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

[1] – JPL, Pasadena, CA
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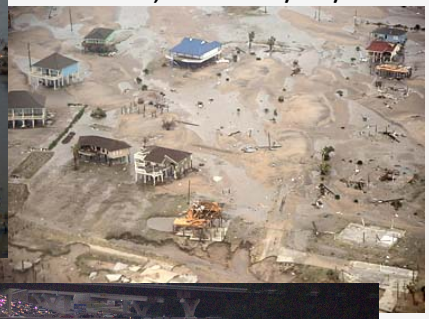
Fusion of Hurricane Models and Observations: Developing the Technology to Improve the Forecasts

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

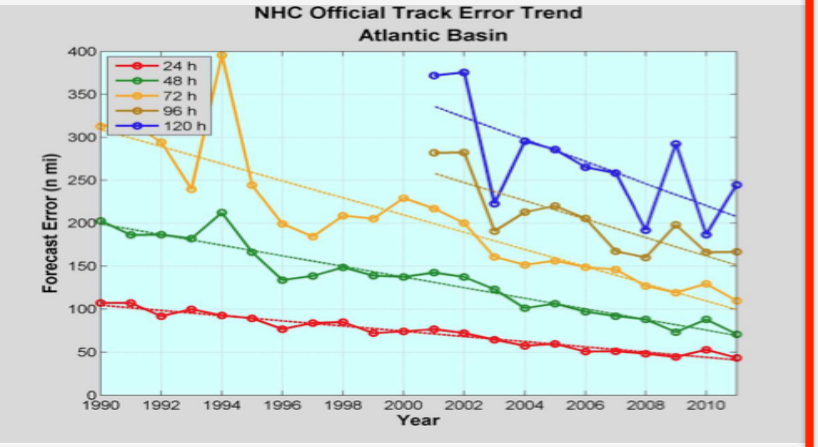
Widespread power outages and subway shutdowns may wind up making **Superstorm Sandy** the second most expensive storm in U.S.

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

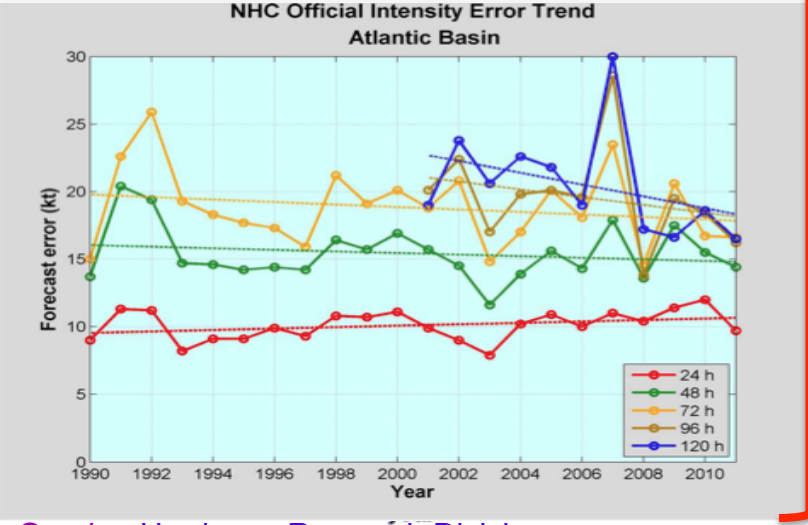
- Some **130,000 died** when a cyclone struck Myanmar along the Andaman Sea in 2008.
- The deadliest U.S. hurricane was the 1900 Galveston storm, which **killed 8,000 to12,000** people and destroyed the city. Katrina (2005) **killed some 1,200 people**, and left hundreds of thousands homeless.
- Sandy 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.

Current state-of-the-art hurricane prediction

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



- **Intensity forecasts have not improved.**



Graphs: Hurricane Research Division

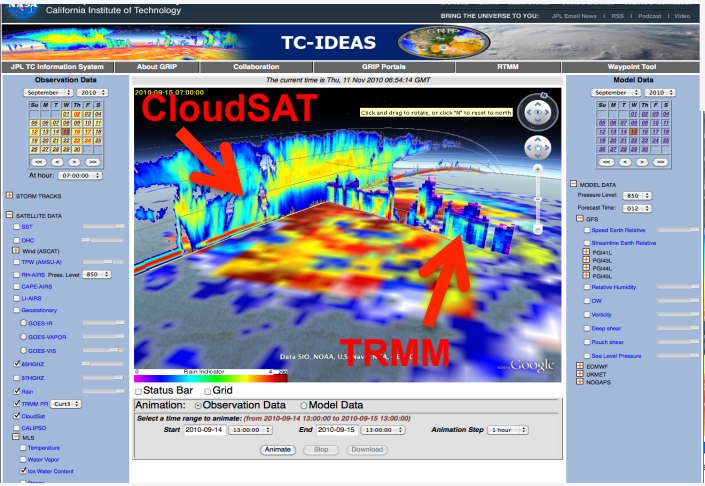
But WHY ???

- 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).

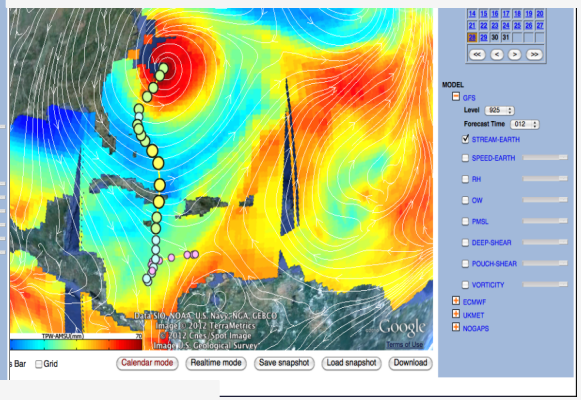
ESTO Earth Science Technology Office

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

- **Is the representation of the precipitation structure correct?**



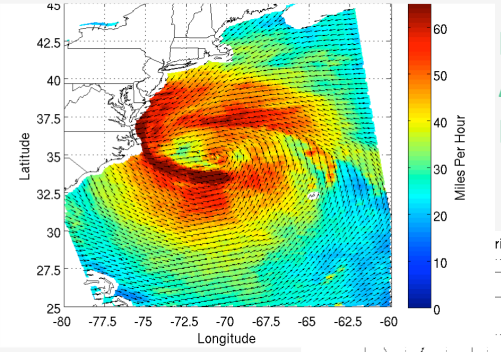
- **Is the environment captured correctly?**
- **Is the interaction between the storm and its environment realistic?**



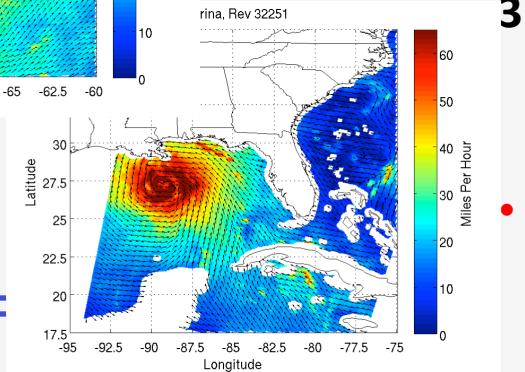
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

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

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.

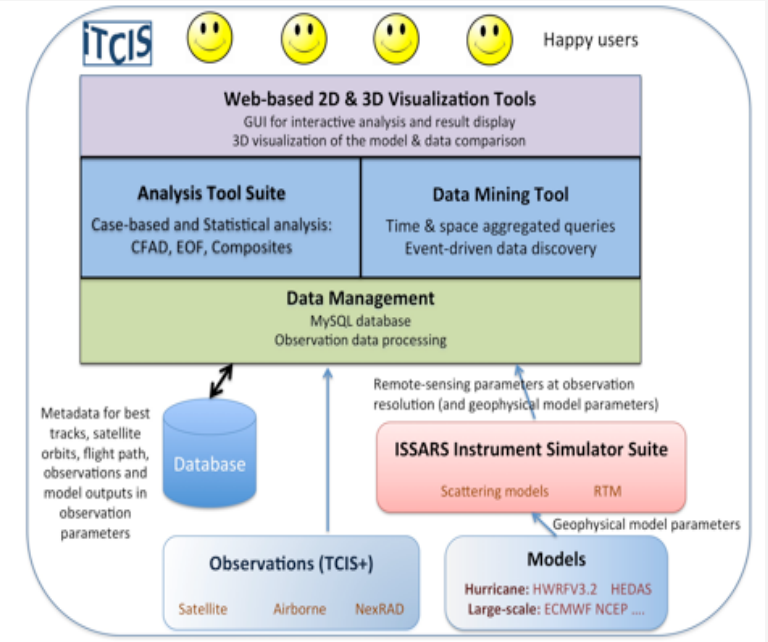
This system is being developed under NASA support:

- **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

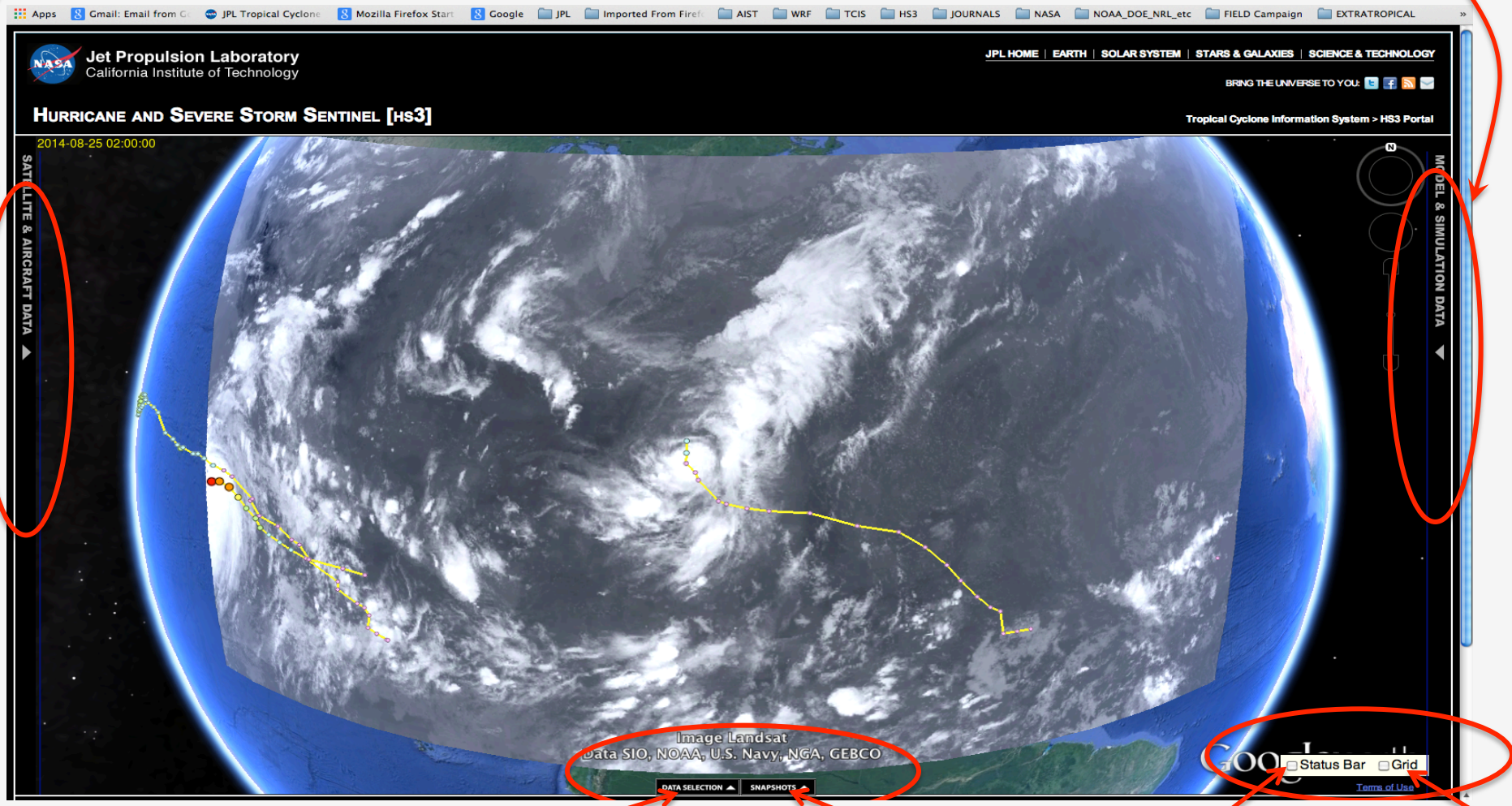
The three components of our system

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):

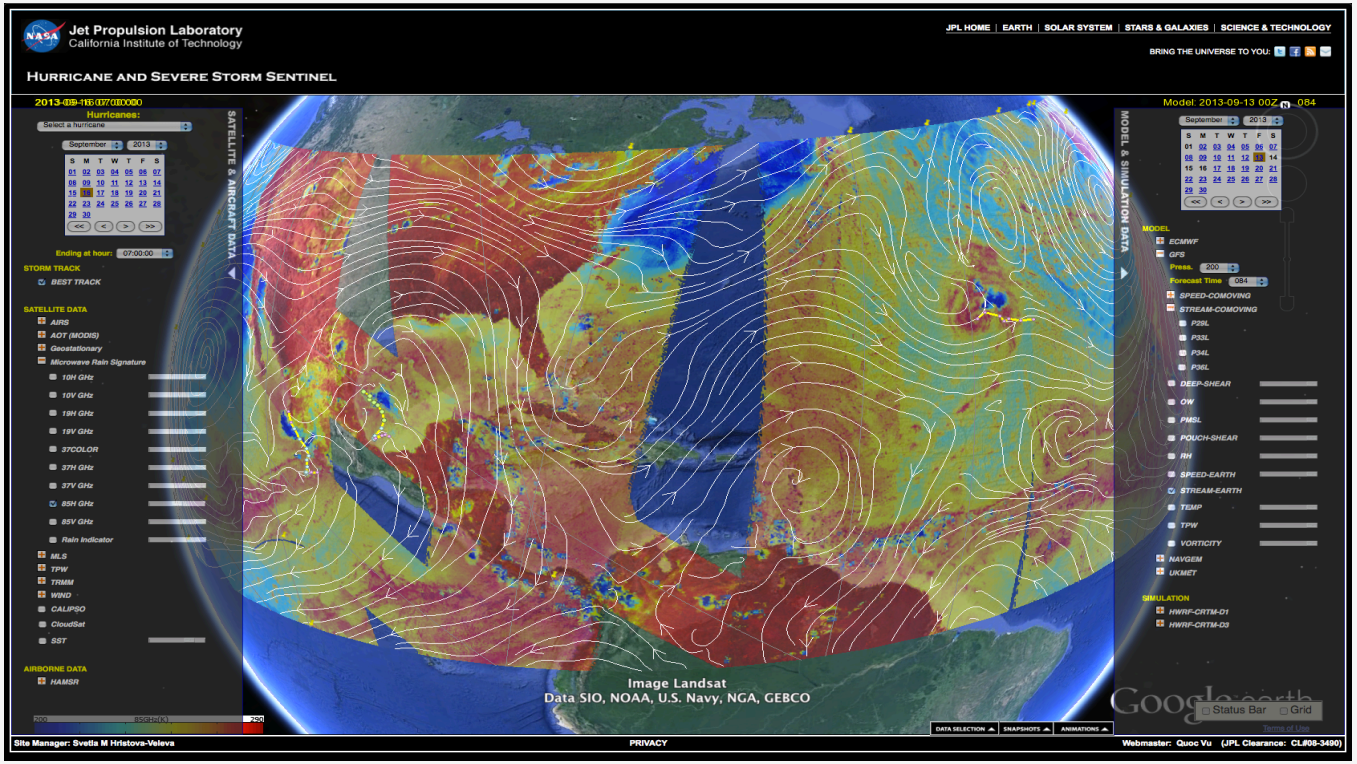
- Observations **- Model data**



Analysis Tools **Save a view** **Overlay Grid** **Find lat/lon of a point**

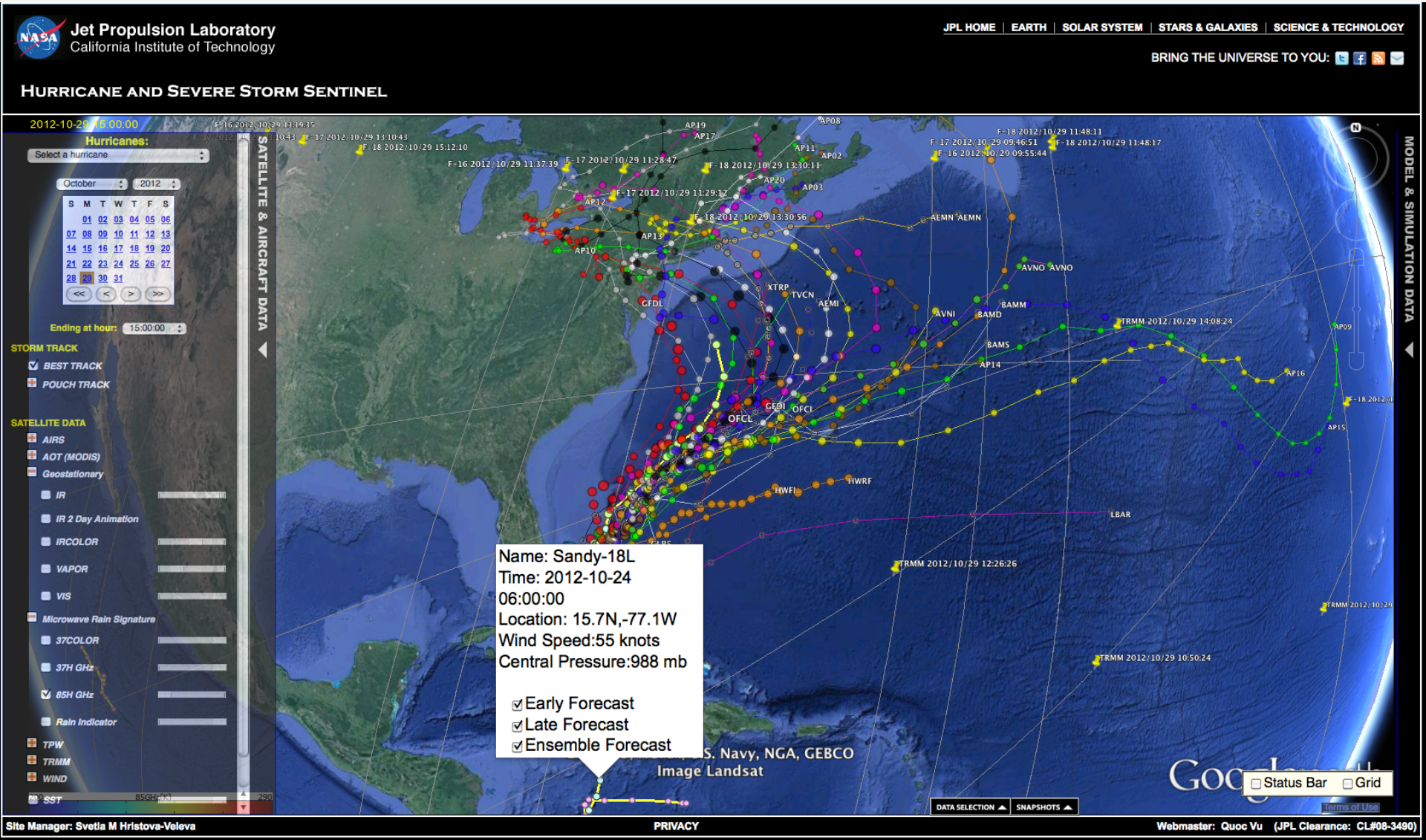
1. Develop Visualization to Enable Analysis:
A. Database Driven and Configurable Web Portal

- **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)

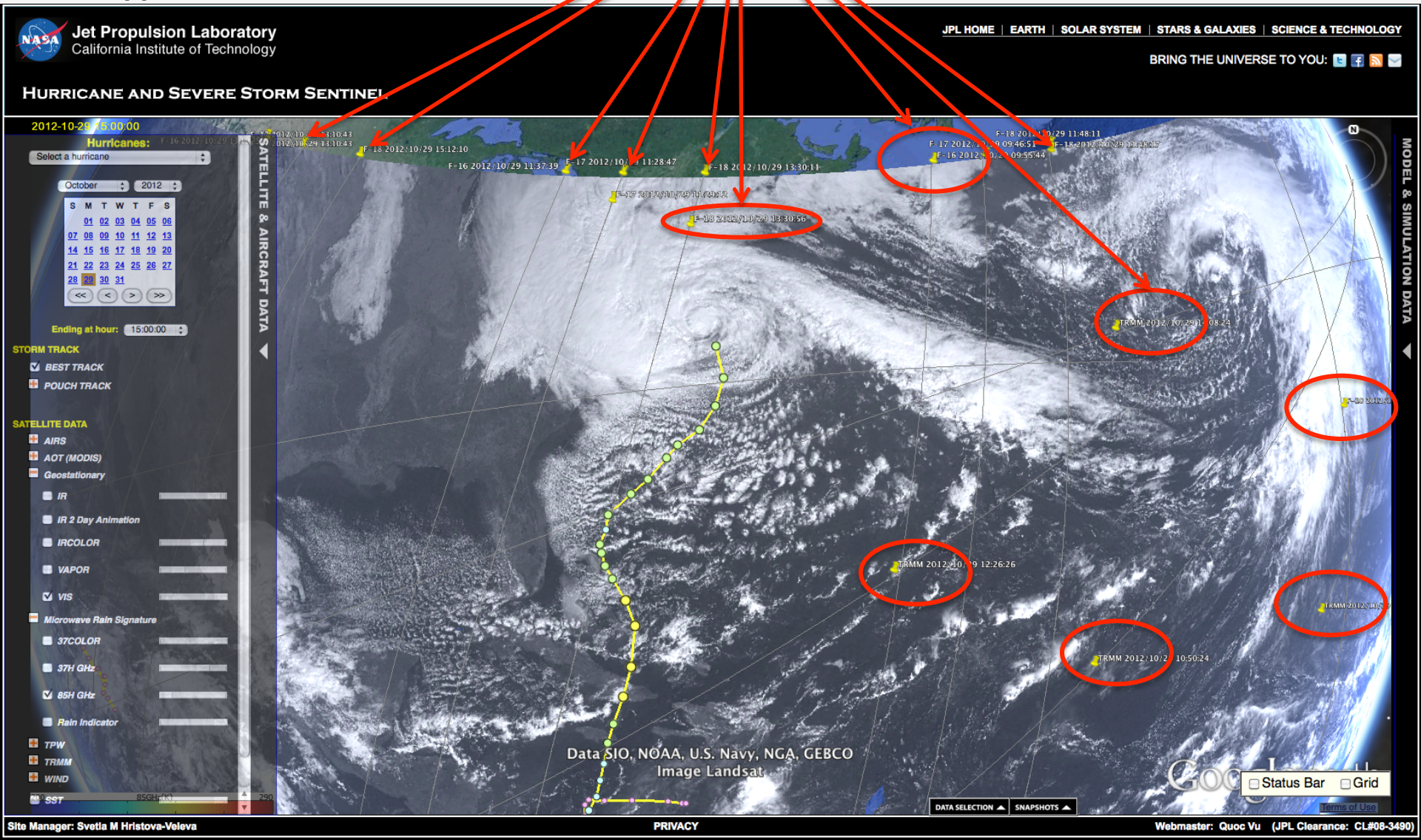
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
Forecast Uncertainty 5 days out - Hurricane Sandy (2012)



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

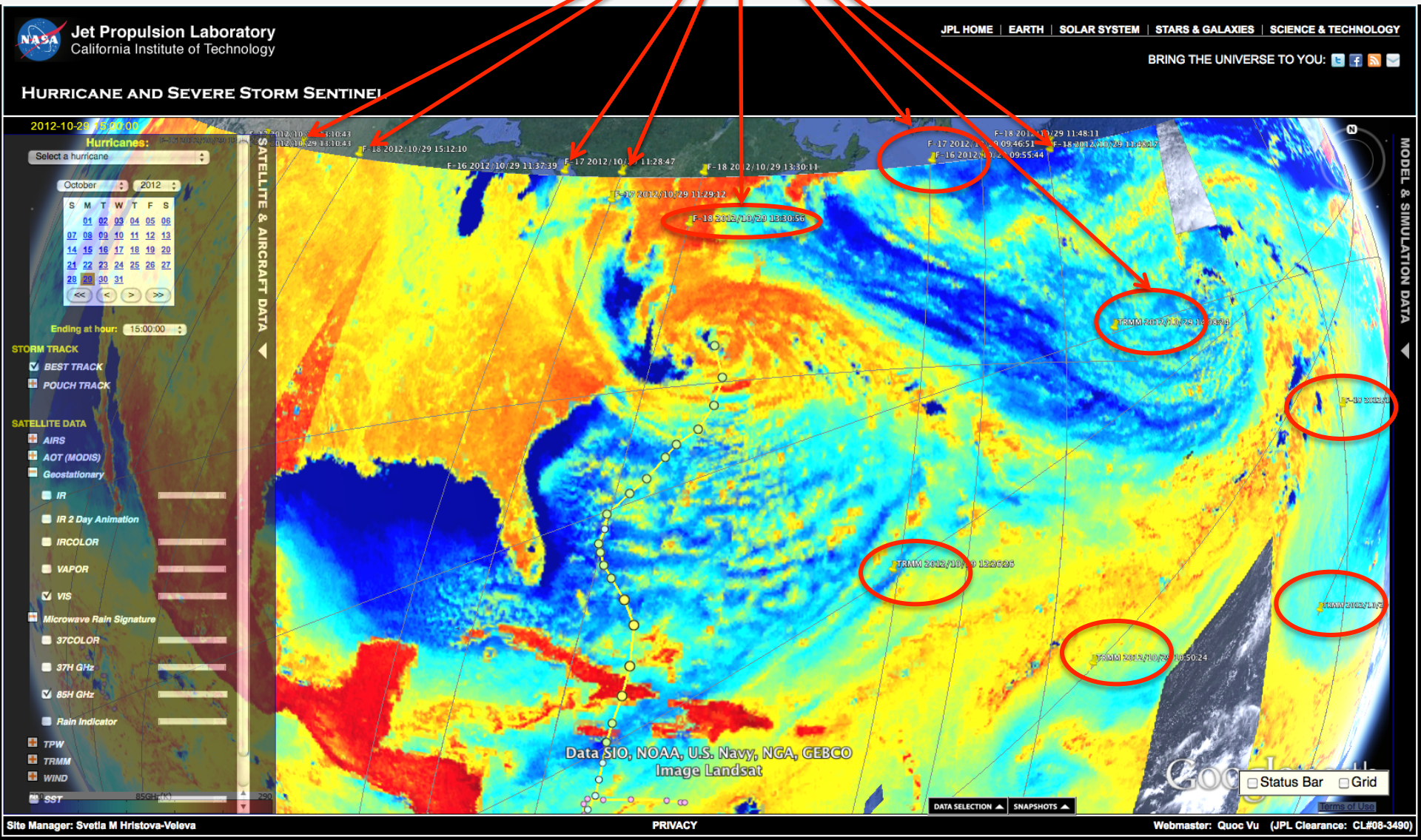
The Power of the Satellite Observations – Hurricane Sandy (2012)

Note the multitude of Polar Orbiting Satellites that supplement GEOS observations

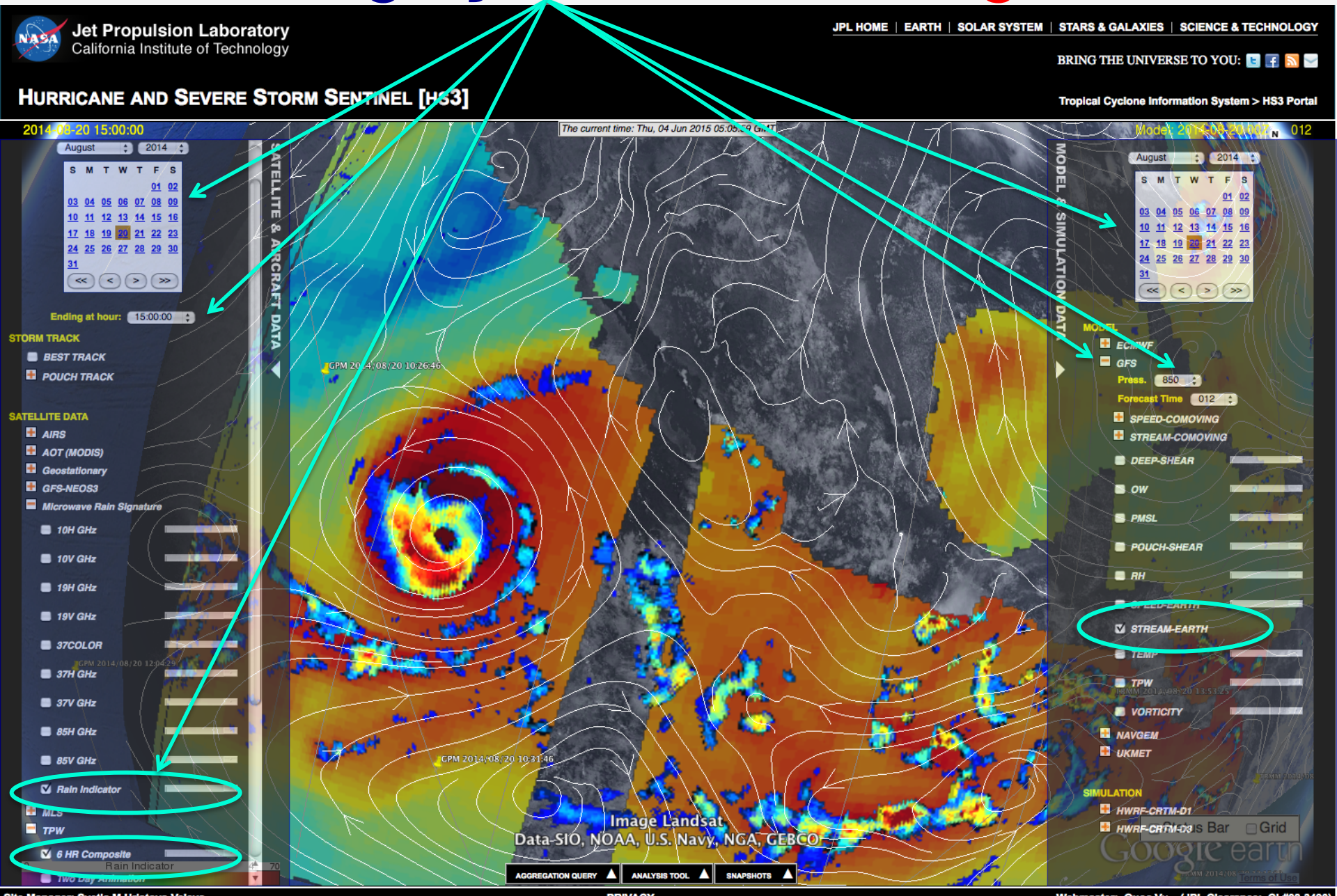


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

The Power of the Satellite Observations – painted in microwave

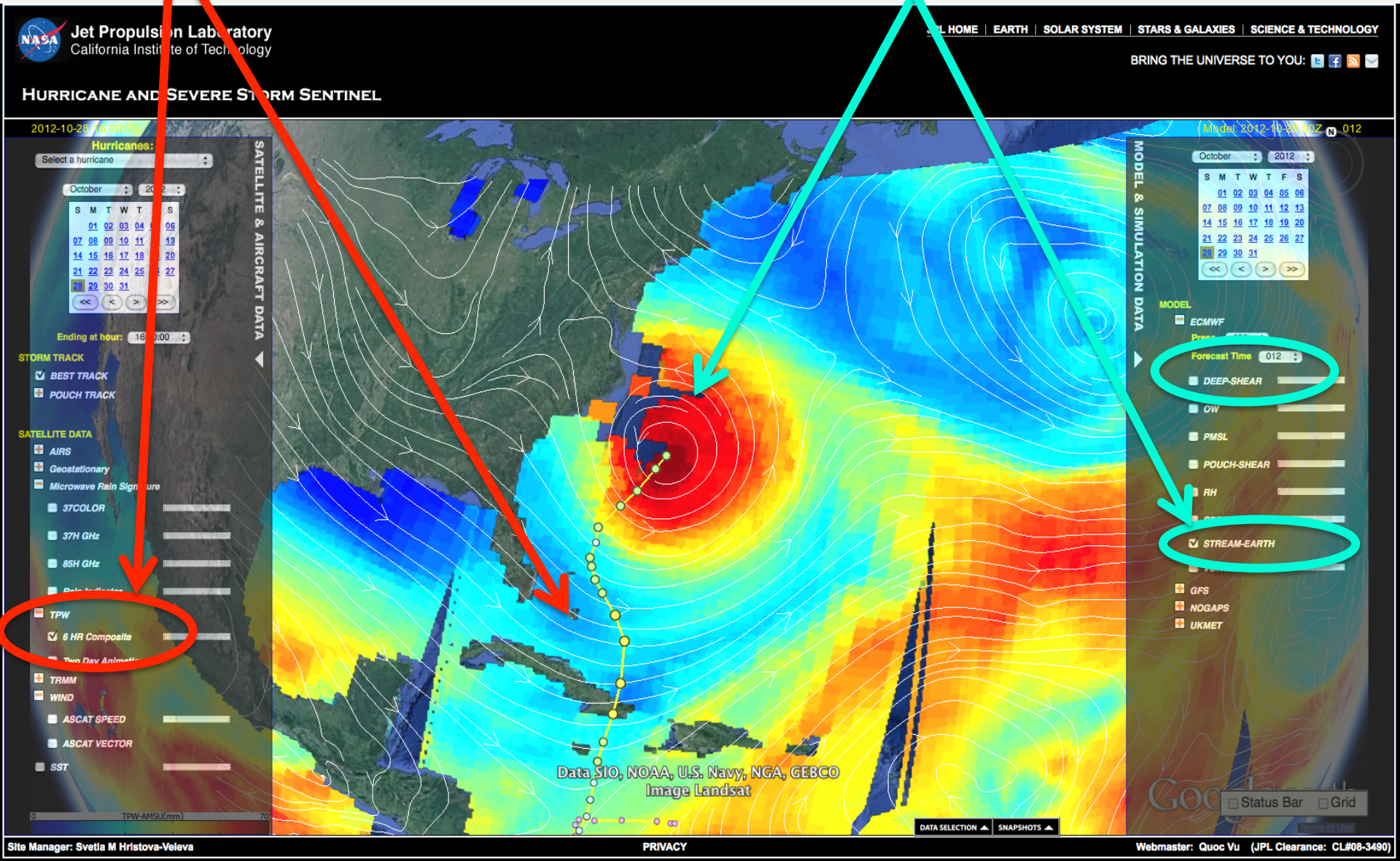


Driving by desire: Interrogate!

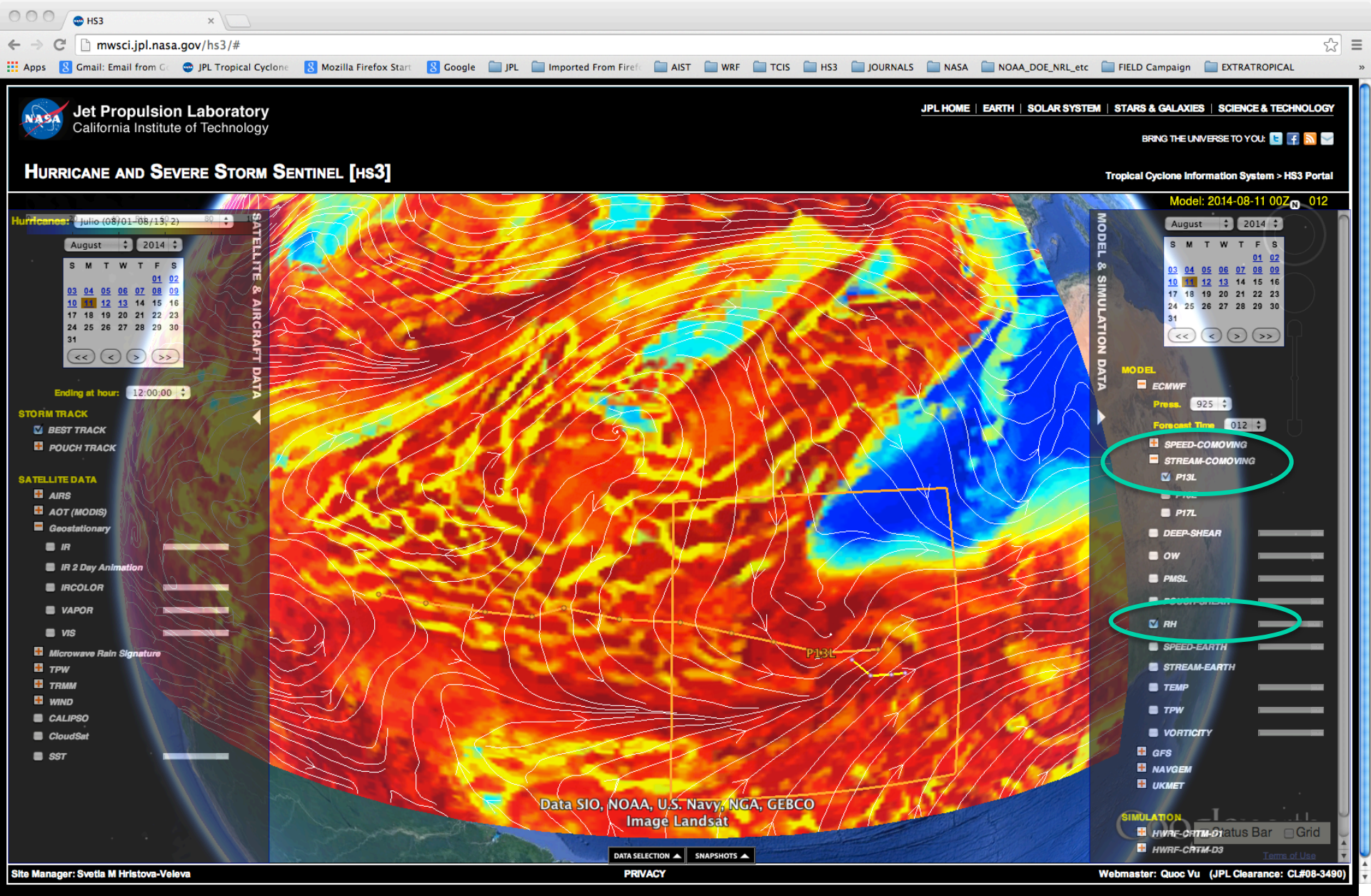


Driving by desire: Investigate and Discover

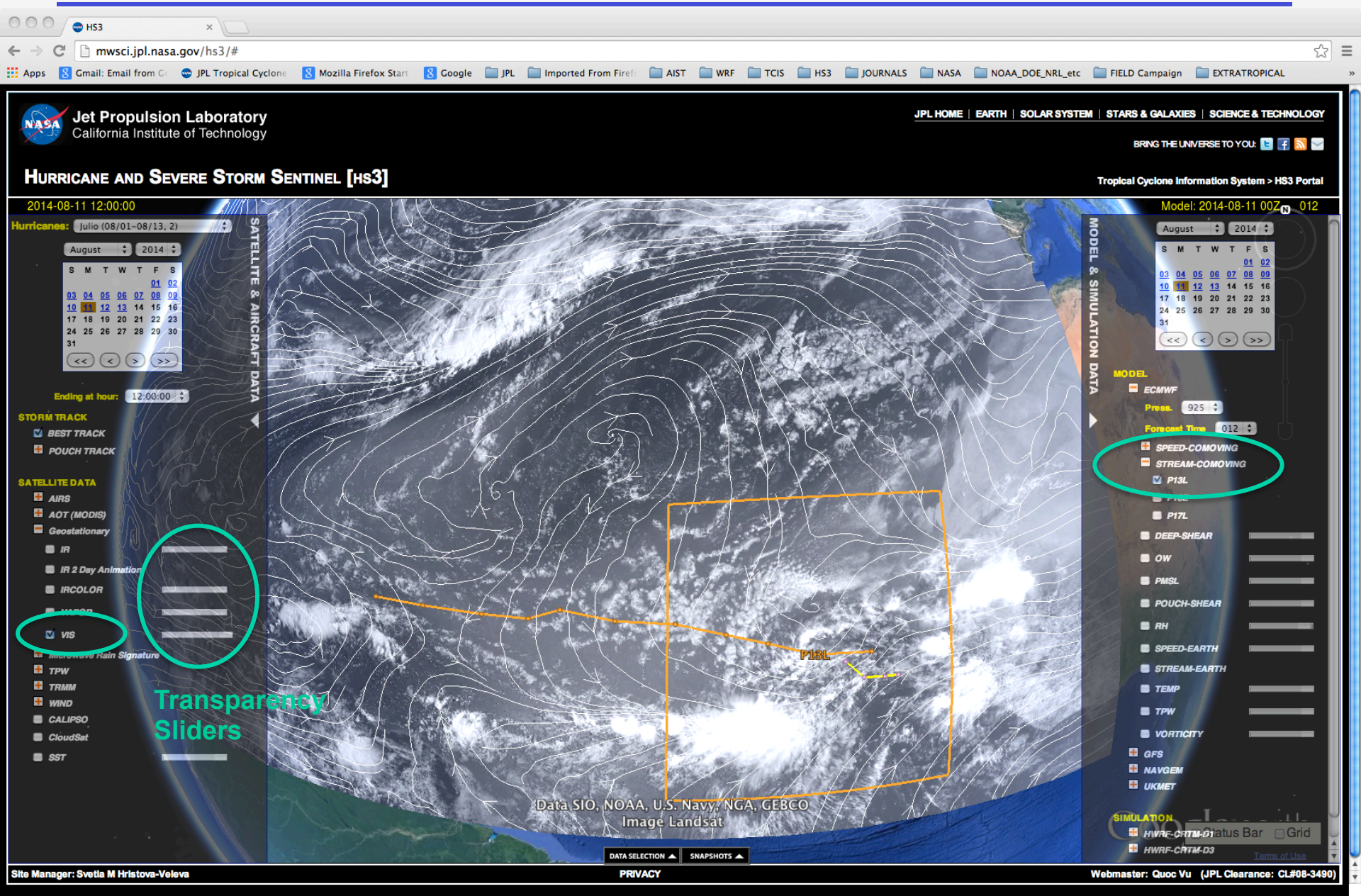
- Is the dry air in the environment (satellite, low TPW) entering the storm ???
- It does not appear so looking at the midlevel flow from the model.



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



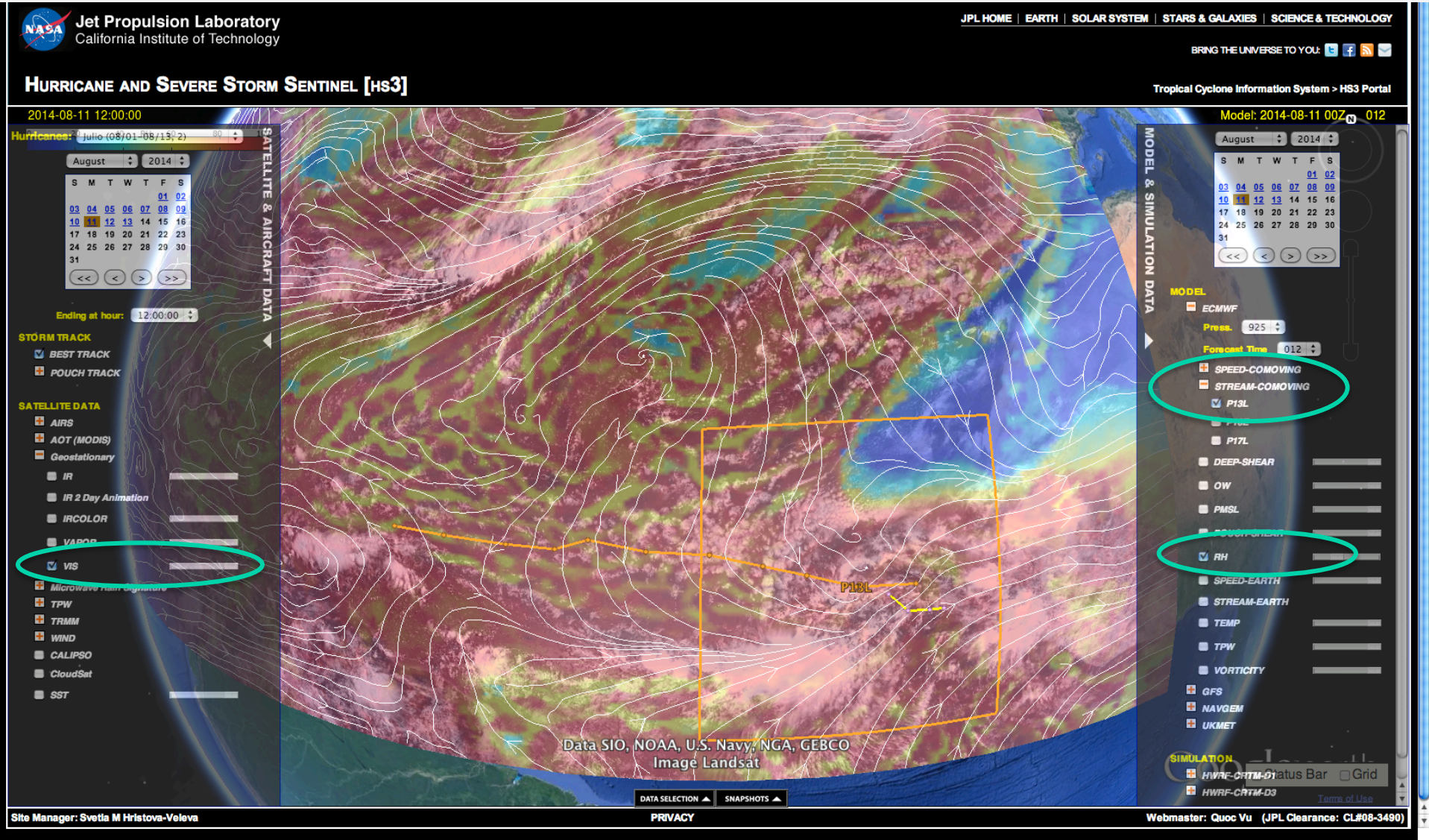
Understanding what is this structure in the model – Tim Dunkerton called it "leopard's fur" pattern in ecmwf RH in the boundary layer



Understanding what is this structure in the model?

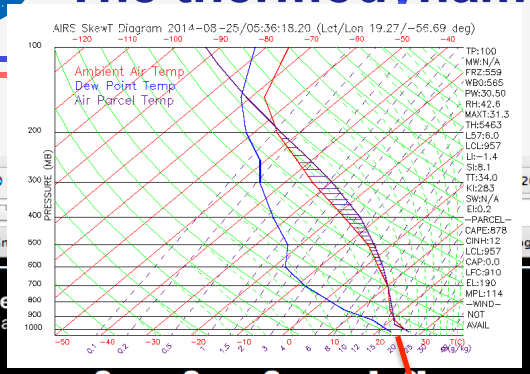
Tim Dunkerton called it "leopard's fur" pattern in ECMWF boundary layer RH

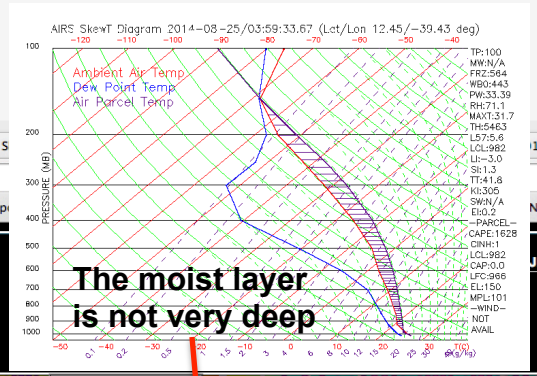
The model/obs overlay collaborates his suggestion that “shallow overturning circulations are responsible for vorticity and RH anomalies alike in these regions”. The Sc in the visible imagery are well correlated with the model's RH and vorticity fields (not shown).



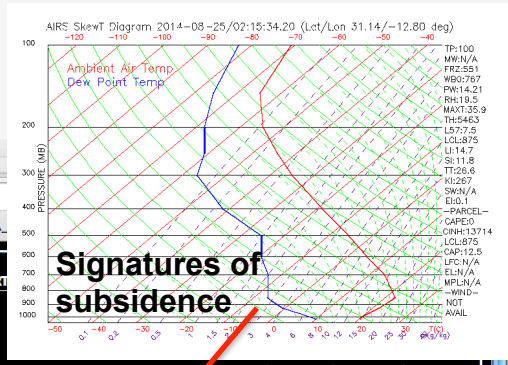
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

The thermodynamics from AIRS





The moist layer is not very deep



Signatures of subsidence

HURRICANE AND SEVERE STORM SENTINEL [HS3]

Tropical Cyclone Information System > HS3 Portal

2014-08-25 08:00:00

The current time:

Model: 2014-08-25 00Z + 012

SATELLITE & AIRCRAFT DATA

MODEL & SIMULATION DATA

2014-08-25/05:36:18.20

(-56.690, 19.270)

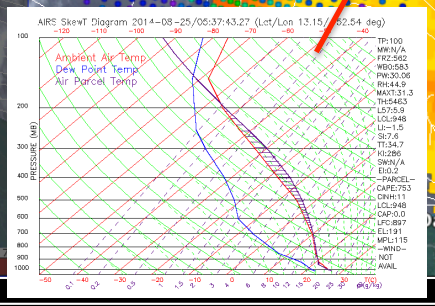
CAPE:878

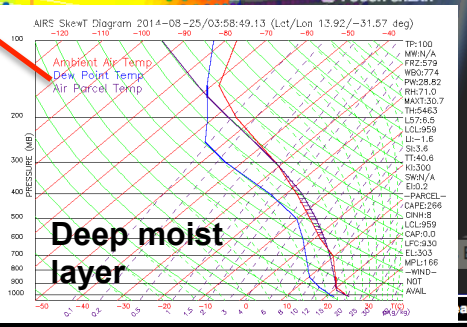
SkewT Plot

P21L

Image Landsat

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



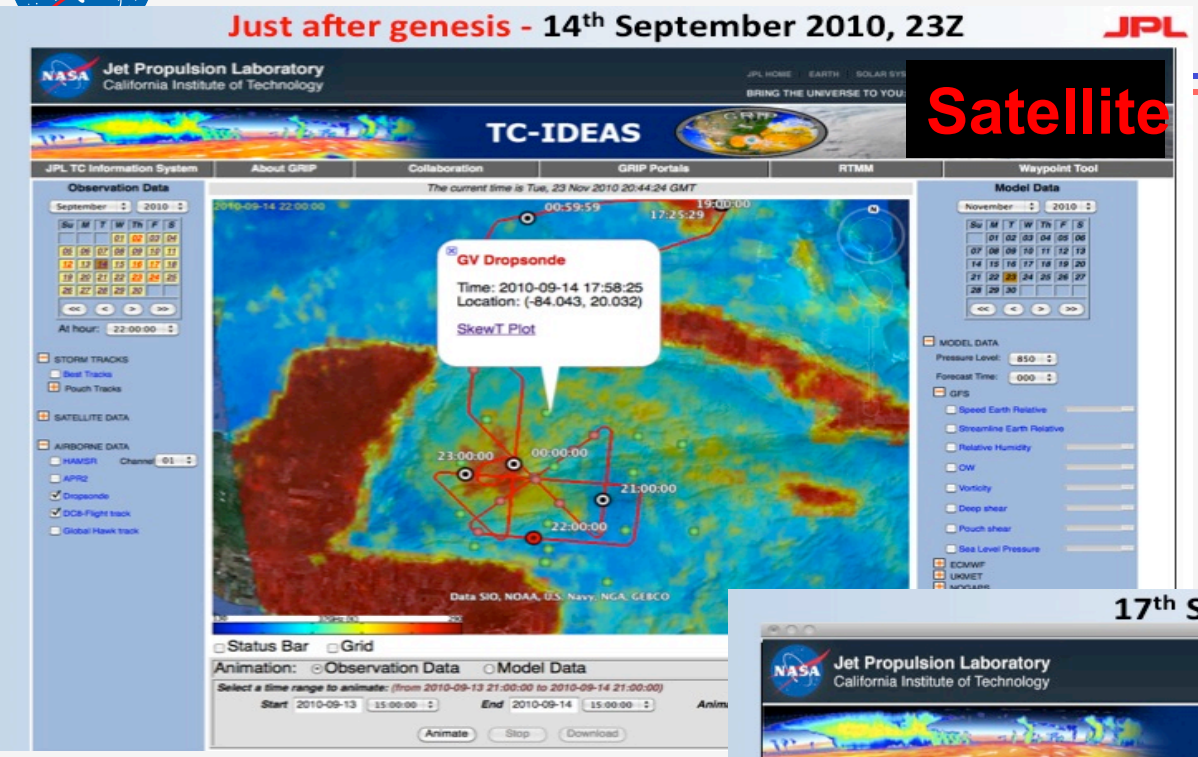


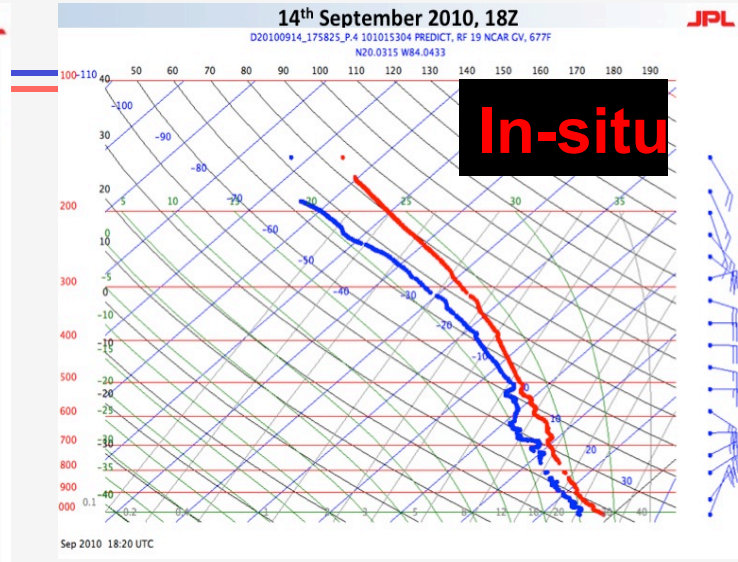
Deep moist layer

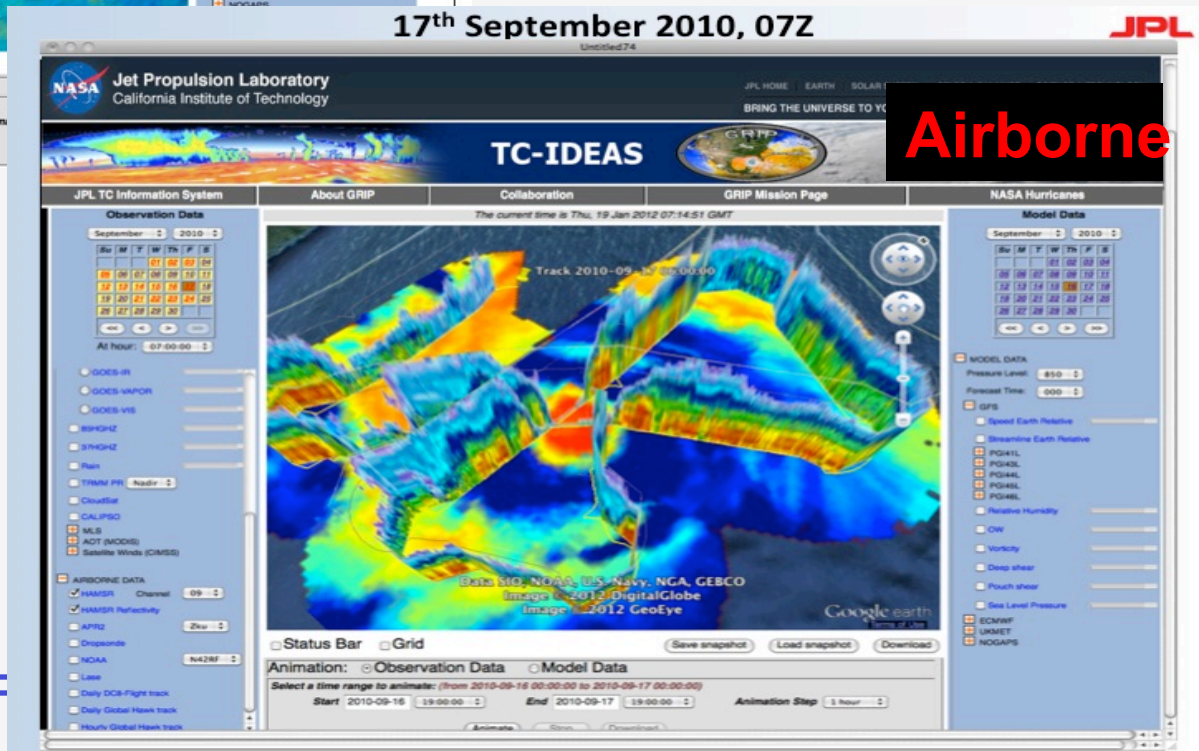
Site Manager: Svetia M Hristova-Veleva

PRIVACY

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







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**

NEOS³ : Purpose

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

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

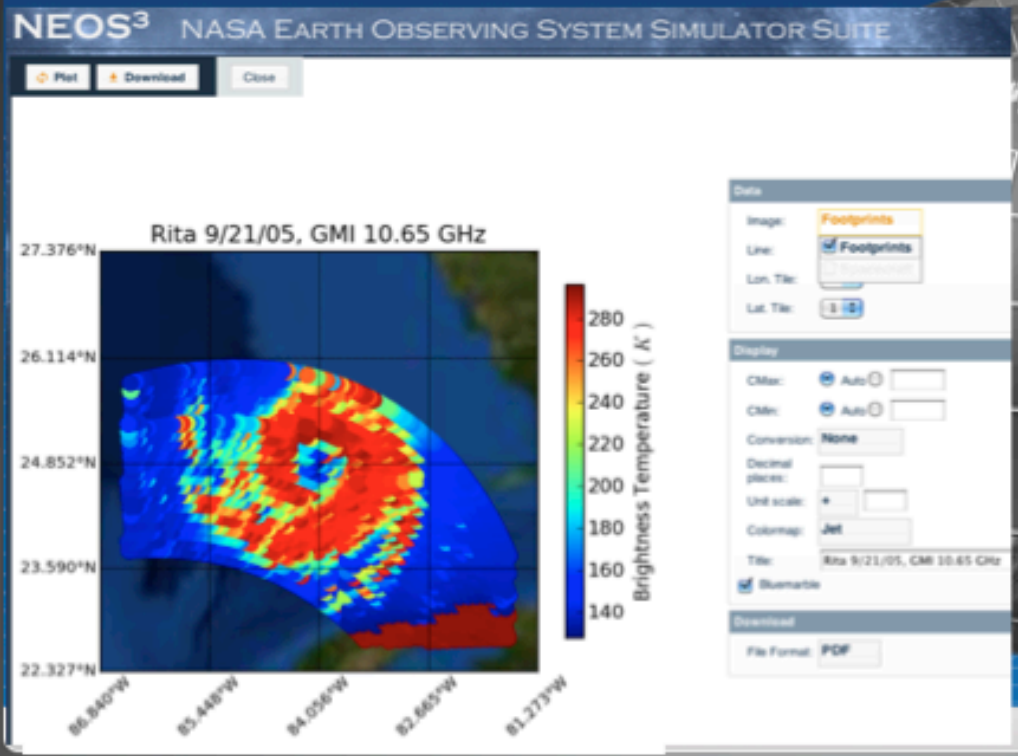
"Flying the satellite over the model fields"

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

NEOS³

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

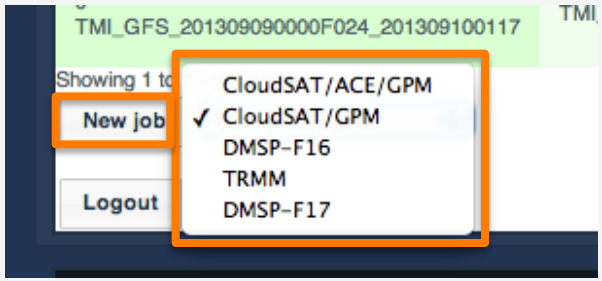
ESTO

2. Projecting the model into the Observational space: *A. Specific NEOS³ Upgrades for TCIS*

- Three functionalities have been added to NEOS³ 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 NEOS³ Integration

- Worked with NEOS³ 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

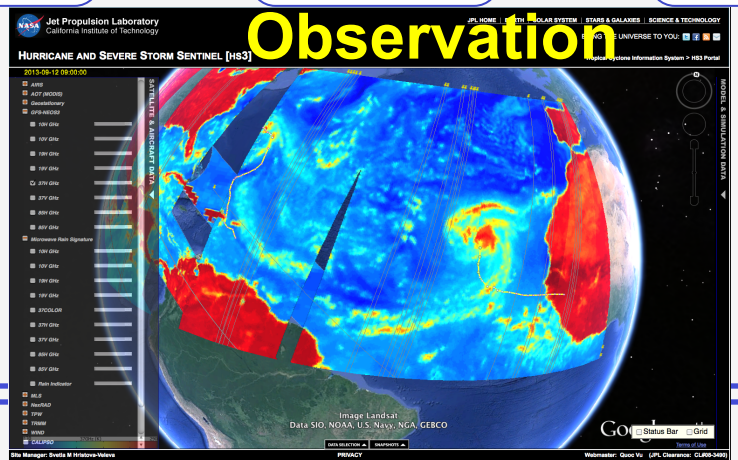
Job Setup [TCIS]
- Request API authentication token
- Create the parent job on the NEOS³ server
- Select the proper XML template for the satellite that gives the list of available sensors

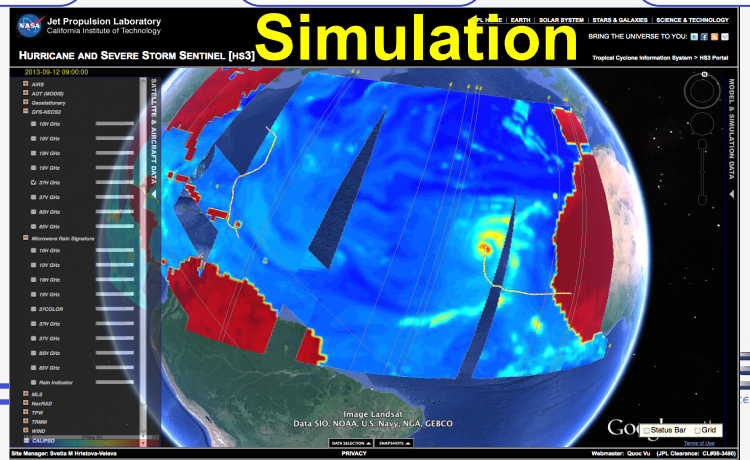
Job Definition [TCIS]
- Find date/time of satellite storm overpasses
- Calculate the model and forecast dates/ times for each observation
- Search for and select the model files
- Send the XML template token to the NEOS³ server

Job Execution [NEOS³]
- For each XML template token, start the child processing job
- Provide status updates through various processing stages

Job Retrieval [TCIS]
- From the TCIS server, poll the NEOS³ server every hour for child job status
- When status is 'finished,' download the netCDF file from the NEOS³ server to the TCIS server
- Delete the completed child job from the NEOS³ server

Job Analysis [TCIS]
- Generate 6-hour composite maps for each simulated product
- Update the database with information on new products to display maps on the portal
- Insert data from the netCDF file into the database for use in the analysis tool

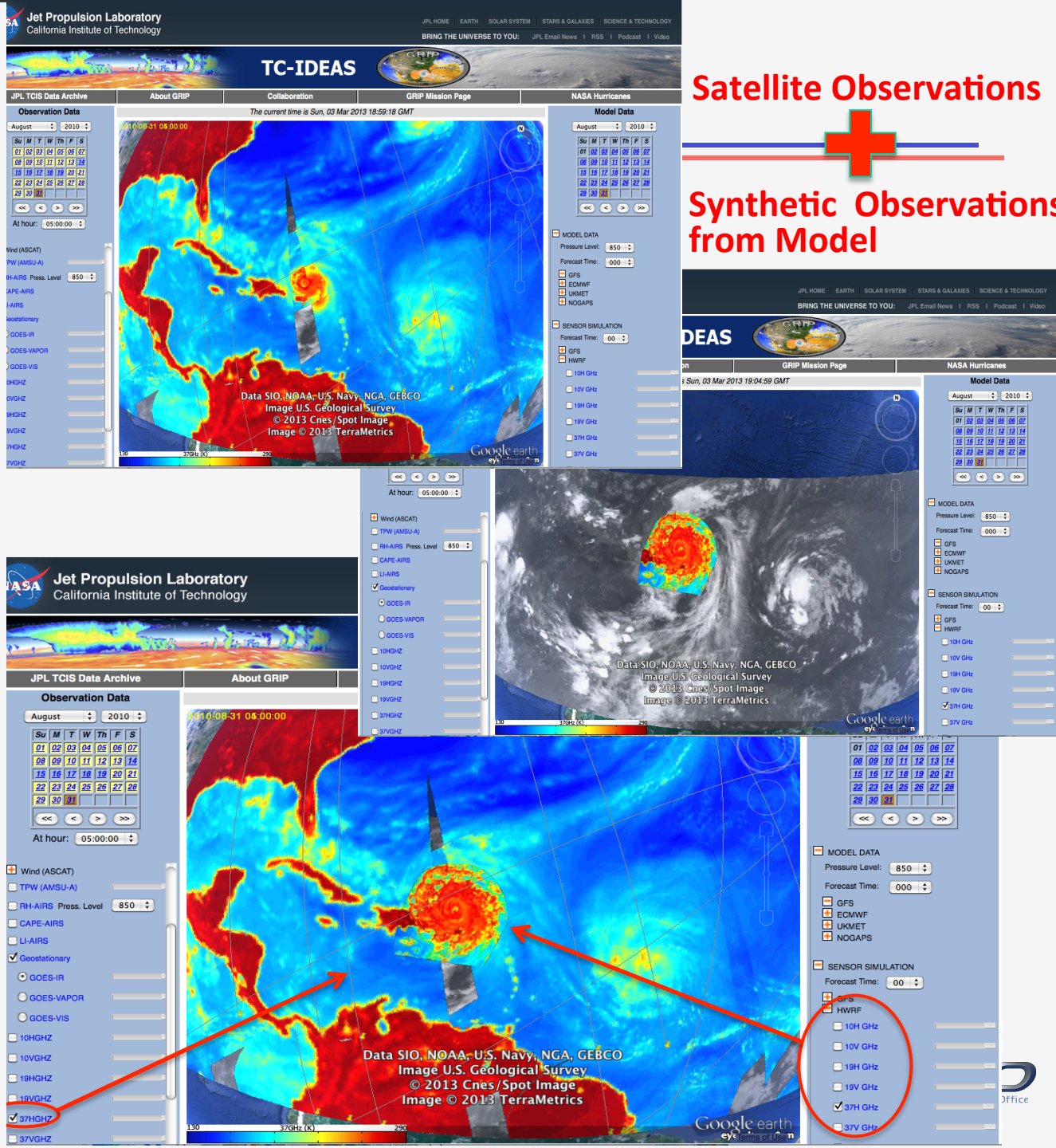




FUSION OF MODELS AND OBSERVATIONS

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^3**
  - 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 !**



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

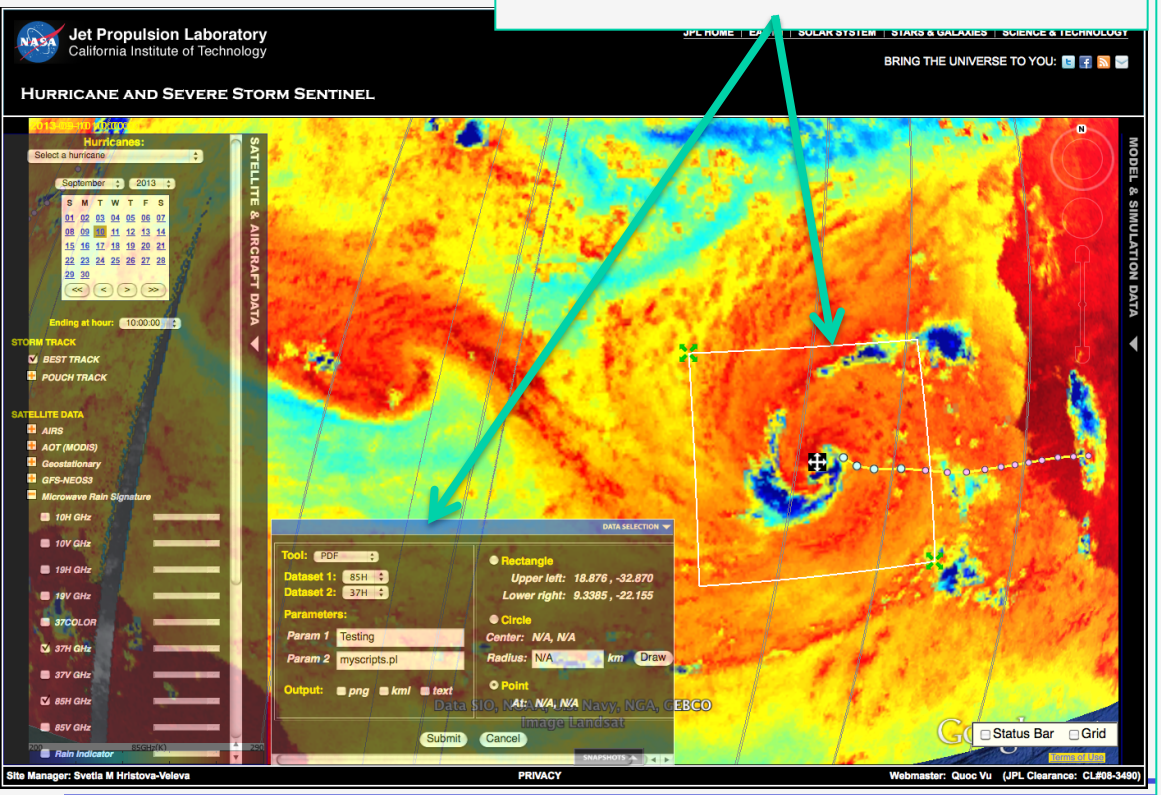
3. Developing analysis tools with the goals to:
   - Understand the observed structure of the hurricanes
   - Evaluate the models

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

1. Select the region of interest
2. Select the tool (e.g. PDF)
3. Specify the details
4. Submit the job …

The Subsetting Tool

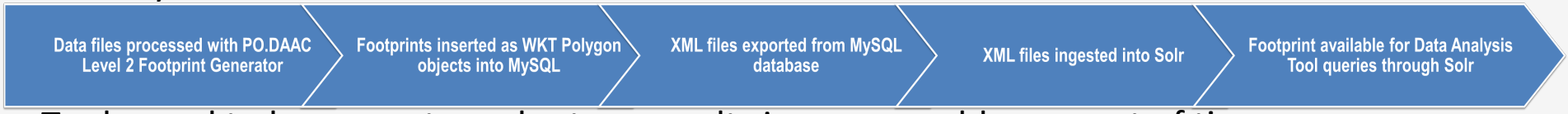


The Framework

- **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)**

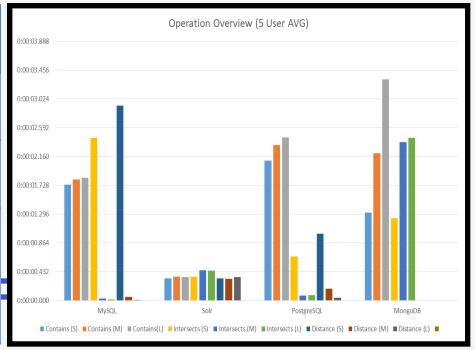
3. On-line Analysis Tools:
B. Geospatial Data Searches – the database

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



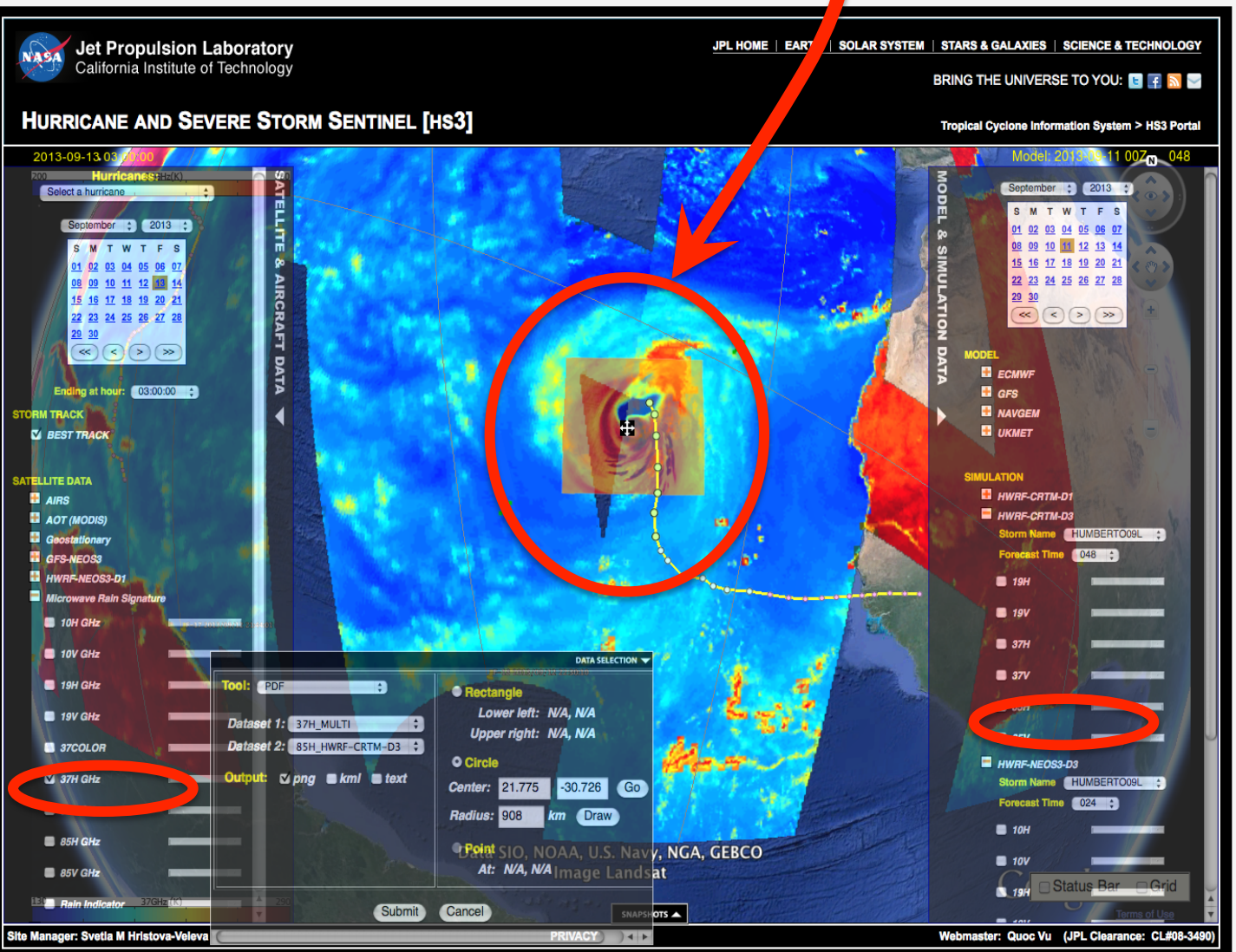
- Tools need to be accurate and return results in a reasonable amount of time
  - Integrated the PO.DAAC Level 2 Footprint Generator into the TCIS to create accurate swath representations for the database
  - Conducted database benchmarking studies to see which database's geospatial search functions consistently returned results the fastest
  - Fine tuned the accuracy and speed options with the L2 Footprint Generator and databases
- Implemented a MySQL + Solr geospatial database solution that
  - quickly and accurately returns results to the TCIS Analysis tools,
  - lessening user wait time and increasing user confidence in analysis tool results

	Entries	Disk Space (GB)	Memory (GB)	Data Length (GB)	Index Length (GB)
MySQL	2108505	1.40	0.00	1.11	0.29
Solr	2108505	2.10	1.20	2.1	N/A
PostgreSQL	2108505	2.50	0.00	1.27	1.10
MongoDB	2106886	78.00	78.00	2.93	77.59



Driving by desire: Evaluate!

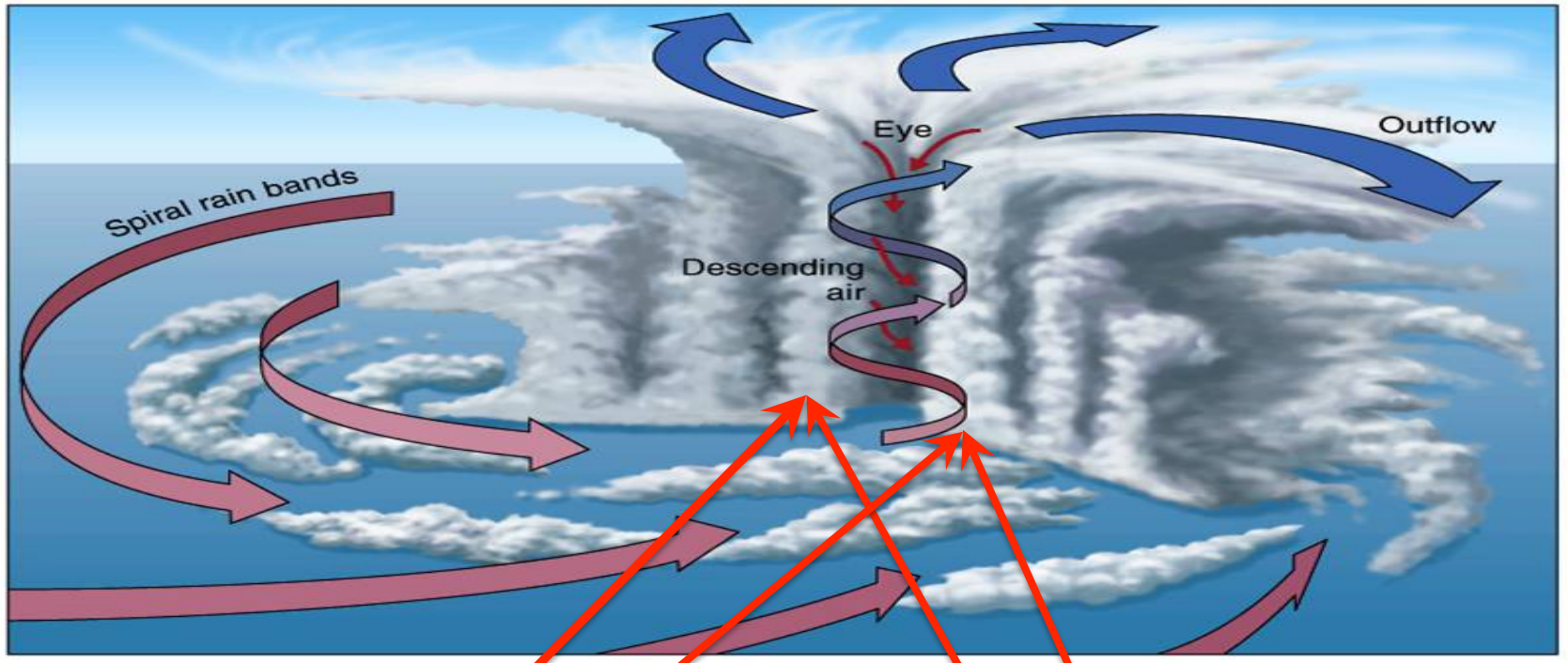
- Interactively select region
- Gather data from **observed** and **synthetic** brightness temperature



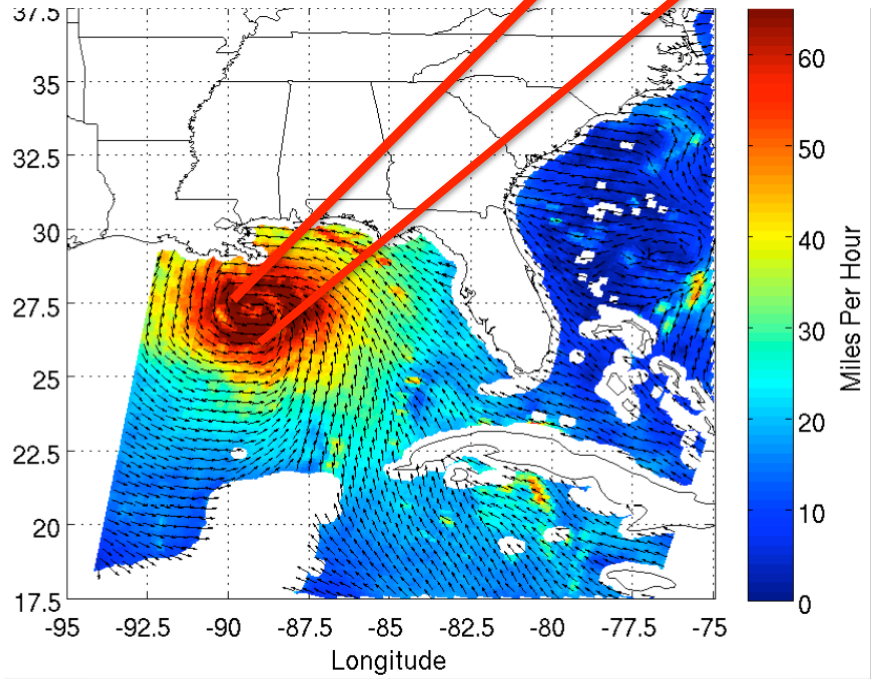
- **PERFORM:**

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

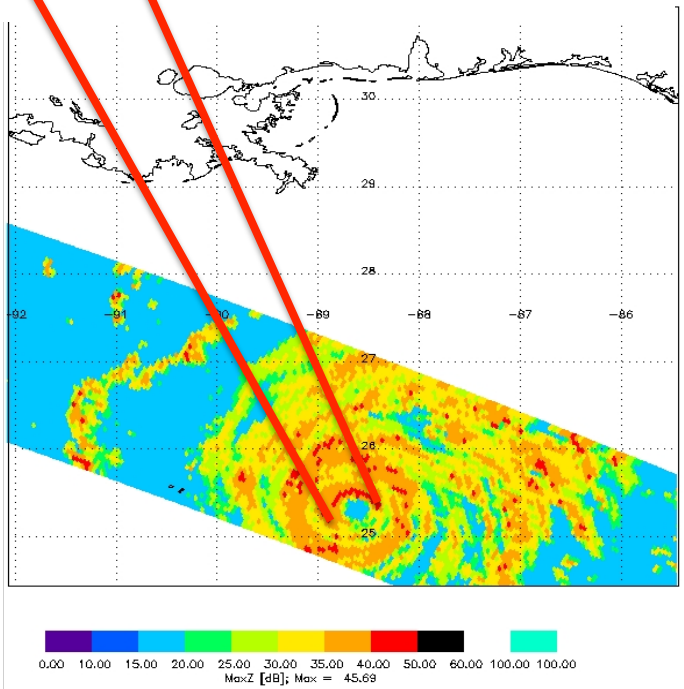
Studying hurricanes



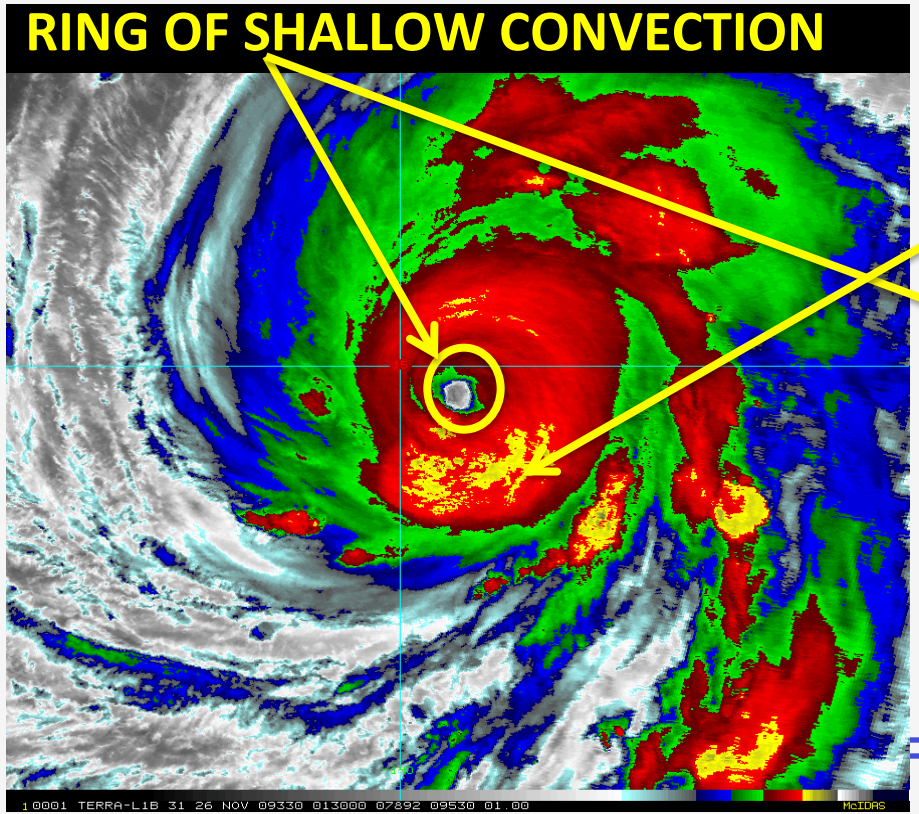
Katrina (2005) as seen from QuikSCAT

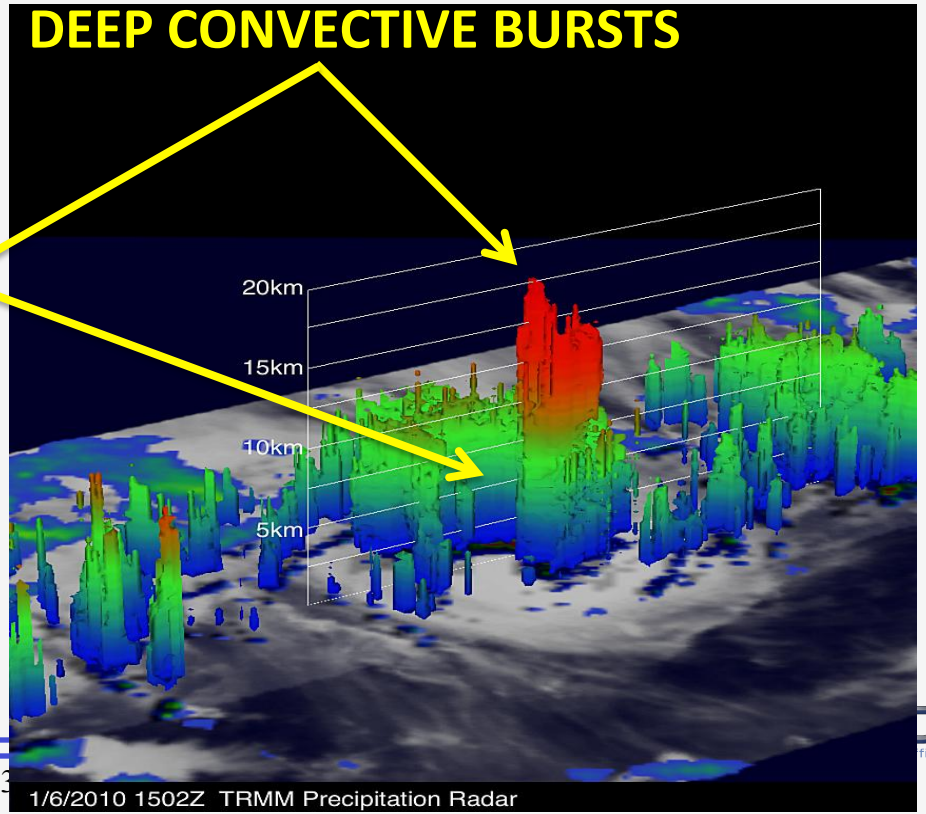


TRMM - max reflectivity



- 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.

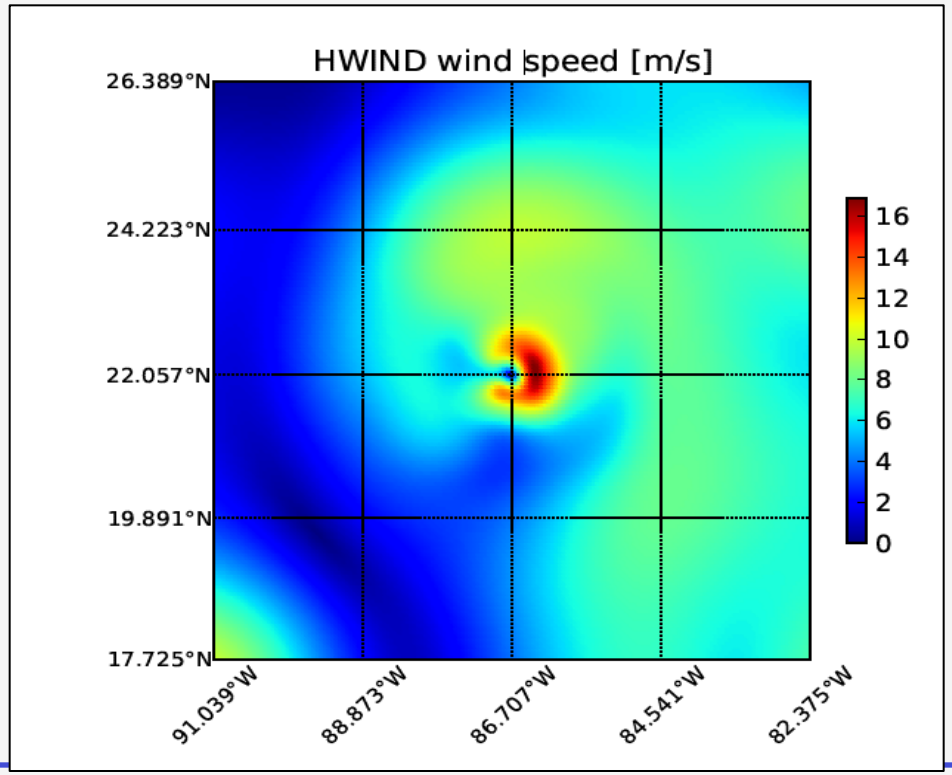


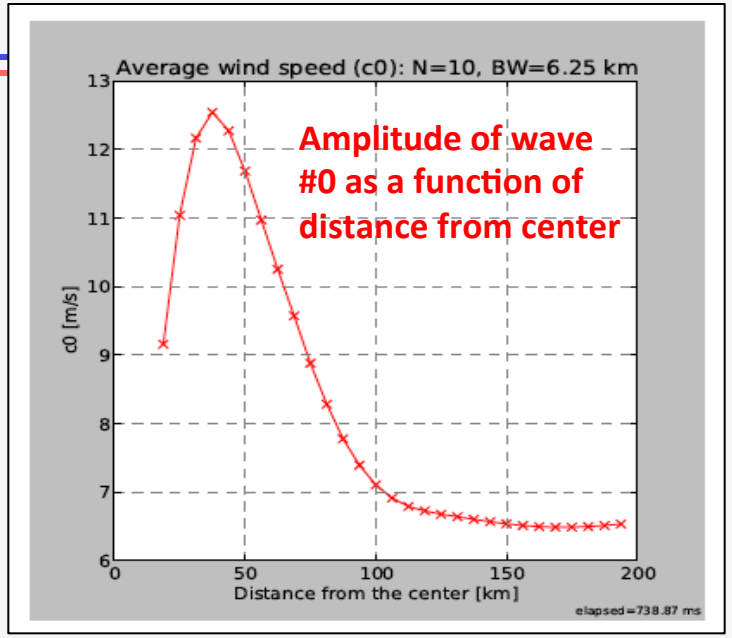


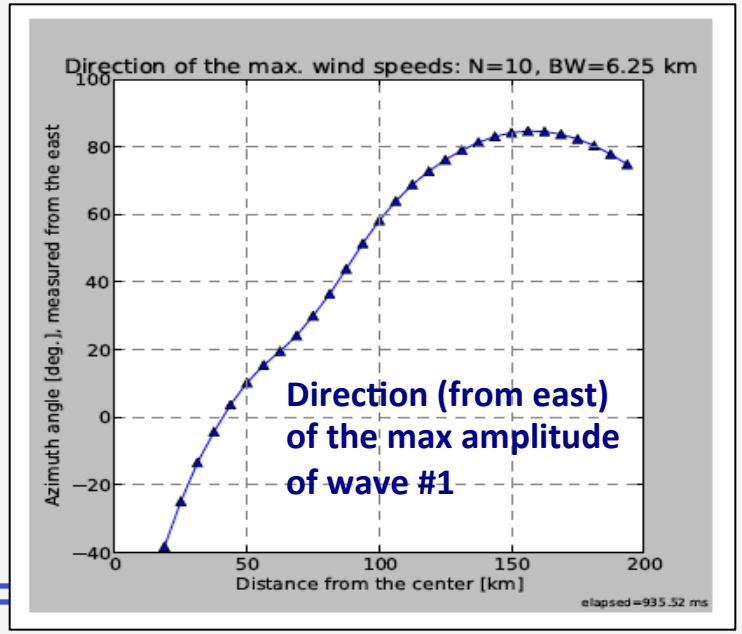
Storm structure Tool: Storm Size and Asymmetry

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







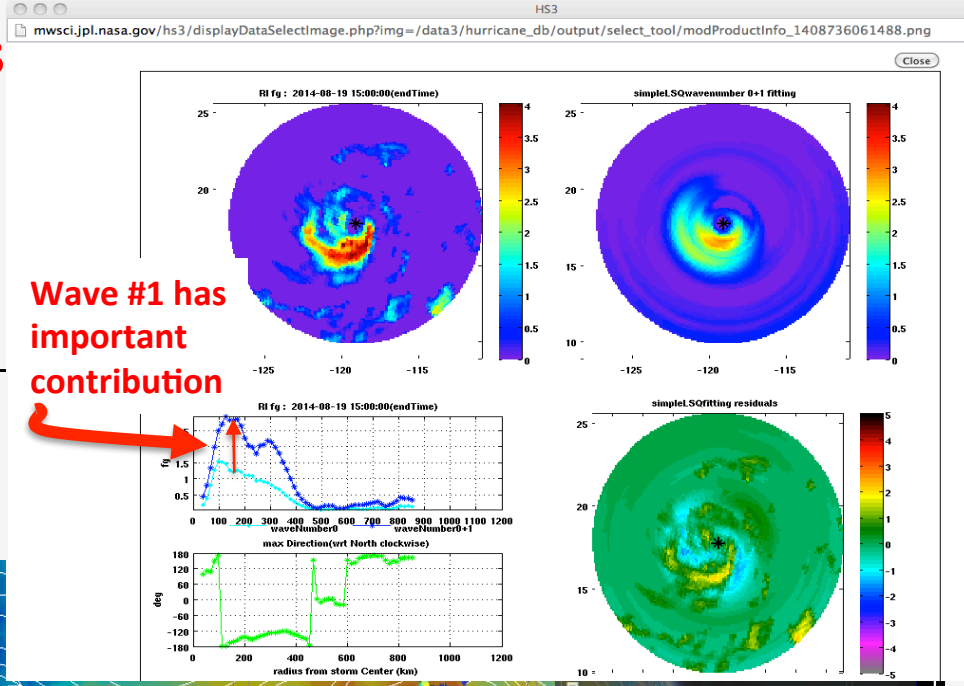
Storm structure Tool: Observations

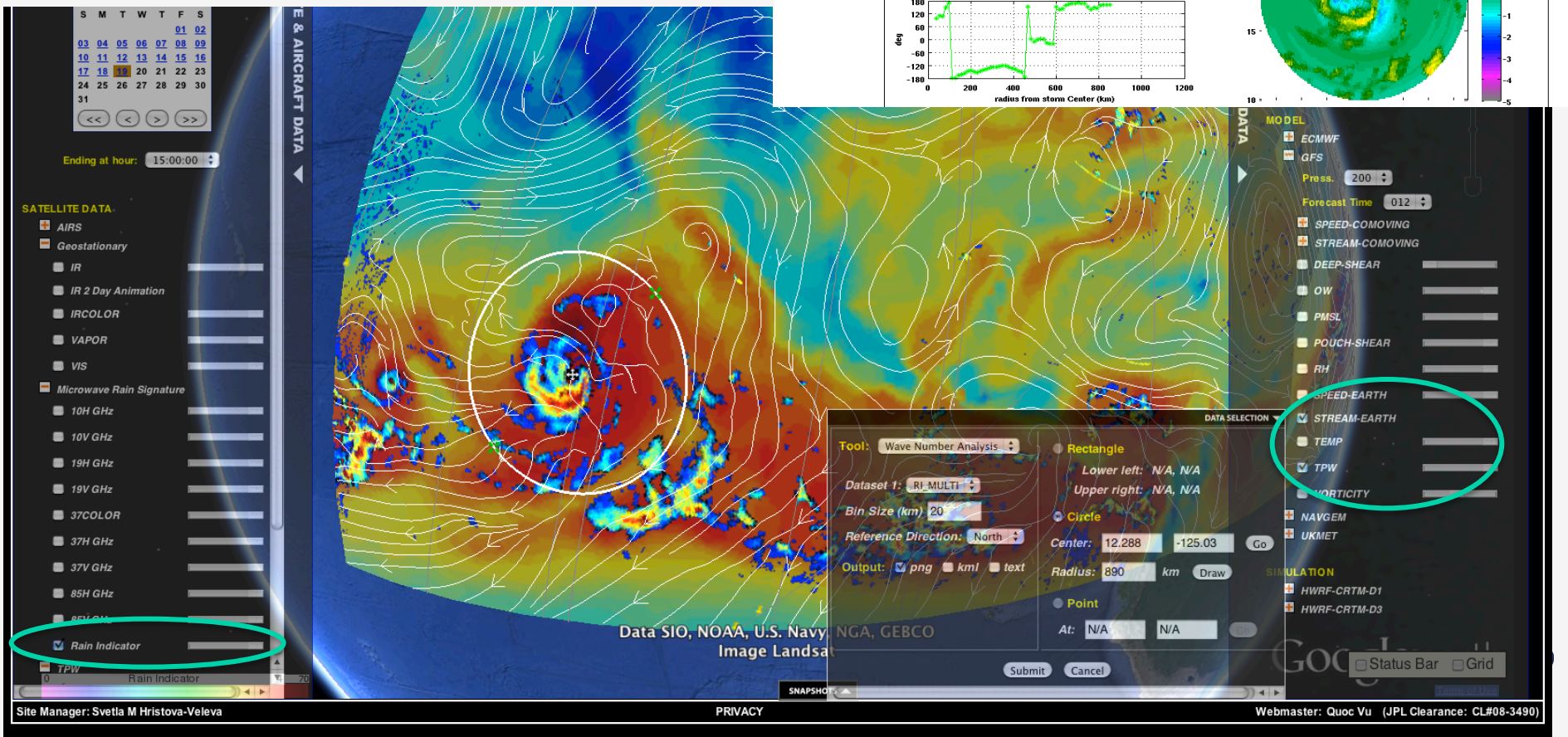
Storm Size and Asymmetry: The Evolution

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



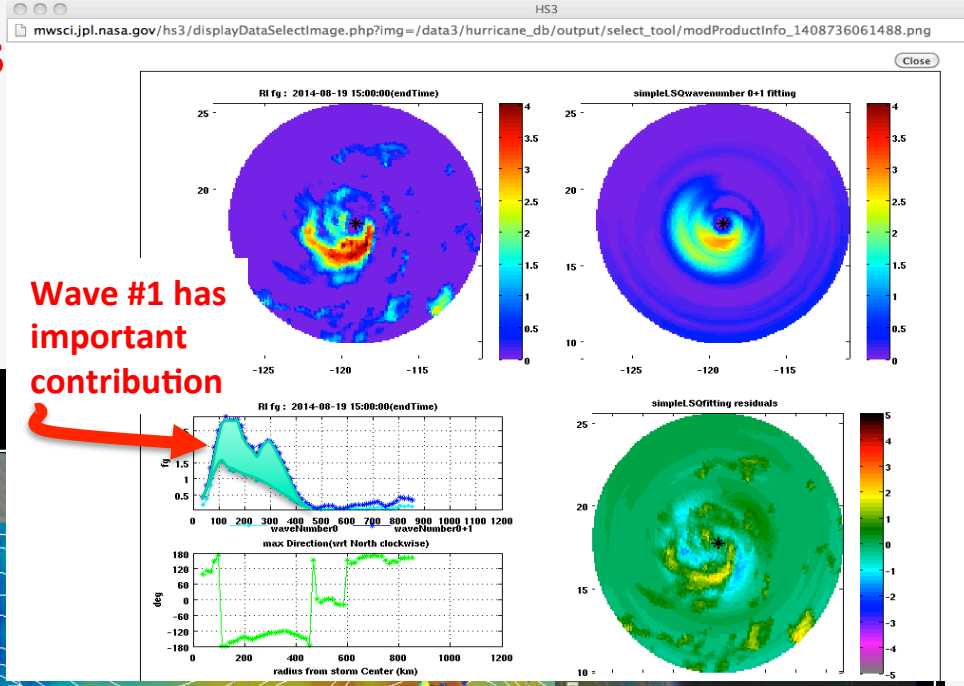


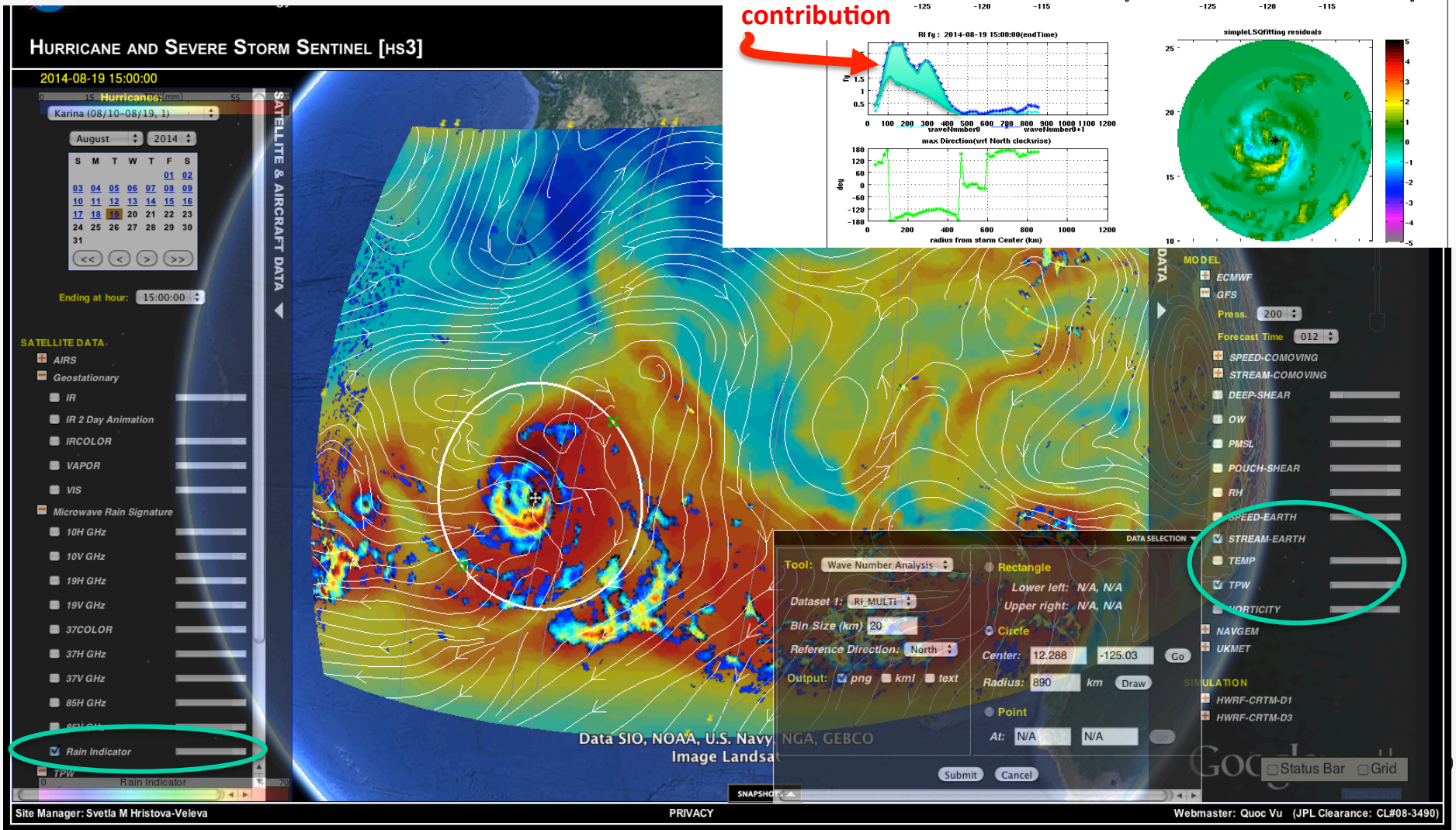
Storm structure Tool: Observations

Storm Size and Asymmetry: The Evolution

The Wave Number Analysis Tool using the Rain Index

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





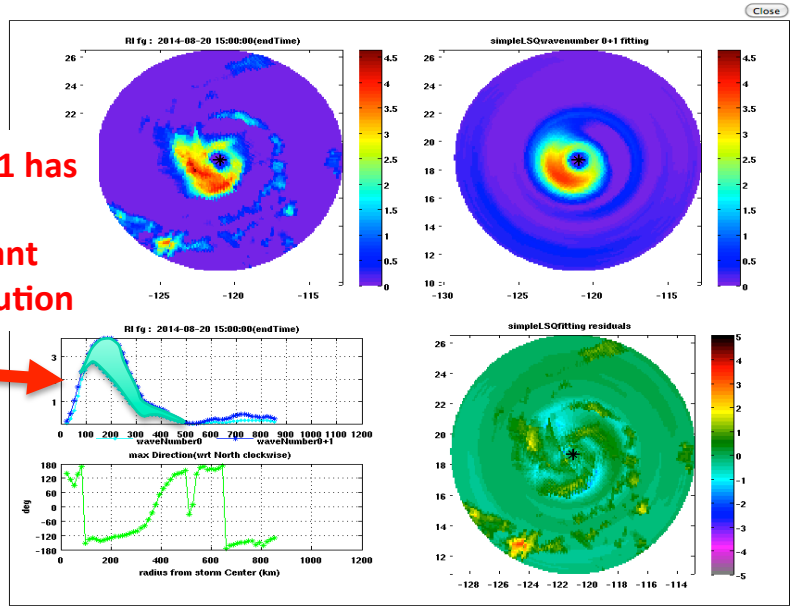
Storm structure Tool:

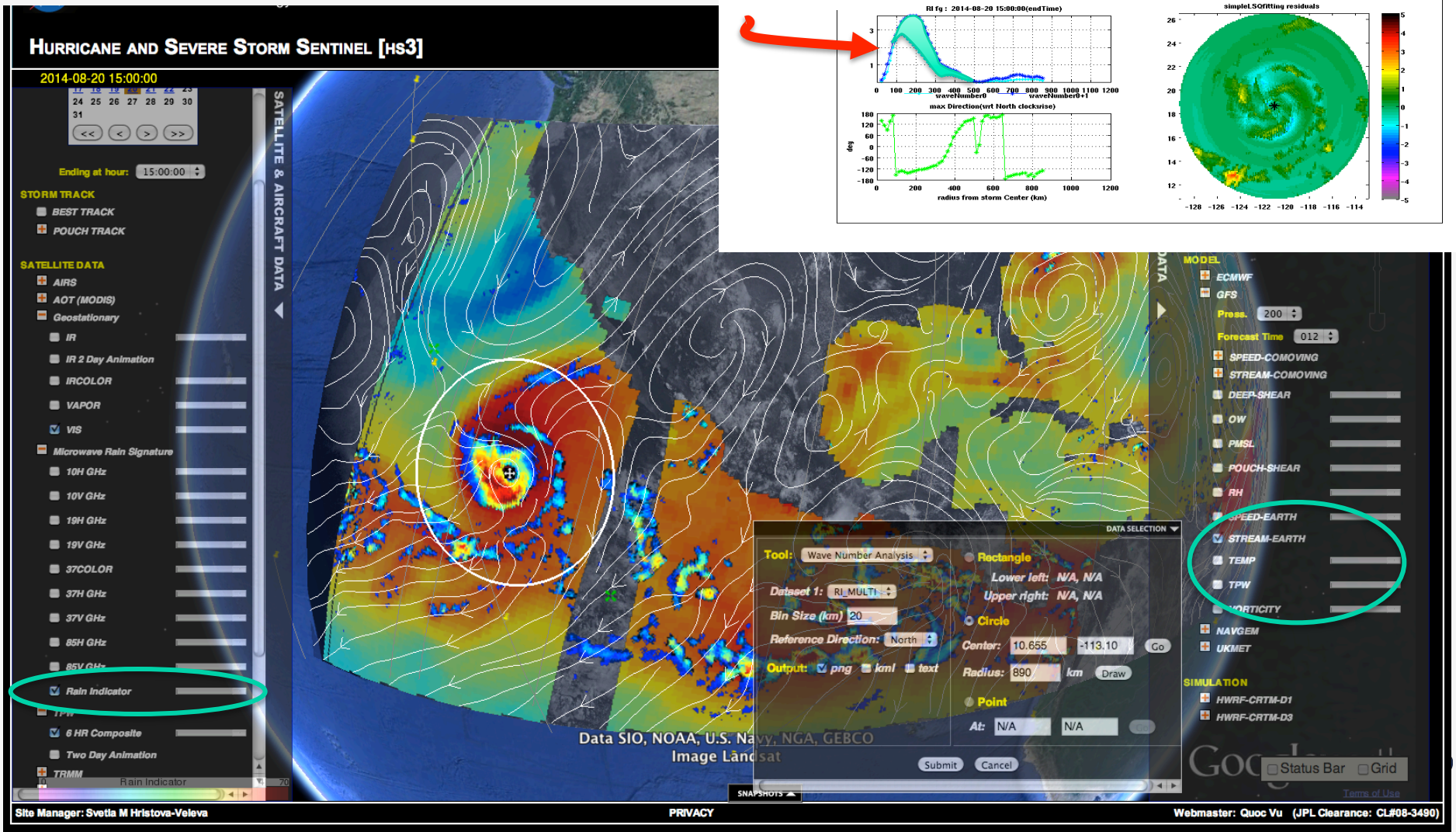
Storm Size and Asymmetry: The Evolution

The Wave Number Analysis Tool using the Rain Index

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

Wave #1 has LESS important contribution



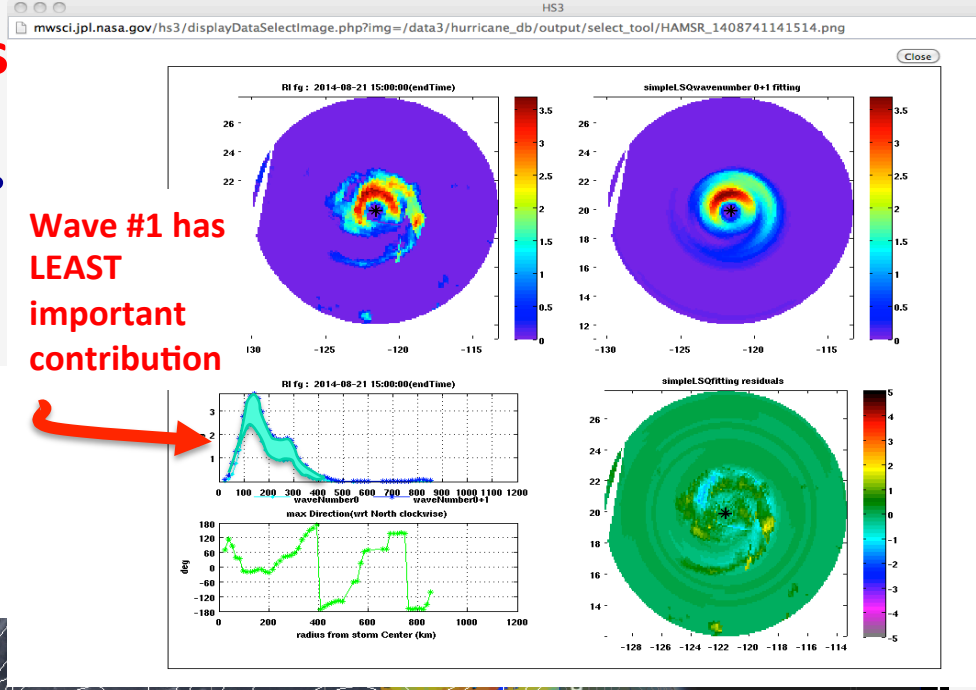


Storm structure Tool: Observations

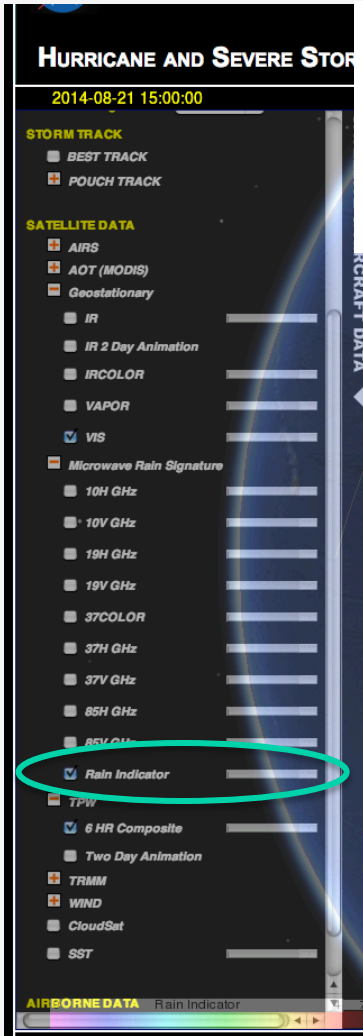
Storm Size and Asymmetry: The Evolution

The Wave Number Analysis Tool using the Rain Index

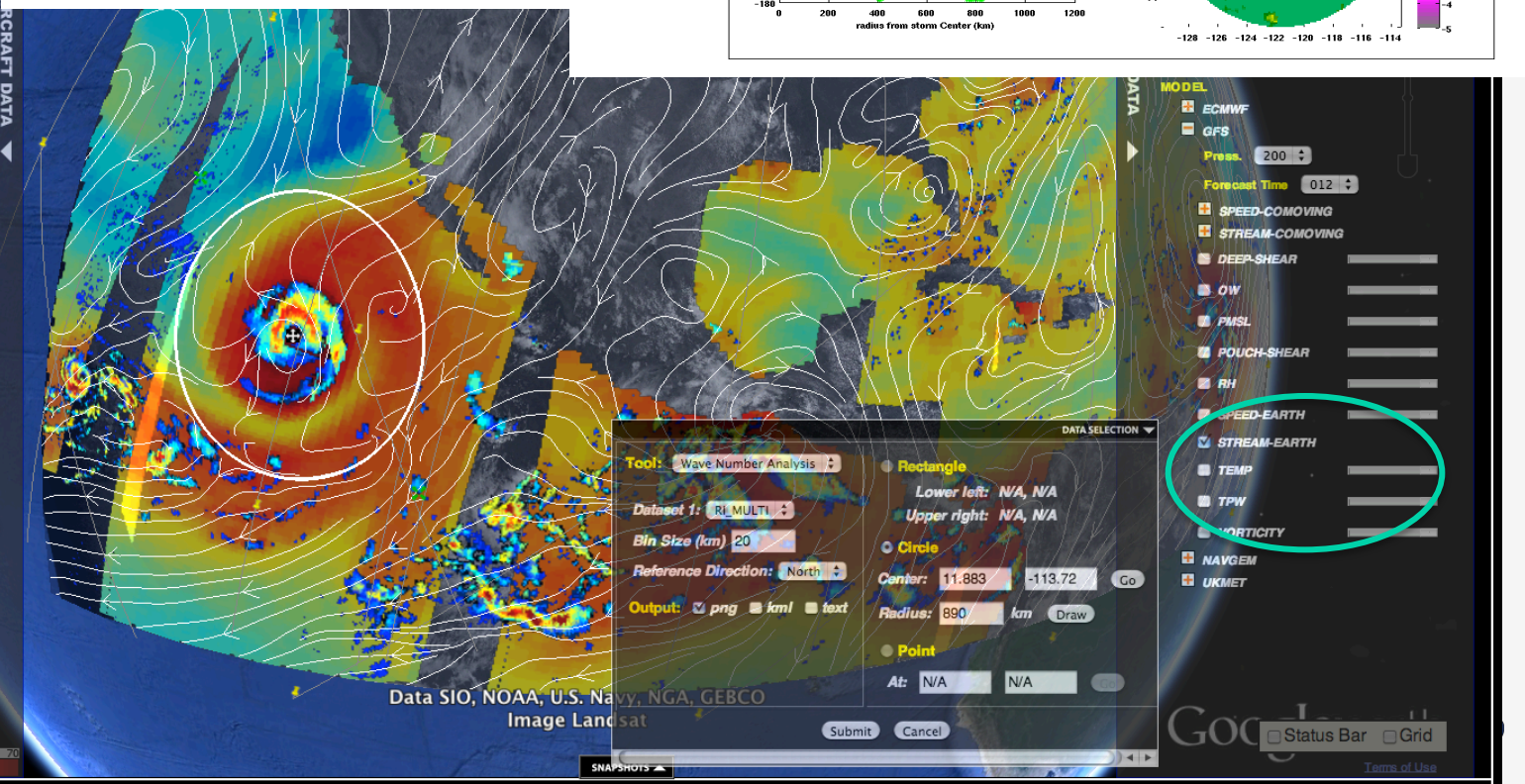
EP hurricane Lowell -08/21/2014: 15Z



Wave #1 has LEAST important contribution



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

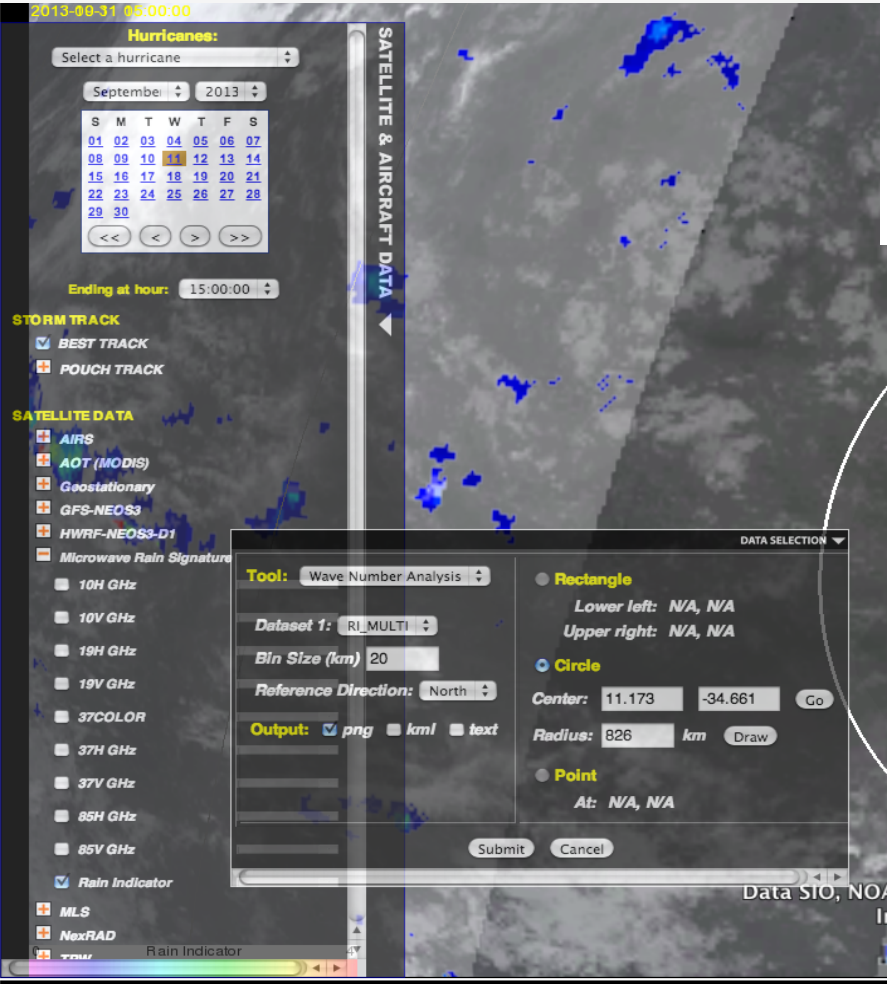


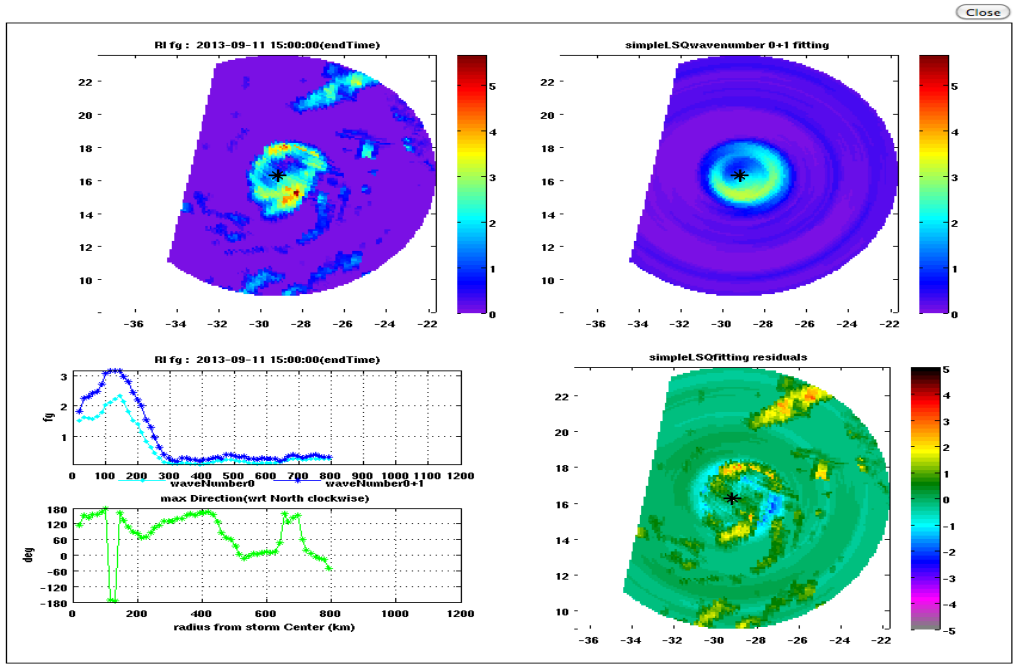
Storm structure Tool:

Observations: Rain

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

Hurricane Humberto -09/11/2013: 15Z



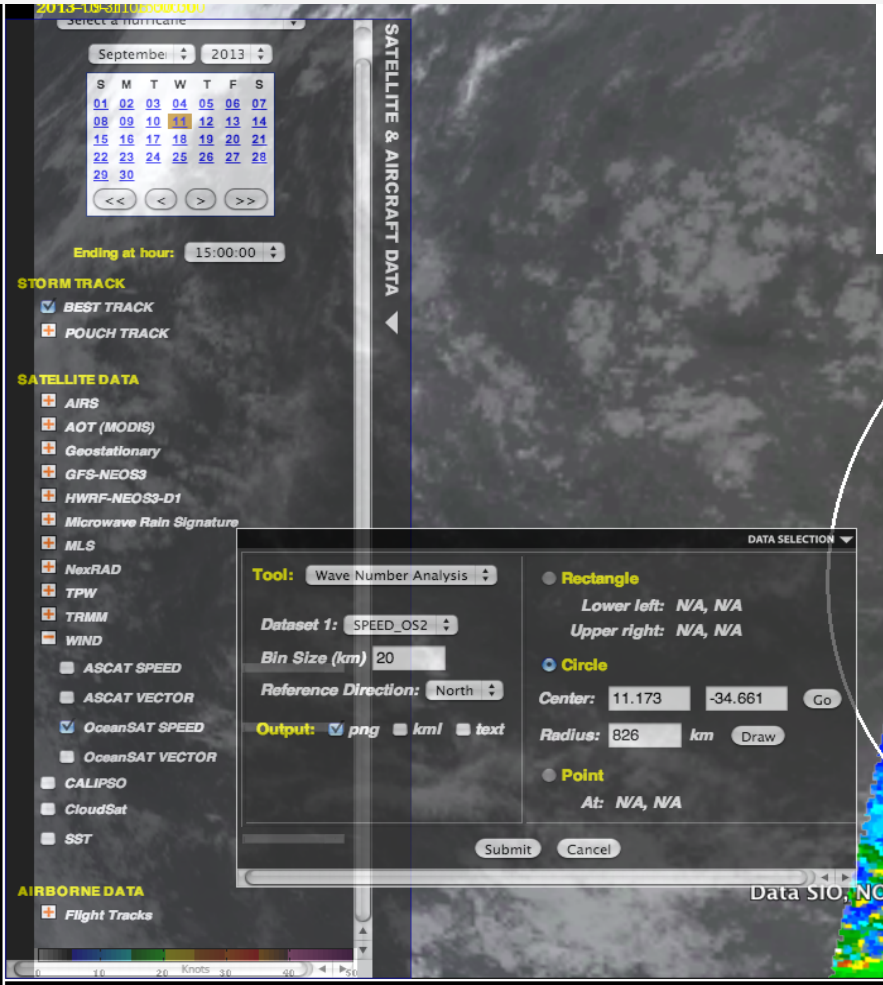


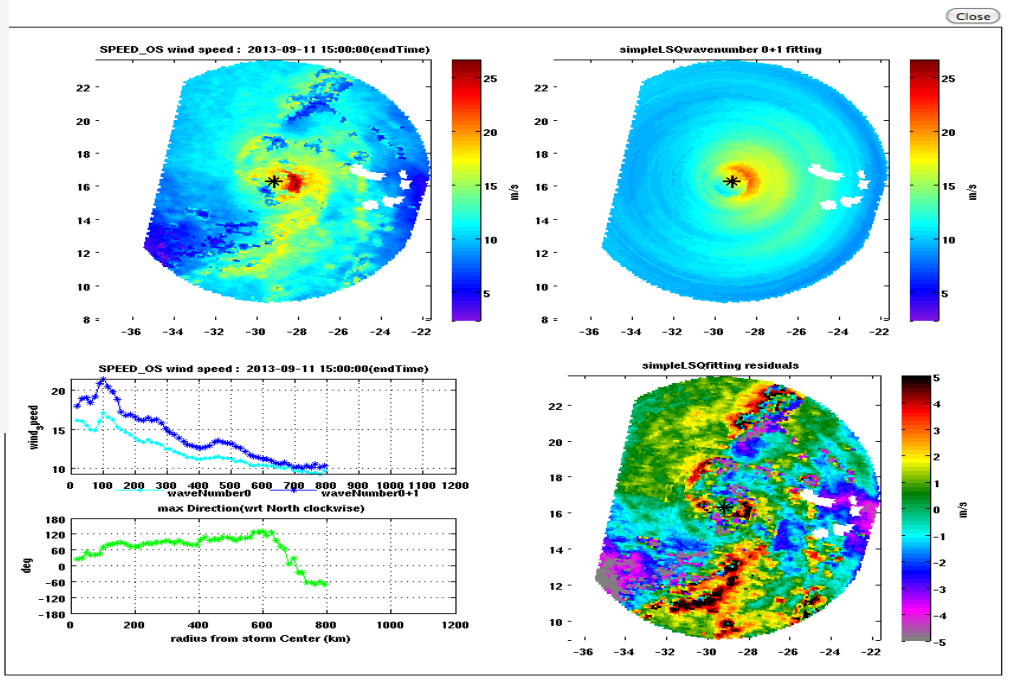
Storm structure Tool:

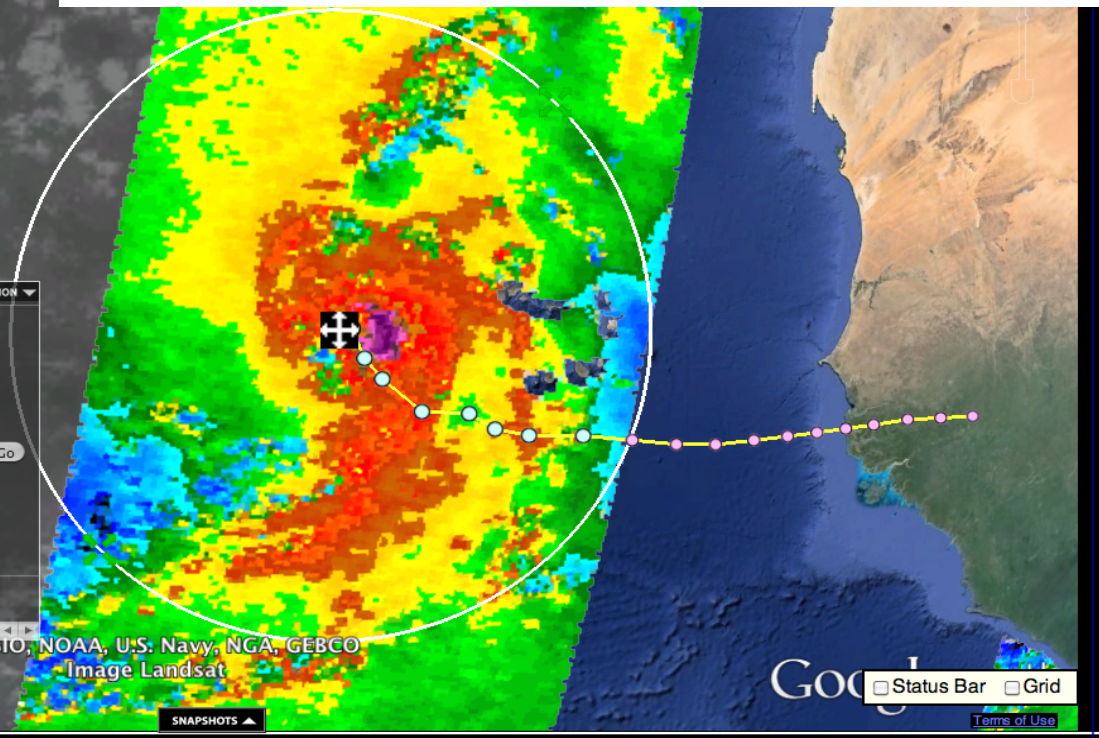
Observations: Wind from OSCAT

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

Hurricane Humberto -09/11/2013: 15Z



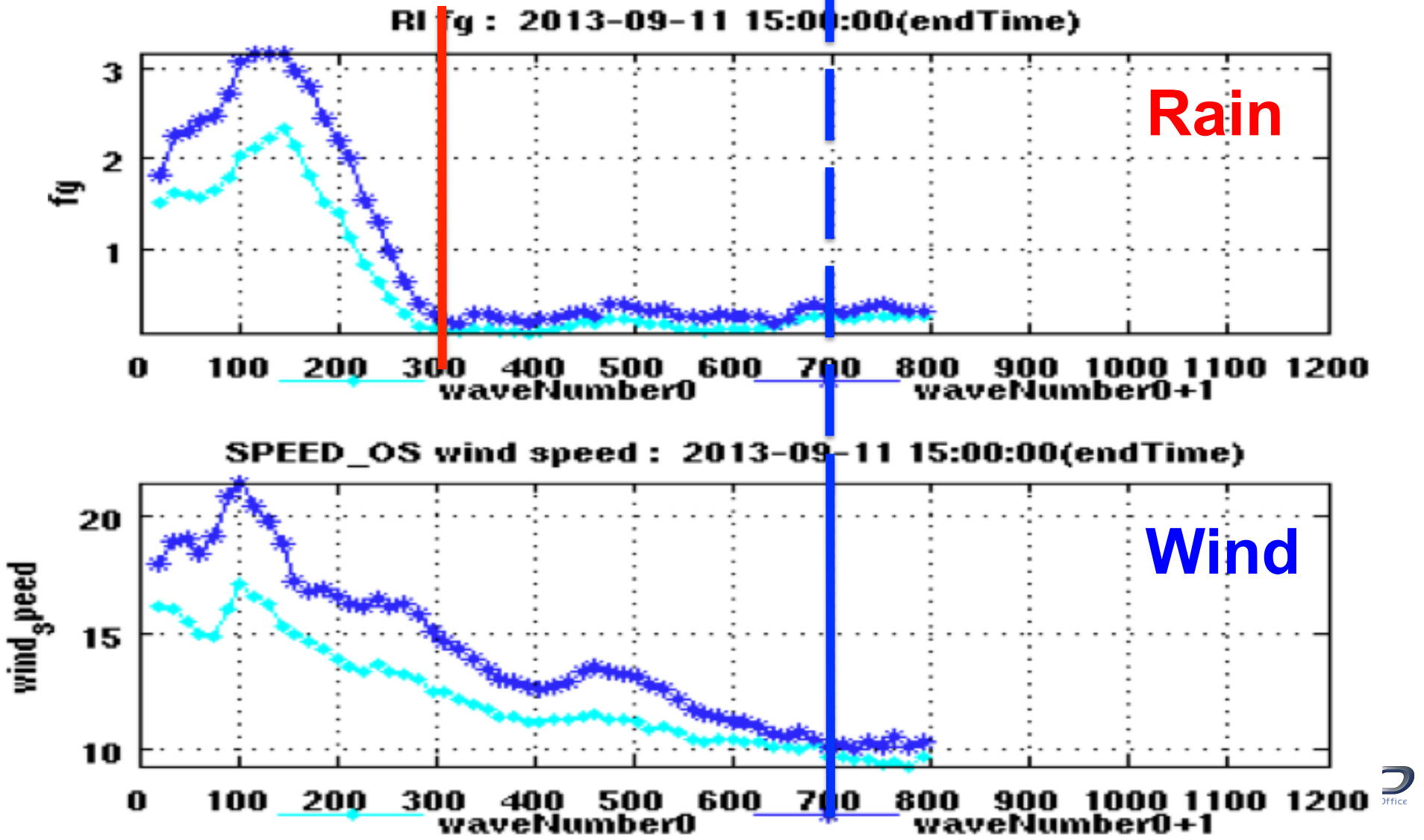




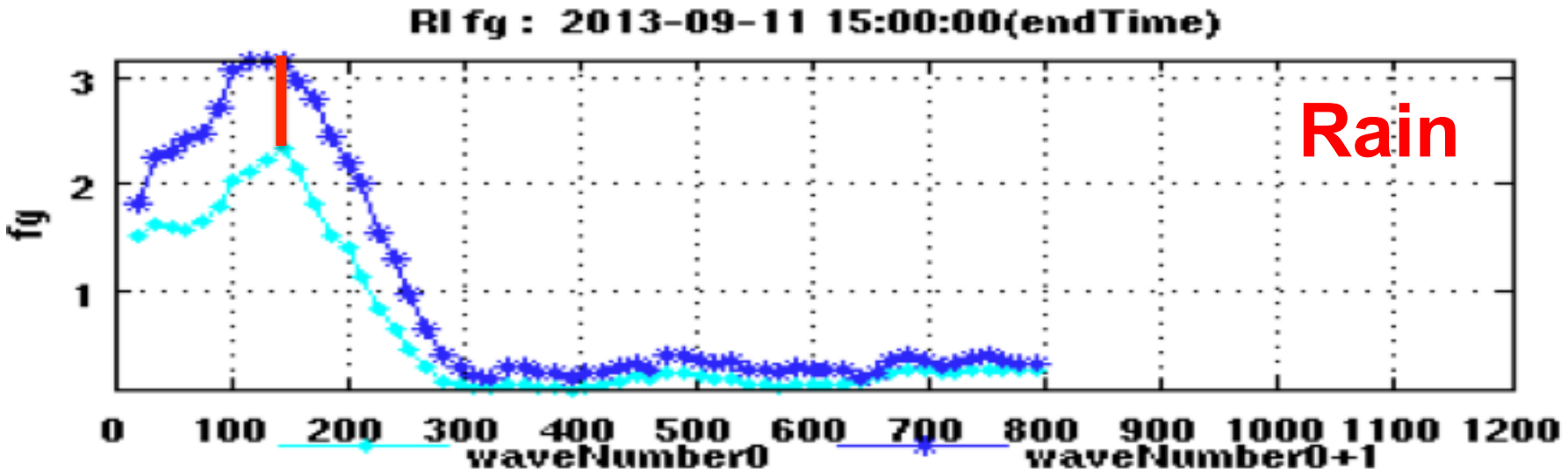
Size of precipitation is much smaller than the size of the wind field

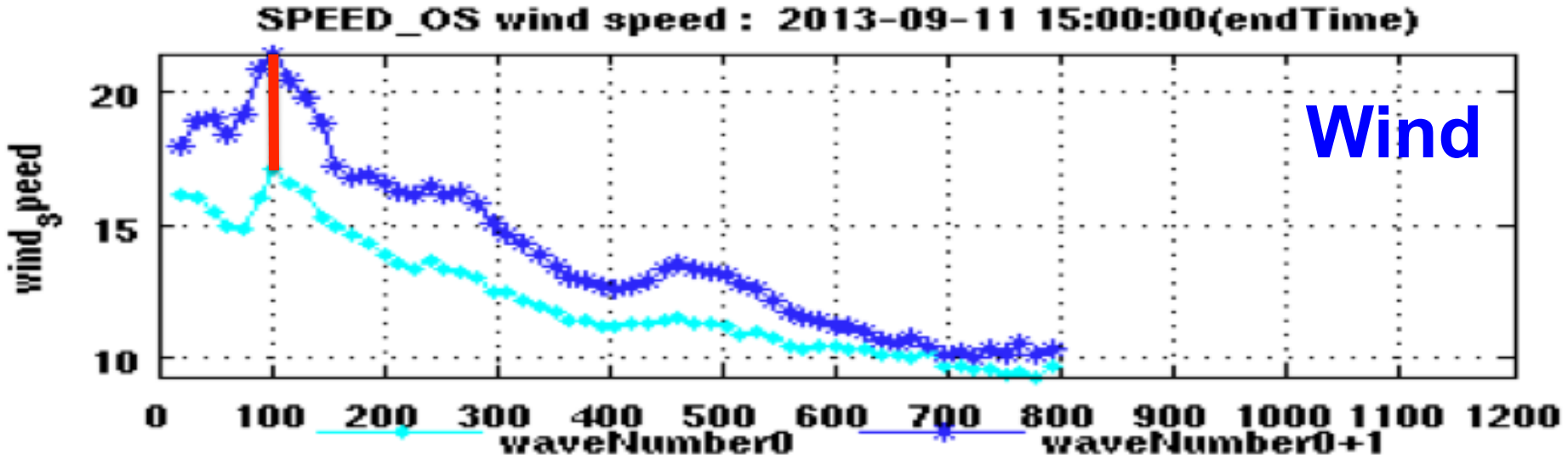
Size of Wind Storm

Size of Rain Storm



The storm is quite asymmetric in both wind and rain





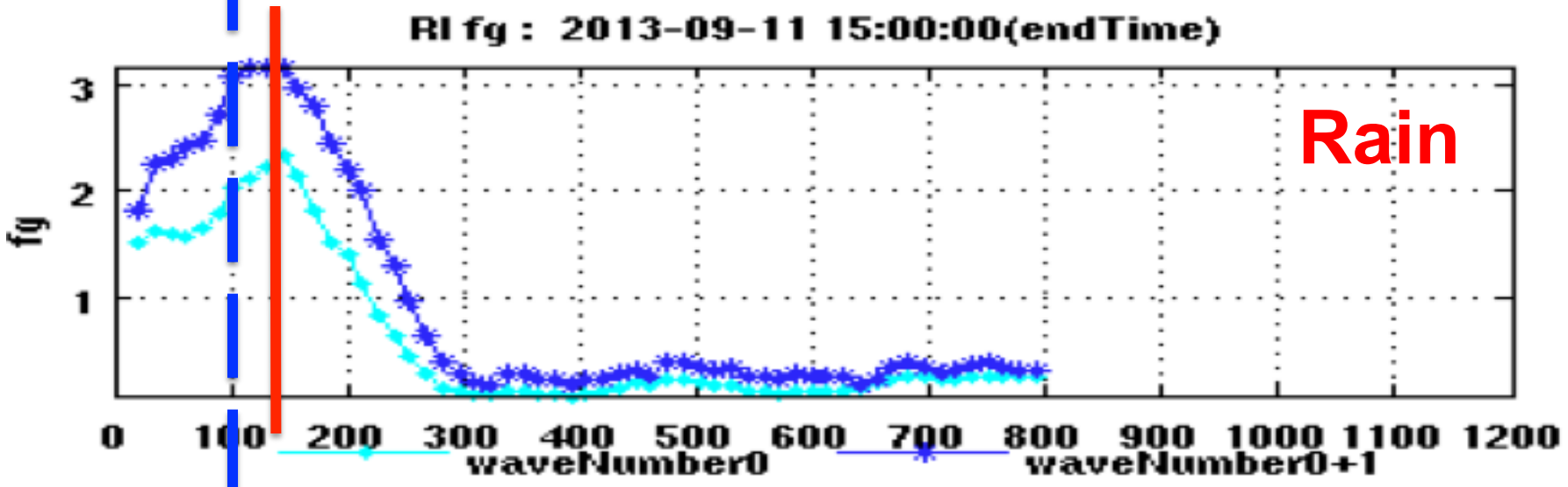
RMW

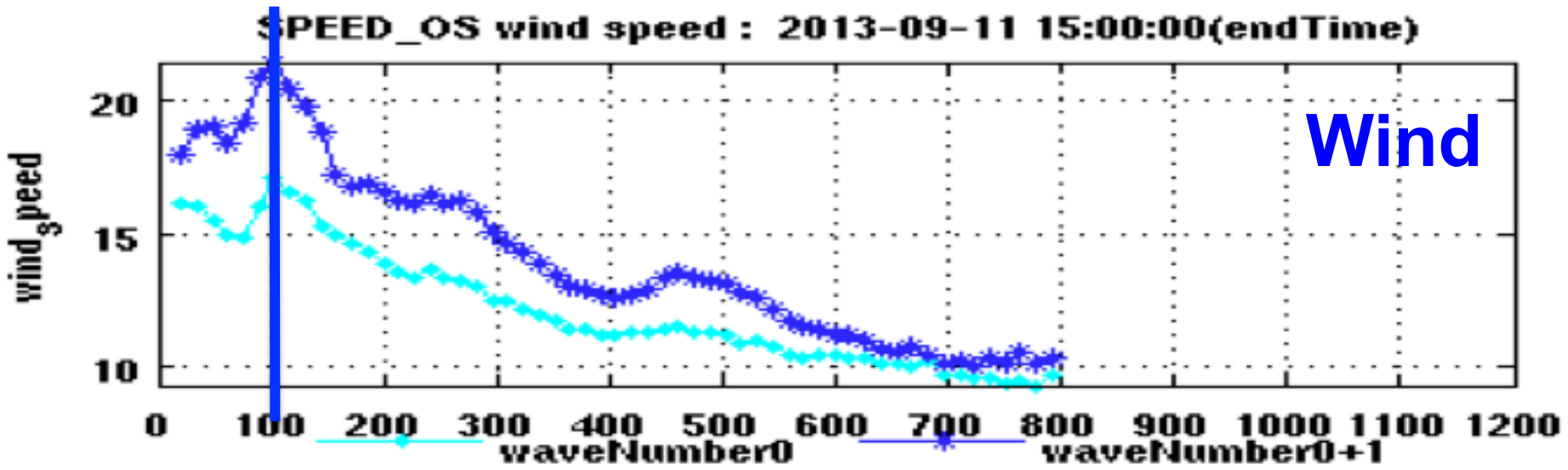
RMR

The storm is quite asymmetric in both wind and rain

Radius of Max Wind (RMW) is smaller than the Radius of Max Rain (RMR).

Conditions are not conducive to Rapid Intensification.





RMW

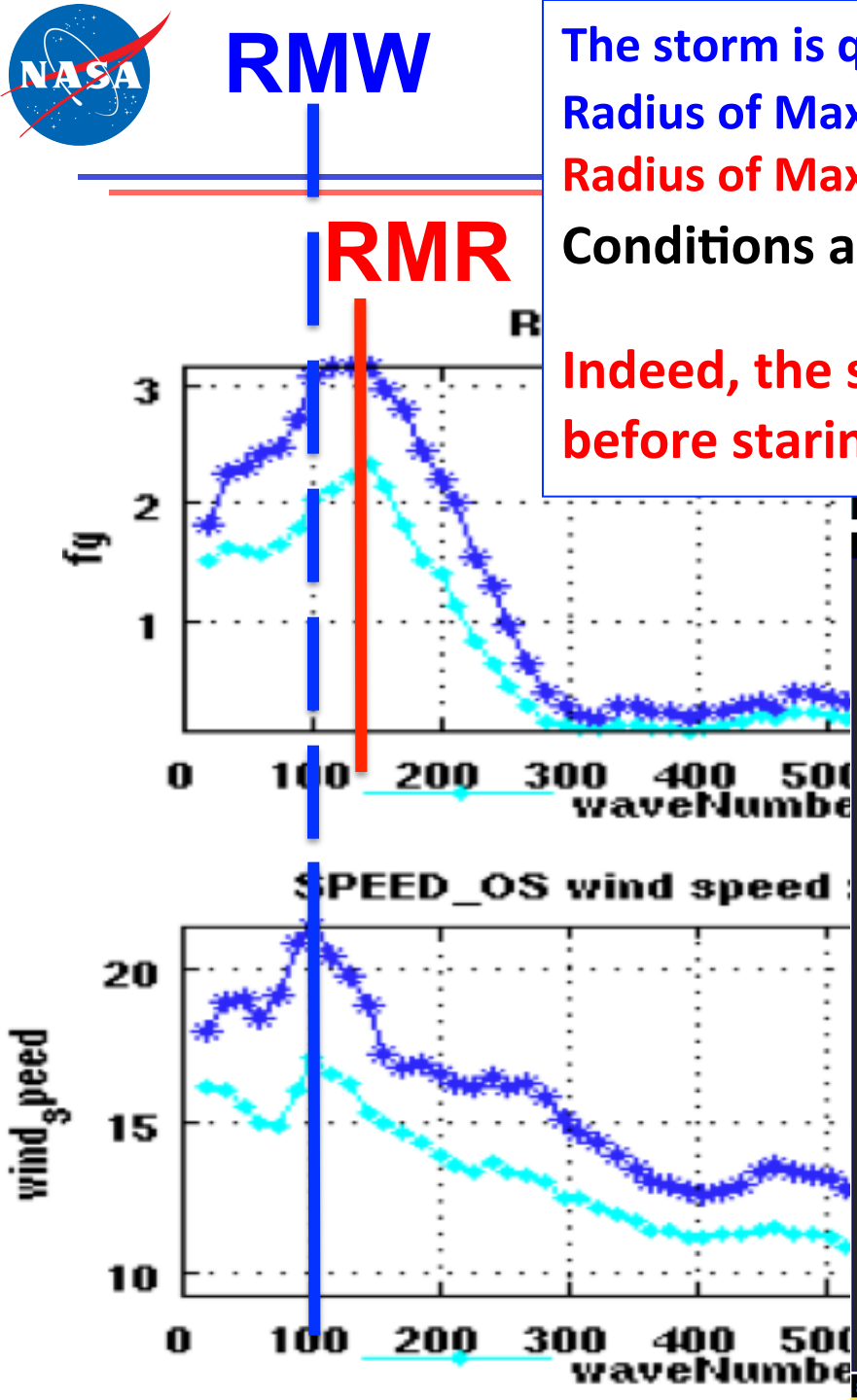
RMR

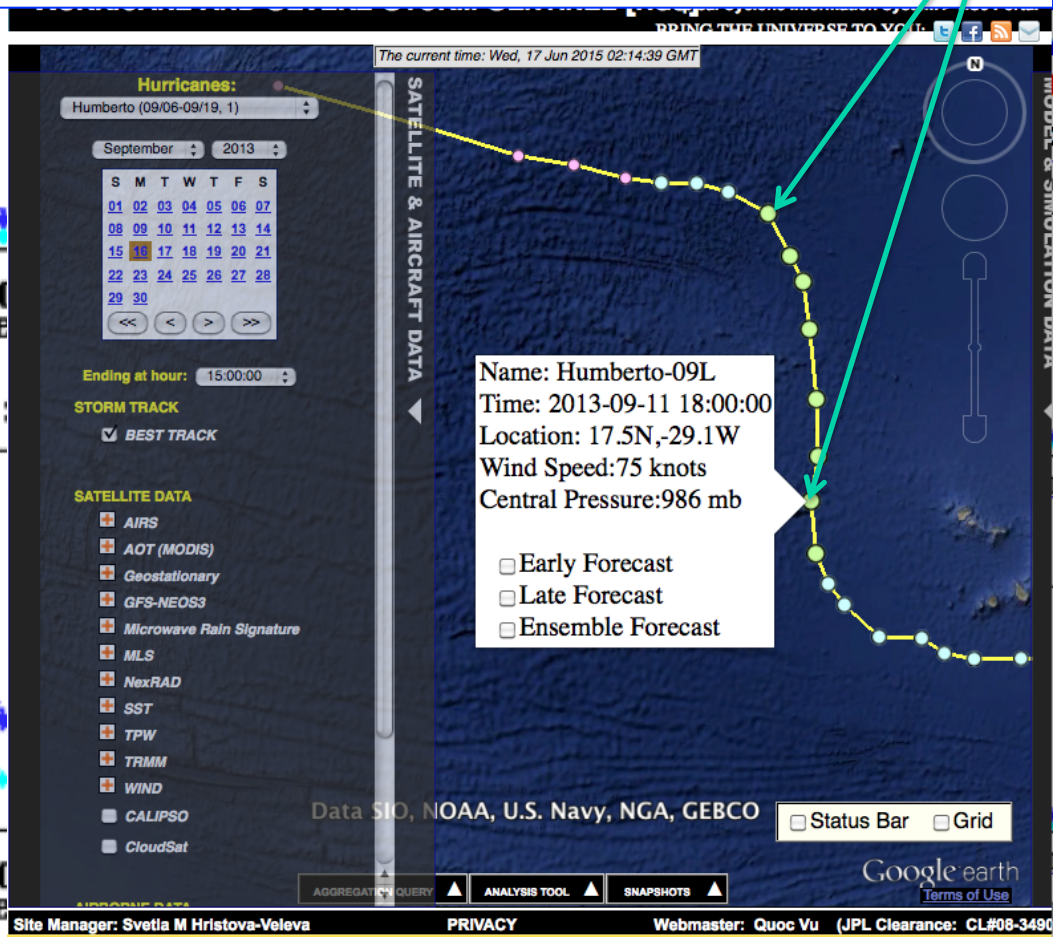
The storm is quite asymmetric in both wind and rain

Radius of Max Wind (RMW) is smaller than the Radius of Max Rain (RMR).

Conditions are not conducive to Rapid Intensification.

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





Long-term Statistics

The JPL TCIS – Tropical Cyclone Information System

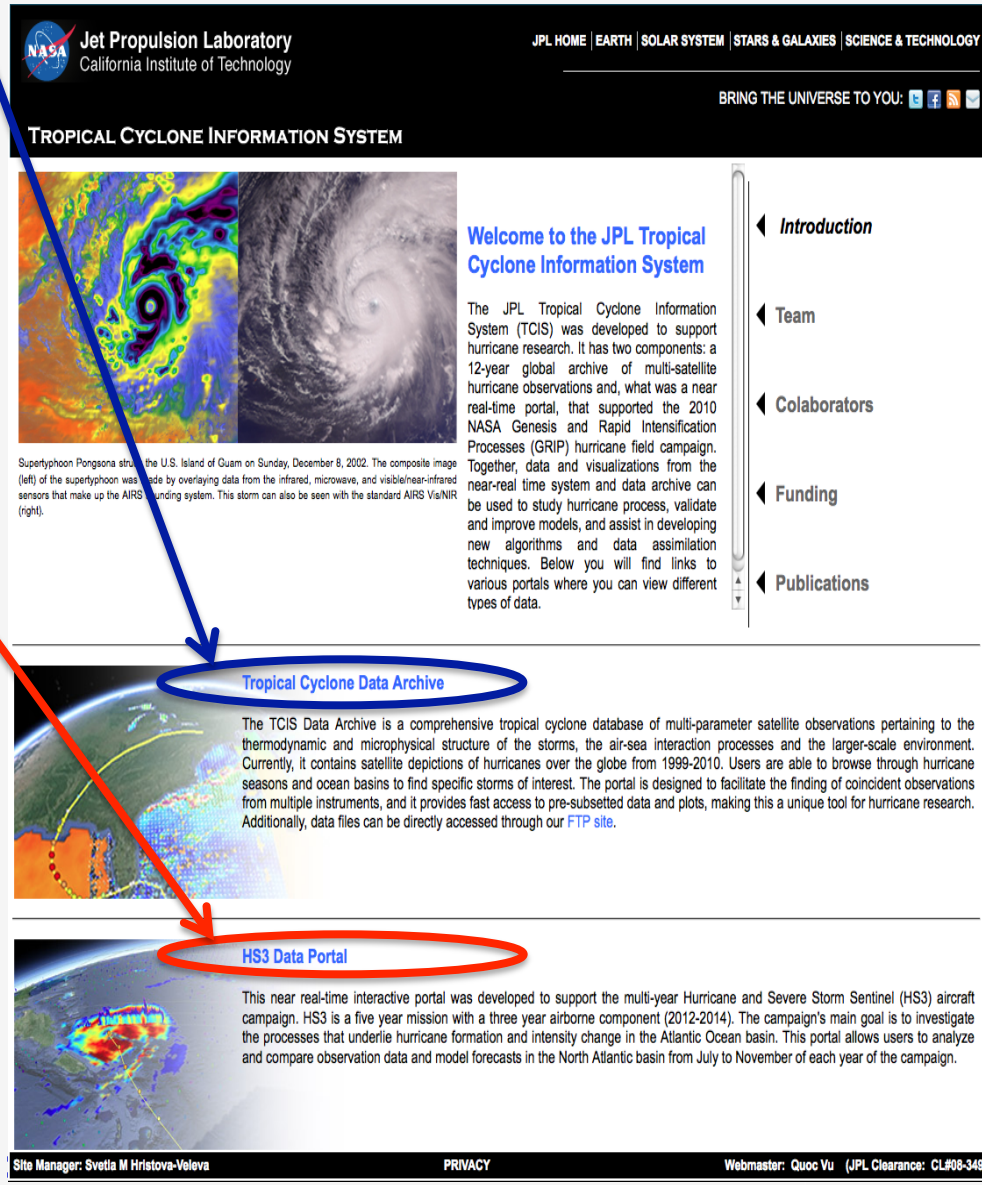
http://tropicalcyclone.jpl.nasa.gov

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.



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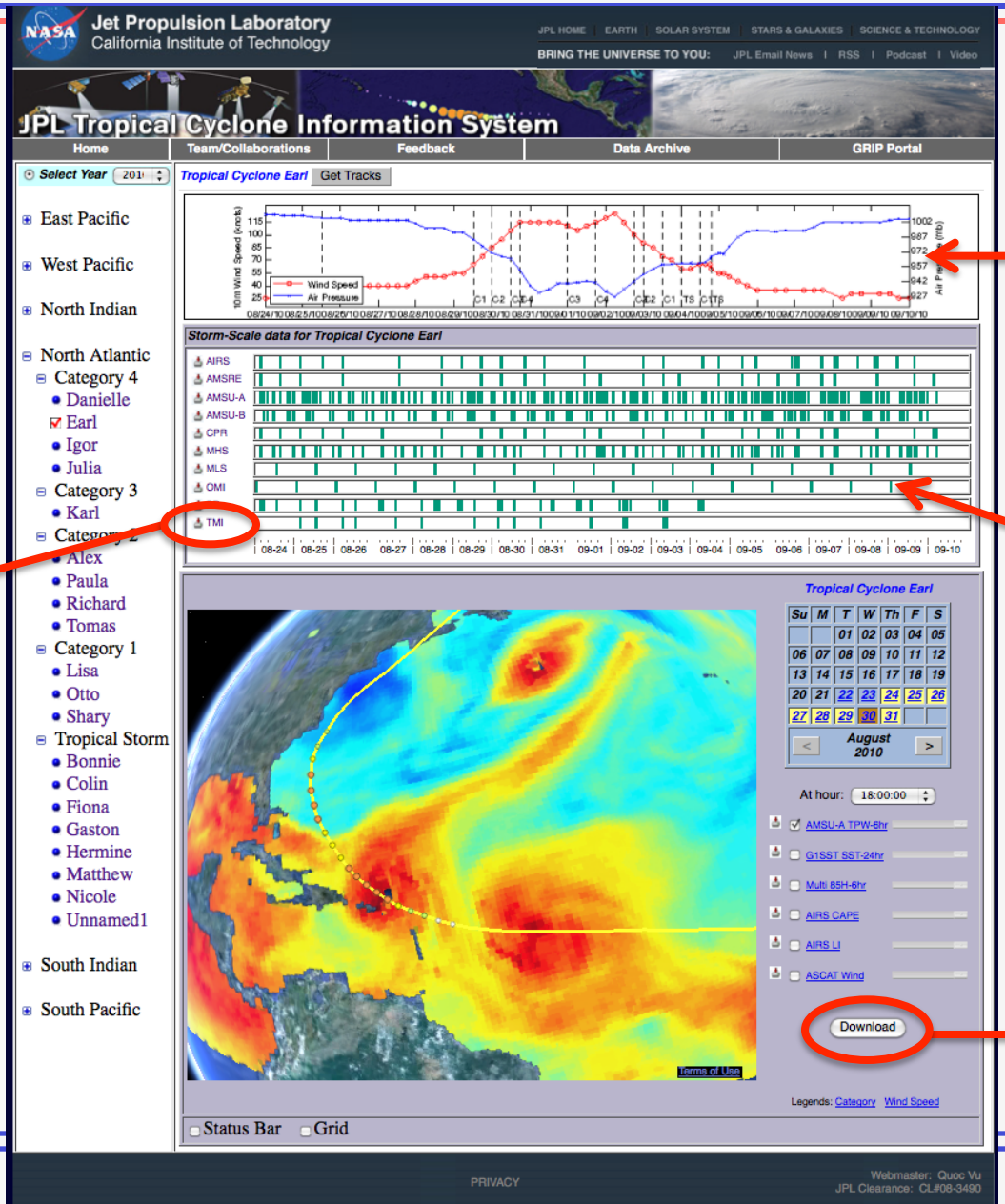


Timeline

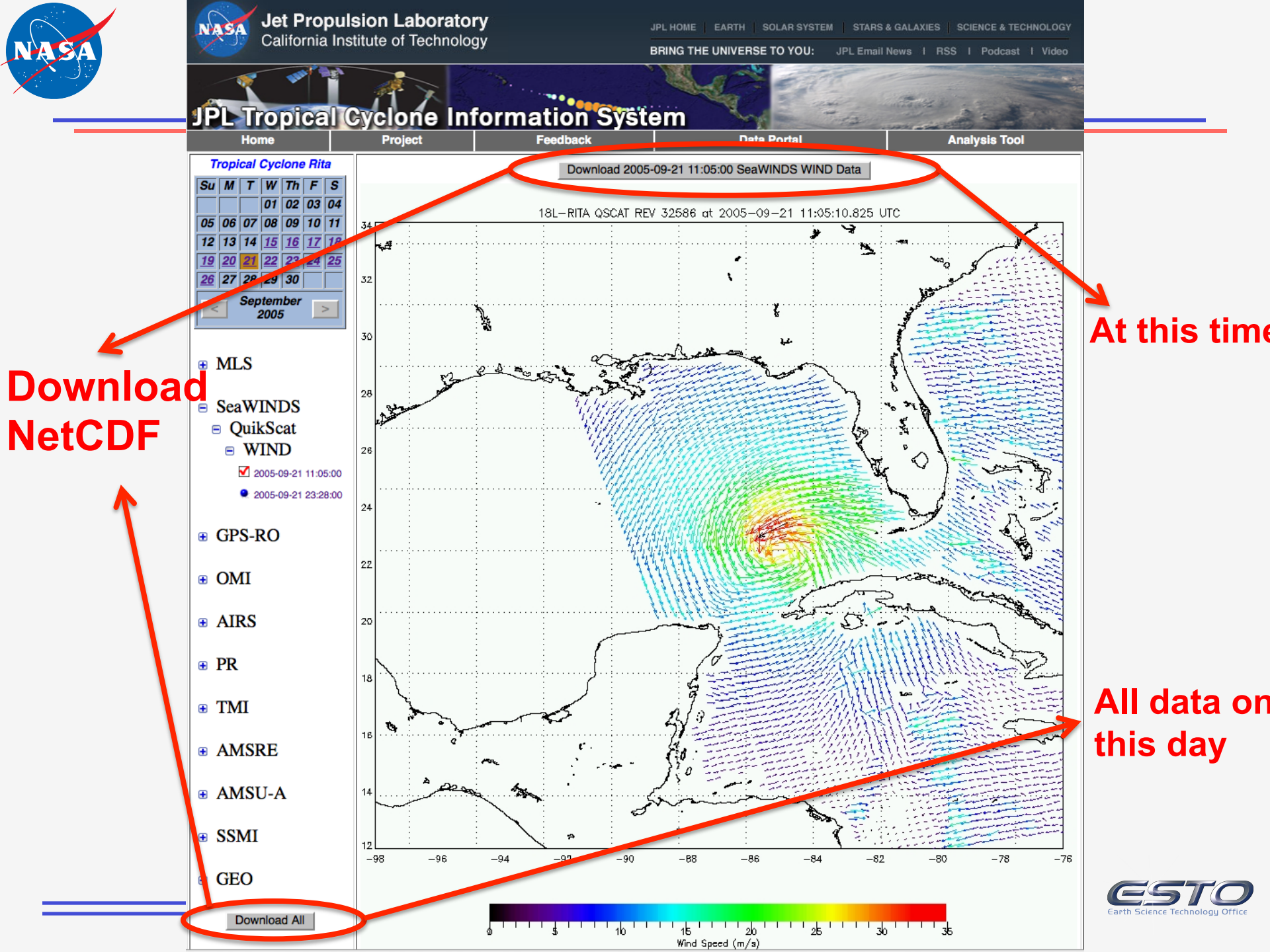
View and download Storm-scale data

Earl, 2010

Download all data from this Instrument (TMI)

Download Selected large-scale data from this day

ESTO
Earth Science Technology Office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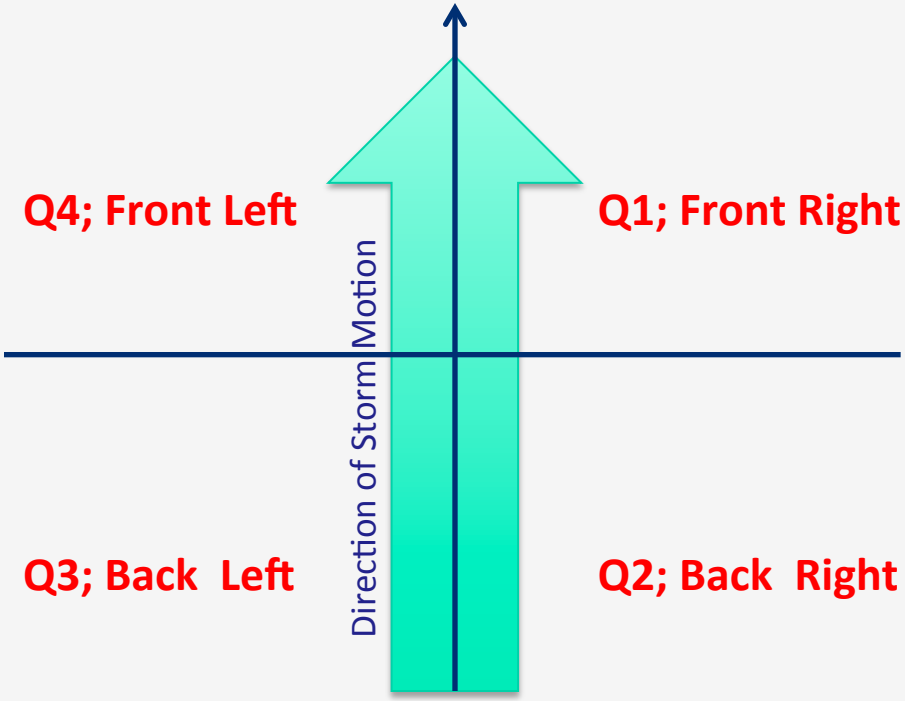
Su M T W Th F S
September 2005
MLS
SeaWINDS
QuikScat
WIND
2005-09-21 11:05:00
2005-09-21 23:28:00
GPS-RO
OMI
AIRS
PR
TMI
AMSRE
AMSU-A
SSMI
GEO
Download All
Download 2005-09-21 11:05:00 SeaWINDS WIND Data
18L-RITA QSCAT REV 32586 at 2005-09-21 11:05:10.825 UTC
Wind Speed (m/s)
Download NetCDF
At this time
All data on this day
ESTO
Earth Science Technology Office

Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

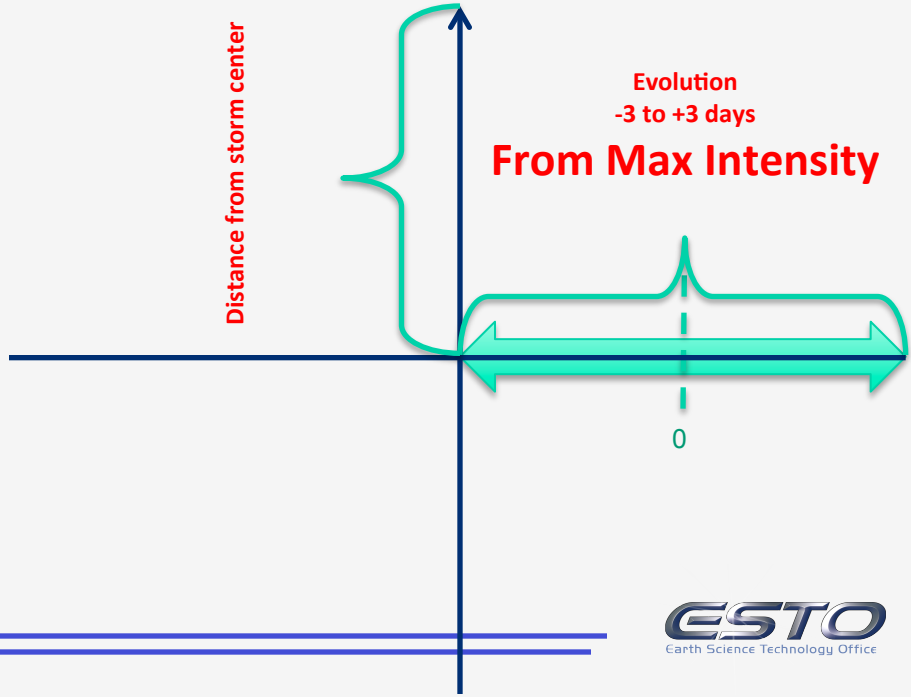
Parameter as a function of:

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



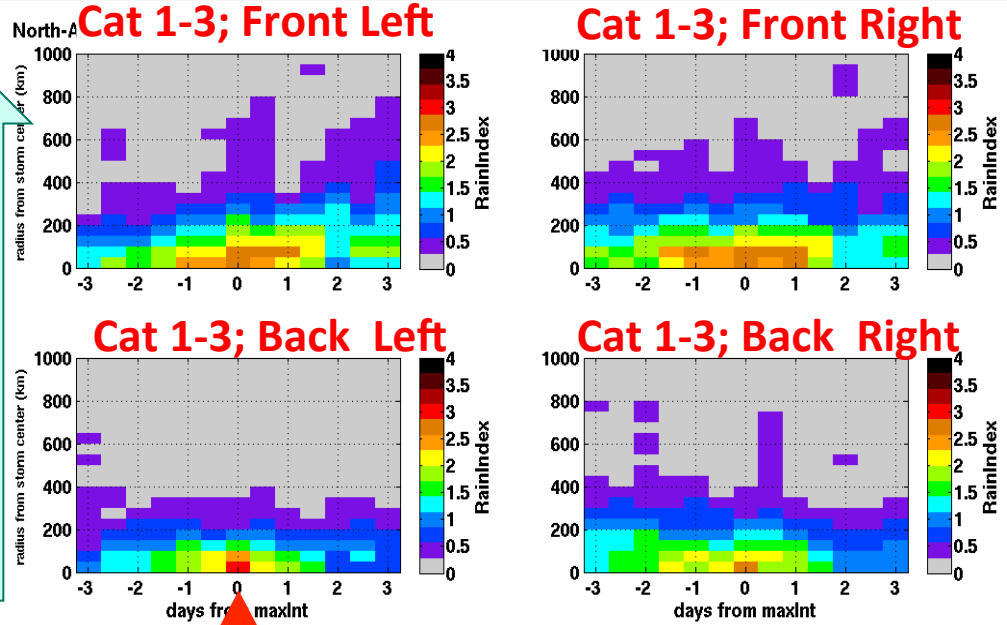
Created composites following similar approaches:

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

Direction of Storm Motion



Day of Maximum Intensity

Evolution of asymmetry

Azimuthal/Range Distributions of

Rain Index

Cat1: 31 cases

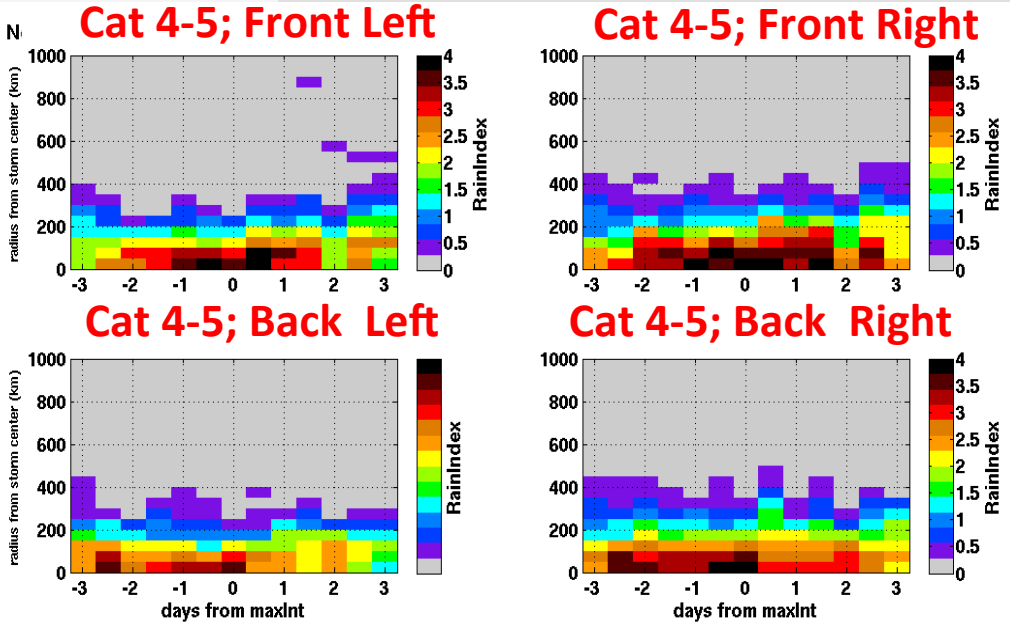
Cat2: 9 cases

Cat3: 12 cases

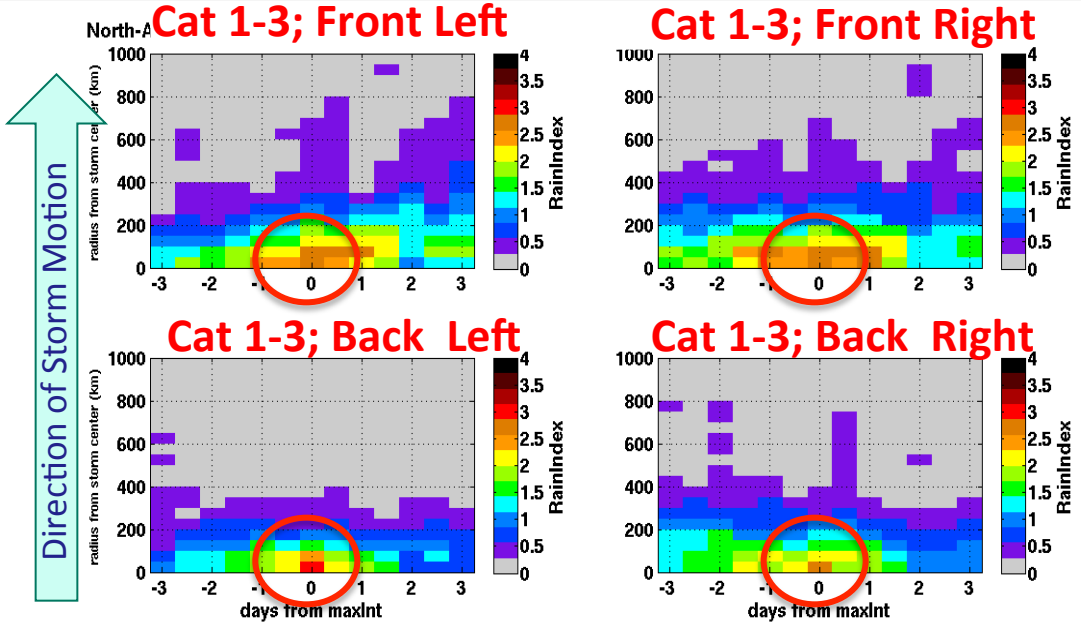
Total Cat1-3 = 52 cases

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

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Cat1: 31 cases
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Total Cat1-3 = 52 cases

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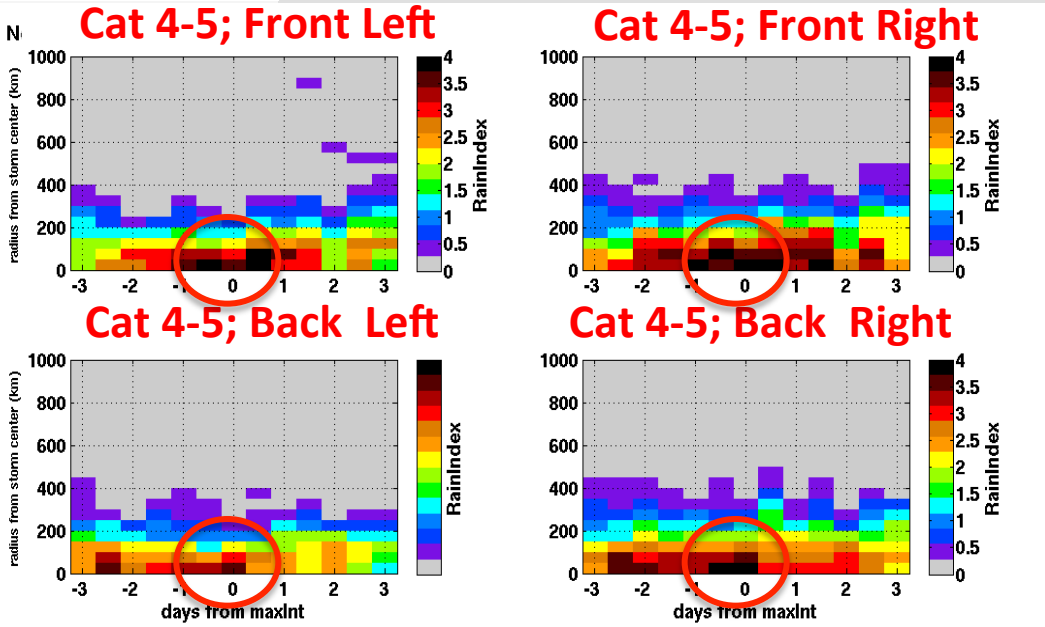
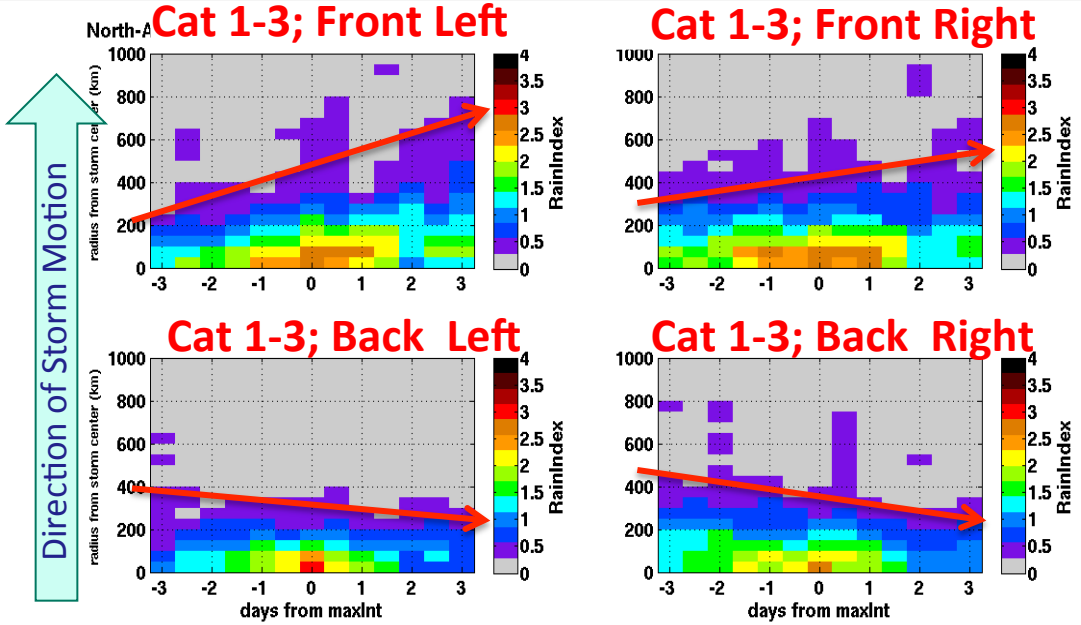
Cat 1-3 have rain fields that are larger, weaker and less symmetric in:

- **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

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Rain Index

Cat1: 31 cases
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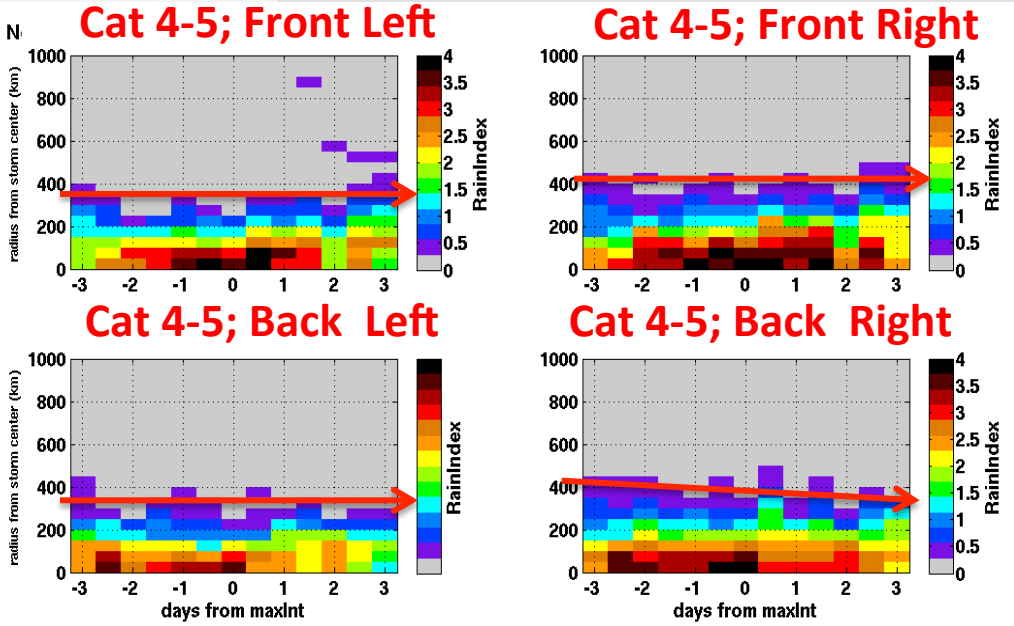
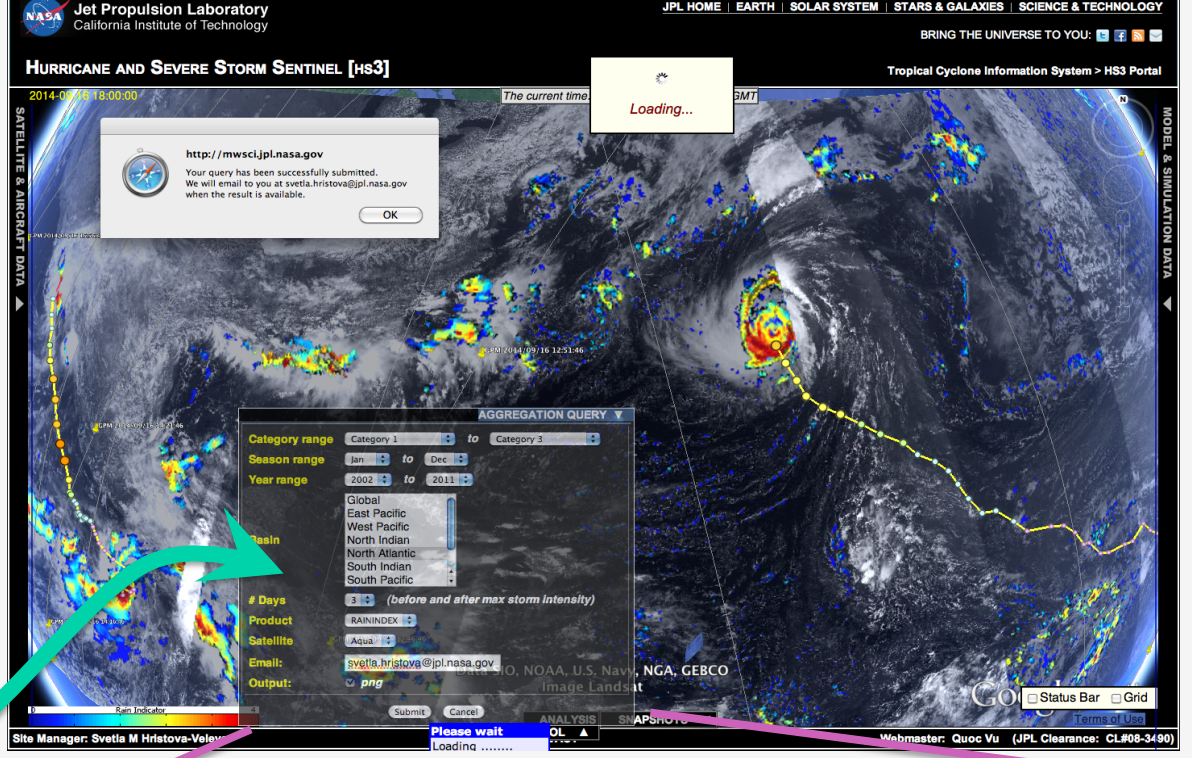
Cat4: 18 cases
Cat5: 7 cases

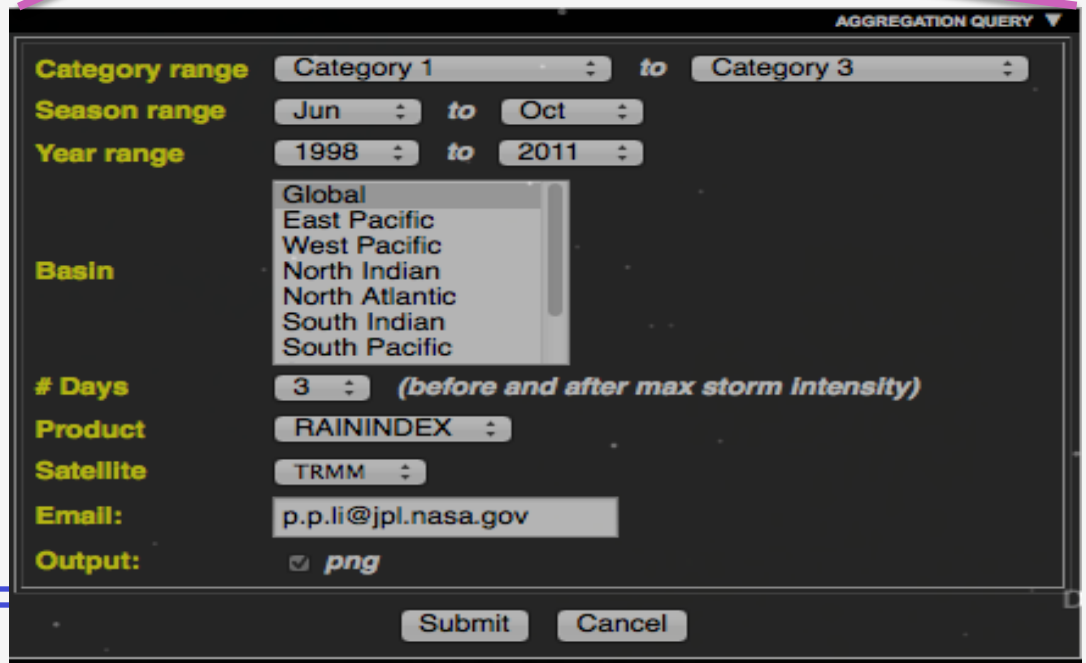
Cat 1-3 have rain fields that are larger, weaker and less symmetric in:

- **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



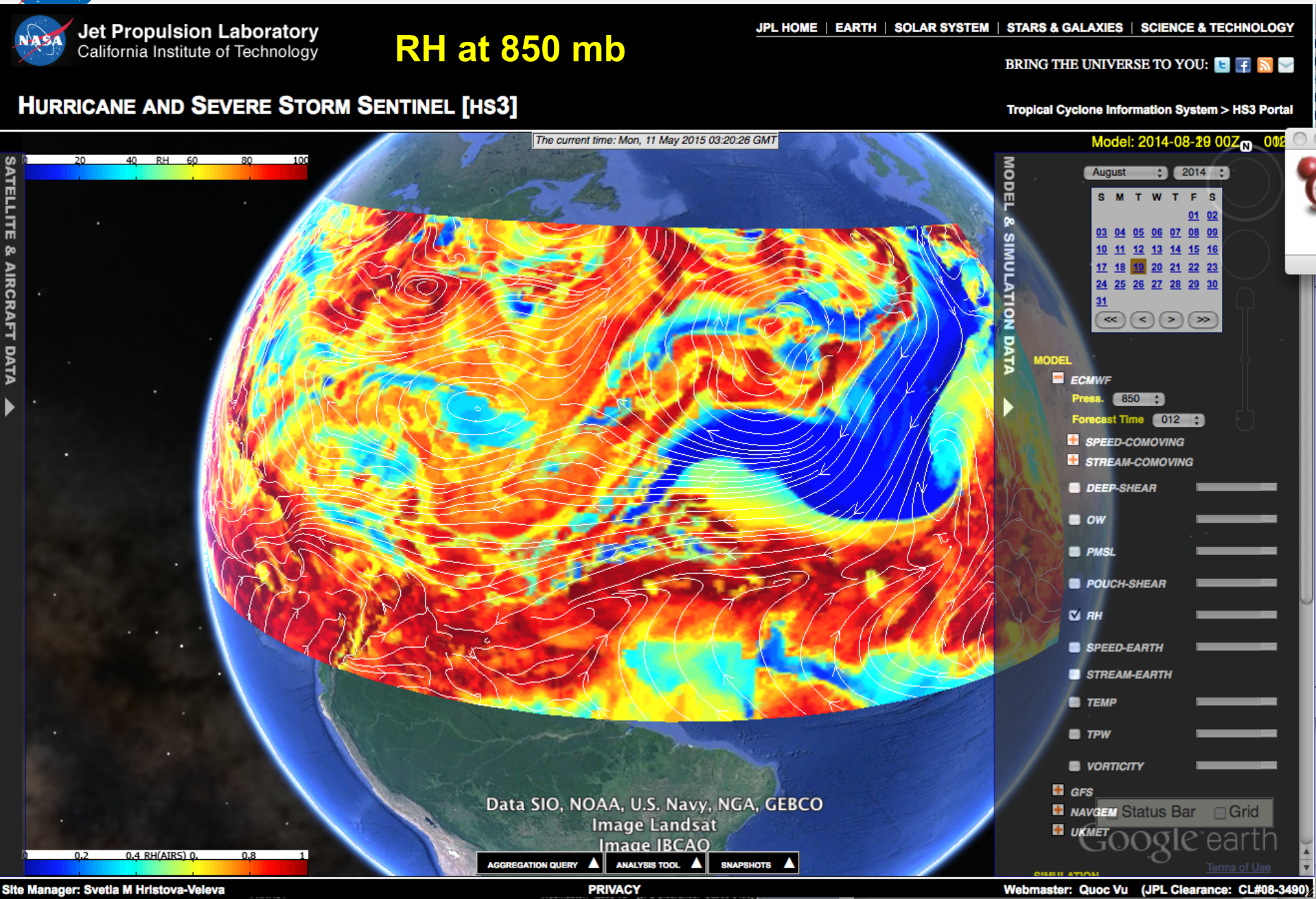
- Such analysis have been performed by researchers
  - Using mostly airborne data and limited satellite data
  - requiring significant investment in time and effort to collect the data
- Developing a system that will allow the user to quickly search our 12+ year global data archive of satellite observations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



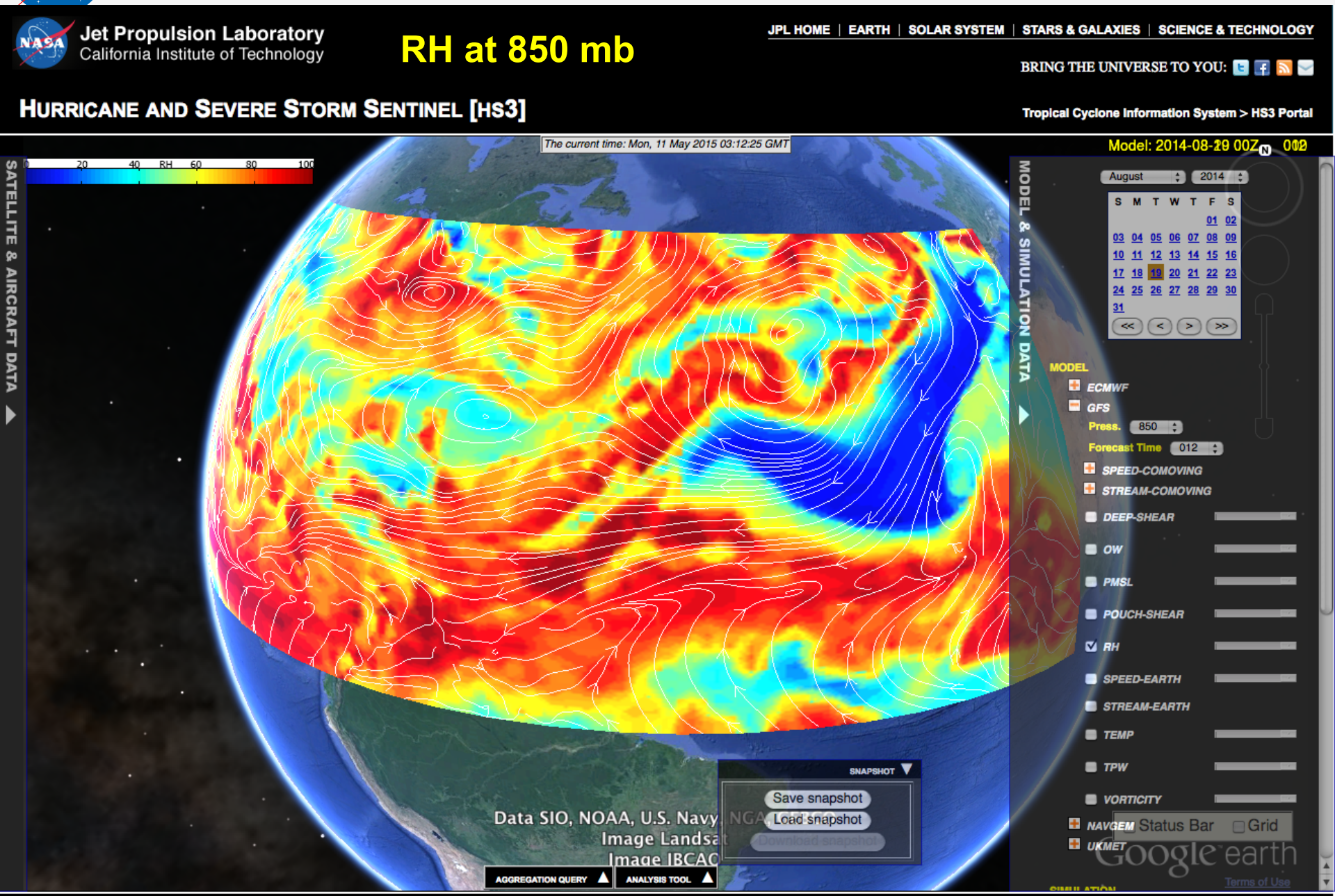


Analyzing the Environment
&
Evaluating the Models

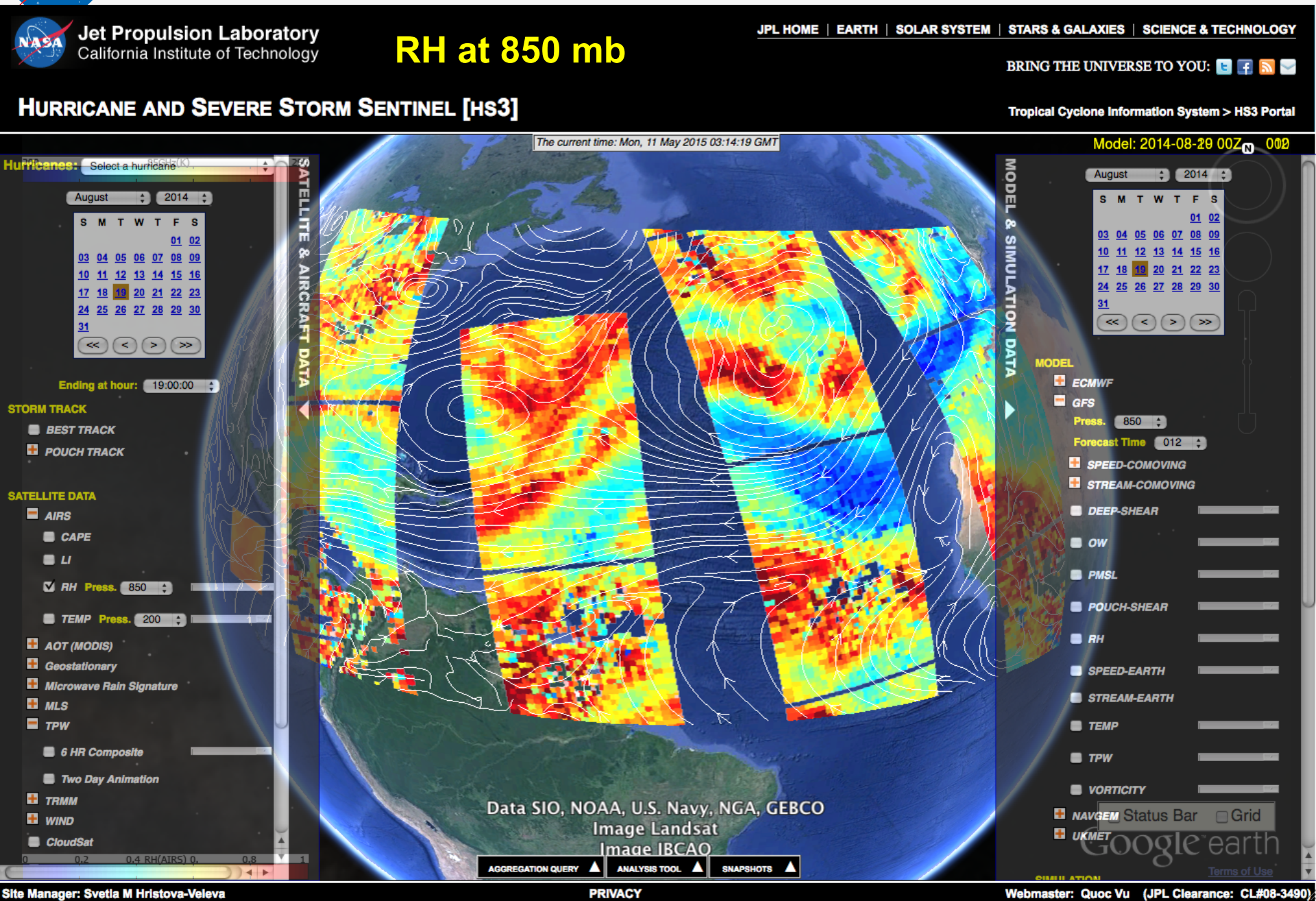
Analysis of the environment - ECMWF



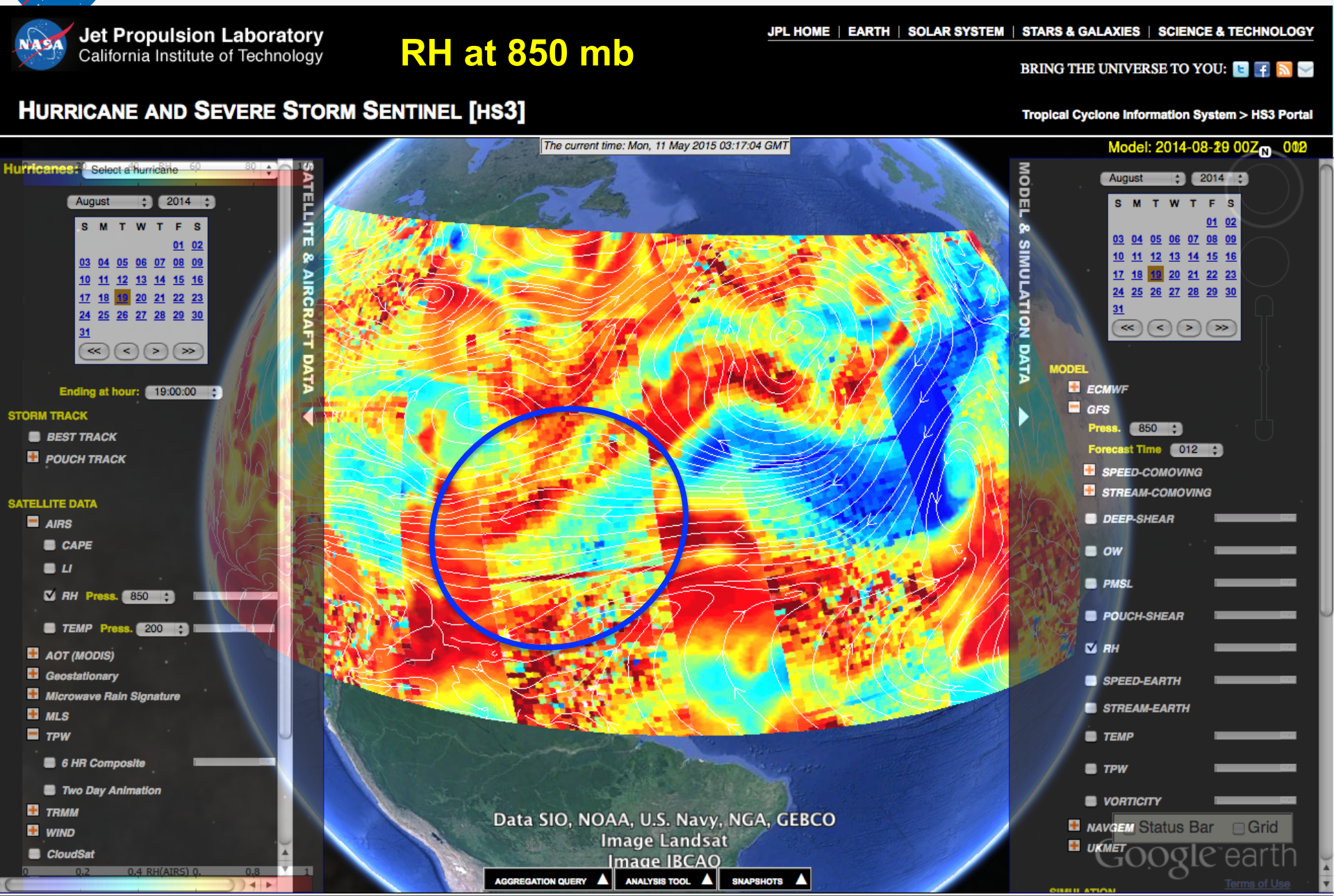
Analysis of the environment - GFS



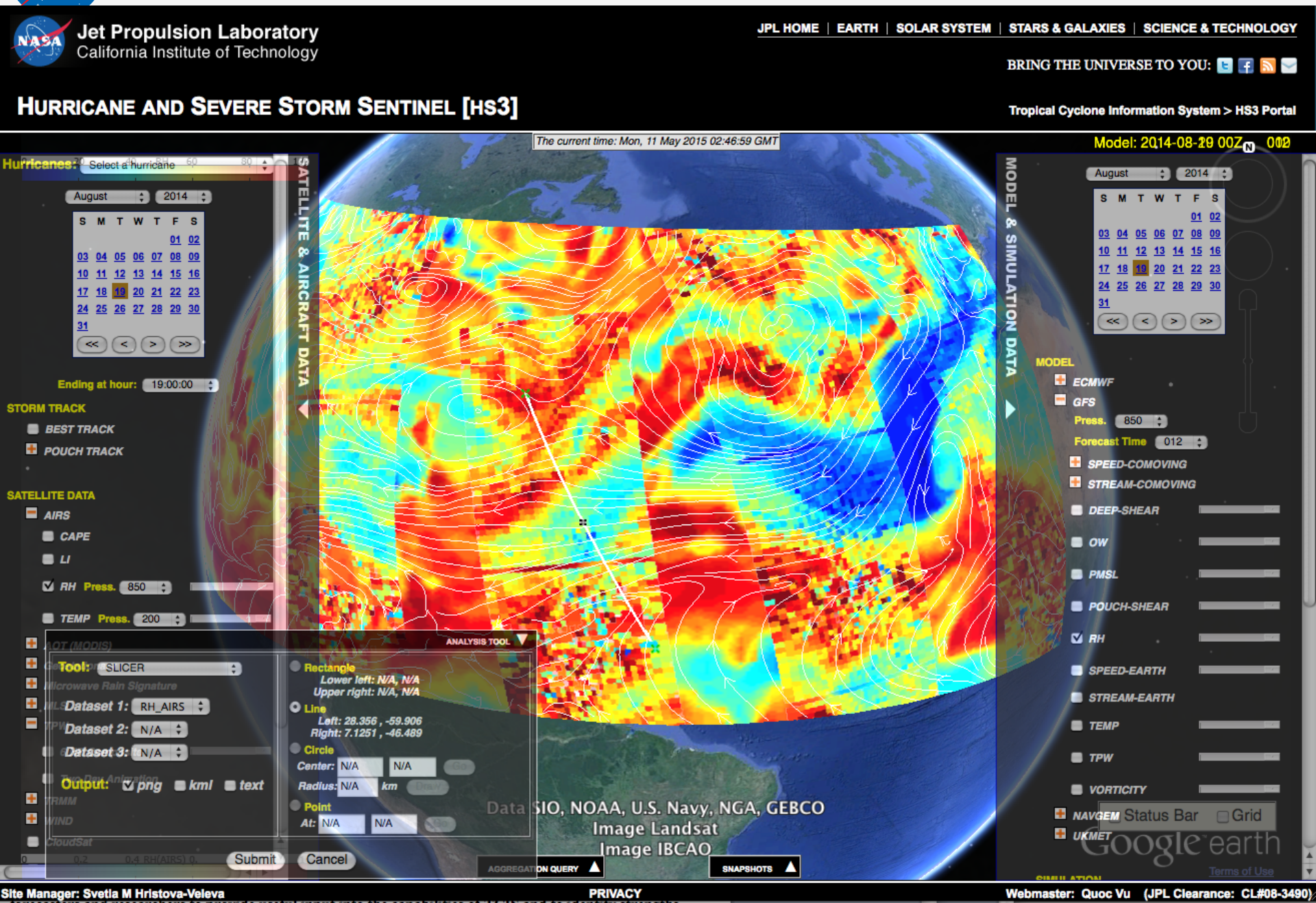
Analysis of the environment – Observations (AIRS)



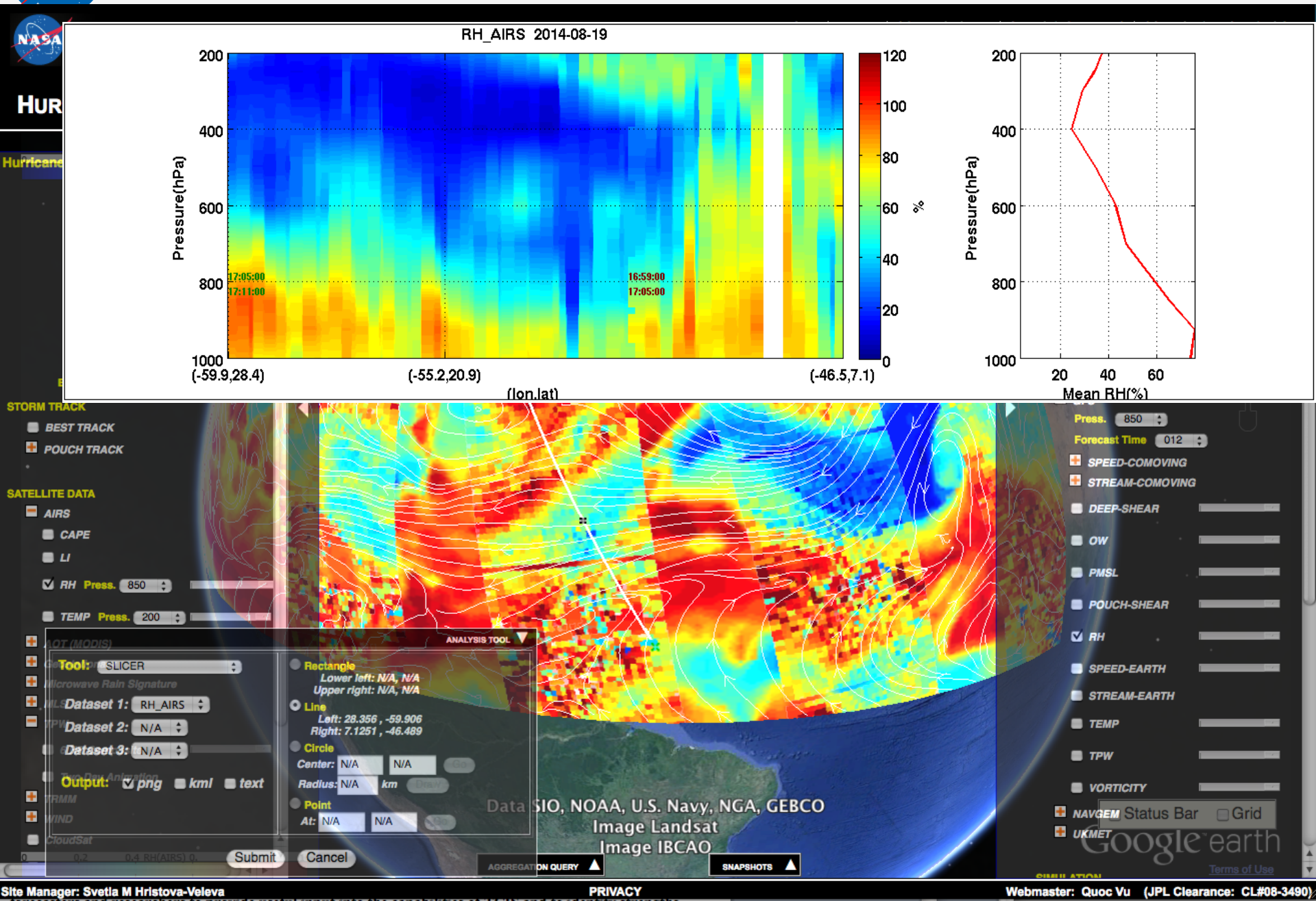
The “Slicer” – analysis of the environment



The “Slicer” – analysis of the environment



The “Slicer” – analysis of the environment



Summary

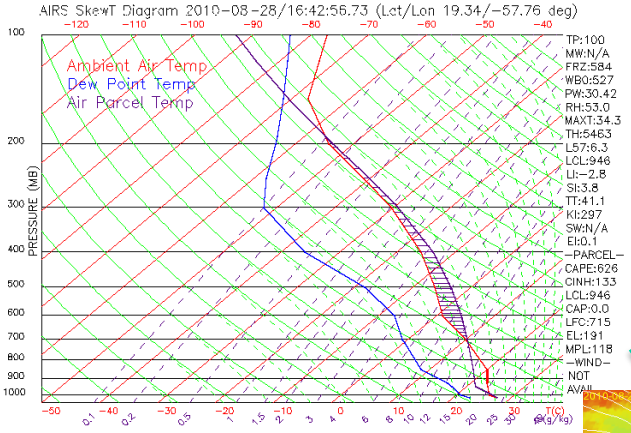
- To achieve the HFIP goals of improving the forecast accuracy of hurricane intensity, track and impact at landfall we first **need to understand whether the models properly reflect the physical processes and their interactions**.
- To address the need for improving the model physics, the 2013 annual 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.**

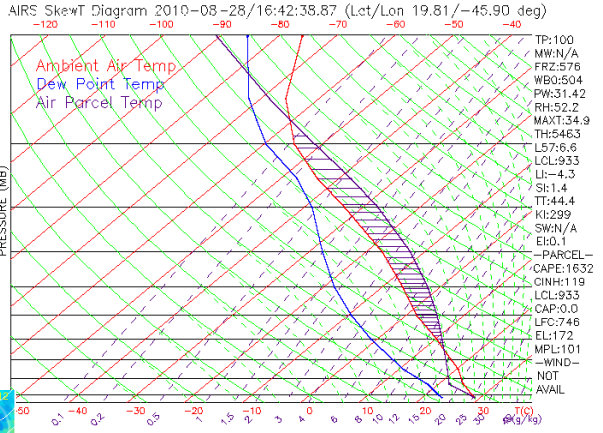
What is unique about our efforts

- **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**

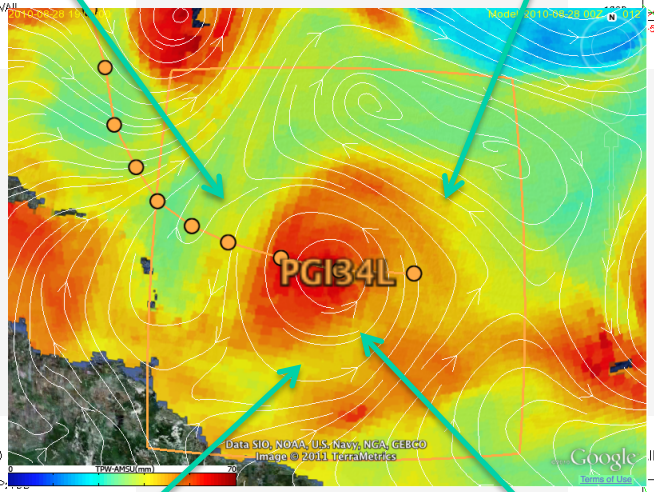

Thank you !

The thermodynamics from AIRS

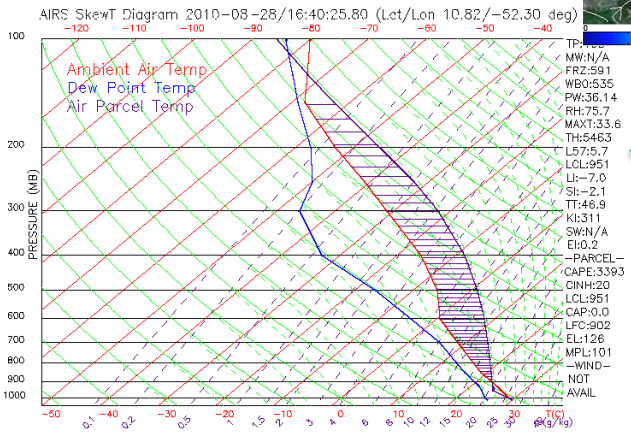


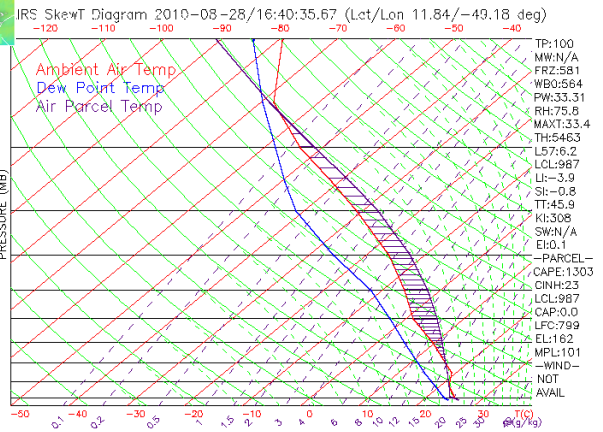


Hurricane Earl;
Aug. 28, 2010
19Z

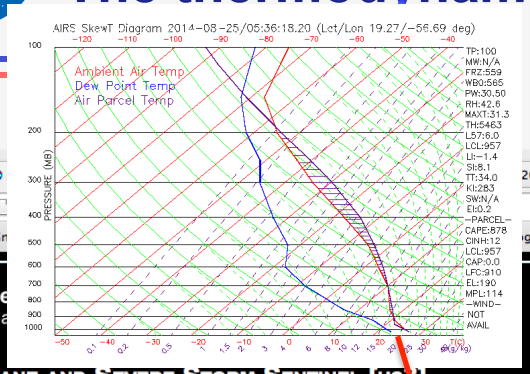


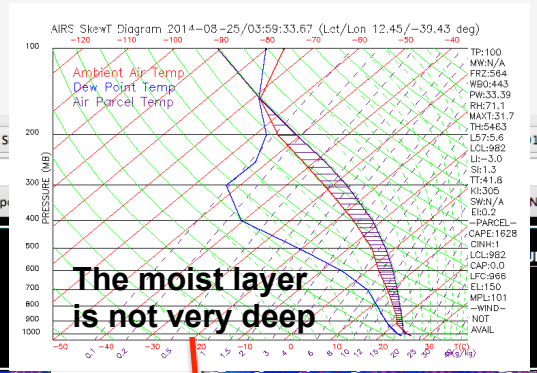
1. **TPW from AMSU**
2. **Soundings from AIR**
3. **Pouch-relative flow from ECMWF**



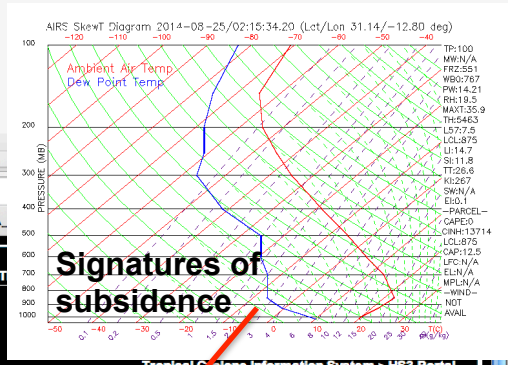


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The thermodynamics from AIRS and the AOT from MODIS





The moist layer is not very deep



Signatures of subsidence

HURRICANE AND SEVERE STORM SENTINEL [HS3]

The current time:

2014-08-25 00:00:00

SATELLITE & AIRCRAFT DATA

MODEL & SIMULATION DATA

Model: 2014-08-25 00Z 012

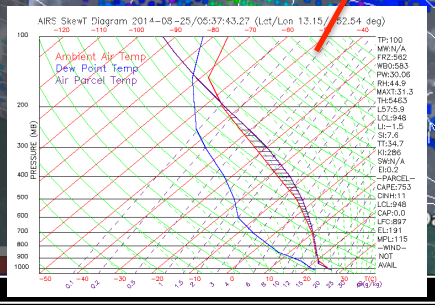
Ending at hour: 08:00:00

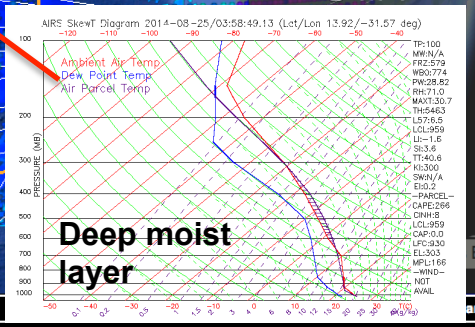
STORM TRACK
- BEST TRACK
- POUCH TRACK

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
- CAPE 4500
- WIND

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

P21L





Deep moist layer

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

DATA SELECTION SNAPSHOTS

PRIVACY

Site Manager: Svetia M Hristova-Veleva

TC-IDEAS

Observation Data

September 2010

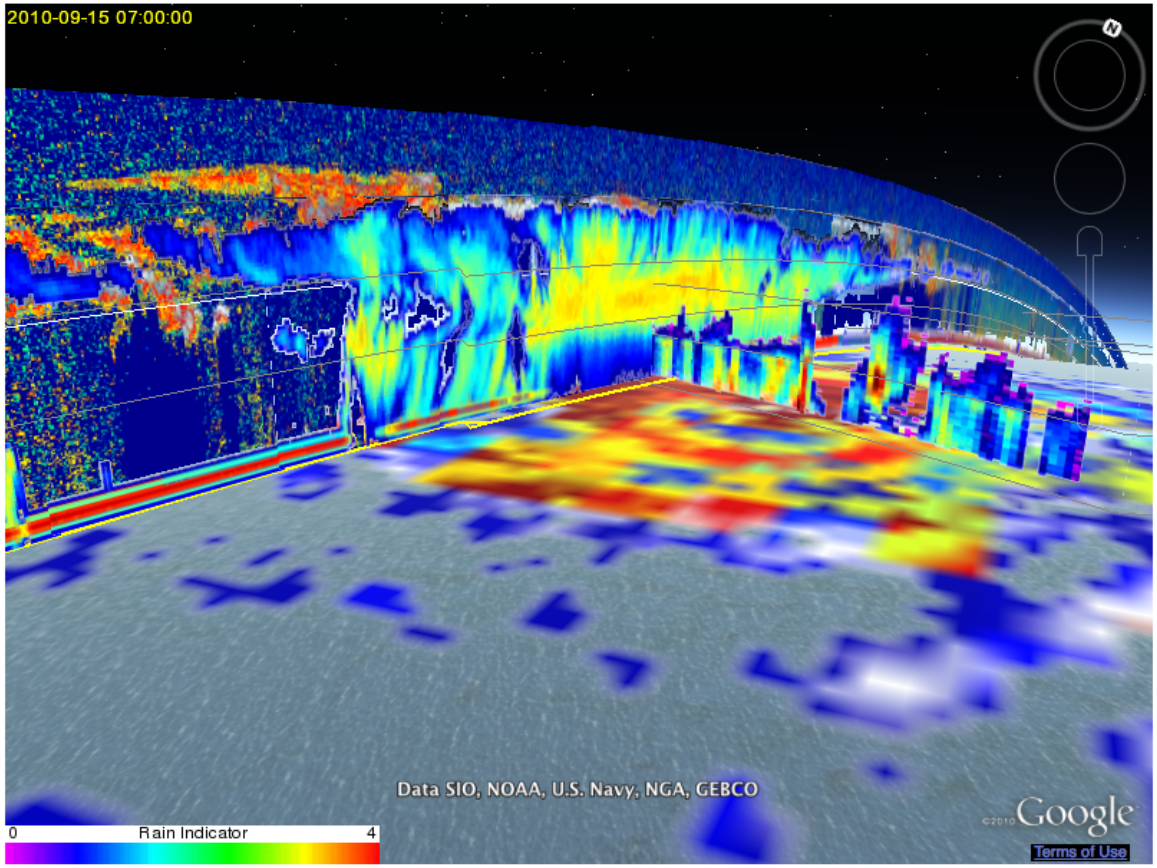
Su	M	T	W	Th	F	S
			01	02	03	04
05	06	07	08	09	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

<< < > >>

At hour: 07:00:00

- STORM TRACKS
  - Best Tracks
  - Pouch Tracks
    - PGI41L
    - PGI43L
    - PGI44L
    - PGI45L
- 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
  - 85HGHZ
  - 37HGHZ
  - 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

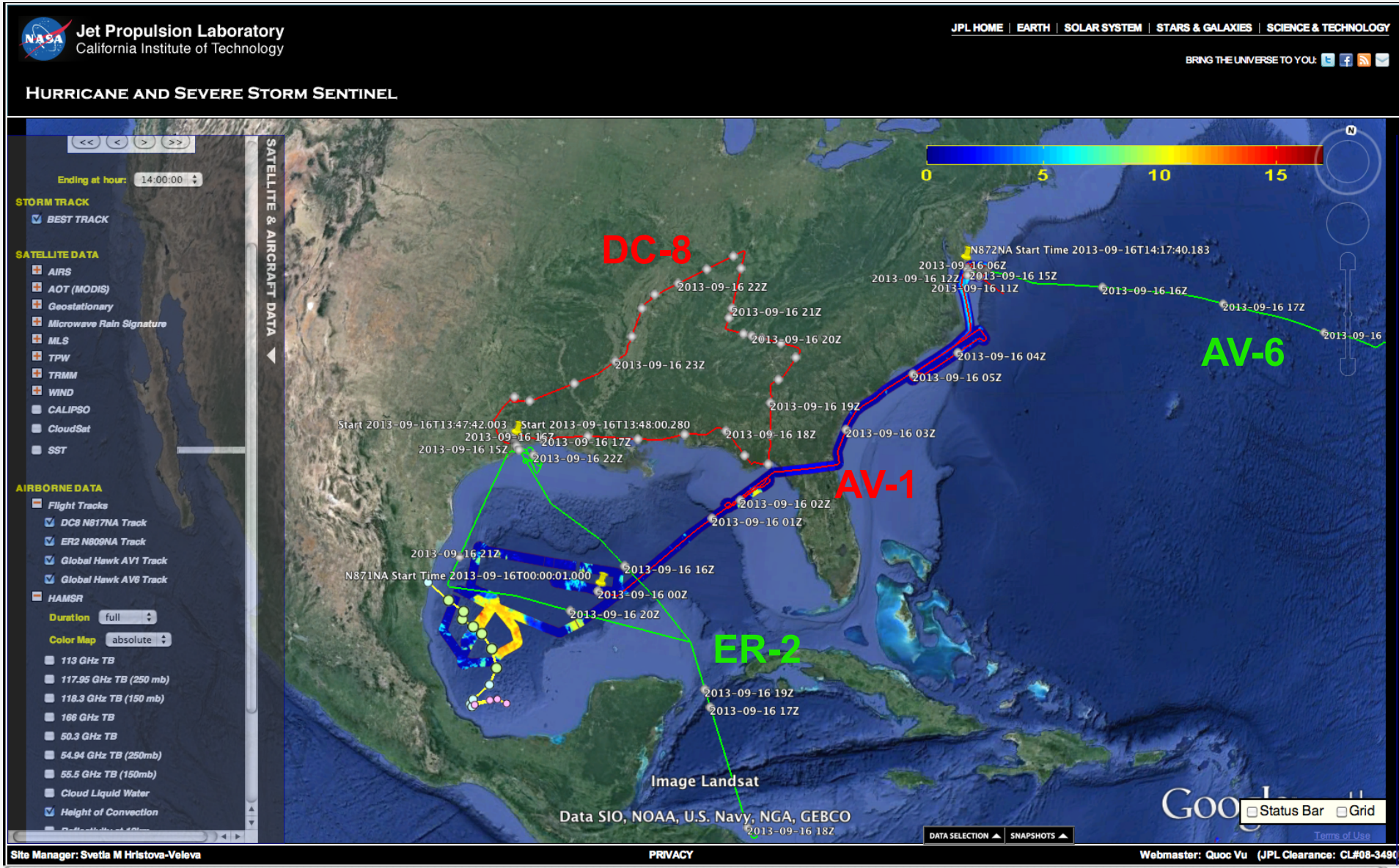
September 2010

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		

<< < > >>

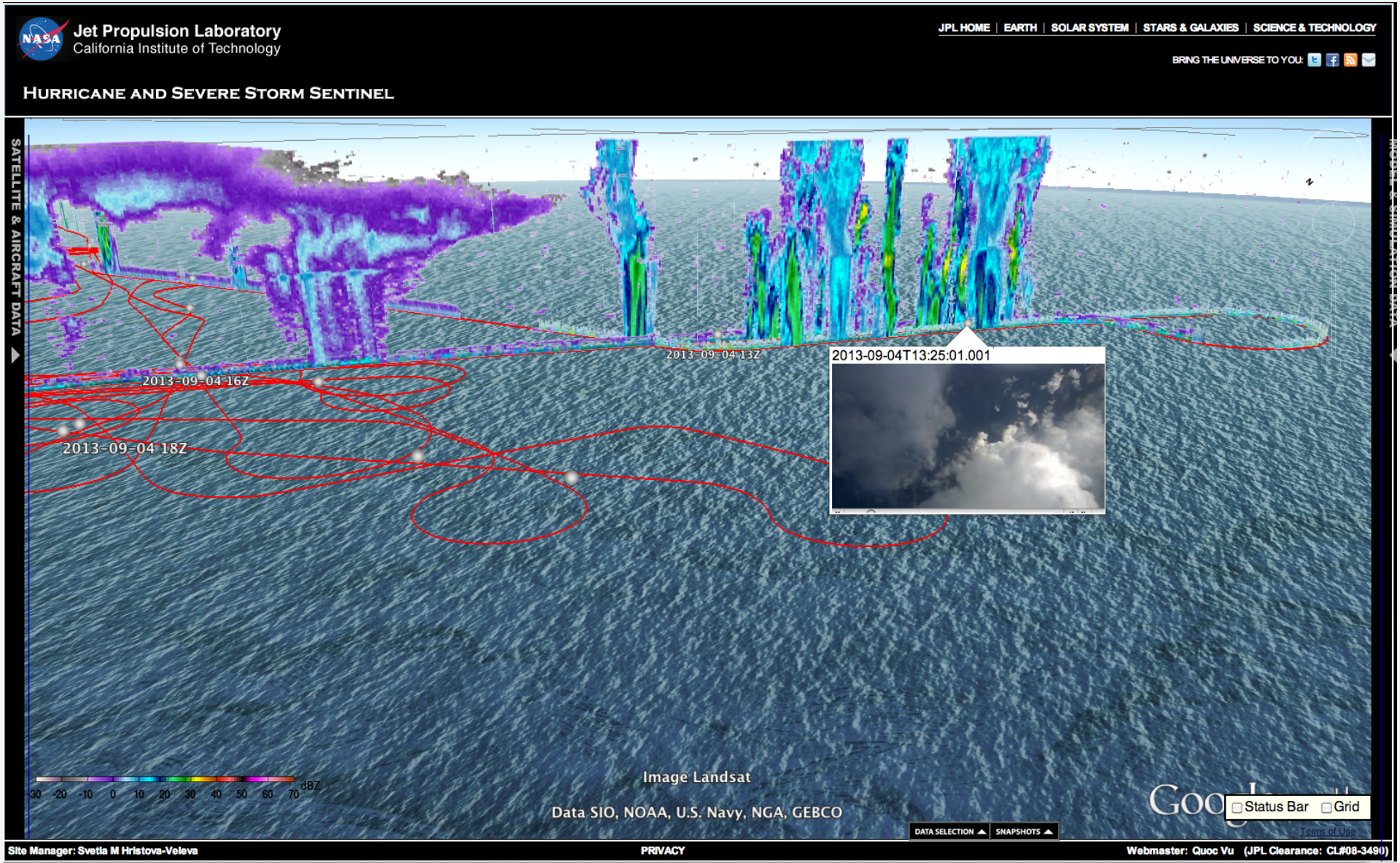
- MODEL DATA
  - Pressure Level: 850
  - Forecast Time: 000
  - GFS
    - Speed Earth Relative
    - Streamline Earth Relative
    - PGI41L
    - PGI43L
    - PGI44L
    - PGI45L
    - PGI46L
    - Relative Humidity
    - OW
    - Vorticity
    - Deep shear
    - Pouch shear
    - Sea Level Pressure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

Airborne Science: HS3 and SEAC4RS
2013-09-16; 14Z - Ingrid;
AV-1 (HAMSR), AV-6, ER2, DC8



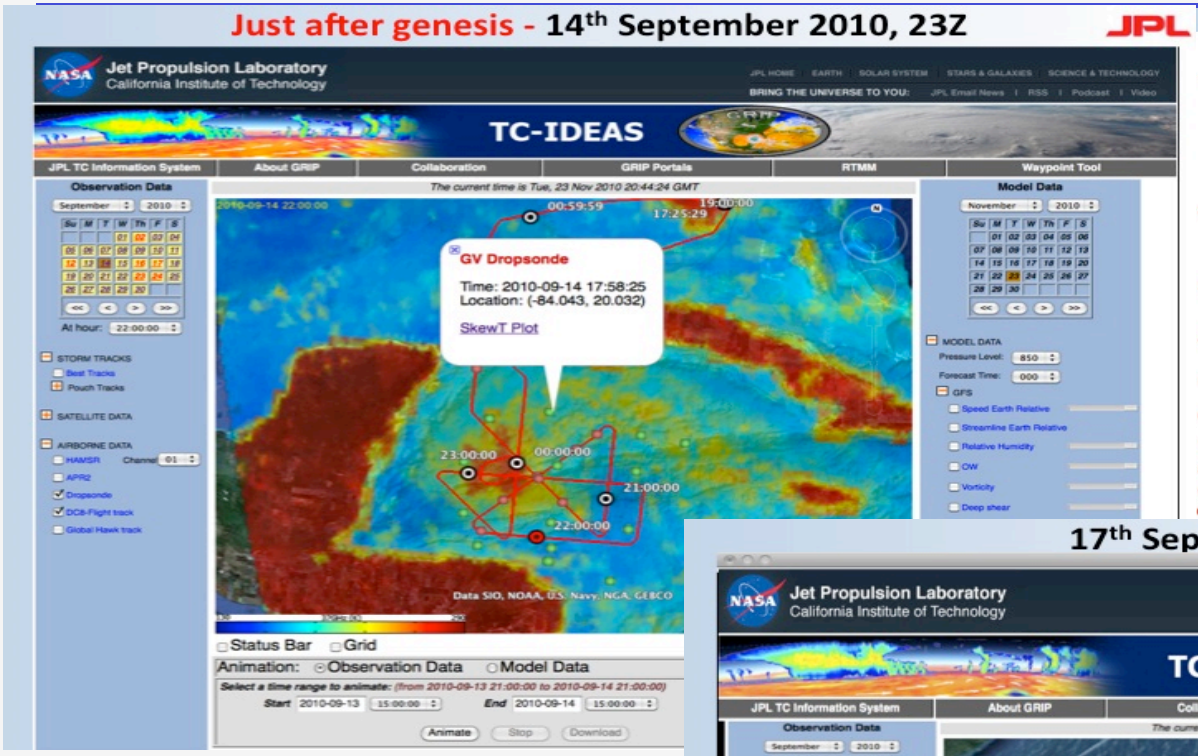
Airborne Science: SEAC4RS–2013-09-04; 14Z

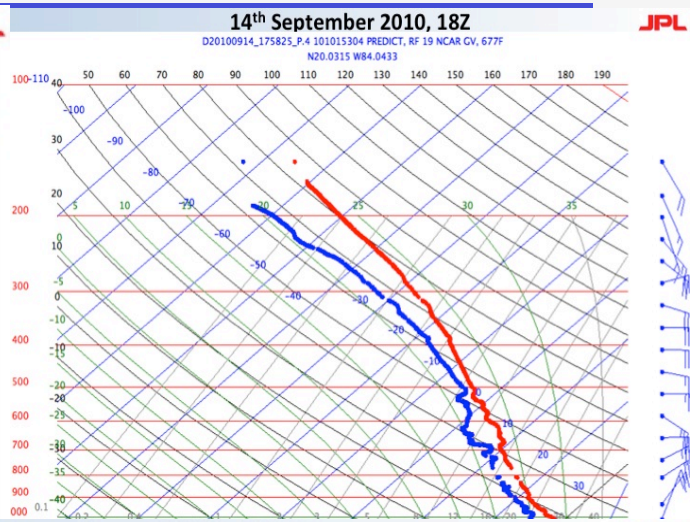
Vertical Cross-section from APR-2 (on DC-8); Nadir-viewing Camera Movies

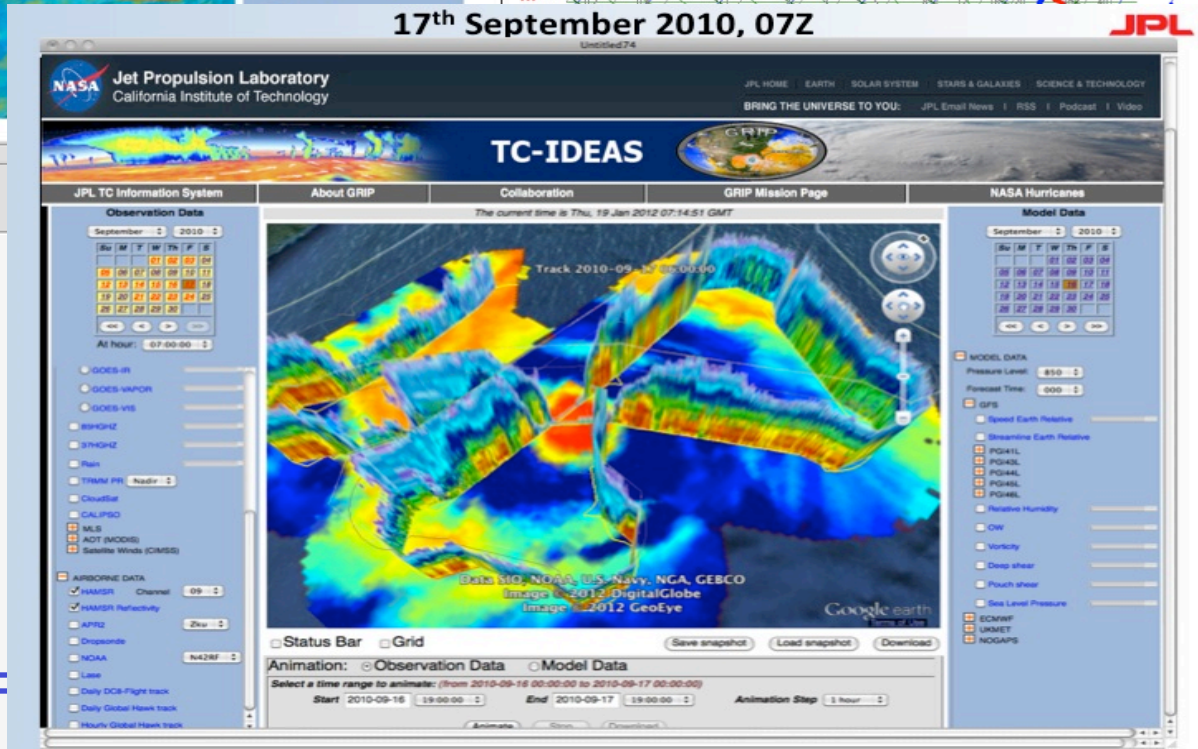


GRIP Portal – NRT in 2010, Atlantic – http://grip.jpl.nasa.gov

The Airborne Observations







Hurricane Karl:

Genesis and Rapid Intensification from

- **satellite,**
- **airborne and**
- **in-situ observations**

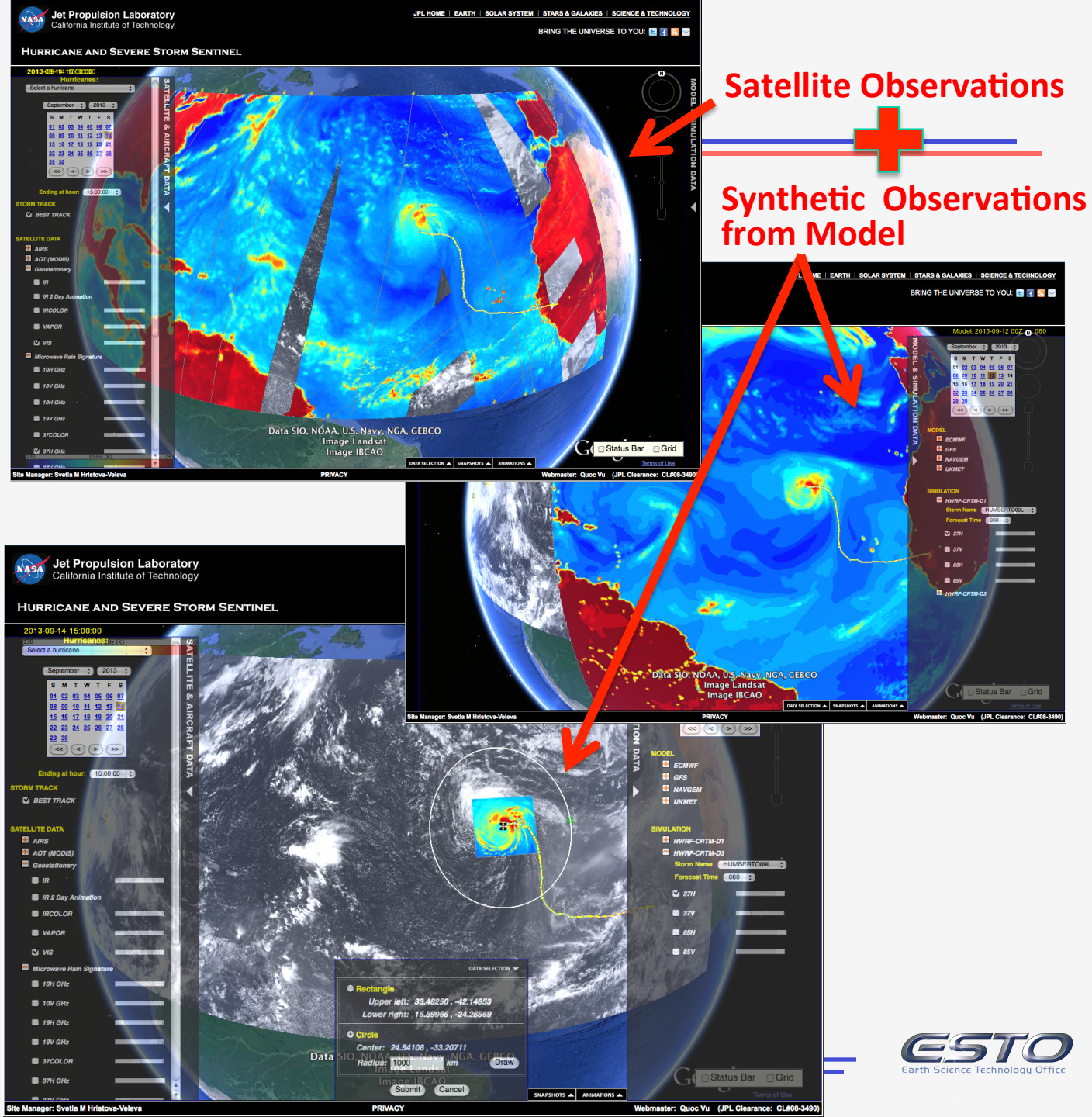
FUSION OF MODELS AND OBSERVATIONS - OPERATIONALLY

Operational HWRF model forecasts are used as input to CRTM

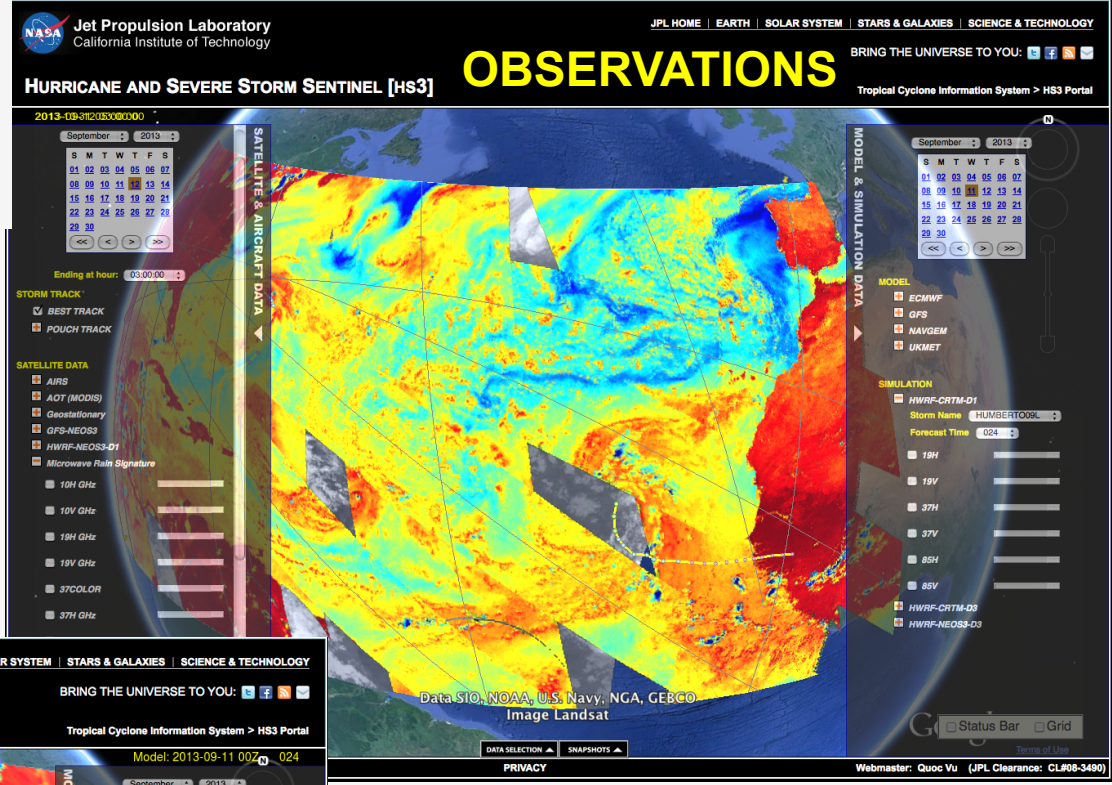
- **Incorporated in the database of satellite obs.**
- **Visualized in the portal**

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^3 and CRTM) will help reveal the uncertainty that comes from the forward modeling itself.

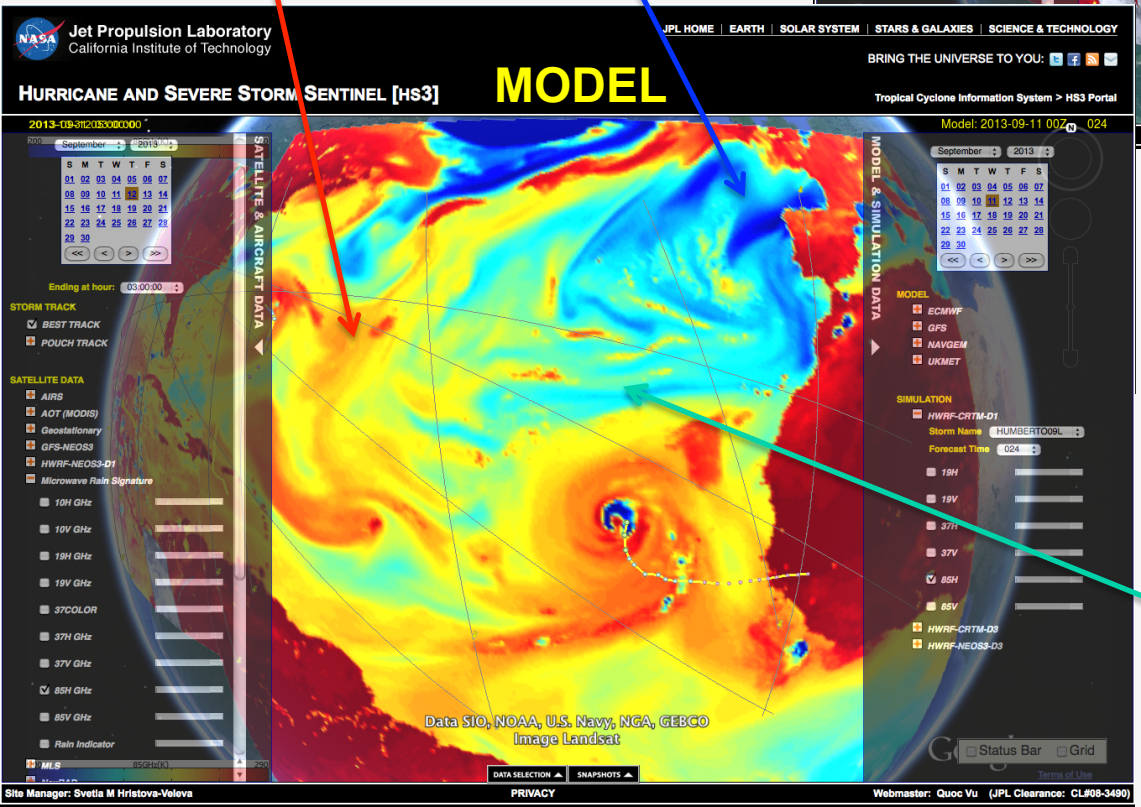


ESTO
Earth Science Technology Office



DRY AIR

MOIST AIR



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

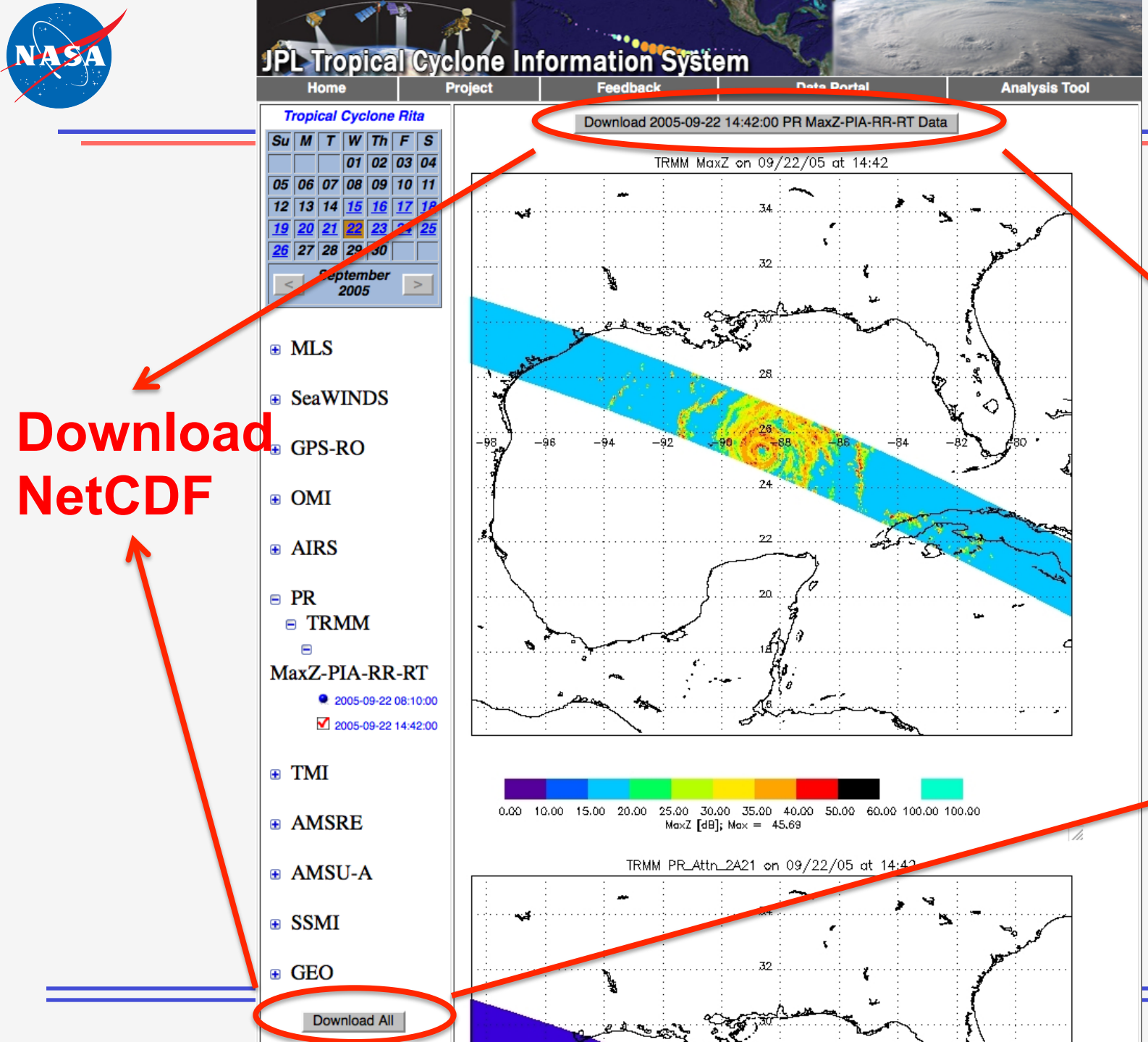
- **From:** Tomislava Vukicevic <Tomislava.Vukicevic@noaa.gov>
- **Date:** Saturday, December 7, 2013 7:01 PM
- **To:** hristova <svetla.hristova@jpl.nasa.gov>
- **Cc:** gopal <Sundararaman.G.Gopalakrishnan@noaa.gov>, Vijay Tallapragada <vijay.tallapragada@noaa.gov>, "Montgomery, Michael (Mike) (CIV)" <mtmontgo@nps.edu>, "Boothe, Mark (CIV)" <maboothe@nps.edu>, "Haddad, Ziad S (334H)" <Ziad.S.Haddad@jpl.nasa.gov>, Bjorn Lambrigtsen <Bjorn.H.Lambrigtsen@jpl.nasa.gov>, "Turk, Joe (334H)" <Joseph.Turk@jpl.nasa.gov>, "Li, P Peggy (398F)" <p.p.li@jpl.nasa.gov>, "Knosp, Brian W (3284)" <brian.w.knosp@jpl.nasa.gov>, "Tanelli, Simone (334H)" <simone.tanelli@jpl.nasa.gov>, "Niamsuwan, Noppasin (334H)" <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



Download NetCDF

At this time

All data on this day

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