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]
Dave Jones[5], Rafael Ameller [5]

[1] – Jet Propulsion Laboratory, California Institute of Technology
[2] – HRD/AOML/NOAA, Miami, FL
[3] – EMC/NCEP/NOAA, College Park, MD
[4] - NPS, Monterey, CA
[5] - StormCenter Communications, Inc

The JPL Tropical Cyclone Information System: a tool to help understanding hurricane processes and evaluating models

Technical Interchange
Caltech, June, 2016

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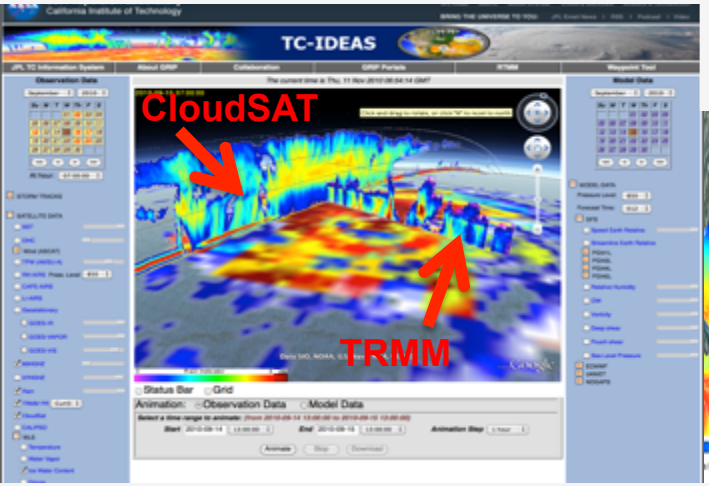
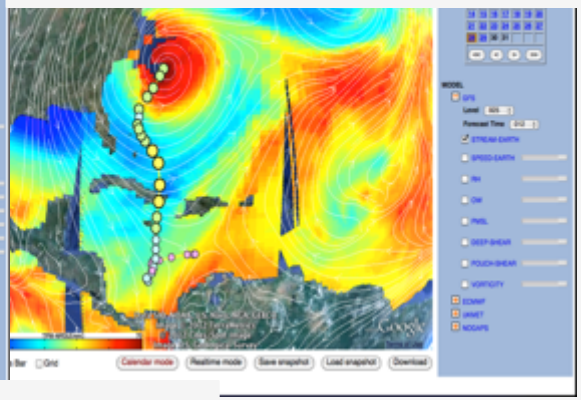
Motivation for our project - The critical pathways to hurricane forecast improvement

- Is the representation of the precipitation structure correct?



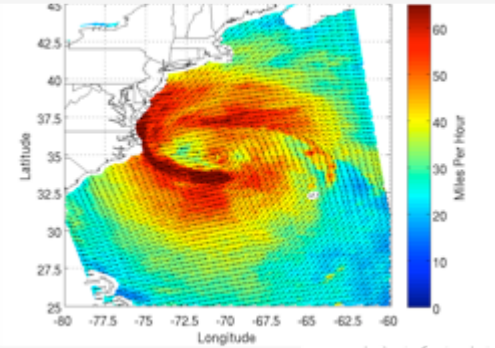
- Is the environment captured correctly?
- Is the interaction between the storm and its environment realistic?



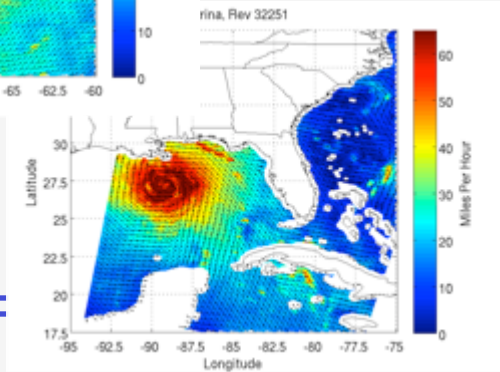
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

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

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

The main goal of this presentation and feedback session is to engage operational hurricane forecasters and researchers to provide useful input into the capabilities of TCIS and to identify strengths and weaknesses that can be addressed in our next version. This feedback session will lead to a modified TCIS that will serve the needs of the Research and Operational communities.

The JPL TCIS – Tropical Cyclone Information System

http://tropicalcyclone.jpl.nasa.gov

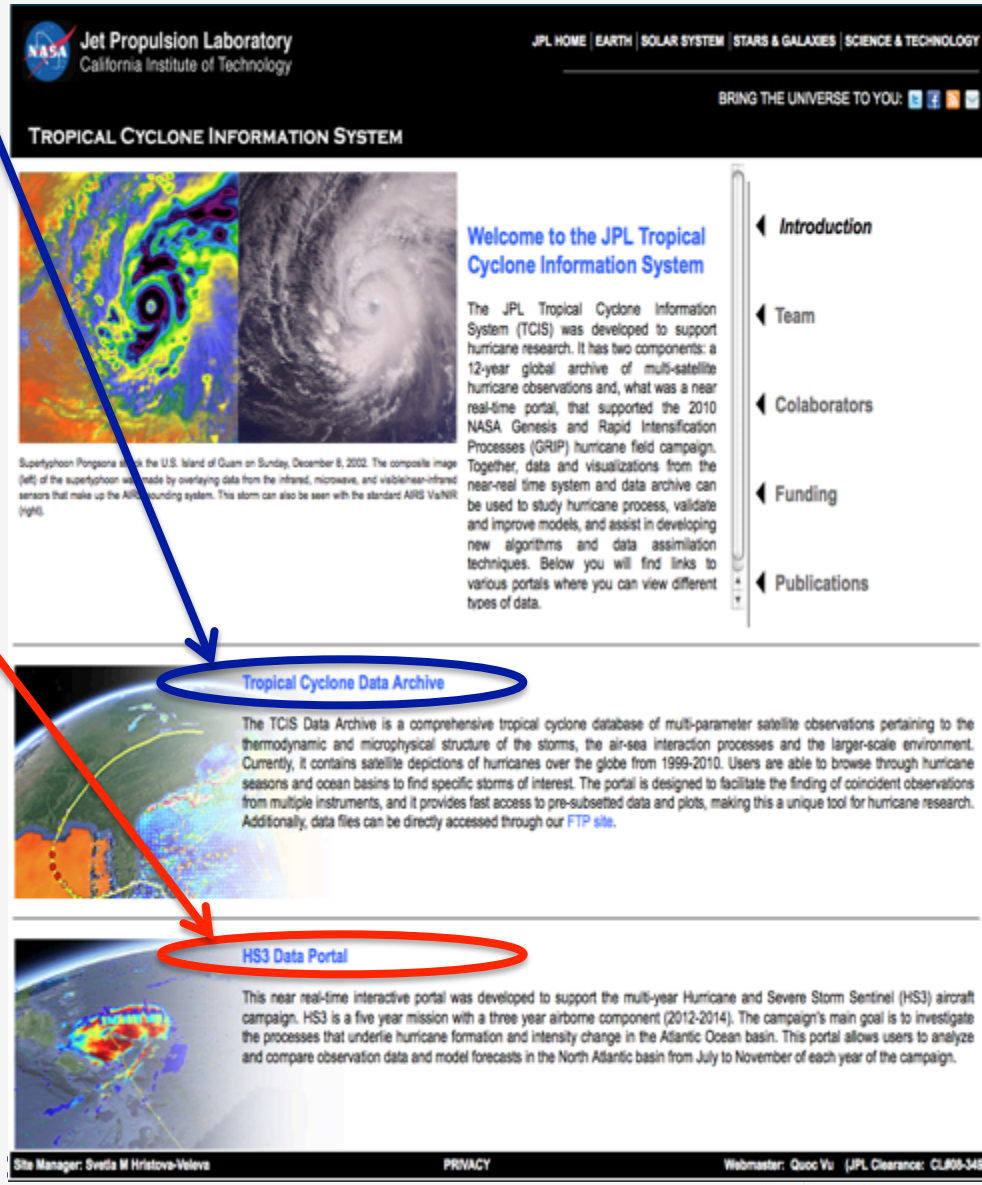
Tropical Cyclone Data Archive

- 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

Interactive NRT Atlantic/East Pac. 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.



The three components of our system

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

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

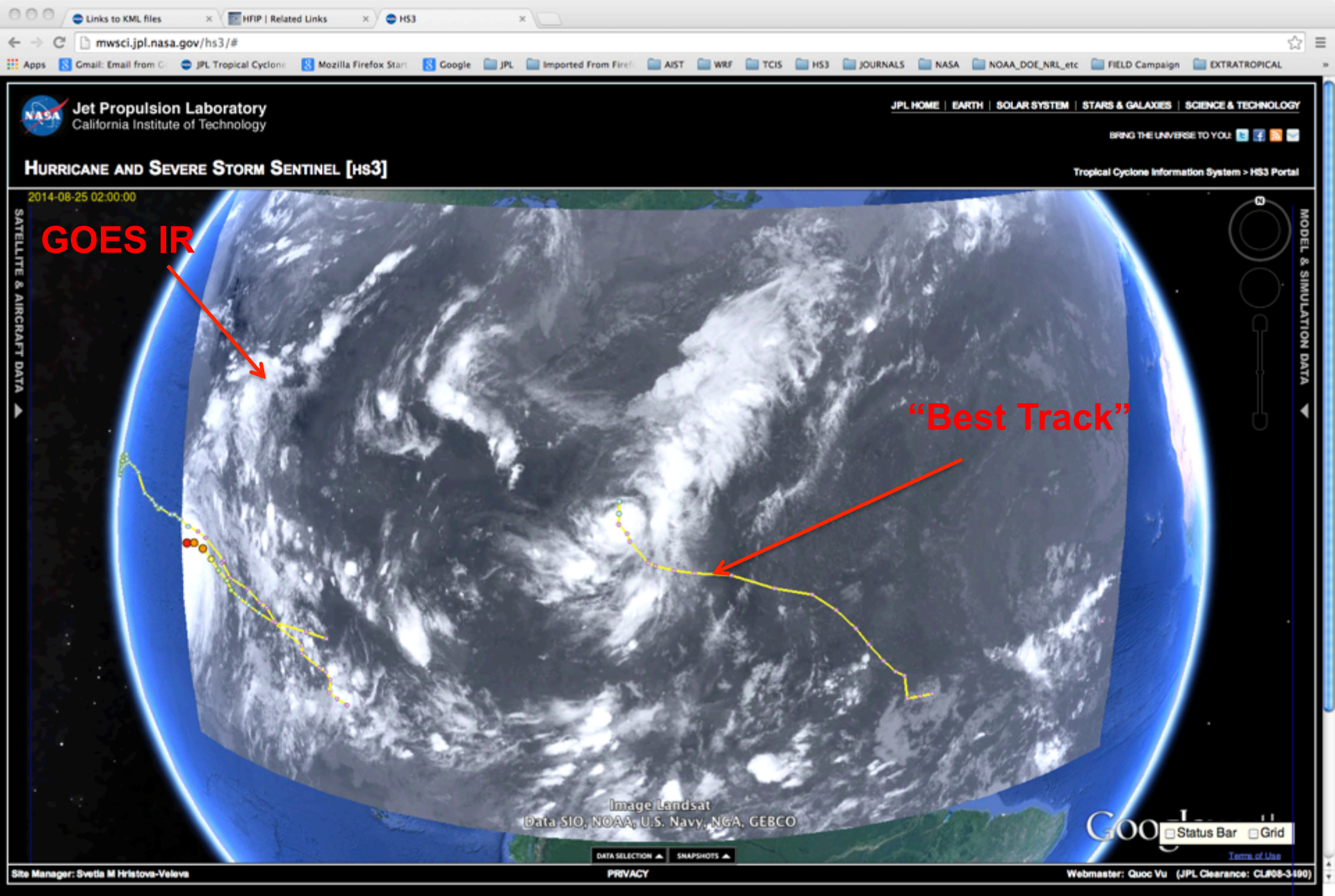
3. Developing analysis tools with the goals to:
   - Understand the observed structure of the hurricanes
   - Evaluate the models

The three components of our system

1. Bringing observations and models into a common analysis system and developing interactive visualization tools.
    a. Features
    b. Products
    c. Interactive Visualization

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

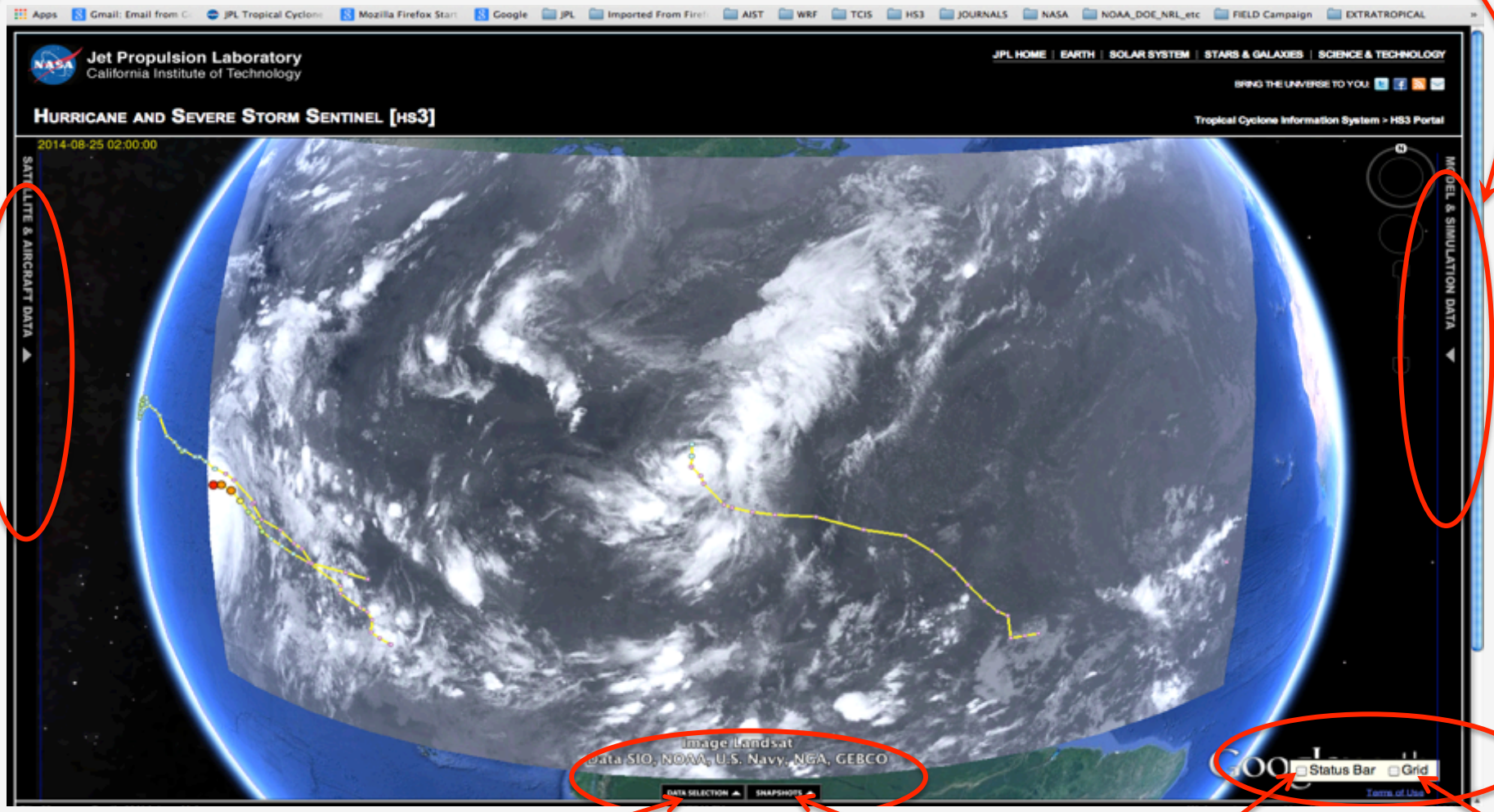
Features (needs Google Earth API; opens on the latest available PMW observations)



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

The three components of our system

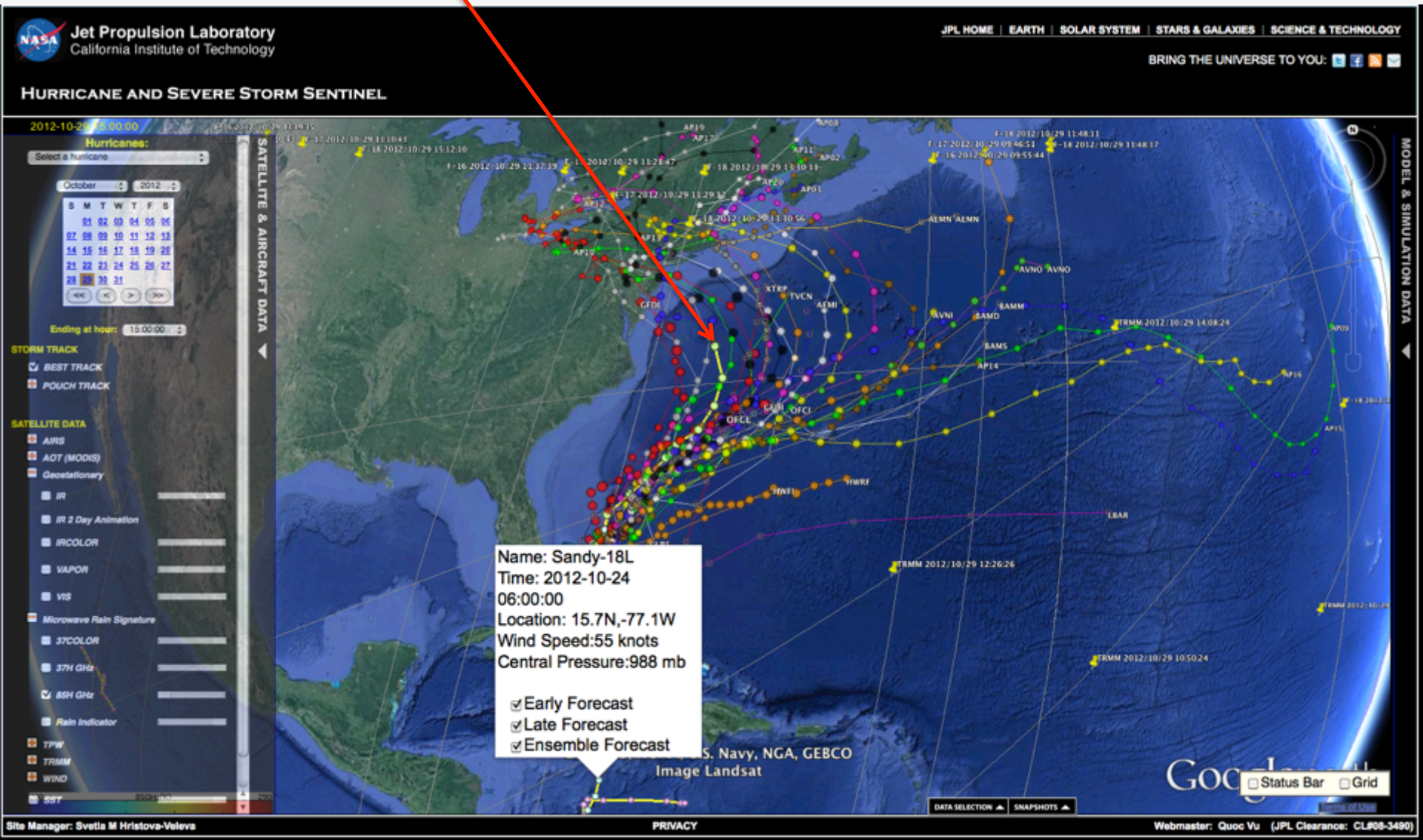
1. Bringing observations and models into a common analysis system and developing interactive visualization tools.
    a. Features
    b. Products
    c. Interactive Visualization

Products

- Observations
  - Ocean surface – SST, ocean surface winds
  - Large-scale atmosphere – TPW(AMSU), AIRS (RH and Temp), AOT
  - Precipitation
    - Geostationary (GOES, MeteoSat) – IR, VIS, color IR
    - Passive Microwave Brightness Temperatures – multi-channel
      - SSMI/SSMIs, GMI, AMSR
    - Rain Index – JPL product based on combination of the PMW TBs
    - active microwave – GPM-DPR, CloudSat
  - Hurricane tracks and ATCF
- Models
  - Geophysical fields from
    - *provided by the Montgomery Research group*
    - GFS, ECMWF, NOGAPS, UKMET
    - RH, Temp, flow (earth-relative and storm-relative)
  - Synthetic data from HWRF
    - *provided by EMC – V. Tallapgragada & S. Trahan*
    - Brightness temperatures at the SSMI/TMI channels

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

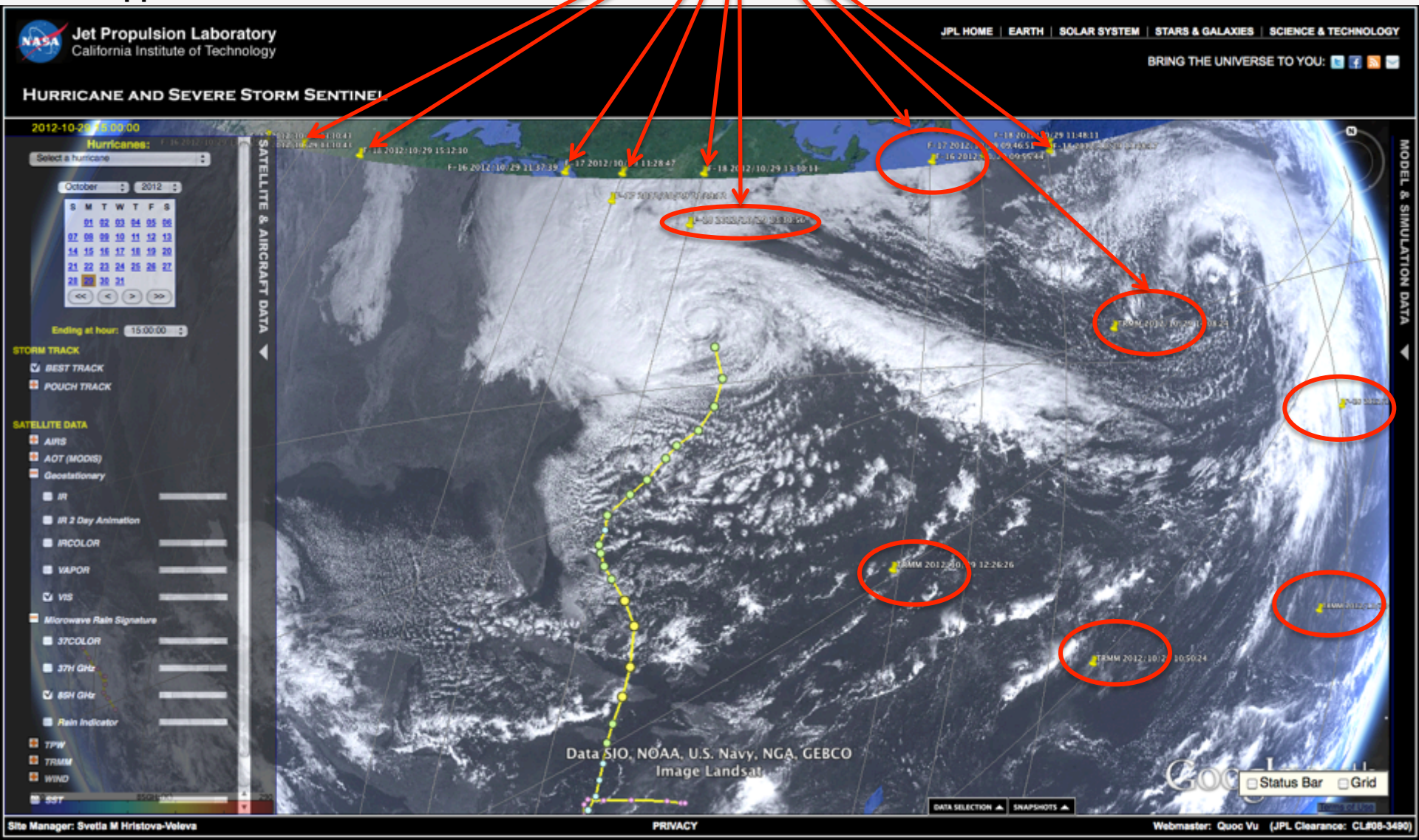
Best Track



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

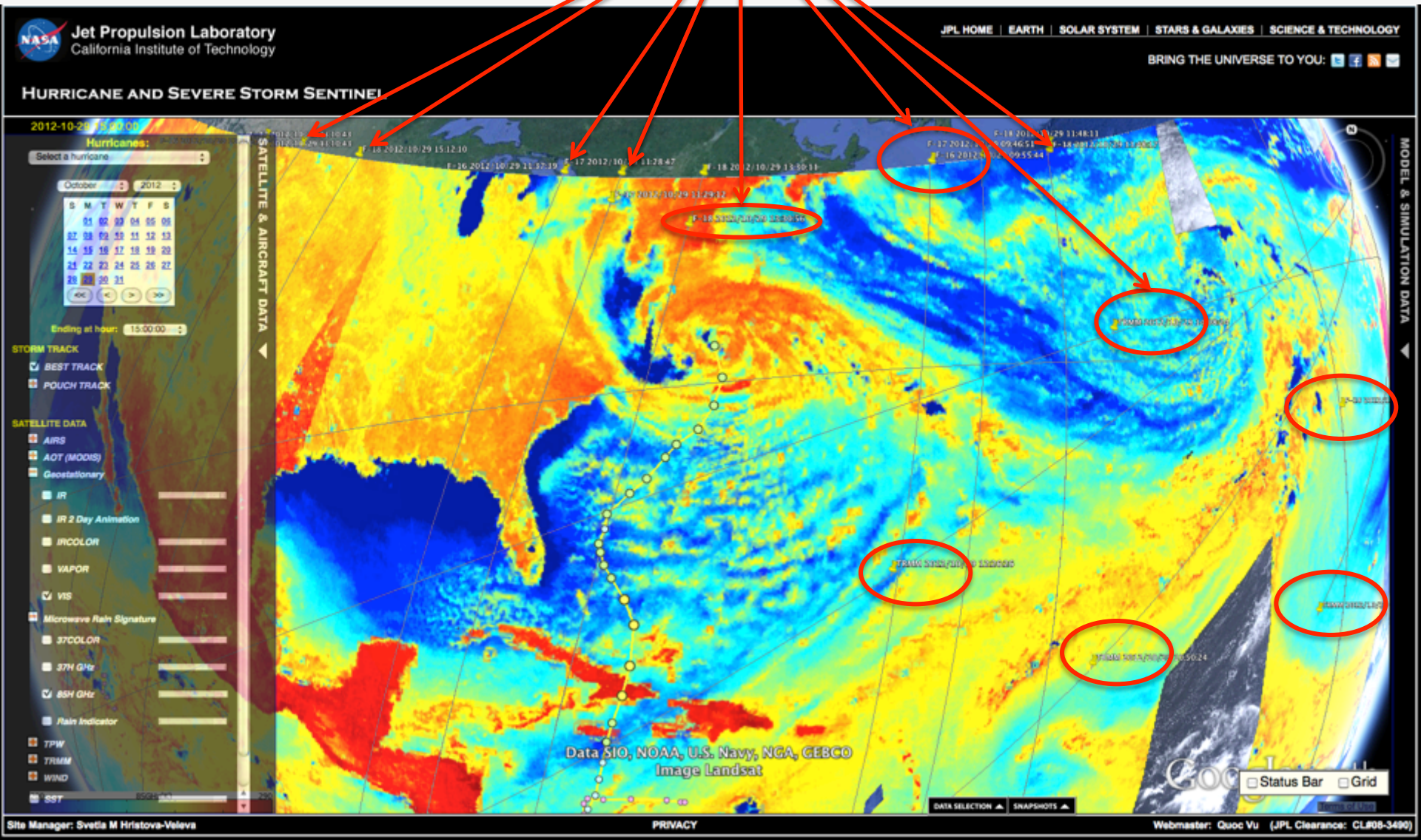
The Power of the Satellite Observations – Hurricane Sandy (2012)

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



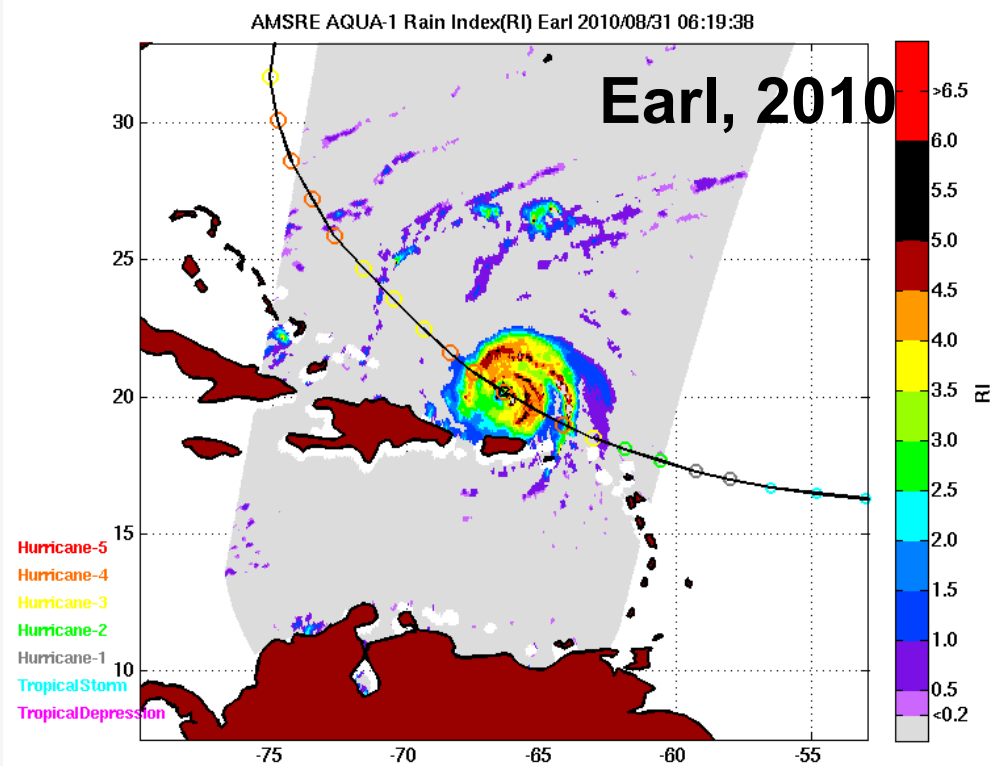
The Rain Indicator – a multi-channel depiction of the storm structure

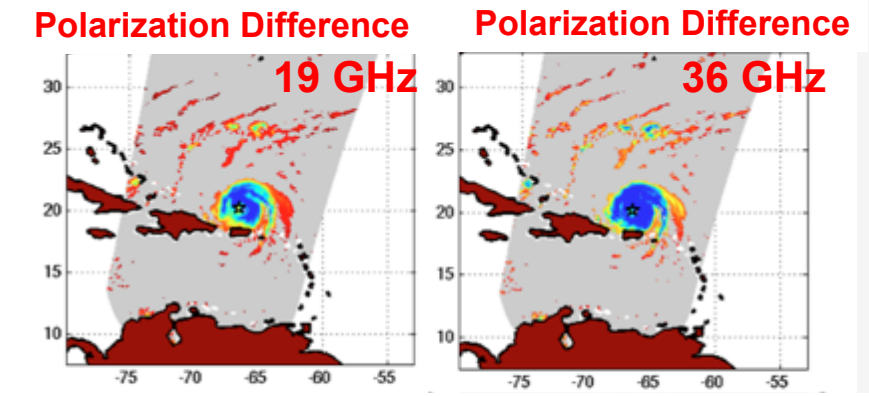
Hristova-Veleva et al., 2013: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", 2013, JAMC 52, 2828–2848

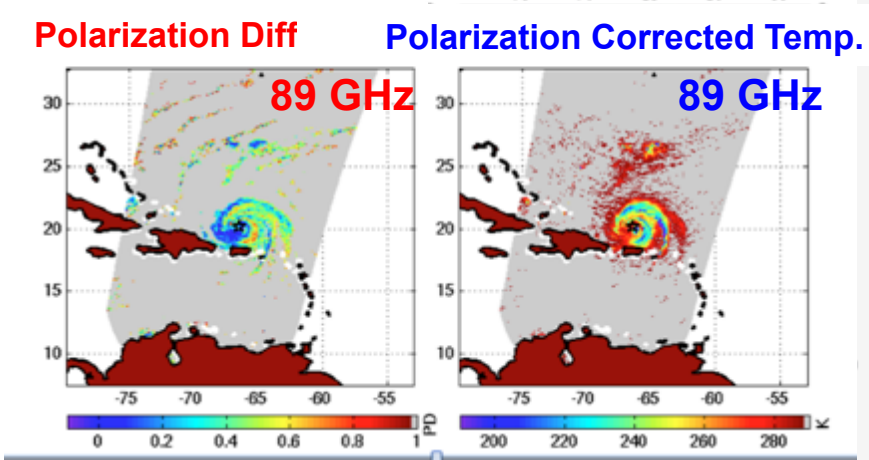
Microwave signals at the top of the atmosphere can be classified into two categories:

- **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**

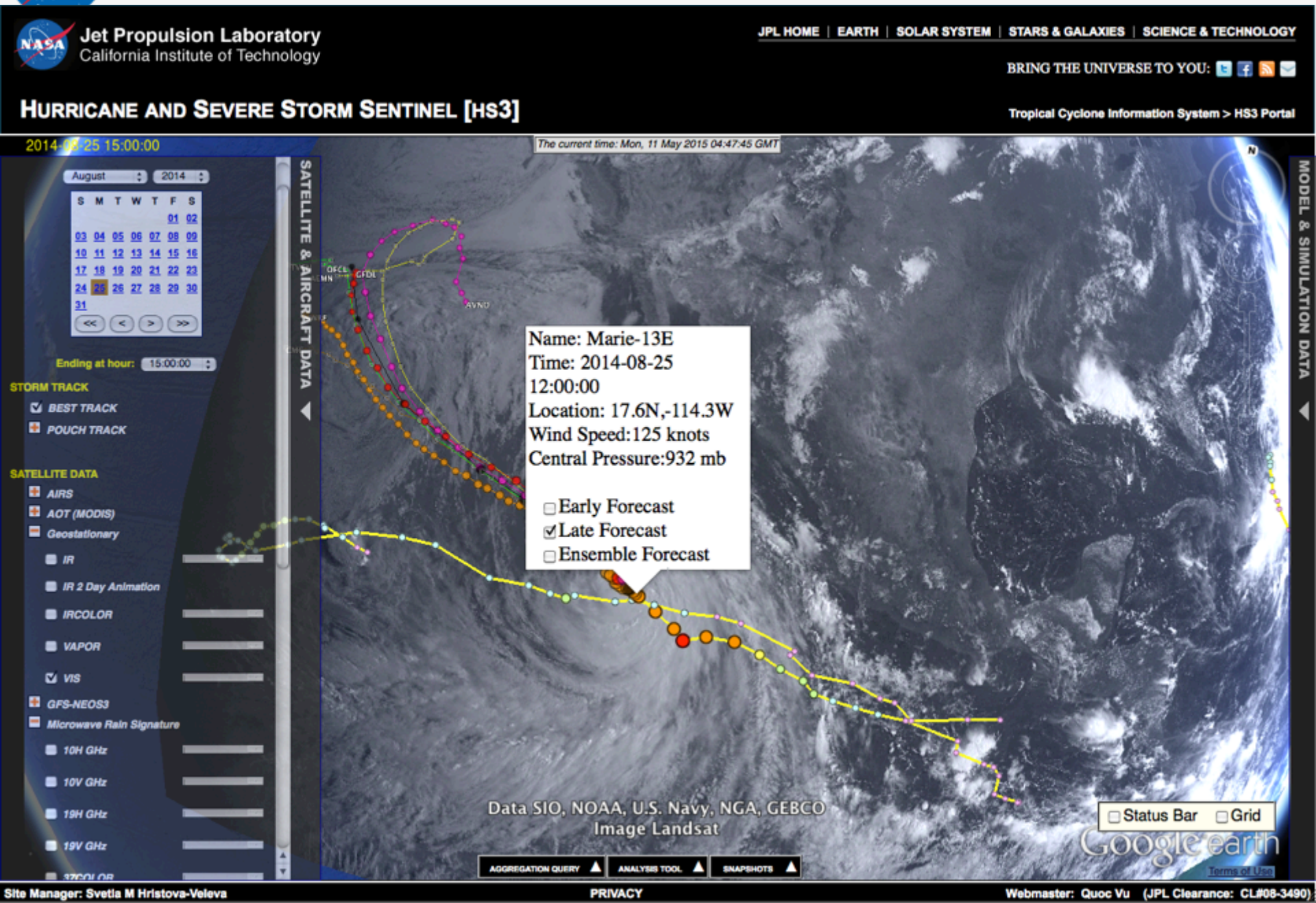
- Hence, both signals have to be incorporated to cover the entire rainfall spectrum.



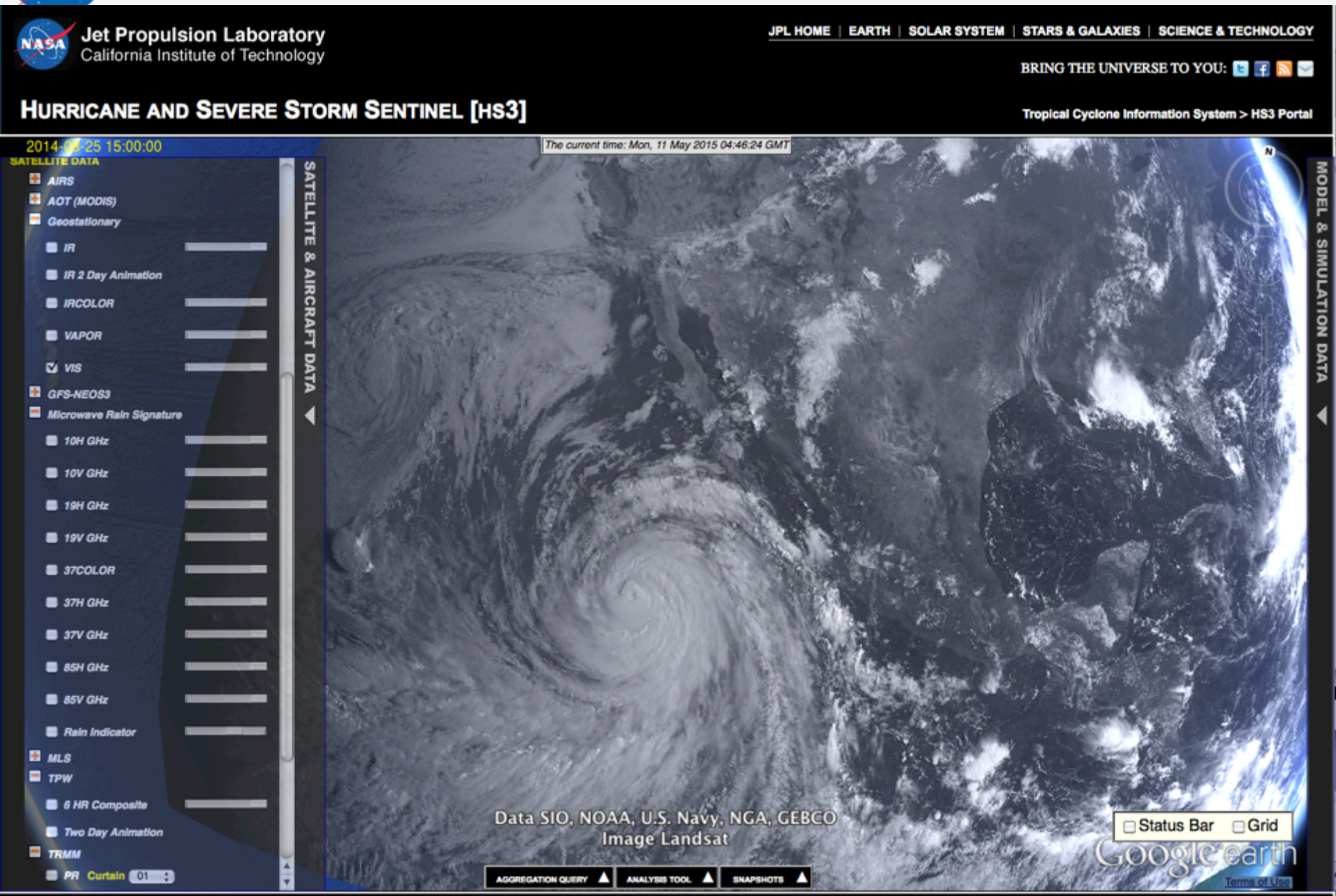




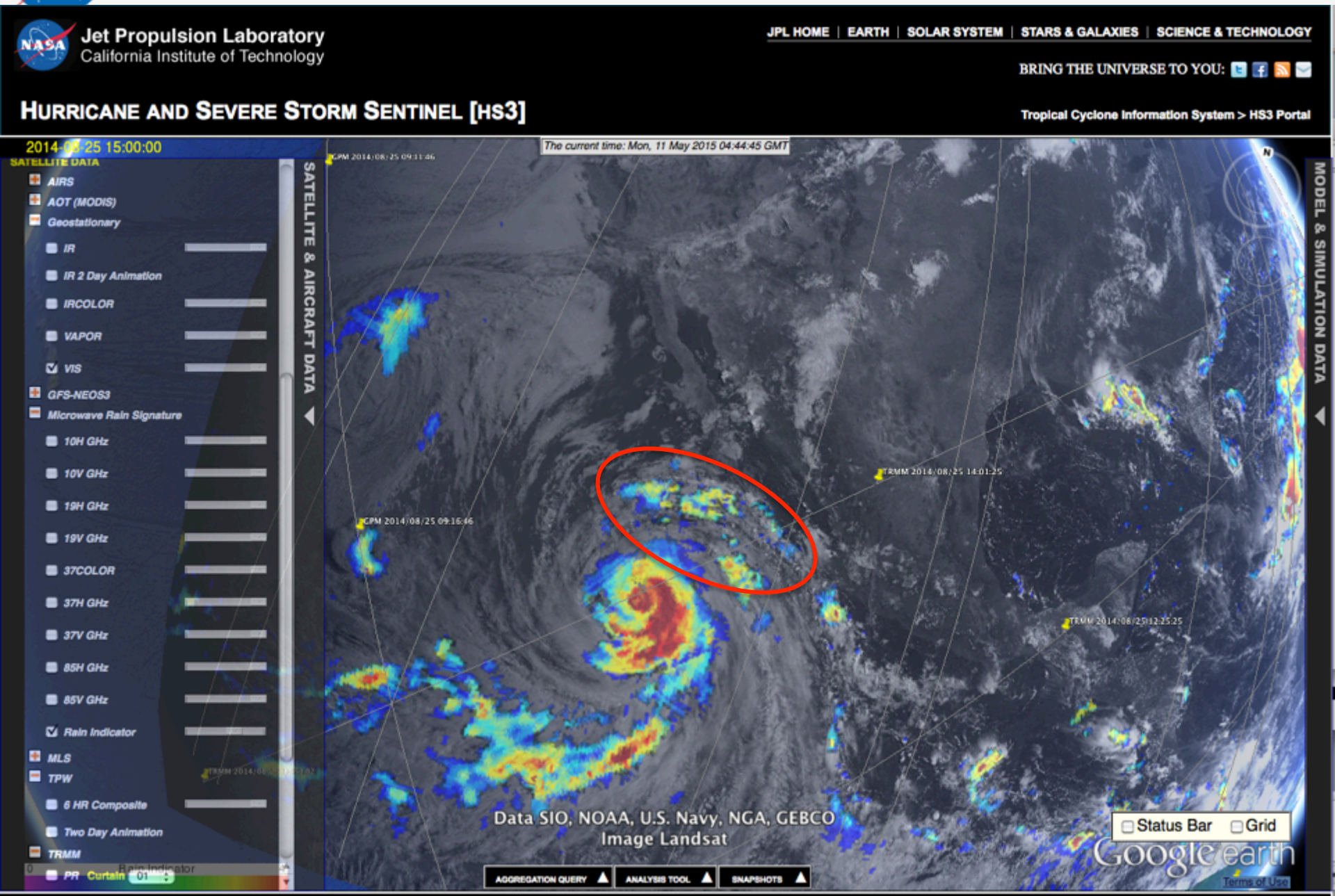
Hurricane Marie (2014) in Vis



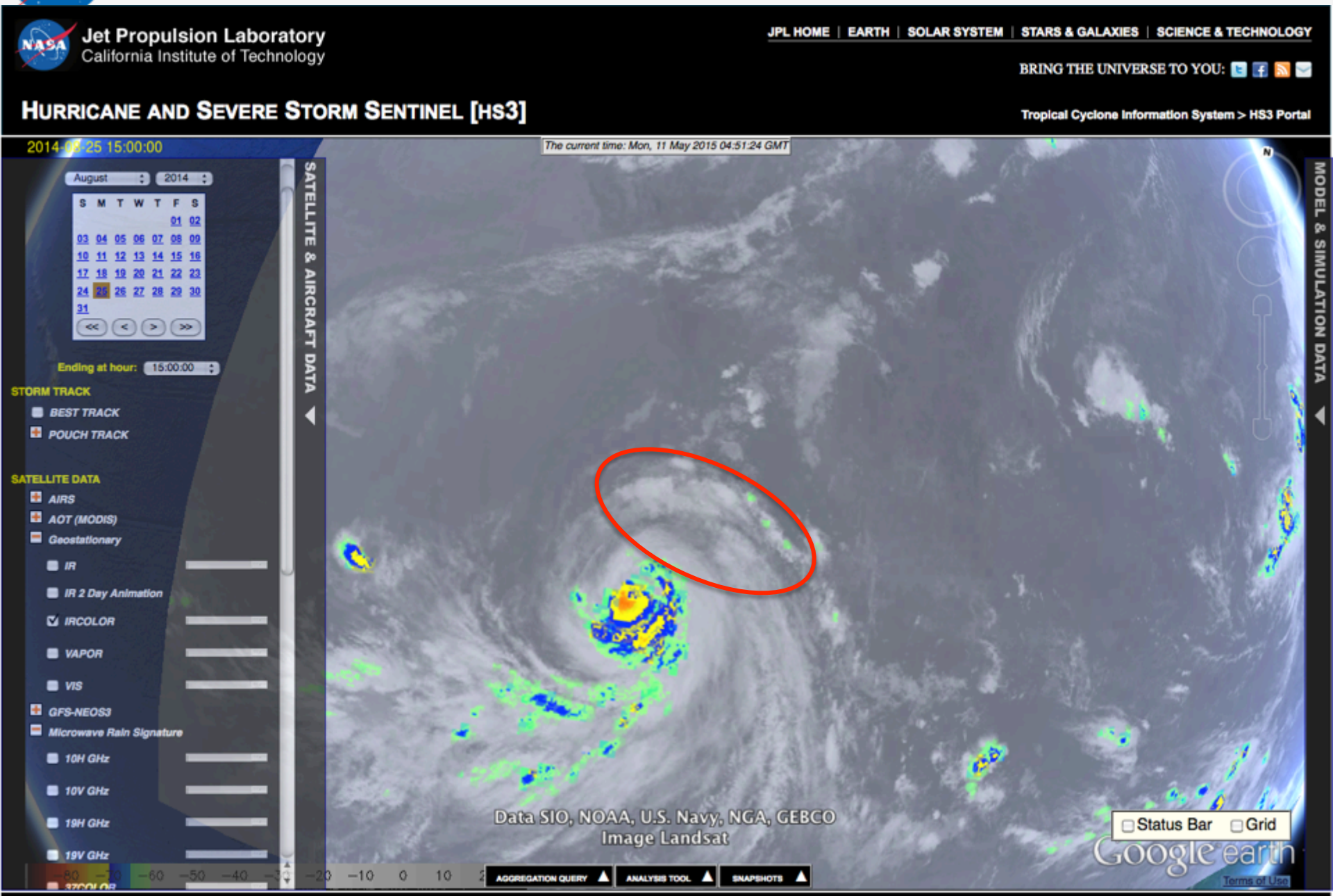
Hurricane Marie(2014) in Vis



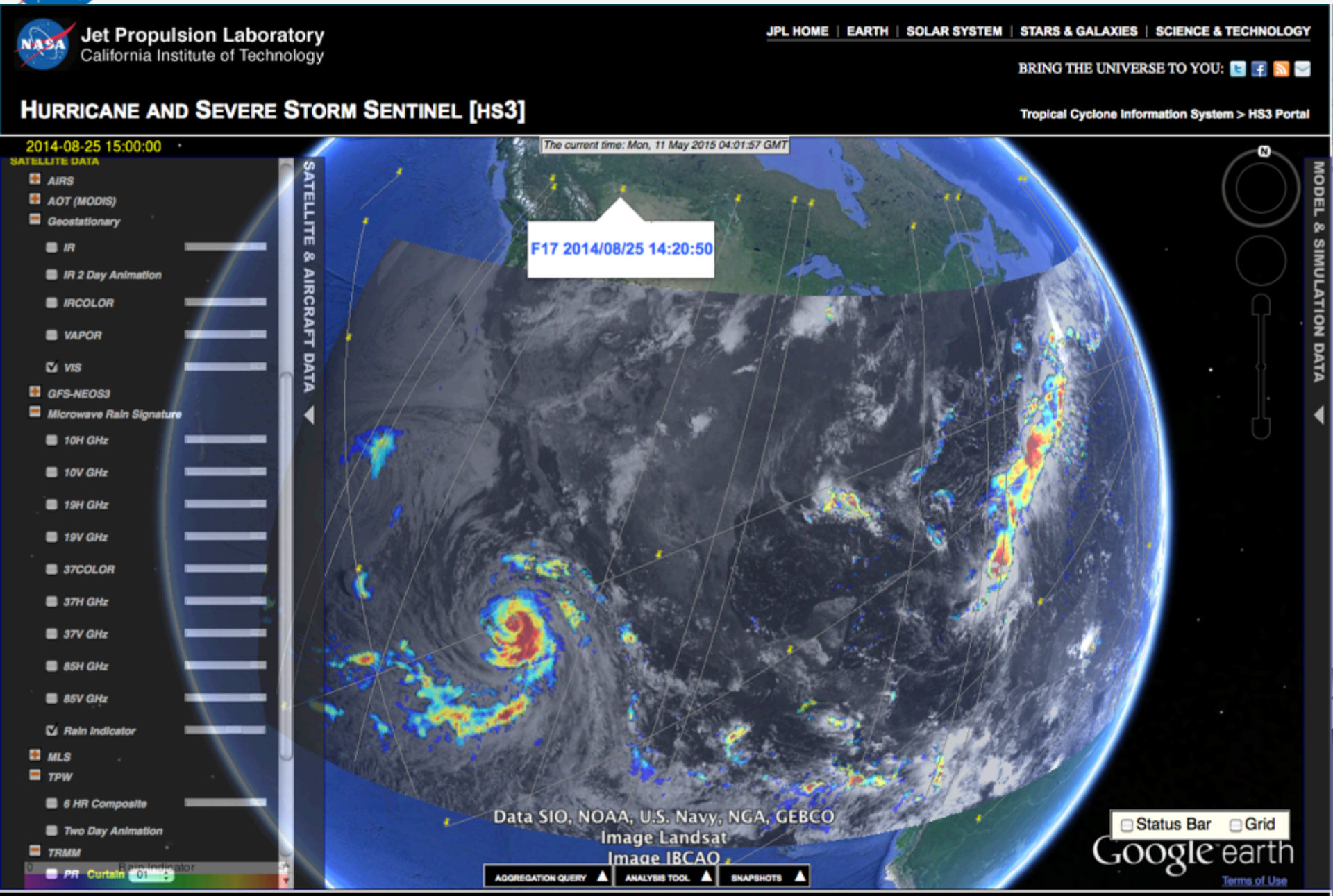
Hurricane Marie(2014) in microwave



Pay attention to the similarities and the differences



A word of caution – pay attention to the time



The three components of our system

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

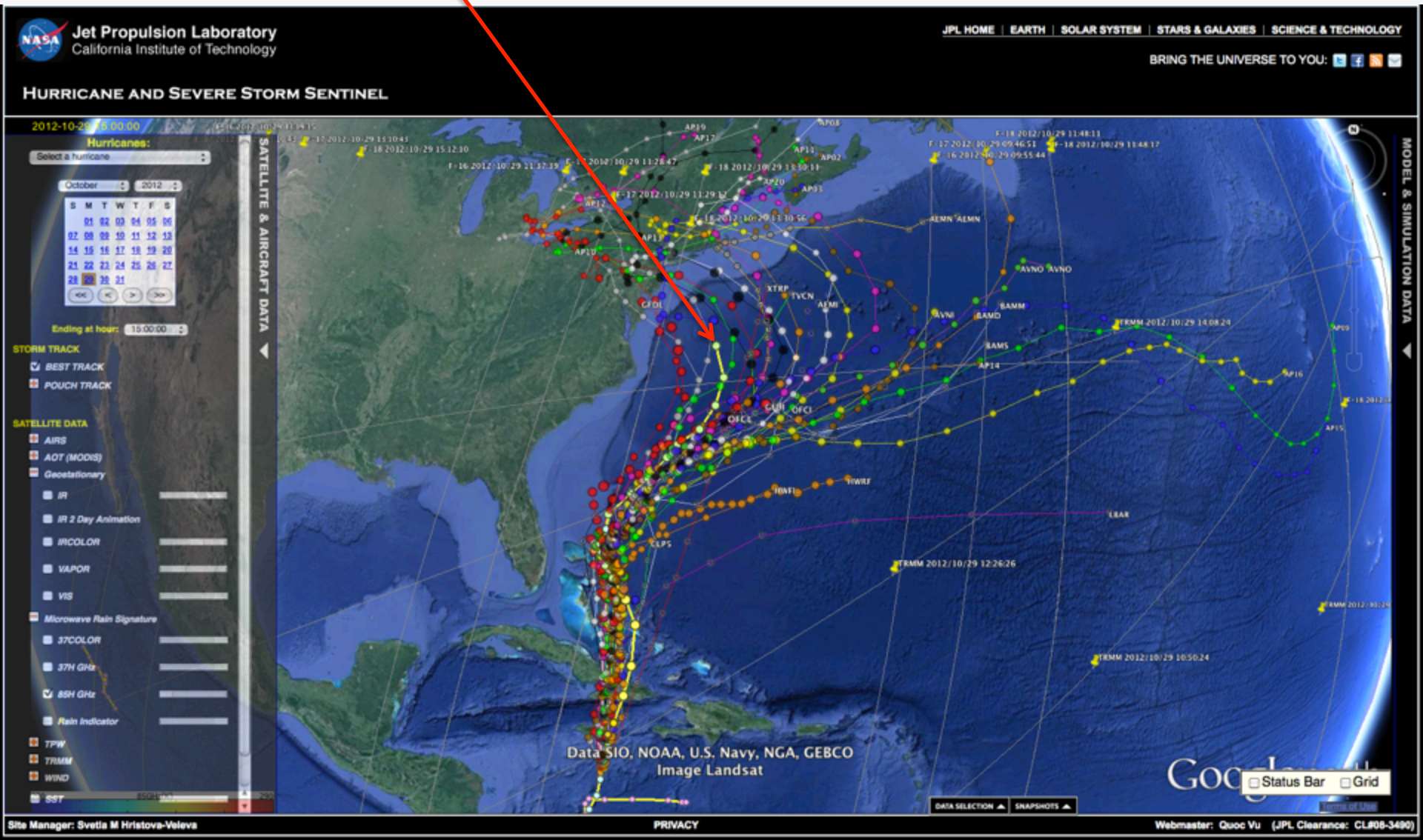
   a. Features

   b. Products

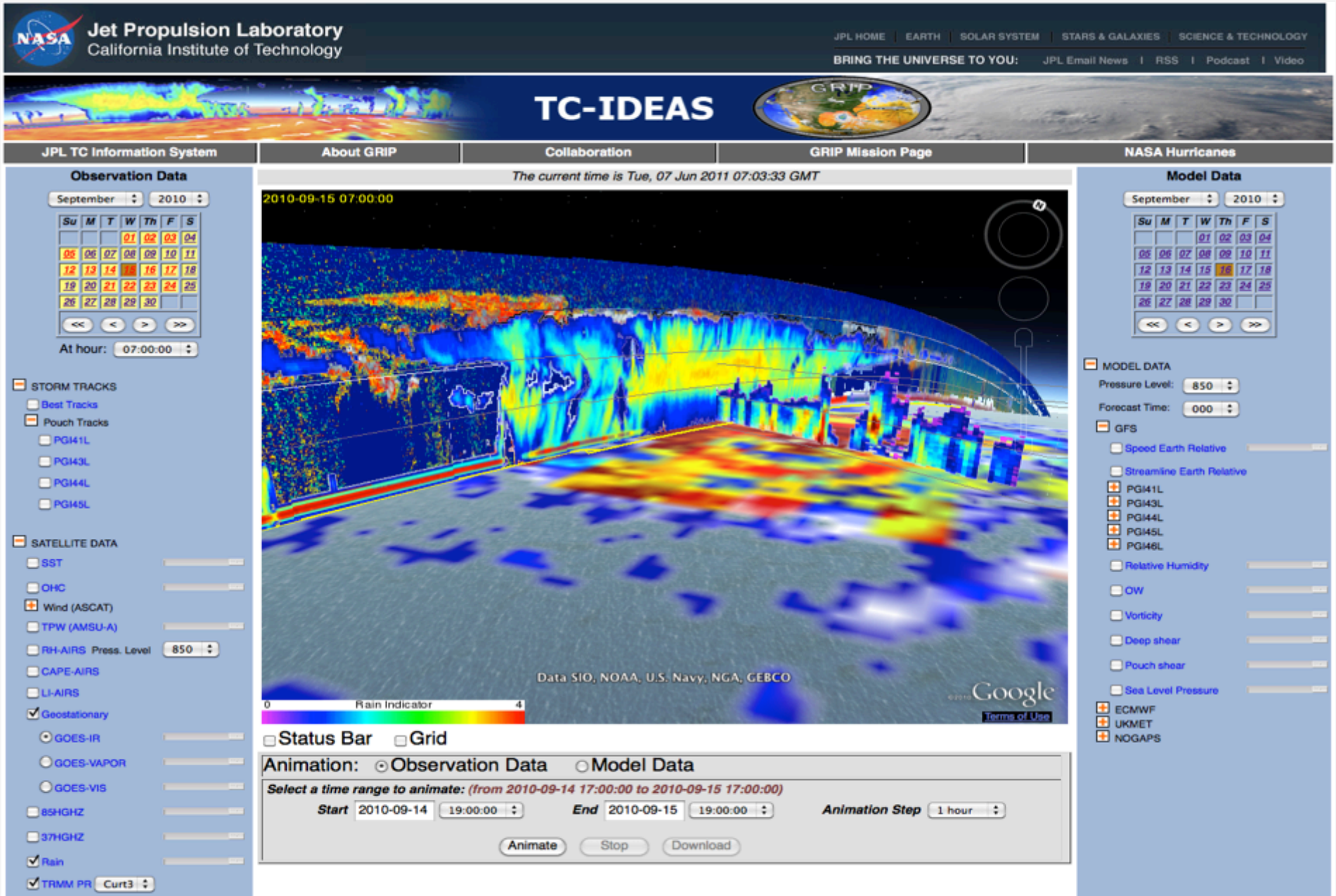
   c. **Interactive Visualization** - Exploratory
      - » Driving by desire
      - » Hurricane tracks and forecasts
      - » 3D view of precipitation
      - » Skew-T plots
      - » Overlaying different products AND MODELS

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

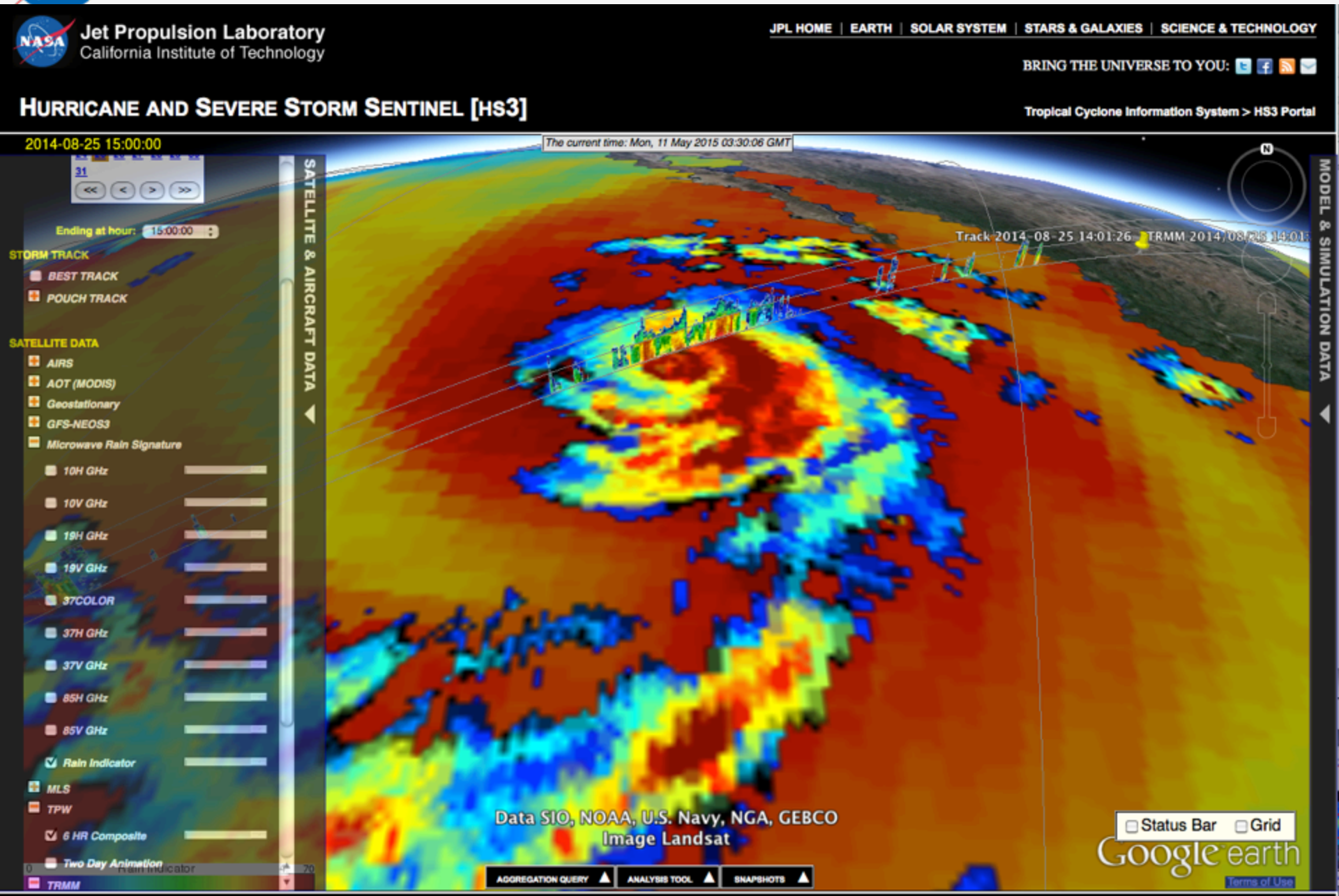
Best Track



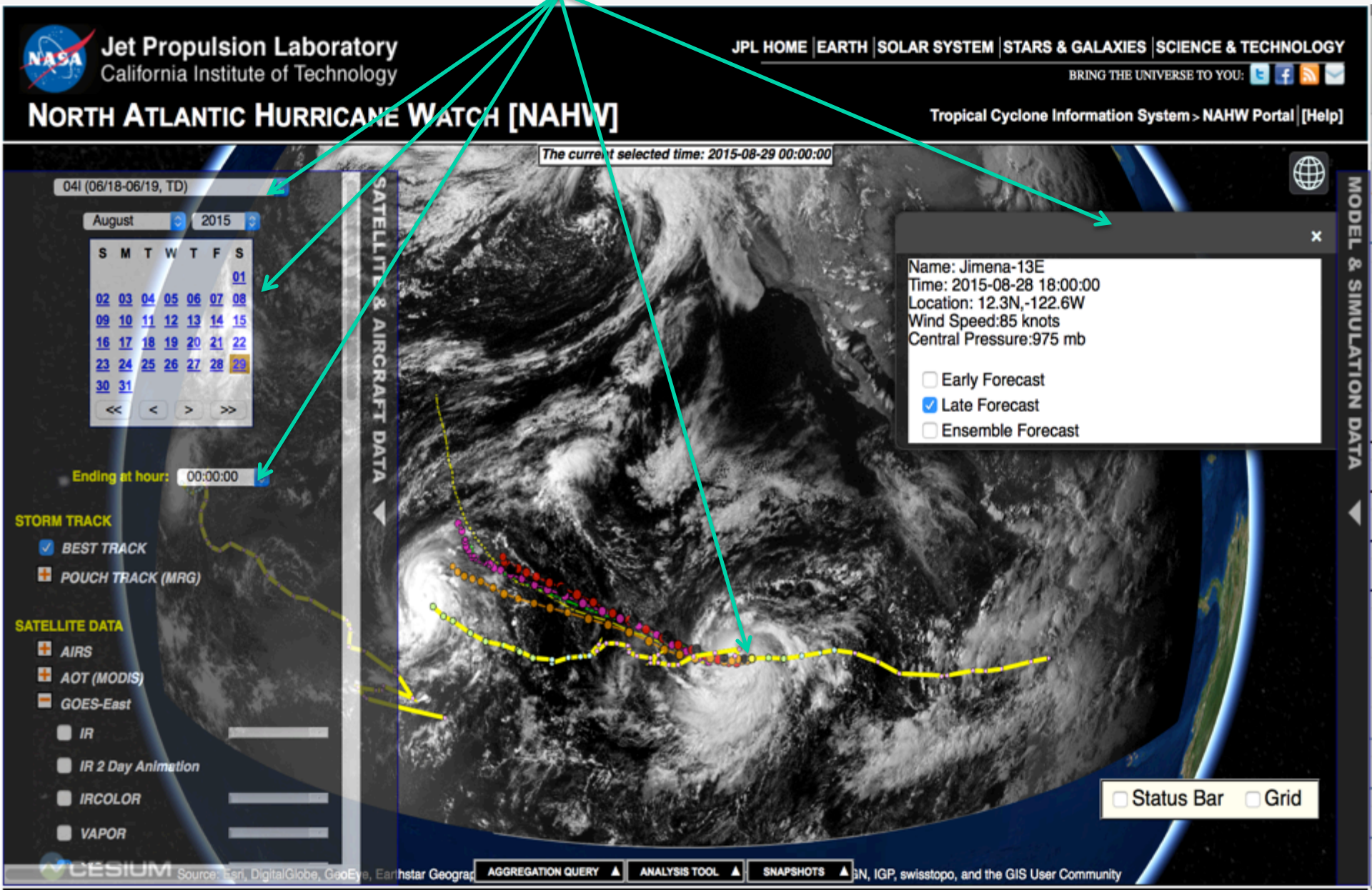
Storms in 3D (2010)



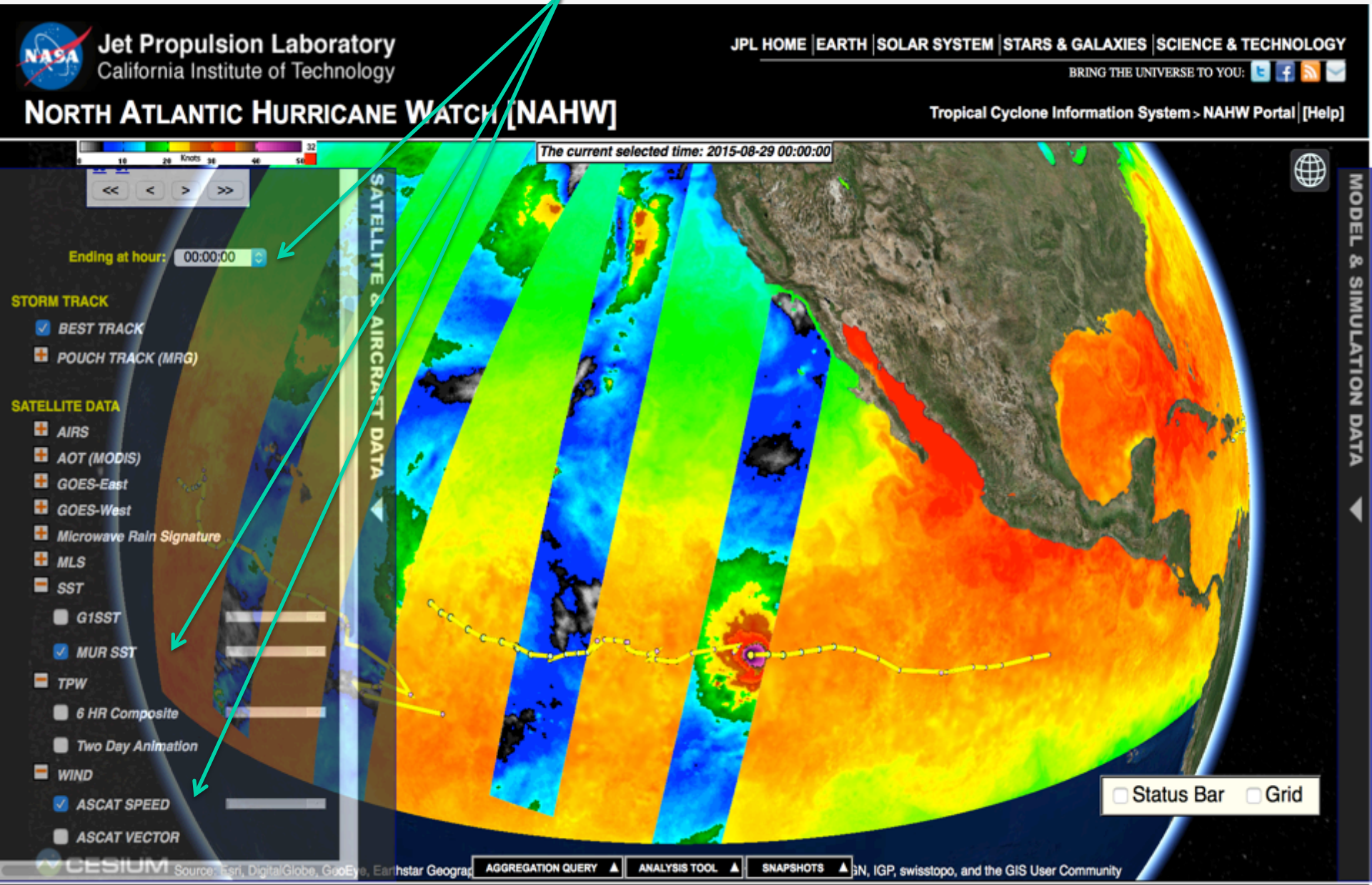
Storms in 3D


Jet Propulsion Laboratory
California Institute of Technology
JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | SCIENCE & TECHNOLOGY
BRING THE UNIVERSE TO YOU:
HURRICANE AND SEVERE STORM SENTINEL [HS3]
Tropical Cyclone Information System > HS3 Portal
2014-08-25 15:00:00
The current time: Mon, 11 May 2015 03:30:06 GMT
Ending at hour: 15:00:00
STORM TRACK
BEST TRACK
POUCH TRACK
SATELLITE DATA
AIRS
AOT (MODIS)
Geostationary
GFS-NEOS3
Microwave Rain Signature
10H GHz
10V GHz
19H GHz
19V GHz
37COLOR
37H GHz
37V GHz
85H GHz
85V GHz
Rain Indicator
MLS
TPW
6 HR Composite
Two Day Animation
TRMM
SATELLITE & AIRCRAFT DATA
MODEL & SIMULATION DATA
Track 2014-08-25 14:01:26
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Status Bar
Grid
Google earth
AGGREGATION QUERY
ANALYSIS TOOL
SNAPSHOTS
Site Manager: Svetla M Hristova-Veleva
PRIVACY
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)

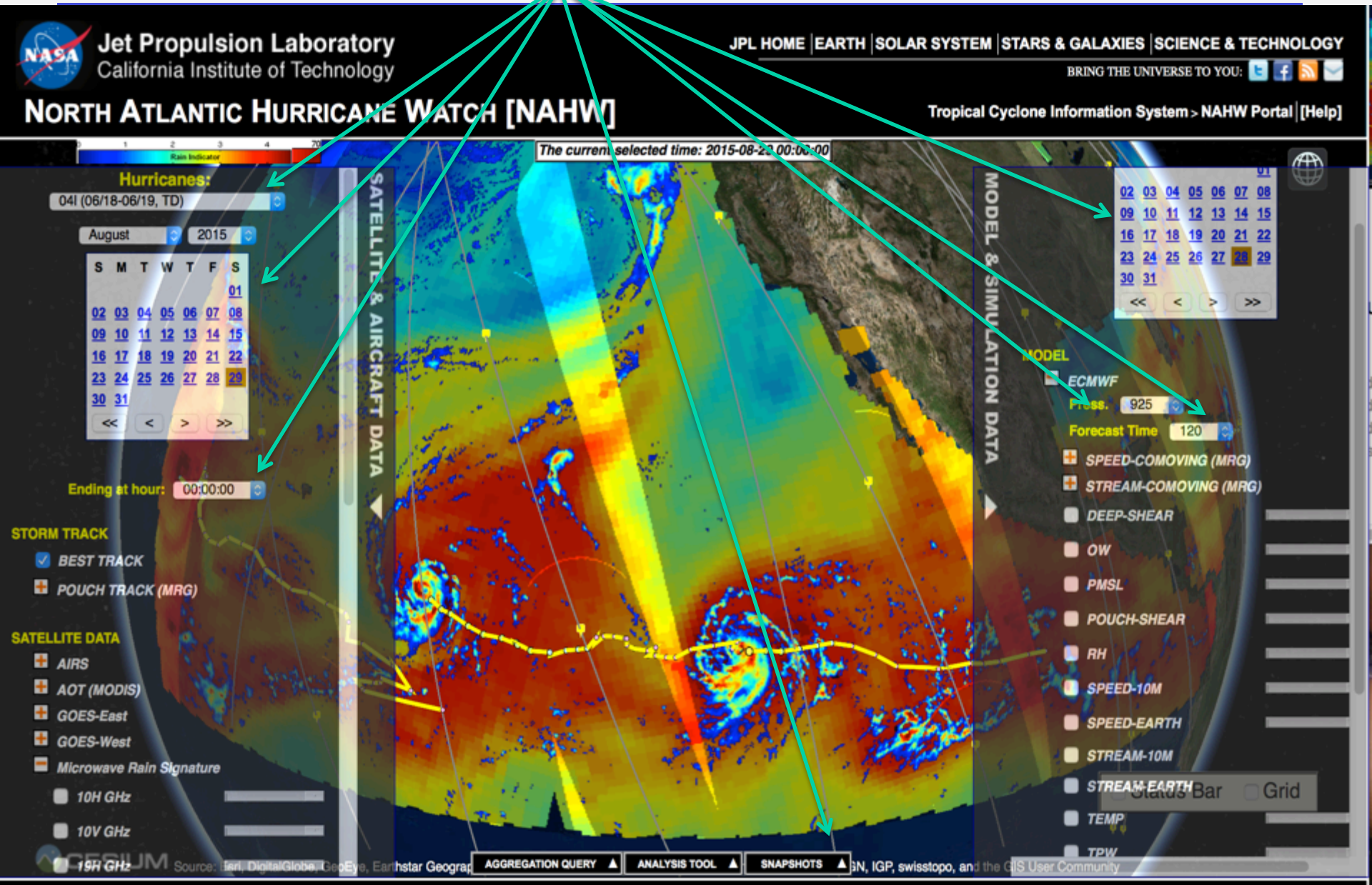
Driving by desire



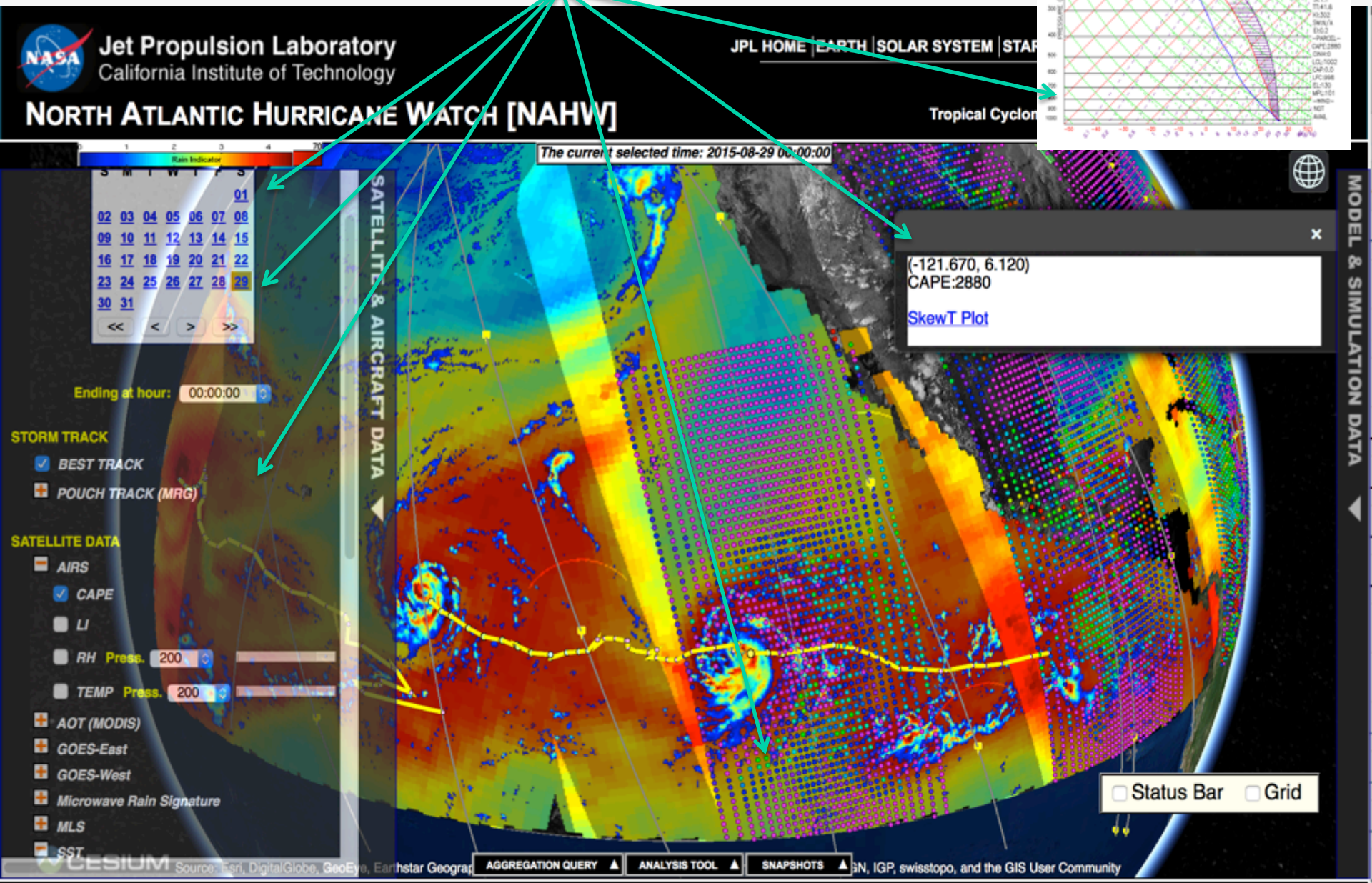
Driving by desire



Driving by desire

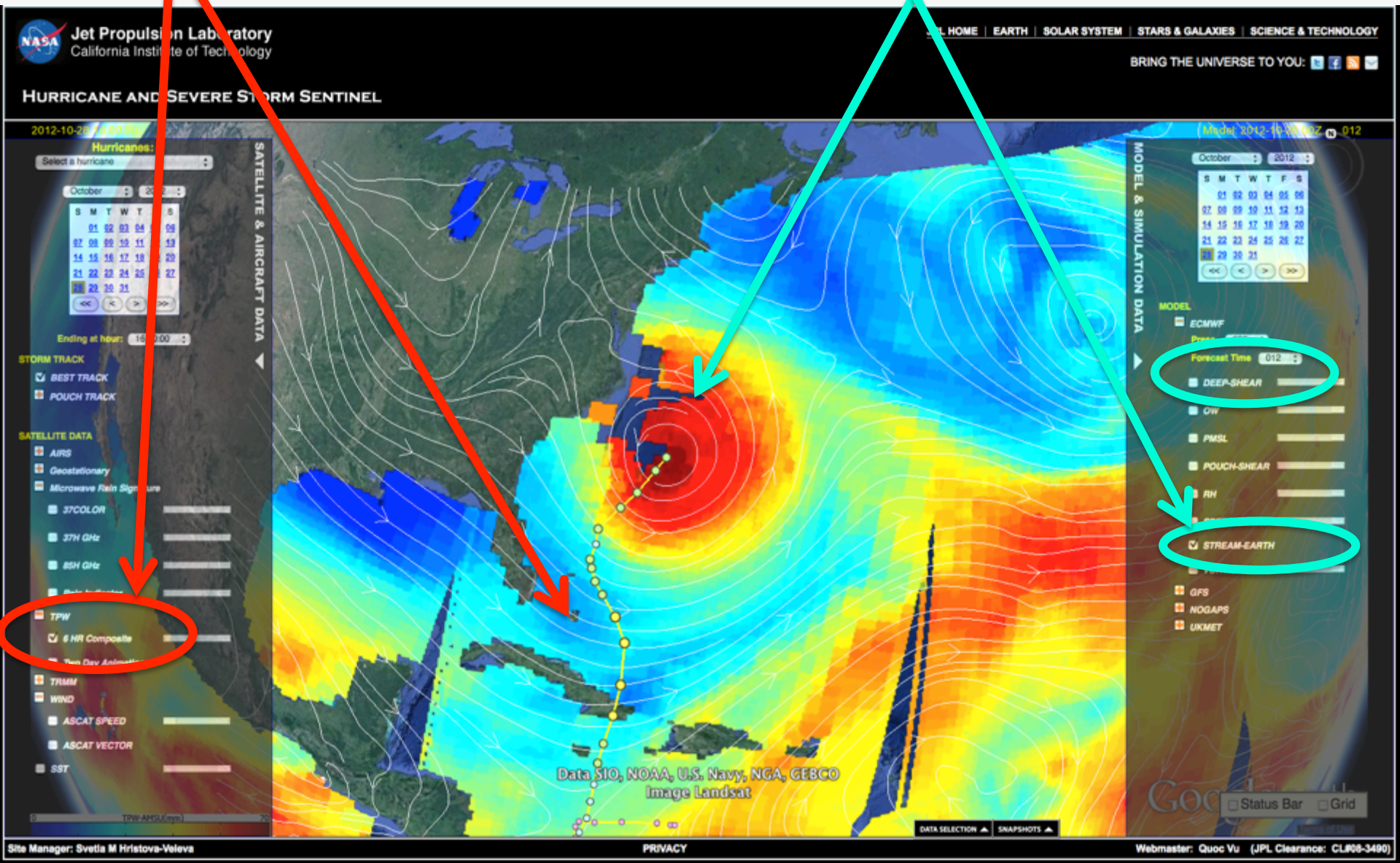


Driving by desire



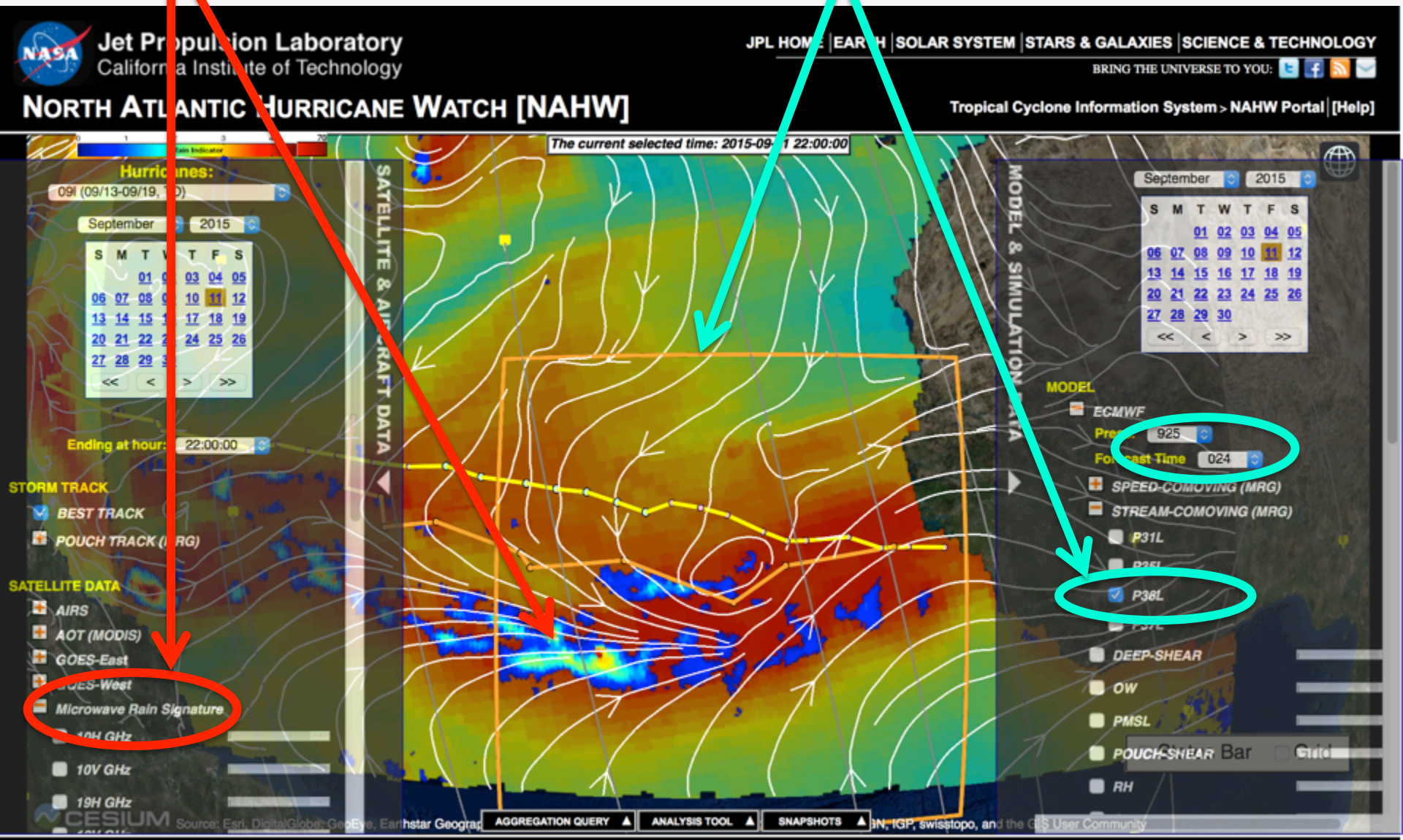
Driving by desire: Investigate and Discover

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



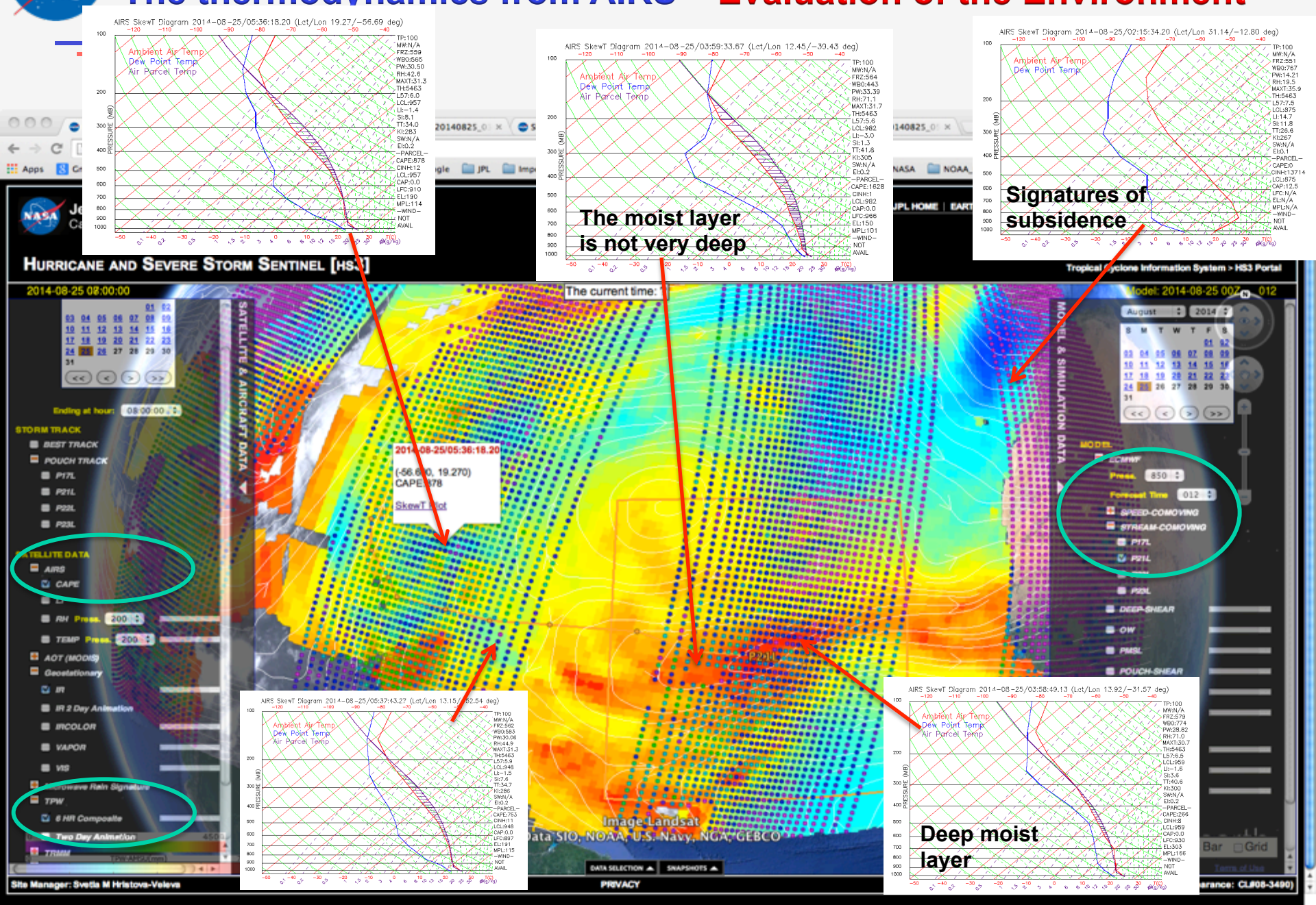
Driving by desire: Investigate and Discover

- A look at the pouches

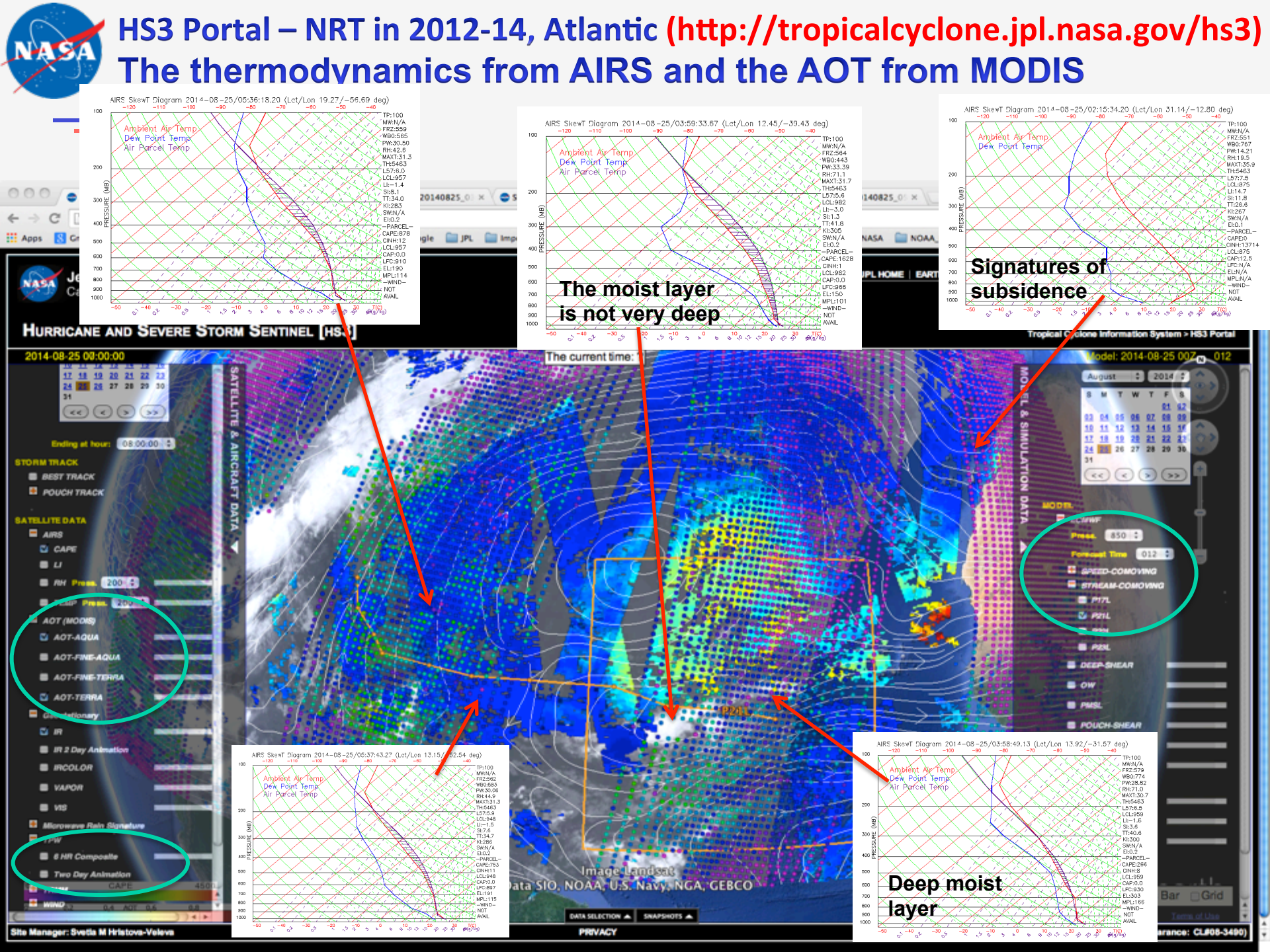


HS3 Portal – NRT in 2012-14, Atlantic (http://tropicalcyclone.jpl.nasa.gov/hs3)

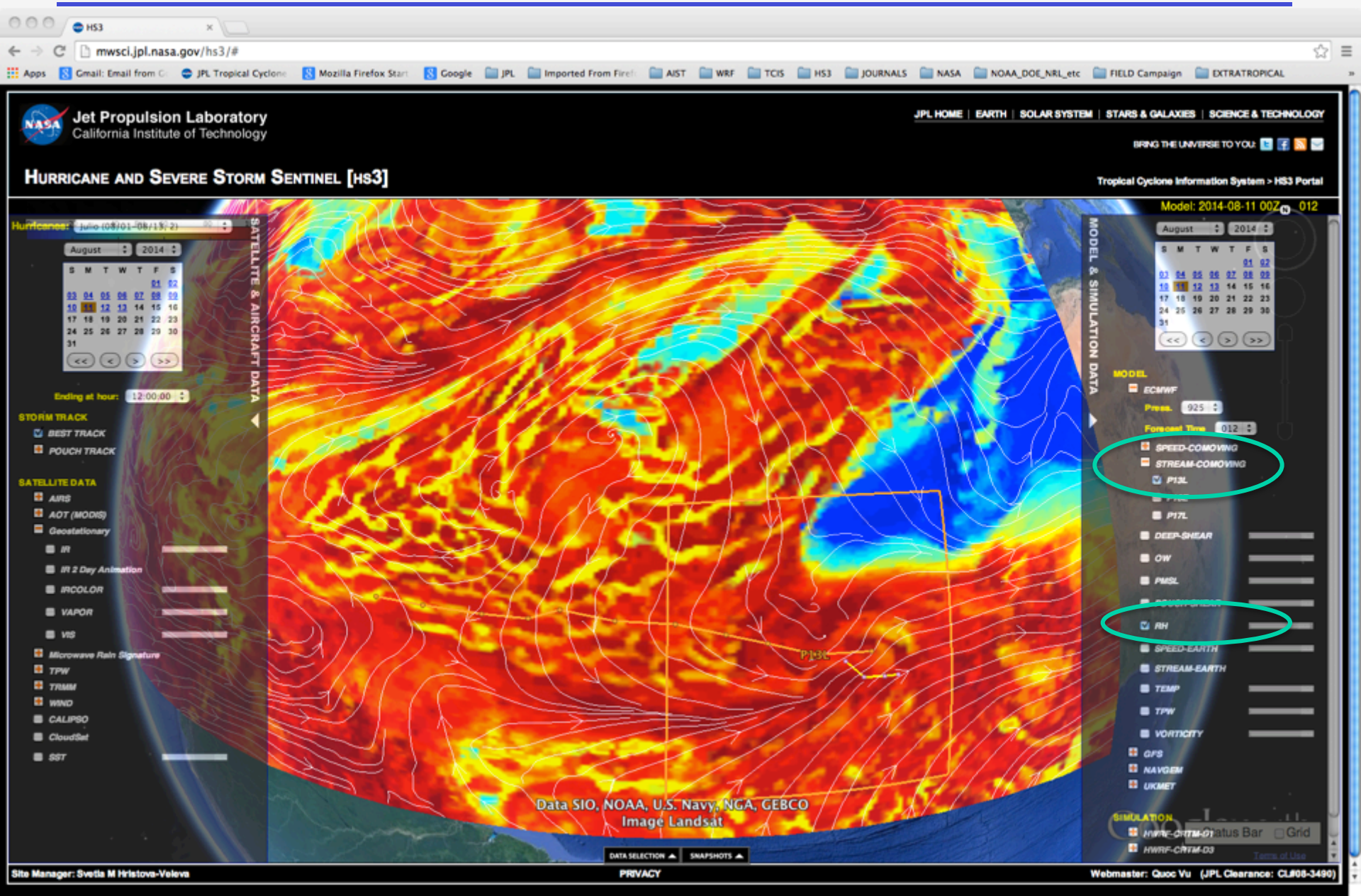
The thermodynamics from AIRS – Evaluation of the Environment



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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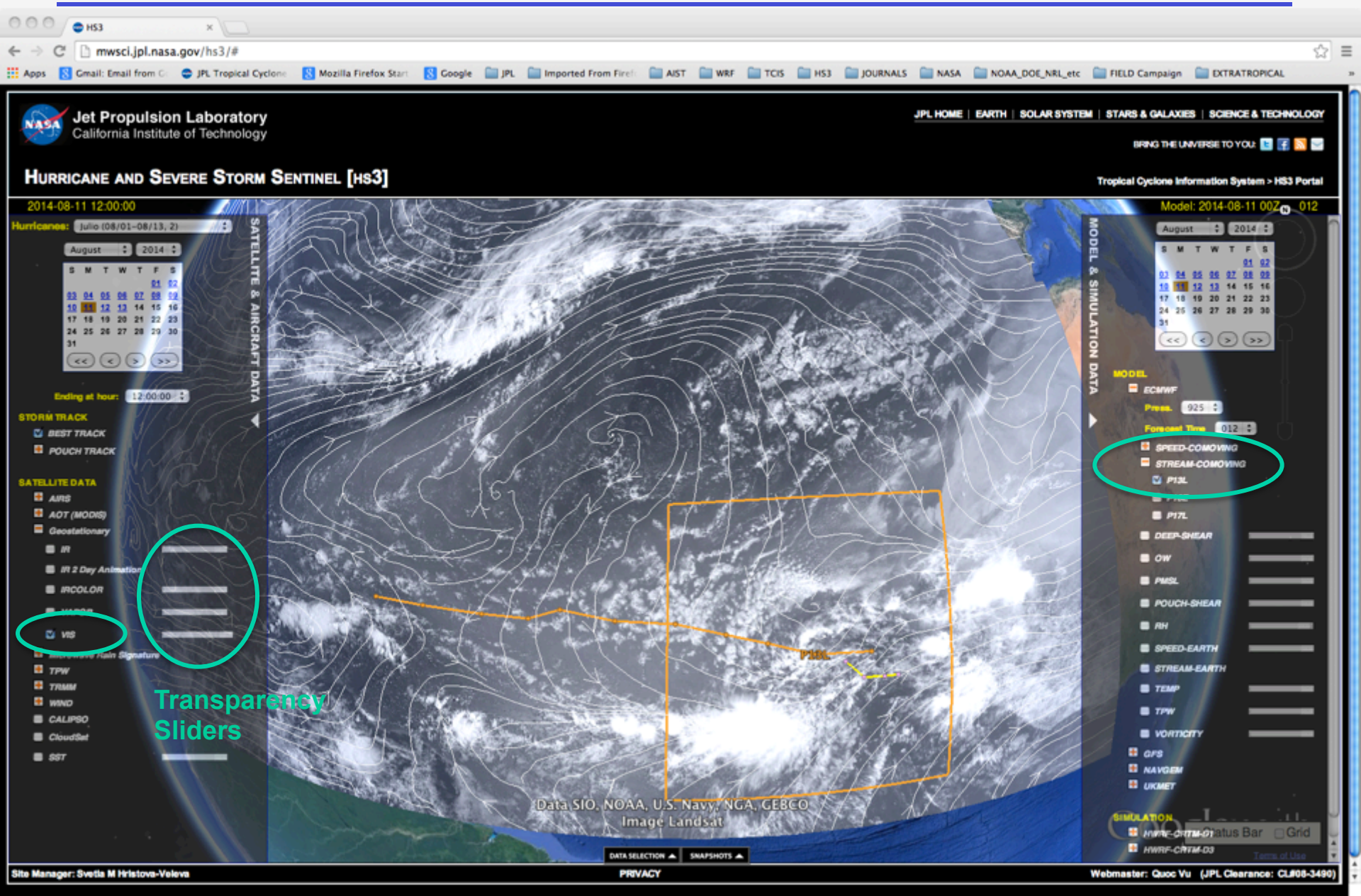
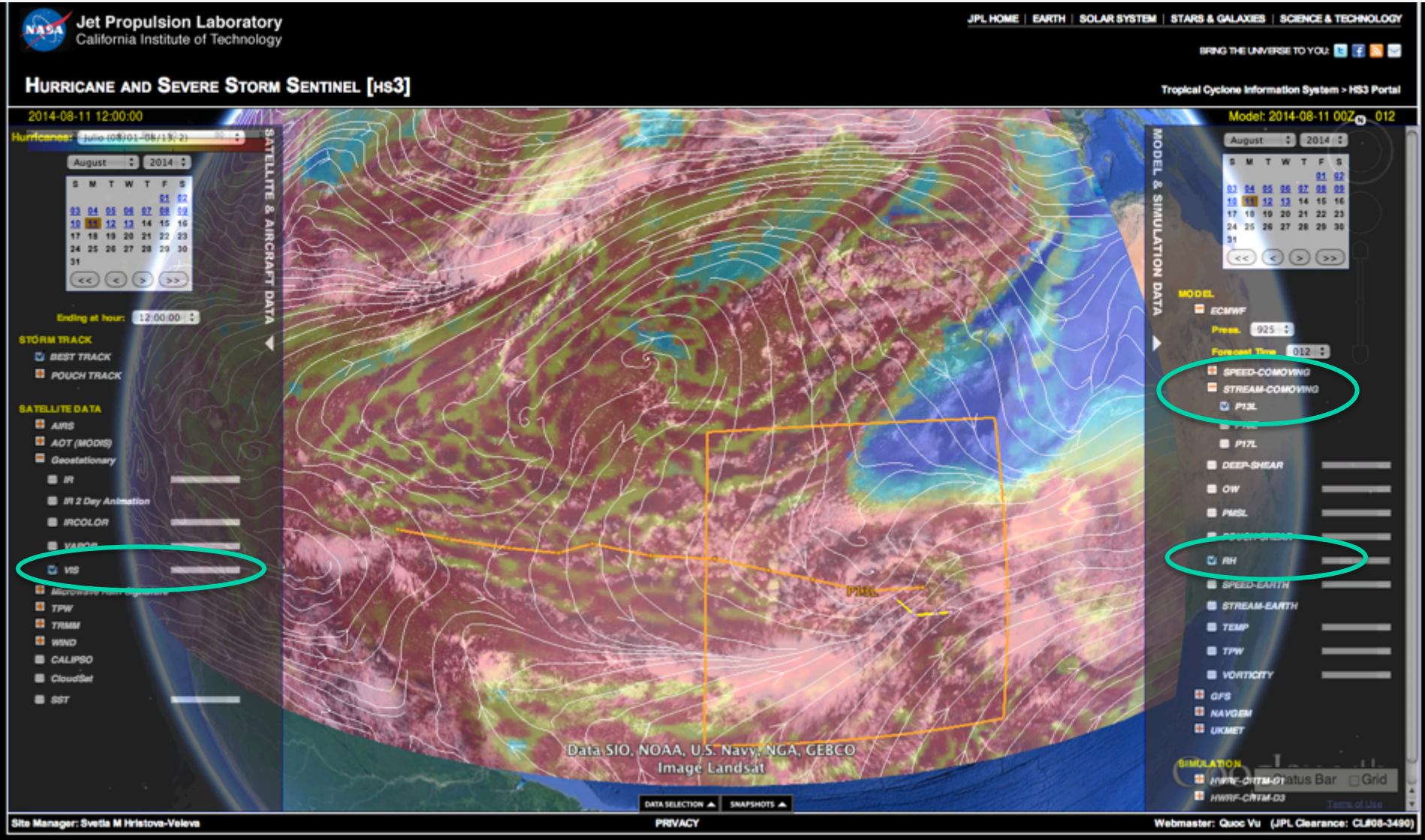


Understanding what is this structure in the model?

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).



The three components of our system

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

2. Projecting the model data into the observational space of the satellite data – the use of instrument simulators to compute brightness temperatures using as input the geophysical fields from the model

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**

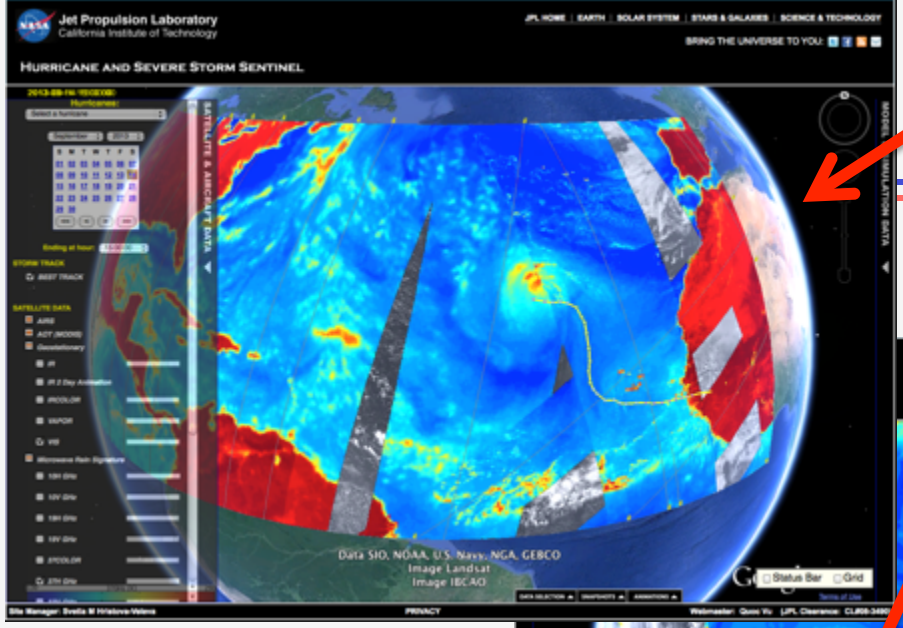
FUSION OF MODELS AND OBSERVATIONS - OPERATIONALLY

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?

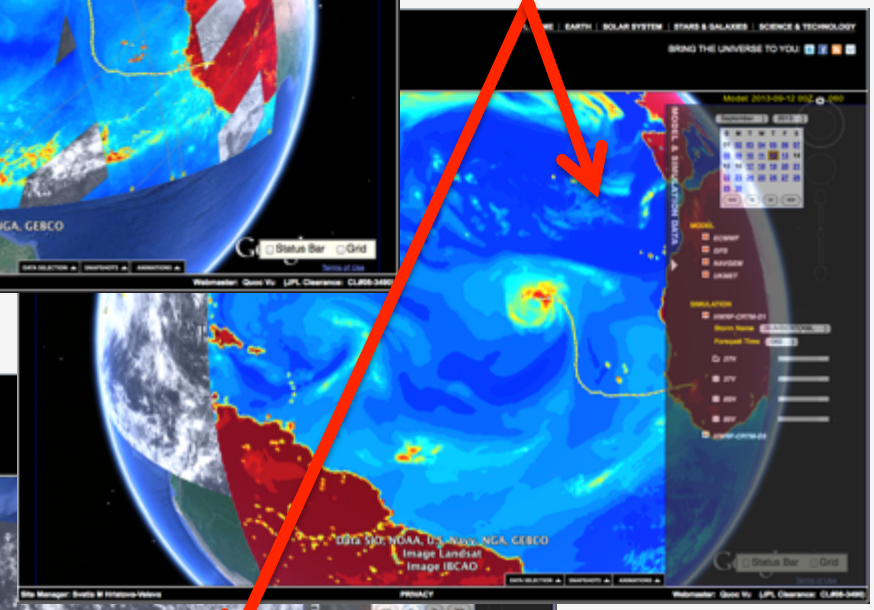
Including simulations from the same NWP model (say HWRF) but produced by different forward simulators and under different micro-physical & electromagnetic assumptions (as in NEOS^3 and CRTM) will help reveal the uncertainty that comes from the forward modeling itself.

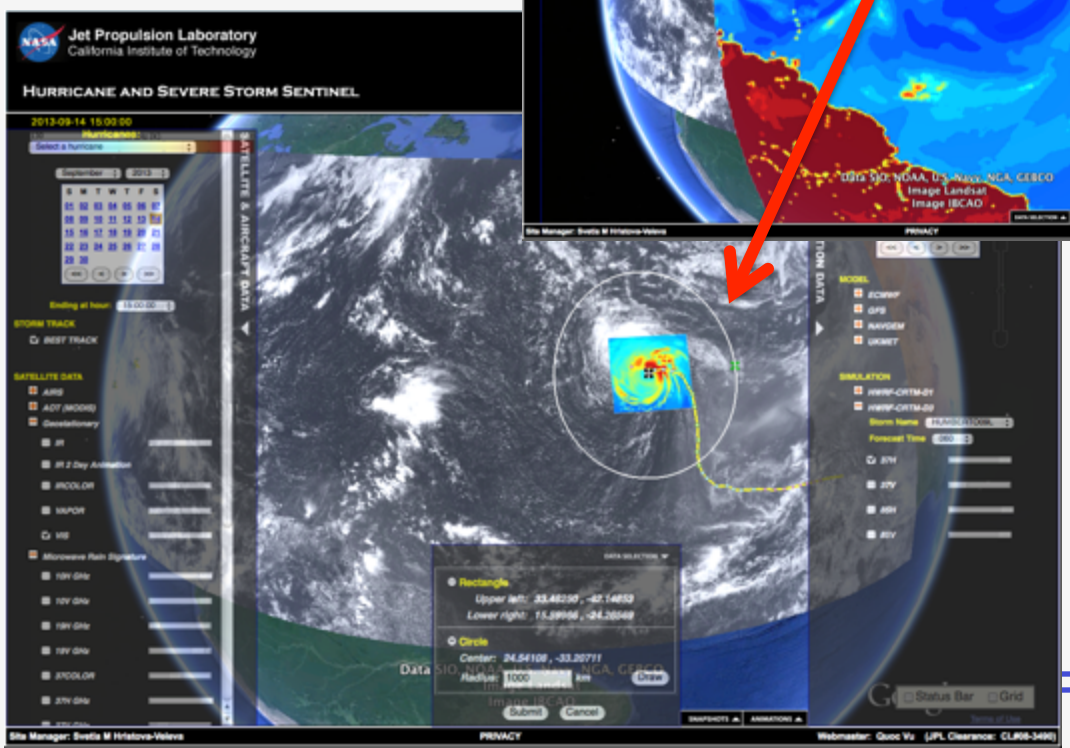


Satellite Observations

+

Synthetic Observations from Model





ESTO
Earth Science Technology Office

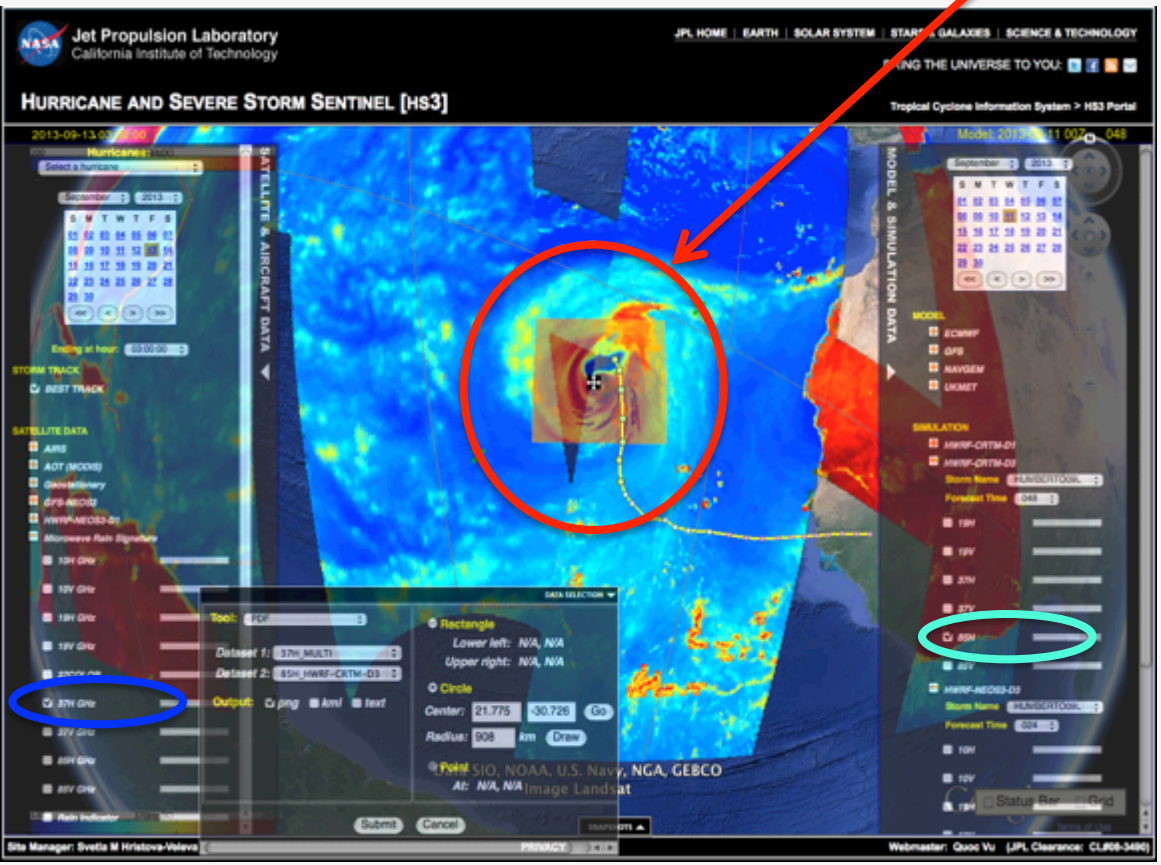
The three components of our system

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

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

3. Developing analysis tools with the goals to:
   - Goals:
     - Understand the observed structure of the hurricanes
     - Evaluate the models
     - Tools - to work with obs and models
       - ARCHER for storm-center fixing
       - Wave Number analysis – for storm structure and asymmetry
       - Slicer – 3D view of thermodynamics; storms
       - Aggregation tools and statistics – access to the 10+ year database of global satellite observations
       - Joint PDFs – understanding of the vertical structure of the precipitation. How are models and observations different

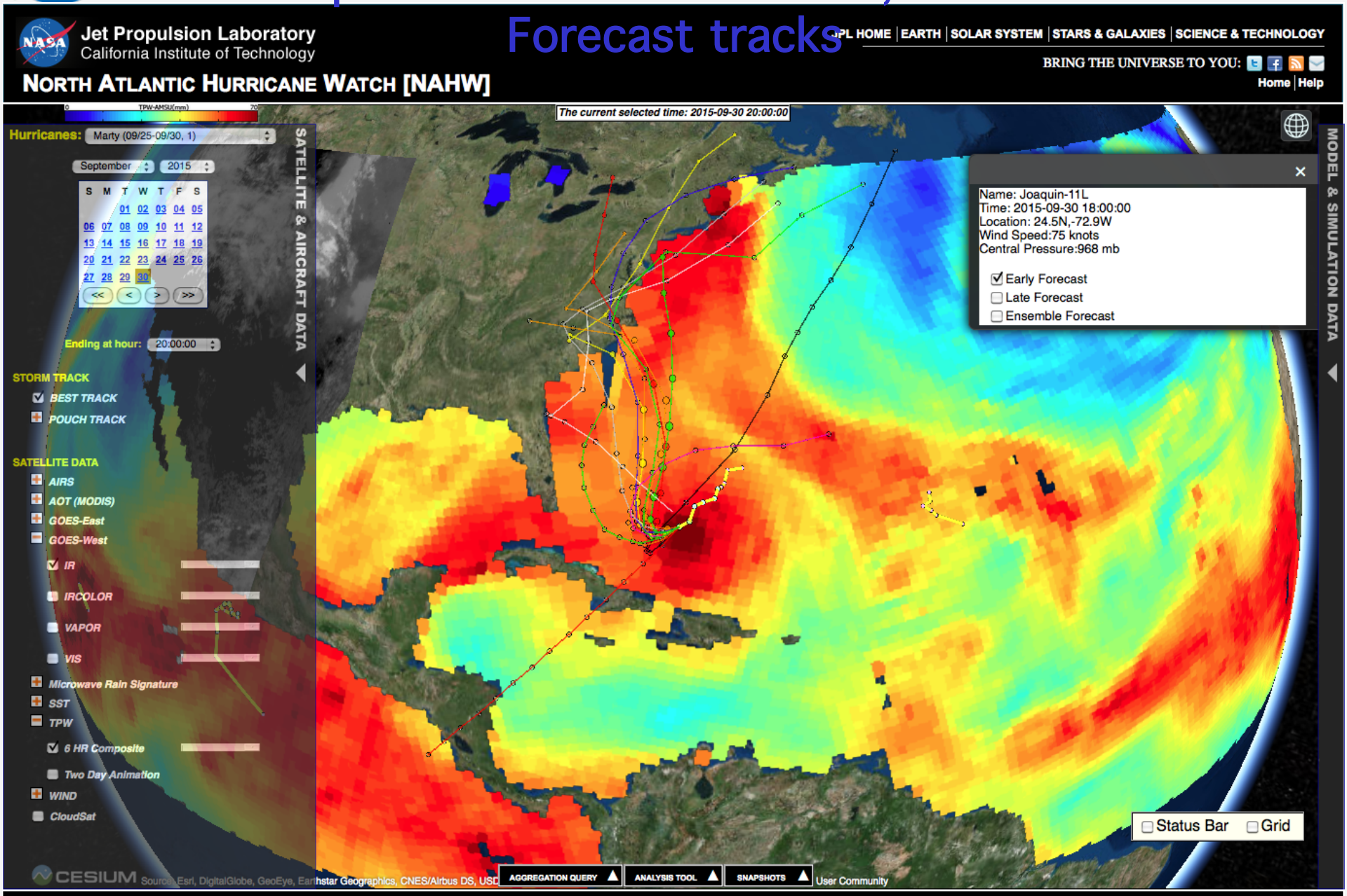
Analysis tools for model validation



- Interactively select region
- Gather data from observed and synthetic
  - brightness temperatures
- Statistical comparisons
  - Storm-relative coordinates
  - EOFs, Joint PDFs of TBs
  - Azimuthal averages =f(r)
- Storm Structure
  - Storm Size/Asymmetry
    - Wave-number analysis
  - Storm Center - ARCHER
  - Convective/Stratiform fractions
- Visualization of analysis

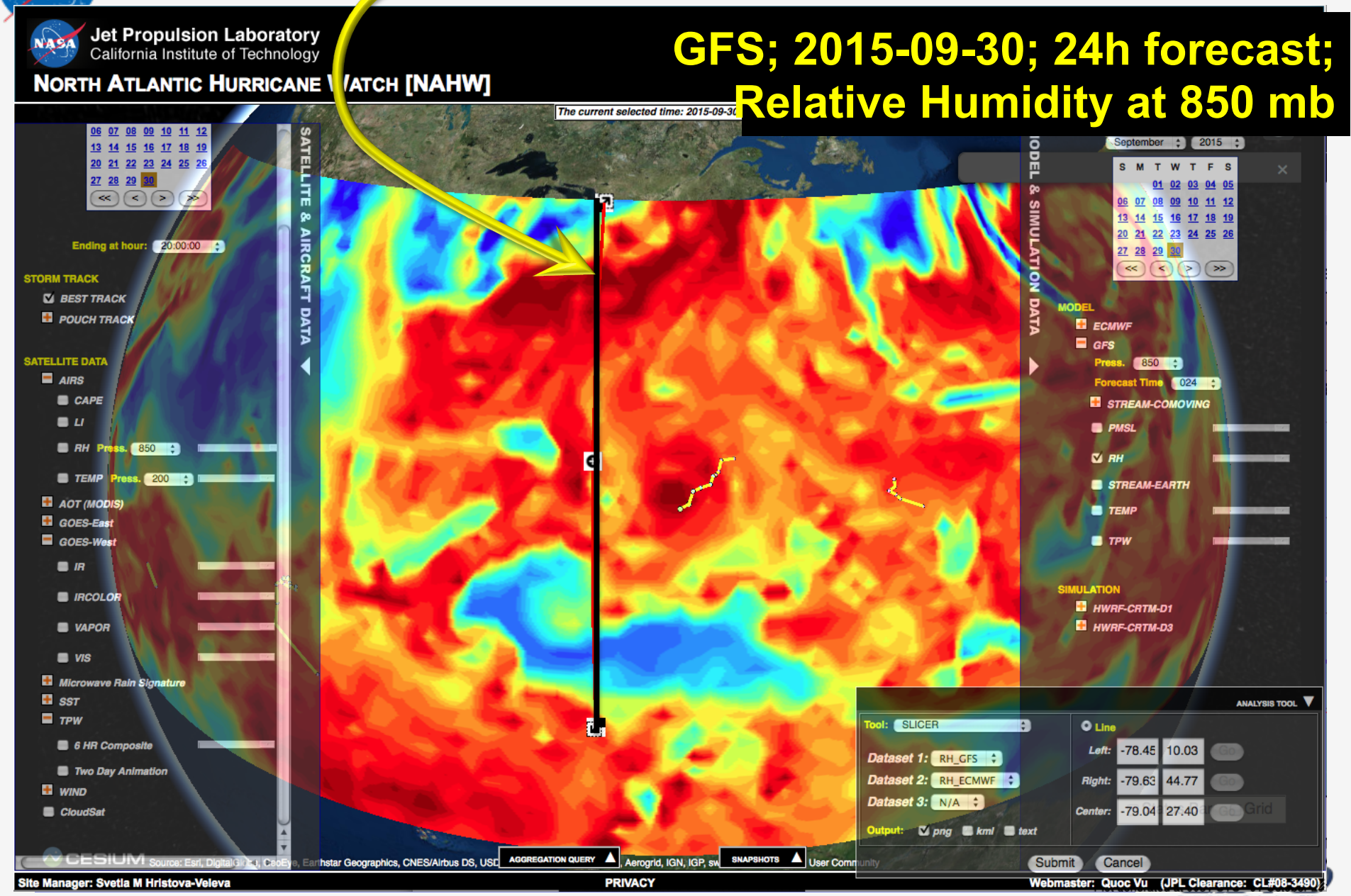
Comparing the Environment in the Large-Scale models and observations

Forecast Uncertainty
Total Precipitable Water from AMSU; Best Track and Forecast tracks



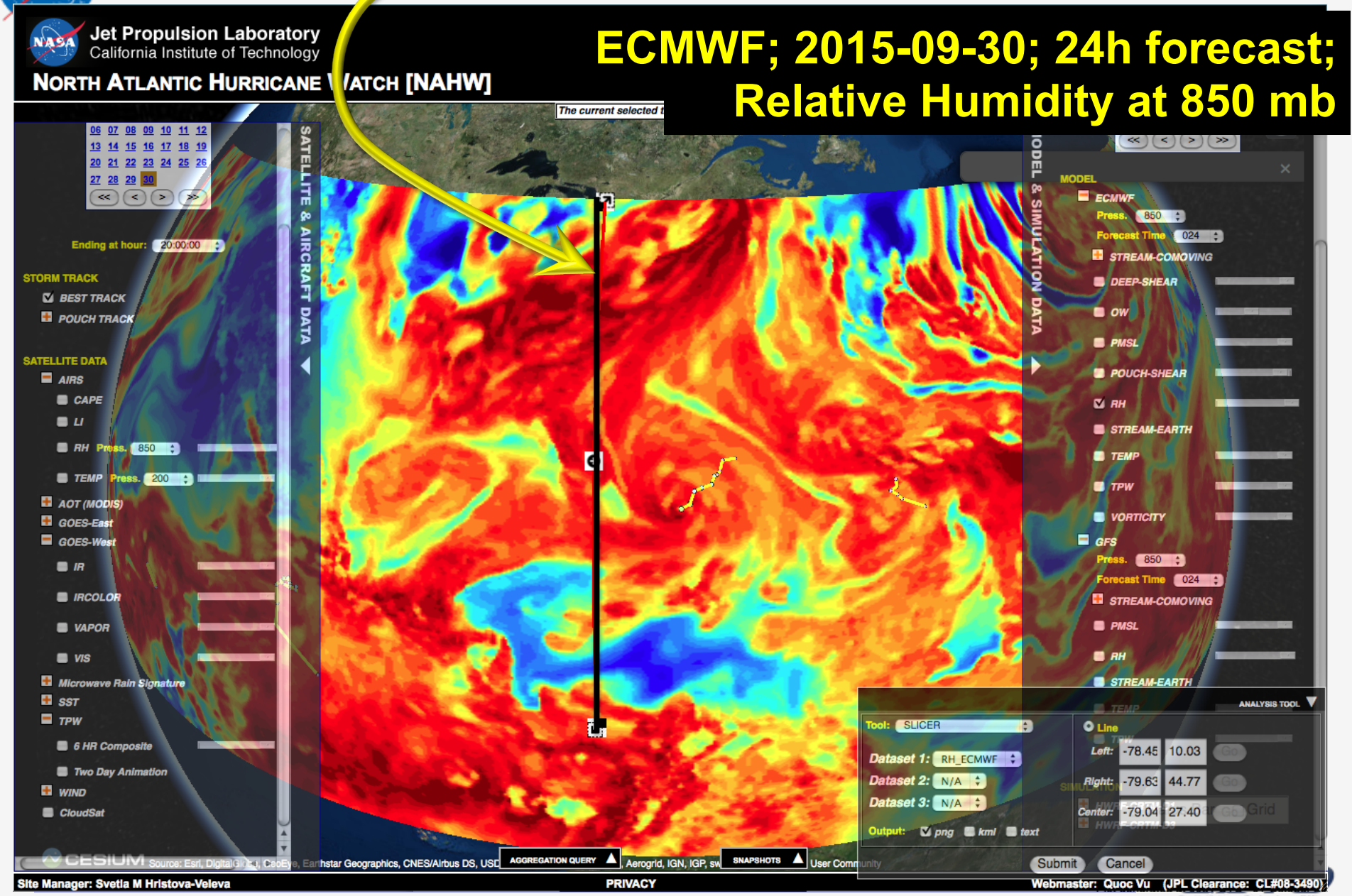
Line for the vertical cross-section shown three slides later

GFS; 2015-09-30; 24h forecast; Relative Humidity at 850 mb

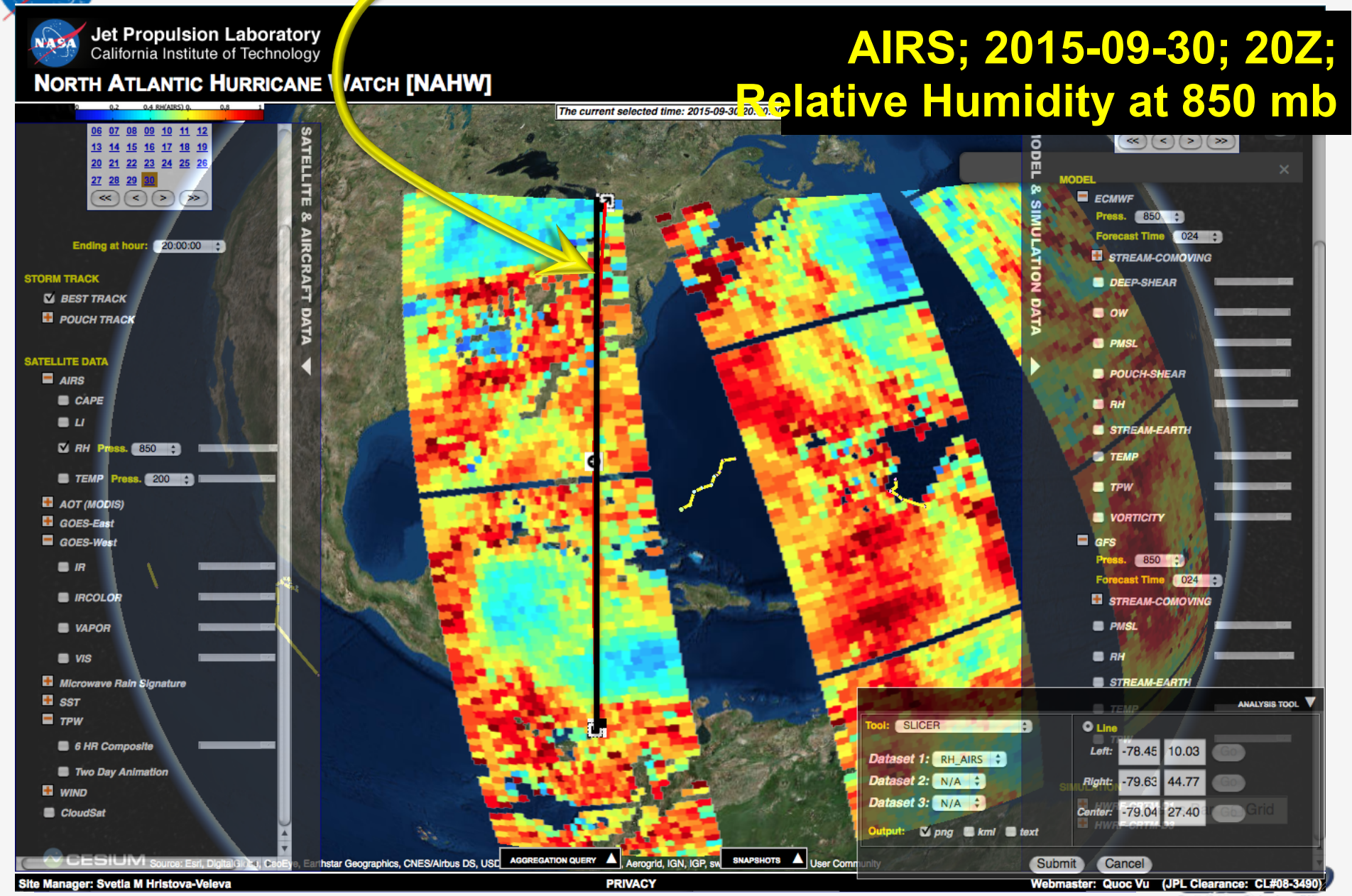


Line for the vertical cross-section shown two slides later

ECMWF; 2015-09-30; 24h forecast; Relative Humidity at 850 mb



Line for the vertical cross-section shown one slide later

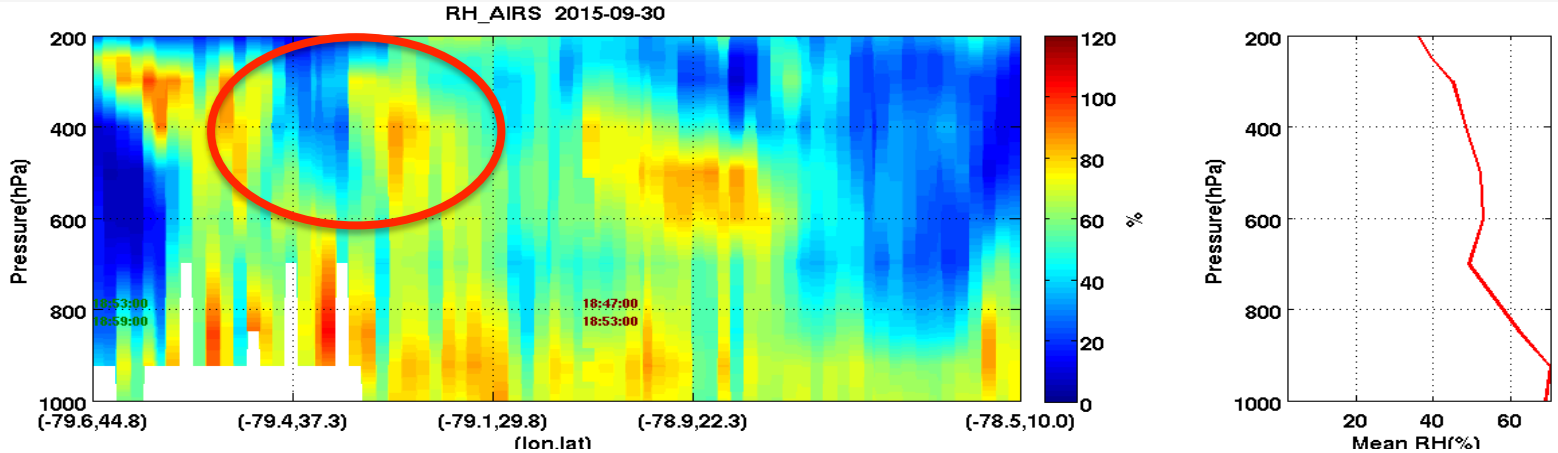


Cross-section Along 79W

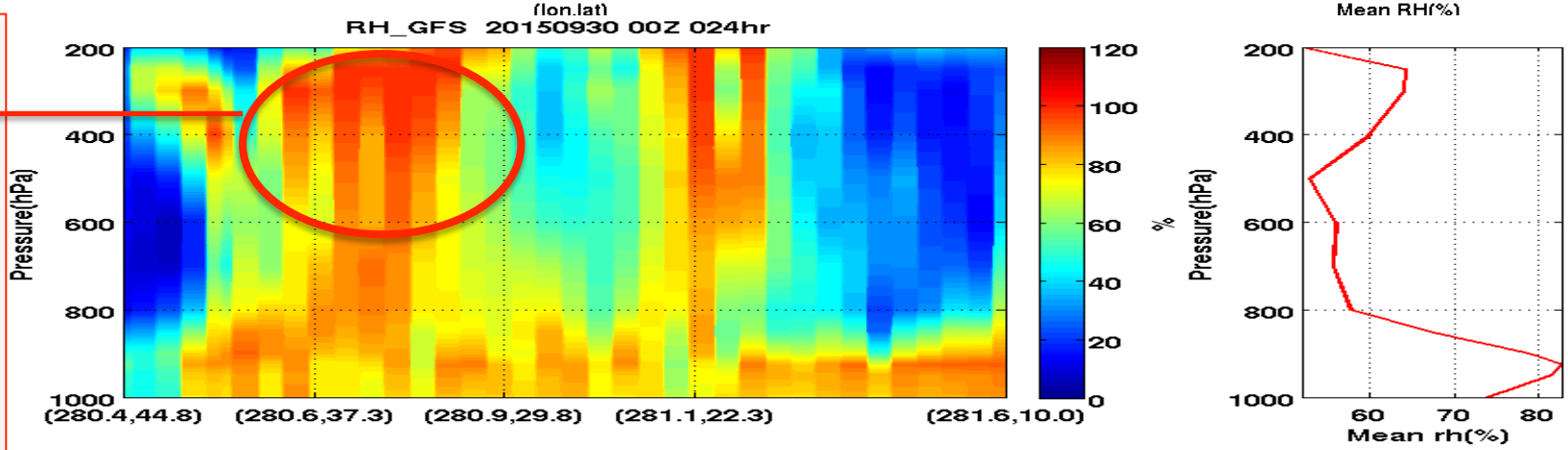
North

South

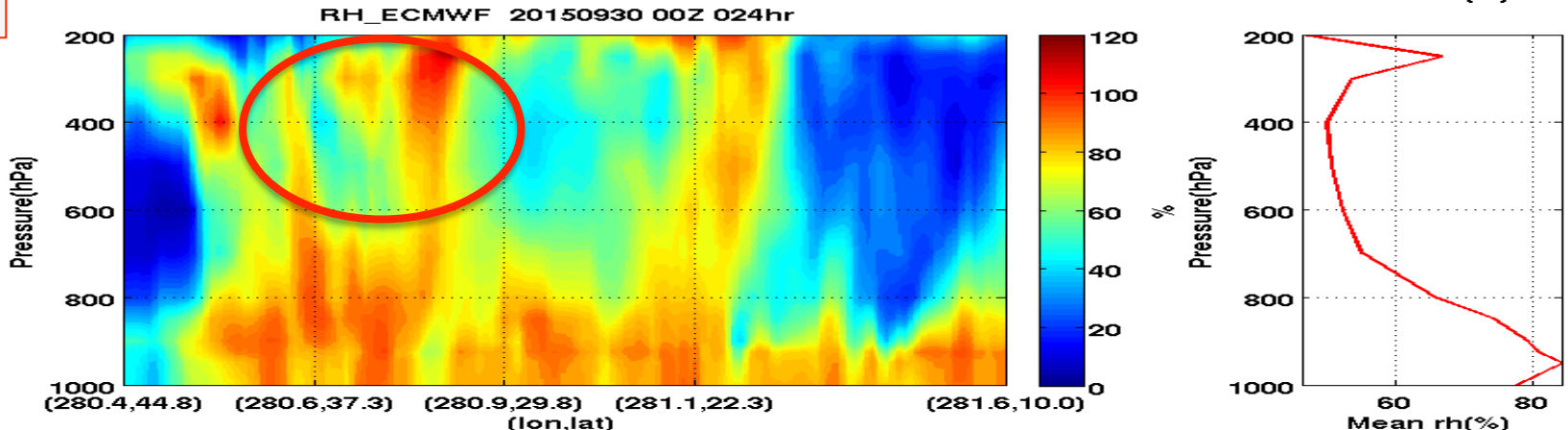
AIRS



Is GFS too moist at upper levels ahead of the storm??

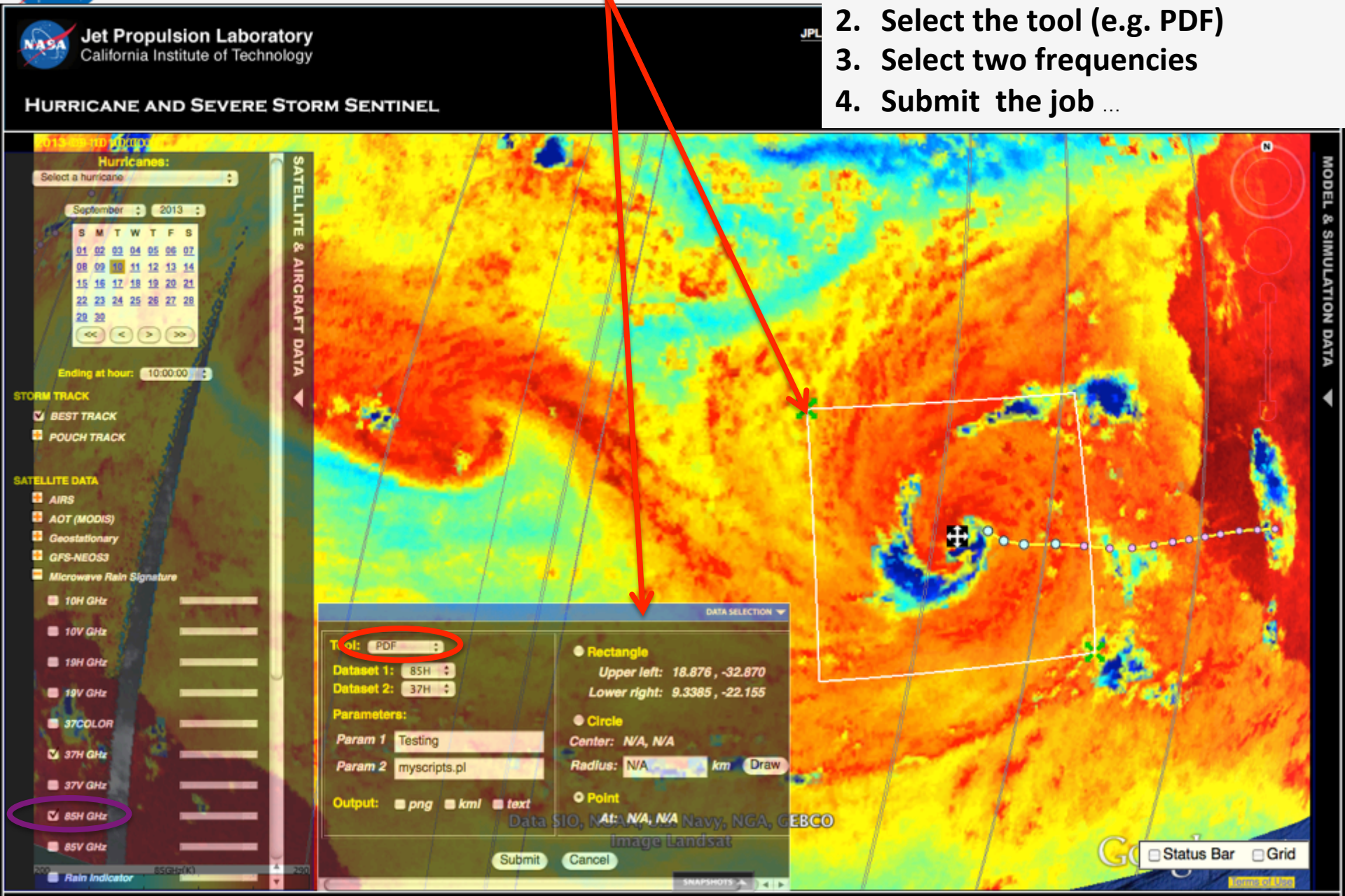


ECMWF



The Selection Tool

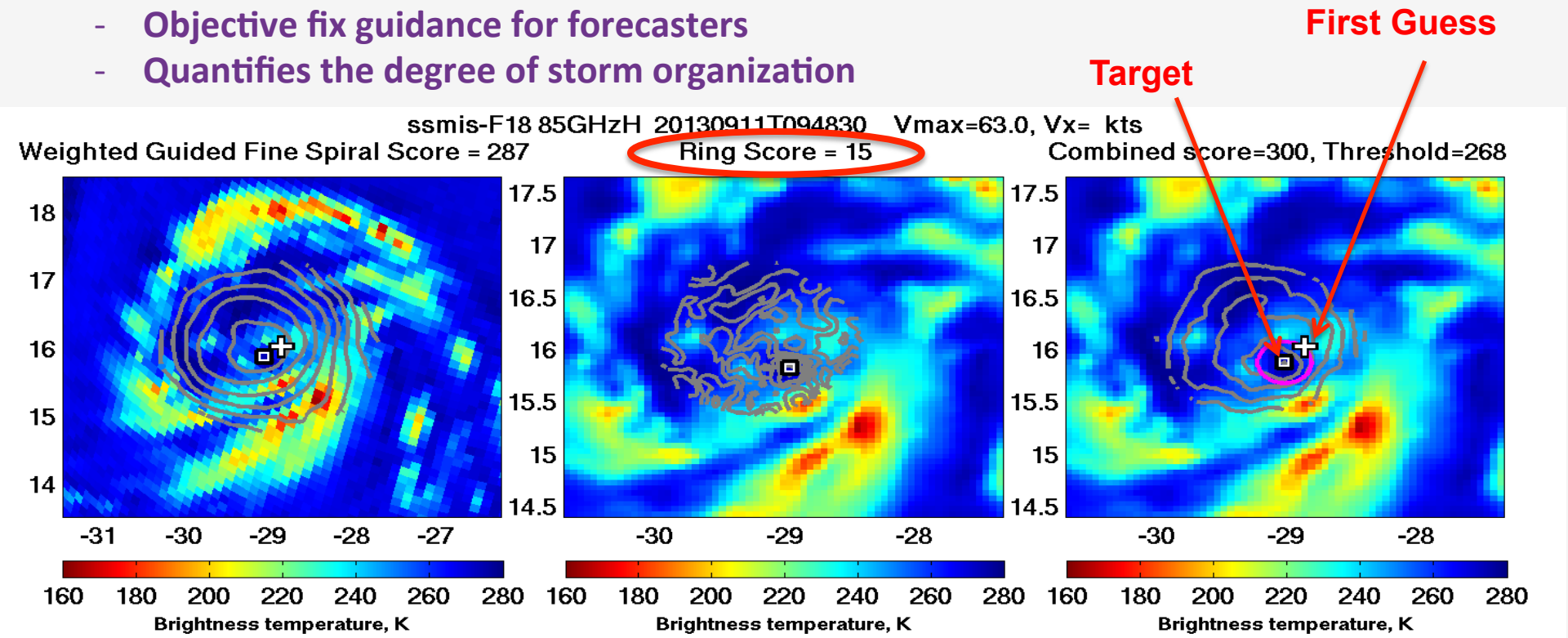
1. Select the region of interest
   - Circle, Square, Point
2. Select the tool (e.g. PDF)
3. Select two frequencies
4. Submit the job …



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

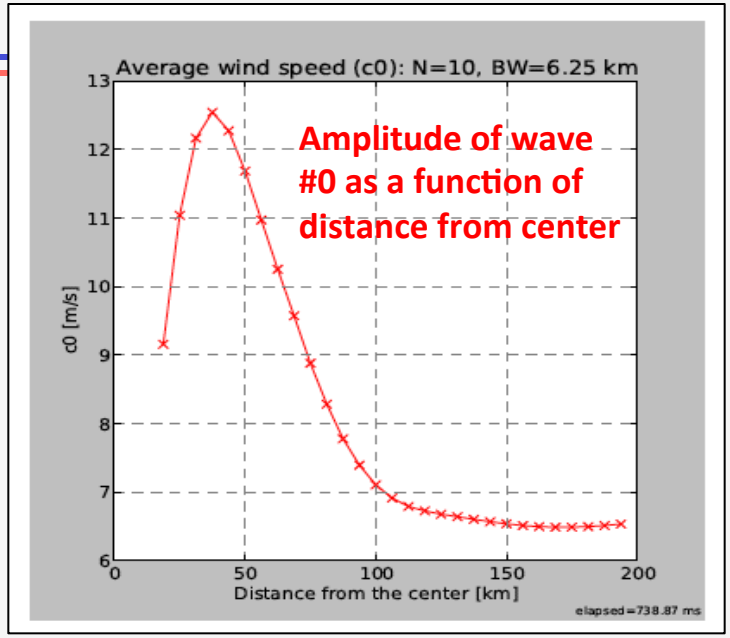


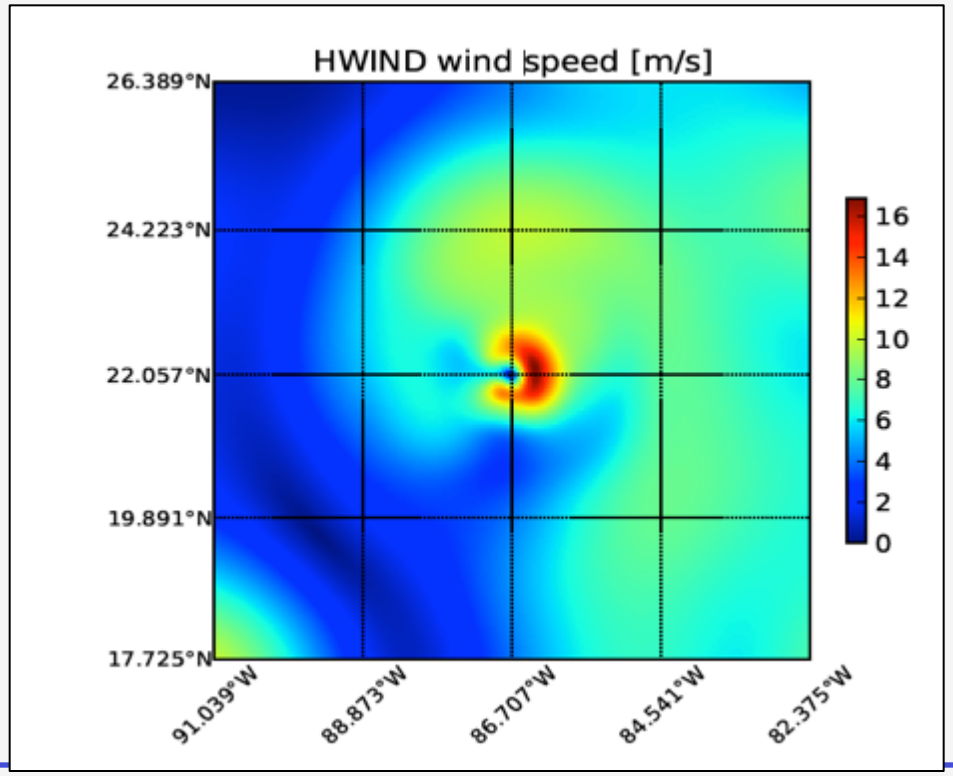
Additional information can be found in Wimmers, A. and C. Velden, 2010: Objectively Determining the Rotational Center of Tropical Cyclones in Passive Microwave Satellite Imagery, *J. Appl. Meteor.*, 49, 2010.

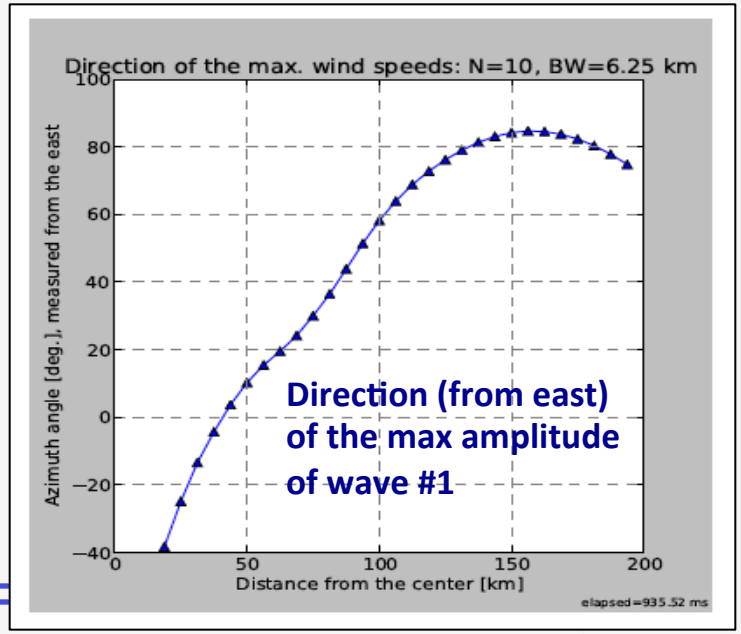
Storm structure Tool: Storm Size and Asymmetry

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







The JPL TCIS – Tropical Cyclone Information System

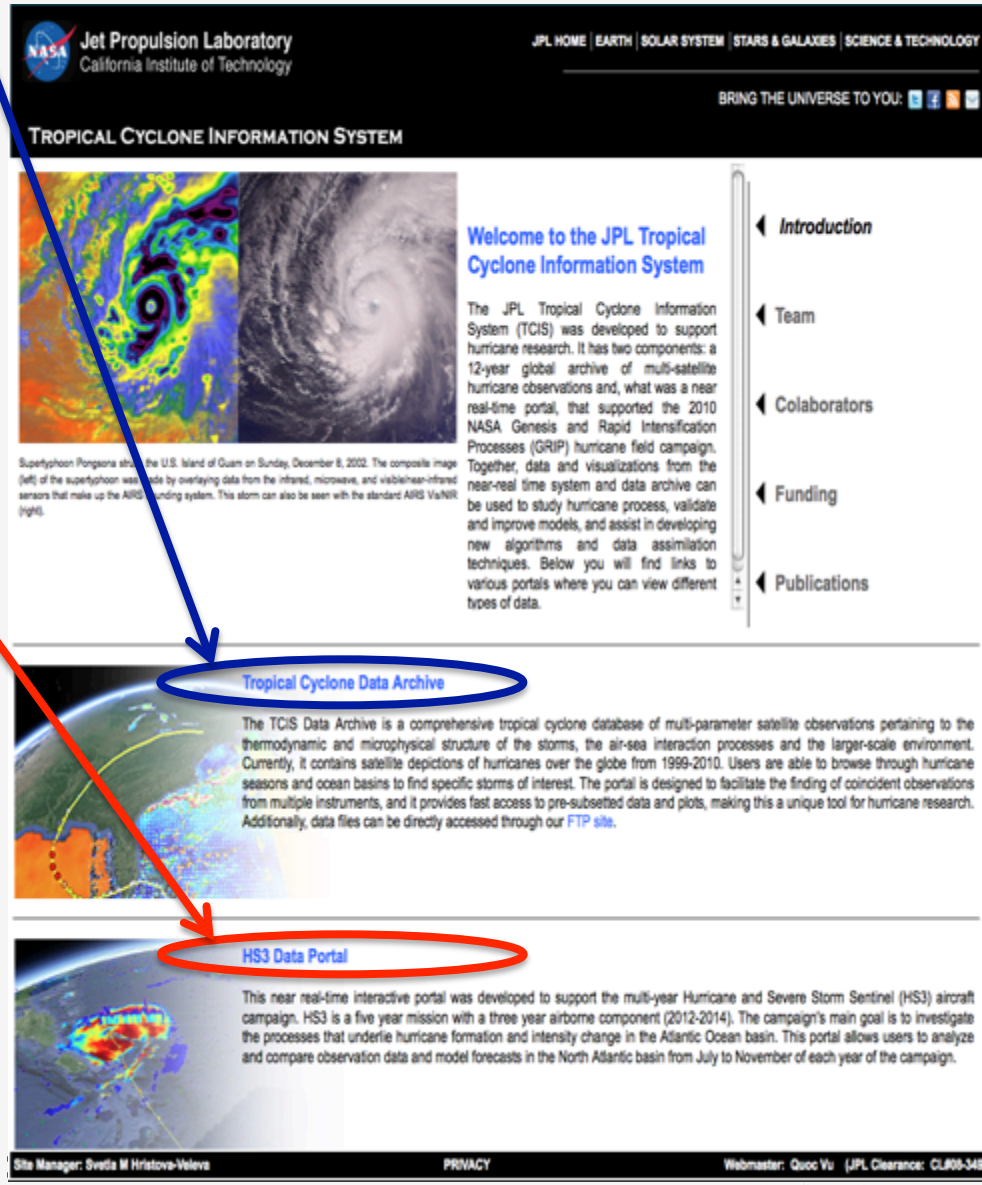
http://tropicalcyclone.jpl.nasa.gov

Tropical Cyclone Data Archive

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

HS3 – Interactive NRT Atlantic portal

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



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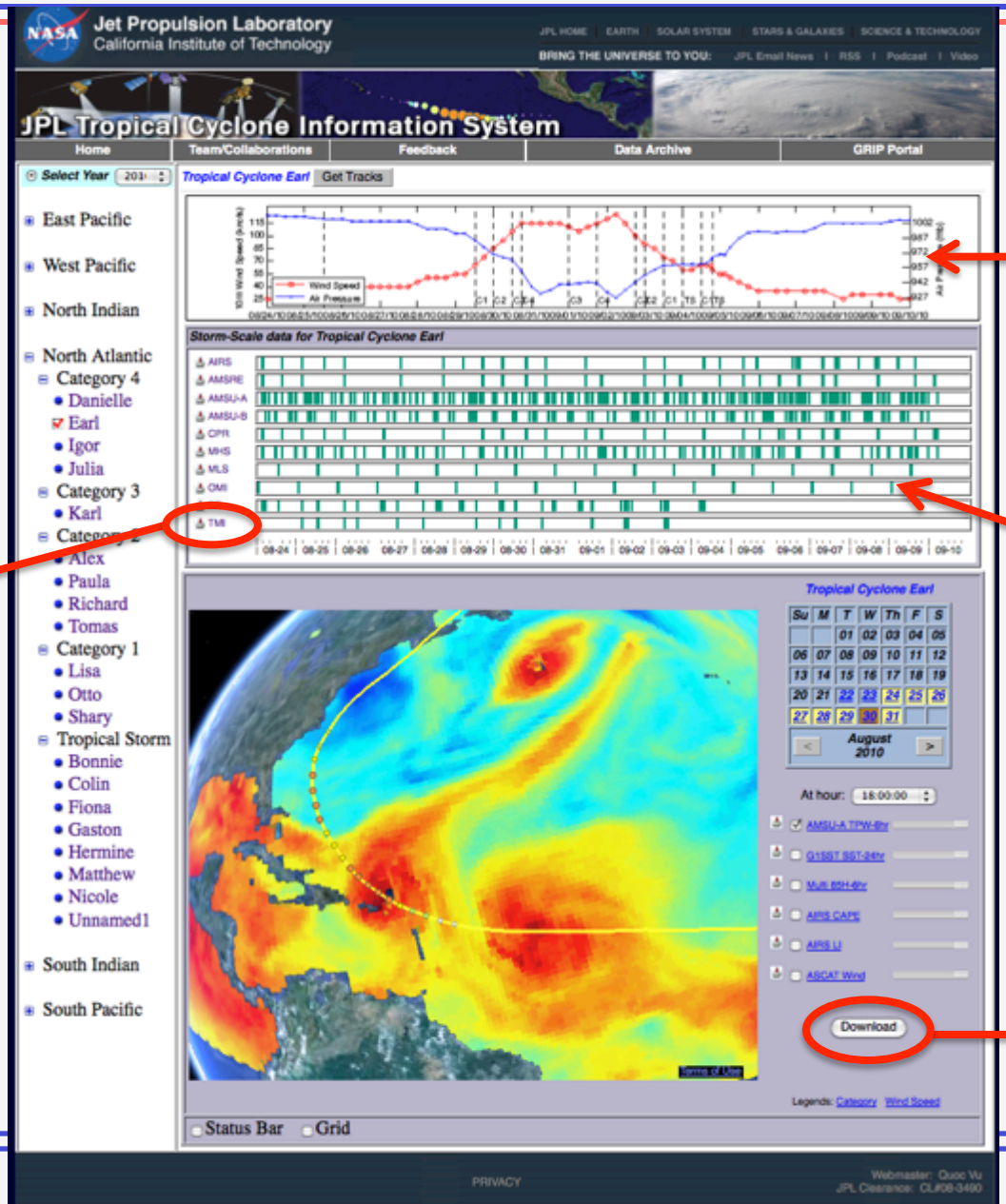


Timeline

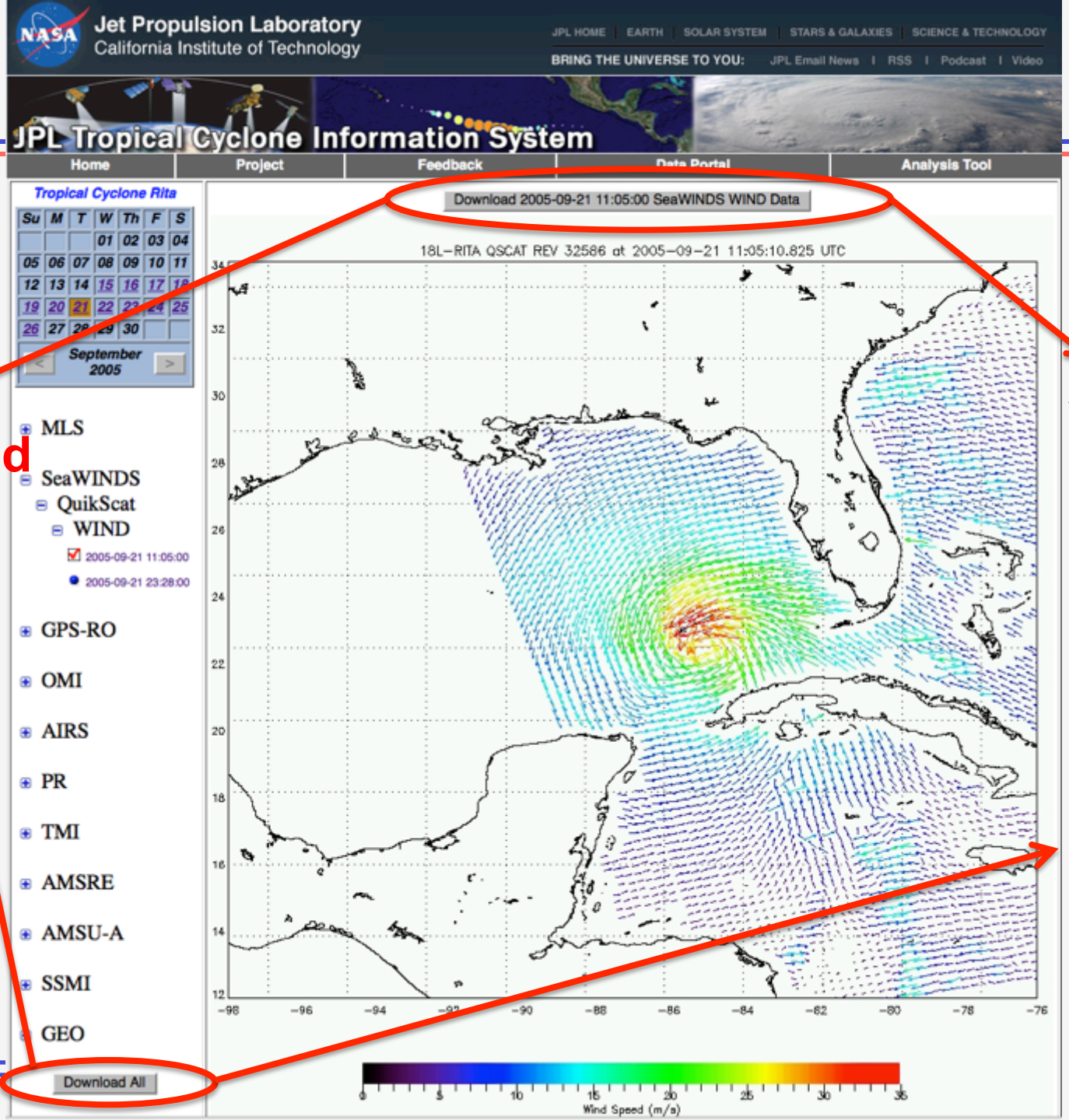
View and download Storm-scale data

Earl, 2010

Download all data from this Instrument (TMI)

Download Selected large-scale data from this day

ESTO
Earth Science Technology Office



Download NetCDF

At this time

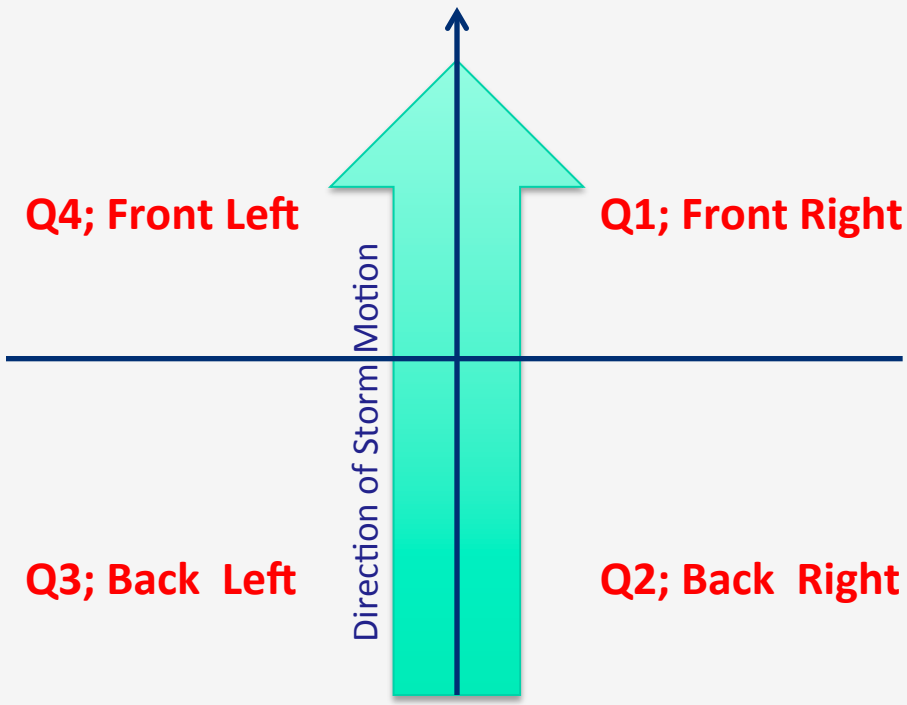
All data on this day

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.

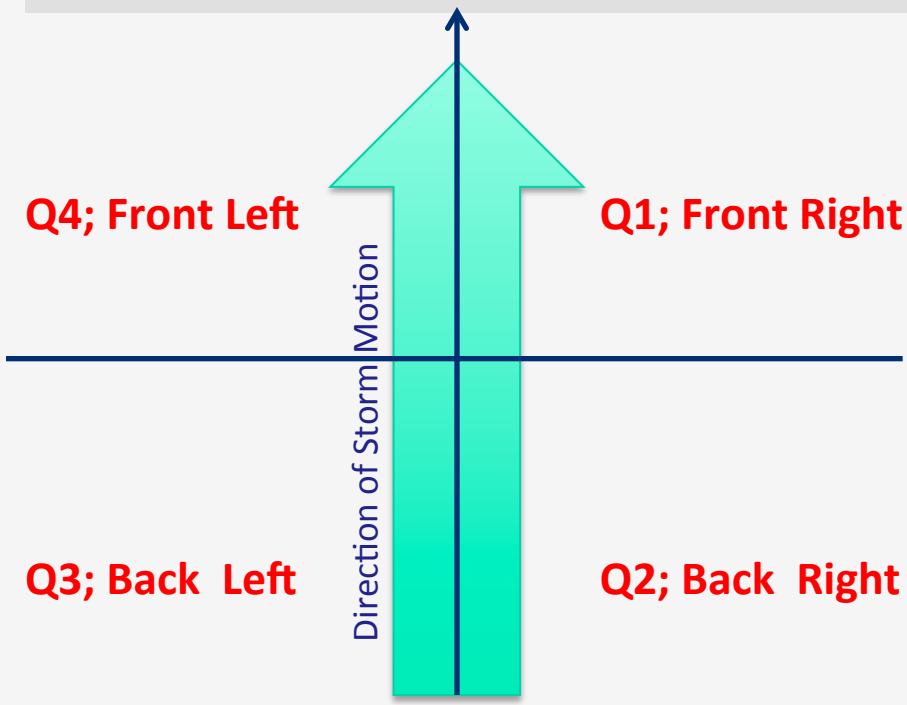
Many others.

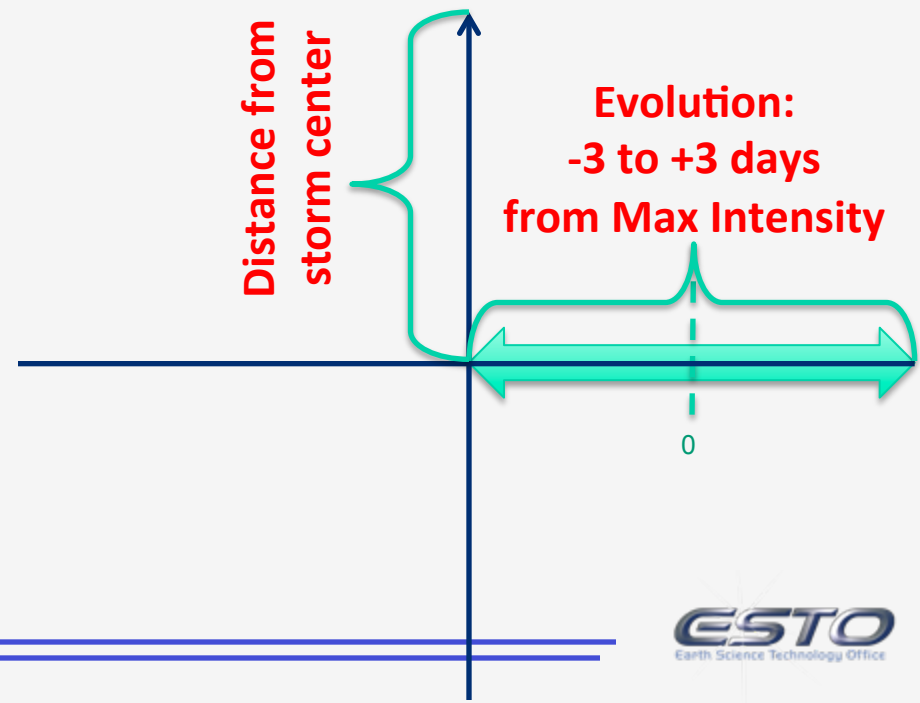
Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

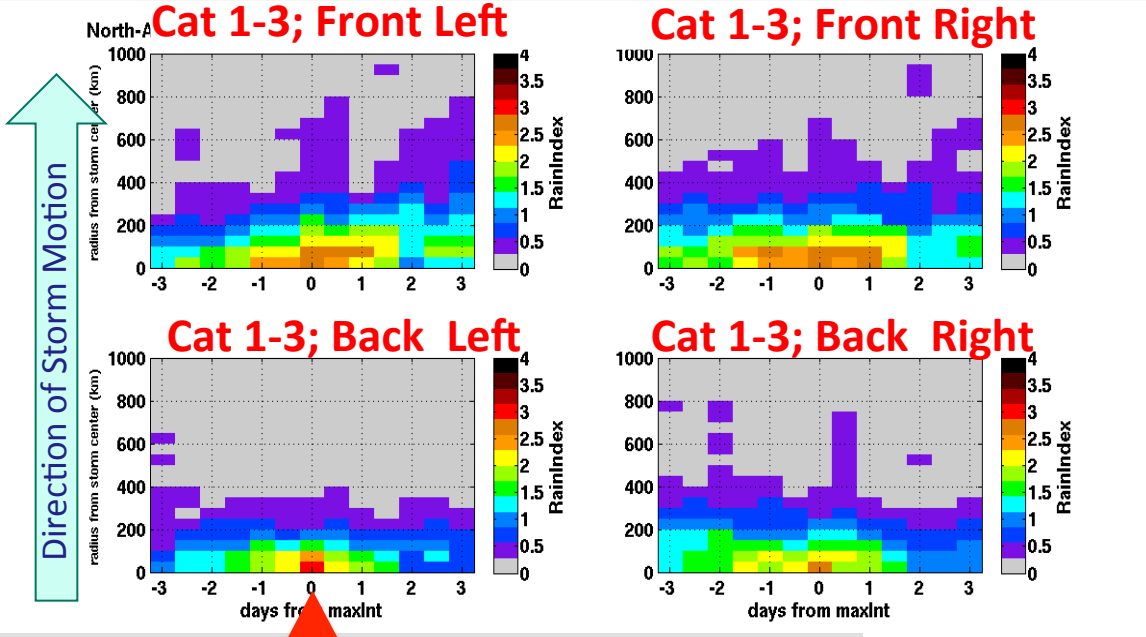
Parameter as a function of:

- 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



Day of Maximum Intensity

Evolution of asymmetry

Azimuthal/Range Distributions of

Rain Index

Cat1: 31 cases

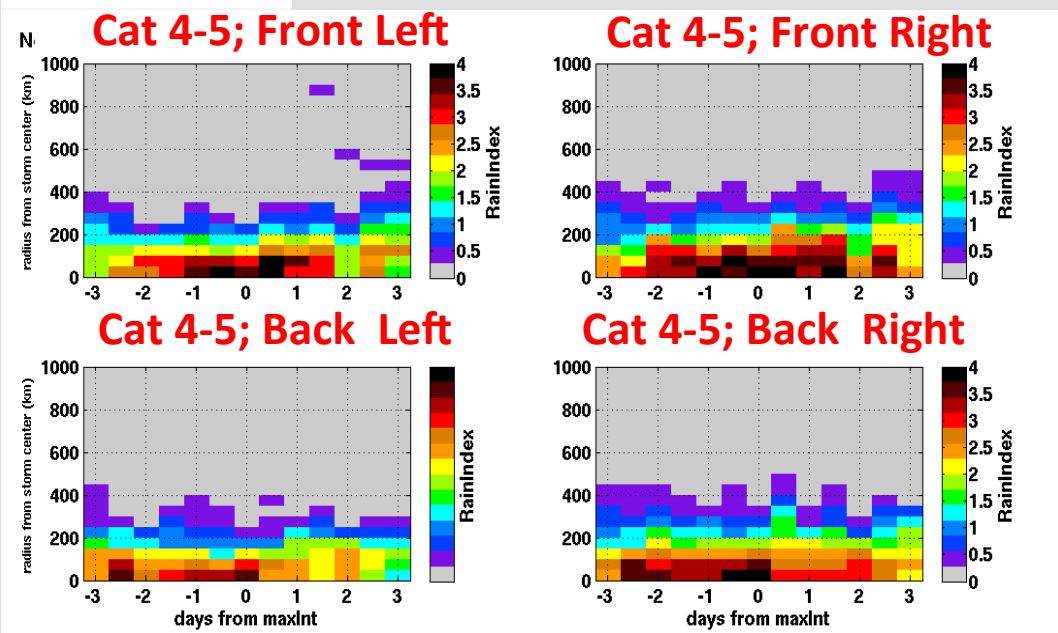
Cat2: 9 cases

Cat3: 12 cases

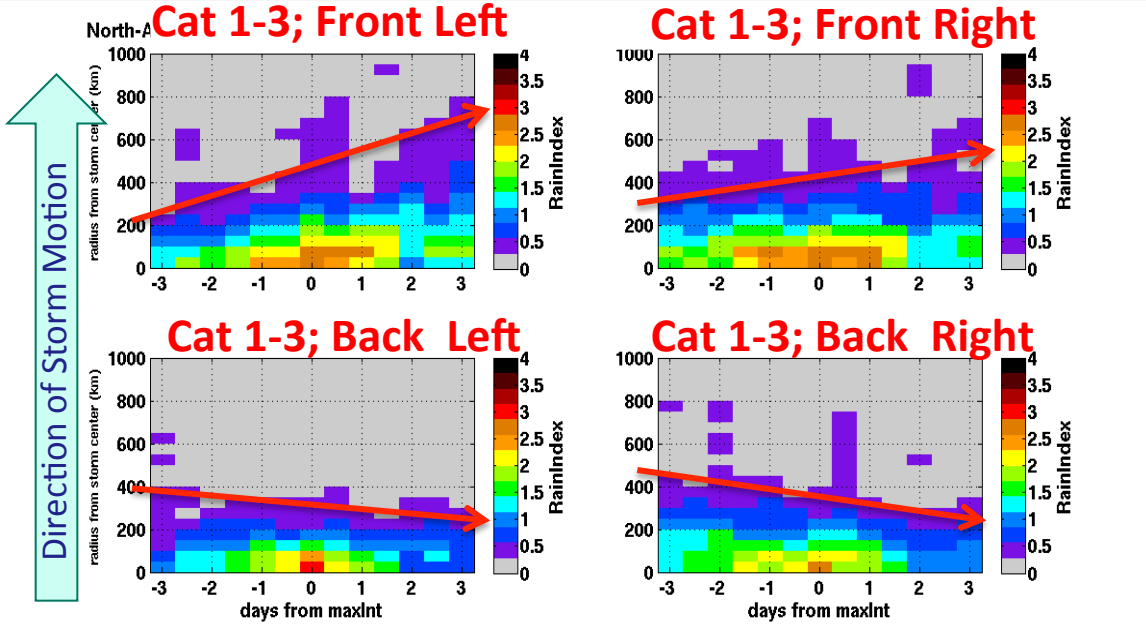
Total Cat1-3 = 52 cases

Cat4: 18 cases

Cat5: 7 cases



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



Evolution of asymmetry

Azimuthal/Range Distributions of

Rain Index

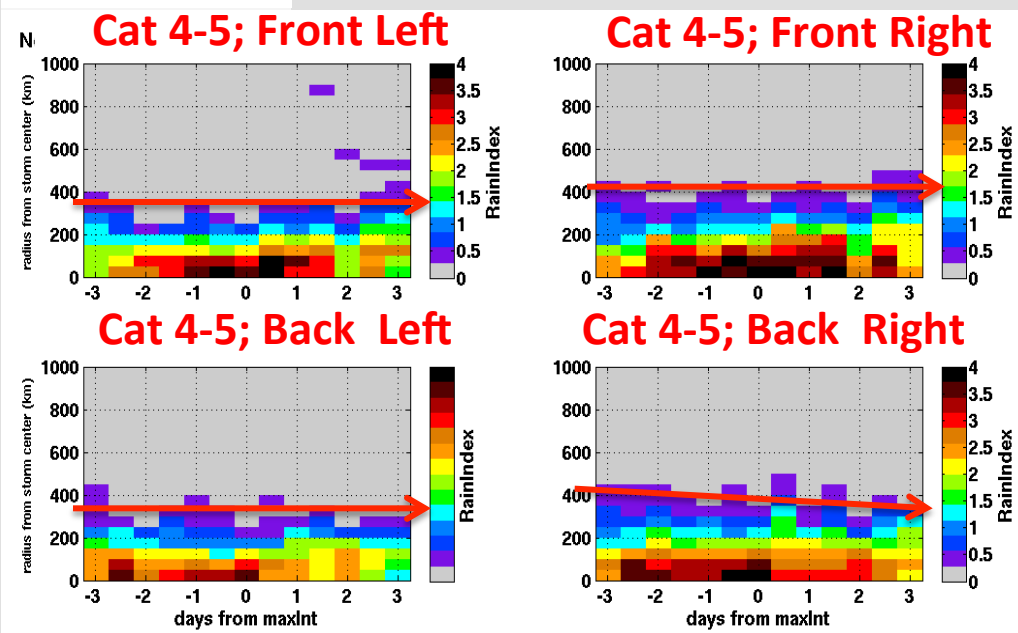
Cat1: 31 cases
Cat2: 9 cases
Cat3: 12 cases

Total Cat1-3 = 52 cases

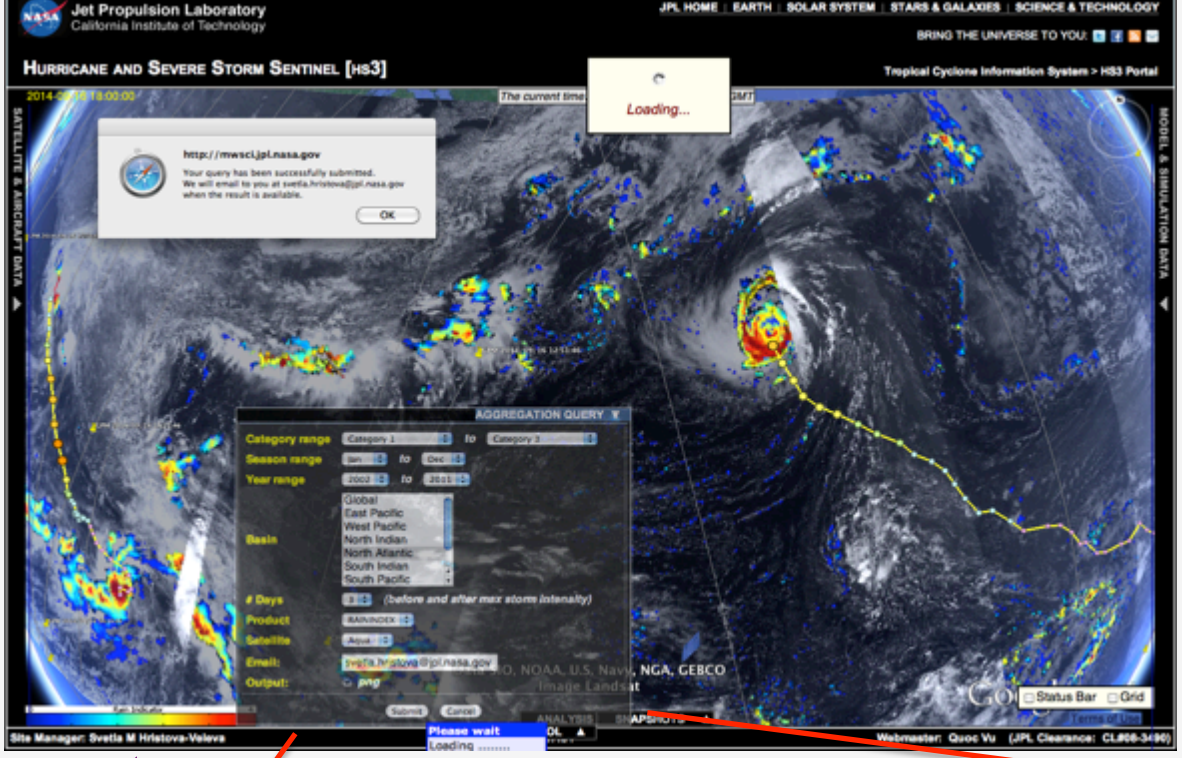
Cat4: 18 cases
Cat5: 7 cases

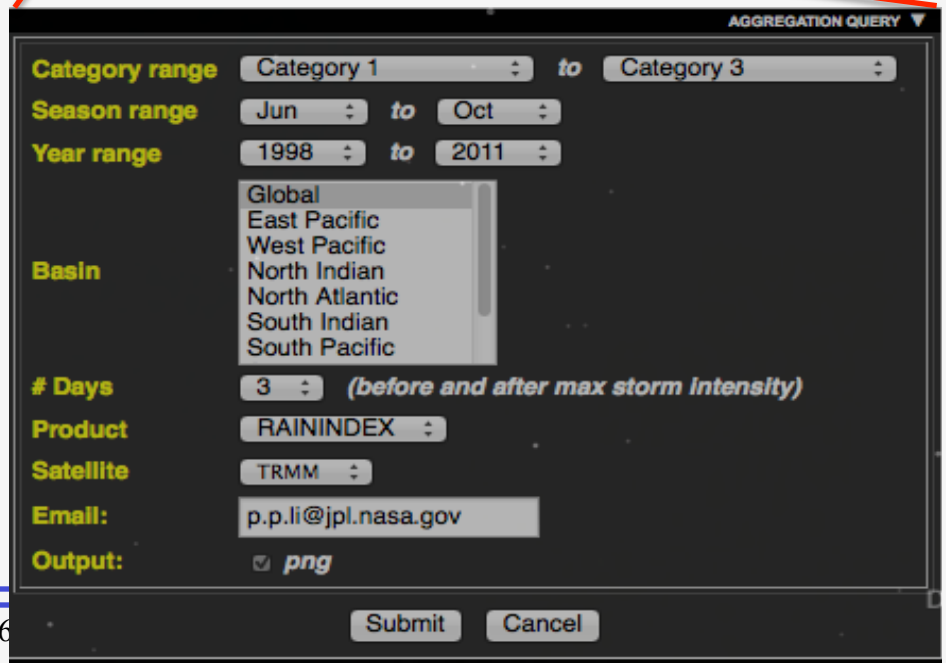
Cat 1-3 have rain fields that are larger, weaker and less symmetric in:

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



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





Summary

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

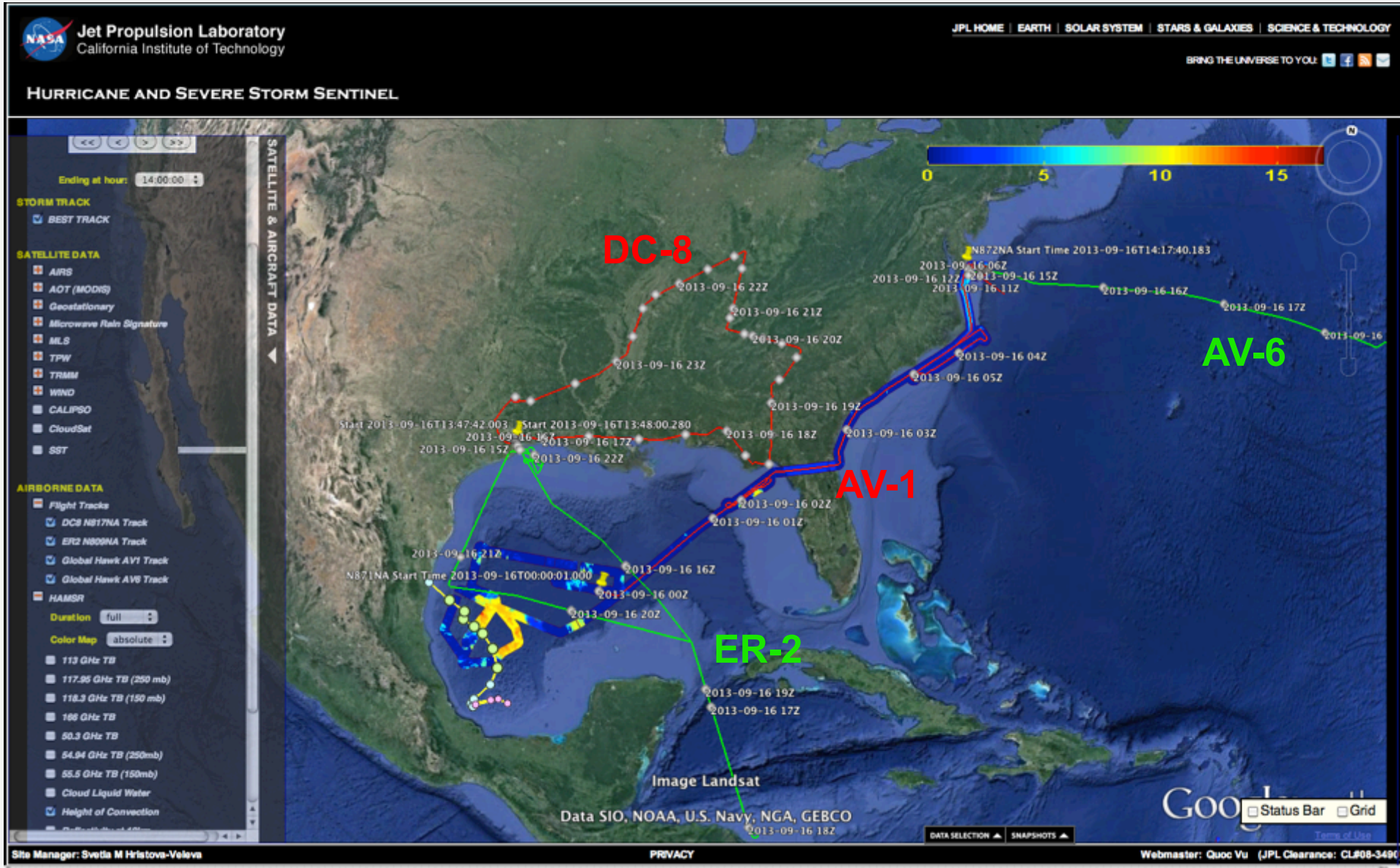
What is unique about our efforts

- Large number of Observations, COMBINED with Models
- Interactive visualization and interrogation
  - Search by Date; Search by Hurricane; "Storm Track", Forecasts Tracks
  - Overlays, Transparency
- Synthetic data from two instrument simulators
  - Simulation of Satellite-like observations
    - Operational – Using CRTM and HWRF; in NRT
    - Research - Orbit-sampling; Antenna-averaging; Instrument specific viewing geometry; Synthetic data from the large-scale models
- On-line Analysis tools
  - Environment
    - the "Slicer"; Skew-T plots
  - Storm structure – Vitals and Vertical structure
    - Storm Center Finding (ARCHER); Wave Number Analysis, Joint PDFs
- Integration with the 12+ year climatology

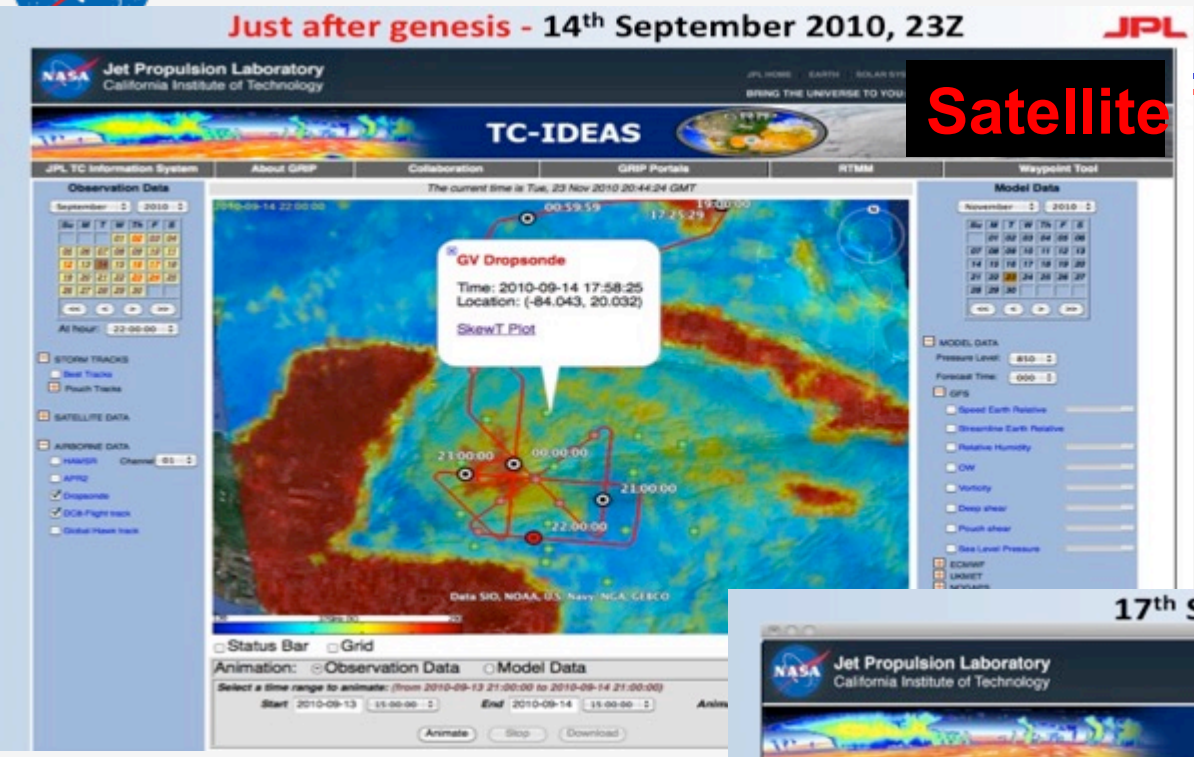
What else we can do

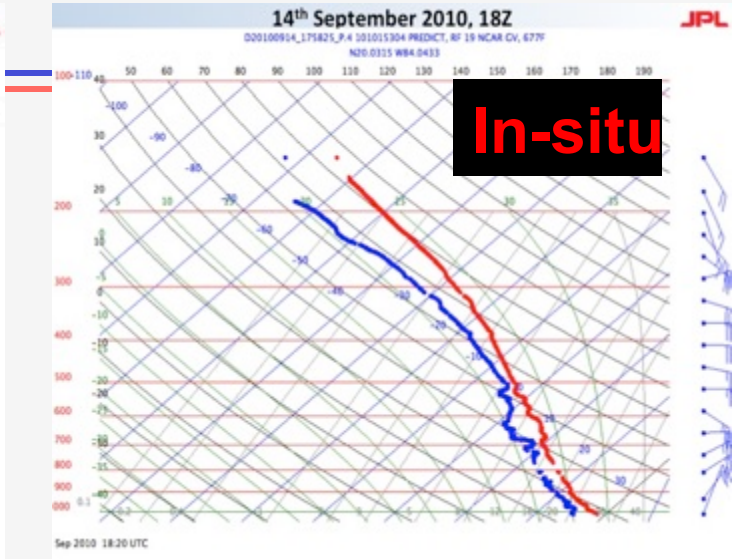
- Bring in the airborne observations
  - Flight tracks
  - Radiosondes (Skew-T plots)
  - Any KML files
- Modify the existing tools to analyze other data
  - Wave number analysis of the TPW

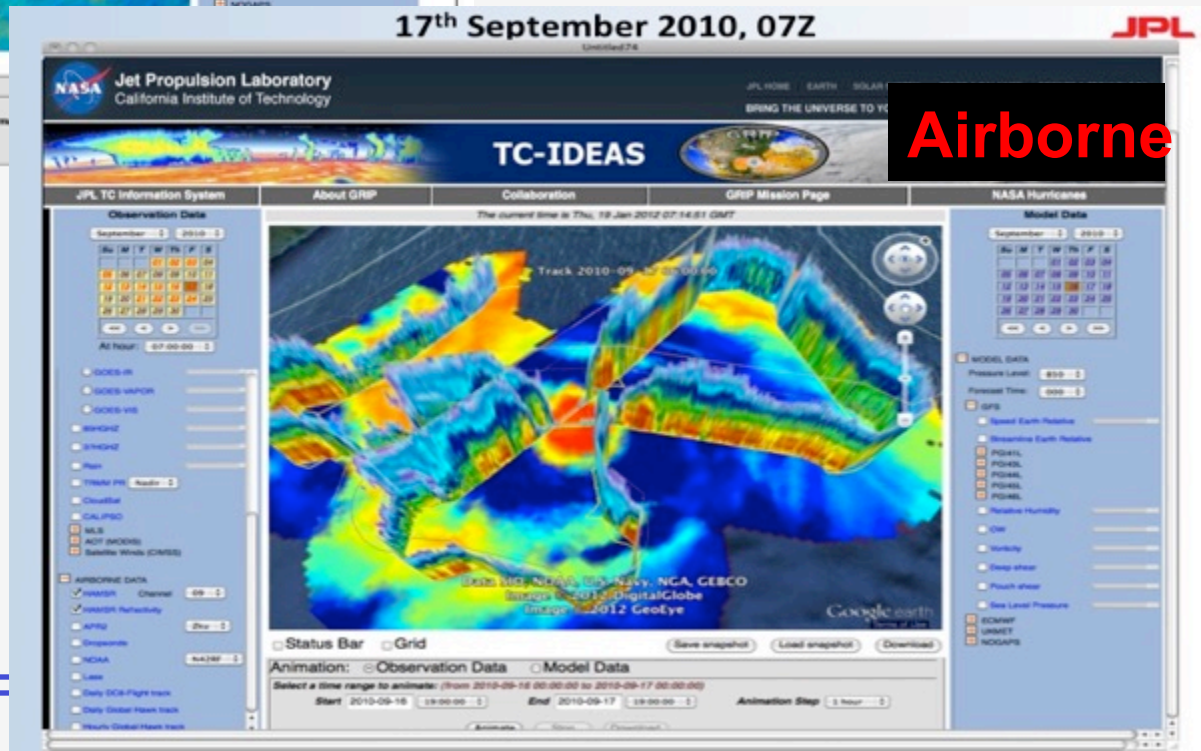
Airborne Science: HS3 and SEAC4RS
2013-09-16; 14Z - Ingrid;
AV-1 (HAMSR), AV-6, ER2, DC8



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







Hurricane Karl (2010):

Genesis and Rapid Intensification from

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

Thank you !