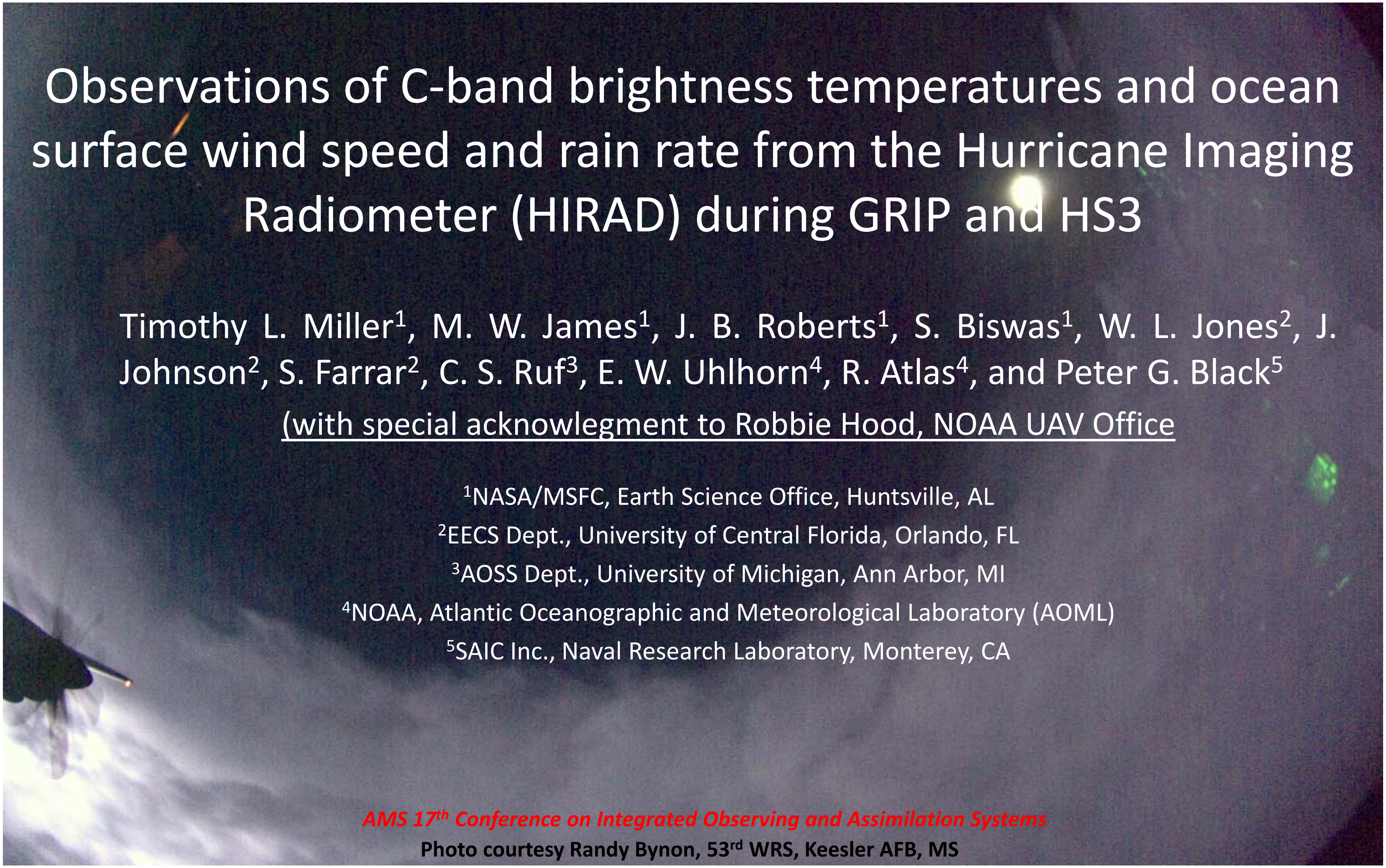

Observations of C-band brightness temperatures and ocean surface wind speed and rain rate from the Hurricane Imaging Radiometer (HIRAD) during GRIP and HS3

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(with special acknowlegment to Robbie Hood, NOAA UAV Office

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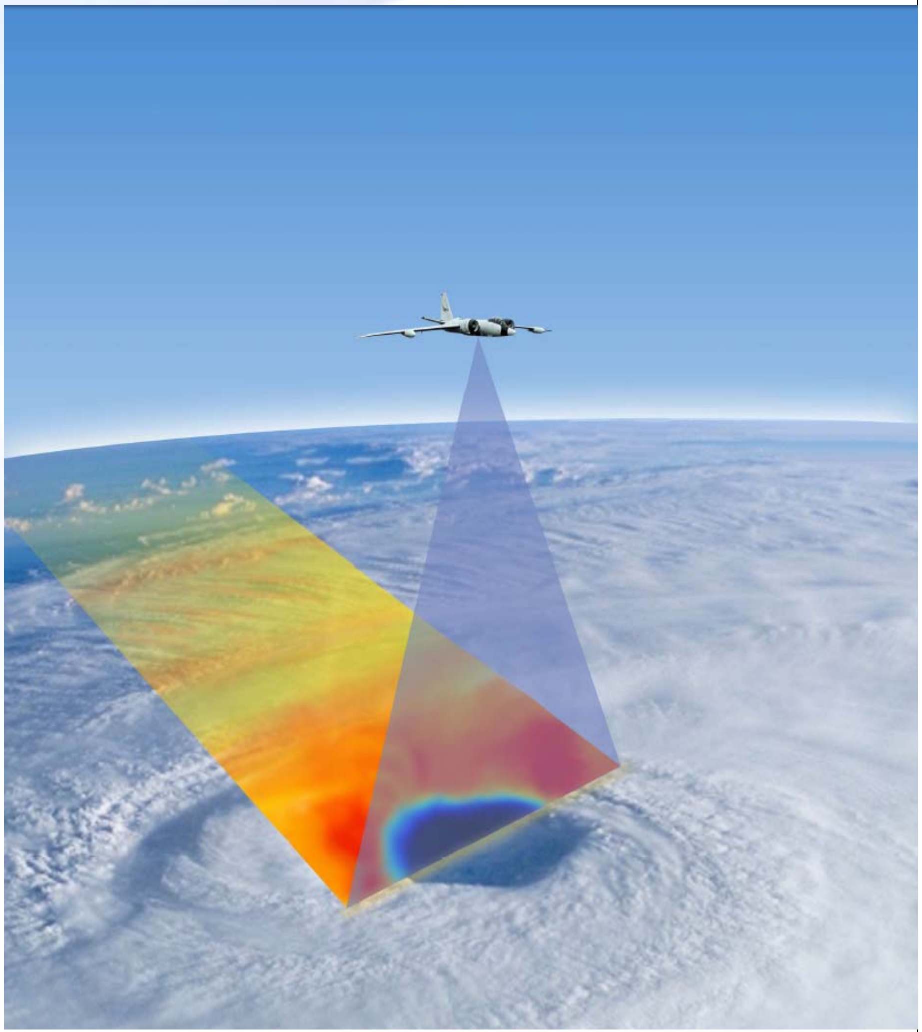
AMS 17th Conference on Integrated Observing and Assimilation Systems

Photo courtesy Randy Bynon, 53rd WRS, Keesler AFB, MS

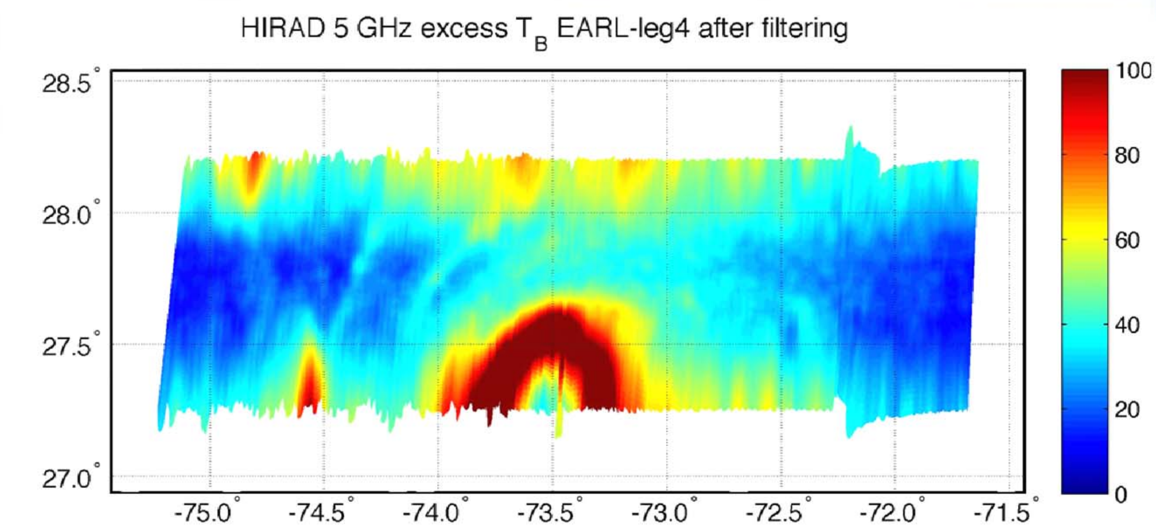
Hurricane Imaging Radiometer (HIRAD)

- A 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 ~ 60-80 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.



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.



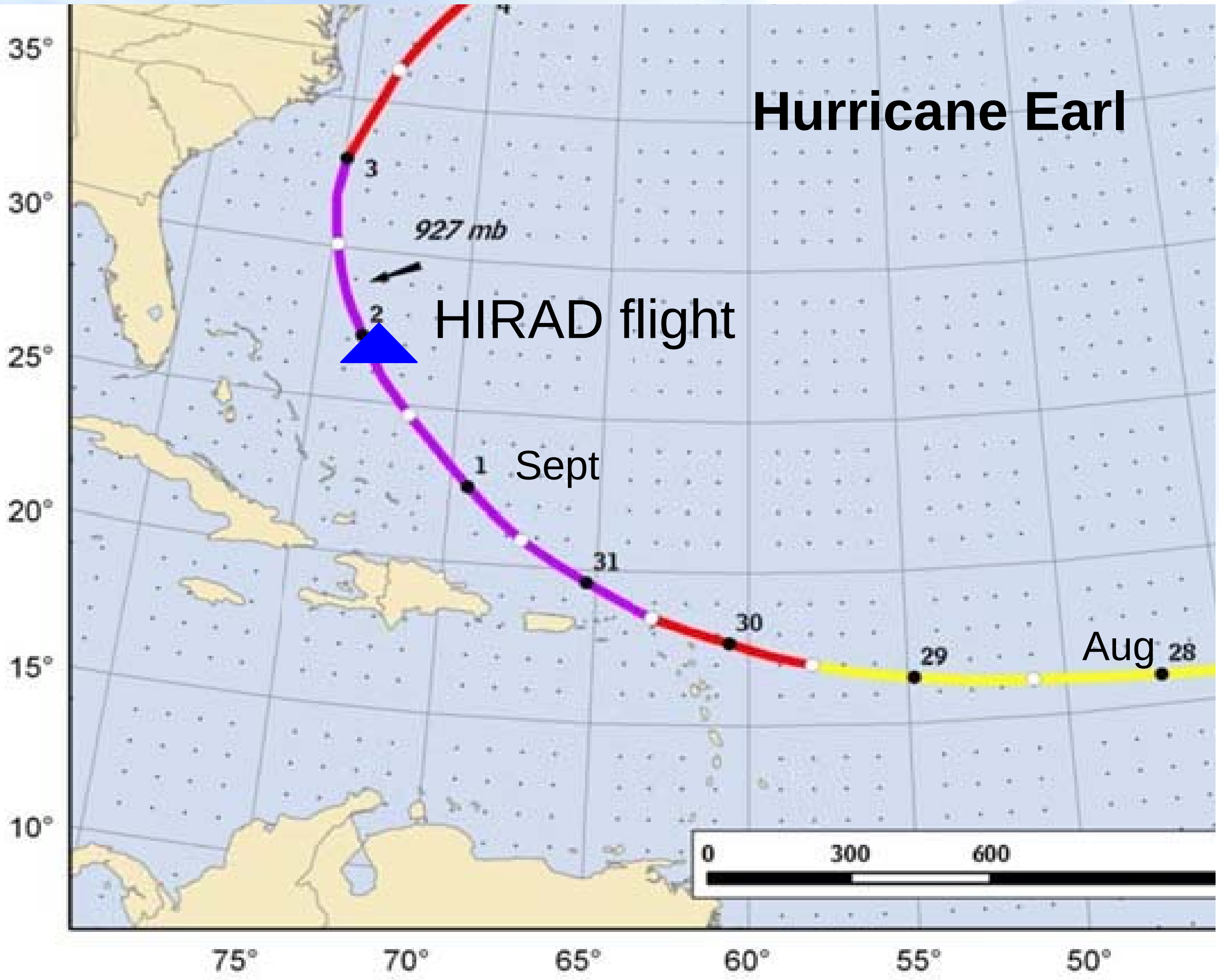
First HIRAD flights: GRIP

HIRAD

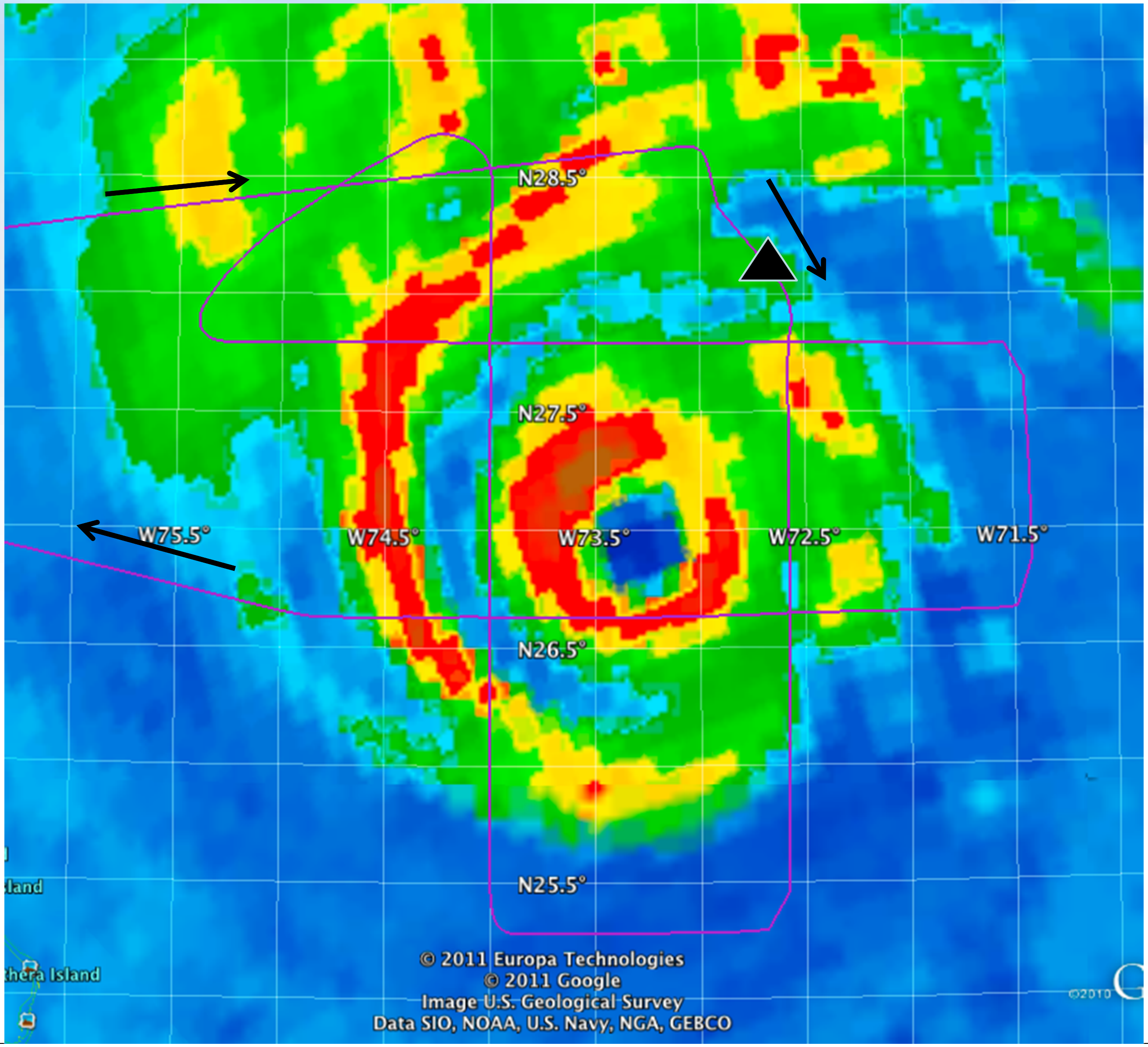
NASA Aircraft:

- Global Hawk –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: Hurricane Imaging Radiometer (HIRAD)**
- **Two key flights: Earl 1-2 Sept, Karl 17 Sept**

Hurricane Earl

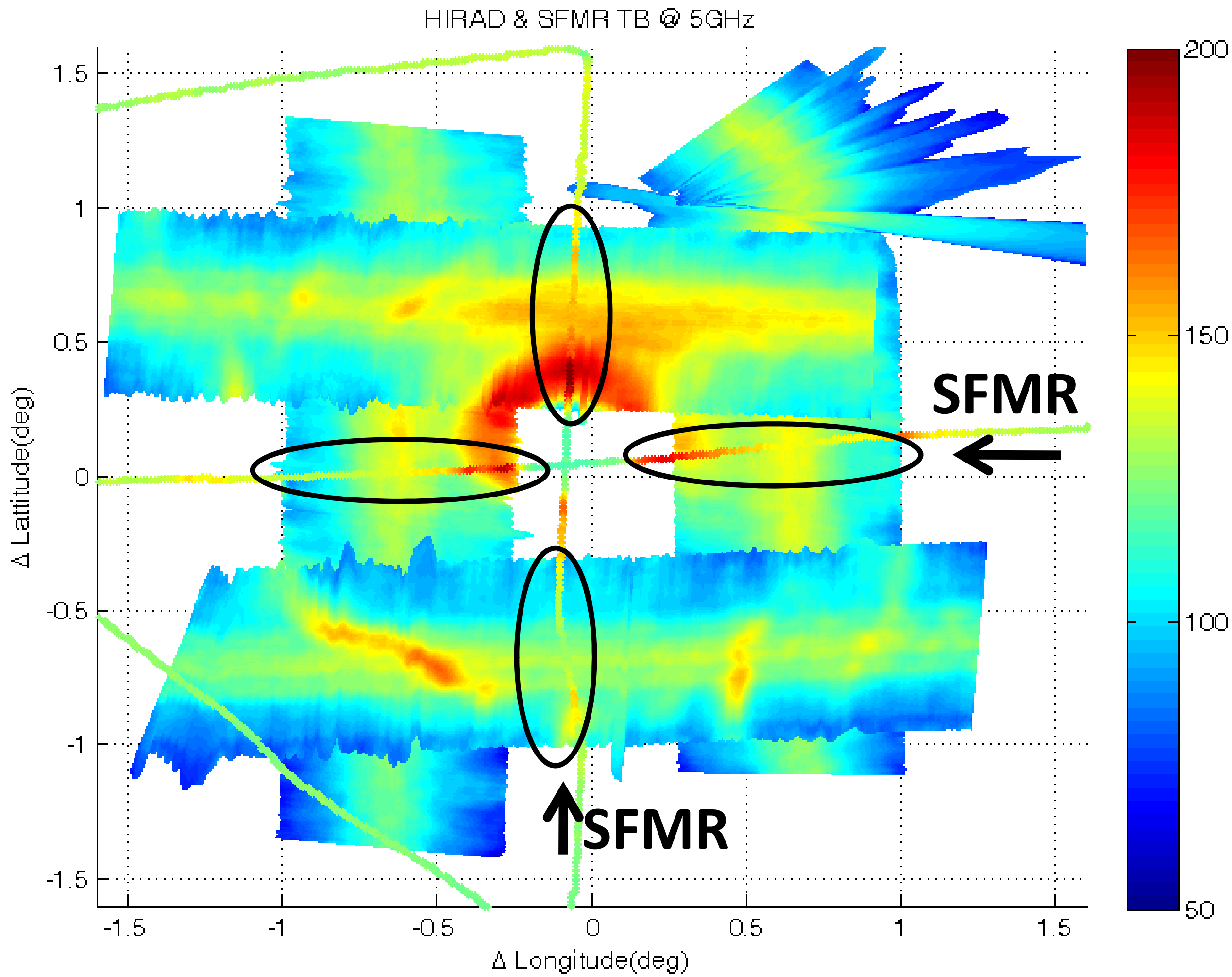


Earl, 2320 UTC, in 85GHz (SSMIS F16)
Triangle indicates WB-57/HIRAD position



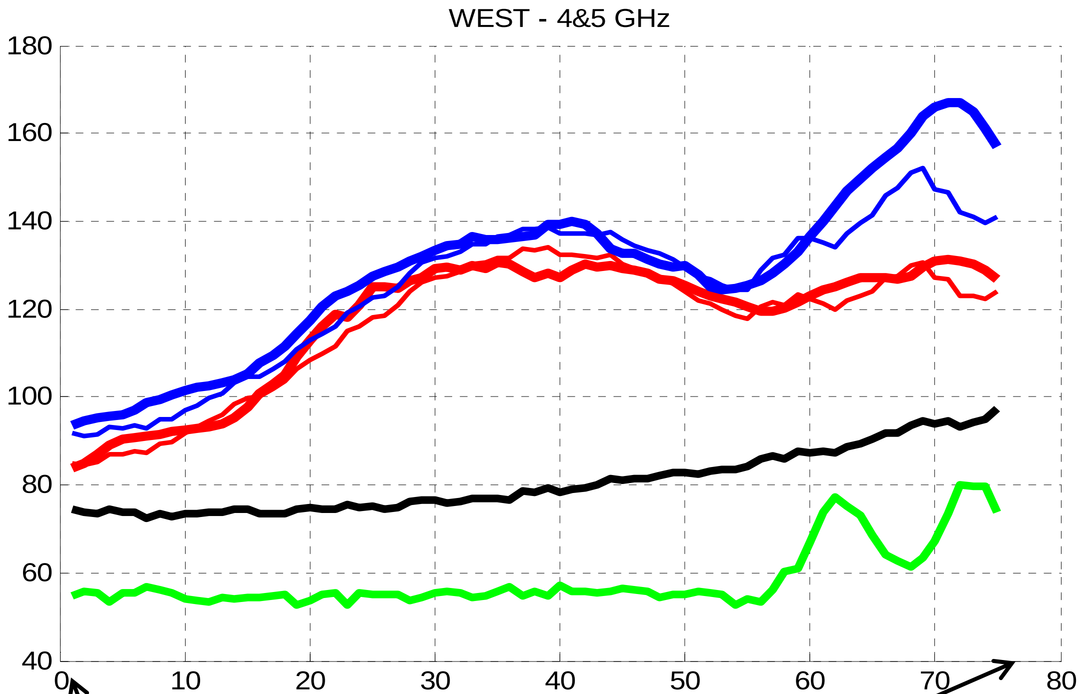
SFMR passes over HIRAD swath

Storm-centric coordinate system



HIRAD and SFMR should match at HIRAD's nadir point

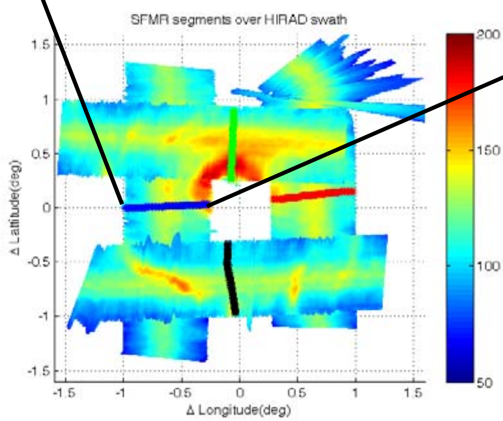
HIRAD/SFMR West Leg Overpass



stop

start

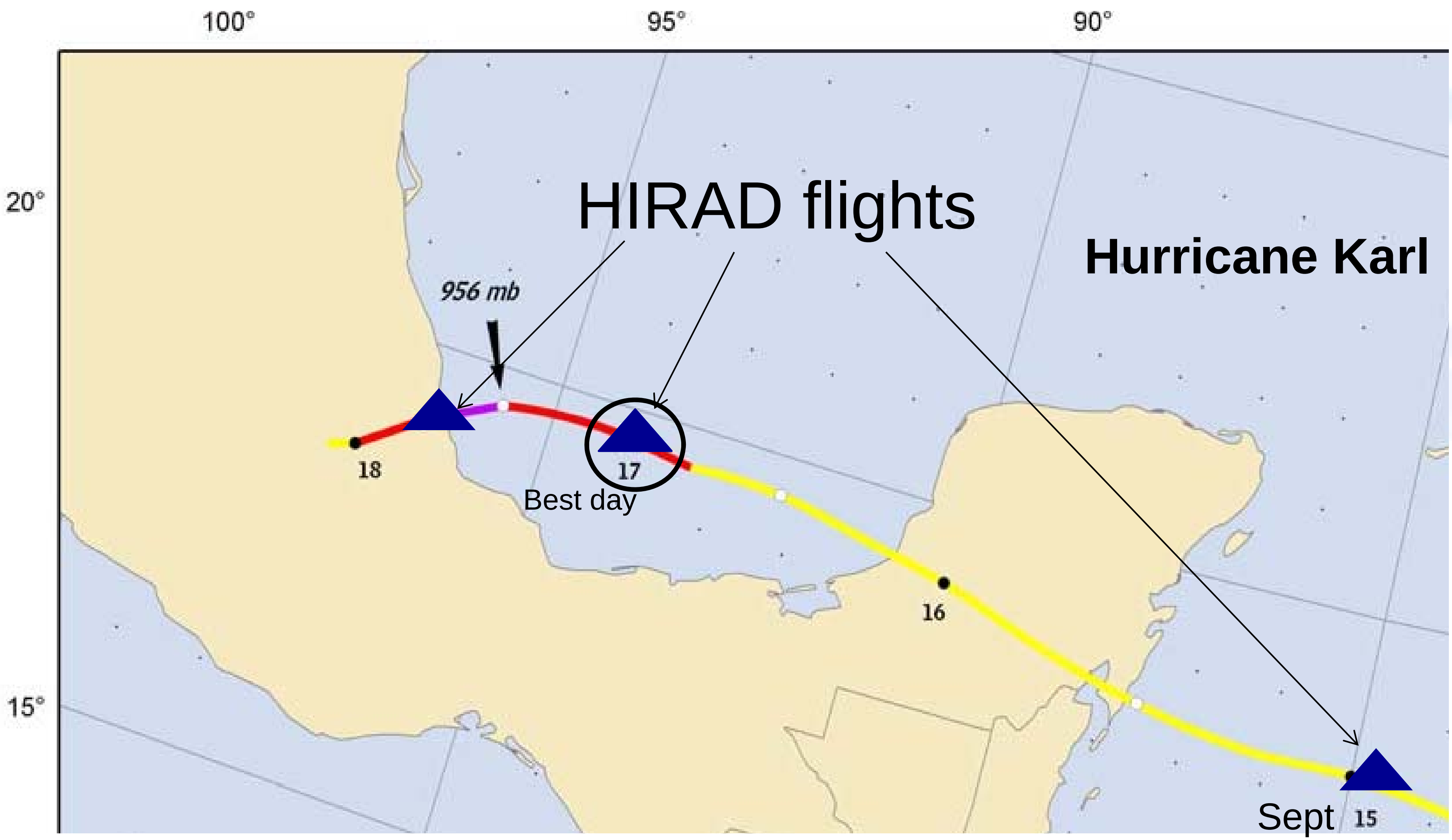
SFMR
Flt Dir



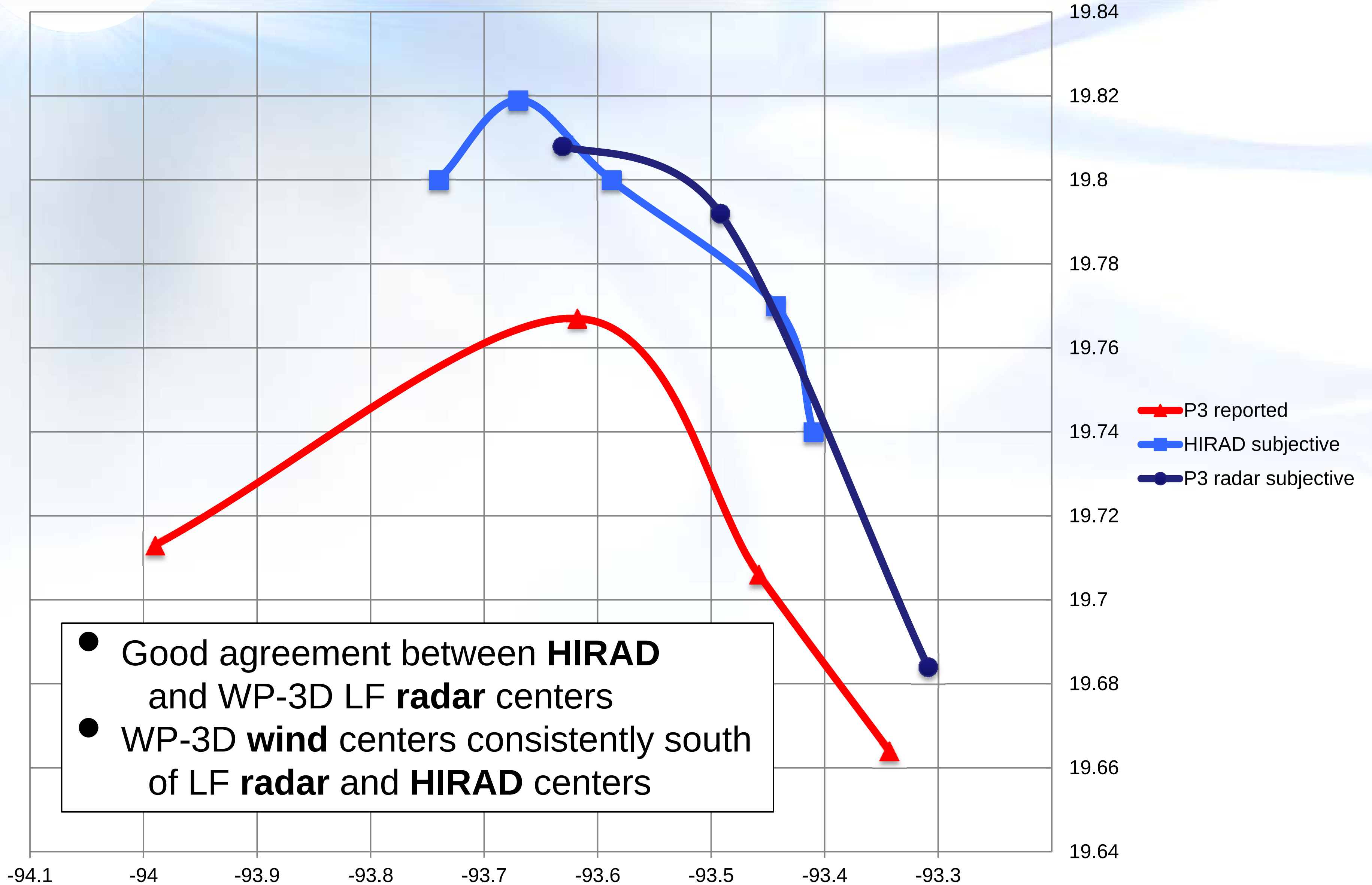
"Model" data are Tb's computed from SFMR wind & rain fields

UCF

Karl Best Track

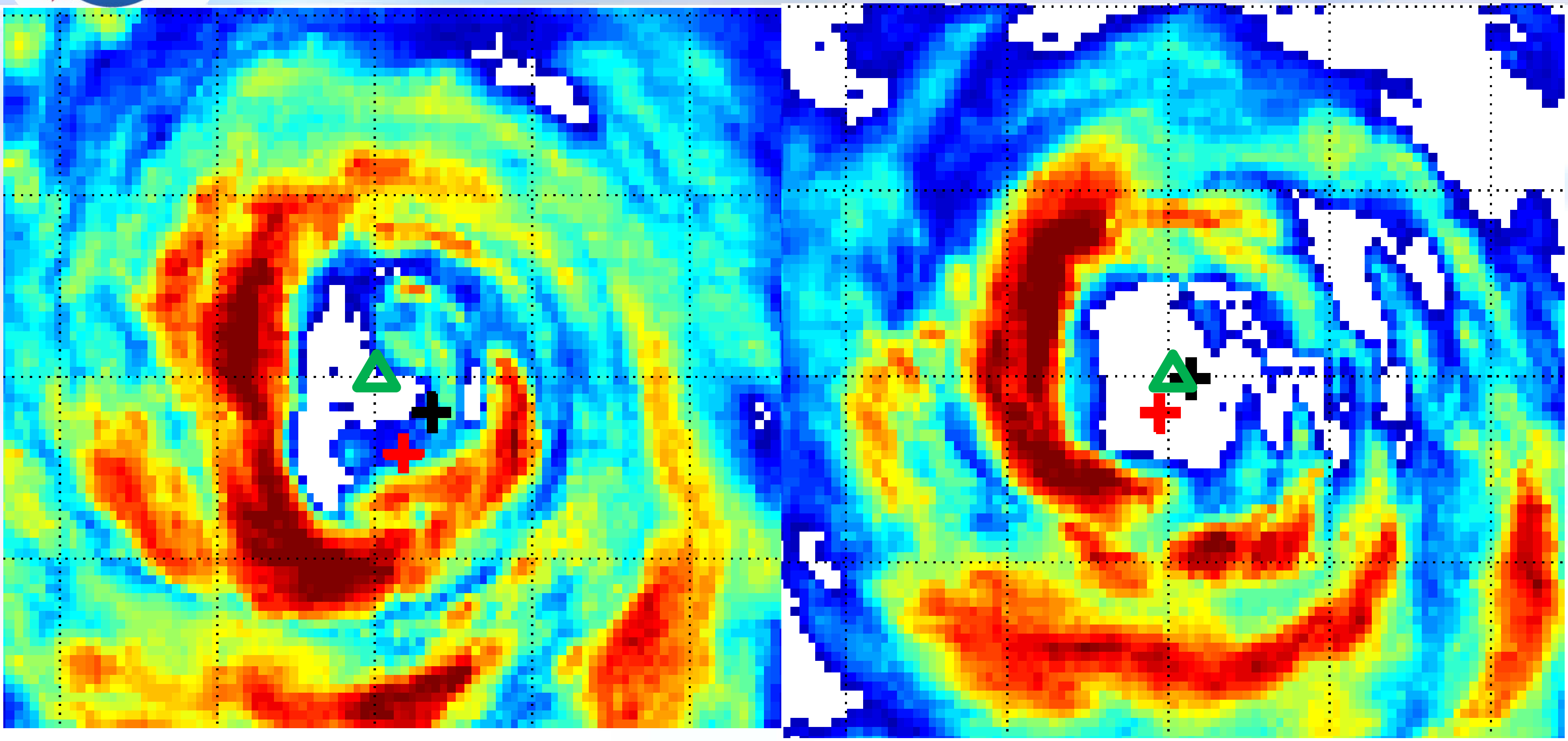


Karl 16 Sept Center Position



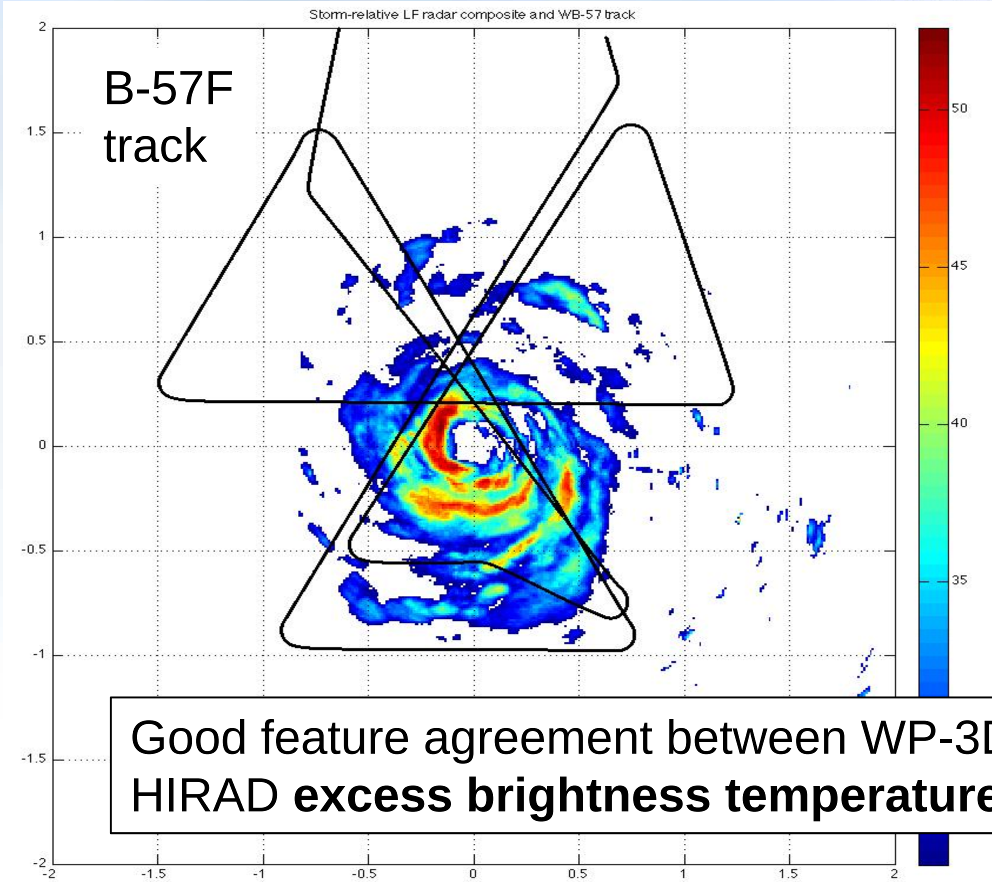
- Good agreement between **HIRAD** and WP-3D LF **radar** centers
- WP-3D **wind** centers consistently south of LF **radar** and **HIRAD** centers

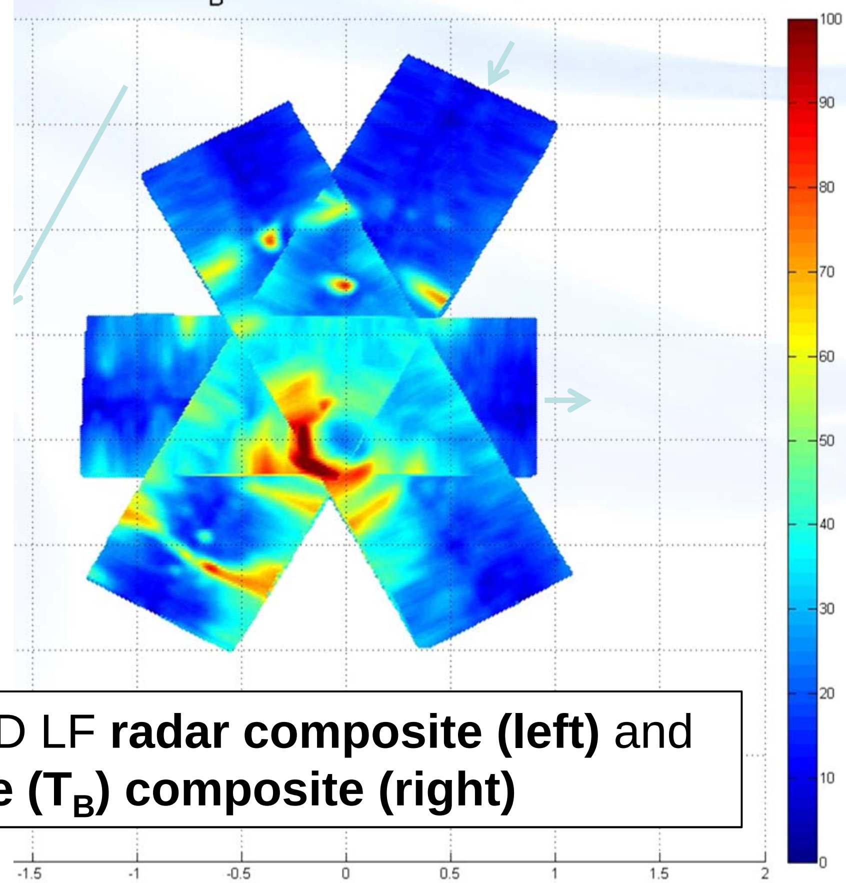
Composite P-3 LF radar reflectivity
Karl 16 Sept 2012



Red "**+**" is P-3 wind center; **Black** "**+**" is HIRAD center;
Green "△" is P-3 radar center

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





Good feature agreement between WP-3D LF **radar composite (left)** and HIRAD **excess brightness temperature (T_B) composite (right)**

P3 radar center crossings

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

HIRAD Calibration Challenges

Wind Speed and Rain Rate coming

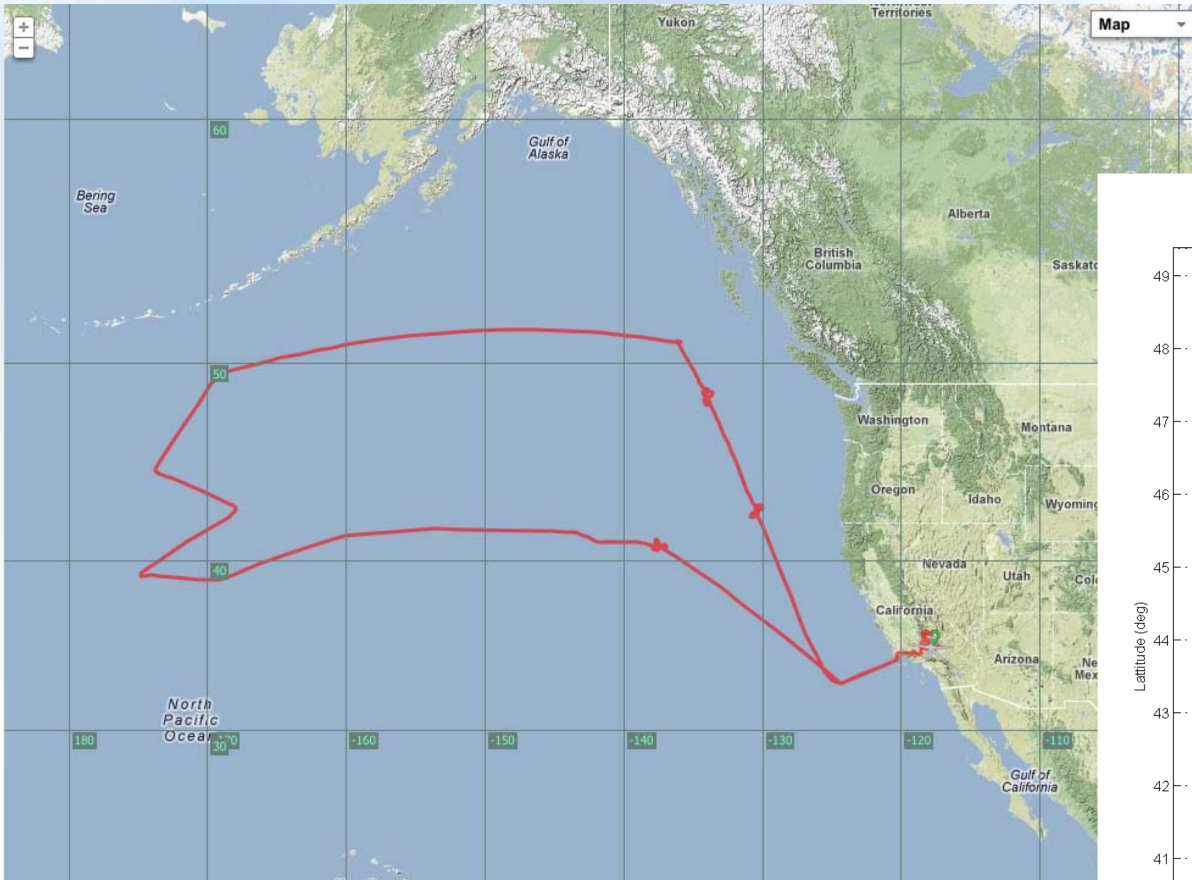
- Rain rate and wind speed retrievals require at least two calibrated frequencies
  - 5 GHz T_Bs (microwave brightness temps) have been successfully produced
  - Calibration of other 3 channels is work in progress; expect to be completed within 3 months
- HIRAD calibration issues and mitigation for HS3
  - 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

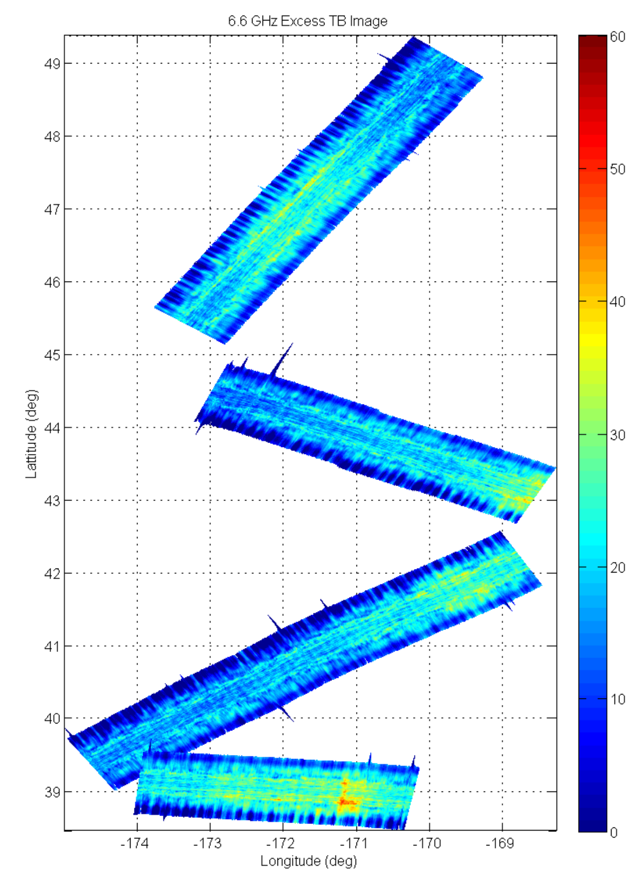
Hurricane and Severe Storm Sentinel (HS3)

- Principal Investigator: Dr. Scott Braun, NASA/GSFC
- Science goals include better understanding of cyclogenesis, intensity changes
- Mission uses a two-Global Hawk AUV configuration:
  - Over-storm reconnaissance
  - Environmental surveillance
- Over-storm vehicle includes **HIRAD**, HAMSR and HIWRAP (2012-14: 100 flight hours/ 1 month duration per season); over-storm vehicle was not ready for 2012 season

Hurricane and Severe Storm Sentinel (HS3)

AV-1 Flight, 5-6 Nov 2012

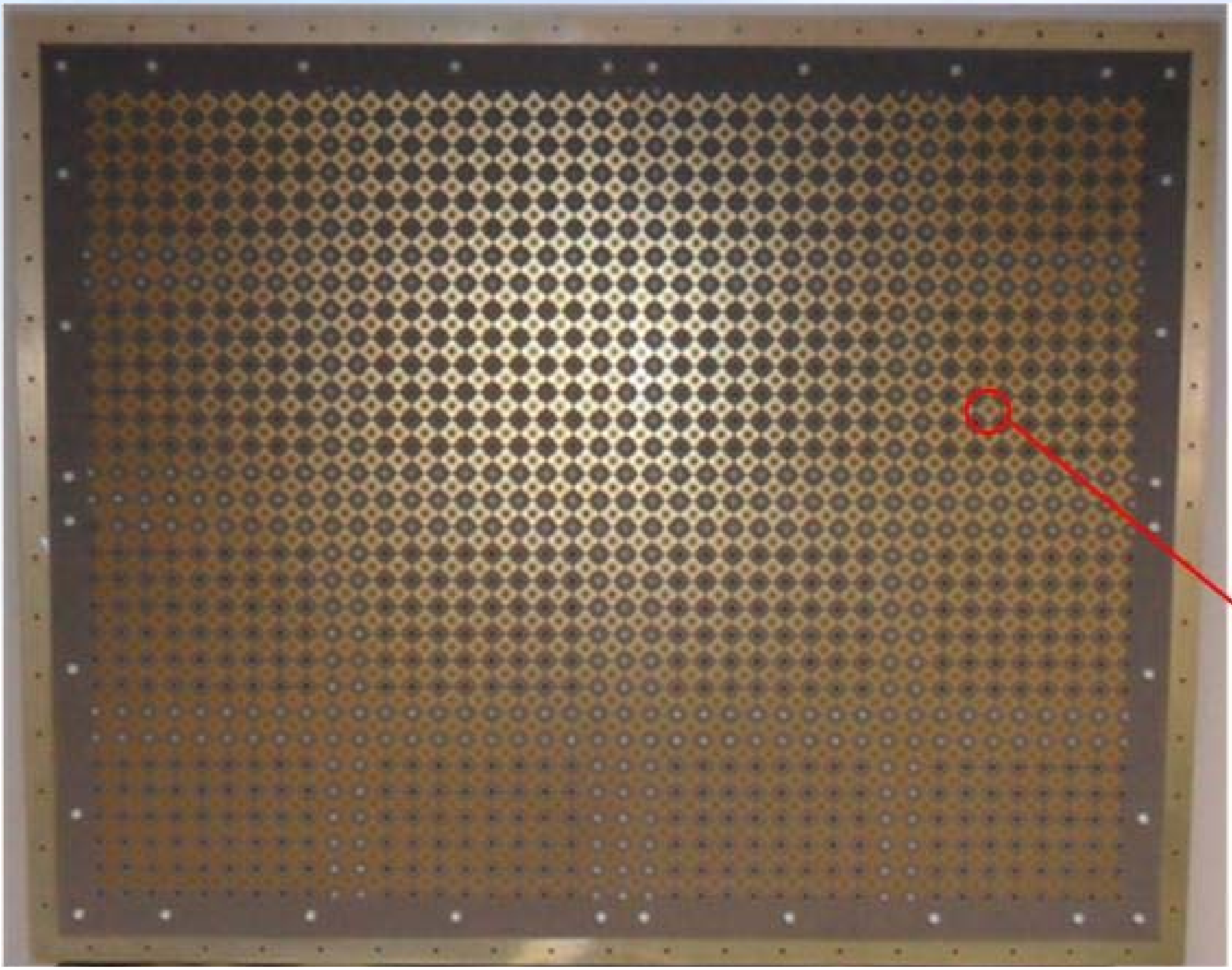




Next-generation HIRAD

- 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 prototype, developed via SBIR, has been built and tested
  - Support for the flight 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 late 2015

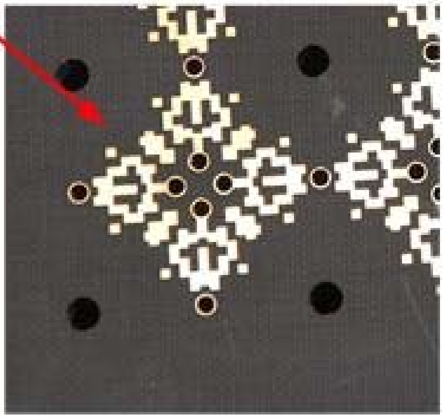
New dual-pol antenna



Key Improvements

A fully polarimetric system will enable wind direction retrievals and will improve wind speed accuracy at large nadir angles.

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 part of the 2012-14 NASA Hurricane and Severe Storm Sentinel (HS3) mission on the Global Hawk, a high-altitude UAV
- The next-generation HIRAD will include wind direction observations, and the technology can 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 the C-band microwave frequencies used (4-7 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 the correlation of HIRAD measured emissivity at operating incidence angles with modeled values. At nadir, these relationships have been validated via SFMR with co-located GPS dropsonde surface wind observations.