

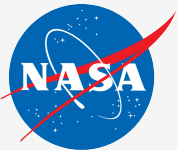
**Svetla Hristova-Veleva<sup>1</sup>, M. Boothe<sup>4</sup>, S. Gopalakrishnan<sup>2</sup>, Z. Haddad<sup>1</sup>,  
M. P. Johnson<sup>1</sup>, B. Knosp<sup>1</sup>, B. Lambrigtsen<sup>1</sup>, F. Marks<sup>2</sup>, P. P. Li<sup>1</sup>,  
M. Montgomery<sup>4</sup>, N. Niamsuwan<sup>1</sup>, W. Poulsen<sup>1</sup>, T.-P. Shen<sup>1</sup>,  
V. Tallapragada<sup>3</sup>, S. Tanelli<sup>1</sup>, S. Trahan<sup>3</sup>, J. Turk<sup>1</sup>, Q. Vu<sup>1</sup>, T. Vukicevic<sup>2</sup>**

- 1 – JPL, Pasadena, CA**
- 2 – HRD/AOML/NOAA, Miami, FL**
- 3 – EMC/NCEP/NOAA, College Park, MD**
- 4 – NPS, Monterey, CA**

# **Analysis Tools for Online Evaluation of the Operational Hurricane Forecasts Using Satellite Data**

**ESTF2014 – October 28<sup>th</sup>, 2014**





# Hurricanes are among the most destructive natural phenomena with huge societal and economic impact.

After **Katrina**:  
Venice, Louisiana - 8/30/2005



After **Ike**:  
Galveston, Texas -9/13/2008



Houston, Texas, 2005 – unnecessary evacuation of 2 million ahead of hurricane **Rita's** landfall



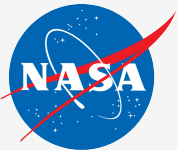
Each year they threaten the US coast, cause damages worth billions and take life.

- Some **130,000 died** when a cyclone struck Myanmar along the Andaman Sea in **2008**.
- The deadliest U.S. hurricane was the **1900 Galveston storm**, which **killed 8,000 to 12,000** people and destroyed the city. **Katrina (2005) killed some 1,200 people**, and left hundreds of thousands homeless.
- **Sandy** is being blamed for about **\$62 billion** in damage and other losses in the U.S. — a number that could increase.
- It is the second-costliest storm in U.S. history after 2005's Hurricane Katrina, which caused **\$128 billion** in damage in inflation-adjusted dollars.

Widespread power outages and subway shutdowns may wind up making **Superstorm Sandy** the second most expensive storm in U.S.



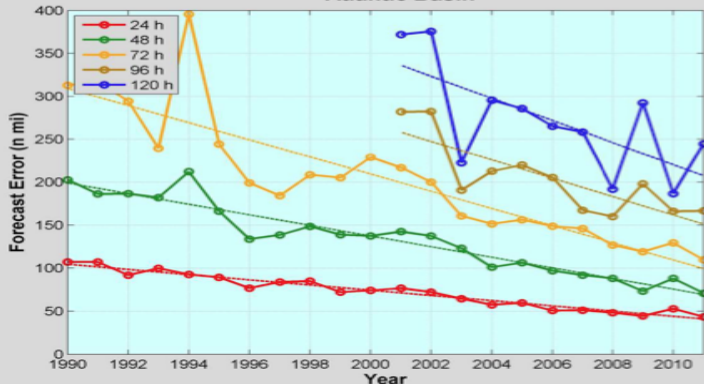




# Current state-of-the-art hurricane prediction

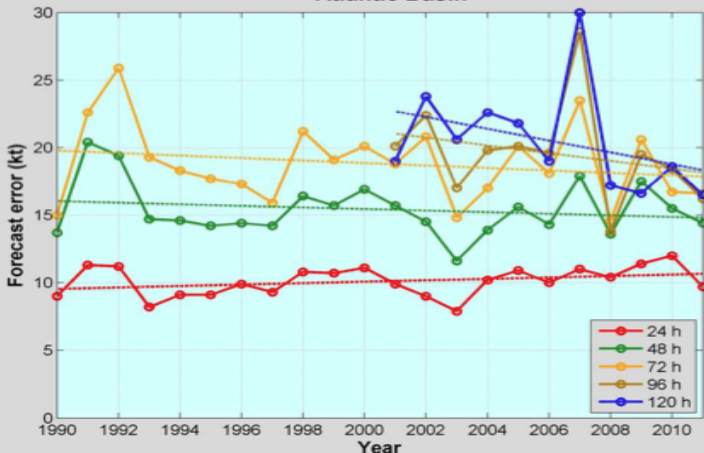
- **25% reduction in 48 hour track error over the past 6 years**

NHC Official Track Error Trend  
Atlantic Basin



- **Intensity forecasts have not improved.**

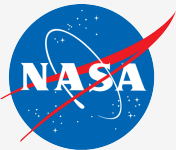
NHC Official Intensity Error Trend  
Atlantic Basin



## But WHY ???

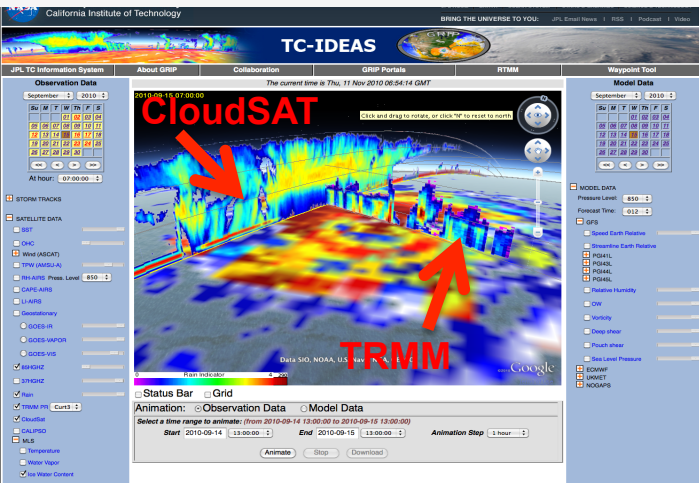
- What are the sources of the intensity errors?
- **Do the models properly reflect the physical processes and their interactions?**
  - Is the representation of the precipitation structure correct?
  - Is the storm scale and asymmetry reflected properly
  - Is the environment captured correctly
  - Is the interaction between the storm and its environment represented accurately
- **Recognizing an urgent need for more accurate hurricane forecasts, NOAA recently established the multi-agency 10-year Hurricane Forecast Improvement Project (HFIP).**



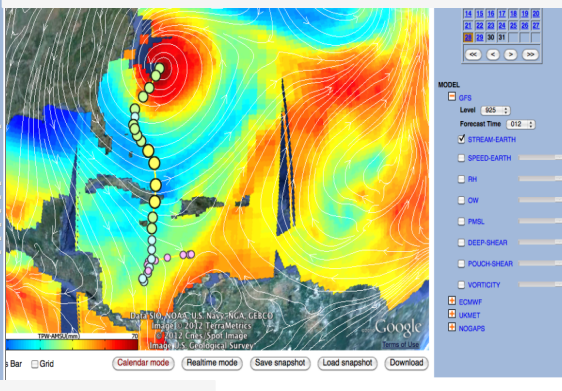


# Motivation for our project - The critical pathways to hurricane forecast improvement

• Is the representation of the precipitation structure correct?



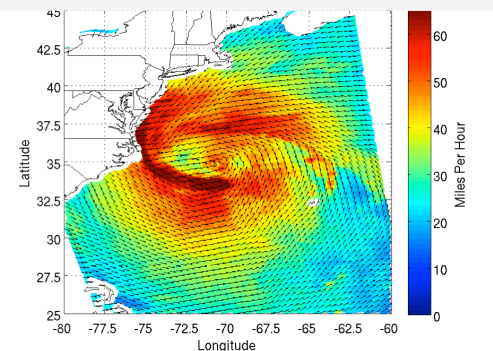
• Is the environment captured correctly?  
• Is the interaction between the storm and its environment realistic?



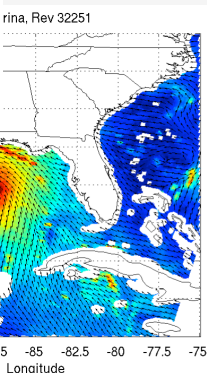
To improve Hurricane Intensity forecasts, we need to understand how well the models reflect the physical processes and their interactions.

**Satellite observations can help in 3 important ways!**

• Is the storm scale and asymmetry reflected properly?



Hurricane Sandy  
As seen by the  
ISRO's OSCAT

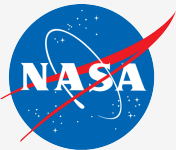


Hurricane Katrina  
As seen by the  
NASA's QuikSCAT

1. Understanding the physical processes
2. Validation and improvement of hurricane models through the use of satellite data
3. Development and implementation of advanced techniques for assimilation of satellite observations inside the hurricane core.

• Despite the significant amount of satellite data today, they are still underutilized in hurricane research and operations, due to complexity and volume.





# The JPL TCIS – Tropical Cyclone Information System

<http://tropicalcyclone.jpl.nasa.gov>

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To facilitate hurricane research, we are developing the JPL Tropical Cyclone Information System (JPL TCIS) of multi-instrument observations and some model data pertaining to:

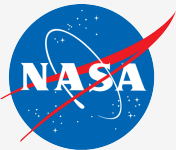
- i) the thermodynamic and microphysical structure of the storms;
- ii) the air-sea interaction processes;
- iii) the larger-scale environment.

This system is being developed under NASA support:

ESTO/AIST funding currently and the Hurricane Science Research Program (HSRP) in the past).

The project is developed in close collaboration with our colleagues from NOAA/EMC and NOAA/AOML/HRD to bring the operational and research versions of HWRF forecasts into the satellite database and to develop a set of on-line analysis tools.





# The JPL TCIS – Tropical Cyclone Information System

<http://tropicalcyclone.jpl.nasa.gov>

## Tropical Cyclone Data Archive

- Satellite depiction of hurricanes over the globe
- 12-year record (1999-2010)
- offers both data and imagery, making it a unique source to support:
  - hurricane research
  - forecast improvement
  - algorithm development
  - instrument design

## HS3 – Interactive NRT Atlantic portal

<http://tropicalcyclone.jpl.nasa.gov/hs3>

- Integrates model forecasts with satellite and airborne observations from a variety of instruments and platforms, allowing for easy model/observations comparisons.
- Allows interrogation of a large number of atmospheric and ocean variables to better understand the large-scale and storm-scale processes associated with hurricane genesis, track and intensity changes.
- Very rich information source during the analysis stages of the field campaigns.

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TROPICAL CYCLONE INFORMATION SYSTEM

Welcome to the JPL Tropical Cyclone Information System

The JPL Tropical Cyclone Information System (TCIS) was developed to support hurricane research. It has two components: a 12-year global archive of multi-satellite hurricane observations and, what was a near real-time portal, that supported the 2010 NASA Genesis and Rapid Intensification Processes (GRIP) hurricane field campaign. Together, data and visualizations from the near-real time system and data archive can be used to study hurricane process, validate and improve models, and assist in developing new algorithms and data assimilation techniques. Below you will find links to various portals where you can view different types of data.

- Introduction
- Team
- Colaborators
- Funding
- Publications

Supertyphoon Pongsona struck the U.S. Island of Guam on Sunday, December 8, 2002. The composite image (left) of the supertyphoon was made by overlaying data from the infrared, microwave, and visible/near-infrared sensors that make up the AIRS sounding system. This storm can also be seen with the standard AIRS Vis/NIR (right).

**Tropical Cyclone Data Archive**

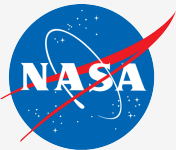
The TCIS Data Archive is a comprehensive tropical cyclone database of multi-parameter satellite observations pertaining to the thermodynamic and microphysical structure of the storms, the air-sea interaction processes and the larger-scale environment. Currently, it contains satellite depictions of hurricanes over the globe from 1999-2010. Users are able to browse through hurricane seasons and ocean basins to find specific storms of interest. The portal is designed to facilitate the finding of coincident observations from multiple instruments, and it provides fast access to pre-subsetted data and plots, making this a unique tool for hurricane research. Additionally, data files can be directly accessed through our [FTP site](#).

**HS3 Data Portal**

This near real-time interactive portal was developed to support the multi-year Hurricane and Severe Storm Sentinel (HS3) aircraft campaign. HS3 is a five year mission with a three year airborne component (2012-2014). The campaign's main goal is to investigate the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. This portal allows users to analyze and compare observation data and model forecasts in the North Atlantic basin from July to November of each year of the campaign.

Site Manager: Svetlita M Hristova-Veleva      PRIVACY      Webmaster: Quoc Vu (JPL Clearance: CL#08-346)



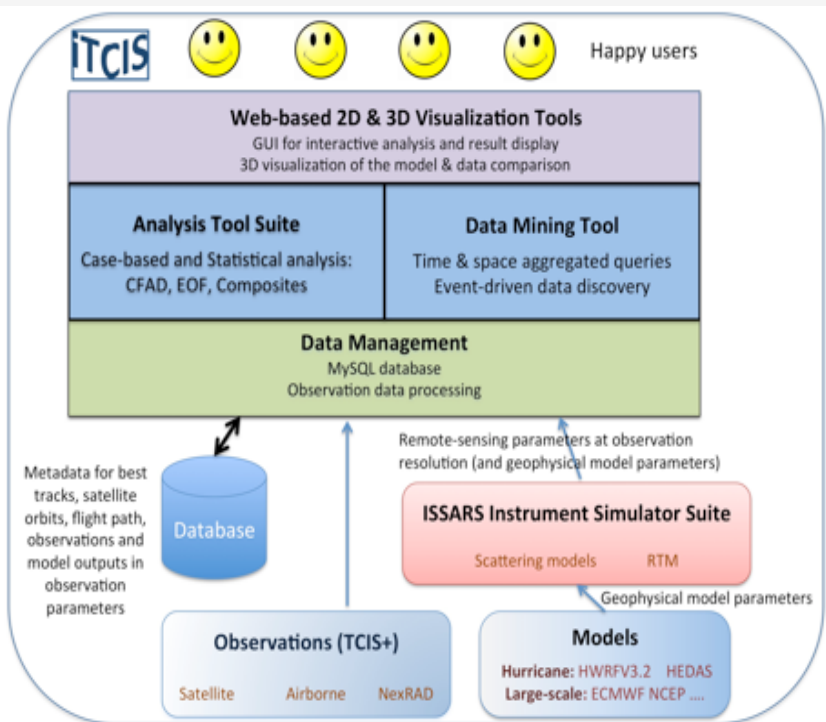


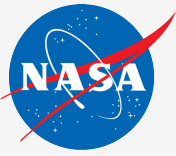
# Goals of our current AIST project

- To develop the technology to provide the fusion of observations (satellite, airborne and surface) and operational model simulations to help improve the understanding and forecasting of the hurricane processes.

We are developing three critical components to allow the merger of observations with model forecasts:

- 1) Couple an instrument simulator (NEOS<sup>3</sup>) with operational hurricane forecast models** and incorporate simulated satellite observables into the existing database of satellite and air-borne observations.
- 2) Develop set of analysis tools** that will enable users to calculate joint statistics, produce composites, compare modeled and observed quantities to facilitate the evaluation of different hurricane models
- 3) Develop visualization to enable analysis** (e.g., data immersion approaches to enable real-time interaction with the models, and visualization of highly complex systems)





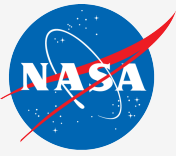
# Outline

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1. Bringing observations and models into a common analysis system and developing interactive visualization tools.
2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators
3. Developing analysis tools with the goals to:
  - Understand the observed structure of the hurricanes
  - Evaluate the models

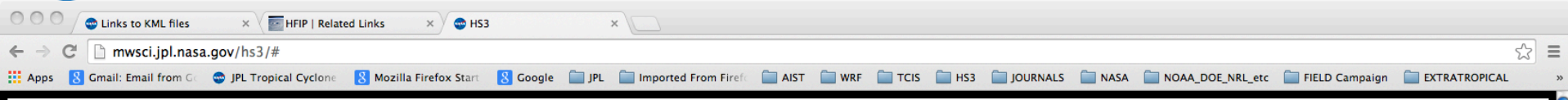




- 
1. Bringing observations and models into a common analysis system and developing interactive visualization tools.



# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>) Features (needs Google Earth API; opens on the latest available PMW observations)



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## HURRICANE AND SEVERE STORM SENTINEL [HS3]

Tropical Cyclone Information System > HS3 Portal

2014-08-25 02:00:00

SATELLITE & AIRCRAFT DATA

MODEL & SIMULATION DATA

GOES IR

"Best Track"

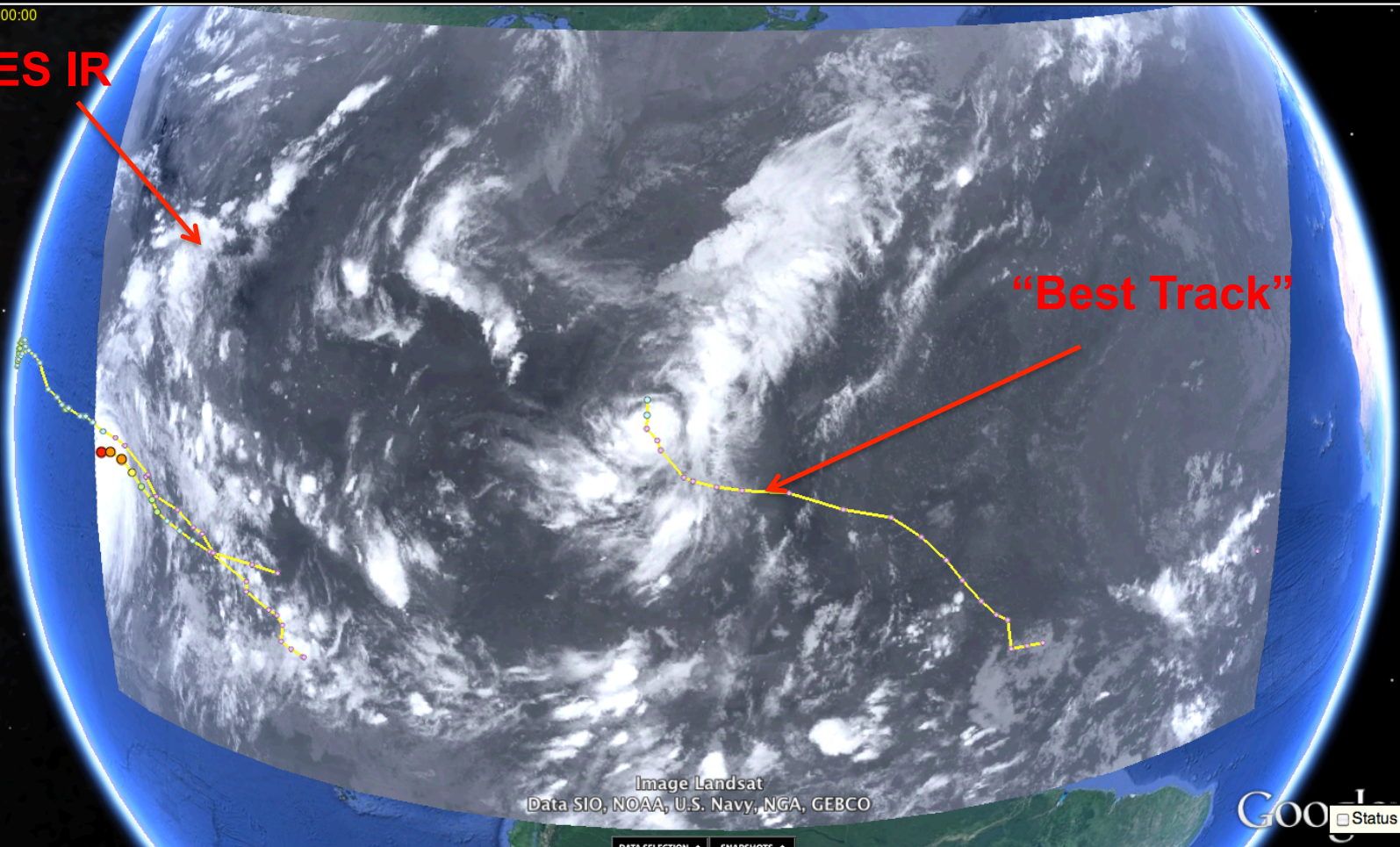
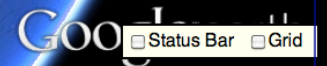


Image Landsat  
Data SIO, NOAA, U.S. Navy, NGA, GEBCO



DATA SELECTION | SNAPSHOTS



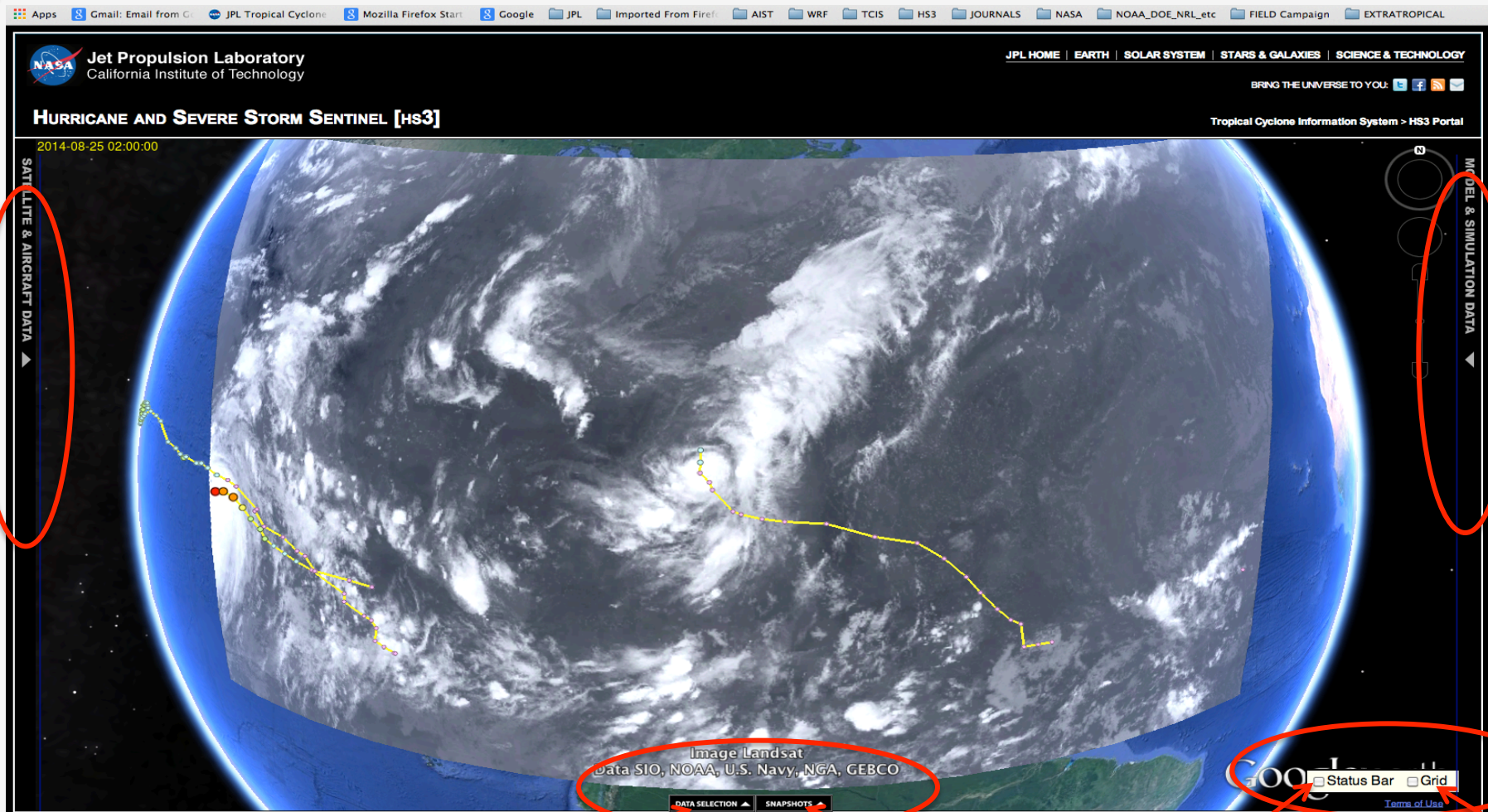


# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>) Features

Two Calendar-driven menus (click on the triangles on the two sides):

- Observations

- Model data

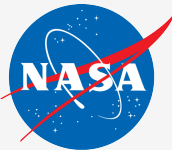


Analysis Tools

Save a view

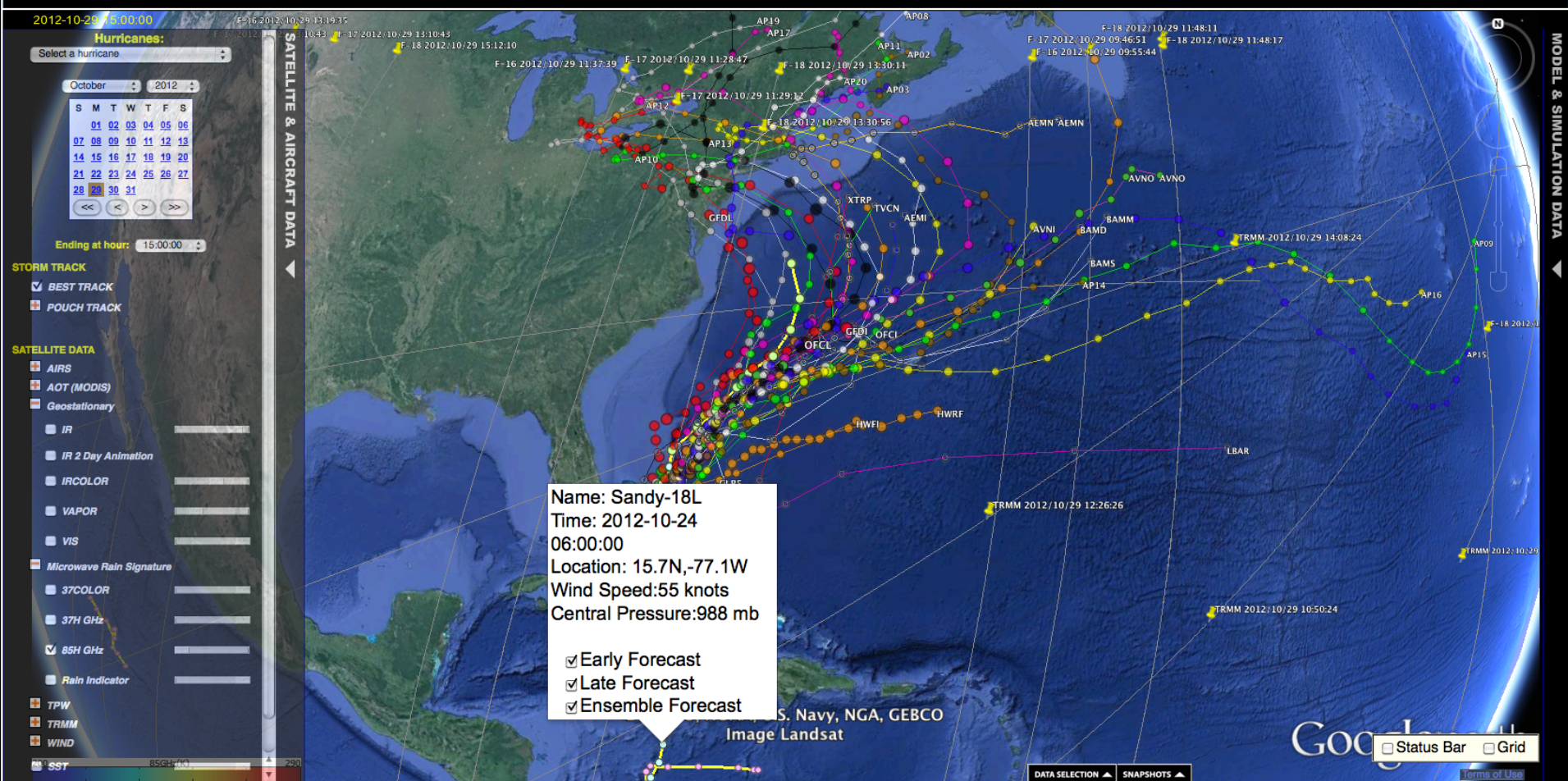
Overlay Grid  
Find lat/lon of a point



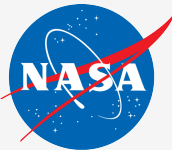


# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>) Forecast Uncertainty 5 days out - Hurricane Sandy (2012)

## HURRICANE AND SEVERE STORM SENTINEL

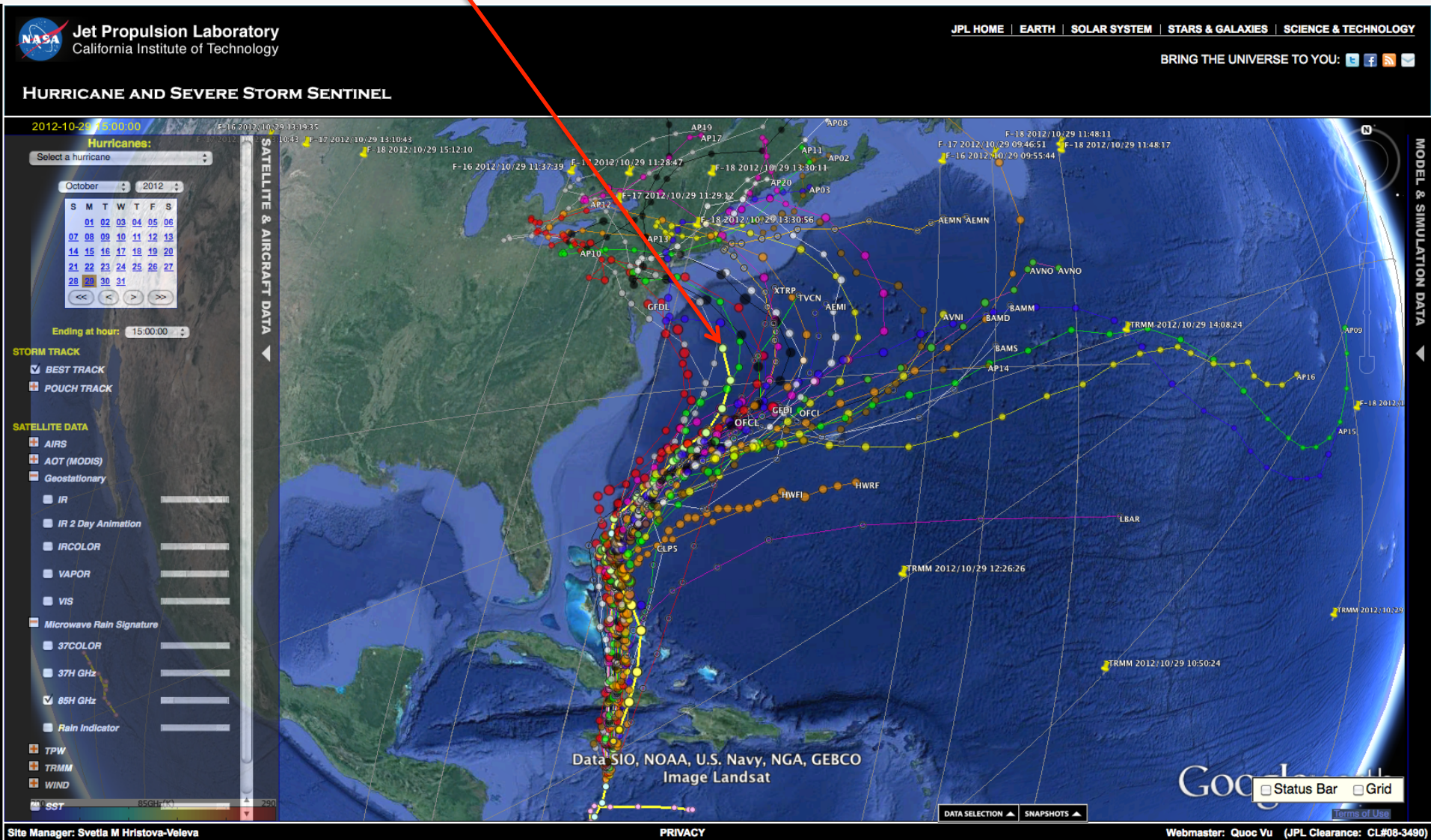




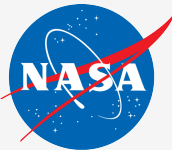


# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>) Forecast Uncertainty 5 days out - Hurricane Sandy (2012)

## Best Track



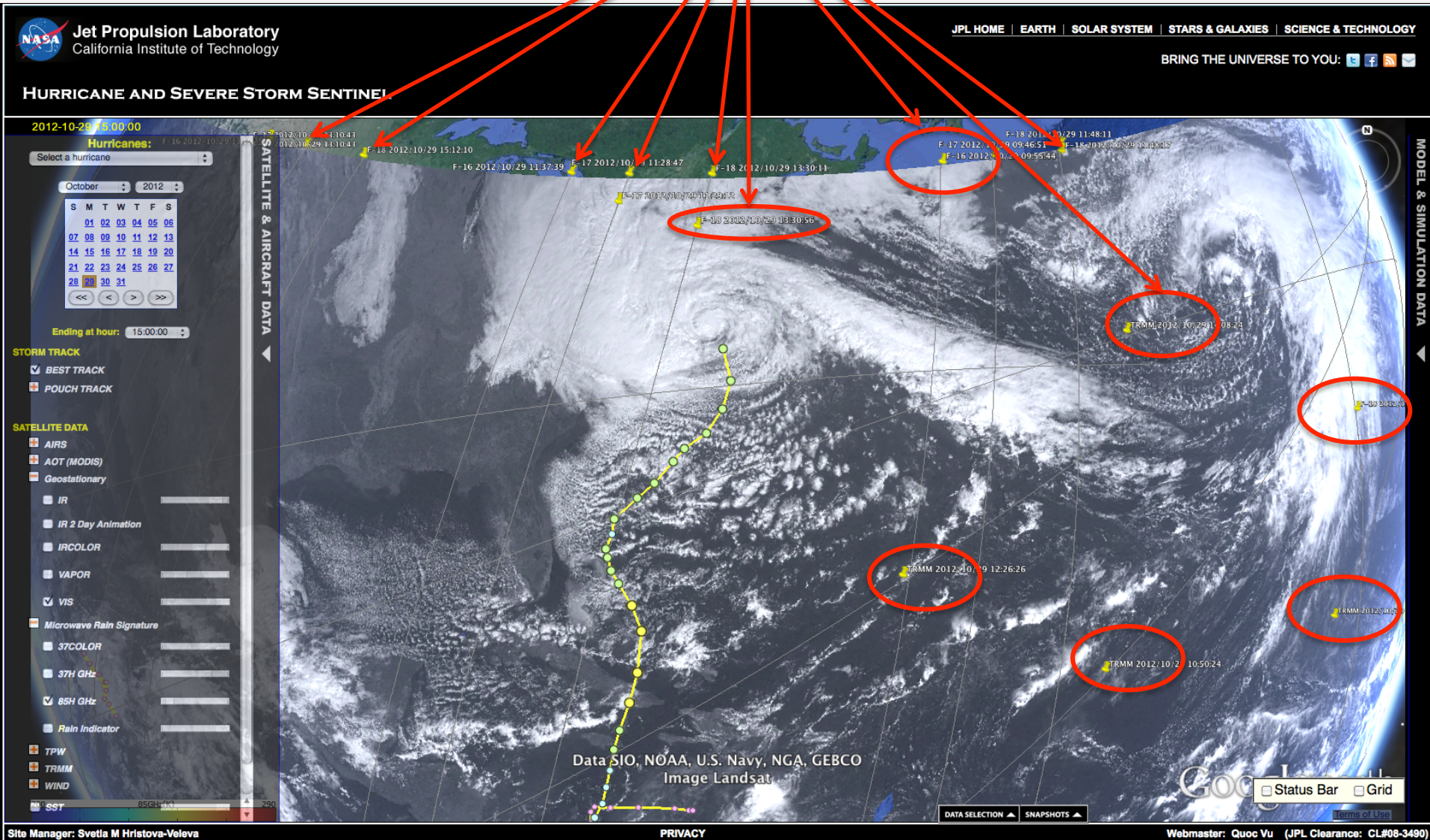




# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>)

## The Power of the Satellite Observations – Hurricane Sandy (2012)

Note the multitude of Polar Orbiting Satellites that supplement GEOS observations







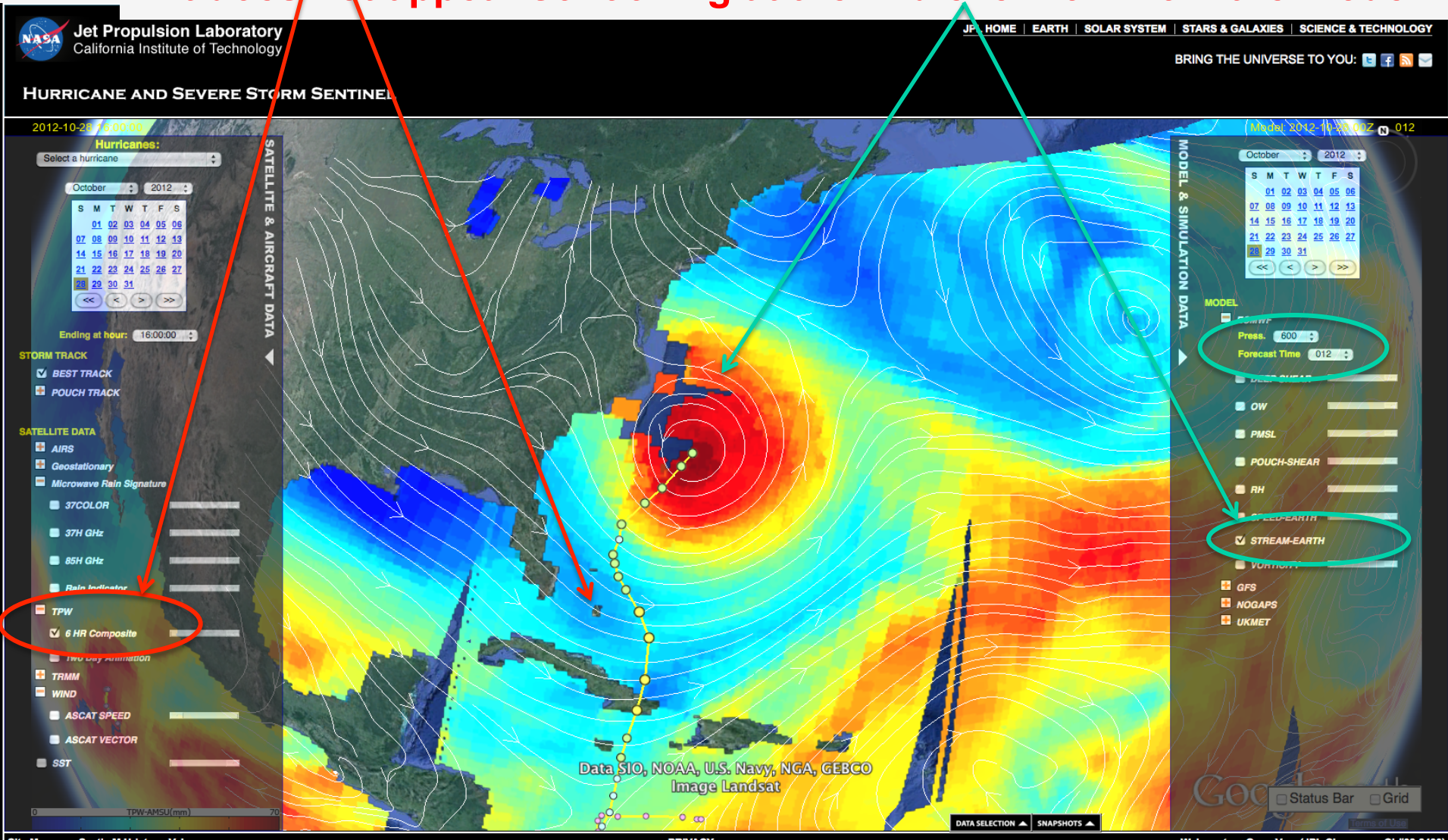




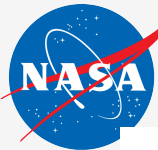
# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>)

## Bringing model and observations together:

- Is the dry air in the environment (low TPW, from satellite observations) entering the storm ???
- It does not appear so looking at the midlevel flow from the model.

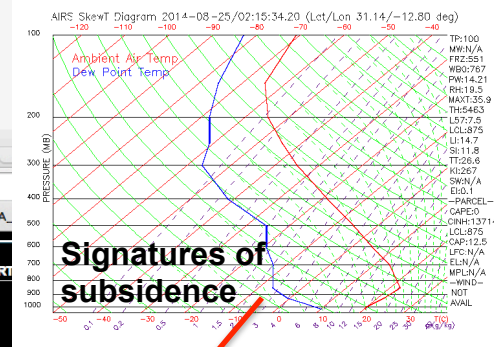
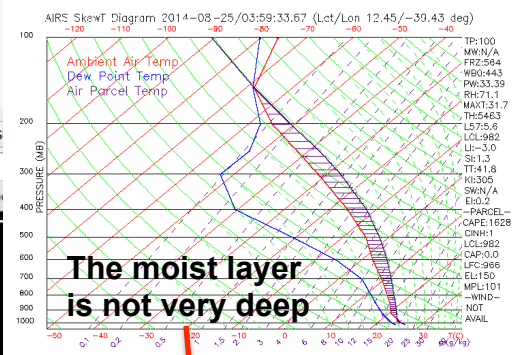
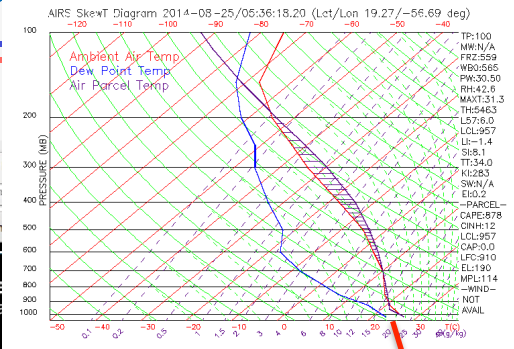






# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>)

## The thermodynamics from AIRS



### HURRICANE AND SEVERE STORM SENTINEL [HS-3]

2014-08-25 08:00:00

Ending at hour: 08:00:00

STORM TRACK

- BEST TRACK
- POUCH TRACK
- P17L
- P21L
- P22L
- P23L

SATELLITE DATA

- AIRS
- CAPE
- RH
- TEMP
- AOT (MODIS)
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- TPW
- 6 HR Composite
- Two Day Animation
- TRMM

2014-08-25/05:36:18.20 (-56.69, 19.270) CAPE:978 SkewT/lot

The current time:

2014-08-25/03:37:43.27 (Lat/Lon 13.15/-32.54 deg)

TP:100  
 MW/N/A  
 FRZ:562  
 WBG:583  
 PW:30.99  
 RH:44.9  
 MAXT:31.3  
 TH54E3  
 L57:5.9  
 LCL:948  
 LI:-1.5  
 SI:7.6  
 TT:34.7  
 KI:285  
 SWN/A  
 EIO:2  
 -PARCEL-  
 CAPE:753  
 CINH:11  
 LCL:948  
 CAP:0.0  
 LFC:987  
 EL:191  
 MPLN:15  
 -WIND-  
 NOT  
 AVAIL

Image Landsat  
 Data SIO, NOAA, U.S. Navy, NGA, GEBCO

2014-08-25/03:58:49.13 (Lat/Lon 13.92/-31.57 deg)

TP:100  
 MW/N/A  
 FRZ:572  
 WBG:774  
 PW:28.82  
 RH:71.0  
 MAXT:30.7  
 TH54E3  
 L57:6.5  
 LCL:959  
 LI:-1.6  
 SI:3.6  
 TT:40.0  
 KI:300  
 SWN/A  
 EIO:2  
 -PARCEL-  
 CAPE:299  
 CINH:8  
 LCL:959  
 CAP:0.0  
 LFC:900  
 EL:303  
 MPLN:166  
 -WIND-  
 NOT  
 AVAIL

Deep moist layer

MODEL & SIMULATION DATA

Model: 2014-08-25 00Z N 012

August 2014

ECMWF  
 Press: 850  
 Forecast Time: 01Z

- SPEED-COMOVING
- STREAM-COMOVING
- P17L
- P21L
- P23L
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR

Site Manager: Svetla M Hristova-Velva

PRIVACY

Bar Grid

Terms of Use

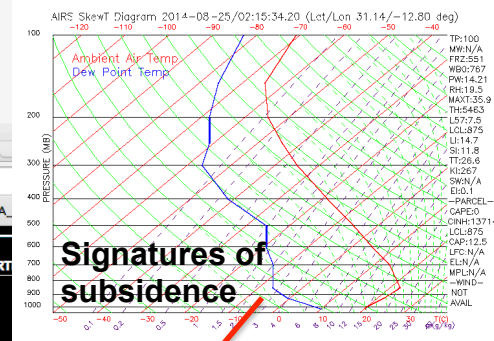
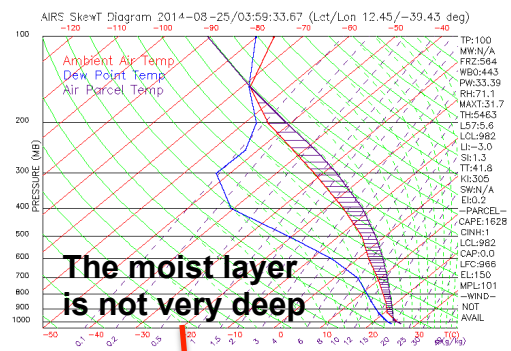
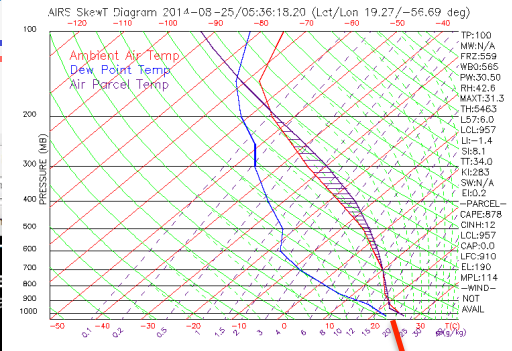
Distance: CL#08-3490





# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>)

## The thermodynamics from AIRS and the AOT from MODIS



### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-25 00:00:00

Ending at hour: 08:00:00

**STORM TRACK**

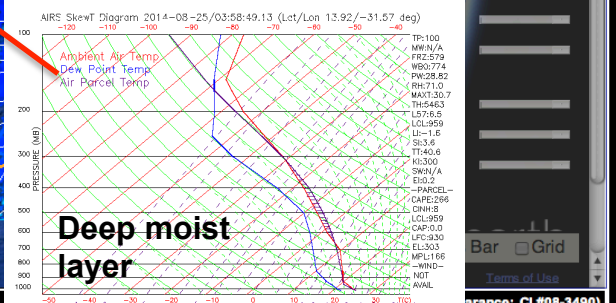
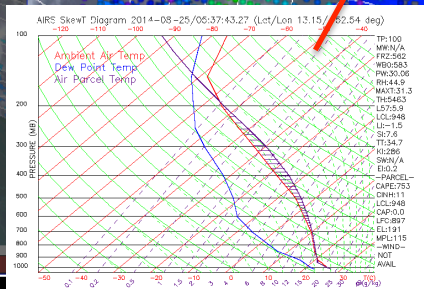
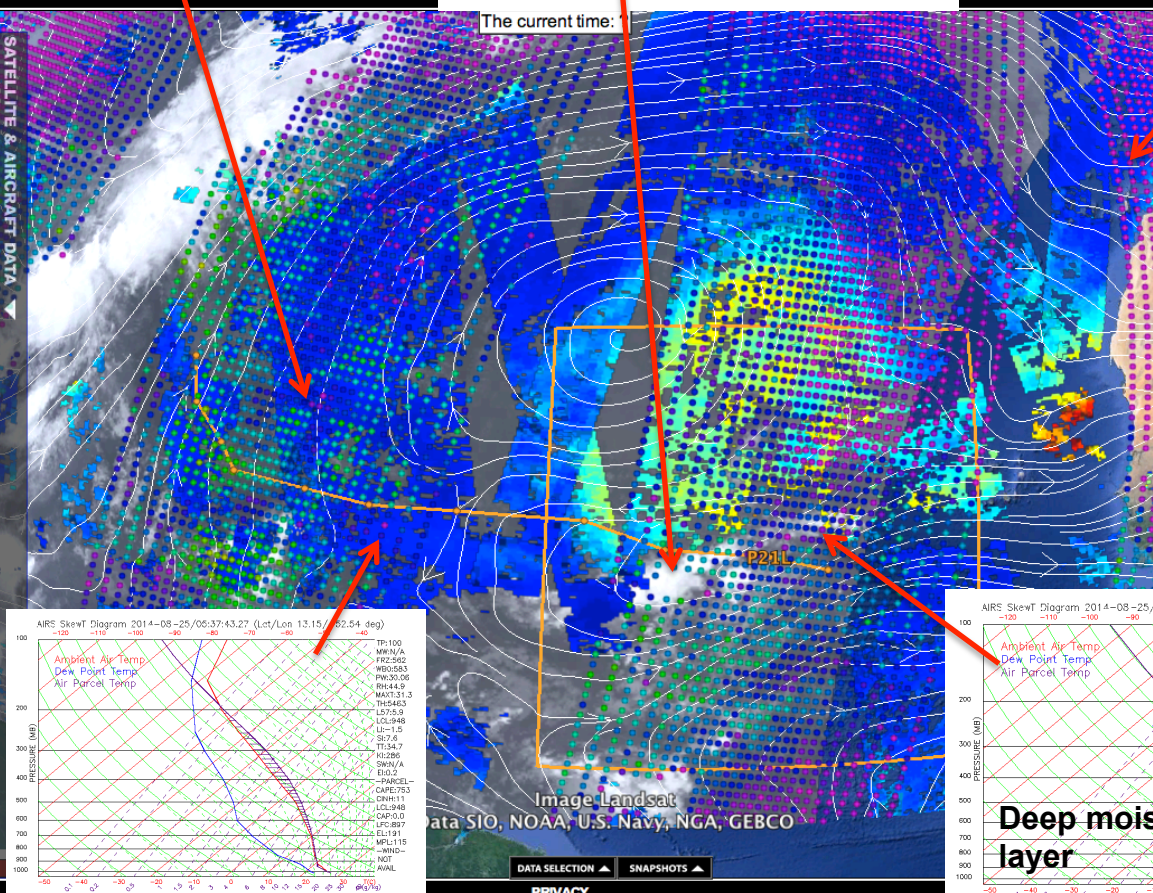
- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- CAPE
- LI
- RH Press: 200
- TEMP Press: 200
- AOT (MODIS)
- AOT-AQUA
- AOT-FINE-AQUA
- AOT-FINE-TERRA
- AOT-TERRA
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- TPW
- 6 HR Composite
- Two Day Animation
- WIND

CAPE: 4500

Site Manager: Svetla M Hristova-Velova



Tropical Cyclone Information System > HS3 Portal

Model: 2014-08-25 00Z 012

August 2014

MODEL & SIMULATION DATA

- ECMWF
- Press: 850
- Forecast Time: 012
- SPEED-COMOVING
- STREAM-COMOVING
- P17L
- P21L
- P23L
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR

Bar Grid

Distance: CL#08-3490

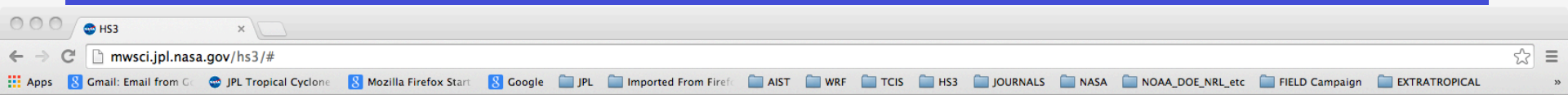








# Understanding what is this structure in the model – Tim Dunkerton called it "leopard's fur" pattern in ecmwf RH in the boundary layer



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## HURRICANE AND SEVERE STORM SENTINEL [hs3]

Tropical Cyclone Information System > HS3 Portal

2014-08-11 12:00:00

Hurricanes: Julio (08/01-08/13, 2)

August 2014

S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 12:00:00

**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- AOT (MODIS)
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VIS**
- Microwave Rain Signature
- TPW
- TRMM
- WIND
- CALIPSO
- CloudSet
- SST

**MODEL & SIMULATION DATA**

MODEL: ECMWF

Press: 925

Forecast Time: 012

- SPEED-COMOVING**
- STREAM-COMOVING**
- P13L
- P17L
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- GFS
- NAVGEM
- UKMET

Simulation: HWRF-CRTM-012 Status Bar [Grid] HWRF-CRTM-03

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat

DATA SELECTION | SNAPSHOTS





# Understanding what is this structure in the model – Tim Dunkerton called it "leopard's fur" pattern in ecmwf RH in the boundary layer

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## HURRICANE AND SEVERE STORM SENTINEL [hs3]

Tropical Cyclone Information System > HS3 Portal

2014-08-11 12:00:00

Model: 2014-08-11 00Z 012

Hurricanes: Julio (08/01-08/13, 2)

August 2014

S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 12:00:00

**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- AOT (MODIS)
- Geostationary
  - IR
  - IR 2 Day Animation
  - IRCOLOR
  - WARP
  - VIS**
- Microwave Rain Signature
- TPW
- TRMM
- WIND
- CALIPSO
- CloudSet
- SST

**MODEL & SIMULATION DATA**

MODEL

- ECMWF
- Press: 925
- Forecast Time: 012
- SPEED-COMOVING**
- STREAM-COMOVING**
- P13L
- P12L
- P17L
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- GFS
- NAVGEM
- UKMET

**Simulation**

- HWRF-CRTM-012 Status Bar
- Grid
- HWRF-CRTM-03

Transparency Sliders

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat

DATA SELECTION | SNAPSHOTS

Site Manager: Svetla M Hristova-Velova | PRIVACY | Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)



# Understanding what is this structure in the model?

Tim Dunkerton called it "leopard's fur" pattern in ECMWF boundary layer RH

The model/obs overlay collaborates his suggestion that "shallow overturning circulations are responsible for vorticity and RH anomalies alike in these regions". The Sc in the visible imagery are well correlated with the model's RH and vorticity fields (not shown).

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### HURRICANE AND SEVERE STORM SENTINEL [H33]

Tropical Cyclone Information System > H33 Portal

2014-08-11 12:00:00

Hurricanes: Julio (08/01-08/13; 2)

August 2014

S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 12:00:00

**SATellite & AIRCRAFT DATA**

**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- AOT (MODIS)
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- TPW
- TRMM
- WIND
- CALIPSO
- CloudSat
- SST

**MODEL & SIMULATION DATA**

**MODEL**

- ECMWF

Press: 925

Forecast Time: 012

- SPEED-COMMOVING
- STREAM-COMMOVING
- P13L
- P17L
- P17L
- DEEP-SHEAR
- OW
- PMSL
- POUCH TRACK
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY

**SIMULATION**

- HWRF-CRTM-D1atus Bar
- Grid
- HWRF-CRTM-D3

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat

Site Manager: Svetla M Hristova-Veleva  
PRIVACY  
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)





# TC-IDEAS



- JPL TC Information System
- About GRIP
- Collaboration
- GRIP Mission Page
- NASA Hurricanes

### Observation Data

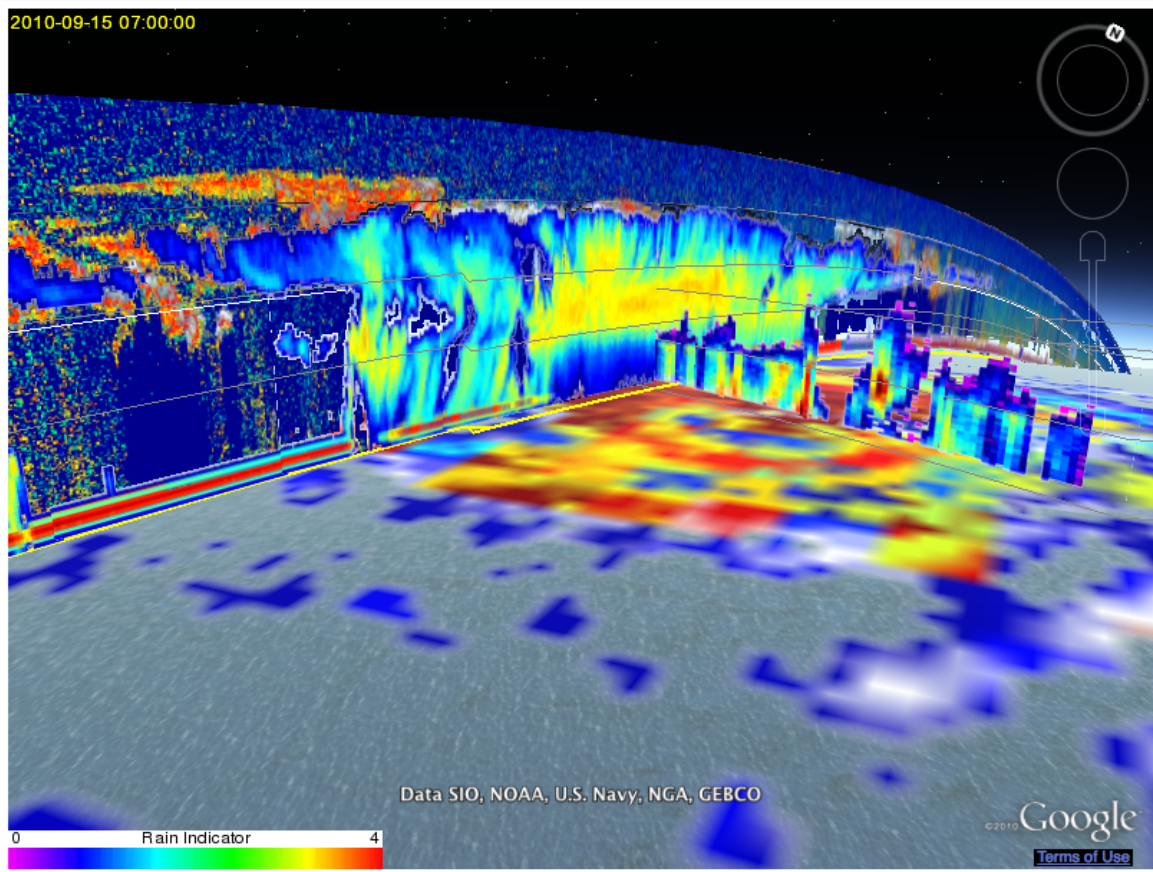
September 2010

Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

At hour: 07:00:00

- STORM TRACKS
  - Best Tracks
  - Pouch Tracks
    - PG141L
    - PG143L
    - PG144L
    - PG145L
- SATELLITE DATA
  - SST
  - OHC
  - Wind (ASCAT)
  - TPW (AMSU-A)
  - RH-AIRS Press. Level: 850
  - CAPE-AIRS
  - LI-AIRS
  - Geostationary
    - GOES-IR
    - GOES-VAPOR
    - GOES-VIS
  - 85GHZ
  - 37GHZ
  - Rain
  - TRMM PR Curt3

The current time is Tue, 07 Jun 2011 07:03:33 GMT



Status Bar  Grid

Animation:  Observation Data  Model Data

Select a time range to animate: (from 2010-09-14 17:00:00 to 2010-09-15 17:00:00)

Start: 2010-09-14 19:00:00 End: 2010-09-15 19:00:00 Animation Step: 1 hour

Animate Stop Download

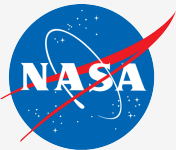
### Model Data

September 2010

Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

- MODEL DATA
  - Pressure Level: 850
  - Forecast Time: 000
- GFS
  - Speed Earth Relative
  - Streamline Earth Relative
  - PGI41L
  - PGI43L
  - PGI44L
  - PGI45L
  - PGI46L
  - Relative Humidity
  - OW
  - Vorticity
  - Deep shear
  - Pouch shear
  - Sea Level Pressure
- ECMWF
- UKMET
- NOGAPS



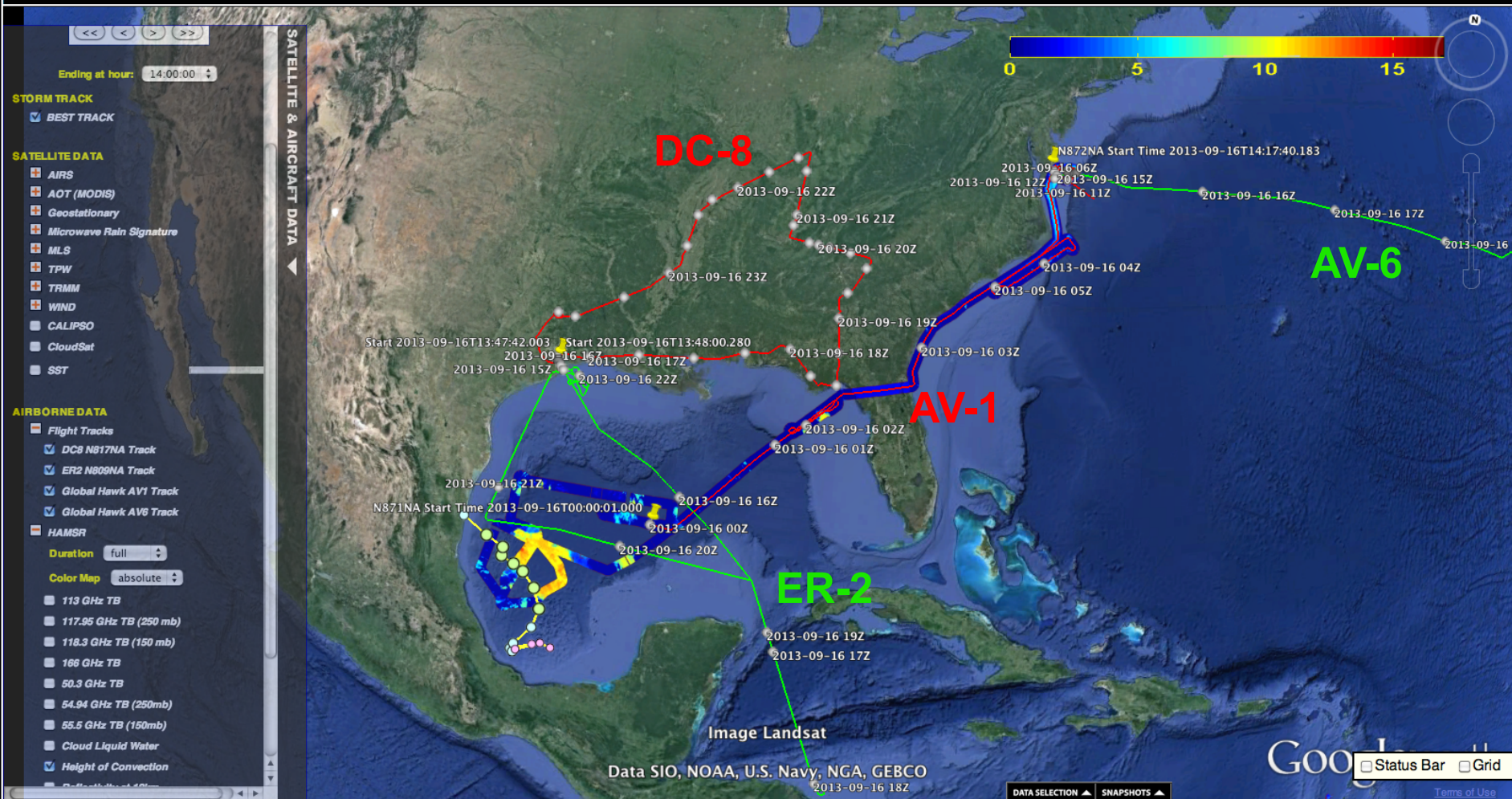


# Airborne Science: HS3 and SEAC4RS

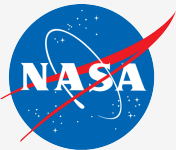
## 2013-09-16; 14Z - Ingrid;

### AV-1 (HAMSR), AV-6, ER2, DC8

#### HURRICANE AND SEVERE STORM SENTINEL











# Airborne Science: SEAC4RS-2013-09-04; 14Z

## Vertical Cross-section from APR-2 (on DC-8);

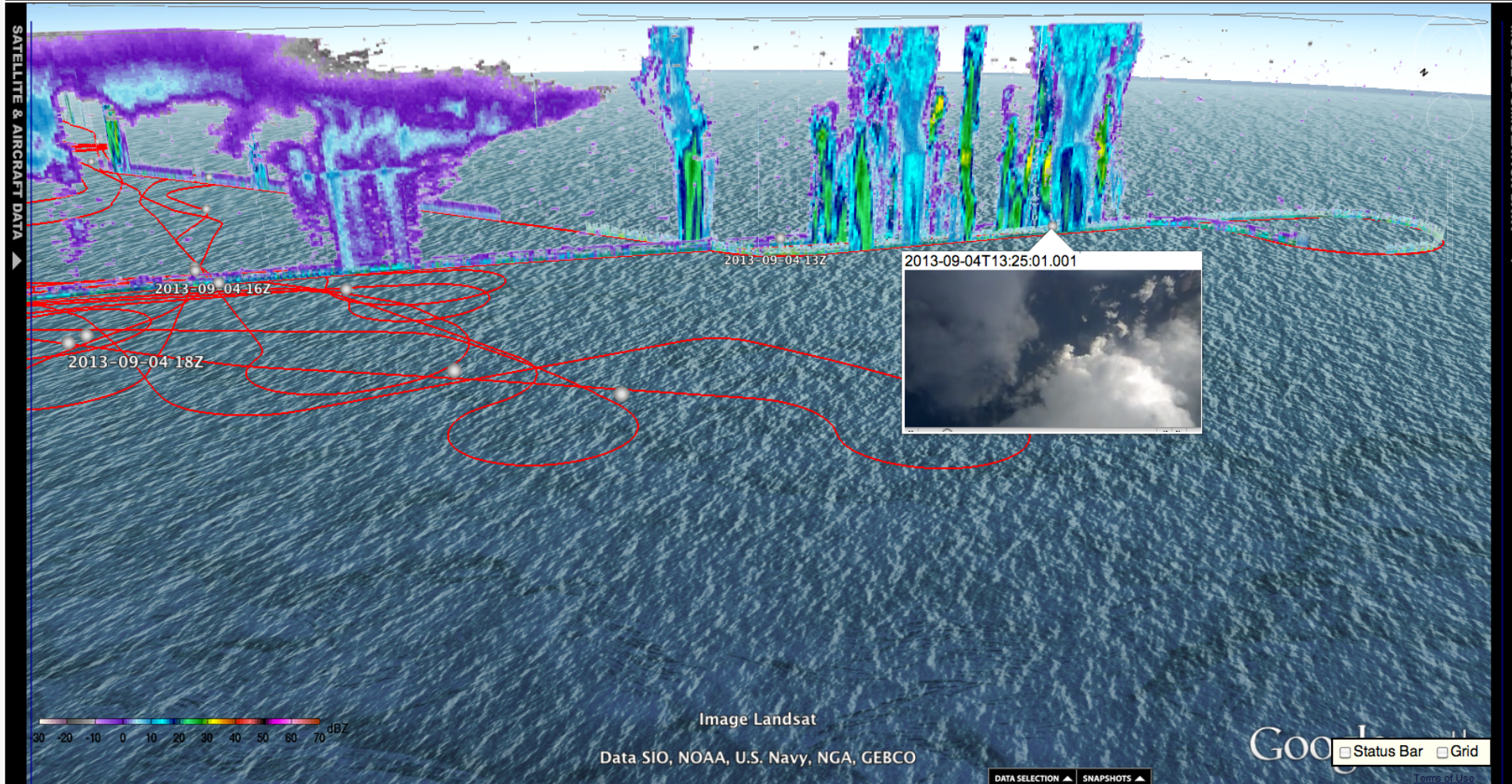
### Nadir-viewing Camera Movies

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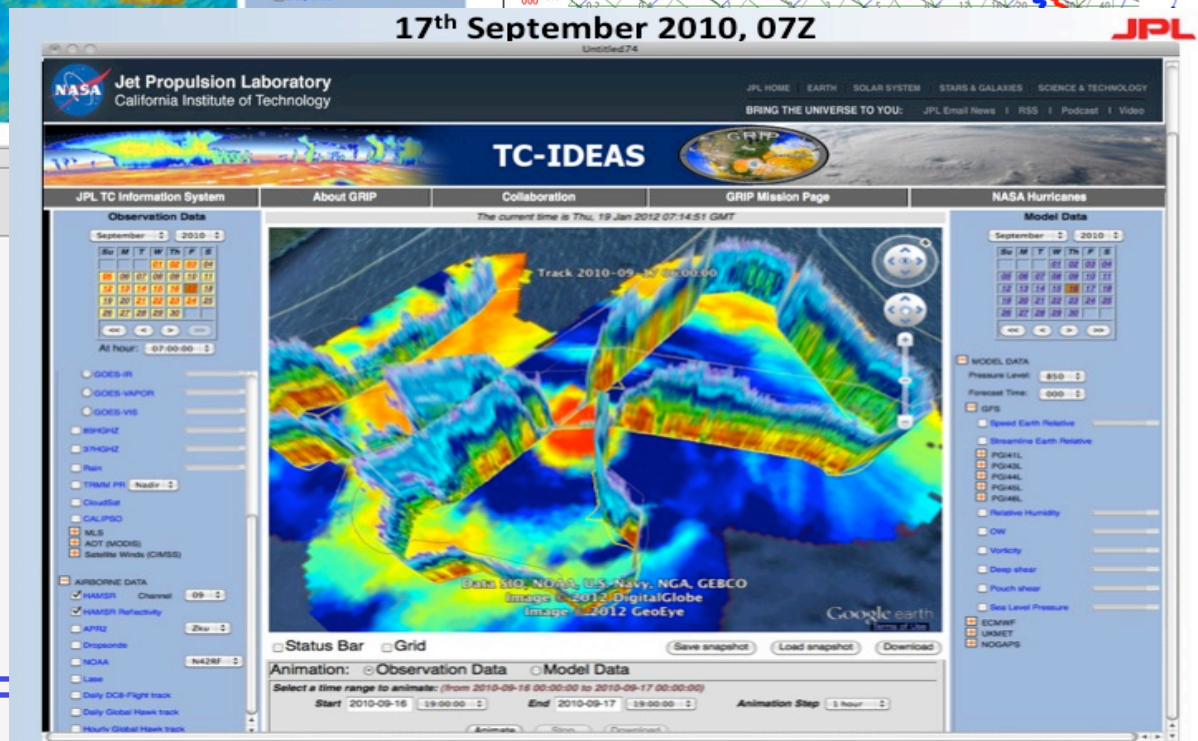
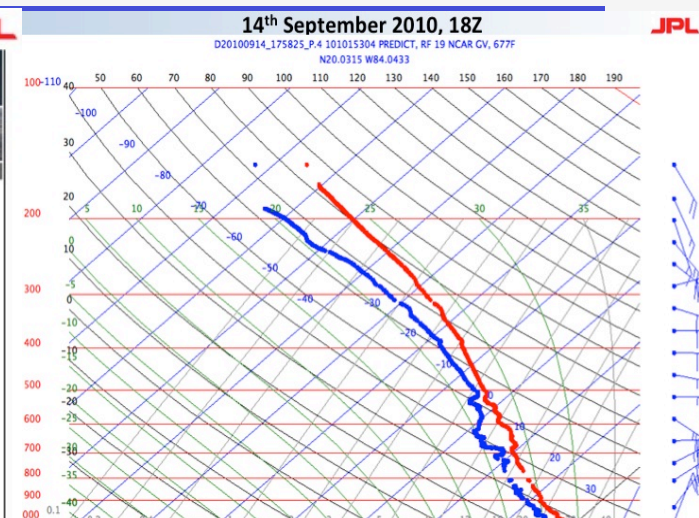
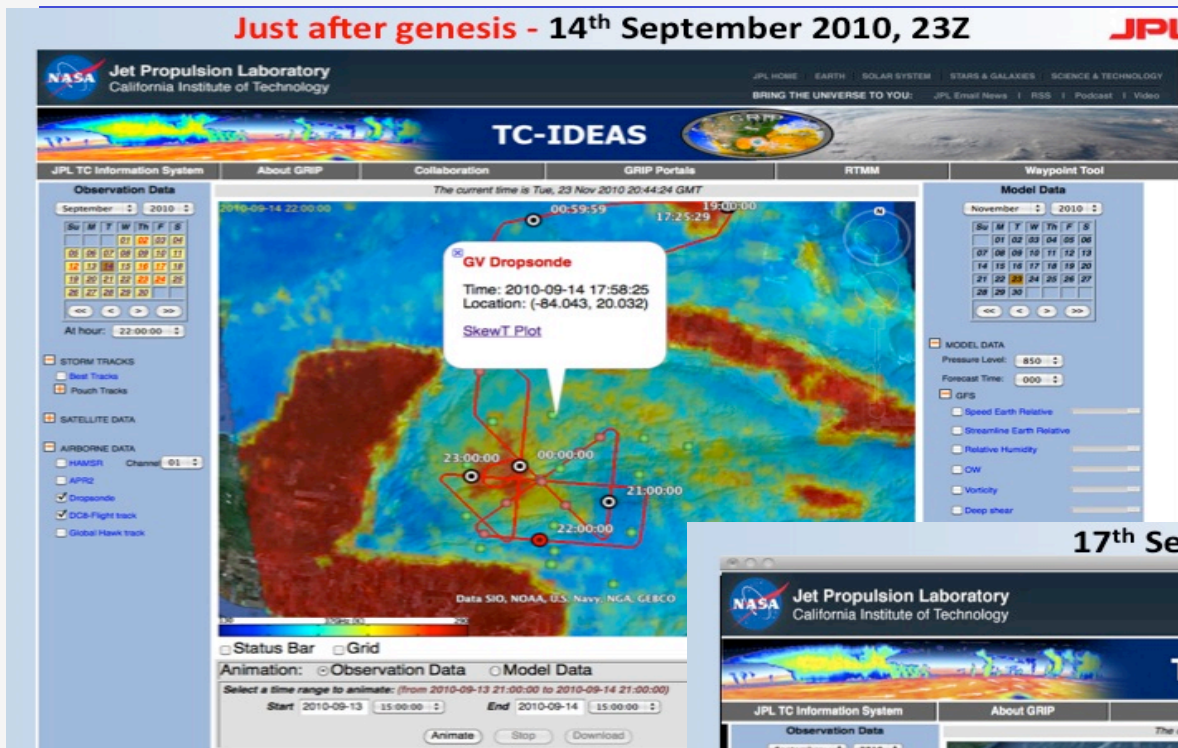
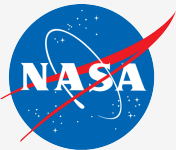
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#### HURRICANE AND SEVERE STORM SENTINEL



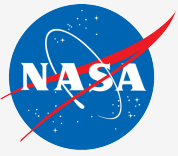




### Hurricane Karl:

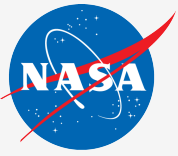
### Genesis and Rapid Intensification from

- satellite,
- airborne and
- in-situ observations



- 
1. Bringing observations and models into a common analysis system and developing interactive visualization tools.
  2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators

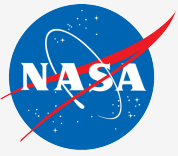




# Motivation: How to Evaluate the Models

---

- **In situ observations** to distinguish between different modeling approaches and improve on the most promising ones.
- These point measurements cannot adequately reflect the space and time correlations characteristic of the convective processes.
- An **alternative approach** to evaluating model assumptions is to:
  - **bring model and observations into a common analysis system**
  - use **multi-parameter remote sensing observations**. In doing so, we could:
    - Compare modeled to retrieved **geophysical parameters**.
      - The satellite retrievals, however, carry their own uncertainty.
    - Compare synthetic to observed **remote-sensing parameters** using **instrument simulators to produce satellite observables from the model**
      - Benefits:
        - » **Increased fidelity of the evaluation results**
        - » **Ability to improve model forecast through data assimilation that also uses the instrument simulators**



# Projecting the operational forecasts into the observational space.

---

- The components of this effort included:
  1. the use of an instrument simulator (the NASA Earth Observing System Simulator Suite - NEOS<sup>3</sup>) to forward simulate microwave radiances and radar reflectivity – *see the talk by Noppasin Niamsuwan at 4:30pm*
    - at the frequency, polarization and observation geometry of the existing instruments (TRMM, AMSR-E, SSMIS)
    - using as input the hydrometeors and the thermodynamic fields produced by the operational forecast models
  2. the development of a strategy for sampling of the model fields according to the characteristics of the existing missions/instruments
    - NOTE – need to sample the model as the satellites sample the globe:
      - Model forecasts are presented as snapshots in time
      - Satellite observations sample the globe at various times
  3. the incorporation of the sensor simulations into the database of satellite and airborne observations. The incorporation strategy includes tools for visualization of models and observations in a common framework.

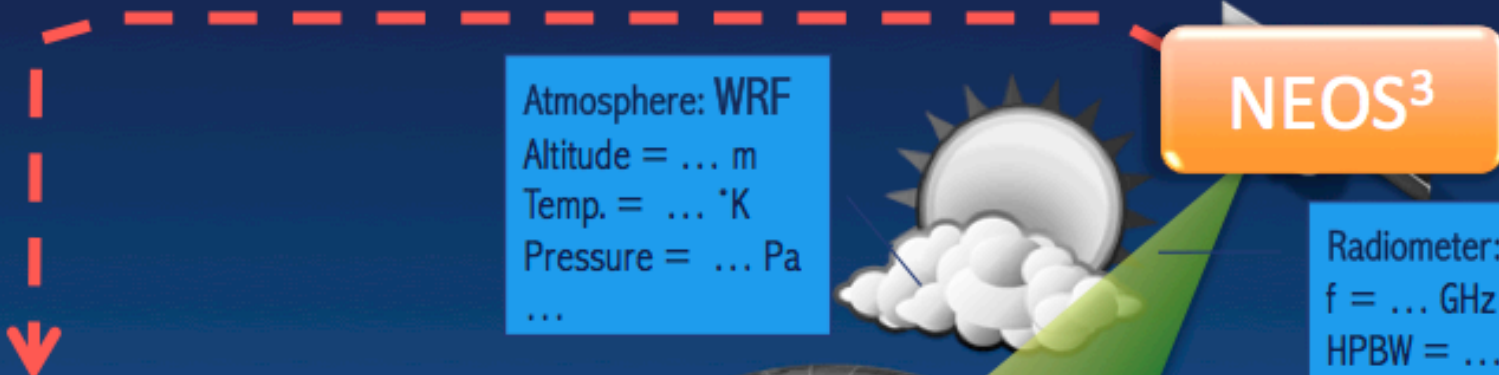


# NEOS<sup>3</sup> : Purpose

PI S. Tanelli: AIST-08 and AIST-11  
See Noppasin's talk at 4:30pm



... to simulate satellite observables from the using as input the hurricane forecast model

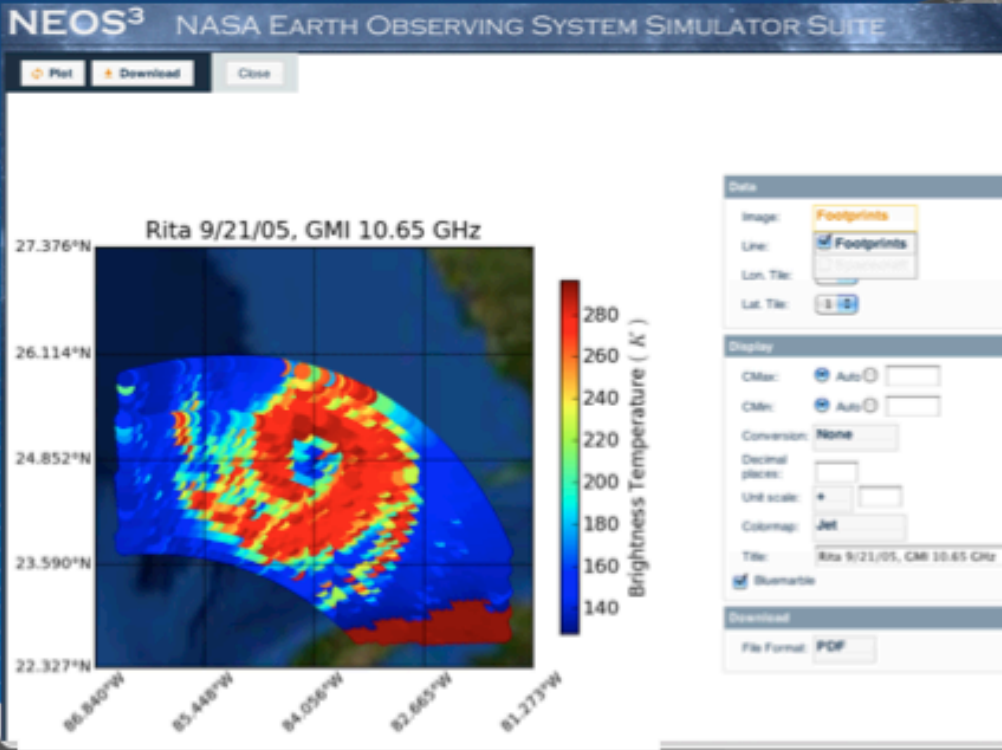


Atmosphere: WRF  
Altitude = ... m  
Temp. = ... °K  
Pressure = ... Pa  
...

NEOS<sup>3</sup>

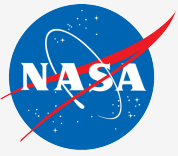
Radiometer: SOI  
f = ... GHz  
HPBW = ... °  
...

Surface: LIS  
Temp. = ... °C  
Surf. wind = ... m/s  
...



LIS: Land Information System  
SOI: Successive Order of Interaction  
WRF: Weather Research Forecasting Model





---

## 2. The framework for satellite-like sampling of the model

- ✓ Developed the **criteria for triggering NEOS<sup>3</sup>, driven by input from the portal.**
- ✓ **Designed scripts to** provide (from the observations) information to NEOS<sup>3</sup>

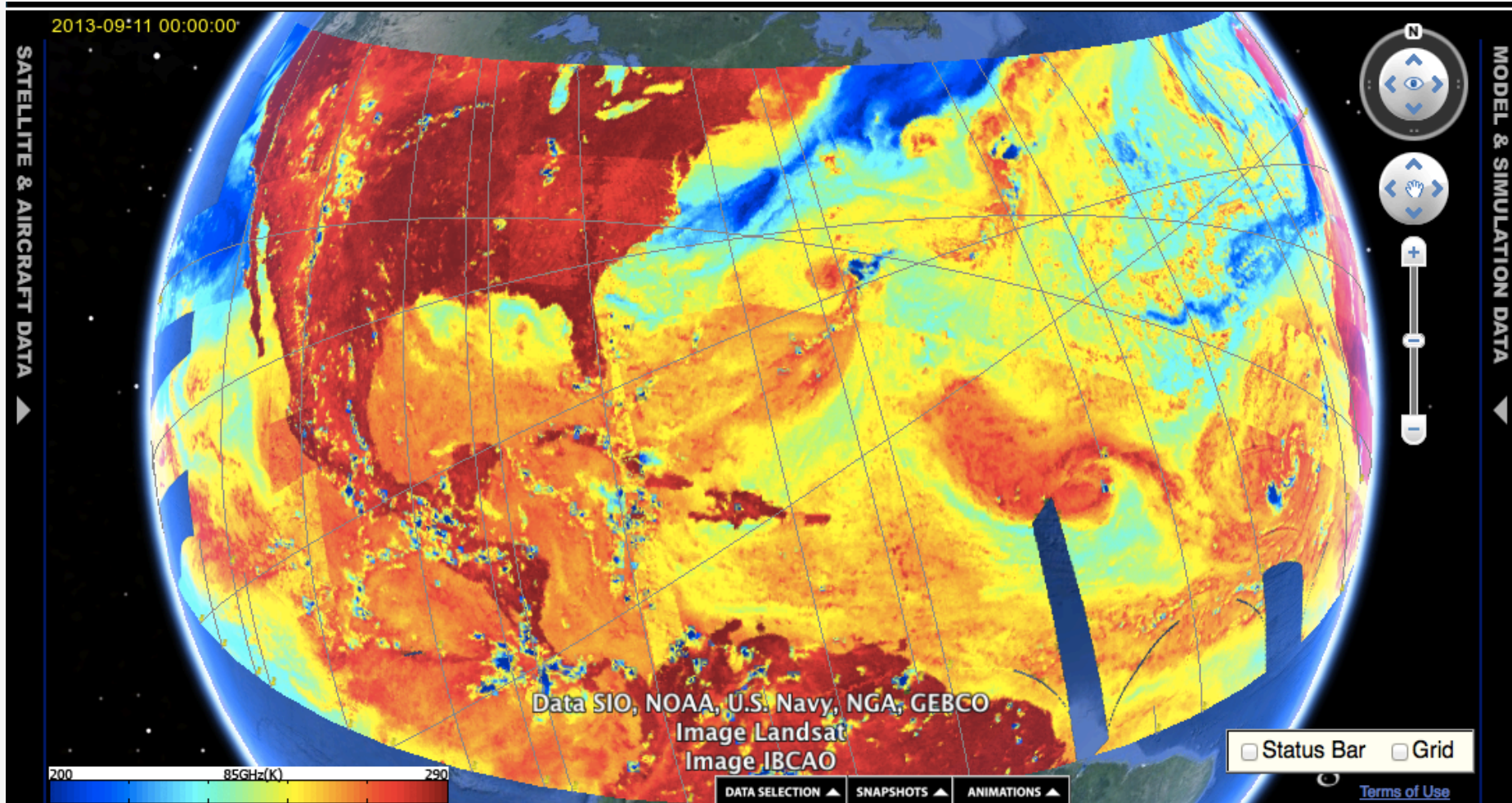
regarding the:

- **Satellite orbit type by:**
  - mission – NOAA (F16-F18) vs TRMM vs AQUA;
  - ascending vs descending orbit
- **Orbit specifics**
  - **Time/longitude/latitude** of the satellite.
- **Selected instrument, SSMI/S vs TMI vs AMSR-E, thus specifying:**
  - frequency, polarization
  - viewing geometry (azimuth, incidence angle, Field-Of-View)

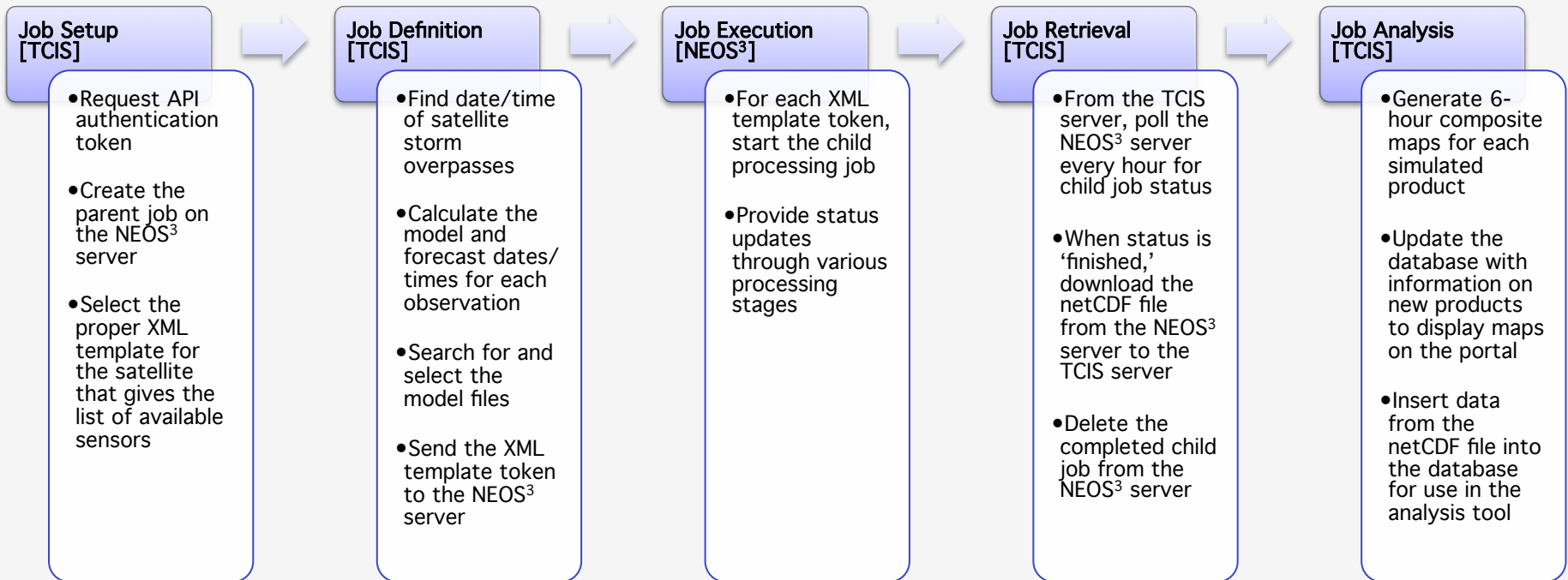


 **TCIS-NEOS<sup>3</sup> Automated Interaction – TCIS Job Definition**

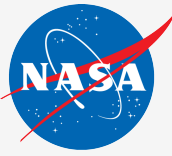
The microwave brightness temperature products are 6 hour composite from multiple sensors, including TMI, SSMI, SSMI/S, and AMSR-2. One satellite location is extracted from each track and sent to NEOS<sup>3</sup> via a TOKEN PUT request.



The TCIS and NEOS<sup>3</sup> servers interact through a series of Python scripts that request and send XML documents, using pre-defined RESTful webservice.

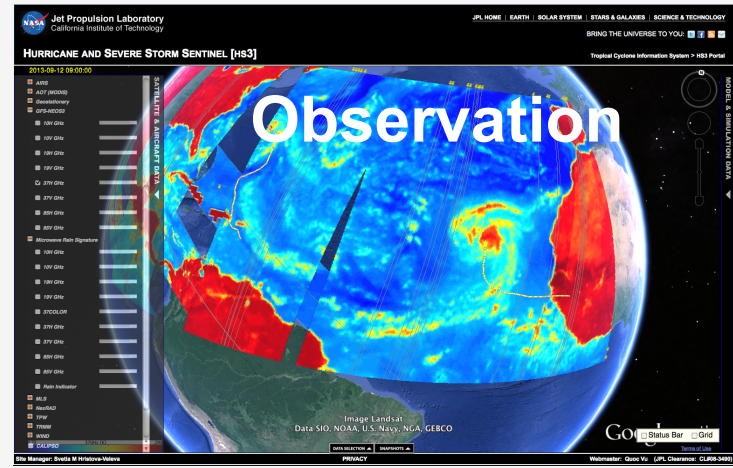
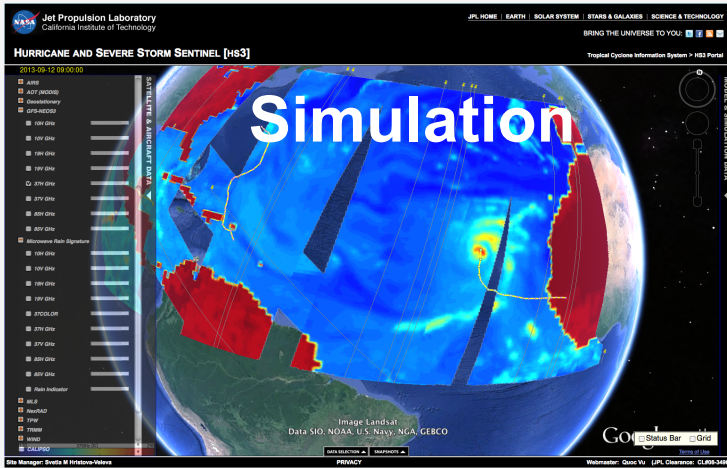






# TCIS-NEOS<sup>3</sup> Automated Integration – SUMMARY

- TCIS uses NEOS3 to simulate brightness temperature observed by multiple instruments: TMI, AMSR2, SSMI, and SSMI/S
  - Access to a suite for instrument simulators
  - Possible to specify explicit microphysics assumption; some additional libraries were contributed by TCIS

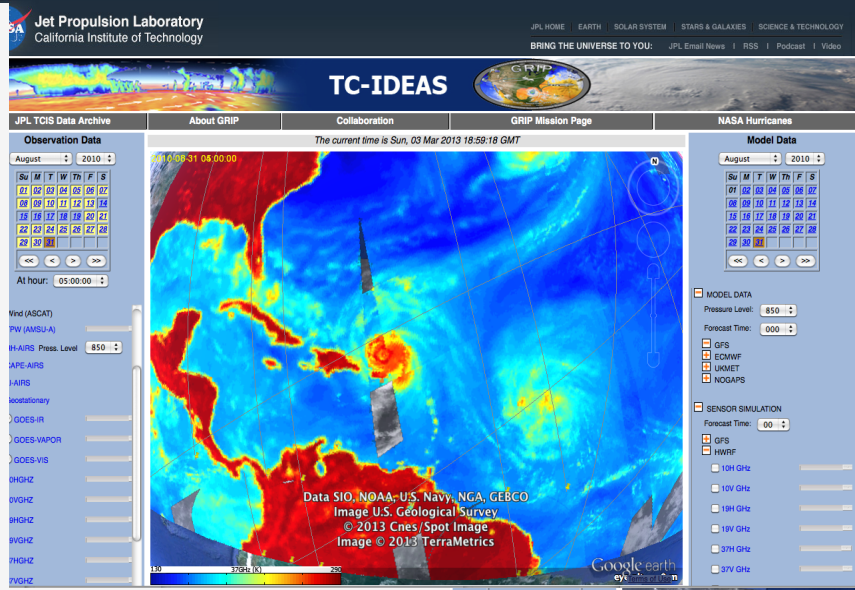


- Submit a simulation request, check the simulation status, and retrieve the simulation product via NEOS<sup>3</sup>'s secured web service
- Computation performance of NEOS<sup>3</sup> is *important* for this process to be practically useful.
  - ~100s simulation jobs of a few hours each for global coverage. High resolution input models (e.g., ECMWF) also demand relatively large memory (on the orders of GBs)

# FUSION OF MODELS AND OBSERVATIONS

Integrating hurricane model forecasts with satellite & airborne observations from a variety of instruments and platforms

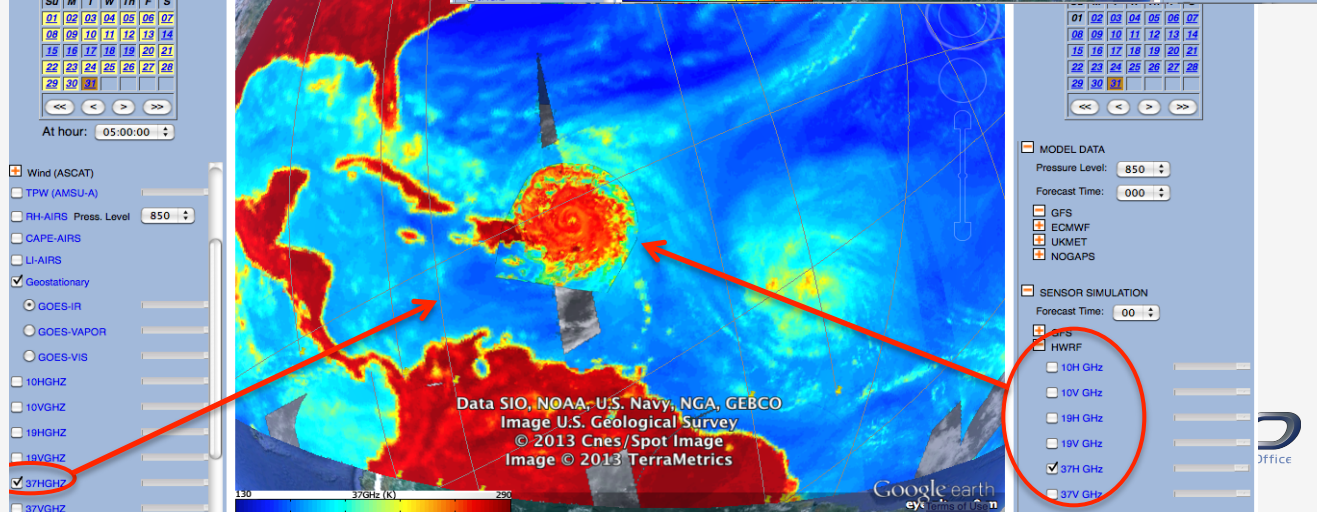
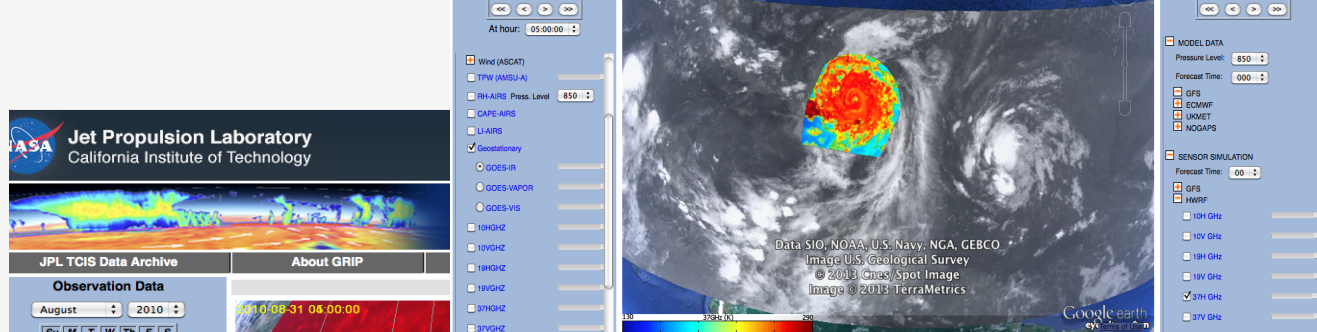
- Research HWRF model forecasts were used as input to NEOS<sup>3</sup>
- Considered are the model microphysical assumptions; the instrument characteristics and sampling
- The synthetic “satellite observations” were:
  - Incorporated in the database of satellite obs.
  - Visualized in the portal
- Limited # of cases!
- Not in NRT!



## Satellite Observations



## Synthetic Observations from Model





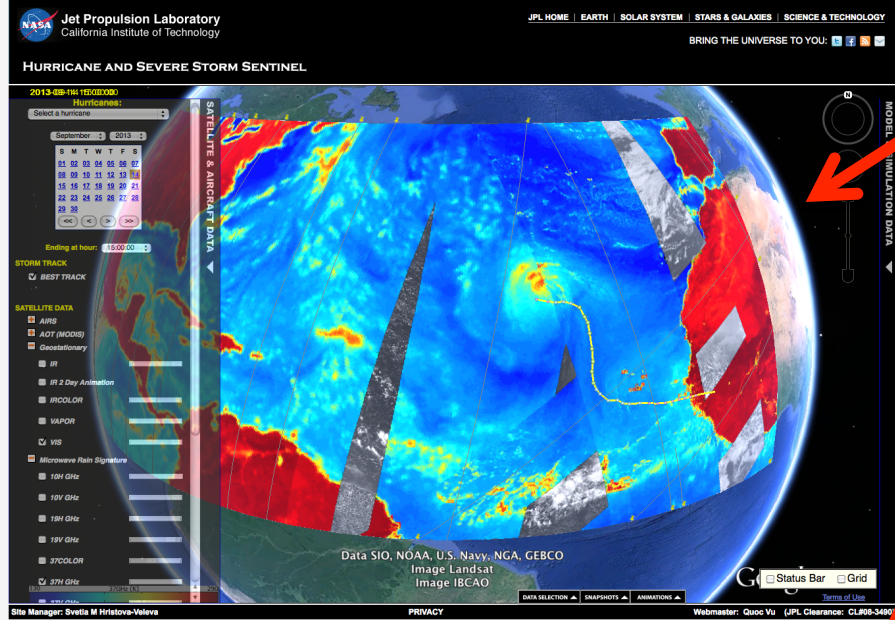
# FUSION OF MODELS AND OBSERVATIONS - OPERATIONALLY

Operational HWRf model forecasts are used as input to CRTM

- Incorporated in the database of satellite obs.
- Visualized in the portal

## Why use a second source?

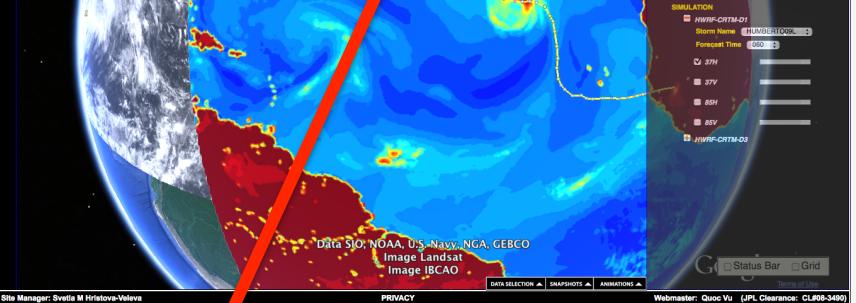
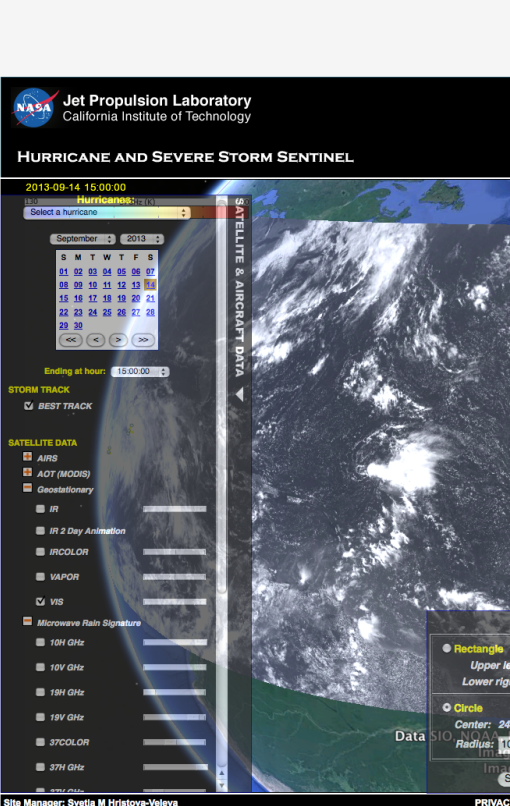
Including simulations from the same NWP model (say HWRf) but produced by different forward simulators and under different micro-physical & electromagnetic assumptions (as in NEOS<sup>3</sup> and CRTM) will help reveal the uncertainty that comes from the forward modeling itself.



Satellite Observations



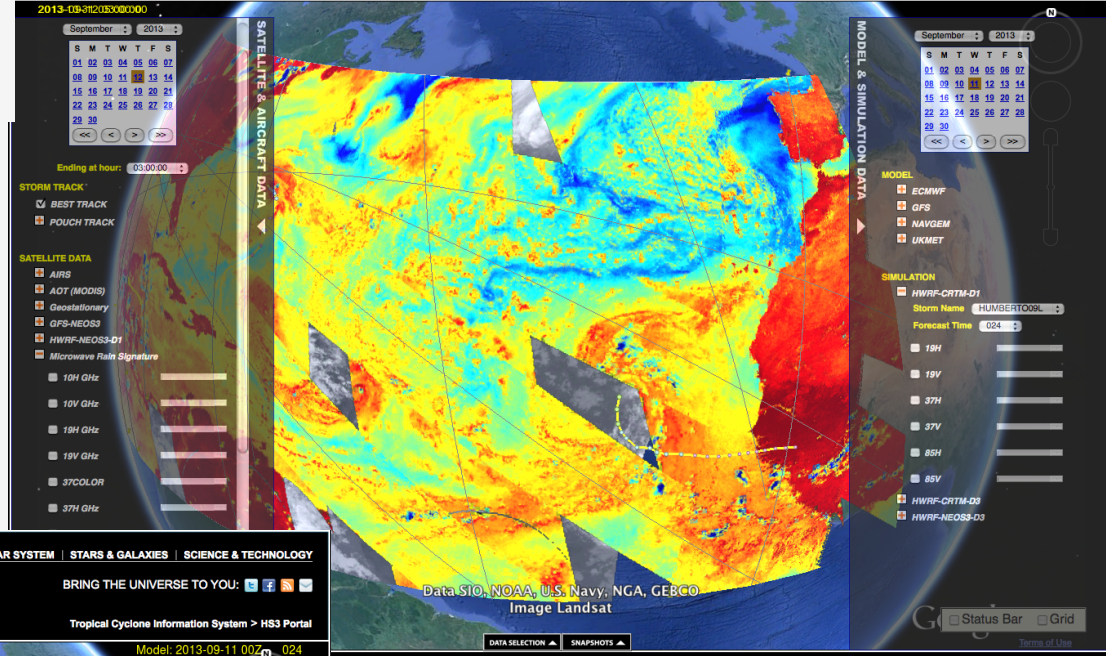
Synthetic Observations from Model



### HURRICANE AND SEVERE STORM SENTINEL [HS3]

# OBSERVATIONS

BRING THE UNIVERSE TO YOU: [social icons]  
Tropical Cyclone Information System > H3S Portal



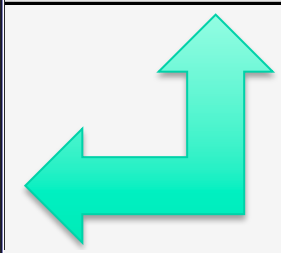
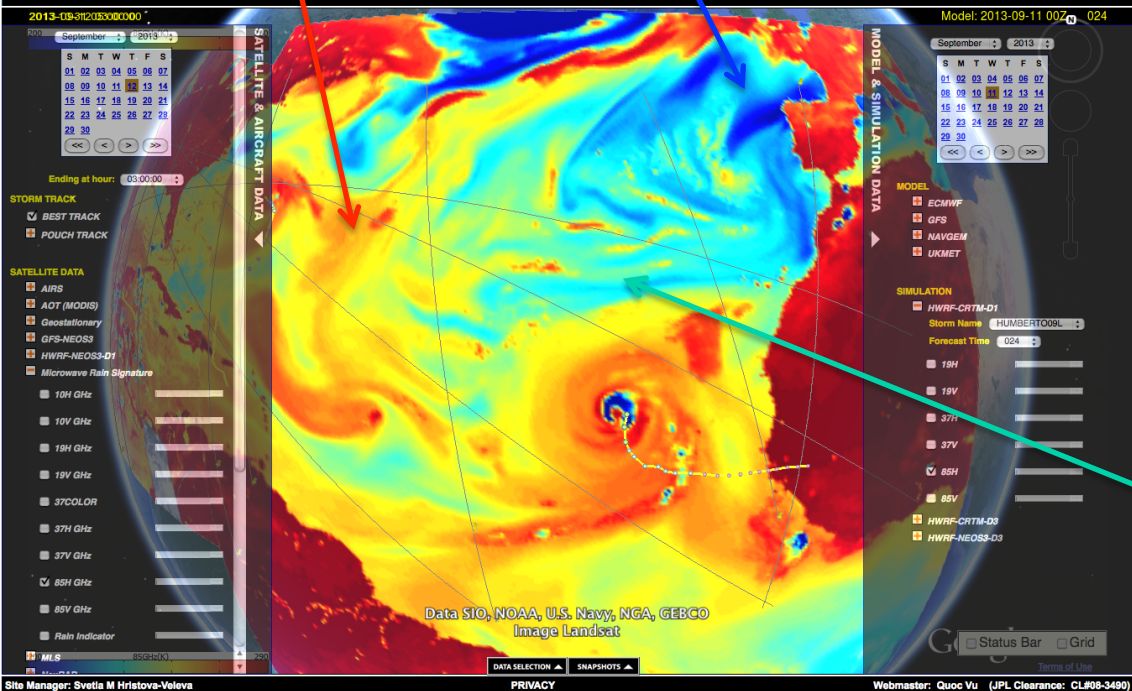
**DRY AIR**

**MOIST AIR**

### HURRICANE AND SEVERE STORM SENTINEL [HS3]

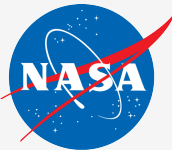
# MODEL

BRING THE UNIVERSE TO YOU: [social icons]  
Tropical Cyclone Information System > H3S Portal

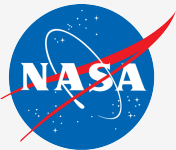


- Overall – a very good comparison
- Area north of the hurricane is a bit too moist in the model

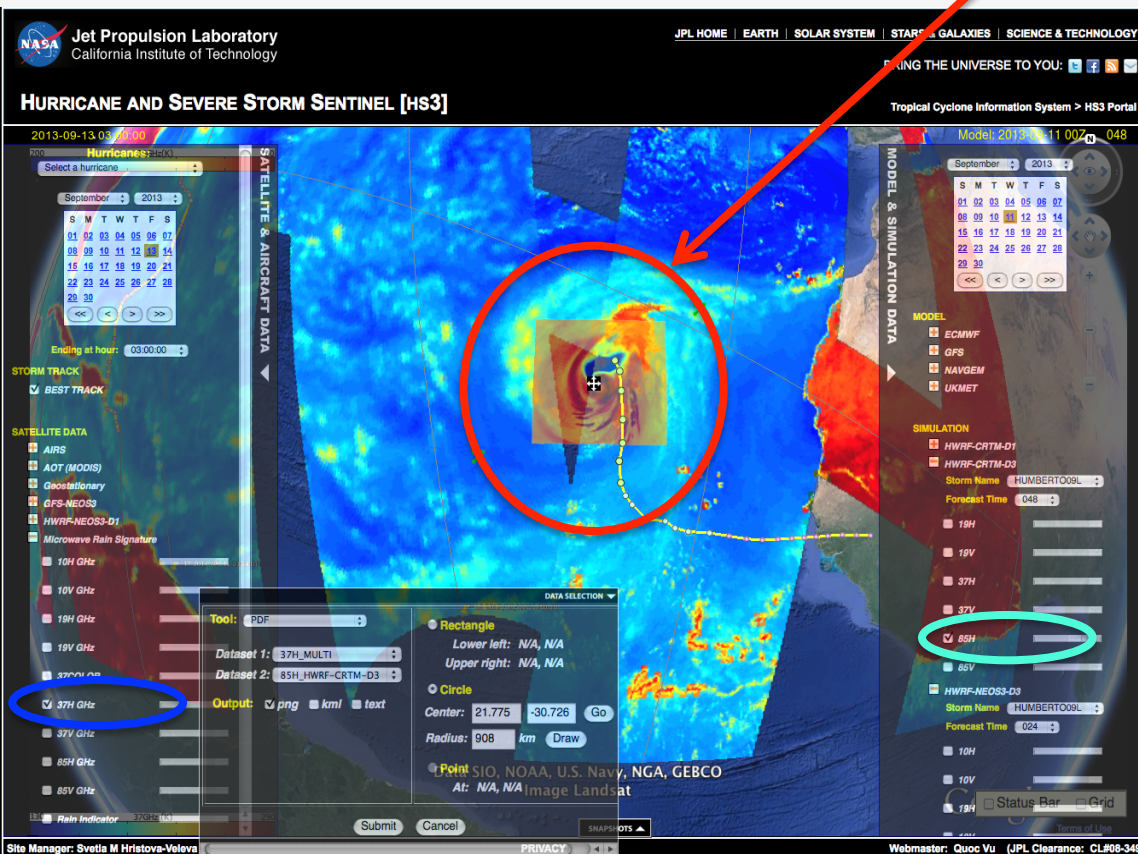




- 
1. Bringing observations and models into a common analysis system and developing interactive visualization tools.
  2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators
  3. **Developing analysis tools with the goals to:**
    - Understand the observed structure of the hurricanes
    - Evaluate the models

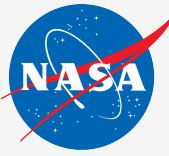


# Analysis tools for model validation



- Interactively select region
- Gather data from observed and synthetic
  - brightness temperatures
  - radar reflectivity
- Statistical comparisons
  - Storm-relative coordinates
  - EOFs, CFADs
  - Azimuthal averages =f(r)
  - Wave-number analysis =f(r)
- Storm Structure
  - Object classification
  - Metrics for model/obs object
- Visualization of analysis





# Interactive tool for data analysis: Implementation Flow Diagram

Select the Products, the time period and the region of interest from the HS3 Portal

- Select a date/time from either the observation calendar or the model calendar
- Display the products of interest by checking the menu buttons on the observation or the model panel
- Select a region of interest by using the Rectangle or Circle selection tool

(Google Earth API, Java Script, PHP)



Subset the data

- Query the database to retrieve all the observations that satisfy the selection criteria
- Prepare data in the format required for the analysis tool

(MySQL, Python)



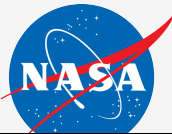
Run the analysis tool and generate the statistical results in form of graphics or text

(Matlab, Fortran, IDL, web services, etc..)



Display the results back to the portal

(Image pop up, tables, GE overlays)



# The Selection Tool

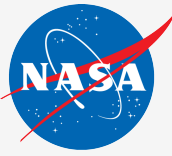
1. Select the region of interest
  - Circle, Square, Point
2. Select the tool (e.g. PDF)
3. Select two frequencies
4. Submit the job ...

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California Institute of Technology

JPL

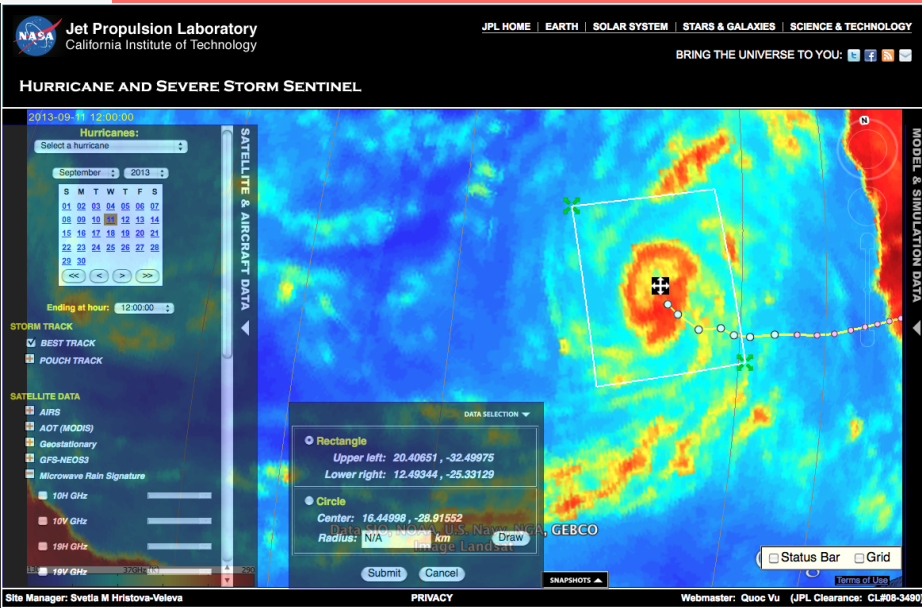
**HURRICANE AND SEVERE STORM SENTINEL**



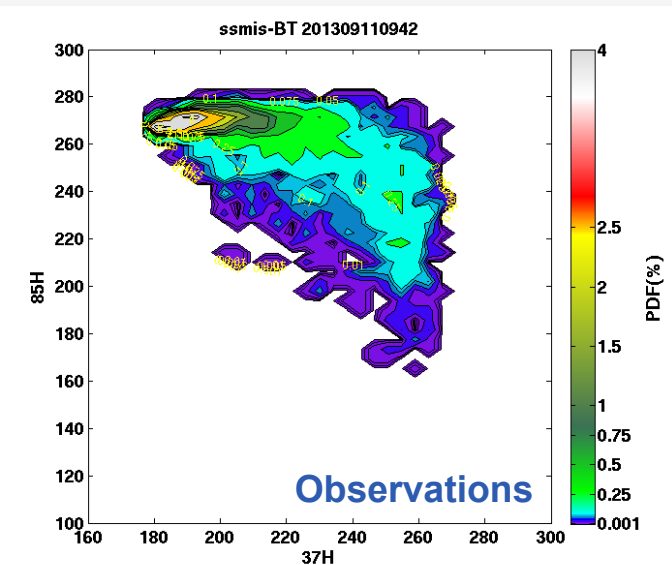


# Statistical Tool: Joint Distribution of Brightness Temperatures

## Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto

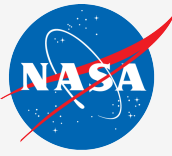


- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm



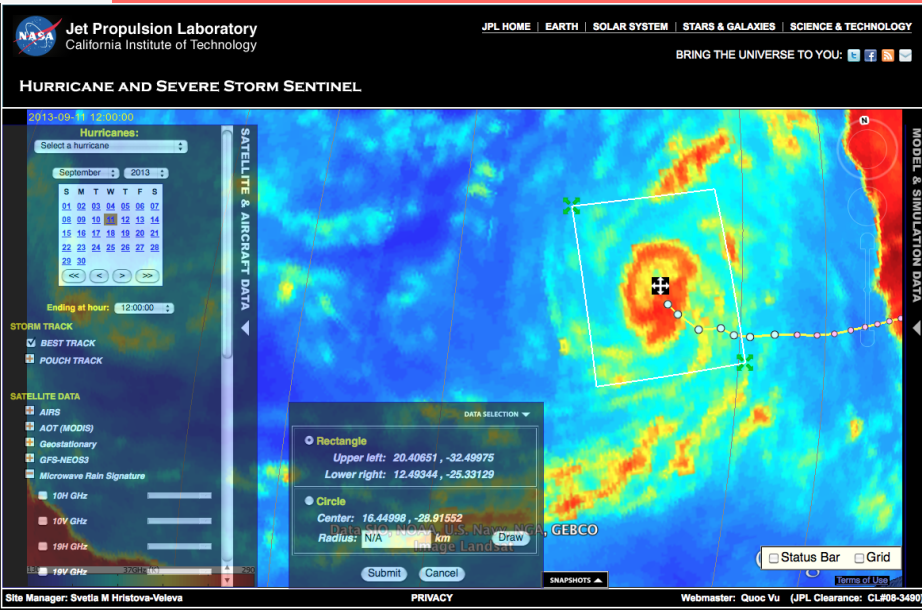
- The Joint PDF illustrates this relationship



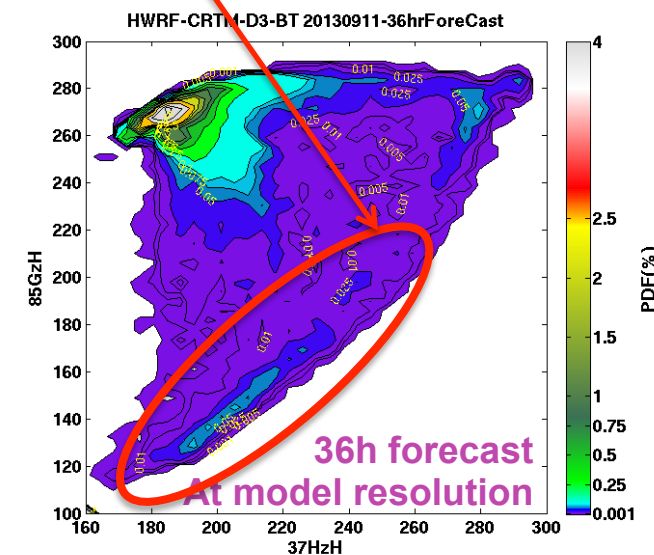
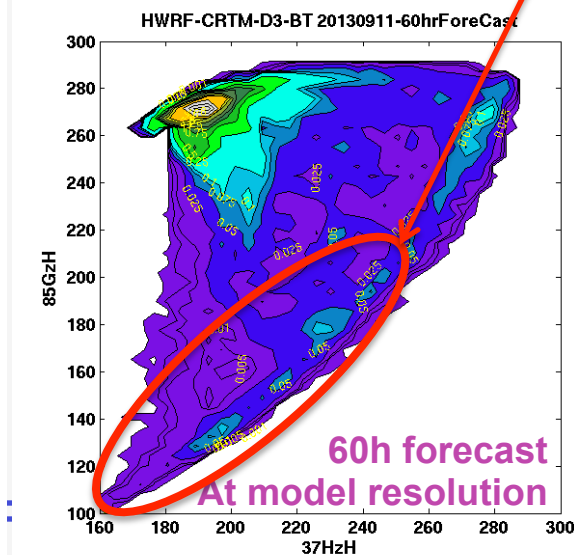
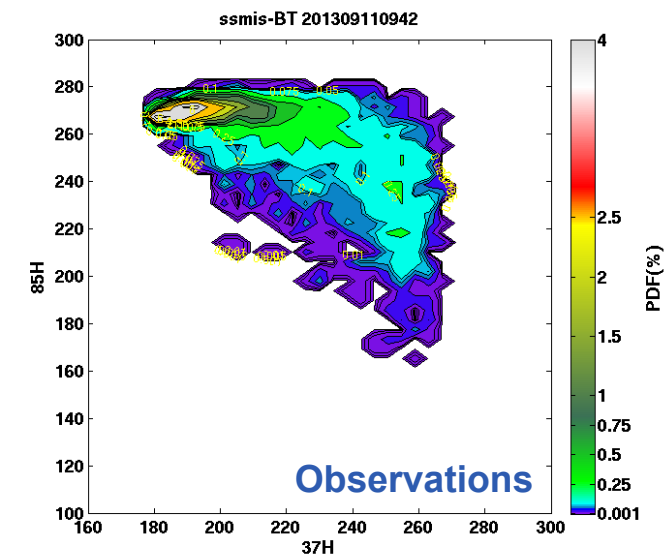


# Statistical Tool: Joint Distribution of Brightness Temperatures

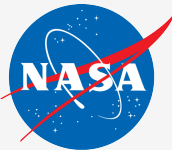
## Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm
- The vertical branch indicates too much scattering of radiation by the frozen precipitation

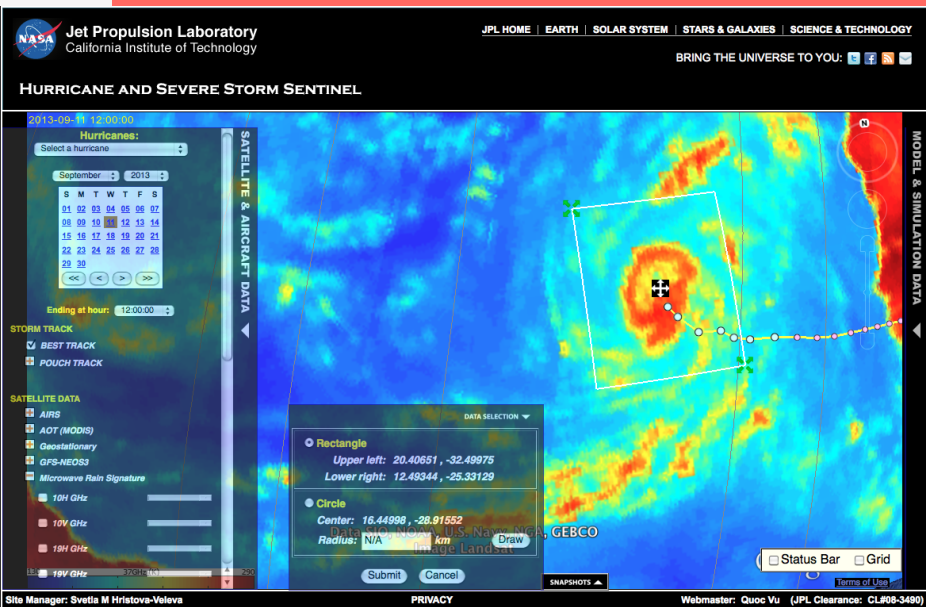




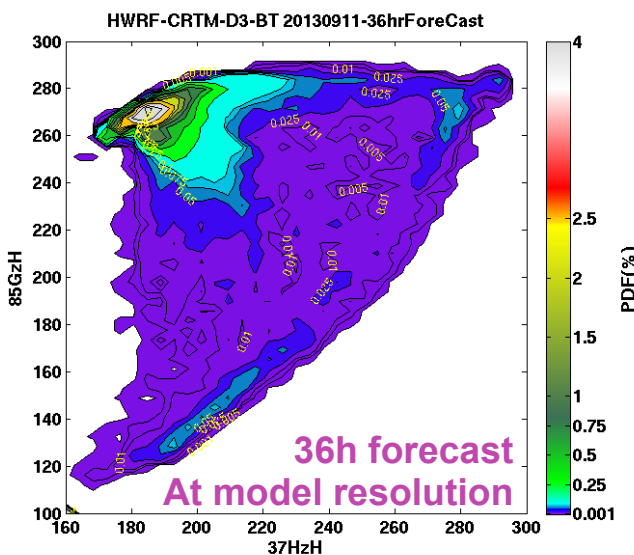
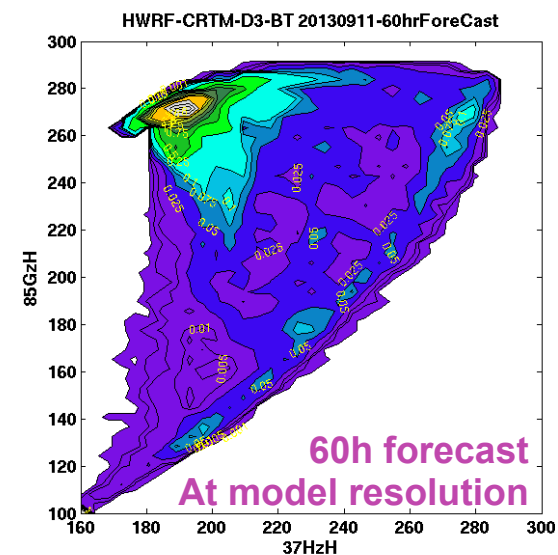
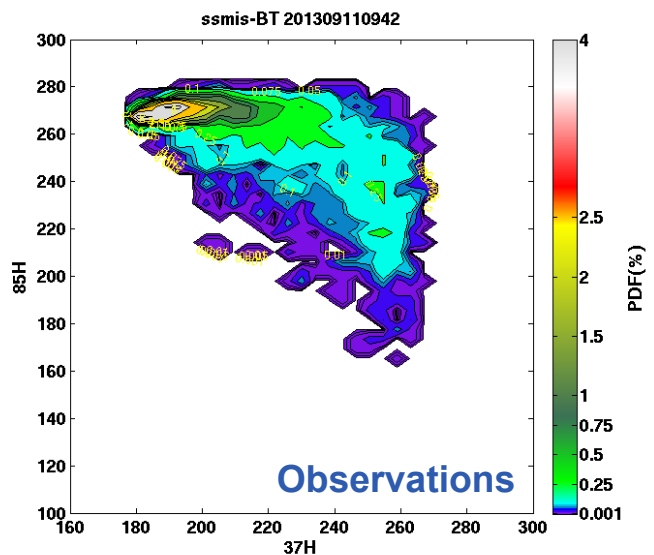


# Statistical Tool: Joint Distribution of Brightness Temperatures

## Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm
- The vertical branch indicates too much scattering of radiation by the frozen precipitation
- Question: Is the ice too much or is its forward modeling inaccurate?
- Need to consider the resolution!



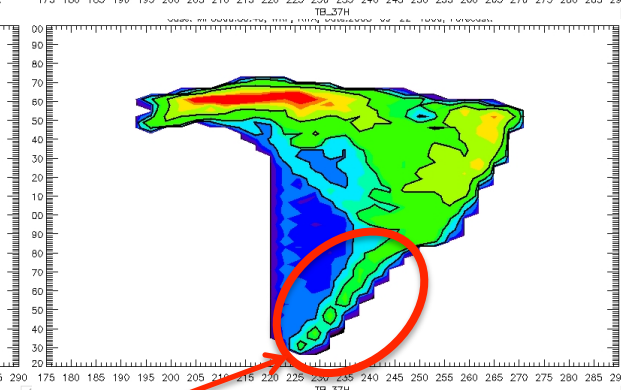
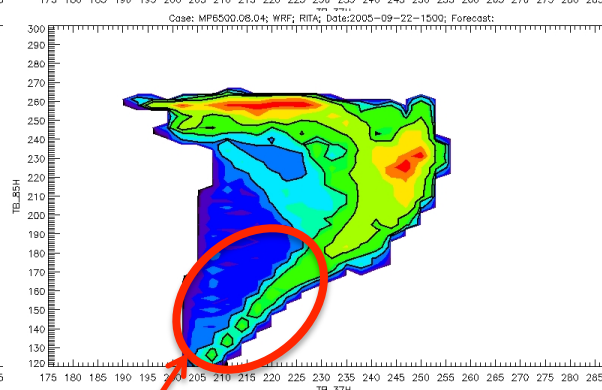
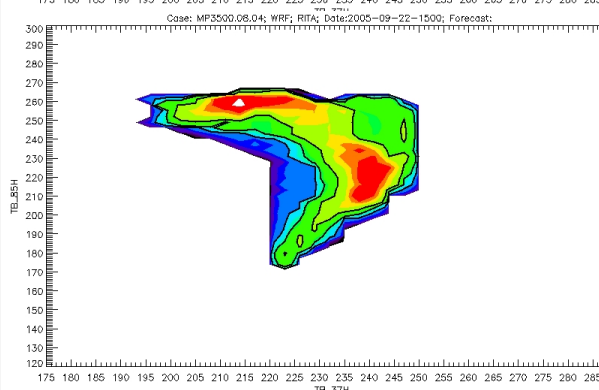
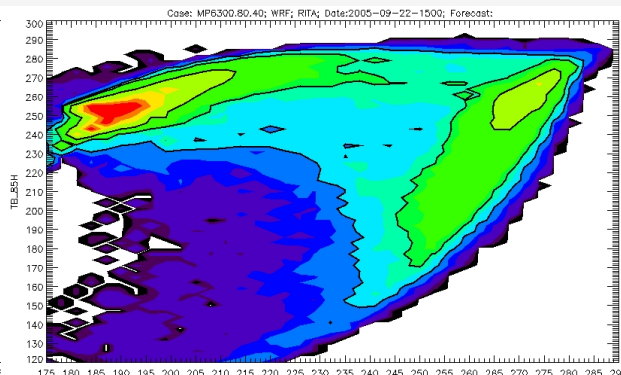
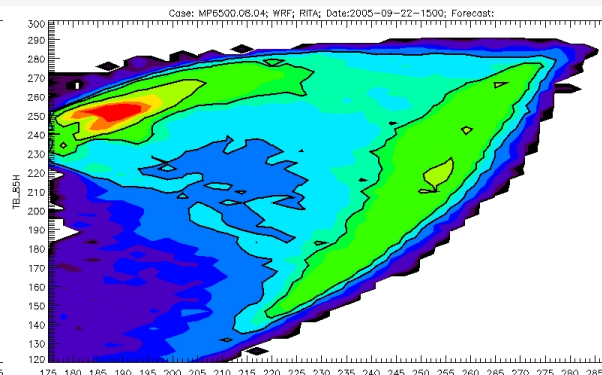
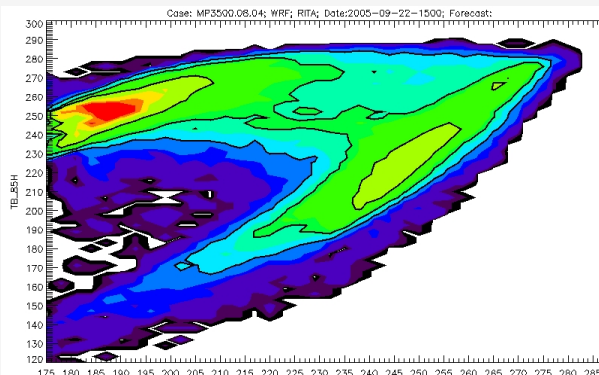


# Joint Distribution (37H vs 85H) – Impact of Resolution

M3-500.08.04

M6-500.08.04

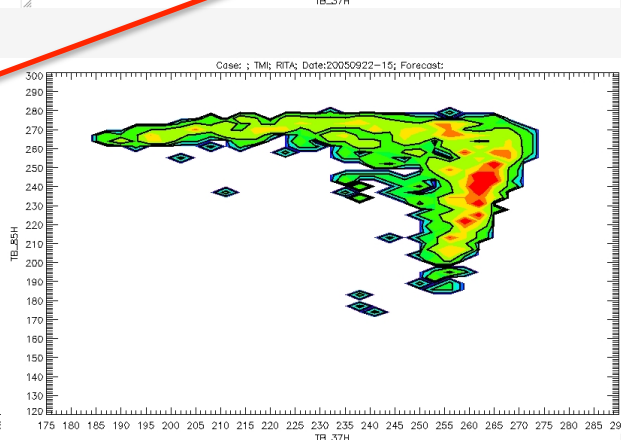
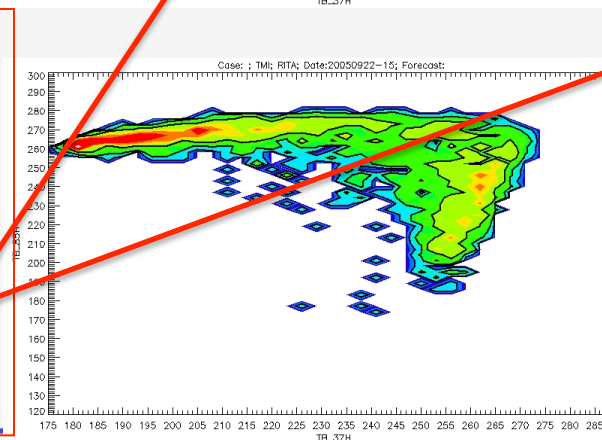
M6-300.80.40



WRF res.

TMI res

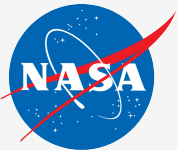
The Joint Distribution of the model data is improved when the synthetic data are convolved with the antenna pattern!!  
Still – too much scattering in the model data.



TMI obs.

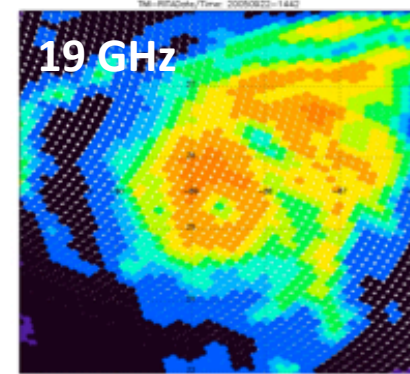
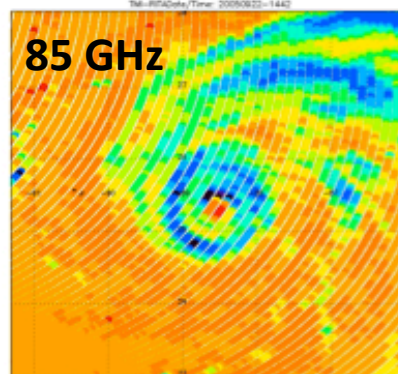
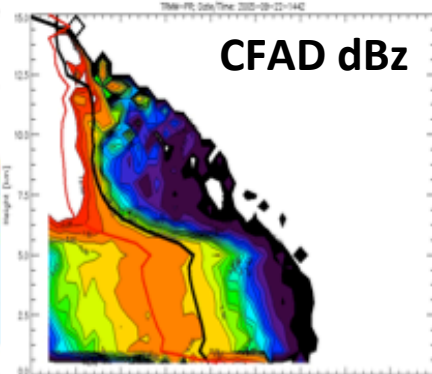
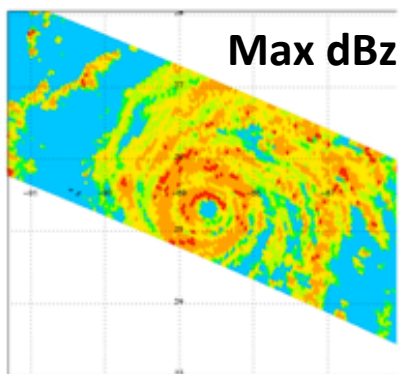




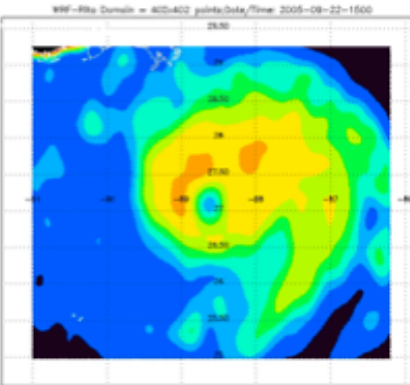
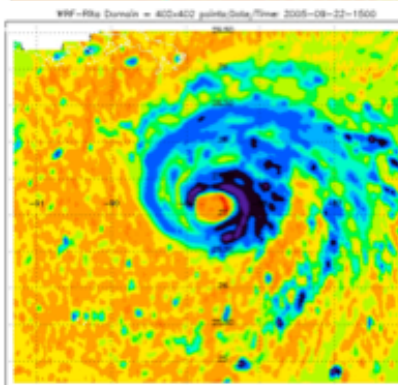
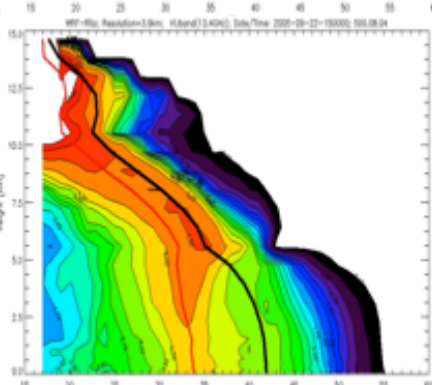
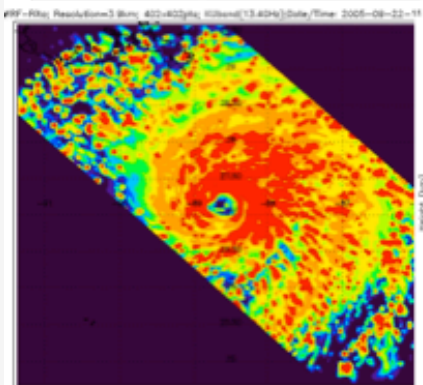


# Example of MODEL EVALUATION – the Impact of Microphysics

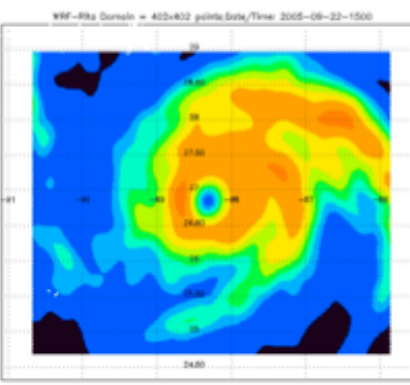
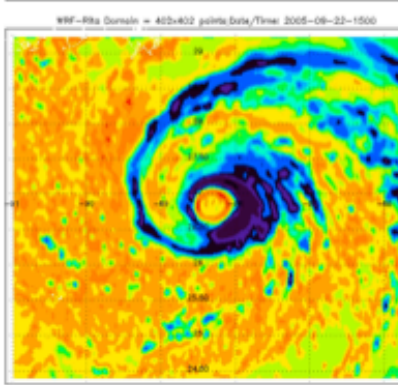
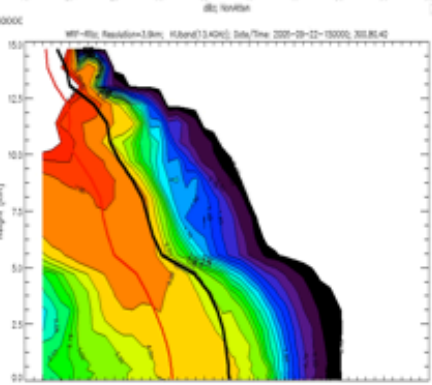
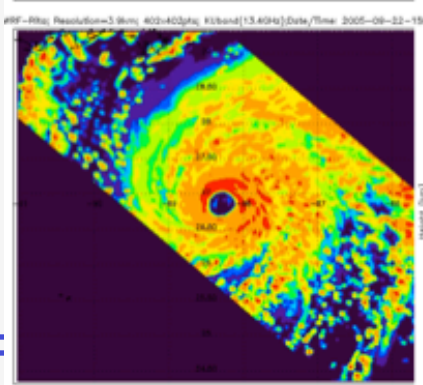
TRMM



WRF  
WSM3



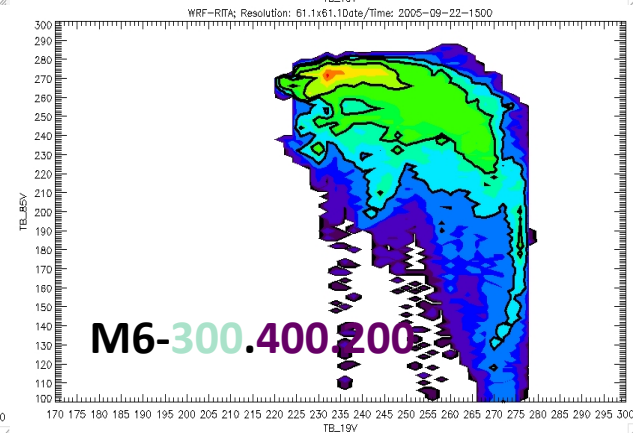
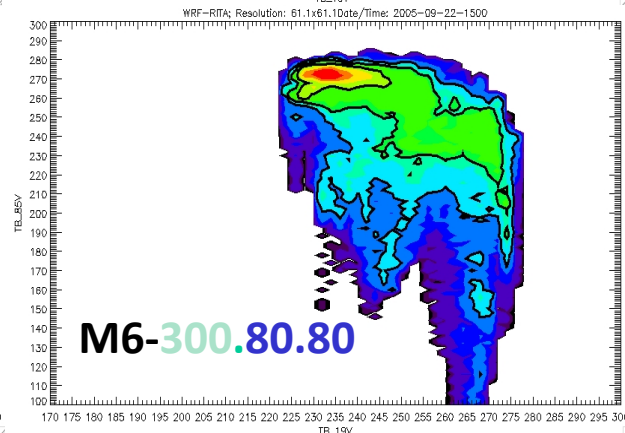
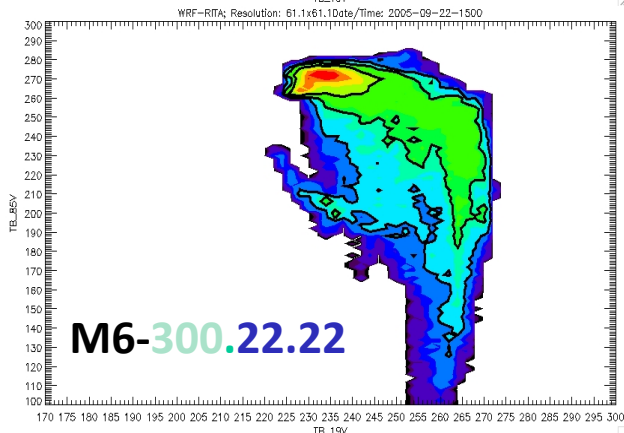
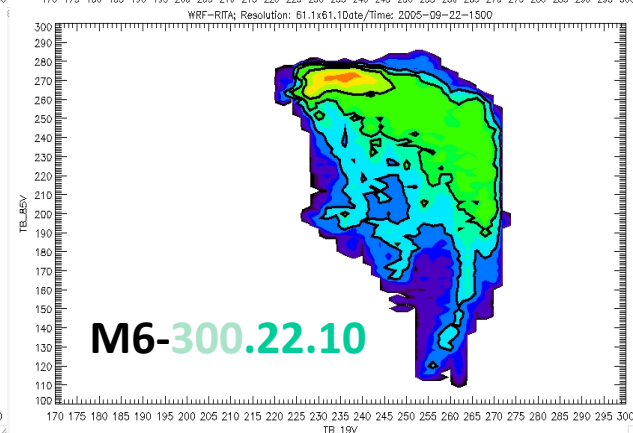
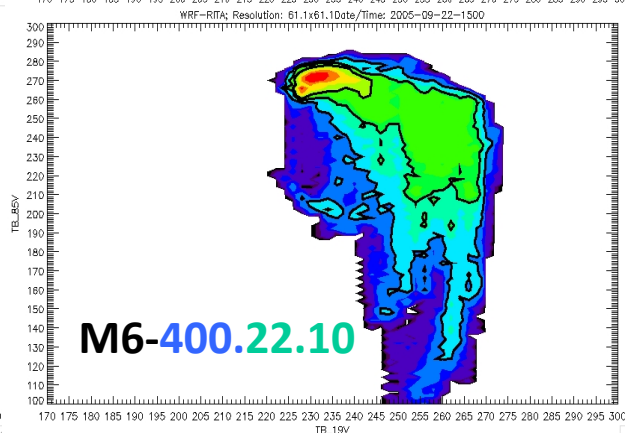
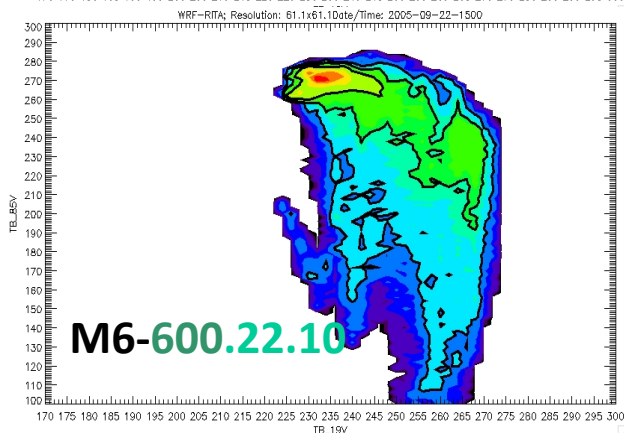
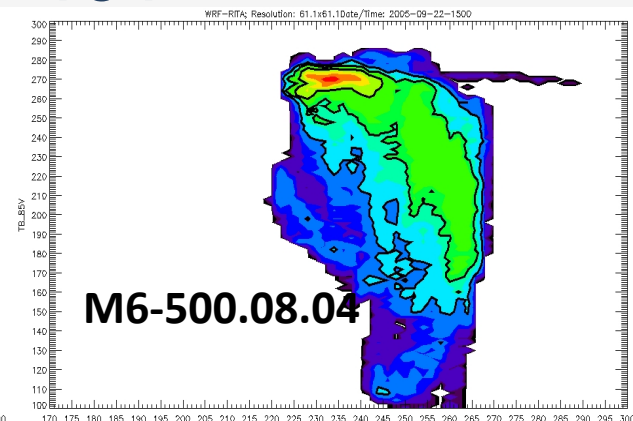
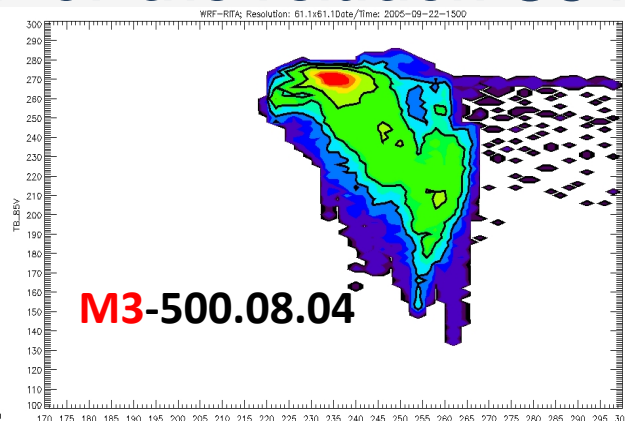
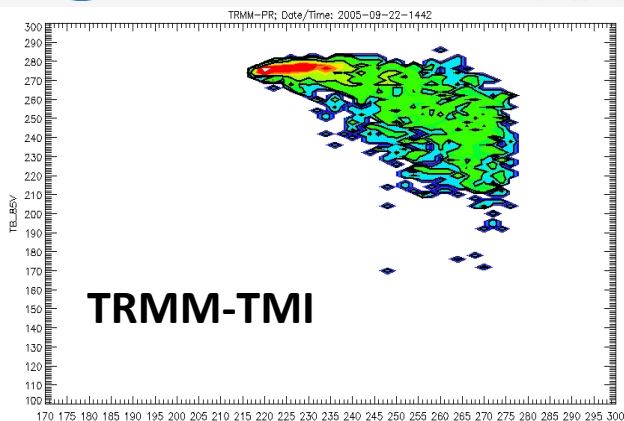
WRF  
WSM6  
New PSD



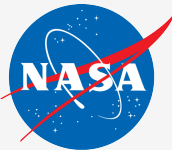


# Joint Distribution (19H vs 85H) – Impact of Microphysics

## PDF of the relation 85V-19V

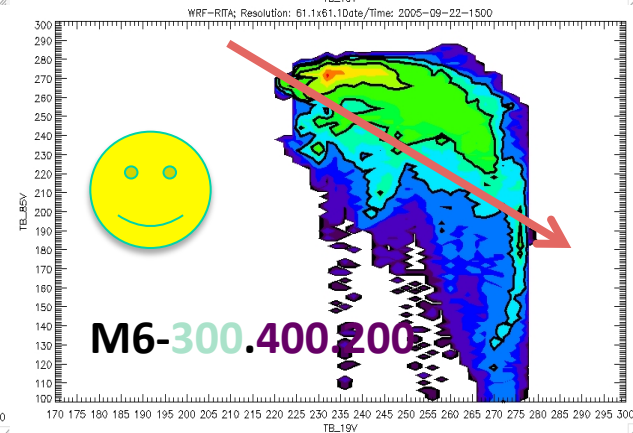
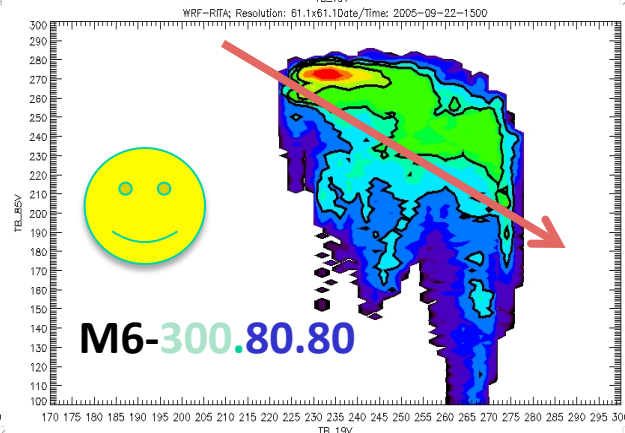
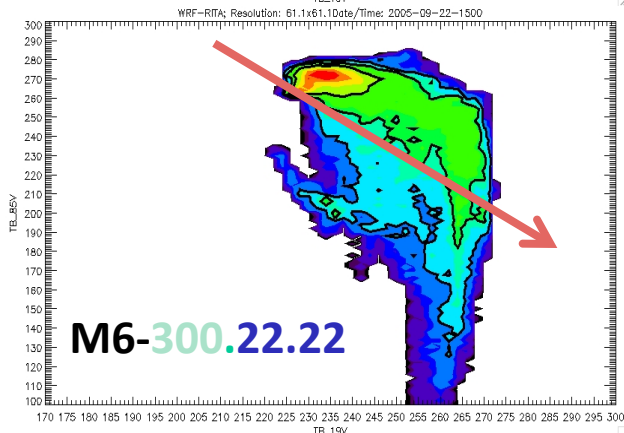
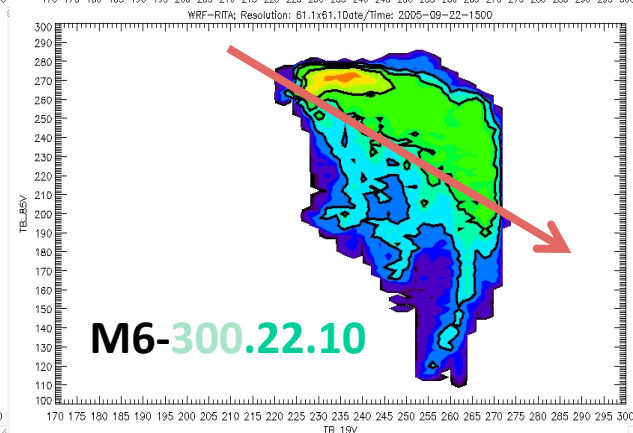
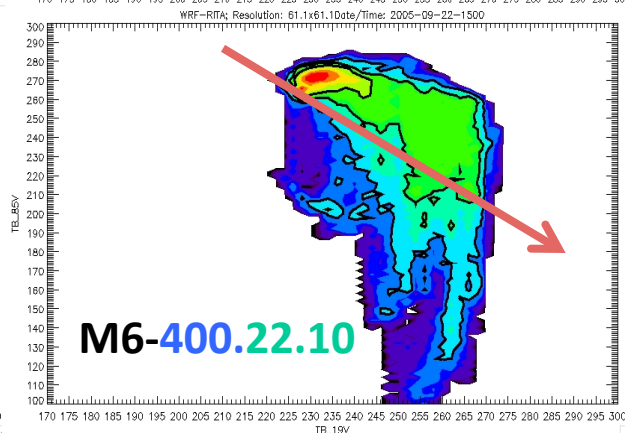
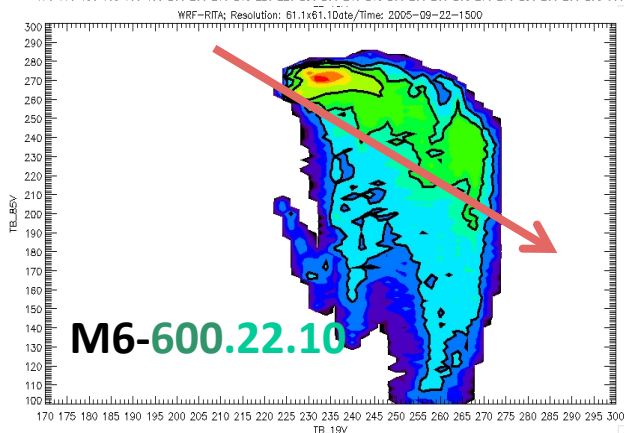
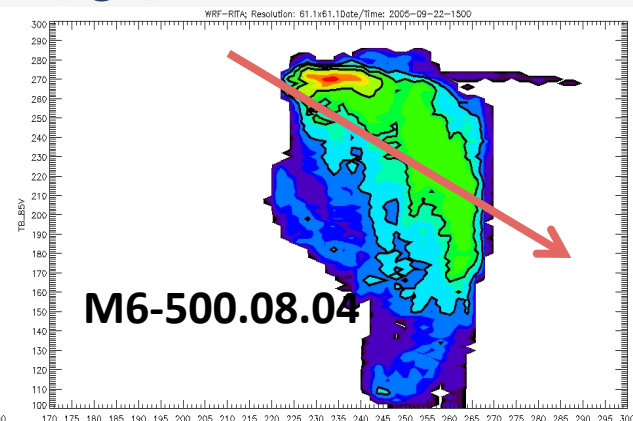
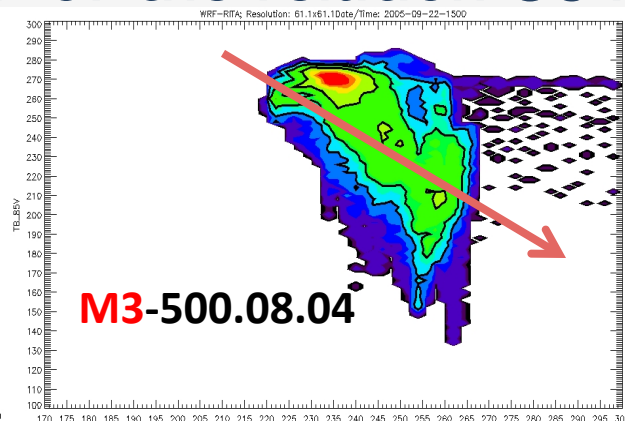
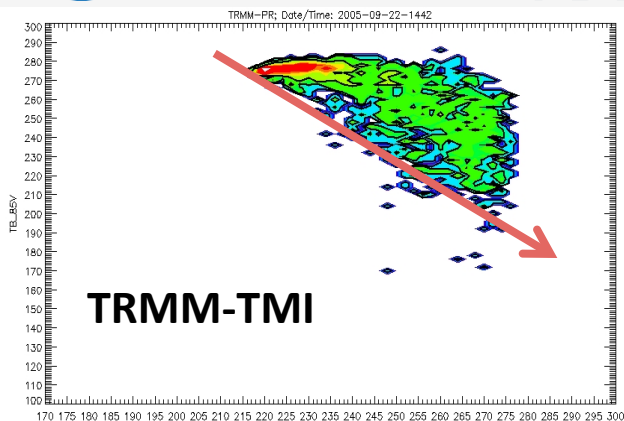






# Joint Distribution (19H vs 85H) – Impact of Microphysics

## PDF of the relation 85V-19V

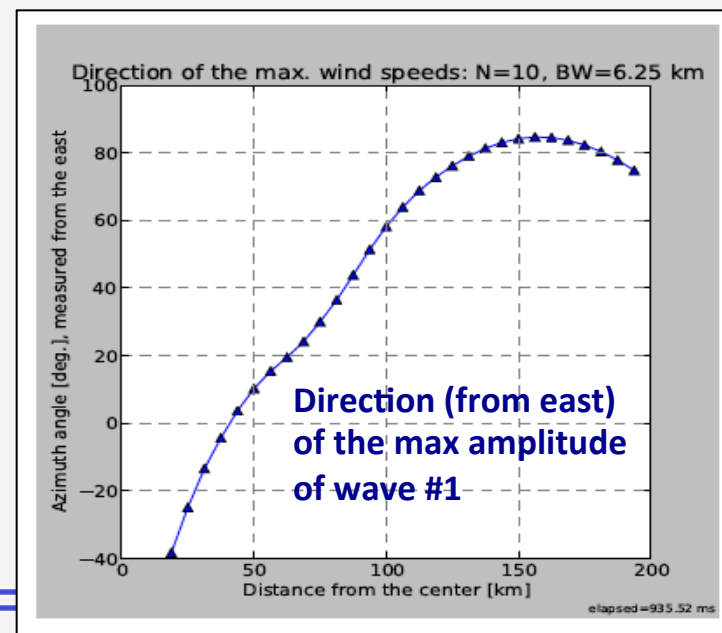
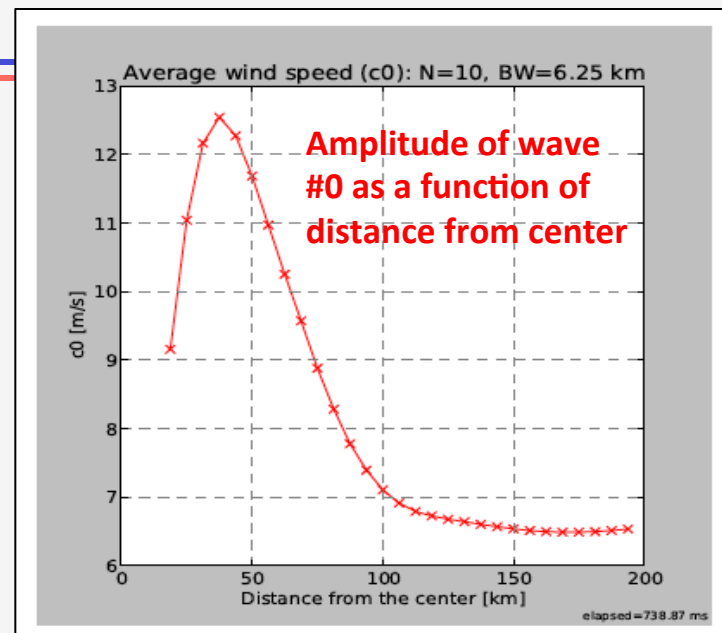
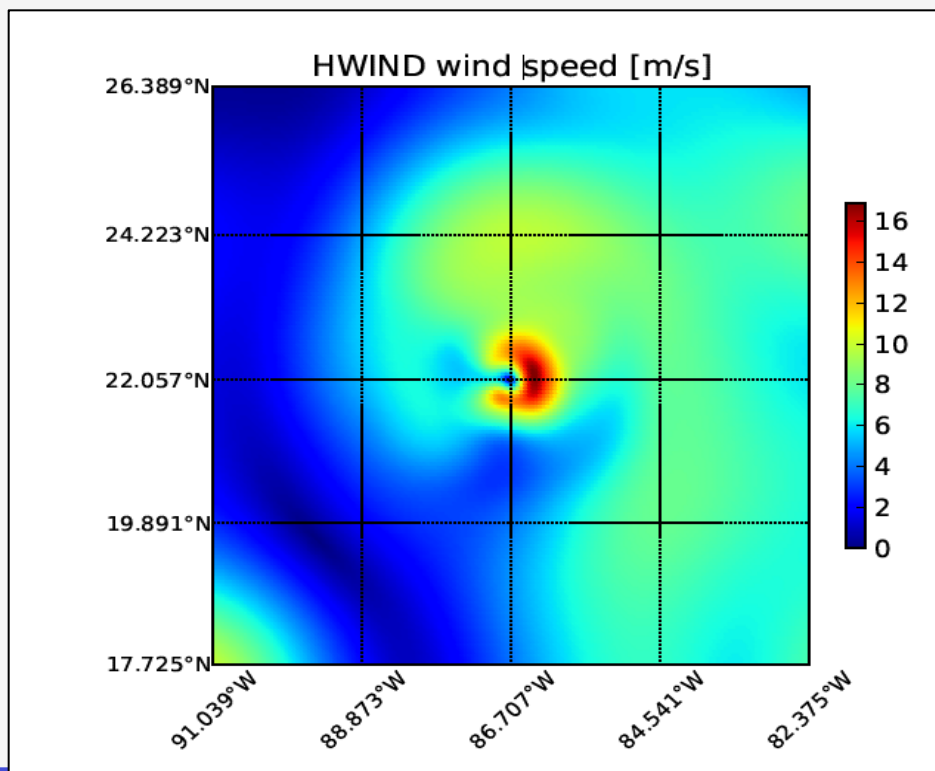




# Storm structure Tool: Storm Size and Asymmetry

## The Wave Number Analysis Tool

- **First adopted and used by NOAA/AOML/HRD**
  - Vukicevic, T., E. Uhlhorn, P. Reasor and B. Klotz, 2013: "A novel multi-scale intensity metric for evaluation of tropical cyclone intensity forecasts", Journal of the Atmospheric Sciences 2013 ;doi: <http://dx.doi.org/10.1175/JAS-D-13-0153.1>
- **Tool Developed for the JPL TCIS by**
  - Z. Haddad, N. Niamsuwan, T.-S. Shen





# Storm structure Tool:

## Storm Size and Asymmetry

### The Wave Number Analysis Tool using the Rain Index (EP hurricane Lowell)

NASA Jet Propulsion Laboratory  
California Institute of Technology

#### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-19 15:00:00

15 Hurricanes (mm)

Karina (08/10-08/19, 1)

August 2014

S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 15:00:00

SATELLITE DATA

AIRS

Geostationary

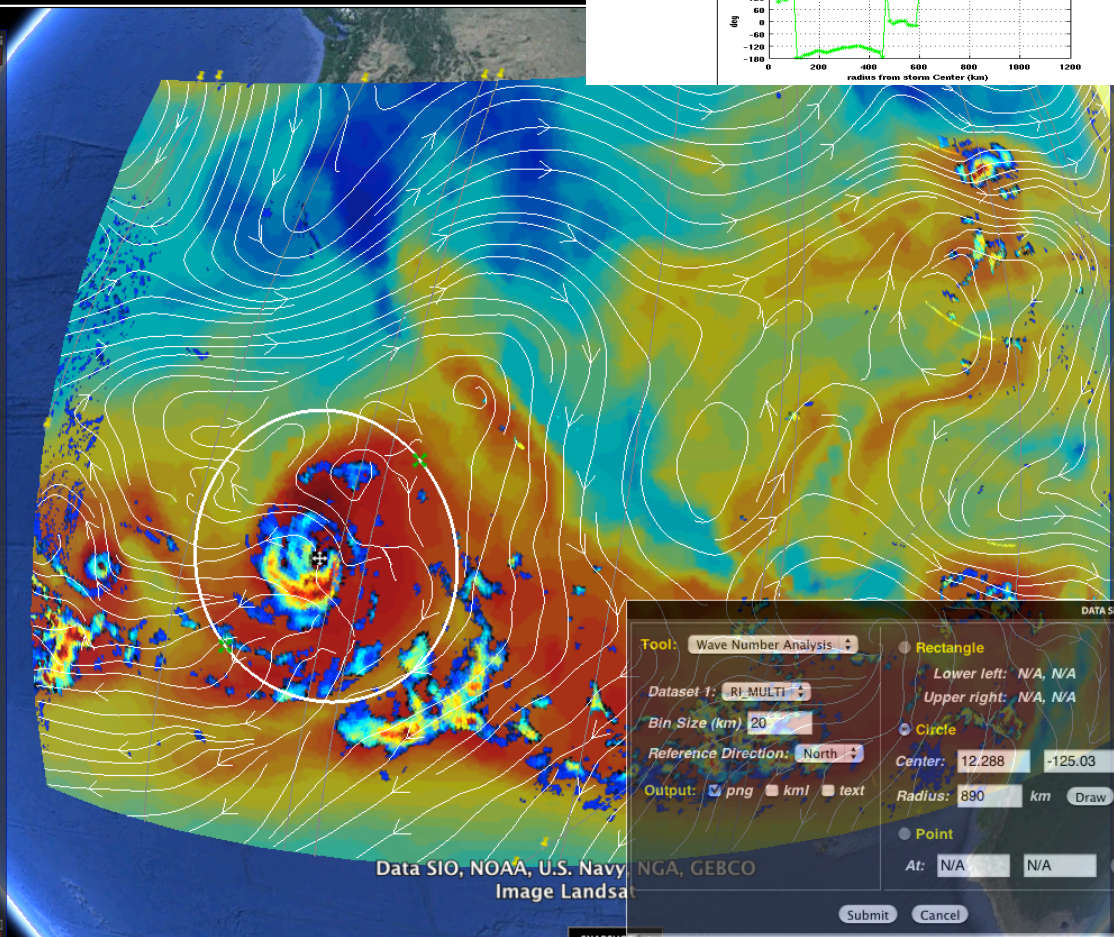
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS

Microwave Rain Signature

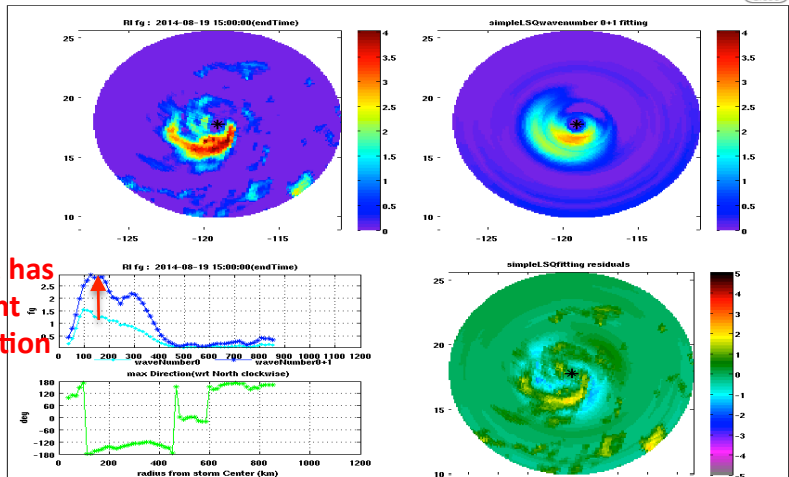
- 10H GHz
- 10V GHz
- 19H GHz
- 19V GHz
- 37COLOR
- 37H GHz
- 37V GHz
- 85H GHz
- 85V GHz

Rain Indicator

TPW Rain Indicator



Wave #1 has important contribution



L & SIMULATION DATA

01	02
03	04
05	06
07	08
09	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26
27	28
29	30
31	

MODEL

- ECMWF
- GFS

Press: 200

Forecast Time: 012

- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY

NAVGENM

- UKMET

SIMULATION

- HWRF-CRTM-D1
- HWRF-CRTM-D3

Tool: Wave Number Analysis

Rectangle

Lower left: N/A, N/A  
Upper right: N/A, N/A

Circle

Center: 12.288, -125.03

Radius: 890 km

Point

At: N/A, N/A

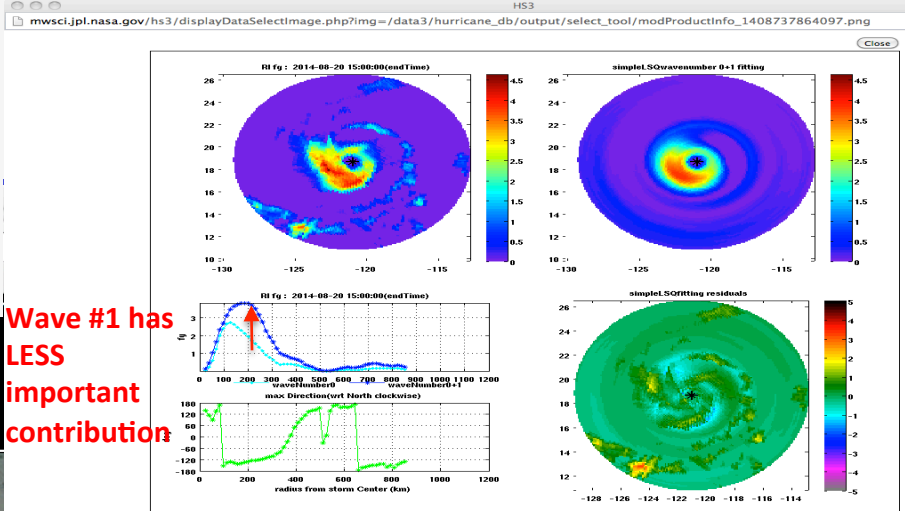
Output:  png  kml  text

Submit Cancel

# Storm structure Tool:

## Storm Size and Asymmetry

### The Wave Number Analysis Tool using the Rain Index (EP hurricane Lowell)

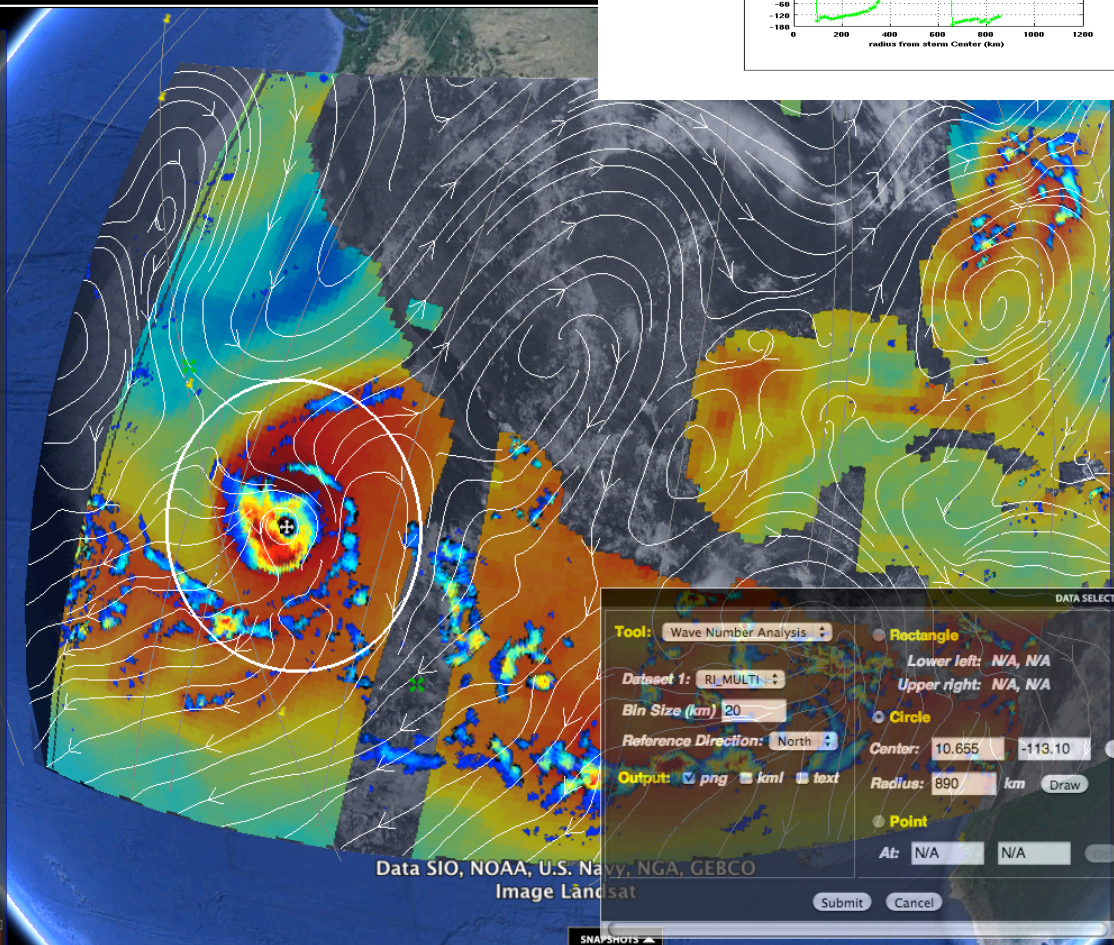


NASA Jet Propulsion Laboratory  
California Institute of Technology

#### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-20 15:00:00

- SATELLITE & AIRCRAFT DATA
- Ending at hour: 15:00:00
- STORM TRACK
  - BEST TRACK
  - POUCH TRACK
- SATELLITE DATA
  - AIRS
  - AOT (MODIS)
  - Geostationary
    - IR
    - IR 2 Day Animation
    - IRCOLOR
    - VAPOR
    - VIS
  - Microwave Rain Signature
    - 10H GHz
    - 10V GHz
    - 19H GHz
    - 19V GHz
    - 37COLOR
    - 37H GHz
    - 37V GHz
    - 85H GHz
    - 85V GHz
  - Rain Indicator
  - TPW
  - RH Composite
  - Two Day Animation



- 8. SIMULATION DATA
- MODEL
  - ECMWF
  - GFS
  - Proas: 200
  - Forecast Time: 012
  - SPEED-COMOVING
  - STREAM-COMOVING
  - DEEP-SHEAR
  - OW
  - PMSL
  - POUCH-SHEAR
  - RH
  - SPEED-EARTH
  - STREAM-EARTH
  - TEMP
  - TPW
  - VORTICITY
- SIMULATION
  - HWRF-CRTM-D1
  - HWRF-CRTM-D3

DATA SELECTION

Tool: Wave Number Analysis

Dataset 1: RI\_MULT1

Bin Size (km): 20

Reference Direction: North

Output:  png  kml  text

Rectangle: Lower left: N/A, N/A; Upper right: N/A, N/A

Circle: Center: 10.655, -113.10; Radius: 890 km

Point: At: N/A, N/A

Buttons: Submit, Cancel



# Storm structure Tool:

## Storm Size and Asymmetry

### The Wave Number Analysis Tool using the Rain Index (EP hurricane Lowell)

NASA Jet Propulsion Laboratory  
California Institute of Technology

#### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-21 15:00:00

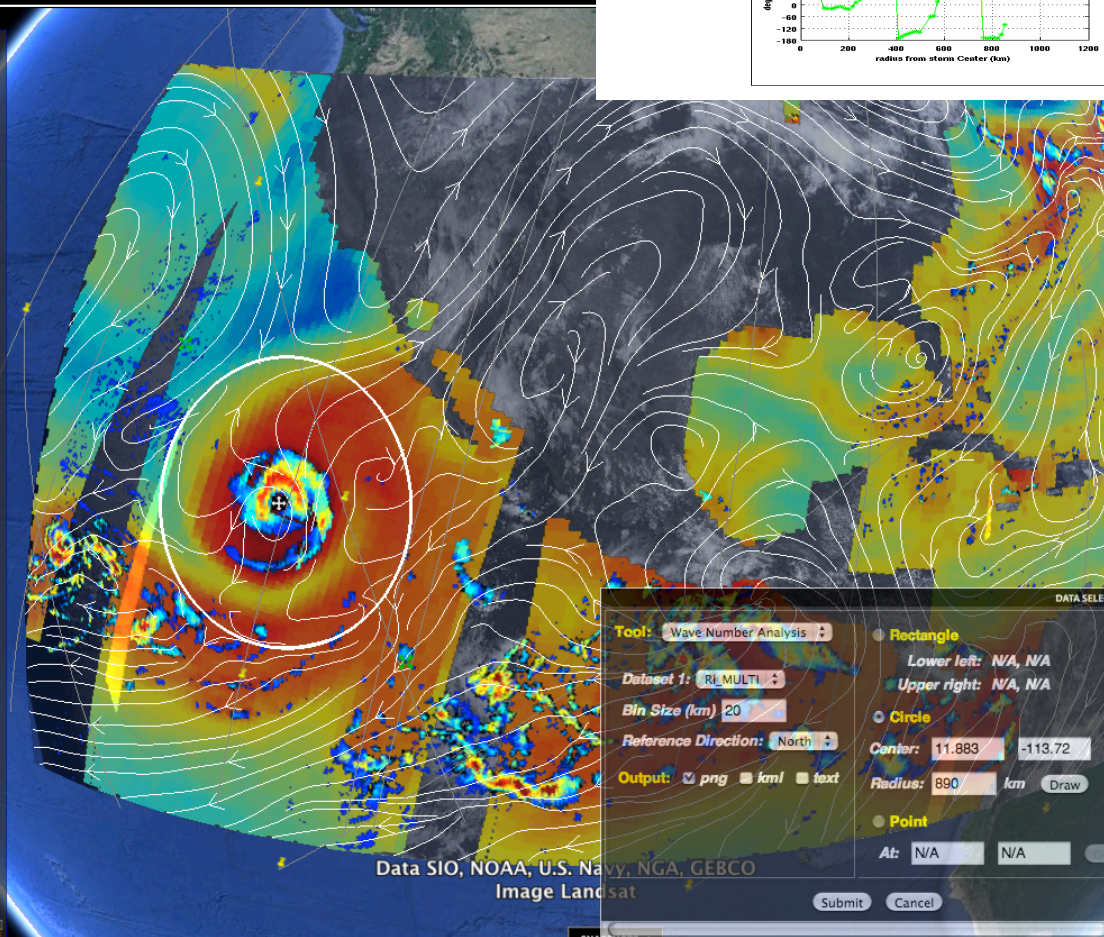
##### STORM TRACK

- BEST TRACK
- POUCH TRACK

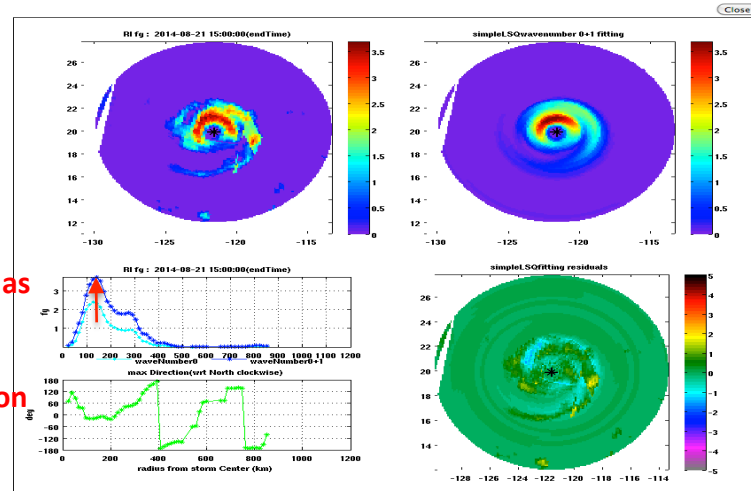
##### SATELLITE DATA

- AIRS
- AOT (MODIS)
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- 10H GHz
- 10V GHz
- 19H GHz
- 19V GHz
- 37COLOR
- 37H GHz
- 37V GHz
- 85H GHz
- 85V GHz
- Rain Indicator
- TPW
- 6 HR Composite
- Two Day Animation
- TRMM
- WIND
- CloudSet
- SST

SATELLITE & AIRCRAFT DATA



Wave #1 has LEAST important contribution



DATA SELECTION

Tool: Wave Number Analysis

Dataset 1: RI MULTI

Bin Size (km): 20

Reference Direction: North

Output:  png  kml  text

Rectangle: Lower left: N/A, N/A; Upper right: N/A, N/A

Circle: Center: 11.883, -113.72; Radius: 890 km

Point: At: N/A, N/A

Submit Cancel

8. SIMULATION DATA

03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

MODEL

- ECMWF
- GFS
- Press: 200
- Forecast Time: 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- PARTICITY
- NAVGEM
- UKMET

Status Bar Grid

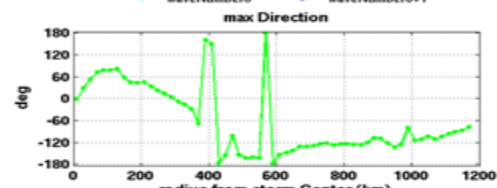
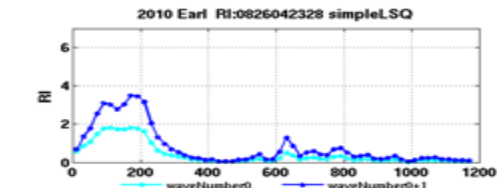
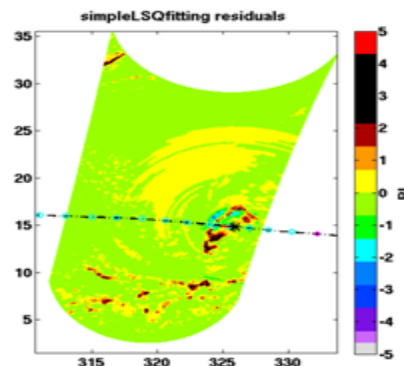
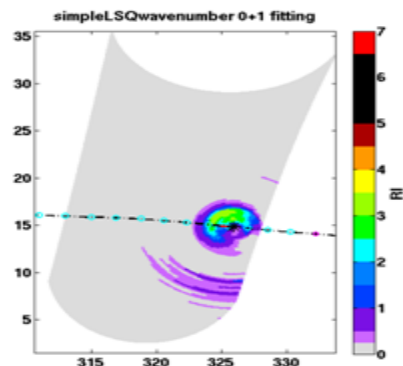
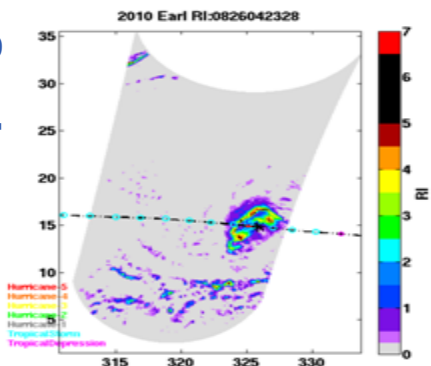


# Storm structure Tool: Storm Size and Asymmetry

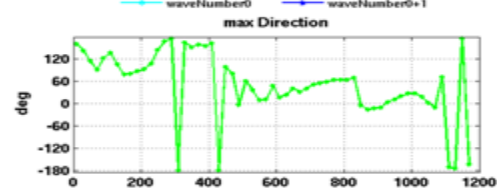
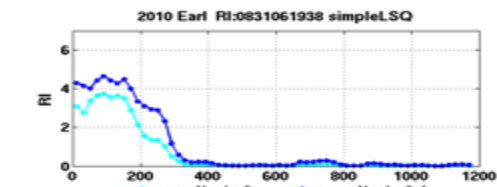
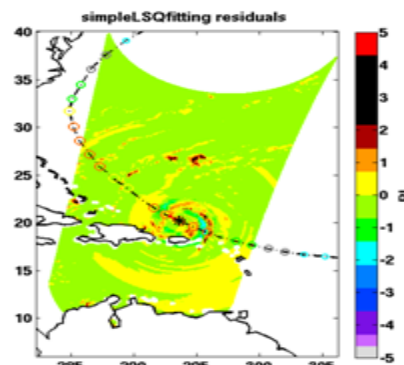
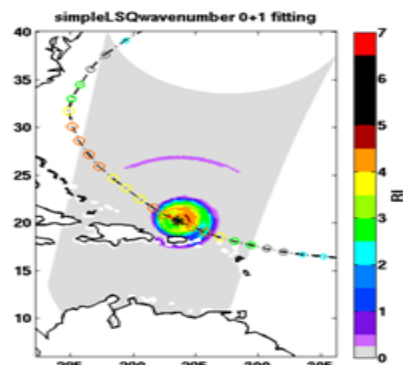
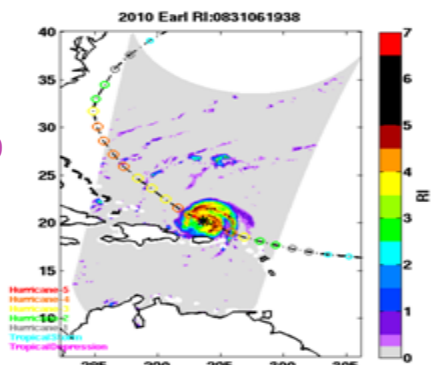
## The Wave Number Analysis Tool using the Rain Index (multi-channel PMW index)

More details in the Rain Index can be found in Hristova-Veleva et al. 2013, JAMC 52, 2828–2848

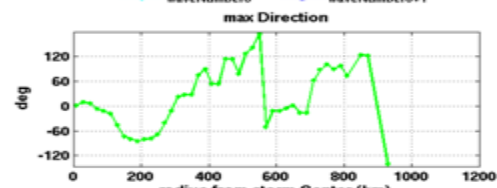
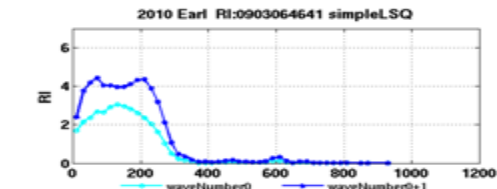
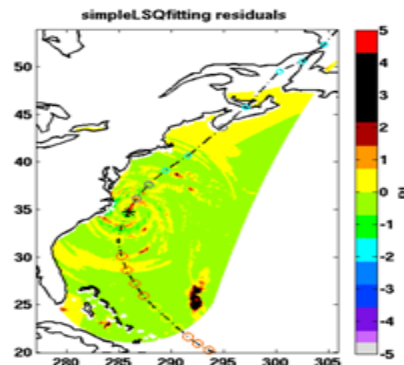
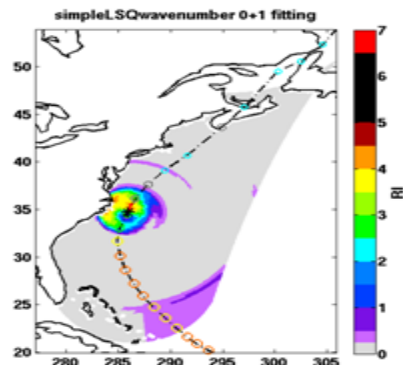
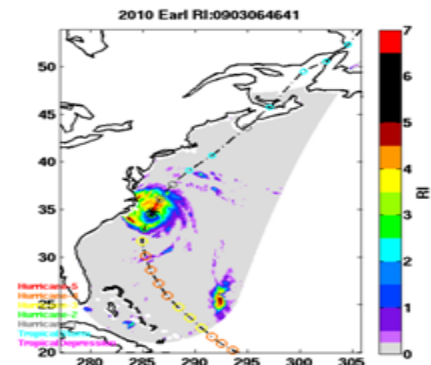
Developing



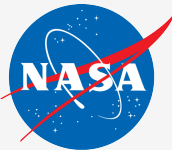
During RI



Mature





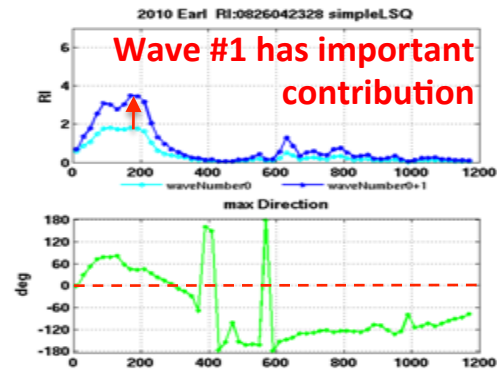
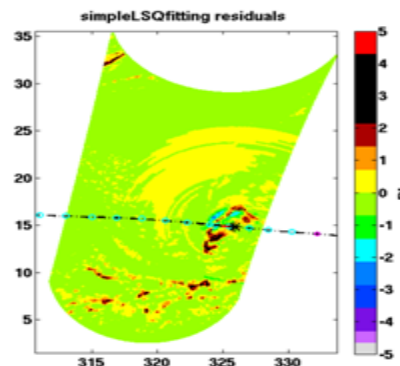
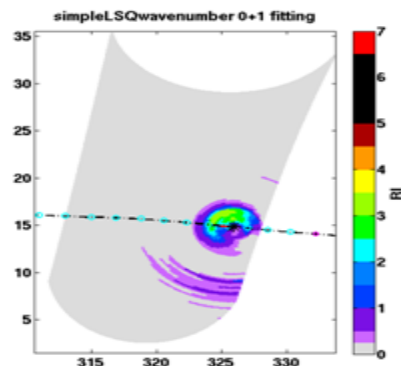
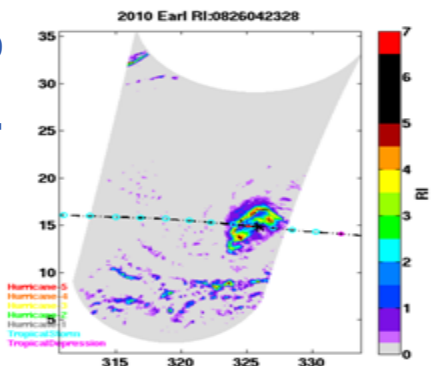


# Storm structure Tool: Storm Size and Asymmetry

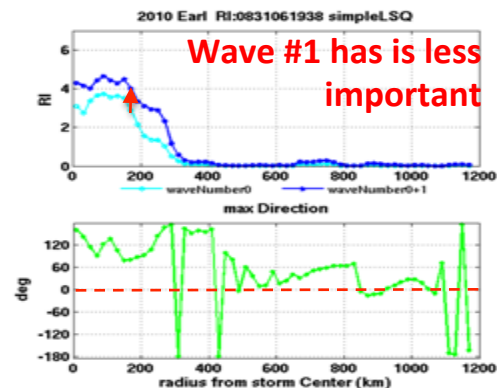
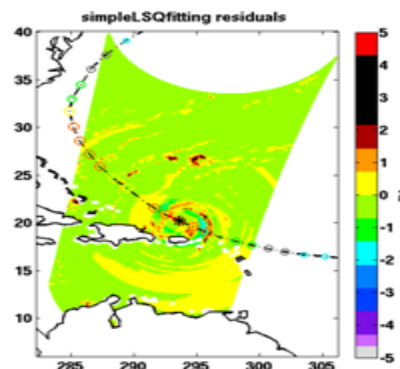
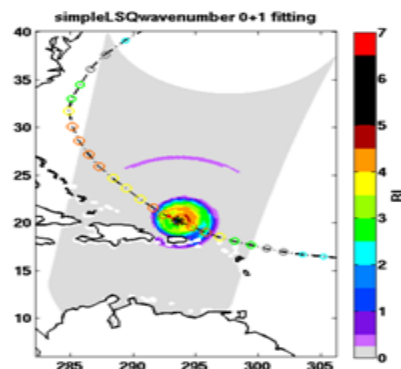
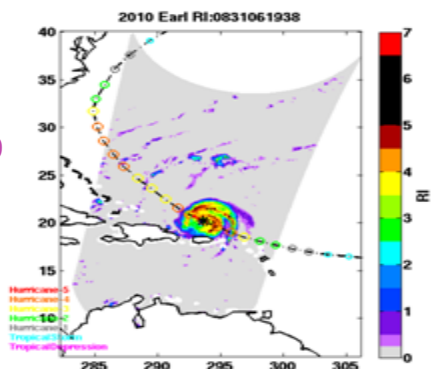
## The Wave Number Analysis Tool using the Rain Index (multi-channel PMW index)

More details in the Rain Index can be found in Hristova-Veleva et al., JAMC, 2013

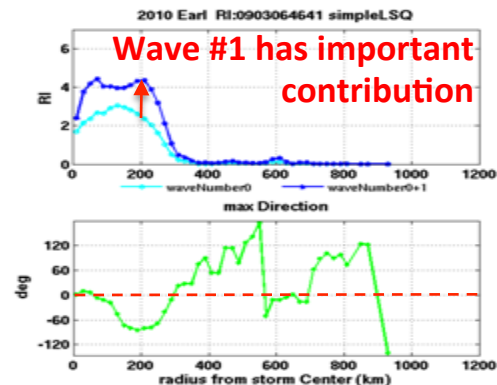
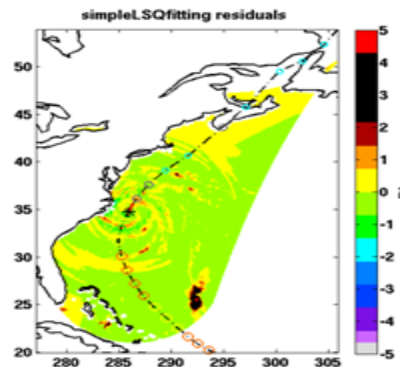
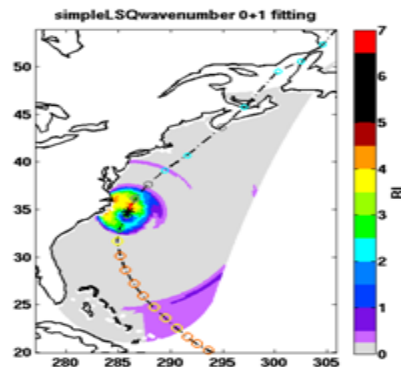
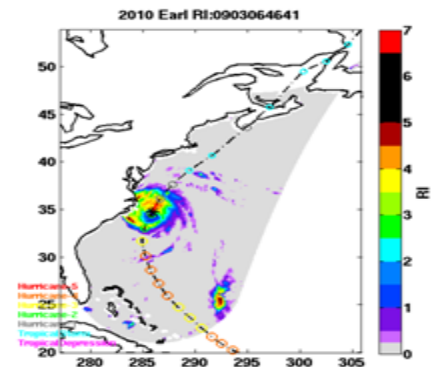
Developing

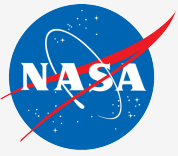


During RI



Mature

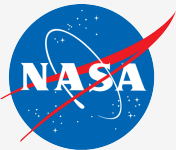




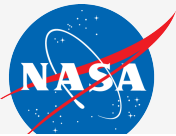
# Summary

- To achieve the HFIP goals of improving the forecast accuracy of hurricane intensity, track and impact at landfall we first **need to understand whether the models properly reflect the physical processes and their interactions.**
- To address the need for improving the model physics, the 2013 annual HFIP meeting suggested that **all available observations (satellite, airborne, in-situ) should be used systematically and extensively to evaluate the model performance.**
- Furthermore, the participants highlighted **the need for developing new metrics and tools for evaluating the:**
  - **storm structure**
  - **the interaction between different physical processes** (multiparameter observations) **and**
  - **the evaluation of the multi-scale interactions** (feedback between the storm and its environment).
- **Such studies require the use of large amounts of satellite data, coming from diverse instruments in order to create robust statistics.** Due to the complexity of the remote sensing data and the volume of the respective model forecast this in-depth evaluation is usually limited to a number of case studies.
- **With the goal to facilitate model evaluation that goes beyond the comparison of "Best Track" metrics, we are working on providing fusion of models and observations by bringing them together into a common system and developing online analysis and visualization tools.**



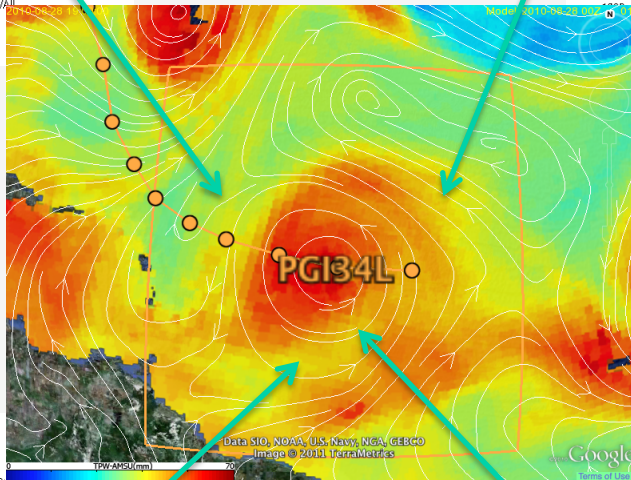
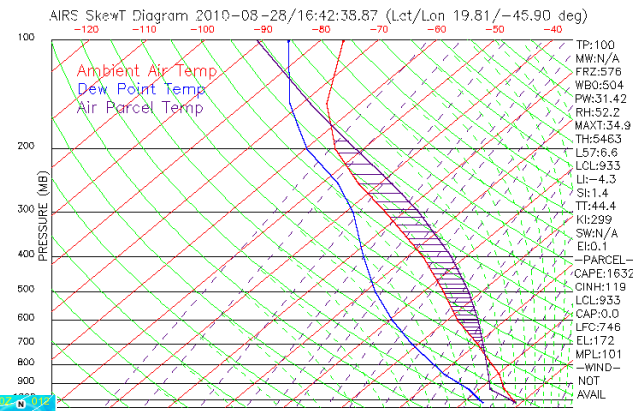
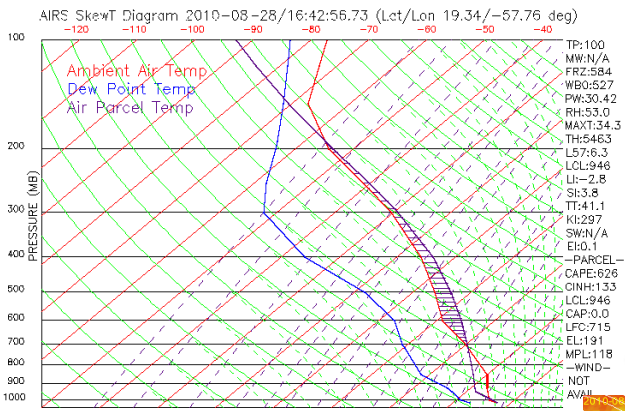


*Thank you !*

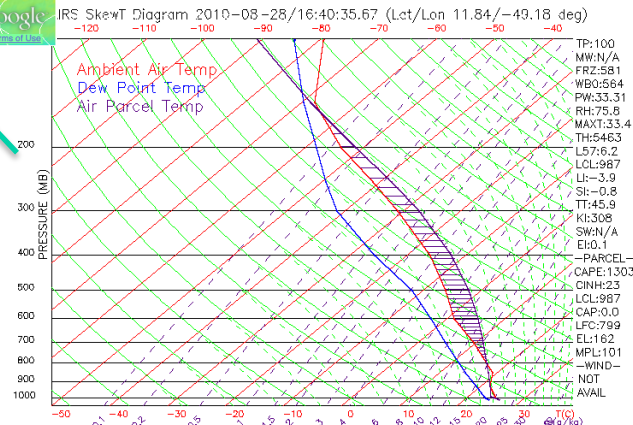
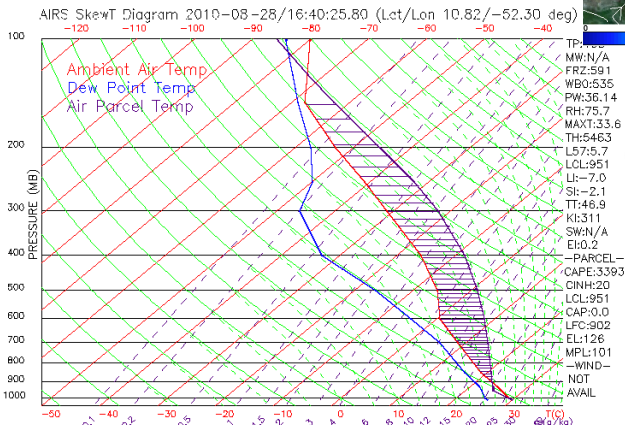


# The thermodynamics from AIRS

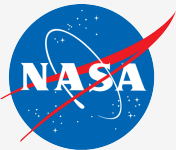
## Hurricane Earl; Aug. 28, 2010 19Z



1. TPW from AMSU
2. Soundings from AIRS
3. Pouch-relative flow from ECMWF







# 17<sup>th</sup> September 2010, 21Z

Untitled76

NASA National Aeronautics and Space Administration

## NASA Airborne Science Data Visualization Portal

The current time is Thu, 19 Jan 2012 07:18:29 GMT

### Observation Data

September 2010

Su	M	T	W	Th	F	S
		01	02	03	04	
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

At hour: 21:00:00

- GOES-IR
- GOES-VAPOR
- GOES-VIS
- 85GHZ
- 37GHZ
- Rain
- TRMM PR Nadir
- CloudSat
- CALIPSO
- MLS
- AOT (MODIS)
- Satellite Winds (CIMSS)

### AIRBORNE DATA

- HAMSR Channel 09
- HAMSR Reflectivity
- APR2 Zku
- Dropsonde
- NOAA N42RF
- Lase
- Daily DC8-Flight track
- Daily Global Hawk track
- Hourly Global Hawk track

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image © 2012 DigitalGlobe  
Image © 2012 GeoEye  
© 2012 Cnes/Spot Image

Google earth Terms of Use

### Model Data

September 2010

Su	M	T	W	Th	F	S
		01	02	03	04	
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

MODEL DATA

Pressure Level: 850

Forecast Time: 000

### GFS

- Speed Earth Relative
- Streamline Earth Relative
- PG141L
- PG143L
- PG144L
- PG145L
- PG146L
- Relative Humidity
- OW
- Vorticity
- Deep shear
- Pouch shear
- Sea Level Pressure

### ECMWF

- UKMET
- NOGAPS

Status Bar  Grid

Save snapshot Load snapshot Download

Animation:  Observation Data  Model Data

Select a time range to animate: (from 2010-09-16 00:00:00 to 2010-09-17 00:00:00)

Start 2010-09-16 19:00:00 End 2010-09-17 19:00:00 Animation Step 1 hour

Animate Stop Download



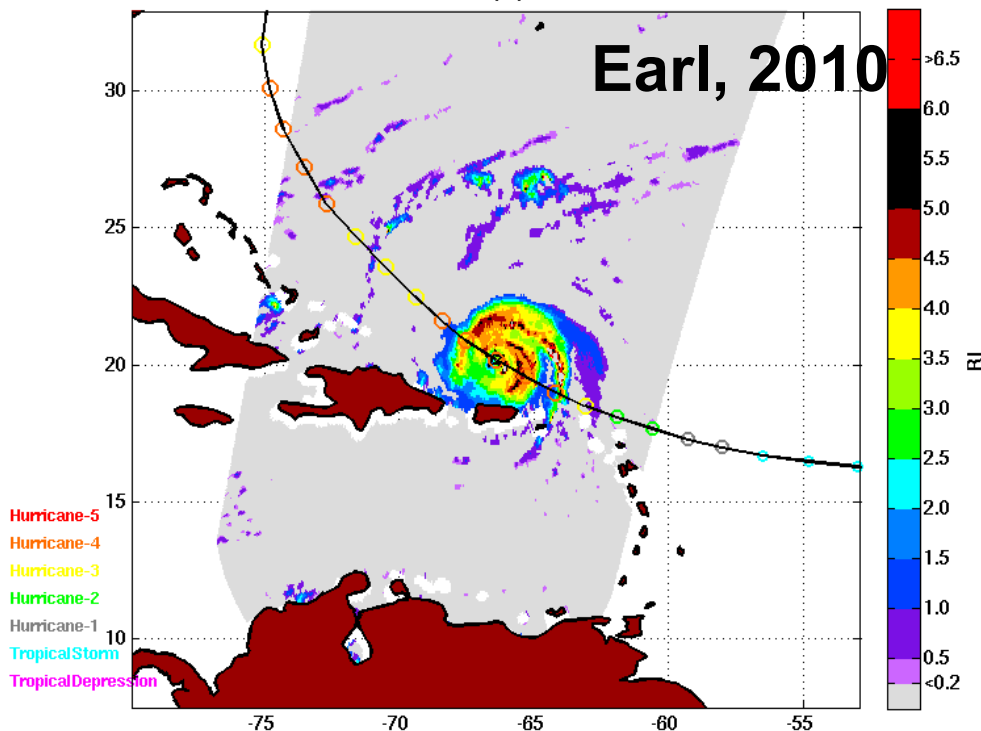
# The Rain Indicator – a multi-channel depiction of the storm structure

*Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828–2848*

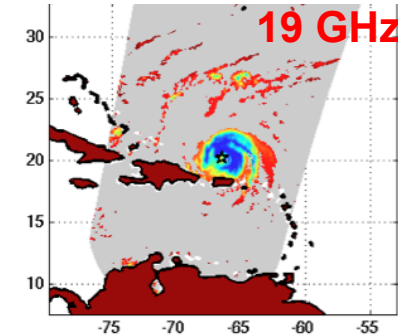
Microwave signals at the top of the atmosphere can be classified into two categories:

- **emission signal** - dominant at lower frequencies; **warming**; **better for light rain**. **Strong emission in the atmosphere reduces the polarization difference (PD) in the ocean surface radiation. Hence, PD is representative of the atmospheric emission.**
- **scattering signal** - dominant at higher frequencies; **cooling**; **better for heavy rain**; **PCT**
- Hence, both signals have to be incorporated to cover the entire rainfall spectrum.

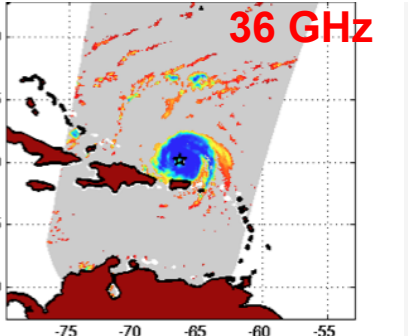
AMSRE AQUA-1 Rain Index(RI) Earl 2010/08/31 06:19:38



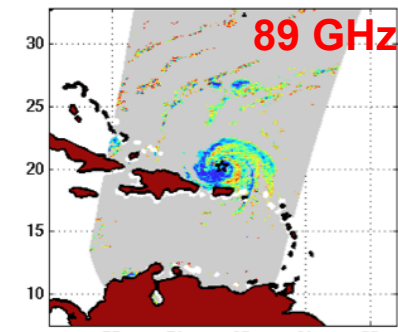
**Polarization Difference**



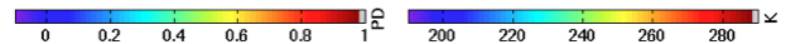
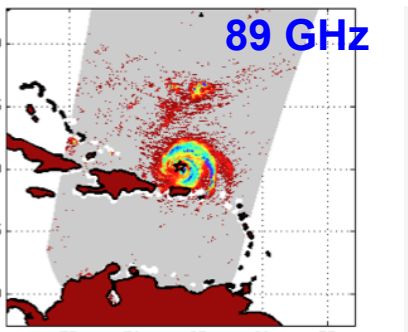
**Polarization Difference**



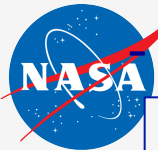
**Polarization Diff**



**Polarization Corrected Temp.**



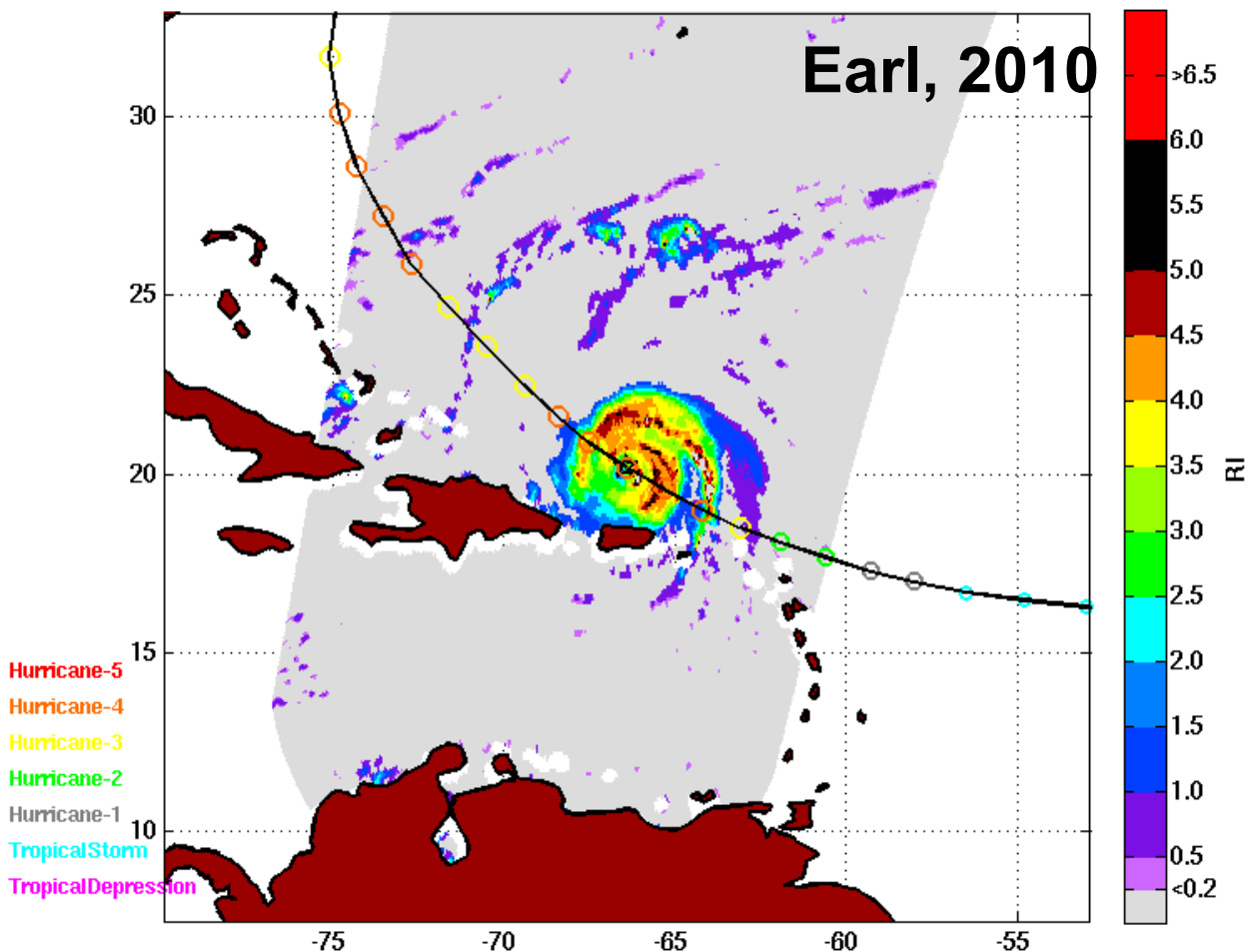




# The Rain Indicator – a multi-channel depiction of the storm structure

Hristova-Veleva et al., 2013: “Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description”, 2013, JAMC 52, 2828–2848

AMSRE AQUA-1 Rain Index(RI) Earl 2010/08/31 06:19:38



## Advantages of Using the Rain Indicator over single passive microwave channels

- combines the emission and scattering signals from the **multi-channel information** to present a **cohesive depiction of the rain and the graupel above**, covering the precipitation spectrum
- Uses polarization difference. Hence, it is **less affected by calibration accuracy.**

# Storm structure Tool:

## Storm Size and Asymmetry

### The Wave Number Analysis Tool using the Rain Index (GPM over Cristobal)

NASA Jet Propulsion Laboratory  
California Institute of Technology

### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-27 06:00:00 The current time

**Hurricanes:**  
Karina (08/10-08/28, 1)

August 2014

S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 06:00:00

**STORM TRACK**  
 BEST TRACK  
 POUCH TRACK

**SATELLITE DATA**  
 AIRS  
 AOT (MODIS)  
 Geostationary  
 Microwave Rain Signature

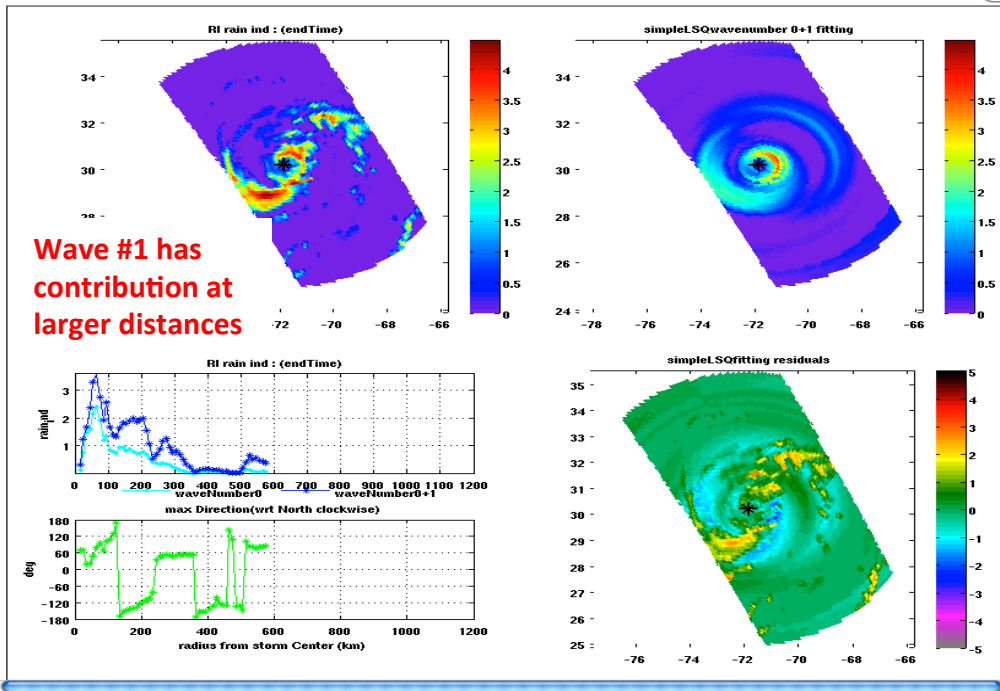
- 10H GHz
- 10V GHz
- 19H GHz
- 19V GHz
- 37COLOR
- 37H GHz
- 37V GHz
- 85H GHz
- 85V GHz

Rain Indicator  
 TPW  
 Rain Indicator

SATELLITE & AIRCRAFT DATA

Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat

Site Manager: Svetla M Hristova-Voleva



MODEL

- ECMWF
- GFS
- NAVGEM
- UKMET

**SIMULATION**

- HWRF-CRTM-D1
- HWRF-CRTM-D3

GOCCO

Status Bar Grid

Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)



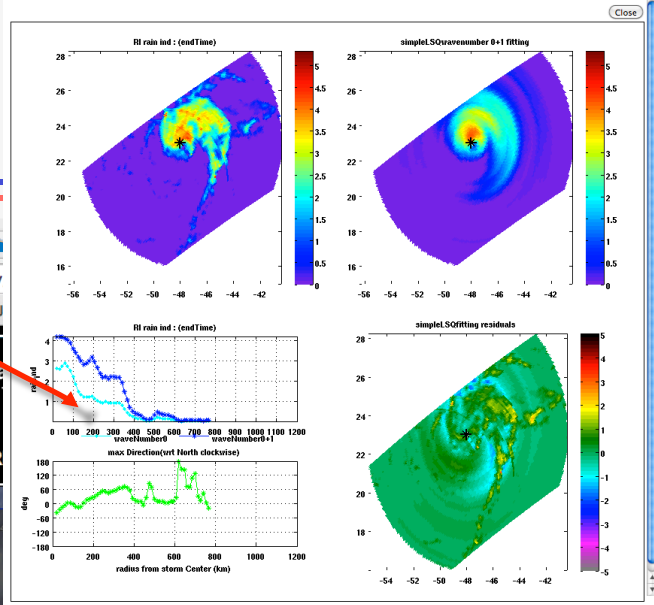


# September 14, 2014 - Edouard

## Geostationary IR - 01Z

### Multi-channel PMW Rain Index

mwsci.jpl.nasa.gov



**NASA Jet Propulsion Laboratory**  
California Institute of Technology

## HURRICANE AND SEVERE WEATHER

2014/09/14 00:00:00

Ending at hour: 01:00:00

**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- AOT (MODIS)
- Geostationary
  - IR
  - IR 2 Day Animation
  - IRCOLOR
  - VAPOR
  - VIS
- Microwave Rain Signature
  - 10H GHz
  - 10V GHz
  - 19H GHz
  - 19V GHz
  - 37COLOR
  - 37H GHz
  - 37V GHz
  - 85H GHz
  - 85V GHz
- Rain Indicator
- TPW
- TRMM
- WIND
  - ASCAT SPEED
  - ASCAT VECTOR
  - SST

**ANALYSIS TOOL**

Tool: Wave Number Analysis

Dataset 1: RI\_MULTI

Bin Size (km) 20

Reference Direction: North

Output:  png  km1  text

**Rectangle**

Lower left: N/A, N/A

Upper right: N/A, N/A

**Circle**

Center: 15.827, -40.929

Radius: 800 km

**Point**

At: N/A, N/A

Submit Cancel

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Tropical Cyclone Information System > HS3 Portal

15 Sep 2014 06:12:18 GMT

GPM 2014/09/13 22:06:46

F18 2014/09/13 22:00:28

F16 2014/09/13 19:11:02

GPM 2014/09/13 23:41:46

GPM 2014/09/13 22:11:46

GPM 2014/09/14 00:00:00

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GPM 2014/09/23 09:00:00

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GPM 2014/09/23 11:00:00

GPM 2014/09/23 12:00:00

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GPM 2014/09/23 16:00:00

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GPM 2014/09/23 20:00:00

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GPM 2014/09/23 22:00:00

GPM 2014/09/23 23:00:00

GPM 2014/09/24 00:00:00

GPM 2014/09/24 01:00:00

GPM 2014/09/24 02:00:00

GPM 2014/09/24 03:00:00

GPM 2014/09/24 04:00:00

GPM 2014/09/24 05:00:00

GPM 2014/09/24 06:00:00

GPM 2014/09/24 07:00:00

GPM 2014/09/24 08:00:00

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GPM 2014/09/24 21:00:00

GPM 2014/09/24 22:00:00

GPM 2014/09/24 23:00:00

GPM 2014/09/25 00:00:00

GPM 2014/09/25 01:00:00

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GPM 2014/09/26 22:00:00

GPM 2014/09/26 23:00:00

GPM 2014/09/27 00:00:00

GPM 2014/09/27 01:00:00

GPM 2014/09/27 02:00:00

GPM 2014/09/27 03:00:00

GPM 2014/09/27 04:00:00

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GPM 2014/09/27 22:00:00

GPM 2014/09/27 23:00:00

GPM 2014/09/28 00:00:00

GPM 2014/09/28 01:00:00

GPM 2014/09/28 02:00:00

GPM 2014/09/28 03:00:00

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GPM 2014/09/30 03:00:00

GPM 2014/09/30 04:00:00

GPM 2014/09/30 05:00:00

GPM 2014/09/30 06:00:00

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GPM 2014/09/30 22:00:00

GPM 2014/09/30 23:00:00

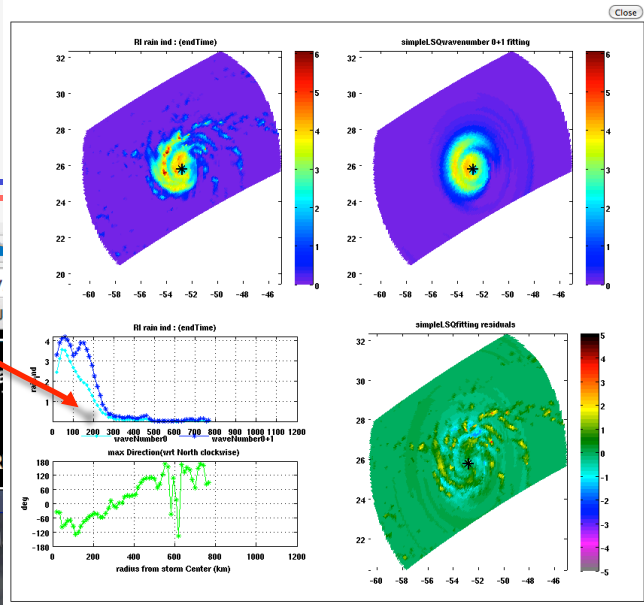
G





# September 15, 2014 - Edouard Geostationary IR - 01Z Multi-channel PMW Rain Index

msci.jp.nasa.gov



NOAA WRF TCIS HS3 JOURNALS NASA NOAA\_DOE\_NRL\_etc FIELD Campaign EXTRATROPICAL

Jet Propulsion Laboratory  
California Institute of Technology

## HURRICANE AND SEVERE WEATHER

2014-09-15 00:00:00  
Hurricanes:

Select a hurricane: **EDOUARD**

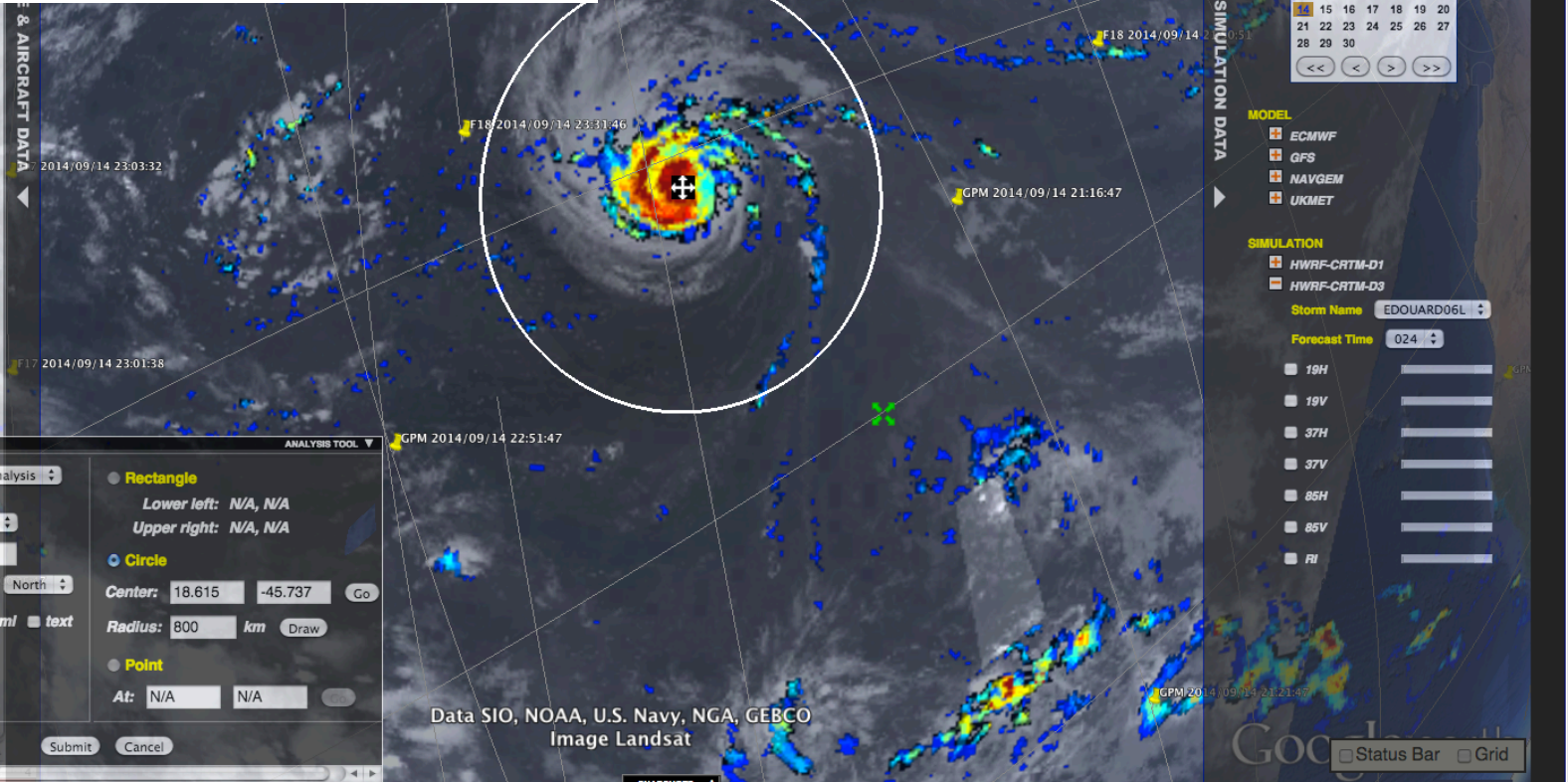
September 2014

S	M	T	W	T	F	S
01	02	03	04	05	06	
07	08	09	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Ending at hour: 01:00:00

SATELLITE DATA

- AOT (MODIS)
- Geostationary
- IR
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
  - 10H GHz
  - 10V GHz
  - 19H GHz
  - 19V GHz
  - 37COLOR
  - 37H GHz
  - 37V GHz
  - 85H GHz
  - 85V GHz
  - Rain Indicator
  - TPW



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Tropical Cyclone Information System > HS3 Portal

15 Sep 2014 06:17:02 GMT

MODEL & SIMULATION DATA

September 2014

S	M	T	W	T	F	S
01	02	03	04	05	06	
07	08	09	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

MODEL

- ECMWF
- GFS
- NAVGEM
- UKMET

SIMULATION

- HWRF-CRTM-D1
- HWRF-CRTM-D3

Storm Name: EDOUARD06L

Forecast Time: 024

- 19H
- 19V
- 37H
- 37V
- 85H
- 85V
- RI

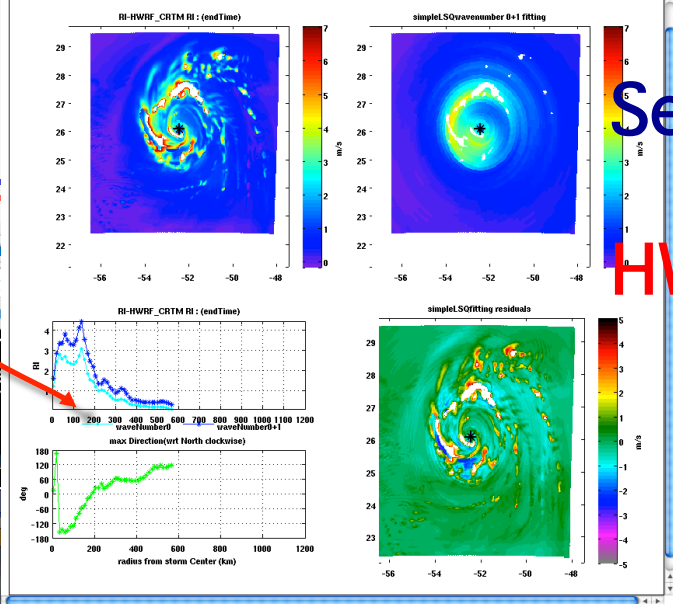
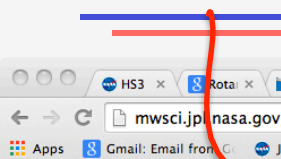
Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat





# September 15, 2014 - Edouard Geostationary IR - 01Z

## HWRF - Multi-channel PMW Rain Index



**NASA Jet Propulsion Laboratory**  
California Institute of Technology

### HURRICANE AND SEVERE WEATHER

2014-09-15 00:00:00  
Hurricane:

Select a hurricane:

September 2014

S	M	T	W	T	F	S
01	02	03	04	05	06	
07	08	09	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Ending at hour: 01:00:00

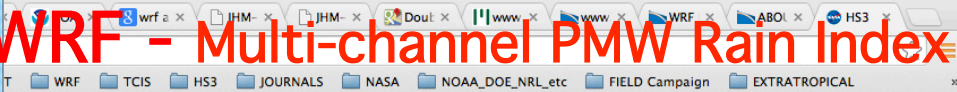
**SATELLITE DATA**

- AOT (MODIS)
- Geostationary
- IR
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
  - 10H GHz
  - 10V GHz
  - 18H GHz
  - 18V GHz
  - 37Bln Size (km) 20
  - 37 Reference Direction: North
  - 85H GHz
  - 85V GHz
  - Rain Indicator
- TFW

**ANALYSIS TOOL**

- Rectangle  
Lower left: N/A, N/A  
Upper right: N/A, N/A
- Circle  
Center: 18.889, -45.301  
Radius: 800 km
- Point  
At: N/A, N/A

Submit Cancel

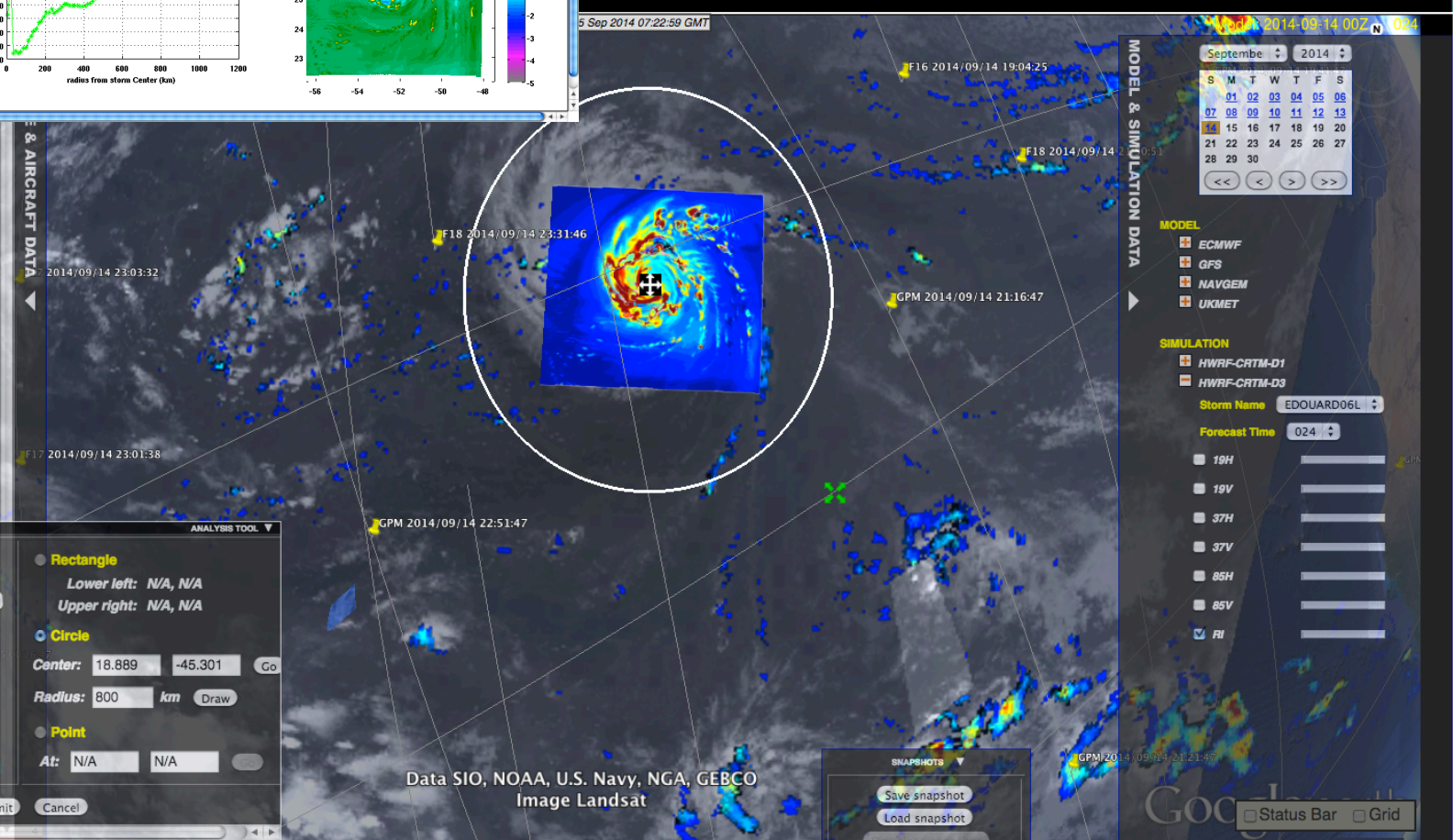


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BRING THE UNIVERSE TO YOU:

Tropical Cyclone Information System > HS3 Portal

5 Sep 2014 07:22:59 GMT



MODEL & SIMULATION DATA

September 2014

S	M	T	W	T	F	S
01	02	03	04	05	06	
07	08	09	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

**MODEL**

- ECMWF
- GFS
- NAVGEM
- UKMET

**SIMULATION**

- HWRF-CRTM-D1
- HWRF-CRTM-D3

Storm Name: EDUARD06L

Forecast Time: 024

- 19H
- 19V
- 37H
- 37V
- 85H
- 85V
- RI

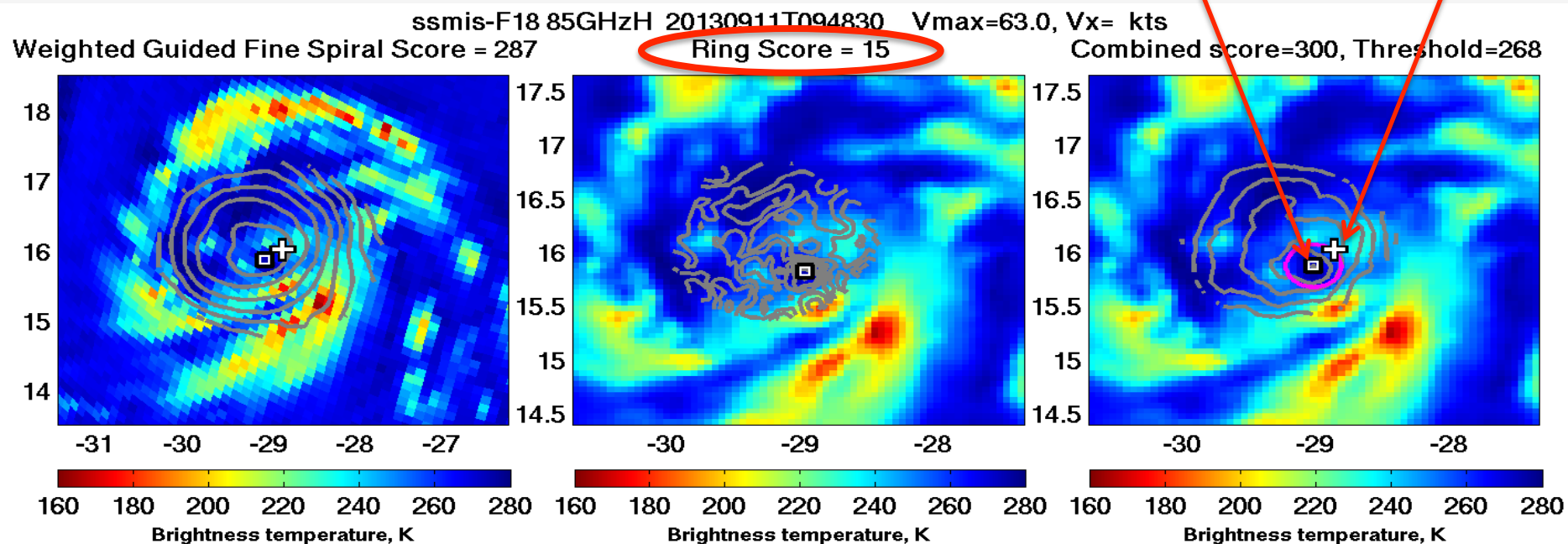
STATUS BAR:  Status Bar  Grid



# Storm structure Tool: Degree of Organization

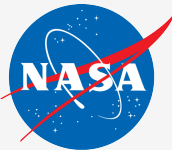
## The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

- Developed by CIMSS/NRL (Wimmers & Velden, 2010)
- We have license to run it and have done some off-line analysis, using the original version
- Coming online soon, with the latest version
- Provides:
  - Objective fix guidance for forecasters
  - Quantifies the degree of storm organization



Additional information can be found in Wimmers, A. and C. Velden, 2010: Objectively Determining the Rotational Center of Tropical Cyclones in Passive Microwave Satellite Imagery, *J. Appl. Meteor.*, 49, 2010.



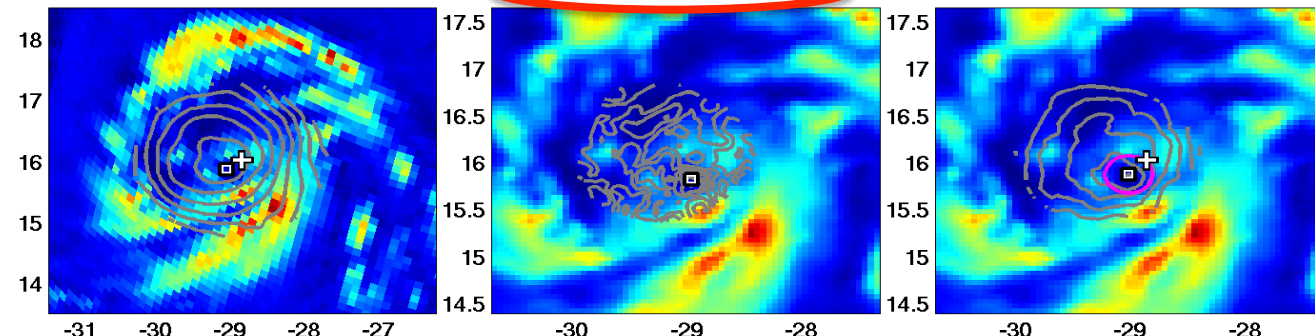


# Storm structure Tool: Degree of Organization

## The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

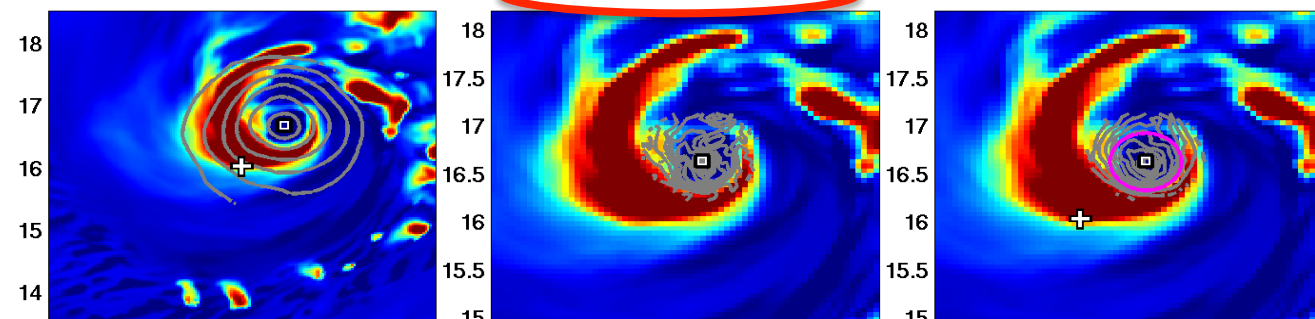
OBSERVED

ssmis-F18 85GHzH 20130911T094830 Vmax=63.0, Vx= kts  
Weighted Guided Fine Spiral Score = 287 **Ring Score = 15** Combined score=300, Threshold=268



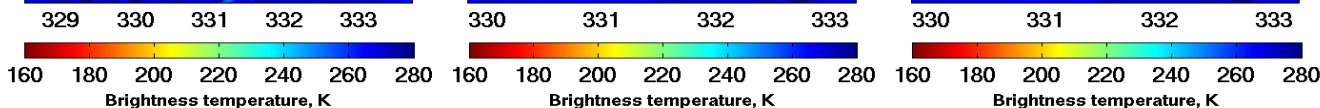
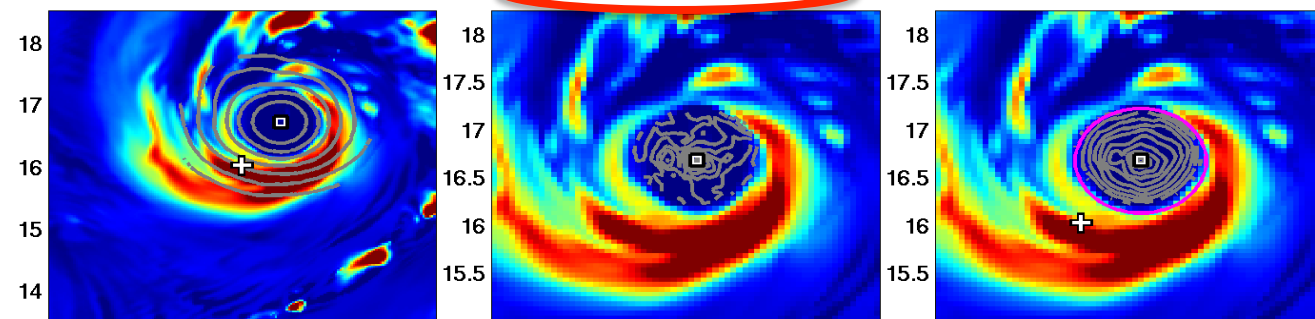
36h forecast

HWRf-CRTM-D3 85GzH 20130910T000000 Vmax=63.0, Vx= kts  
Weighted Guided Fine Spiral Score = 329 **Ring Score = 57** Combined score=386, Threshold=268



60h forecast

HWRf-CRTM-D3 85GzH 20130909T000000 Vmax=63.0, Vx= kts  
Weighted Guided Fine Spiral Score = 402 **Ring Score = 53** Combined score=455, Threshold=268



- ARCHER scores suggest the model forecasts over-predicted the structure in this case.
- This conclusion is in agreement with the model-predicted intensity parameters:
  - Observed:
    - Vmax = 65kts
    - MSLP = 989 mb
  - 36h forecast
    - Vmax = 72 kts
    - MSLP = 977mb
  - 60h forecast
    - Vmax = 83 kts
    - MSLP = 971mb

# Storm structure Tool: Degree of organization ARCHER (EP hurricane Lowell)

NASA Jet Propulsion Laboratory  
California Institute of Technology

## HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-20 15:00:00

Hurricanes:

Karina (08/10-08/22, 1)

August 2014

S	M	T	W	T	F	S
						01 02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 15:00:00

**STORM TRACK**  
 BEST TRACK  
 POUCH TRACK

**SATELLITE DATA**  
 AIRS  
 AOT (MODIS)  
 Geostationary  
 Microwave Rain Signature

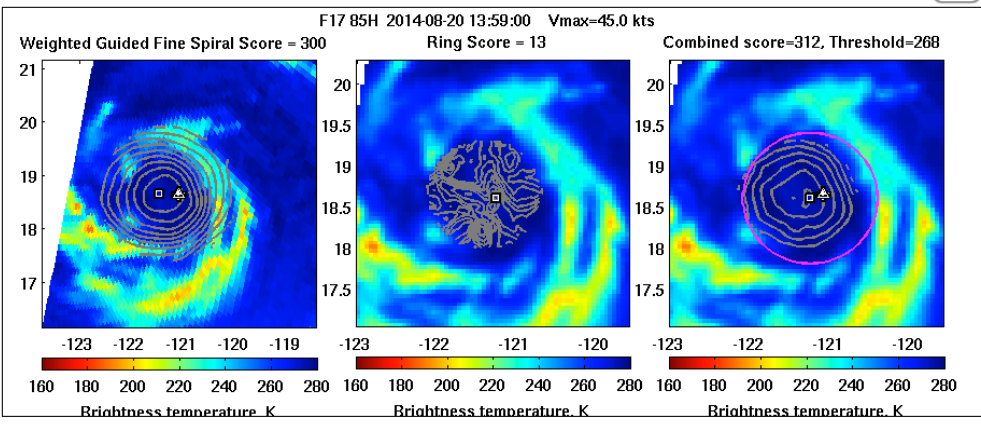
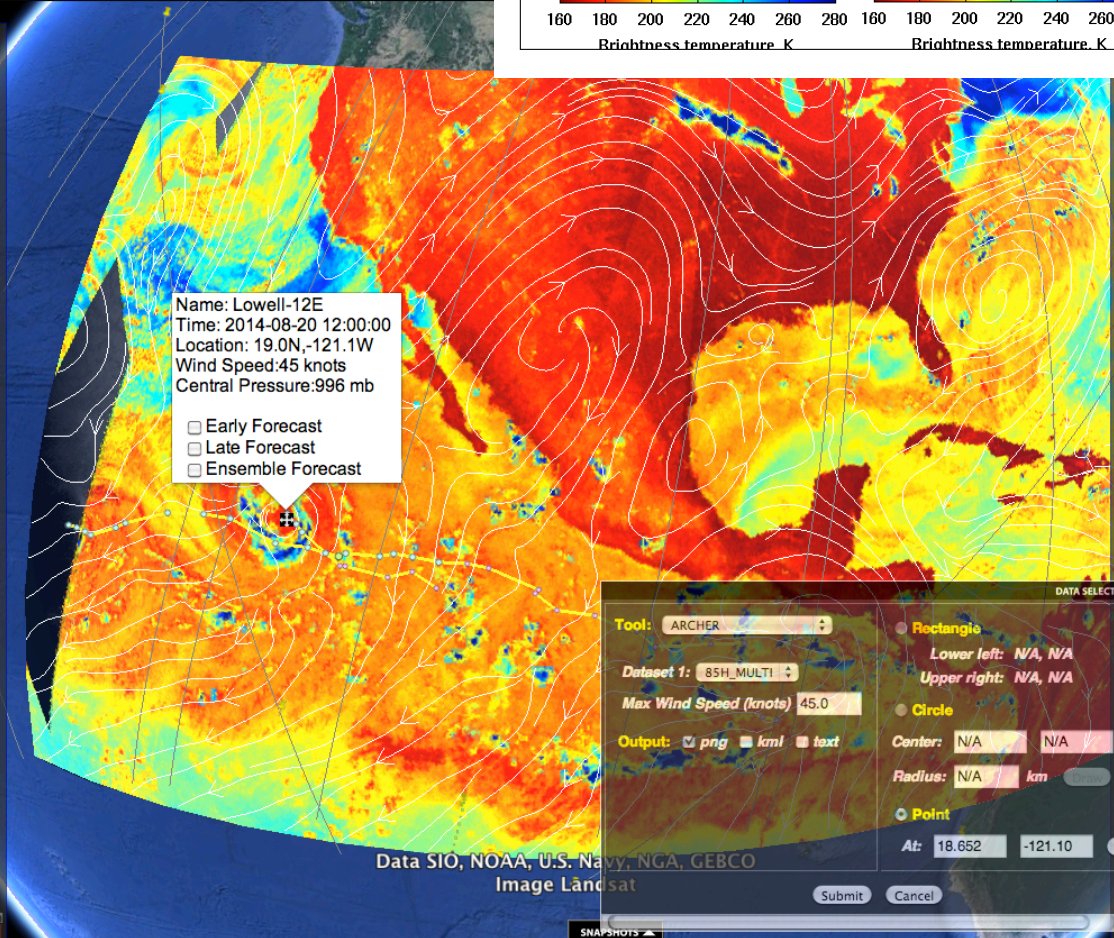
- 10H GHz
- 10V GHz
- 19H GHz
- 19V GHz
- 37COLOR
- 37H GHz
- 37V GHz
- 85H GHz
- 85V GHz
- Rain Indicator

TPW  
 6 HR Composite  
 Two Day Animation

SATELLITE & AIRCRAFT DATA

Name: Lowell-12E  
 Time: 2014-08-20 12:00:00  
 Location: 19.0N, -121.1W  
 Wind Speed: 45 knots  
 Central Pressure: 996 mb

Early Forecast  
 Late Forecast  
 Ensemble Forecast



**DATA SELECTION**

Tool: ARCHER

Dataset 1: 85H\_MULTI

Max Wind Speed (knots) 45.0

Output:  png  kml  text

Rectangle  
 Lower left: N/A, N/A  
 Upper right: N/A, N/A

Circle  
 Center: N/A, N/A  
 Radius: N/A km

Point  
 At: 18.652 -121.10

Submit Cancel

L & SIMULATION DATA

MODEL

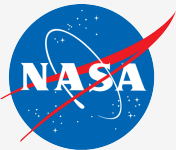
- ECMWF
- GFS
- Pres: 200
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- NAVGEM
- UKMET

**SIMULATION**

- HWRP-CRTM-D1
- HWRP-CRTM-D3

Google Status Bar Grid





# The JPL TCIS – Tropical Cyclone Information System

<http://tropicalcyclone.jpl.nasa.gov>

## Tropical Cyclone Data Archive

- Satellite depiction of hurricanes over the globe
- 12-year record (1999-2010)
- offers both data and imagery, making it a unique source to support:
  - hurricane research
  - forecast improvement
  - algorithm development
  - instrument design

## HS3 – Interactive NRT Atlantic portal

- Integrates model forecasts with satellite and airborne observations from a variety of instruments and platforms, allowing for easy model/observations comparisons.
- Allows interrogation of a large number of atmospheric and ocean variables to better understand the large-scale and storm-scale processes associated with hurricane genesis, track and intensity changes.
- Very rich information source during the analysis stages of the field campaigns.

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California Institute of Technology

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### TROPICAL CYCLONE INFORMATION SYSTEM

Welcome to the JPL Tropical Cyclone Information System

The JPL Tropical Cyclone Information System (TCIS) was developed to support hurricane research. It has two components: a 12-year global archive of multi-satellite hurricane observations and, what was a near real-time portal, that supported the 2010 NASA Genesis and Rapid Intensification Processes (GRIP) hurricane field campaign. Together, data and visualizations from the near-real time system and data archive can be used to study hurricane process, validate and improve models, and assist in developing new algorithms and data assimilation techniques. Below you will find links to various portals where you can view different types of data.

- Introduction
- Team
- Colaborators
- Funding
- Publications

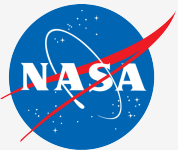
**Tropical Cyclone Data Archive**

The TCIS Data Archive is a comprehensive tropical cyclone database of multi-parameter satellite observations pertaining to the thermodynamic and microphysical structure of the storms, the air-sea interaction processes and the larger-scale environment. Currently, it contains satellite depictions of hurricanes over the globe from 1999-2010. Users are able to browse through hurricane seasons and ocean basins to find specific storms of interest. The portal is designed to facilitate the finding of coincident observations from multiple instruments, and it provides fast access to pre-subsetted data and plots, making this a unique tool for hurricane research. Additionally, data files can be directly accessed through our [FTP site](#).

**HS3 Data Portal**

This near real-time interactive portal was developed to support the multi-year Hurricane and Severe Storm Sentinel (HS3) aircraft campaign. HS3 is a five year mission with a three year airborne component (2012-2014). The campaign's main goal is to investigate the processes that underlie hurricane formation and intensity change in the Atlantic Ocean basin. This portal allows users to analyze and compare observation data and model forecasts in the North Atlantic basin from July to November of each year of the campaign.

Site Manager: Svetlita M Hristova-Velova      PRIVACY      Webmaster: Quoc Vu (JPL Clearance: CL#08-346)



- 
- A wide variety of data types
  - Organized by year, basin, storm - no need to search!
  - DATA and imagery
  - Large-scale and storm scale
    - Large-scale (over the ocean basins; +2 days on either side)
      - SST (Sea Surface Temperature)
      - Scatterometer winds (ASCAT)
      - TPW (Total Precipitable Water) from AMSU
      - Thermodynamic atmospheric structure from AIRS
    - Storm scale
      - 2000 x 2000km regions centered on the “Best Track” that was interpolated to the time of the satellite observation
      - Geostationary IR: GOES, MTSAT, FY2, Meteosat, MSG (HURSAT Version 5)
      - Multi-frequency brightness temperatures from TRMM-TMI, AMSR-E, SSMI
      - full set of radar observations from TRMM-PR and CloudSAT
      - QuikSCAT and OSCAT surface winds – new JPL product (Stiles et al., 2013)
      - MLS, OMI
- 
-



Satellite depictions of hurricanes over the globe

12-year record (1999-2010)

Offers both data and imagery, making it a unique source to support hurricane research.

# JPL TCIS – The Tropical Cyclone Data Archive

<http://tropicalcyclone.jpl.nasa.gov>

Earl, 2010  
Download all data from this Instrument (TMI)

The screenshot shows the JPL Tropical Cyclone Information System interface. At the top, it displays the NASA logo and the Jet Propulsion Laboratory (California Institute of Technology) name. The main header reads "JPL Tropical Cyclone Information System" with navigation tabs for Home, Team/Collaborations, Feedback, Data Archive, and GRIP Portal. A "Select Year" dropdown is set to 2010, and "Tropical Cyclone Earl" is selected. The left sidebar lists various tropical cyclones, with "Earl" under "Category 4" checked. The main content area features a "Timelin e" graph showing "10m Wind Speed (m/s)" and "Air Pressure (mb)" from 08/24/10 to 09/10/10. Below the graph is "Storm-Scale data for Tropical Cyclone Earl" with a table of instrument data points. At the bottom, a large satellite image of the storm is shown with a "Download" button circled in red.

Timelin e

View and download Storm-scale data

Download Selected large-scale data from



# JPL Tropical Cyclone Information System

Home

Project

Feedback

Data Portal

Analysis Tool

## Tropical Cyclone Rita

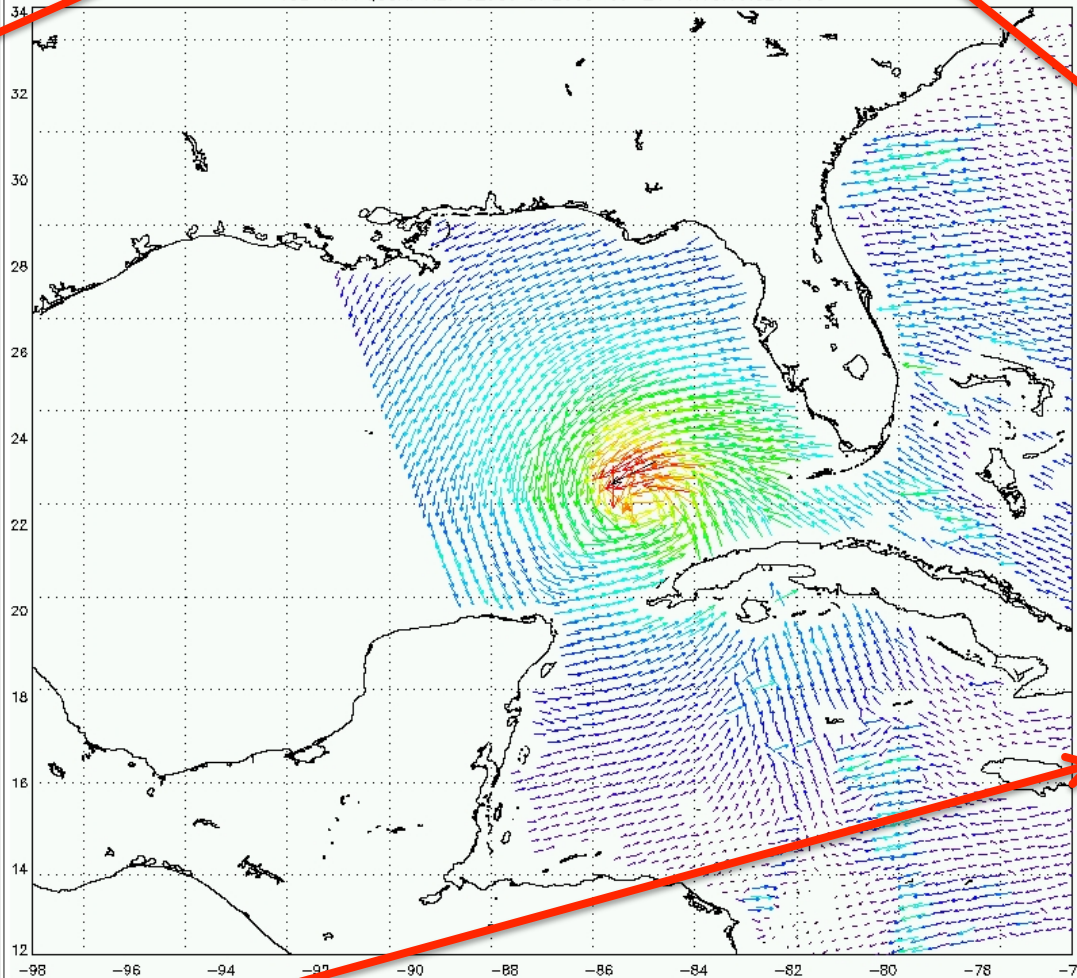
Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

September 2005

- MLS
- SeaWINDS
- QuikScat
- WIND
  - 2005-09-21 11:05:00
  - 2005-09-21 23:28:00
- GPS-RO
- OMI
- AIRS
- PR
- TMI
- AMSRE
- AMSU-A
- SSMI
- GEO

Download 2005-09-21 11:05:00 SeaWINDS WIND Data

18L-RITA QSCAT REV 32586 at 2005-09-21 11:05:10.825 UTC



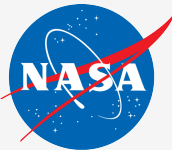
Download All

At this time

All data on this day

Download NetCDF





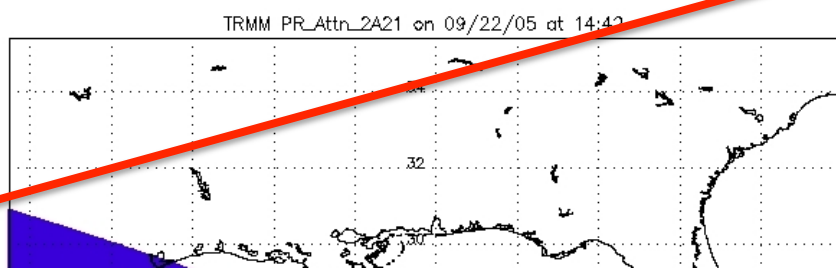
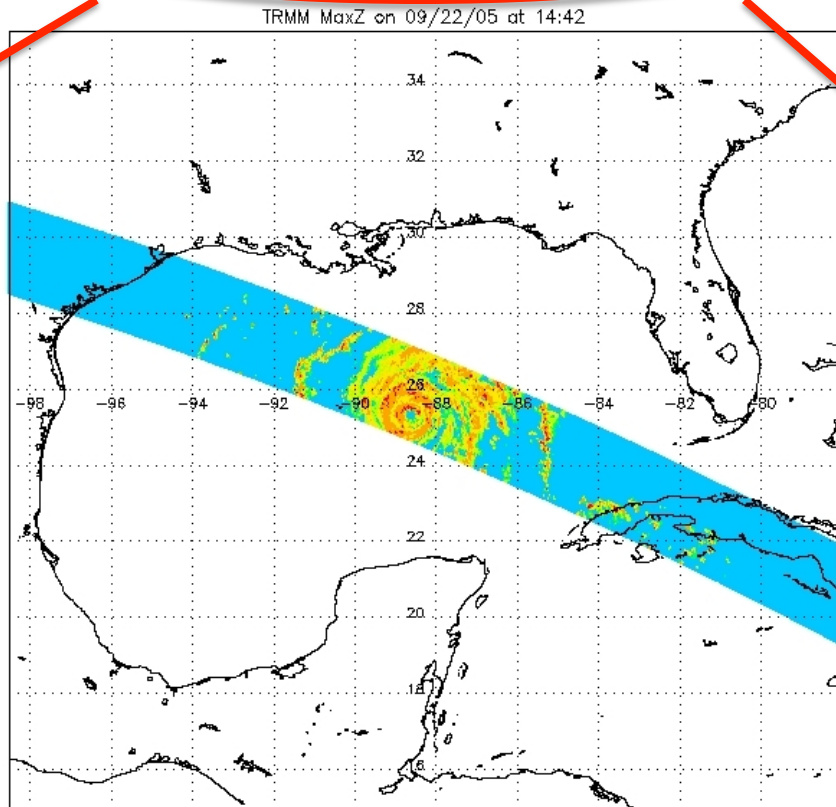
Tropical Cyclone Rita

Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

September 2005

- MLS
- SeaWINDS
- GPS-RO
- OMI
- AIRS
- PR
- TRMM
- MaxZ-PIA-RR-RT
  - 2005-09-22 08:10:00
  - 2005-09-22 14:42:00
- TMI
- AMSRE
- AMSU-A
- SSMI
- GEO

Download 2005-09-22 14:42:00 PR MaxZ-PIA-RR-RT Data



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At this time

All data on this day



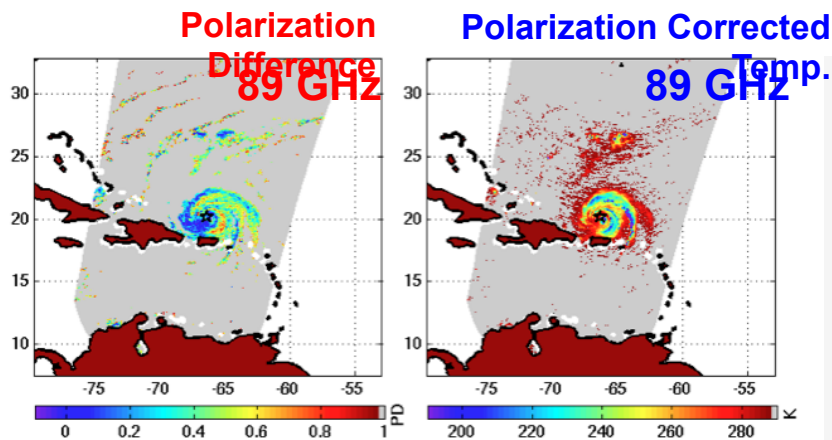
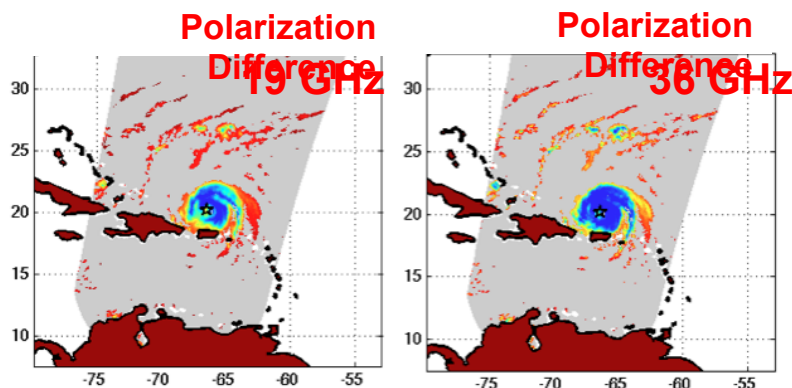
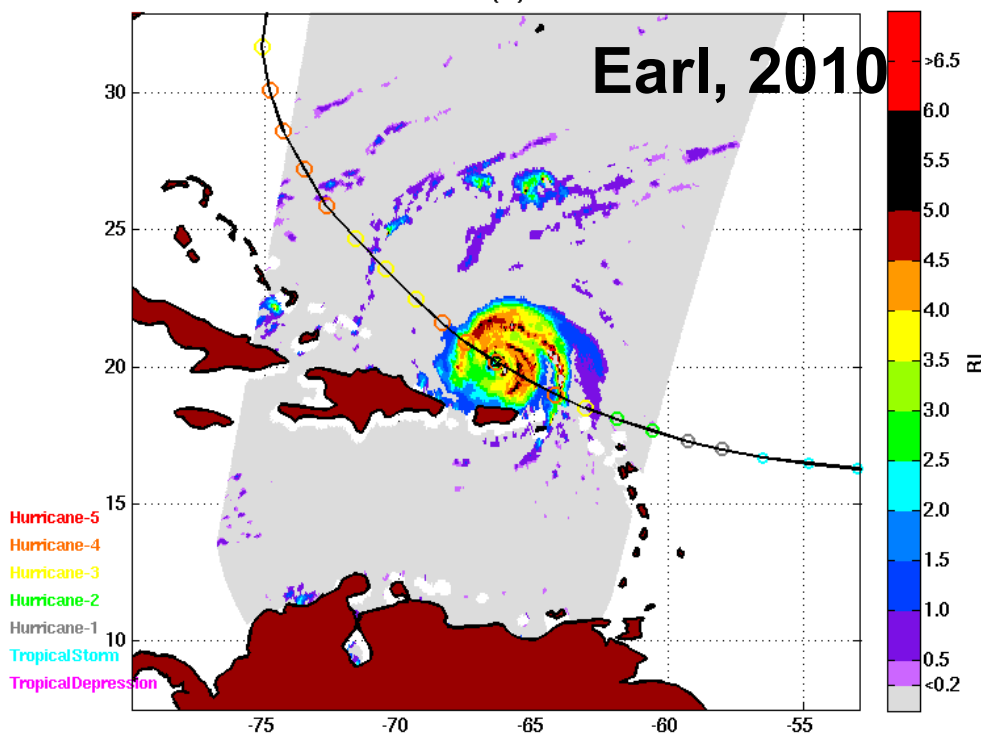
# The Rain Indicator – a multi-channel depiction of the storm structure

*Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828-2848*

Microwave signals at the top of the atmosphere can be classified into two categories:

- **emission signal** - dominant at lower frequencies; **warming**; **better for light rain**. **Strong emission in the atmosphere reduces the polarization difference (PD) in the ocean surface radiation. Hence, PD is representative of the atmospheric emission.**
- **scattering signal** - dominant at higher frequencies; **cooling**; **better for heavy rain**; **PCT**
- Hence, both signals have to be incorporated to cover the entire rainfall spectrum.

AMSRE AQUA-1 Rain Index(RI) Earl 2010/08/31 06:19:38



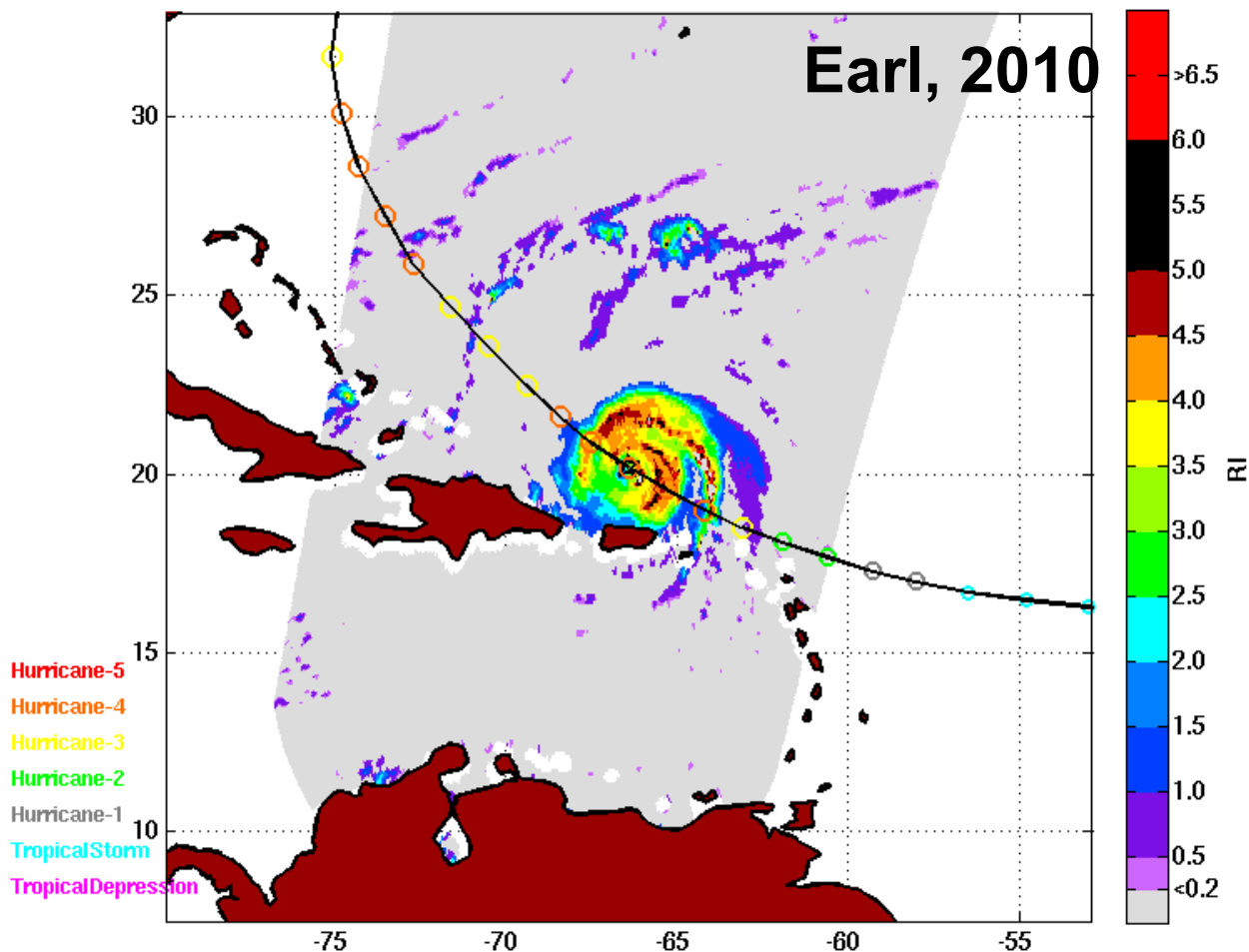




# The Rain Indicator – a multi-channel depiction of the storm structure

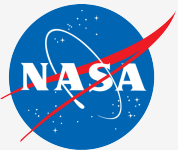
*Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828-2848*

AMSRE AQUA-1 Rain Index(RI) Earl 2010/08/31 06:19:38



## Advantages of Using the Rain Indicator over single passive microwave channels

- combines the emission and scattering signals from the **multi-channel information** to present a **cohesive depiction of the rain and the graupel above**, covering the precipitation spectrum
- Uses polarization difference. Hence, it is **less affected by calibration accuracy**.

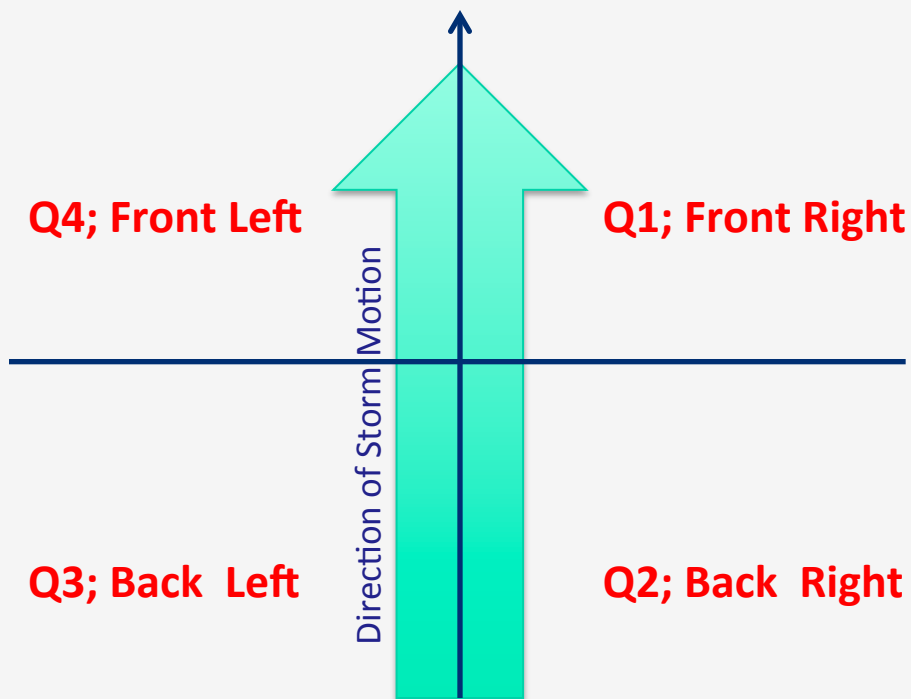


# Asymmetry and Evolution

## Statistics from observations ; North Atlantic Hurricanes

Parameter as a function of:

- Quadrant with respect to storm motion



### Created composites following similar approaches:

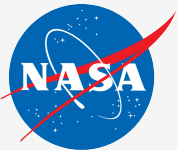
*Lonfat, M., F.D. Marks, and S.S.Chen, 2004: "Precipitation Distribution in Tropical Cyclones using the Tropical Rainfall Measuring Mission (TRMM) microwave imager : A Global Perspective" MWR 132(7)*

*Rogers et al., 2012 : "Multiscale analysis of mature tropical cyclone structure from airborne Doppler composites," MWR, 140 (1)*

*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, J. H. Jiang, 2012: "Relationship of Environmental Relative Humidity with Tropical Cyclone Intensity and Intensification Rate over North Atlantic", Geophys. Res. Lett., 39, L20809, doi: 10.1029/2012GL053546.*





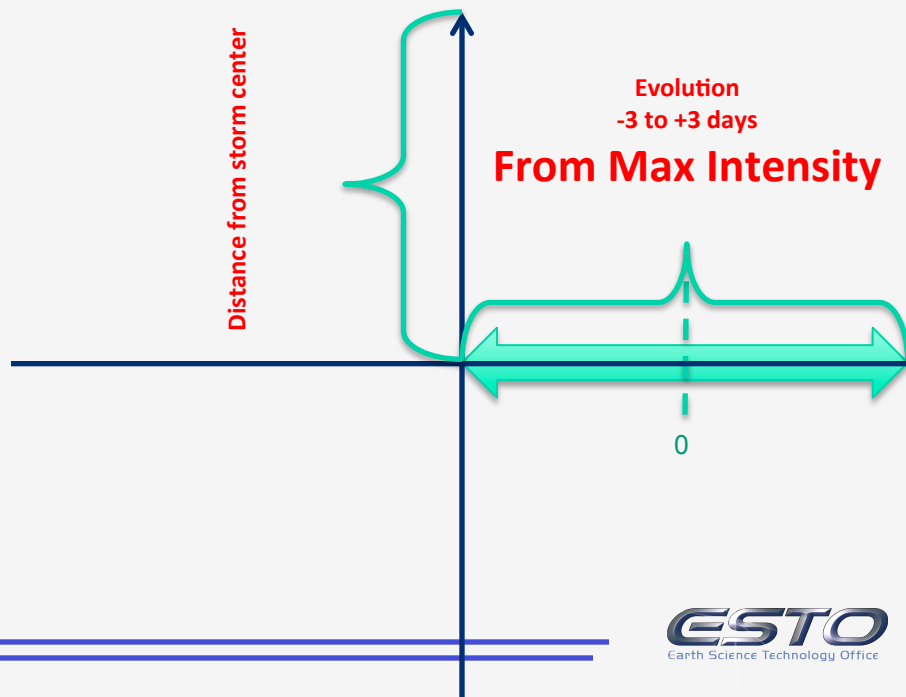
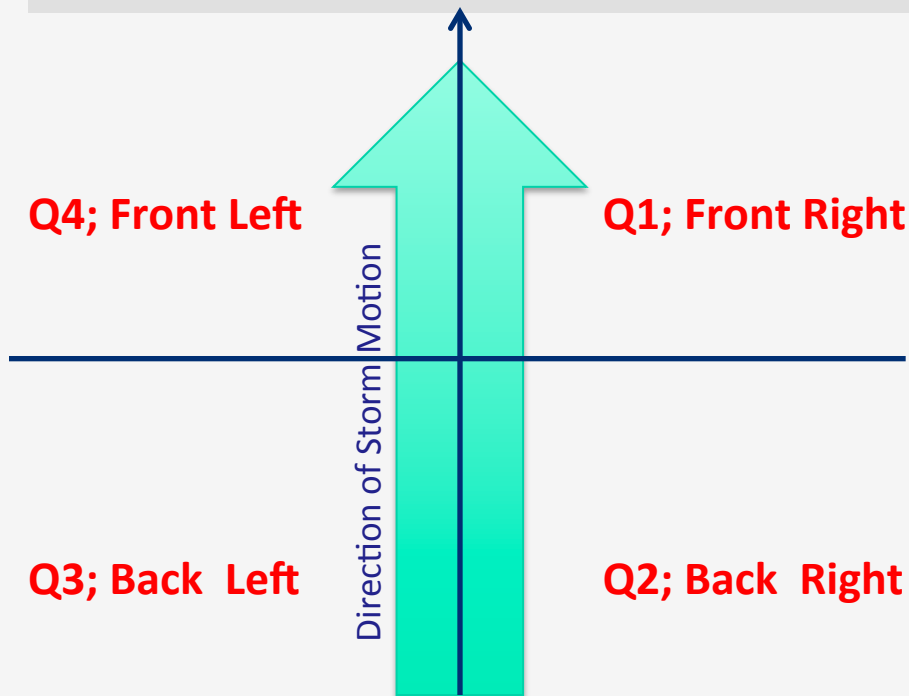


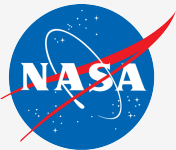
# Asymmetry and Evolution

## Statistics from observations ; North Atlantic Hurricanes

Parameter as a function of:

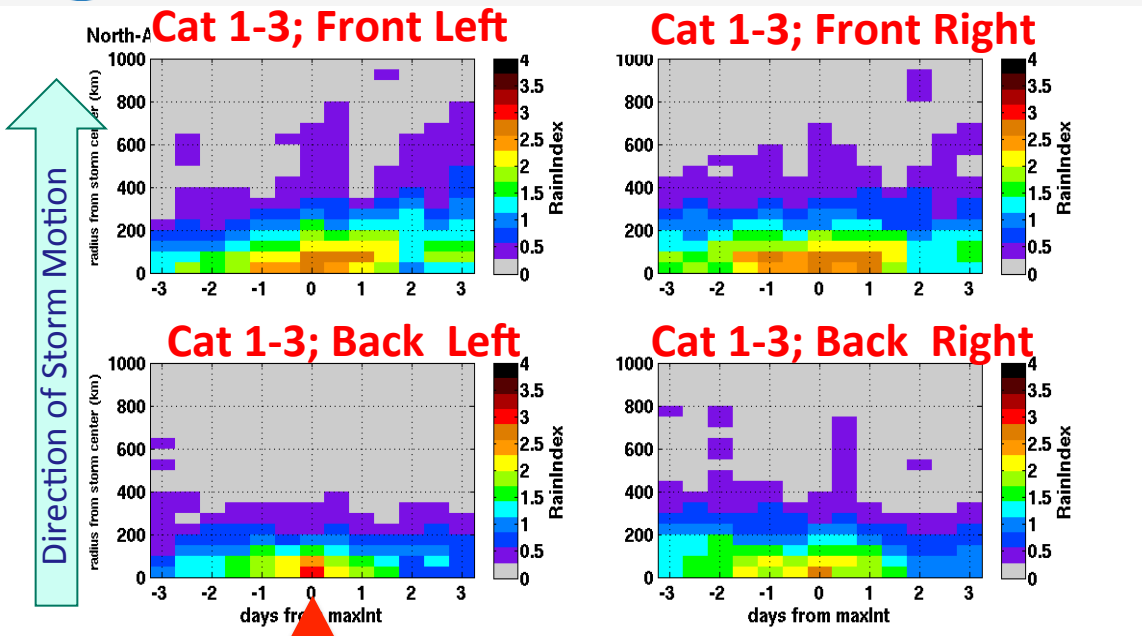
- Quadrant with respect to storm motion
- distance from storm center (y-axis)
- days from maximum intensity (x-axis)





# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



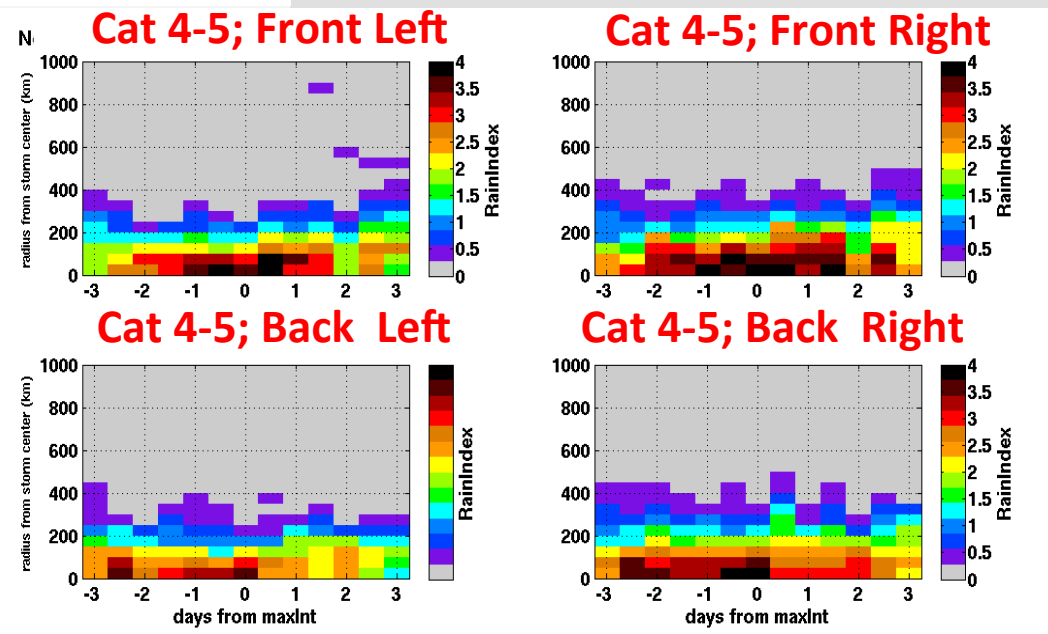
Evolution of asymmetry  
Azimuthal/Range Distributions of

# Rain Index

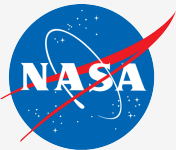
**Cat1: 31 cases**  
**Cat2: 9 cases**  
**Cat3: 12 cases**

**Total Cat1-3 = 52 cases**

**Cat4: 18 cases**  
**Cat5: 7 cases**

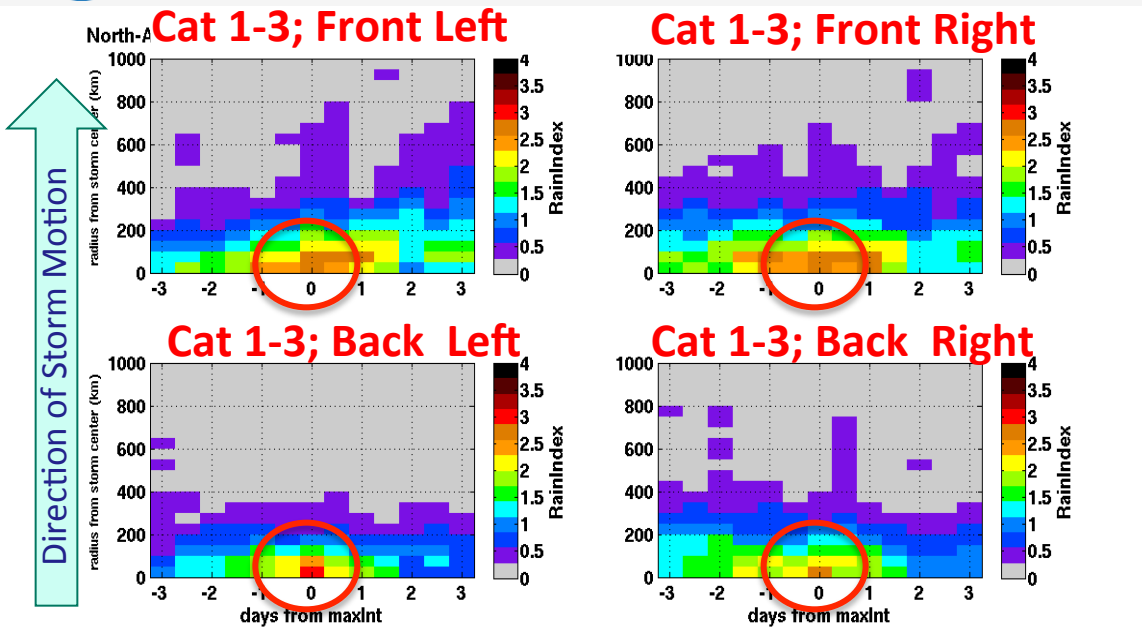






# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



Evolution of asymmetry  
Azimuthal/Range Distributions of

# Rain Index

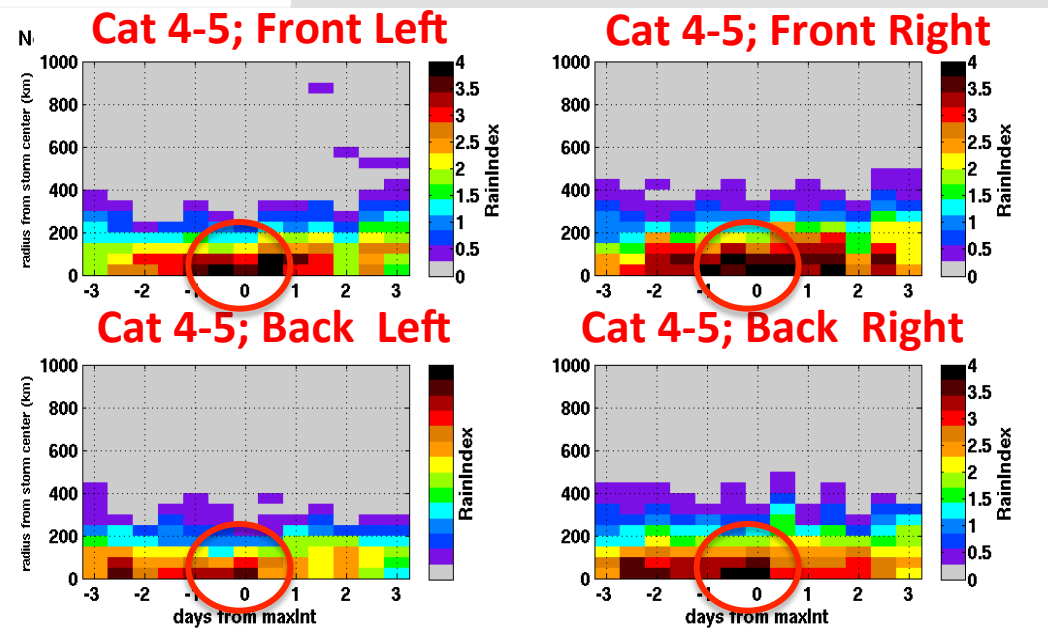
Cat1: 31 cases  
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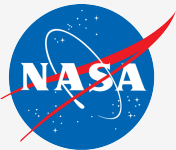
**Total Cat1-3 = 52 cases**

Cat4: 18 cases  
Cat5: 7 cases

**Cat 1-3 have rain fields that are larger, weaker and less symmetric in:**

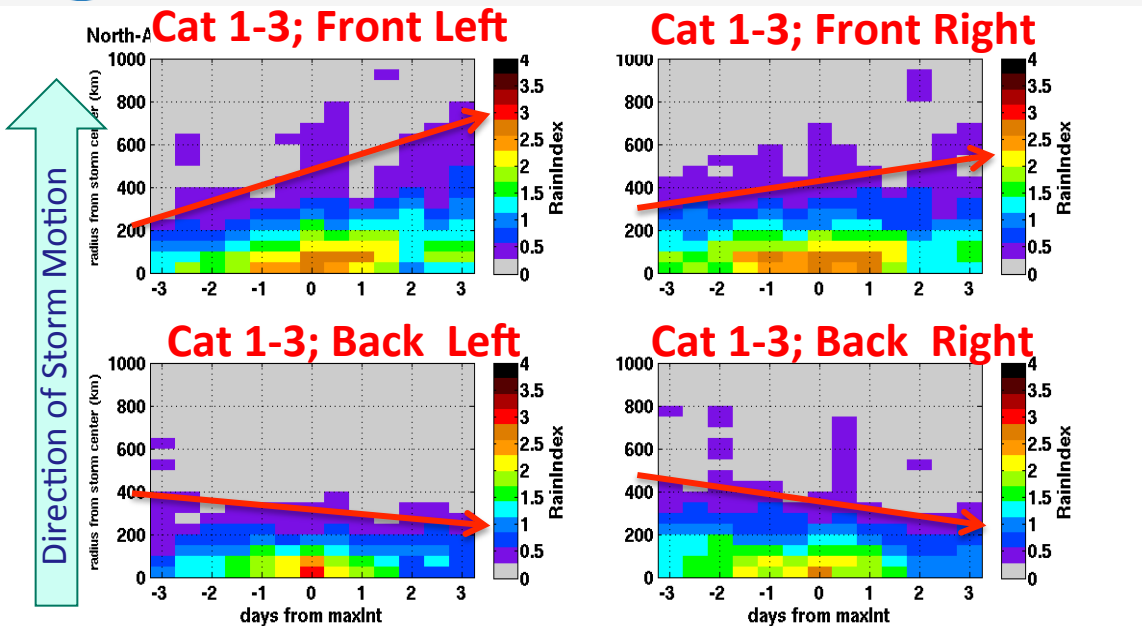
- Space
  - More intense precipitation is in the front 2 quadrants





# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



Evolution of asymmetry  
Azimuthal/Range Distributions of

# Rain Index

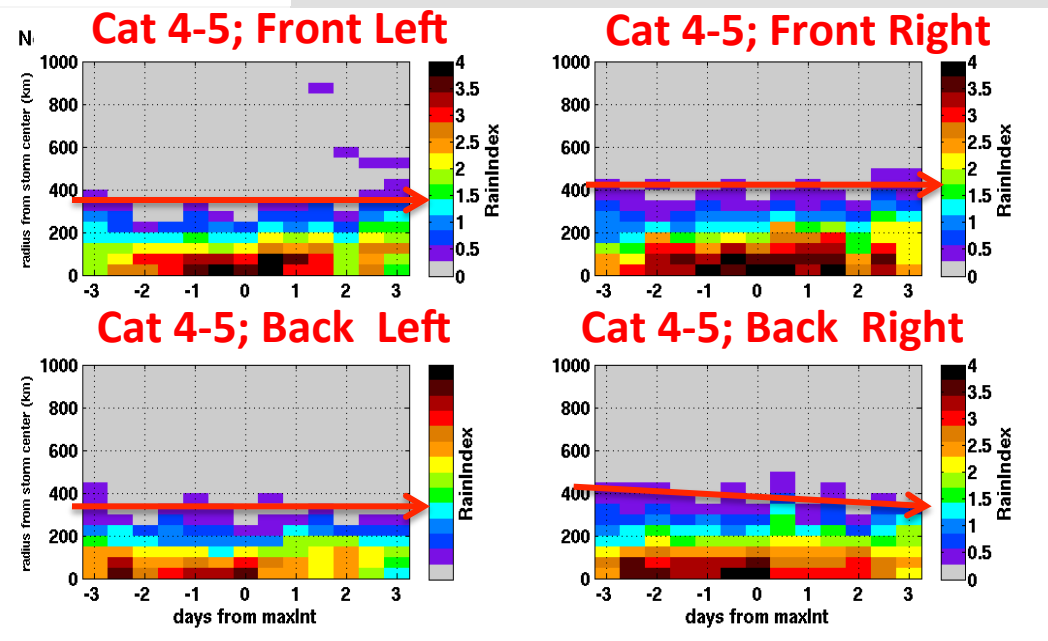
Cat1: 31 cases  
Cat2: 9 cases  
Cat3: 12 cases

**Total Cat1-3 = 52 cases**

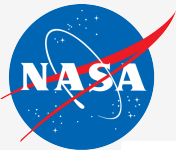
Cat4: 18 cases  
Cat5: 7 cases

**Cat 1-3 have rain fields that are larger, weaker and less symmetric in:**

- Space
  - More intense precipitation is in the front 2 quadrants
- Time
  - Tendency for radial expansion of precipitation after the peak of the storm. Only in the front 2 quadrants.
  - Increase in asymmetry

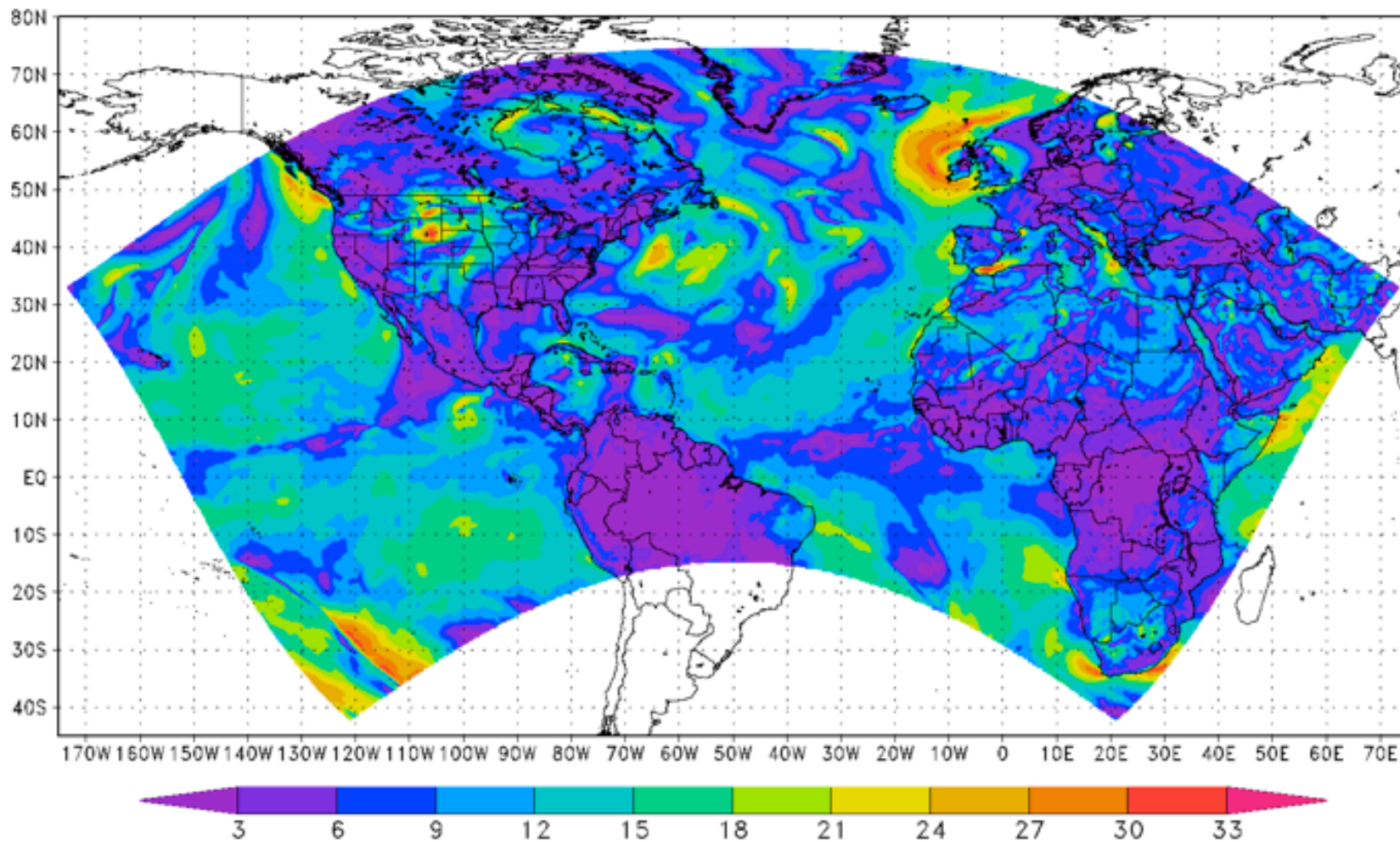


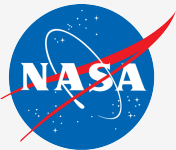




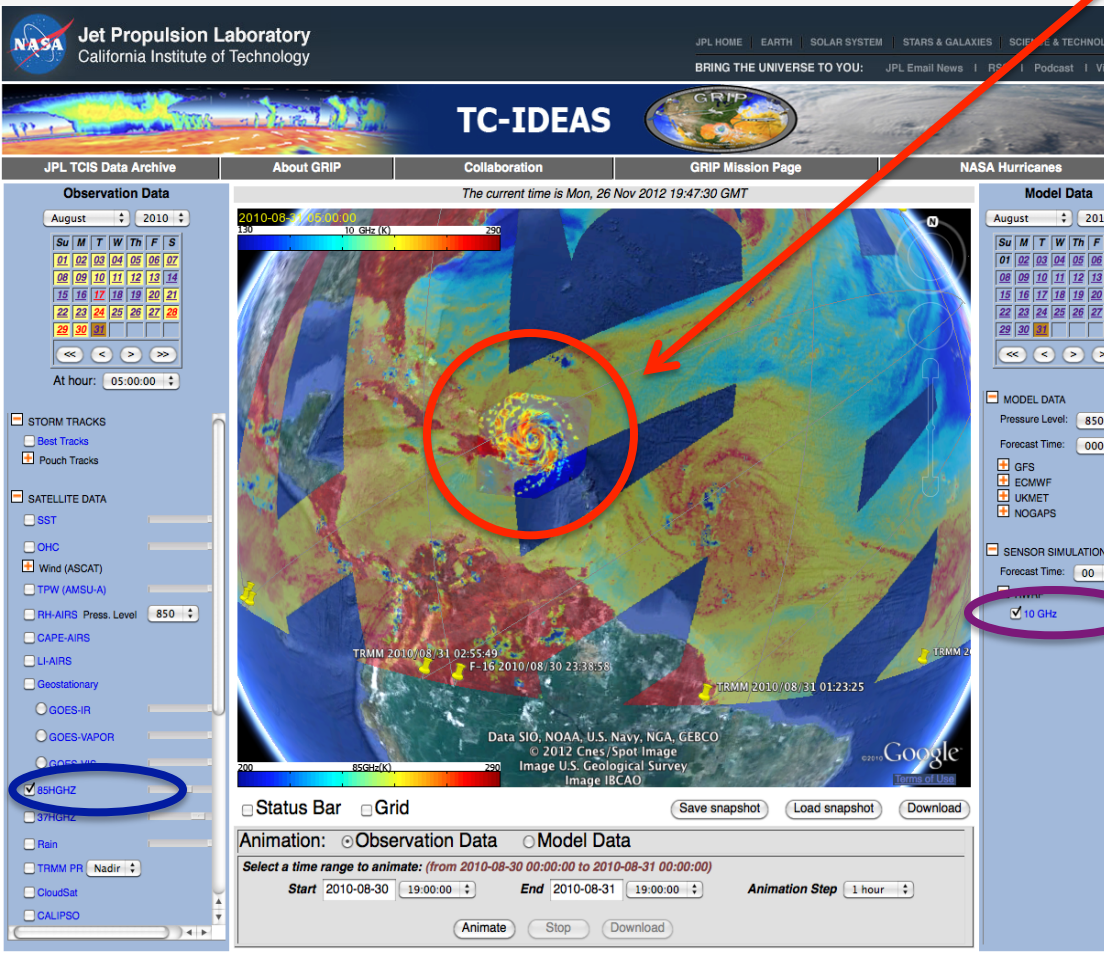
# Basin-scale HWRF – coming up!

AL/EP Cyclogenesis Domain (dx=27km) / 10m Wind [kt]





# Now: Developing analysis tools for model validation



- Interactively select region
- Gather data from observed and synthetic brightness temperatures
- Statistical comparisons
  - Storm-relative coordinates
  - EOFs, CFADs, PDFs
  - Azimuthal averages =f(r)
- Storm Structure
  - Object classification
  - Metrics for model/obs classification
  - ARCHER
  - Wave Number Analysis
- Visualization of analysis

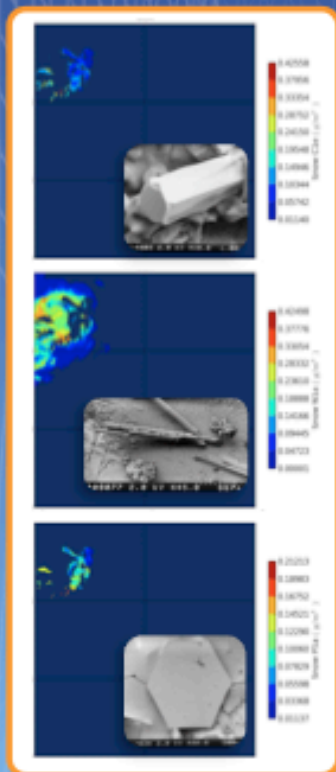


# NEOS<sup>3</sup> : example of the 3 stages

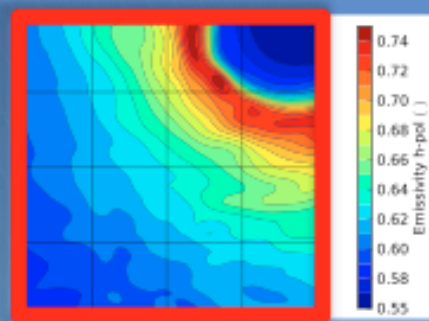
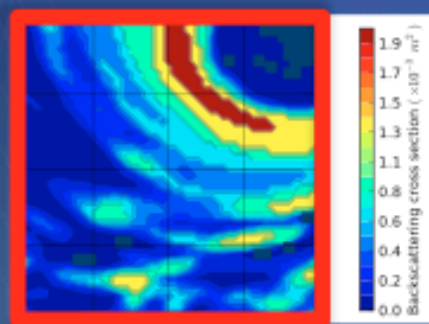


High modularity is *exploited* by enabling the user to pick options via a web interface

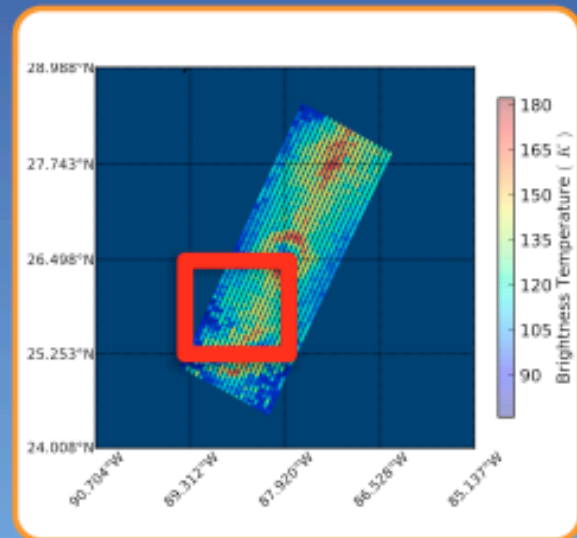
Mixing ratio by particle types



Atmospheric scattering



Brightness Temperature



Surface scattering

IRM

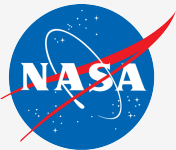
Geophysics

SEAM

Electromagnetics

ISM

Propagation & Instruments



# Focus on the model – including the operational HWRF model forecast

## 2. Integration of TCIS and NEOS<sup>3</sup>

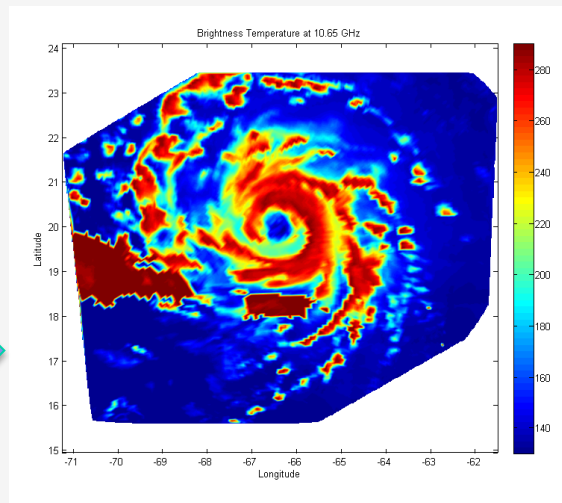
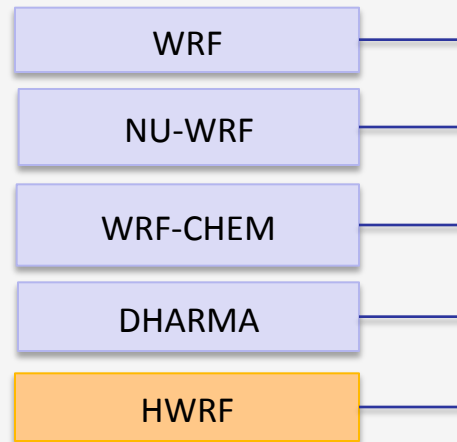
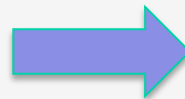
### a) New IRM module: HWRF reader

- Despite the name, the output format of HWRF is significantly different from that of all the other WRF-family.
  - Some of the quantities are reported in non-standard units (not a significant problem).
  - The sampling grid is not a regular 3-D sampling (a more time-consuming problem).

- The module is completed and tested

### b) Full simulations of HWRF

- First full simulations with HWRF input have been obtained, some passed QC some did not. Bug fixes and upgrades are in progress.



Failed QC: too large of a Tile selection. Flat Earth effects visible on TI-RTM

Passed QC

