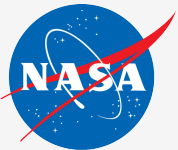


Svetla Hristova-Veleva<sup>1</sup>, M. Boothe<sup>4</sup>, S. Gopalakrishnan<sup>2</sup>, Z. Haddad<sup>1</sup>,  
M. P. Johnson<sup>1</sup>, B. Knosp<sup>1</sup>, B. Lambrigtsen<sup>1</sup>, F. Marks<sup>2</sup>, P. P. Li<sup>1</sup>,  
M. Montgomery<sup>4</sup>, N. Niamsuwan<sup>1</sup>, W. Poulsen<sup>1</sup>, T.-P. Shen<sup>1</sup>, B. Stiles<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

# Fusion of Hurricane Models and Observations: Developing the Technology to Improve the Forecasts

ESTF15  
Pasadena, CA  
June 25, 2015



# 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

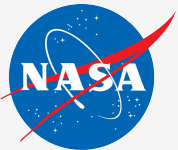


Each year they threaten the US coast, cause damages worth billions and take life.

- 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.

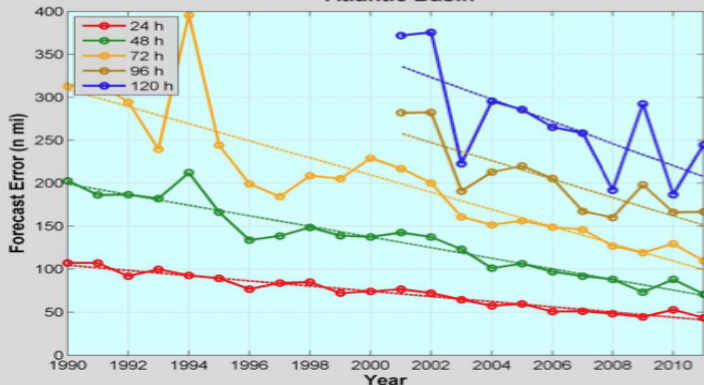




# Current state-of-the-art hurricane prediction

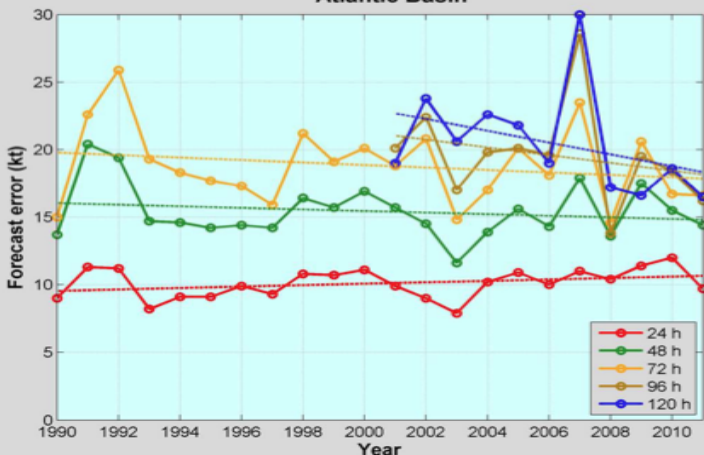
- **25% reduction in 48 hour track error over the past 6 years**

NHC Official Track Error Trend  
Atlantic Basin



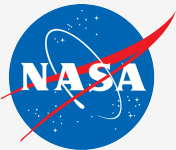
- **Intensity forecasts have not improved.**

NHC Official Intensity Error Trend  
Atlantic Basin



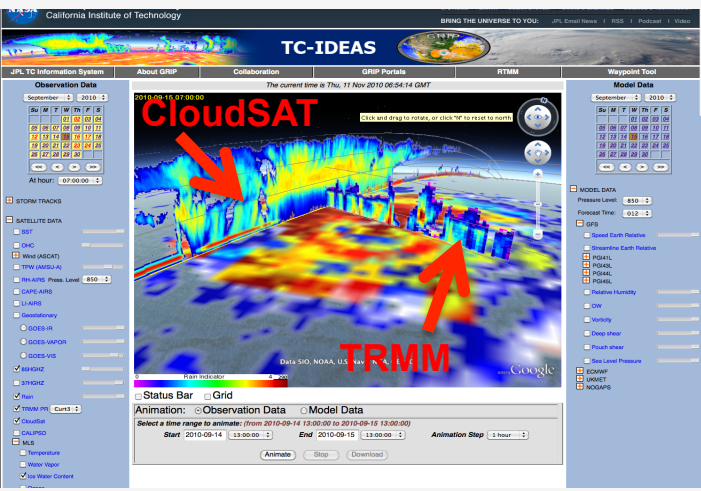
## But WHY ???

- 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).**

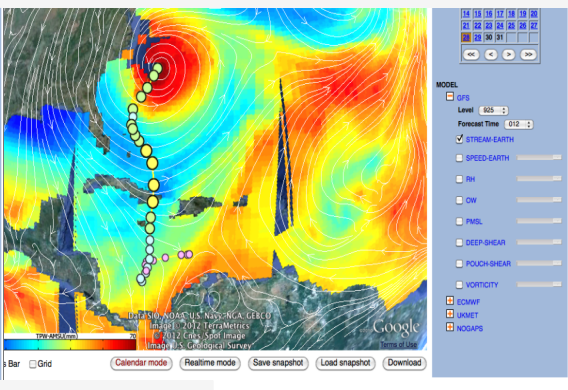


# Motivation for our project - The critical pathways to hurricane forecast improvement

• Is the representation of the precipitation structure correct?



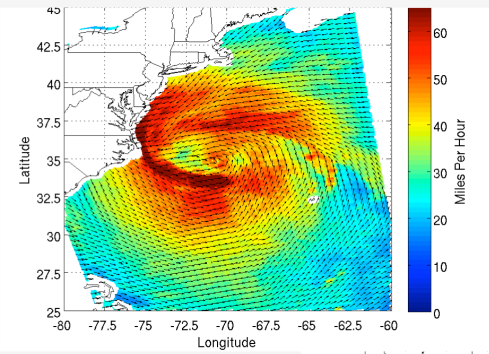
• Is the environment captured correctly?  
• Is the interaction between the storm and its environment realistic?



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

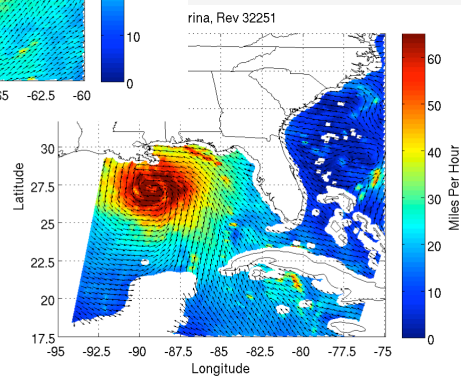
**Satellite observations can help in 3 important ways!**

• Is the storm scale and asymmetry reflected properly?



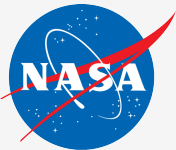
Hurricane Sandy  
As seen by the  
ISRO's OSCAT

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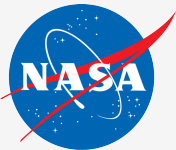
To facilitate hurricane research, we are developing the JPL Tropical Cyclone Information System (JPL TCIS) of multi-instrument observations and some model data pertaining to:

- 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
- the Hurricane Science Research Program (HSRP) in the past.

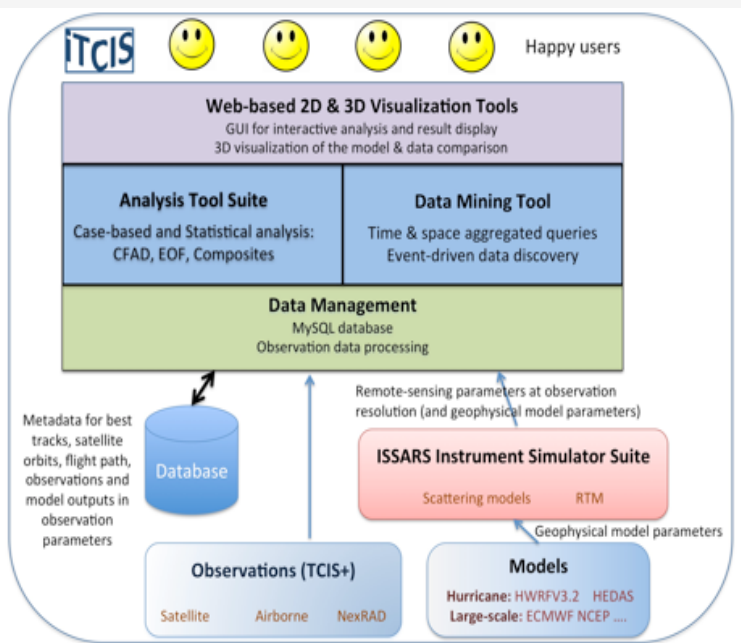
The project is developed in close collaboration with our colleagues from NOAA/EMC and NOAA/AOML/HRD to bring the operational and research versions of HWRF forecasts into the satellite database and to develop a set of on-line analysis tools.



# Objectives for the project

- The main objective of this 3-year effort is 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 will develop three critical components that will allow the merger of observations with model forecasts:

- 1) **Develop visualization to enable analysis** (e.g., data immersion approaches to enable real-time interaction with the models, and visualization of highly complex systems).
- 2) **the coupling of the instrument simulator with operational hurricane forecast models and incorporation of simulated satellite observables into the existing database of satellite and air-borne observations.**
- 3) **Developing tools to manage the validation and assessment of model-data intercomparisons** to more easily evaluate the performance of different models





# The three components of our system

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

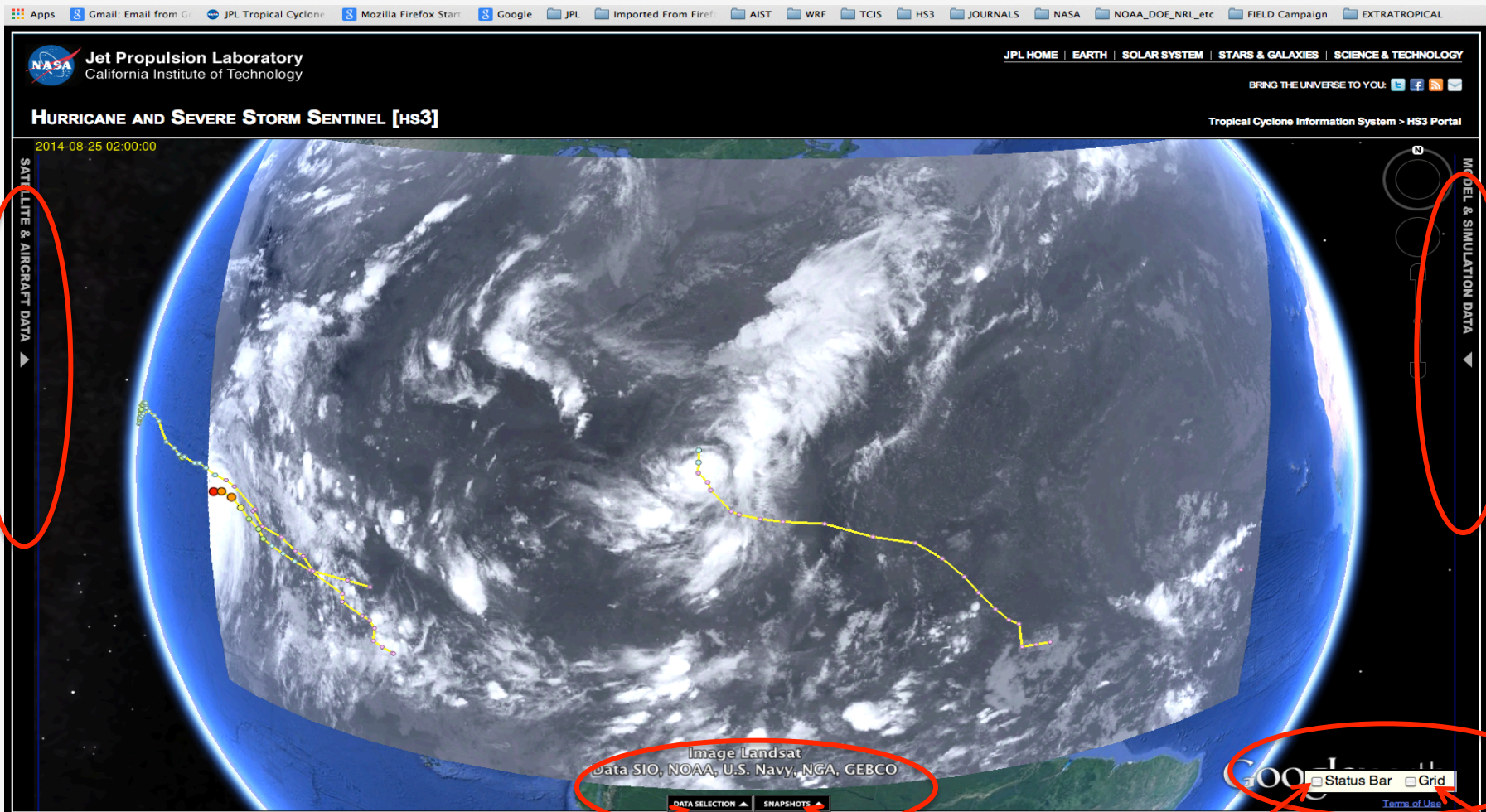


# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>) Features

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

- Observations

- Model data

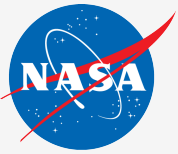


Analysis Tools

Save a view

Overlay Grid  
Find lat/lon of a point



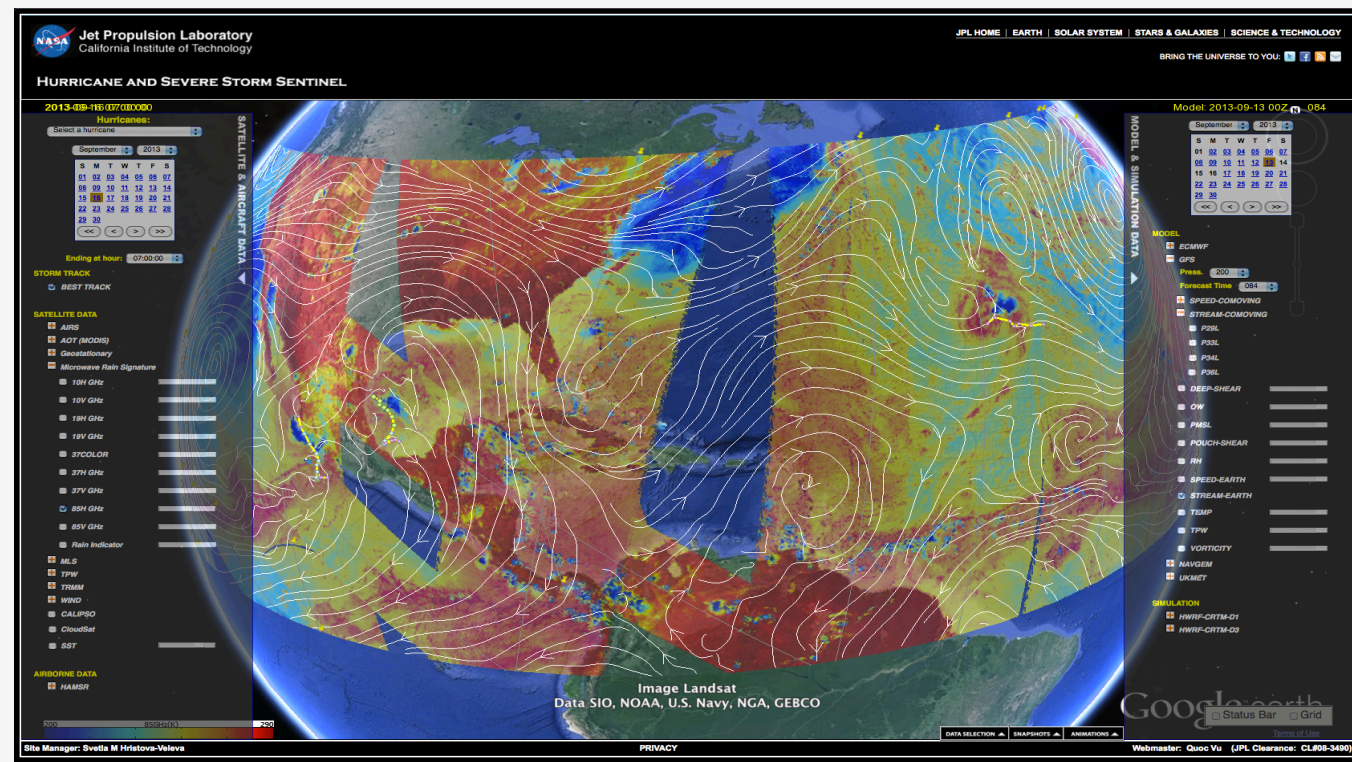


# 1. Develop Visualization to Enable Analysis:

## A. Database Driven and Configurable Web Portal

- **New website front end is driven by the database**

- Products, plots, and analysis tools only show up if data is available in the database for the date the user selects

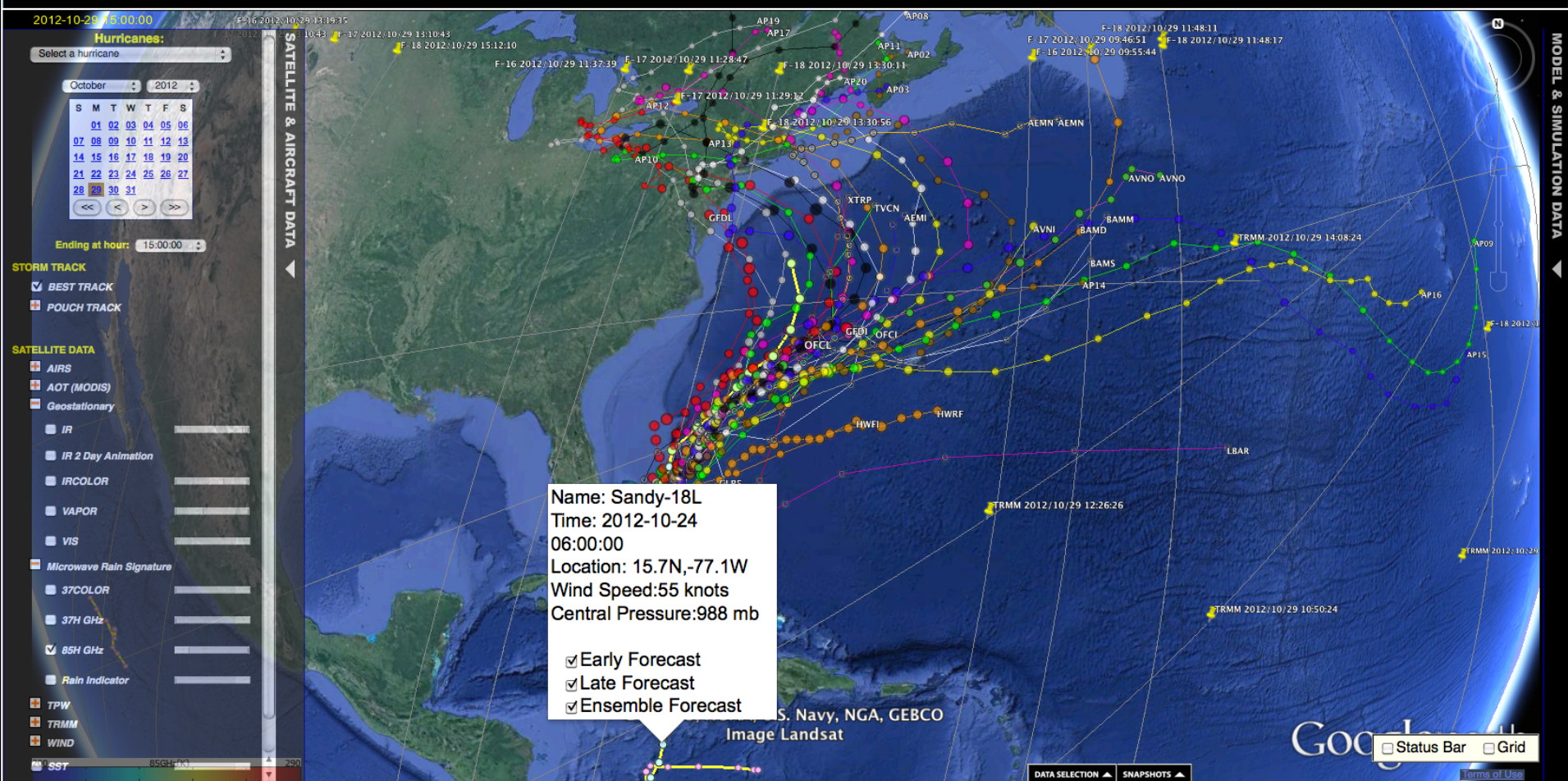


- **Database architecture was redesigned to enable easy portal configuration**
  - Uses MySQL InnoDB table architectures with foreign keys to associated products, files, missions, etc.
  - New portals can be started on the fly
  - Can support multiple missions (i.e. new RapidScat portal)



# 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

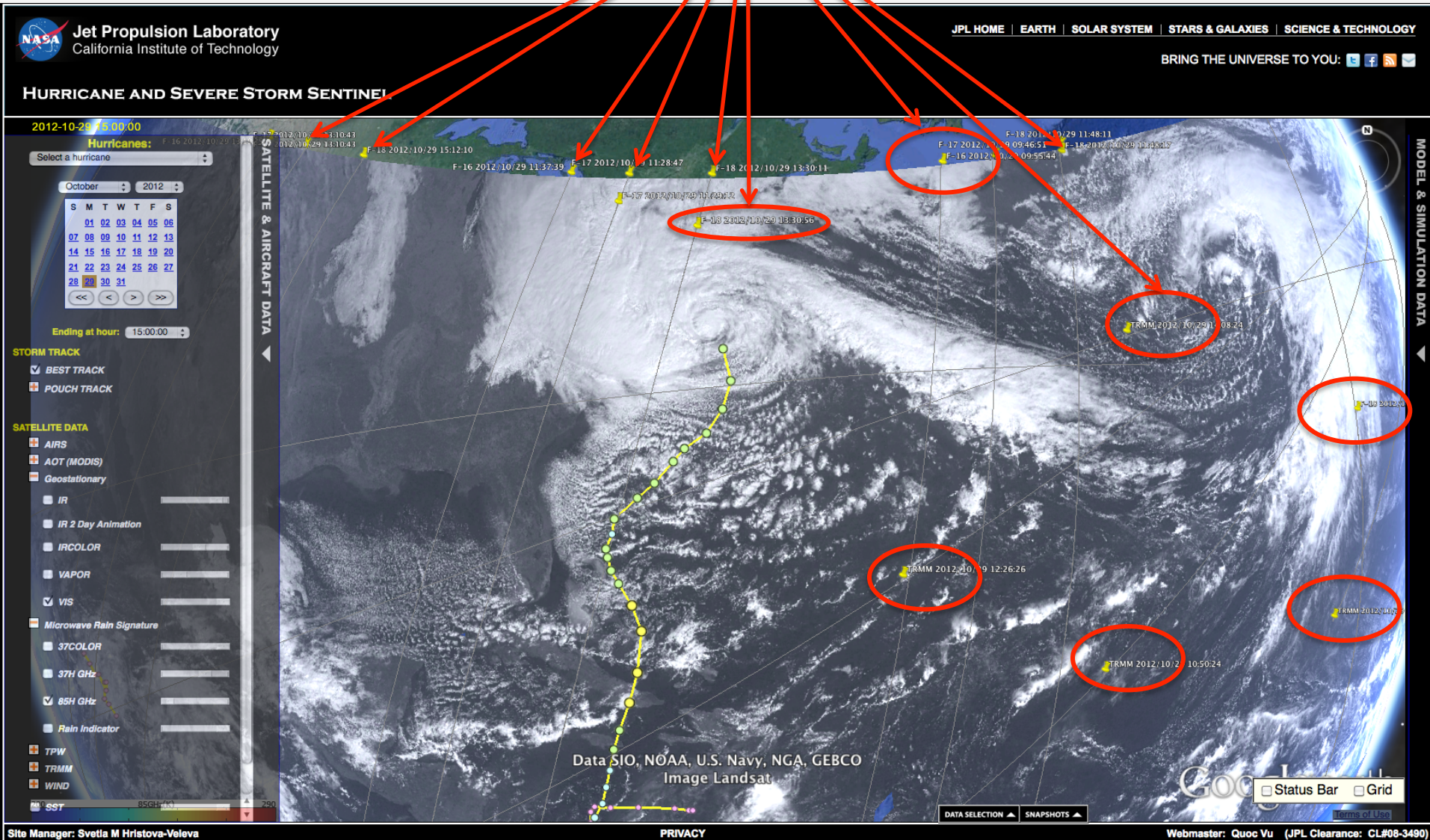




# HS3 Portal – NRT in 2012-14, Atlantic (<http://tropicalcyclone.jpl.nasa.gov/hs3>)

## 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>)

## The Power of the Satellite Observations – painted in microwave

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### HURRICANE AND SEVERE STORM SENTINEL

2012-10-29 11:29:00

Hurricanes:

Select a hurricane

October 2012

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
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- 37COLOR
- 37H GHz
- 85H GHz
- Rain Indicator
- TPW
- TRMM
- WIND
- SST

SATELLITE & AIRCRAFT DATA

MODEL & SIMULATION DATA

F-18 2012/10/29 11:30:11  
F-17 2012/10/29 11:28:47  
F-18 2012/10/29 13:30:11  
F-17 2012/10/29 11:29:12  
F-18 2012/10/29 13:30:56  
F-18 2012/10/29 11:48:11  
F-17 2012/10/29 09:46:51  
F-18 2012/10/29 11:49:33  
F-16 2012/10/29 09:55:44  
TRMM 2012/10/29 08:58:58  
TRMM 2012/10/29 12:56:55  
TRMM 2012/10/29 10:50:24  
TRMM 2012/10/29 11:02:44

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

GOOGLE

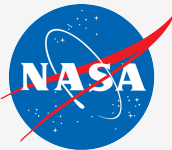
Status Bar Grid

DATA SELECTION SNAPSHOTS

Site Manager: Svetia M Hristova-Veleva

PRIVACY

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



# Driving by desire: Interrogate!

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Tropical Cyclone Information System > HS3 Portal

## HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-20 15:00:00

The current time: Thu, 04 Jun 2015 05:05:29 GMT

Model 2014-08-20 15:00:00 N 012

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						

August 2014

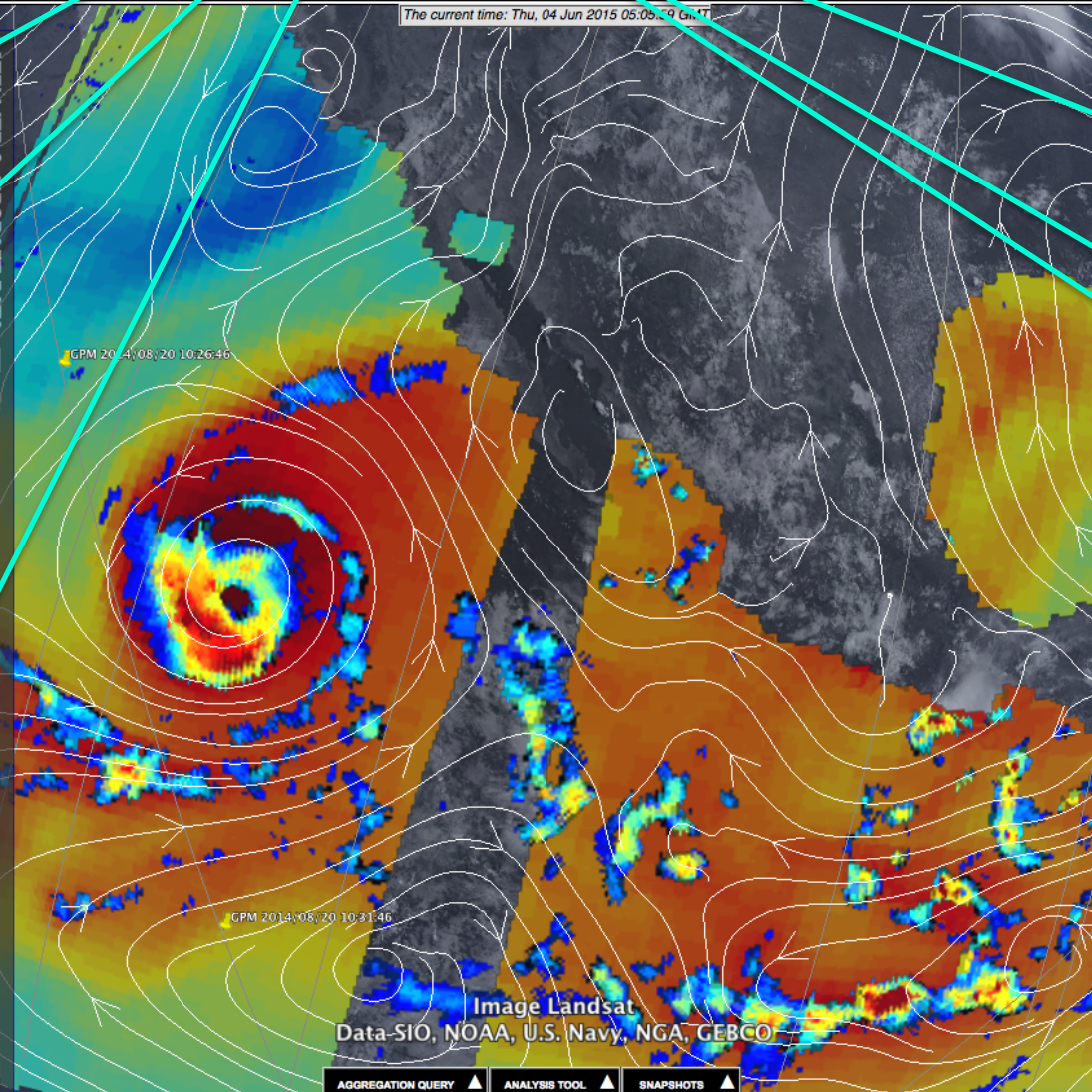
S	M	T	W	T	F	S
					01	02
03	04	05	06	07	08	09
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						

Ending at hour: 15:00:00

- STORM TRACK**
- BEST TRACK
  - POUCH TRACK

- SATELLITE DATA**
- AIRS
  - AOT (MODIS)
  - Geostationary
  - GFS-NEOS3
  - Microwave Rain Signature
    - 10H GHz
    - 10V GHz
    - 19H GHz
    - 19V GHz
    - 37COLOR
    - 37H GHz
    - 37V GHz
    - 85H GHz
    - 85V GHz
  - Rain Indicator
  - MLS
  - TPW
  - 6 HR Composite
  - Two Day Animation

- MODEL & SIMULATION DATA**
- MODEL
- ECMWF
  - GFS
    - Press: 850
    - 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-D3S Bar
  - Grid

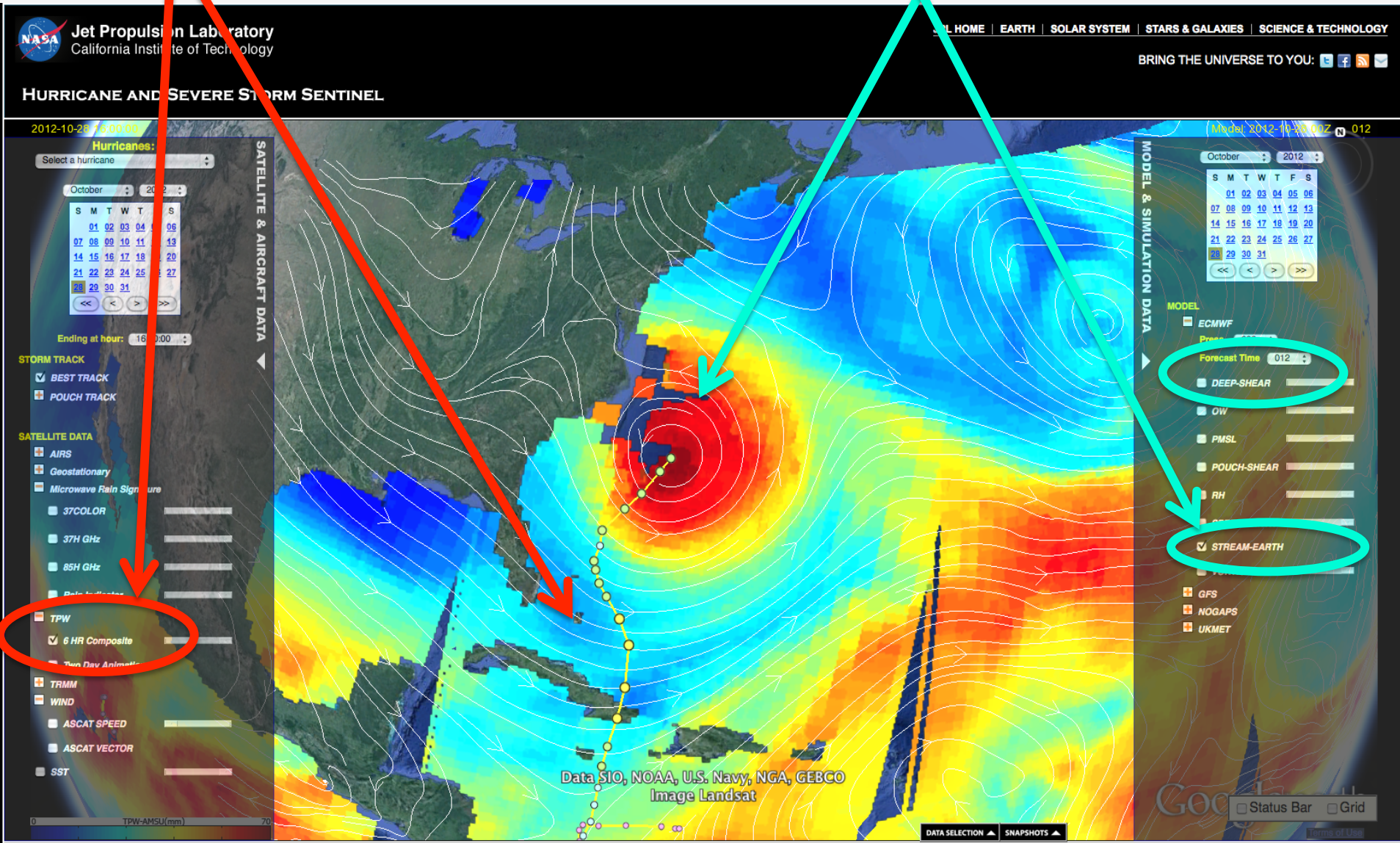


AGGREGATION QUERY | ANALYSIS TOOL | SNAPSHOTS

Google earth

# Driving by desire: Investigate and Discover

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





# 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

Model: 2014-08-11 00Z 012

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
  - VAPOR
  - VIS
- Microwave Rain Signature
  - TPW
  - TRMM
  - WIND
  - CALIPSO
  - CloudSet
  - SST

**MODEL & SIMULATION DATA**

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

**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)



# 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)

Model: 2014-08-11 00Z 012

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

**Transparency Sliders**

**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-D3

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 [H3]

Tropical Cyclone Information System > H3 Portal

2014-08-11 12:00:00

Model: 2014-08-11 00Z 012

**SATellite & AIRCRAFT DATA**

Hurricanes: July (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
- VAPOR
- VIS
- Microwave Rain Signature
- TPW
- TRMM
- WIND
- CALIPSO
- CloudSat
- SST

**MODEL & SIMULATION DATA**

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						

**MODEL**

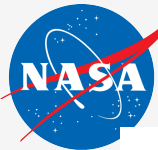
- ECMWF
- Press: 925
- Forecast Time: 012
- SPEED-COMMOVING
- STREAM-COMMOVING
- P13L
- P17L
- DEEP-SHEAR
- OW
- PMSL
- POUCH TRACK
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- GFS
- NAVGEM
- UKMET

**SIMULATION**

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

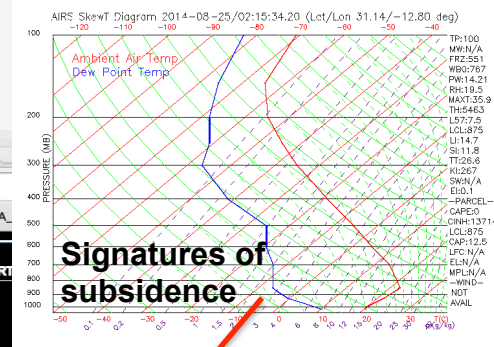
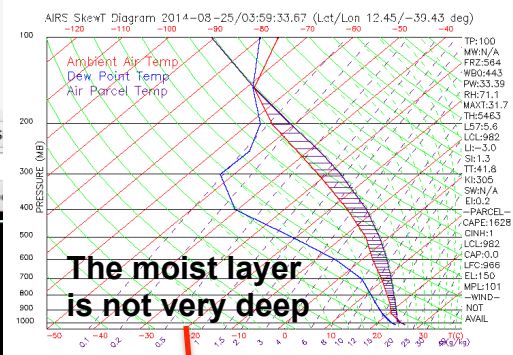
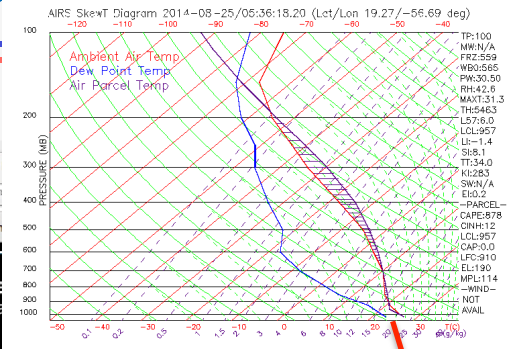
Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat

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



# 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

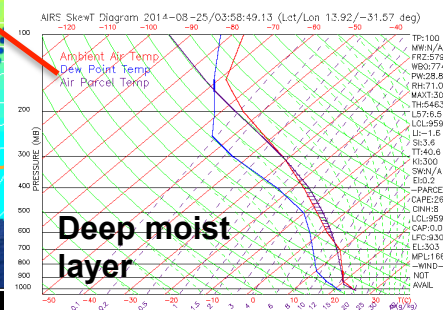
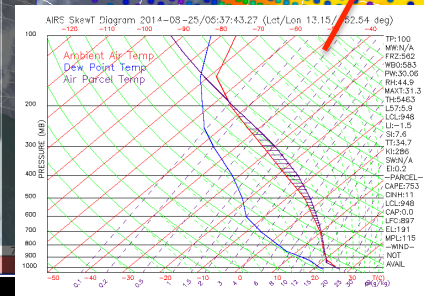
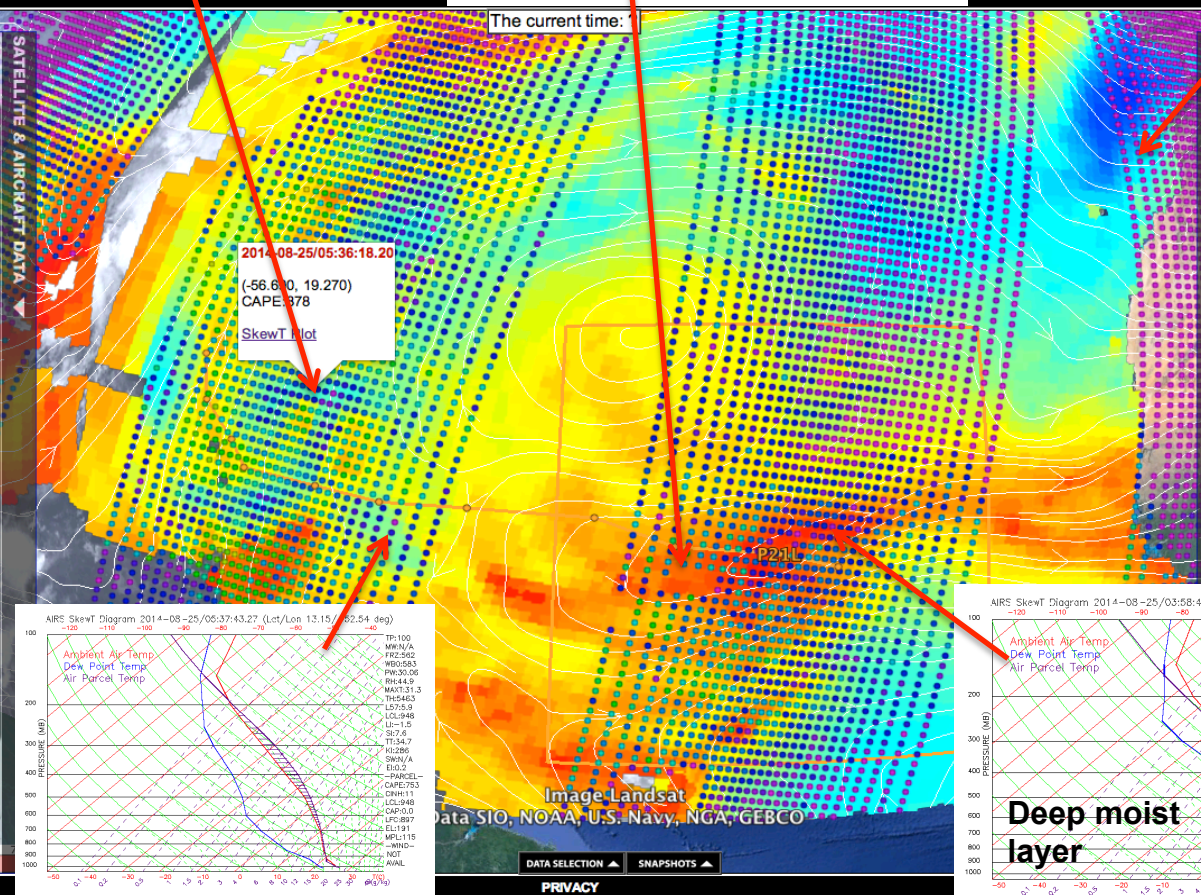
01	02
03	04
05	06
07	08
09	10
11	12
13	14
15	16
17	18
19	20
21	22
23	24
25	26
27	28
29	30
31	

Ending at hour: 08:00:00

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

**SATELLITE DATA**

- AIRS
- CAPE
- RH
- Pres.: 200
- TEMP
- Pres.: 200
- AOT (MODIS)
- Geostationary
- IR
- IR 2 Day Animation
- IRCOLOR
- VAPOR
- VIS
- Microwave Rain Signature
- TPW
- 6 HR Composite
- Two Day Animation: 4500
- TRMM
- TPW-AMSU (mm)



Tropical Cyclone Information System - HS3 Portal

Model: 2014-08-25 00Z N 012

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						

MODEL & SIMULATION DATA

MODEL: ECMWF

Press.: 850

Forecast Time: 01Z

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

Bar Grid

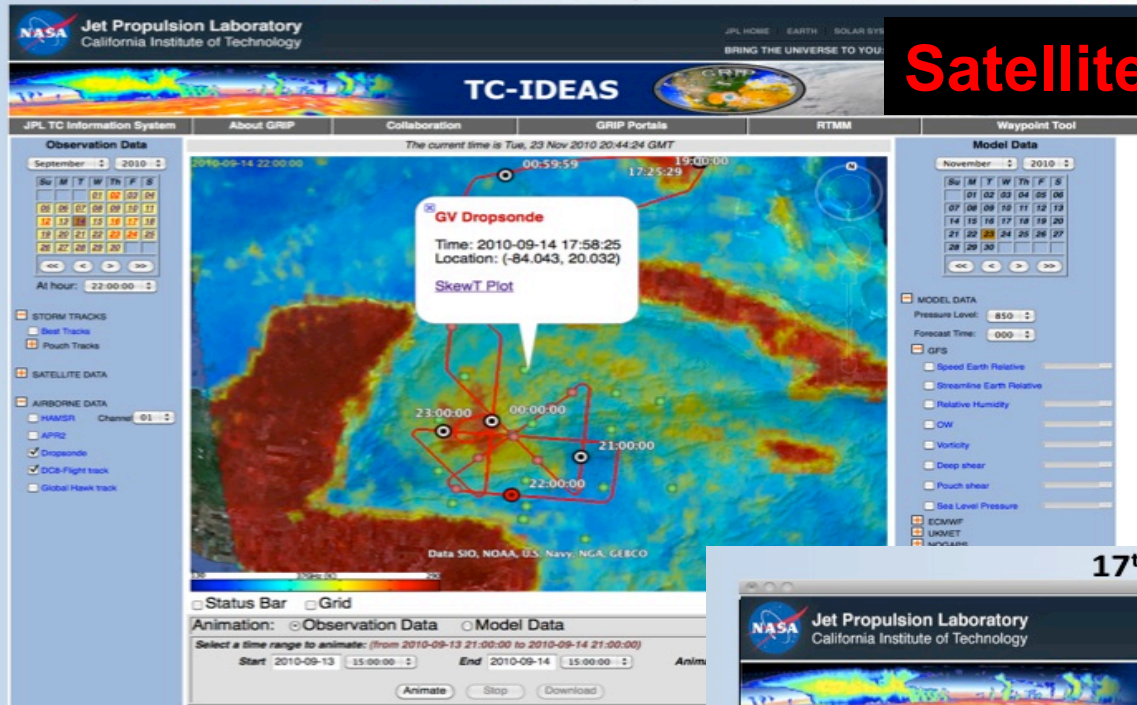
Site Manager: Svetla M Hristova-Velva

PRIVACY

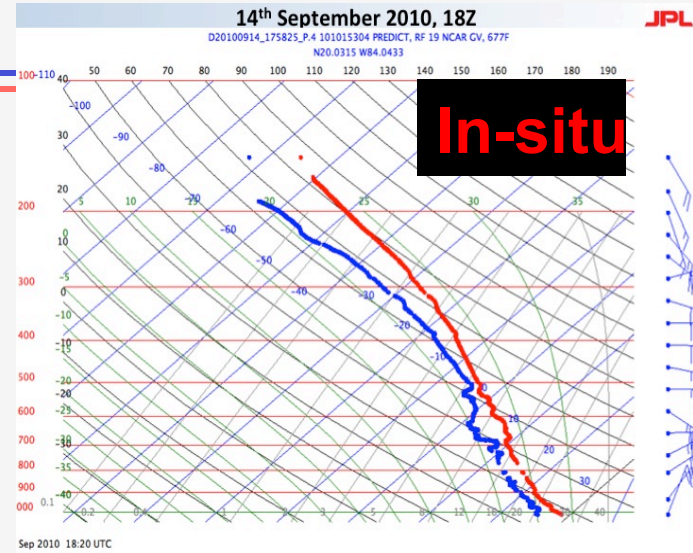
Distance: CL#08-3490

# GRIP Portal – NRT in 2010: Satellite observations providing context for airborne data

Just after genesis - 14<sup>th</sup> September 2010, 23Z

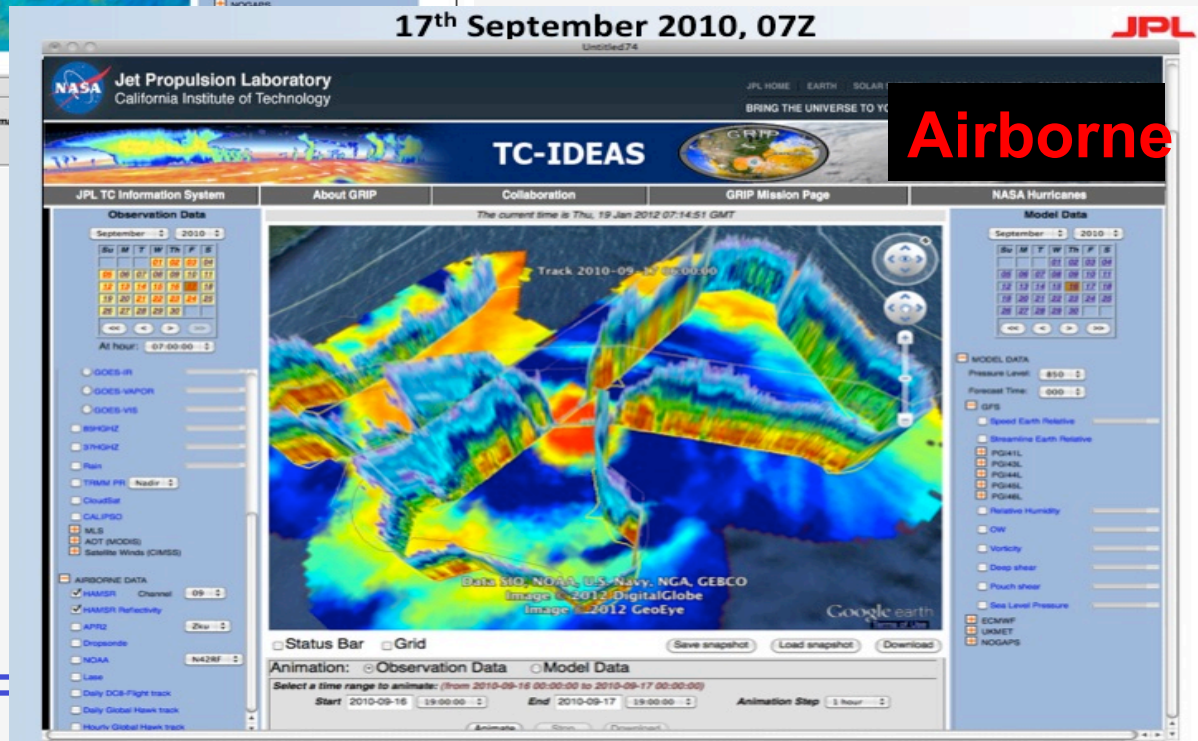


JPL



JPL

17<sup>th</sup> September 2010, 07Z

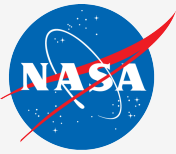


JPL

Hurricane Karl (2010):

Genesis and Rapid Intensification from

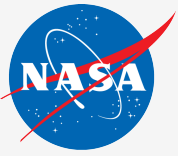
- satellite,
- airborne and
- in-situ observations



# The three components of our system

---

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**

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

PI S. Tanelli: AIST-08 and AIST-11



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

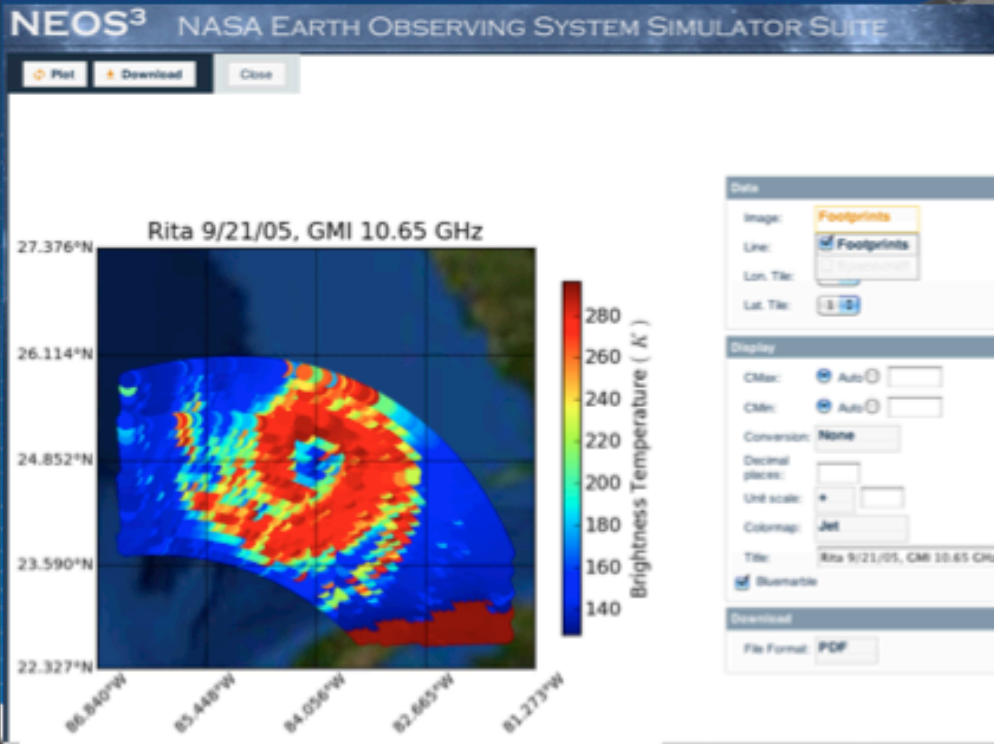
*"Flying the satellite over the model fields"*

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

NEOS<sup>3</sup>

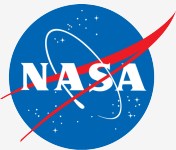
Radiometer: SOI  
f = ... GHz  
HPBW = ... °  
...

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



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

ESTO

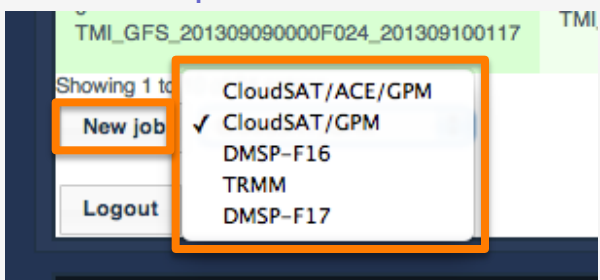


## 2. Projecting the model into the Observational space: A. Specific NEOS<sup>3</sup> Upgrades for TCIS

- Three functionalities have been added to NEOS<sup>3</sup> to support TCIS

1. **Templates:** Contain default parameters for specific instruments (SSMI, SSMI/S, TMI, AMSR-E, and GMI)

### Available Templates



### Job Descriptor file: Complex. Constant

```
...  
<pz-lat description="Latitude" units="deg,,">  
  <_decimal>#TOKEN#</_decimal>  
  <_unit>deg</_unit>  
</pz-lat>  
  
<pz-lon description="Longitude" units="deg,,">  
  <_decimal>-85.87</_decimal>  
  <_unit>deg</_unit>  
</pz-lon>  
...
```

### Token file: Simple. Variable

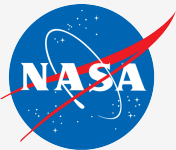
```
<task name="Location #1">  
  <TOKEN>10</TOKEN>  
</task>  
  
<task name="Location #2">  
  <TOKEN>22</TOKEN>  
</task>
```



2. **Tokens:** Compact input files exposing only a few selected parameters needed by TCIS.

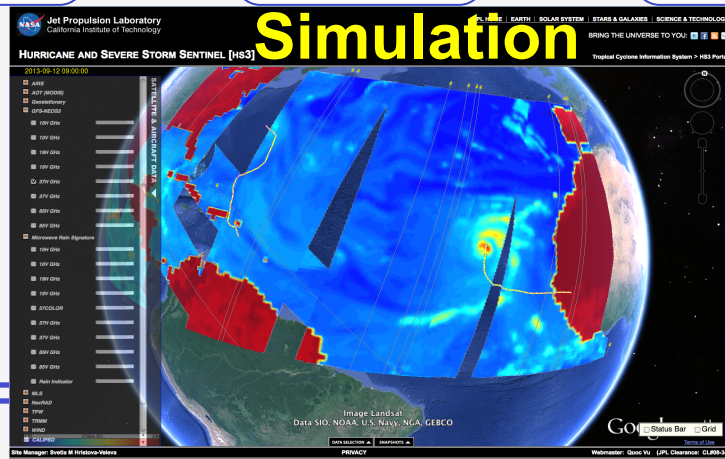
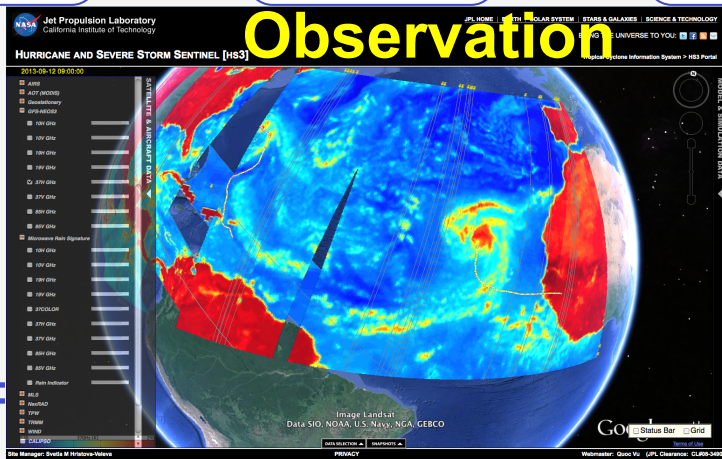
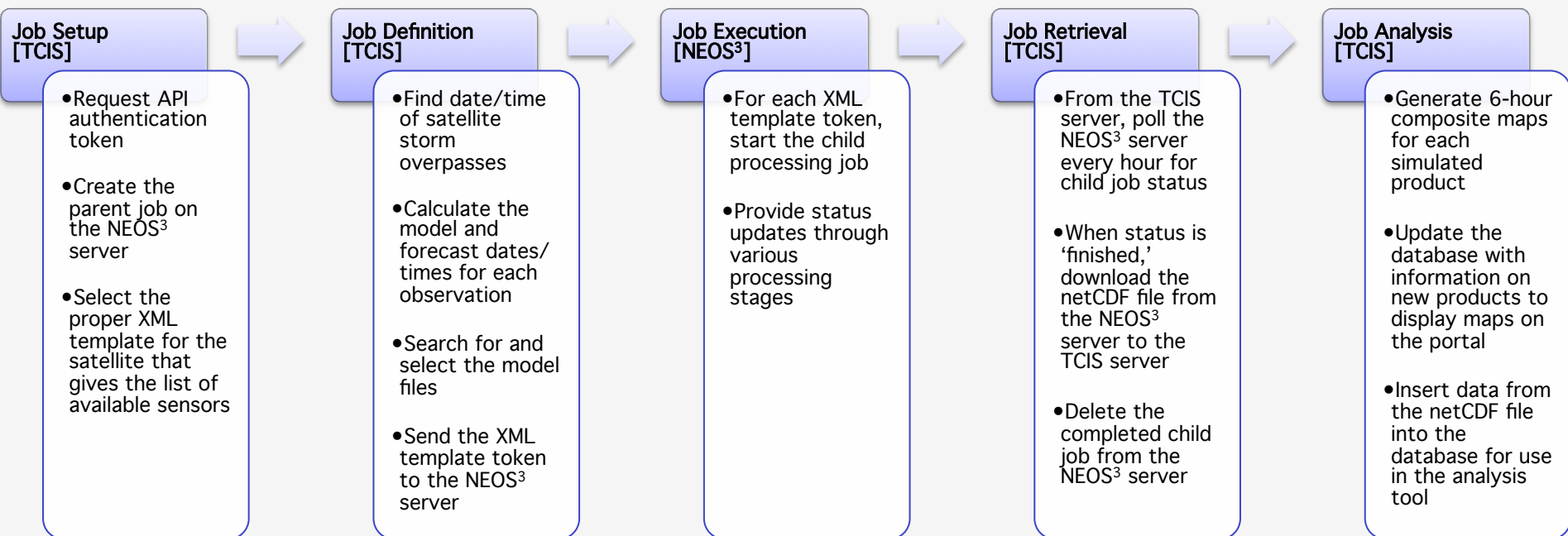
- More manageable (10s instead of 100s parameters to specify)
- Less prone to error

3. **Web Service:** Interface allowing TCIS to communicate with NEOS3, triggering simulation process and retrieve the simulated products



## 2. Projecting the model into the Observational space: B. TCIS and NEOS<sup>3</sup> Integration

- Worked with NEOS<sup>3</sup> team to develop an API that can launch simulations through web services: Users (TCIS) will not have to use a web interface to launch multiple jobs

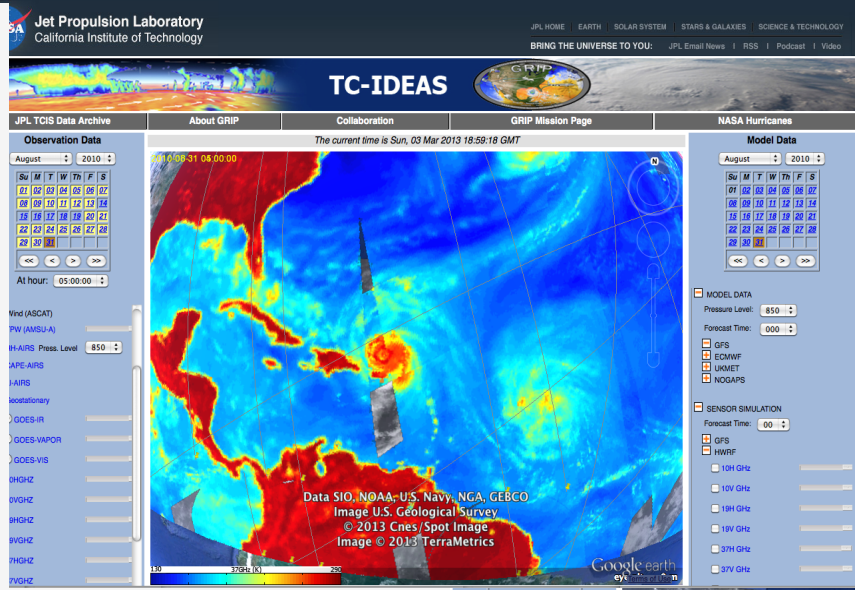




# FUSION OF MODELS AND OBSERVATIONS

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

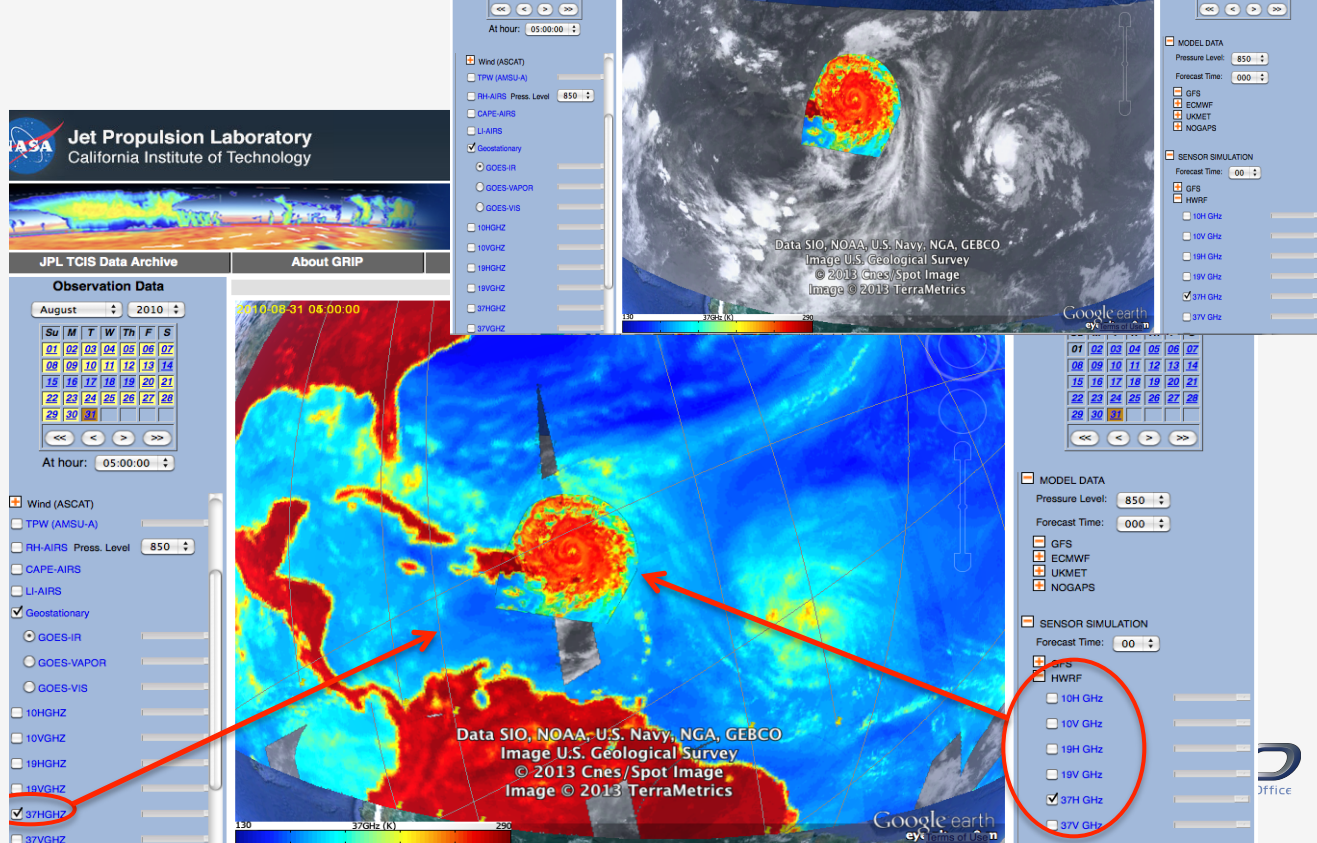
- Research HWRF model forecasts were used as input to NEOS<sup>3</sup>
- Considered are the model microphysical assumptions; the instrument characteristics and sampling
- The synthetic “satellite observations” were:
  - Incorporated in the database of satellite obs.
  - Visualized in the portal
- Limited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



## Satellite Observations



## Synthetic Observations from Model

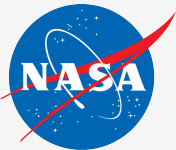




# The three components of our system

---

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



### 3. On-line Analysis Tools:

## A. Geospatial Data Searches – the web interface and database

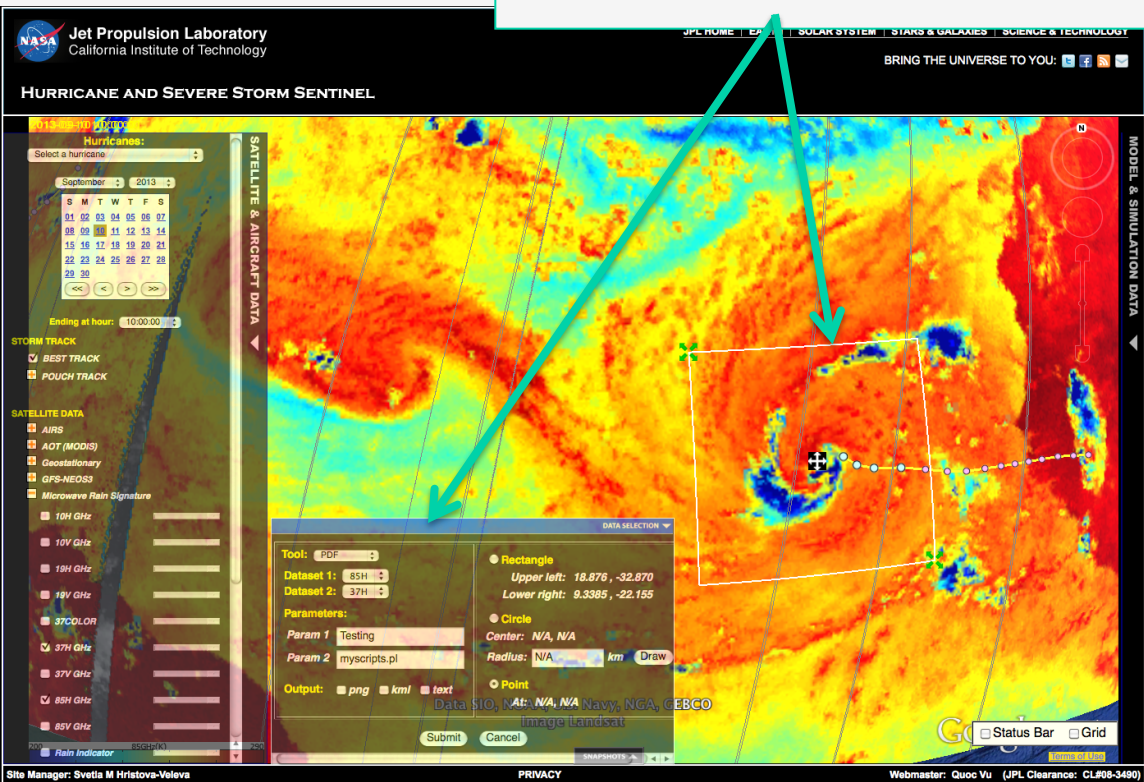
- The TCIS Analysis Tools rely on geospatial searches to find a region of data that a user wants to analyze

- Select the region of interest
- Select the tool (e.g. PDF)
- Specify the details
- Submit the job ...

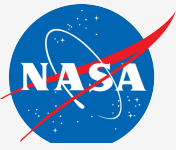
### The Subsetting Tool

#### The Framework

- Subset and re-format data into consistent format
- Store swath footprints as geometric objects in the database for efficient sub-setting
- Database support for the analysis tools
  - The selection criteria vary depending on the tool and the input datasets. For some of the tools, we need to select a single swath from the composite image. For other tools, we need to use the 2D composite maps.
- User interface - developing and integration with the database and the tools (Subsetting tool)

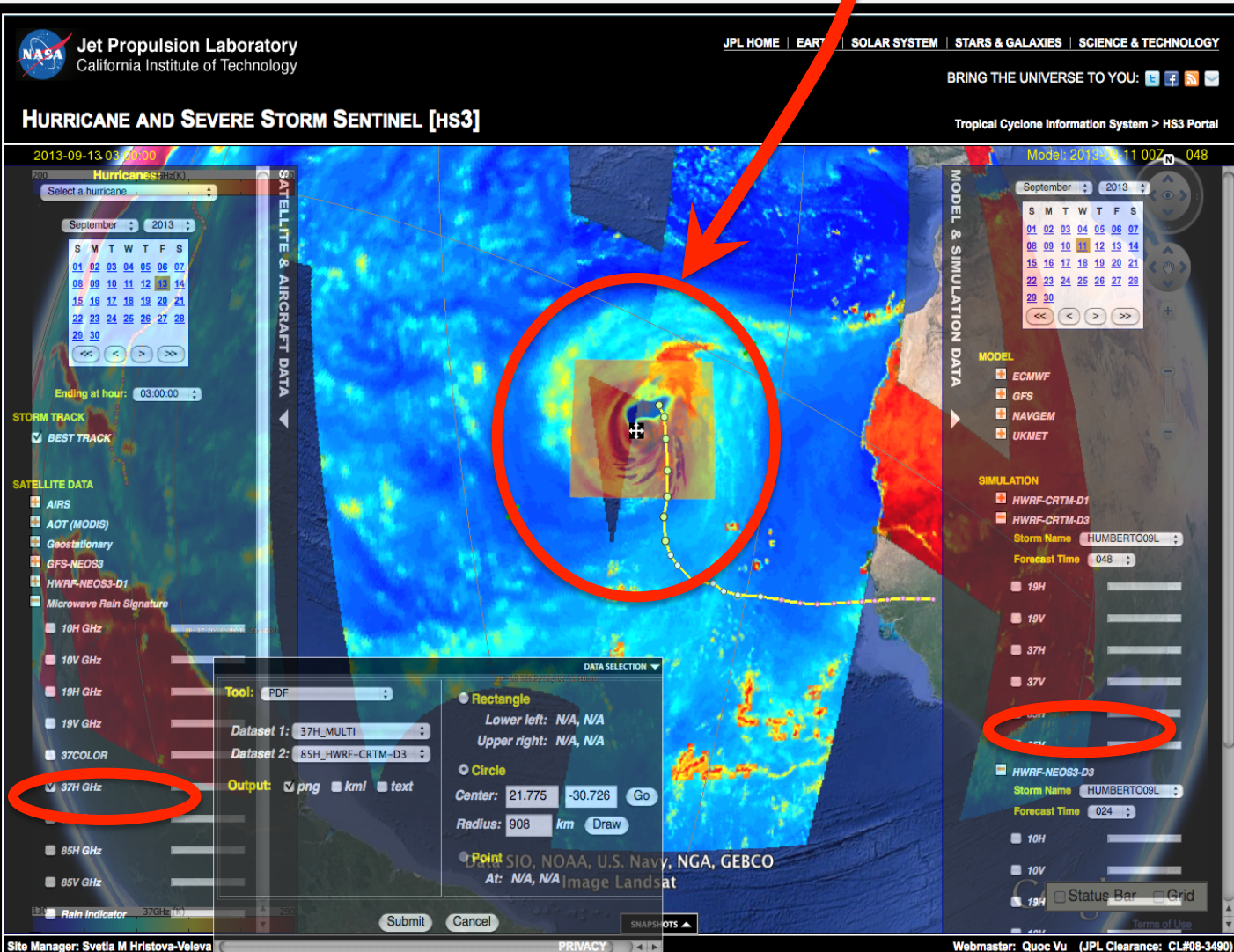




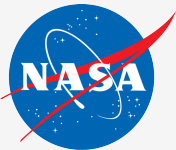


# Driving by desire: Evaluate!

- Interactively select region
- Gather data from observed and synthetic brightness temperature



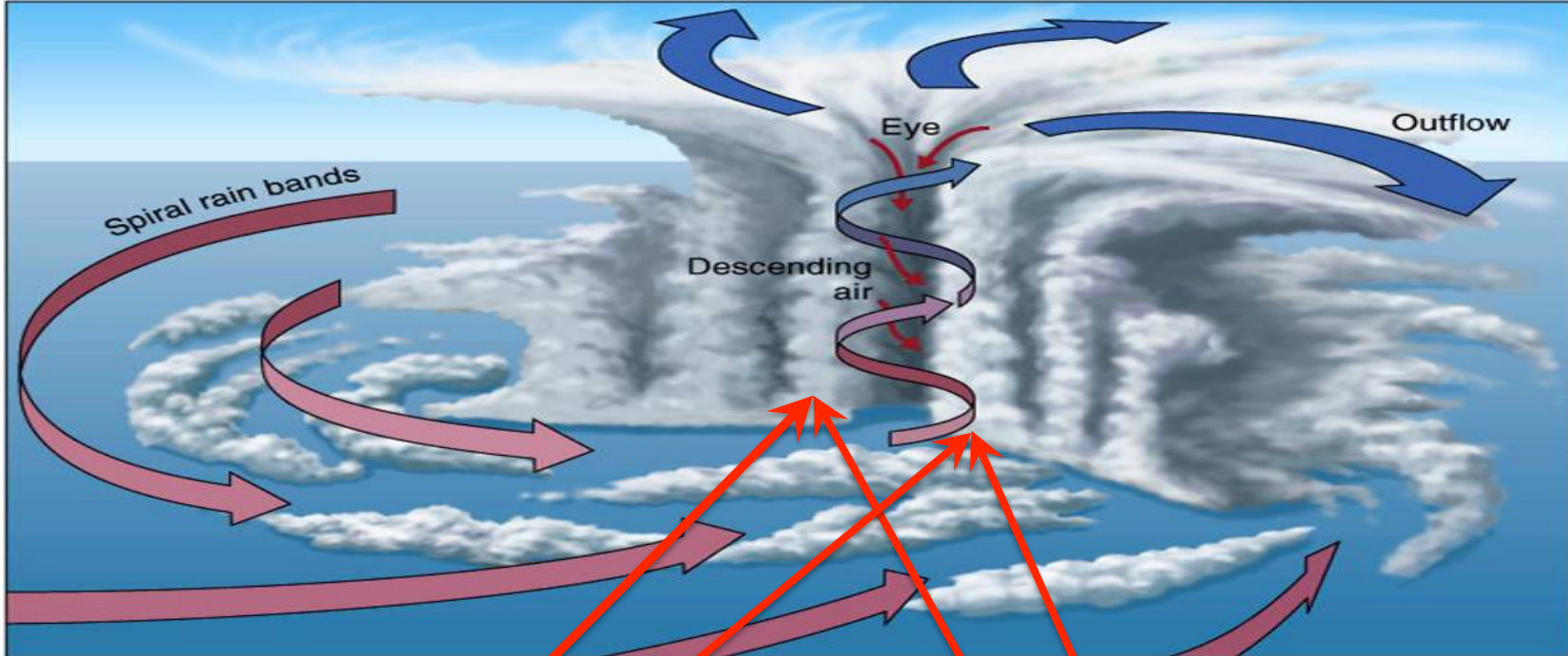
- **PERFORM:**
- Statistical evaluation
  - EOFs, Joint PDFs
  - Azimuthal averages
- Storm Structure
  - Storm Size/ Asymmetry
  - Wave-number analysis
  - Storm Center - ARCHER
  - Convective/ Stratiform
- Visualization of analysis



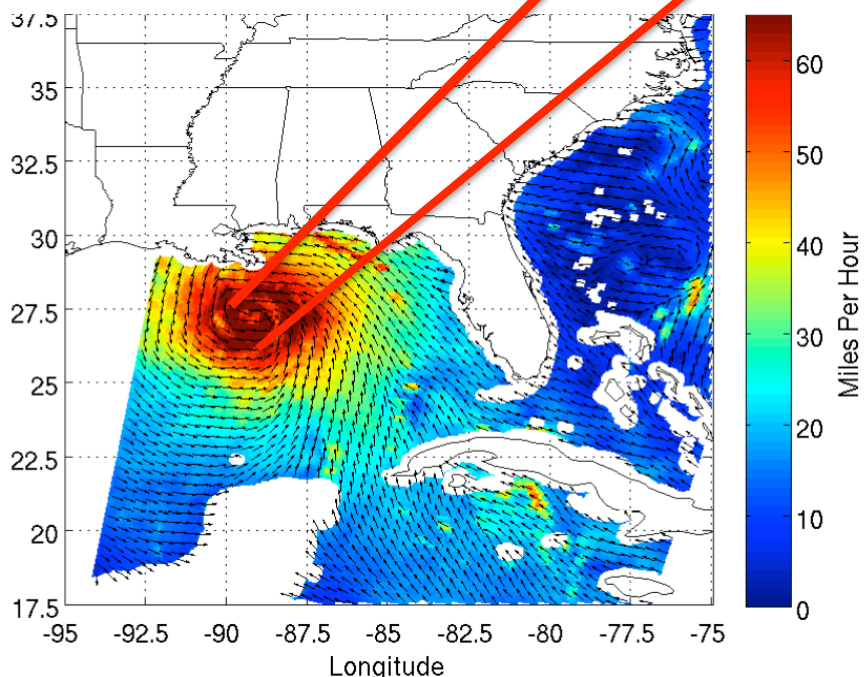
---

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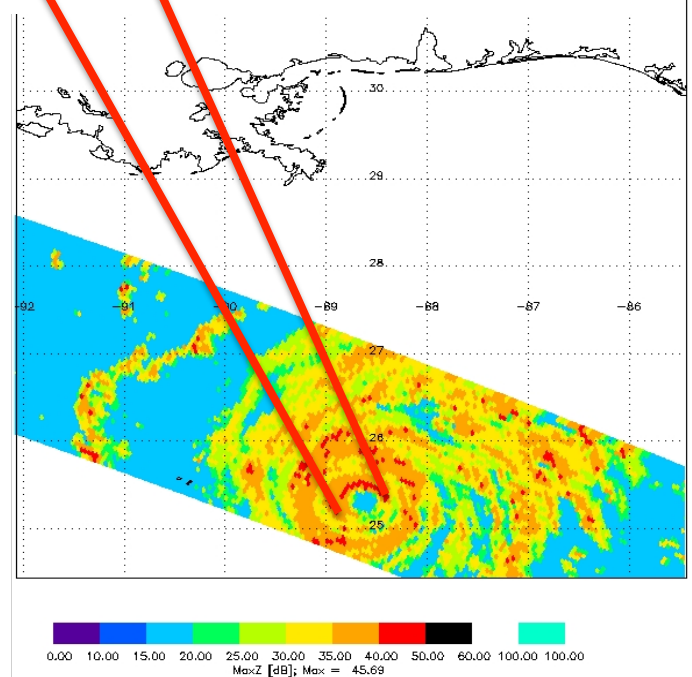
# Studying hurricanes



**Katrina (2005) as seen from QuikSCAT**

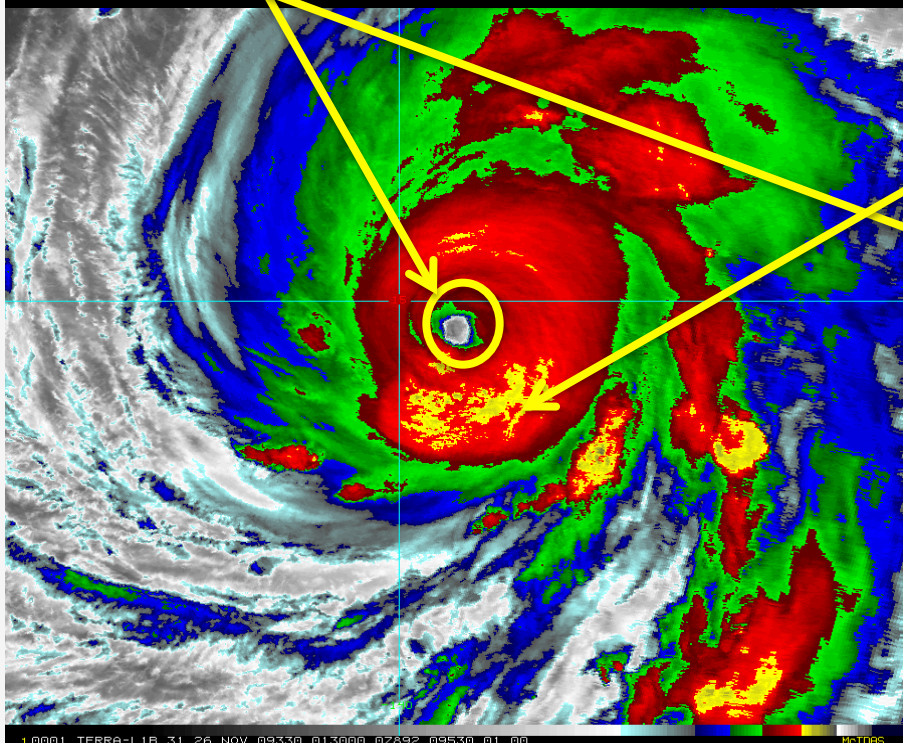


**TRMM - max reflectivity**

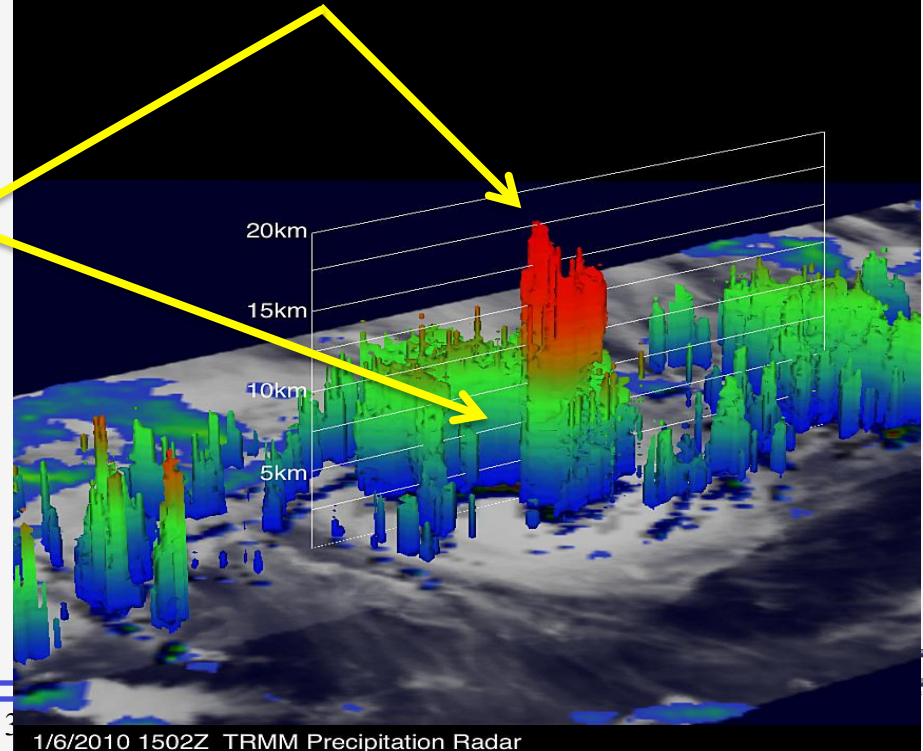


- Recent studies have linked RI to intermittent occurrence of deep, strong convective bursts within the inner core, occupying as little as 5–10% of the area of the hurricane eyewall.
- However, an alternative hypothesis is that RI follows abundant and well organized but weaker convection in the inner-core region. A continuous azimuthally symmetric eye wall (i.e., a ring) of precipitation then indicates the imminent onset of RI. This occurs when the ring is closed and dominated by shallow precipitation extending from near the freezing level to the surface. In this scenario, individual deep and strong convective bursts may still be embedded in the outer edge of the ring but play only a secondary role in RI.
- We use observations from scatterometers and radiometers to investigate whether storm asymmetry decreases in association with increase in storm intensity.

### RING OF SHALLOW CONVECTION



### DEEP CONVECTIVE BURSTS



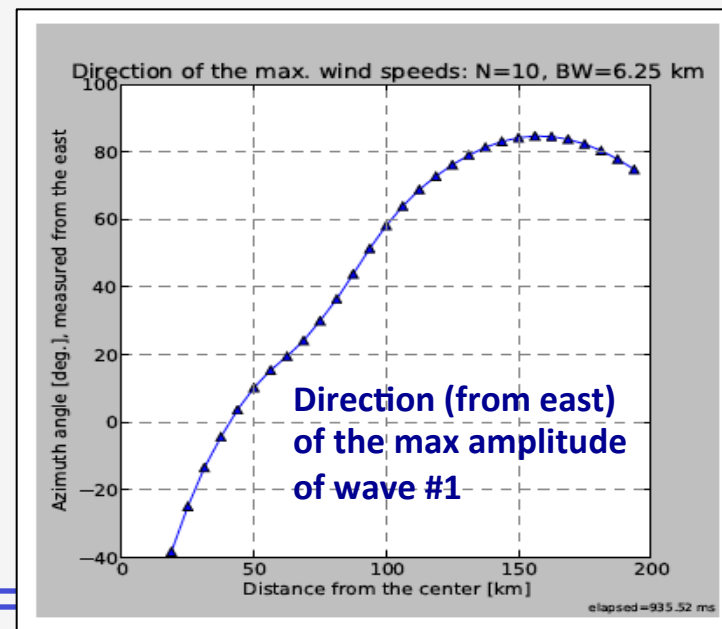
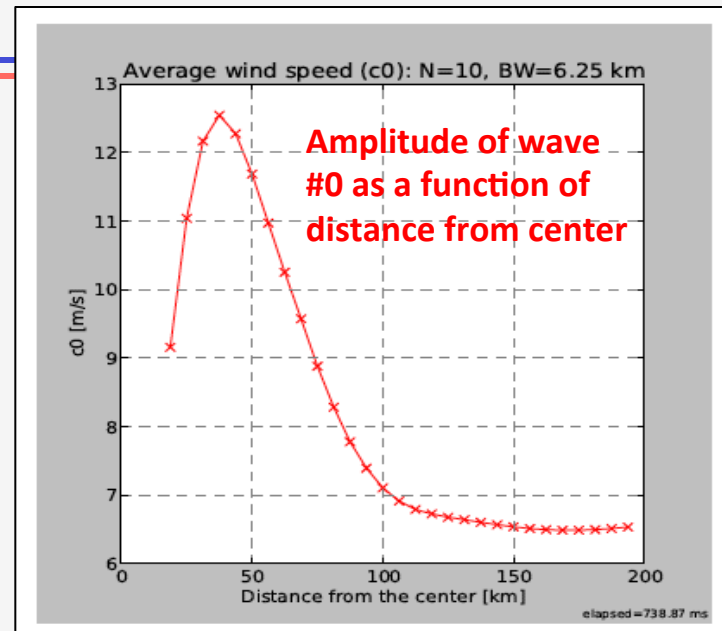
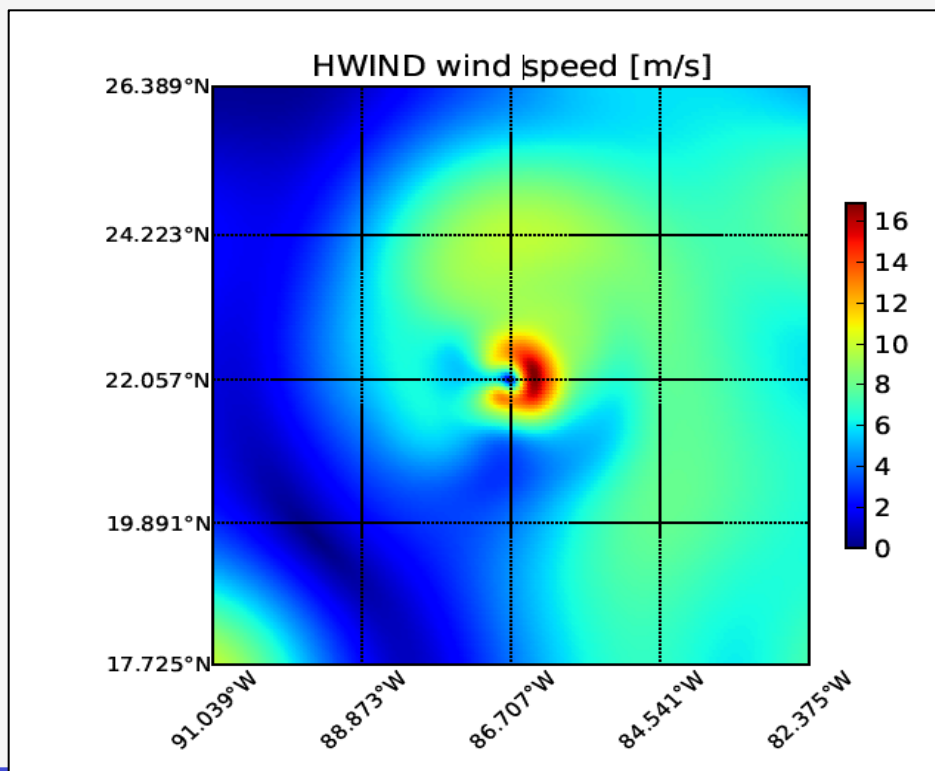




# Storm structure Tool: Storm Size and Asymmetry

## 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



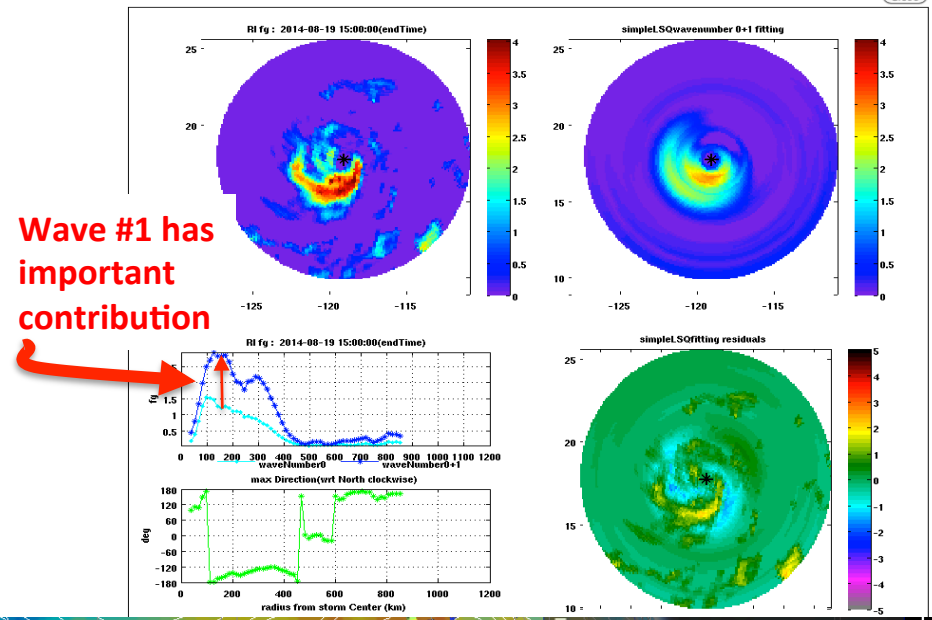
# Storm structure Tool: Observations

## Storm Size and Asymmetry: The Evolution

### The Wave Number Analysis Tool using the Rain Index

EP hurricane Lowell -08/19/2014: 15Z

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>



S M T W T F S

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

MODEL

ECMWF

GFS

Press: 200

Forecast Time: 01Z

SPEED-COMOVING

STREAM-COMOVING

DEEP-SHEAR

OW

PMSL

POUCH-SHEAR

RH

SPEED-EARTH

STREAM-EARTH

TEMP

TPW

VORTICITY

NAVGEN

UKMET

SIMULATION

HWRP-CRTM-D1

HWRP-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

Dataset 1: RI-MULTI

Bin Size (km): 20

Reference Direction: North

Output:  png  kml  text

Submit Cancel

# Storm structure Tool: Observations

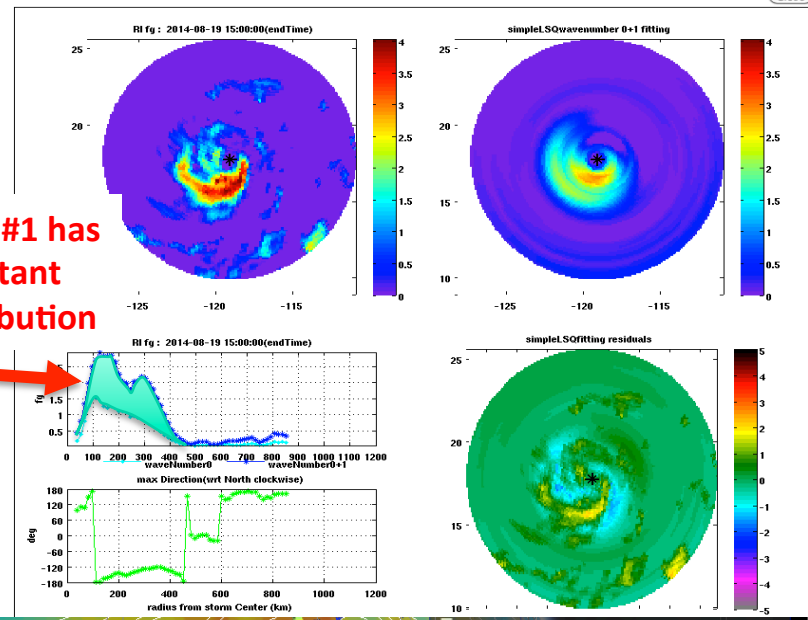
## Storm Size and Asymmetry: The Evolution

## The Wave Number Analysis Tool using the

## Rain Index

## EP hurricane Lowell -08/19/2014: 15Z

Wave #1 has important contribution



### HURRICANE AND SEVERE STORM SENTINEL [HS3]

2014-08-19 15:00:00

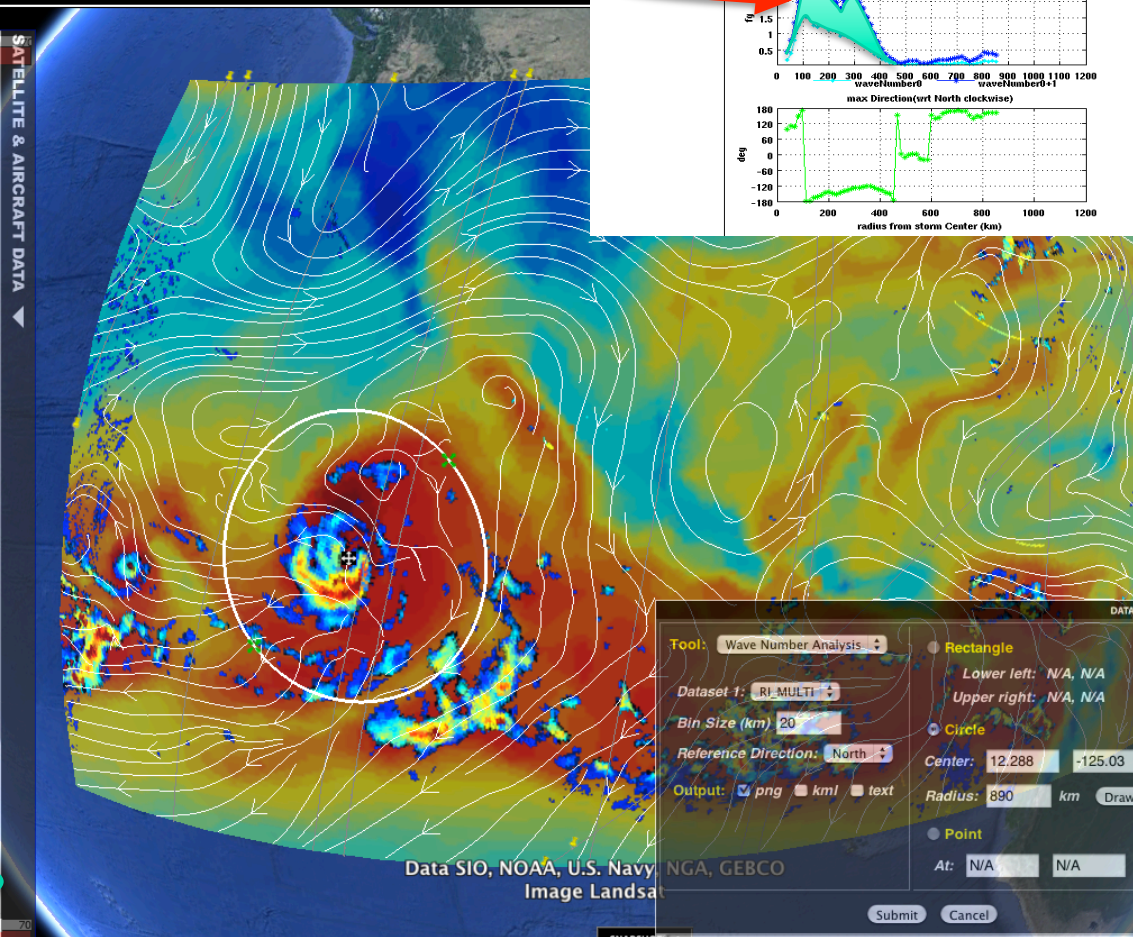
15 Hurricanes (mm)

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

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

NAVGEM

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

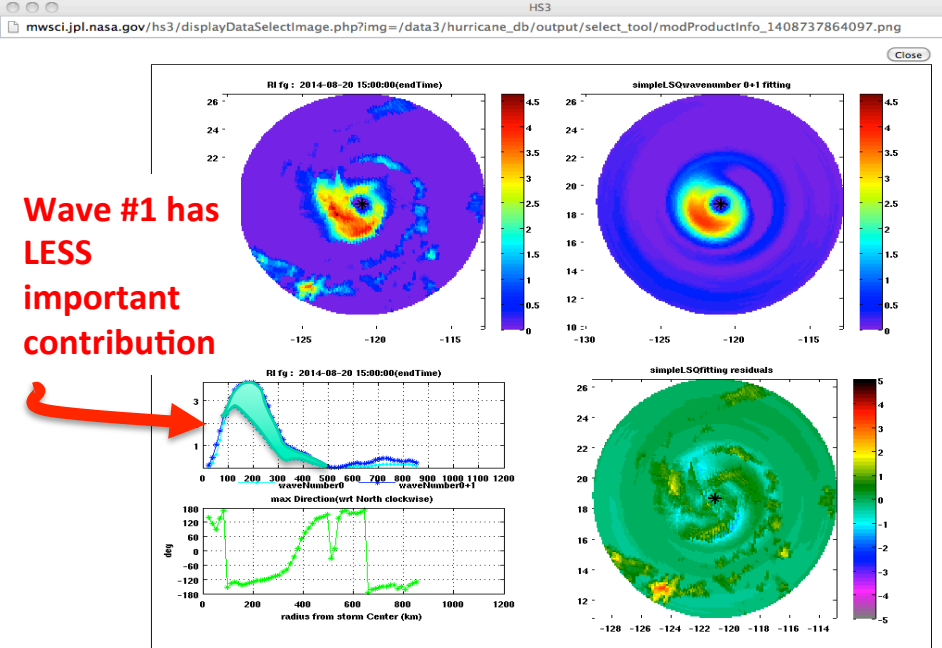
Output:  png  kml  text

Submit Cancel

# Storm structure Tool:

Storm Size and Asymmetry: **The Evolution**  
 The Wave Number Analysis Tool using the  
 Rain Index

EP hurricane Lowell -08/20/2014: 15Z



Wave #1 has  
 LESS  
 important  
 contribution

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

2014-08-20 15:00:00

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
- TRMM
- 6 HR Composite
- Two Day Animation
- TRMM Rain Indicator

**SATELLITE & AIRCRAFT DATA**

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

**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**

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

**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: 10.655, -113.10; Radius: 890 km

Point: At: N/A, N/A

Submit Cancel

# Storm structure Tool: Observations

## Storm Size and Asymmetry: The Evolution The Wave Number Analysis Tool using the Rain Index

### EP hurricane Lowell -08/21/2014: 15Z

**HURRICANE AND SEVERE STORM TRACK**

2014-08-21 15:00:00

**STORM TRACK**

- BEST TRACK
- POUCH TRACK

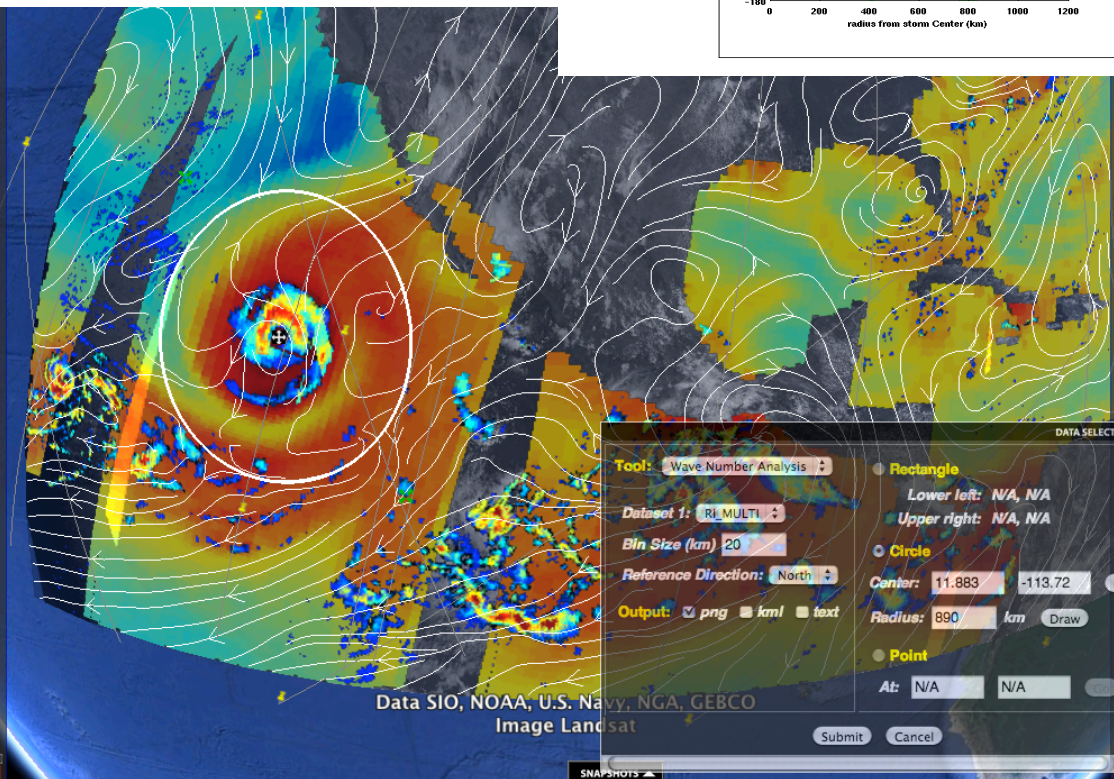
**SATELLITE DATA**

- 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

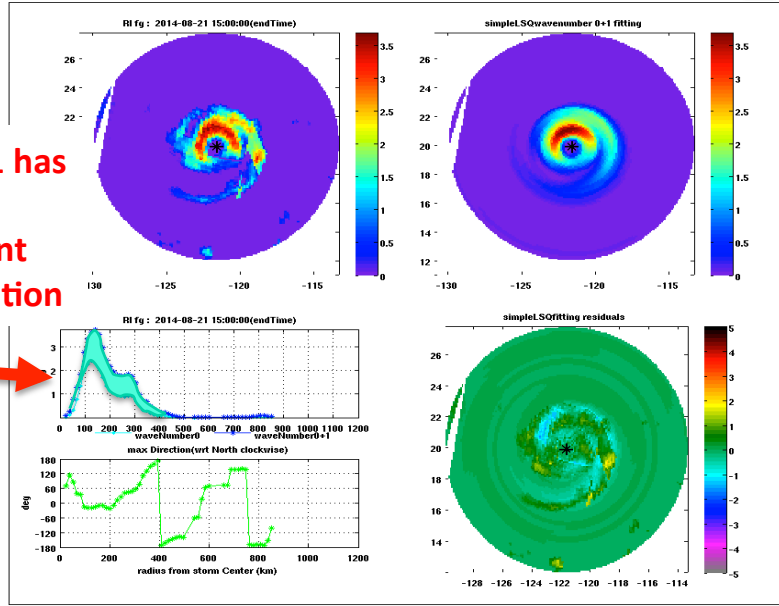
**AIRBORNE DATA**

- Rain Indicator

**Most Intense:**  
**Time: 2014-08-21 12:00:00**  
**Wind Speed: 65 knots**  
**Central Pressure: 982 mb**



**Wave #1 has LEAST important contribution**



**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: 11.883, -113.72; Radius: 890 km

Point: At: N/A, N/A

Submit Cancel

**MODEL DATA**

- 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

Google Status Bar Grid

# Storm structure Tool:

## Observations: Rain

### Storm Size and Asymmetry: The Wave Number Analysis Tool using the Rain Index

### Hurricane Humberto -09/11/2013: 15Z

2013-09-31 05:00:00

**Hurricanes:**  
Select a hurricane

September 2013

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: 15:00:00

**STORM TRACK**  
 BEST TRACK  
 POUCH TRACK

**SATELLITE DATA**

- AIRS
- AOT (MODIS)
- Geostationary
- GFS-NEOS3
- HWRF-NEOS3-D1
- Microwave Rain Signature
  - 10H GHz
  - 10V GHz
  - 19H GHz
  - 19V GHz
  - 37COLOR
  - 37H GHz
  - 37V GHz
  - 85H GHz
  - 85V GHz
- Rain Indicator
- MLS
- NexRAD
- Rain Indicator

**Tool: Wave Number Analysis**

**Dataset 1:** RI\_MULTI

**Bin Size (km):** 20

**Reference Direction:** North

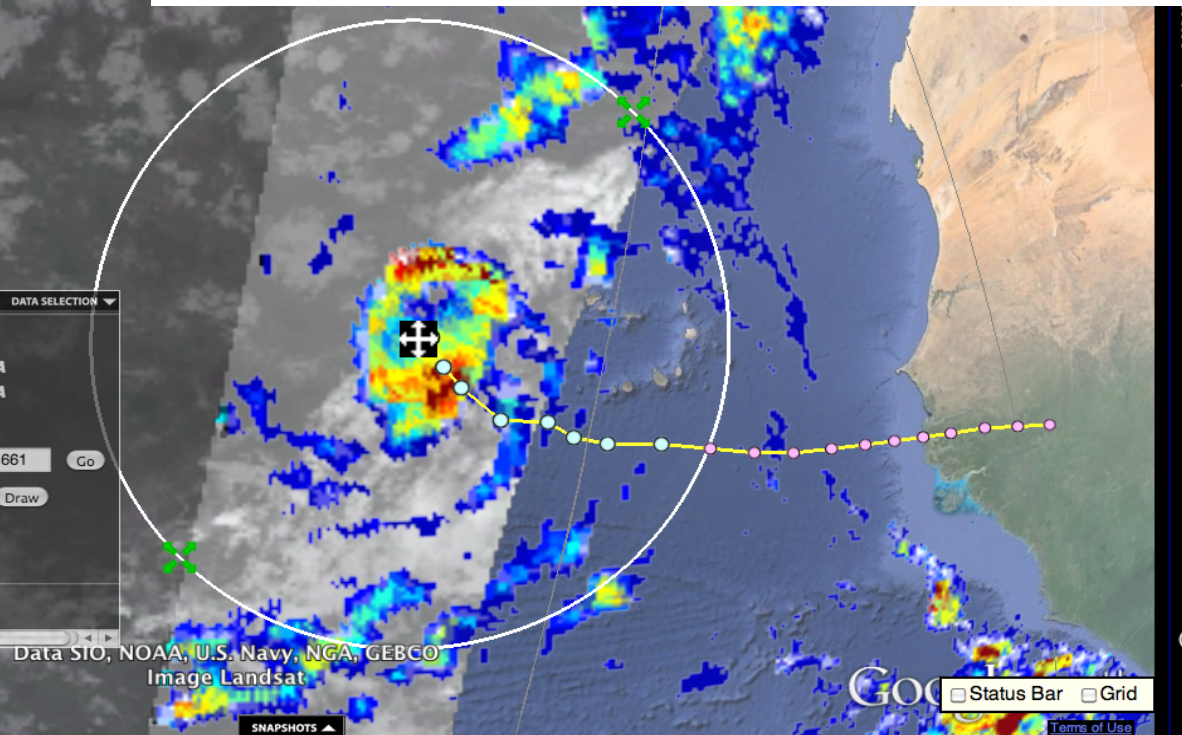
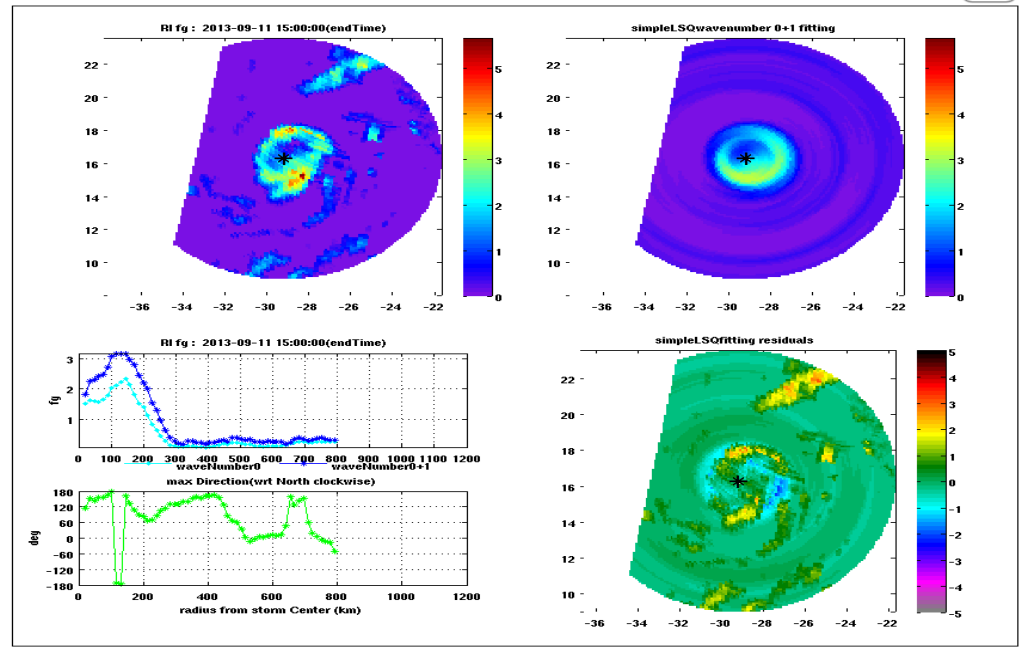
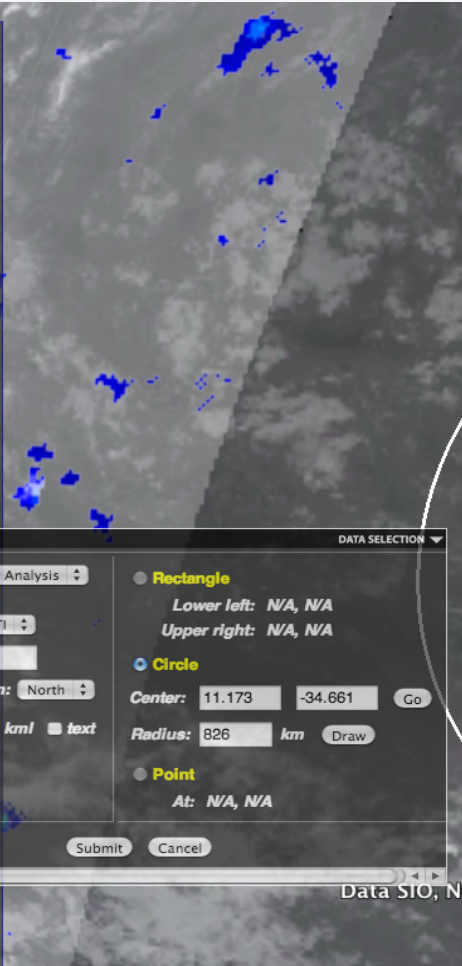
**Output:**  png  kml  text

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

**Circle**  
Center: 11.173, -34.661   
Radius: 826 km

**Point**  
At: N/A, N/A

SATELLITE & AIRCRAFT DATA

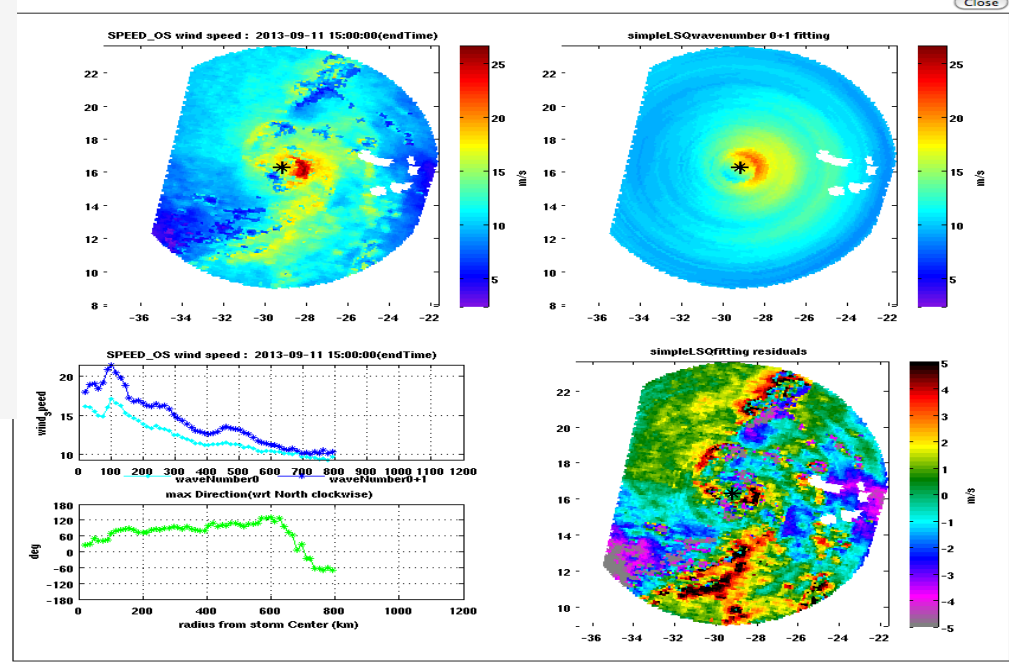


# Storm structure Tool:

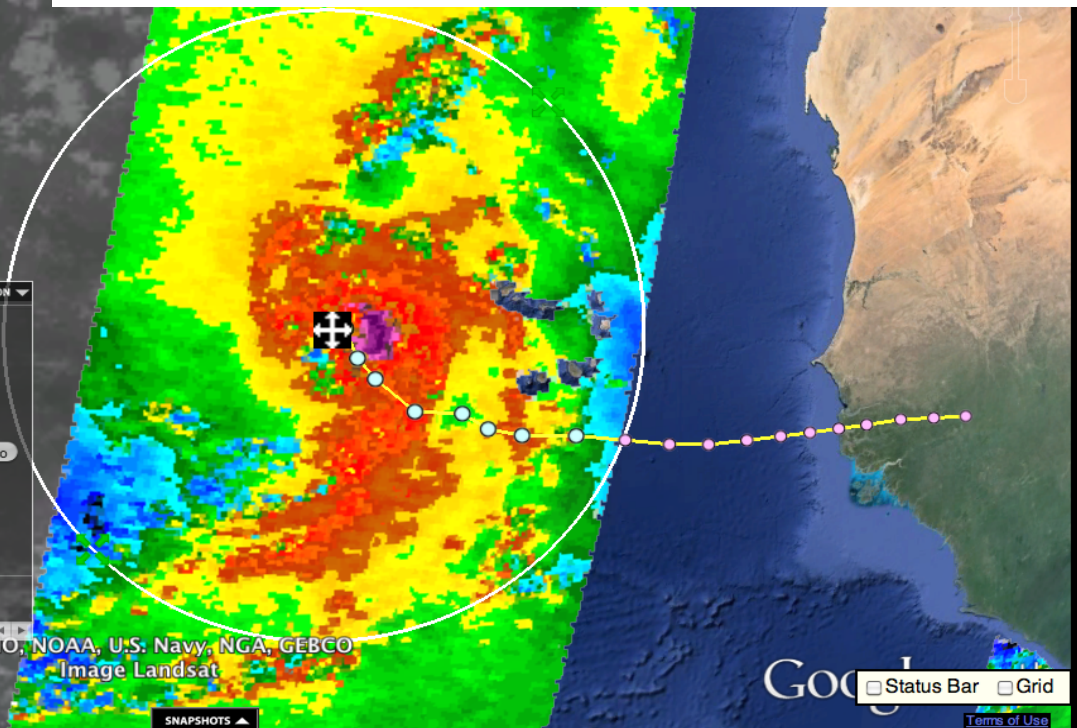
## Observations: Wind from OSCAT

### Storm Size and Asymmetry: The Wave Number Analysis Tool using the Rain Index

### Hurricane Humberto -09/11/2013: 15Z



The screenshot shows the web interface for the Storm Structure Tool. On the left, there is a navigation panel with sections for 'STORM TRACK' (BEST TRACK, POUCH TRACK), 'SATELLITE DATA' (AIRS, AOT, Geostationary, GFS-NEOS3, HWRF-NEOS3-D1, Microwave Rain Signature, MLS, NexRAD, TPW, TRMM, WIND), and 'AIRBORNE DATA' (Flight Tracks). The 'WIND' section is expanded, showing options for ASCAT SPEED, ASCAT VECTOR, OceansAT SPEED, OceansAT VECTOR, CALIPSO, CloudSat, and SST. A 'DATA SELECTION' dialog box is open in the foreground, showing 'Tool: Wave Number Analysis', 'Dataset 1: SPEED\_OS2', 'Bin Size (km): 20', 'Reference Direction: North', 'Output: png', and 'Circle' selection. The dialog also shows a 'Rectangle' selection with 'Lower left: N/A, N/A' and 'Upper right: N/A, N/A', and a 'Point' selection with 'At: N/A, N/A'. The background shows a satellite image of the storm with a white circle indicating the analysis area.

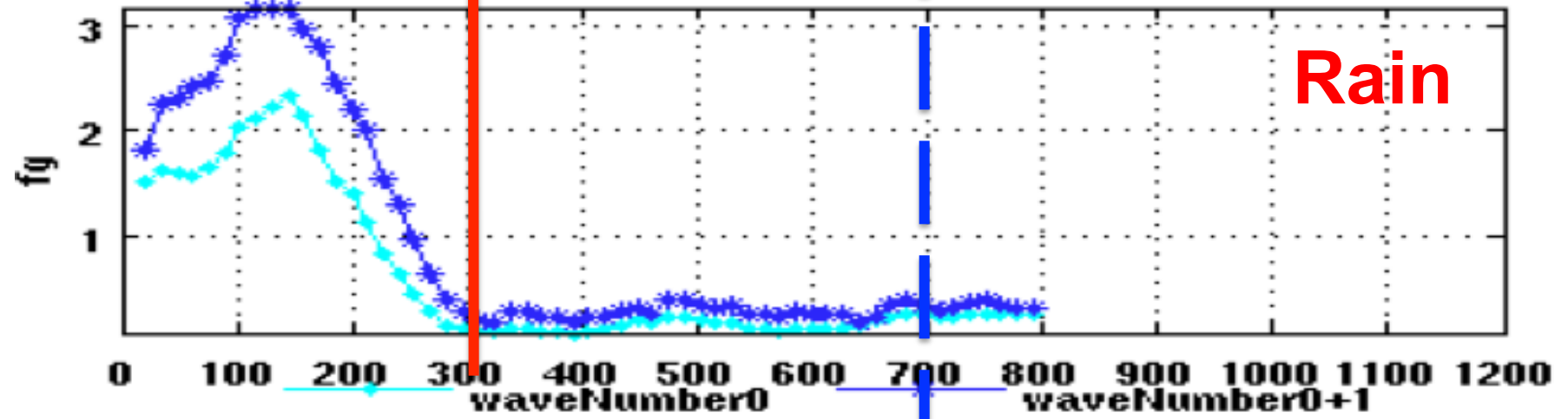


Size of precipitation is much smaller than the size of the wind field

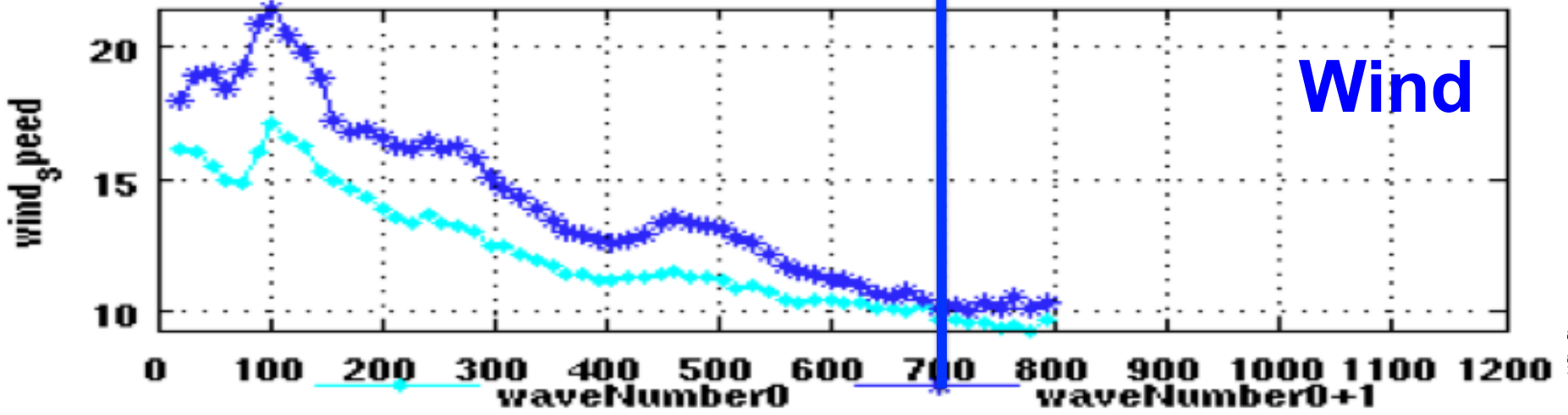
# Size of Wind Storm

## Size of Rain Storm

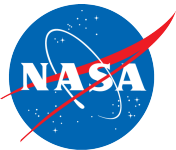
RI fg : 2013-09-11 15:00:00(endTime)



SPEED\_OS wind speed : 2013-09-11 15:00:00(endTime)

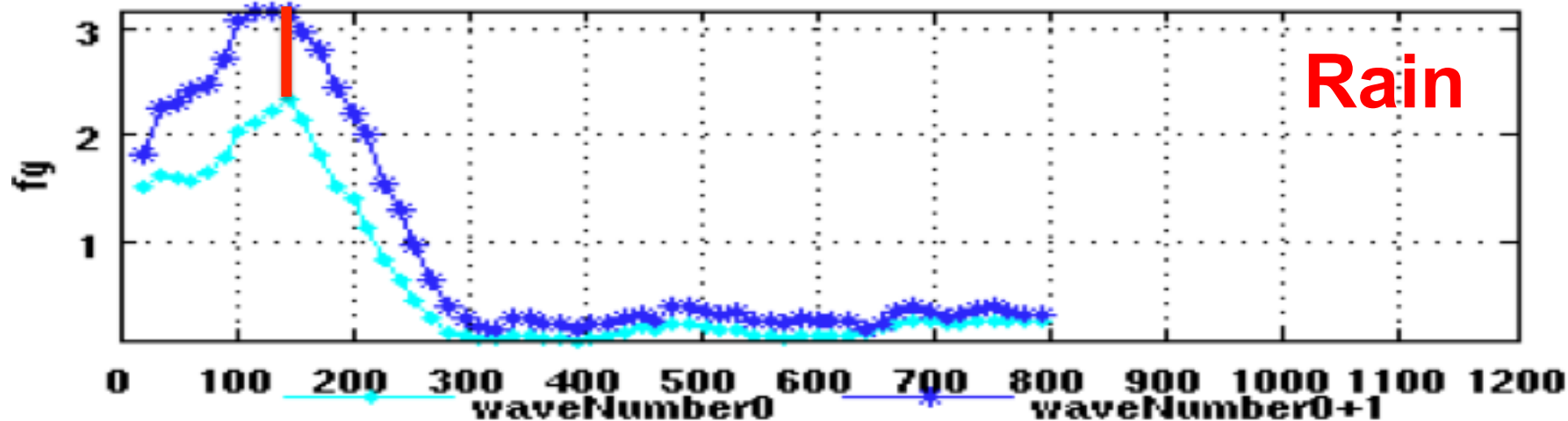




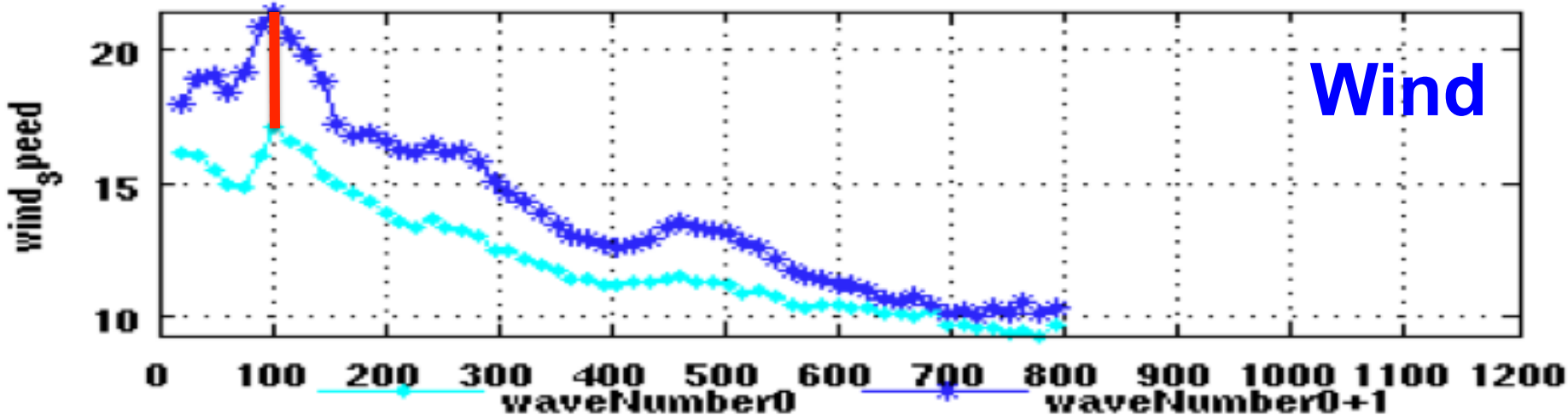


The storm is quite asymmetric in both wind and rain

RI fg : 2013-09-11 15:00:00(endTime)



SPEED\_OS wind speed : 2013-09-11 15:00:00(endTime)





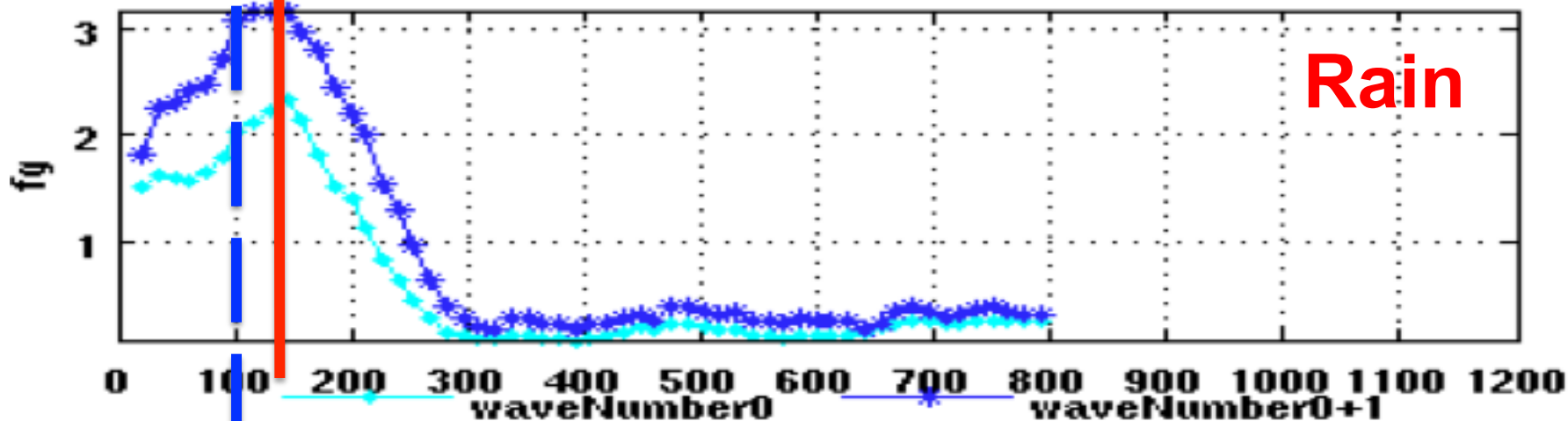
# RMW

The storm is quite asymmetric in both wind and rain  
Radius of Max Wind (RMW) is smaller than the  
Radius of Max Rain (RMR).

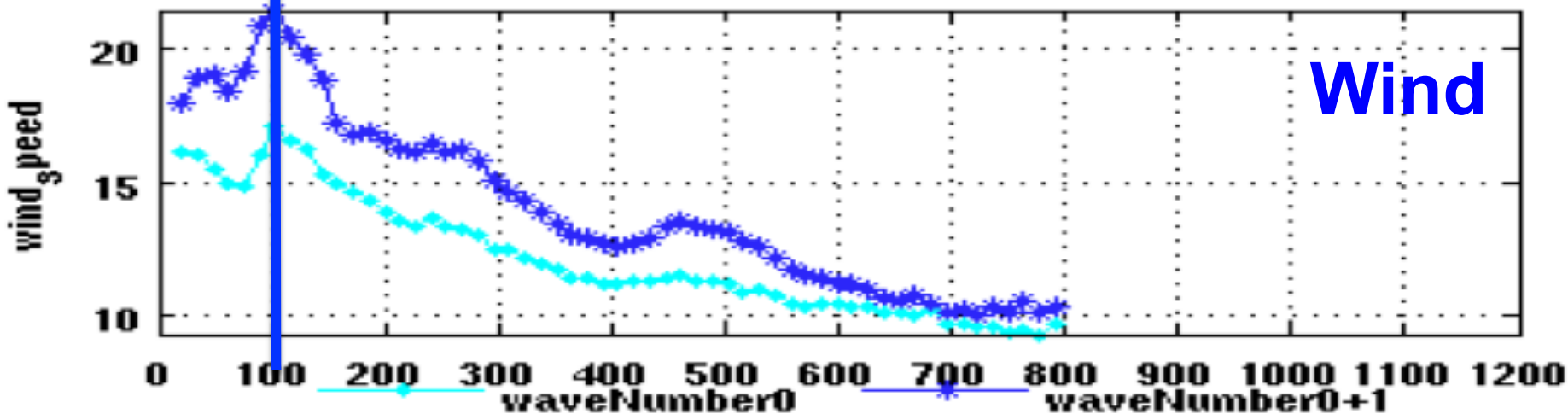
# RMR

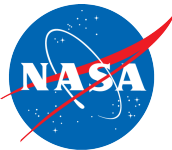
Conditions are not conducive to Rapid Intensification.

RI fg : 2013-09-11 15:00:00(endTime)



SPEED\_OS wind speed : 2013-09-11 15:00:00(endTime)





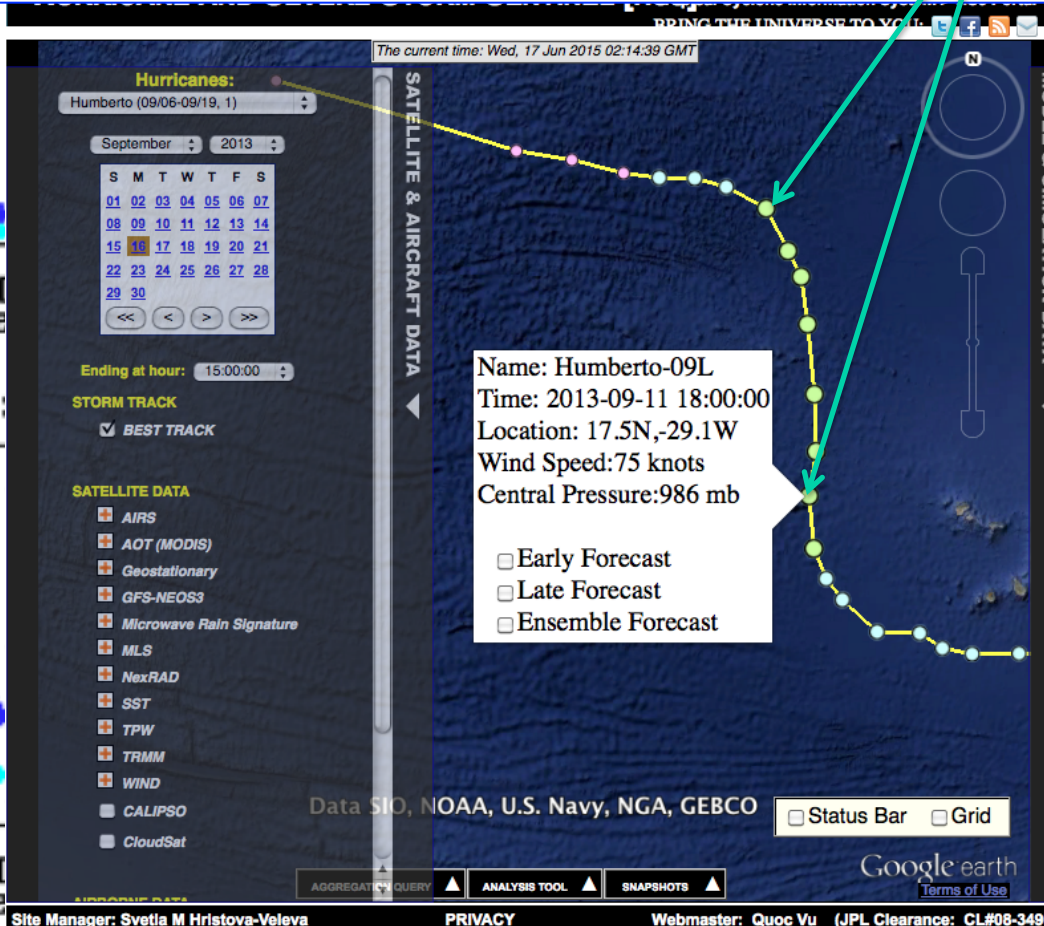
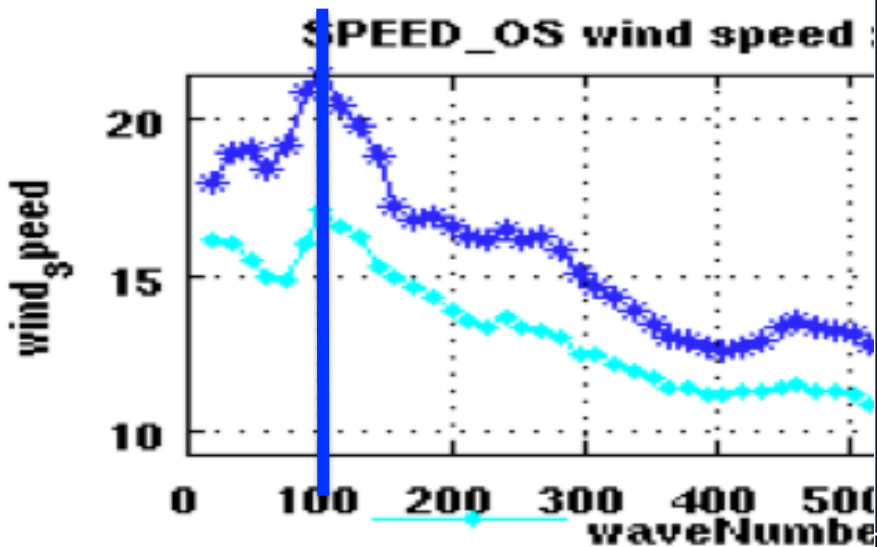
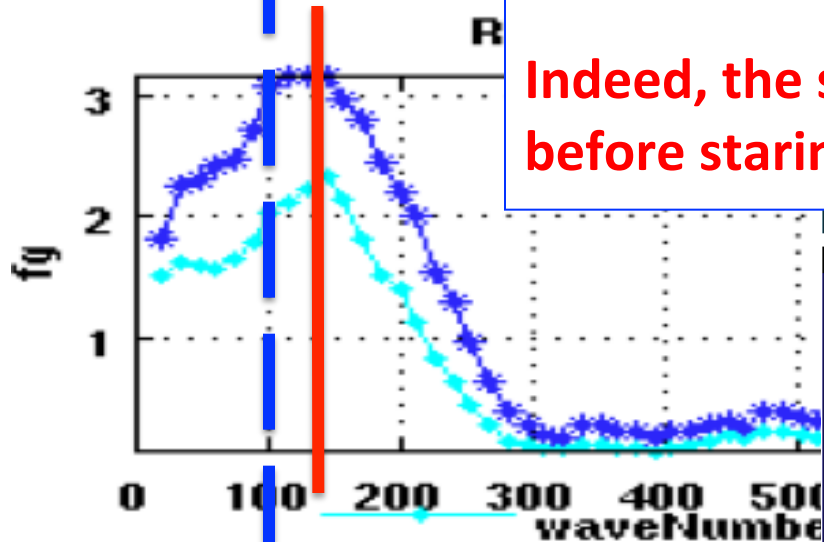
# RMW

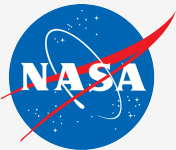
The storm is quite asymmetric in both wind and rain  
Radius of Max Wind (RMW) is smaller than the  
Radius of Max Rain (RMR).

# RMR

Conditions are not conducive to Rapid Intensification.

Indeed, the storm remained very steady for 36 hours,  
before starting to weaken on 09/13/2013 at 06Z

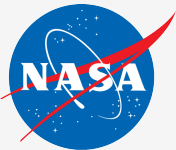




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# Long-term Statistics



# 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.

Jet Propulsion Laboratory  
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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
- Collaborators
- 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: Svetlana M Hristova-Veleva      PRIVACY      Webmaster: Quoc Vu (JPL Clearance: CL#08-346)

# JPL TCIS – The Tropical Cyclone Data Archive

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

- 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.

**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 'Jet Propulsion Laboratory California Institute of Technology'. Below this is a navigation bar with links for Home, Team/Collaborations, Feedback, Data Archive, and GRIP Portal. The main content area is titled 'Tropical Cyclone Earl' and includes a 'Get Tracks' button. A line graph shows '10m Wind Speed (knots)' and 'Air Pressure (mb)' over time from August 24 to September 10, 2010. Below the graph is a table of 'Storm-Scale data for Tropical Cyclone Earl' with columns for various instruments: AIRS, AMSRE, AMSU-A, AMSU-B, CPR, MHS, MLS, and OMI. A satellite imagery map shows the storm's path over the Pacific Ocean. To the right of the map is a calendar for August 2010, with the 29th circled in red. Below the calendar is a 'Download' button, also circled in red. The page footer includes 'Status Bar', 'Grid', 'Privacy', and 'Webmaster: Quoc Vu JPL Clearance: OL#08-3490'.

**Timeline**

**View and download Storm-scale data**

**Download Selected large-scale data from this day**



# JPL Tropical Cyclone Information System

Home

Project

Feedback

Data Portal

Analysis Tool

## Tropical Cyclone Rita

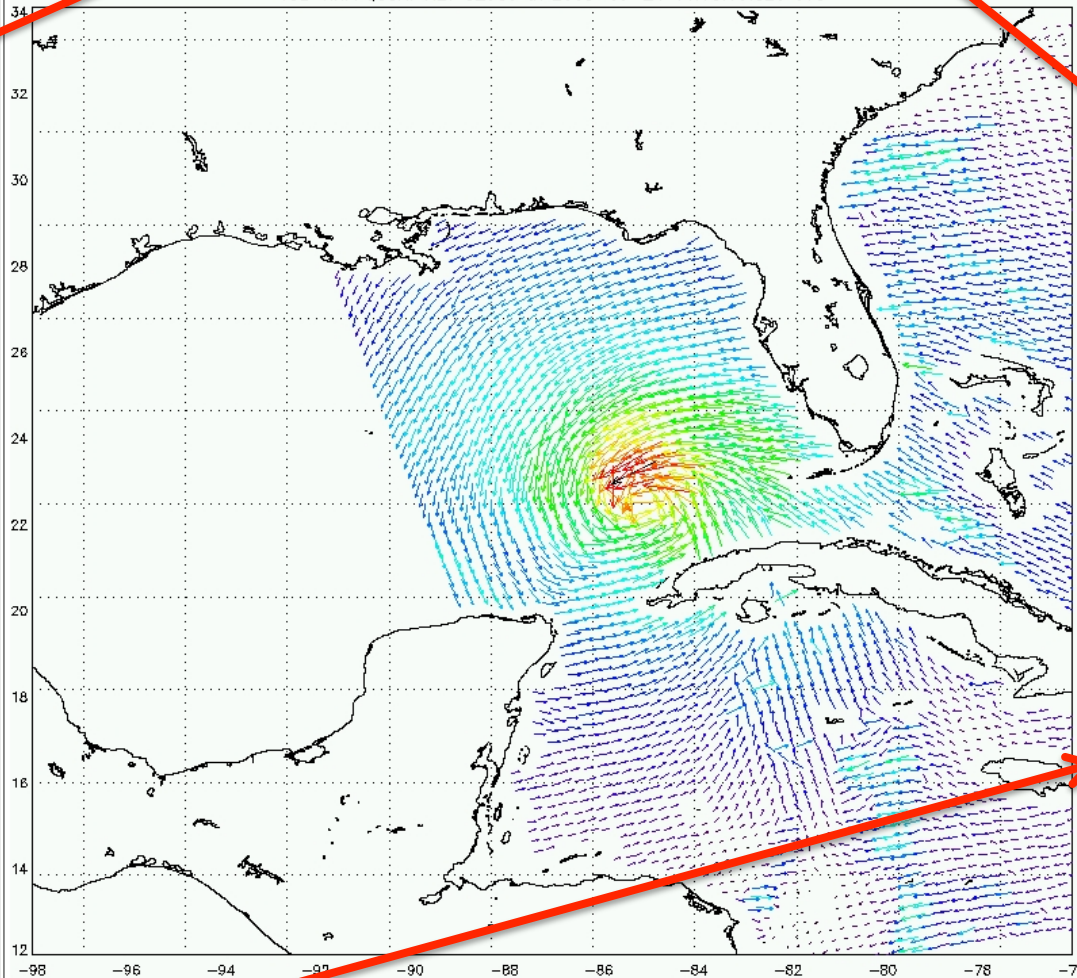
Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

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

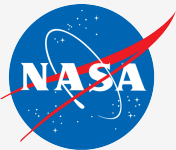


Download All

At this time

All data on this day

Download NetCDF

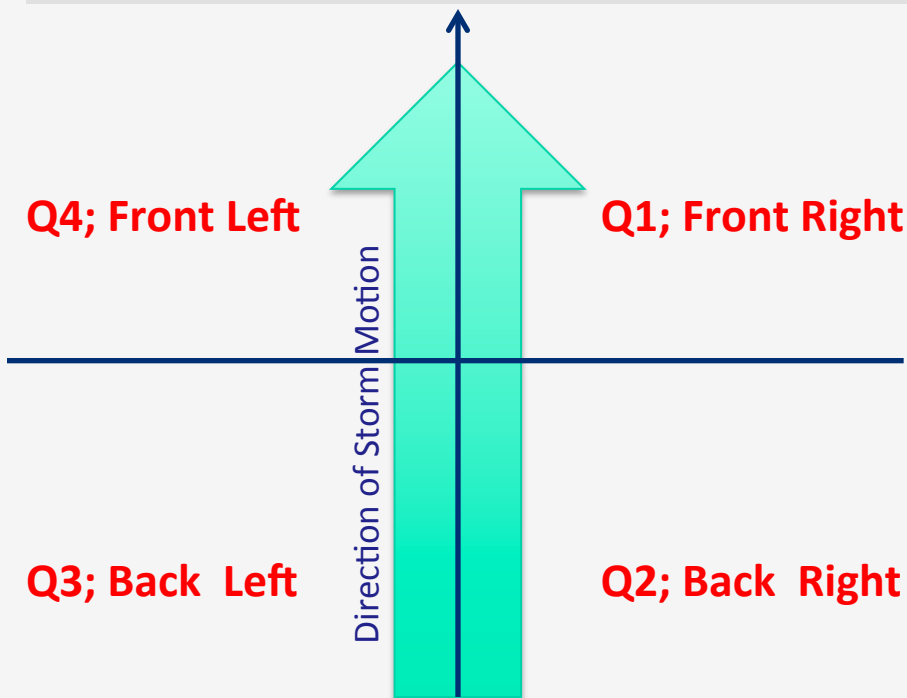


# Asymmetry and Evolution

## Statistics from observations ; North Atlantic Hurricanes

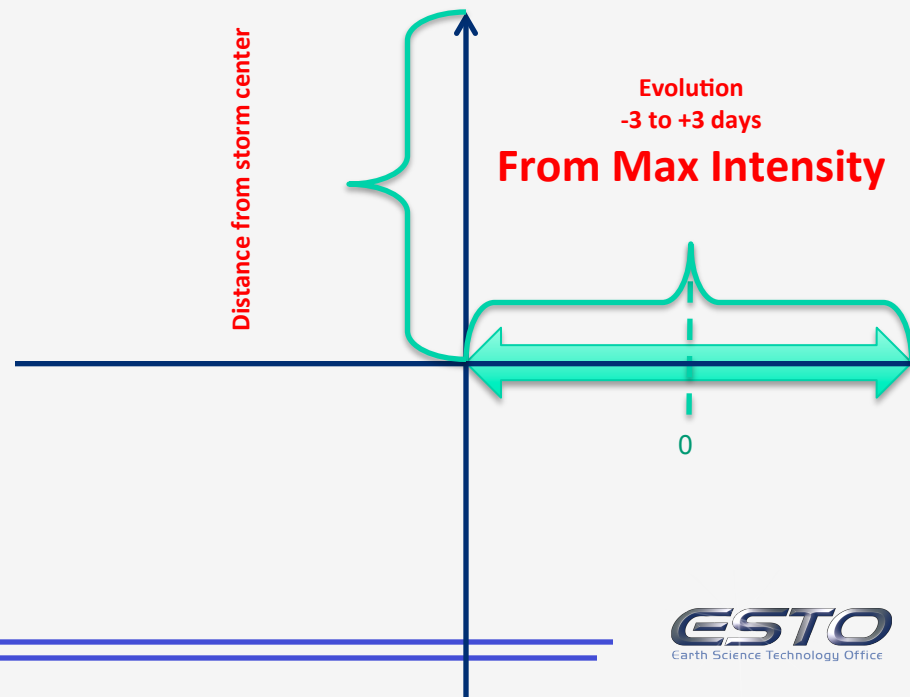
Parameter as a function of:

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

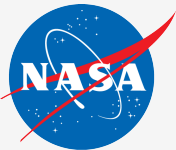


**Created composites following similar approaches:**

*Lonfat, M., F.D. Marks, and S. S.Chen, 2004*  
*Rogers et al., 2012*  
*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*  
*Many others.*

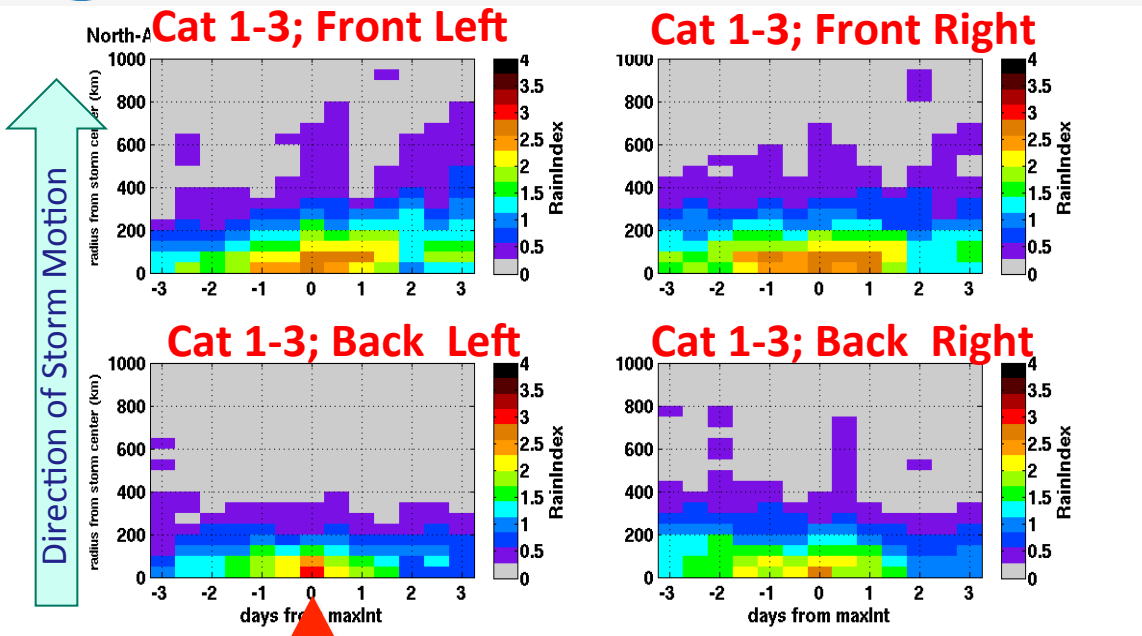






# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



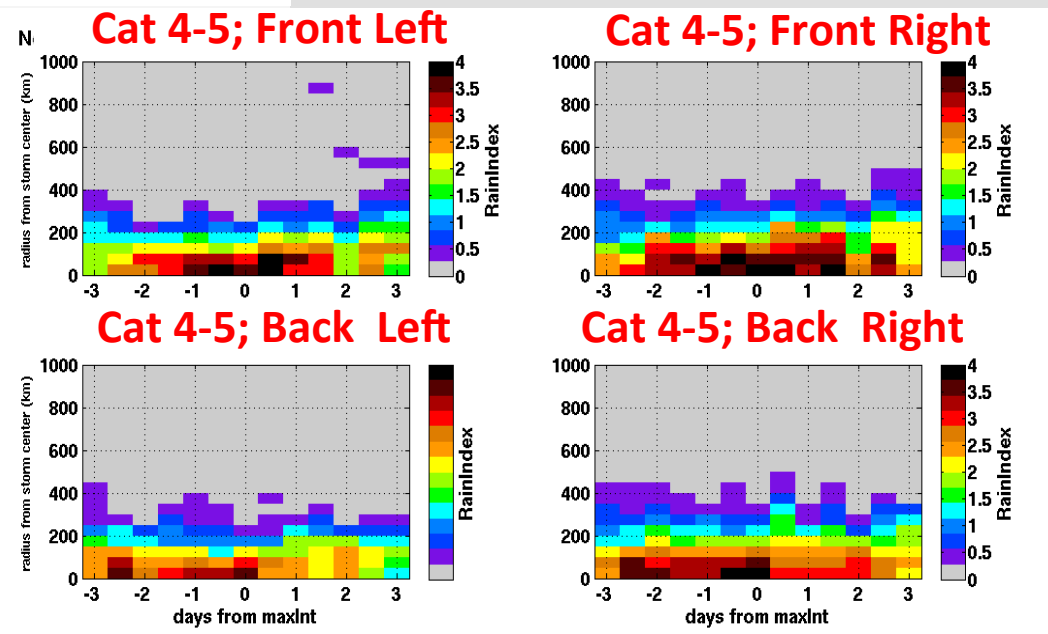
Evolution of asymmetry  
Azimuthal/Range Distributions of

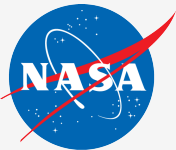
# Rain Index

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

**Total Cat1-3 = 52 cases**

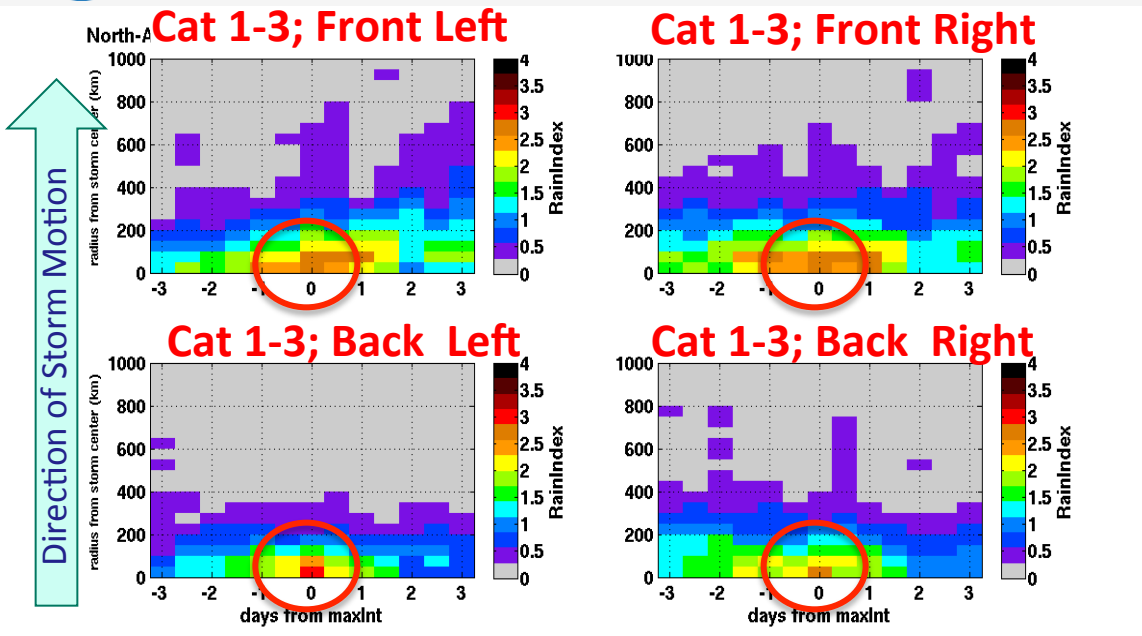
Cat4: 18 cases  
Cat5: 7 cases





# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



Evolution of asymmetry  
Azimuthal/Range Distributions of

# Rain Index

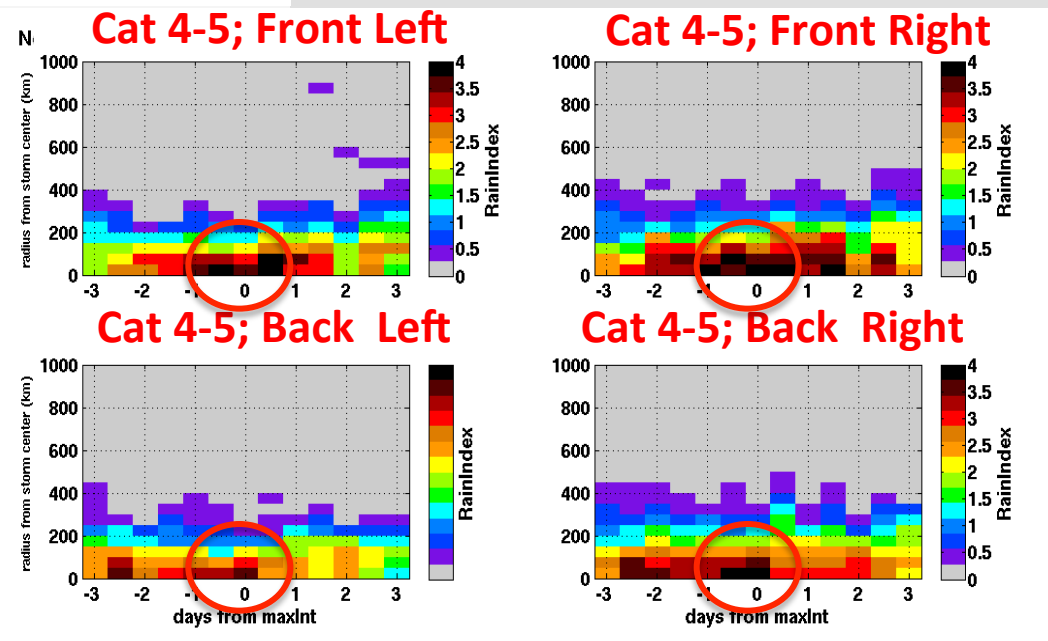
Cat1: 31 cases  
Cat2: 9 cases  
Cat3: 12 cases

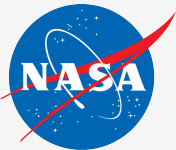
**Total Cat1-3 = 52 cases**

Cat4: 18 cases  
Cat5: 7 cases

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

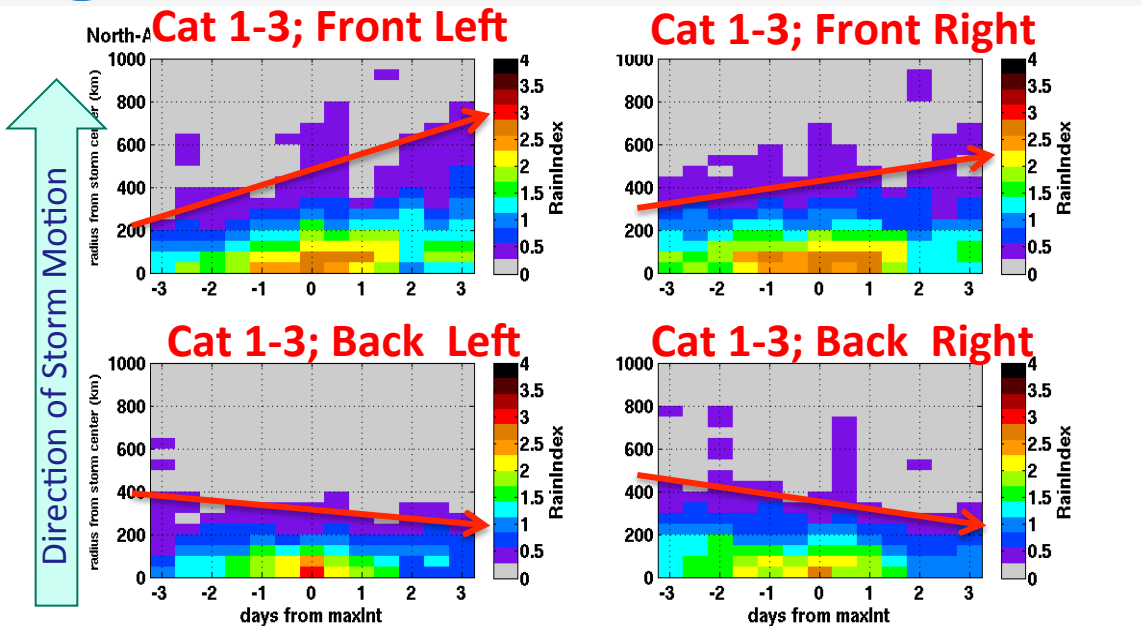
- Space
  - More intense precipitation is in the front 2 quadrants





# 9-year statistics from AMSR-E observations

## North Atlantic Hurricanes; 2002-2011



Evolution of asymmetry  
Azimuthal/Range Distributions of

# Rain Index

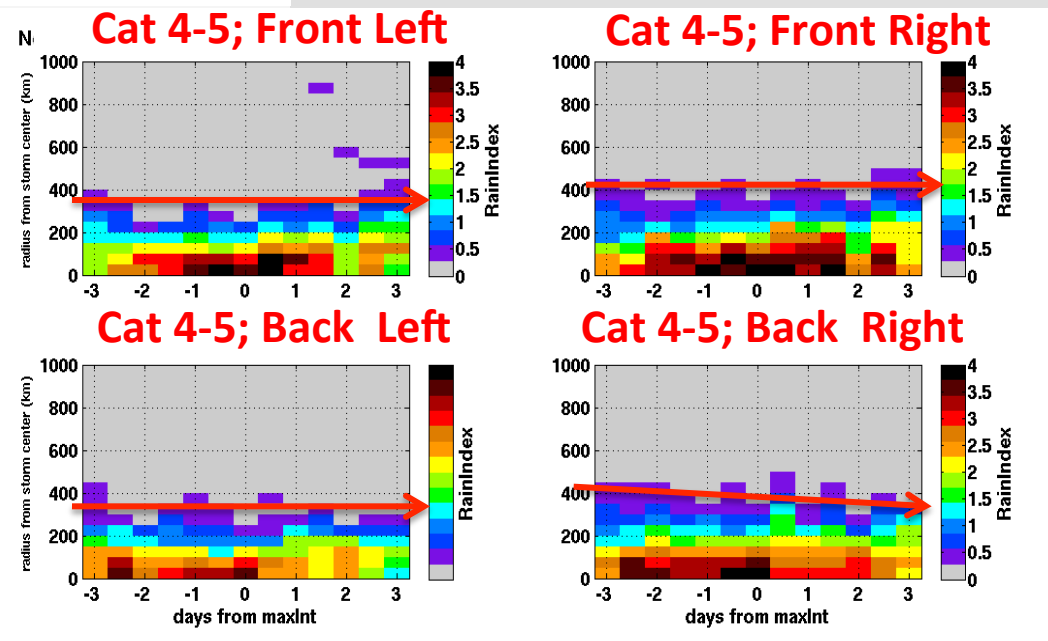
Cat1: 31 cases  
Cat2: 9 cases  
Cat3: 12 cases

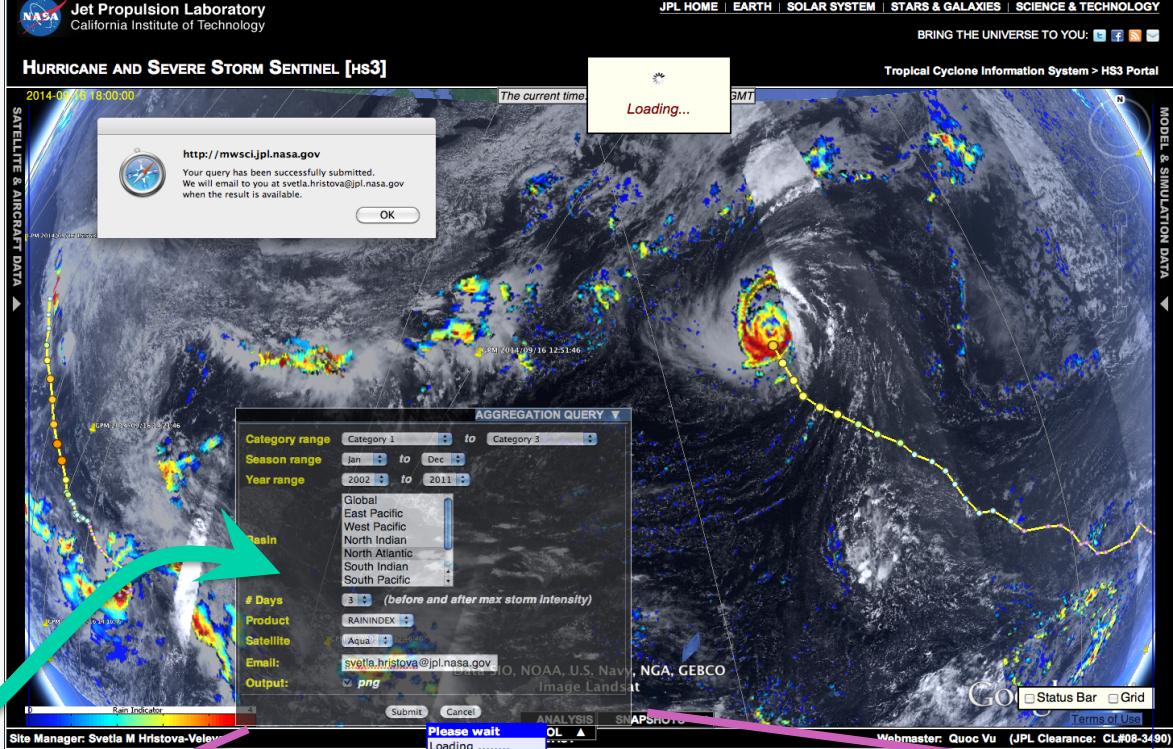
**Total Cat1-3 = 52 cases**

Cat4: 18 cases  
Cat5: 7 cases

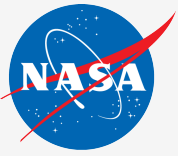
**Cat 1-3 have rain fields that are larger, weaker and less symmetric in:**

- 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





- Such analysis have been performed by researchers
  - Using mostly airborne data and limited satellite data
  - requiring significant investment in time and effort to collect the data
- Developing a system that will allow the user to quickly search our 12+ year global data archive of satellite observations of hurricanes
  - will greatly facilitate statistical analysis of satellite data
  - should help speed up the discovery of critical hurricane processes



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# Analyzing the Environment & Evaluating the Models



# Analysis of the environment - ECMWF



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California Institute of Technology

## RH at 850 mb

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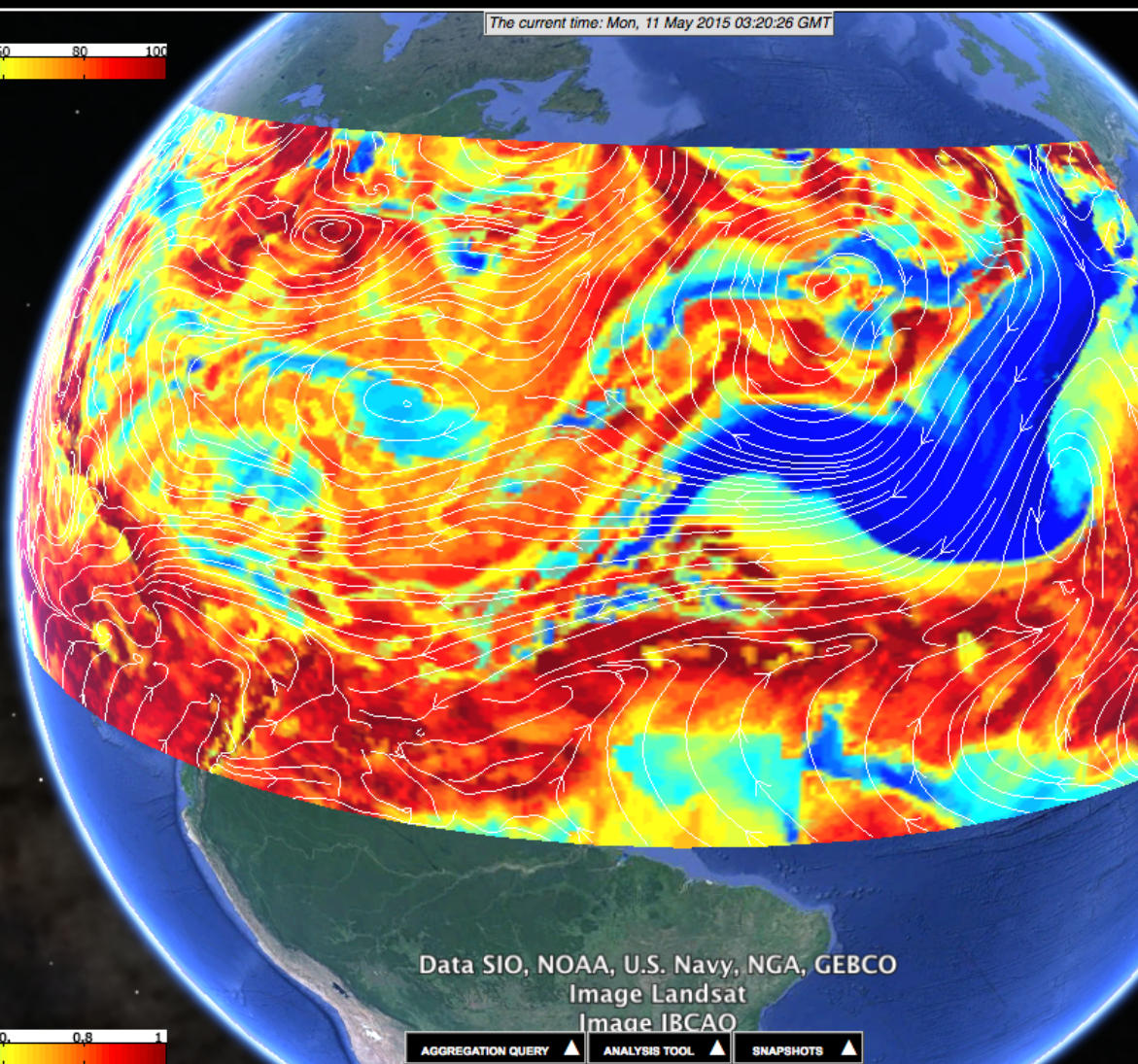
Tropical Cyclone Information System > HS3 Portal

## HURRICANE AND SEVERE STORM SENTINEL [HS3]

The current time: Mon, 11 May 2015 03:20:26 GMT

Model: 2014-08-29 00Z N 002

SATELLITE & AIRCRAFT DATA



MODEL & SIMULATION DATA

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								

**MODEL**

- ECMWF
- Press. 850
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY

GFS

NAVGEM  Status Bar  Grid

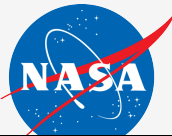
UKMET

Google Earth

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



AGGREGATION QUERY ▲ ANALYSIS TOOL ▲ SNAPSHOTS ▲



# Analysis of the environment - GFS



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California Institute of Technology

## RH at 850 mb

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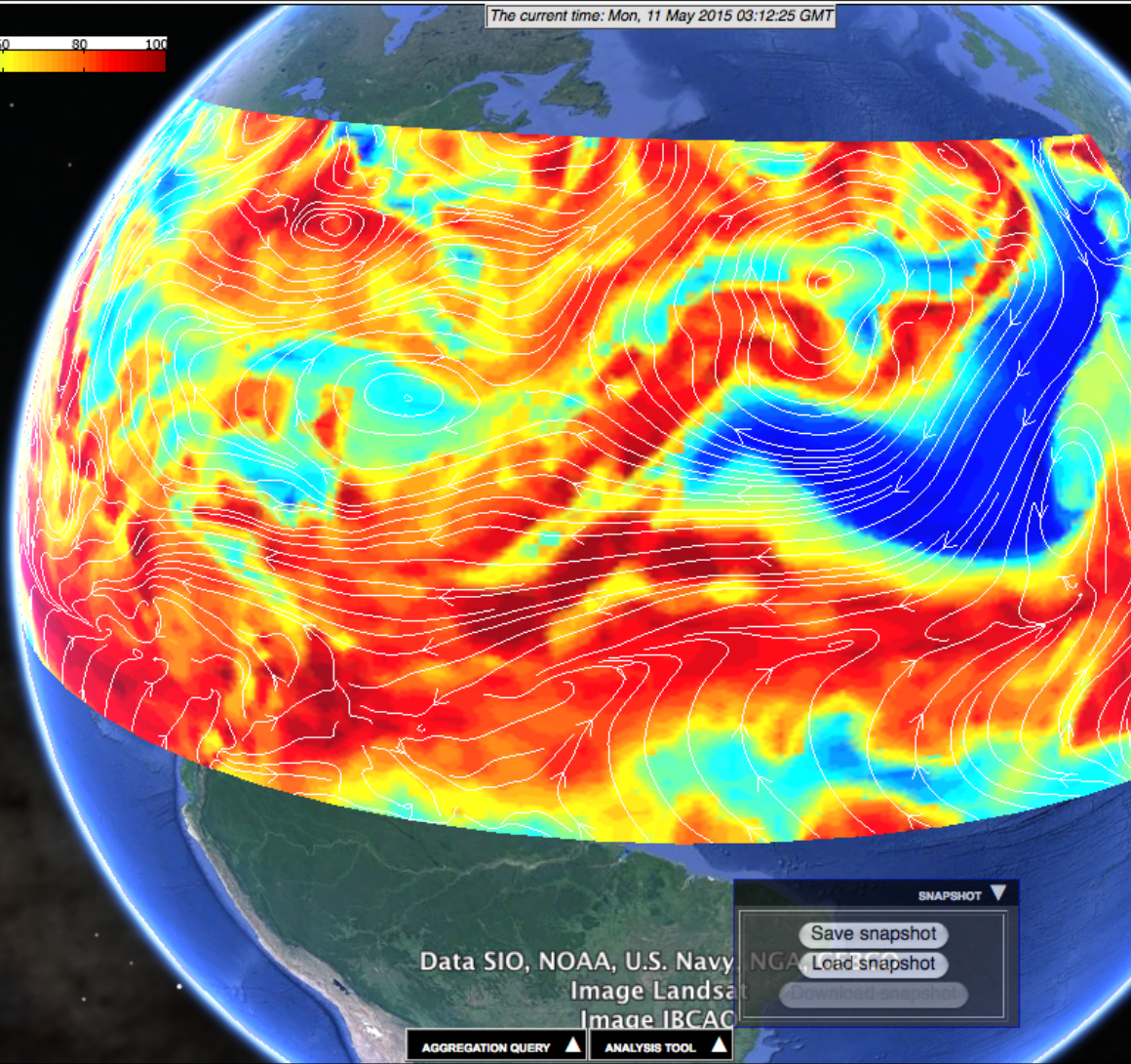
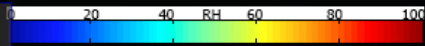
### HURRICANE AND SEVERE STORM SENTINEL [HS3]

Tropical Cyclone Information System > HS3 Portal

The current time: Mon, 11 May 2015 03:12:25 GMT

Model: 2014-08-29 00Z N 002

SATELLITE & AIRCRAFT DATA



MODEL & SIMULATION DATA

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						

<< < > >>

MODEL

- ECMWF
- GFS
- Press. 850
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- NAVGEM Status Bar  Grid
- UKMET

Google Earth

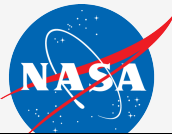
SNAPSHOT

Save snapshot

Load snapshot

Data SIO, NOAA, U.S. Navy, NGA, NASA, Image Landsat, Image IBCAO

AGGREGATION QUERY ANALYSIS TOOL



# Analysis of the environment – Observations (AIRS)



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Tropical Cyclone Information System > HS3 Portal

### HURRICANE AND SEVERE STORM SENTINEL [HS3]

The current time: Mon, 11 May 2015 03:14:19 GMT

Model: 2014-08-29 00Z N 000

Hurricanes: Select a hurricane

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: 19:00:00

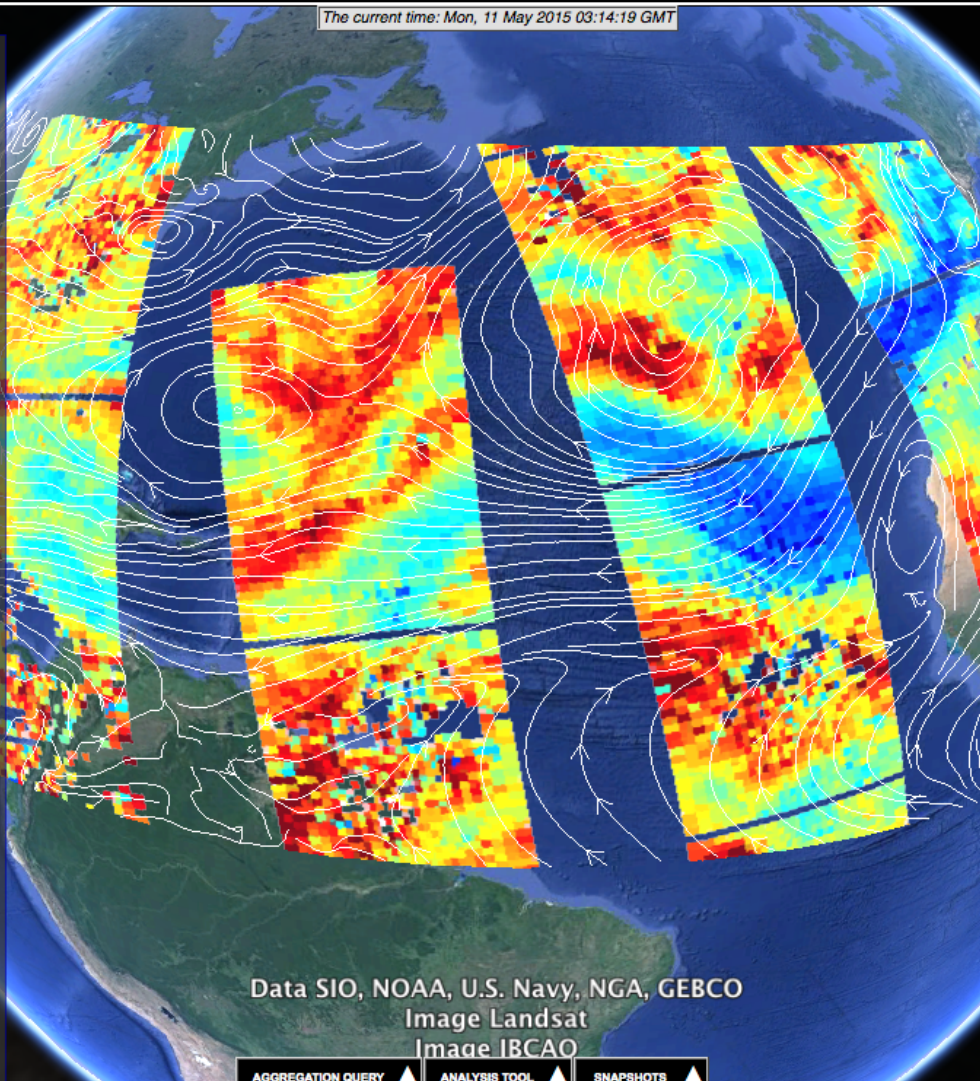
#### STORM TRACK

- BEST TRACK
- POUCH TRACK

#### SATELLITE DATA

- AIRS
- CAPE
- LI
- RH Press. 850
- TEMP Press. 200
- AOT (MODIS)
- Geostationary
- Microwave Rain Signature
- MLS
- TPW
- 6 HR Composite
- Two Day Animation
- TRMM
- WIND
- CloudSat

SATELLITE & AIRCRAFT DATA



MODEL & SIMULATION DATA

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

#### MODEL

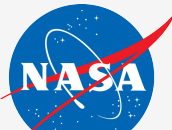
- ECMWF
- GFS
- Press. 850
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY

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

AGGREGATION QUERY | ANALYSIS TOOL | SNAPSHOTS

NAVGEM Status Bar | Grid  
UKMET  
Google earth  
Terms of Use





# The "Slicer" – analysis of the environment



Jet Propulsion Laboratory  
California Institute of Technology

## RH at 850 mb

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Tropical Cyclone Information System > HS3 Portal

### HURRICANE AND SEVERE STORM SENTINEL [HS3]

The current time: Mon, 11 May 2015 03:17:04 GMT

Model: 2014-08-29 00Z N 002

Hurricanes: Select a hurricane 50 80

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: 19:00:00

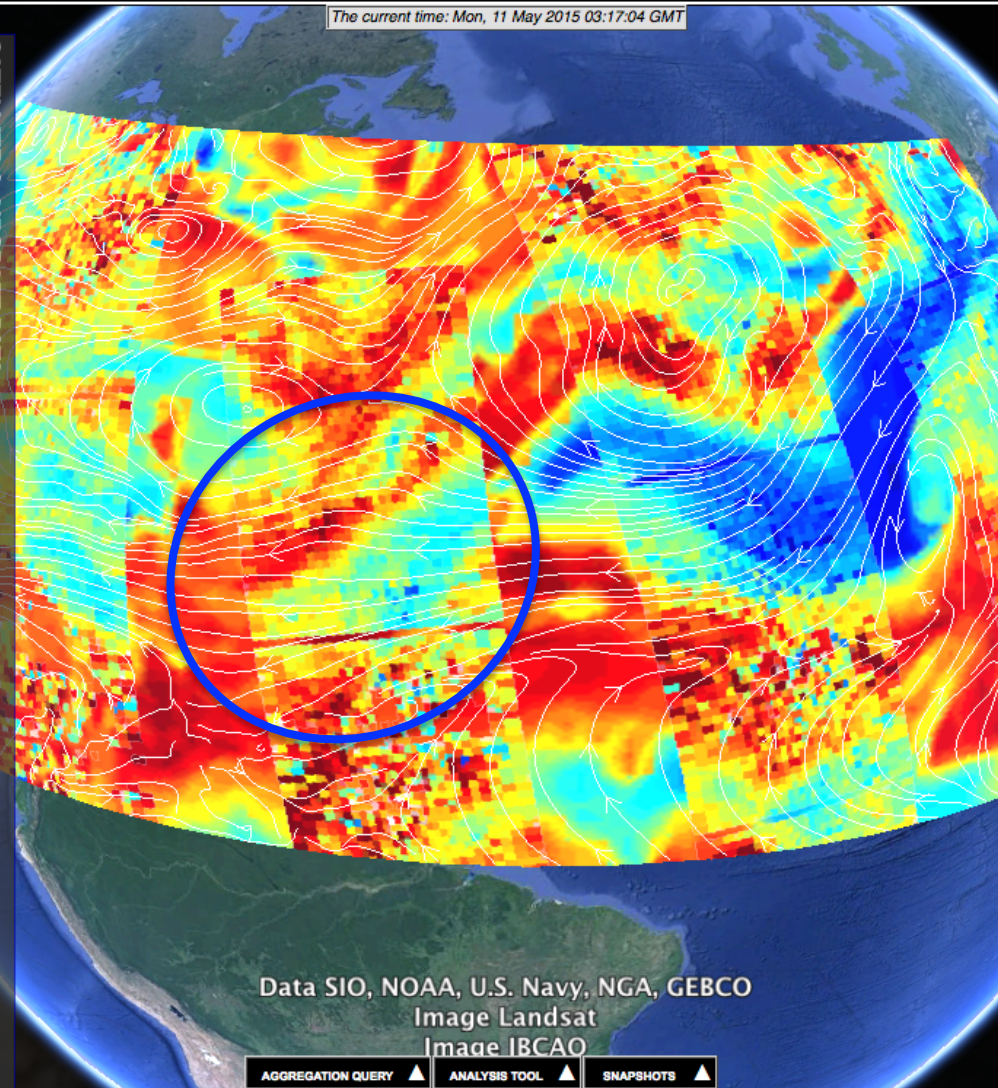
**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- CAPE
- LI
- RH Press. 850
- TEMP Press. 200
- AOT (MODIS)
- Geostationary
- Microwave Rain Signature
- MLS
- TPW
- 6 HR Composite
- Two Day Animation
- TRMM
- WIND
- CloudSat

0 0.2 0.4 RH(AIRS) 0.6 0.8



MODEL & SIMULATION DATA

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						

**MODEL**

- ECMWF
- GFS
- Press. 850
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- NAVGEM Status Bar
- Grid
- UKMET

Google earth

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

AGGREGATION QUERY ▲ ANALYSIS TOOL ▲ SNAPSHOTS ▲



# The "Slicer" – analysis of the environment

## HURRICANE AND SEVERE STORM SENTINEL [HS3]

Model: 2Q14-08-29 00Z 000

The current time: Mon, 11 May 2015 02:46:59 GMT

Hurricanes: Select a hurricane

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: 19:00:00

### STORM TRACK

- BEST TRACK
- POUCH TRACK

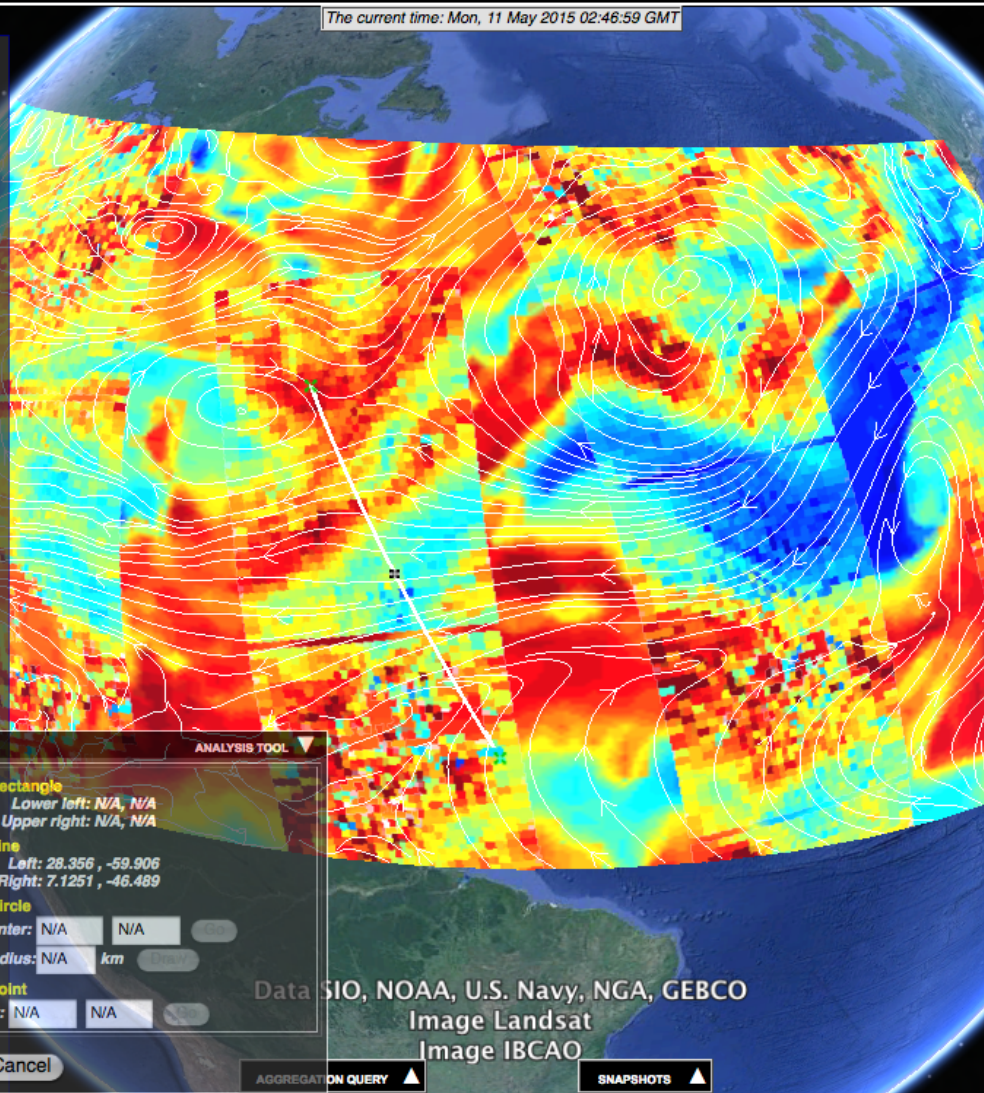
### SATELLITE DATA

- AIRS
- CAPE
- LI
- RH Press. 850
- TEMP Press. 200

### LOT (MODIS)

- SLICER
- Microwave Rain Signature
- Dataset 1: RH\_AIRS
- Dataset 2: N/A
- Dataset 3: N/A
- Output:  png  kml  text
- TRMM
- WIND
- CloudSat

SATELLITE & AIRCRAFT DATA



MODEL & SIMULATION DATA

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						

### MODEL

- ECMWF
- GFS
- Press. 850
- Forecast Time 012
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY
- NAVGEM Status Bar
- Grid
- UKMET

ANALYSIS TOOL

- Rectangle  
Lower left: N/A, N/A  
Upper right: N/A, N/A
- Line  
Left: 28.356, -59.906  
Right: 7.1251, -46.489
- Circle  
Center: N/A, N/A  
Radius: N/A km
- Point  
At: N/A, N/A

Submit Cancel

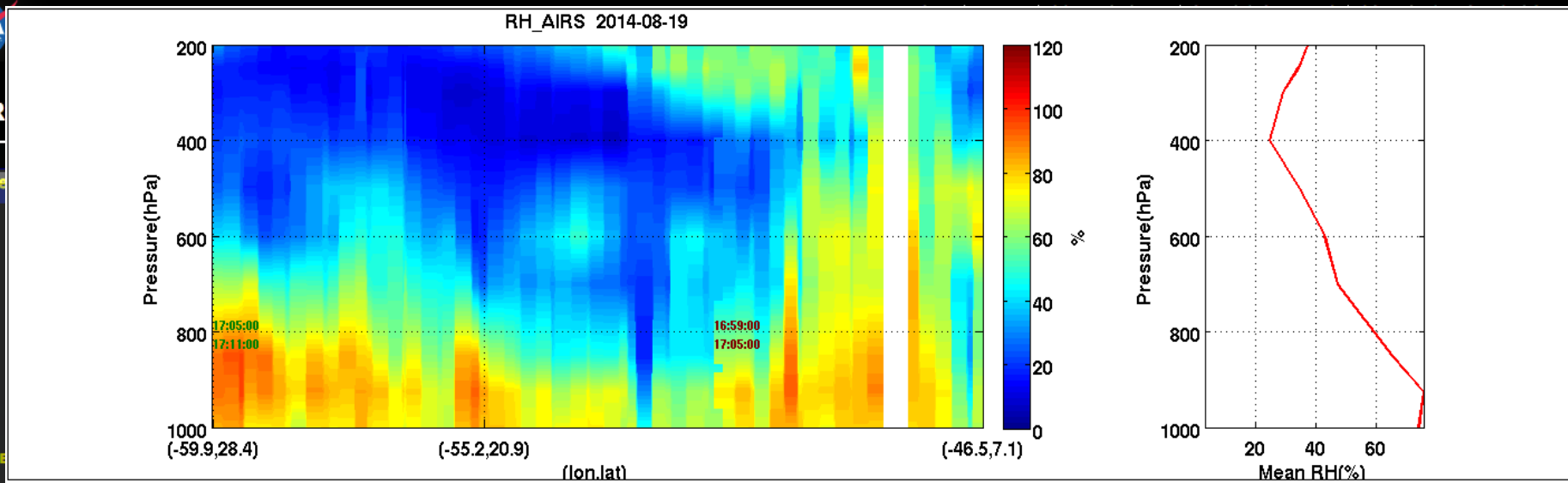
Data SIO, NOAA, U.S. Navy, NGA, GEBCO  
Image Landsat  
Image IBCAO





# The "Slicer" – analysis of the environment

HUR  
Hurricane



**STORM TRACK**

- BEST TRACK
- POUCH TRACK

**SATELLITE DATA**

- AIRS
- CAPE
- LI
- RH Press. 850
- TEMP Press. 200

**LOT (MODIS)**

- Microwave Rain Signature
- ILS Dataset 1: RH\_AIRS
- Dataset 2: N/A
- Dataset 3: N/A

**Output:**  png  kml  text

Analysis Tool: SLICER

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

**Line**  
Left: 28.356, -59.906  
Right: 7.1251, -46.489

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

**Point**  
At: N/A, N/A

Submit Cancel

Press. 850

Forecast Time 012

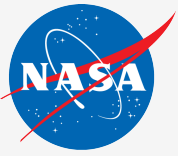
- SPEED-COMOVING
- STREAM-COMOVING
- DEEP-SHEAR
- OW
- PMSL
- POUCH-SHEAR
- RH
- SPEED-EARTH
- STREAM-EARTH
- TEMP
- TPW
- VORTICITY

NAVGEM Status Bar  Grid

UKMET

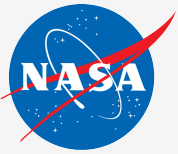
Google earth

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



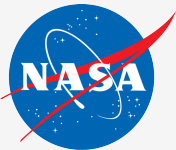
# Summary

- 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.**

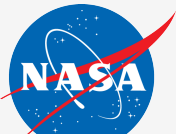


# What is unique about our efforts

- **Large number of Observations, COMBINED with Models**
  - New source for all radar and passive microwave data –PPS – with consistent format and inter-calibration, lower latency and higher reliability
- **Interactive visualization and interrogation**
  - Search by Date; Search by Hurricane; “Storm Track”, Forecasts Tracks
  - Overlays, Transparency
- **Synthetic data from two instrument simulators**
  - Simulation of Satellite-like observations
    - Operational – Using CRTM and HWRF; in NRT
    - Research - Orbit-sampling; Antenna-averaging; Instrument specific viewing geometry; Synthetic data from the large-scale models
- **On-line Analysis tools**
  - Environment
    - the “Slicer”; Thermodynamics from AIRS –Skew-T plots, at pressure levels
  - Storm structure – Vitals and Vertical structure
    - Storm Center Finding (ARCHER); Wave Number Analysis, Joint PDFs; PCA/EOFs
- **Integration with the 12+ year climatology**



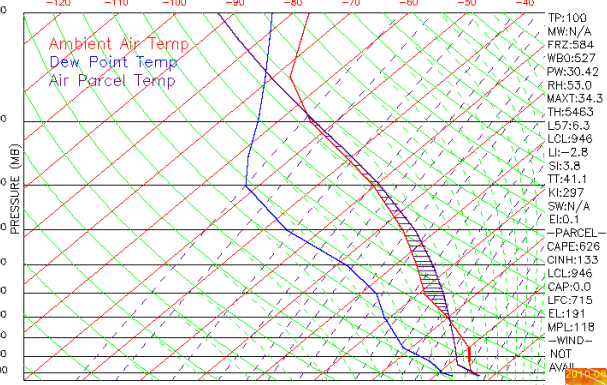
*Thank you !*



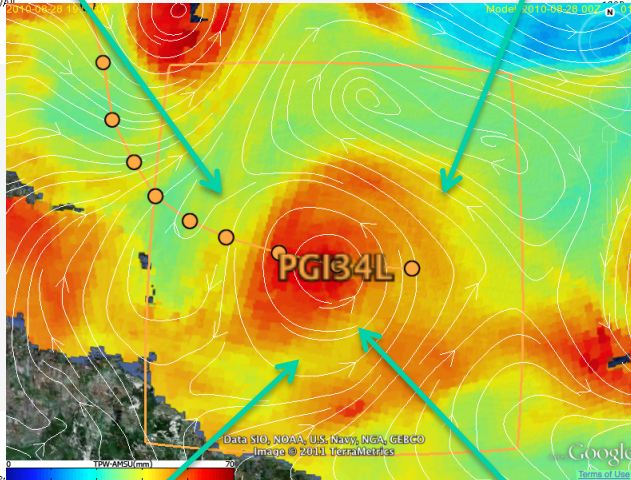
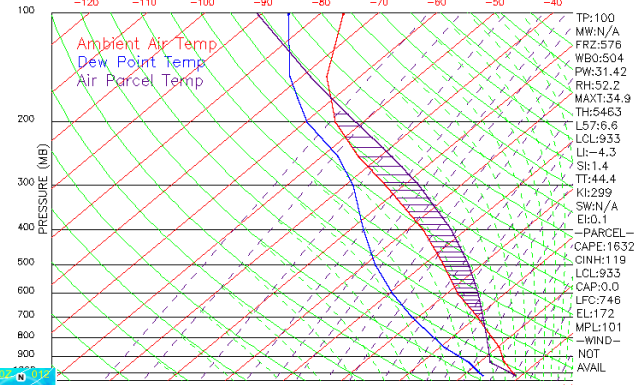
# The thermodynamics from AIRS

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

AIRS SkewT Diagram 2010-08-28/16:42:56.73 (Lat/Lon 19.34/-57.76 deg)

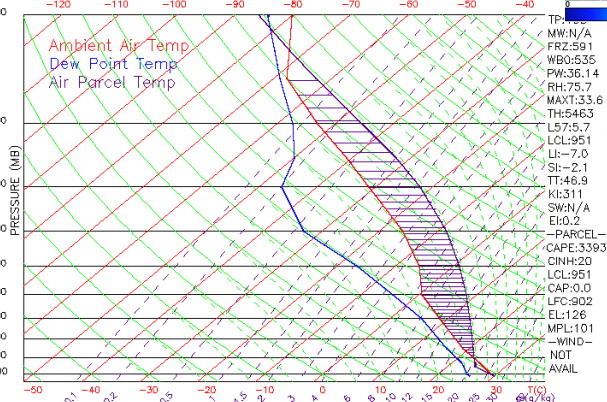


AIRS SkewT Diagram 2010-08-28/16:42:38.87 (Lat/Lon 19.81/-45.90 deg)

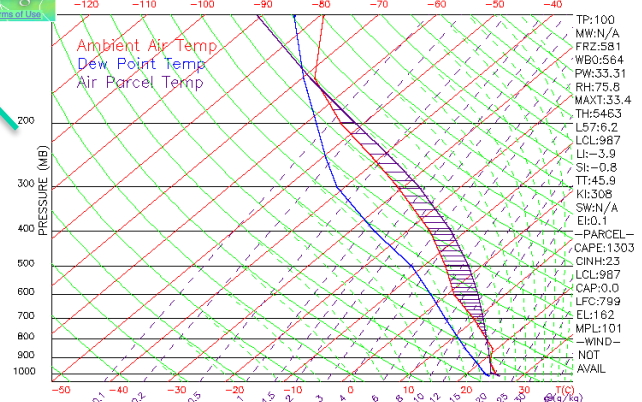


1. TPW from AMSU
2. Soundings from AIRS
3. Pouch-relative flow from ECMWF

AIRS SkewT Diagram 2010-08-28/16:40:25.80 (Lat/Lon 10.82/-52.30 deg)



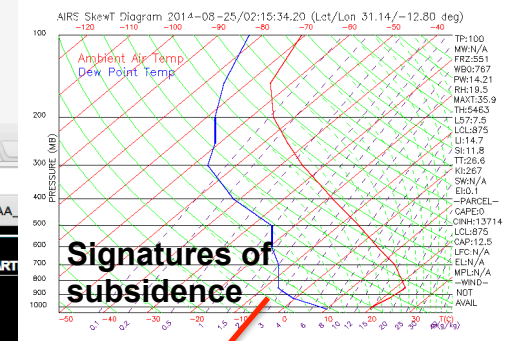
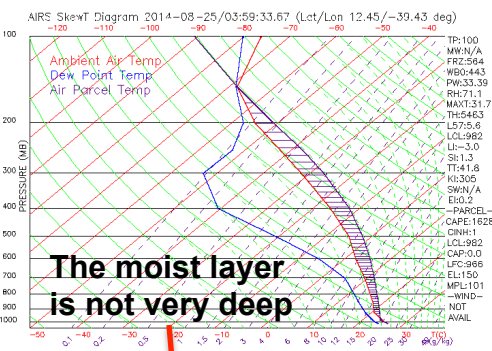
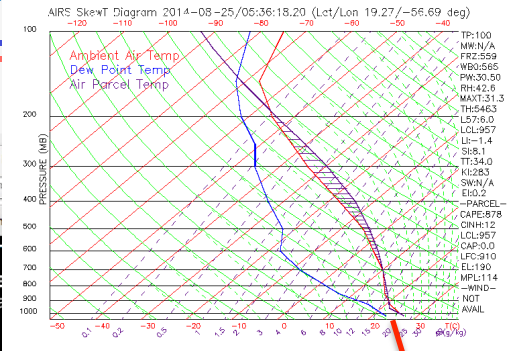
AIRS SkewT Diagram 2010-08-28/16:40:35.67 (Lat/Lon 11.84/-49.18 deg)





# 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

Model: 2014-08-25 00Z 012

MODEL & SIMULATION DATA

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

Image Landsat

DATA SELECTION | SNAPSHOTS

PRIVACY

Site Manager: Svetla M Hristova-Velova

Distance: 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

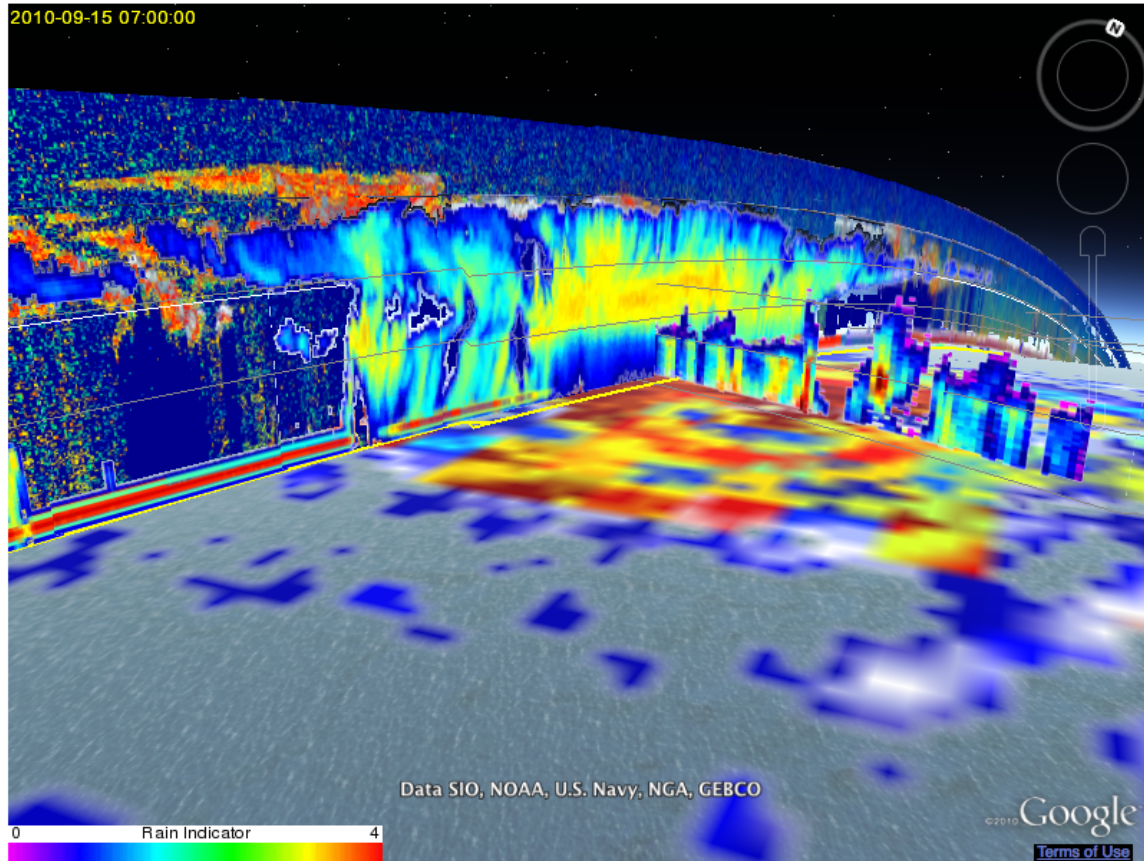
- Best Tracks
- Pouch Tracks
  - PG141L
  - PG143L
  - PG144L
  - PG145L

### 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

2010-09-15 07:00:00



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



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

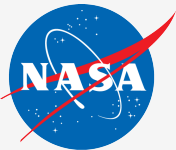
September 2010

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
  - PG141L
  - PG143L
  - PG144L
  - PG145L
  - PG146L
  - Relative Humidity
  - OW
  - Vorticity
  - Deep shear
  - Pouch shear
  - Sea Level Pressure
- ECMWF
- UKMET
- NOGAPS

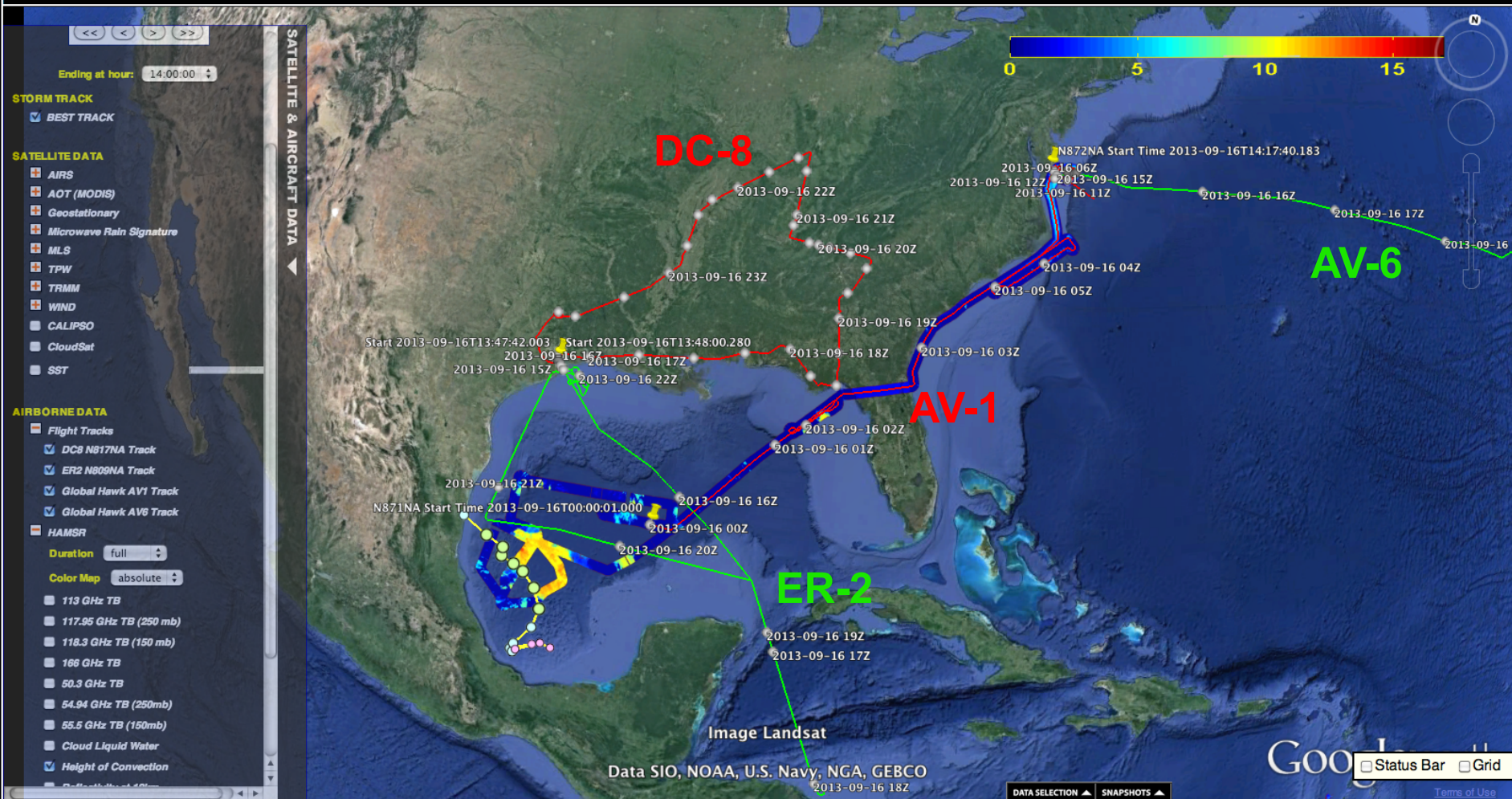


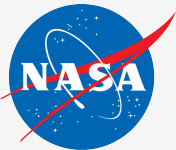
# Airborne Science: HS3 and SEAC4RS

## 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);

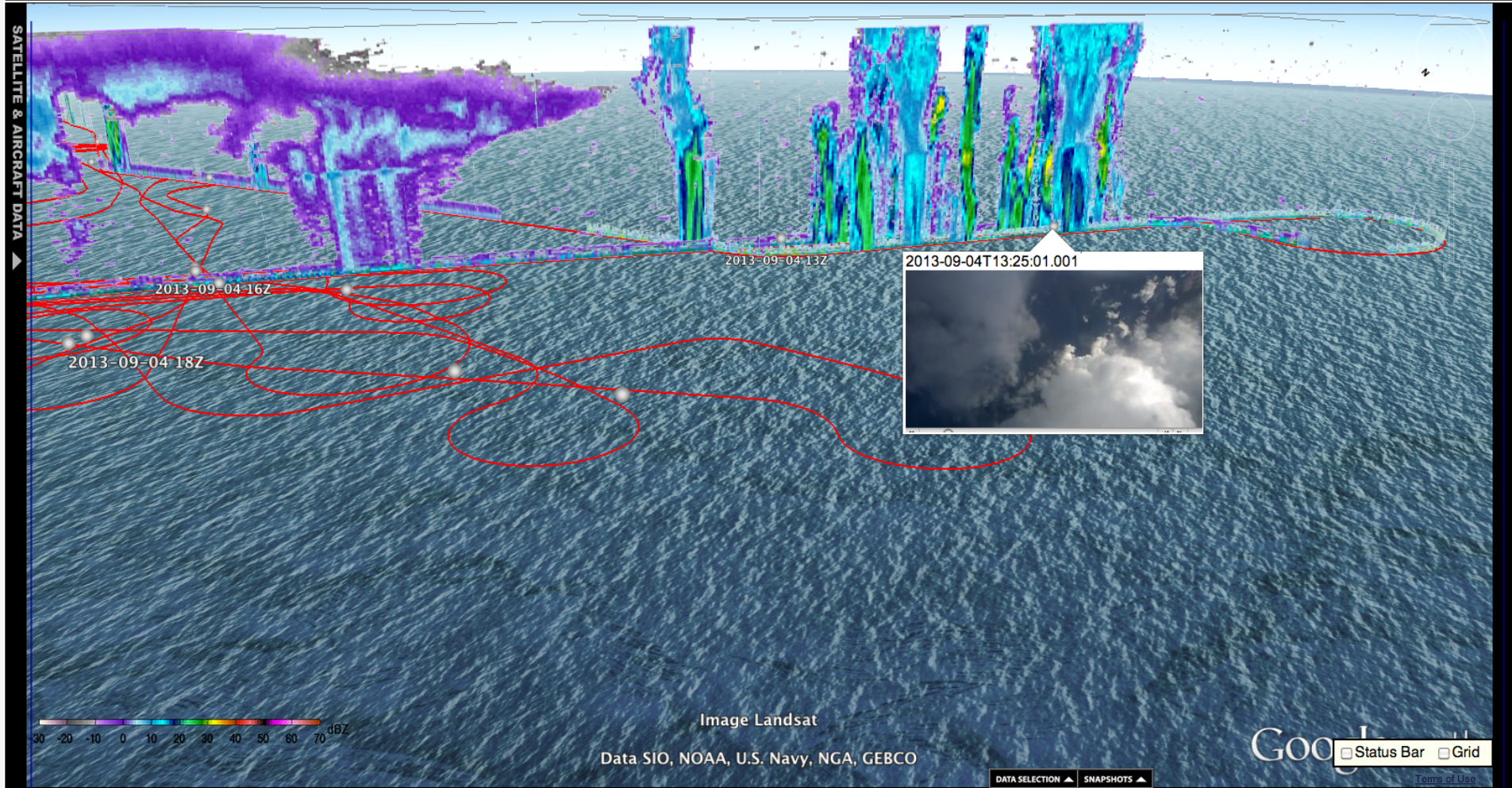
### Nadir-viewing Camera Movies

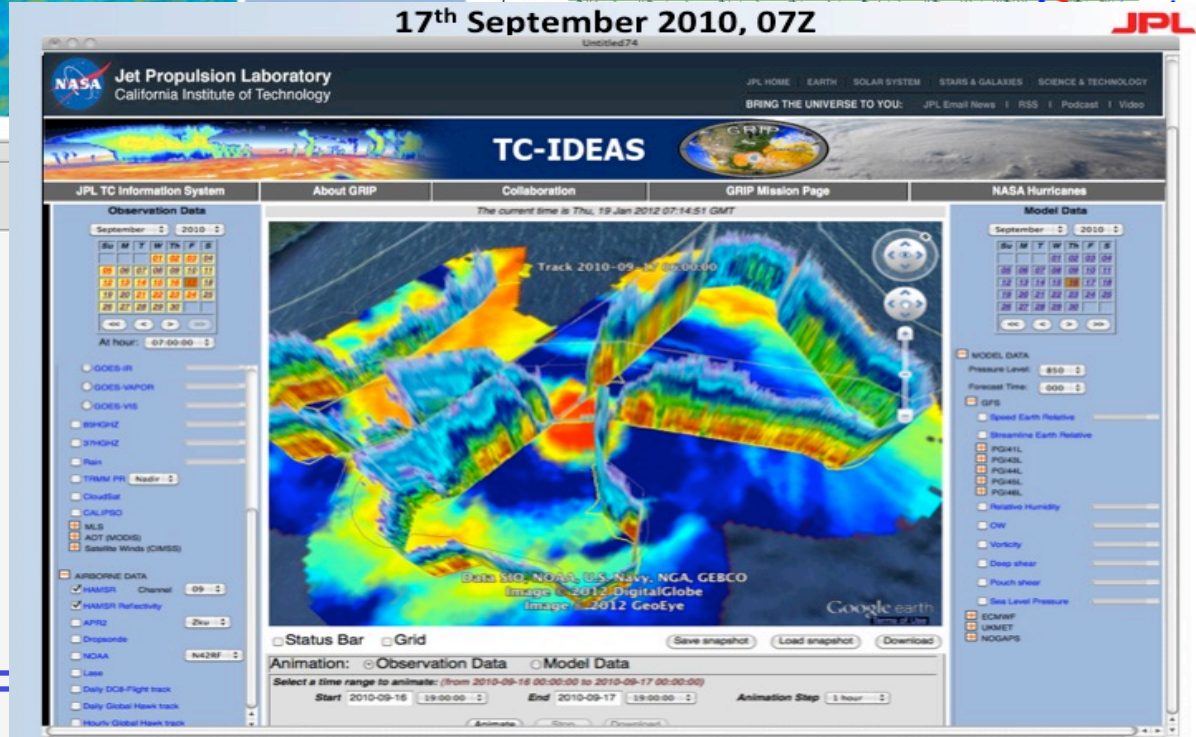
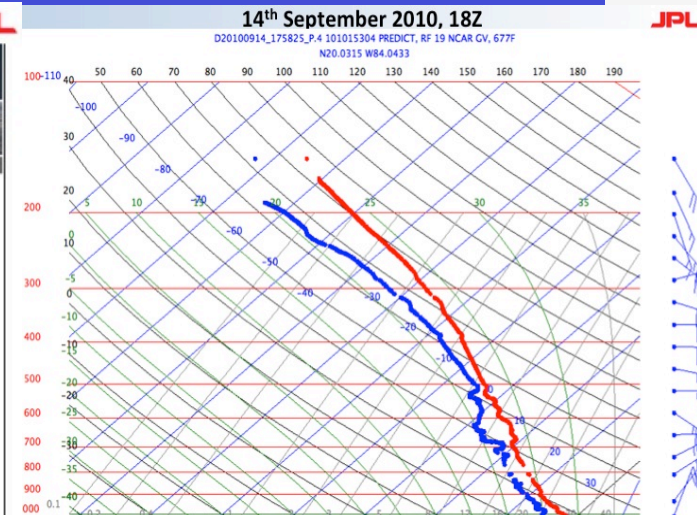
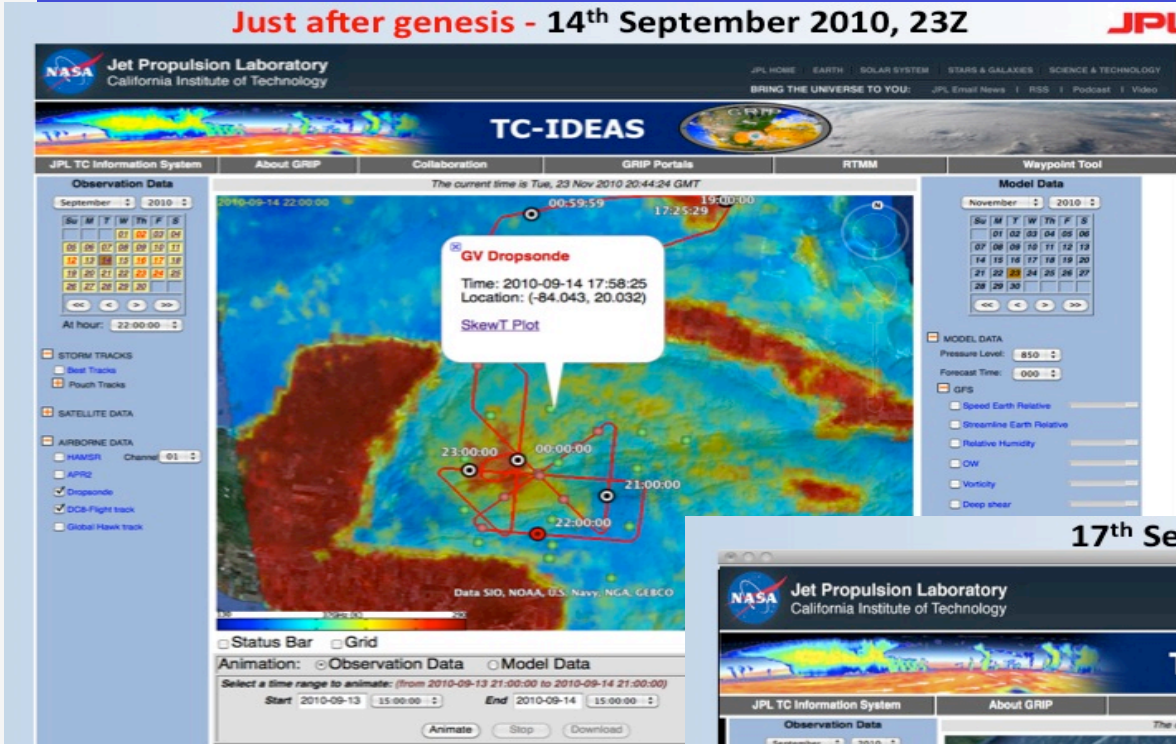
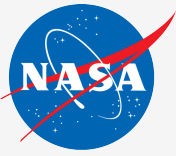
 **Jet Propulsion Laboratory**  
California Institute of Technology

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BRING THE UNIVERSE TO YOU:    

#### HURRICANE AND SEVERE STORM SENTINEL





### Hurricane Karl:

### Genesis and Rapid Intensification from

- satellite,
- airborne and
- in-situ observations

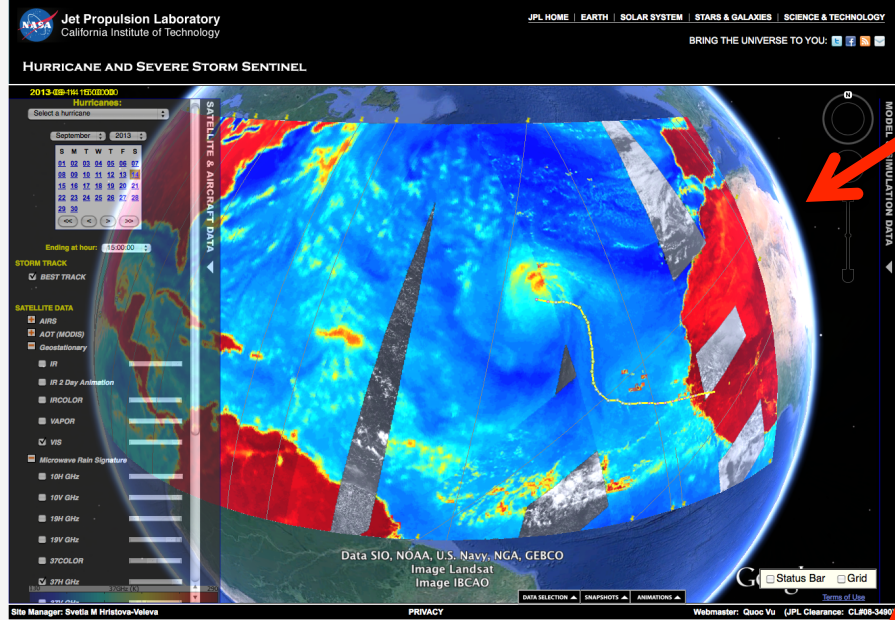
# FUSION OF MODELS AND OBSERVATIONS - OPERATIONALLY

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?

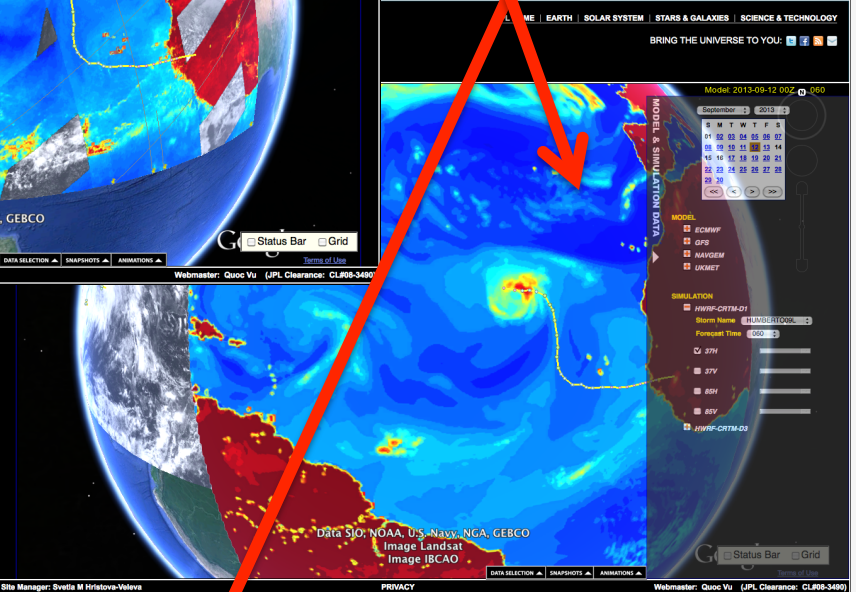
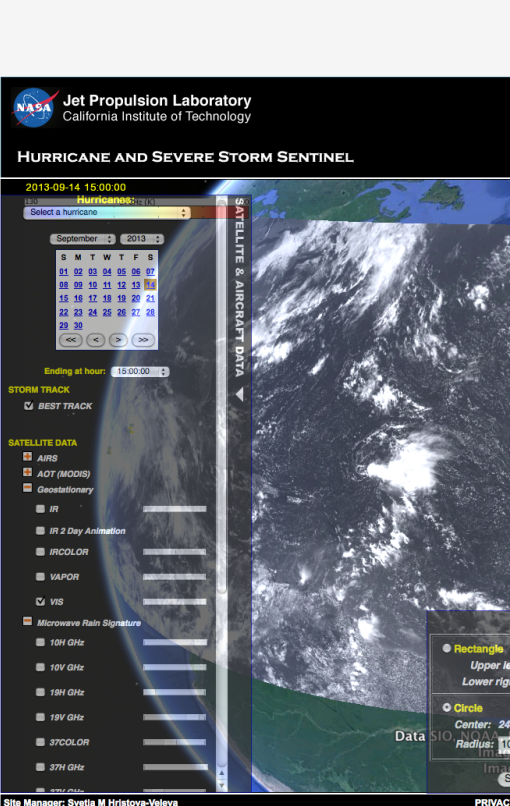
Including simulations from the same NWP model (say HWRf) but produced by different forward simulators and under different micro-physical & electromagnetic assumptions (as in NEOS<sup>3</sup> and CRTM) will help reveal the uncertainty that comes from the forward modeling itself.



Satellite Observations



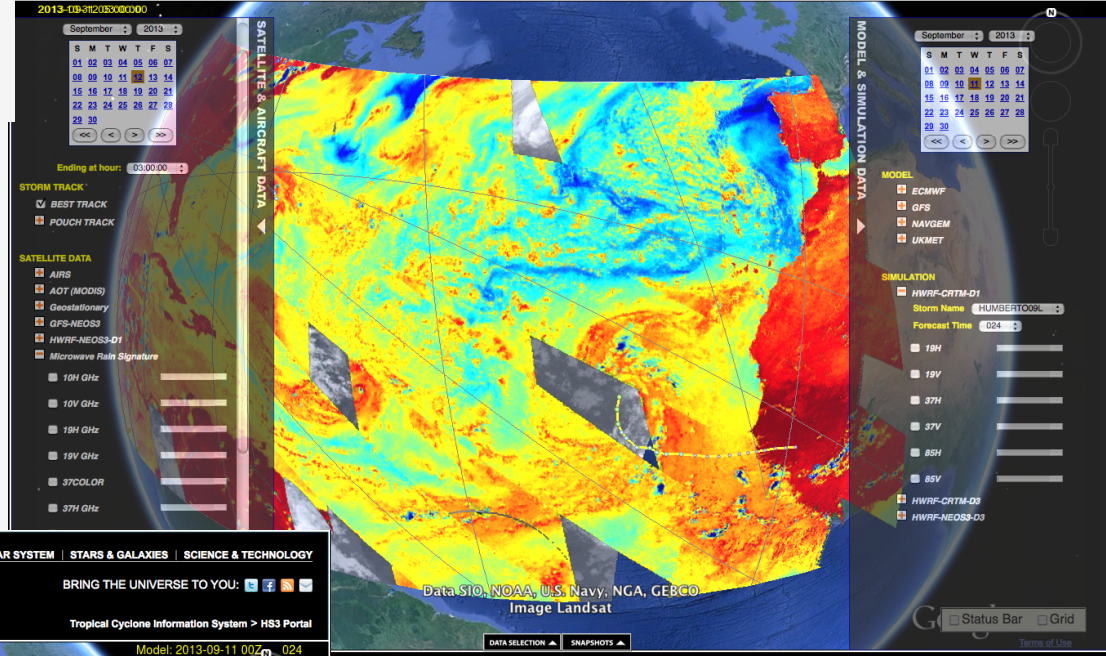
Synthetic Observations from Model



### HURRICANE AND SEVERE STORM SENTINEL [HS3]

# OBSERVATIONS

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



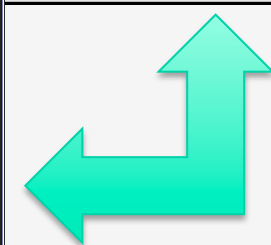
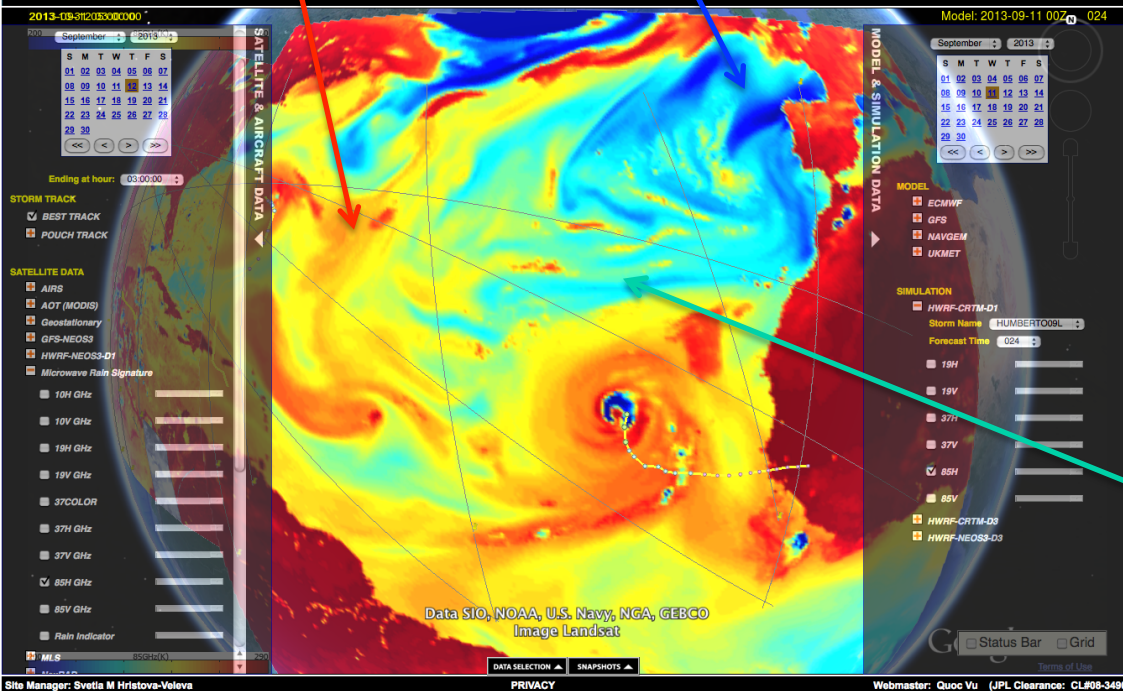
**DRY AIR**

**MOIST AIR**

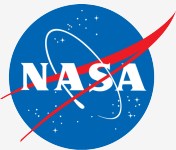
### HURRICANE AND SEVERE STORM SENTINEL [HS3]

# 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



- 
- **From:** Tomislava Vukicevic <[Tomislava.Vukicevic@noaa.gov](mailto:Tomislava.Vukicevic@noaa.gov)>
  - **Date:** Saturday, December 7, 2013 7:01 PM
  - **To:** hristova <[svetla.hristova@jpl.nasa.gov](mailto:svetla.hristova@jpl.nasa.gov)>
  - **Cc:** gopal <[Sundararaman.G.Gopalakrishnan@noaa.gov](mailto:Sundararaman.G.Gopalakrishnan@noaa.gov)>, Vijay Tallapragada <[vijay.tallapragada@noaa.gov](mailto:vijay.tallapragada@noaa.gov)>, "Montgomery, Michael (Mike) (CIV)" <[mtmontgo@nps.edu](mailto:mtmontgo@nps.edu)>, "Boothe, Mark (CIV)" <[maboothe@nps.edu](mailto:maboothe@nps.edu)>, "Haddad, Ziad S (334H)" <[Ziad.S.Haddad@jpl.nasa.gov](mailto:Ziad.S.Haddad@jpl.nasa.gov)>, Bjorn Lambrigtsen <[Bjorn.H.Lambrigtsen@jpl.nasa.gov](mailto:Bjorn.H.Lambrigtsen@jpl.nasa.gov)>, "Turk, Joe (334H)" <[Joseph.Turk@jpl.nasa.gov](mailto:Joseph.Turk@jpl.nasa.gov)>, "Li, P Peggy (398F)" <[p.p.li@jpl.nasa.gov](mailto:p.p.li@jpl.nasa.gov)>, "Knosp, Brian W (3284)" <[brian.w.knosp@jpl.nasa.gov](mailto:brian.w.knosp@jpl.nasa.gov)>, "Tanelli, Simone (334H)" <[simone.tanelli@jpl.nasa.gov](mailto:simone.tanelli@jpl.nasa.gov)>, "Niamsuwan, Noppasin (334H)" <[Noppasin.Niamsuwan@jpl.nasa.gov](mailto:Noppasin.Niamsuwan@jpl.nasa.gov)>
  - **Subject:** Re: AGU session on Big Data Analytic Systems
  - The portal with tools is huge step forward for both the TC physical analysis and model evaluation with satellite data. Finally, the data can be used by many: equivalent of iphone-revolution :) Great work
  - Thanks
  - Tomi
  - Meteorologist / Senior Research Scientist
  - National Oceanographic and Atmospheric Administration
  - Atlantic Oceanographic & Meteorological Laboratory
  - Hurricane Research Division
  - 4301 Rickenbacker Causeway, Miami, FL 33149
  - Tel: (305) 361-4403
  - Fax: (305) 361-4402



# JPL Tropical Cyclone Information System

Home Project Feedback Data Portal Analysis Tool

## Tropical Cyclone Rita

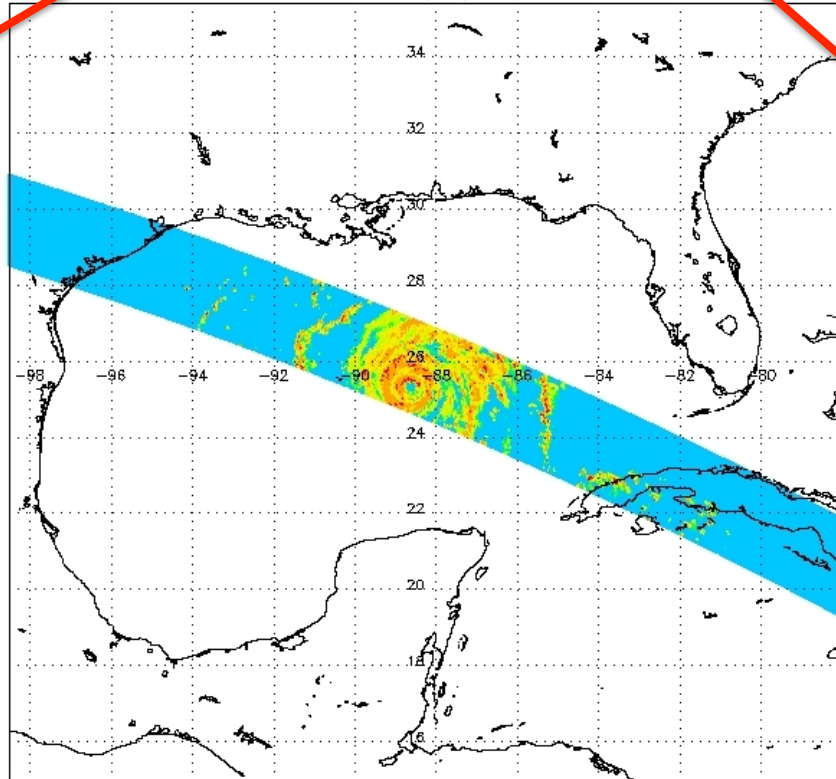
Su	M	T	W	Th	F	S
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19	20	21	22	23	24	25
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September 2005

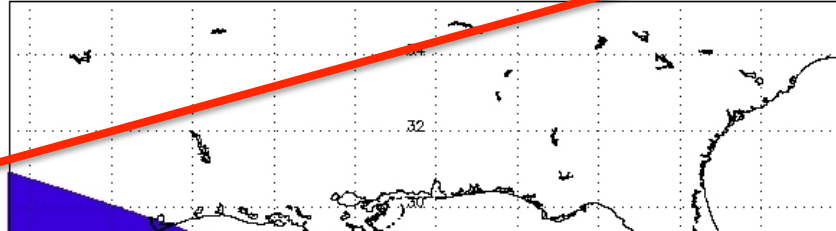
- MLS
- SeaWINDS
- GPS-RO
- OMI
- AIRS
- PR
  - TRMM
    - MaxZ-PIA-RR-RT
      - 2005-09-22 08:10:00
      - 2005-09-22 14:42:00
- TMI
- AMSRE
- AMSU-A
- SSMI
- GEO

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

TRMM MaxZ on 09/22/05 at 14:42



TRMM PR\_Attn\_2A21 on 09/22/05 at 14:42



Download All

Download NetCDF

At this time

All data on this day