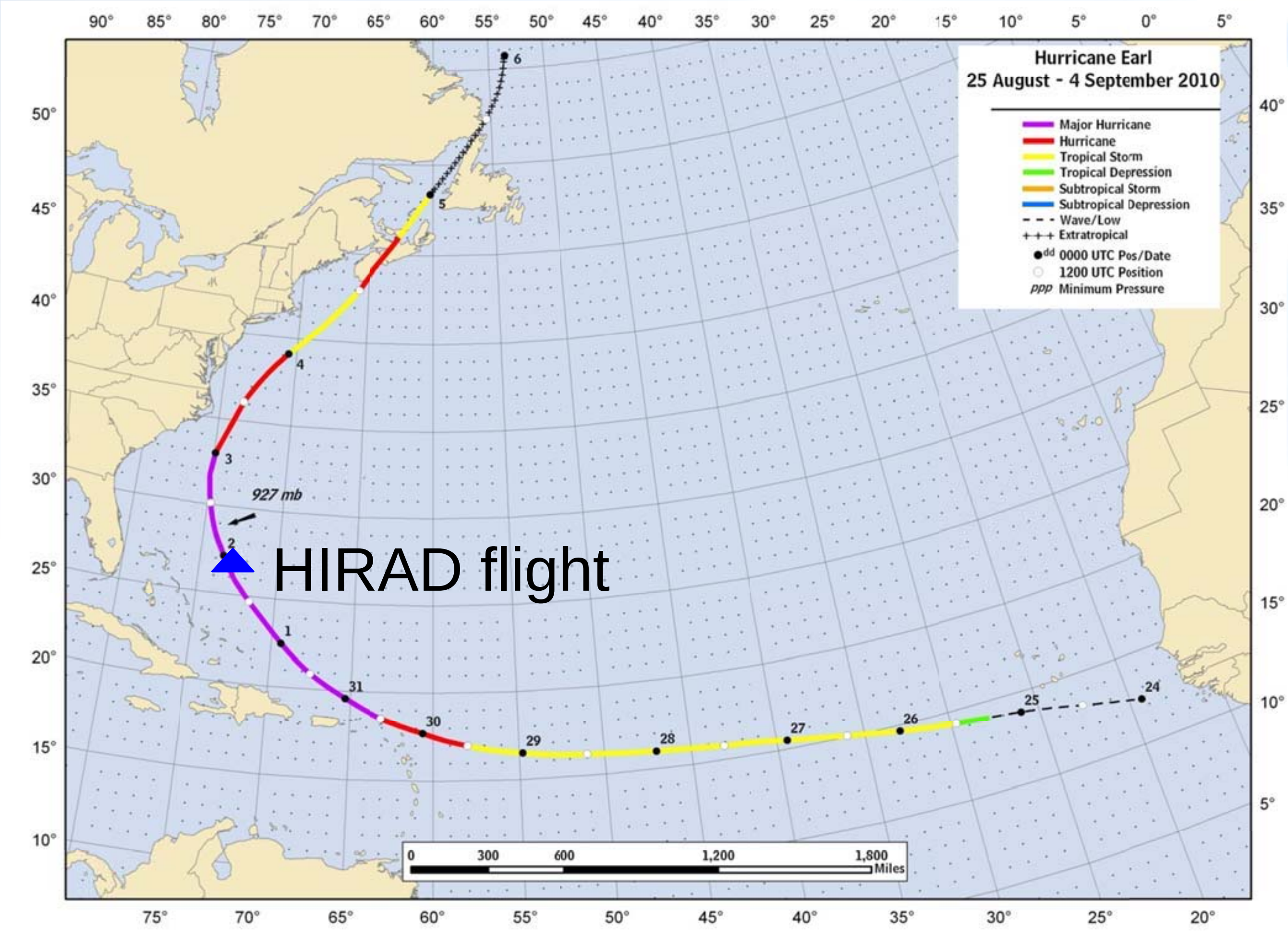
WB-57 pilots; Science & ground support crew

First HIRAD flights: GRIP

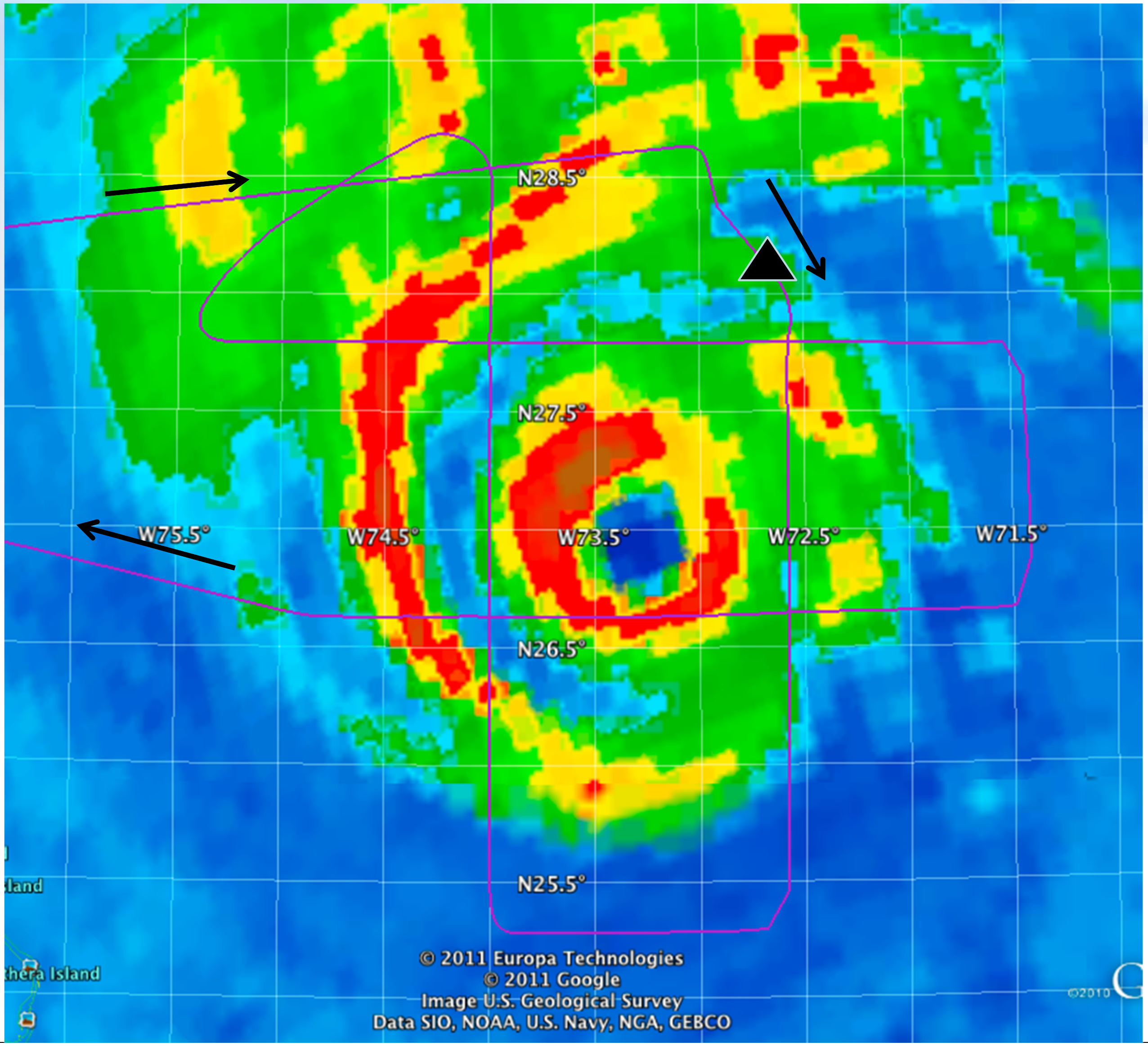
NASA Aircraft:

- Global Hawk – Unmanned Aerial System based at Dryden Flight Facility, California
  - Instruments: Lightning Instrument Package (LIP), High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP), and High Altitude MMIC Sounding Radiometer (HAMSR)
- DC-8 – Based in Fort Lauderdale
  - Dropsondes, LASE, DAWN, APR-2, MMS, CAPS, CSI, PIP
- WB-57 – Based in Houston, Tampa
  - Hurricane Imaging Radiometer (HIRAD)

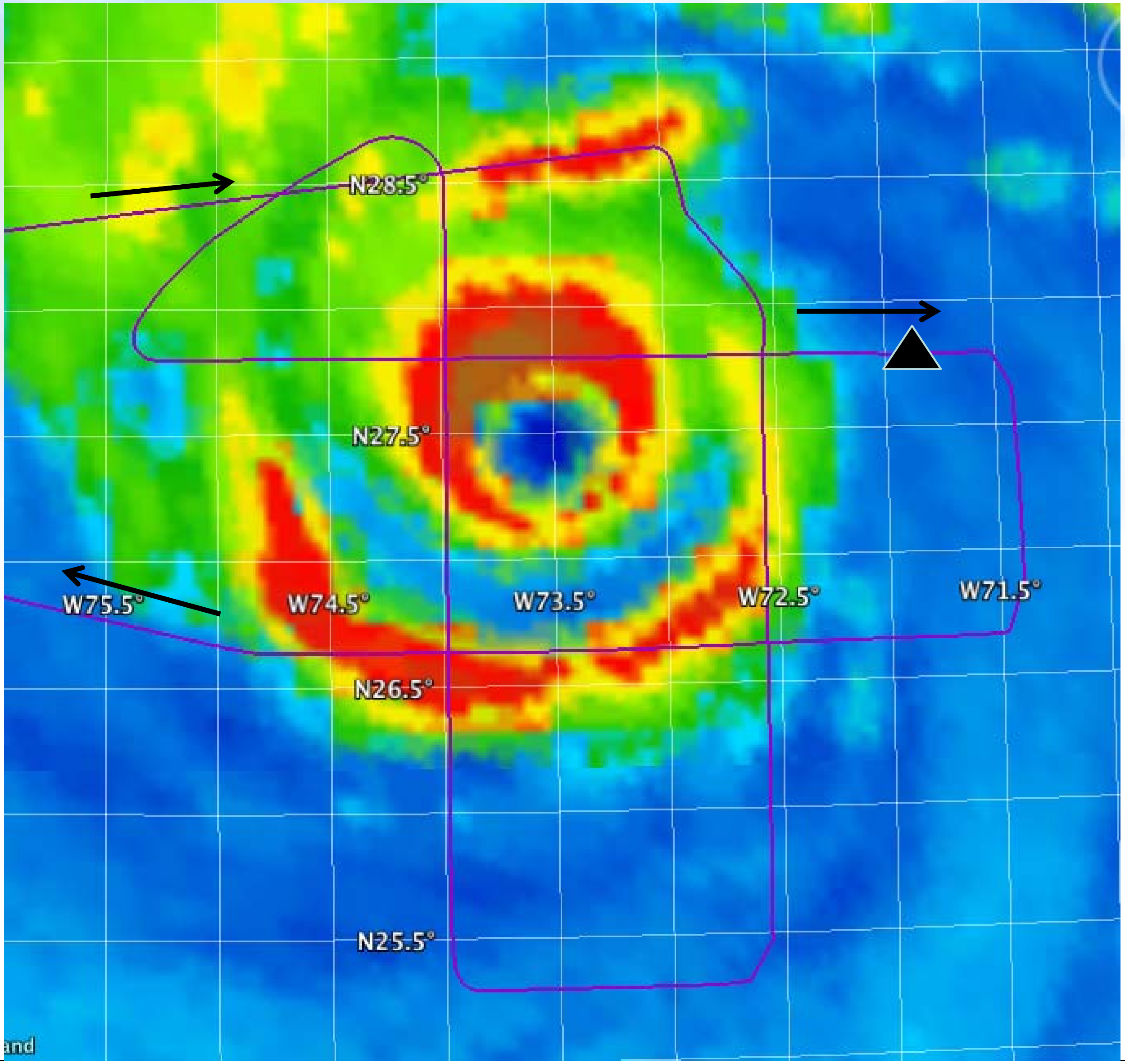
Hurricane Earl



Earl, 2320 UTC, in 85GHz (SSMIS F16)
Triangle indicates WB-57/HIRAD position

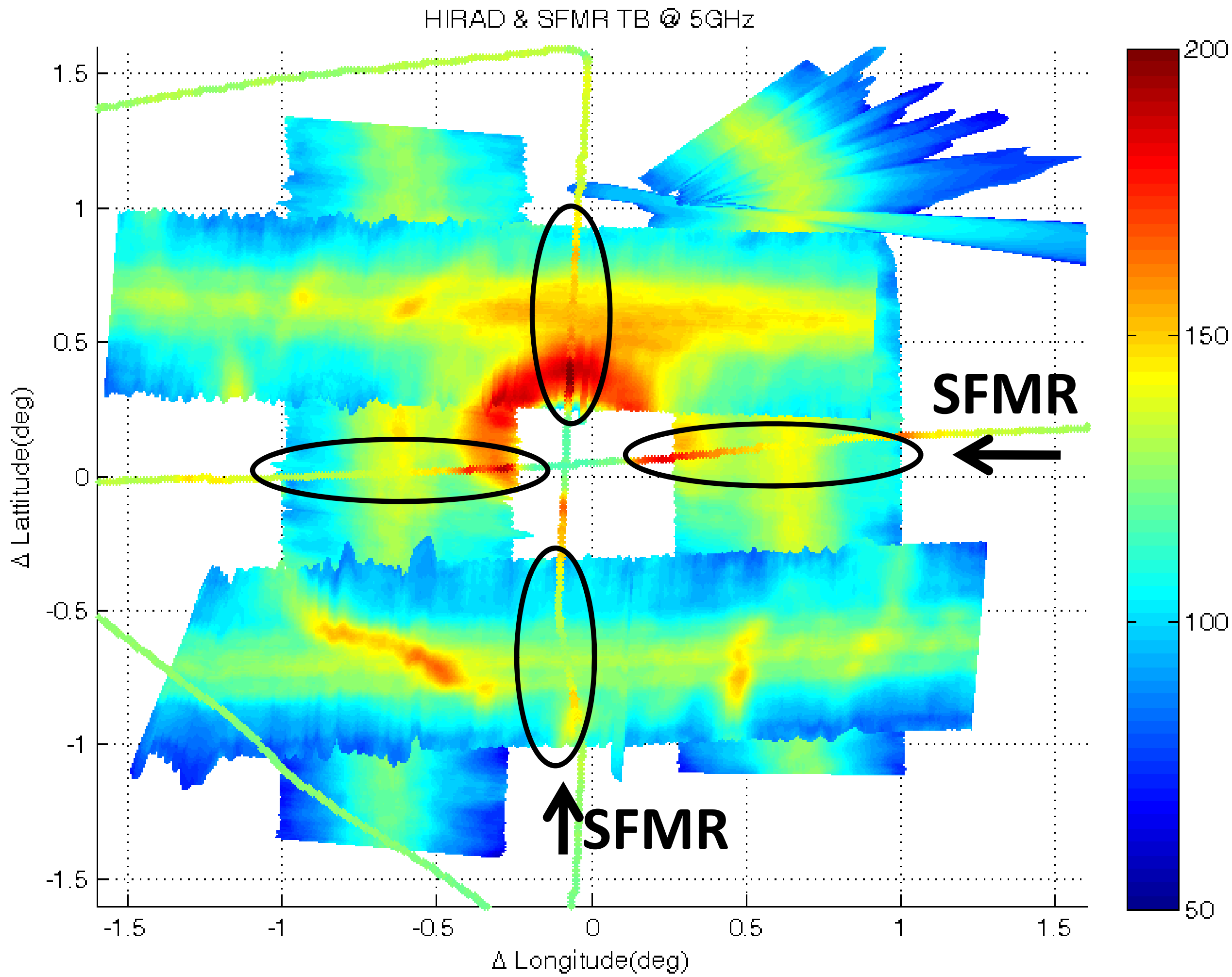


Earl, 0059 UTC, in 85GHz (SSMIS F18)
Triangle indicates WB-57/HIRAD position



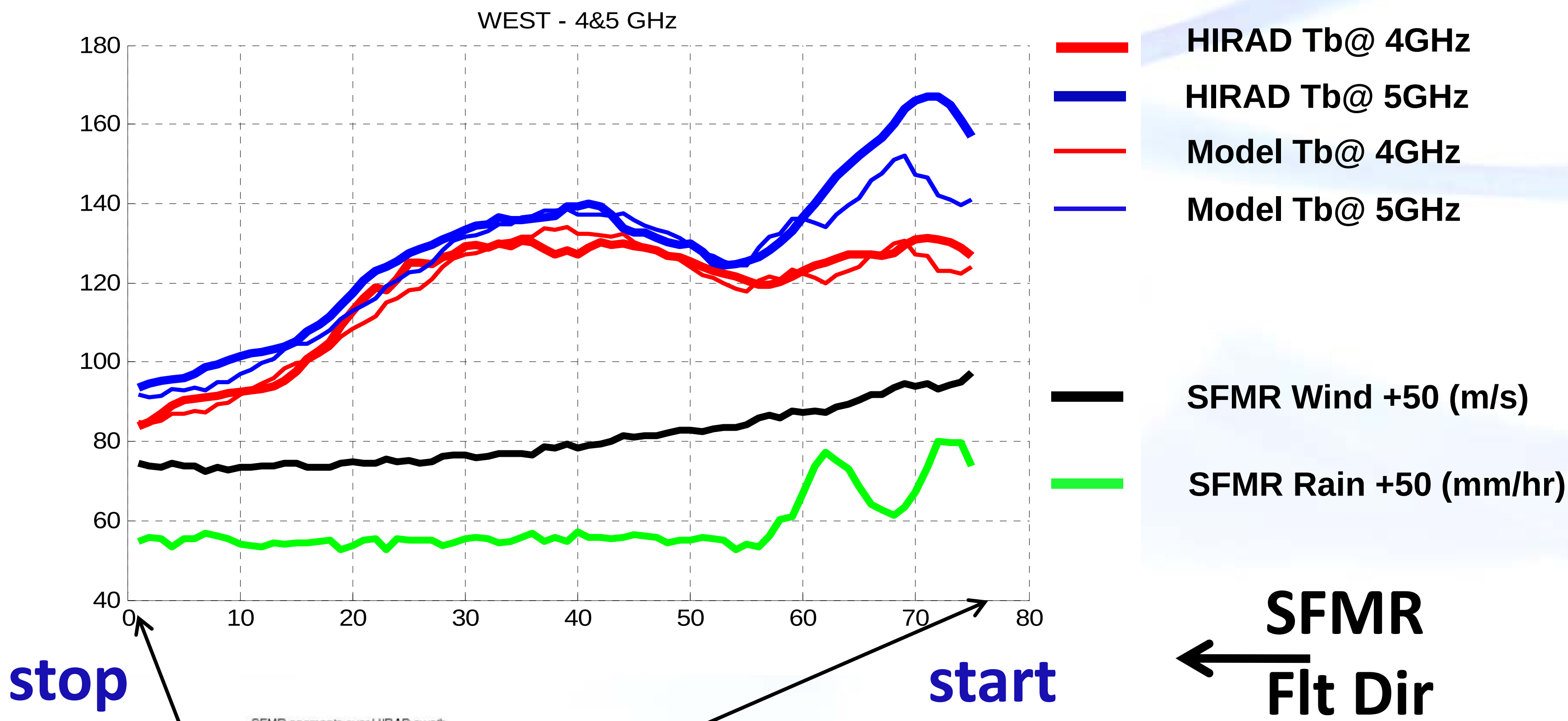
SFMR passes over HIRAD swath

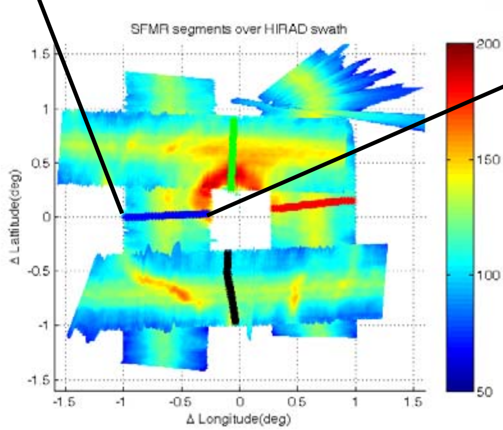
Storm-centric coordinate system



HIRAD and SFMR should match at HIRAD's nadir point

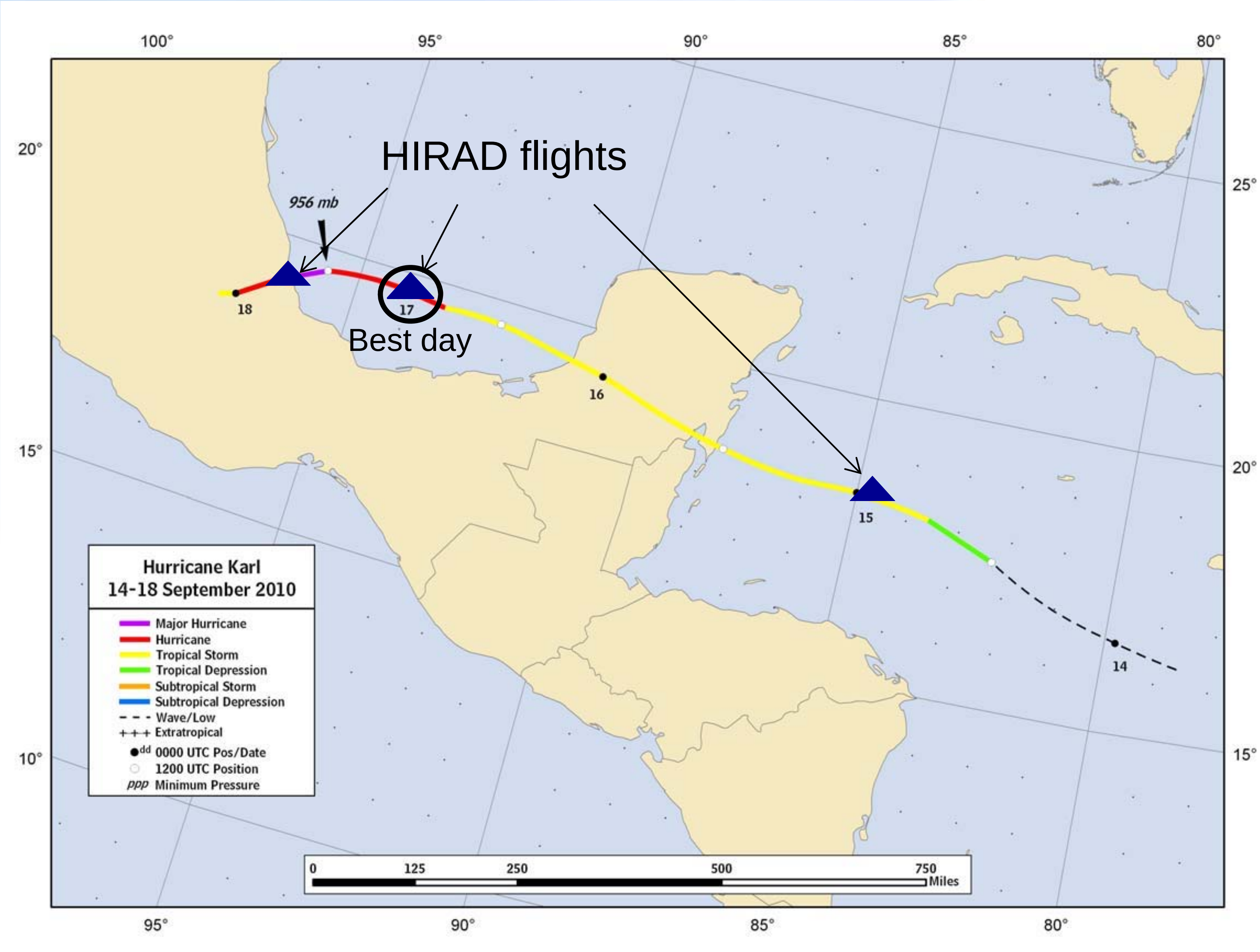
HIRAD/SFMR West Leg Overpass



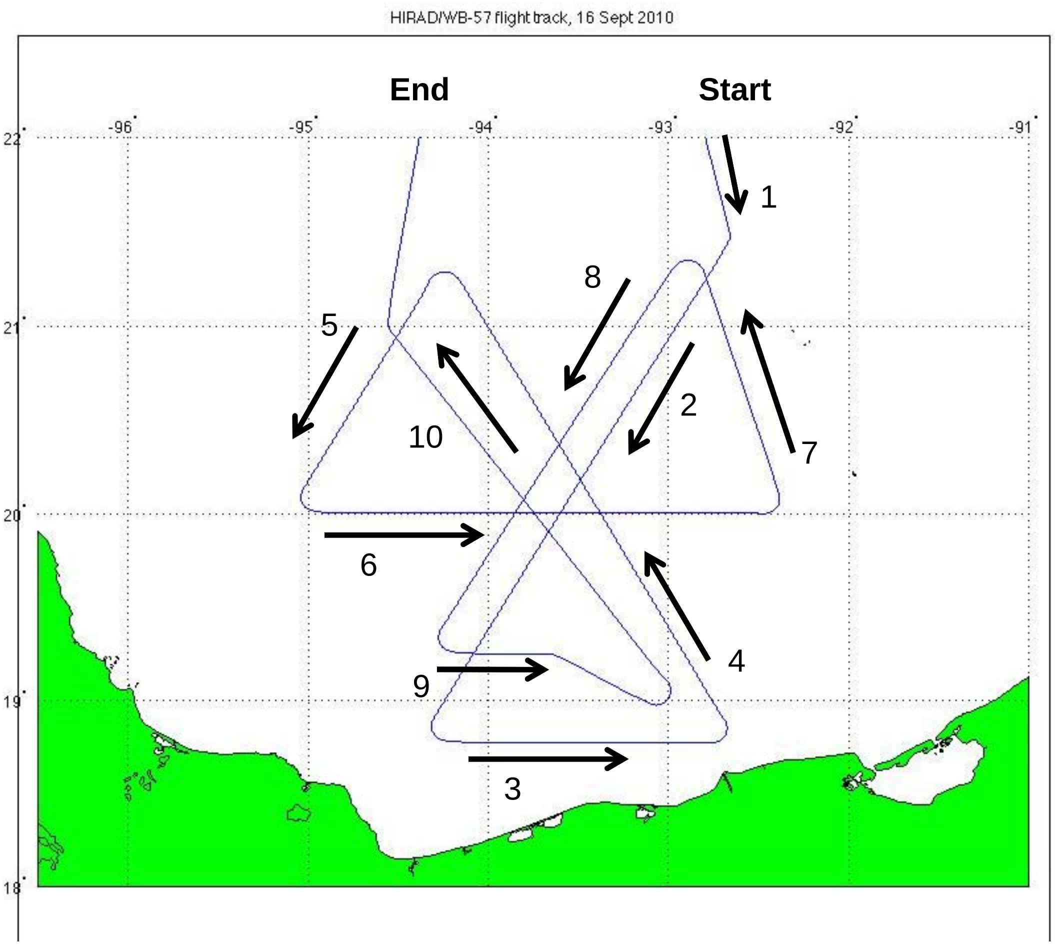


“Model” data are Tb’s computed from SFMR wind & rain fields

Karl Best Track



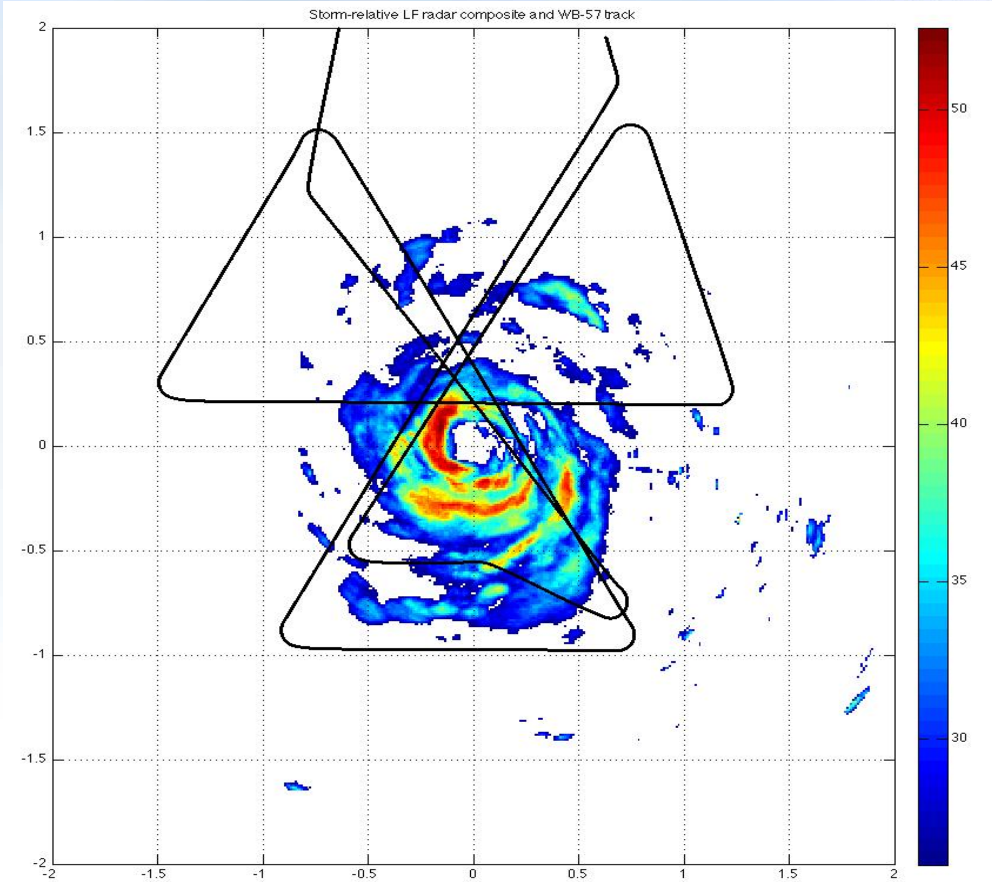
HIRAD / WB-57 flight track and legs definitions, Karl Sept 16



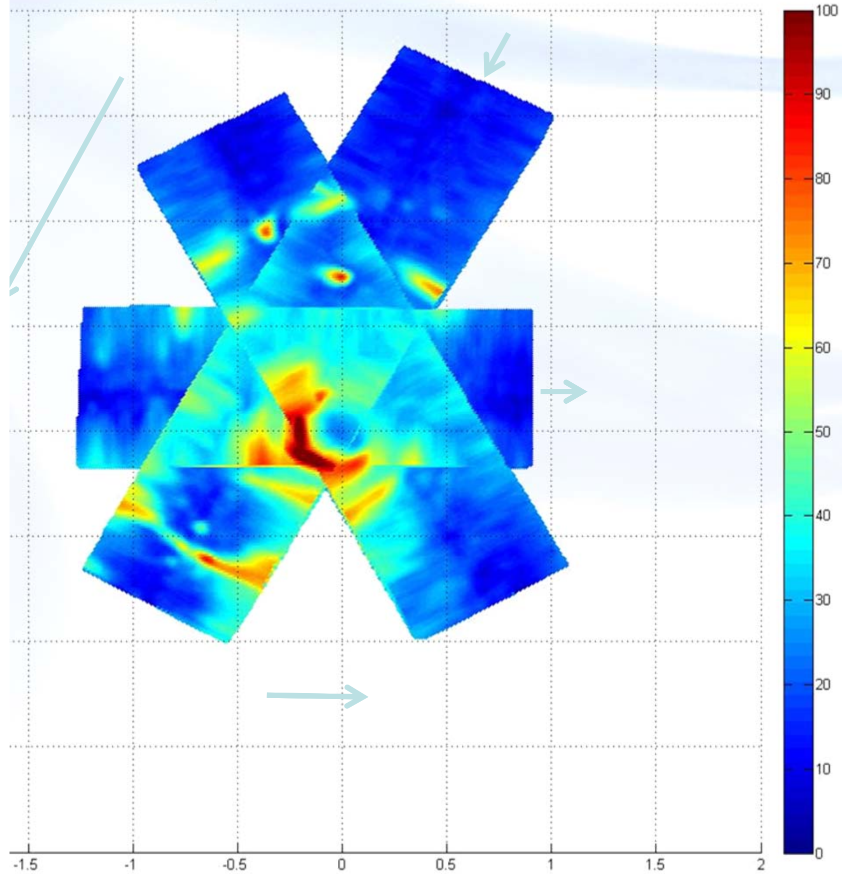
Relative location of WB-57 overpass in Karl to P3 radar composite

- The storm-relative WB-57 flight track is shown over an image of radar reflectivity from the NOAA P-3.
- The storm center as determined from HIRAD data is used as the origin of the P3 radar and HIRAD brightness temp composite
- In following slides, we show that the P3 LF radar reflectivity composite and HIRAD excess brightness temperature (T_B) composite produced by Karl's precipitation pattern, agree very well.
- Storm center locations derived from radar and HIRAD also show good agreement.

P3 radar reflectivity (left)
HIRAD excess Tb 5 GHz (right)



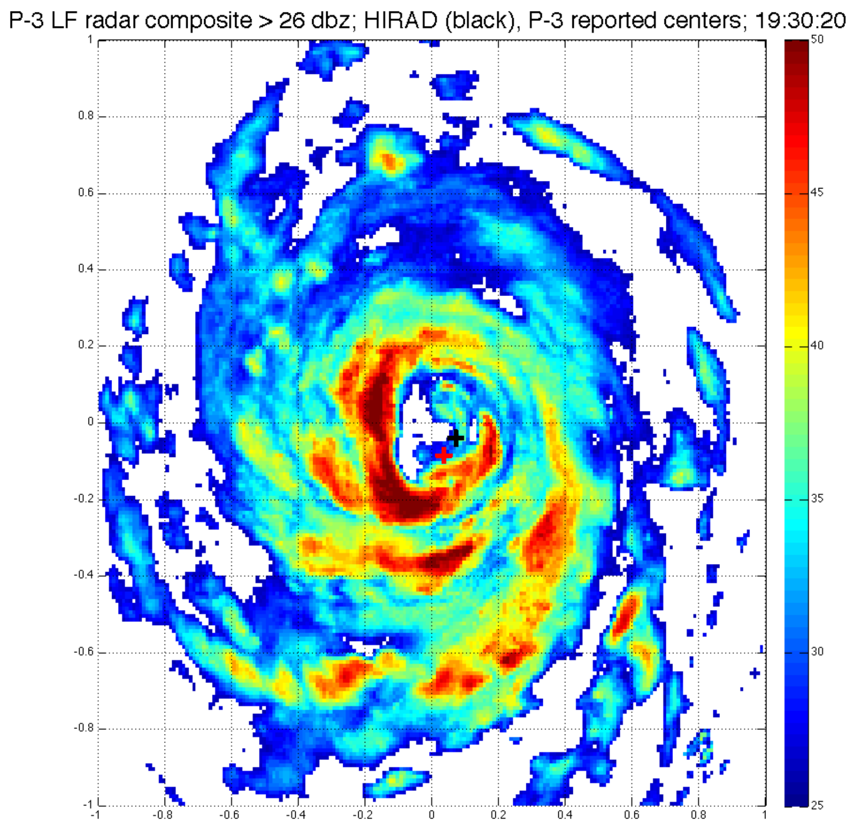
HIRAD 5 GHz excess T_B filtered 16 Sep Karl legs 2, 4 and 6, 65 deg

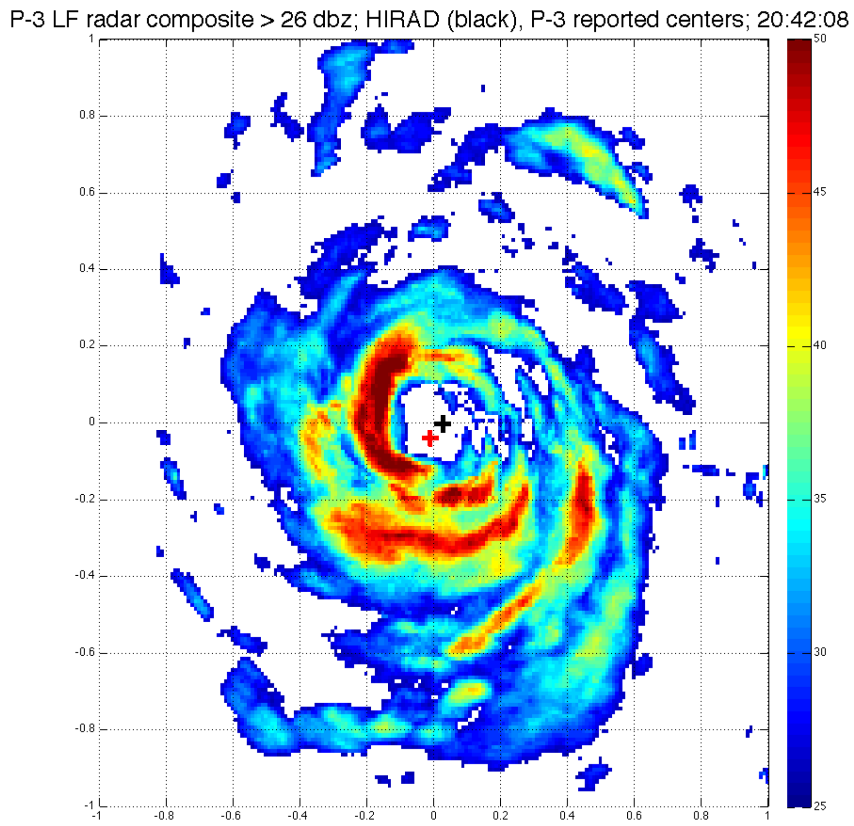


P3 radar center crossings

WB-57 HIRAD center crossings at 19:16:49, 19:52:37, 20:33:44

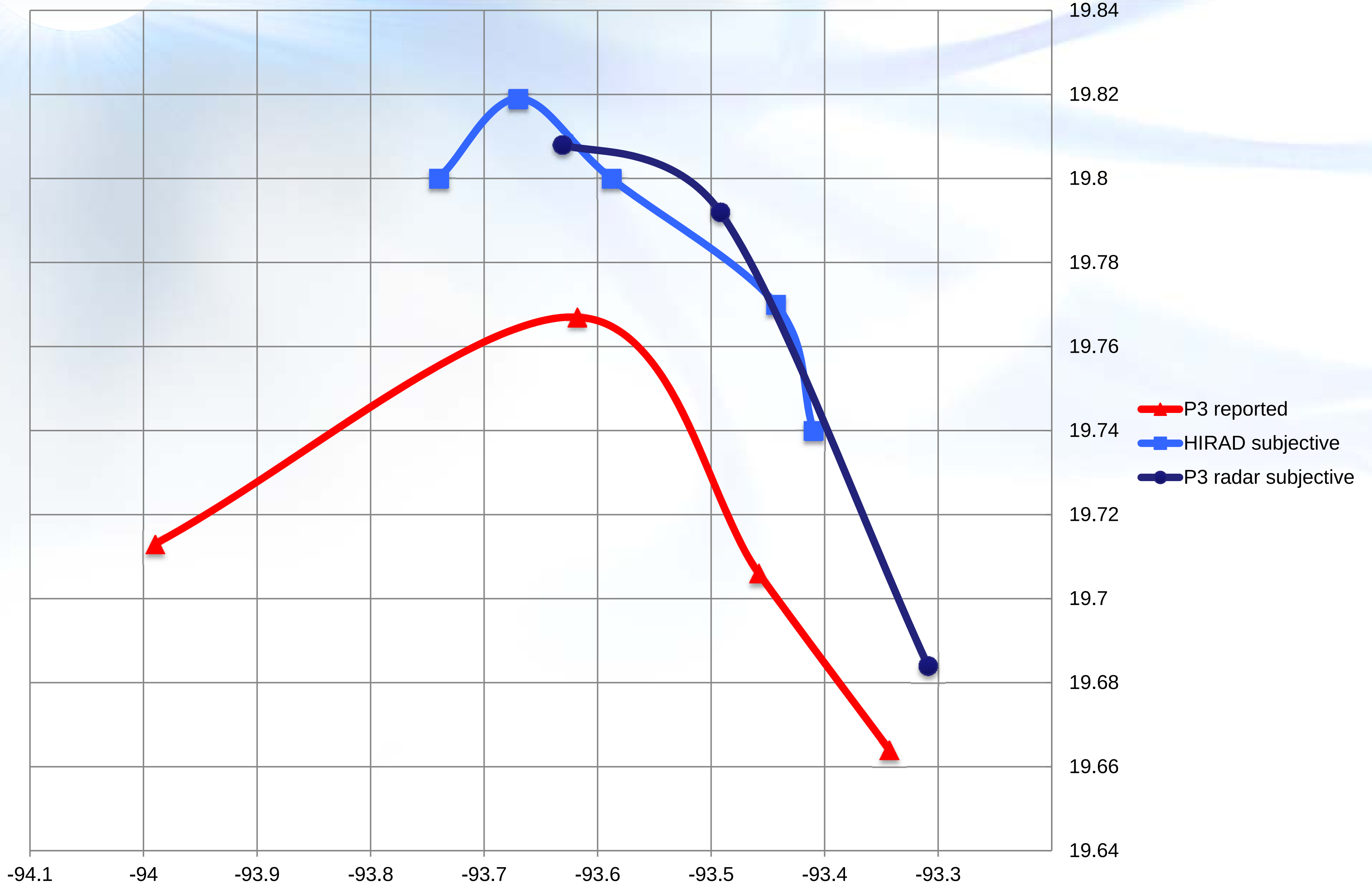
Composite P-3 LF radar reflectivity
Karl 16 Sept 2012





Red "**+**" is P-3 reported center; Black "**+**" is HIRAD center

Karl 16 Sept Center Position



HIRAD Calibration Challenges

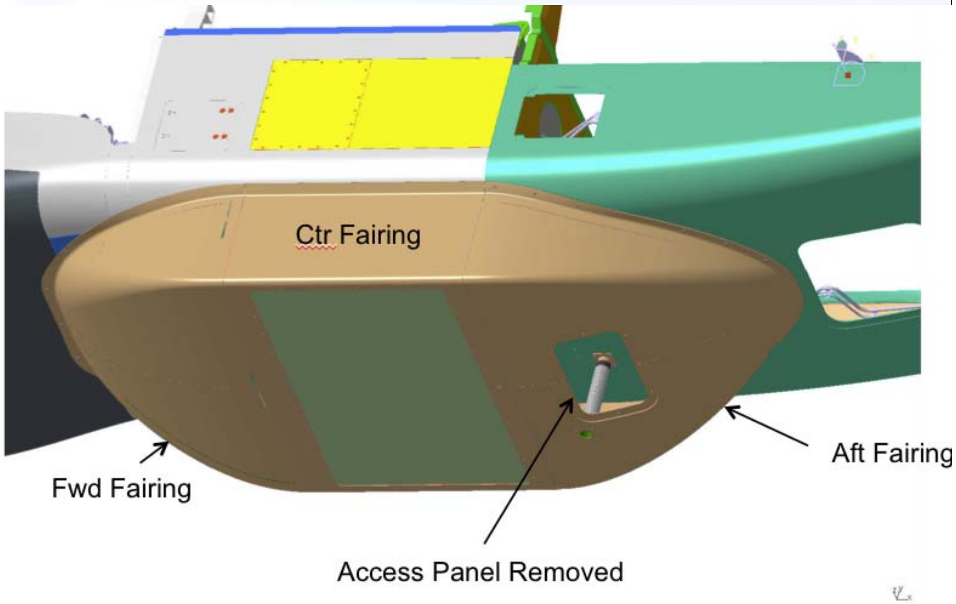
Wind Speed and Rain Rate coming

- Rain rate and wind speed retrievals require at least two calibrated frequencies
  - 5 GHz T_Bs (microwave brightness temps) have been successfully produced
  - Calibration of other 3 channels is work in progress; expect to be completed within 3 months
- HIRAD calibration issues and mitigation for HS3
  - Calibration uses internal reference blackbody targets and noise diodes
  - Dependence of calibration algorithm on reference T_Bs has uncorrected instrument temperature dependence (~25^o C variation during GRIP flights)
  - Temperature correction algorithm being developed for GRIP (requires additional instrument characterization testing)
  - Thermal control subsystem being upgraded for HS3 to greatly reduce instrument temperature fluctuations

NASA Venture-class Mission

HS3: Hurricane and Severe Storm Sentinel

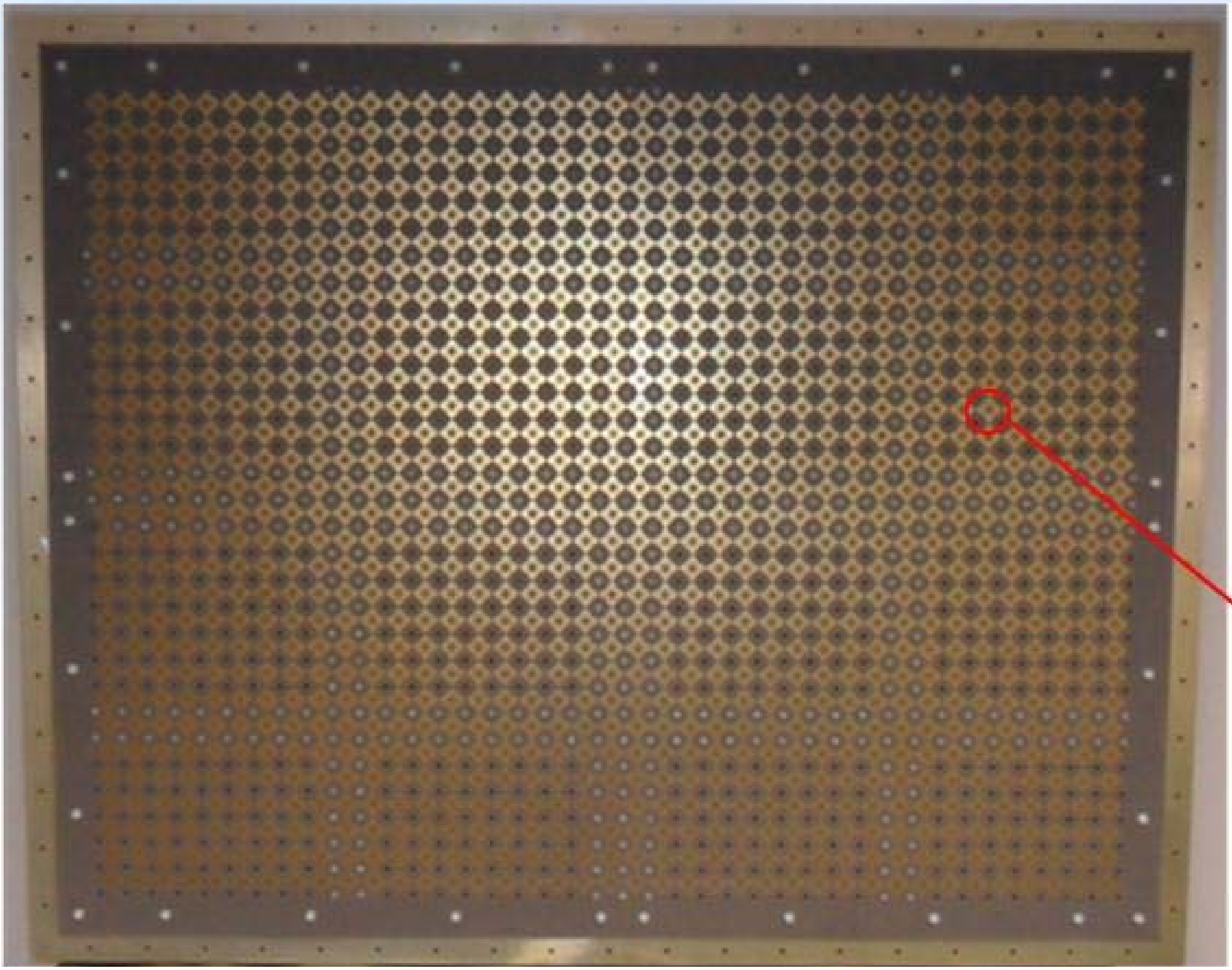
- Principal Investigator: Dr. Scott Braun, NASA/GSFC
- Science goals include better understanding of cyclogenesis, intensity changes
- Two Global Hawks will be used, one concentrating on the storm / disturbance structures, and the other on the larger-scale environment
- Ensemble of instruments include sounders, wind and microphysics lidars, dropsondes, radars, and HIRAD (which will be on the over-storm GH, along with HAMSR and HIWRAP)
- Flights will occur during seasons 2012, 2013, and 2014, concentrating on the North Atlantic basin.



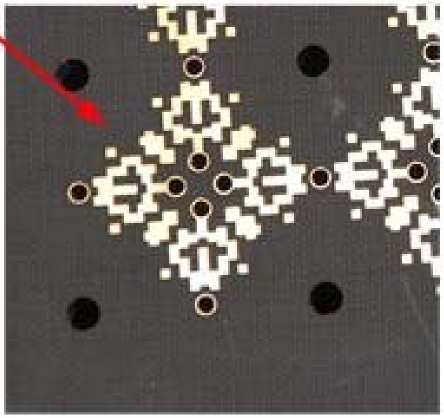
Next-generation HIRAD

- A dual polarized HIRAD system is being designed to add the following capabilities:
  - Wind direction measurement, in addition to speed
  - Improved accuracy in T_B measurement for improved surface wind speed and rain rate observations, especially at large off-nadir angles
- The first step in developing this system has been accomplished:
  - Dual-pol, phased-array antenna, developed via SBIR, has been built
  - Detailed tests are to be conducted during the spring and summer of 2012
- Support for the remainder of system will be proposed in response to FY13 Instrument Incubator Program announcement of opportunity
  - A new system capable of wind speed, direction and rain rate observations over a wide swath will be ready for flight tests in FY15

New dual-pol antenna



View of single dual polarized balanced output antenna element



Summary

- HIRAD is a new technology developed by NASA/MSFC, in partnership with NOAA and the Universities of Central Florida, Michigan, and Alabama-Huntsville
- HIRAD is designed to measure wind speed and rain rate over a wide swath in heavy-rain, strong-wind conditions
- HIRAD is expected to eventually fly routinely on unmanned aerial vehicles (UAVs) such as Global Hawk over hurricanes threatening the U.S. coast and other Atlantic basin areas, and possibly in the Western Pacific as well
- HIRAD first flew on GRIP in 2010 and is planned to fly 2012-14 on the NASA Hurricane and Severe Storm Sentinel (HS3) missions on the Global Hawk, a high-altitude UAV (described in a separate presentation by Scott Braun)
- HIRAD technology will eventually be used on a satellite platform to extend the dynamical range of Ocean Surface Wind (OSV) observations from space

Principles of Operation

Addendum

- HIRAD measures 'emissivity' over a range of incidence angles, emitted from ocean surface foam coverage (a function of wind speed) and intervening rain.
- At C-band microwave frequencies (4-8 GHz), wind-driven foam coverage is invariant with frequency while at the same time rainfall emissivity is a strong function of frequency.
- These physical characteristics allow two geophysical variables (wind speed and rain rate) to be derived from emissivity measurements at 4-6 discrete C-band frequencies, which is an 'over-determined', 'least-squares' problem solvable with conventional mathematical techniques.
- Surface wind speed and rain rate retrievals are derived from empirical correlation of HIRAD measured emissivity at operating incidence angles with co-located GPS dropsonde surface wind observations and accepted functional relations for rain attenuation vs frequency.