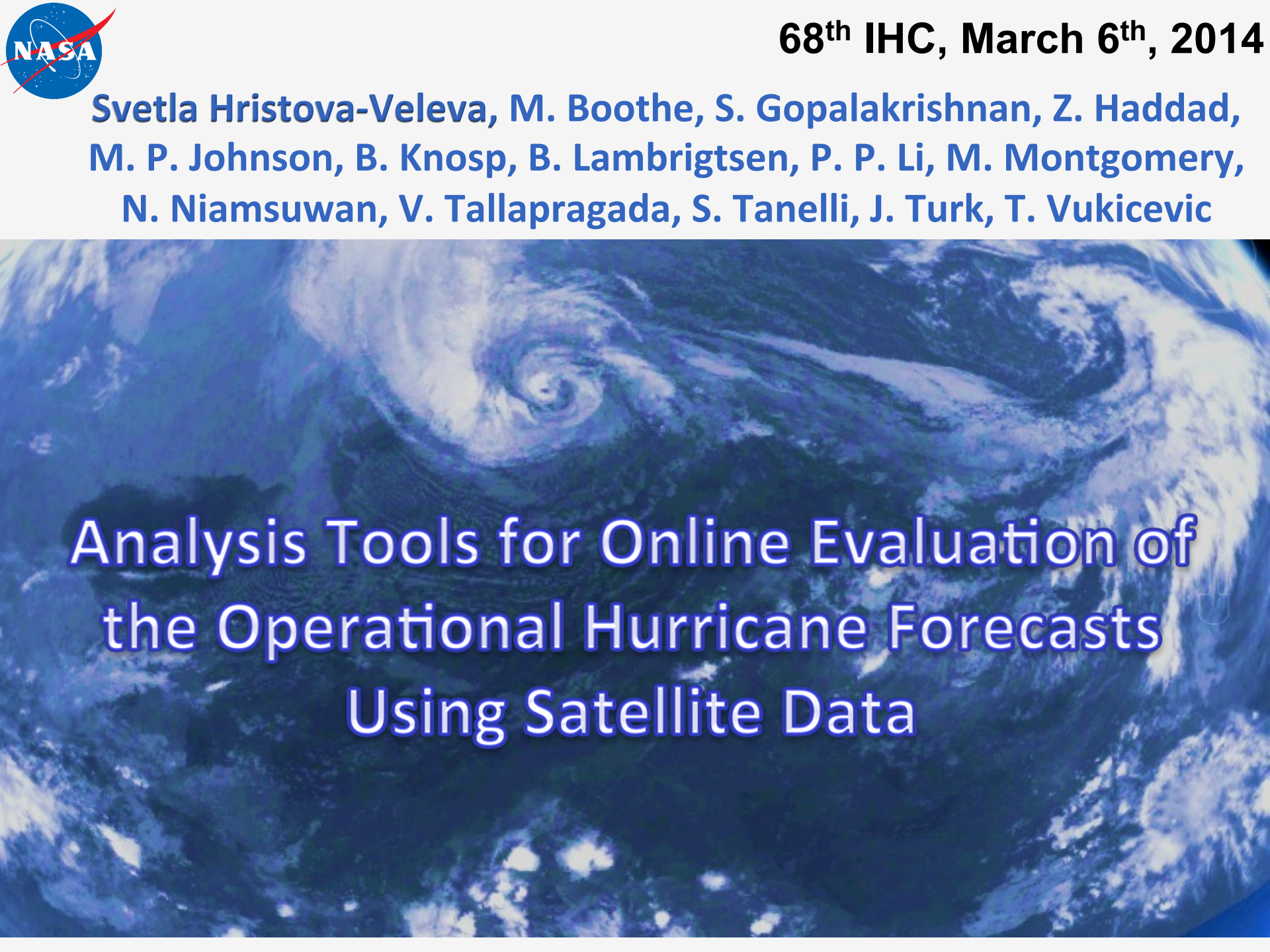
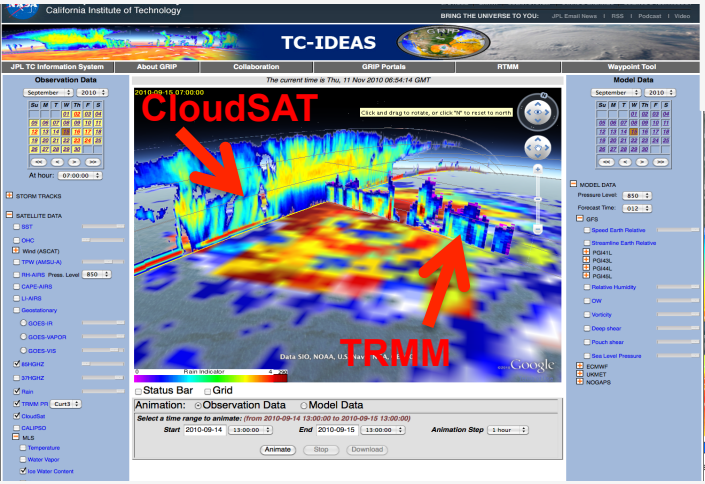
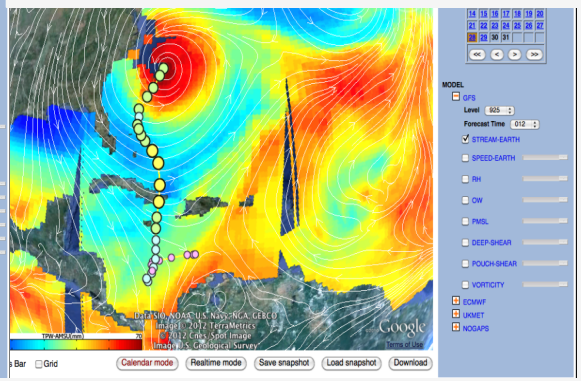

68th IHC, March 6th, 2014
Svetla Hristova-Veleva, M. Boothe, S. Gopalakrishnan, Z. Haddad, M. P. Johnson, B. Knosp, B. Lambrigtsen, P. P. Li, M. Montgomery, N. Niamsuwan, V. Tallapragada, S. Tanelli, J. Turk, T. Vukicevic
Analysis Tools for Online Evaluation of the Operational Hurricane Forecasts Using Satellite Data

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

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



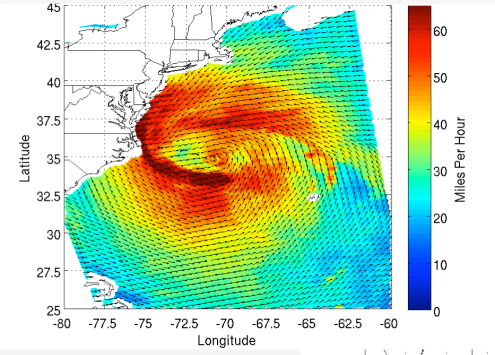
- **Is the environment captured correctly?**
- **Is the interaction between the storm and its environment realistic?**



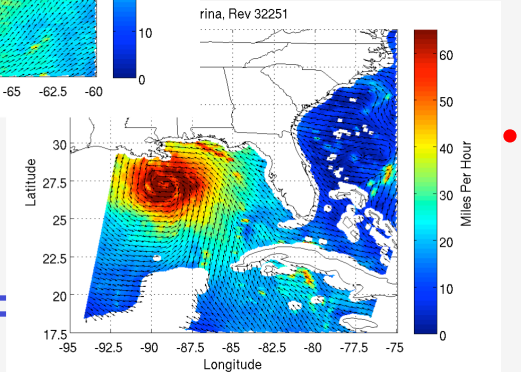
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

Satellite observations can help in 2 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. **Validation and improvement of hurricane models through the use of satellite data**
2. **Development and implementation of advanced techniques for assimilation of satellite observations inside the hurricane core.**

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

The JPL TCIS – Tropical Cyclone Information System

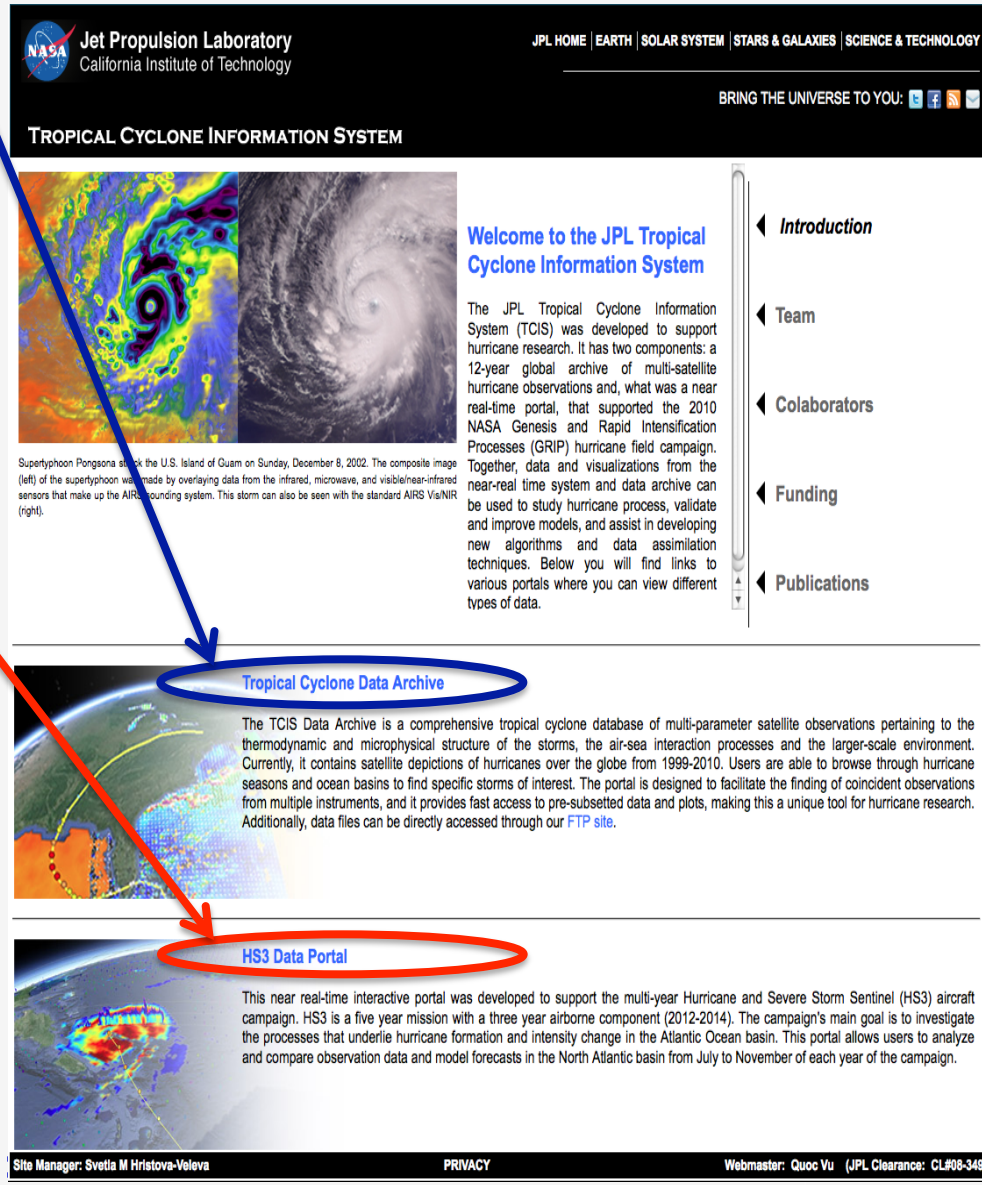
http://tropicalcyclone.jpl.nasa.gov

Tropical Cyclone Data Archive

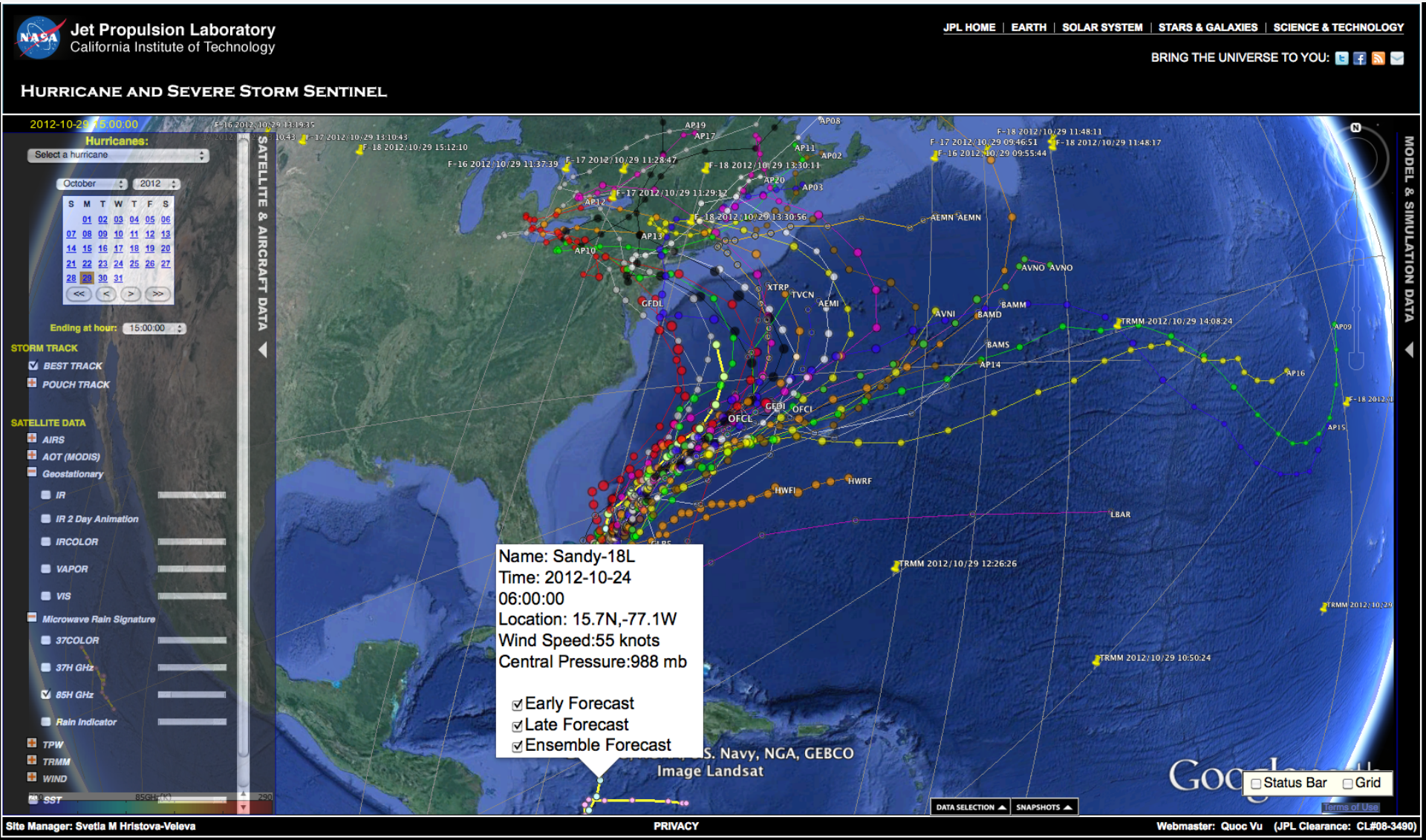
- Satellite depiction of hurricanes over the globe
- 12-year record (1999-2010)
- offers both data and imagery, making it a unique source to support:
  - hurricane research
  - forecast improvement
  - algorithm development
  - instrument design

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.

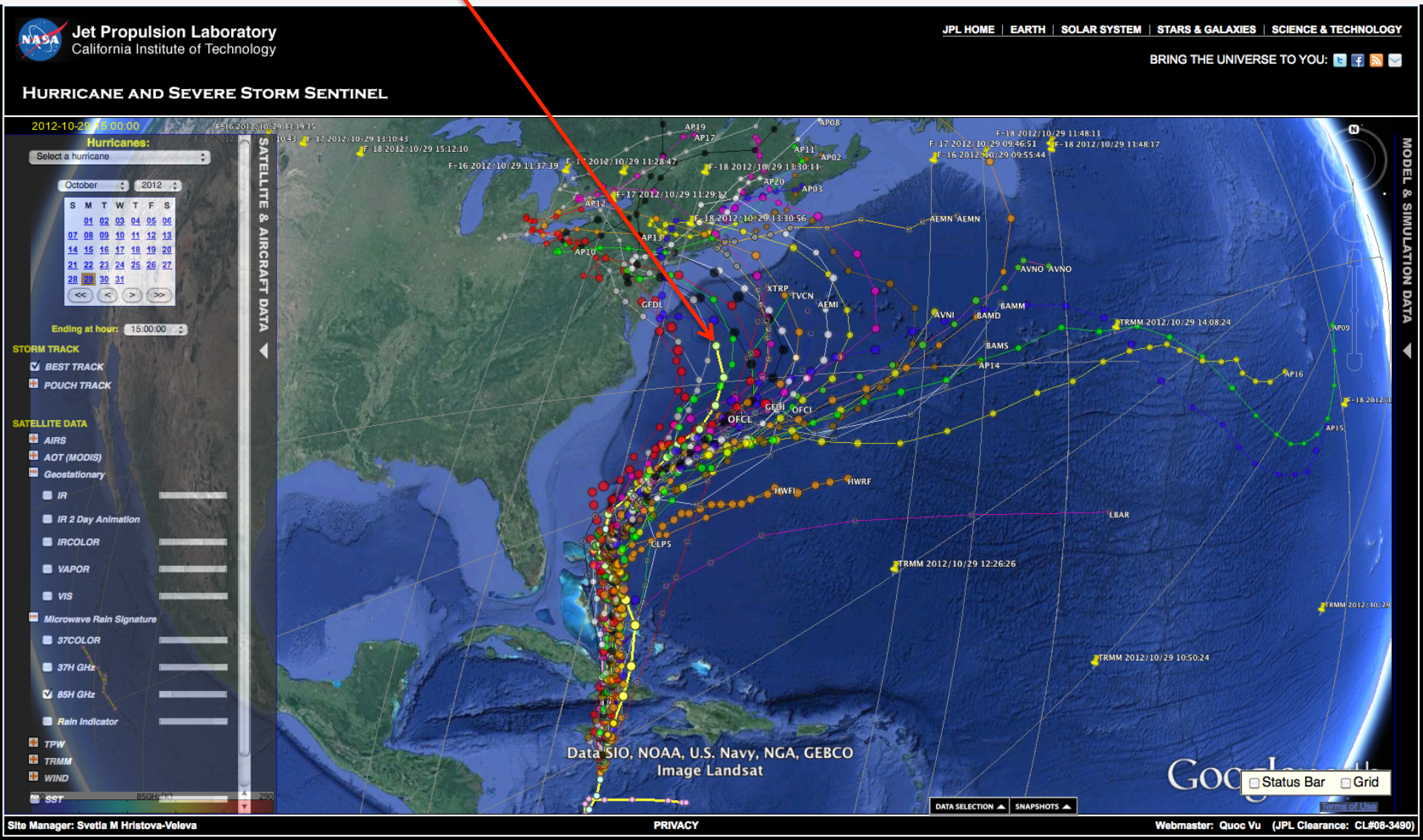


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)
Forecast Uncertainty 5 days out - Hurricane Sandy (2012)



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

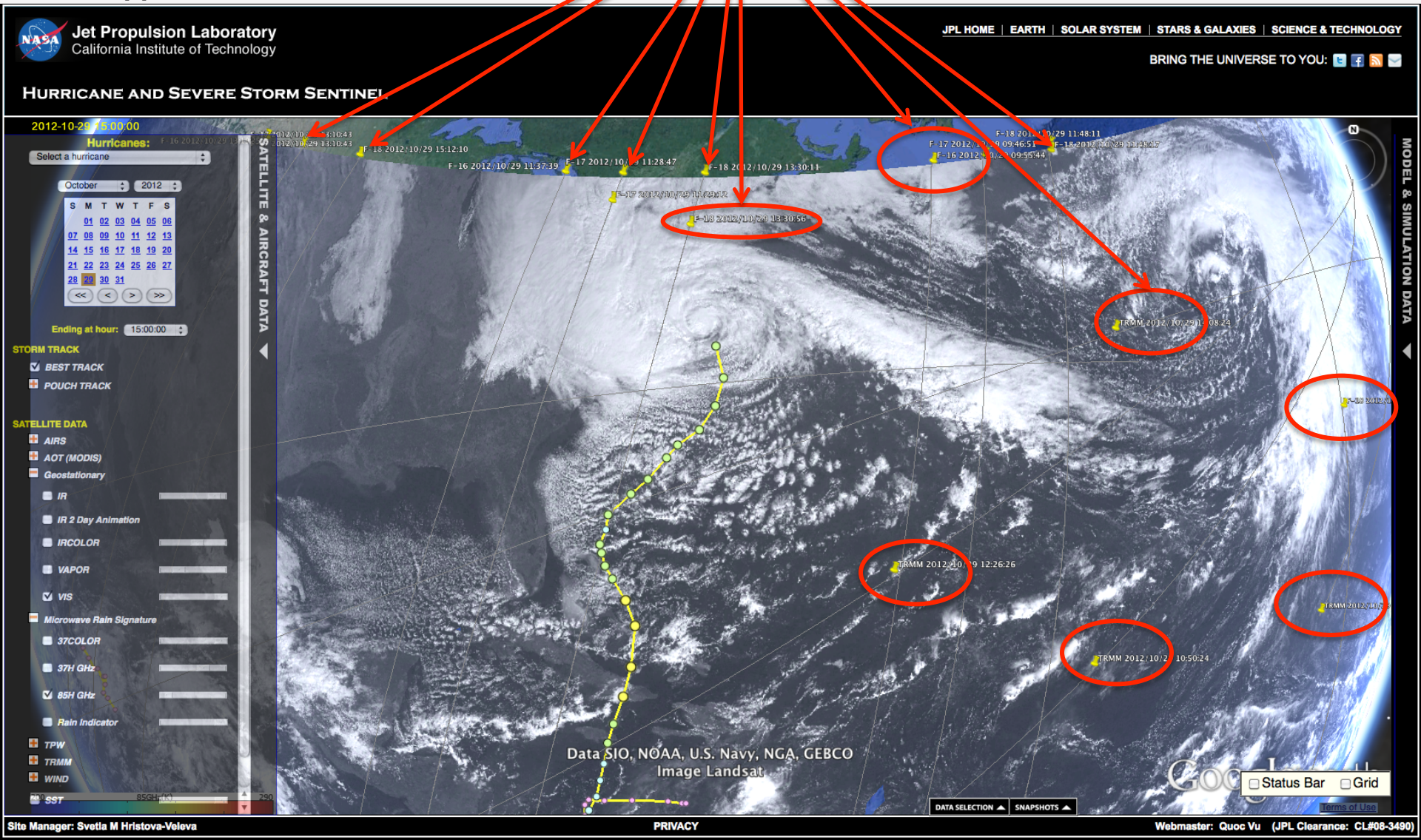
Best Track



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

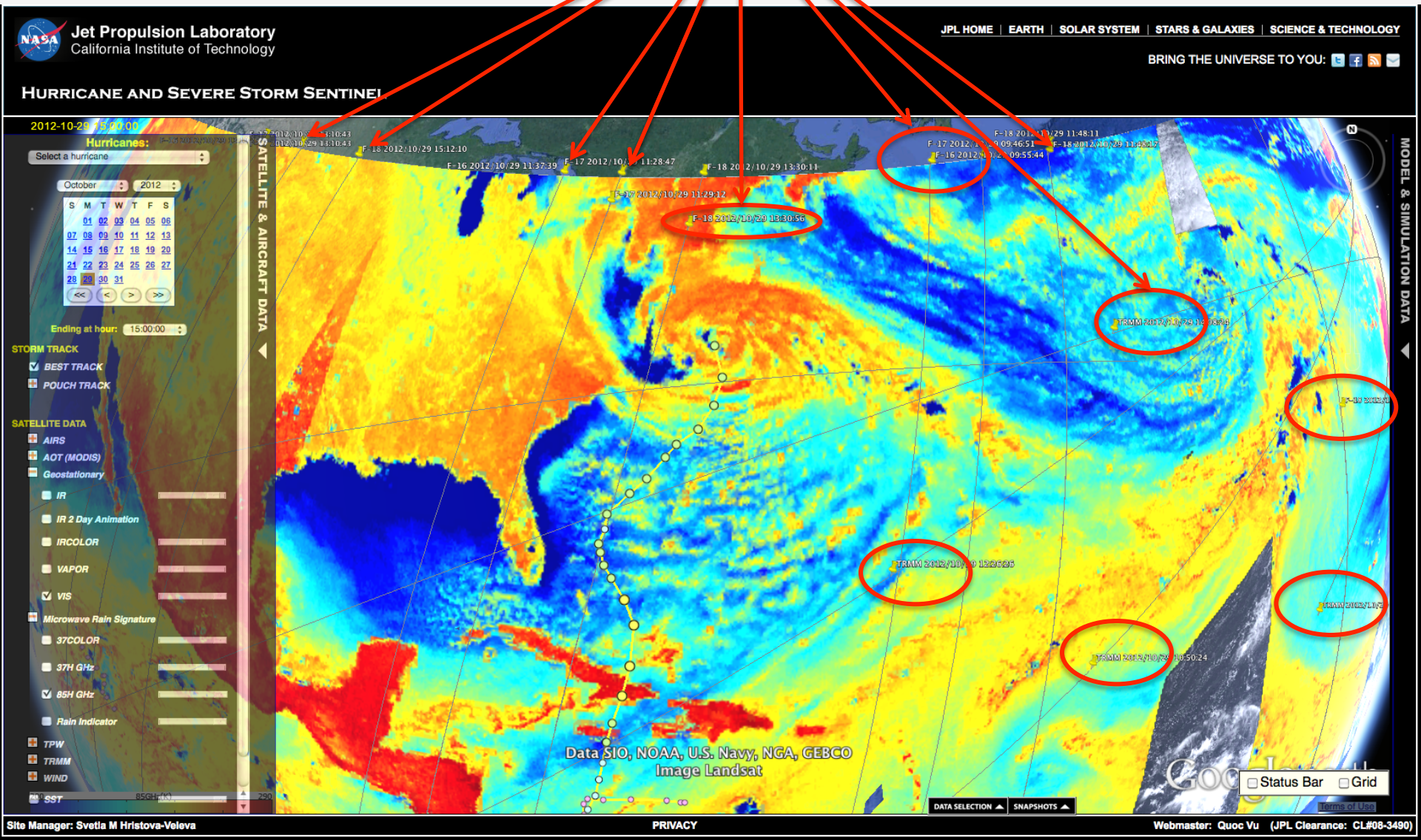
The Power of the Satellite Observations – Hurricane Sandy (2012)

Note the multitude of Polar Orbiting Satellites that supplement GEOS observations



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

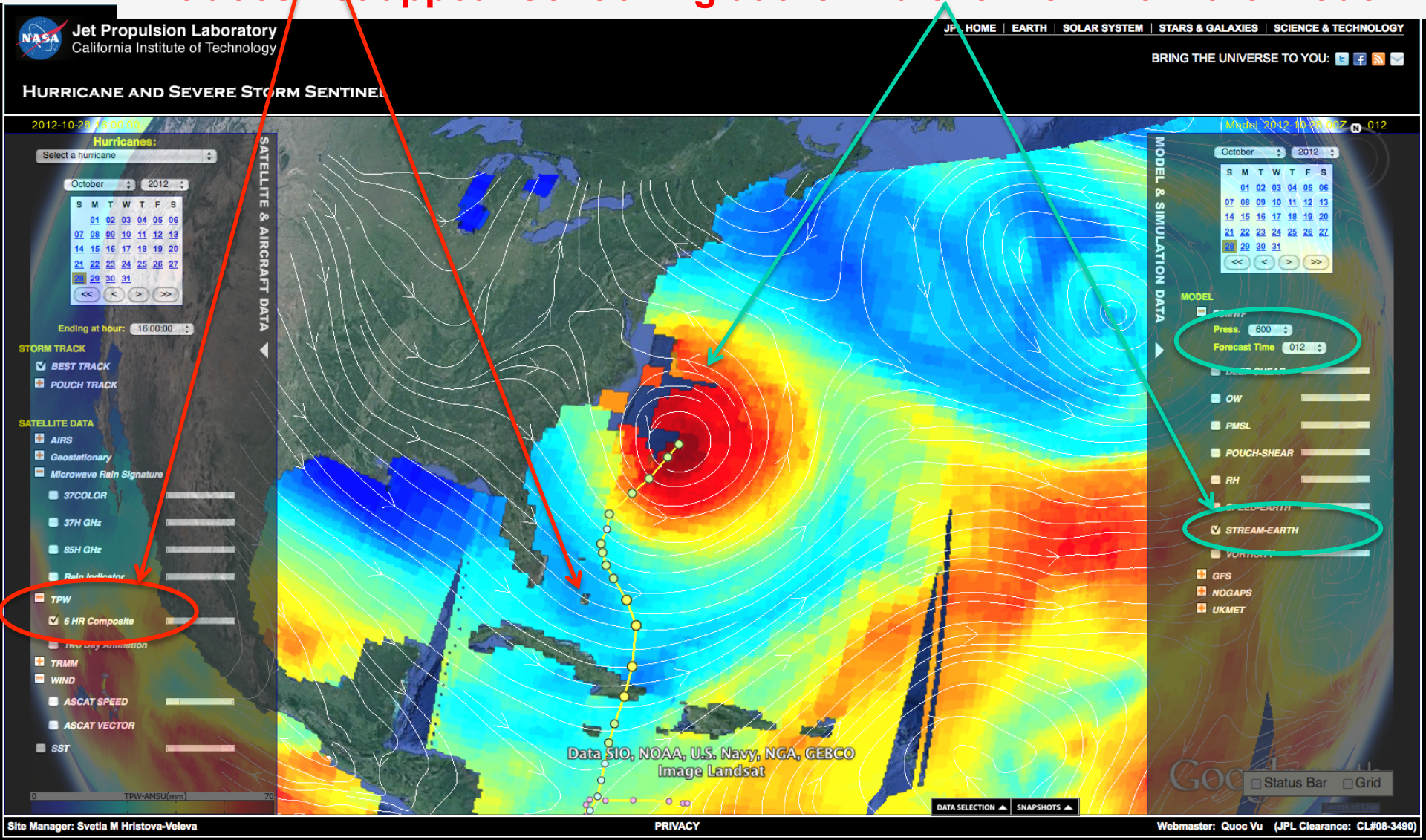
The Power of the Satellite Observations – painted in microwave



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

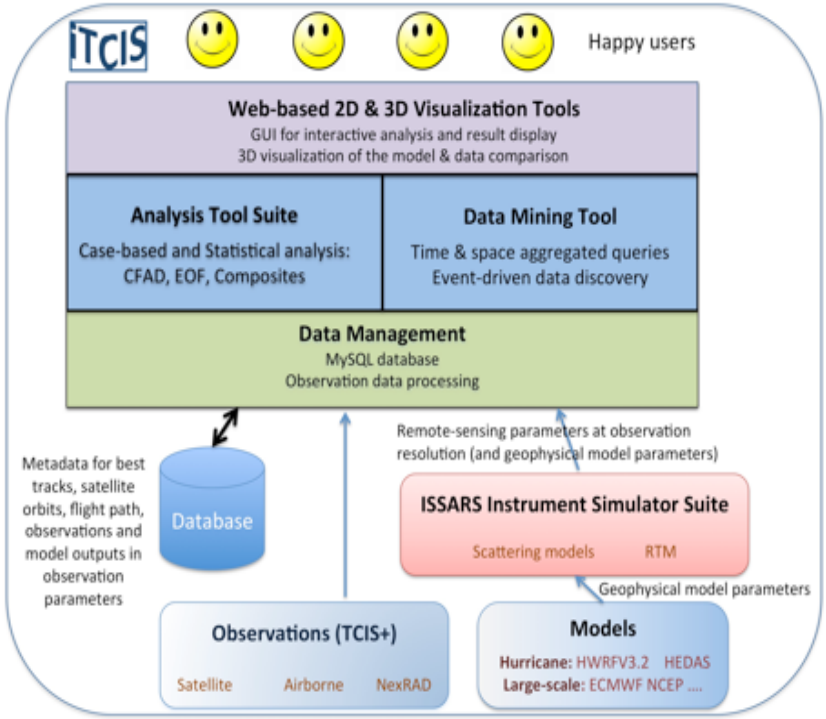
Bringing model and observations together:

- 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.



Goal of our current project – Bringing the multitude of NASA and NOAA satellite observations to bear on a problem with significant societal impacts.

- **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.**



Will develop three critical components that will allow the merger of observations with model forecasts:

1) Couple instrument simulator 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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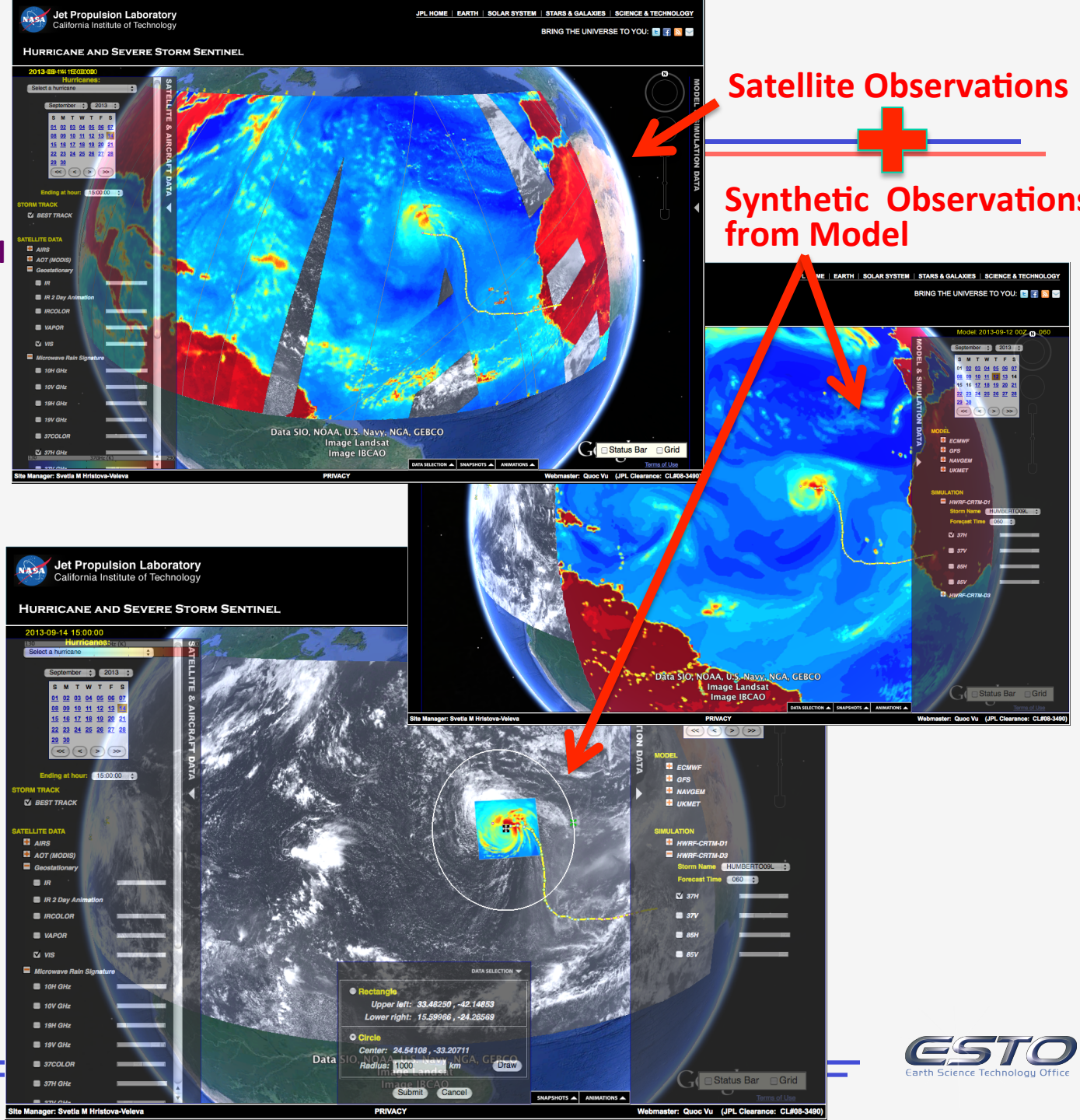
FUSION OF MODELS AND OBSERVATIONS

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

- Operational HWRF model forecasts are used as input to CRTM
- The synthetic "satellite observations" are:
  - Incorporated in the database of satellite obs.
  - Visualized in the portal



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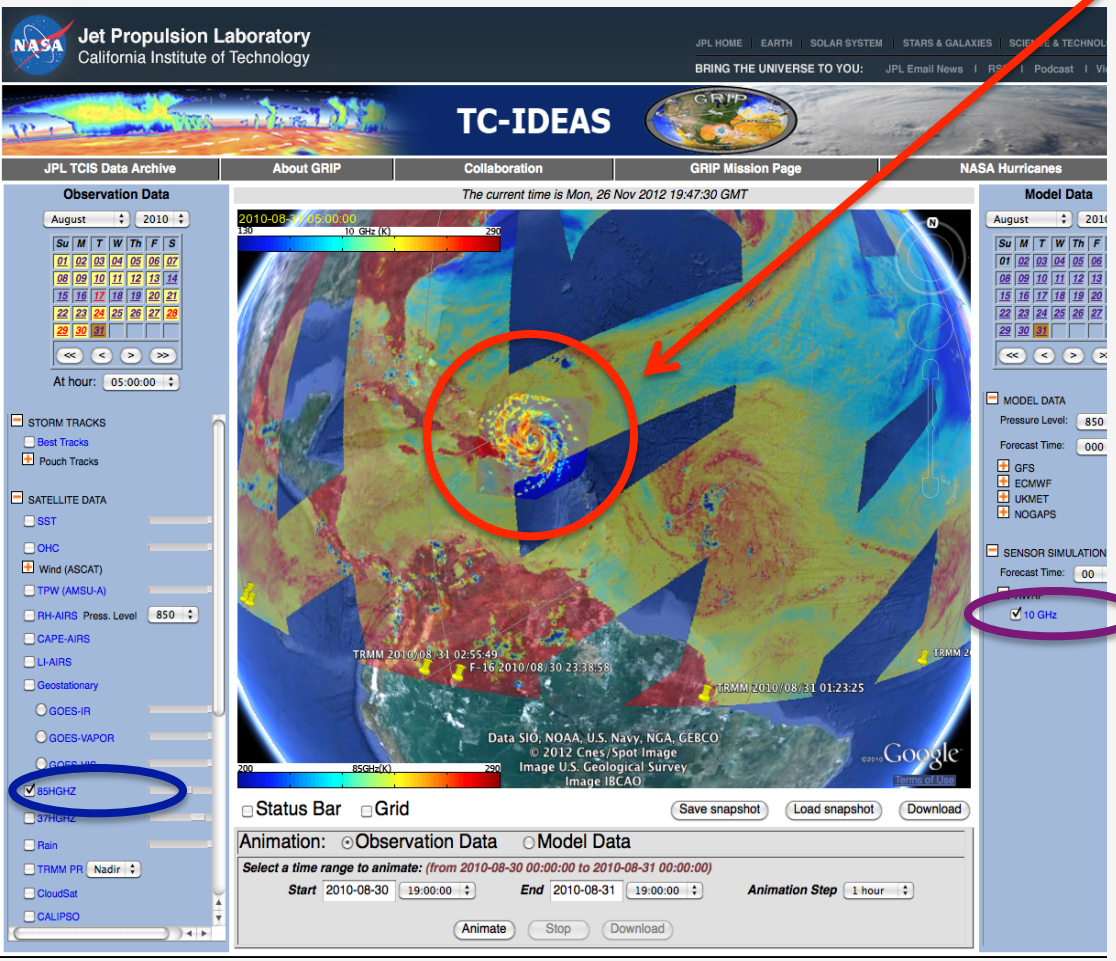
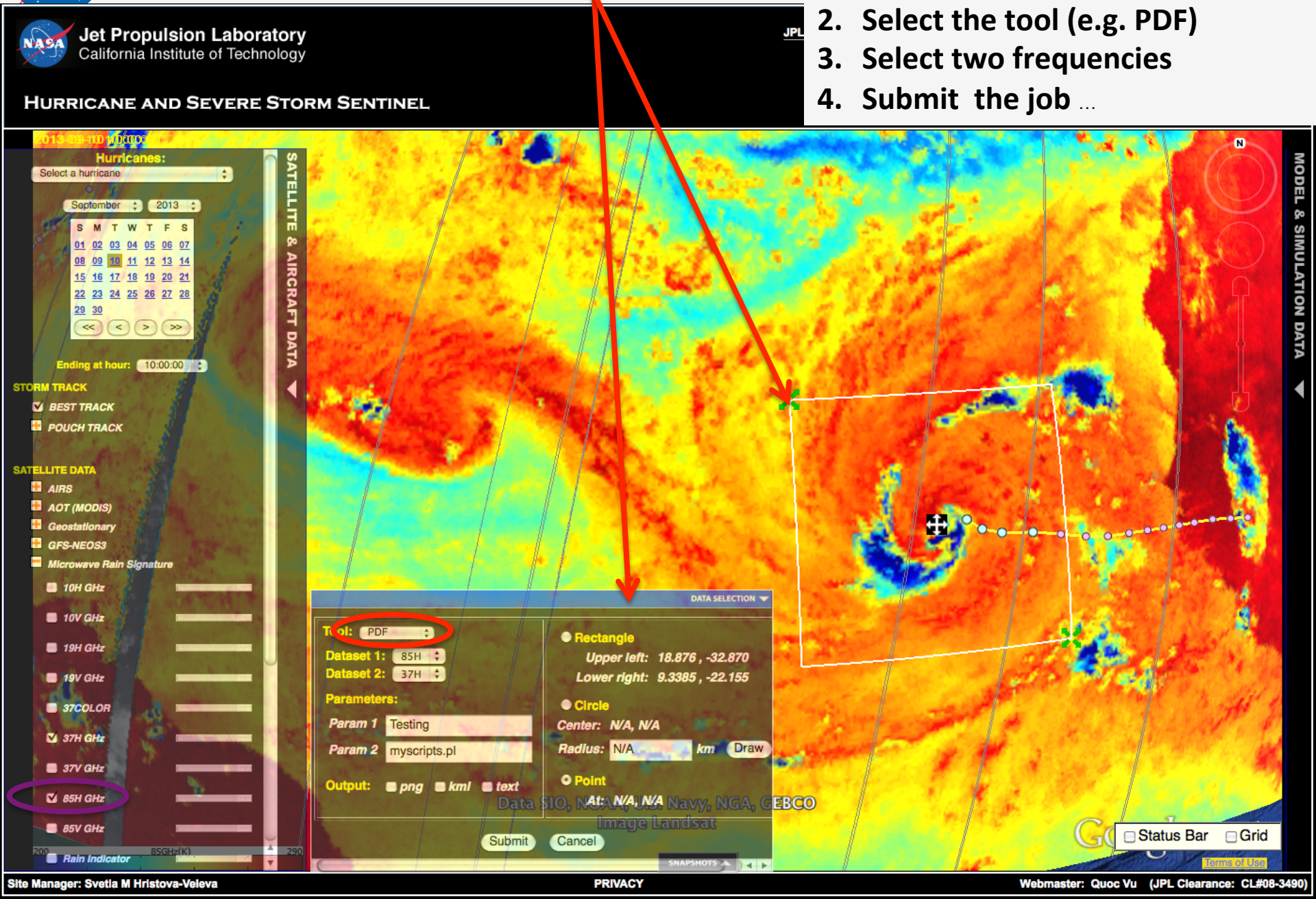
Now: Developing analysis tools for model validation



- 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

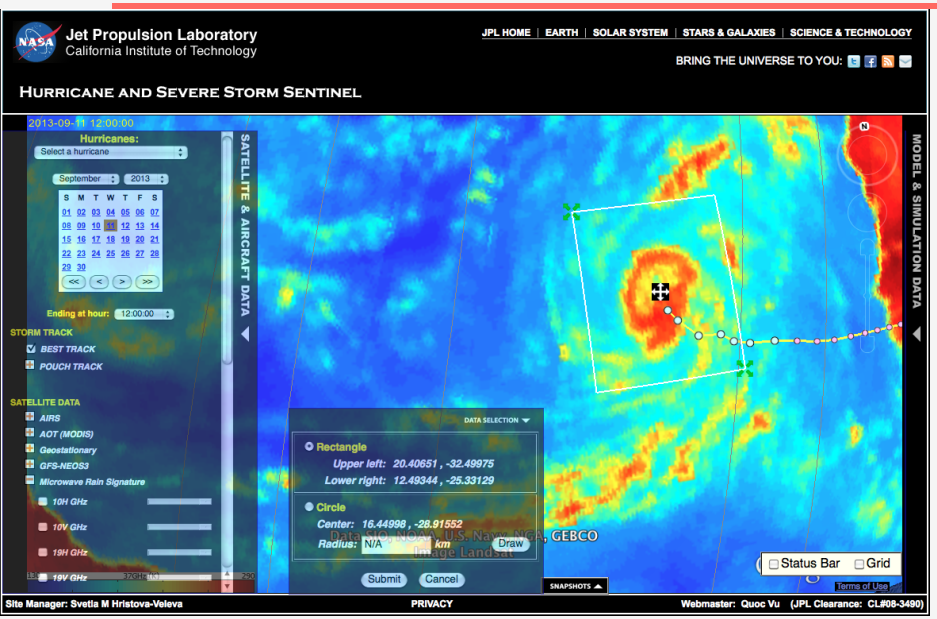
The Selection Tool

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

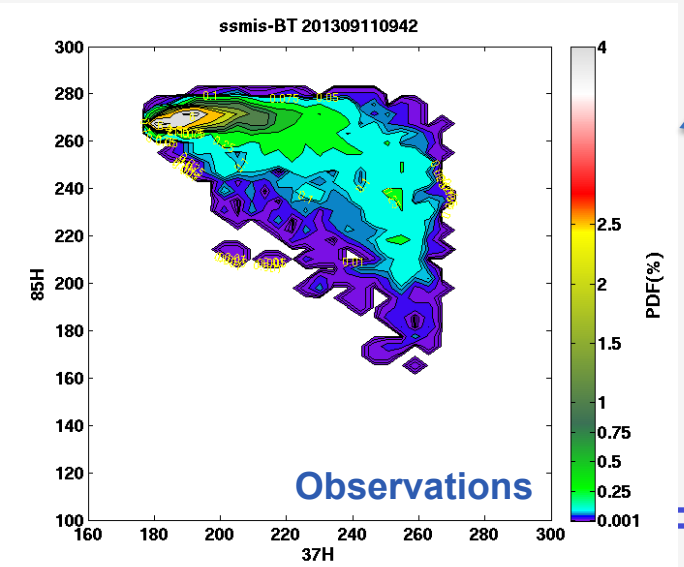


Statistical Tool: *Joint Distribution of Brightness Temperatures*

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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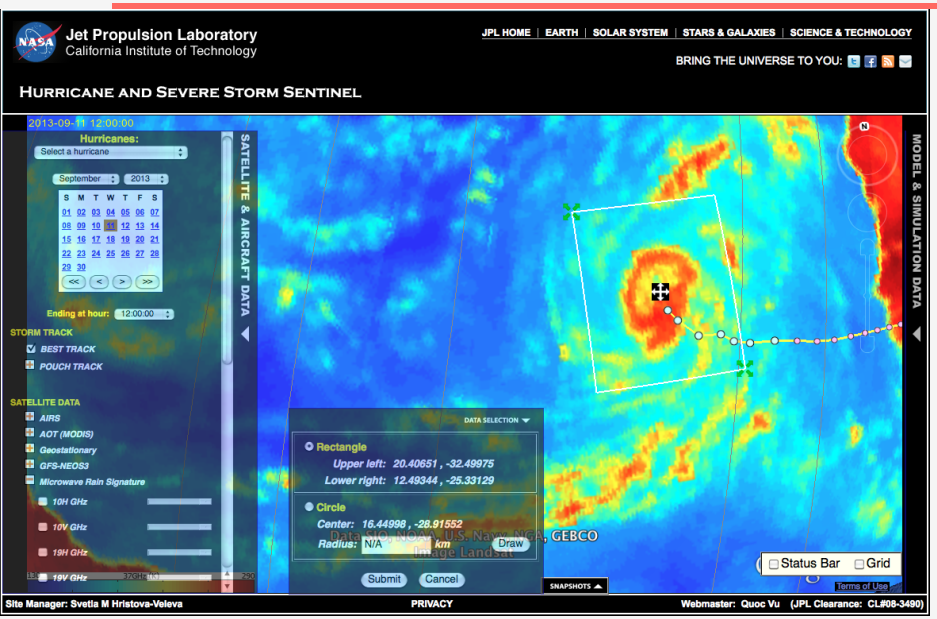
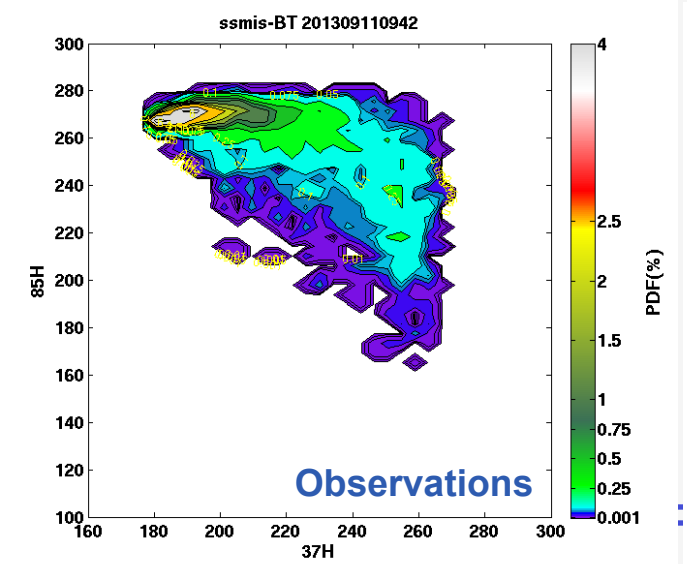
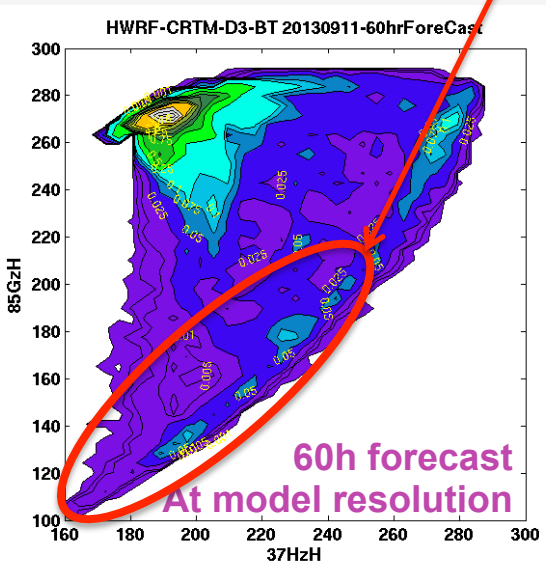
Statistical Tool: *Joint Distribution of Brightness Temperatures*

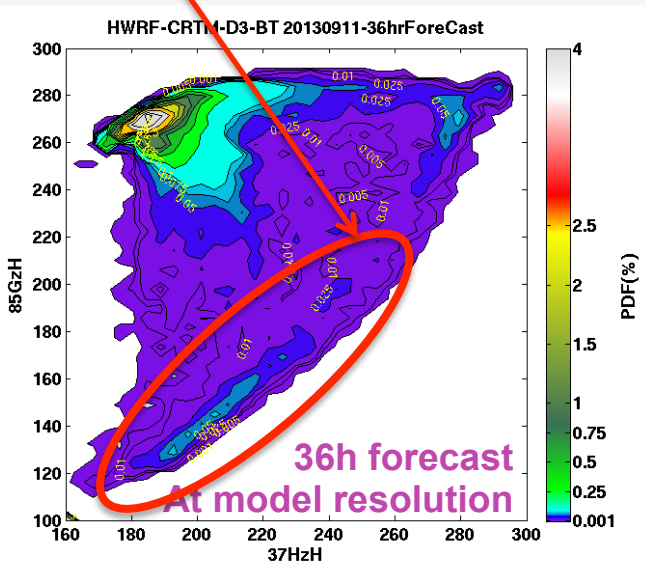
Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



- 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

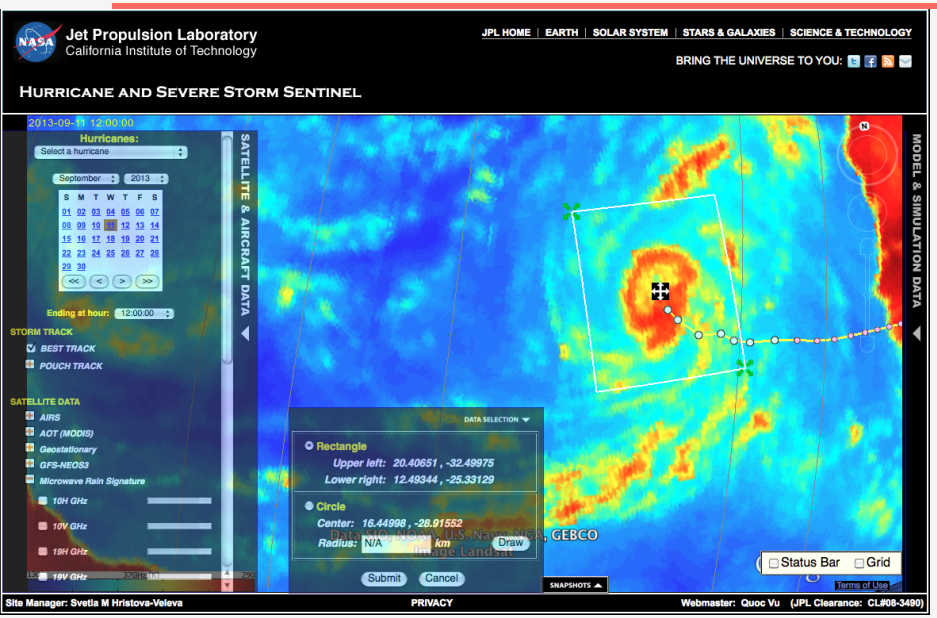




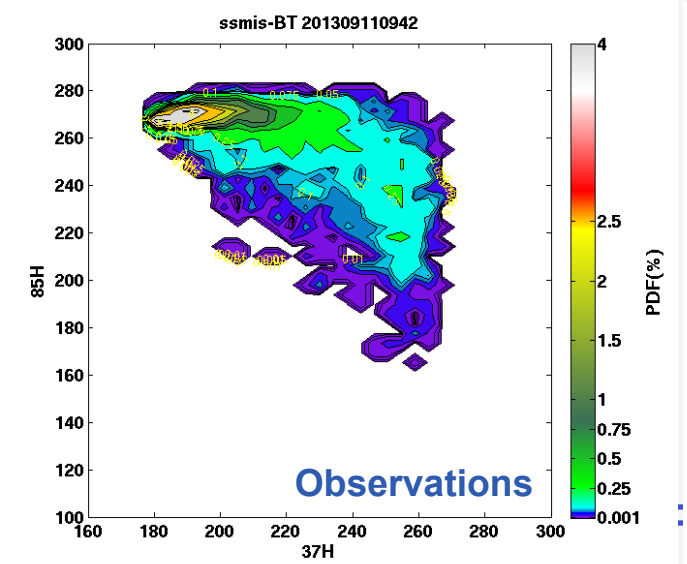


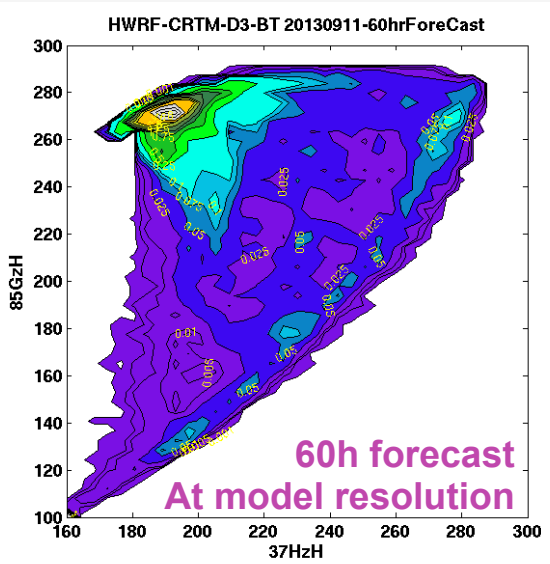
Statistical Tool: *Joint Distribution of Brightness Temperatures*

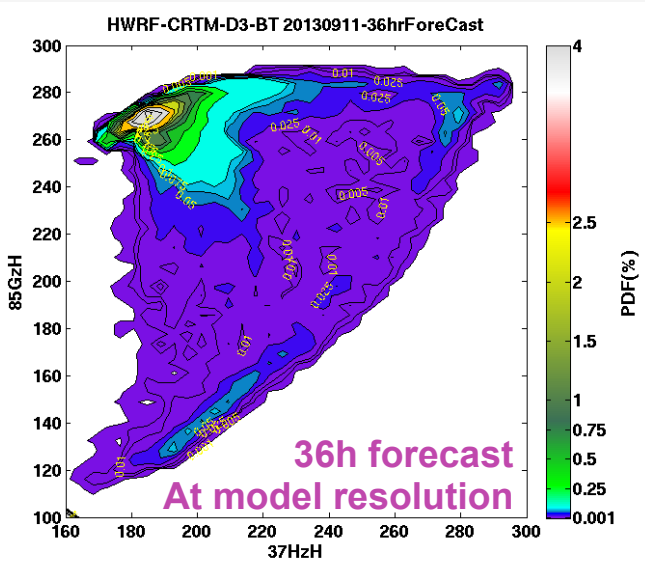
Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



- 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!

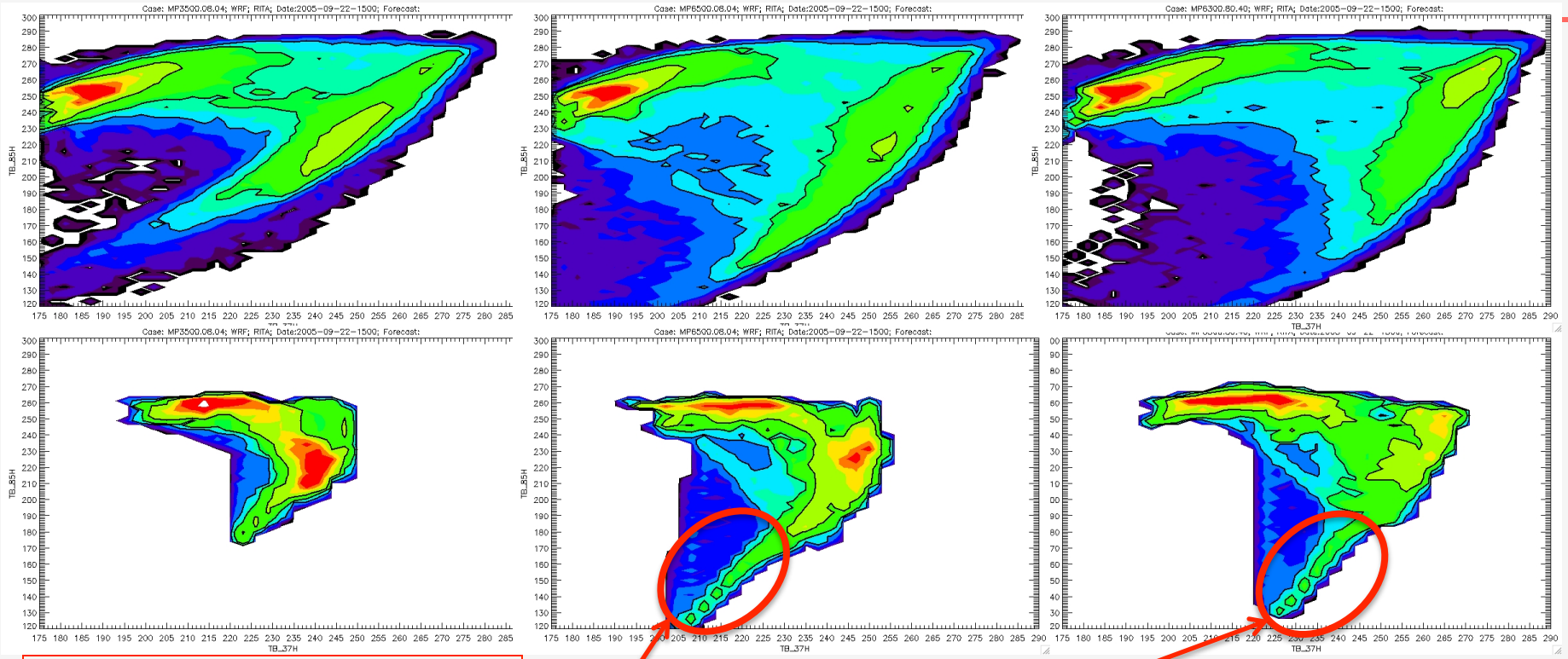


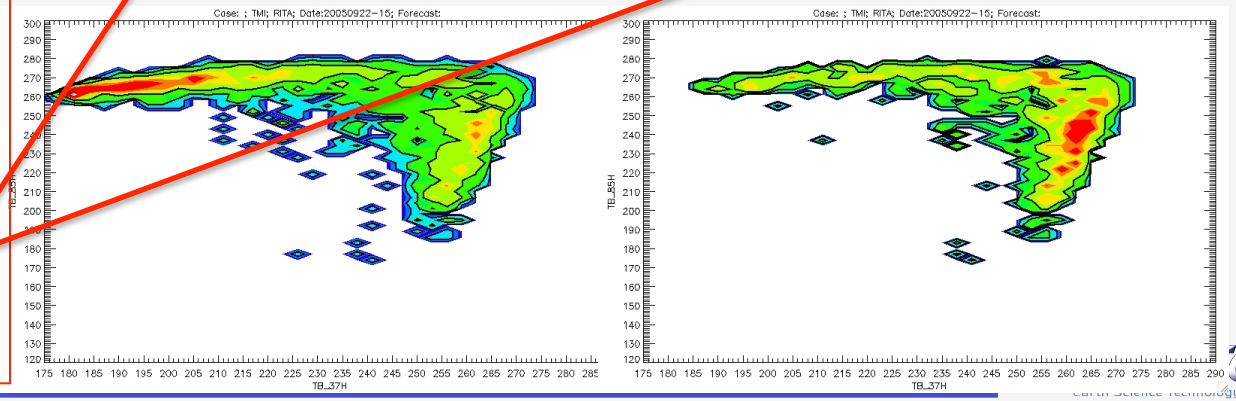




Joint Distribution (37H vs 85H) – *Impact of Resolution*

M3-500.08.04 M6-500.08.04 M6-300.80.40



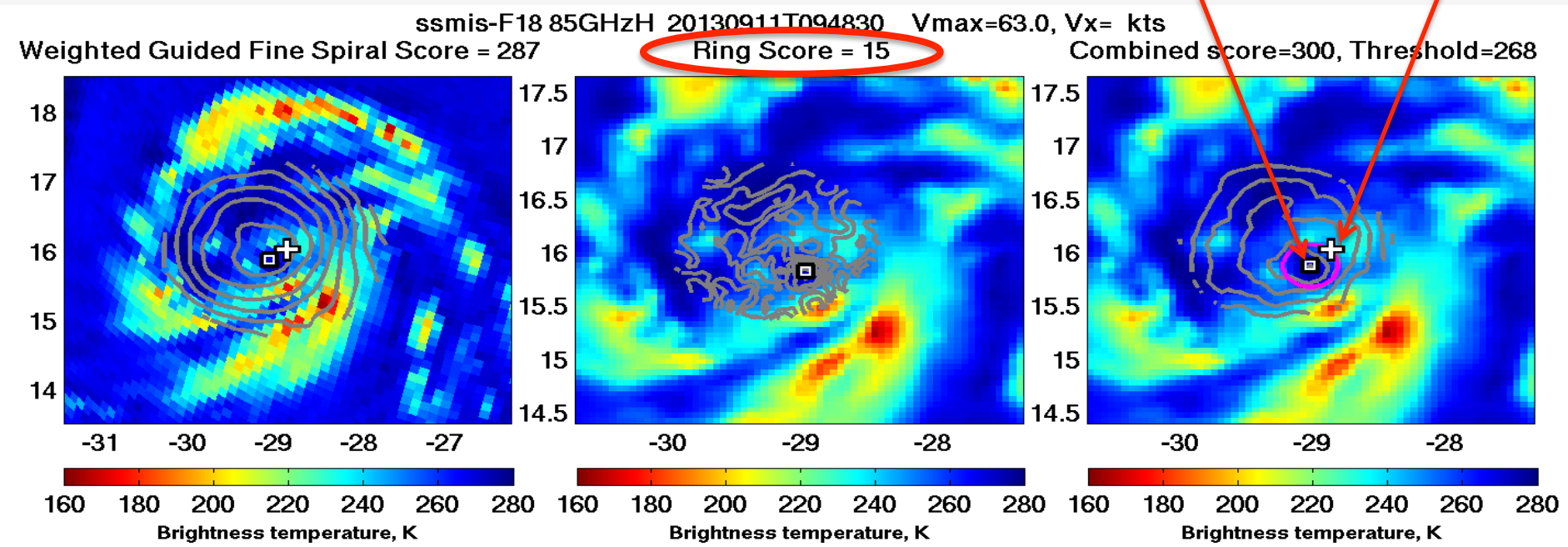


The Joint Distribution of the model data is improved when the synthetic data are convolved with the antenna pattern!!
Still – too much scattering in the model data.

Storm structure Tool: Degree of Organization

The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

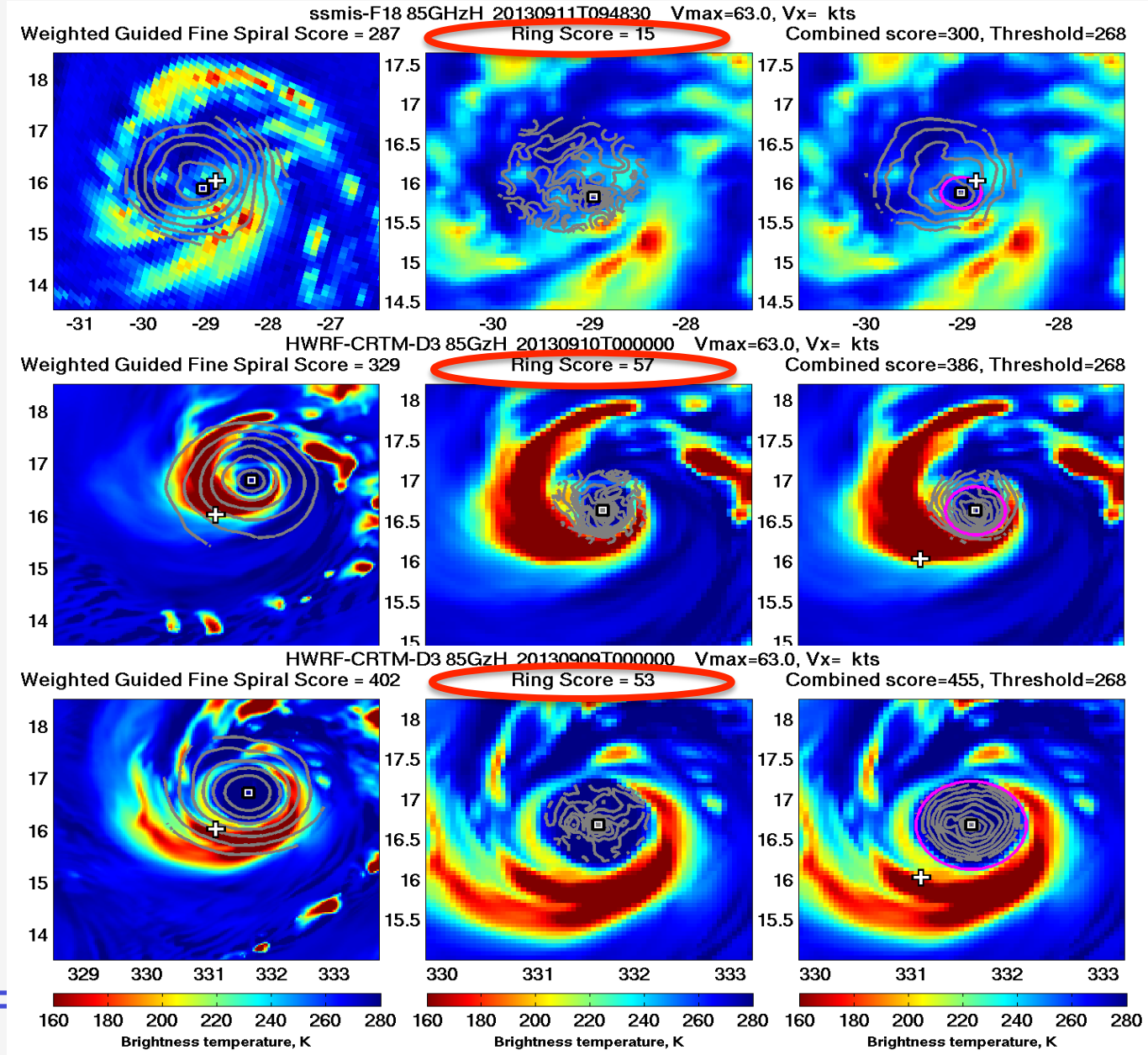
- Developed by CIMSS/NRL (Wimmers & Velden, 2010)
- We have license to run it and have done some off-line analysis, using the original version
- Coming online soon, with the latest version
- Provides:
  - Objective fix guidance for forecasters
  - Quantifies the degree of storm organization



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)

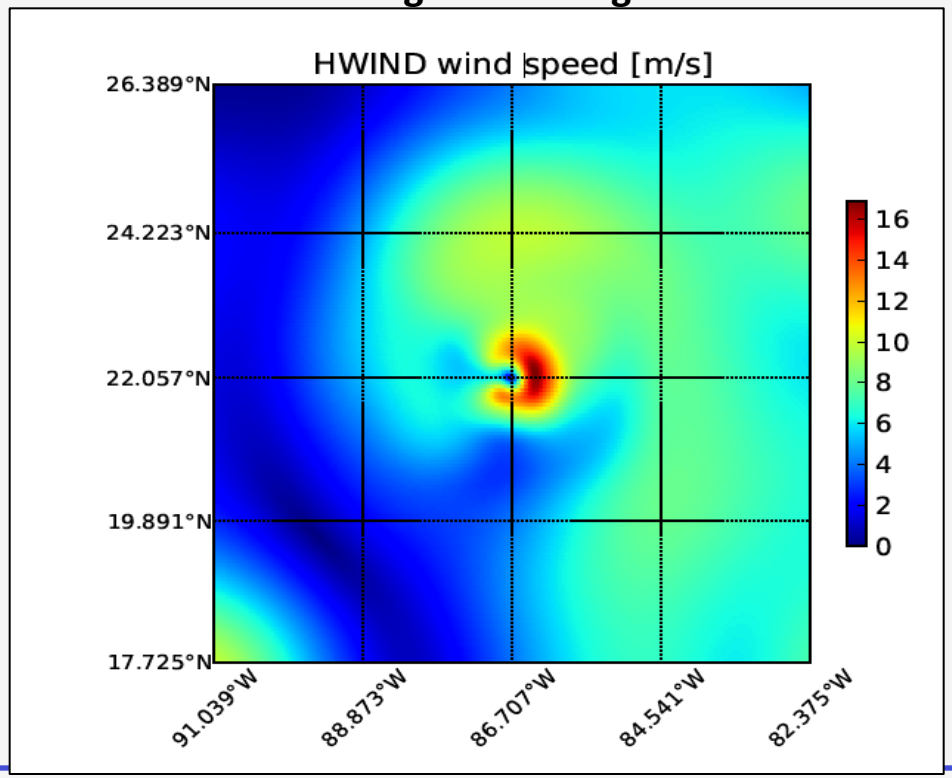


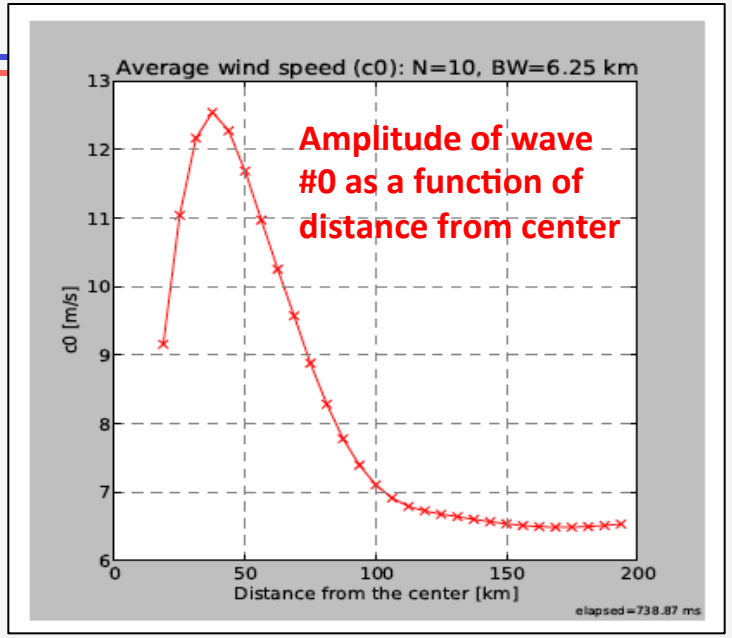
- ARCHER scores suggest the model forecasts over-predicted the structure in this case.
- This conclusion is in agreement with the model-predicted intensity parameters:
  - Observed:
    - Vmax = 65kts
    - MSLP = 989 mb
  - 36h forecast
    - Vmax = 72 kts
    - MSLP = 977mb
  - 60h forecast
    - Vmax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

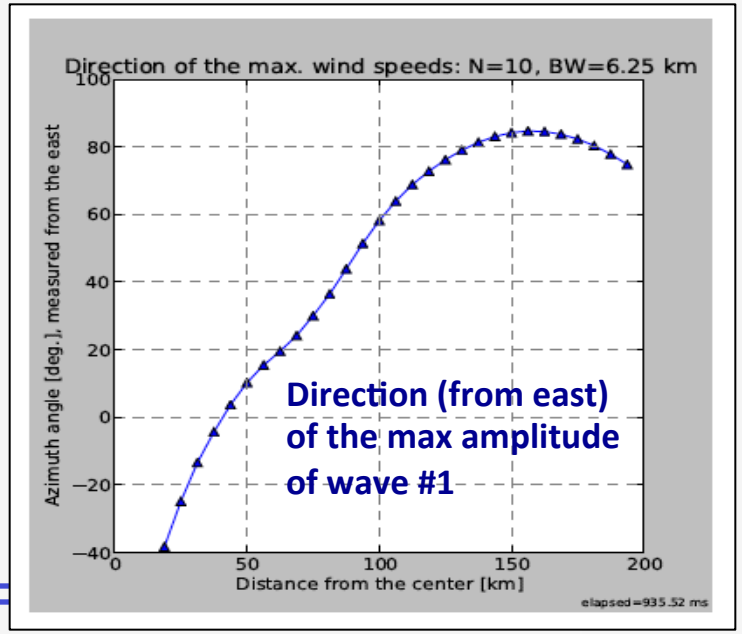
Storm structure Tool: Storm Size and Asymmetry

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
  - Will be available during the coming season







Storm structure Tool: Storm Size and Asymmetry

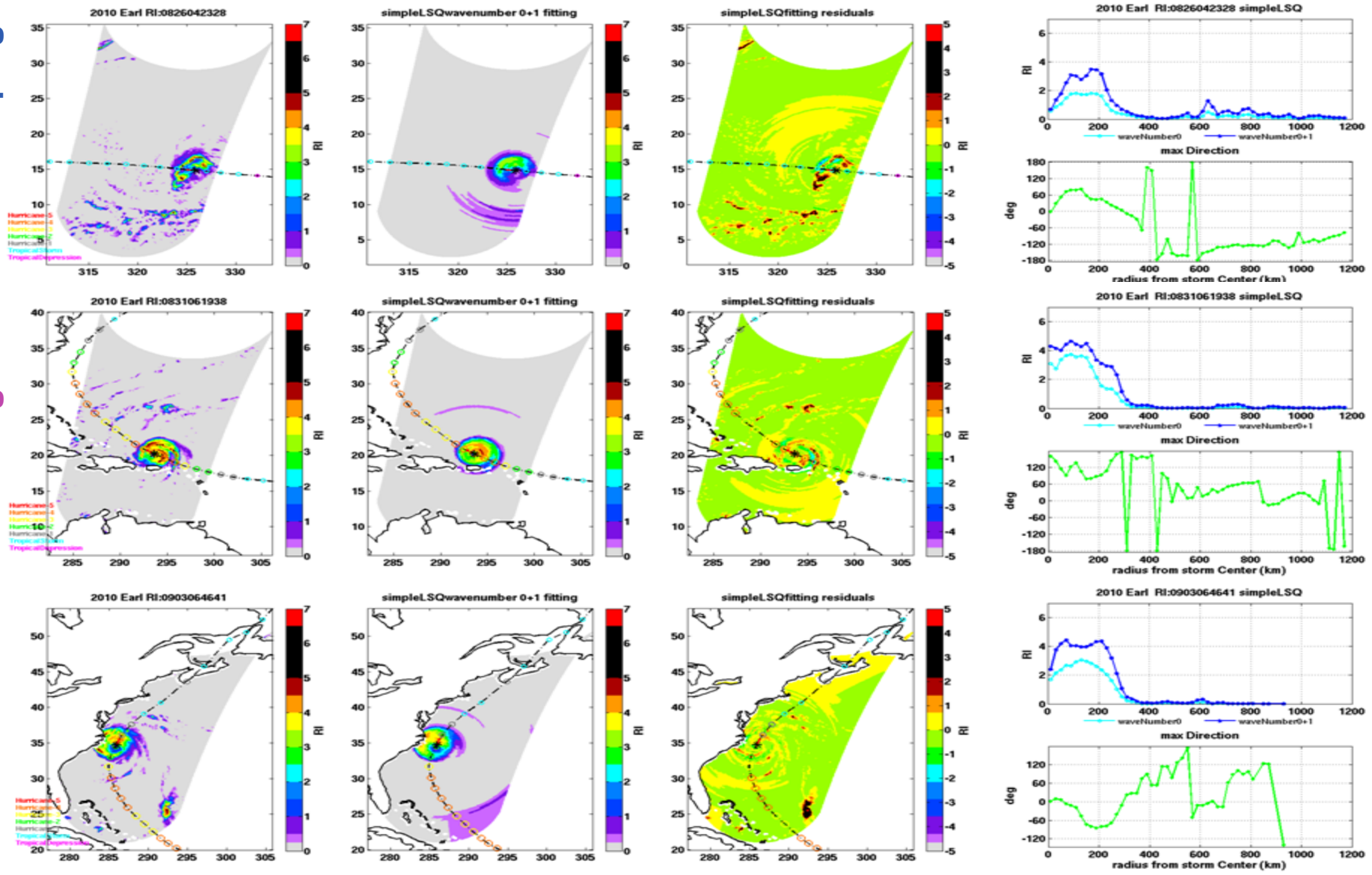
The Wave Number Analysis Tool using the Rain Index (multi-channel PMW index)

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

Developing

During RI

Mature



Storm structure Tool: Storm Size and Asymmetry

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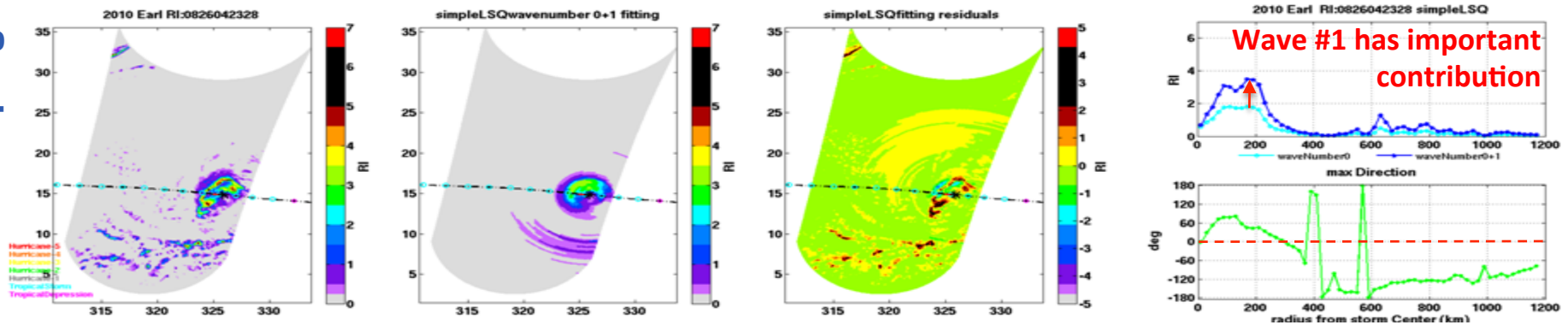
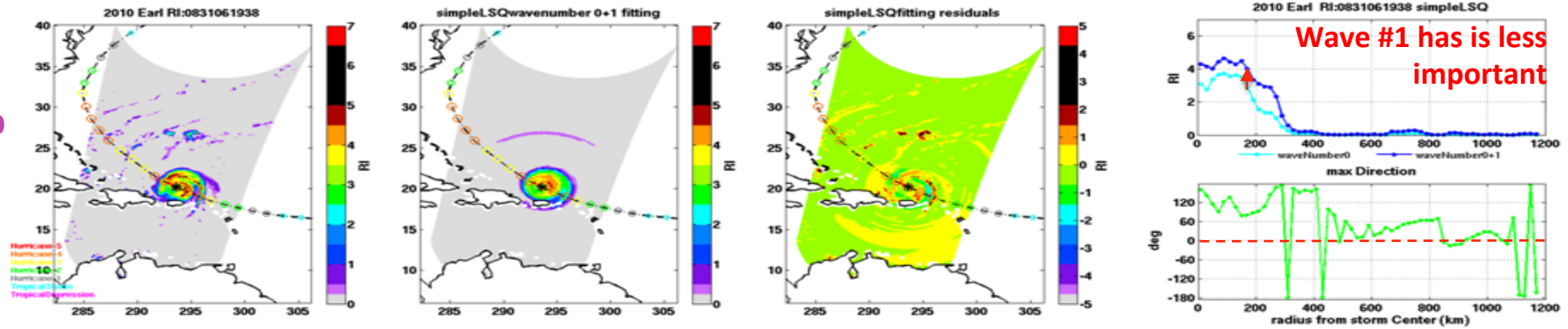
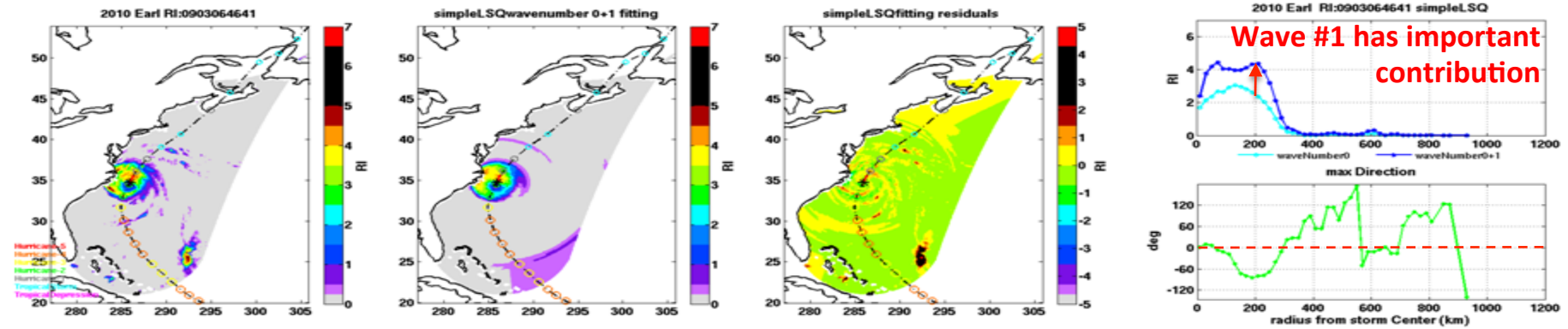
Developing



During RI



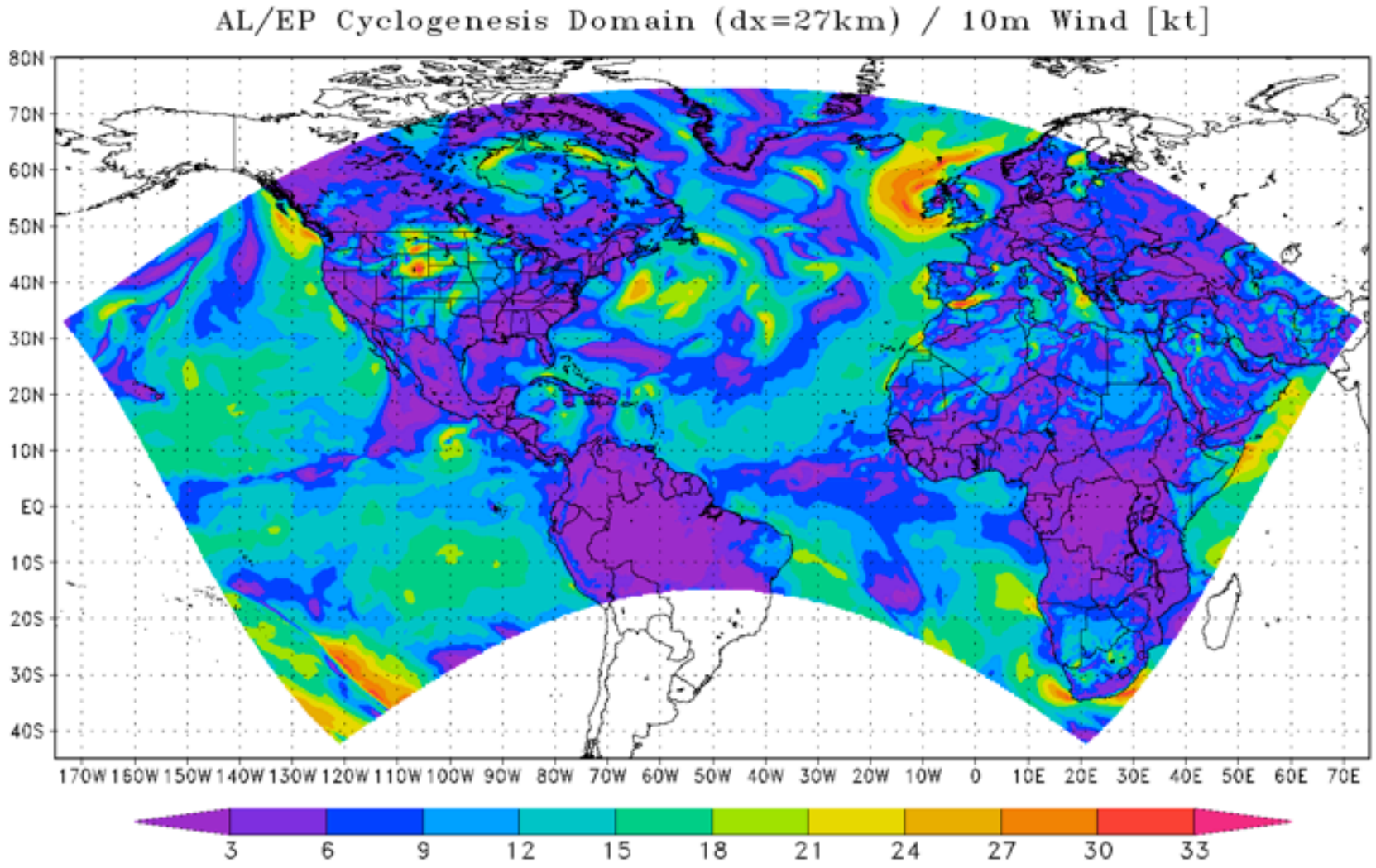
Mature



Summary

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

Basin-scale HWRF – coming up!

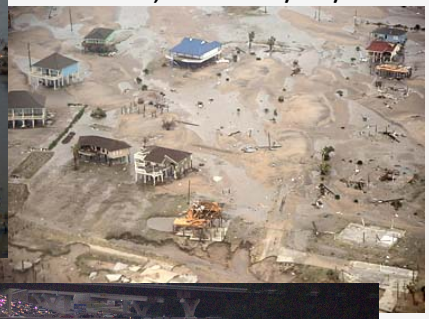



Thank you !

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

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

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



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

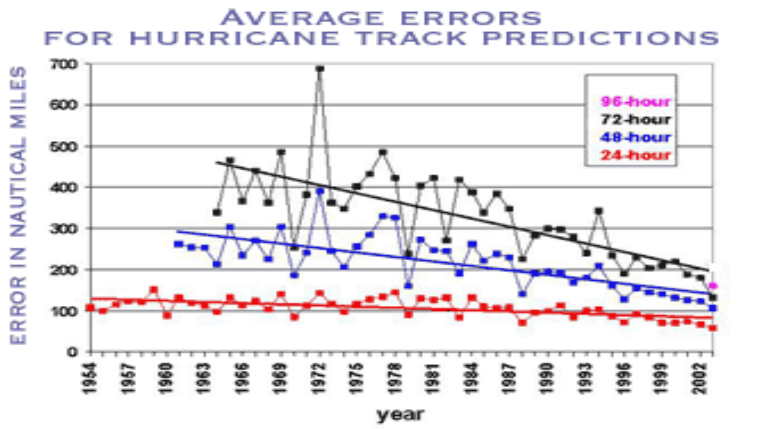
Each year they threaten the US coast, cause damages worth billions and take life.

- Some **130,000 died** when a cyclone struck Myanmar along the Andaman Sea in 2008.
- The deadliest U.S. hurricane was the 1900 Galveston storm, which **killed 8,000 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.

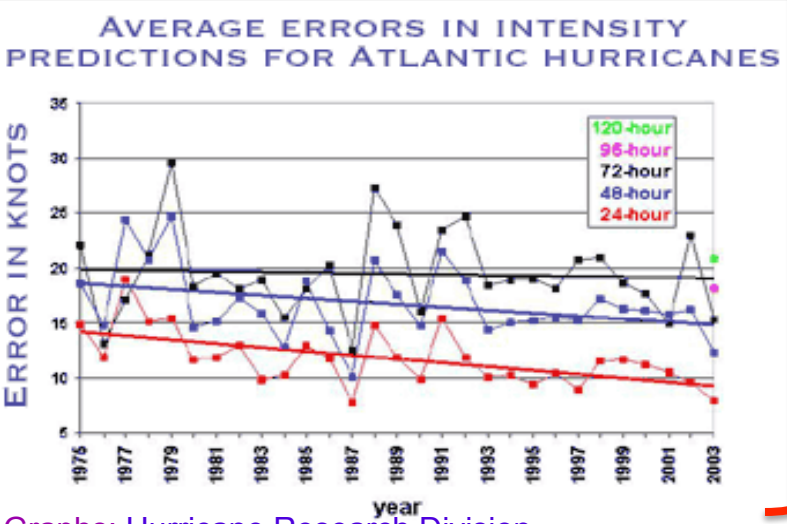
Widespread power outages and subway shutdowns may wind up making **Superstorm Sandy** the second most expensive storm in U.S.

Current state-of-the-art hurricane prediction

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



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



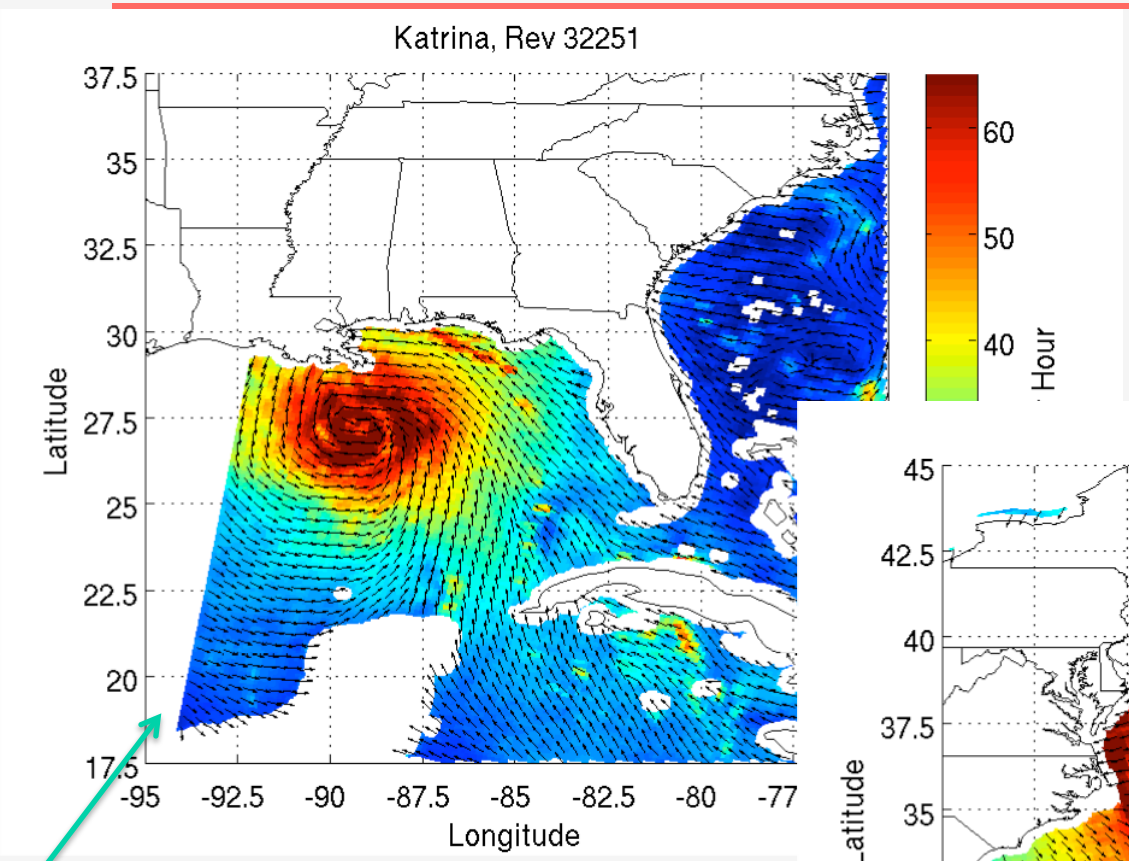
Graphs: Hurricane Research Division

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).

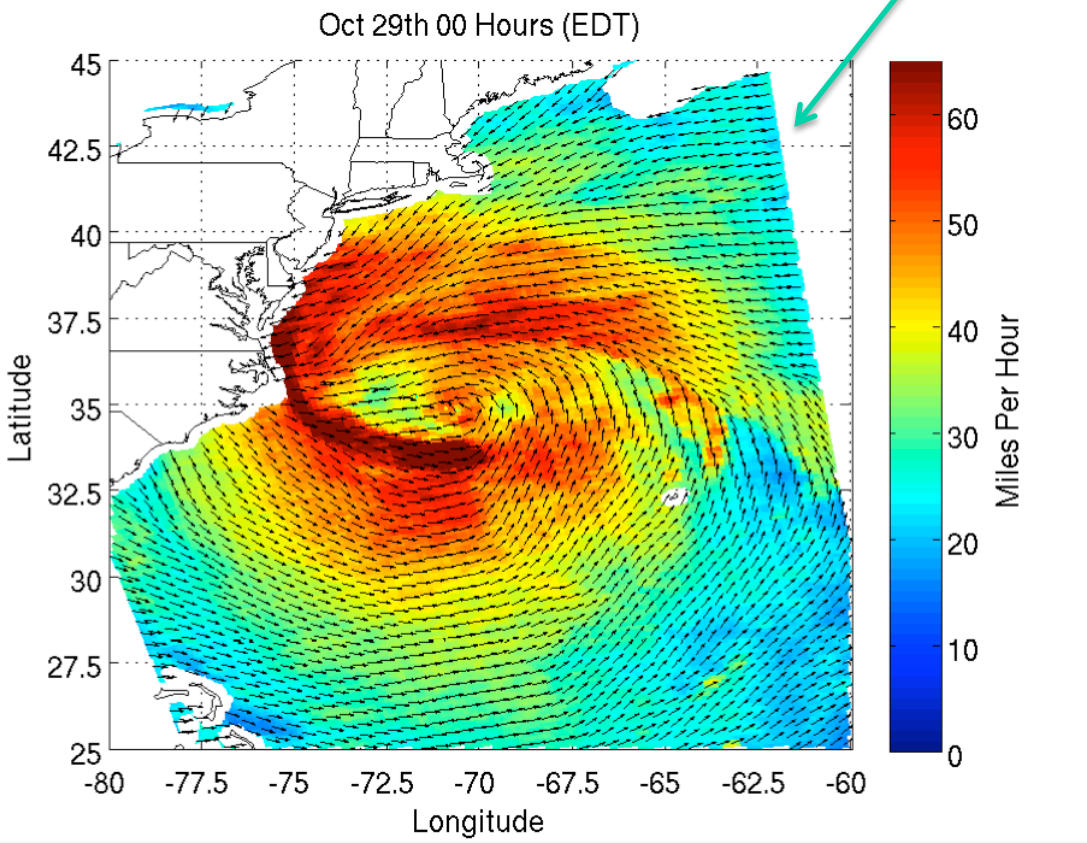
ESTO Earth Science Technology Office

How does the size of Sandy compare to Katrina



Hurricane Katrina
As seen by the
NASA's QuikSCAT

Hurricane Sandy
As seen by the
ISRO's OSCAT



Storm structure Tool:

The Automated Rotational Center Hurricane Eye Retrieval (ARCHER)

- Developed by CIMSS (Wimmers & Velden, 2010, JAMC)
- We have license to run it and have done some off-line analysis, using the original version
- Coming online soon, with the latest version