68th IHC Final Plenary Session

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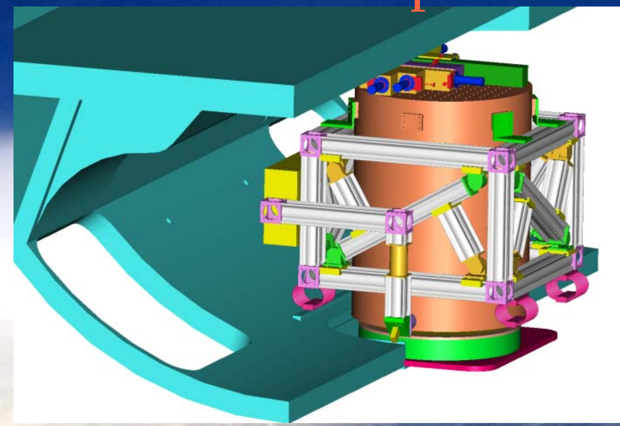
Earth Science Division
NASA Headquarters
March 6, 2014

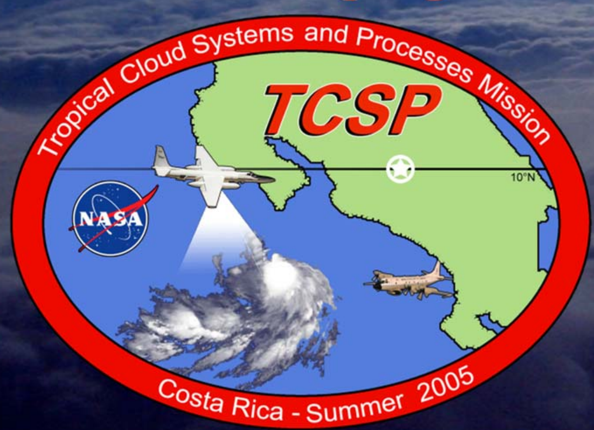
NASA Hurricane Research Focus Areas

Satellite remote sensing

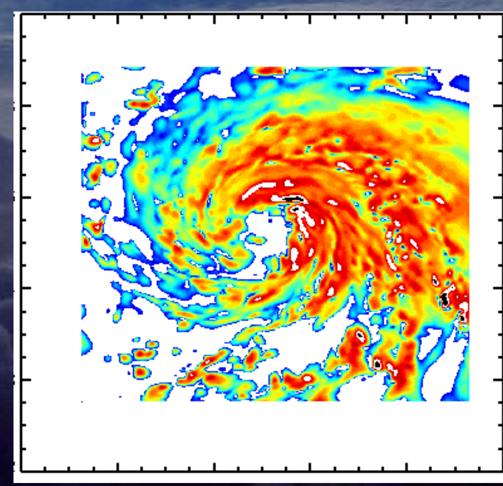
Sensor development



Field campaigns



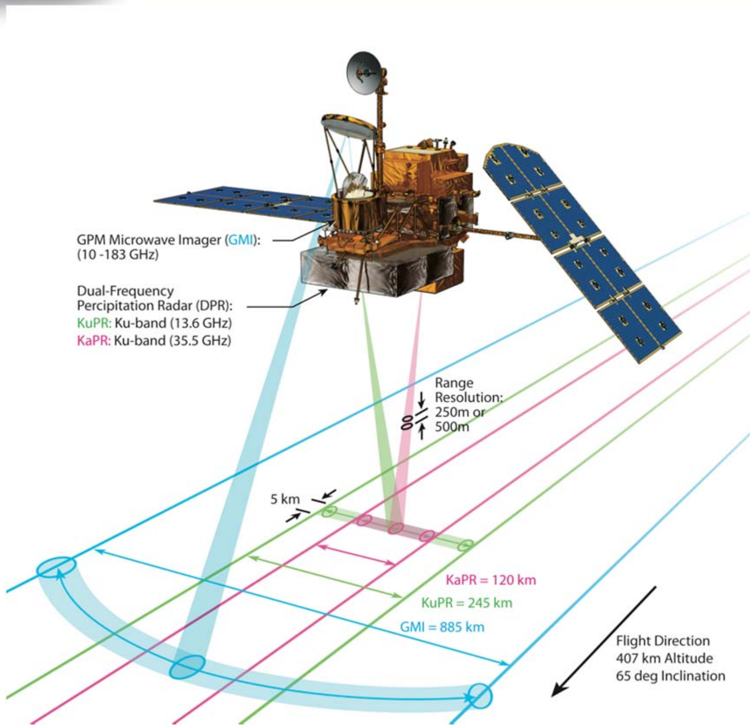
Numerical modeling



NASA Earth Science Operating Missions 2014

GPM will extend the TRMM data record

Core Observation Geometry and Instruments



Orbit: 407 km; 65 degree inclination

GPM Microwave Imager (GMI)

- Passive microwave radiometer with hot and cold calibration, includes novel calibration engineering
- Provides measurements of precipitation (rain and snow) intensity and distribution over wide swath (880 km)
- High spatial resolution (down to ~5km footprints)
- 166 Kg, 162 W, 34.9 Kbs Science,1.2 m diameter reflector

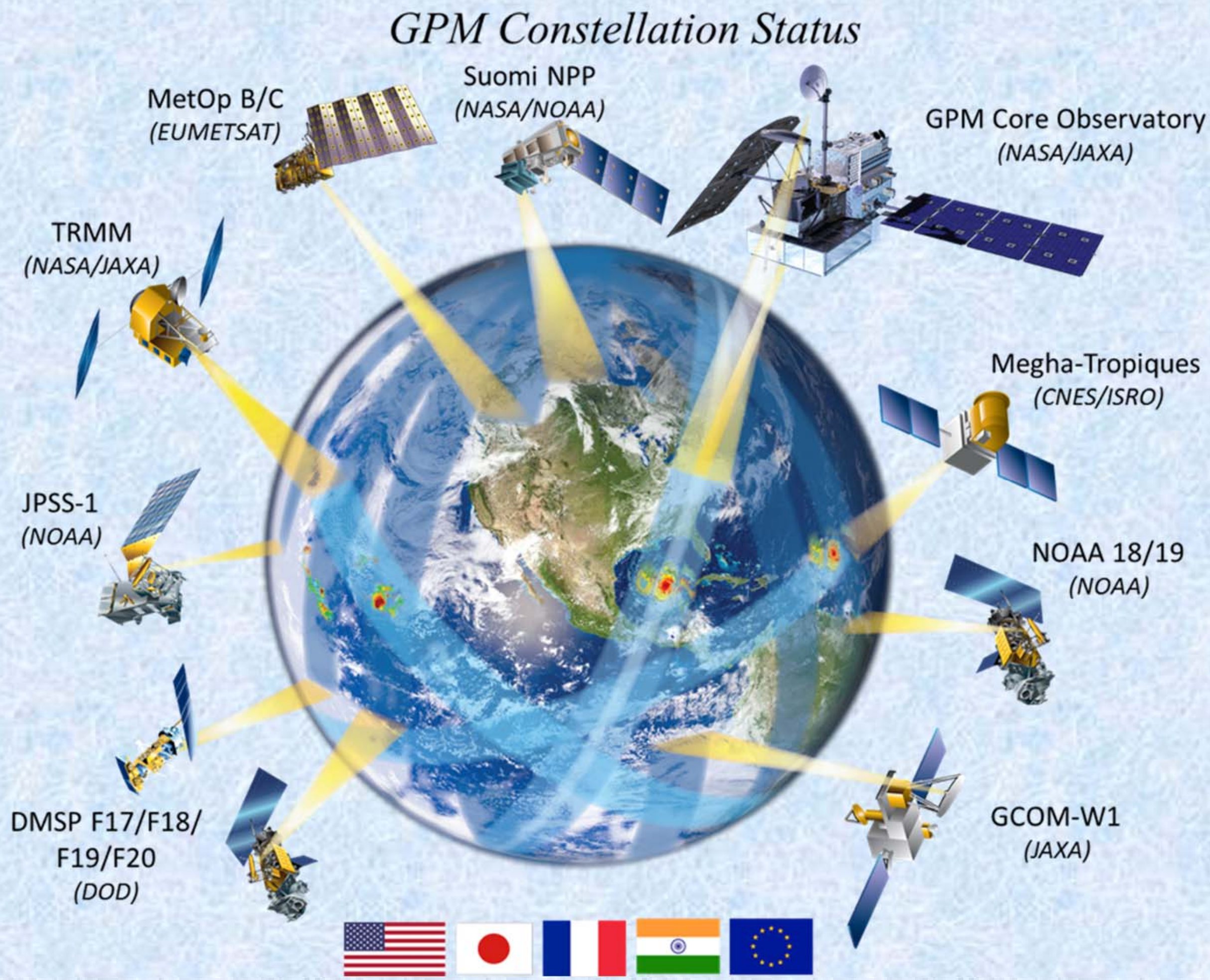
Dual-frequency (Ku-Ka band) Precipitation Radar (DPR)

- KuPR similar to TRMM, KaPR added for GPM
- Provides three-dimensional measurements of precipitation structure, precipitation particle size distribution (PSD) and precipitation intensity and distribution
- High spatial resolution (5km footprints)

	KuPR	KaPR
Frequency	13.597 , 13.603 GHz	35.547 , 35.553 GHz
Min. detectable rainfall rate	0.5 mm/hr	0.2 mm/hr
Data Rate	< 109 kbps	< 81 kbps
Mass	< 472 kg	< 336kg
Power Consumption	< 446 W	< 344 W
Size	2.5 × 2.4 × 0.6 m	1.2 × 1.4 × 0.7 m

GMI Frequencies	GMI Polarizations
10.65 GHz	V/H
18.7 GHz	V/H
23.8 GHz	V
36.5 GHz	V/H
89 GHz	V/H
166 GHz	V/H
183 GHz	Va/Vb (±3 & ±7)

GPM's International Scope



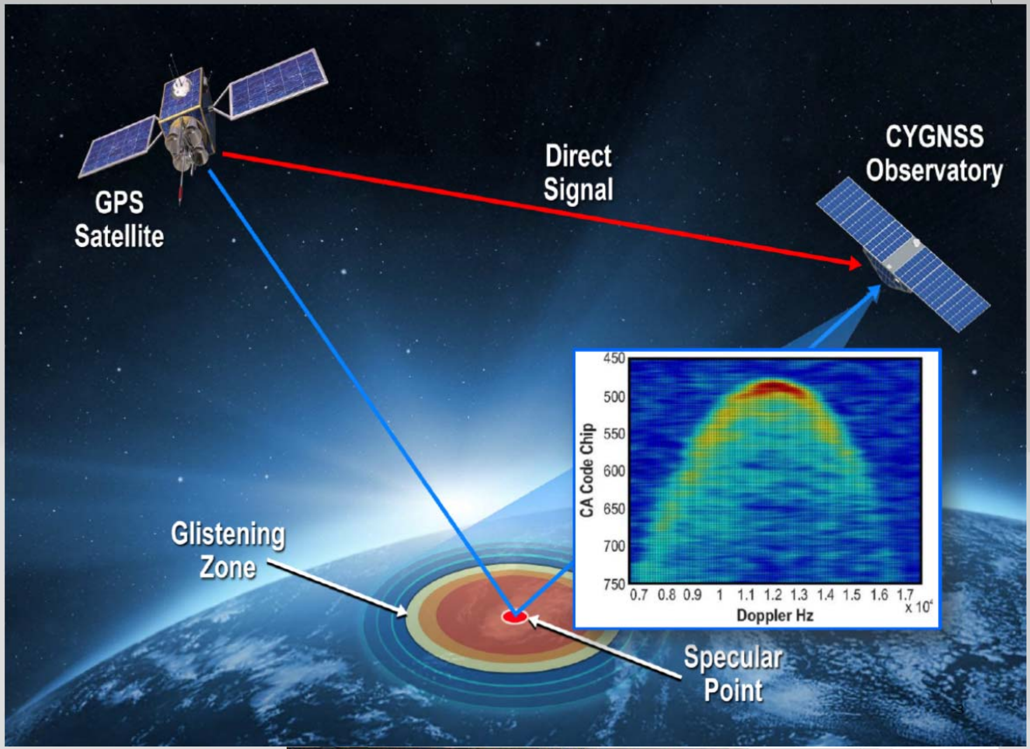
Active Joint Projects (19 PI's from 13 countries)

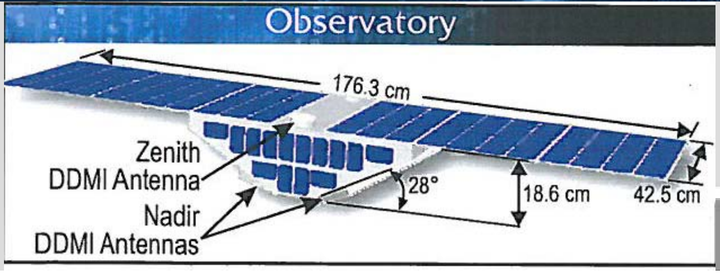
Earth Venture-2

(CYGNSS) Cyclone Global Navigation Satellite System

Principal Investigator: Chris Ruf
University of Michigan, Ann Arbor, MI

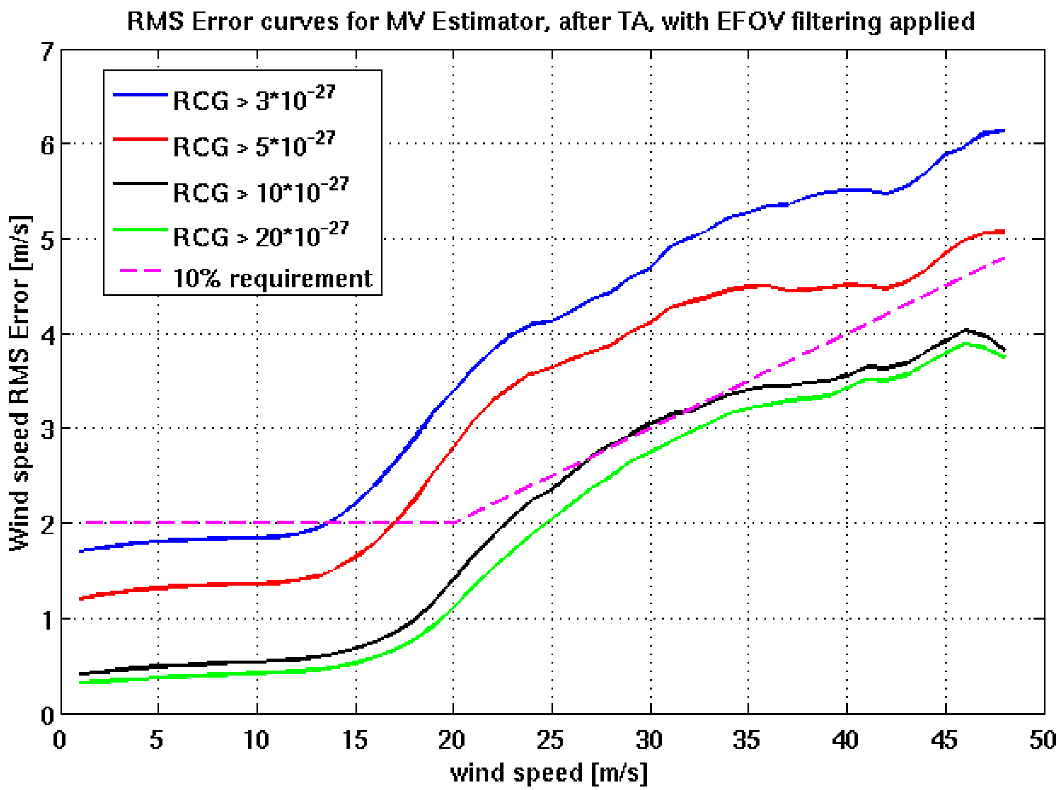
Cost: NASA – $150M BY14, Launch ~October 2016





- CYGNSS Science Goal
  - Understand the coupling between ocean surface properties, moist atmospheric thermodynamics, radiation, and convective dynamics in the inner core of a tropical cyclone (TC)
- CYGNSS Objectives
  - Measure ocean surface wind speed **in all precipitating conditions**, including those experienced in the TC eyewall
  - Measure ocean surface wind speed in the TC inner core **with sufficient frequency to resolve genesis and rapid intensification**
- Game Changing Capabilities
  - Traditional satellite remote sensing of surface winds cannot penetrate intense precipitation
    - Active (radar) and passive (radiometer) sensors operate at 1-5 cm wavelength – too much scattering and attenuation
  - Traditional LEO polar orbiters have >12 hr revisit time – too infrequent to observe rapid intensive phase of TC development
- CYGNSS uses a new measurement technique and a new satellite mission architecture

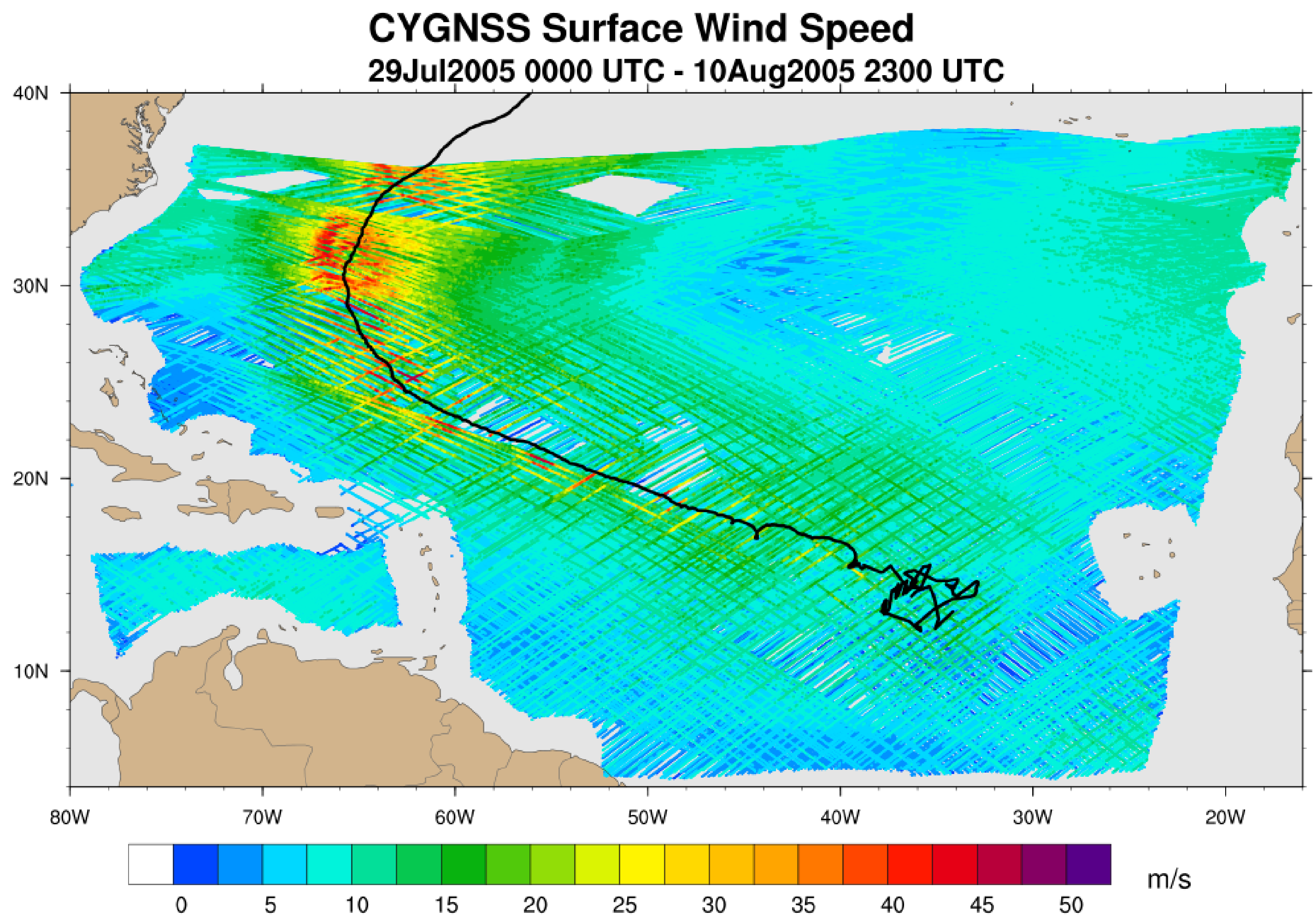
RMS Error for different RCG thresholds (25 km spatial resolution)



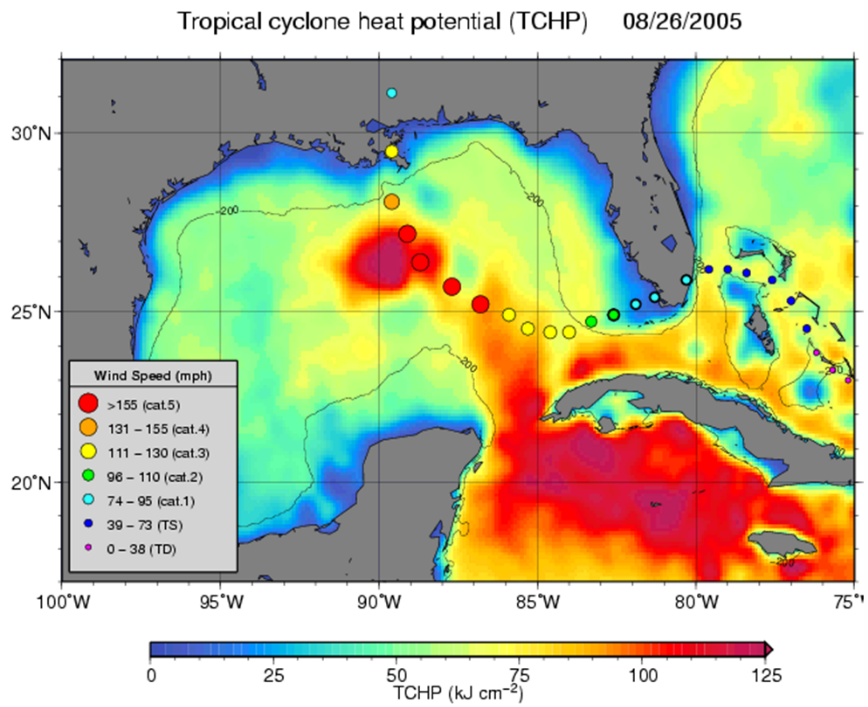
RCG = Range Corrected Gain

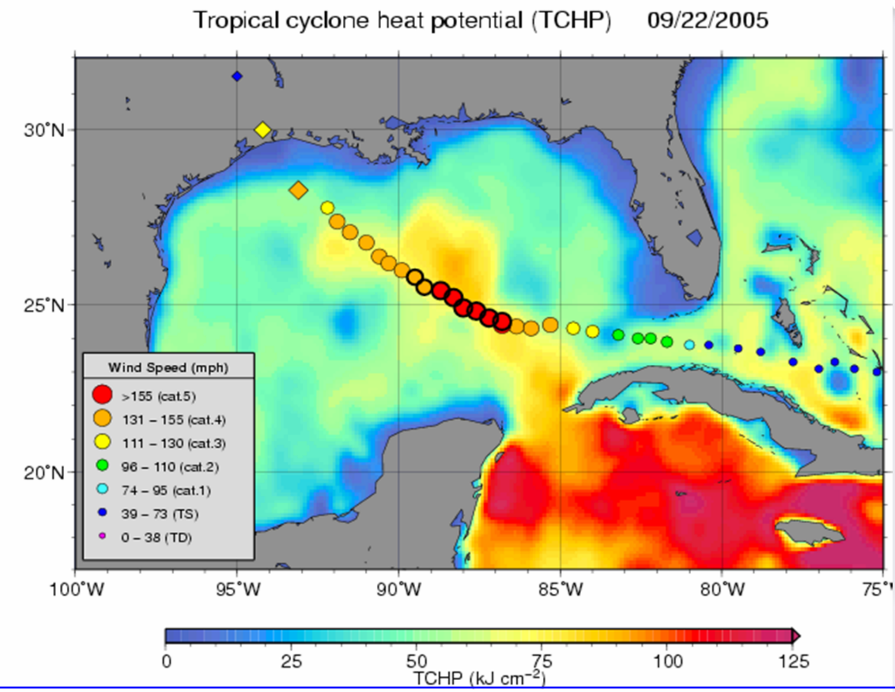
Wind speed range	<20m/s	>20m/s
RCG lower bound	**>5**	**>10**
Avg. RMS error	**1.4 m/s**	**9.2%**

CYGNSS Peak Hold Wind Retrieval for Full 13 Day Nature Run



Packing Heat in the Gulf





- **Altimetry combined with SST data and a two-layer model is used to calculate Tropical Cyclone Heat Potential (TCHP)**
- **TCHP is a measure of the oceanic heat content from the sea surface to the 26°C isotherm**
- **Both hurricanes rapidly intensified to category 5 as they passed over the Loop Current and a warm ring, then diminished to category 4 and category 3, respectively, by the time they traveled over cooler waters**
- **High values of TCHP may be linked to hurricane intensification. (**17 % improvement in the 96 hour forecast of Hurricane Ivan)

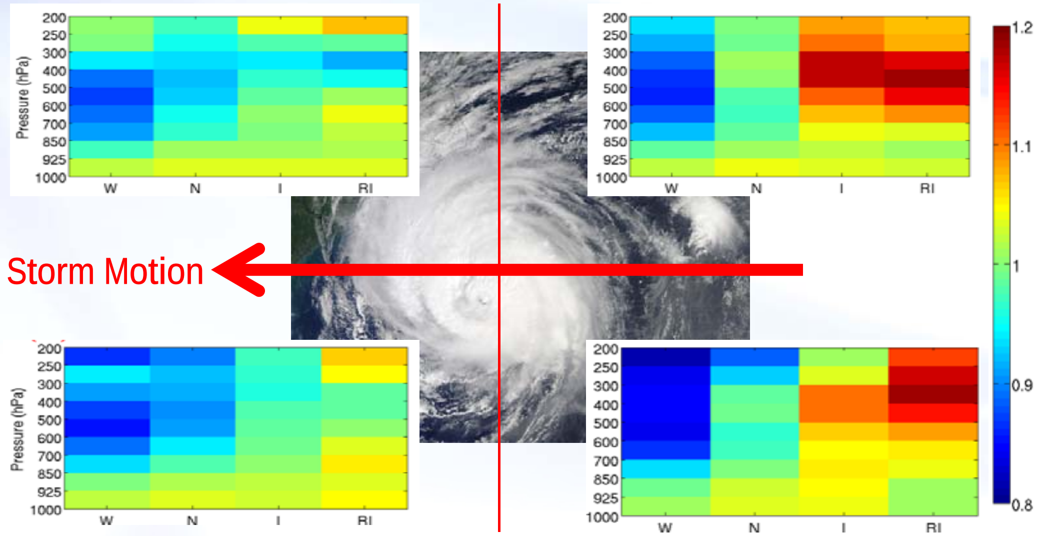
First Satellite Analysis to Quantify the Relationship Between Relative Humidity and Hurricane Intensification

Wu, L., H. Su, R.G. Fovell, B. Wang, J.T. Shen, B.H. Kahn, S.M. Hristova-Veleva, B.H. Lambrigtsen, E.J. Fetzer and J.H. Jiang (2012): Relationship of environmental relative humidity with North Atlantic tropical cyclone intensity and intensification rate, *Geophys. Res. Lett.* 39, 20809, 10.1029/2012GL053546.

Nine years of Aqua AIRS humidity data encompassing 198 North Atlantic tropical cyclones revealed that:

- **Intensifying hurricanes reside in a moister environment than weakening storms.**

Normalized RH 400 - 600 km away from TC center in four quadrants



W: Weakening; **N**: Neutral; **I**: Intensifying; **RI**: Rapidly Intensifying

- Relative humidity (RH) tends to increase with hurricane intensity and intensification rate.
- Substantial azimuthal asymmetry in RH exists at radial distances > 400 km.
- In the front-right quadrant relative to storm motion, rapidly intensifying hurricanes are associated with strong decrease of upper tropospheric RH from near to far environment.

- NASA Press Release: http://www.nasa.gov/mission_pages/aqua/hurricane20121128.html
- KABC News Coverage: http://abclocal.go.com/kabc/video?id=8901861&pid=8901860

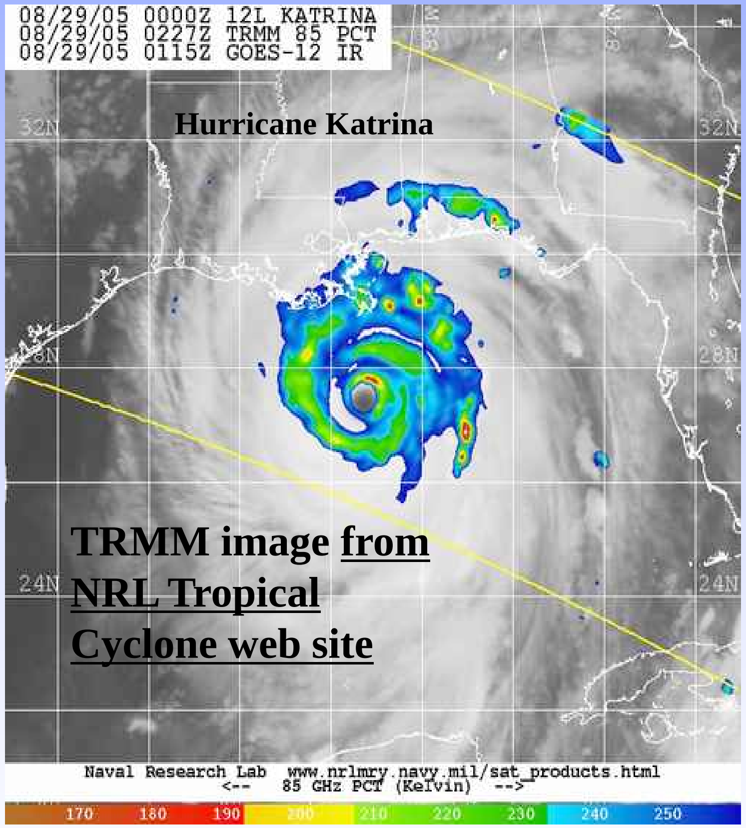
❖ **We acknowledge the funding support from NASA HSRP program.**

Jet Propulsion Laboratory
California Institute of Technology

TRMM Data Used for Hurricane/Typhoon Monitoring

TRMM TMI data used by NOAA and int'l agencies for tropical cyclone detection, location and intensity estimation--600 TRMM-based tropical cyclone "fixes" every year

TRMM orbit advantageous for tropical cyclone monitoring--despite narrow swath it is always in tropics, sampling about same as one SSM/I over all tropics, but TRMM sampling best in 10-35° latitude storm band. TMI resolution twice as good as SSM/I, about same as AMSR. Precessing orbit provides off-time observations relative to sun-synchronous microwave observations.



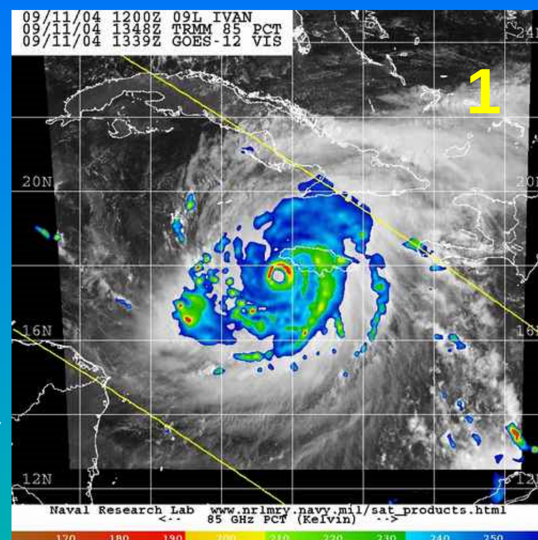
TRMM Microwave Imager Captures Dramatic Eyewall Replacement Cycle in Hurricane Ivan (Atlantic, 2004)

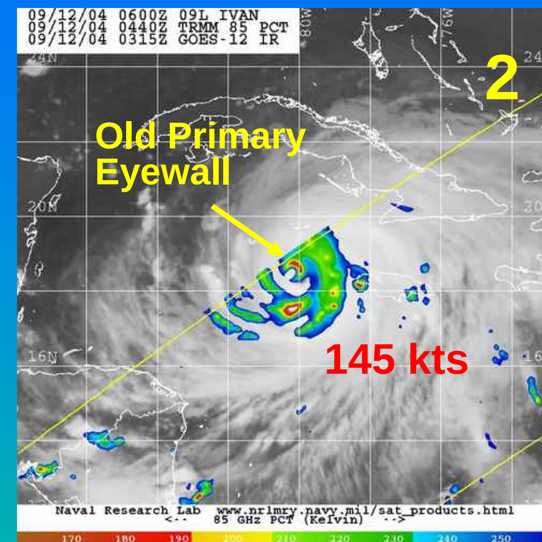
Eyewall replacement is associated w/ intensity change - and intensity change is poorly forecast

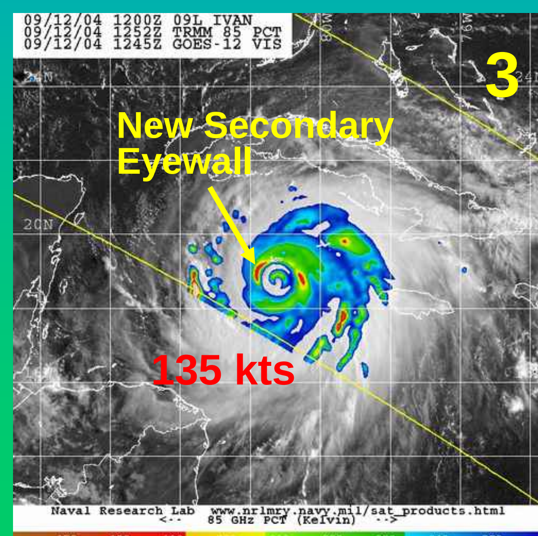
TRMM Microwave Imager witnessed complete cycle of outer secondary eyewall formation > inward contraction > dissipation of primary eyewall

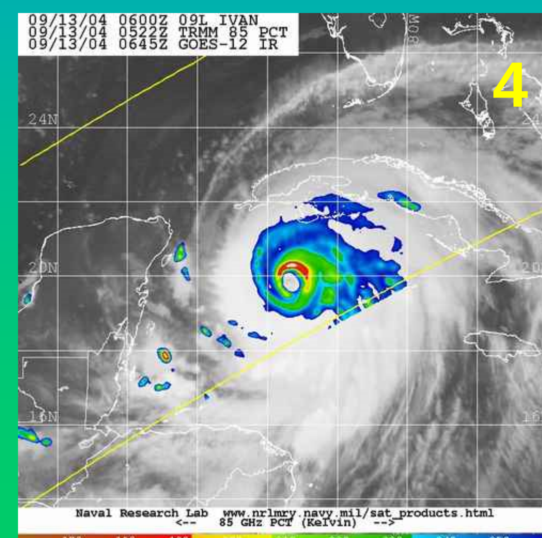
Ivan's intensity decreased during the height of eyewall replacement

High-resolution microwave imager like TMI can witness dynamic, storm-internal processes which alter intensity level

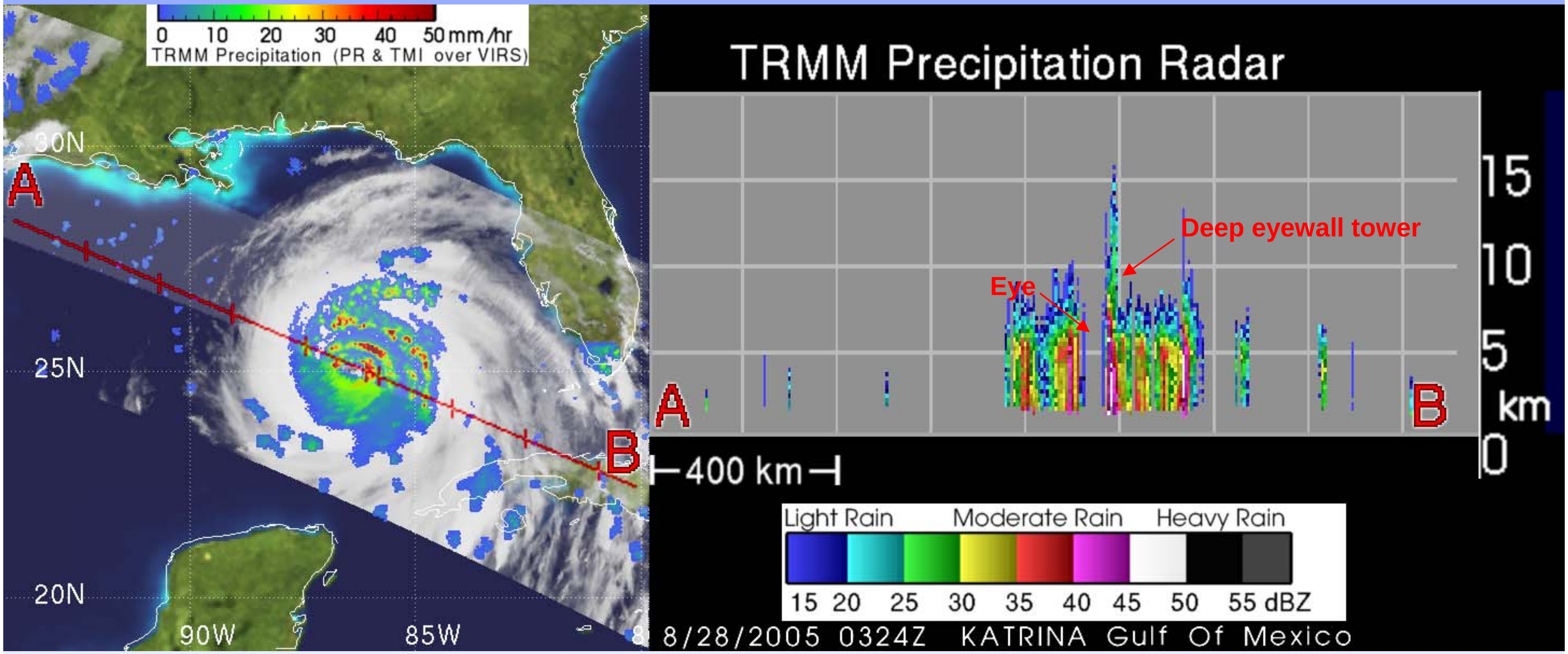








TRMM Precipitation Radar View of Hurricane Katrina



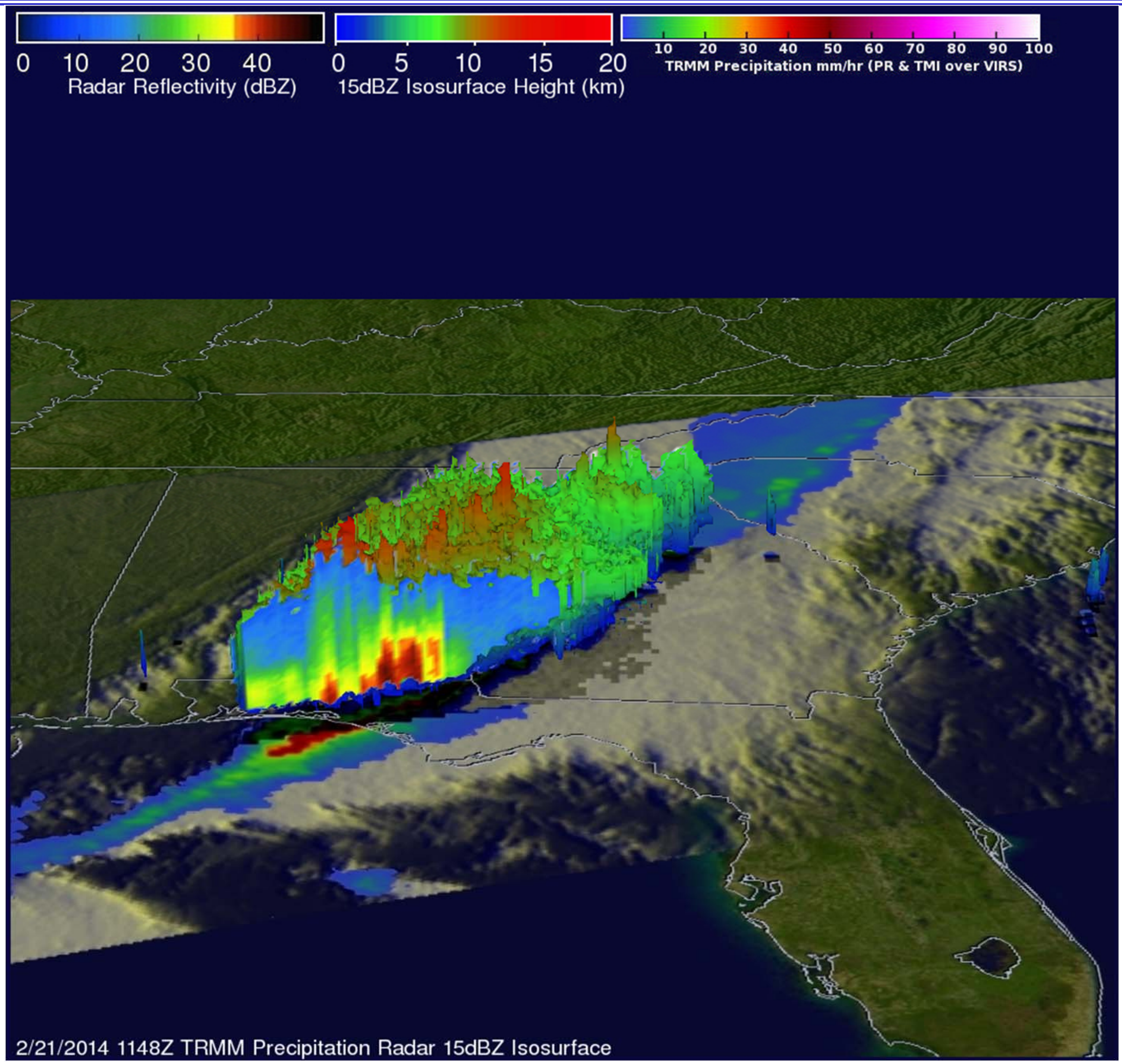
- **Vertical rain structure as revealed by the TRMM Precipitation Radar in near-real time**
- **TRMM is the only satellite that can provide rain structure information over open oceans, the breeding and intensification grounds of most tropical cyclones**
- **Energy-releasing deep convective clouds (to 16 km) in the eyewall of Katrina on August 28 occurred while the storm was intensifying to Cat 5; TRMM data have established this association in many storms**

TRMM Tropical Rainfall Measuring Mission

Friday, February 21, 2014

TRMM Sees Tornadic Thunderstorms

The 3-D image shows a TRMM Precipitation Radar (PR) slice through the line of severe thunderstorms. One tall thunderstorm in the Florida panhandle was shown reaching heights of about 13.8km (~8.5 miles) and returning Radar reflectivity values of over 58dBZ to the satellite. Rain was found by TRMM PR to be falling at a rate of over 89mm/hr (~3.5 inches) in the same storm.



Satellite Mission Wish List

- 3D-Winds : Three-Dimensional Tropospheric Winds from Space-based Lidar
- PATH : Precipitation and All-Weather Temperature and Humidity
- NEXRAD in Space

NASA's Airborne Science Program

- Responsible for providing aircraft systems that further science and advance the use of satellite data. Primary objectives:
    - Conduct in-situ atmospheric measurements with varying horiz. and vertical resolutions
    - Collect hi-res imagery for focused process studies and sub-pixel resolution for spaceborne calibration
    - Demonstrate and exploit the capabilities of UAS for science investigations
    - Test new sensor technologies in space-like environments
    - Calibrate/validate space-base measurements and retrieval algorithms

NASA Hurricane Field Experiments

Field programs coordinated with other Federal Agencies

1998

2001

2005

2006

2010

2012-2014*

NASA sponsored field campaigns have helped us develop a better understanding of many hurricane properties including inner core dynamics, rapid intensification and genesis

* Years of field deployment only

The Genesis and Rapid Intensification Processes (GRIP) Experiment

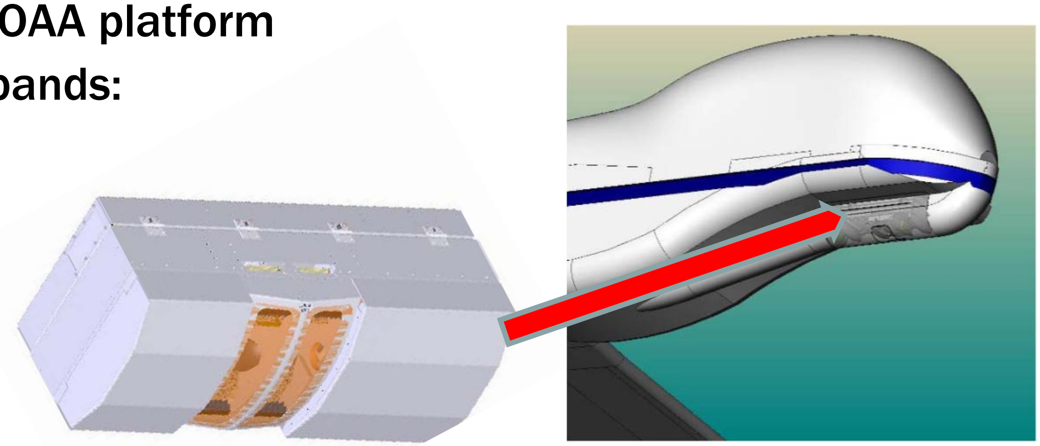
DC8: Up to 40 kft, 8-10 h duration

DC8 Instruments include LASE, APR2, DAWN, and dropsondes

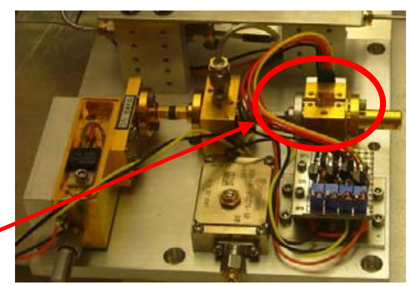
JPL **H**igh **A**ltitude **M**MIC **S**ounding **R**adiometer (HAMSR)

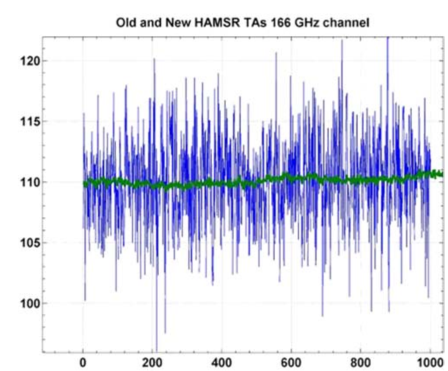
Jet Propulsion Laboratory
California Institute of Technology

- **JPL High Altitude MMIC Sounding Radiometer (HAMSR)**
  - **Microwave radiometer for 3-D all-weather temperature and water vapor sounding, similar to AMSU on NOAA platform**
  - **25 sounding channels in three bands:**
    50-60 GHz, 118 GHz, 183 GHz
- **Cross track scanning**
  - **$\pm$ 45° off nadir**
  - **40 km swath at 20 km**
  - **2 km resolution**
- **Flew in CAMEX-4, TCSP, NAMMA and GRIP**



- **Upgraded for Global Hawk operations under NASA AITT**
  - **New state of the art receiver technology (developed under ESTO/ACT)**
  - **Upgraded data system for real time communication**
  - **Compact instrument packaging**





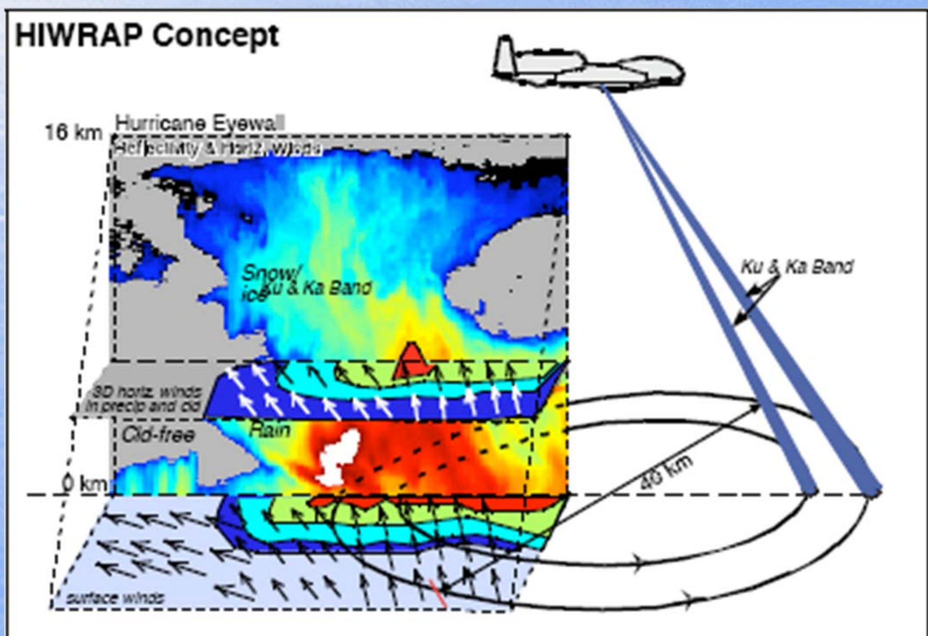
Noise reduced from 2 K to 0.2 K

High-Altitude Imaging Wind and Rain Airborne Profiler (HIWRAP)

MEASUREMENTS GOALS:

Map the 3-dimensional winds and precipitation within hurricanes and other severe weather events.

Map ocean surface winds in clear to light rain regions using scatterometry.



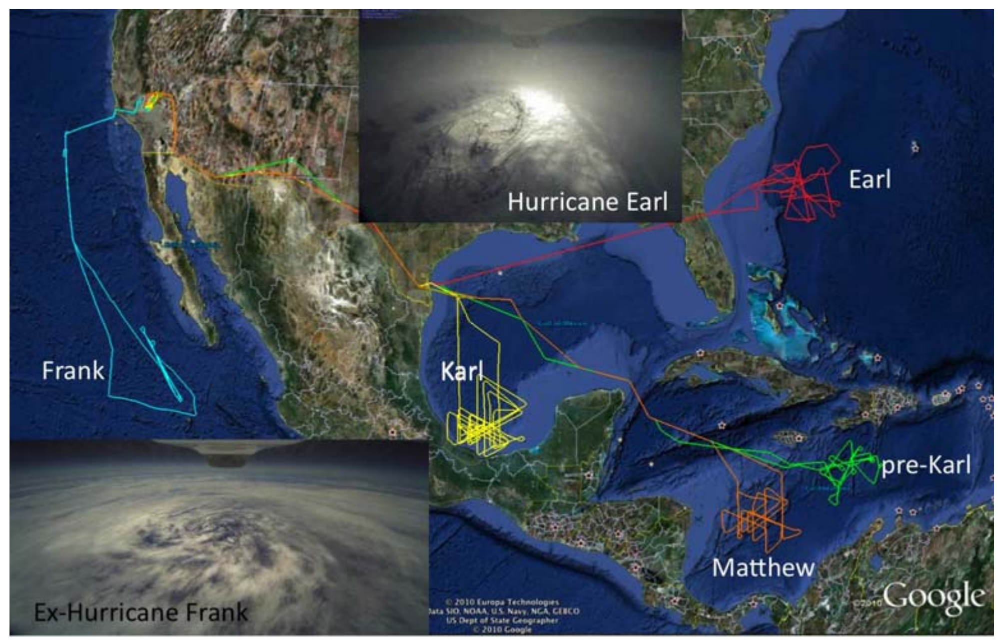
NASA Global Hawk:
19 km altitude, 30 hours

HIWRAP Characteristics:

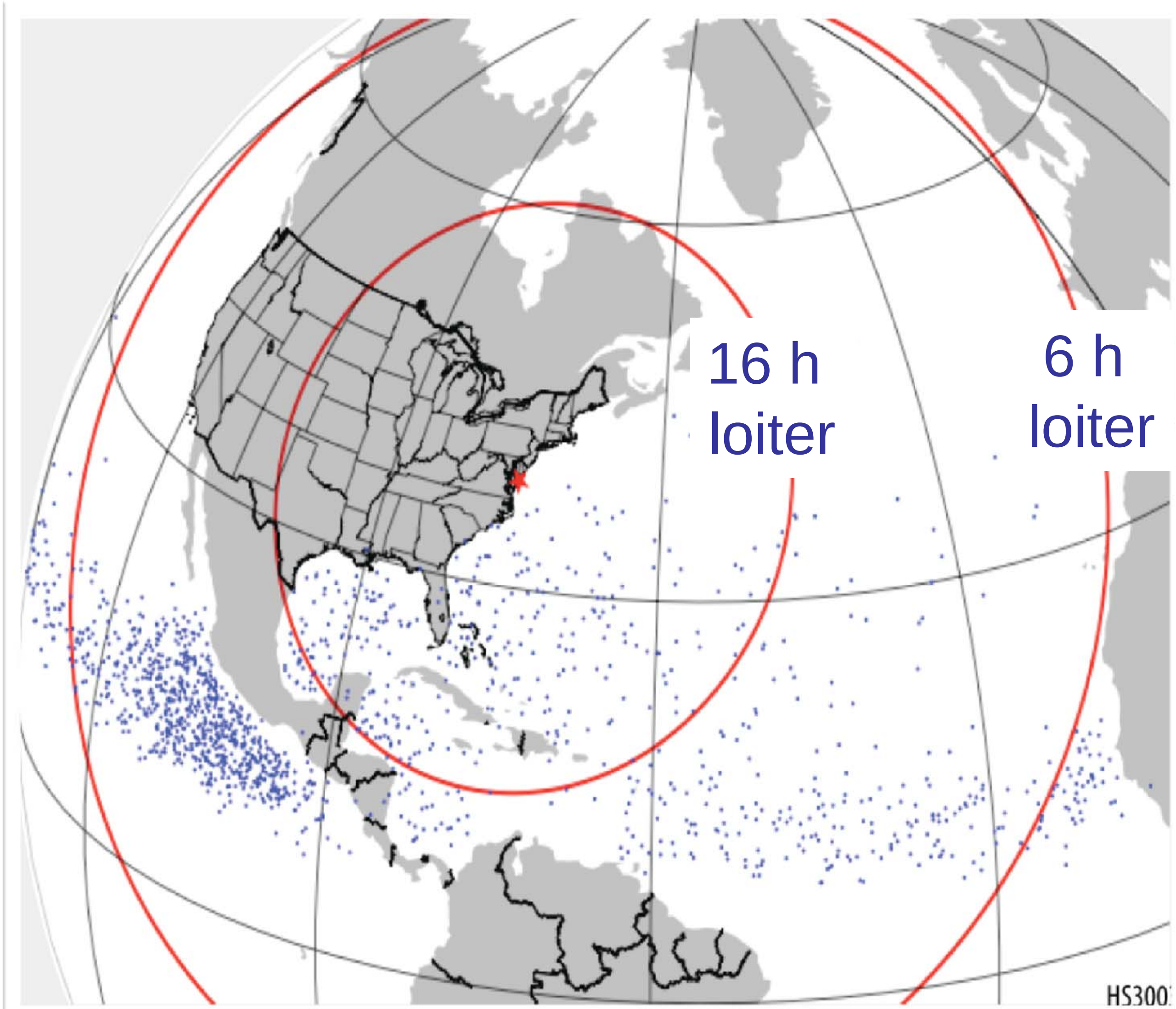
- *Conically scanning.*
- *Simultaneous Ku/Ka-band & two beams @30 and 40 deg*
- *Winds using precipitation & clouds as tracers.*
- *Ocean vector wind scatter-*ometry similar to QuikScat.

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



A Wallops Deployment Provides Great Coverage of the Atlantic



Dots indicate genesis locations. Range rings assume 26-h flights.

Hurricane and Severe Storm Sentinel (HS3)

Science Goal: To understand hurricane genesis and intensification.

Key Science Questions:

- How do hurricanes form?
- What causes rapid intensity changes?
- What is the role of deep convective cores in intensification?
- What's the role of the Saharan Air Layer?

Deployment Details:

- Deployments in hurricane seasons of 2012-2014
- Based at NASA's Wallops Flight Facility in Virginia
- 275 science flight hours (~10-11 26-hour flights) per deployment

<u>Two Global Hawk (GH) aircraft</u>

Environment GH instrumentation

- TWiLiTE (direct detection wind lidar)
- CPL (cloud & aerosol lidar)
- Scanning HIS (T, RH)
- Dropsondes (wind, T, RH)

Over-storm GH instrumentation

- HIWRAP (3-D preip. + 3D winds + sfc winds)
- HIRAD (sfc winds and rain)
- HAMSR (T, RH, hydrometeor profiles)

Summary

- NASA satellite sensors are helping to expand weather/hurricane research frontiers
- NASA sponsored field campaigns have helped us develop a better understanding of many hurricane properties including inner core dynamics, rapid intensification and genesis
- NASA satellite sensor data is being under utilized in hurricane research (assimilation of satellite data has a much greater potential impact on the track and intensity forecasts)