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], V. Tallapragada[3], S. Tanelli[1], S. Trahan[3], J. Turk[1], Q. Vu[1], T. Vukicevic[2]

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

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

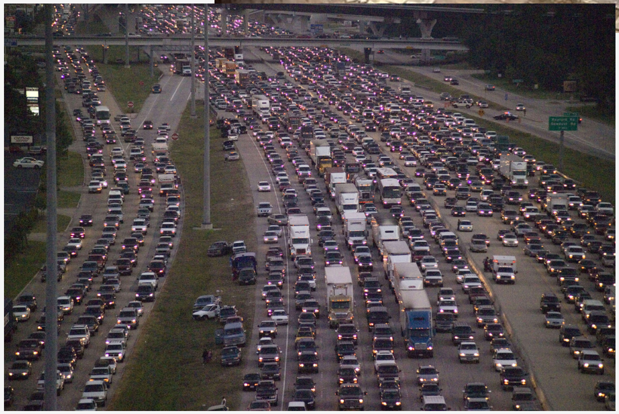
ESTF2014 – October 28th, 2014

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

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

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

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



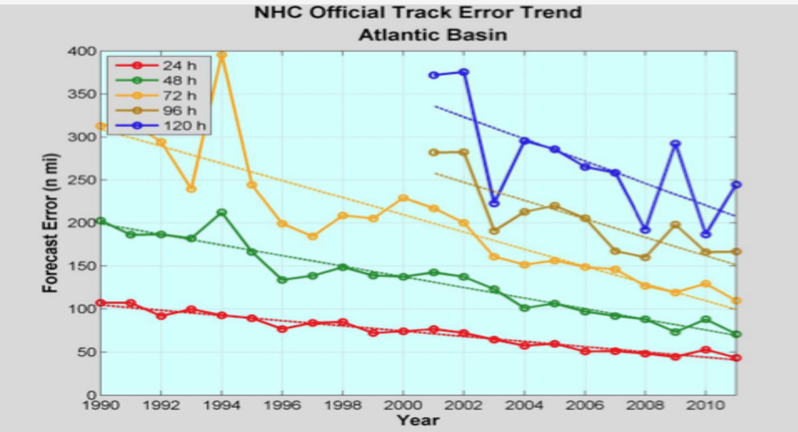
Widespread power outages and subway shutdowns may wind up making **Superstorm Sandy** the second most expensive storm in U.S.

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

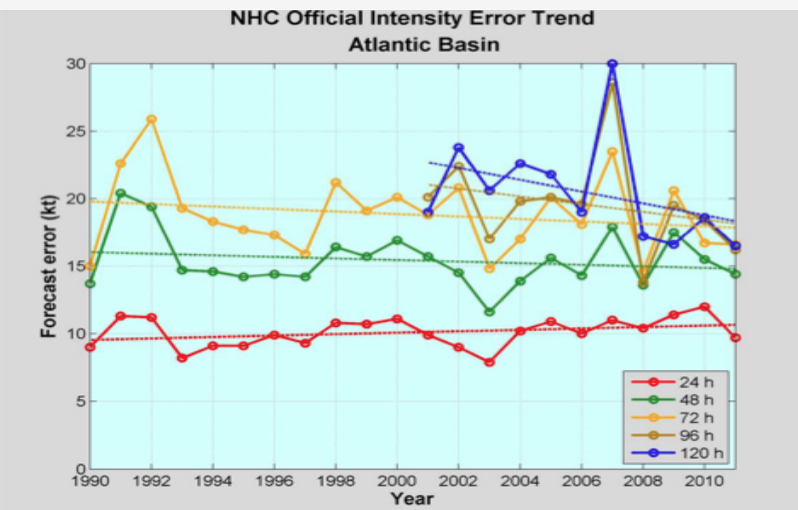
- Some **130,000 died** when a cyclone struck Myanmar along the Andaman Sea in 2008.
- The deadliest U.S. hurricane was the 1900 Galveston storm, which **killed 8,000 to12,000** people and destroyed the city. Katrina (2005) **killed some 1,200 people**, and left hundreds of thousands homeless.
- Sandy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

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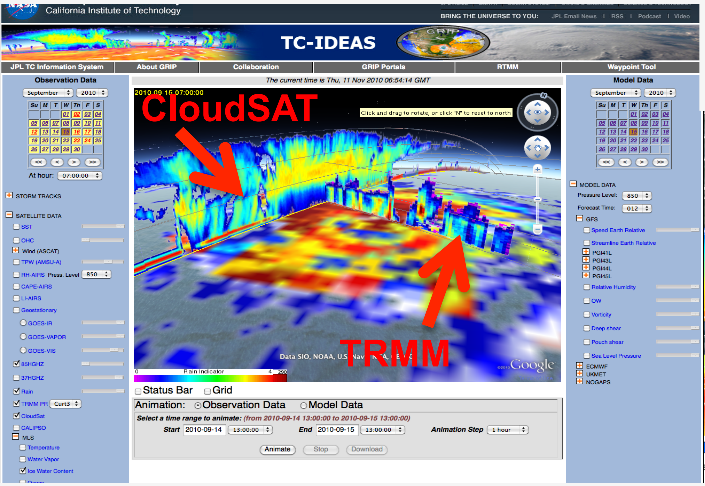
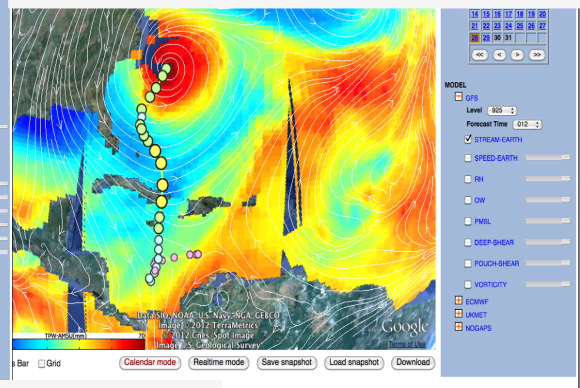
Motivation for our project -
The critical pathways to hurricane forecast improvement

- Is the representation of the precipitation structure correct?



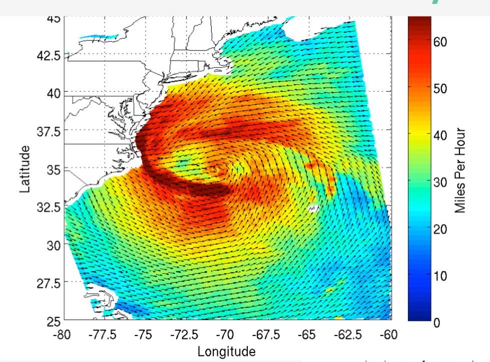
- Is the environment captured correctly?
- Is the interaction between the storm and its environment realistic?



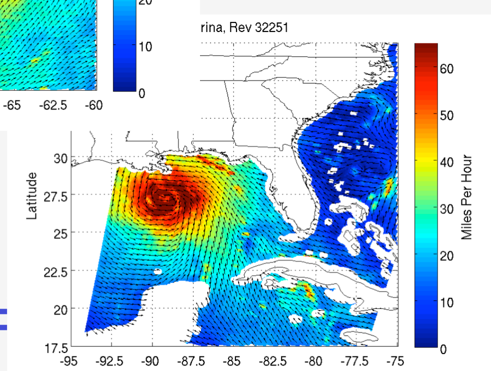
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

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 currentlyand 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.

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The JPL TCIS – Tropical Cyclone Information System

http://tropicalcyclone.jpl.nasa.gov

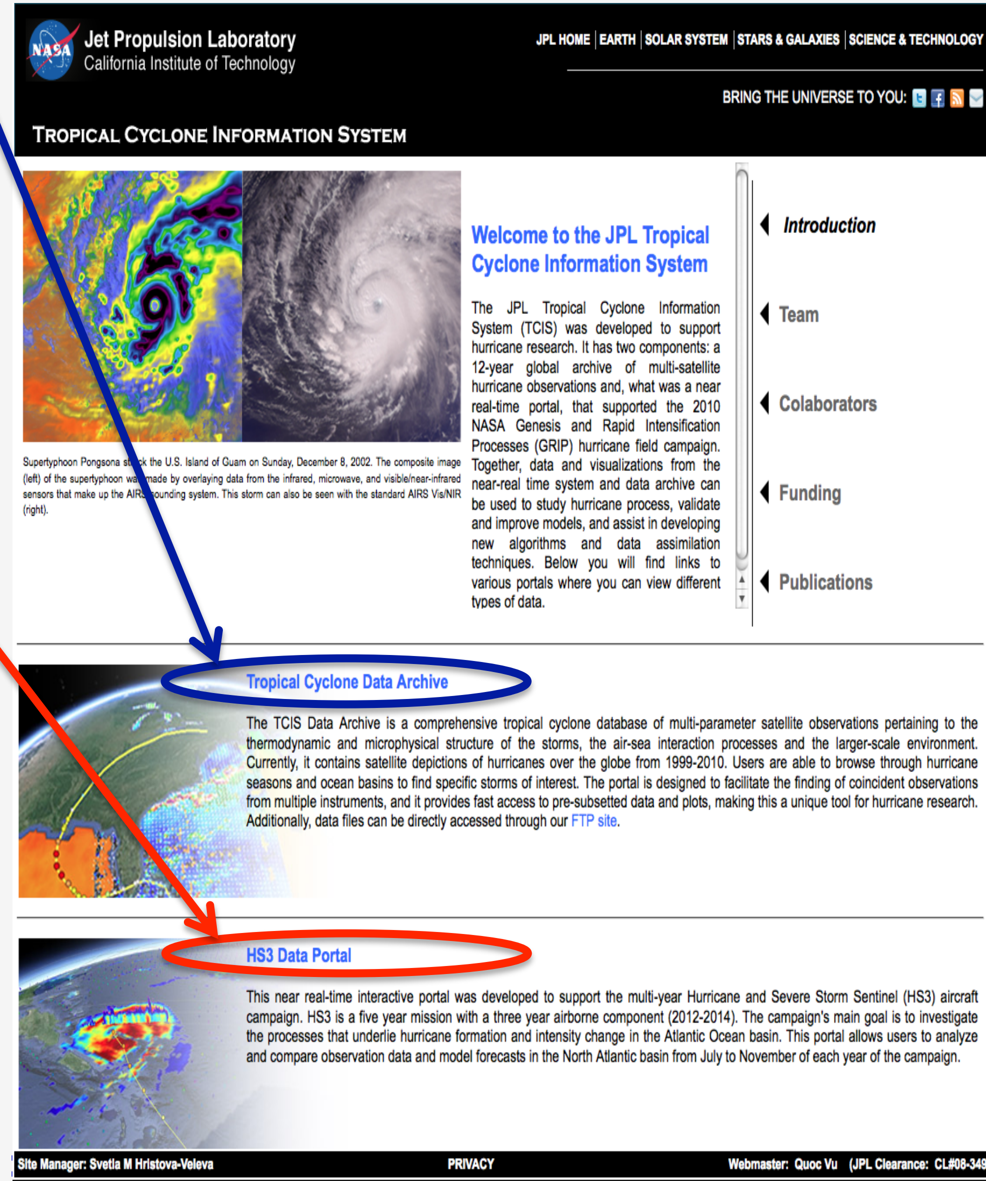
Tropical Cyclone Data Archive

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

HS3 – Interactive NRT Atlantic portal

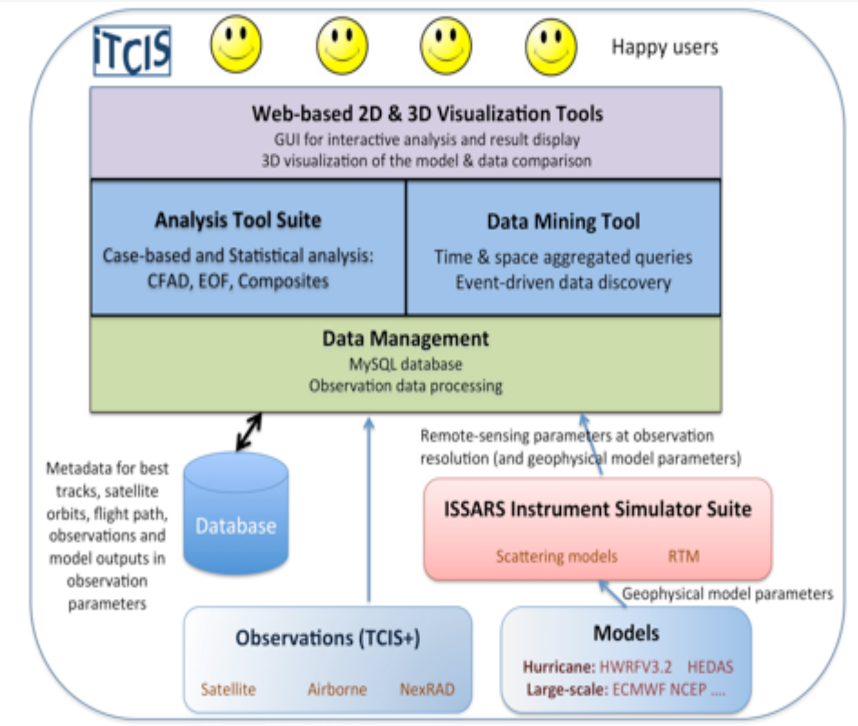
http://tropicalcyclone.jpl.nasa.gov/hs3

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



Goals of our current AIST project

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



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

1) Couple an instrument simulator (NEOS^3) with operational hurricane forecast models and incorporate simulated satellite observables into the existing database of satellite and air-borne observations.

2) Develop set of analysis tools that will enable users to calculate joint statistics, produce composites, compare modeled and observed quantities to facilitate the evaluation of different hurricane models

3) Develop visualization to enable analysis (e.g., data immersion approaches to enable real-time interaction with the models, and visualization of highly complex systems)

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Outline

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

2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators

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

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

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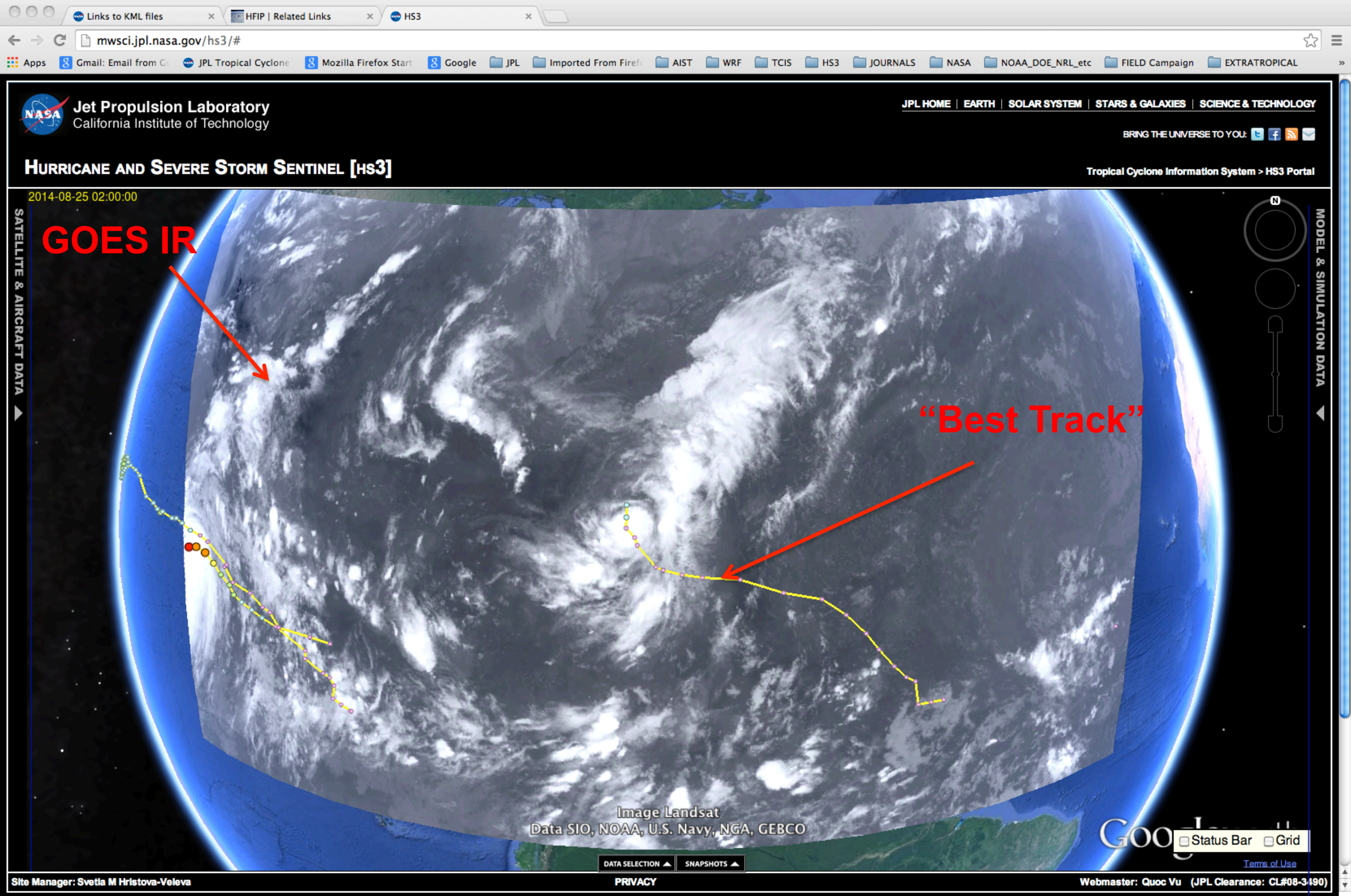
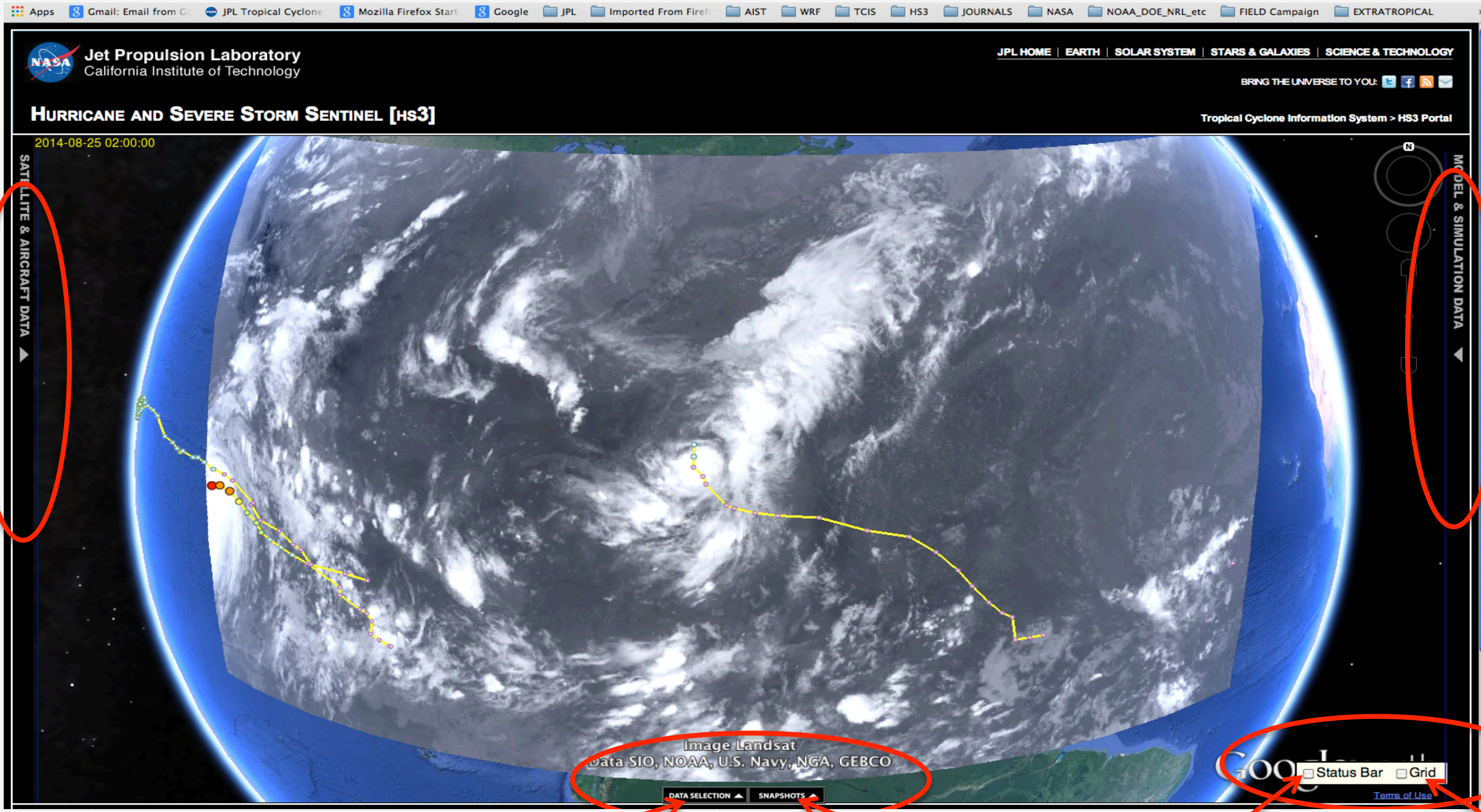
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
Features (needs Google Earth API; opens on the latest available PMW observations)



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

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

- Observations - Model data



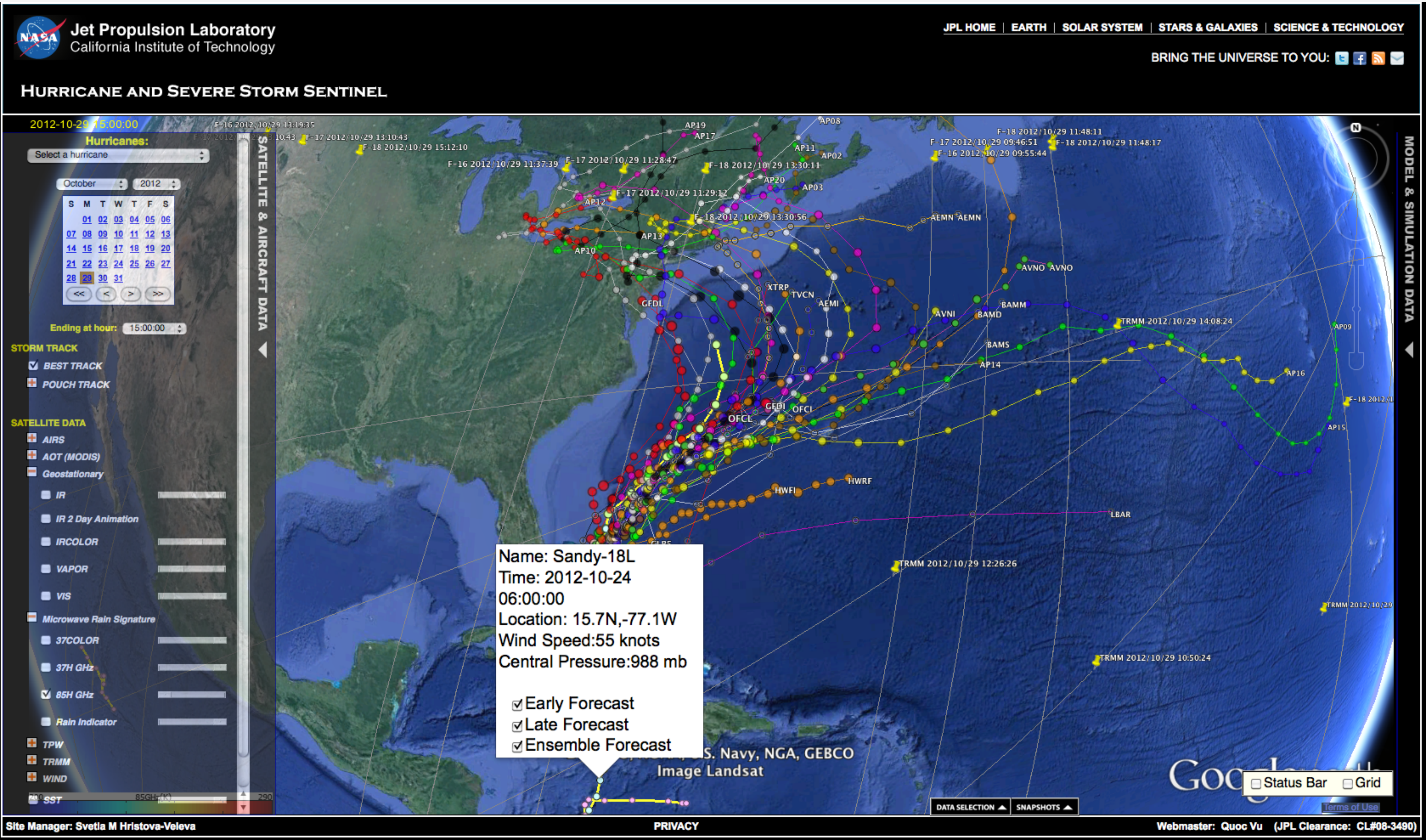
Analysis Tools

Save a view

Overlay Grid

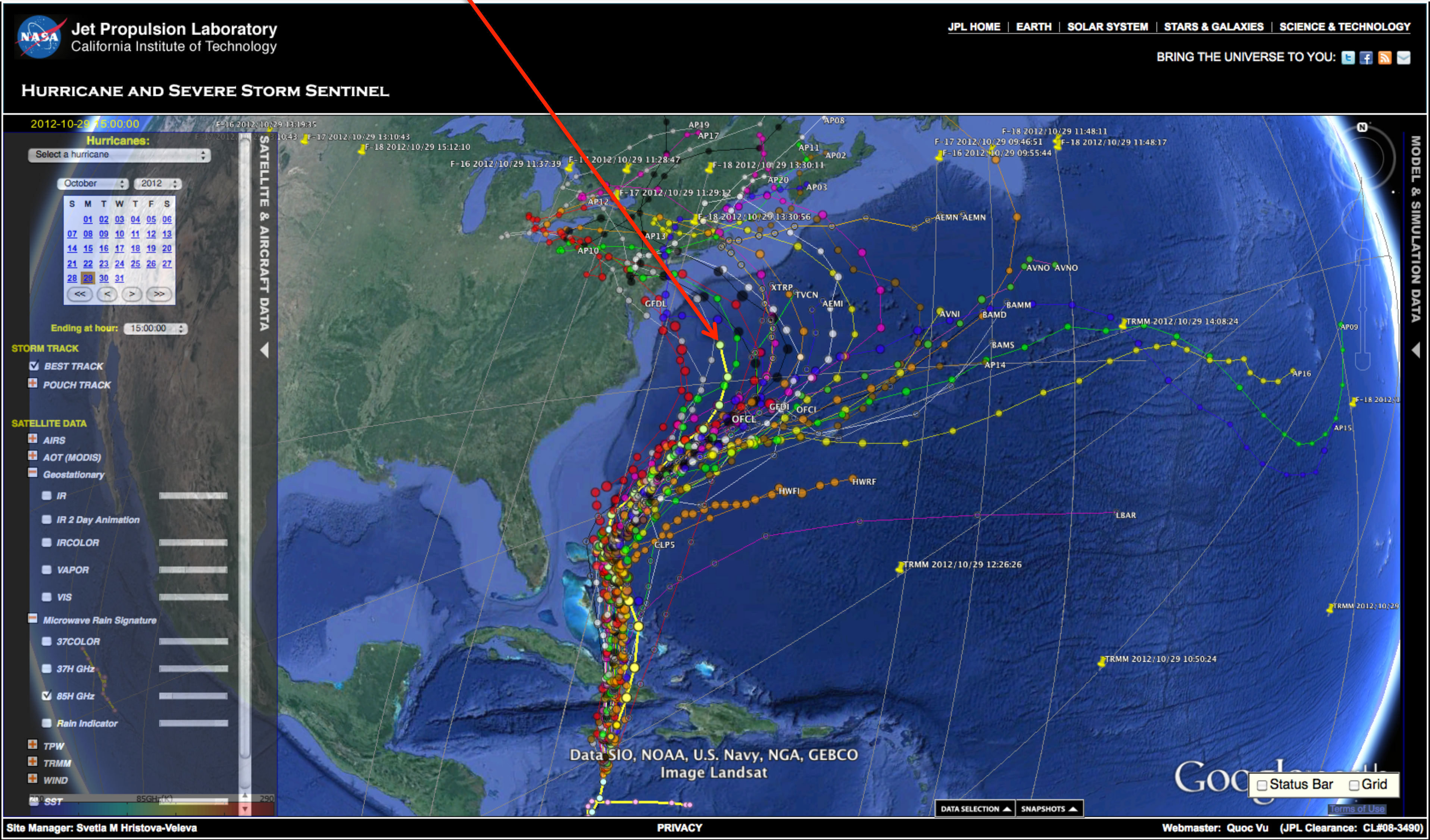
Find lat/lon of a point

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



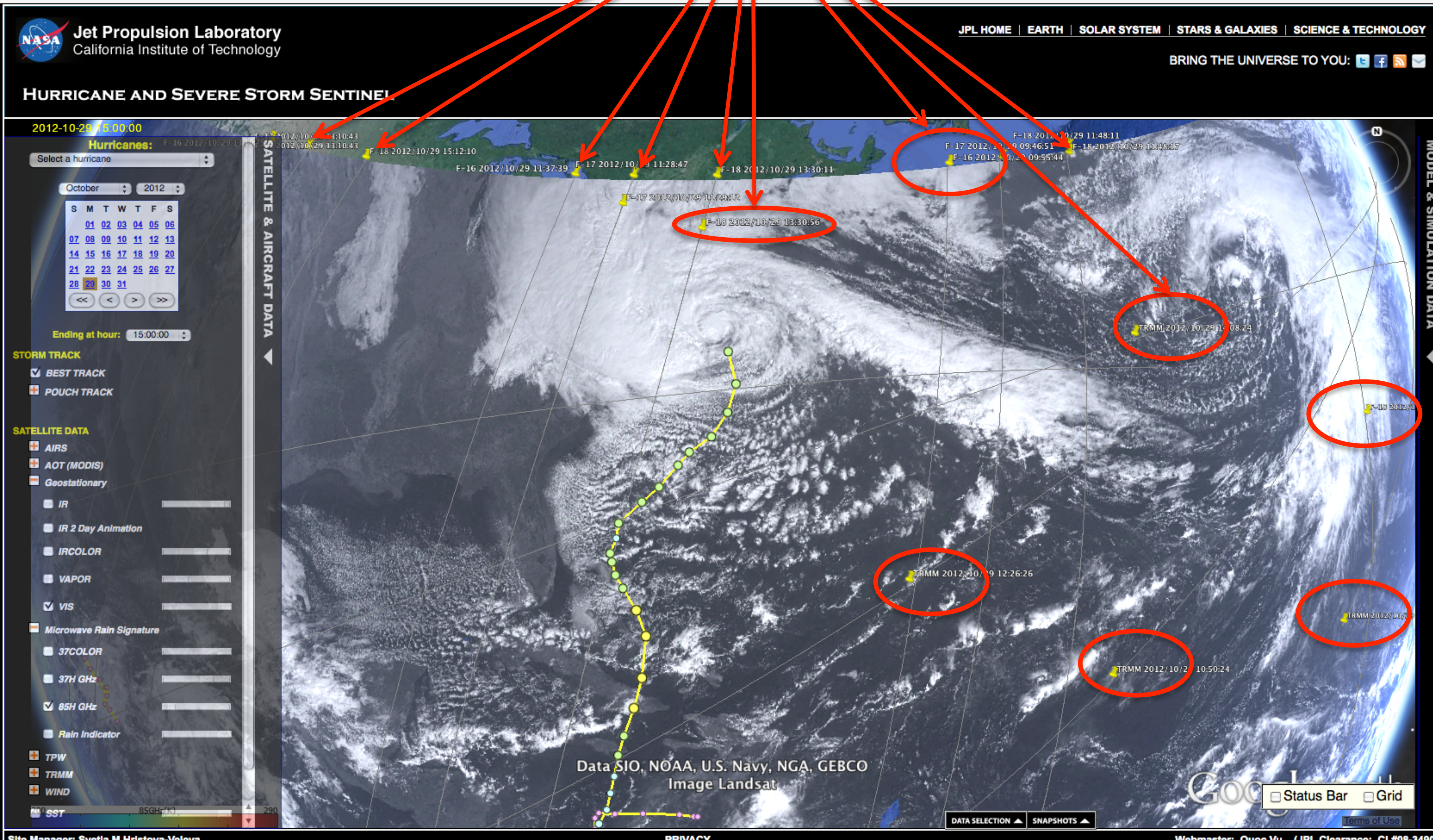
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
Forecast Uncertainty 5 days out - Hurricane Sandy (2012)

Best Track

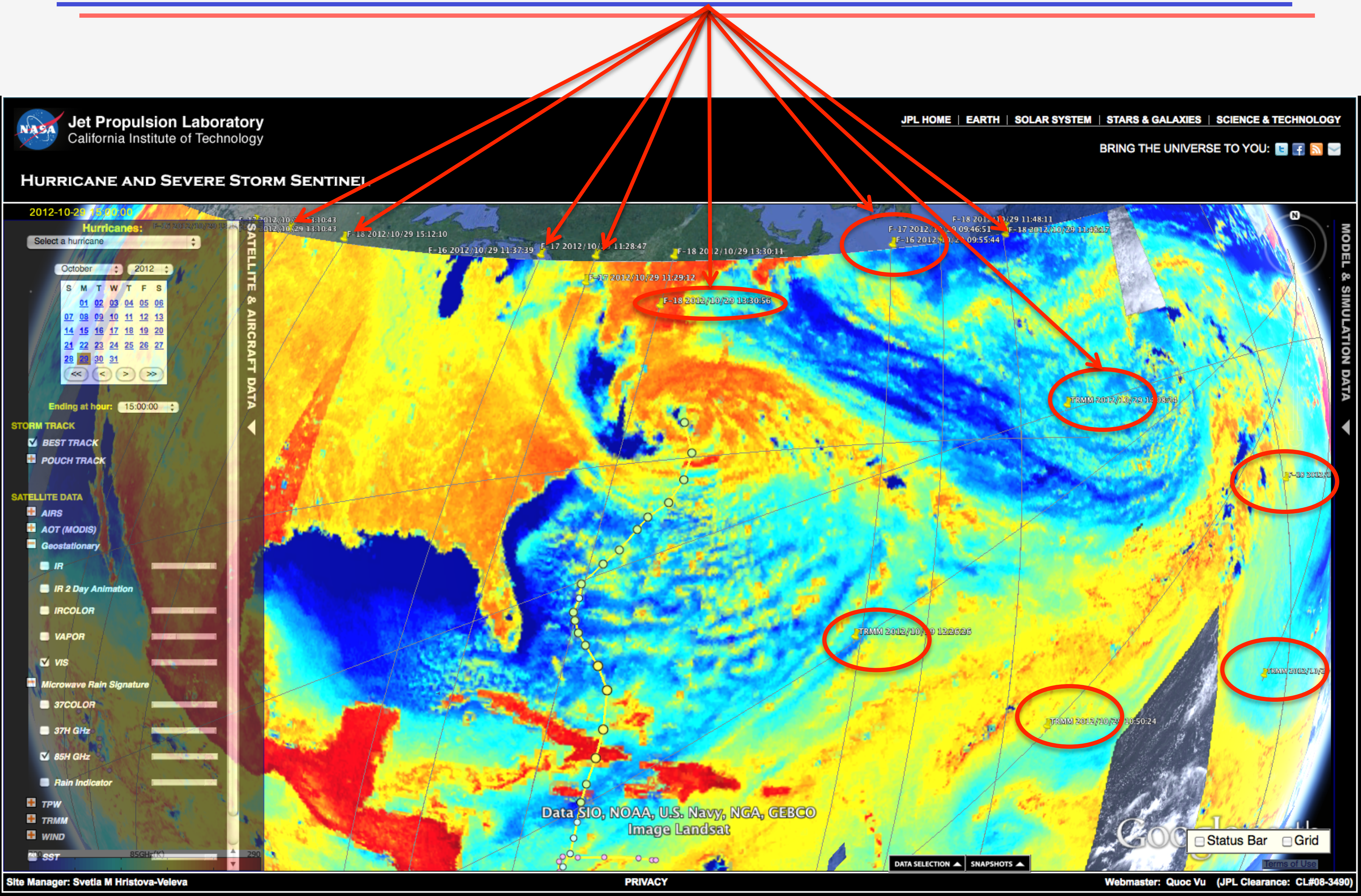


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The Power of the Satellite Observations – Hurricane Sandy (2012)

Note the multitude of Polar Orbiting Satellites that supplement GEOS observations



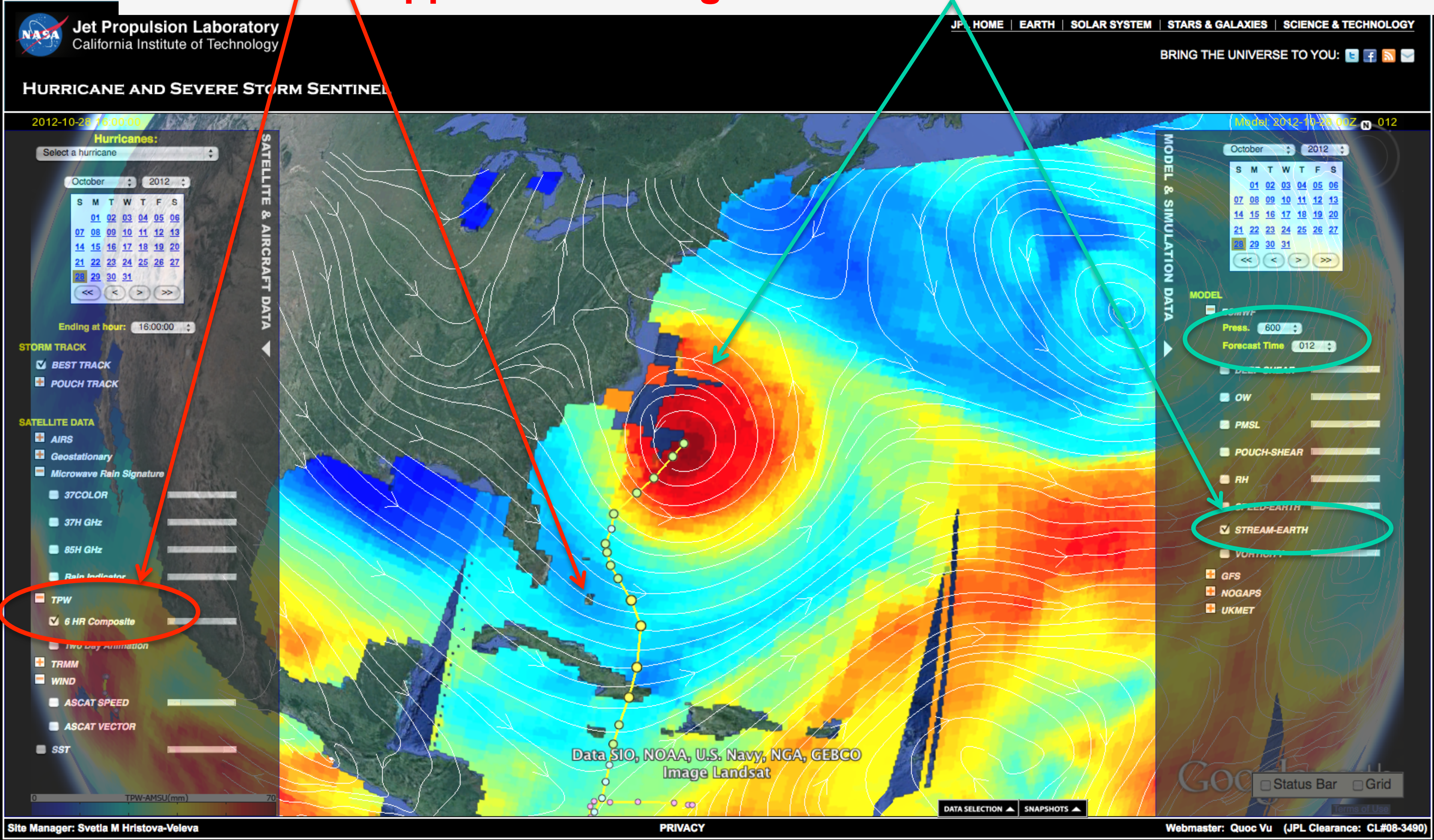
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The Power of the Satellite Observations – painted in microwave



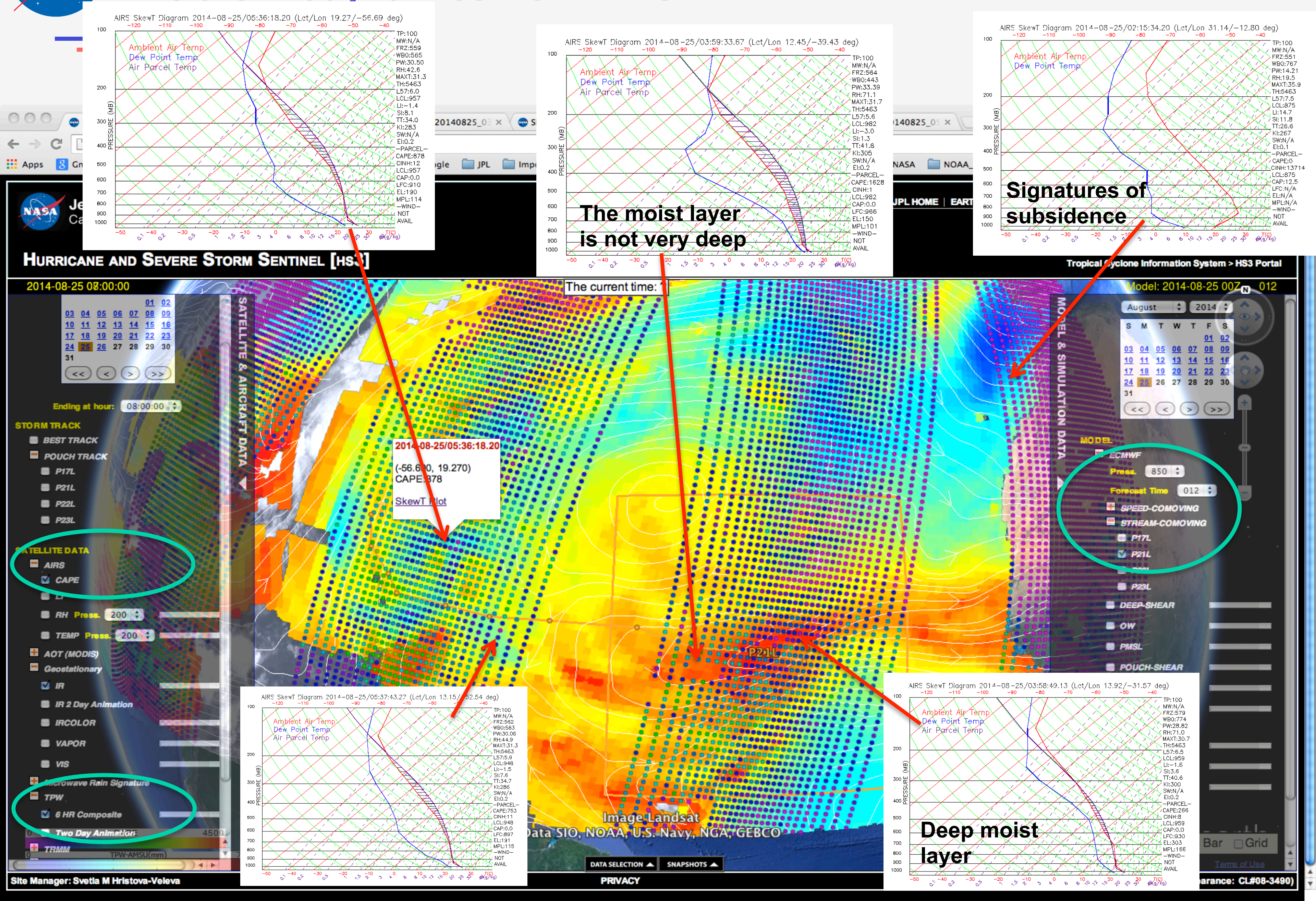
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

Bringing model and observations together:

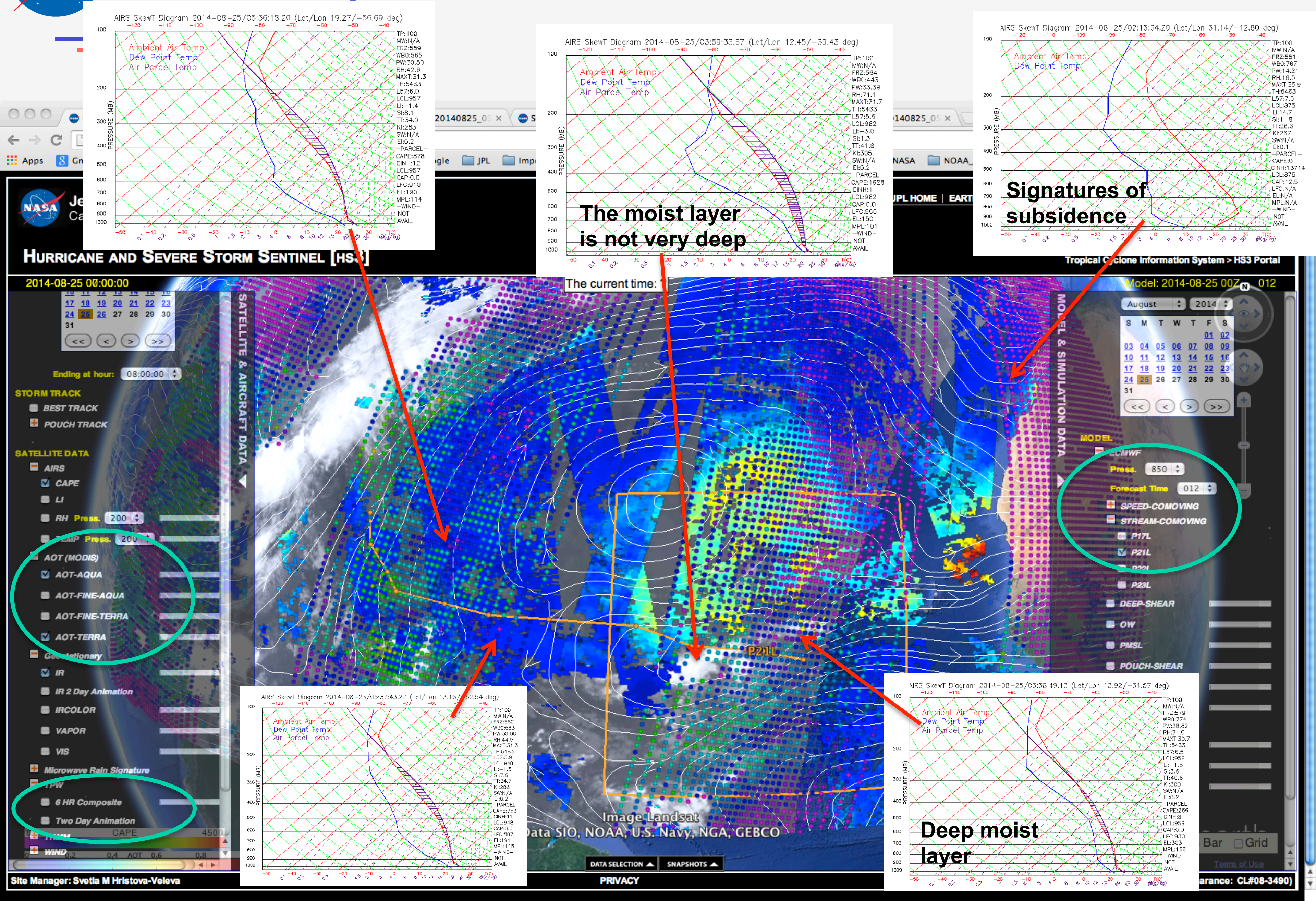
- Is the dry air in the environment (low TPW, from satellite observations) entering the storm ???
- It does not appear so looking at the midlevel flow from the model.



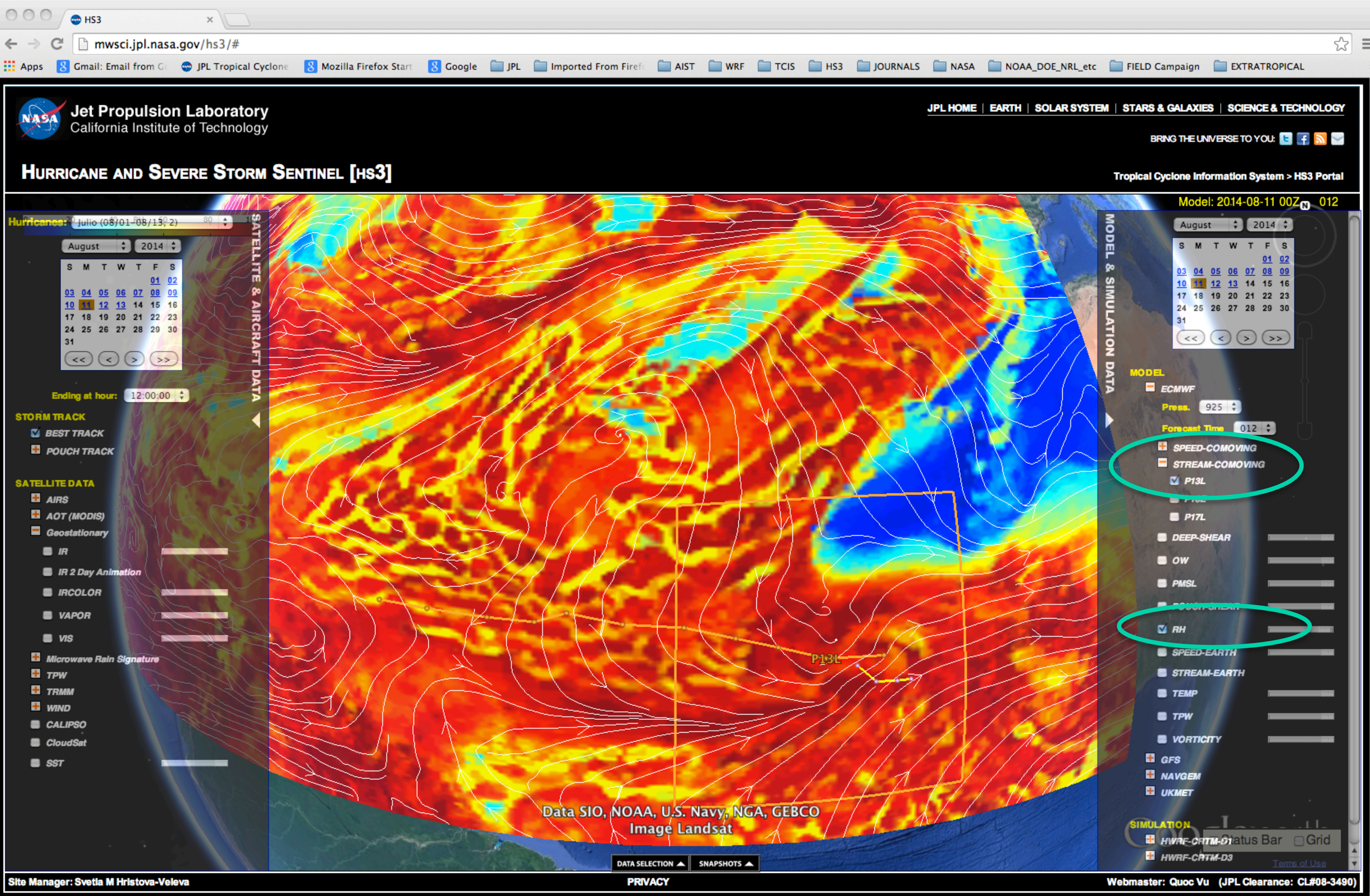
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The thermodynamics from AIRS



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



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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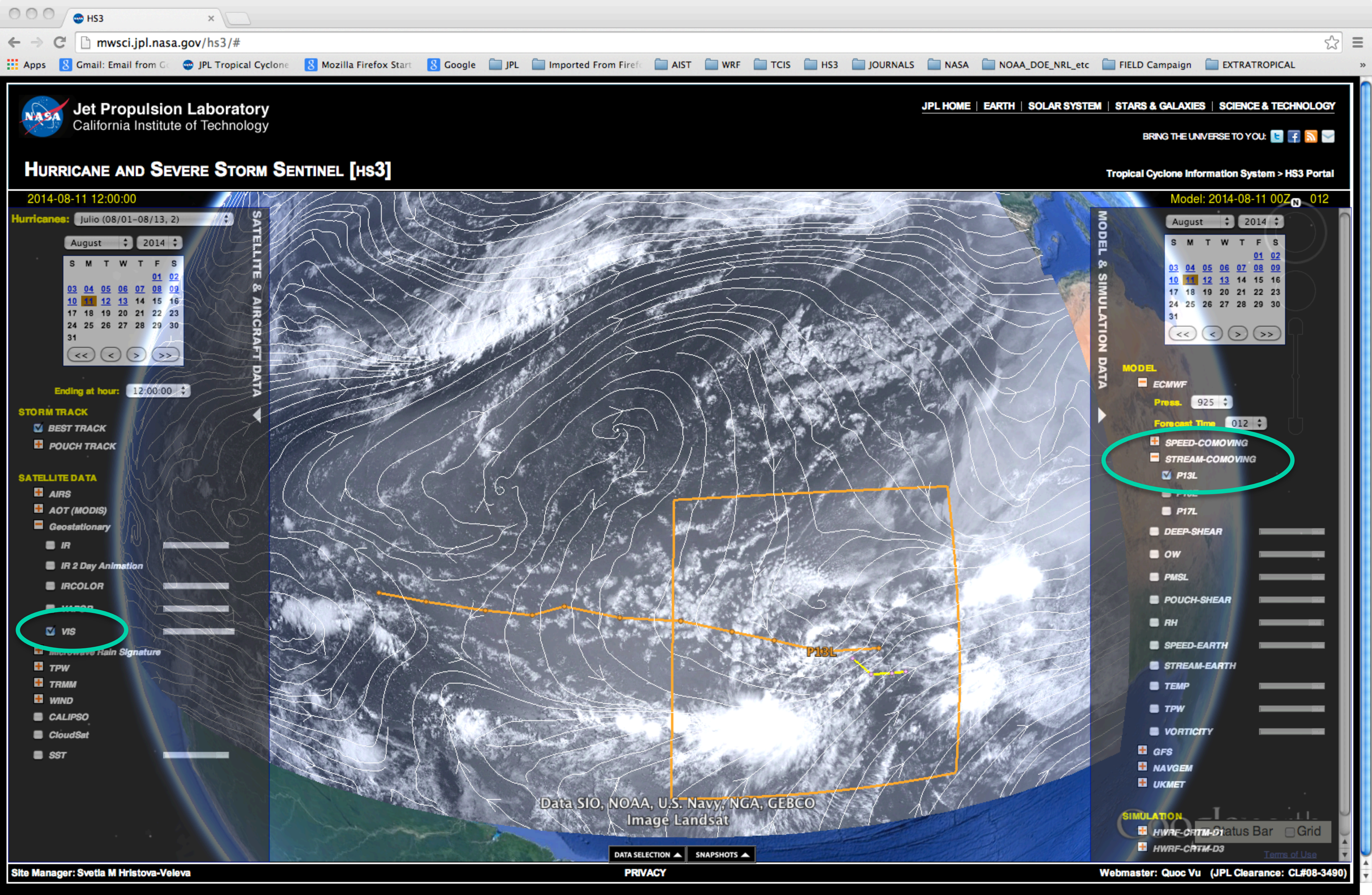
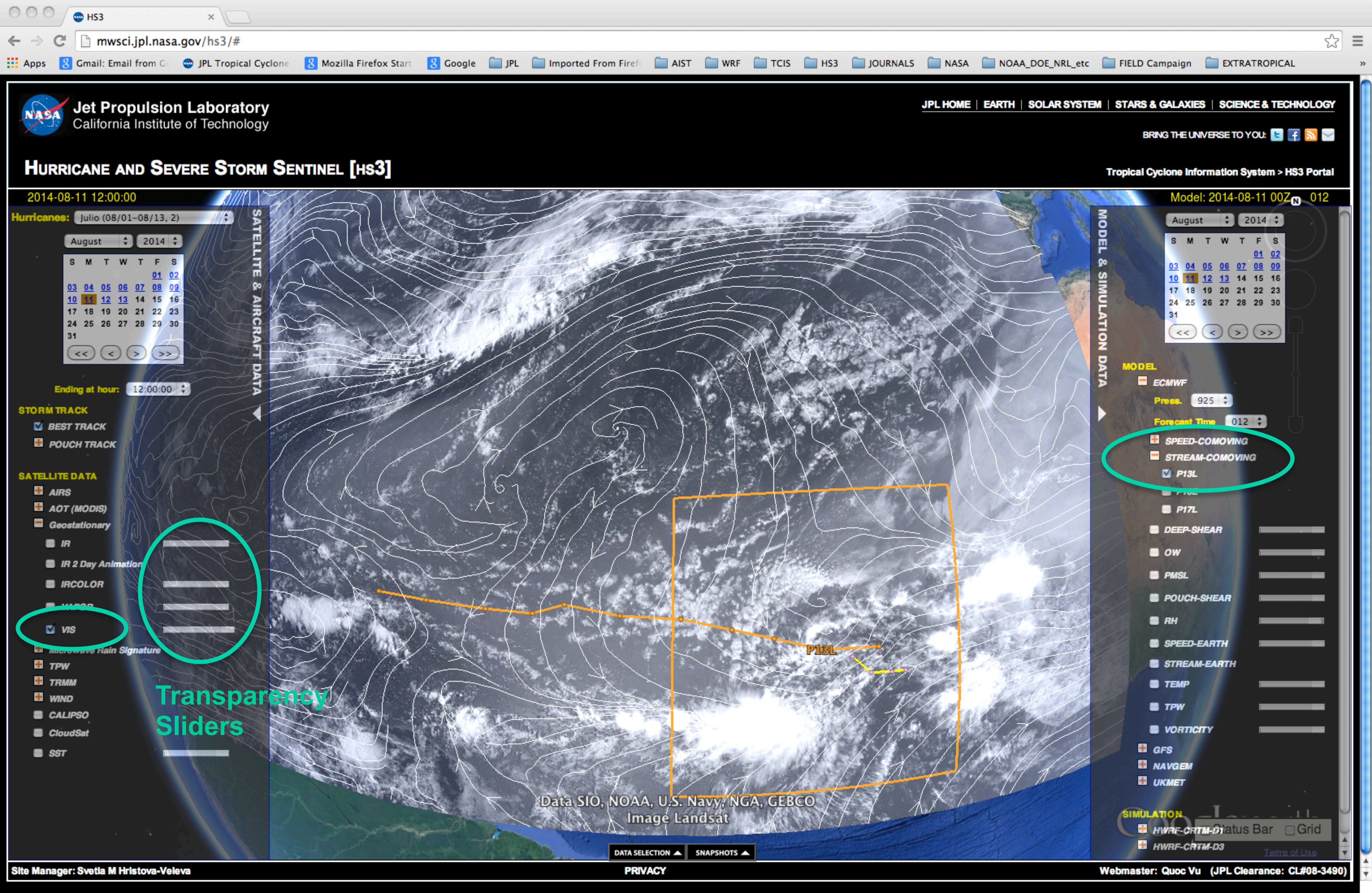


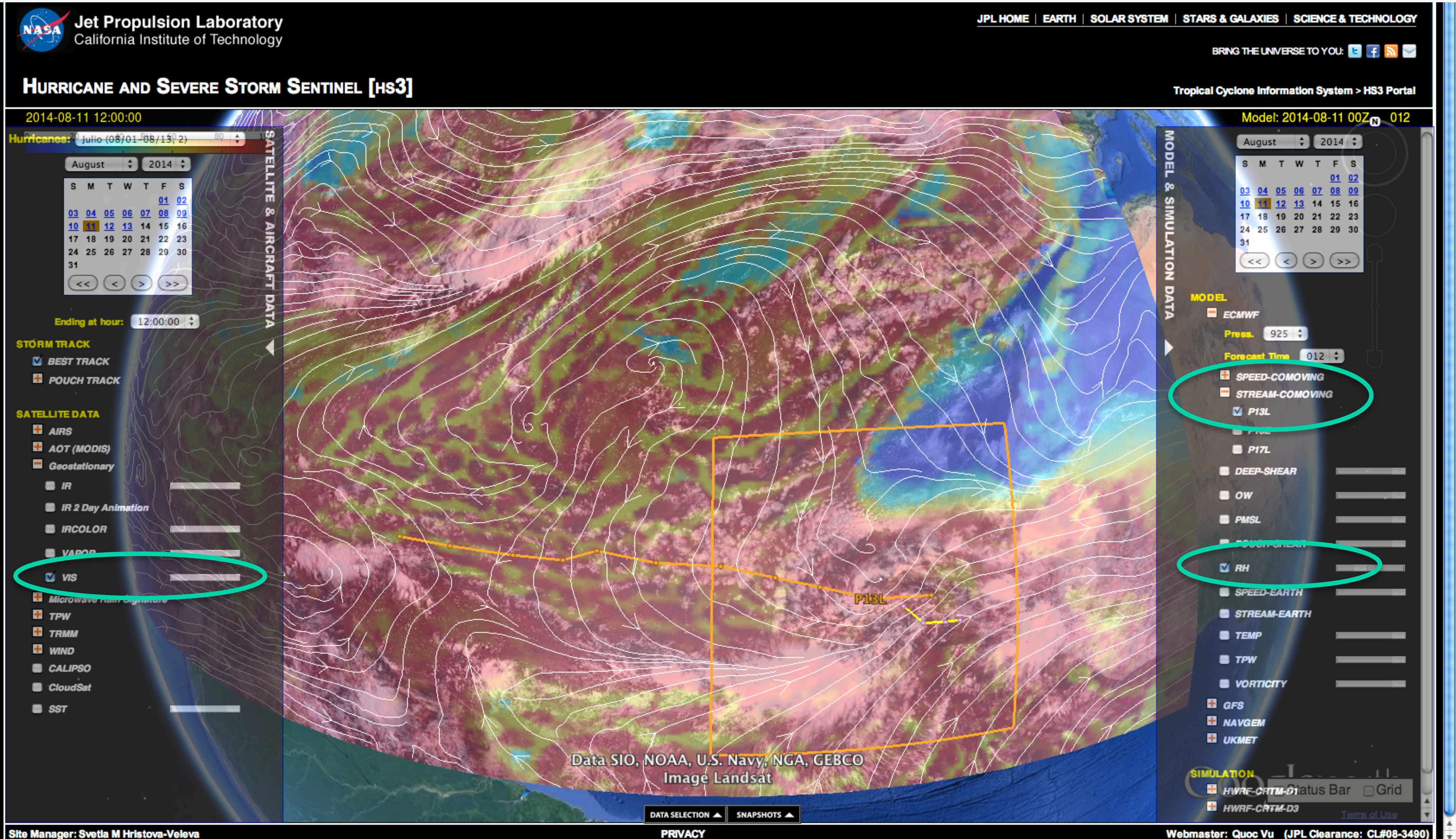
Understanding what is this structure in the model – Tim Dunkerton called it "leopard's fur" pattern in ecmwf RH in the boundary layer



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).



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TC-IDEAS

GRIP

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		

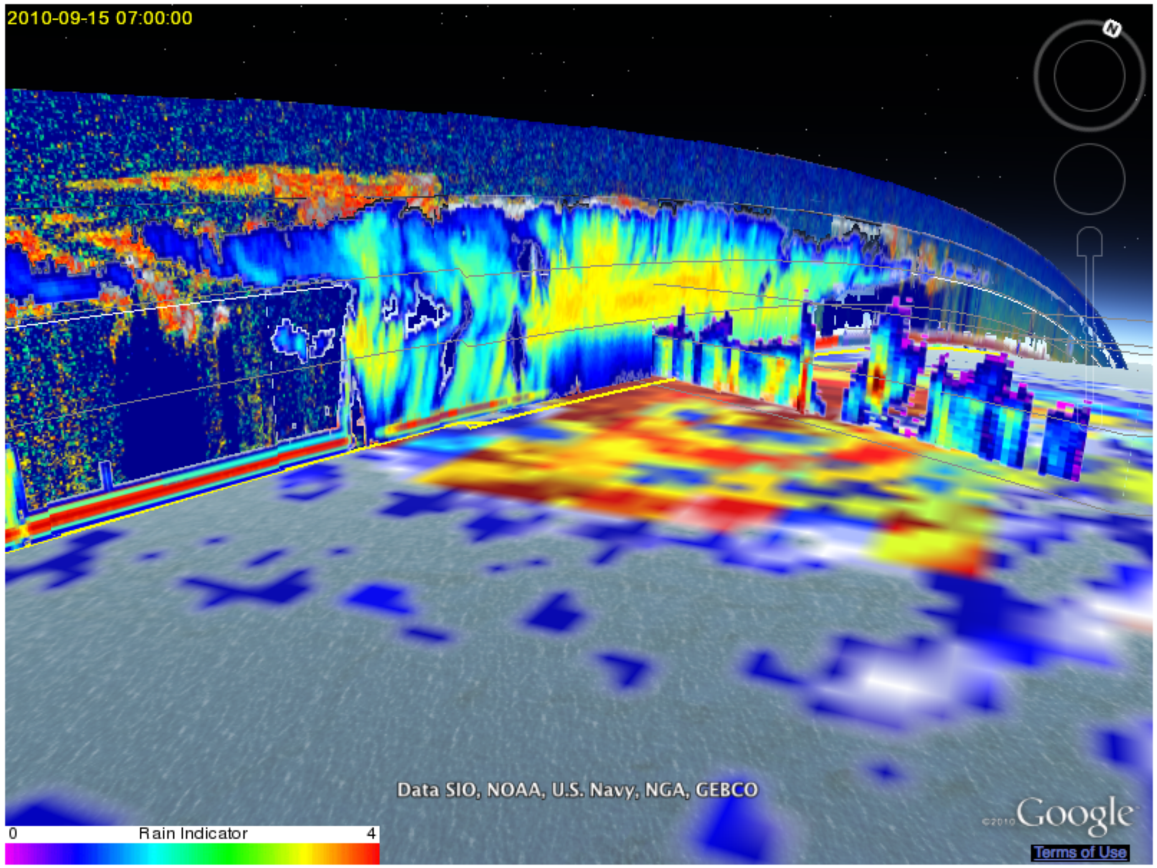
<< < > >>

At hour: 07:00:00

STORM TRACKS
- Best Tracks
- Pouch Tracks
  - 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		

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MODEL DATA

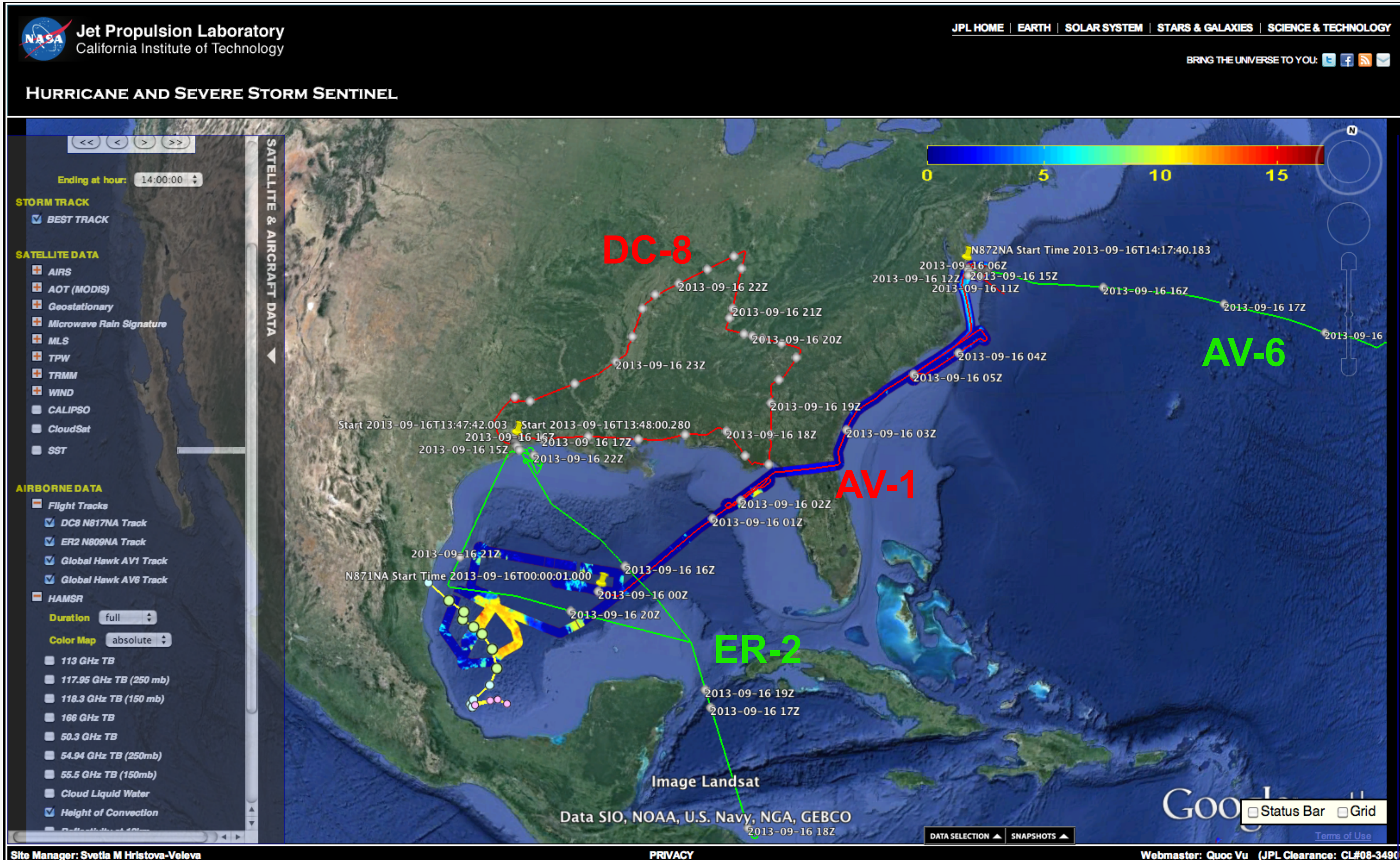
Pressure Level: 850

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

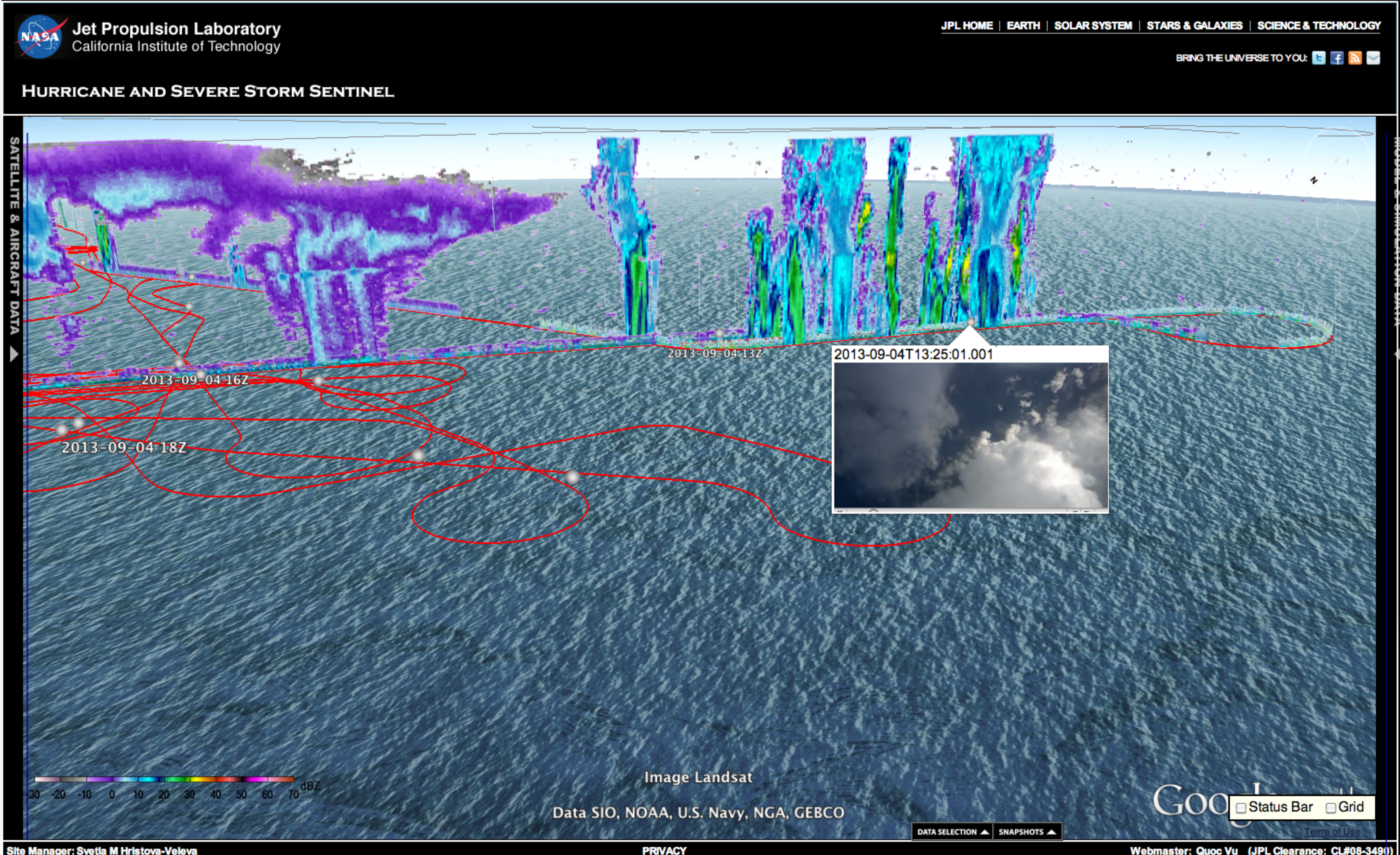
ECMWF
UKMET
NOGAPS

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



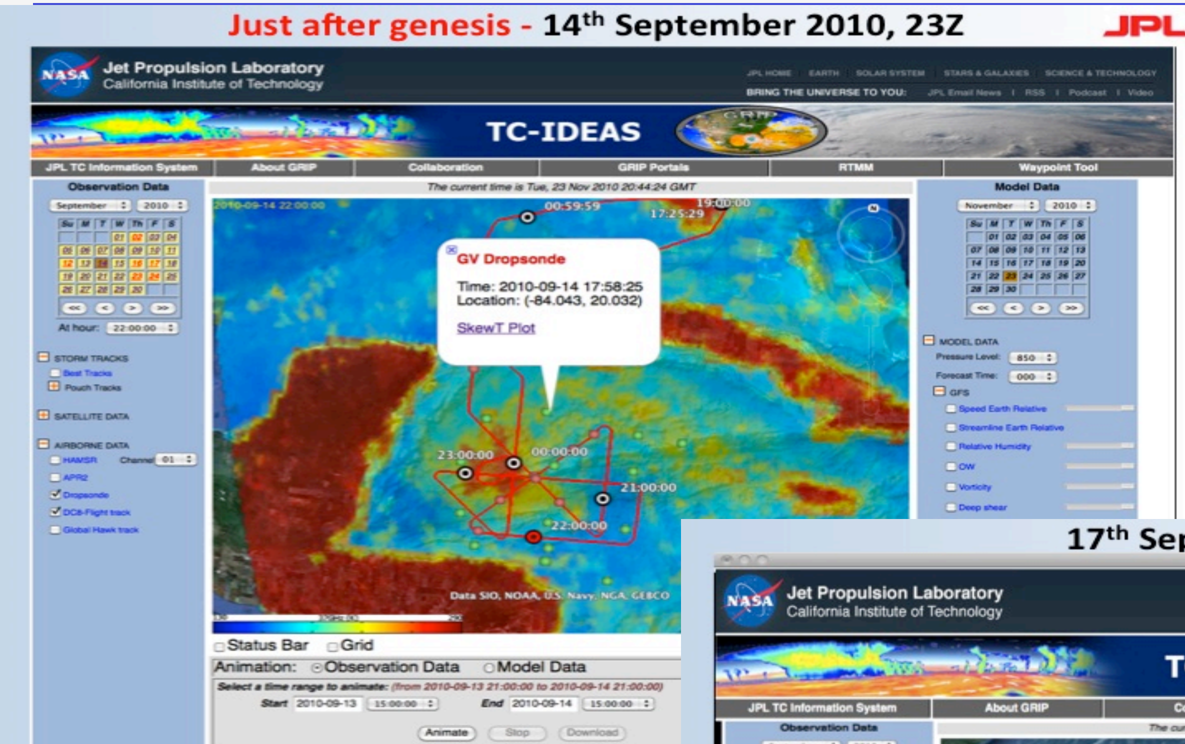
Airborne Science: SEAC4RS–2013-09-04; 14Z

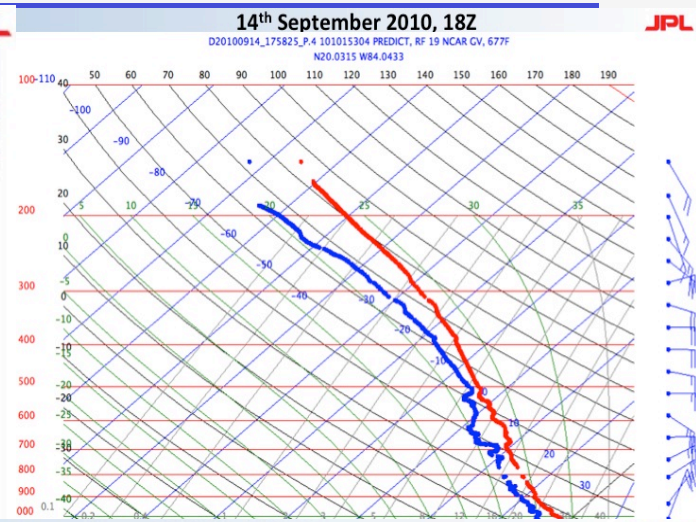
Vertical Cross-section from APR-2 (on DC-8); Nadir-viewing Camera Movies

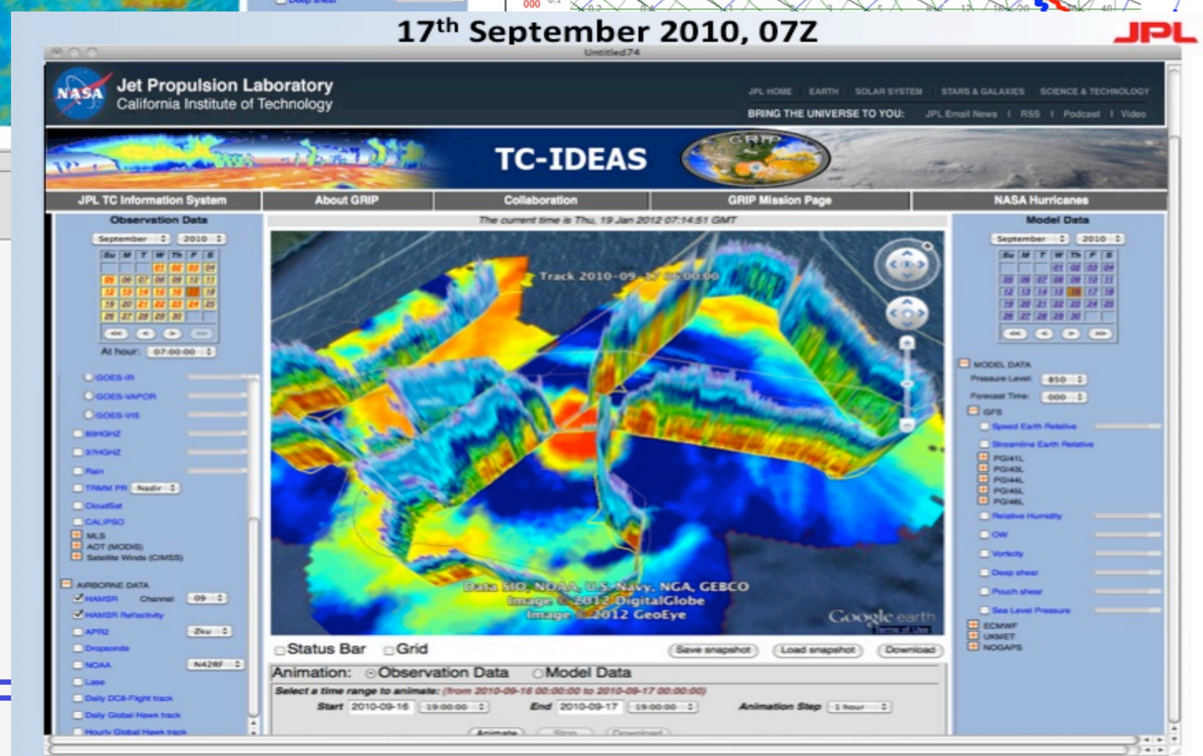


GRIP Portal – NRT in 2010, Atlantic – http://grip.jpl.nasa.gov

The Airborne Observations







Hurricane Karl:

Genesis and Rapid Intensification from

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

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**

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Projecting the operational forecasts into the observational space.

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

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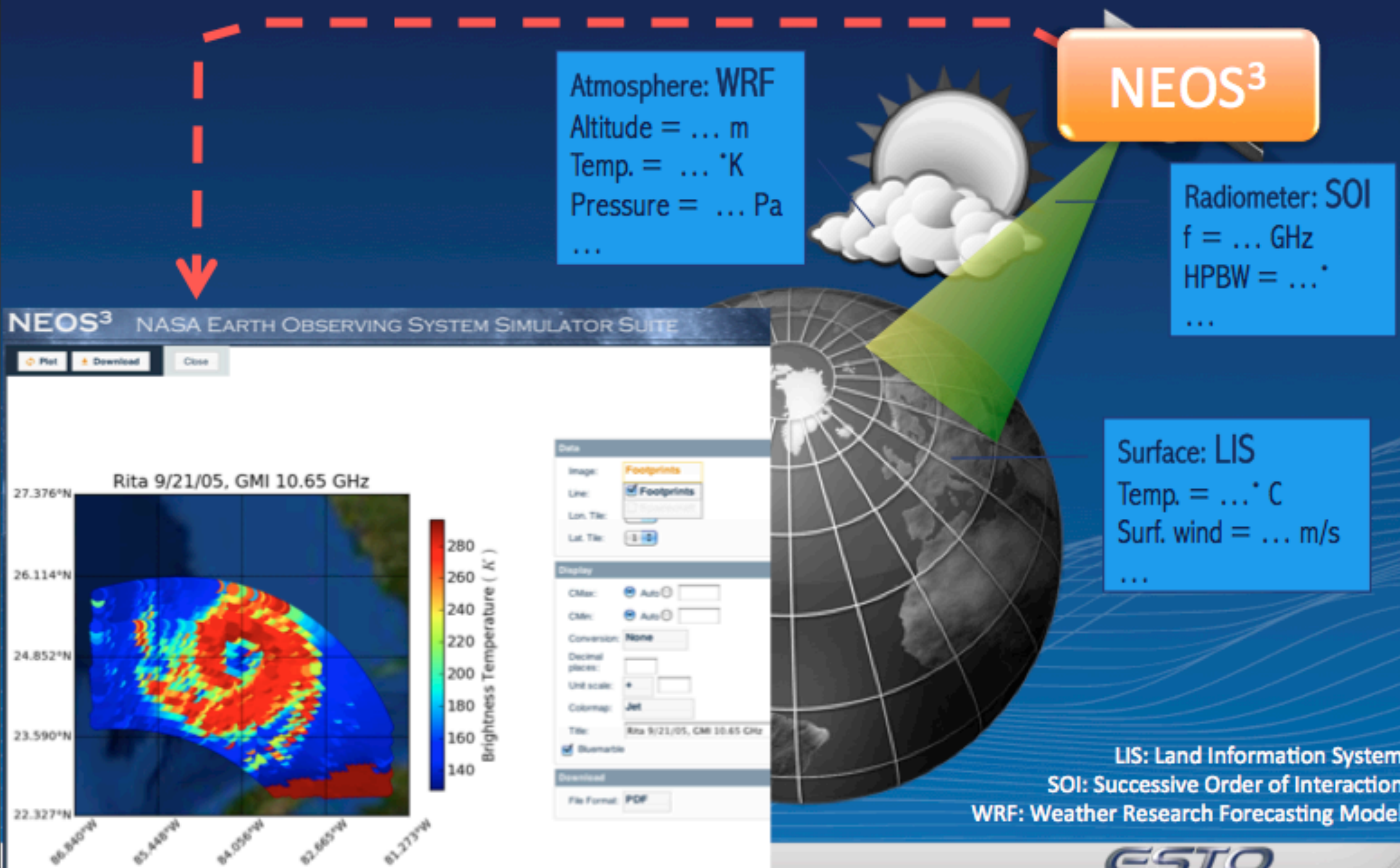
NEOS^3 : Purpose

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

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



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

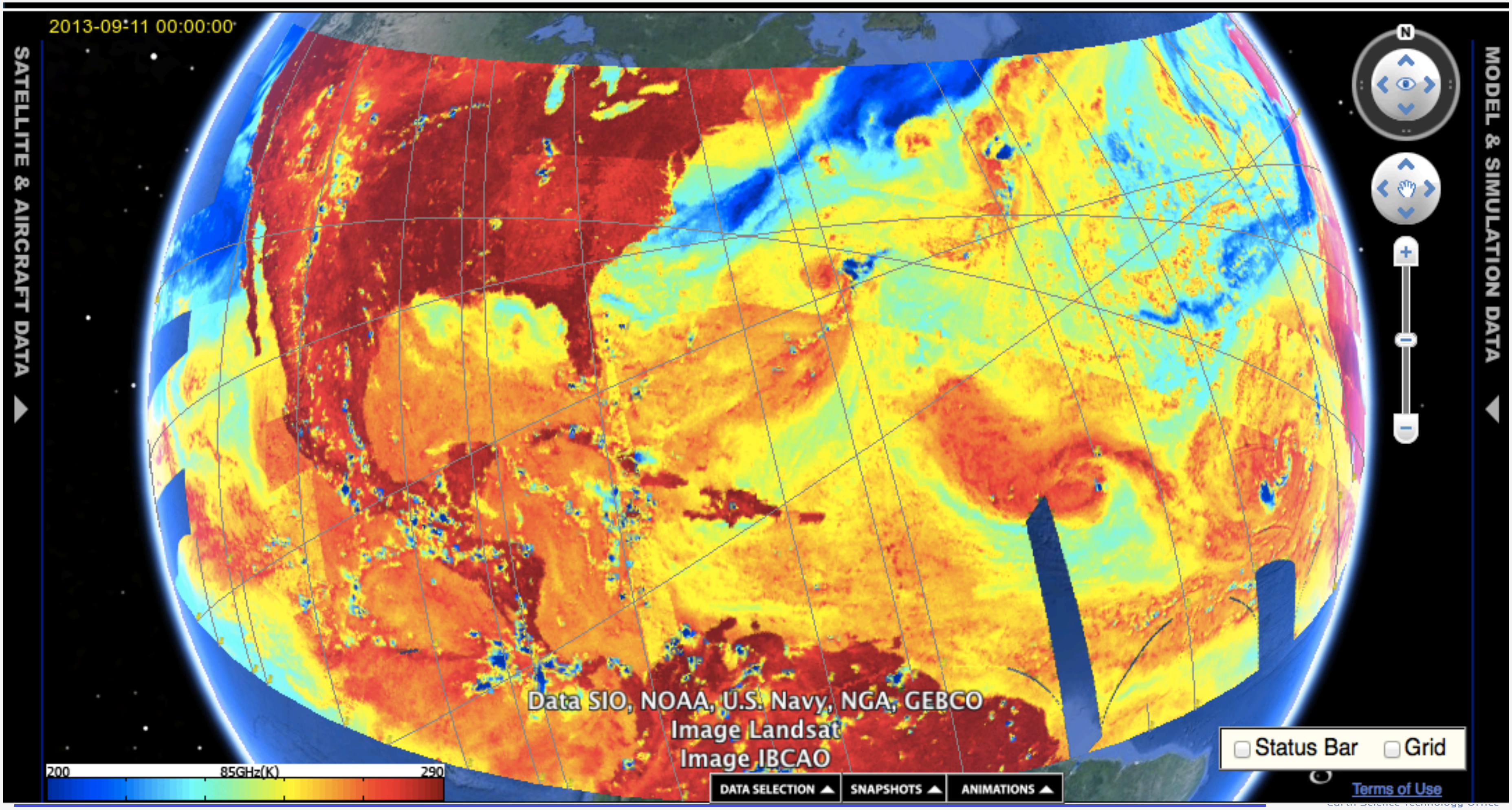
ESTO

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

- ✓ Developed the **criteria for triggering NEOS^3, driven by input from the portal.**
- ✓ **Designed scripts to** provide (from the observations) information to NEOS^3 regarding the:
  - **Satellite orbit type by:**
    - mission – NOAA (F16-F18) vs TRMM vs AQUA;
    - ascending vs descending orbit
  - **Orbit specifics**
    - **Time**/longitude/latitude of the satellite.
  - **Selected instrument, SSMI/S vs TMI vs AMSR-E, thus specifying:**
    - frequency, polarization
    - viewing geometry (azimuth, incidence angle, Field-Of-View)

TCIS-NEOS³ Automated Interaction – *TCIS Job Definition*

The microwave brightness temperature products are 6 hour composite from multiple sensors, including TMI, SSMI, SSMI/S, and AMSR-2. One satellite location is extracted from each track and sent to NEOS³ via a TOKEN PUT request.



TCIS-NEOS³ Automated Interaction – The *Job Processes*

The TCIS and NEOS³ servers interact through a series of Python scripts that request and send XML documents, using pre-defined RESTful webservices.

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]

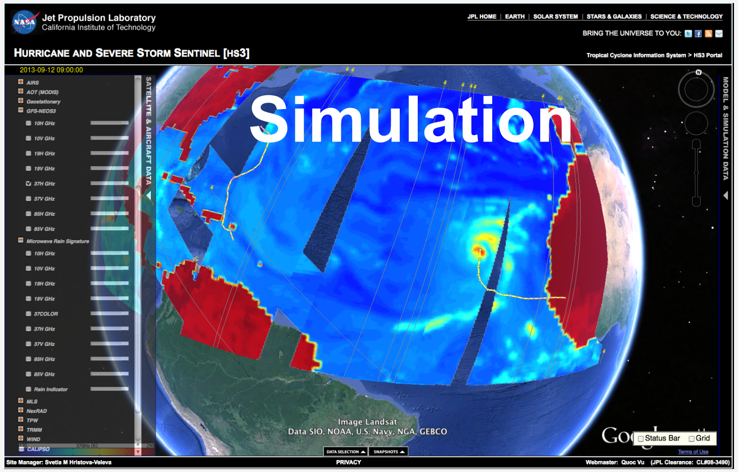
- From the TCIS server, poll the NEOS³ server every hour for child job status
- When status is 'finished,' download the netCDF file from the NEOS³ server to the TCIS server
- Delete the completed child job from the NEOS³ server

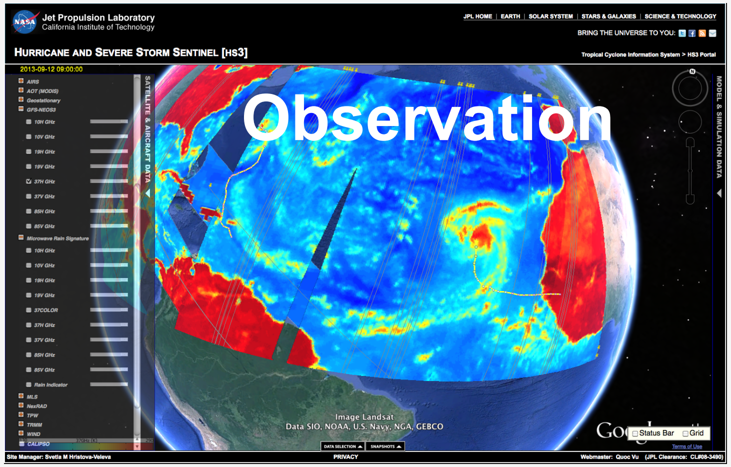
Job Analysis [TCIS]

- 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

TCIS-NEOS3 Automated Integration – *SUMMARY*

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



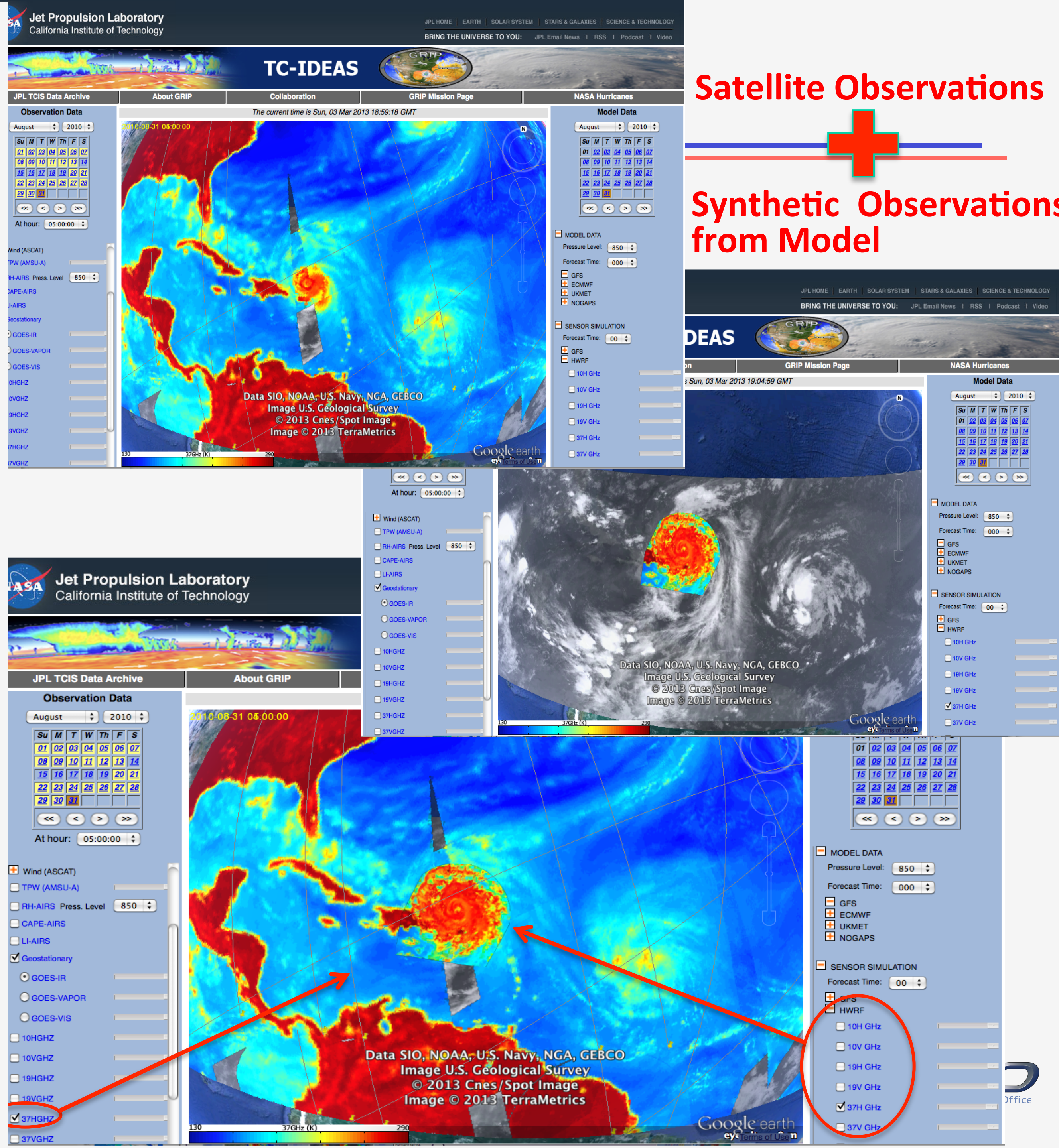


- Submit a simulation request, check the simulation status, and retrieve the simulation product via NEOS3's secured web service
- Computation performance of NEOS3 is *important* for this process to be practically useful.
  - ~100s simulation jobs of a few hours each for global coverage. High resolution input models (e.g., ECMWF) also demand relatively large memory (on the orders of GBs)

FUSION OF MODELS AND OBSERVATIONS

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

- Research HWRF model forecasts were used as input to NEOS[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 !



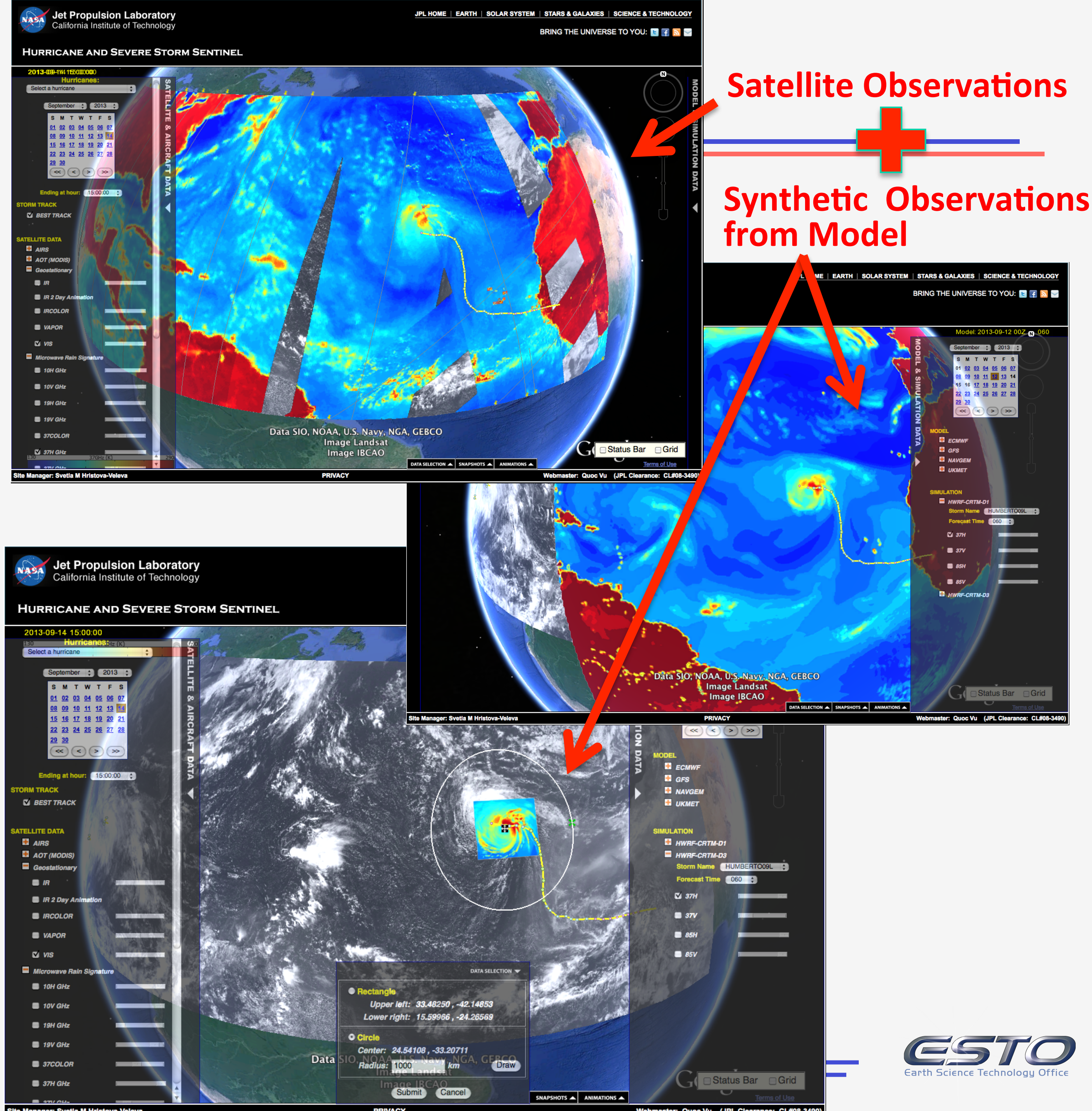
FUSION OF MODELS AND OBSERVATIONS - OPERATIONALLY

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.



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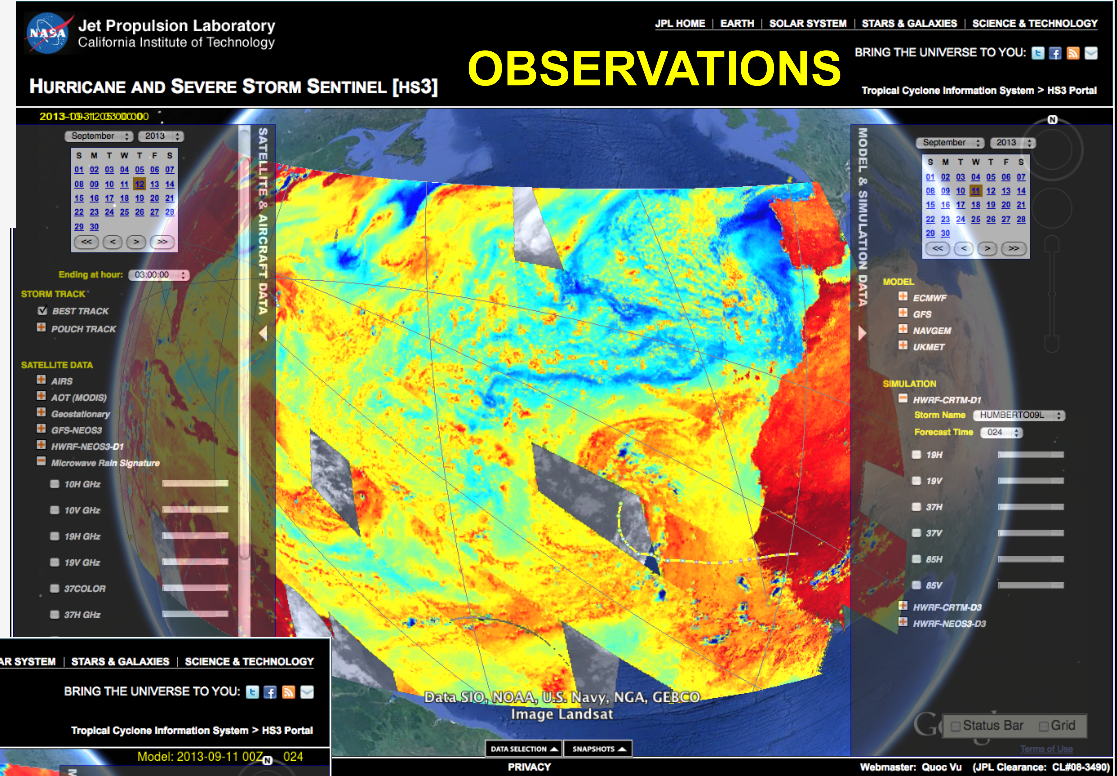
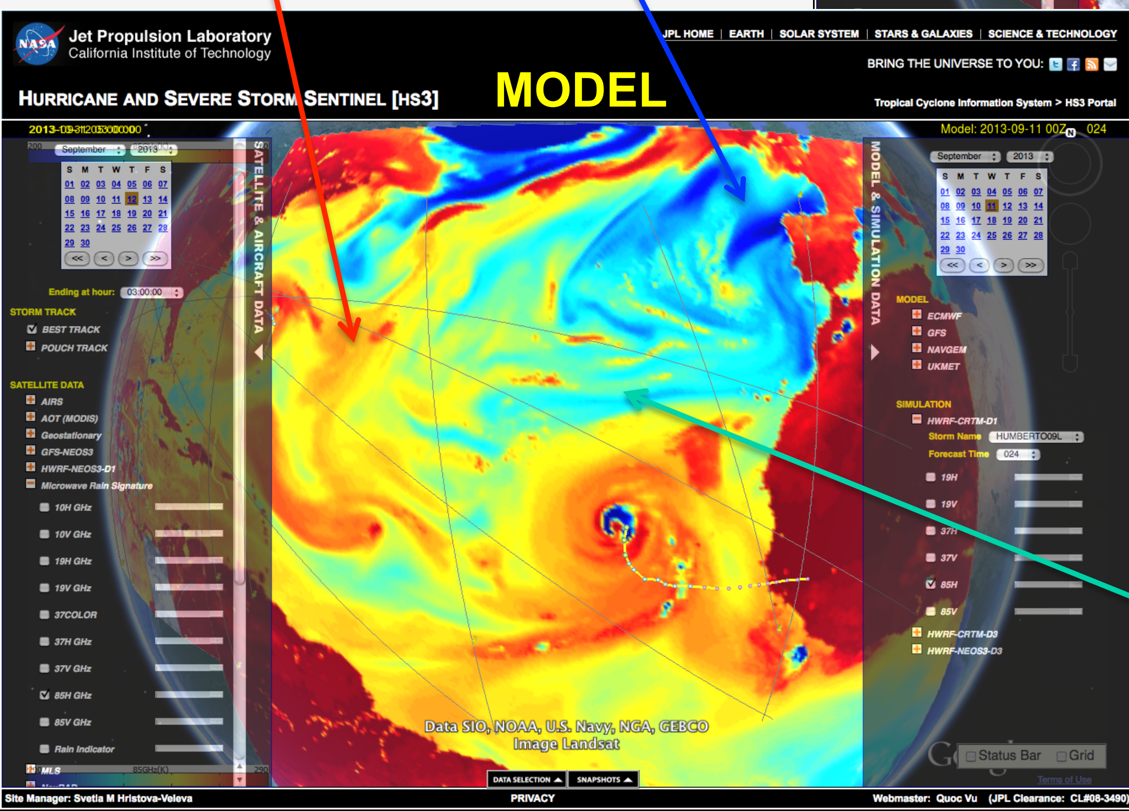
DRY AIR

MOIST AIR





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

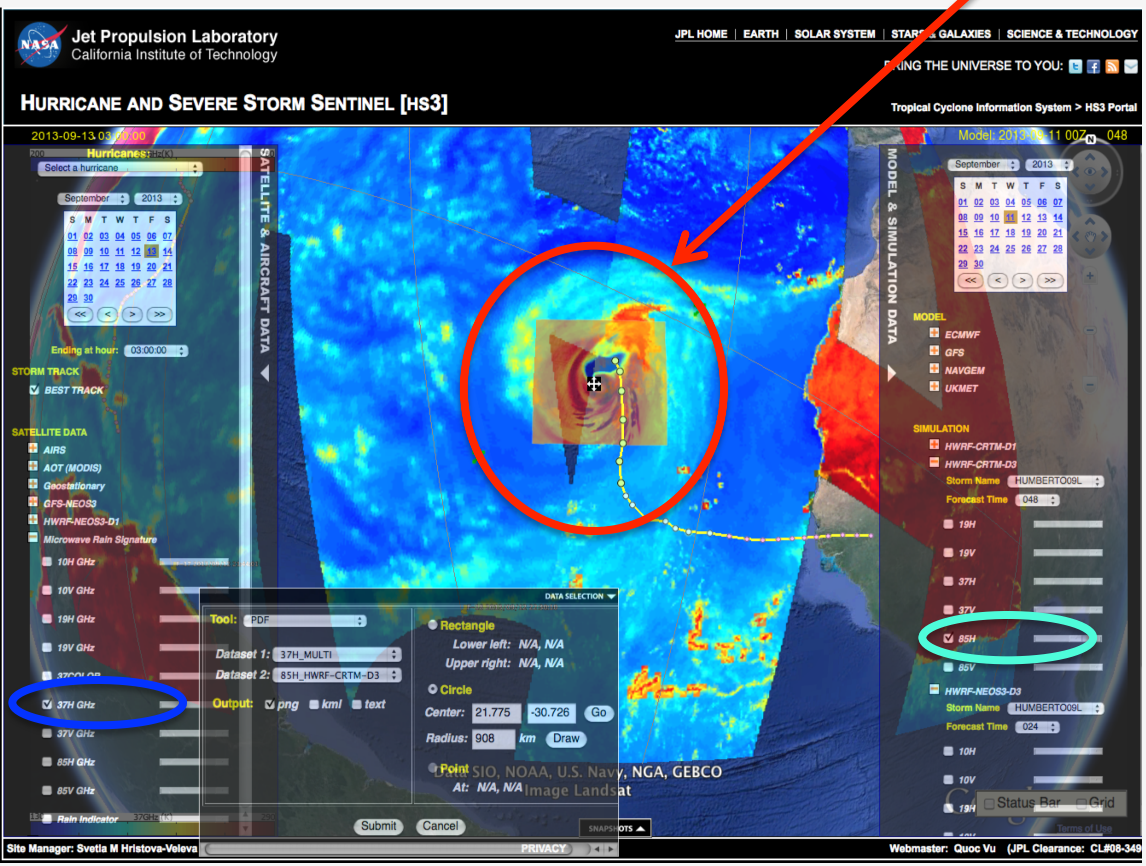
1. Bringing observations and models into a common analysis system and developing interactive visualization tools.

2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators

3. Developing analysis tools with the goals to:

- Understand the observed structure of the hurricanes
- Evaluate the models

Analysis tools for model validation



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

Interactive tool for data analysis: *Implementation Flow Diagram*

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

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

(Google Earth API, Java Script, PHP)

↓

Subset the data

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

(MySQL, Python)

↓

Run the analysis tool and generate the statistical results in form of graphics or text
(Matlab, Fortran, IDL, web services, etc..)

↓

Display the results back to the portal
(Image pop up, tables, GE overlays)

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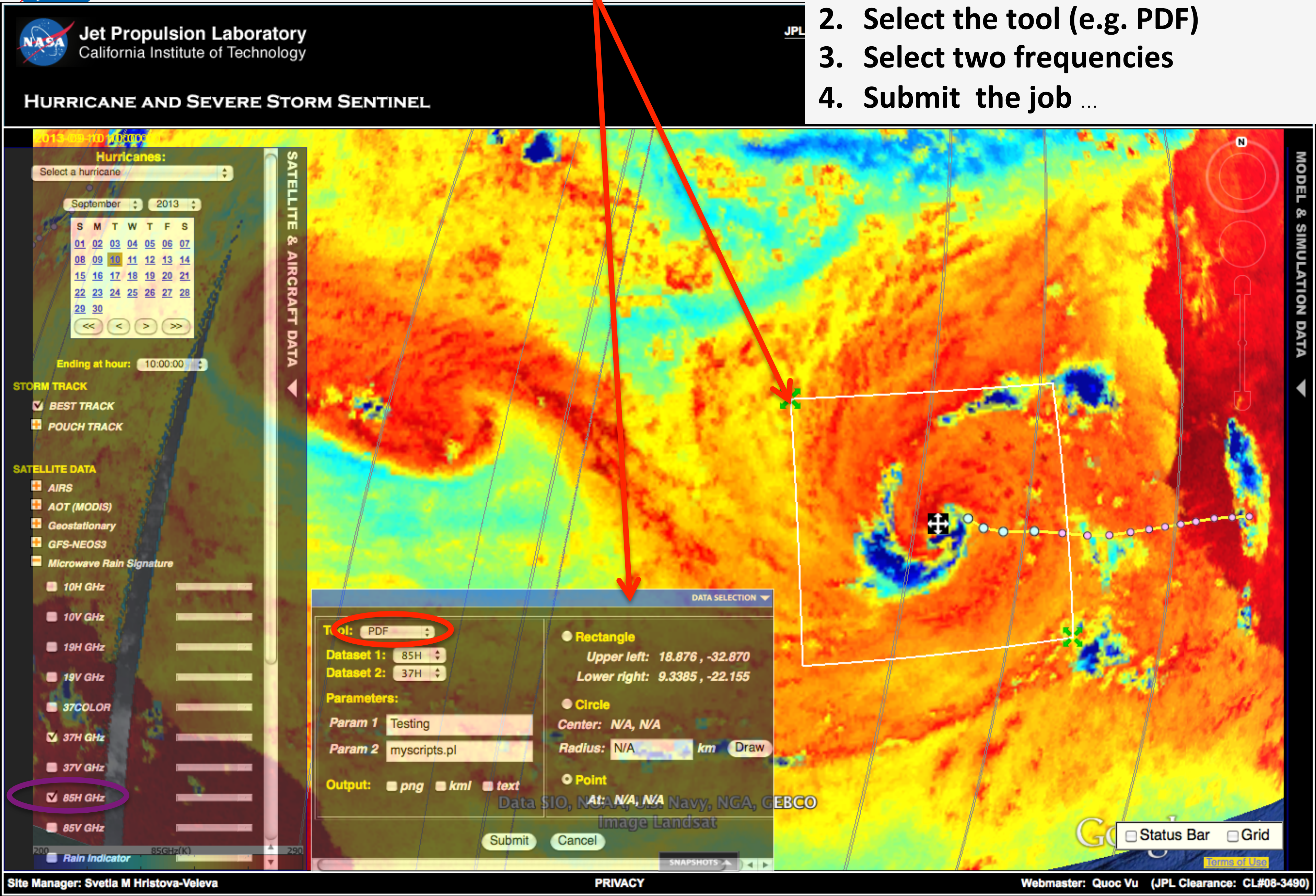
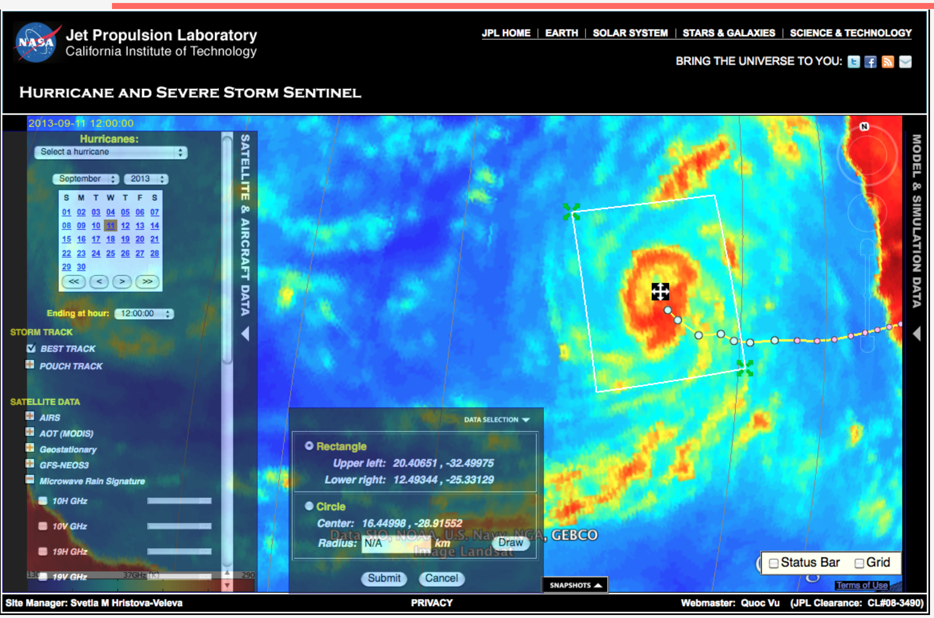
The Selection Tool

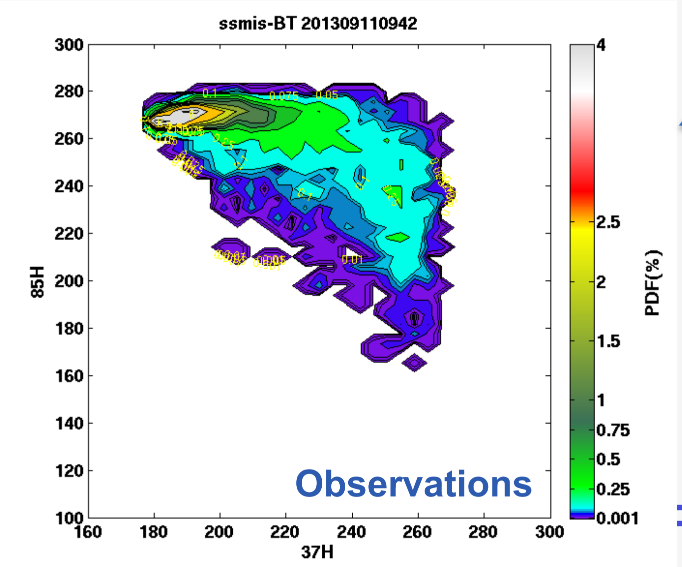
1. Select the region of interest
    - Circle, Square, Point
2. Select the tool (e.g. PDF)
3. Select two frequencies
4. Submit the job …



Statistical Tool: *Joint Distribution of Brightness Temperatures* Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



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



- The Joint PDF illustrates this relationship

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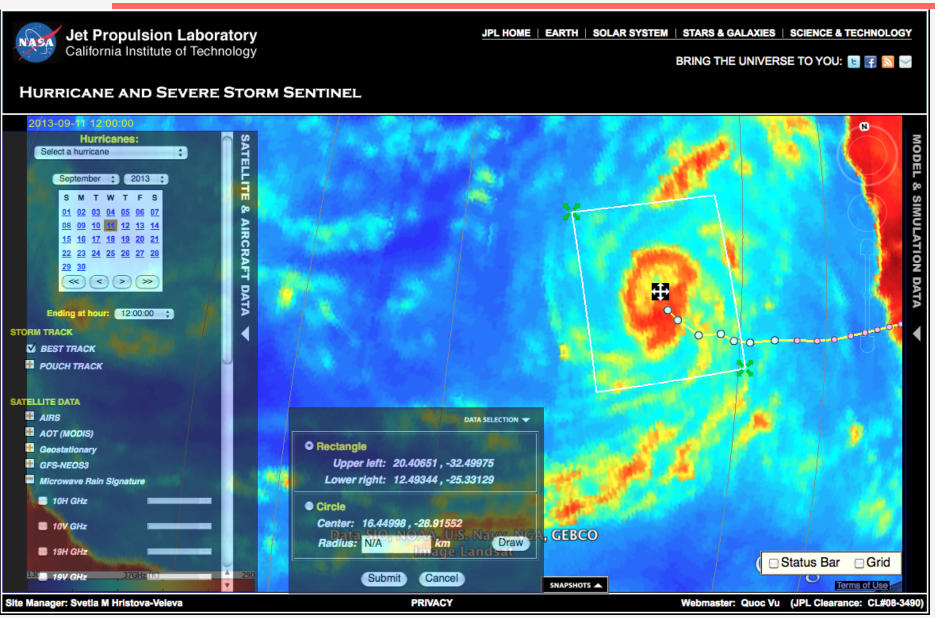
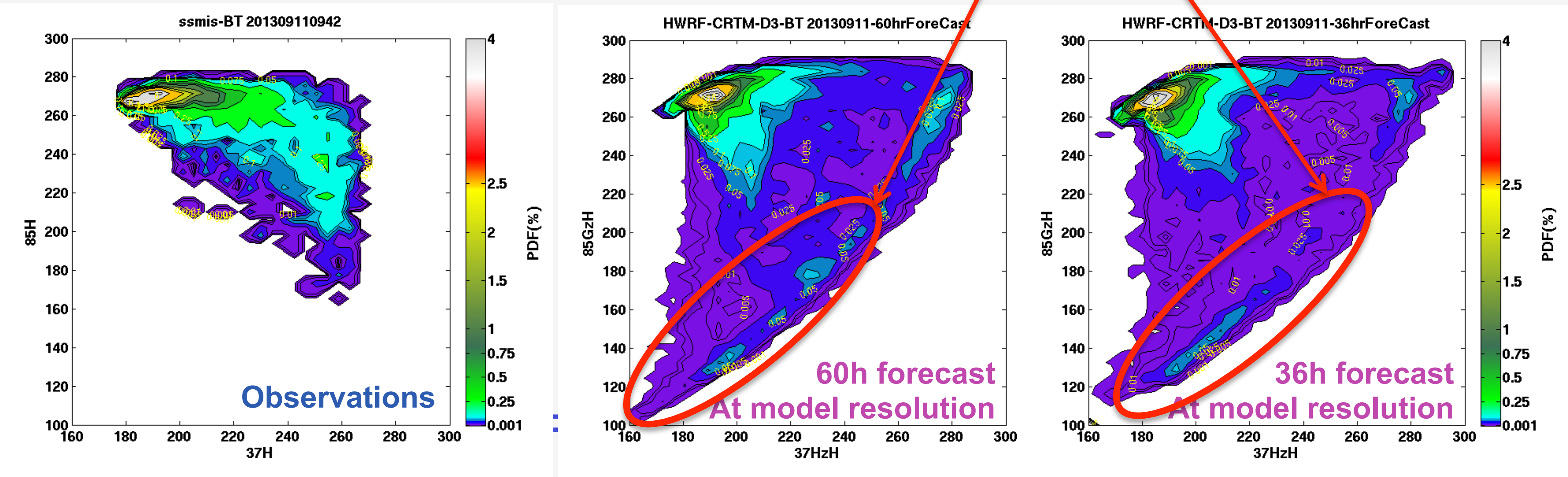
Statistical Tool: *Joint Distribution of Brightness Temperatures* Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto

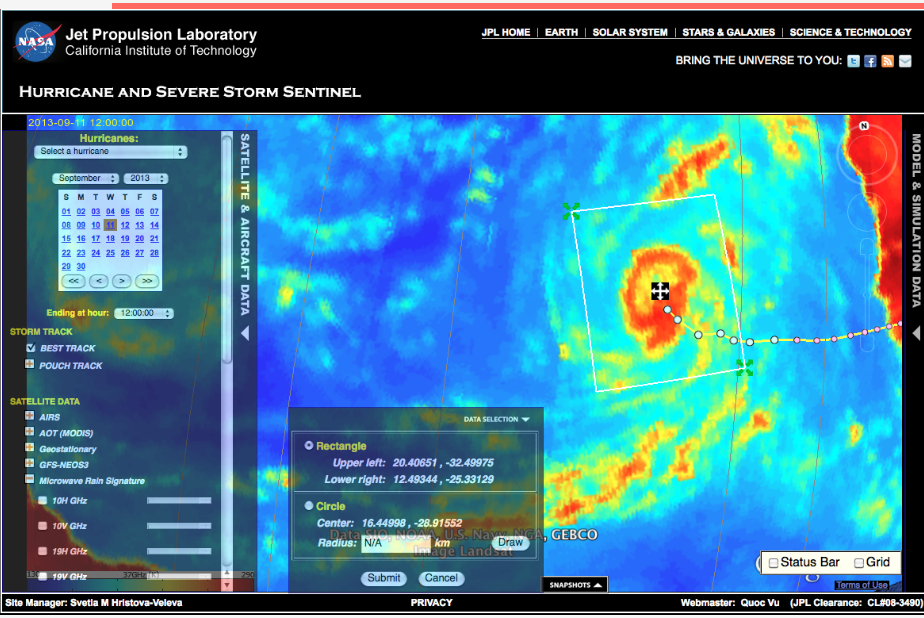


- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm
- The vertical branch indicates too much scattering of radiation by the frozen precipitation

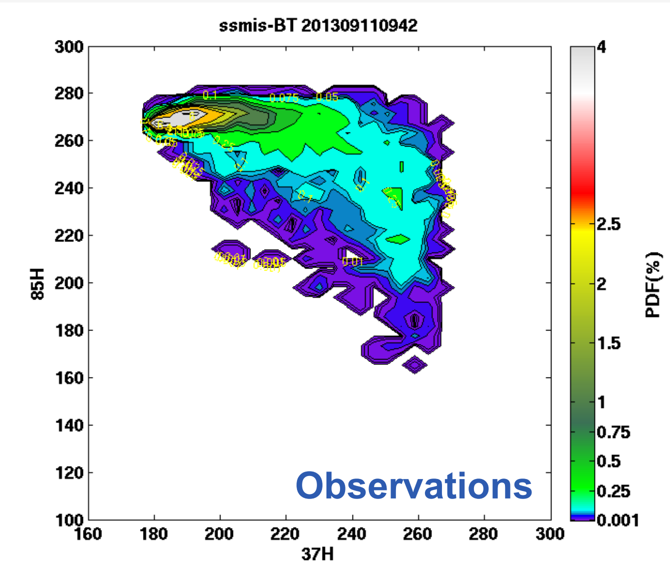


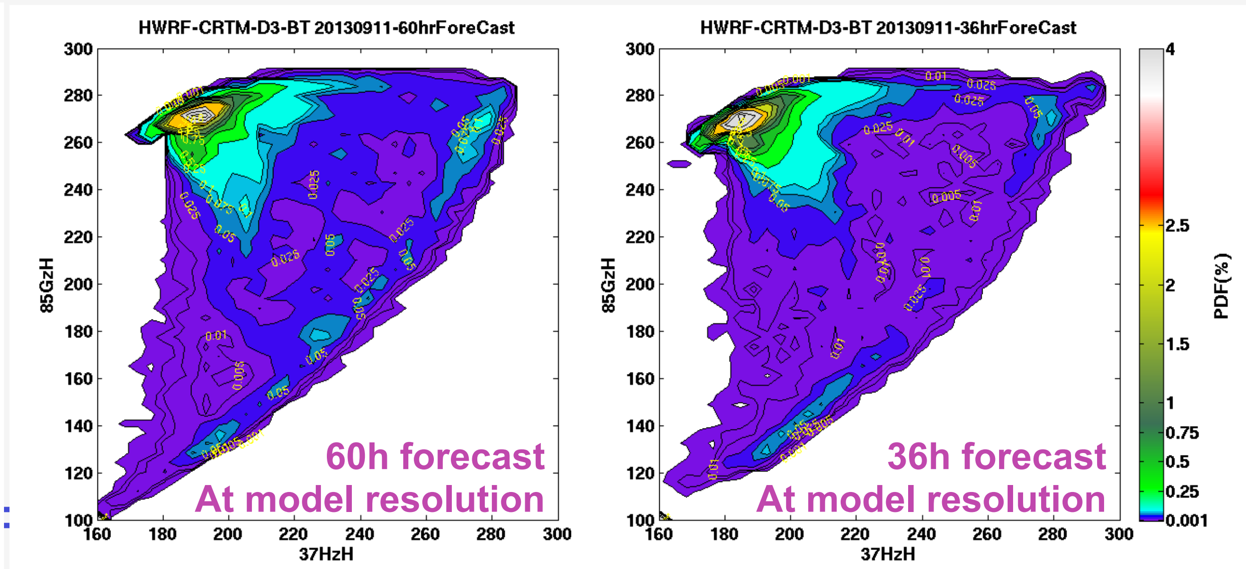
Statistical Tool: *Joint Distribution of Brightness Temperatures*

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



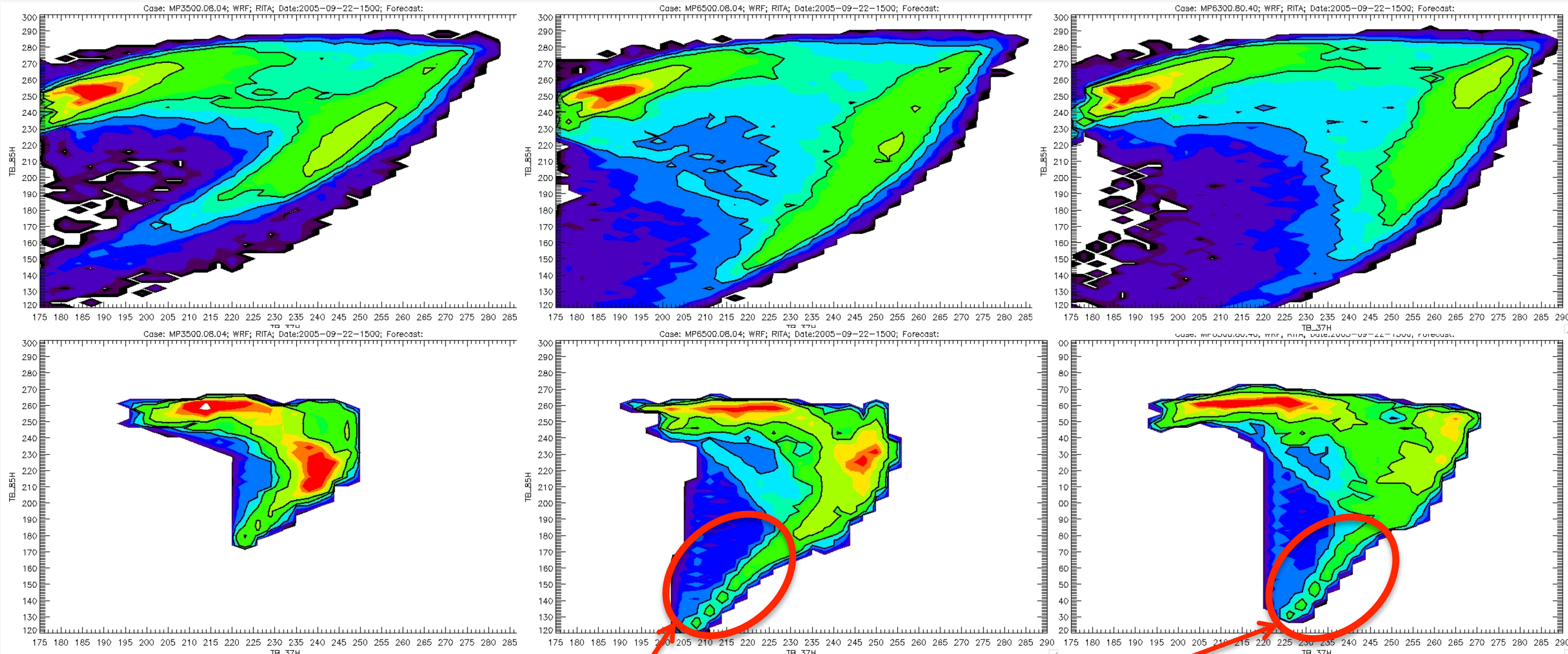
- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm
- The vertical branch indicates too much scattering of radiation by the frozen precipitation
- Question: Is the ice too much or is its forward modeling inaccurate?
  - Need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





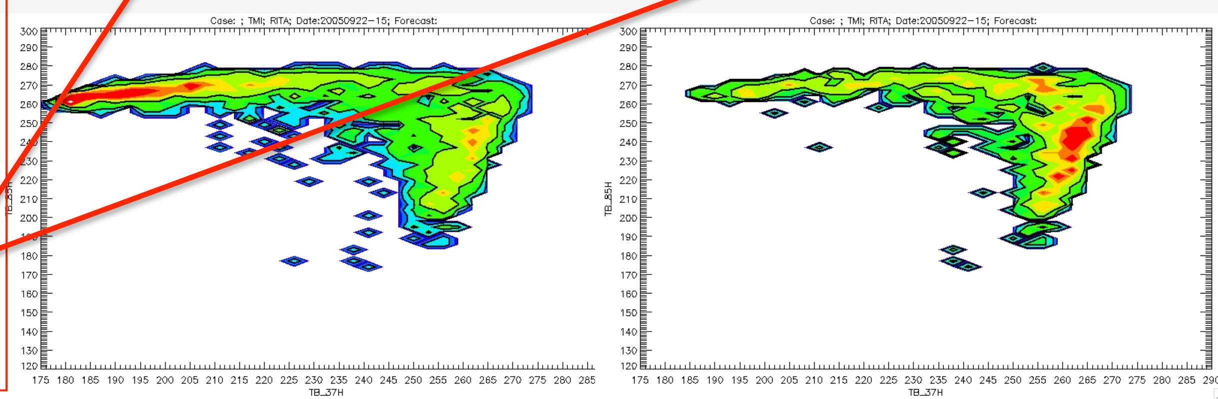
Joint Distribution (37H vs 85H) – *Impact of Resolution*

M3-500.08.04 M6-500.08.04 M6-300.80.40



WRF res.

TMI res.



TMI obs.

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

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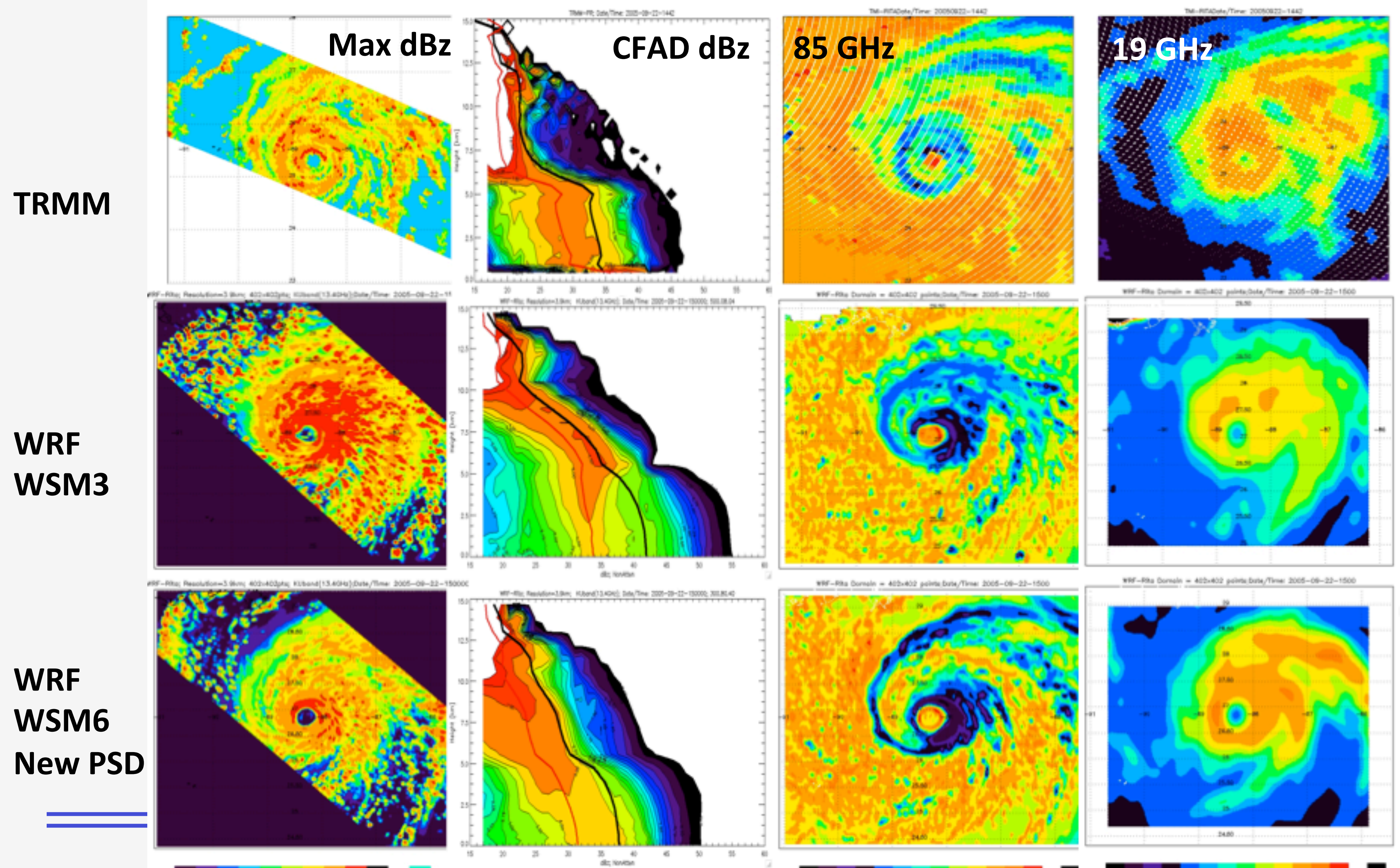
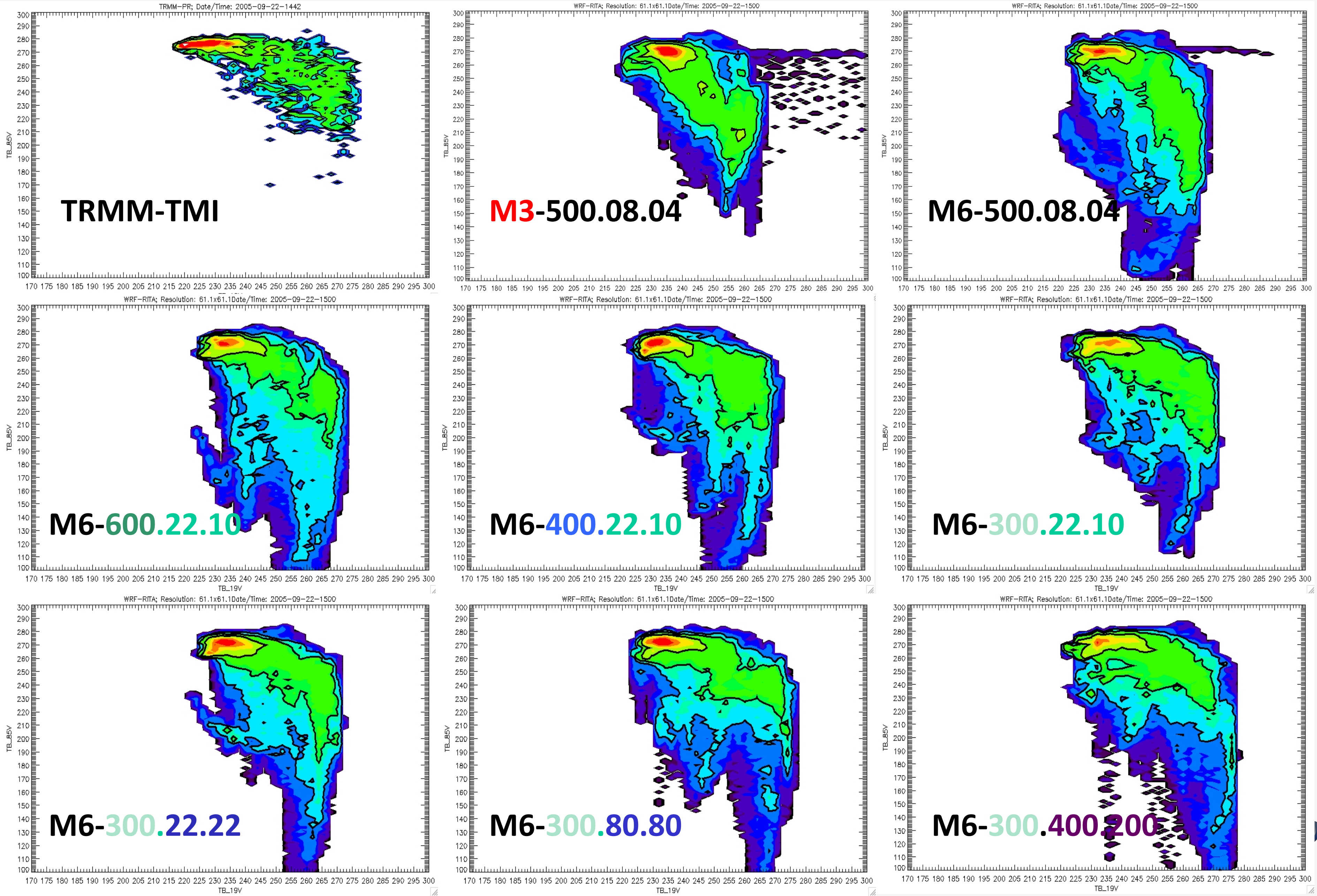
Example of MODEL EVALUATION – the Impact of Microphysics



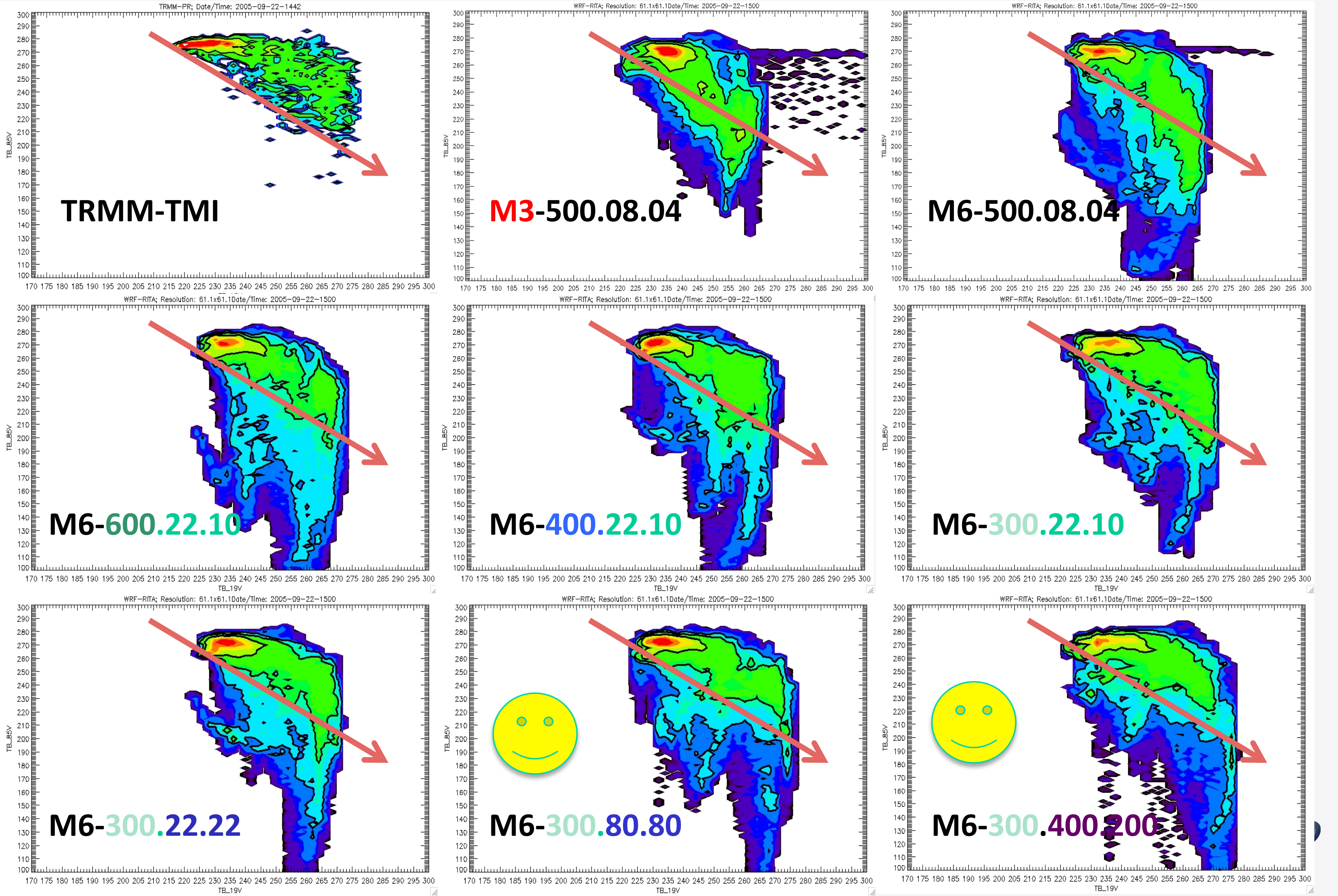
Joint Distribution (19H vs 85H) – *Impact of Microphysics*

PDF of the relation 85V-19V



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

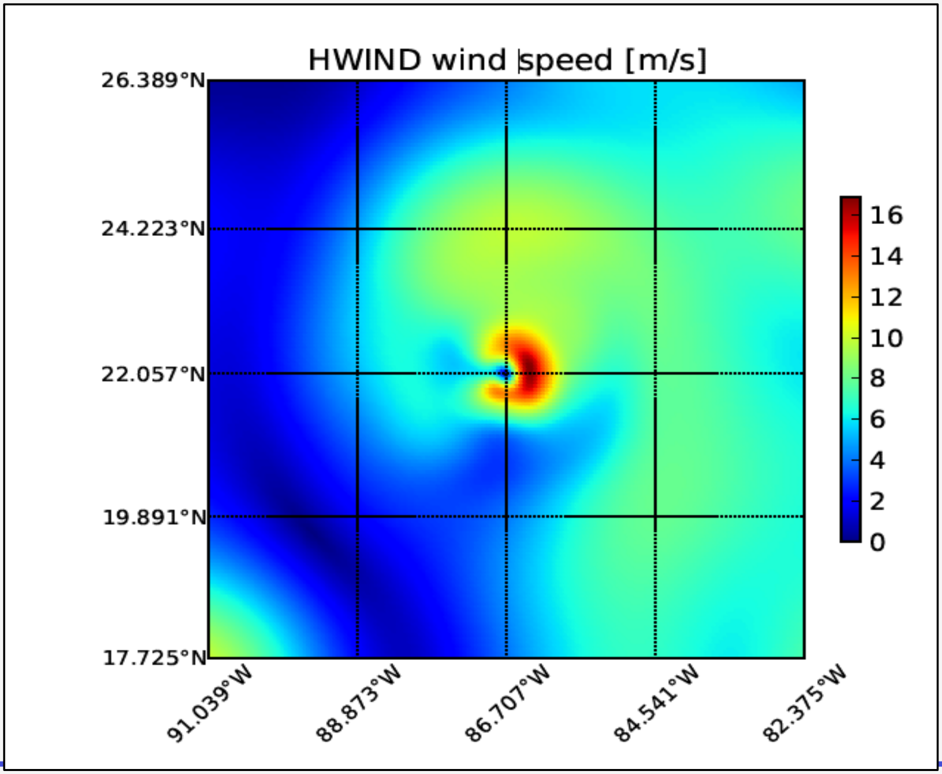
PDF of the relation 85V-19V

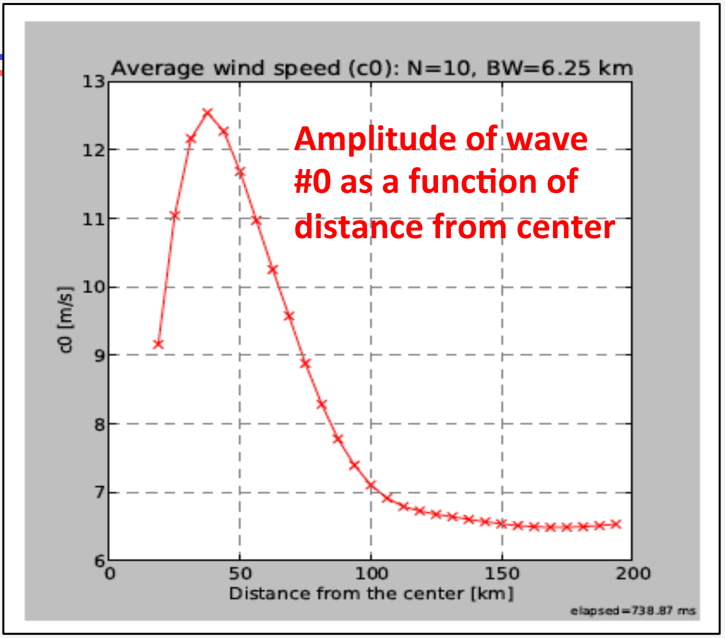


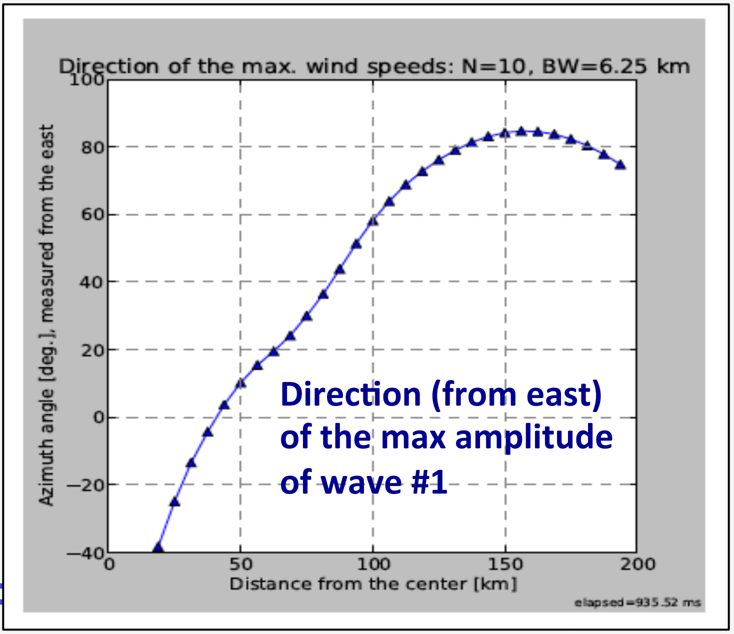
Storm structure Tool: Storm Size and Asymmetry

The Wave Number Analysis Tool

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



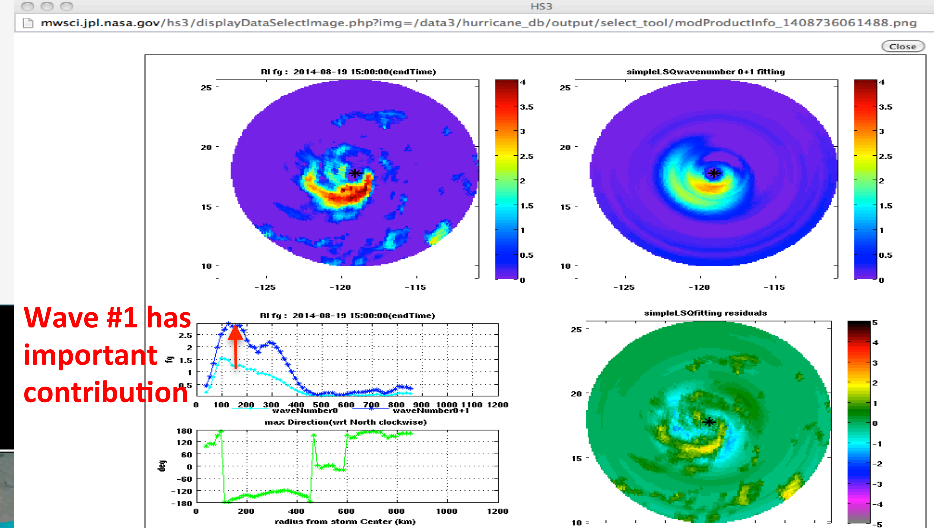


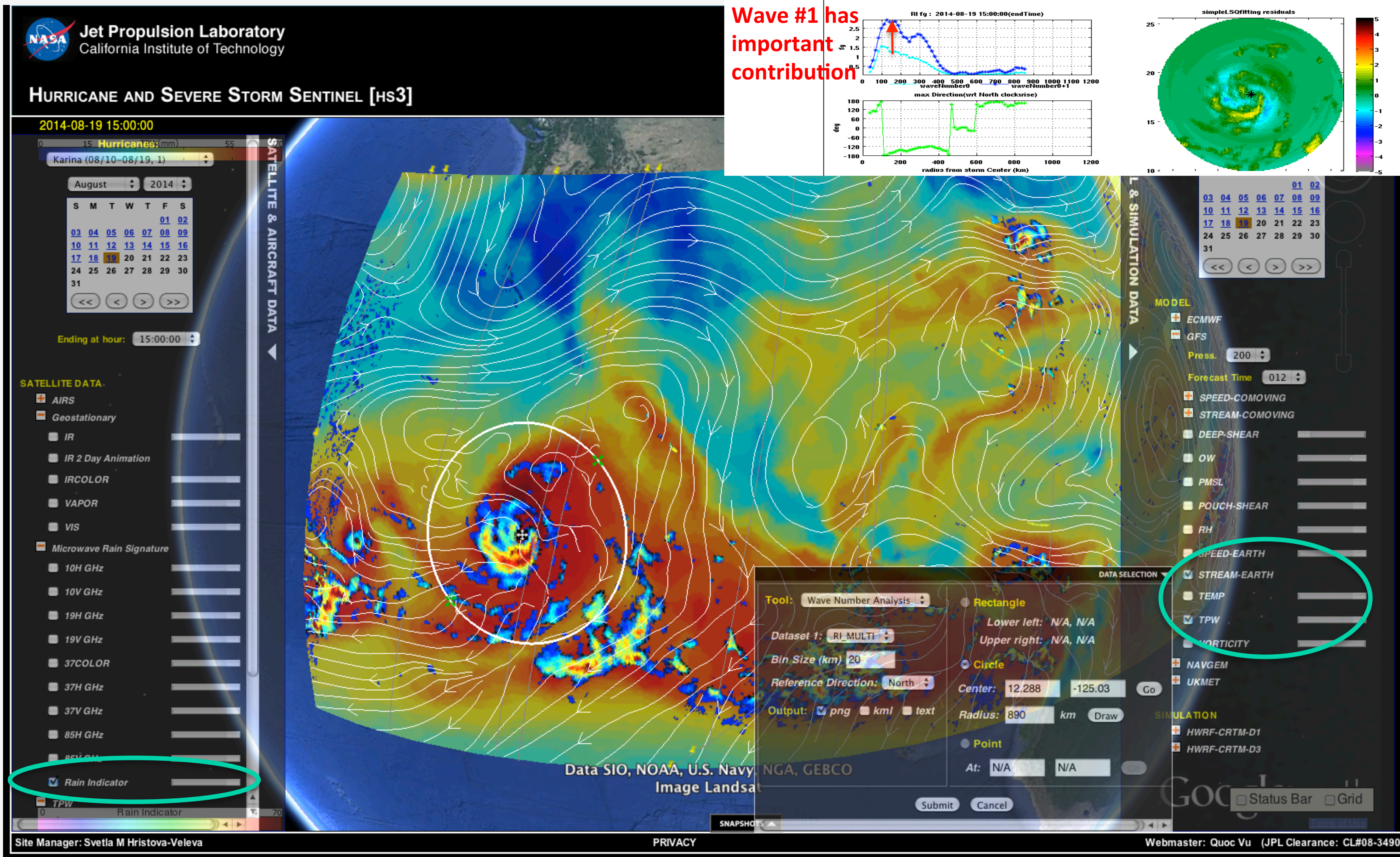


Storm structure Tool:

Storm Size and Asymmetry

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





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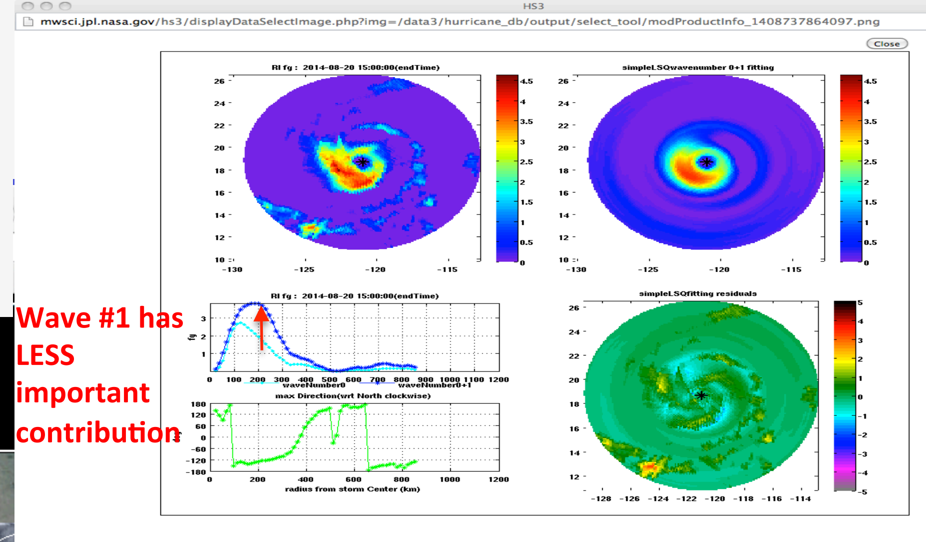
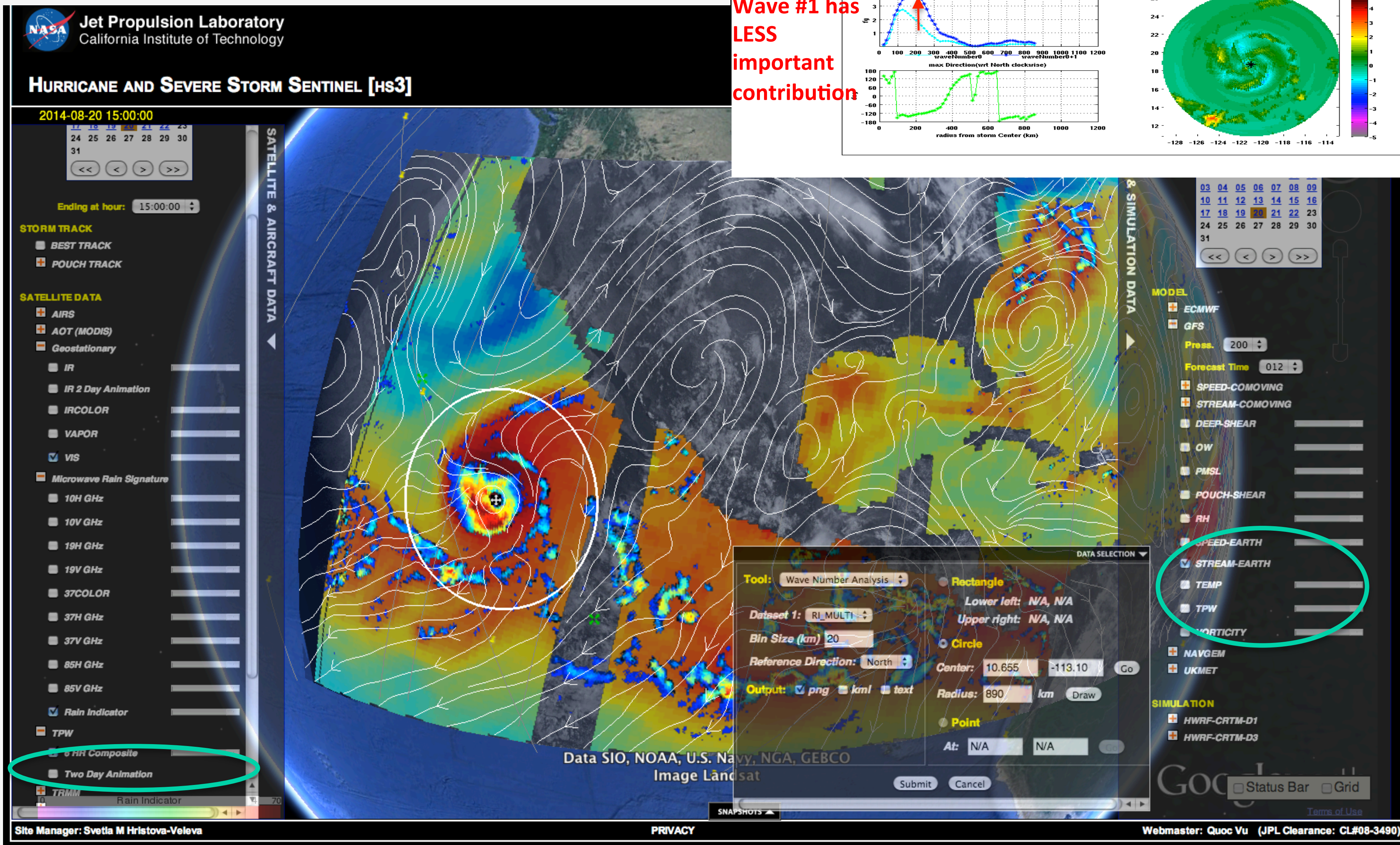


Wave #1 has LESS important contribution



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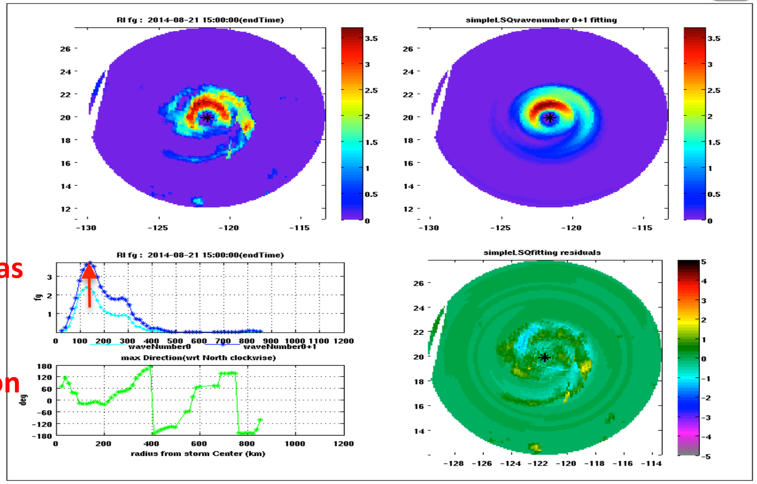
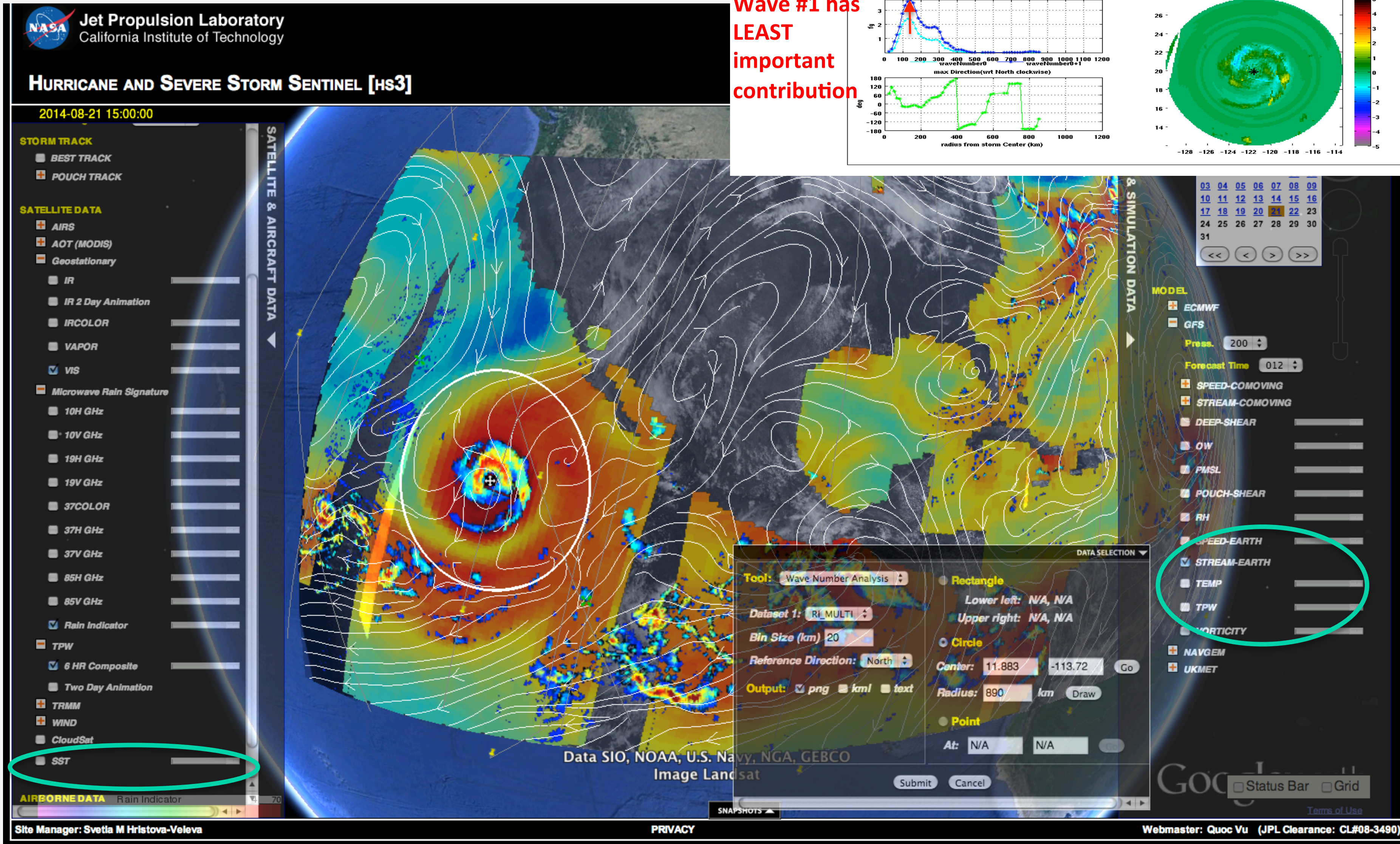


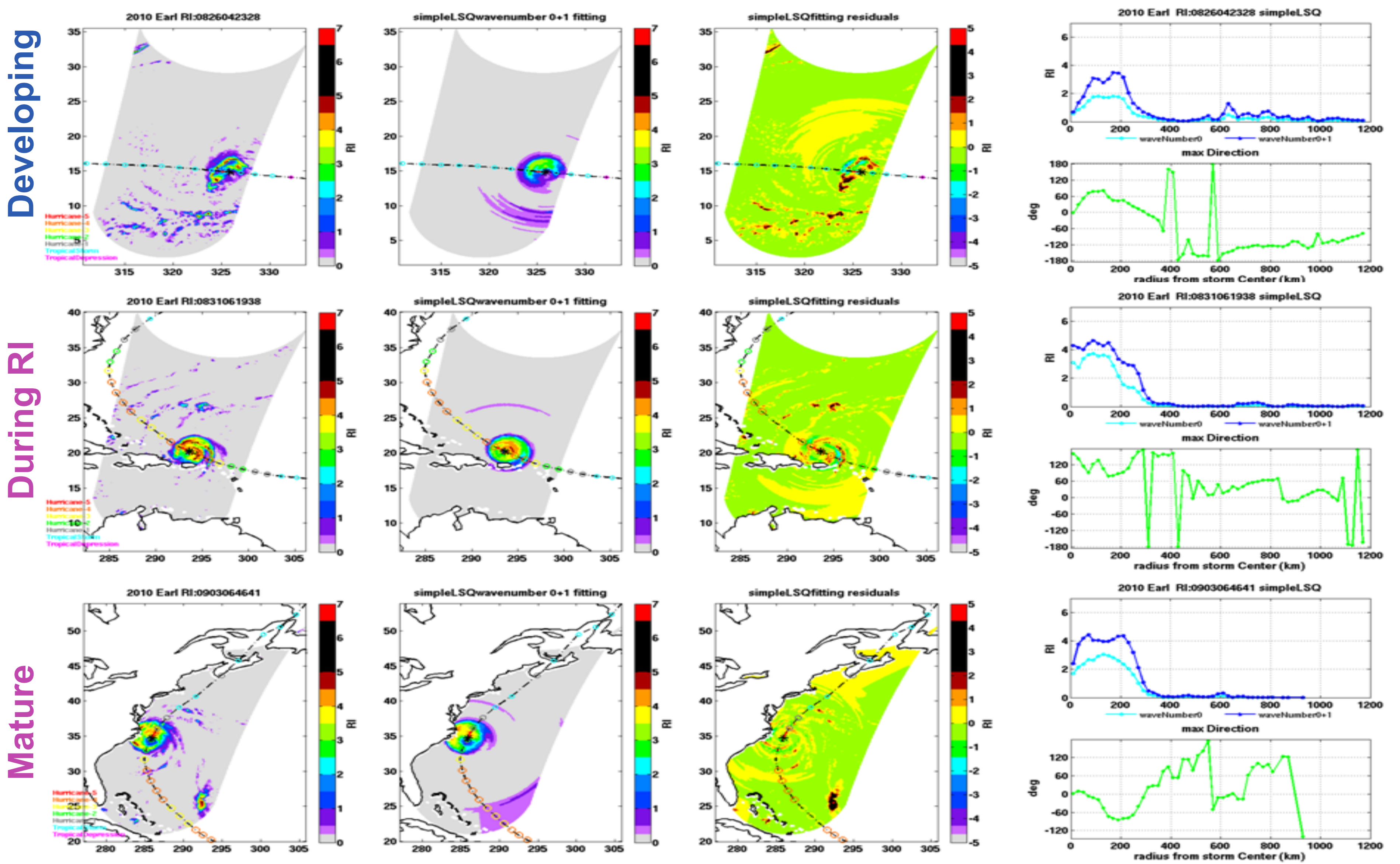
Wave #1 has LEAST important contribution



Storm structure Tool: Storm Size and Asymmetry

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

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



Storm structure Tool: Storm Size and Asymmetry

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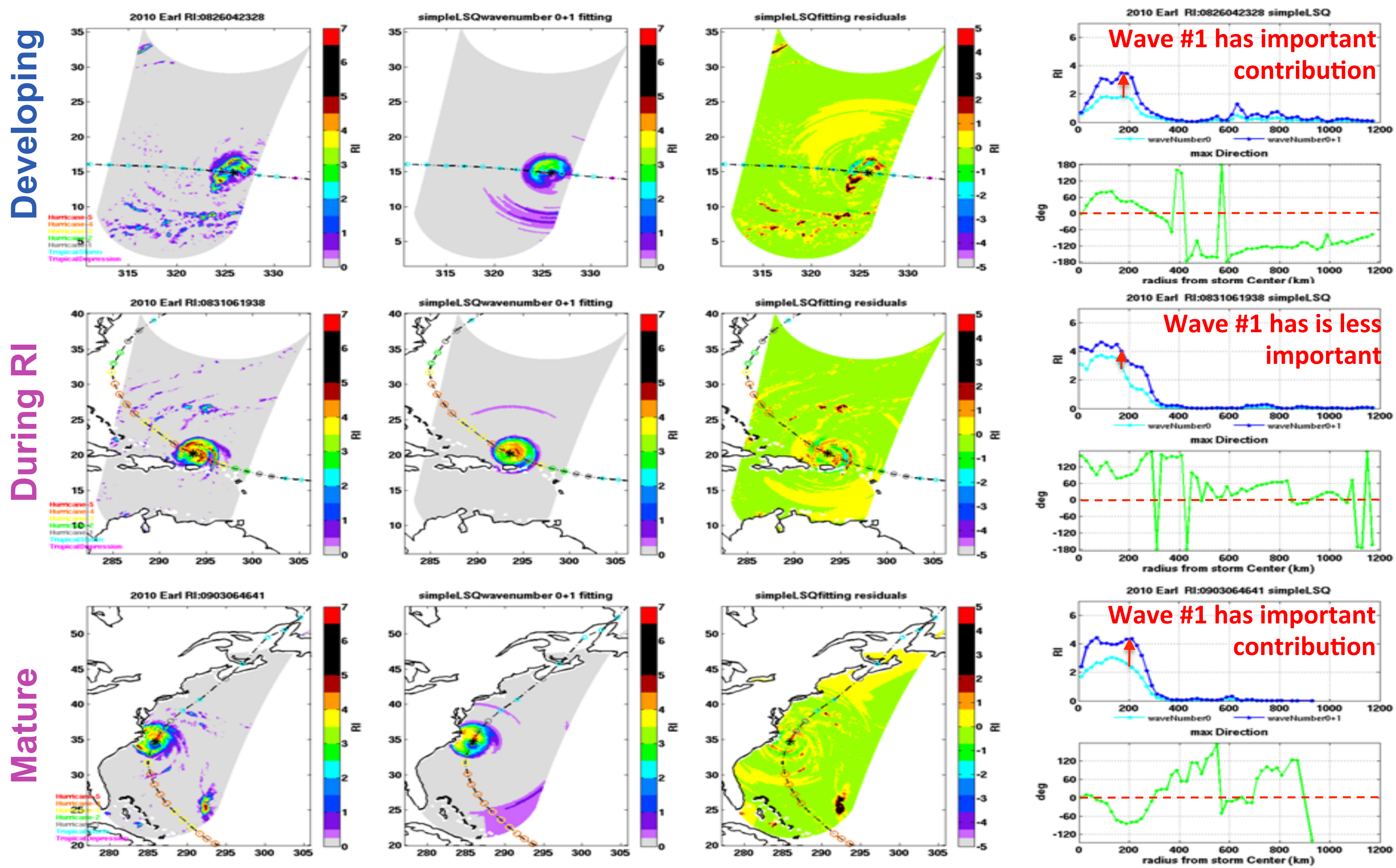
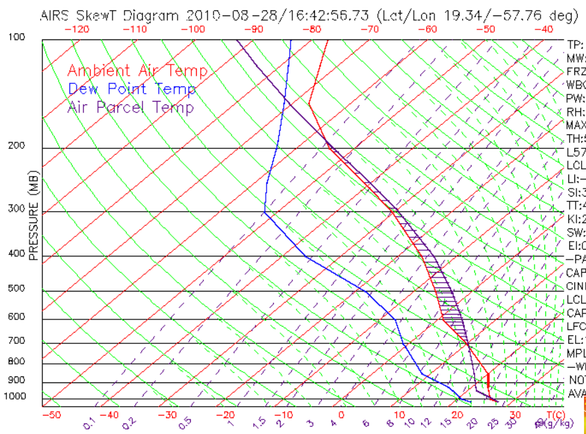


Summary

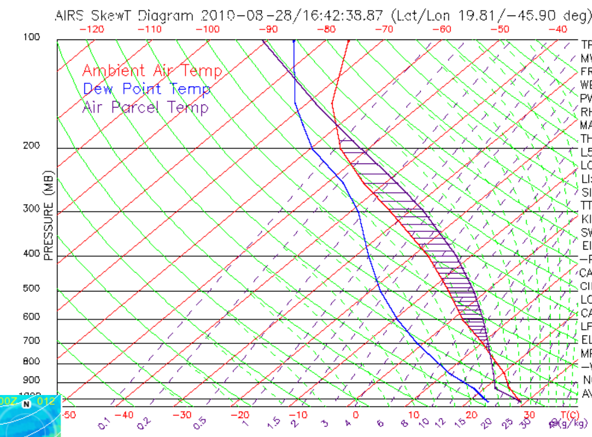
- To achieve the HFIP goals of improving the forecast accuracy of hurricane intensity, track and impact at landfall we first **need to understand whether the models properly reflect the physical processes and their interactions**.
- To address the need for improving the model physics, the 2013 annual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

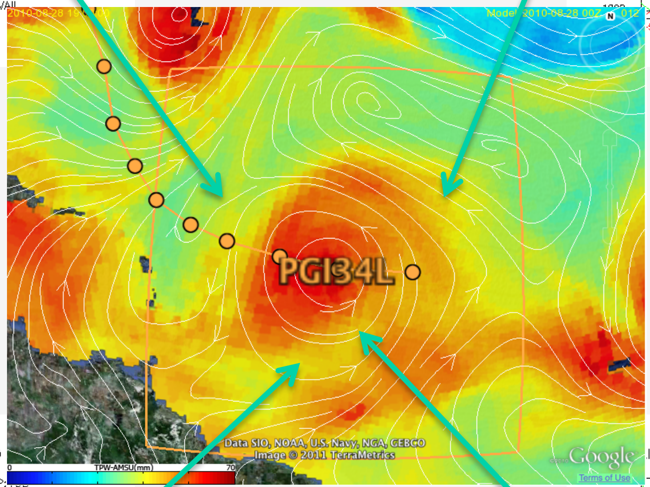

Thank you !

The thermodynamics from AIRS

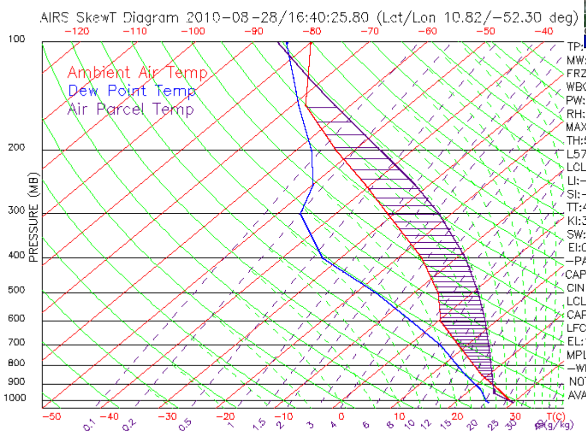


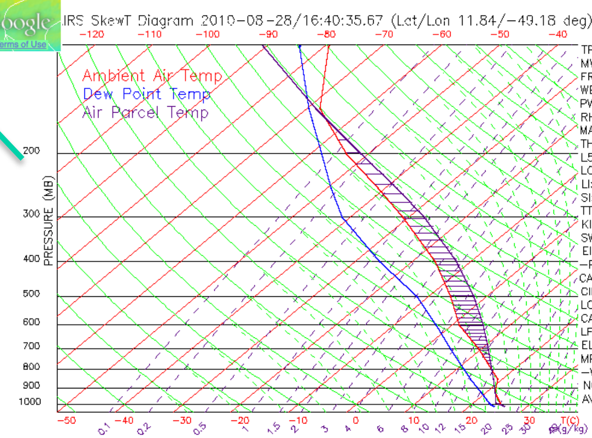
Hurricane Earl; Aug. 28, 2010 19Z



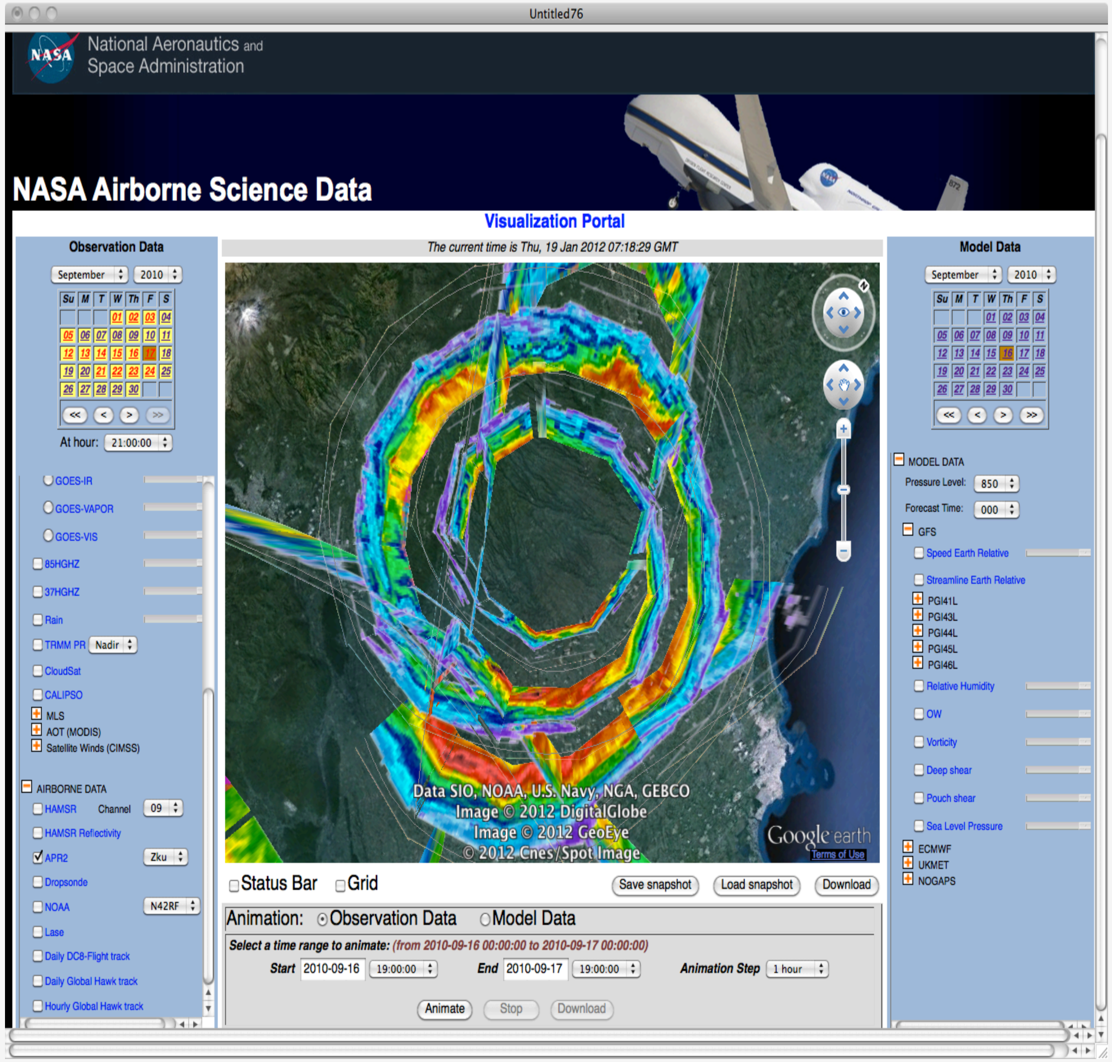


1. TPW from AMSU
2. Soundings from AIRS
3. Pouch-relative flow from ECMWF





17th September 2010, 21Z



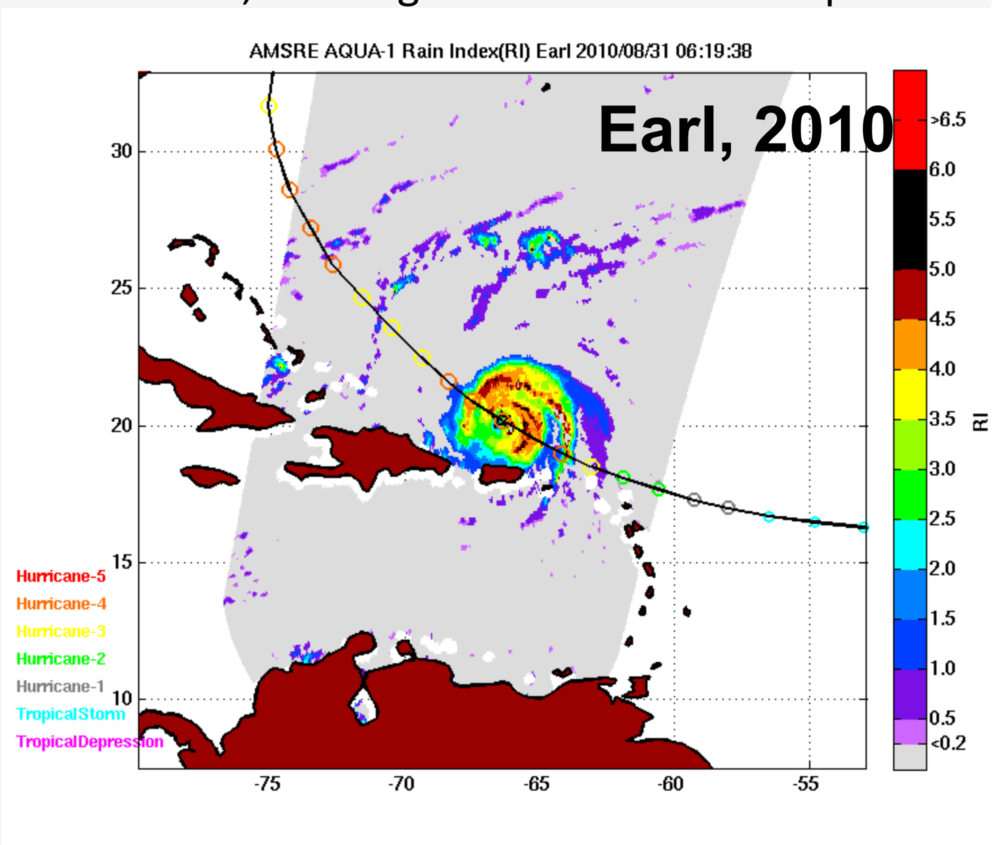
The Rain Indicator – a multi-channel depiction of the storm structure

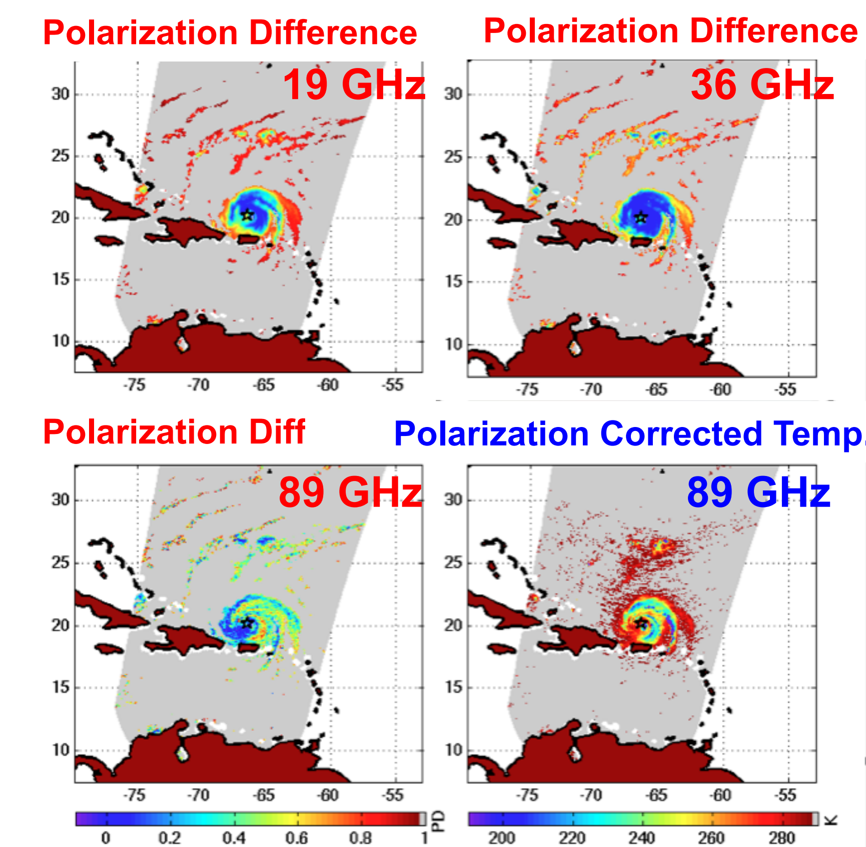
Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828–2848

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

- **emission signal** - dominant at lower frequencies; **warming**; **better for light rain**. ***Strong emission in the atmosphere reduces the polarization difference (PD) in the ocean surface radiation. Hence, PD is representative of the atmospheric emission.***
- **scattering signal** -dominant at higher frequencies; **cooling; better for heavy rain; PCT**

• Hence, both signals have to be incorporated to cover the entire rainfall spectrum.





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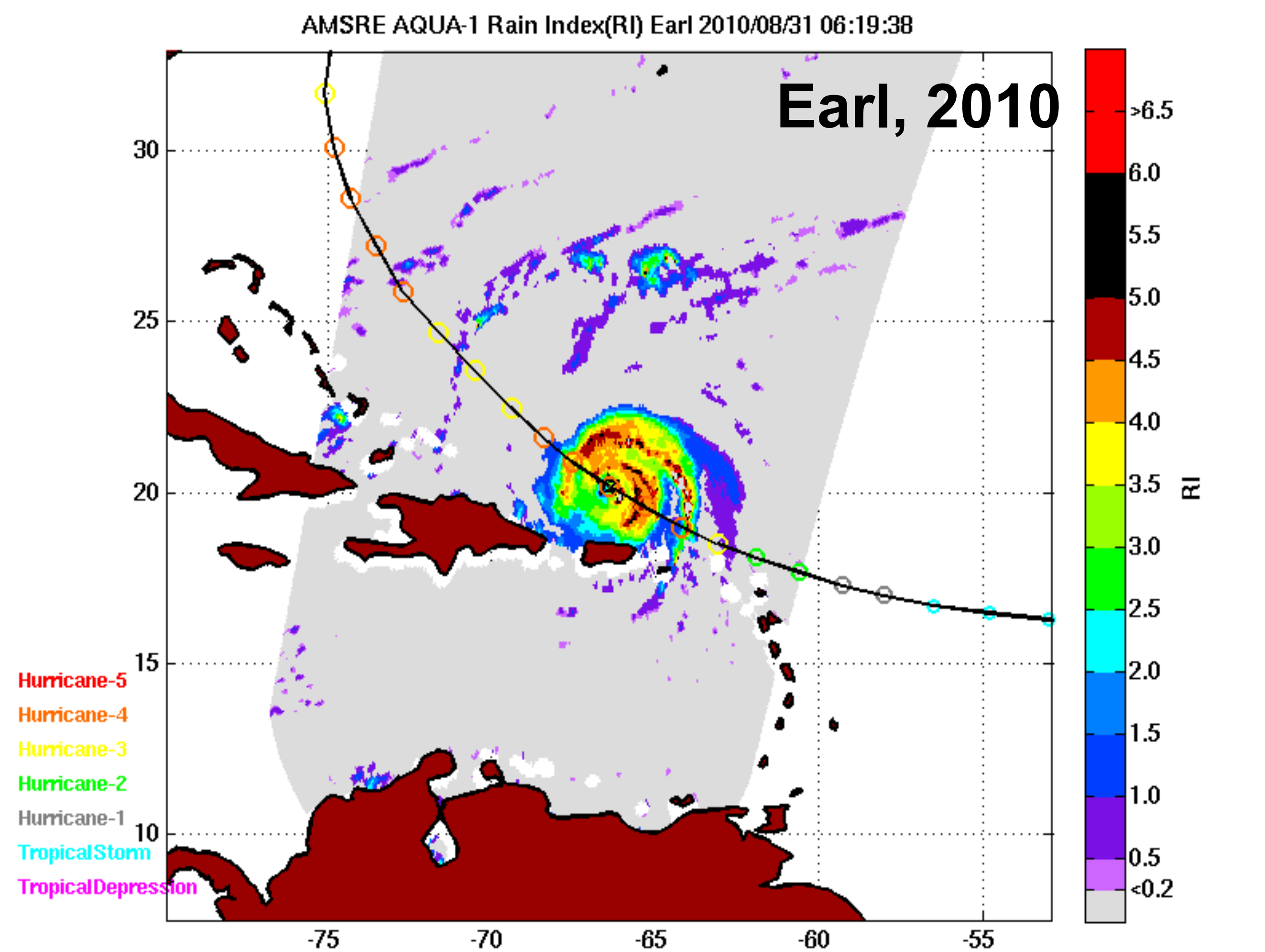


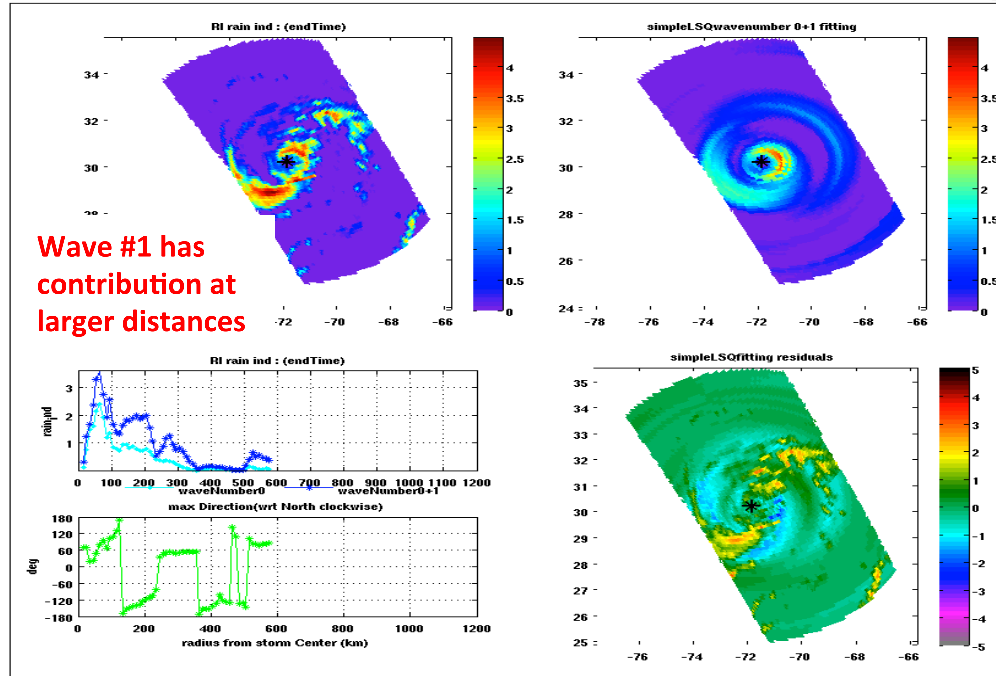
Advantages of Using the Rain Indicator over single passive microwave channels

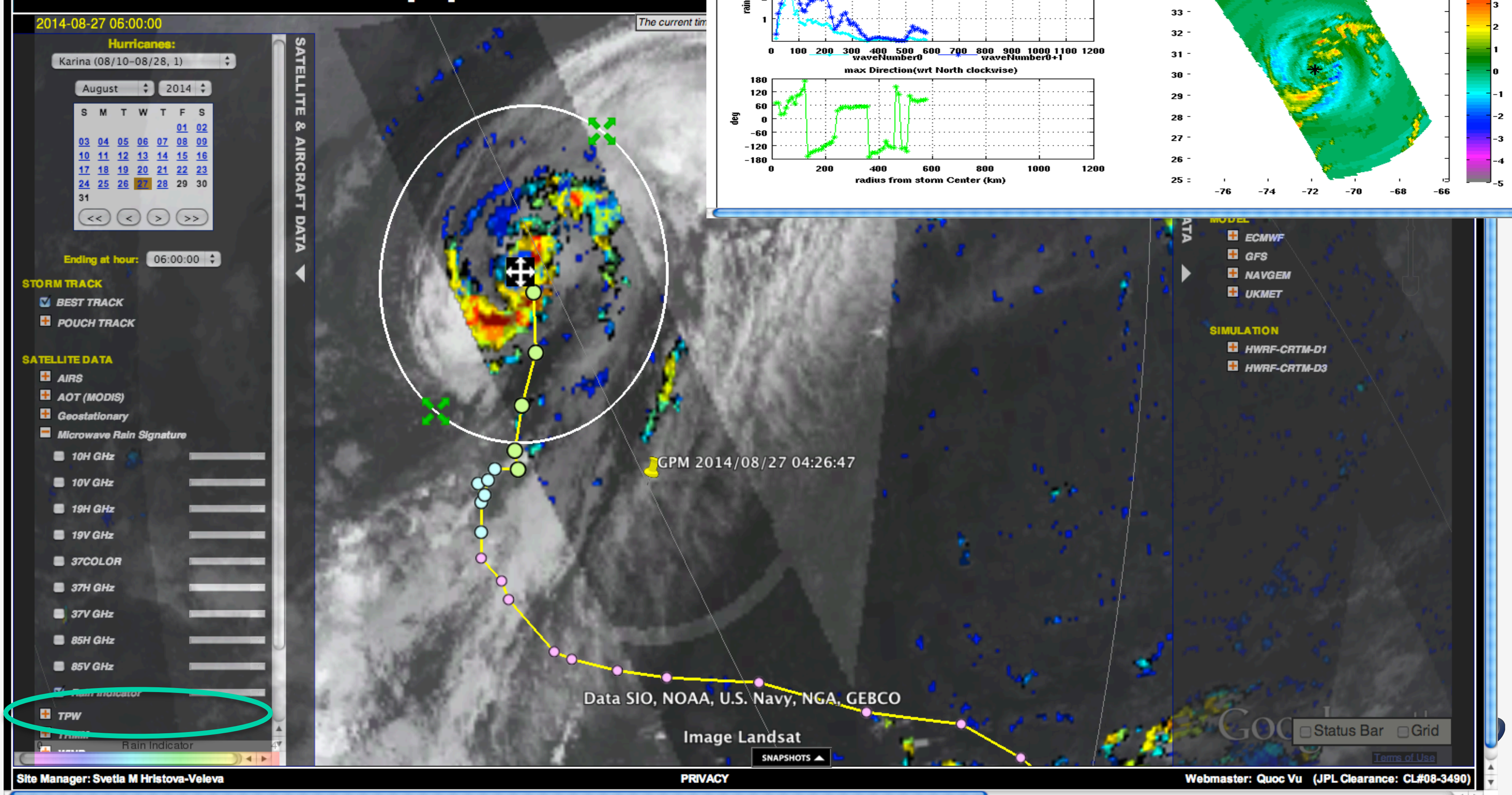
- combines the emission and scattering signals from the **multi-channel information to present a cohesive depiction of the rain and the graupel above**, covering the precipitation spectrum
- Uses polarization difference. Hence, it is **less affected by calibration accuracy**.

Storm structure Tool:

Storm Size and Asymmetry

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



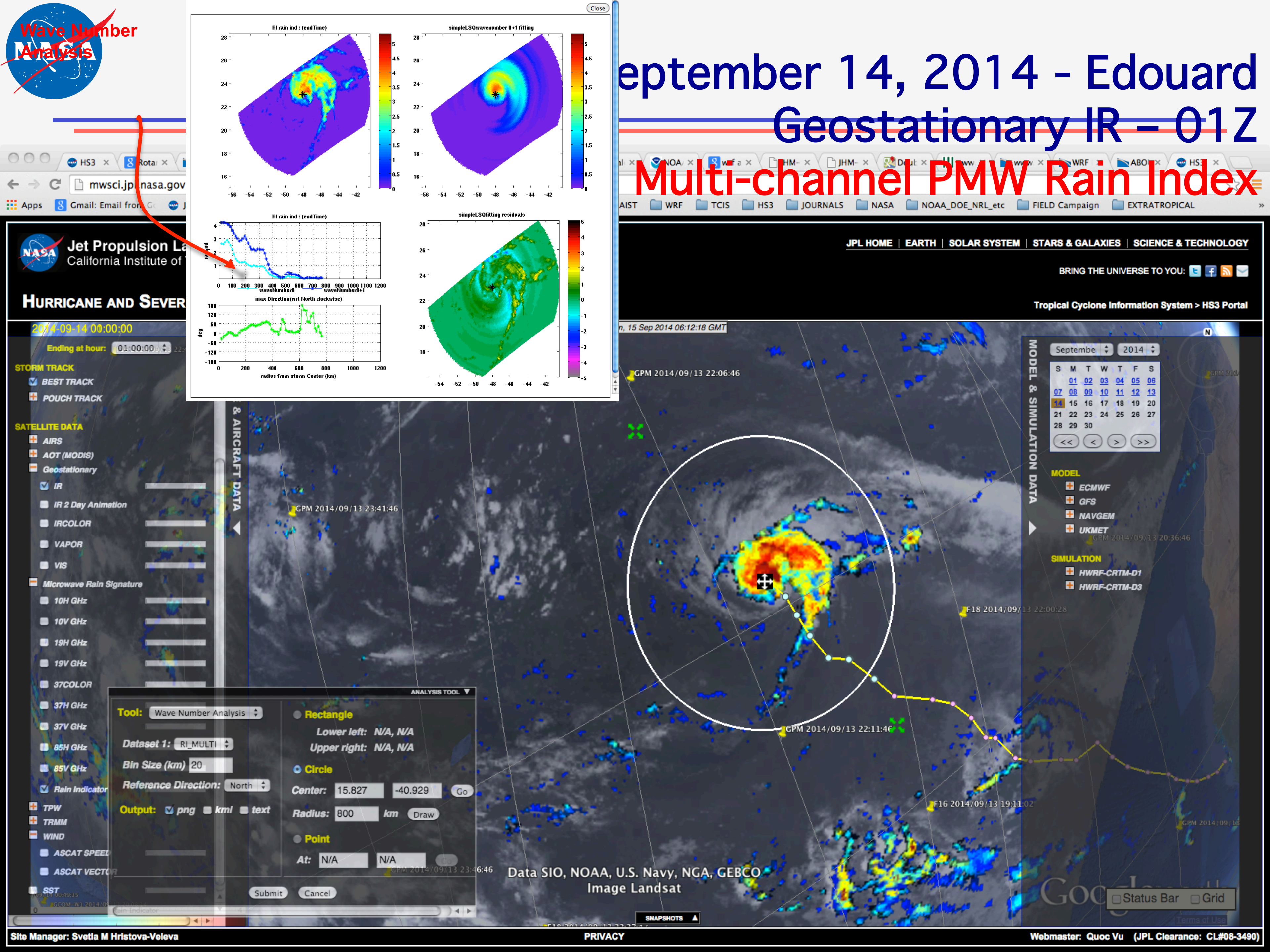


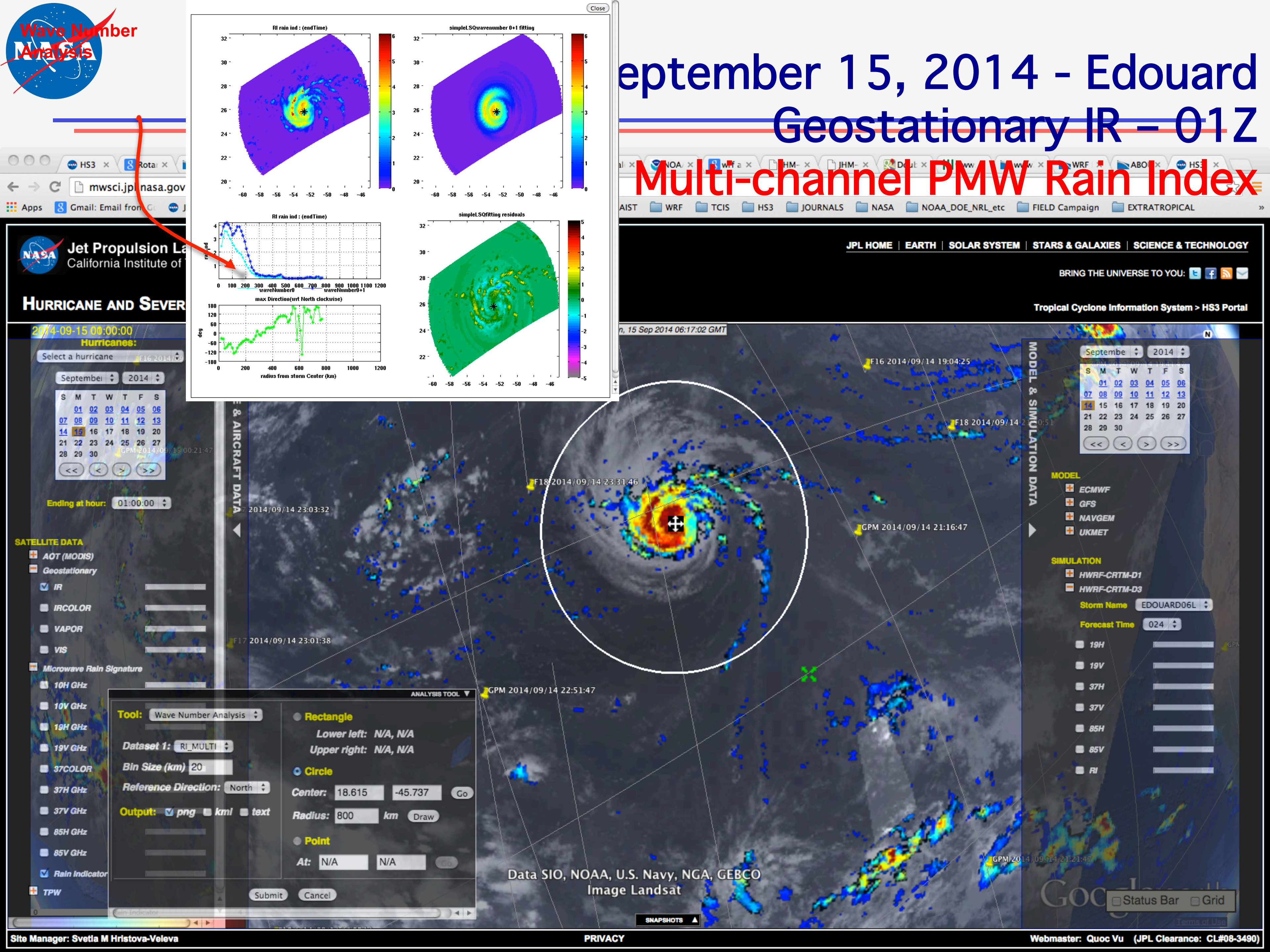
eptember 14, 2014 - Edouard

Geostationary IR – 01Z

Multi-channel PMW Rain Index

Wave Number Analysis



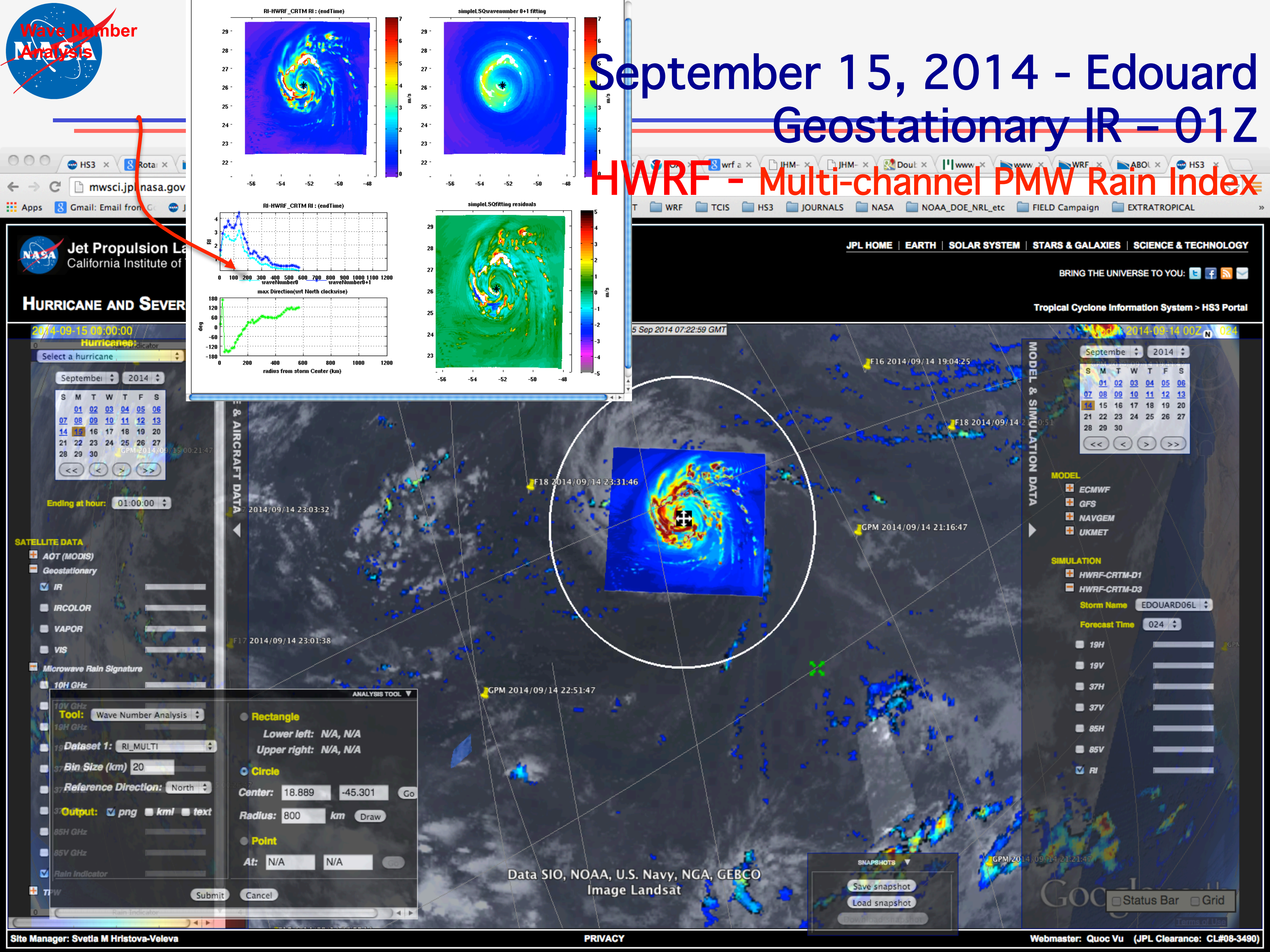


Wave Number Analysis
eptember 15, 2014 - Edouard
Geostationary IR – 01Z
Multi-channel PMW Rain Index
RI rain ind : (endTime)
simpleLSQwavenumber 0+1 fitting
simpleLSQfitting residuals
max Direction(wrt North clockwise)
radius from storm Center (km)
Jet Propulsion Laboratory
California Institute of Technology
Hurricane and Severe Storm Sentinel
JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | SCIENCE & TECHNOLOGY
BRING THE UNIVERSE TO YOU:
Tropical Cyclone Information System > HS3 Portal
2014-09-15 00:00:00
Hurricanes:
Ending at hour: 01:00:00
SATELLITE DATA
AOT (MODIS)
Geostationary
IR
IRCOLOR
VAPOR
VIS
Microwave Rain Signature
Rain Indicator
TPW
MODEL & SIMULATION DATA
MODEL
ECMWF
GFS
NAVGEM
UKMET
SIMULATION
HWRF-CRTM-D1
HWRF-CRTM-D3
Storm Name EDOUARD06L
Forecast Time 024
ANALYSIS TOOL
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: 18.615 -45.737
Radius: 800 km
Point
At: N/A N/A
Submit
Cancel
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)

September 15, 2014 - Edouard Geostationary IR – 01Z

HWRF - Multi-channel PMW Rain Index

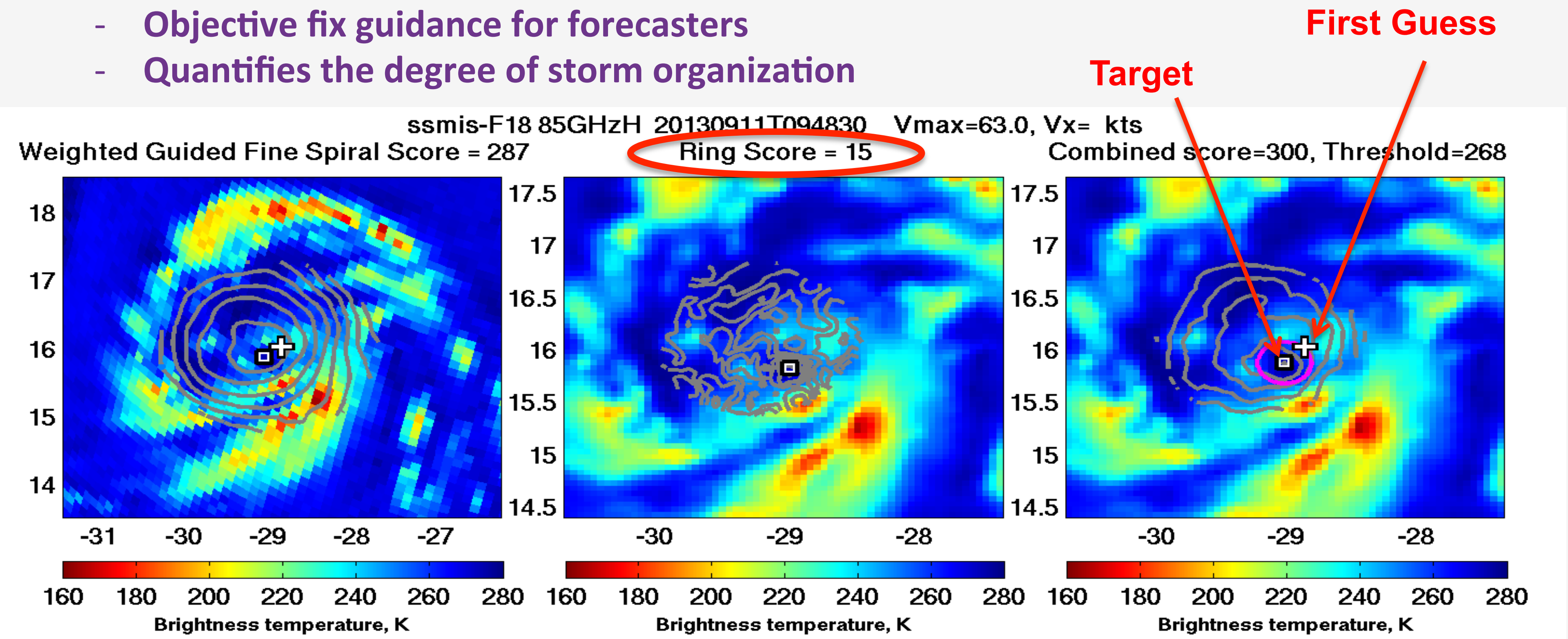
Wave Number Analysis



Storm structure Tool: Degree of Organization

The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

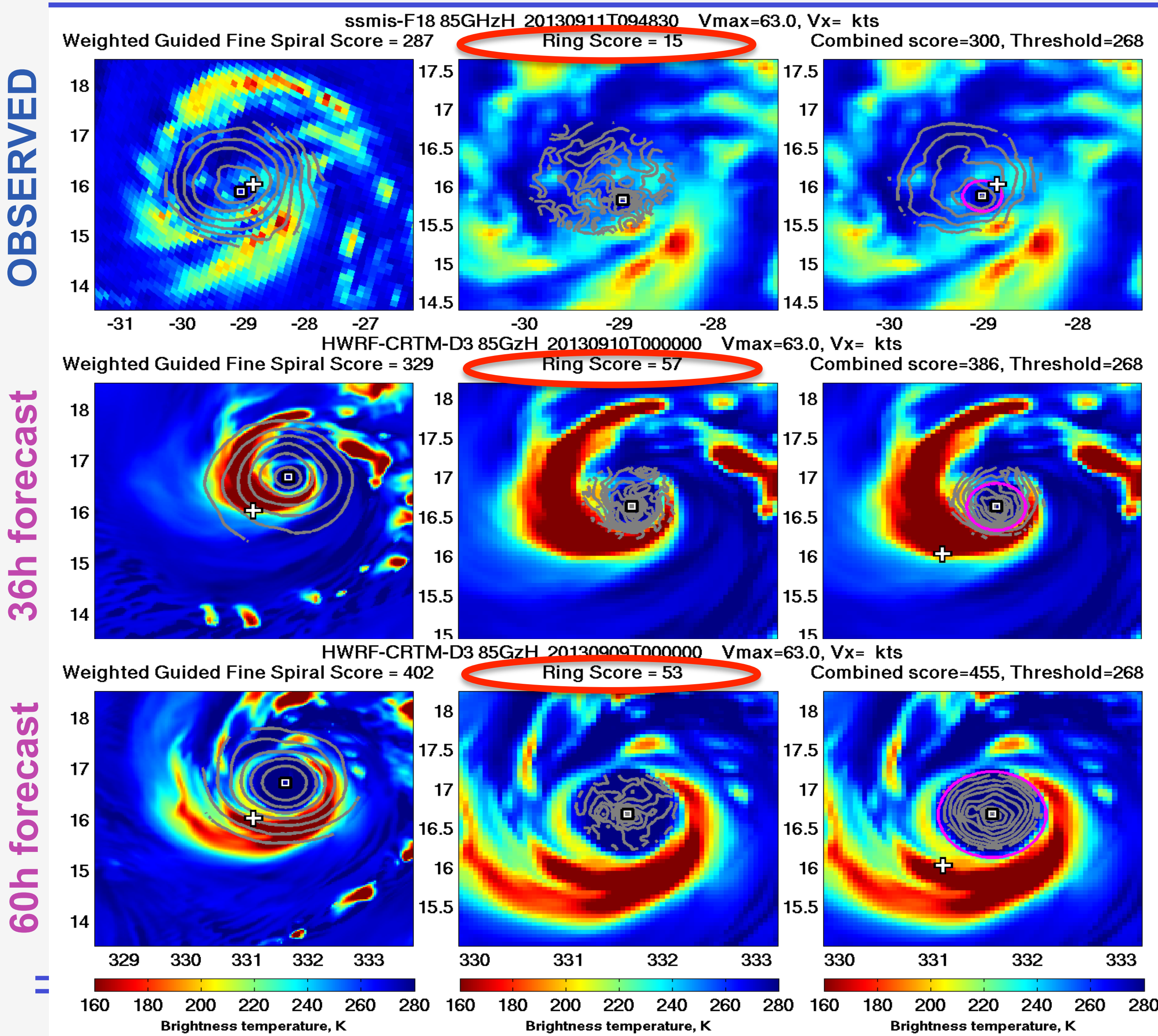
- Developed by CIMSS/NRL (Wimmers & Velden, 2010)
- We have license to run it and have done some off-line analysis, using the original version
- Coming online soon, with the latest version
- Provides:
  - Objective fix guidance for forecasters
  - Quantifies the degree of storm organization



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

Storm structure Tool: Degree of Organization

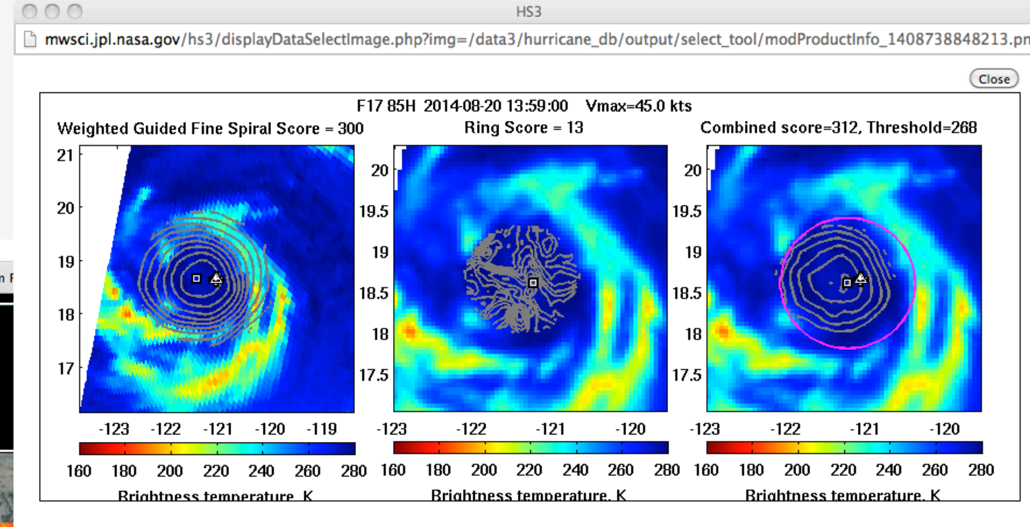
The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

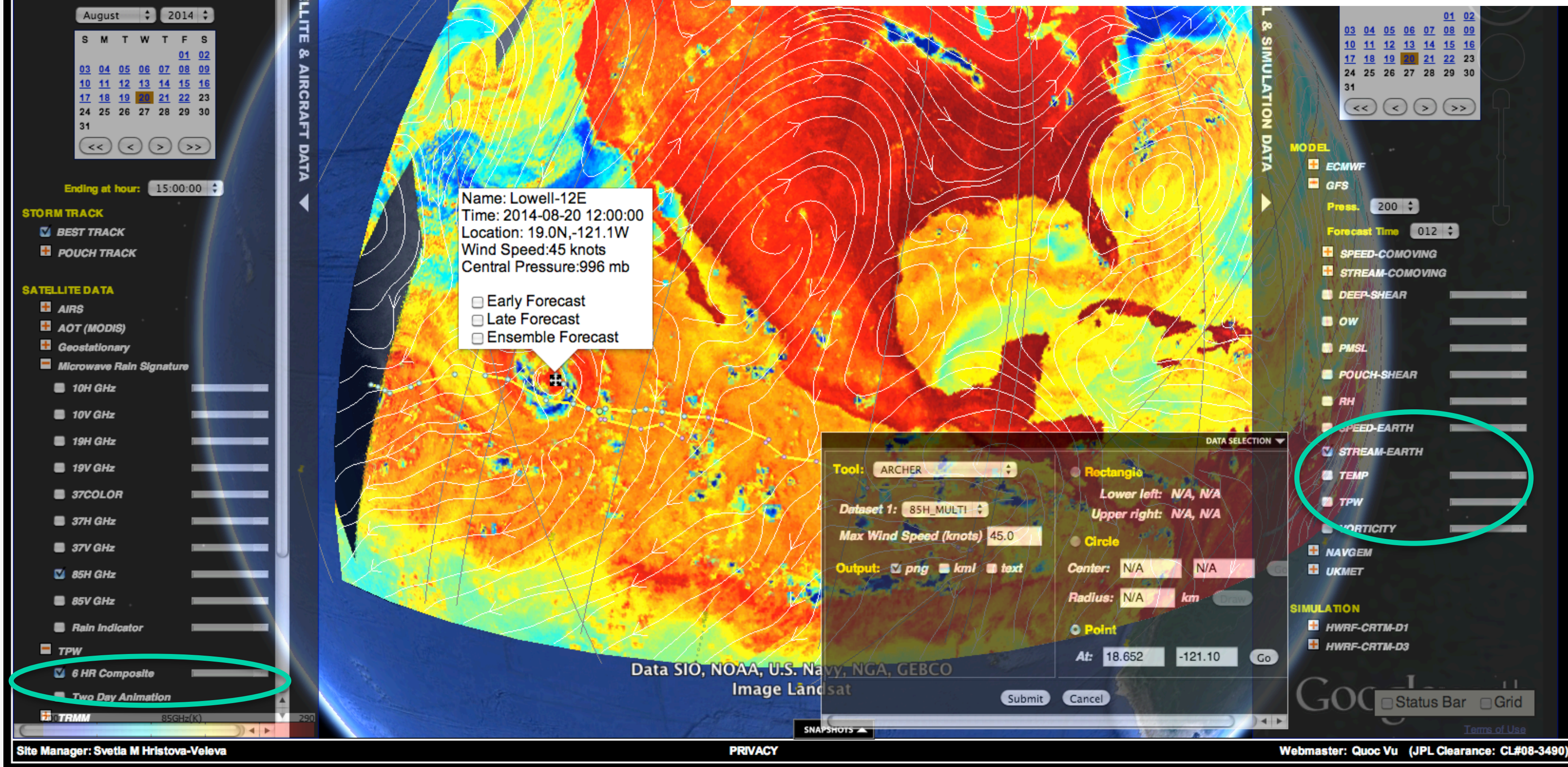


- **ARCHER scores suggest the model forecasts over-predicted the structure in this case.**
- **This conclusion is in agreement with the model-predicted intensity parameters:**
- **Observed:**
  - Vmax = 65kts
  - MSLP = 989 mb
- **36h forecast**
  - Vmax = 72 kts
  - MSLP = 977mb
- **60h forecast**
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

Storm structure Tool: Degree of organization

ARCHER (EP hurricane Lowell)





The JPL TCIS – Tropical Cyclone Information System

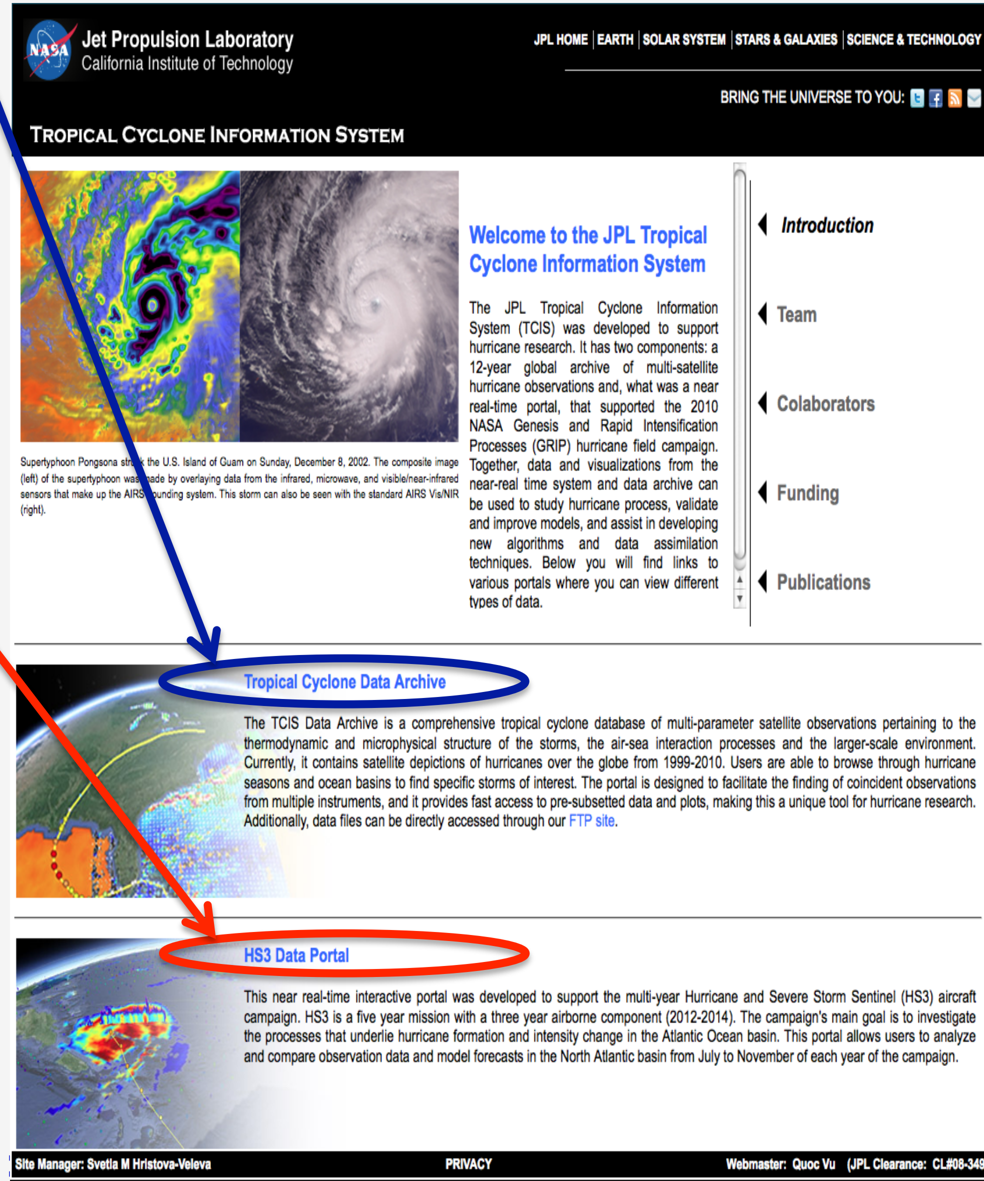
http://tropicalcyclone.jpl.nasa.gov

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.**



The 12-year Global Data Archive

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

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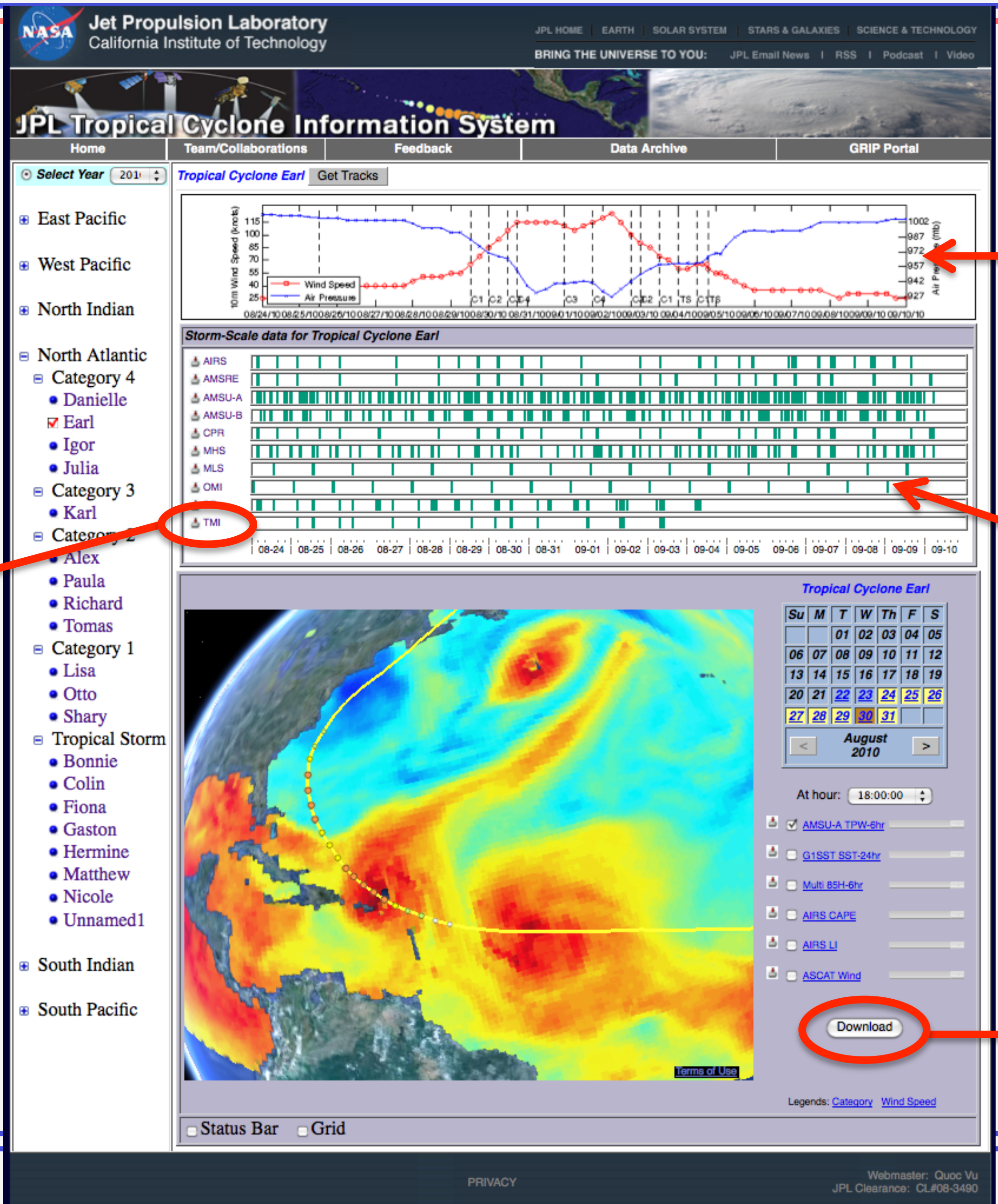
- Satellite depictions of hurricanes over the globe
- 12-year record (1999-2010)
- Offers both data and imagery, making it a unique source to support hurricane research.

JPL TCIS – The Tropical Cyclone Data Archive

http://tropicalcyclone.jpl.nasa.gov



Timeline

View and download Storm-scale data

Earl, 2010

Download all data from this Instrument (TMI)

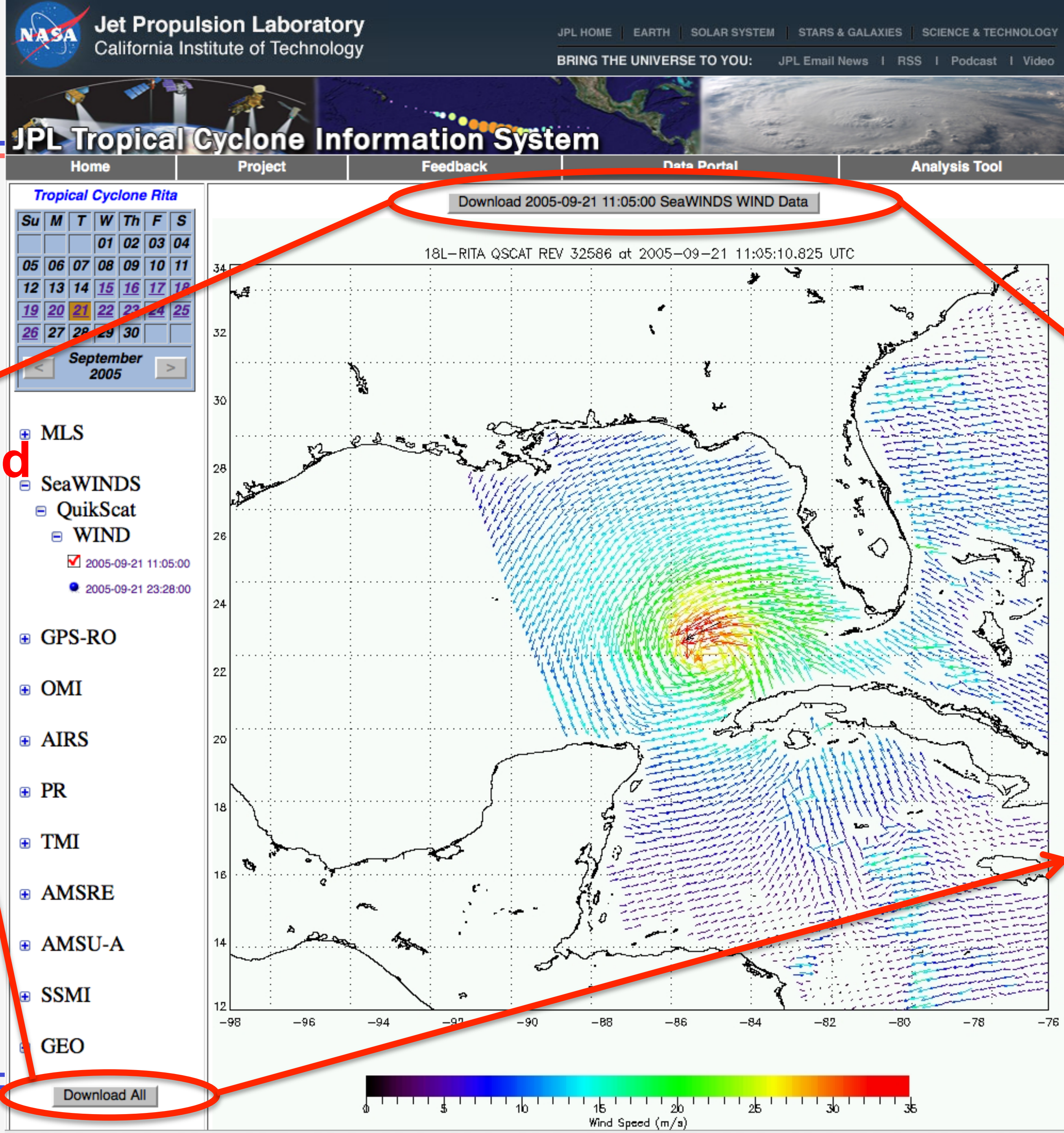
Download Selected large-scale data from

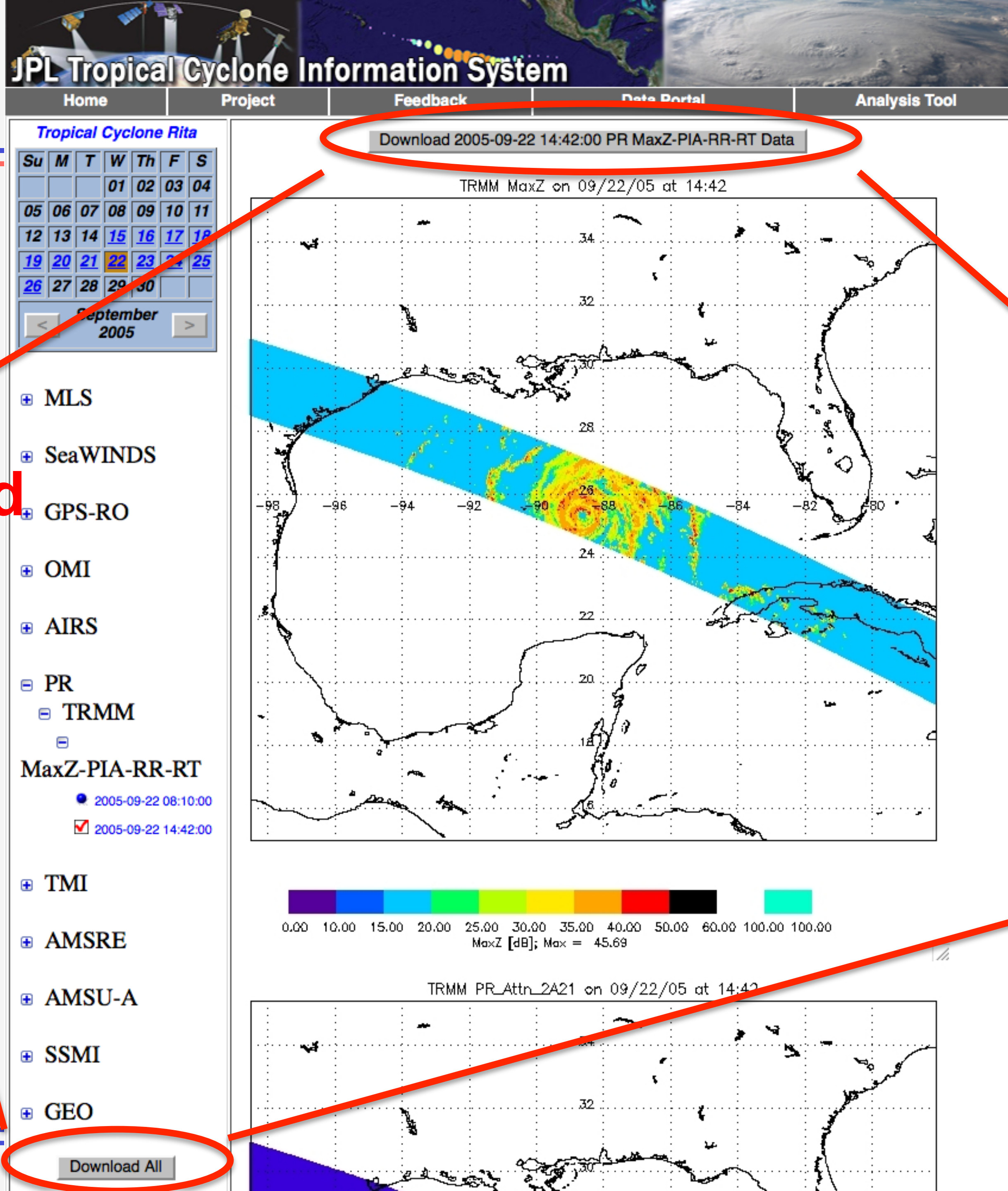
ESTO
Earth Science Technology Office

At this time

Download NetCDF

All data on this day





Download NetCDF

At this time

All data on this day

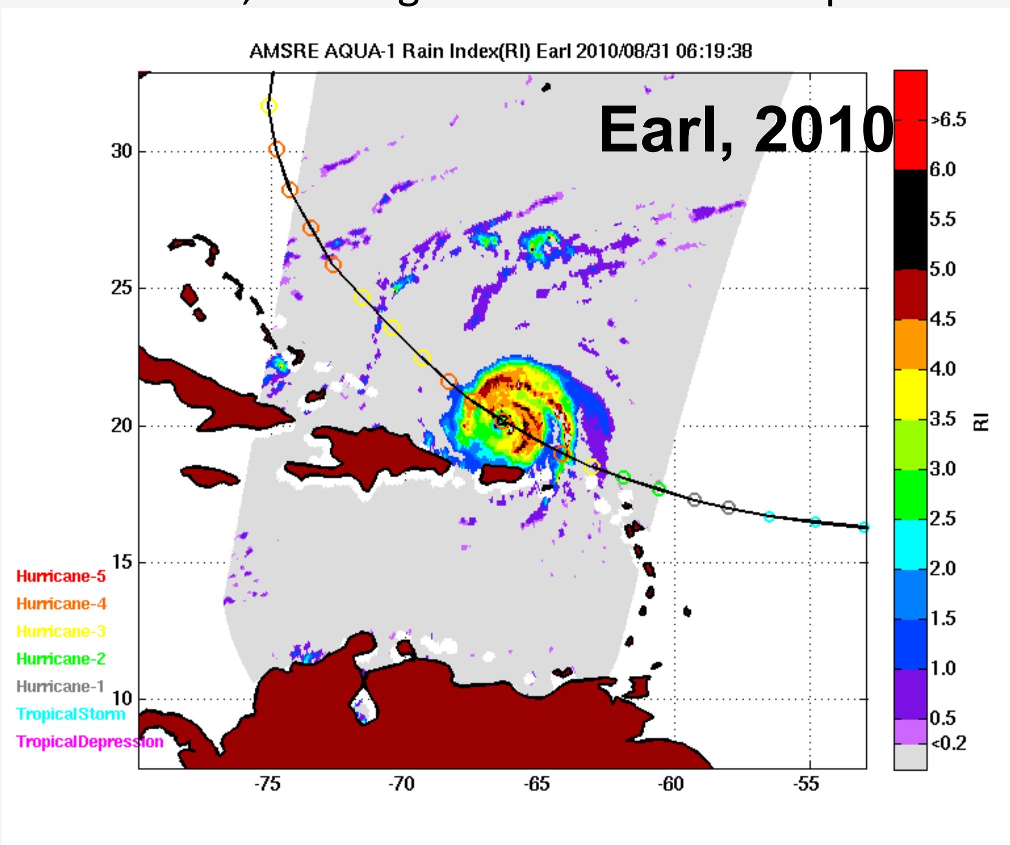
The Rain Indicator – a multi-channel depiction of the storm structure

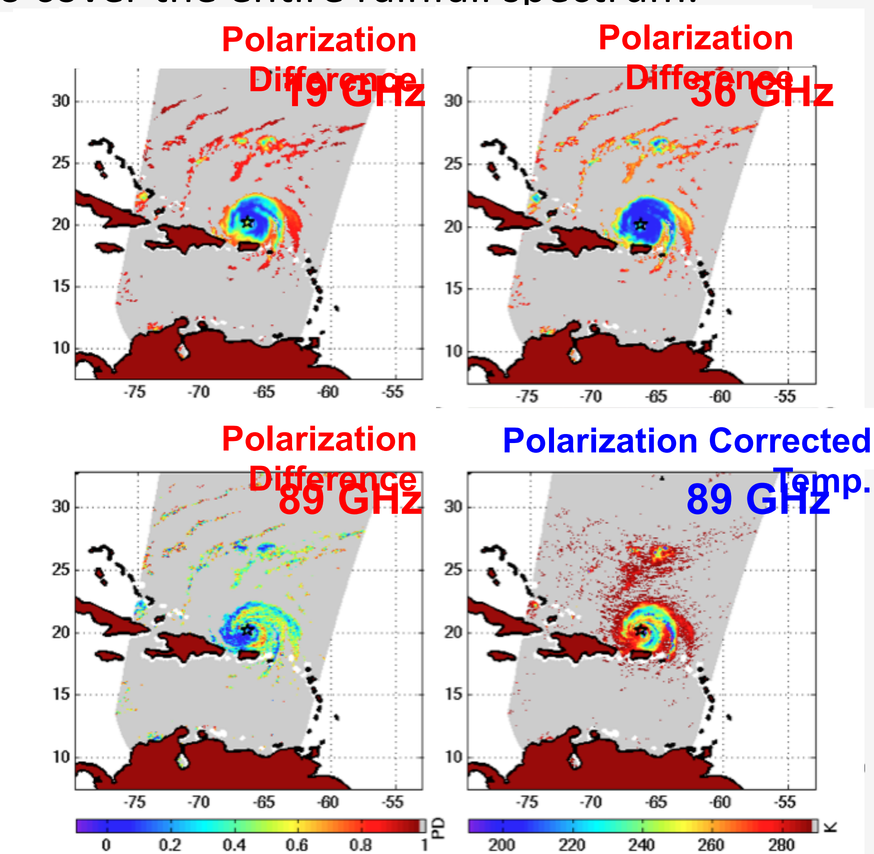
Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive ~~Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite~~ Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828–2848

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

- **emission signal** - dominant at lower frequencies; **warming**; **better for light rain**. ***Strong emission in the atmosphere reduces the polarization difference (PD) in the ocean surface radiation. Hence, PD is representative of the atmospheric emission.***
- **scattering signal** -dominant at higher frequencies; **cooling; better for heavy rain; PCT**

• Hence, both signals have to be incorporated to cover the entire rainfall spectrum.





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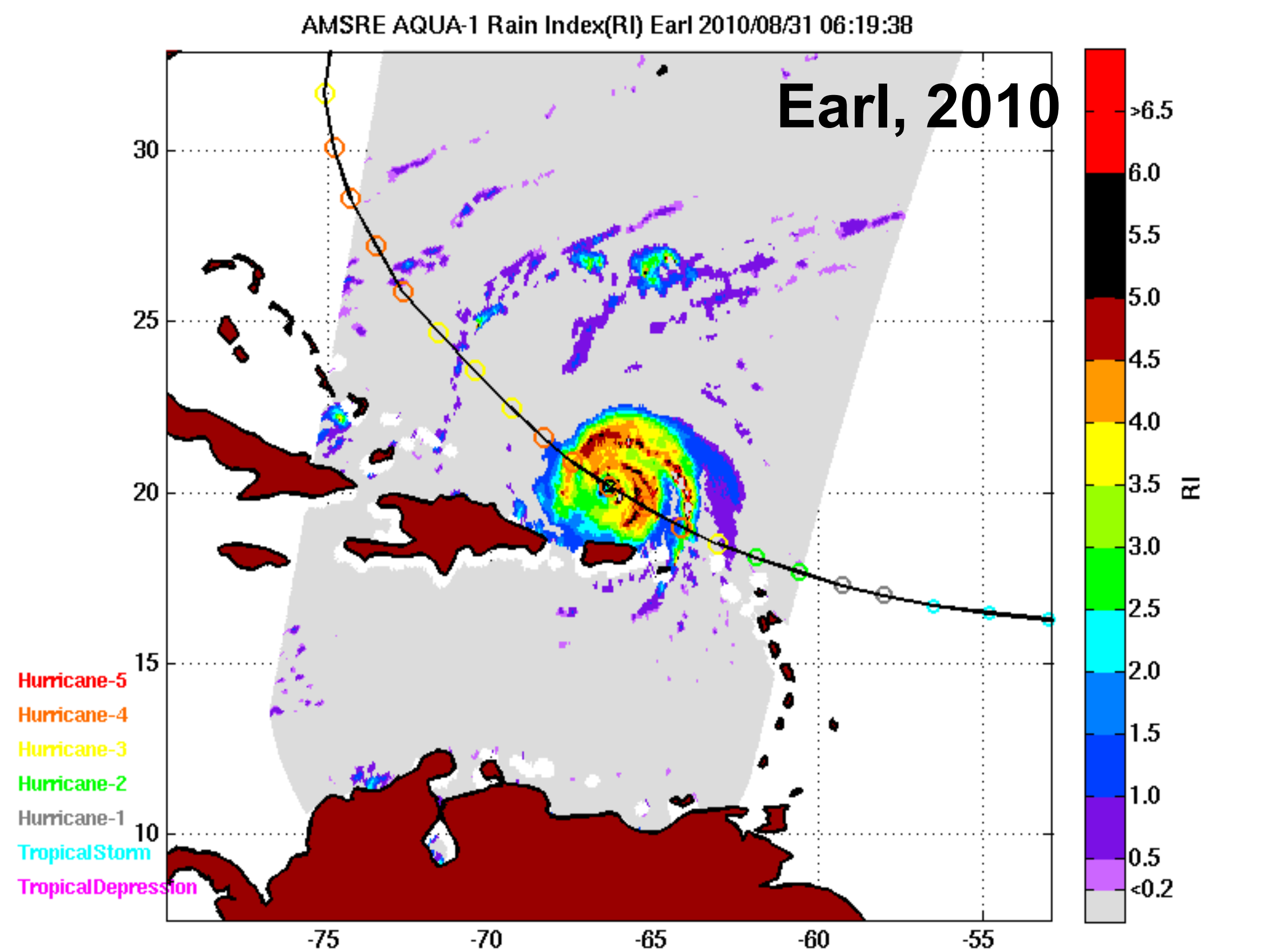

Advantages of Using the Rain Indicator over single passive microwave channels

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

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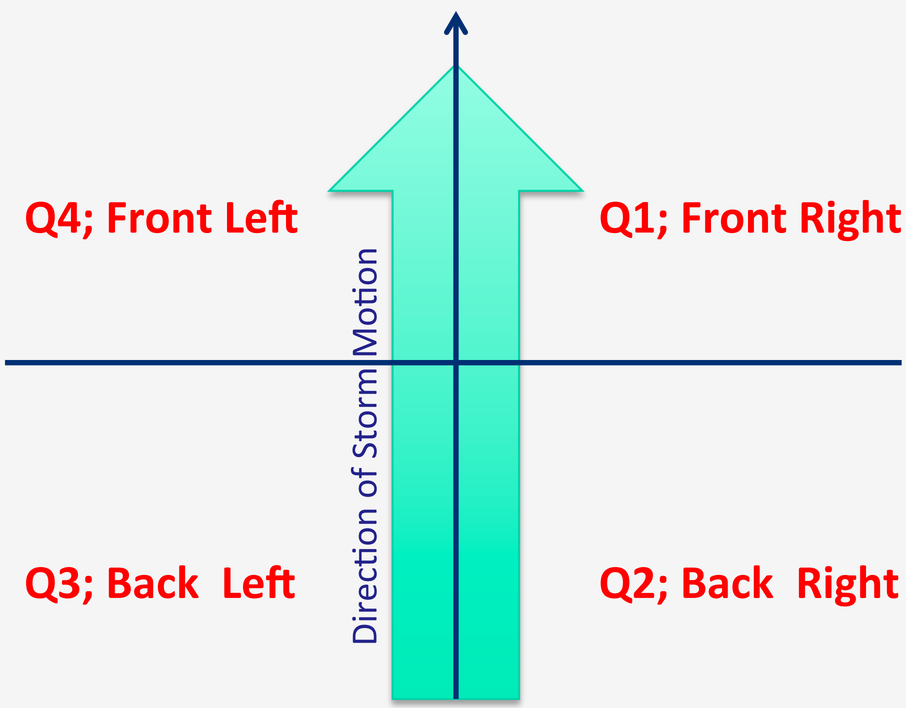
Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

Parameter as a function of:

- Quadrant with respect to storm motion



Created composites following similar approaches:

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

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

Wu, L, H. Su, R. G. Fovell, B. Wang, J. T. Shen, B. H. Kahn, S. M. Hristova-Veleva, B. H. Lambrigtsen, E. J. Fetzer, J. H. Jiang, 2012: "Relationship of Environmental Relative Humidity with Tropical Cyclone Intensity and Intensification Rate over North Atlantic", Geophys. Res. Lett., 39, L20809, doi: 10.1029/2012GL053546.

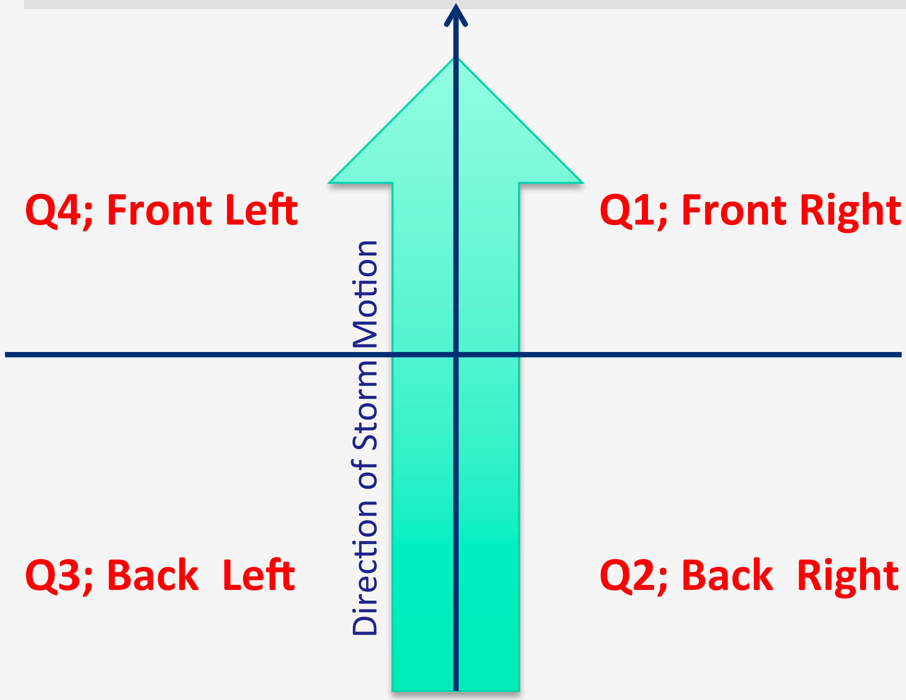
ESTO Earth Science Technology Office

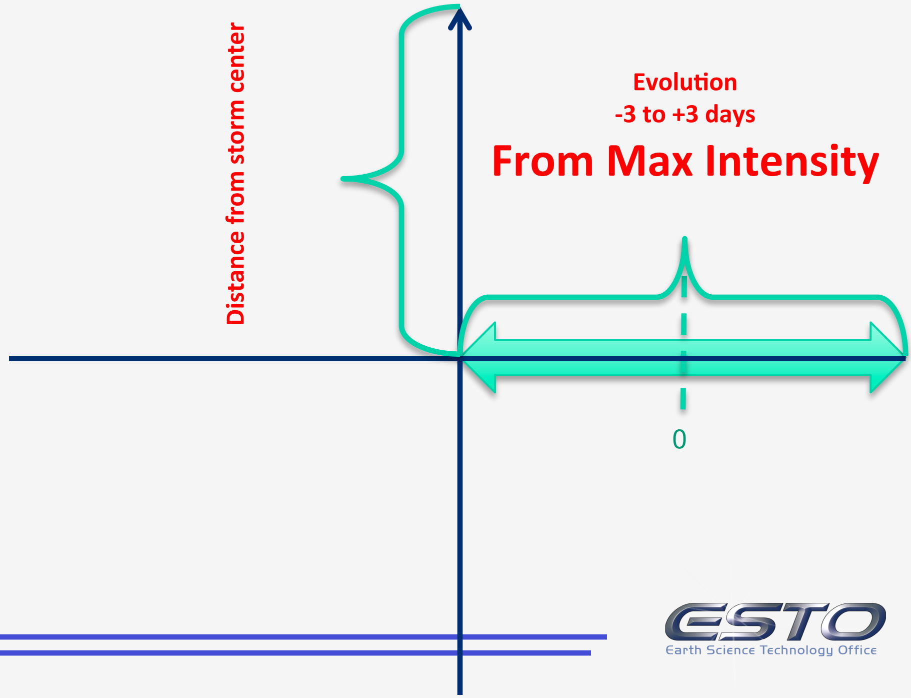
Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

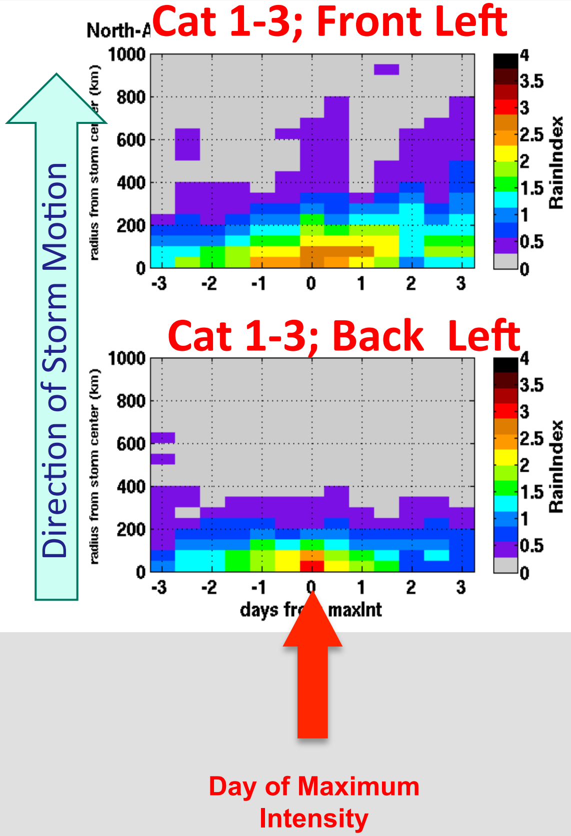
Parameter as a function of:

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





9-year statistics from AMSR-E observations North Atlantic Hurricanes; 2002-2011



Evolution of asymmetry

Azimuthal/Range Distributions of

Rain Index

Cat1: 31 cases

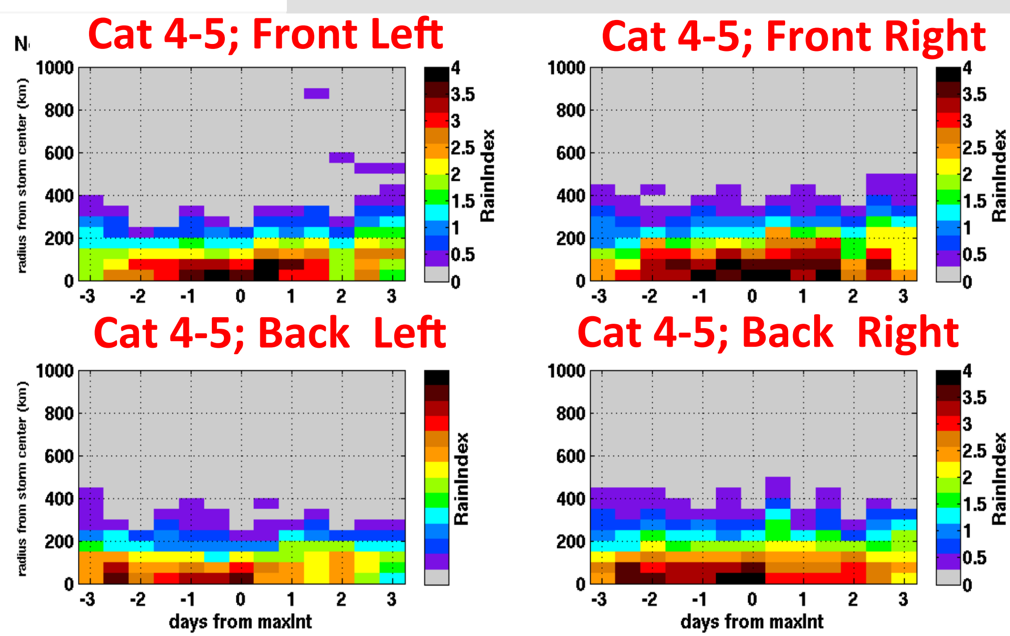
Cat2: 9 cases

Cat3: 12 cases

Total Cat1-3 = 52 cases

Cat4: 18 cases

Cat5: 7 cases



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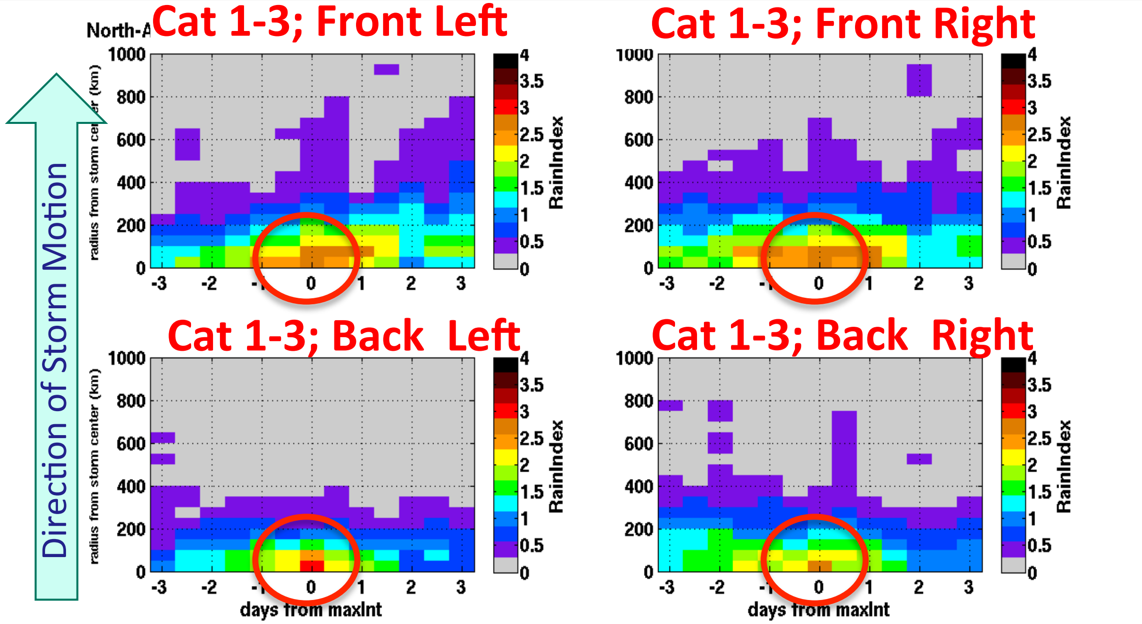

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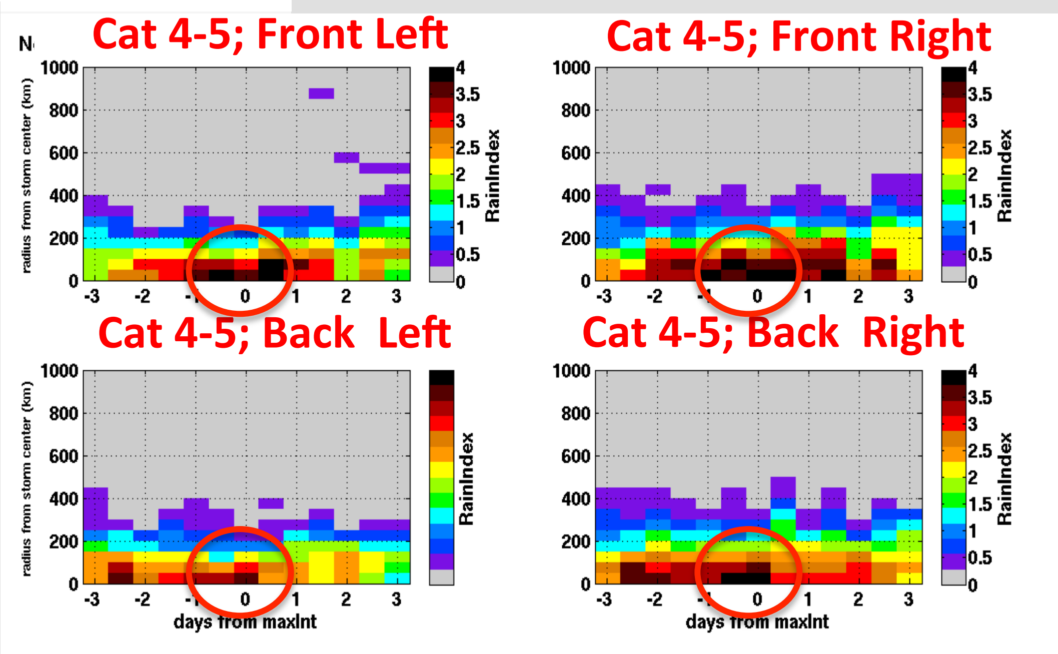
- **Space**
  - More intense precipitation is in the front 2 quadrants



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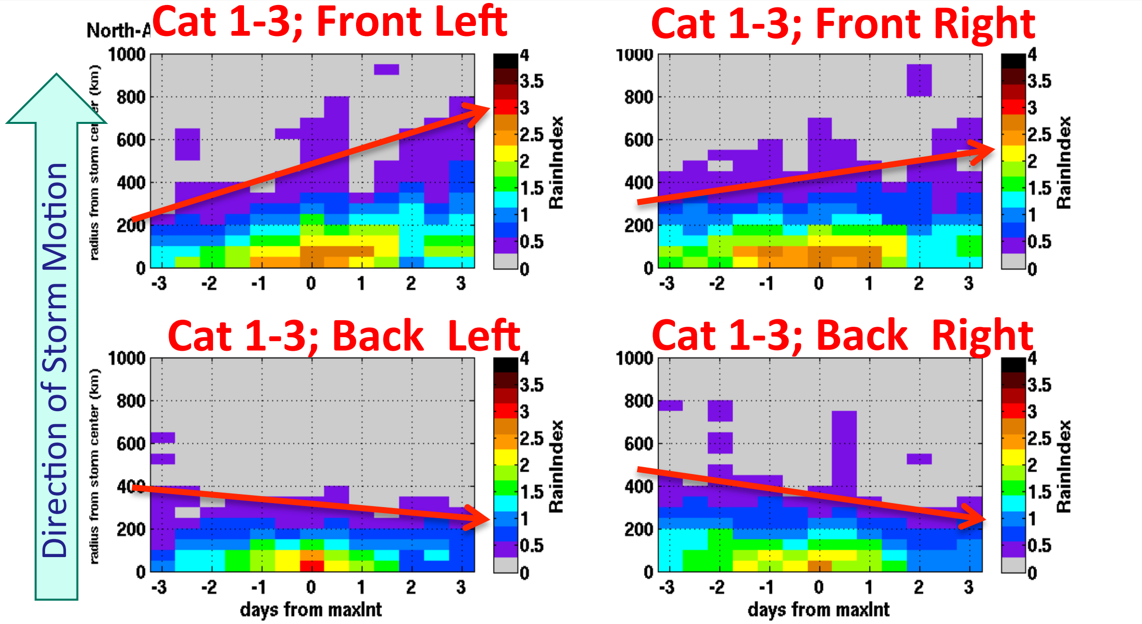

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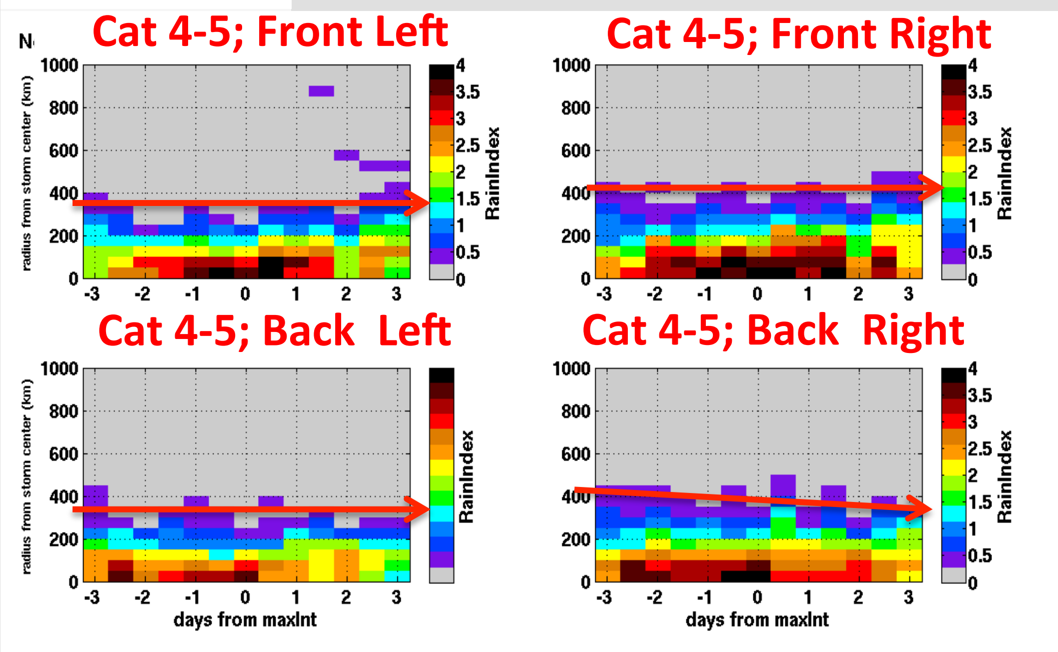
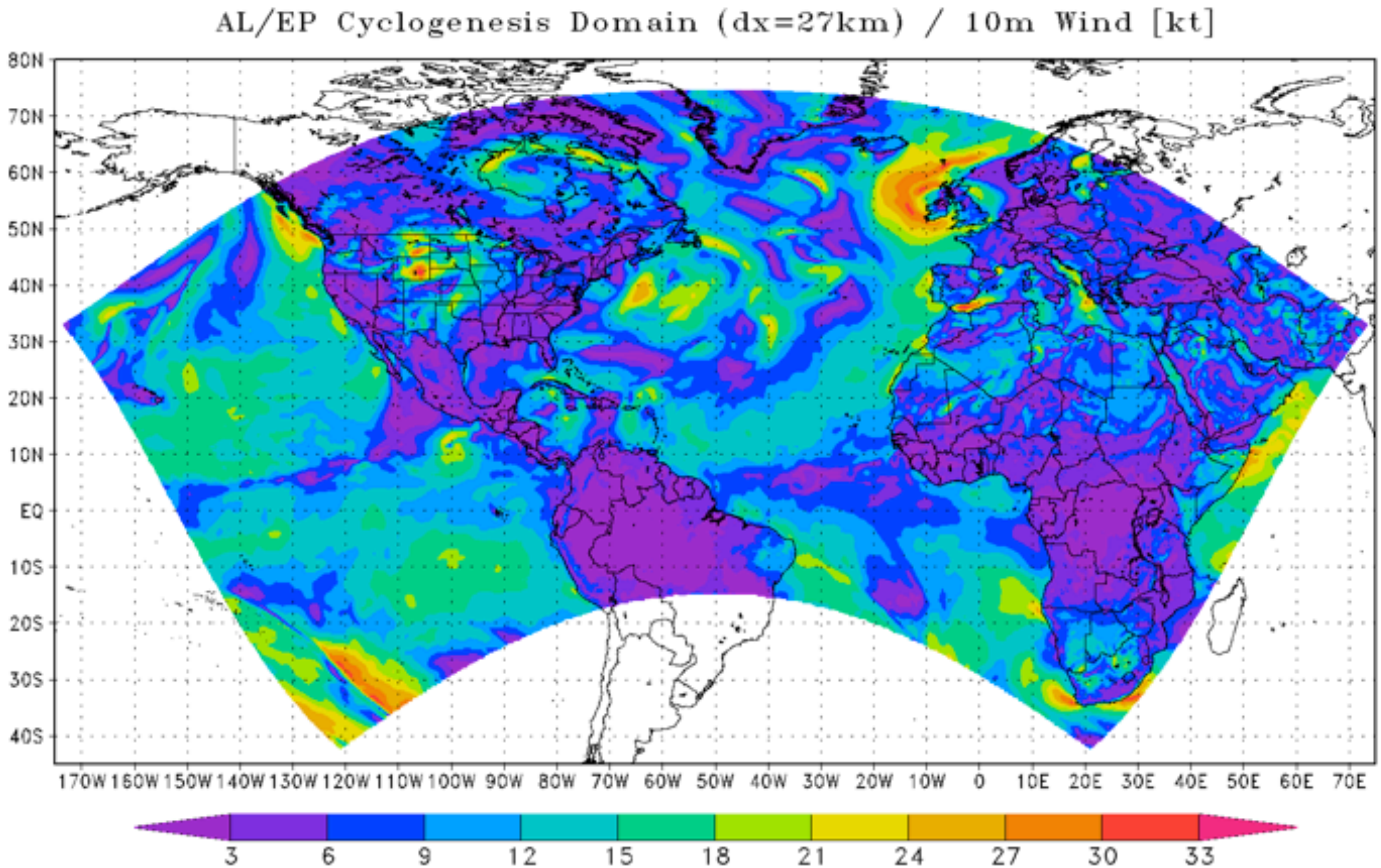
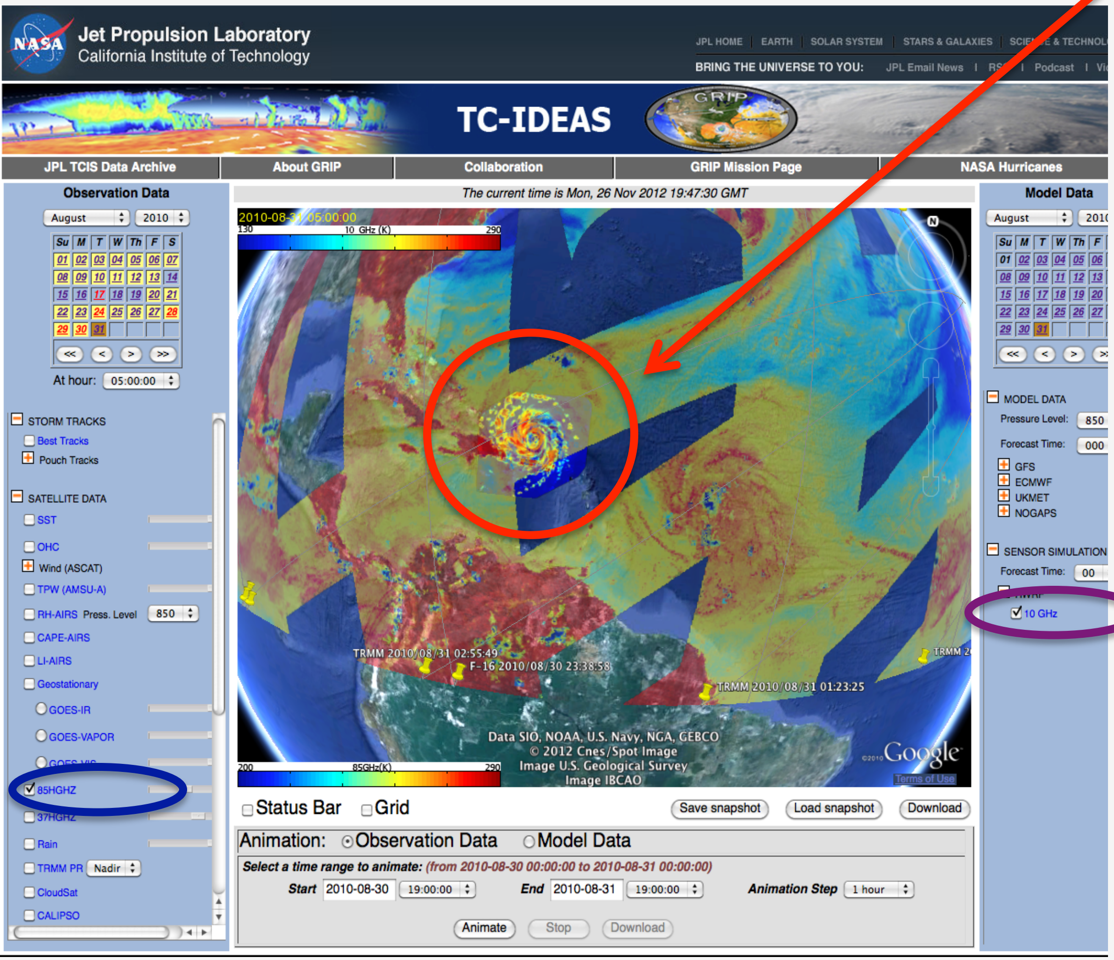
- **Space**
  - More intense precipitation is in the front 2 quadrants
- **Time**
  - Tendency for radial expansion of precipitation after the peak of the storm. Only in the front 2 quadrants.
  - Increase in asymmetry



Basin-scale HWRF – coming up!



Now: Developing analysis tools for model validation

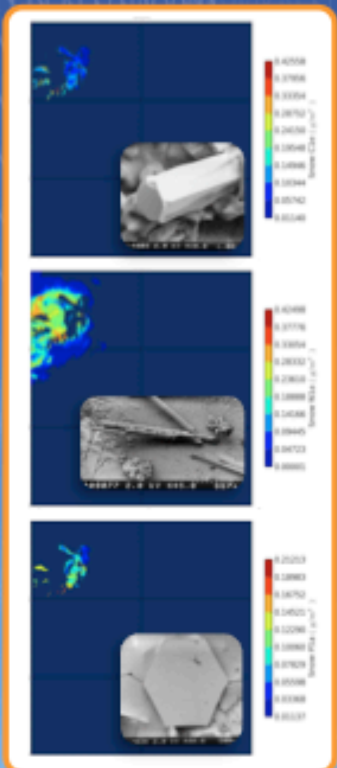


- Interactively select region
- Gather data from observed and synthetic brightness temperatures
- Statistical comparisons
  - Storm-relative coordinates
  - EOFs, CFADs, PDFs
  - Azimuthal averages =f(r)
- Storm Structure
  - Object classification
  - Metrics for model/obs classification
  - ARCHER
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

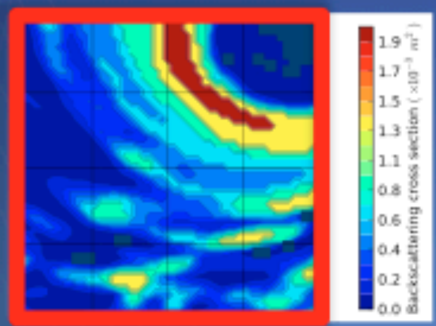
NEOS^3 : example of the 3 stages

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

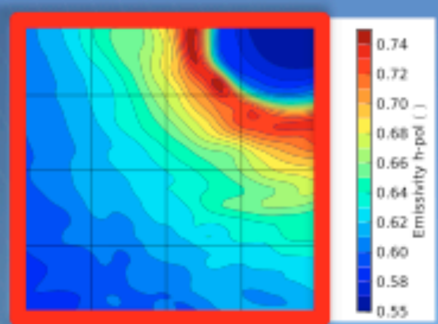
Mixing ratio by particle types



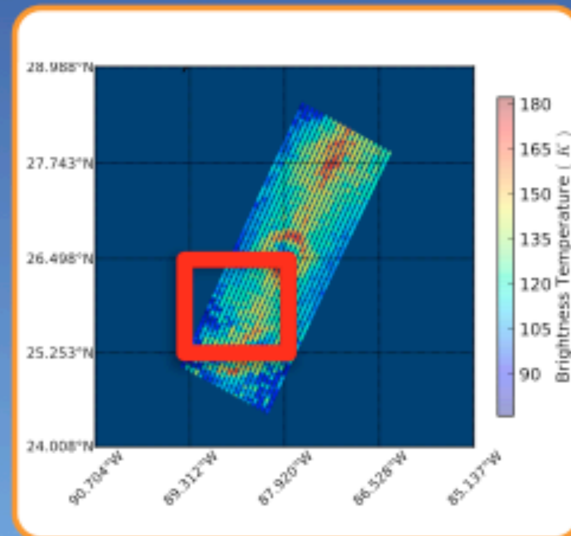
Atmospheric scattering



Surface scattering



Brightness Temperature



IRM Geophysics

SEAM Electromagnetics

ISM Propagation & Instruments

ESTO

Focus on the model – including the operational HWRF model forecast

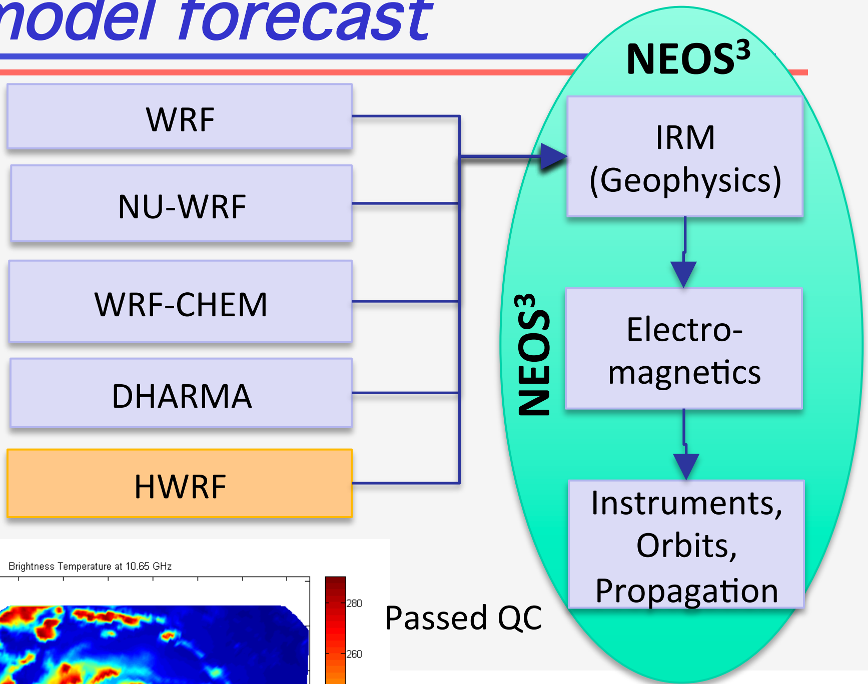
2. Integration of TCIS and NEOS^3

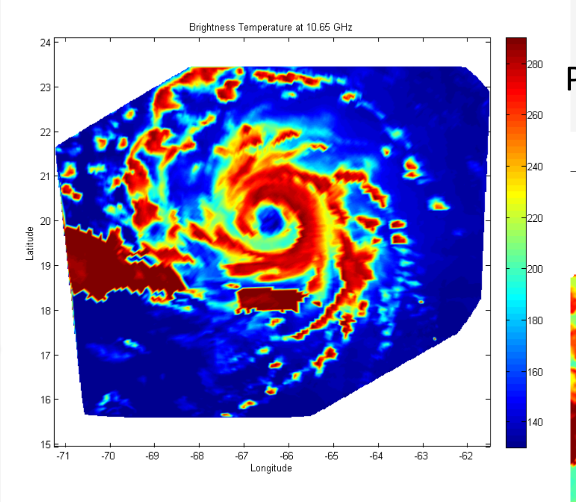
a) New IRM module: HWRF reader

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

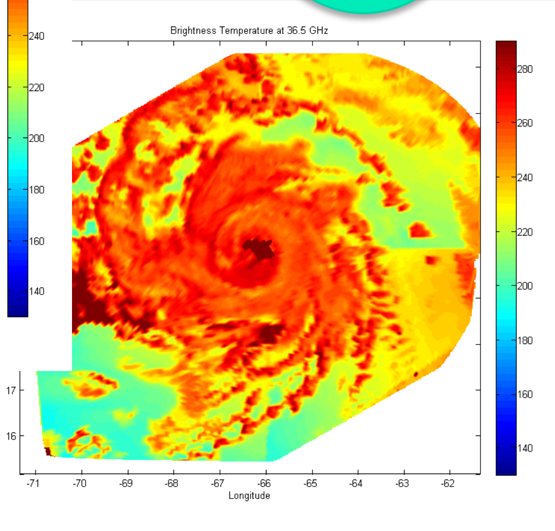
b) Full simulations of HWRF

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





Passed QC



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