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]

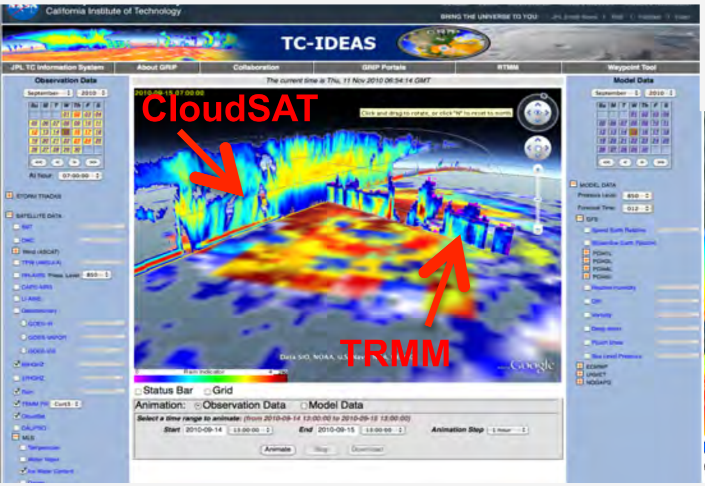
[1] – JPL, Pasadena, CA
[2] – HRD/AOML/NOAA, Miami, FL
[3] – EMC/NCEP/NOAA, College Park, MD
[4] - NPS, Monterey, CA

The JPL Tropical Cyclone Information System

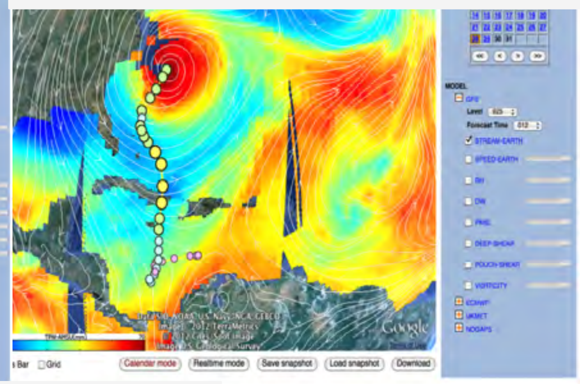
HFIP – August 27th, 2014

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

- Is the representation of the precipitation structure correct?



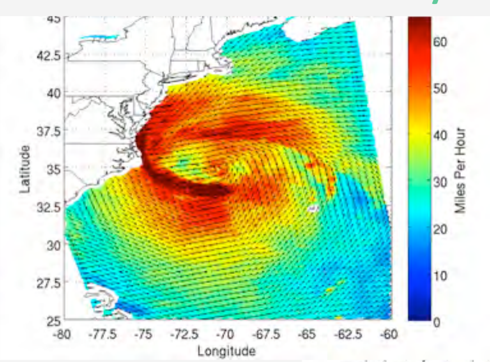
- Is the environment captured correctly?
- Is the interaction between the storm and its environment realistic?



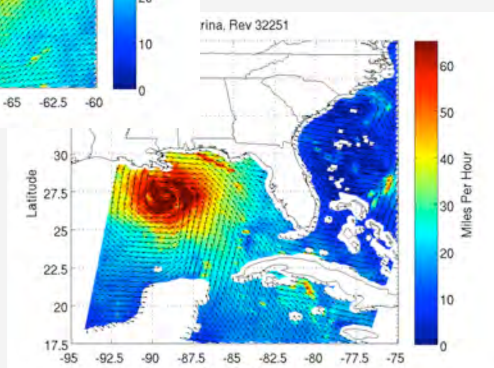
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

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, and the Hurricane Science Research Program (HSRP) in the past).

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

The JPL TCIS – Tropical Cyclone Information System

http://tropicalcyclone.jpl.nasa.gov

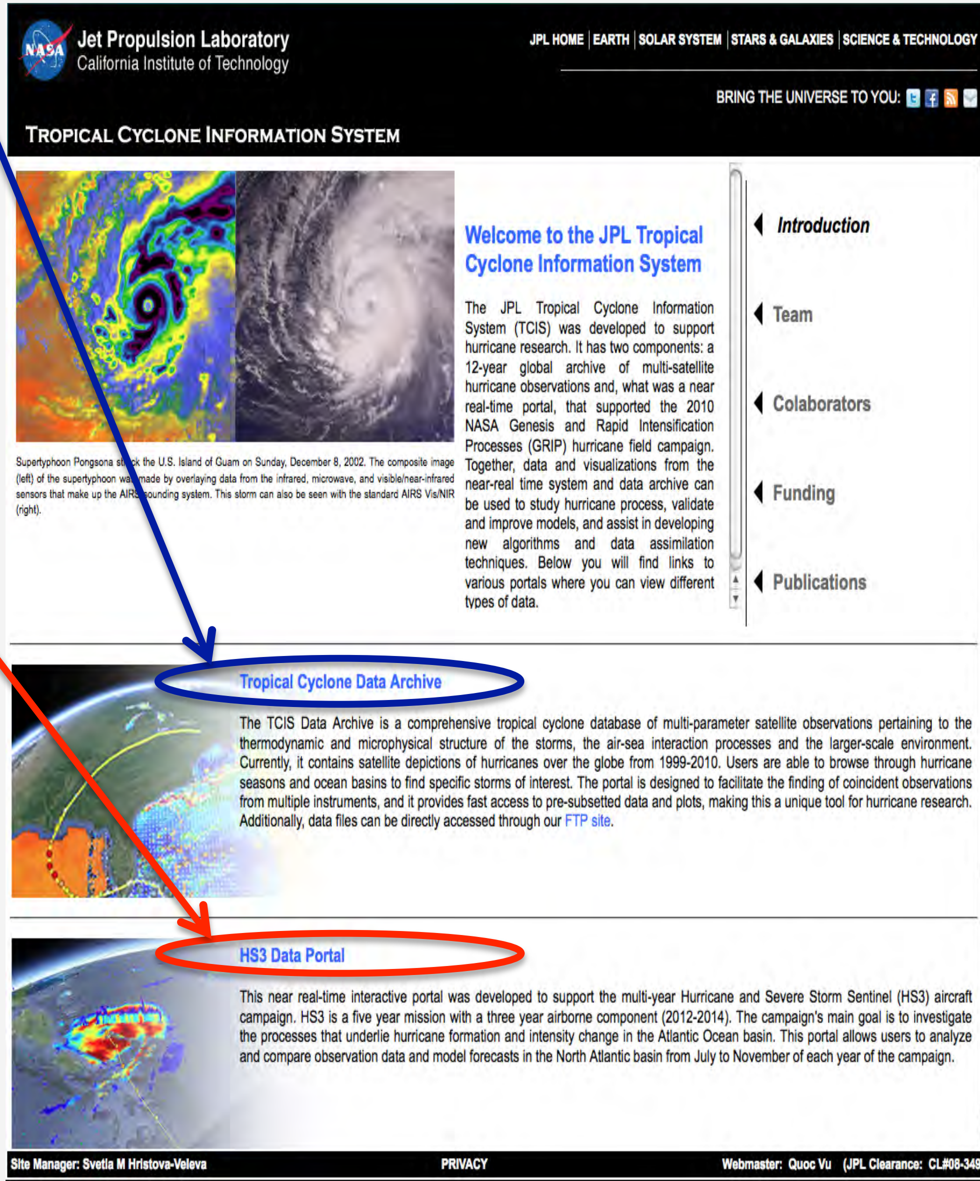
Tropical Cyclone Data Archive

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

HS3 – Interactive NRT Atlantic portal

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

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



Part 1: The Interactive NRT Atlantic portal

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

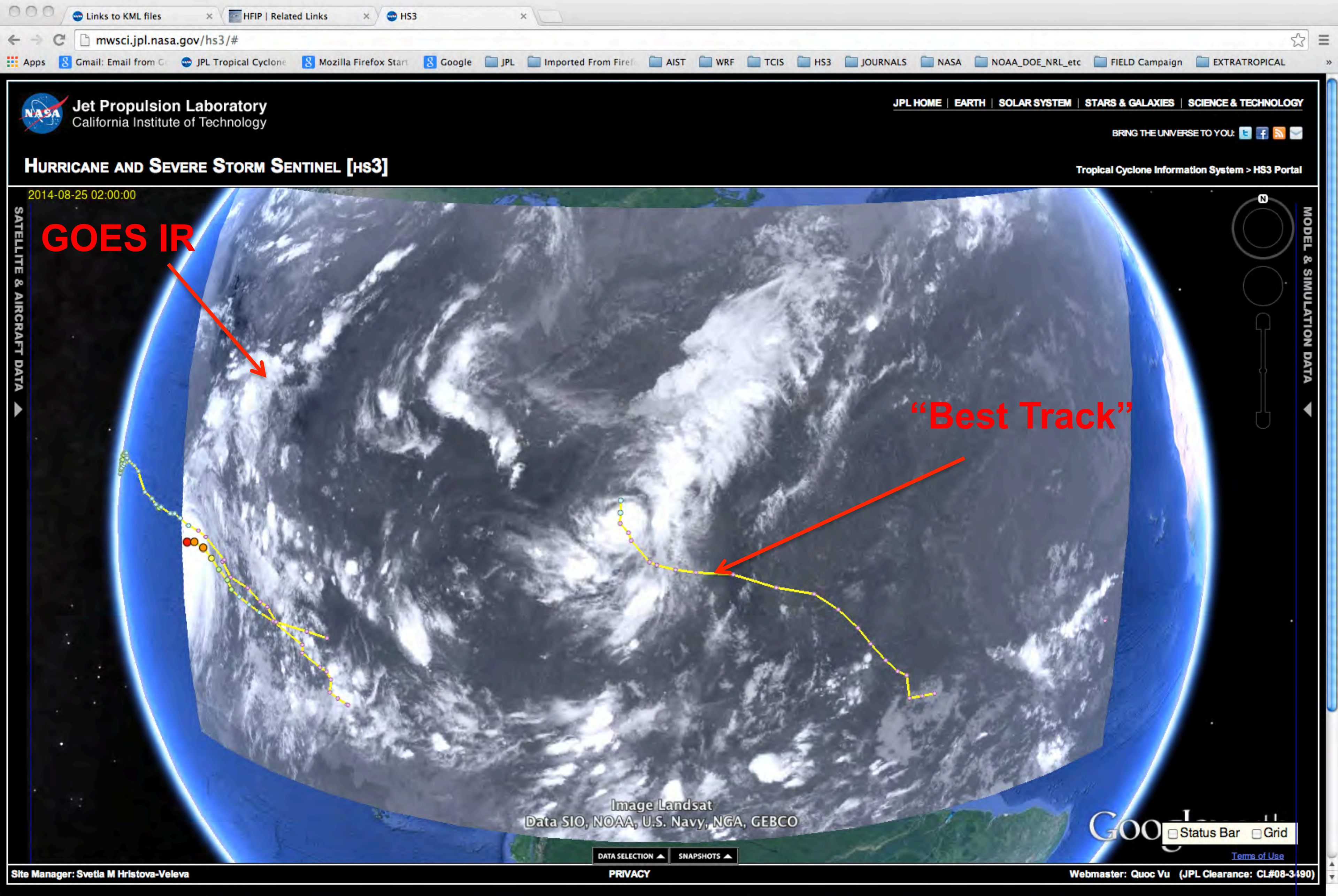
2. Analysis tools

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

- Satellite Observations
  - Geostationary (IR, VIS, IRcolor, vapor) – hourly; 2-day IR animations
  - Thermodynamics
    - TPW from AMSU – 6h composite, 2-day animations
    - AISR – soundings, RH and temperature at pressure levels
  - Aerosol Optical Thickness (MODIS) - daily
  - Storm structure – 6h composites
    - Passive Microwave Observations(8 channels, the Rain Index) – multi-satellite
    - 3D from TRMM-PR curtains, coming up are the GPM-DPR obs.
  - SST – multi-instrument product; daily
  - Ocean Surface winds from scatterometer observations – 6h composites
- Models – ECMWF, GFS, NAVGEM, UKMET
  - Model fields and pouch analysis provided by the Montgomery Research Group
- HWRF synthetic data
  - provided by EMC (Vijay Tallapragada and Sam Trahan)
- Hurricane tracks – from observations and models (pouch tracks)
- Limited set of airborne observations (HAMSR, dropsondes, APR2)

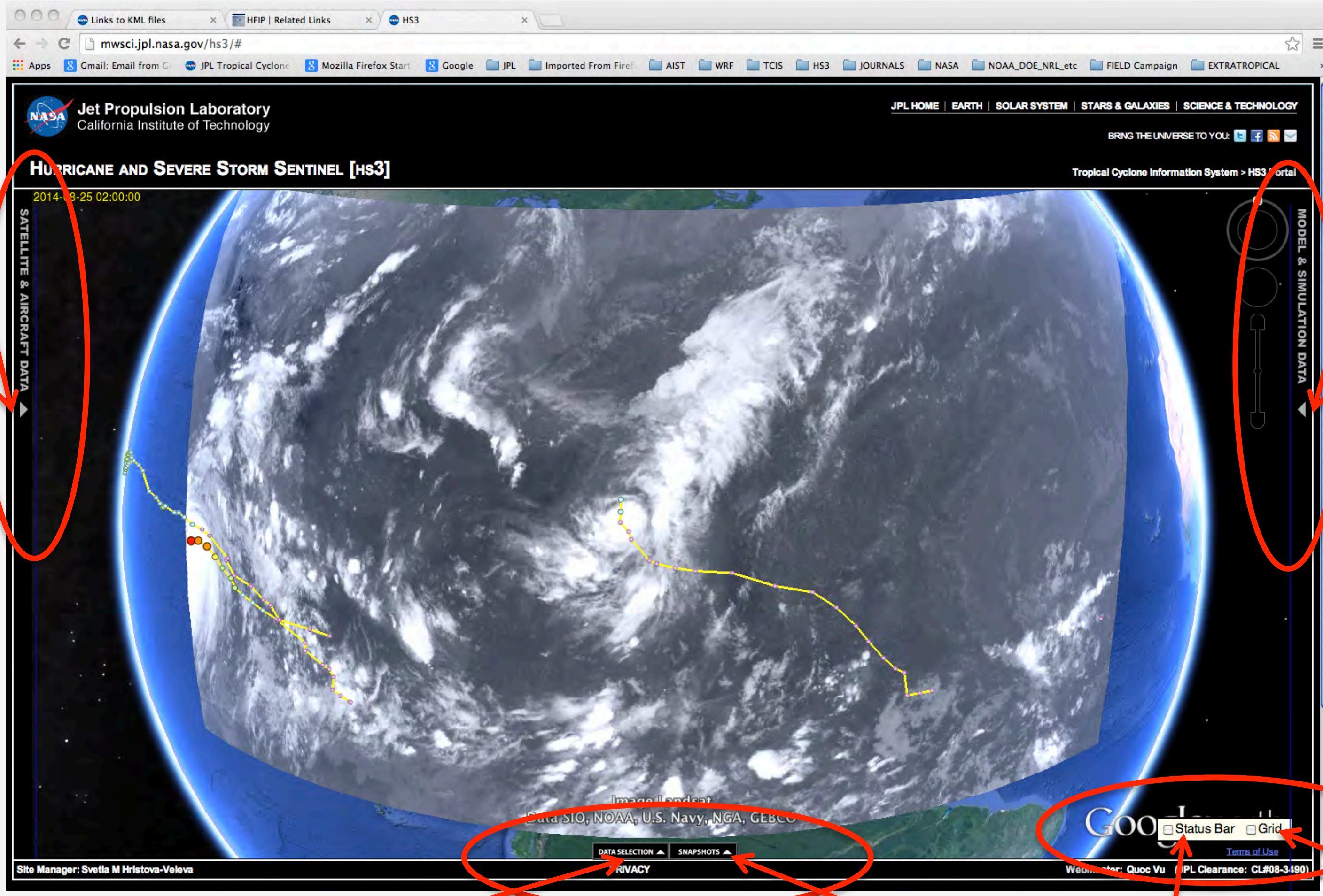
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

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

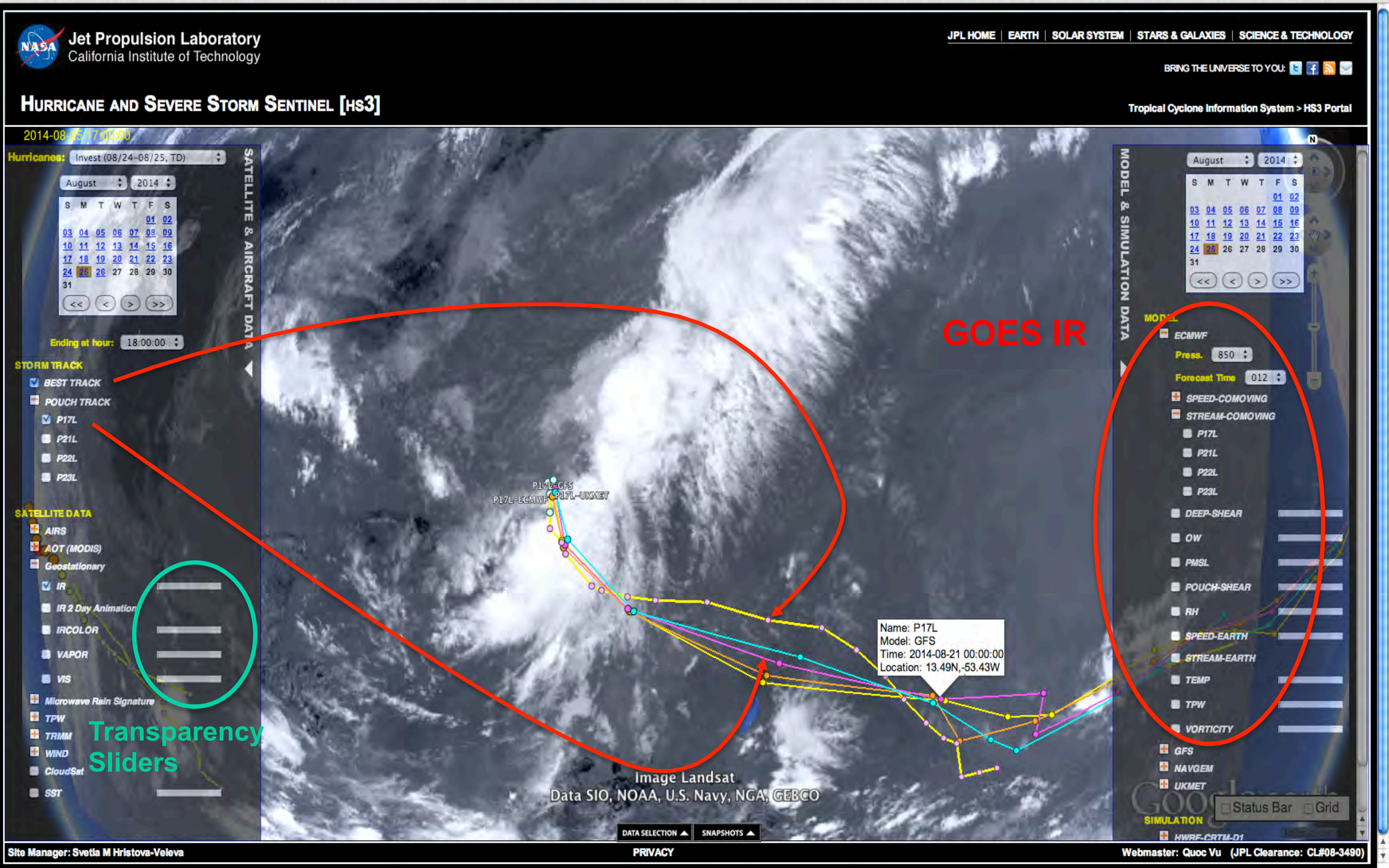
Two Calendar-driven menus (click on the triangles on the two sides):
- Observations **- Model data**



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

Bringing models and observations together (The portal combines satellite, some airborne, and model data and provides interactive visualization to allow the users to relate the observed and the forecasted parameters)

"Best Track" and Pouch tracks



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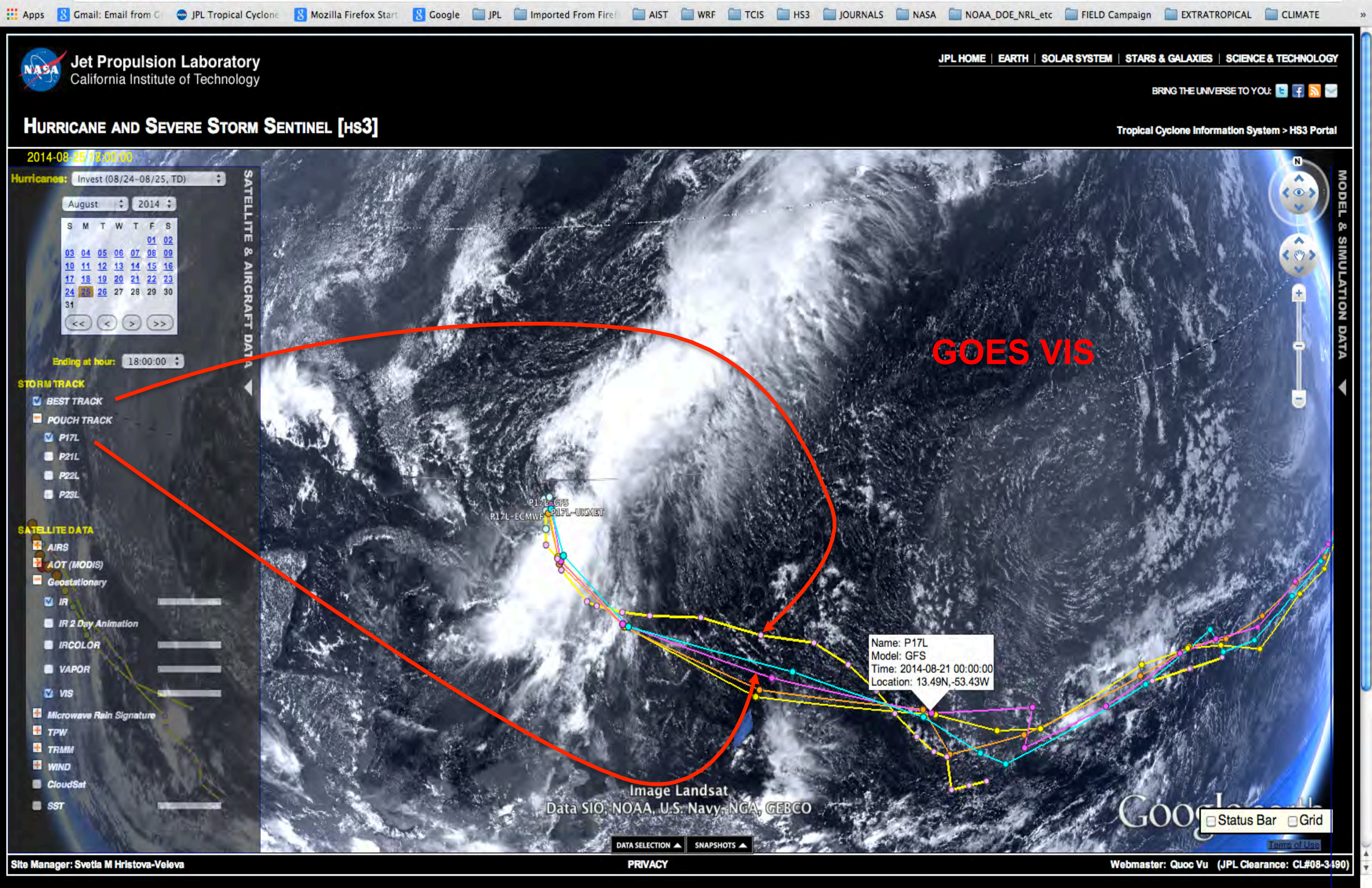
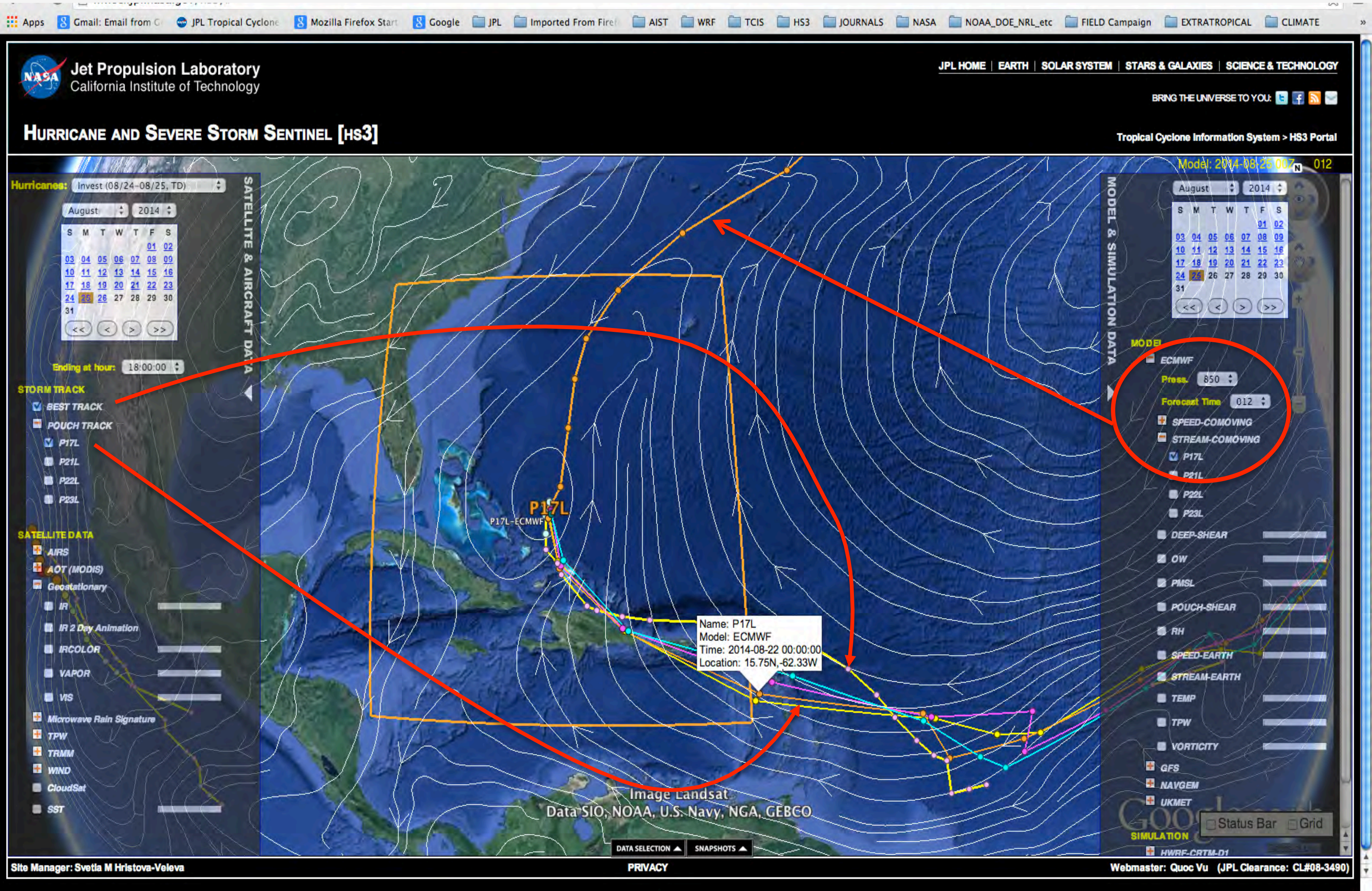


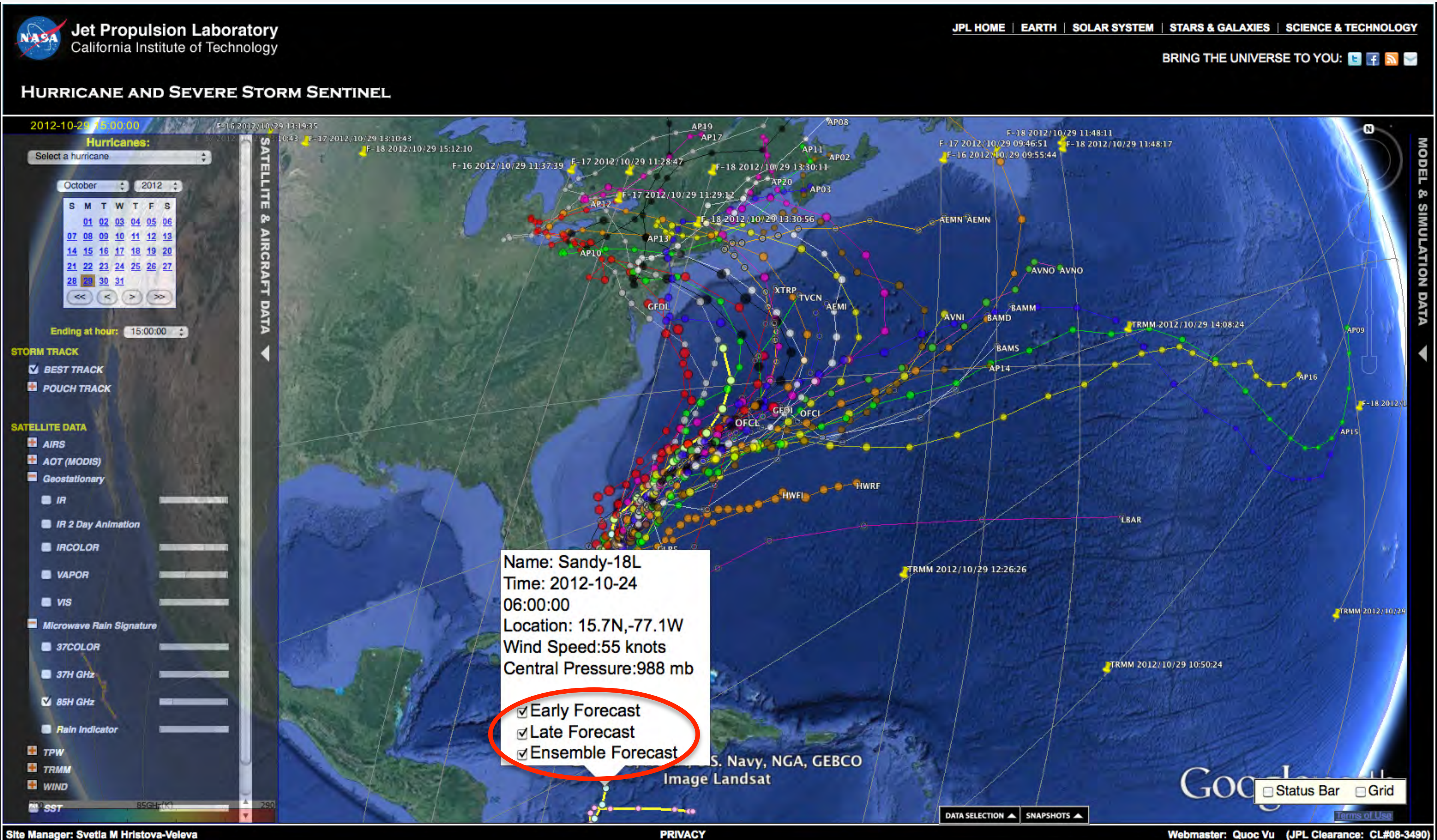
Bringing models and observations together (The portal combines satellite, some airborne, and model data and **provides interactive visualization** to allow the users to relate the observed and the forecasted parameters)

"Best Track", Pouch tracks and Pouch forecasts, Pouch-relative model flow



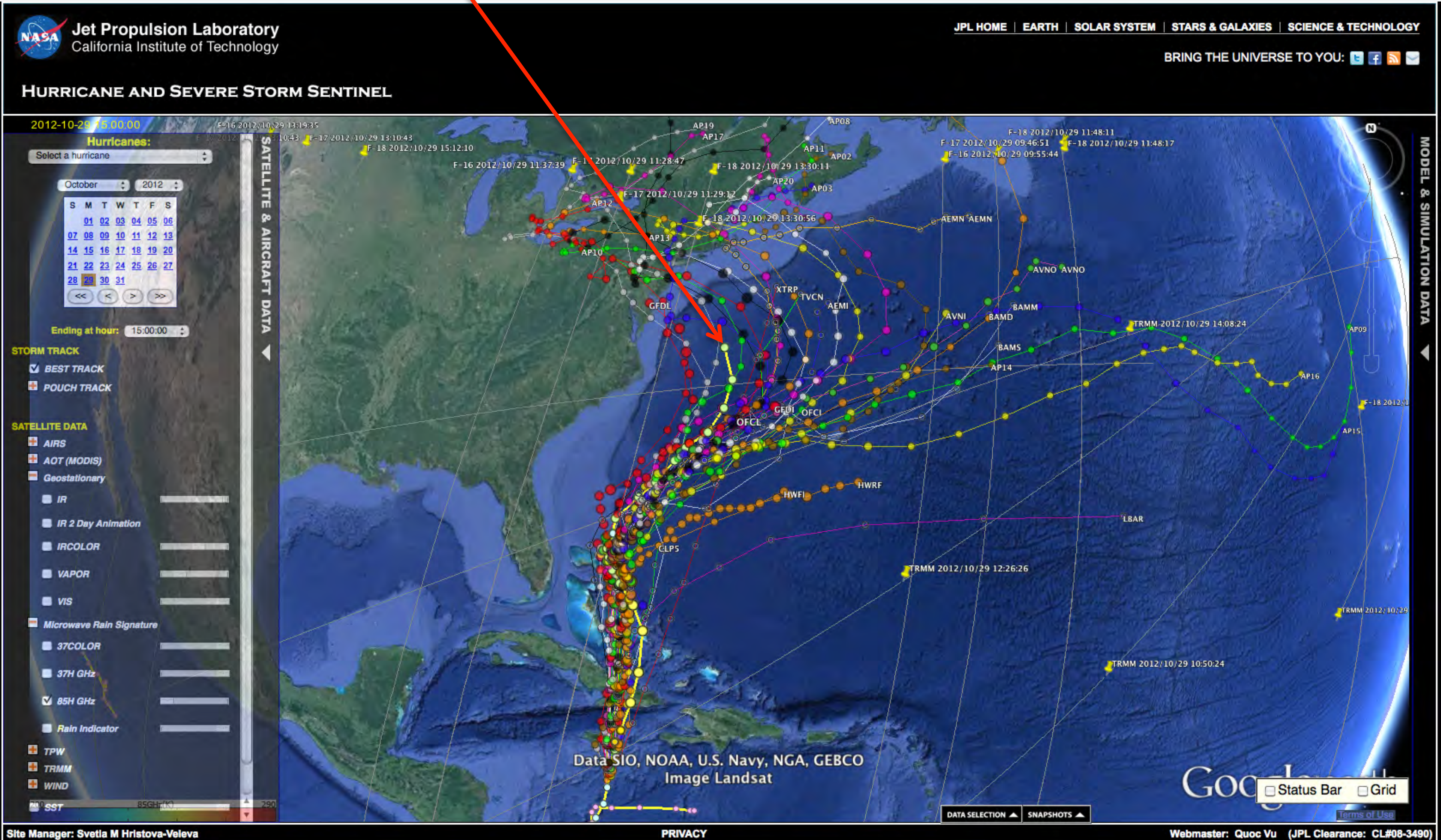
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

Forecast Uncertainty 5 days out - Hurricane Sandy (2012)



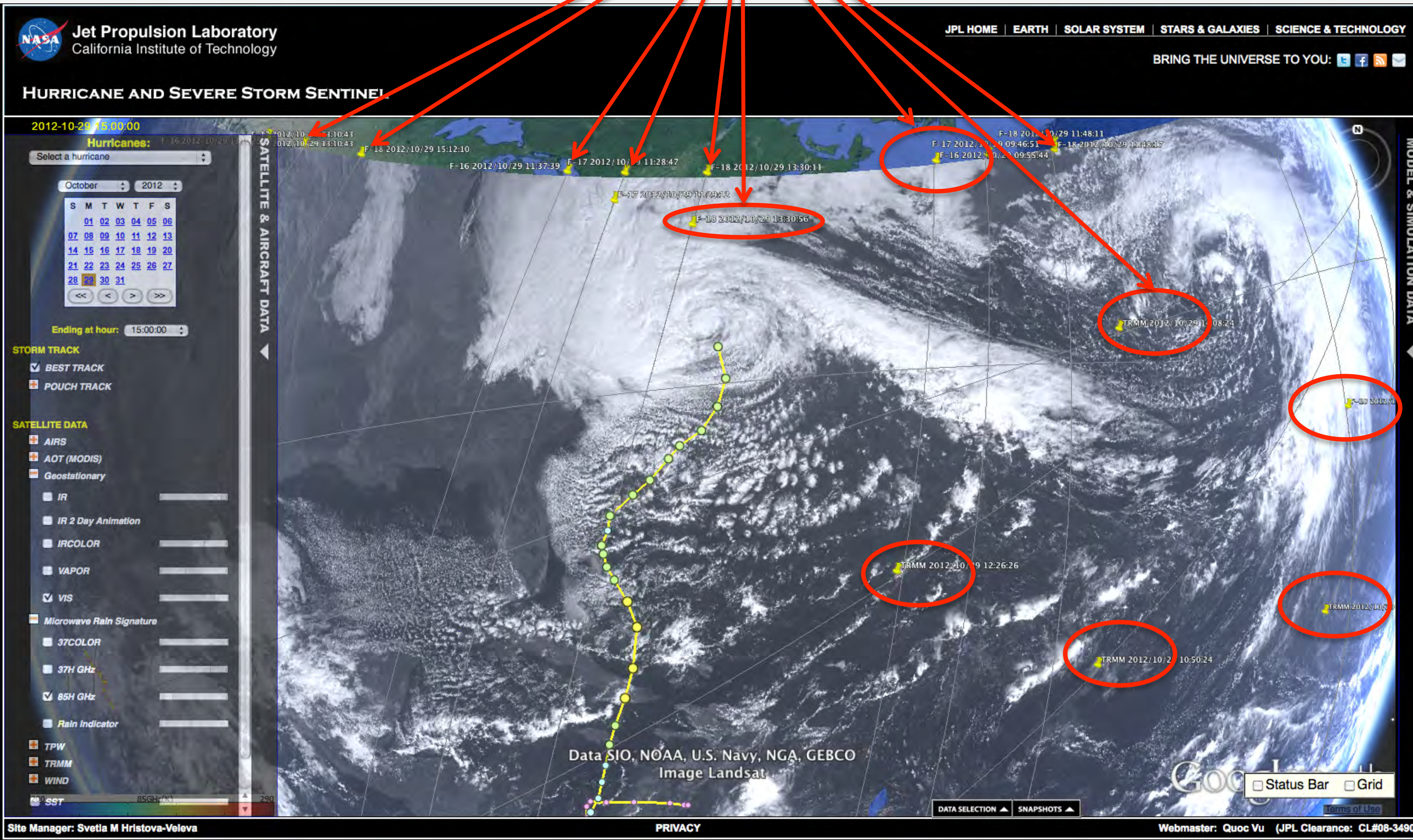
HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
Forecast Uncertainty 5 days out - Hurricane Sandy (2012)

Best Track

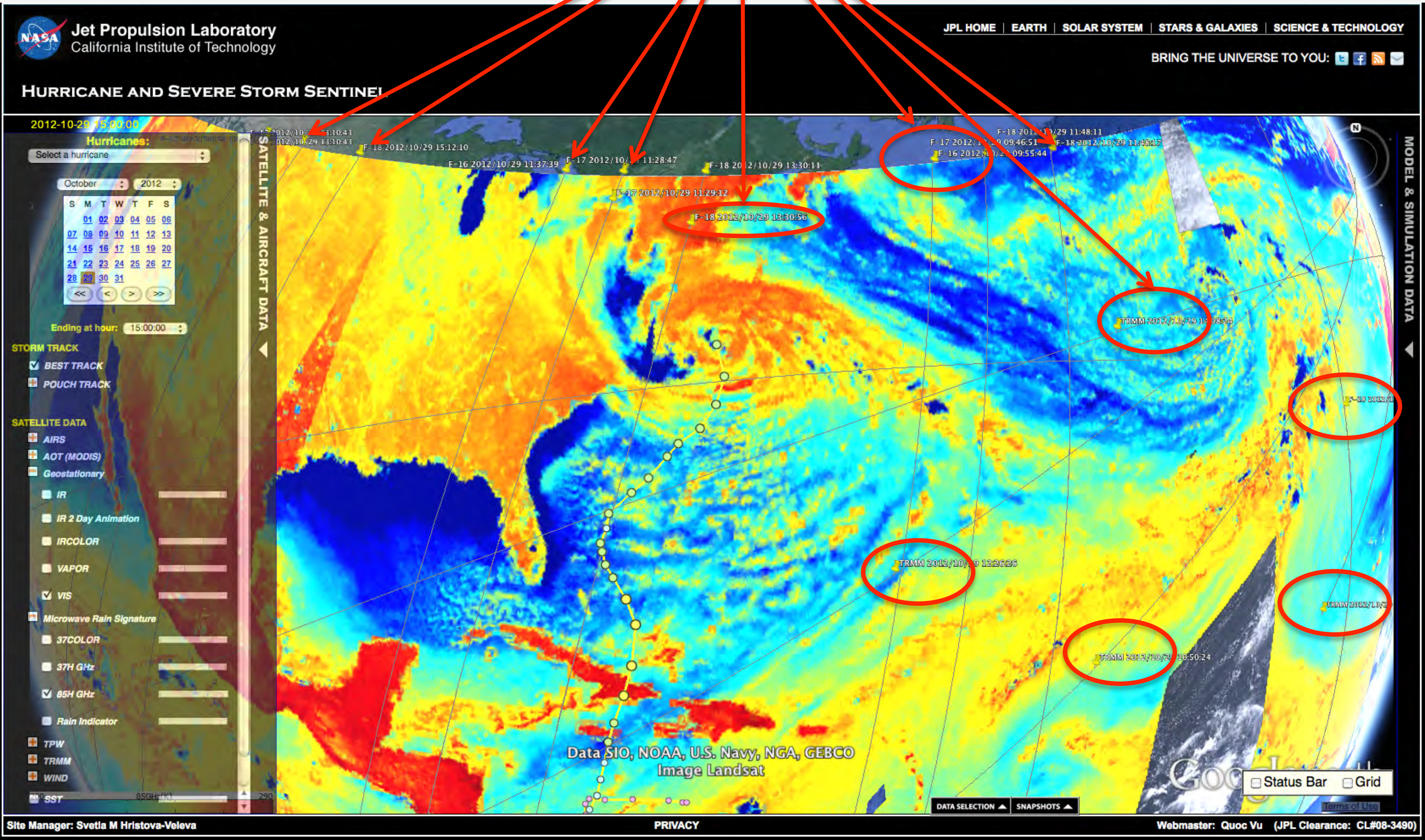


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The Power of the Satellite Observations – Hurricane Sandy (2012)

Note the multitude of Polar Orbiting Satellites that supplement GEOS observations

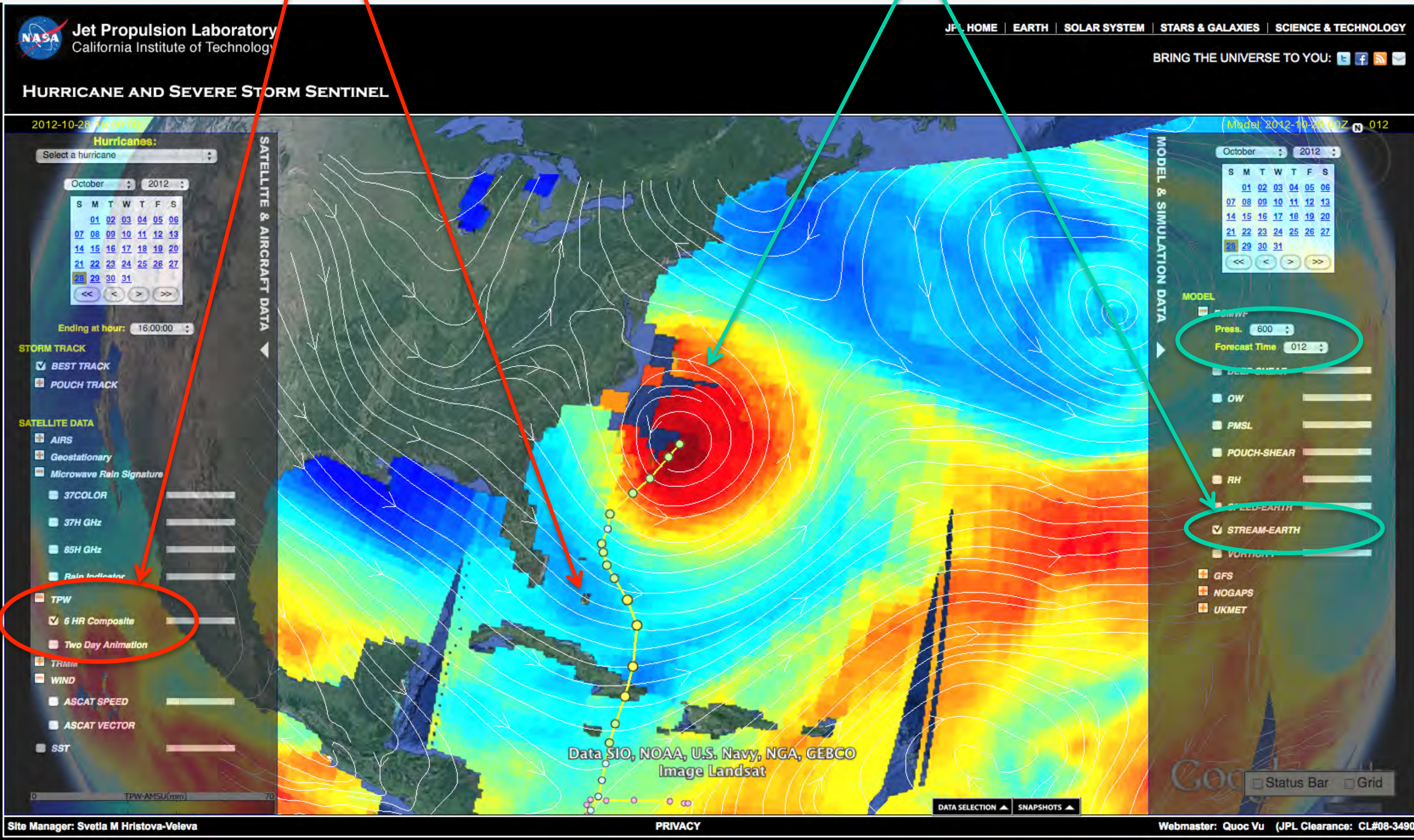


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The Power of the Satellite Observations – 6h composites of 85-91GHz obs

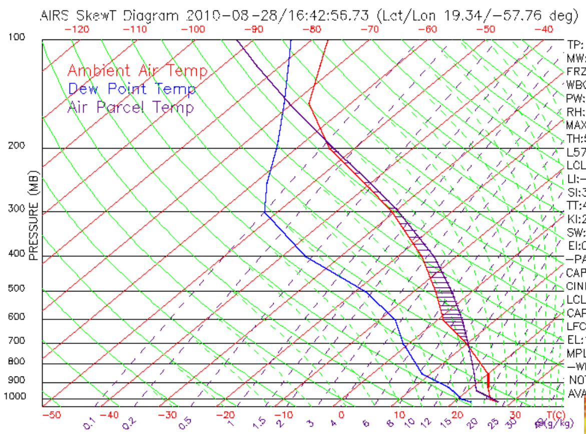


Bringing model and observations together:

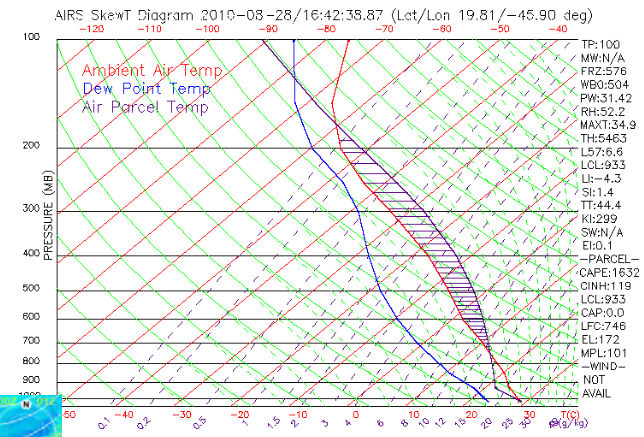
- Is the dry air in the environment (low TPW, from satellite observations) entering the storm ???
- It does not appear so looking at the midlevel flow from the model.

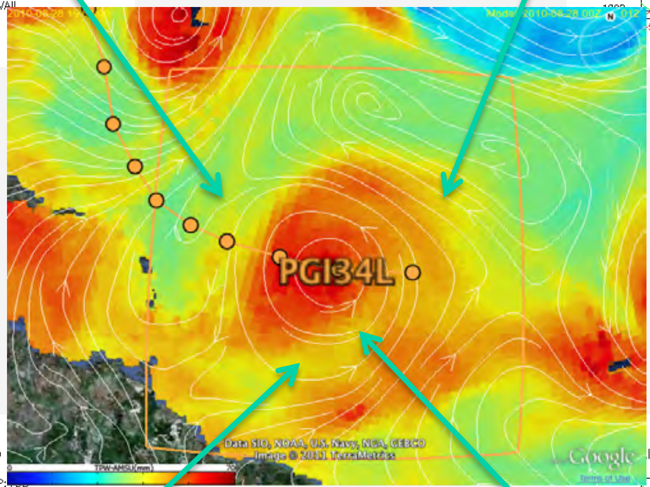


The thermodynamics from AIRS

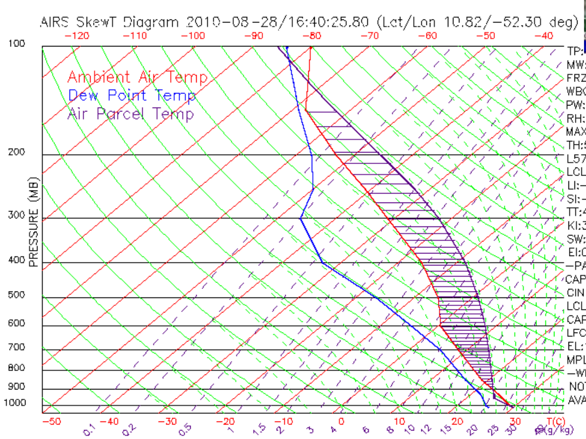


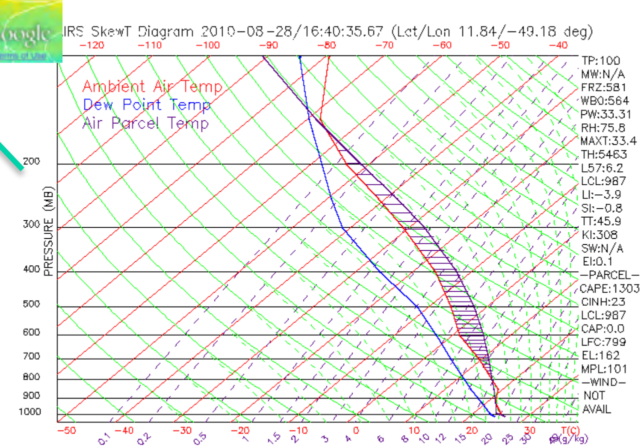
Hurricane Earl; Aug. 28, 2010 19Z



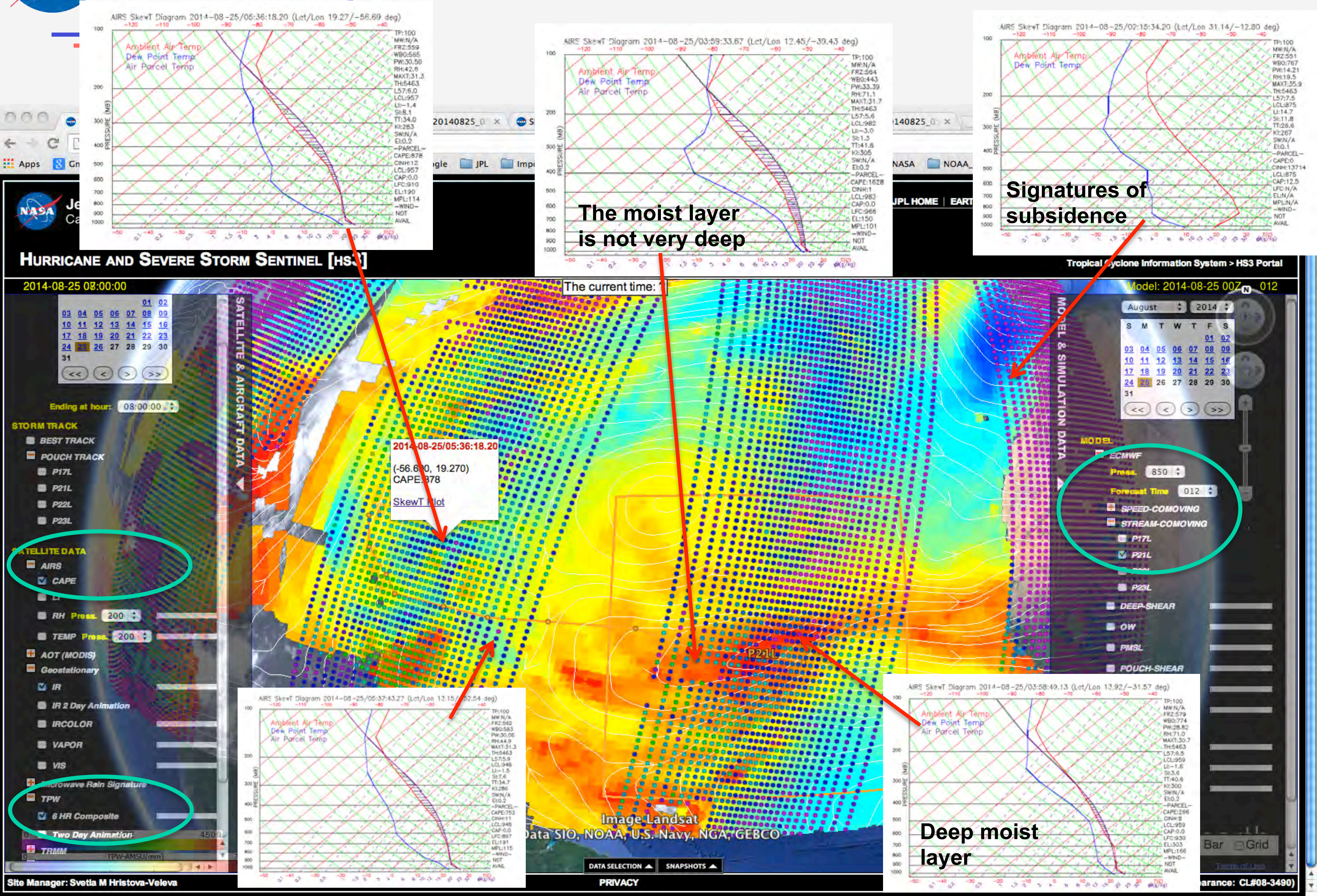


1. **TPW from AMSU**
2. **Soundings from AI**
3. **Pouch-relative flow from ECMWF**



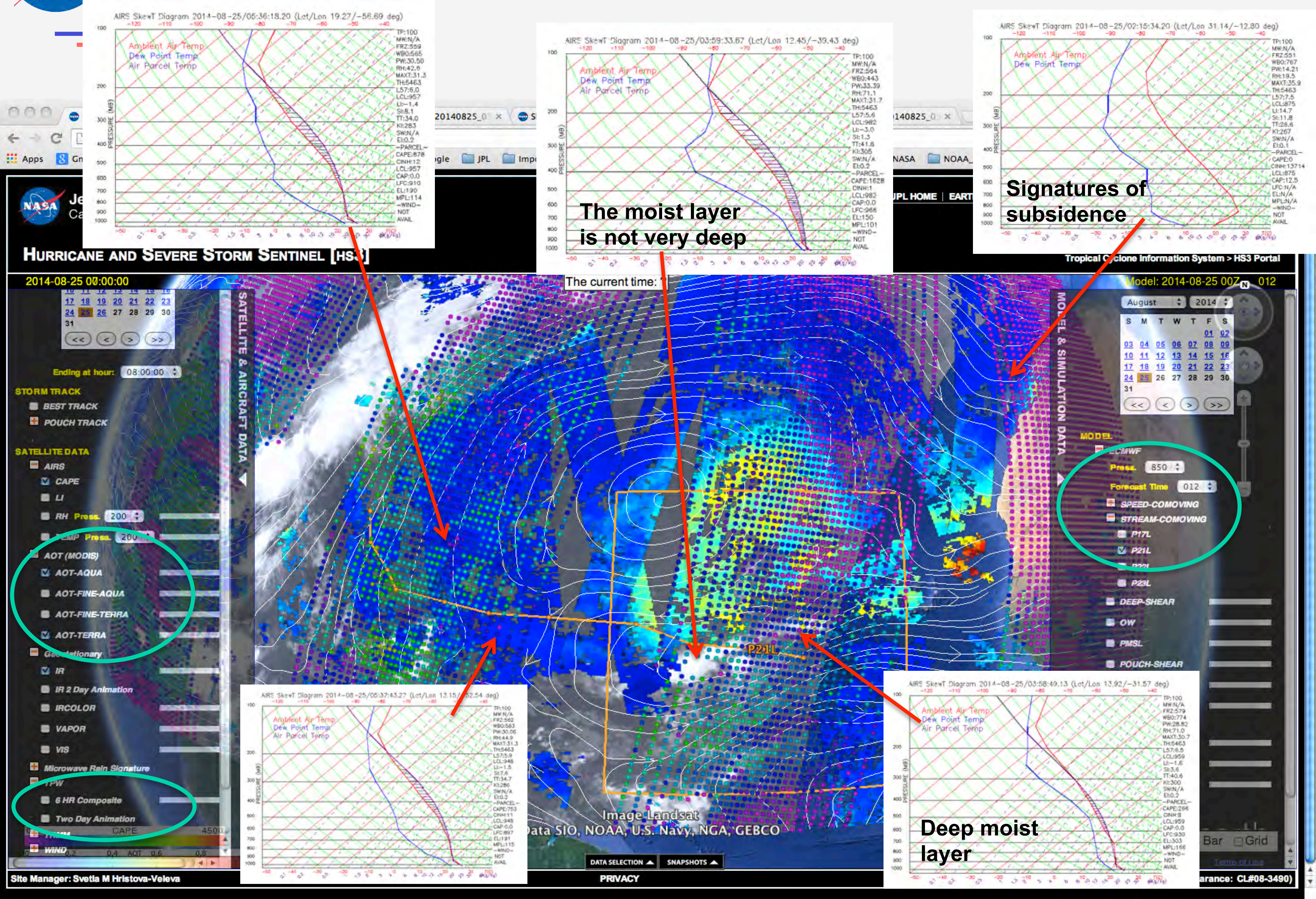


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
The thermodynamics from AIRS

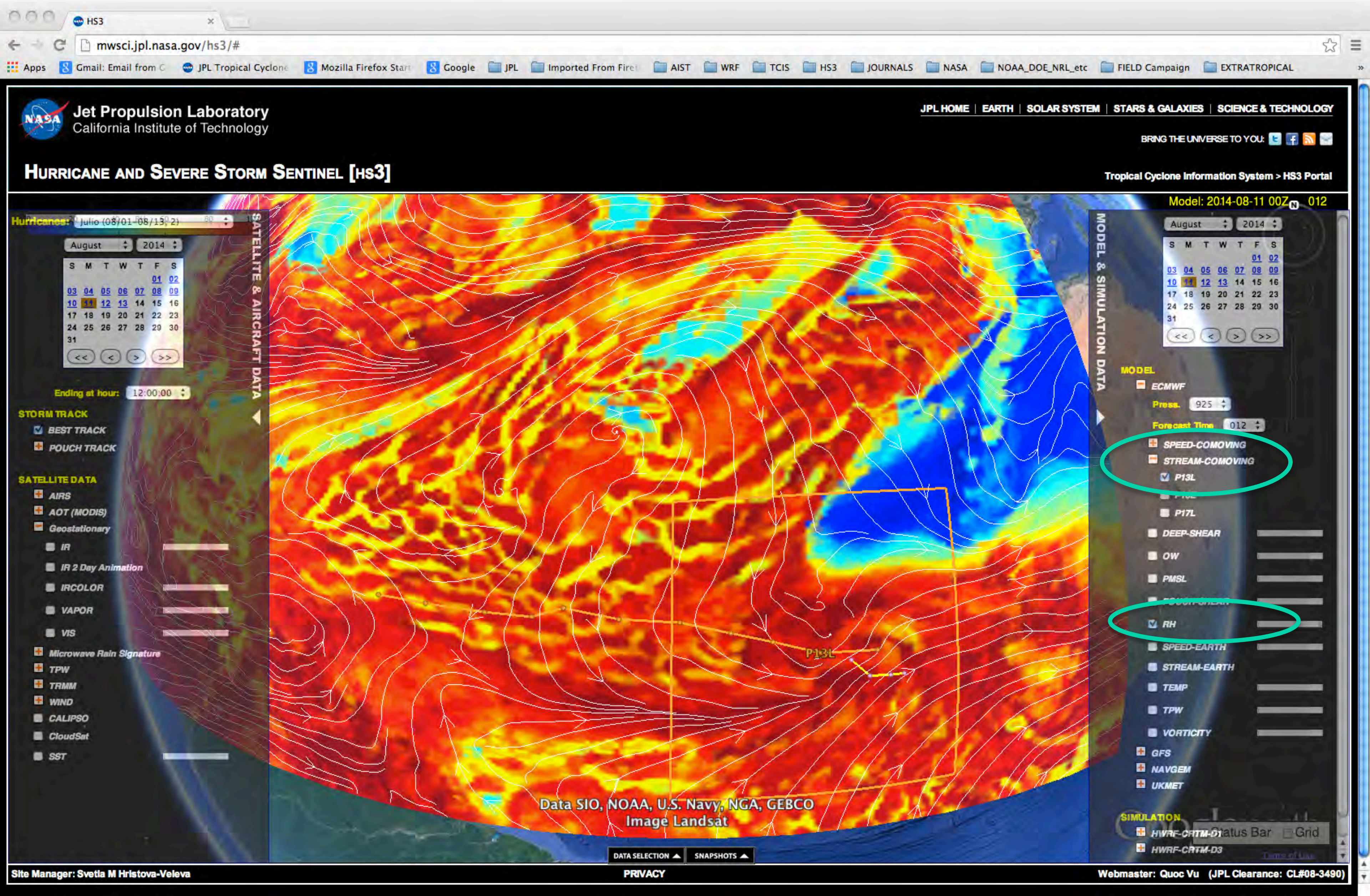


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

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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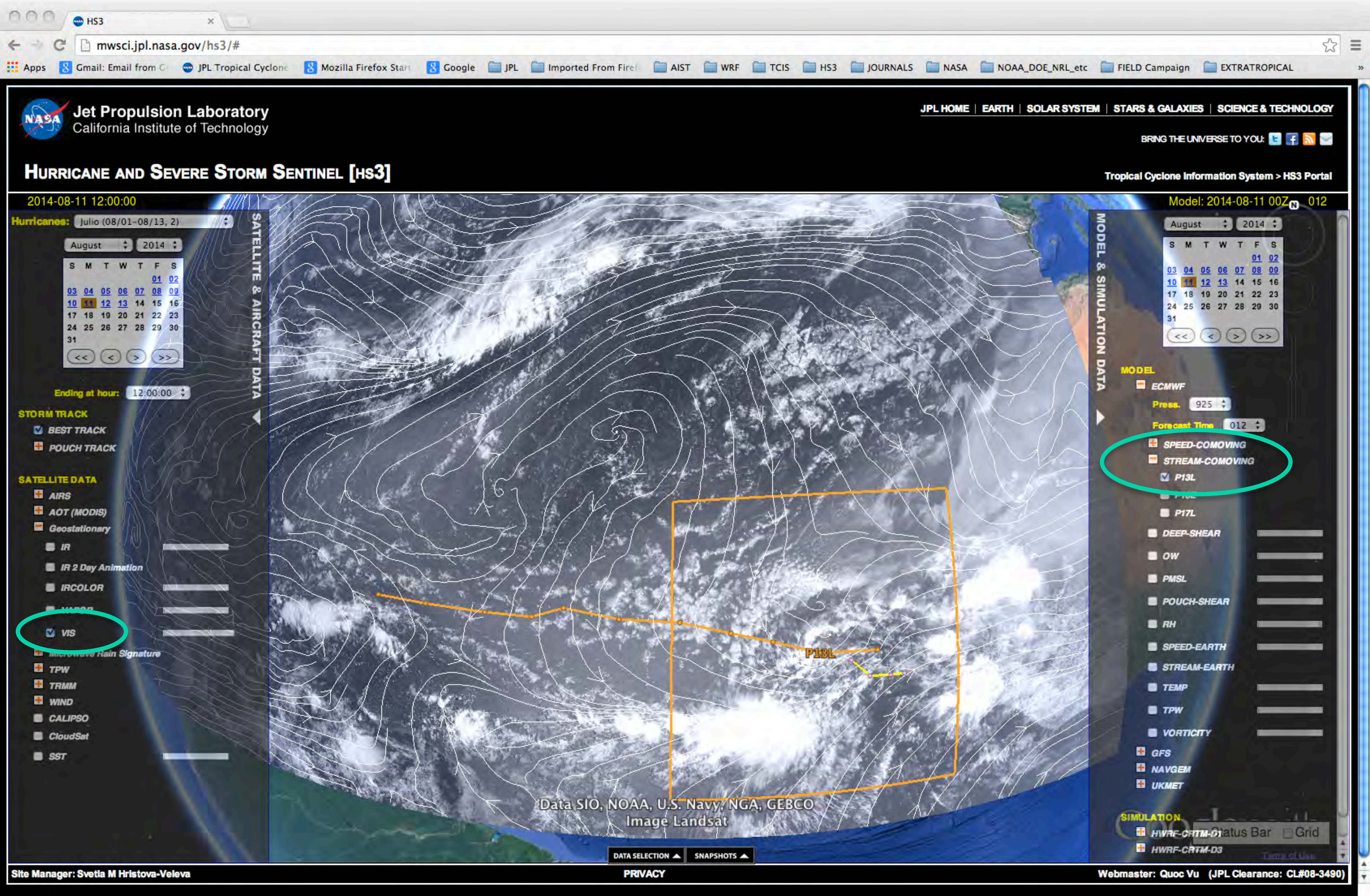
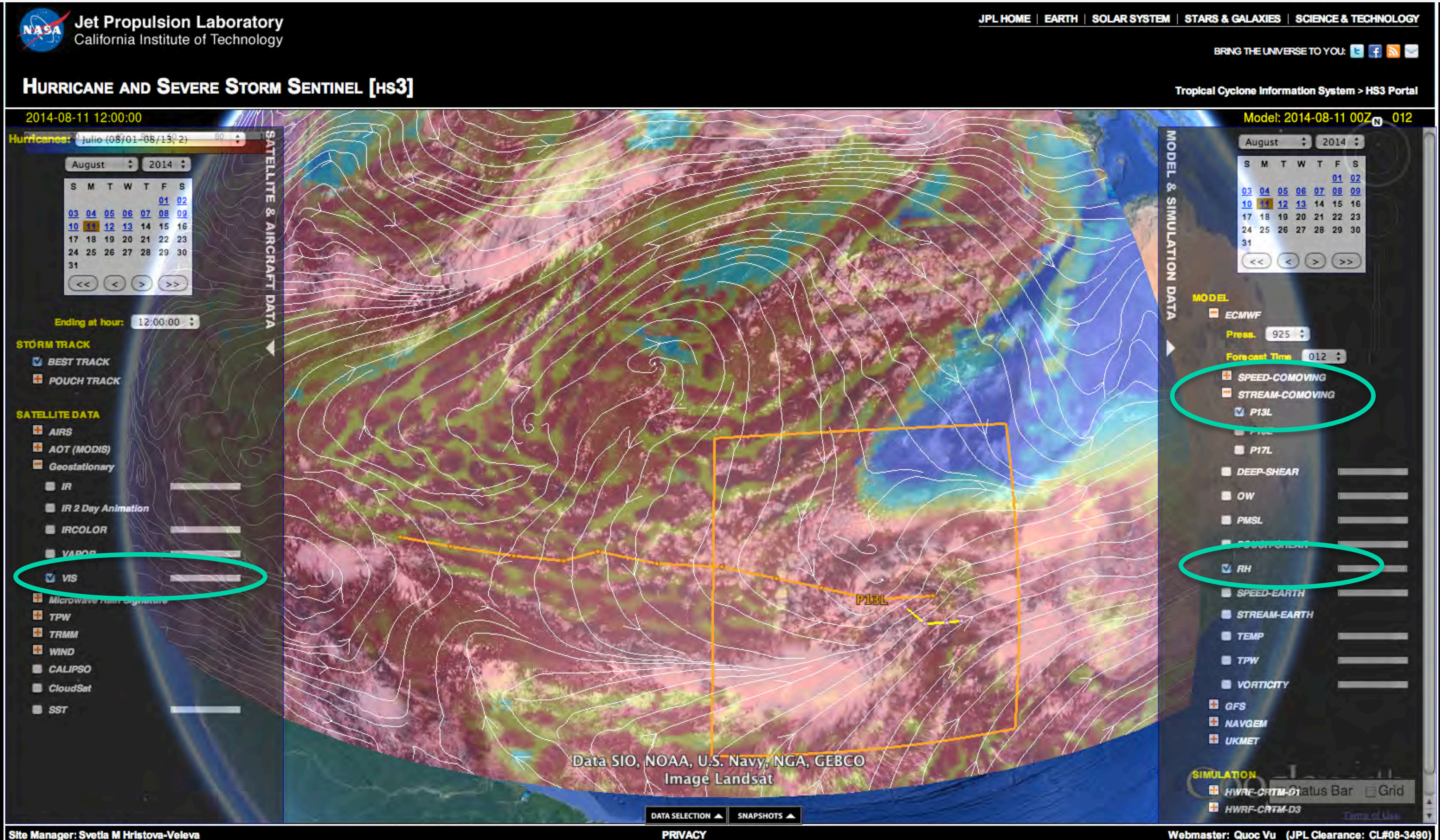


Understanding what is this structure in the model?

Tim Dunkerton called it "leopard's fur" pattern in ECMWF 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).

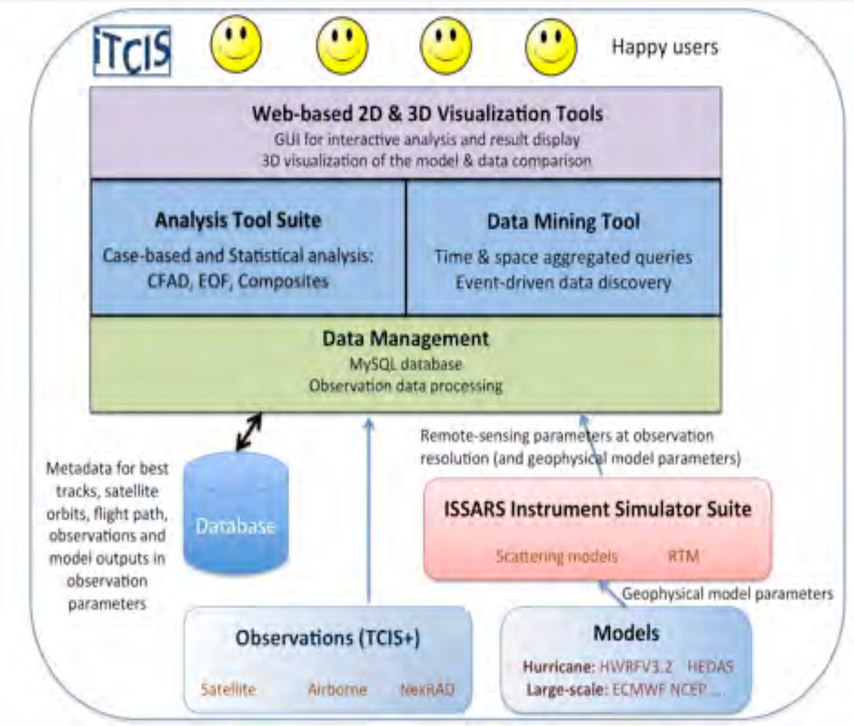


How best to Evaluate the Models (*with an eye on the microphysics*)

- In situ microphysical 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 microphysical assumptions is to 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.
- To increase the fidelity of the evaluation results, we should
  - bring model and observations into a common analysis system
  - use instrument simulators to produce satellite observables from the model fields and compare to the observed.
  - Improve model forecast through data assimilation that also uses the instrument simulators

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

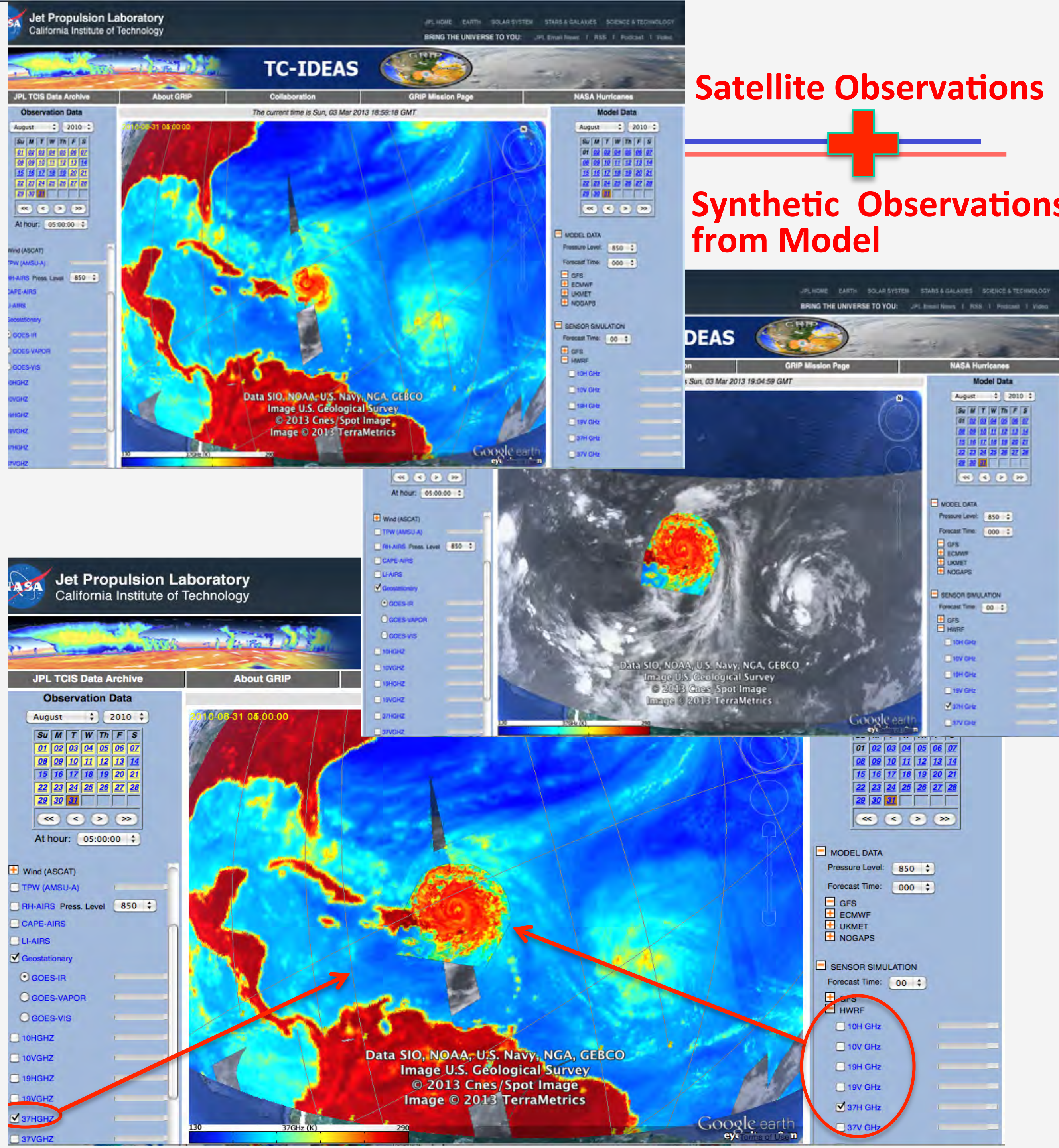
2) Develop set of analysis tools that will enable users to calculate joint statistics, produce composites, compare modeled and observed quantities to facilitate the evaluation of different hurricane models

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)

FUSION OF MODELS AND OBSERVATIONS

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

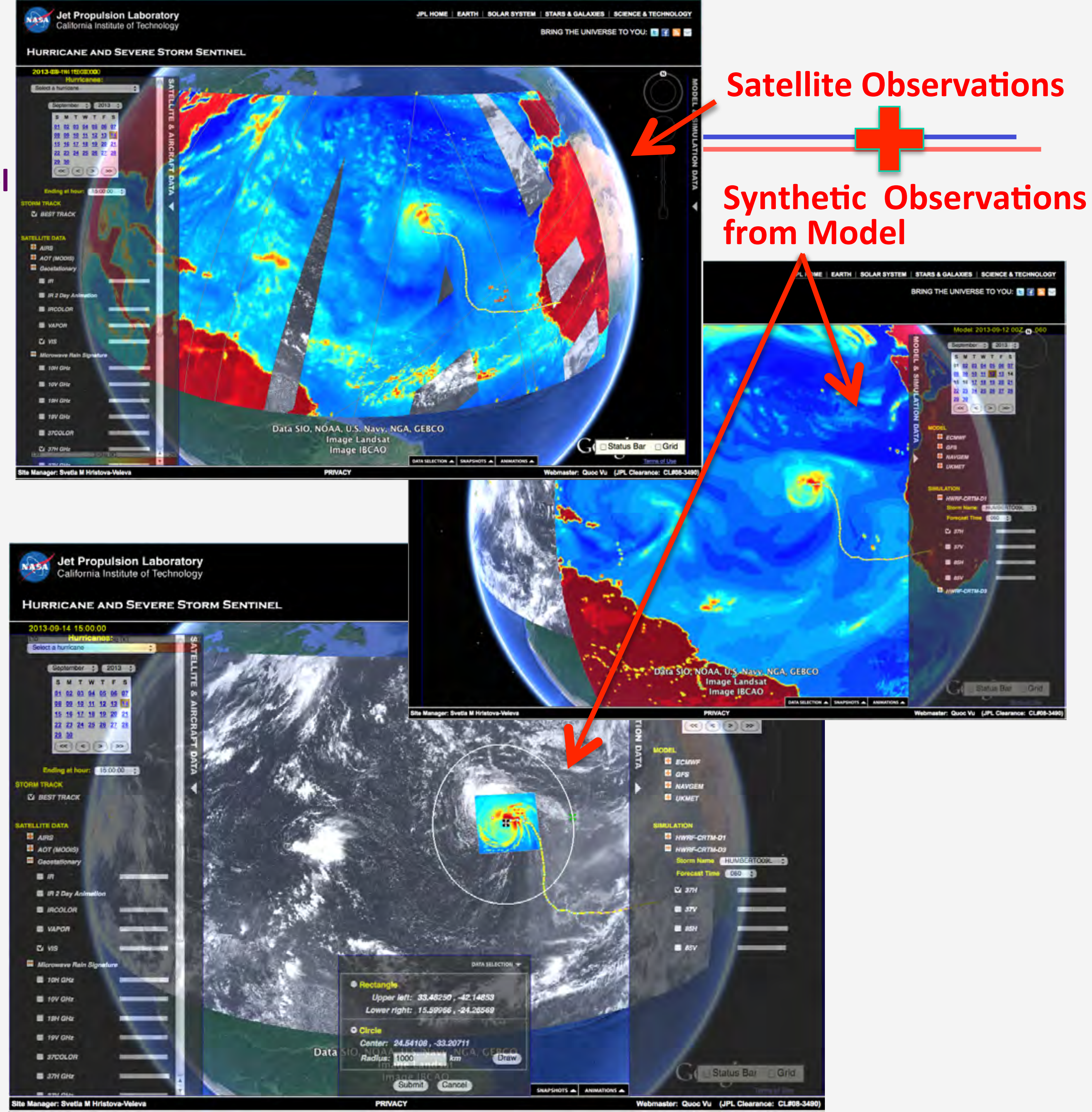
- Research HWRF model forecasts were used as input to NEOS[3]
  - Considered are the model microphysical assumptions; the instrument characteristics and sampling
- The synthetic "satellite observations" were:
  - Incorporated in the database of satellite obs.
  - Visualized in the portal
- Limited #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



FUSION OF MODELS AND OBSERVATIONS

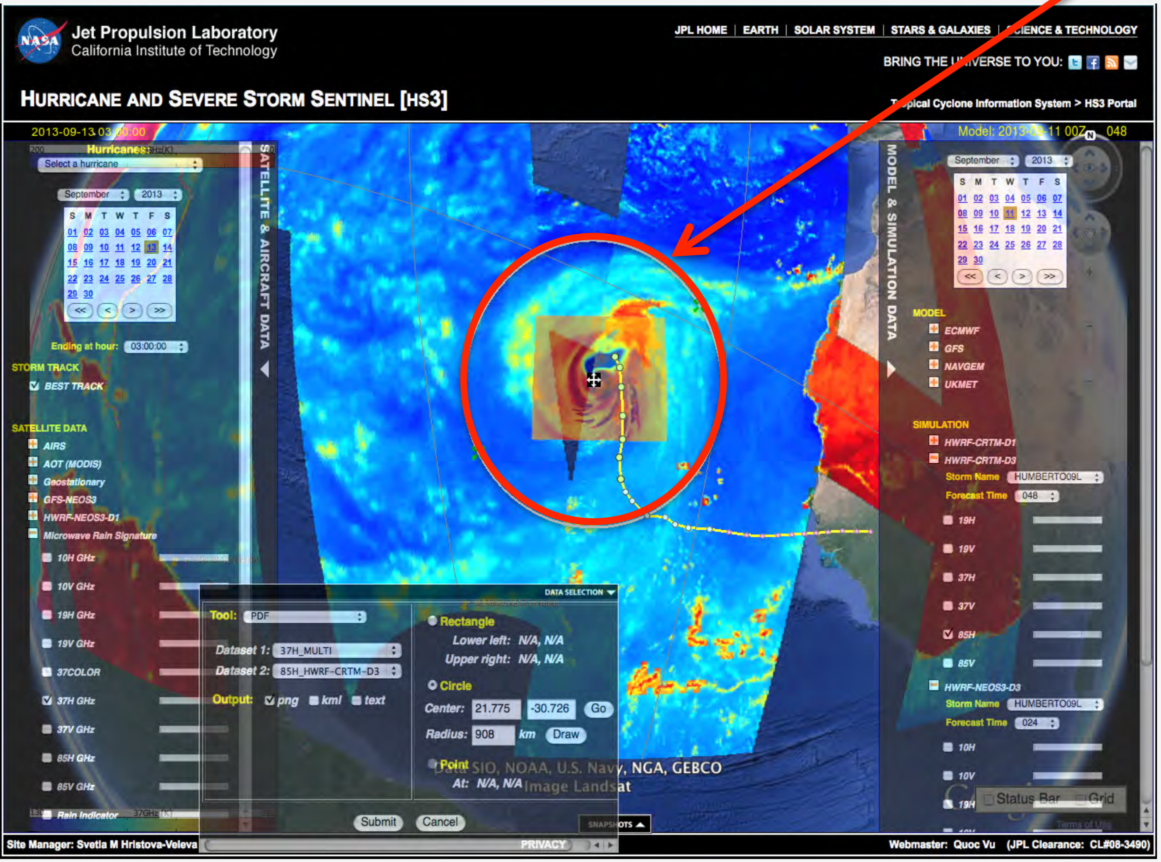
Integrating hurricane model forecasts with satellite & airborne observations from a variety of instruments and platforms

- **<u>Operational HWRF</u> model forecasts are used as input <u>to CRTM, provided courtesy of EMC</u>**
- **Including synthetic satellite observations** from the same model (HWRF) but produced by different forward simulators (NEOS^3 and CRTM) will be of high interest in revealing the uncertainty that comes from the instrument simulators themselves.



2. Analysis Tools

Analysis tools that can be applied to both observed and synthetic data for on-line statistical and structural analysis



- Interactively select region
- Gather data from observed and synthetic sources
  - brightness temperatures
- Statistical comparisons
  - Storm-relative coordinates
  - Joint PDFs
  - Azimuthal averages
- Storm Structure
  - ARCHER
  - Wave Number Analysis
  - Object classification
  - Metrics for model/obs objects
- Visualization of analysis

2. Analysis tools

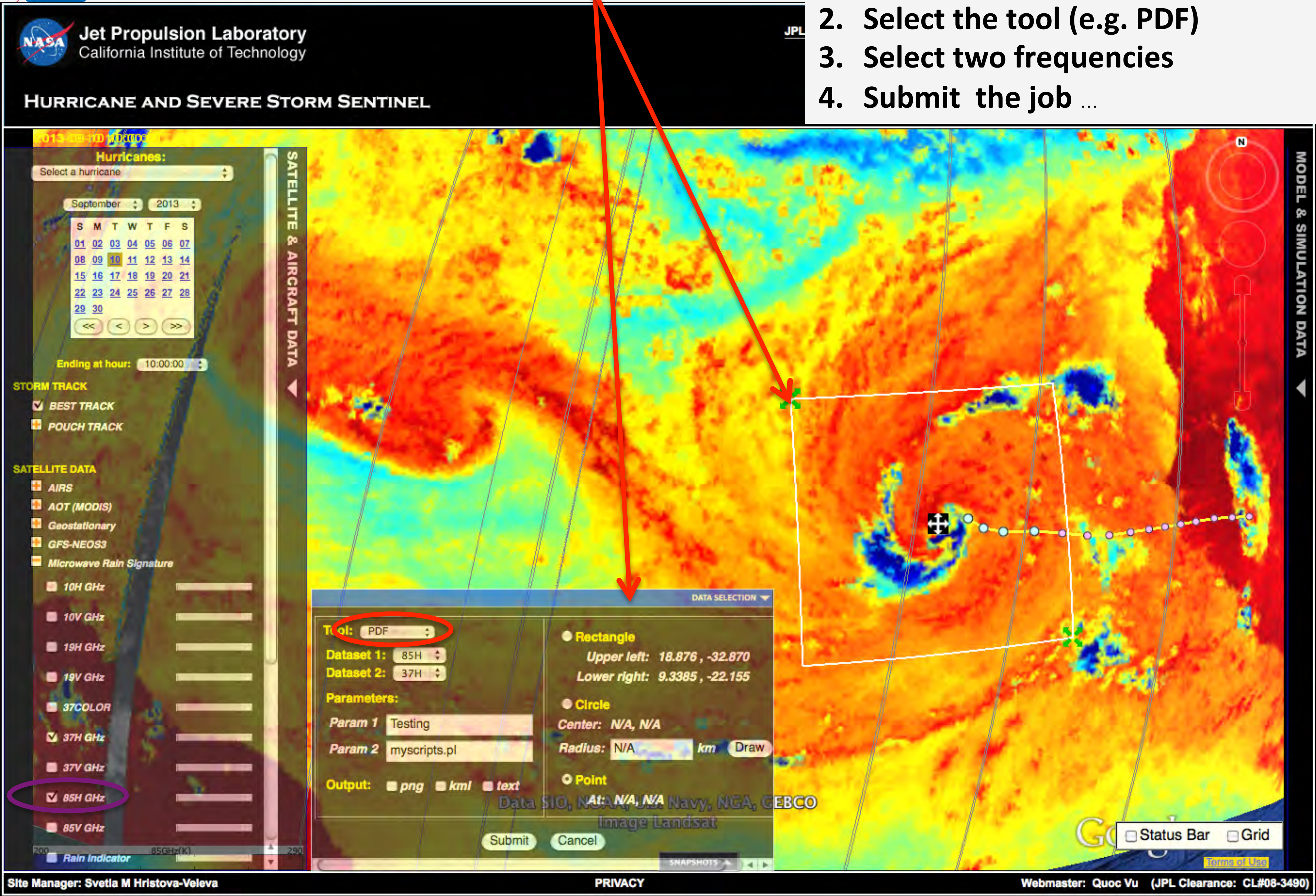
general requirement – the data need to be displayed

- **Statistical tool to evaluate the storm vertical structure**
  - Emphasis on microphysics – *the Joint Probability Density Functions (Joint PDF)*
    - *Any pair of passive microwave brightness temperatures*
    - *Either from observations or from model*
    - *Describes the manifolds occupied by the observations and the models*
    - *Could be used to provide information on the correlations between the warm rain (lower frequencies) and frozen precipitation above (higher frequencies), hence, information on the vertical structure*

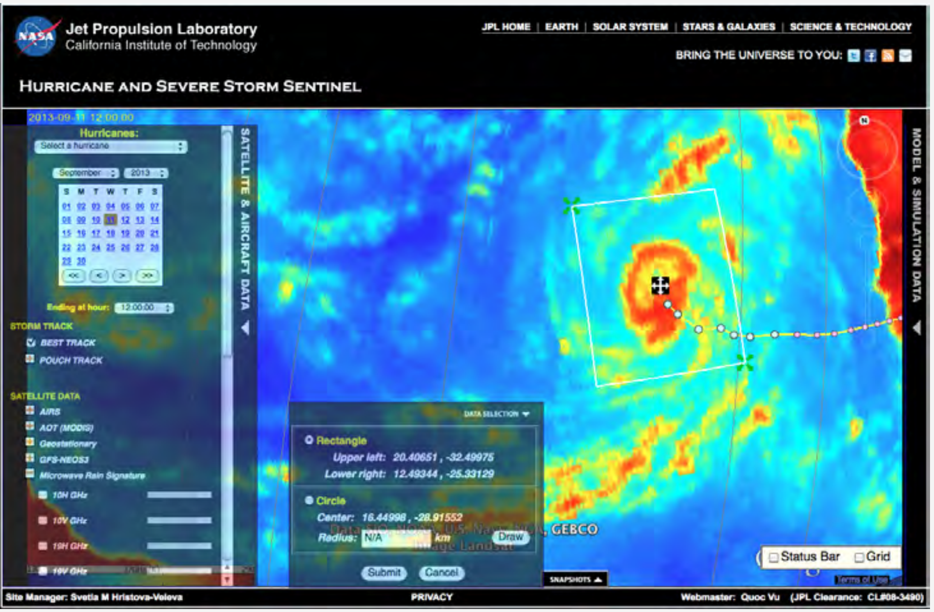
- **Storm structure Tools**
  - Degree of organization - *The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)*
    - *Works with 85 GHz brightness temperatures (observations or model)*
  - Storm Size and Asymmetry - *The Wave Number Analysis Tool*
    - *Works with either*
      - *the Rain Index (computed from multi-channel passive microwave observations and soon with model data)*
      - *or with the surface winds (from observations)*

The Selection Tool

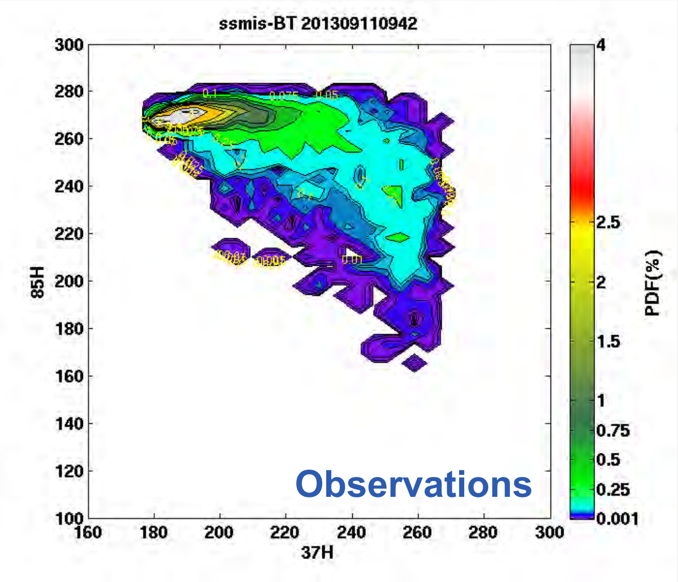
1. Select the region of interest
    - Circle, Square, Point
2. Select the tool (e.g. PDF)
3. Select two frequencies
4. Submit the job …



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

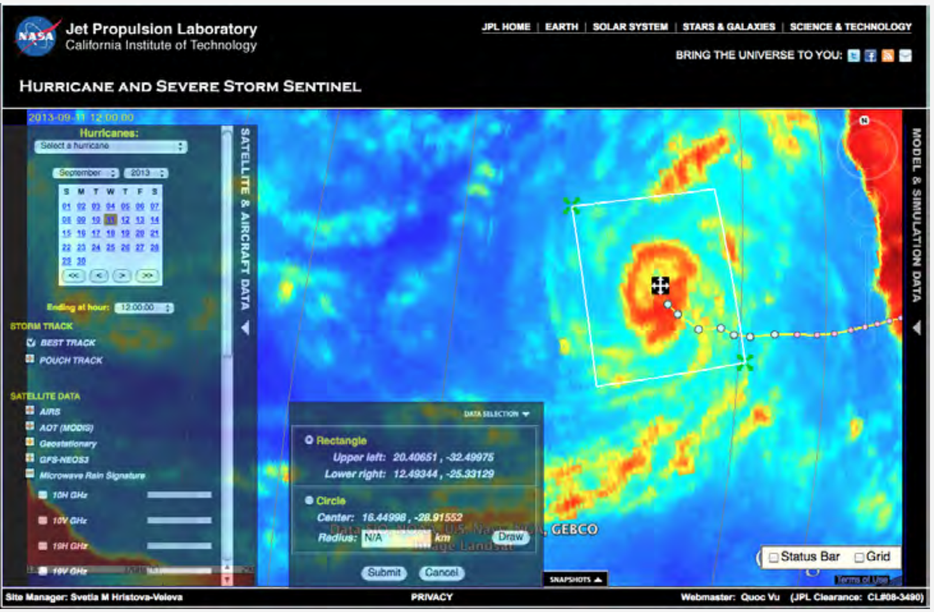


- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm

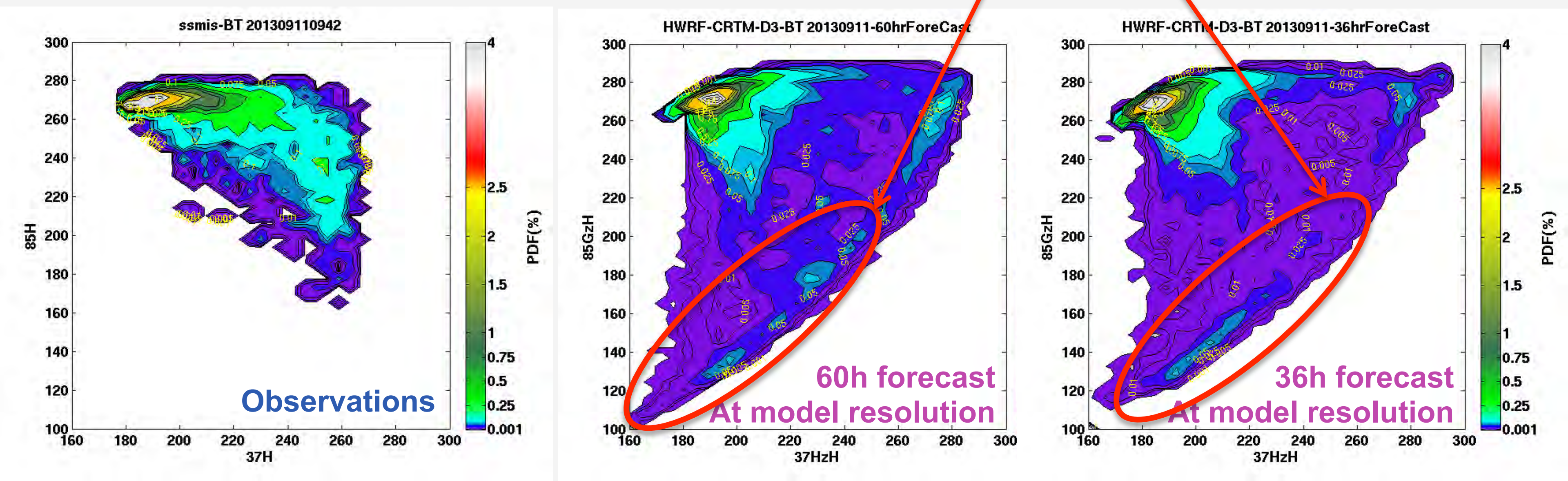


- The Joint PDF illustrates this relationship

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



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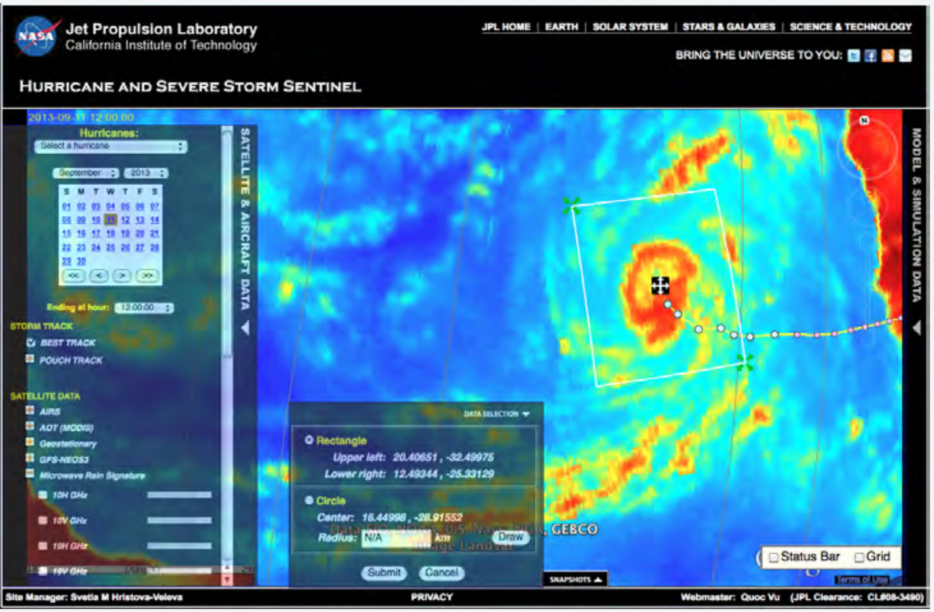
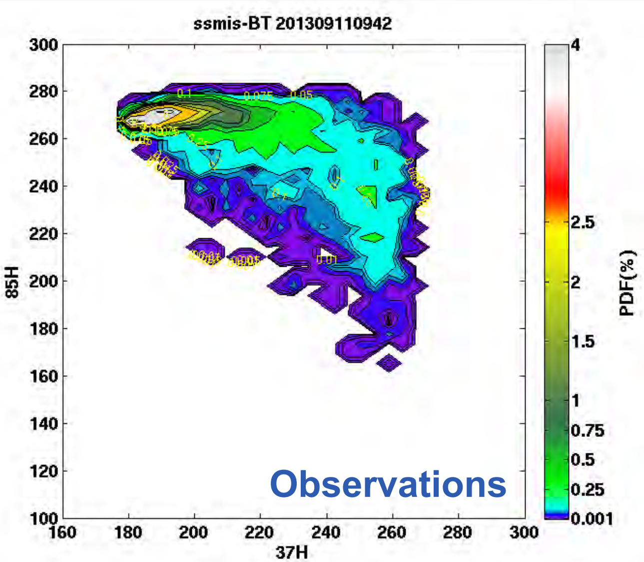
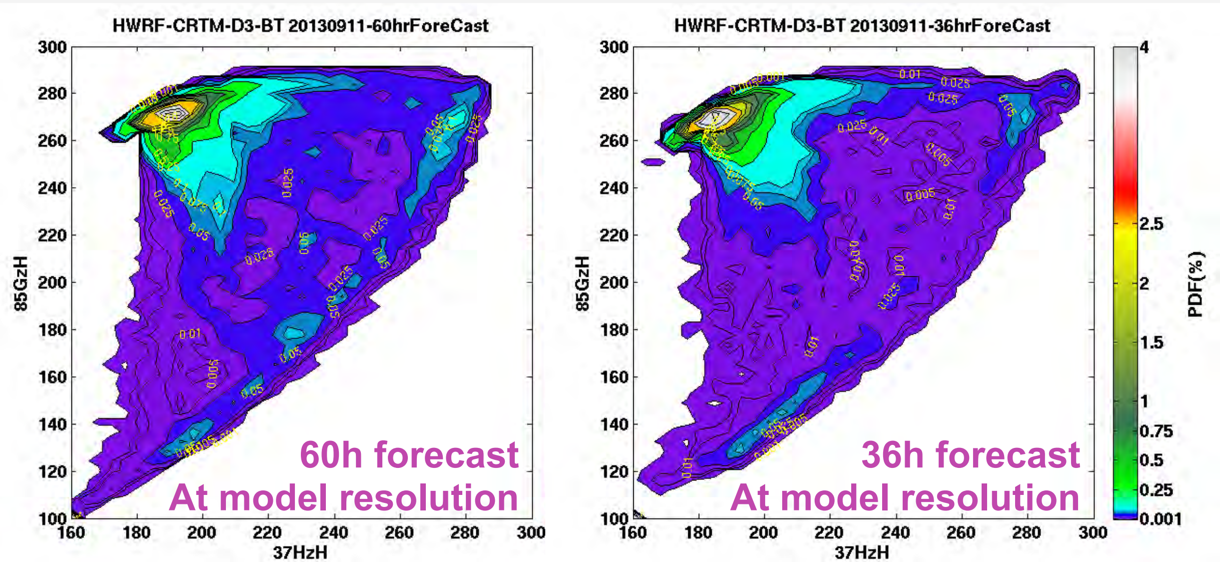


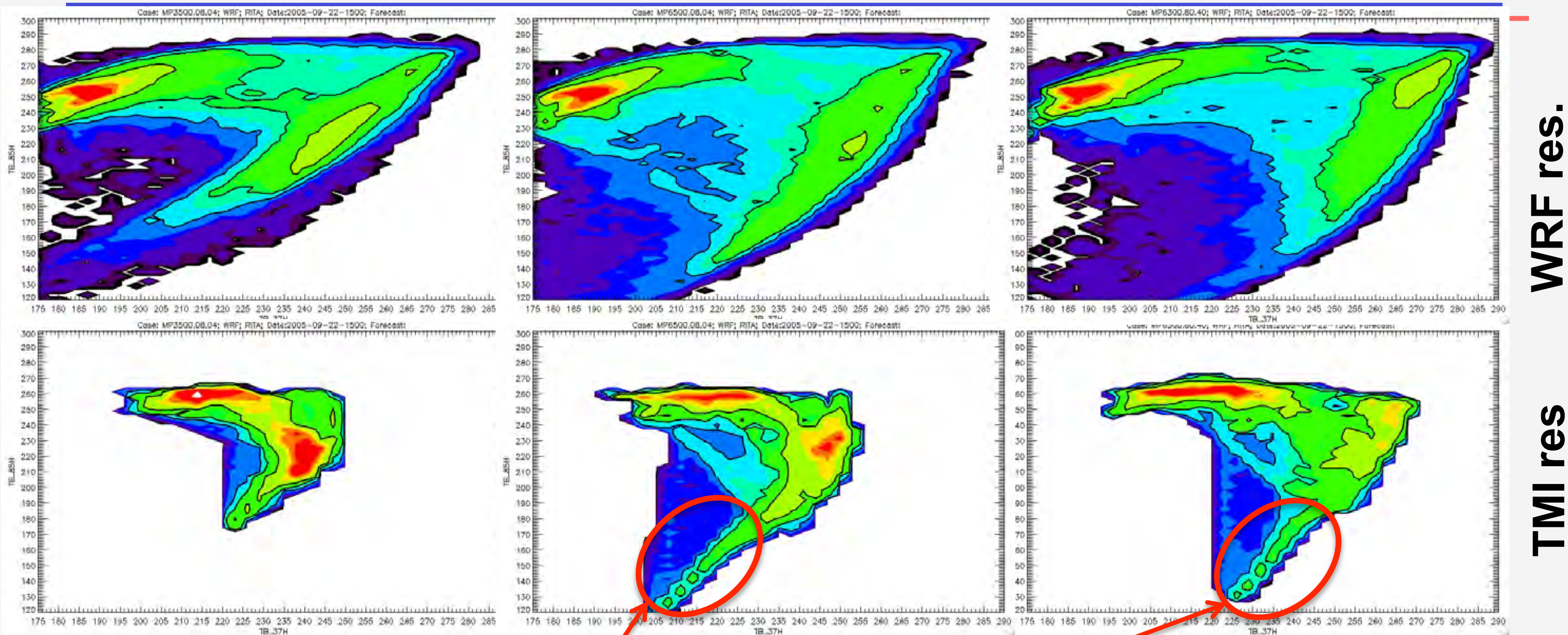
- The statistical relationship between the 37 GHz TBs and the 85 GHz TB presents information on the vertical structure of the storm
- The vertical branch indicates too much scattering of radiation by the frozen precipitation
- Question: Is the ice too much or is its forward modeling inaccurate?
  - Need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



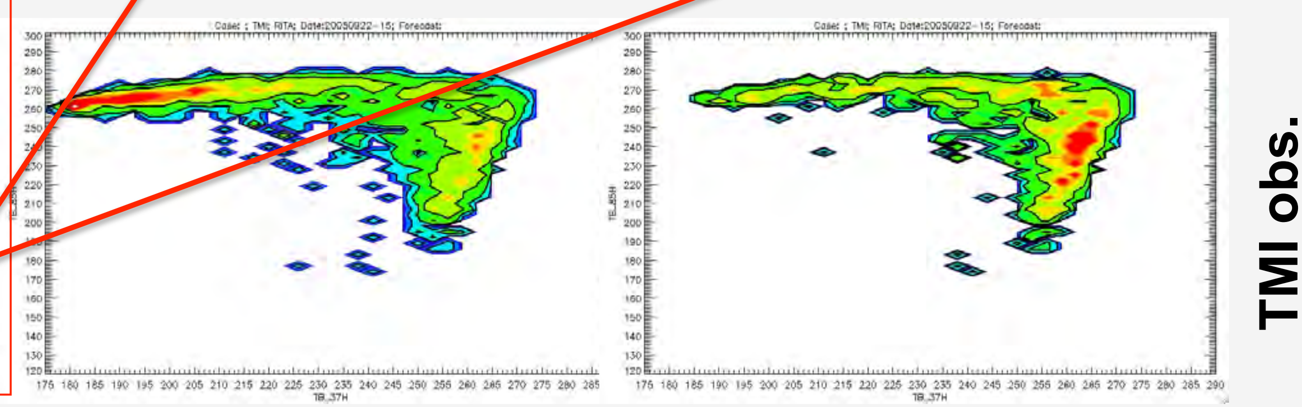


Joint Distribution (37H vs 85H) – *Impact of Resolution*

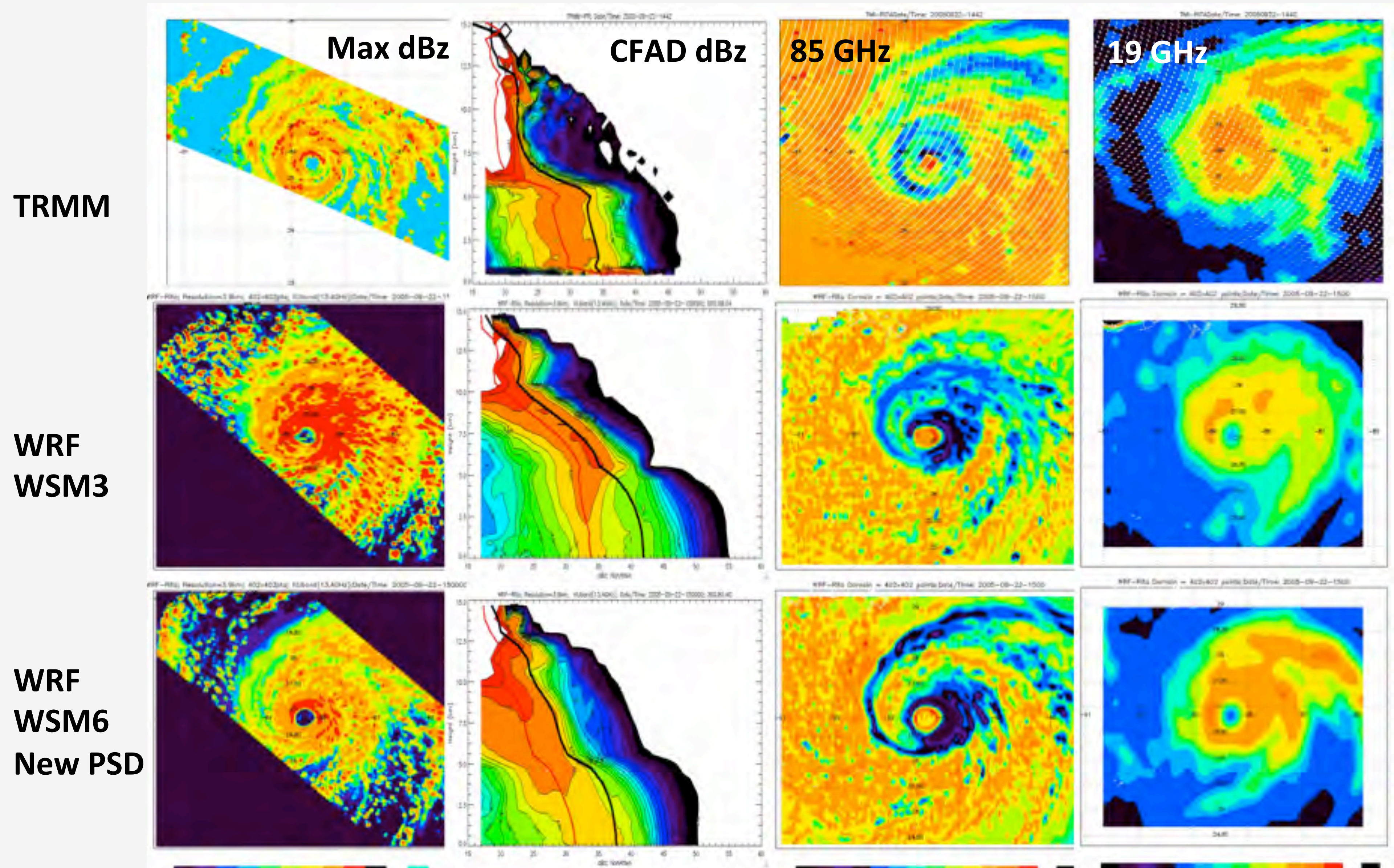
M3-500.08.04 M6-500.08.04 M6-300.80.40



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.

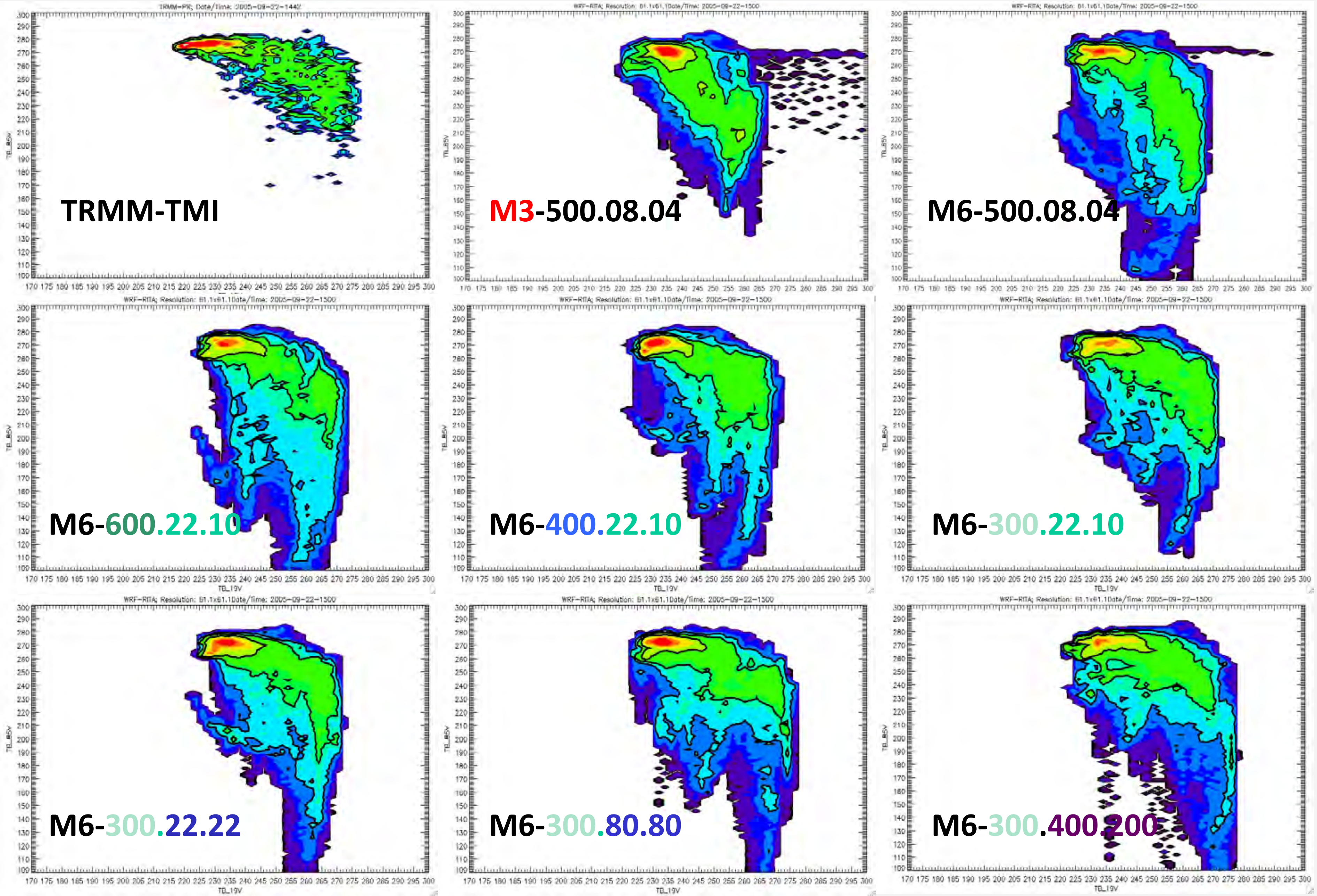


Example of MODEL EVALUATION – the Impact of Microphysics



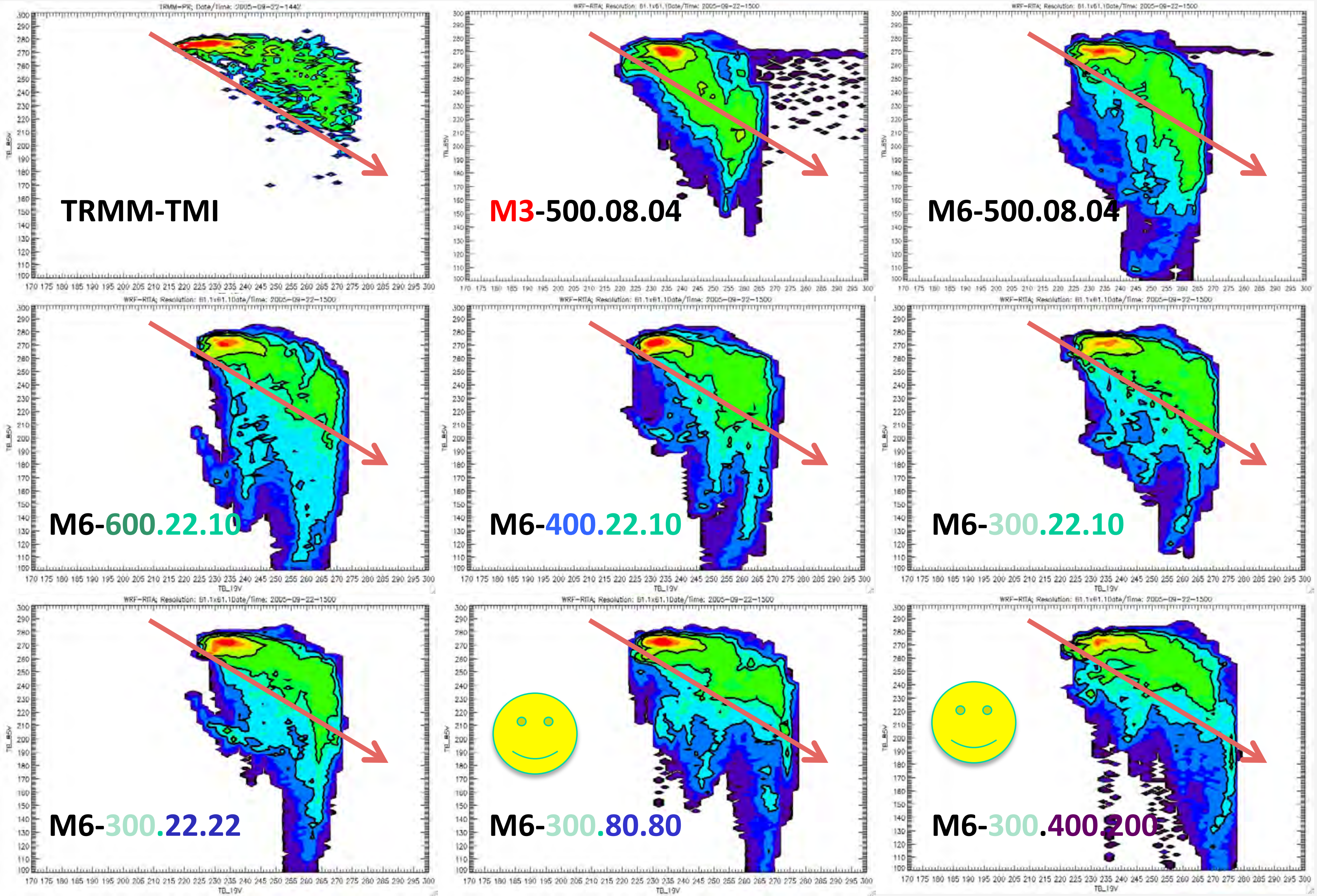
Joint Distribution (19H vs 85H) – *Impact of Microphysics*

PDF of the relation 85V-19V



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

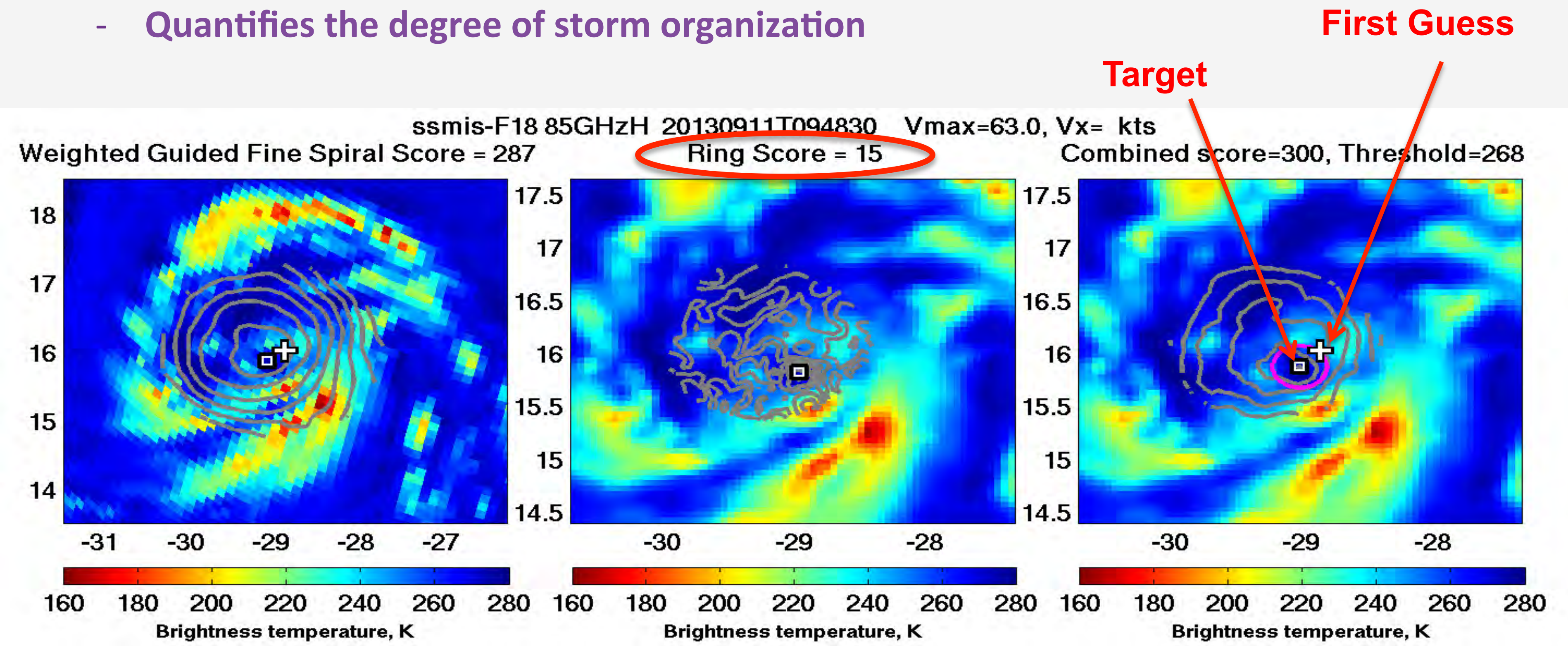
PDF of the relation 85V-19V



Storm structure Tool: Degree of Organization

The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

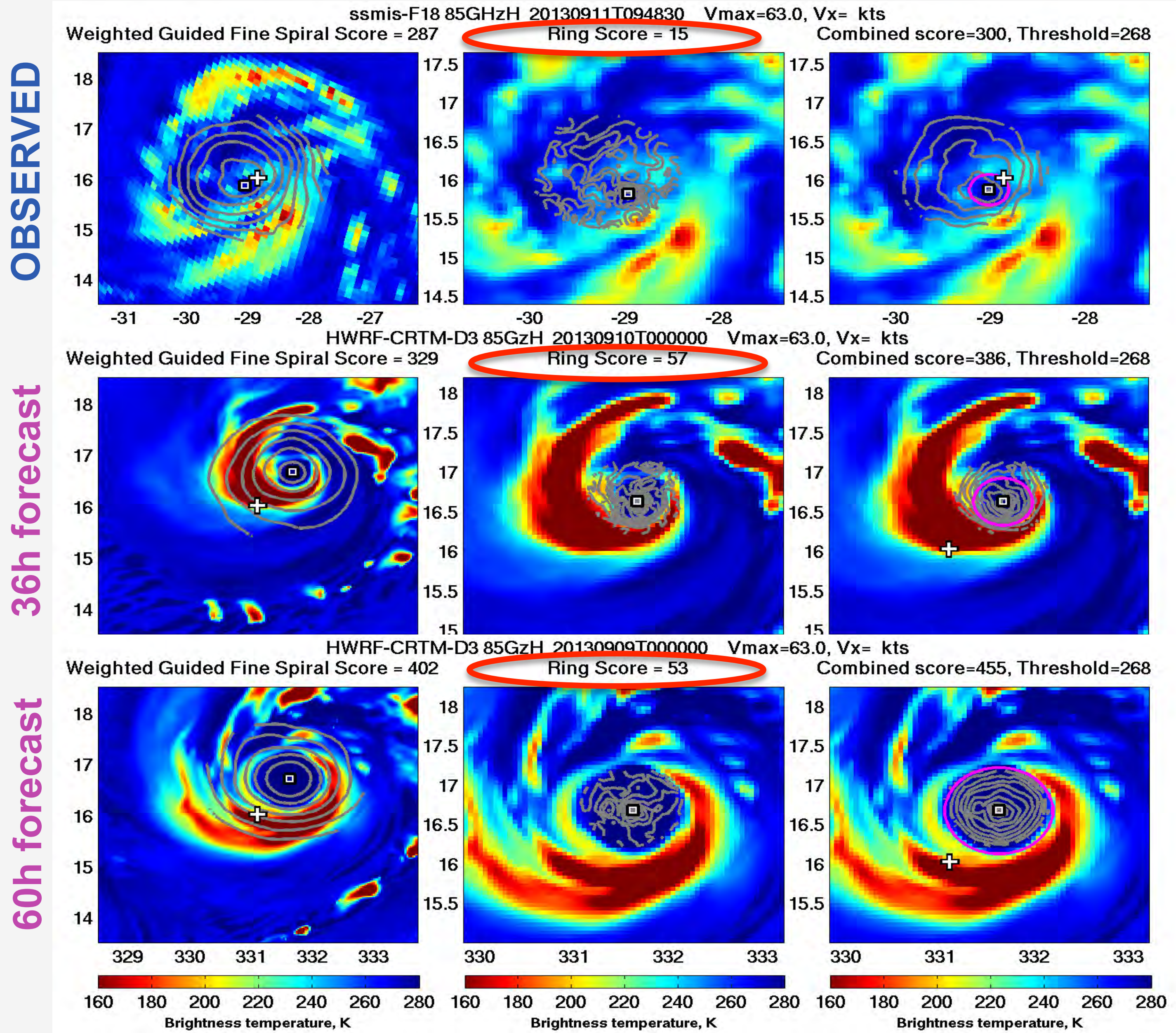
- Developed by CIMSS/NRL (Wimmers & Velden, 2010)
- We have license to run it and have done some off-line analysis, using the original version
- Provides:
  - Objective fix guidance for forecasters
  - Quantifies the degree of storm organization



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.

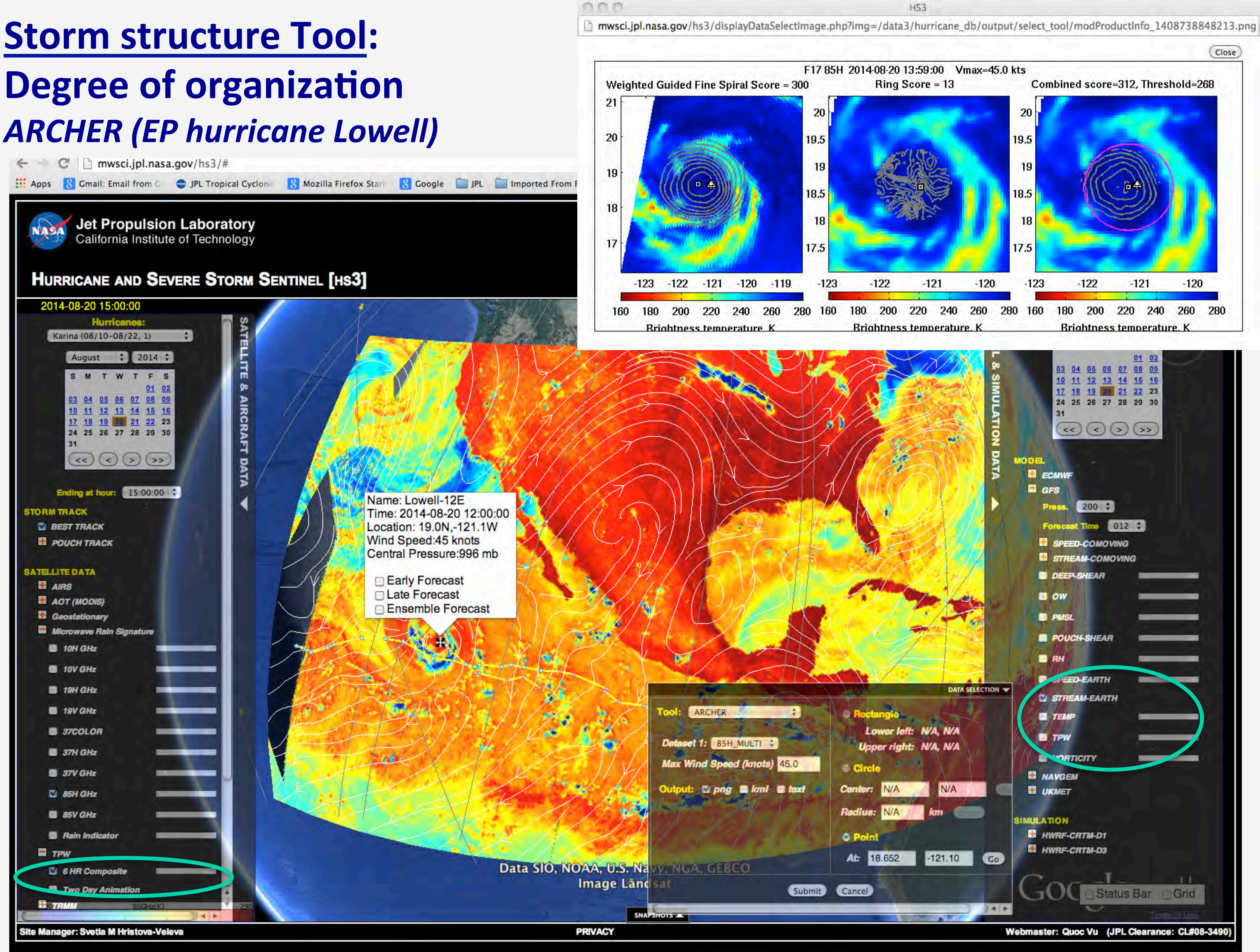
Storm structure Tool: Degree of Organization

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)



Storm structure Tool: Storm Size and Asymmetry

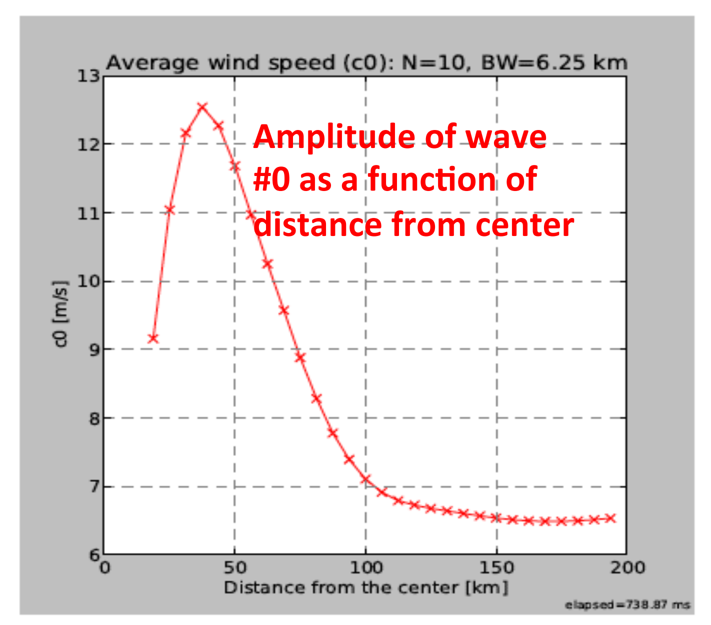
The Wave Number Analysis Tool

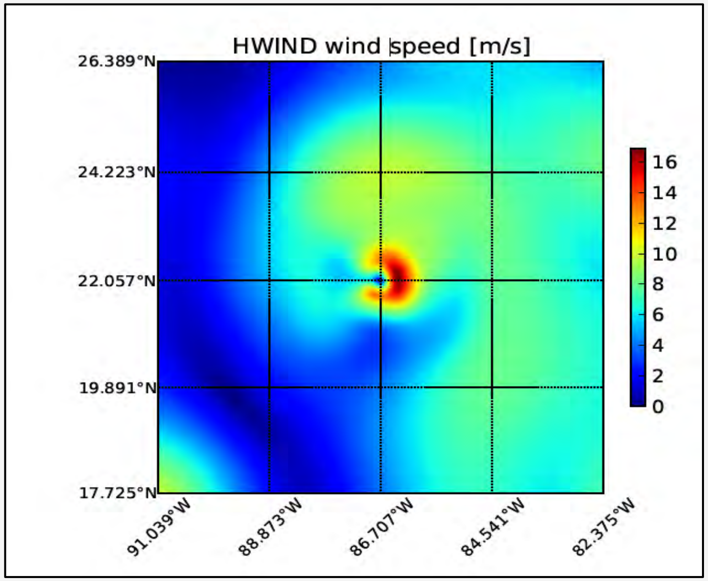
First adopted and used by NOAA/AOML/HRD

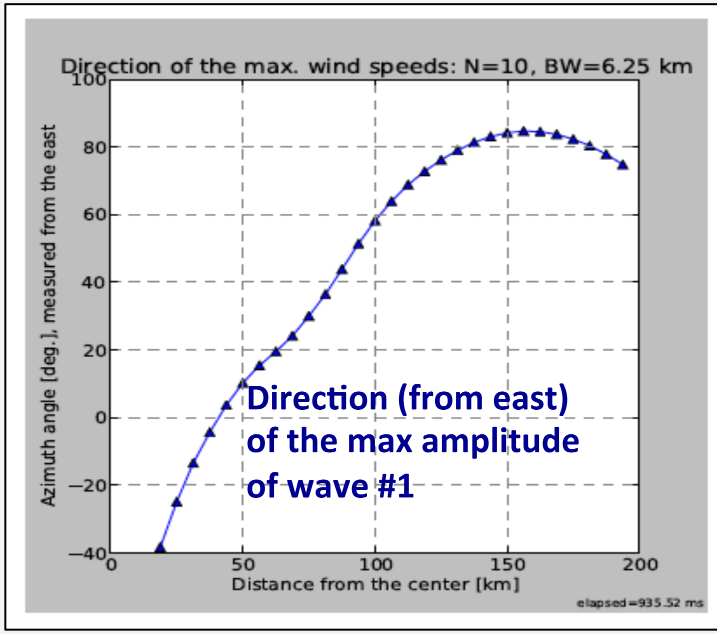
- *Lonfat, M., F.D. Marks, and S.S.Chen, 2004: "Precipitation Distribution in Tropical Cyclones using the Tropical Rainfall Measuring Mission (TRMM) microwave imager : A Global Perspective" MWR 132(7)*
- Vukicevic, T., E. Uhlhorn, P. Reasor and B. Klotz, 2013: "*A novel multi-scale intensity metric for 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
- Available now
- **Works with:**
  - **Surface winds**
  - **Rain Index**







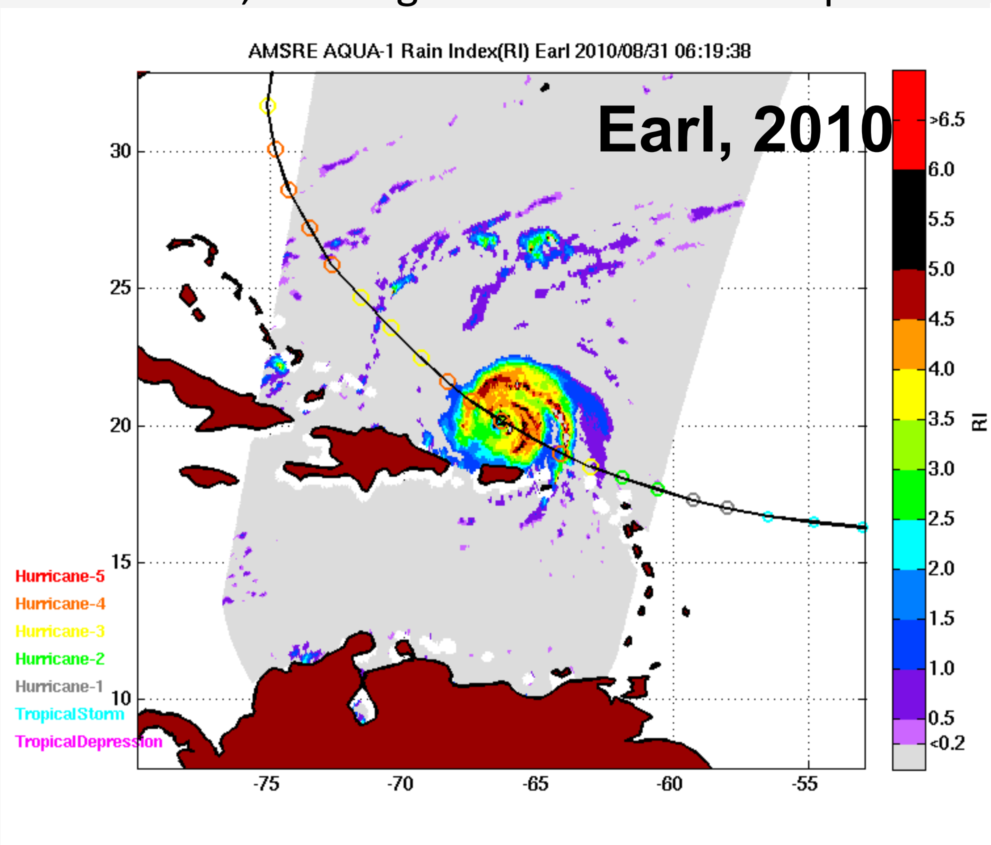
The Rain Indicator – a multi-channel depiction of the storm structure

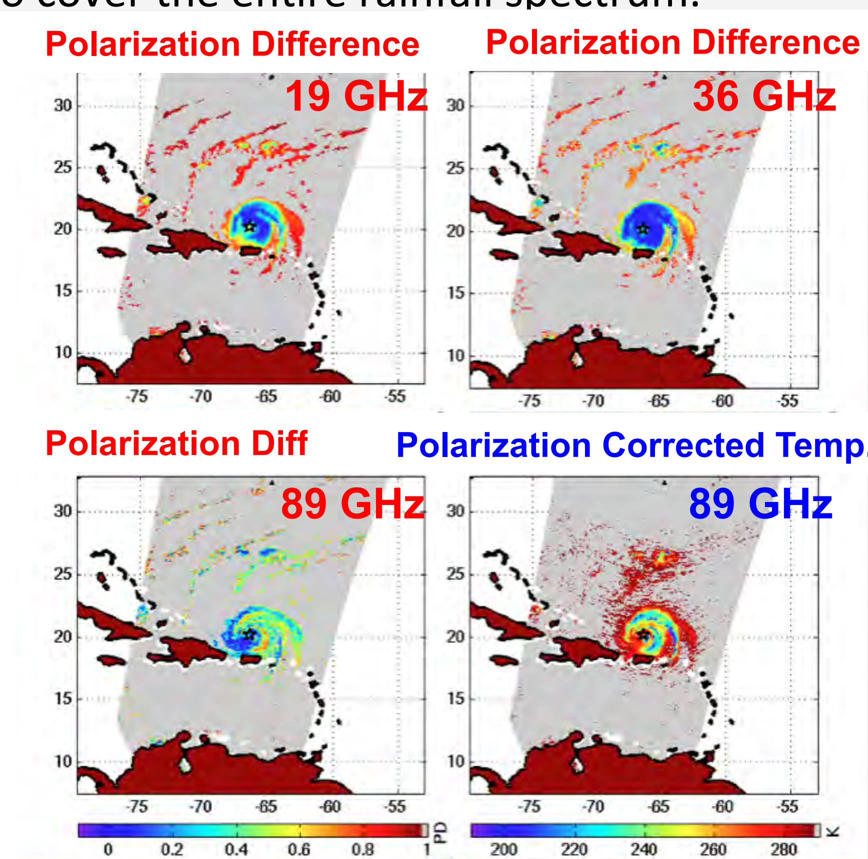
Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828–2848

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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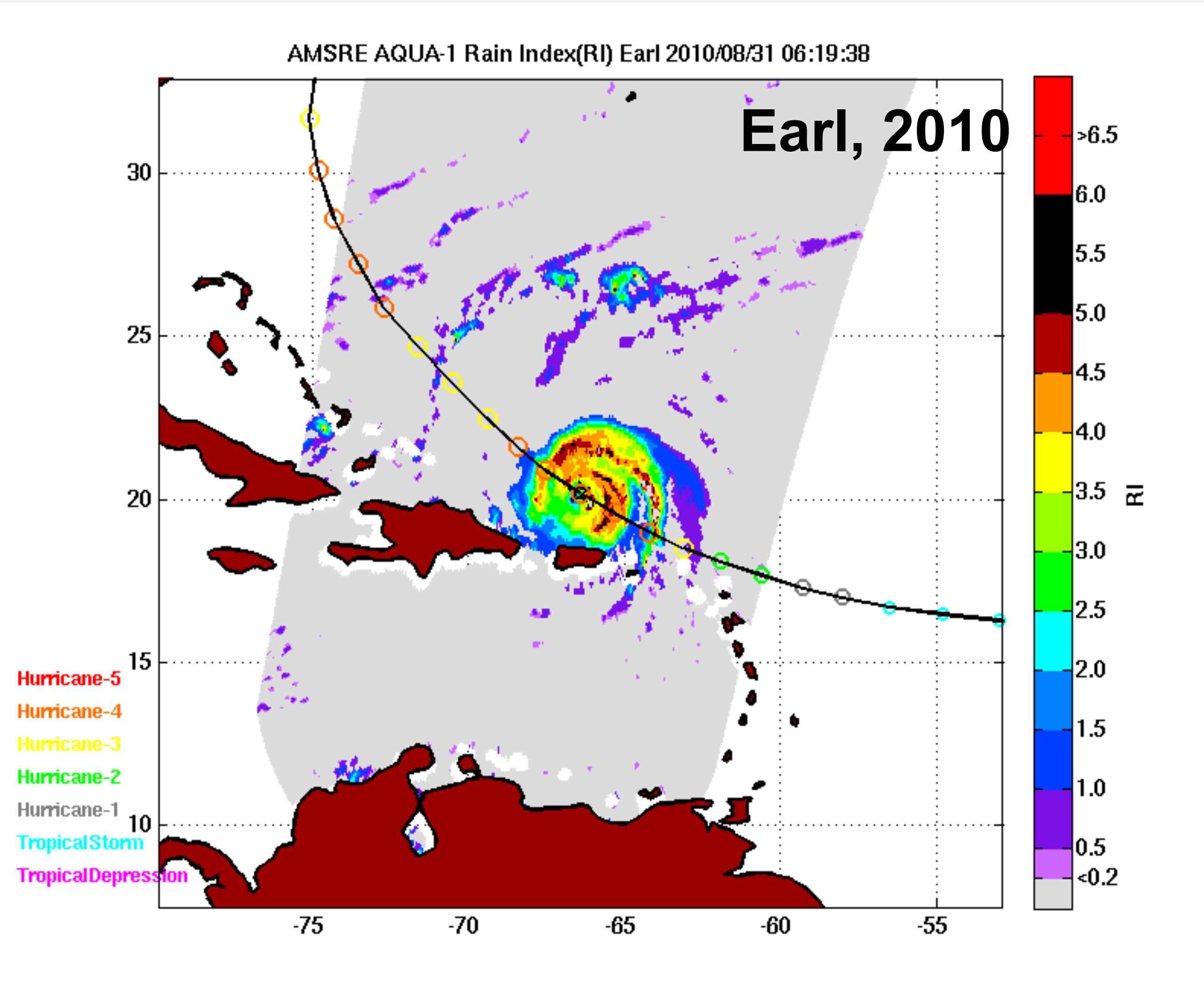


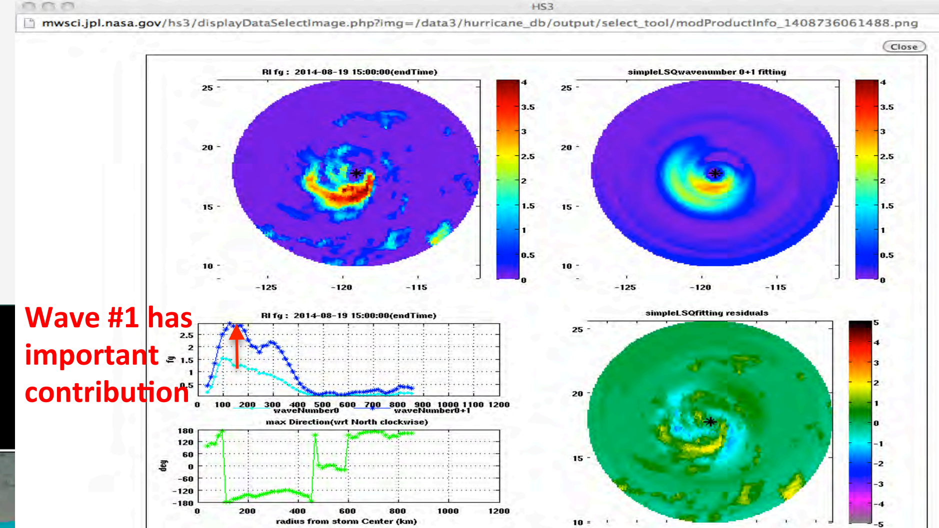
Advantages of Using the Rain Indicator over single passive microwave channels

- 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**.

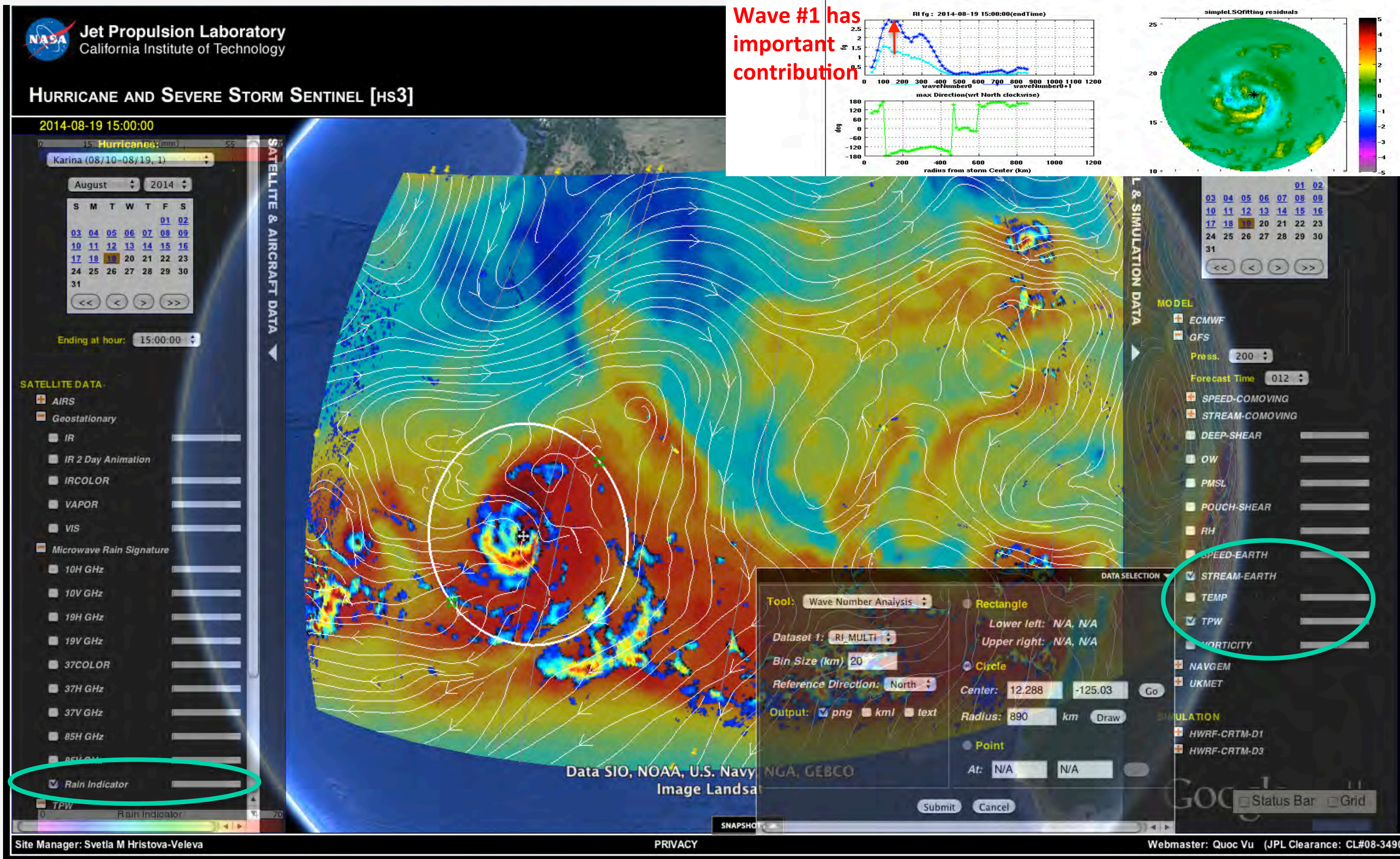
Storm structure Tool:

Storm Size and Asymmetry

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



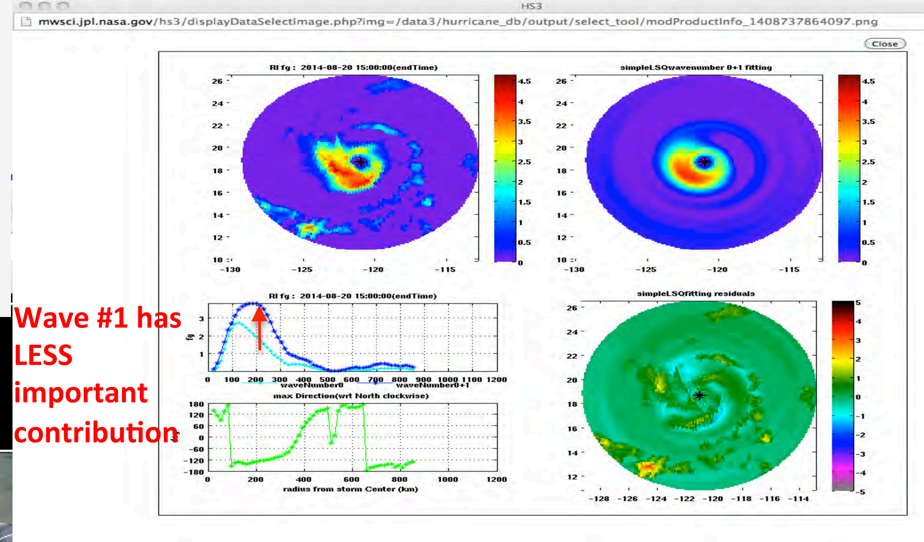
Wave #1 has important contribution



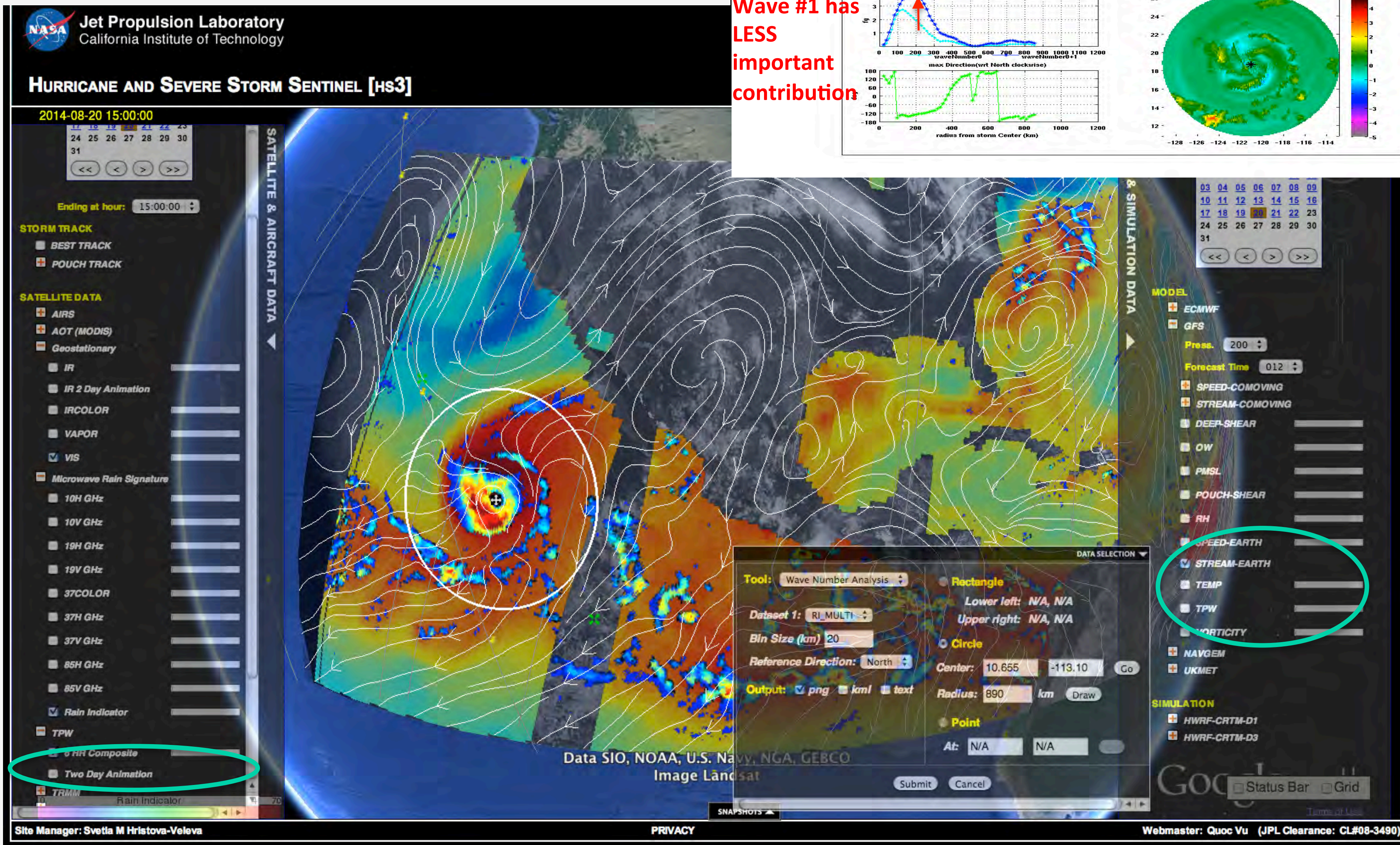
Storm structure Tool:

Storm Size and Asymmetry

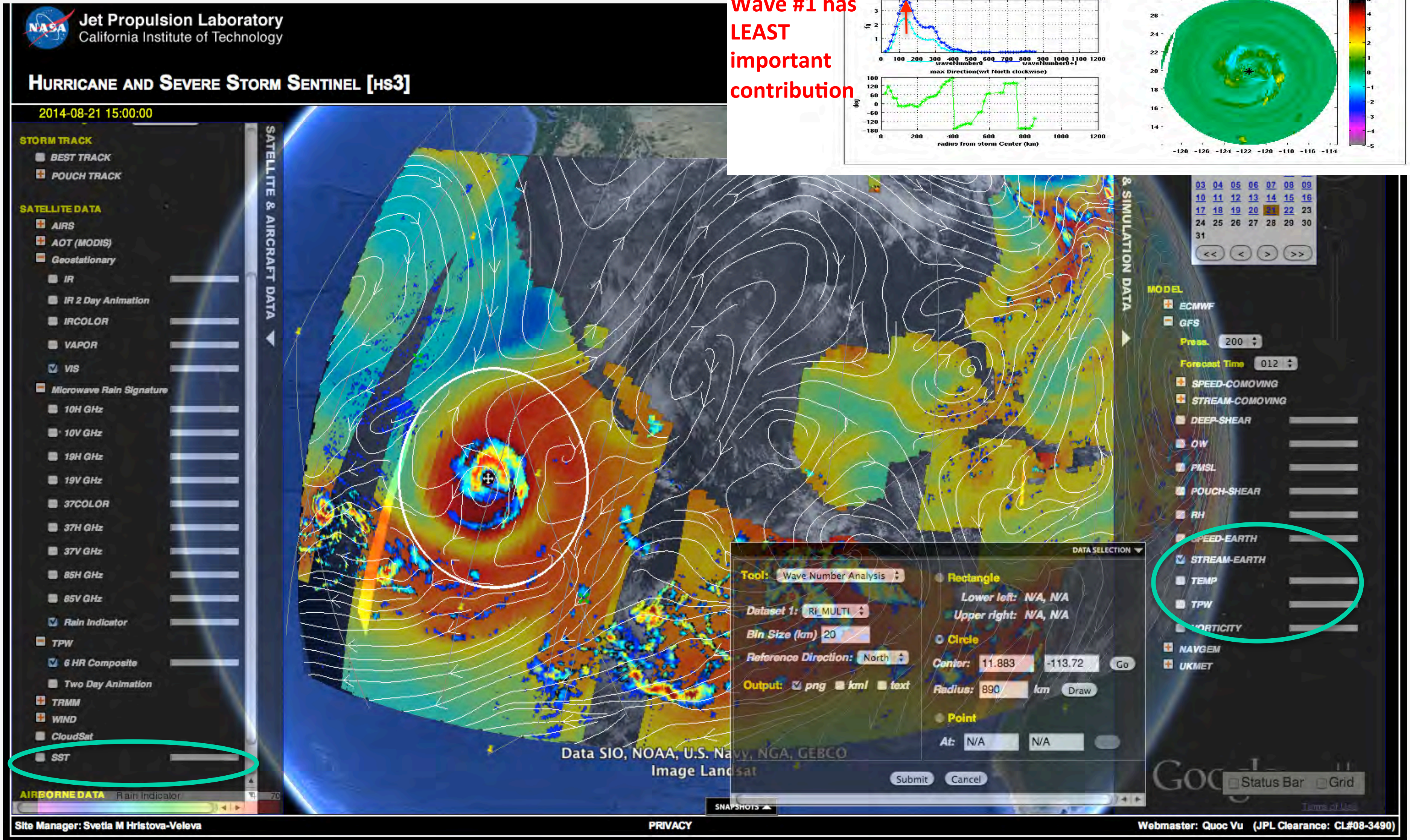
The Wave Number Analysis Tool using the Rain Index (EP hurricane Lowell)

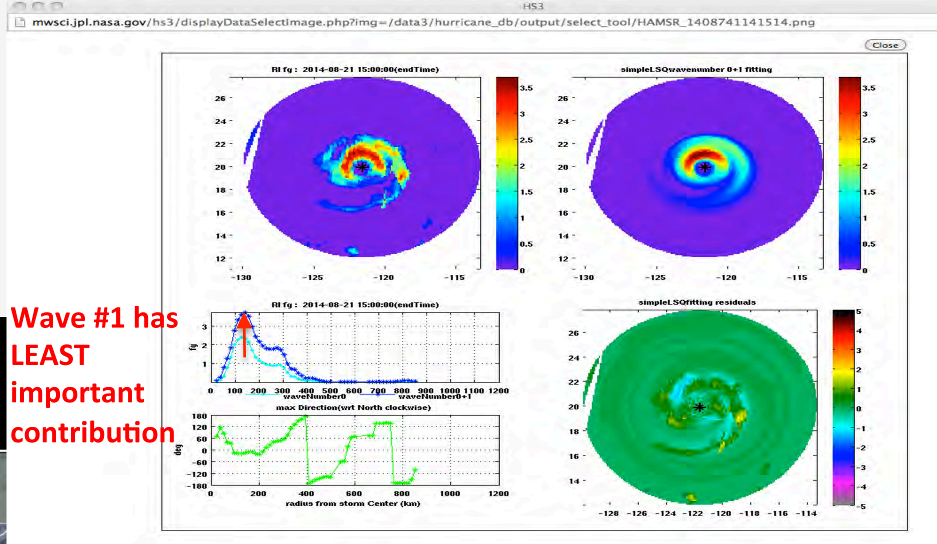


Wave #1 has LESS important contribution



Storm structure Tool:
Storm Size and Asymmetry
The Wave Number Analysis Tool using the Rain Index (EP hurricane Lowell)



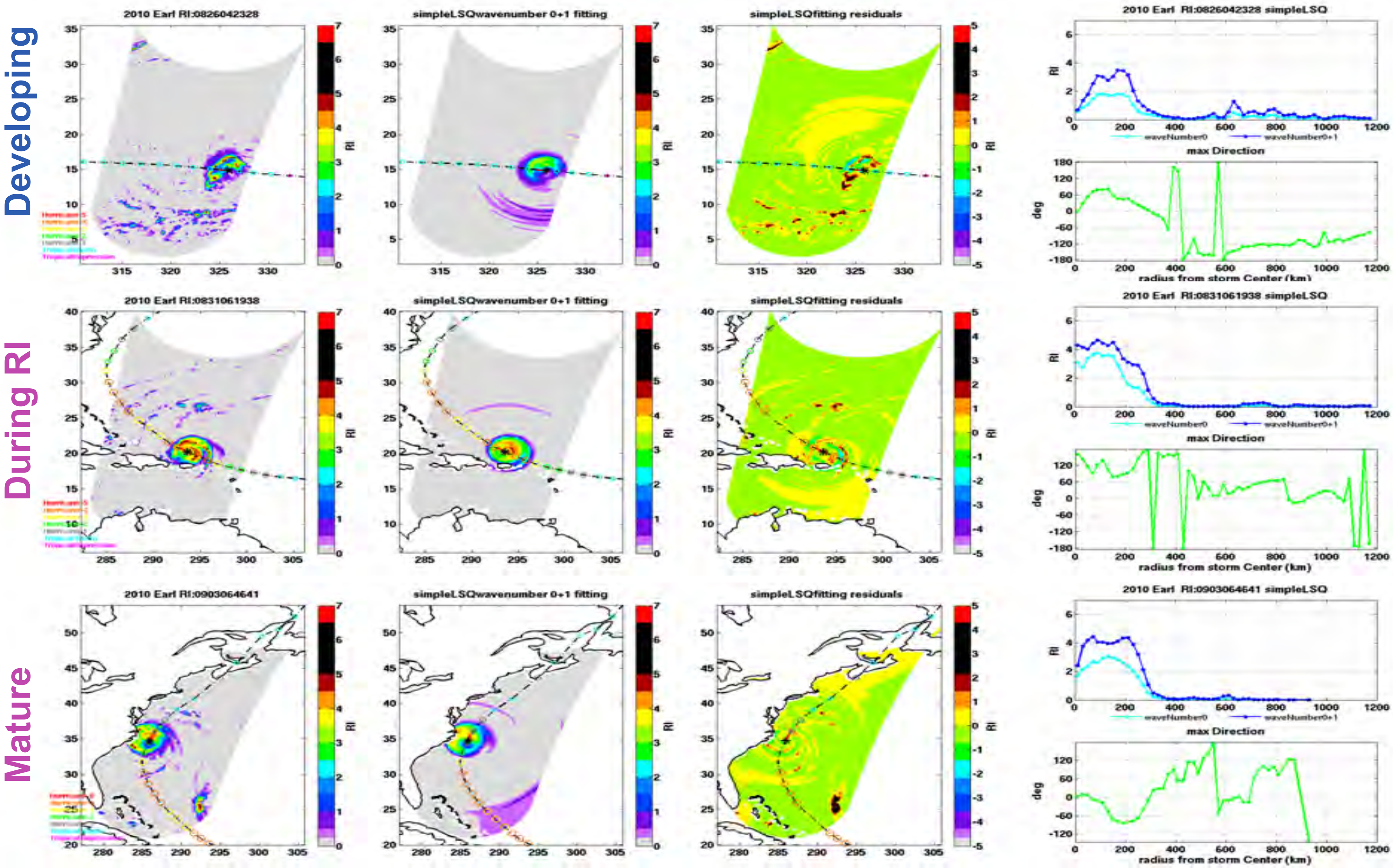


Wave #1 has LEAST important contribution

Storm structure Tool: Storm Size and Asymmetry

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

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



Storm structure Tool: Storm Size and Asymmetry

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

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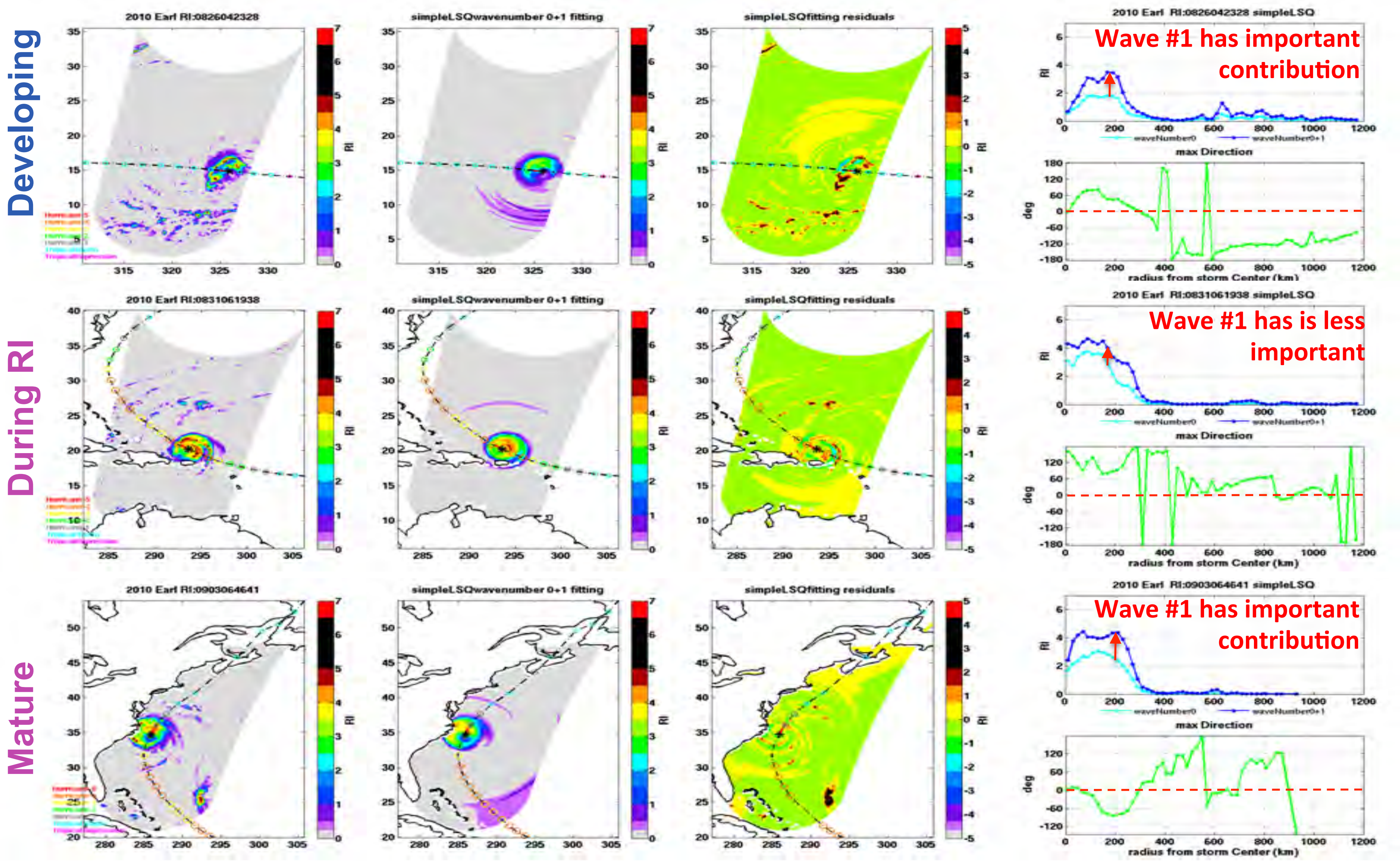
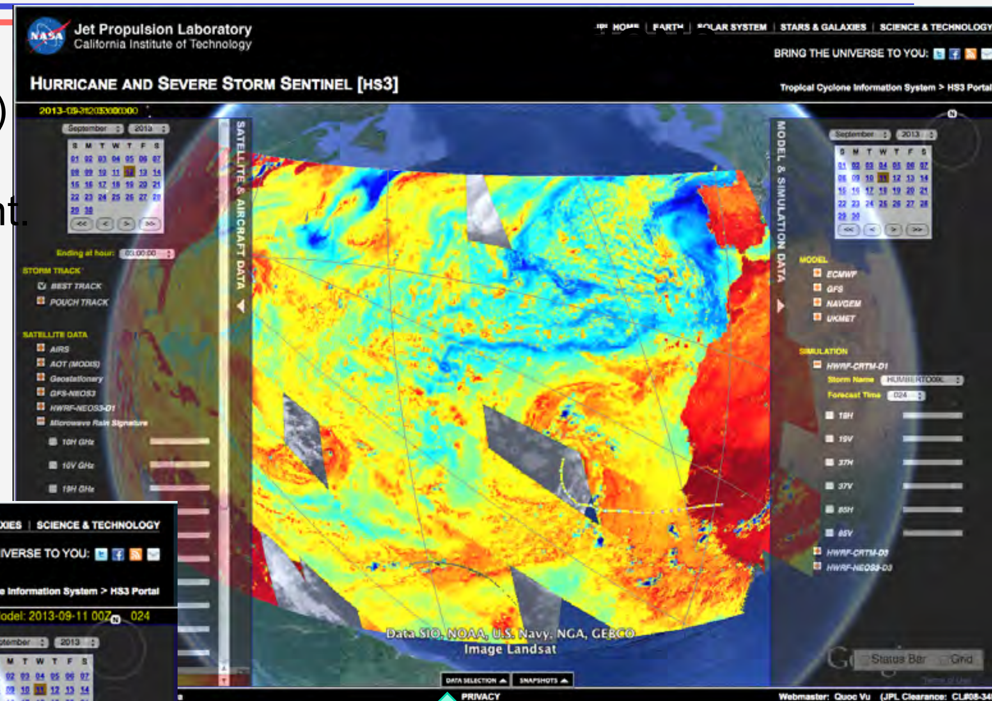


Task Summary – Major Accomplishments

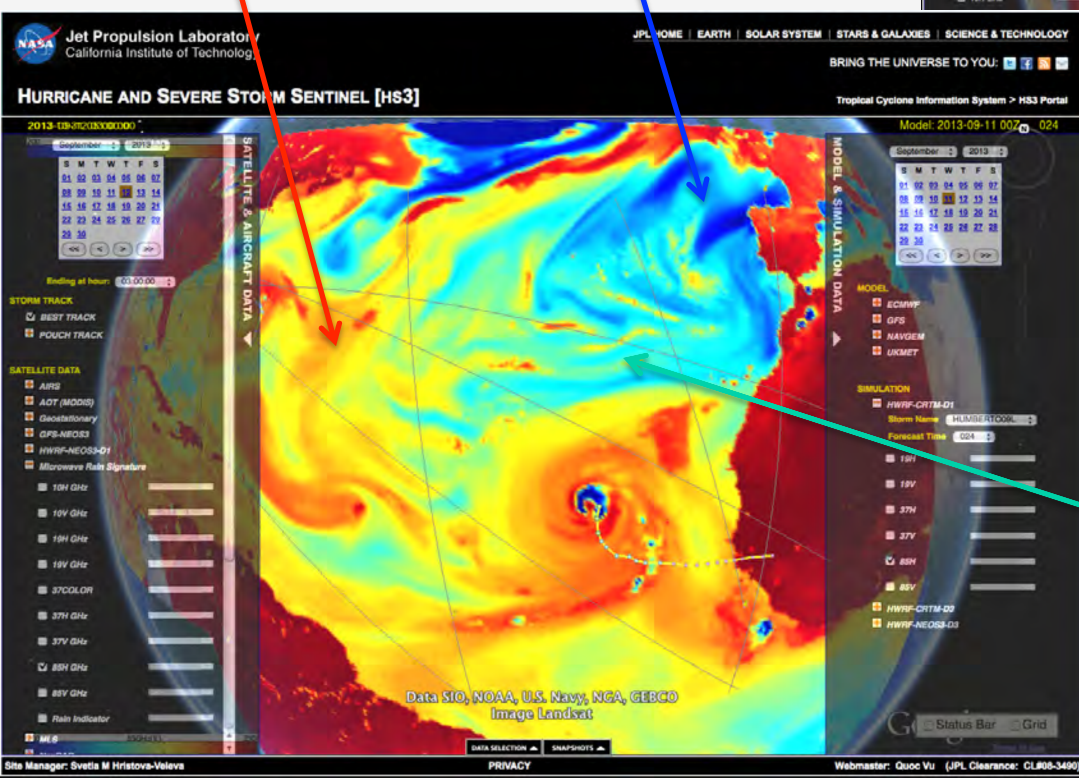
How to evaluate whether the model represents the environment well

An example of how observed and synthetic brightness temperatures (85 GHz in this case) can be used to evaluate whether the model properly represents the large-scale environment. HWRF model based on (NEOS[3]) and the operational CRTM instrument simulators



DRY AIR

MOIST AIR

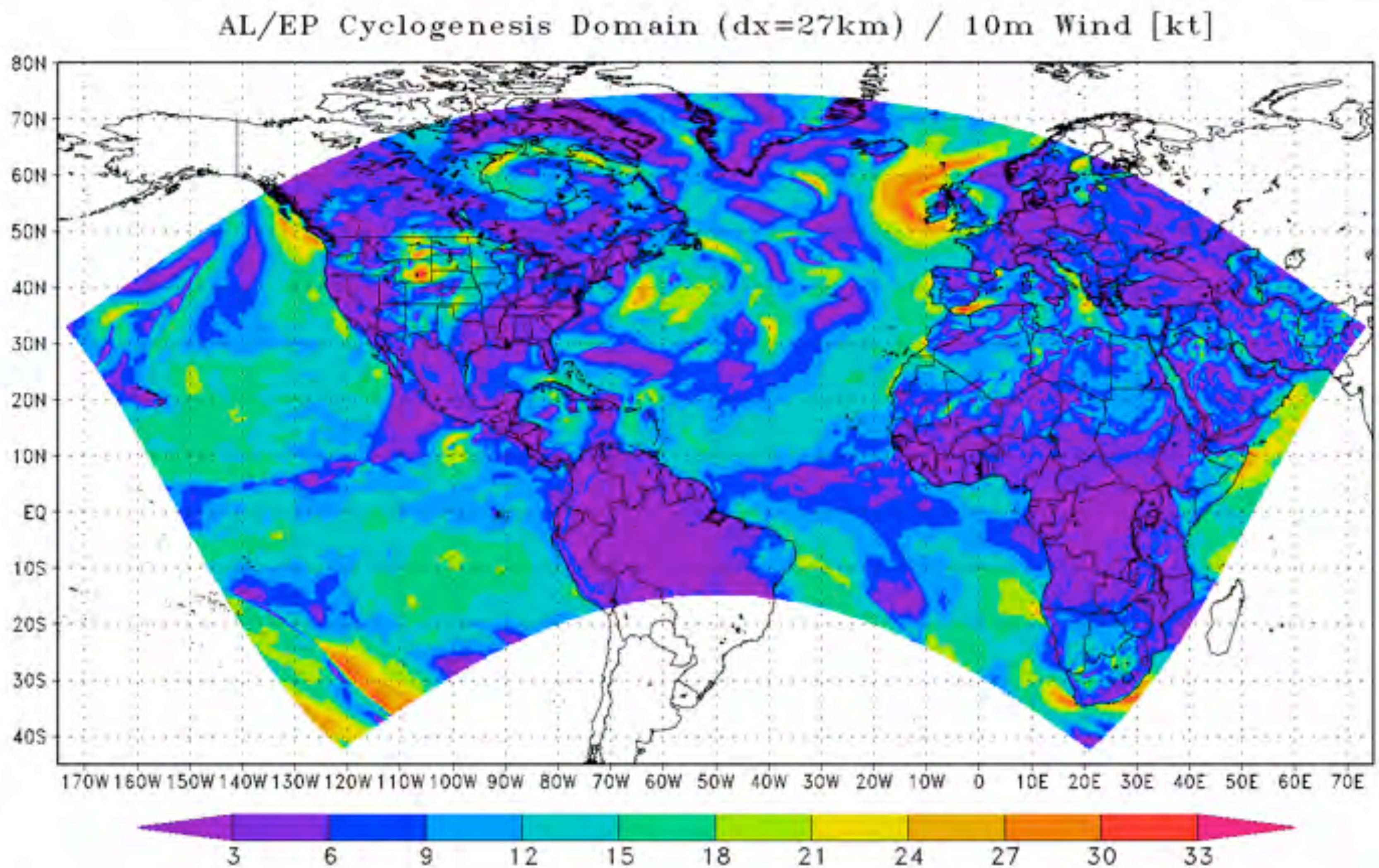


- Overall – a very good comparison of brightness temperatures
- Area north of the hurricane is a bit too moist in the model

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.**
- Our system is ***under development. Expected that many components will be operational during the coming season***. Stay tuned …☺

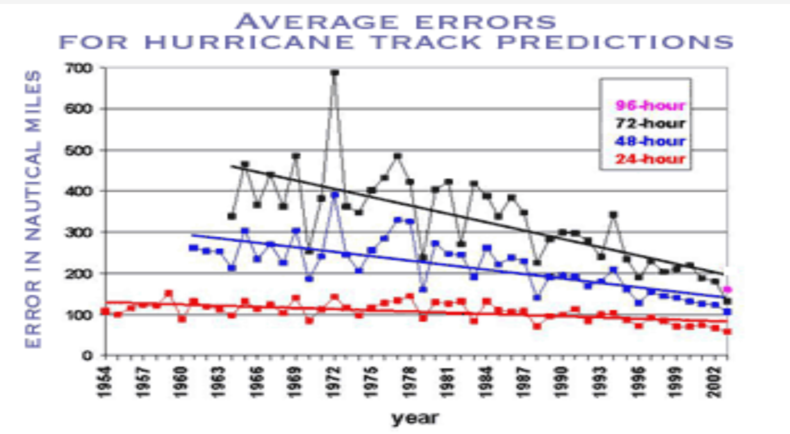
Basin-scale HWRF – coming up!



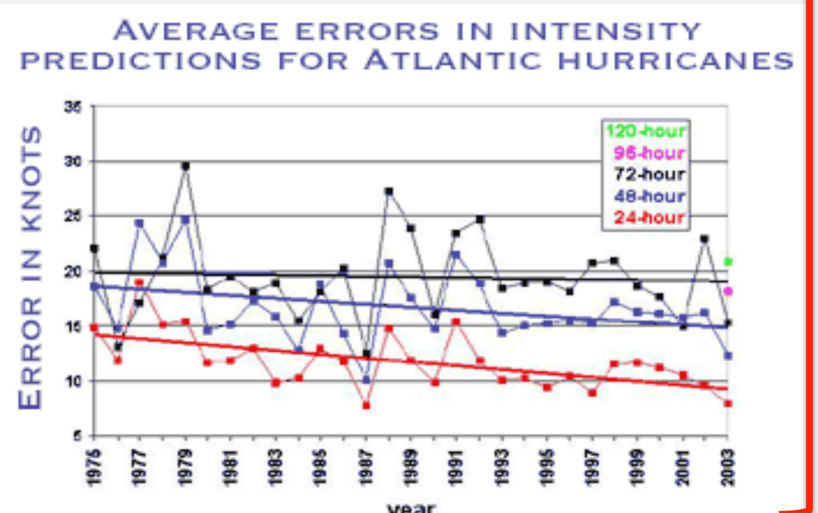

Thank you !

Current state-of-the-art hurricane prediction

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



- **Intensity forecasts have not improved as fast.**



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).