Jet Propulsion Laboratory
California Institute of Technology

The JPL Tropical Cyclone Information System: A Wealth of Data for Quickly Advancing the Physical Understanding and Forecasting of Hurricanes.

Svetla Hristova-Veleva[1], P. Peggy Li[1], Brian Knosp[1], Quoc Vu[1], F. Joseph Turk[1], William L. Poulsen[1], Ziad Haddad[1], Bjorn Lambrigtsen[1], Bryan Stiles[1], Tsae-Pyng Shen[1], Noppasin Niamsuwan[1], Simone Tanelli[1], Ousmane Sy[1], Hui Su[1], Deborah G. Vane[1], Yi Chao[1], Philip S. Callahan[1], R. Scott Dunbar[1], Michael Montgomery[2], Mark Boothe[2], Vijay Tallapragada[3], Samuel Trahan[3], Anthony J. Wimmers[4], Robert Holz[4], Jeffrey Reid[5], Frank Marks[6], Tomislava Vukicevic[6], Saiprasanth Bhalachandran[7], Hua Leighton[8], Sundararaman Gopalakrishnan[6], Andres Navarro [9], Francisco J. Tapiador[9]

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[5] – *Naval Research Laboratory, Monterey, CA*
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[8] – *Hurricane Research Division/AOML/NOAA/University of Miami, RSMAS*
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July 9th, 2021

Thanks to Robin Vane for video

1. Motivation:

The critical pathway to hurricane forecast improvement is to use observations and models together to:

- Advance the still-lacking understanding of the governing processes
- Evaluate and improve models through the use of satellite data
- Develop advanced techniques for assimilating 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 their volume and complexity*** (indirect and very nonlinear sensitivity to the most important underlying model variables).

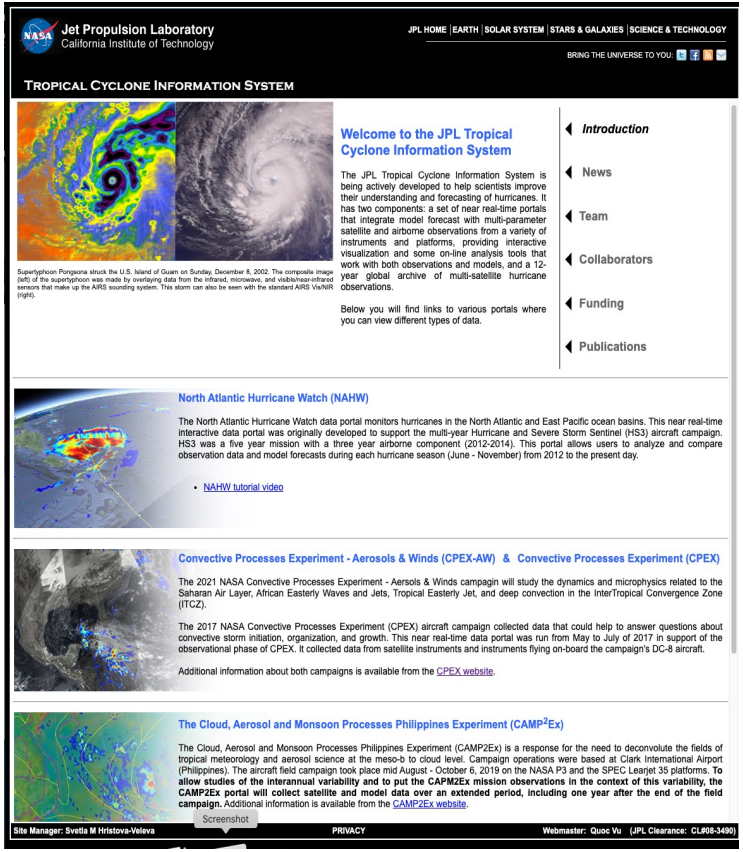
To support the needs of the research and operational communities, several NASA –funded efforts resulted in the development of the Tropical Cyclone Information System – a hurricane-specific Data Analytic Center Framework

The TCIS components:

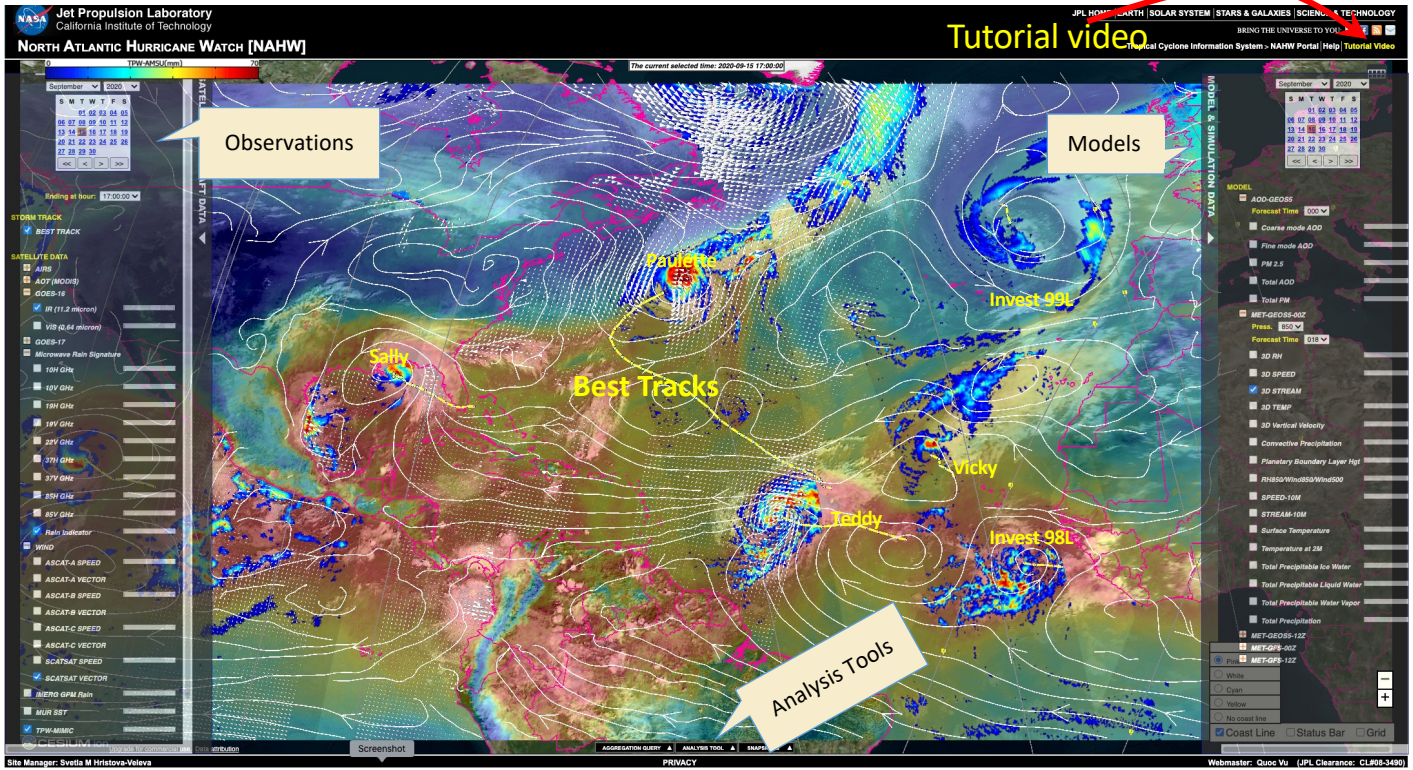
- **Three interactive portals:**
  - the **North Atlantic Hurricane Watch** (NAHW - https://nahw.jpl.nasa.gov)
  - **data portals to support field campaigns to study tropical convection**
    - They serve as a very rich information source during the planning and particularly during the analysis stages of field campaigns
    - **NASA's 2017 Convective Processes Experiment (CPEX)** https://cpex.jpl.nasa.gov)
    - **NASA's 2019 CAMP2Ex** - https://camp2ex.jpl.nasa.gov
    - **NASA's 2021 CPEX-AW** – https://cpex-aw.jpl.nasa.gov

- A 12-year-long (1999–2011) **global data archive (TCDA)** of satellite observations of tropical cyclones (non-interactive).
  - a one-stop place to obtain an extensive set of multi-parameter data from multiple observing systems.
  - offers both digital data and imagery, subset to the domain and time of interest, thus greatly reducing the volume of unwanted data.
  - This makes TCDA a valuable source to quickly build statistics in support of research, forecast improvement and algorithm development

https://tropicalcyclone.jpl.nasa.gov



JPL TCIS - Interactive Visualization of multiparameter observations and models



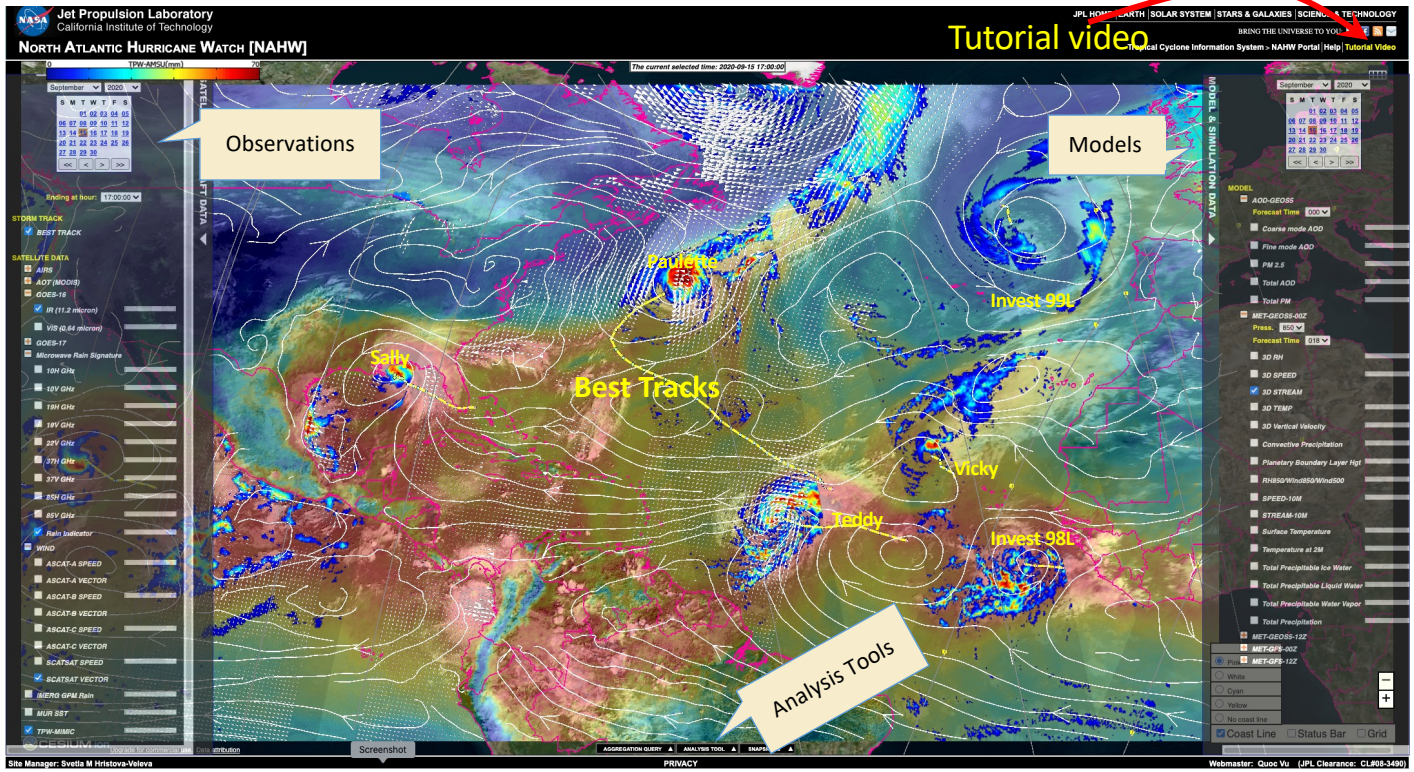
To support the needs of the research and operational communities, several NASA-funded efforts resulted in the development of the JPL Tropical Cyclone Information System – a Data Analytic Center Framework that:

- ingests and processes dozens of data streams
- combines model forecasts with satellite and airborne observations, bringing them all within a common system.

This system

- provides interactive visualization
- supports some on-line analysis tools that can be used with both observations and models.

JPL TCIS - Interactive Visualization of multiparameter observations and models



The goal of the JPL TCIS data analytic framework is to help scientist:

1. **gain intuition in the complex multi-scale interactions that lead to the evolution of tropical convection in general and hurricane processes, in particular**
2. **To support airborne flight campaigns: planning**, in-air flight operations
3. **To provide a common system for post-event exploratory analysis**
4. **To provide the data** (satellite and model) that are included in the TCIS

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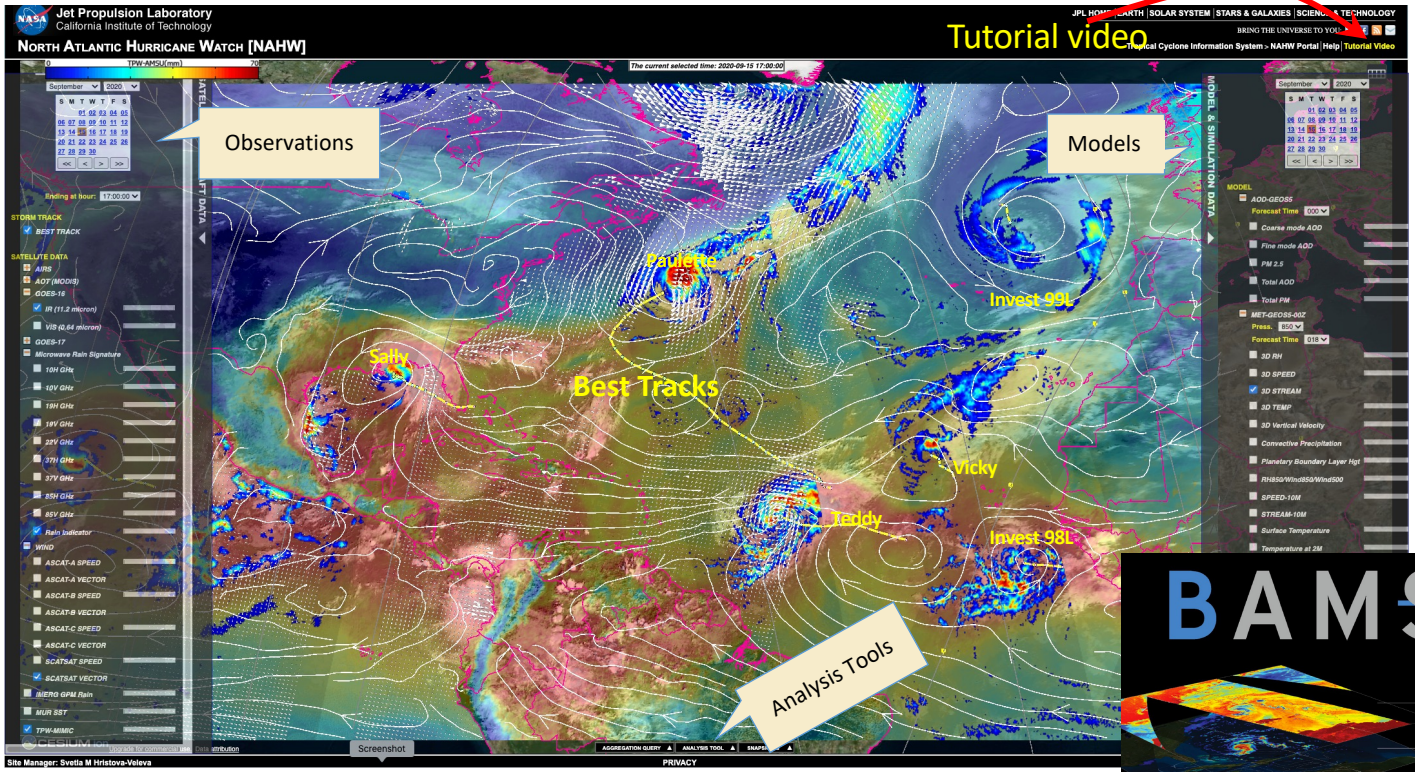
JPL TCIS - Interactive Visualization of multiparameter observations and models



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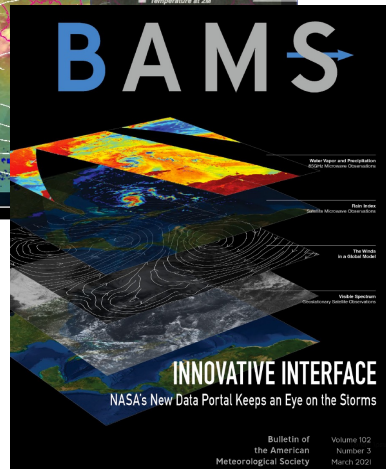


The JPL TCIS is described in the March 2021 issue of BAMS and featured on the Cover.

Table 1. Summary of the spatial and temporal coverage for all components of TCIS. The domain of the NAHW has expanded over the years. Given are the dimensions of the current domain.

Portals	Temporal Coverage	Domain
NAHW	2012-present	*Latitude: **10S – 60N**; Longitude: **175W – 0W***
CAMP2Ex	2018-present	Latitude: **15S – 35N**; Longitude: **40E – 180E**
CPEX	05/15/2017 – 07/15/2017	Latitude: **10N – 40N**; Longitude: **100W – 45W**
CPEX-AW	June 2020 - present	Latitude: **5S – 45N**; Longitude: **100W – 40E**
TC Data Archive	1999-2010	**Global**

Table 2. Types and sources for the satellite data routinely included in TCIS

The color-coding reflects the following:

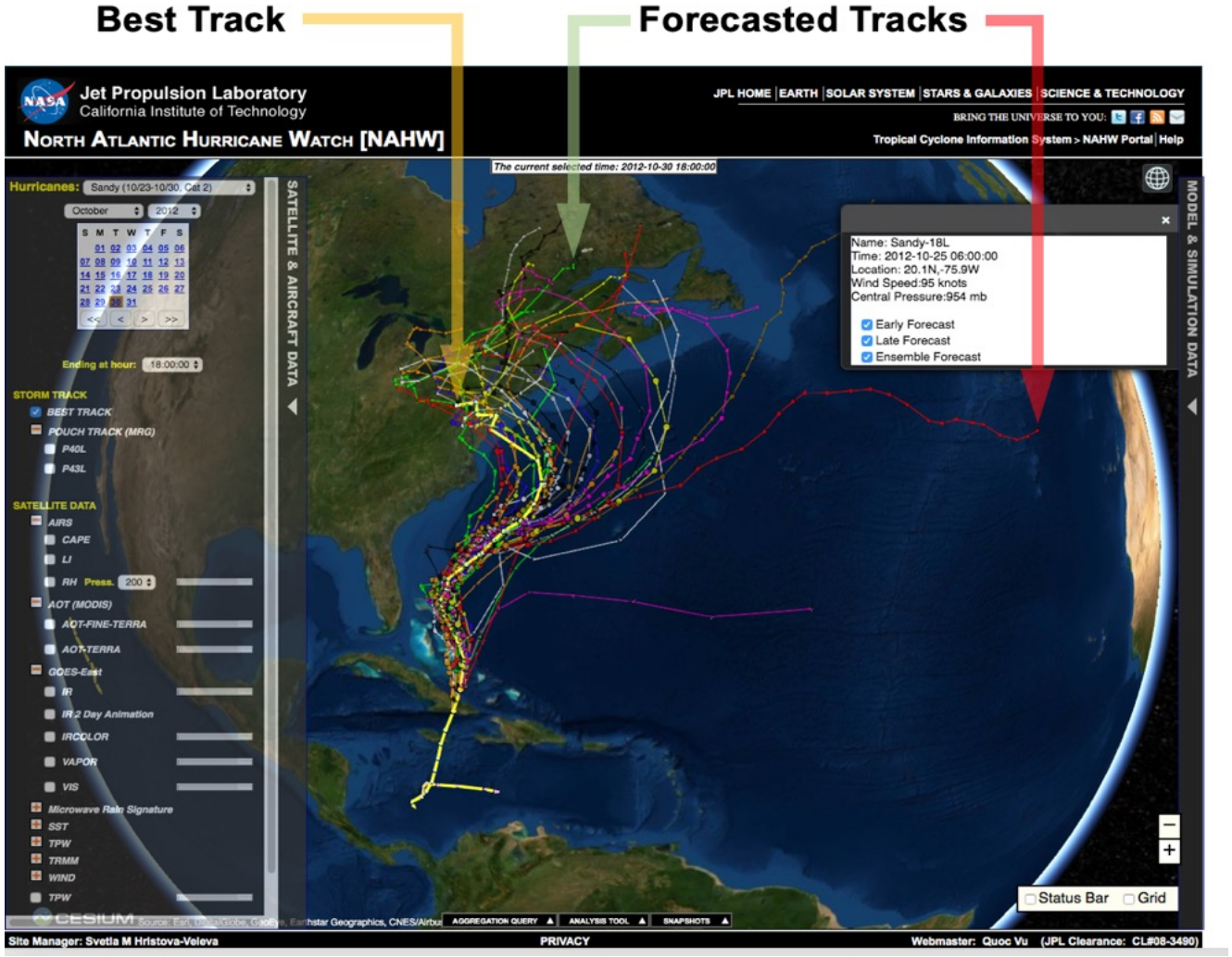
***** Atmospheric composition ***** Thermodynamics *****Surface *****Convective Activity

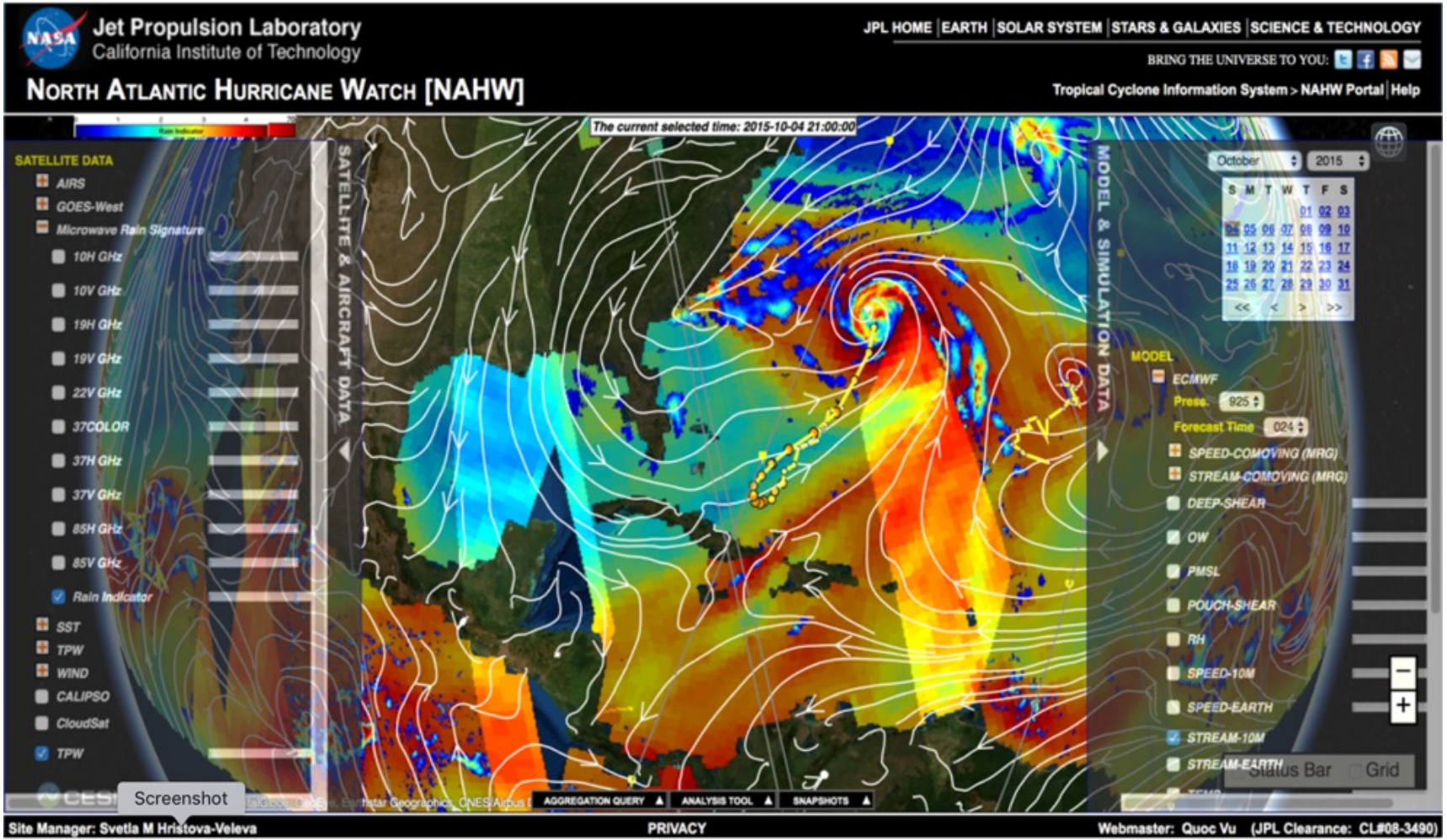
SENSORS	DATA PRODUCTS	DATA SOURCES
MODIS	Aerosol Optical Thickness	LAADS DAAC
AIRS	Temperature and Water Vapor – vertical profiles;	GES-DISC
MHS, ATMS (NOAA, MetOp, NPP)	Total Precipitable Water	NOAA-NESDIS, CLASS
MUR-SST	Sea Surface Temperature	JPL PO.DAAC
QuikSCAT; RapidScat	Surface vector winds over the oceans	JPL PO.DAAC
ASCAT-A; ASCAT-B	Surface vector winds over the oceans	KNMI/JPL PO.DAAC
ScatSat	Surface vector winds over the ocean	JPL product from ISRO's observations
SMAP	Surface wind speed over the ocean	JPL product
CYGNSS	Surface wind speed over the ocean	JPL P0.DAAC
GOES-E and GOES-W; Himawari-AHI	Geostationary IR (~ 11 um and ~6.7 um water vapor); VIS	NOAA/CLASS; NRL; CIMSS-SSEC;
TMI, GMI, AMSR2, SSMI, SSMIS	Brightness temperatures 10-89 GHz;	GPM - NASA GSFC PPS
TMI, GMI, AMSR2, SSMIS	Rain Indicator – 2D maps of relative rain intensity	JPL Derived Product
GPM-IMERG	Integrated Multi-instrument 1-hour rain totals	GPM - NASA GSFC PPS
"Best Track"	Hurricane location, estimated maximum wind speed and minimum MSLP, updated every 6 hours	NCAR/RAL**
TC DATA ARCHIVE ONLY		
OMI	Ozone – total column;	GES-DISC
MLS	Ozone - vertical profiles:	GES-DISC
MLS	Temperature, Water Vapor - vertical profiles	GES-DISC
MLS	Ice Content – vertical profiles	GES-DISC
TRMM-PR	Precipitation; Radar Reflectivity – 3D structure	GPM - NASA GSFC PPS
CloudSat	Clouds and precipitation; Radar Backscatter; vertical profiles	Cloudsat Data Processing Center/CSU

Table 3. Types and sources of model fields available in TCIS. For each model, listed are the specific portals which provide the data. Period of availability is given in parenthesis.

MODELS	DATA PRODUCTS	DATA SOURCES
GFS - NAHW - CPEX - CAMP2Ex	- Temperature, Relative Humidity, Horizontal wind - **at standard pressure levels;** - **2D fields:** o 10m winds/2m temperature/SST/MSLP o Integrated Precipitable Water; shear (deep and low-level)	NOMADS/NCEP /NOAA MRG
ECMWF - NAHW (2012-2016)	- *Temperature,* Relative Humidity, Horizontal wind - **at standard pressure levels;** - **2D fields:** o Integrated Precipitable Water o Shear (deep and low-level)	MRG
UKMET - NAHW (2012-2014)	- *Temperature,* Relative Humidity, Horizontal wind - **at standard pressure levels;** - **2D fields:** o Integrated Precipitable Water o Shear (deep and low-level)	MRG
ECMWF - CAMP2Ex (2019-present)	- Temperature, Relative Humidity, Horizontal wind, Vertical velocity - **at standard pressure levels;** - **2D fields:** o 10m winds/2m temperature/2m dewpoint/SST/MSLP o Integrated Precipitable Water o Total Precipitation	CAMP²Ex Team
GEOS5 - CAMP2Ex (07/2019-present) - NAHW (10/2019-present)	- Temperature, Relative Humidity, Horizontal Wind, vertical velocity - **at standard pressure levels;** - **2D fields:** o 10m winds/2m temperature/2m humidity; o Integrated Precipitable Water; Integrated Ice Water Path; Integrated Liquid Water o **Aerosol Optical Depth/Tickness (AOD) - Total** o **AOD Coarse Mode** o **AOD Fine Mode**	NCCS/GSFC MDISC
HWRF (regional model) - NAHW (2013-2015)	- **Synthetic microwave brightness temperatures** - **Rain Index**	EMC/NCEP /NOAA

2. Features

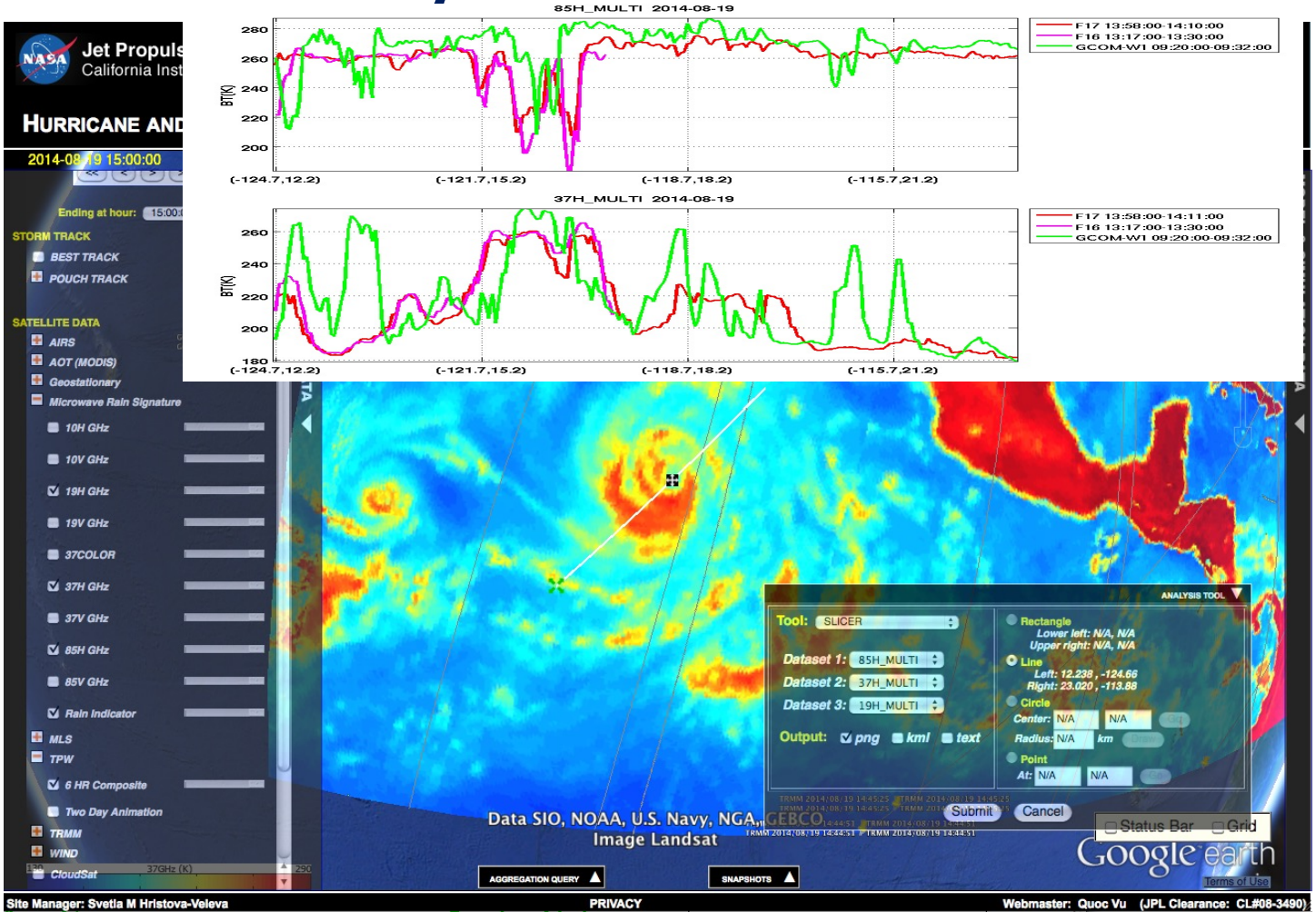

Best Track
Forecasted Tracks
Jet Propulsion Laboratory
California Institute of Technology
NORTH ATLANTIC HURRICANE WATCH [NAHW]
JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | SCIENCE & TECHNOLOGY
BRING THE UNIVERSE TO YOU:
Tropical Cyclone Information System > NAHW Portal | Help
The current selected time: 2012-10-30 18:00:00
Hurricanes: Sandy (10/23-10/30, Cat 2)
October 2012
Ending at hour: 18:00:00
STORM TRACK
BEST TRACK
POUCH TRACK (MRG)
P40L
P43L
SATELLITE DATA
AIRS
CAPE
LI
RH Press. 200
AOT (MODIS)
AOT-FINE-TERRA
AOT-TERRA
GOES-East
IR
IR 2 Day Animation
IRCOLOR
VAPOR
VIS
Microwave Rain Signature
SST
TPW
TRMM
WIND
TPW
SATELLITE & AIRCRAFT DATA
MODEL & SIMULATION DATA
Name: Sandy-18L
Time: 2012-10-25 06:00:00
Location: 20.1N,-75.9W
Wind Speed:95 knots
Central Pressure:954 mb
Early Forecast
Late Forecast
Ensemble Forecast
Status Bar
Grid
CESIUM
AGGREGATION QUERY
ANALYSIS TOOL
SNAPSHOTS
Site Manager: Svetla M Hristova-Veleva
PRIVACY
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)


Jet Propulsion Laboratory
California Institute of Technology
JPL HOME | EARTH | SOLAR SYSTEM | STARS & GALAXIES | SCIENCE & TECHNOLOGY
BRING THE UNIVERSE TO YOU:
NORTH ATLANTIC HURRICANE WATCH [NAHW]
Tropical Cyclone Information System > NAHW Portal | Help
The current selected time: 2015-10-04 21:00:00
SATELLITE DATA
AIRS
GOES-West
Microwave Rain Signature
10H GHz
10V GHz
19H GHz
19V GHz
22V GHz
37COLOR
37H GHz
37V GHz
85H GHz
85V GHz
Rain Indicator
SST
TPW
WIND
CALIPSO
CloudSat
TPW
SATELLITE & AIRCRAFT DATA
MODEL & SIMULATION DATA
October
2015
MODEL
ECMWF
Press
925
Forecast Time
024
SPEED-COMOVING (MRG)
STREAM-COMOVING (MRG)
DEEP-SHEAR
OW
PMSL
POUCH-SHEAR
RH
SPEED-10M
SPEED-EARTH
STREAM-10M
STREAM-EARTH
Status Bar
Grid
AGGREGATION QUERY
ANALYSIS TOOL
SNAPSHOTS
Screenshot
Site Manager: Svetla M Hristova-Veleva
PRIVACY
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)

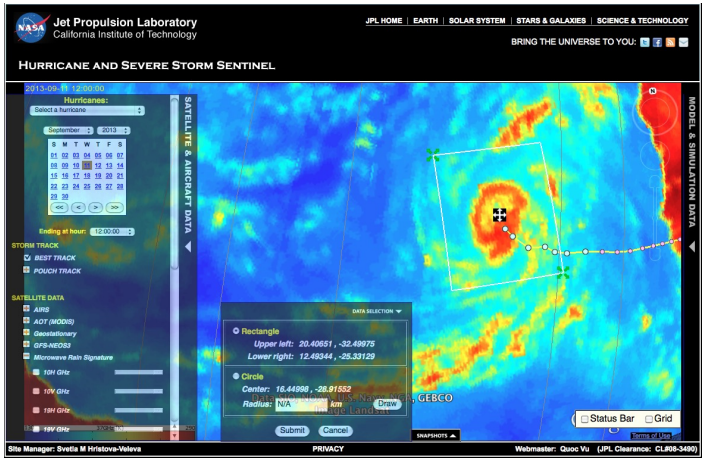
3. Analysis Tools

Looking at the storm structure

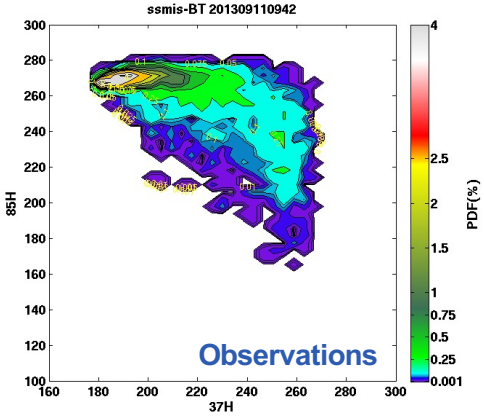
The “Slicer” – analysis of the Storm

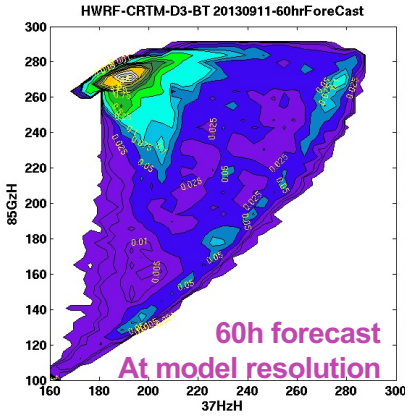


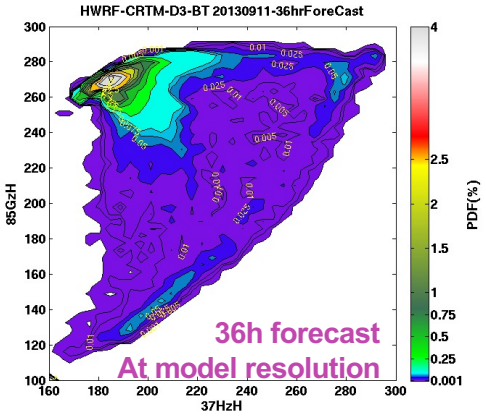
Statistical Tool: *Joint Distribution of Brightness Temperatures*
Example: The Joint PDF of 37GHz and 85GHz TBs; Humberto



- 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!



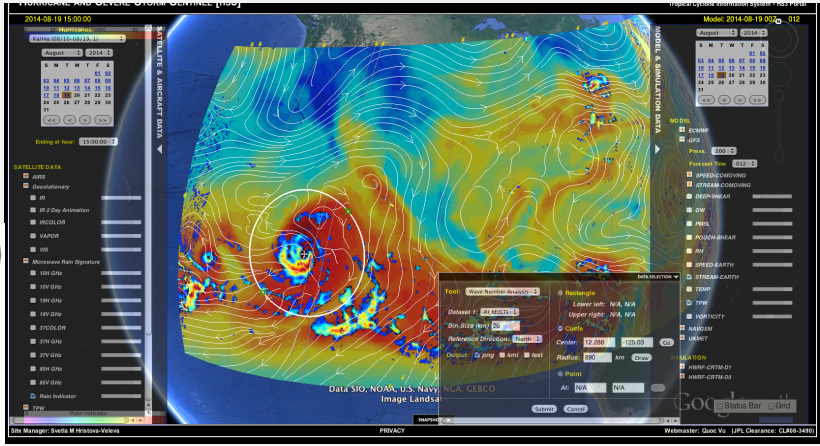




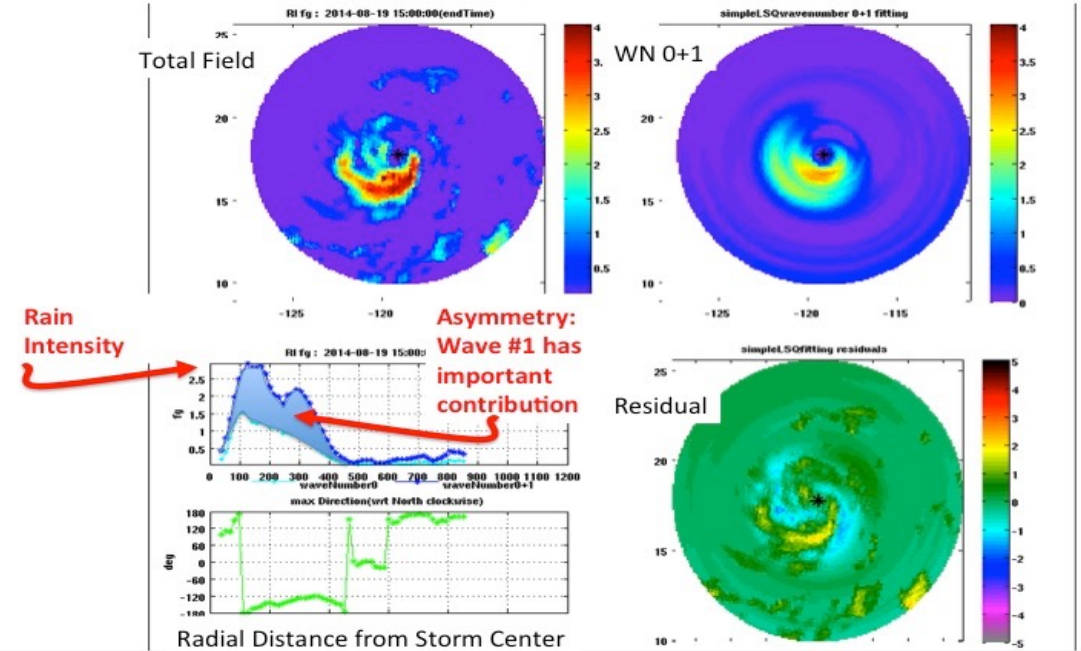
TOOLS:

Wave Number Analysis (WNA) (online)

The JPL Tropical Cyclone Information System and The North Atlantic Hurricane Watch



Wave Number Analysis of the Rain Field (as depicted by the Rain Index) passive microwave observations: FEATURES of the Rain Field



WNA can be used to evaluate three important quantities:

- **the degree of storm symmetry**
- **the precipitation intensity**
- **the radial distribution of precipitation/wind**

Questions regarding hurricane evolution:

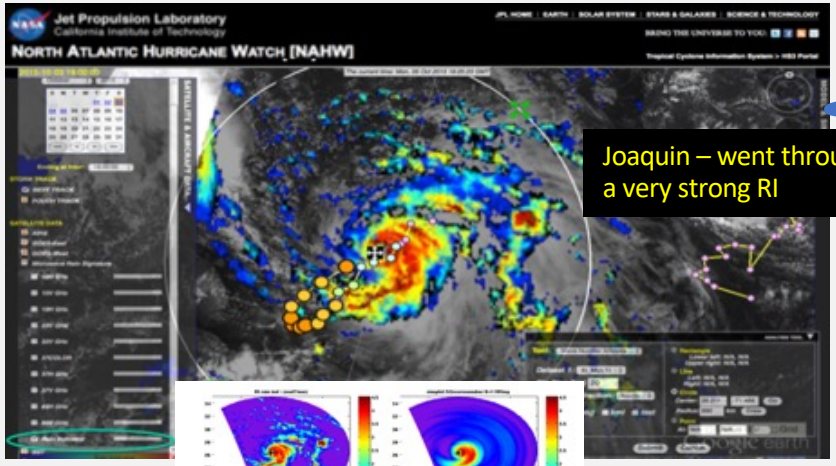
What is the role of the azimuthally symmetric, weak convection?

What is the role of the isolated, intense convection?

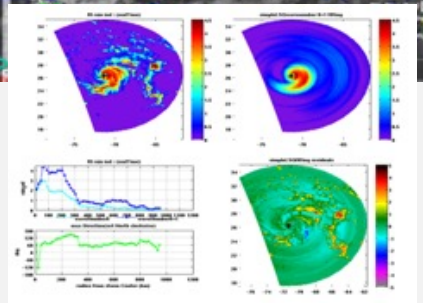
What is the importance of the radial distribution of convection?

Can we use satellite observations to understand these roles? – It seems so …☺

The JPL Tropical Cyclone Information System and
The North Atlantic Hurricane Watch



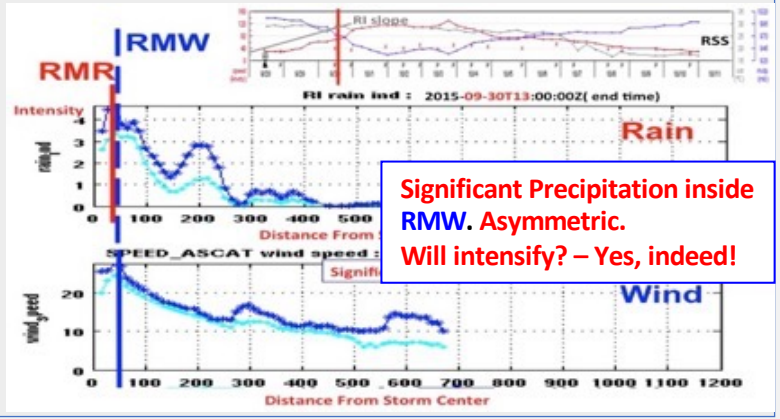
Joaquin – went through a very strong RI



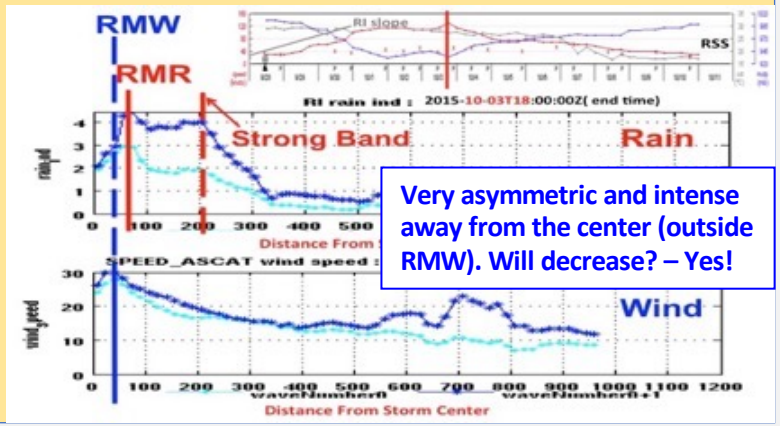
Wave Number Analysis (online)

Possible predictors for the Rapid Intensification and evolution of hurricanes from satellite observations of precipitation and surface winds

Svetla Hristova-Veleva Z. Haddad, B. Stiles, T.-P. Shen, N. Niamsuwan, F. J. Turk, P. P. Li, B. Knosp, Q. Vu, B. Lambrigtsen, W. Poulsen



Significant Precipitation inside RMW. Asymmetric.
Will intensify? – Yes, indeed!



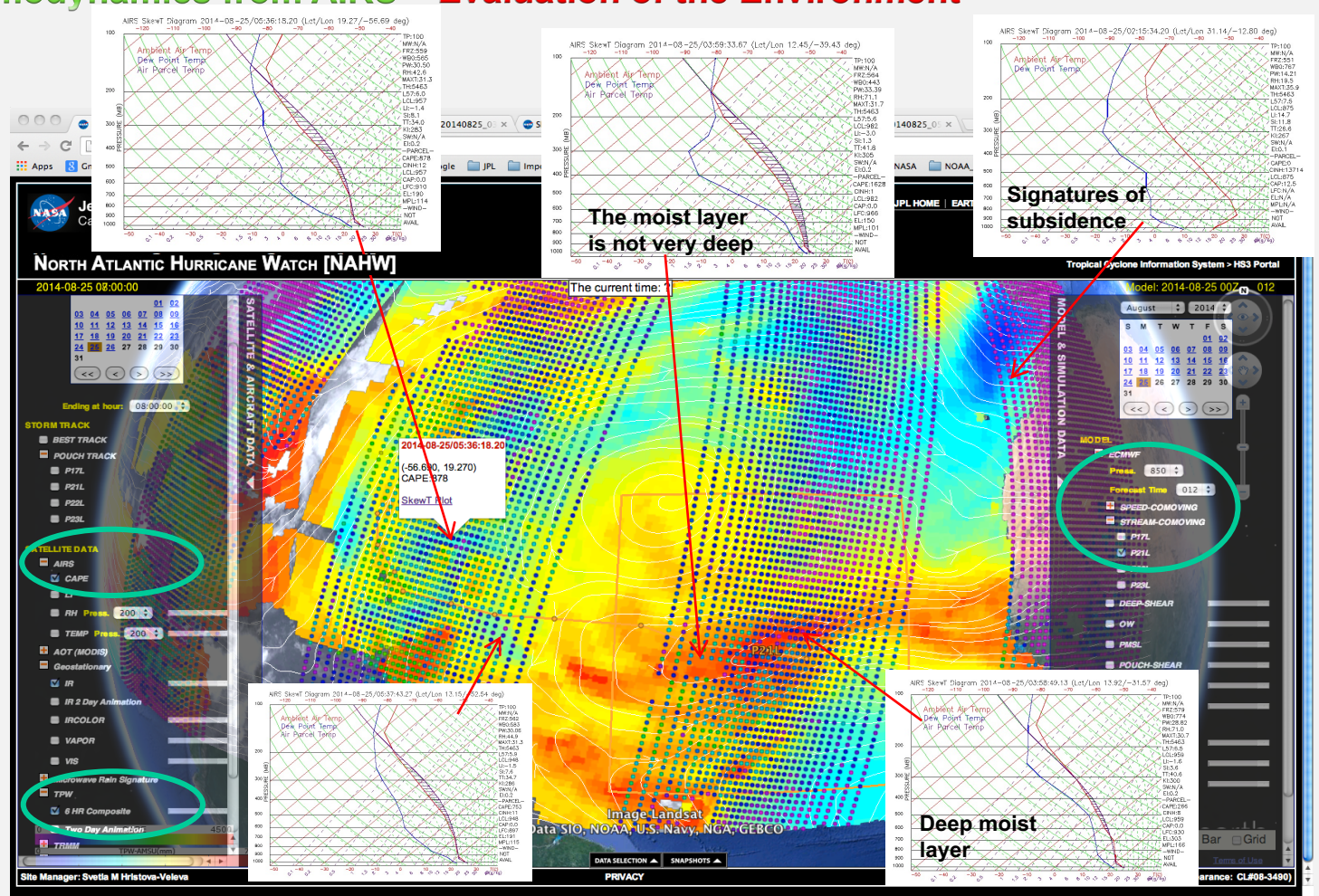
Very asymmetric and intense away from the center (outside RMW). Will decrease? – Yes!

3. Analysis Tools

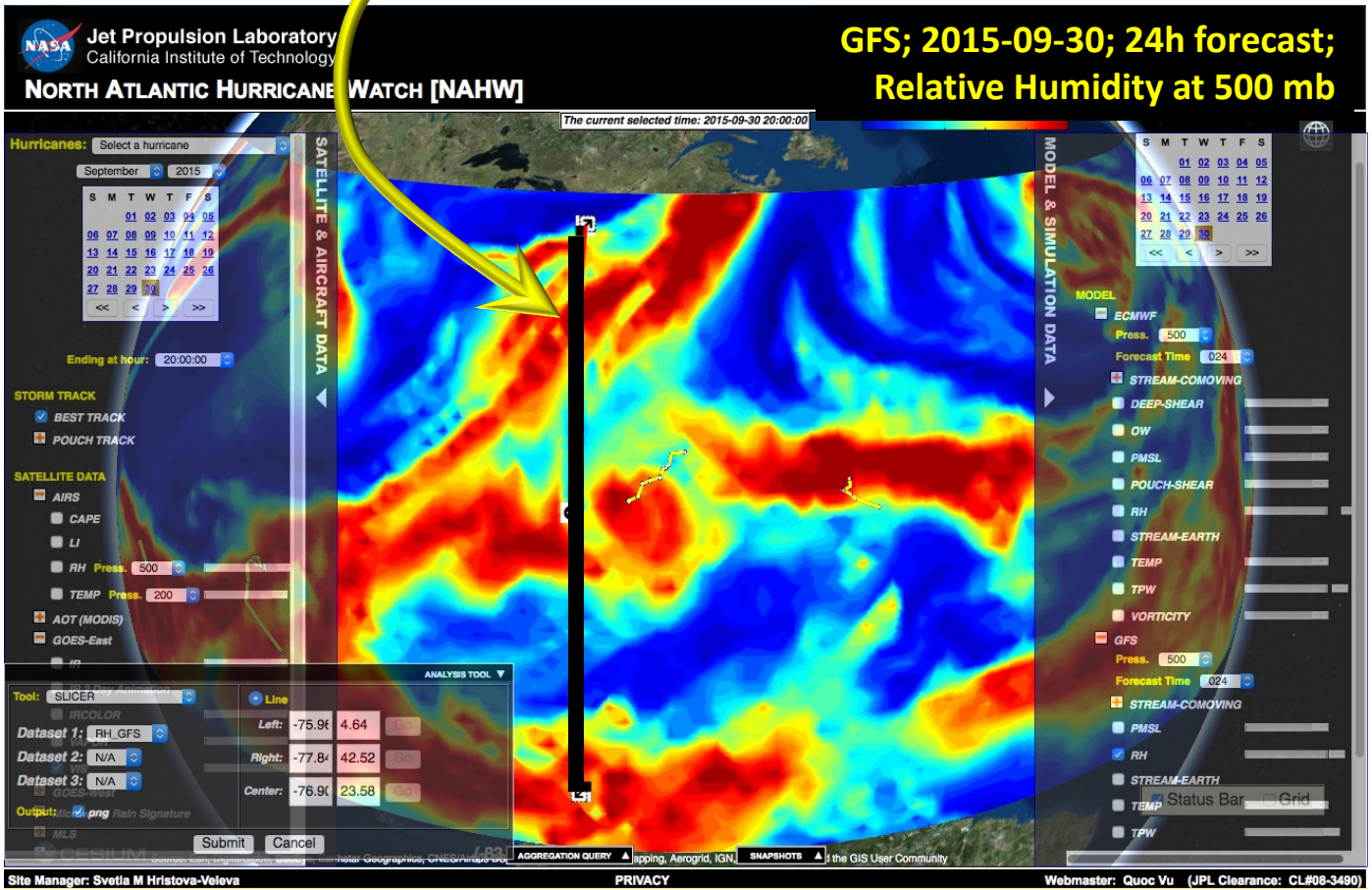
Analyzing the moisture in the environment

NAHW Portal – NRT in 2012-14, Atlantic (https://nahw.jpl.nasa.gov/)

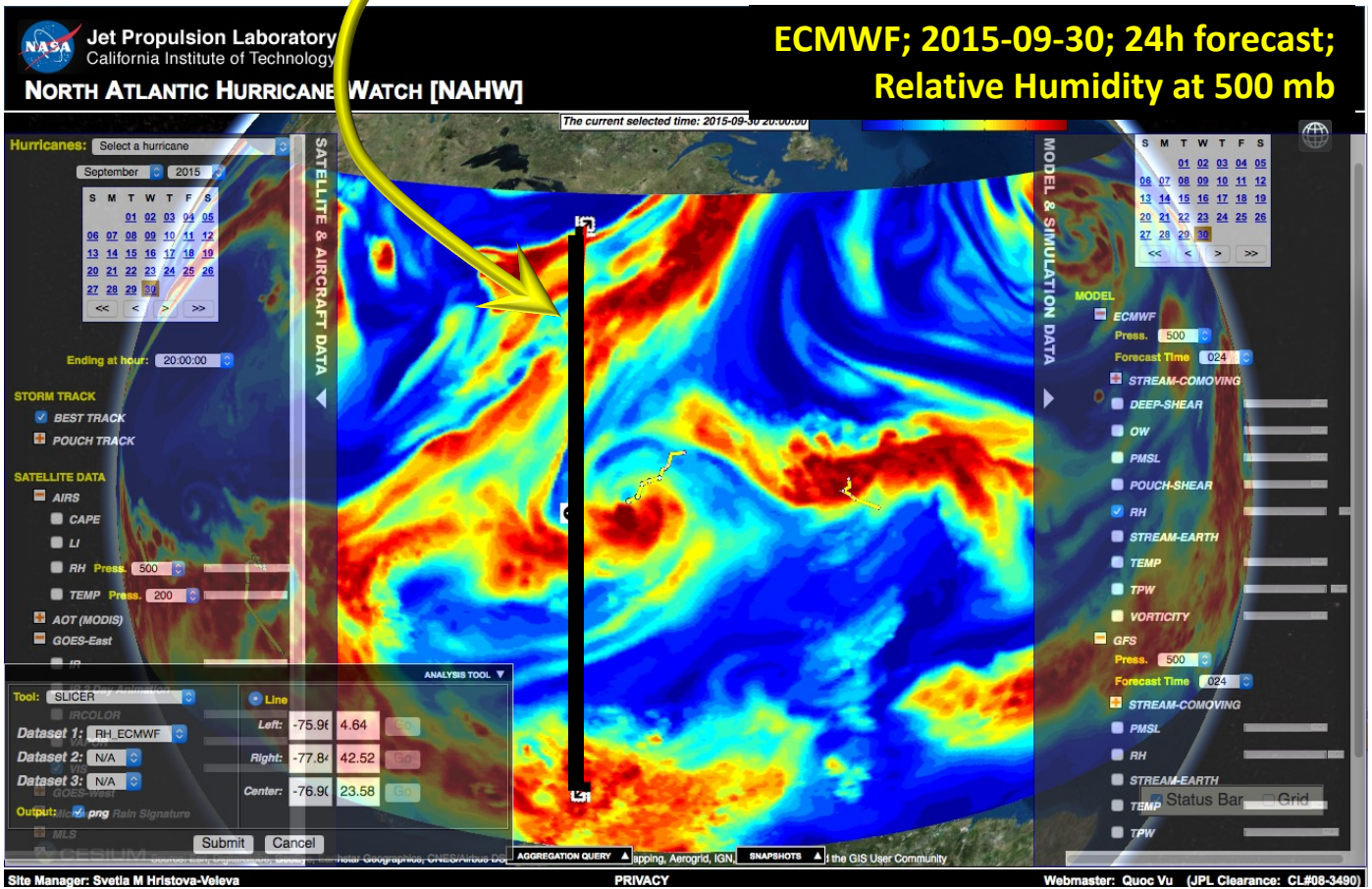
The thermodynamics from AIRS – Evaluation of the Environment



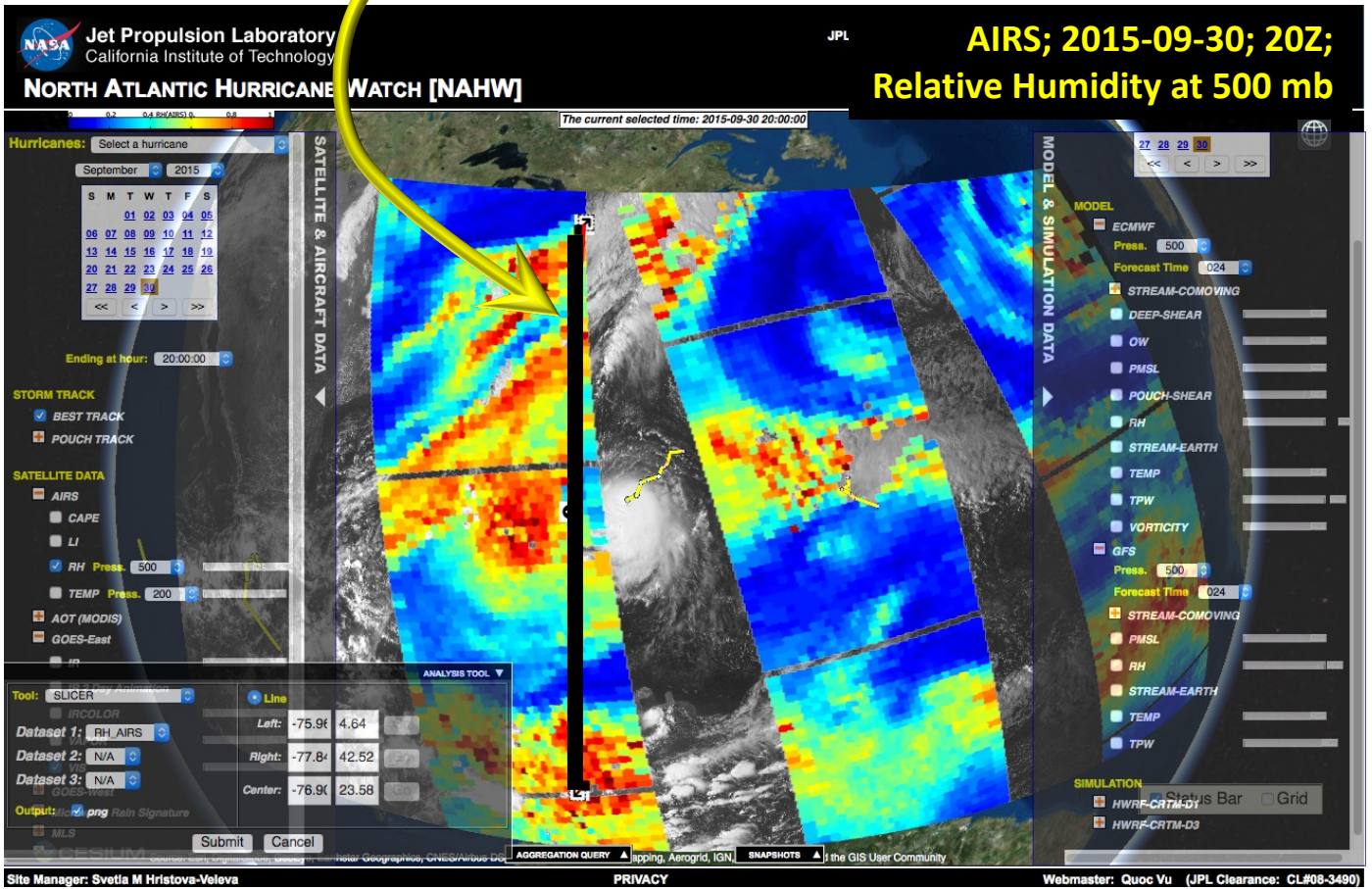
Line for the vertical cross-section shown three slides later



Line for the vertical cross-section shown two slides later



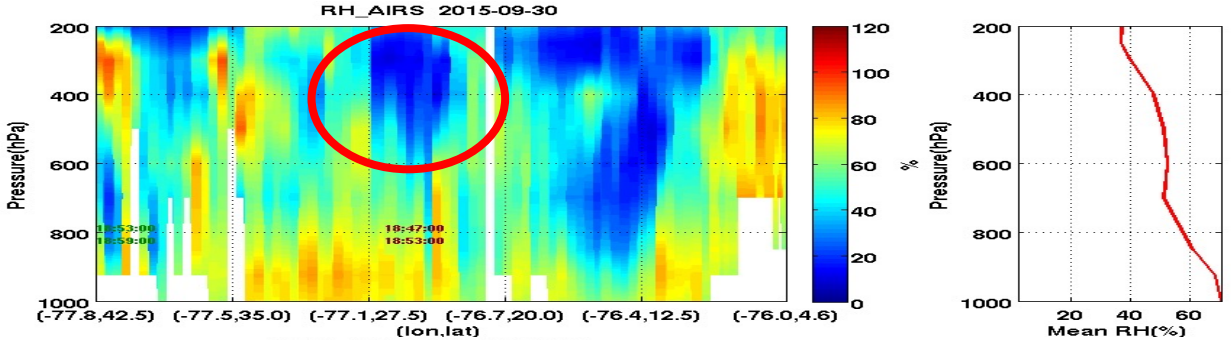
Line for the vertical cross-section shown on the next slide



North

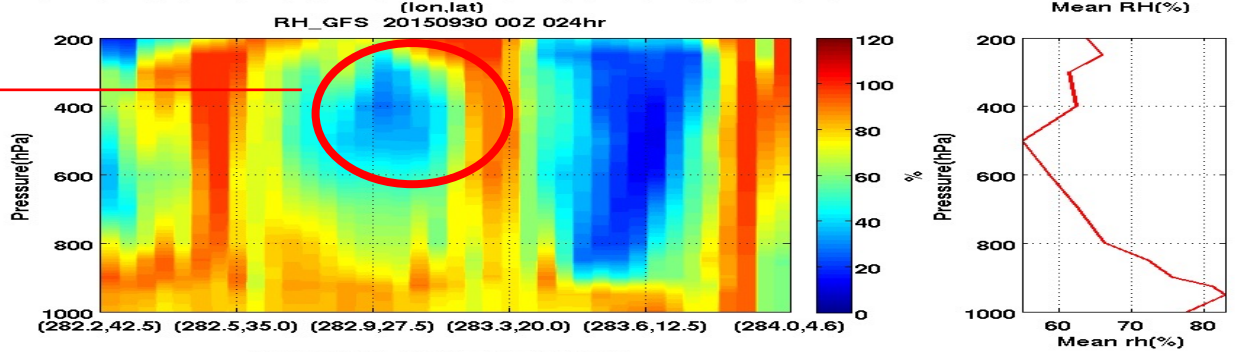
Cross-section Along 77W

South



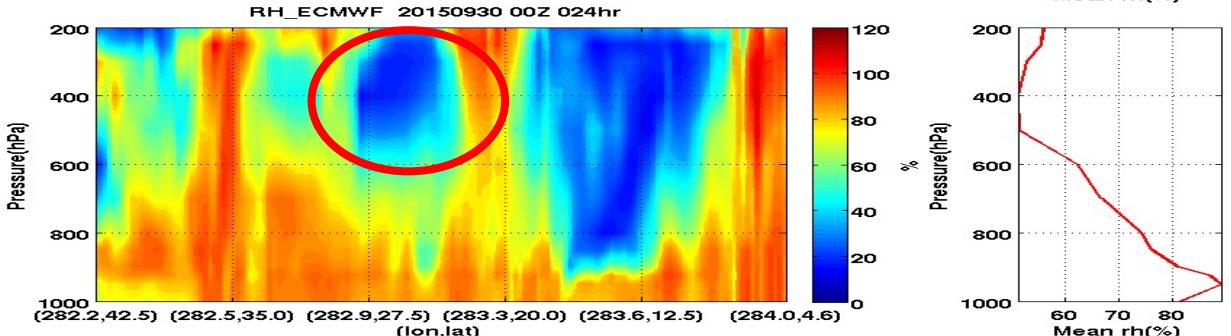
AIRS

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



GFS

Both models seem to have deep layers of moisture that are not seen in the AIRS observations.



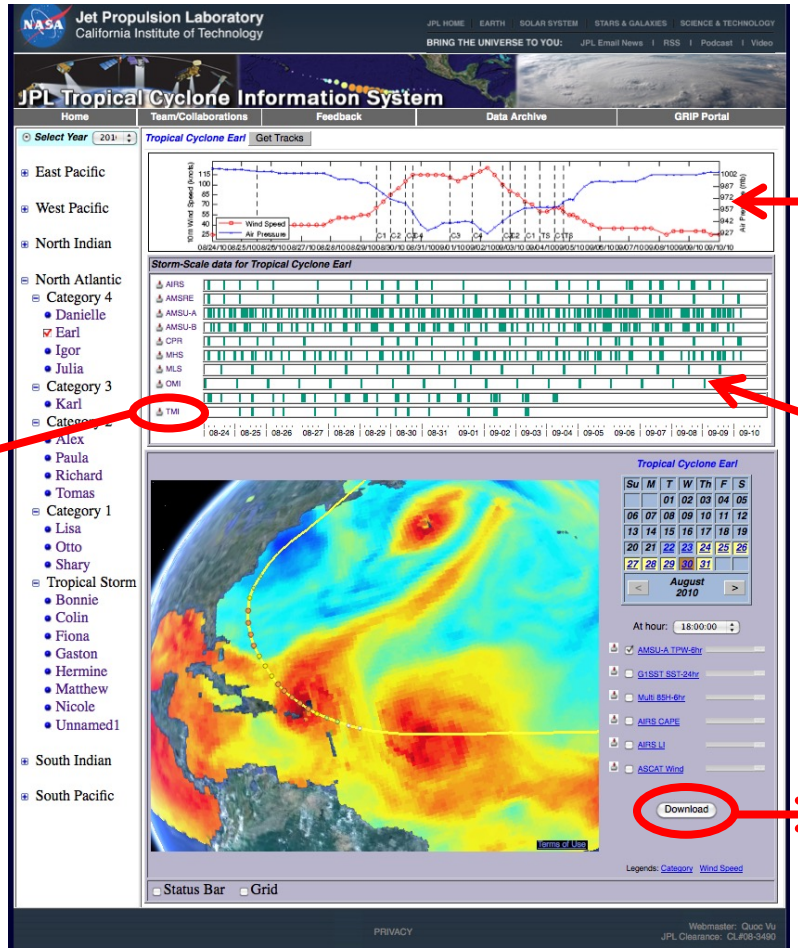
ECMWF

4. TC Data Archive

JPL TCIS – The Tropical Cyclone Data Archive

http://tropicalcyclone.jpl.nasa.gov

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



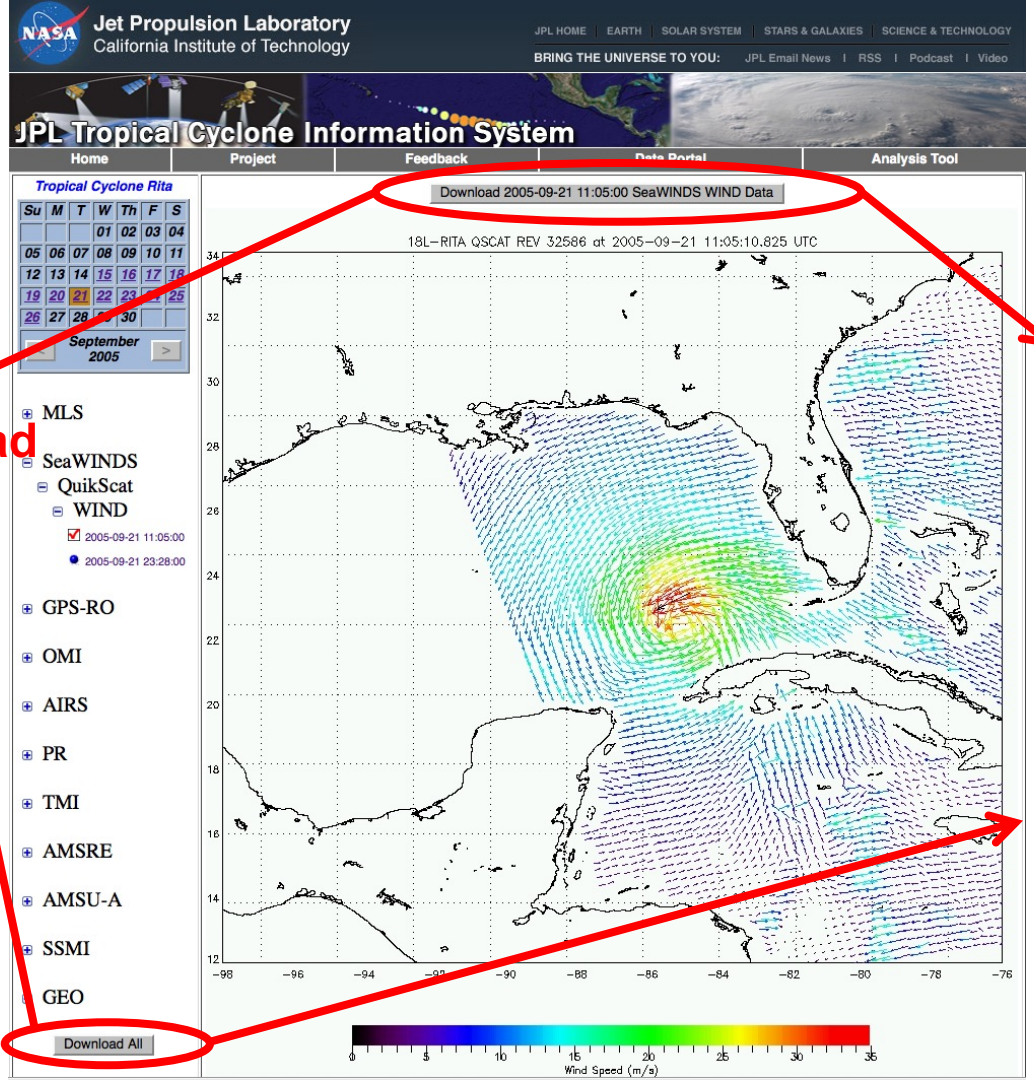
Timeline

View and download Storm-scale data

Earl, 2010

Download all data from this Instrument (TMI)

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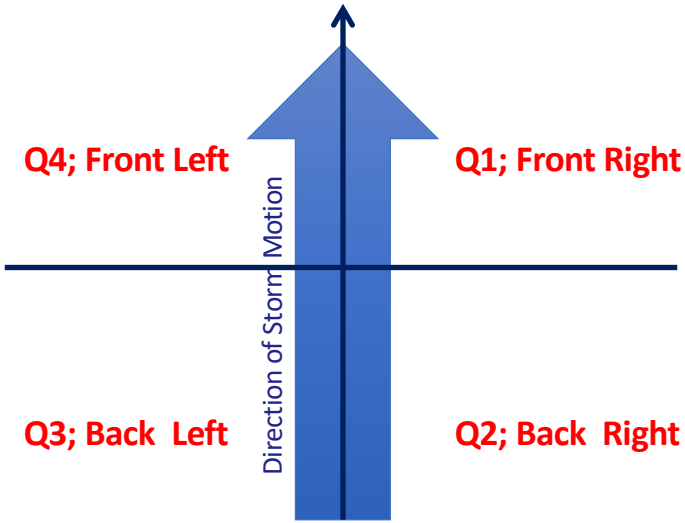
Tropical Cyclone Rita
Su M T W Th F S
September 2005
MLS
SeaWINDS
QuikScat
WIND
2005-09-21 11:05:00
2005-09-21 23:28:00
GPS-RO
OMI
AIRS
PR
TMI
AMSRE
AMSU-A
SSMI
GEO
Download All
Download 2005-09-21 11:05:00 SeaWINDS WIND Data
18L-RITA QSCAT REV 32586 at 2005-09-21 11:05:10.825 UTC
Wind Speed (m/s)
Download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

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.

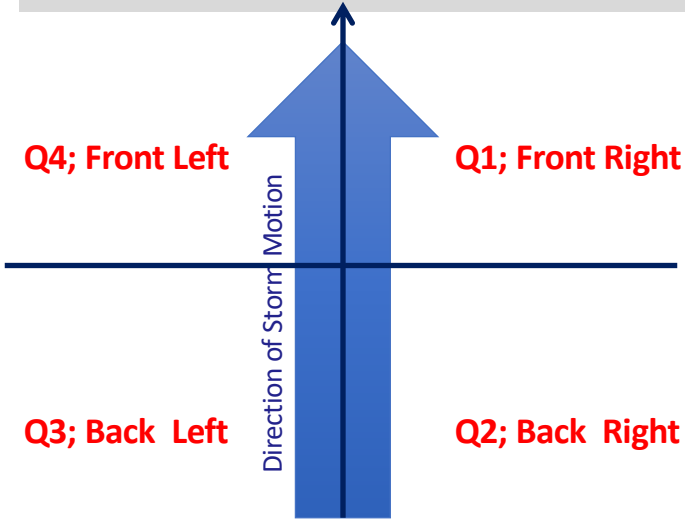
Many others.

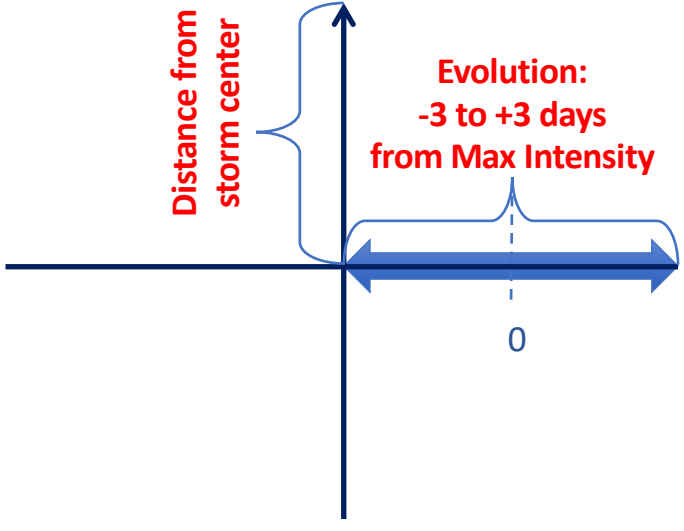
Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

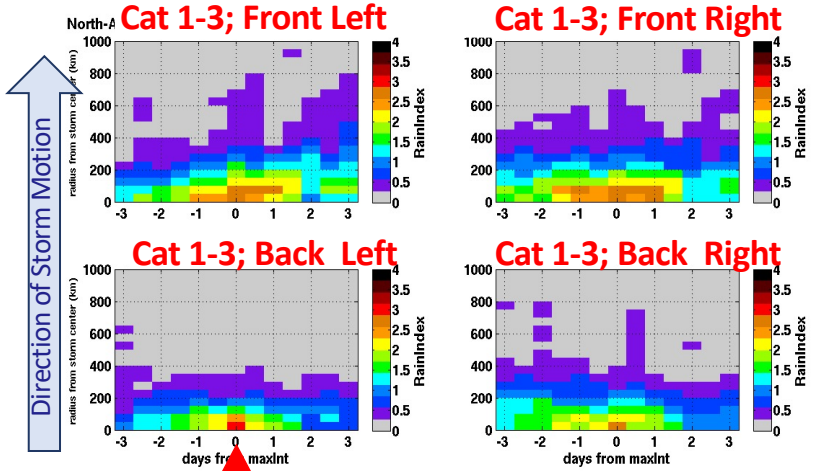
Parameter as a function of:

- 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

<u>Evolution of asymmetry</u>

Azimuthal/Range Distributions

of **Rain Index**

Cat1: 31 cases

Cat2: 9 cases

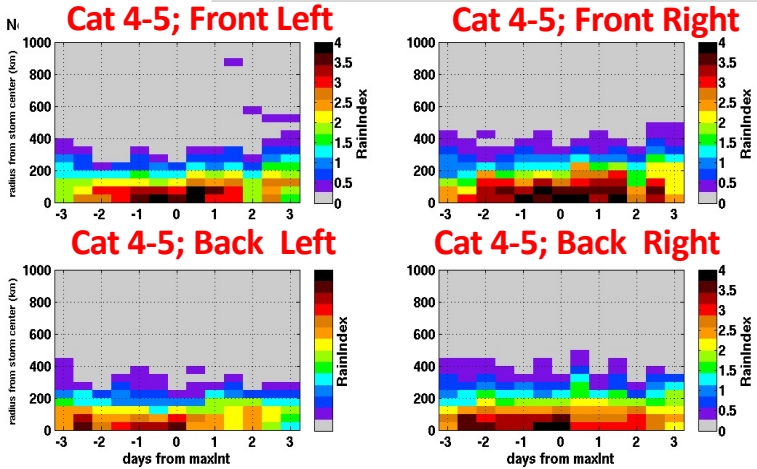
Cat3: 12 cases

Total Cat1-3 = 52 cases

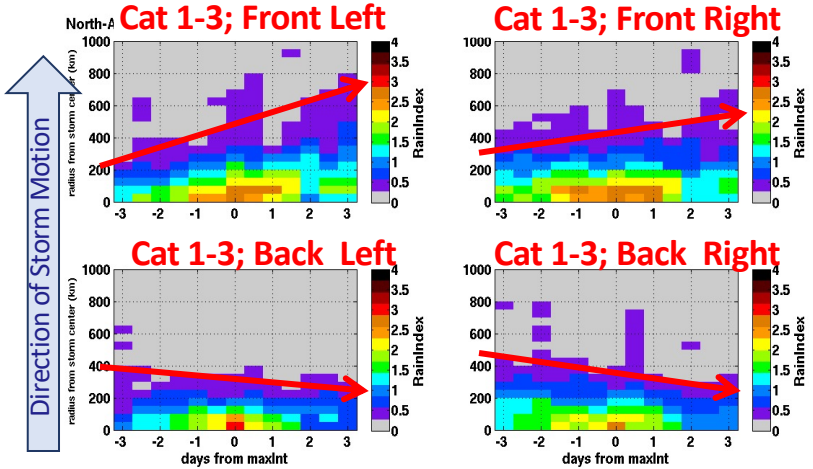
Cat4: 18 cases

Cat5: 7 cases

Total Cat4-5 = 25 cases



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



Evolution of asymmetry

Azimuthal/Range Distributions

of **Rain Index**

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Total Cat1-3 = 52 cases

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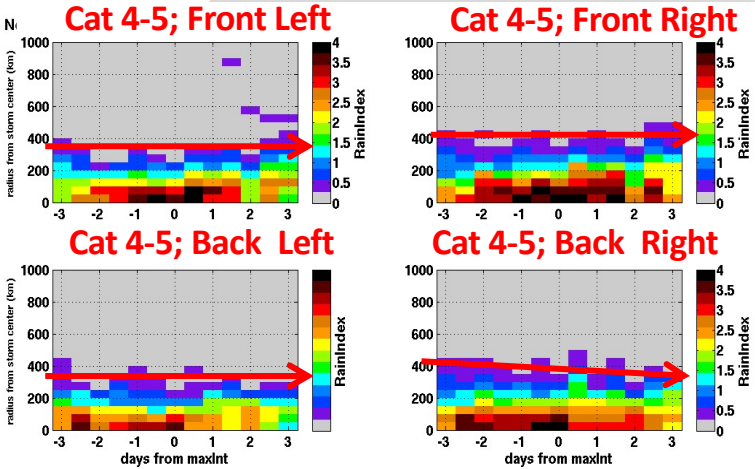
Total Cat4-5 = 25 cases

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



Thank you!