Svetla Hristova-Veleva, Ziad Haddad, Bryan Stiles,
Tsae-Pyng Shen, Noppasin Niamsuwan, F. Joe Turk,
P.Peggy Li, Brian Knosp, Quoc Vu, Bjorn Lambrigtsen, William Poulsen

Jet Propulsion Laboratory, California Institute of Technology

Possible predictors for the RI and evolution of hurricanes from near-coincident satellite observations of the structure of precipitation and surface winds: Hurricane Joaquin

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Government sponsorship acknowledged.

Joaquin

- Hurricane Joaquin, the strongest Atlantic hurricane since Igor in 2010, developed on September 27th 2015. Of particular interest to our study is the evolution of Joaquin's intensity.

- Early in its lifecycle the hurricane underwent a Rapid Intensification (RI) and saw a pressure drop of 57 millibars in about 39 hours, going from a strong tropical storm to a Category 4 hurricane.

Could we predict that?
Current Hypotheses

- Research over the past decade has indicated that the hurricane inner core processes might play a crucial role in determining the storm's intensity and size.
- Yet, understanding of these processes is still lacking, bringing to the forefront the need to investigate the important role of the inner-core convective organization.
- Recent studies have linked hurricane's Rapid Intensification (RI) to intermittent occurrence of deep, strong convective bursts within the inner core (e.g. Hendricks et al., 2004; Montgomery et al., 2006; Rogers, 2010) occupying as little as 5–10% of the area of the hurricane eyewall.
- An alternative hypothesis is that RI follows abundant and well organized but weaker convection in the inner-core region (Gopalakrishnan et al., 2011). A continuous (at least 90%) azimuthally symmetric eye wall (i.e., a ring) of shallow warm precipitation indicates the imminent onset of RI (Kieper and Jiang, 2012).

The physics

- A very important aspect of the RI process is regarding the location of the convective activity with respect to the vortex structure as depicted by the Radius of Maximum Wind (RMW).
- Rogers et al., 2013 found that for intensifying hurricanes the peak in the distribution of deep convective clouds (CBs) was preferentially located inside the RMW, whereas for steady-state hurricanes the CBs were primarily located outside the RMW.
- Such a difference in the radial distribution of CBs was deemed important based on balance arguments (e.g. Shapiro and Willoughby,1982; Vigh and Schubert, 2009).

Approach

- Motivated by this, we examine the relationship between:
  - the structure of the 2D precipitation
  - the structure of the near-surface wind fields.
- We relate the evolution of these two fields, as determined from near-simultaneous satellite observations, to the hurricane intensity changes and we find potential predictive capabilities.

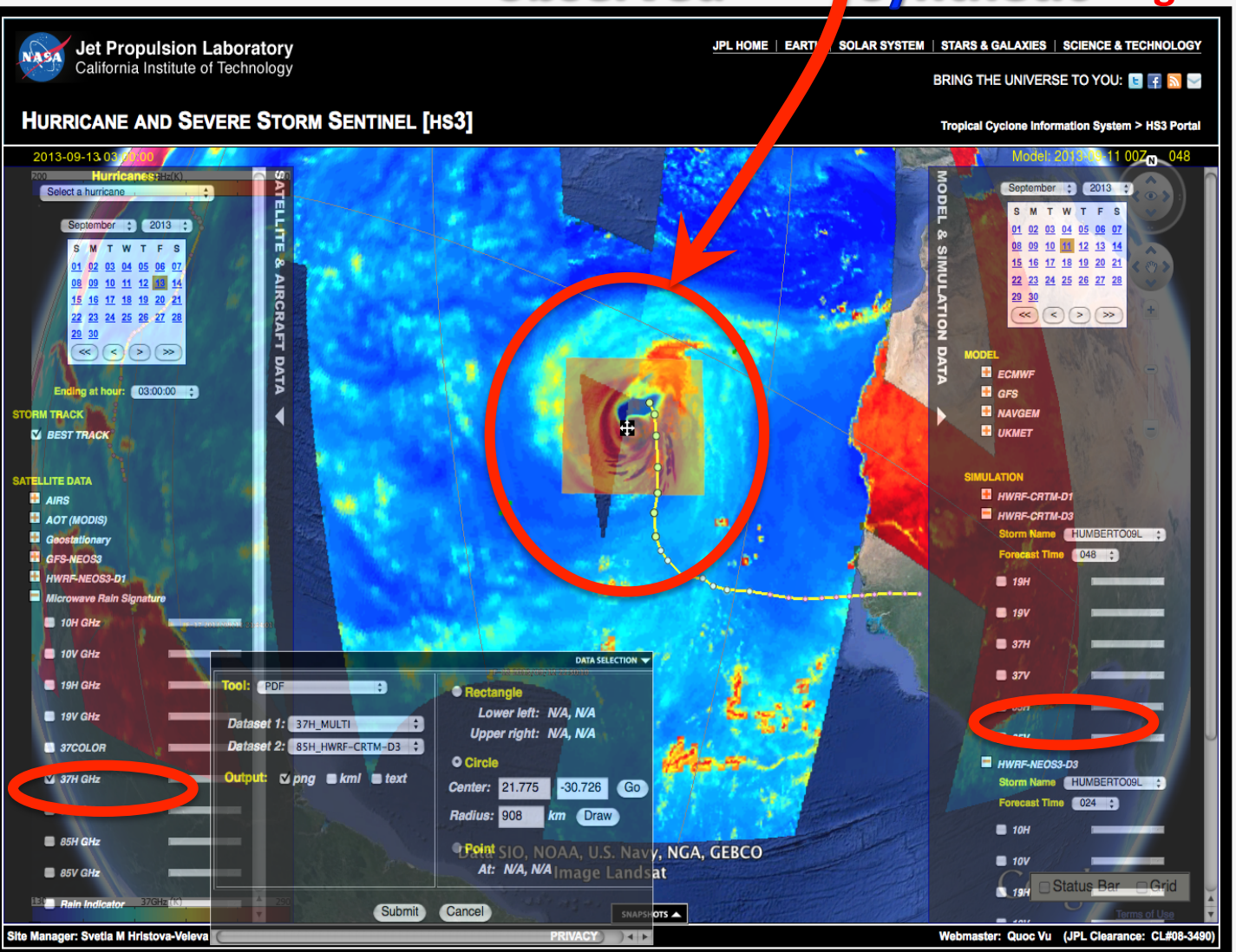
Data, tools and sources

- The study utilizes observations and on-line analysis tools provided by the JPL Tropical Cyclone Information System (TCIS), developed to support hurricane research.
- TCIS has two components:
  - The Tropical Cyclone Data Archive - a 12-year global archive of multi–satellite hurricane observations;
  - The North Atlantic Hurricane Watch (NAHW - http://mwsci.jpl.nasa.gov/nahw) - a data portal that monitors hurricanes in the North Atlantic and East Pacific ocean basins. This portal allows users to analyze and compare observation data and model forecasts during each hurricane season (June - November) from 2012 to the present day.
- Data, analysis and visualizations from the TCIS can be used to study hurricane process, validate and improve models, and assist in developing new algorithms and data assimilation techniques.

The North Atlantic Hurricane Watch: On-line Analysis Tools:

http://mwsci.jpl.nasa.gov/nahw

- Interactively select region
- Gather data from **observed** and **synthetic** brightness temperature



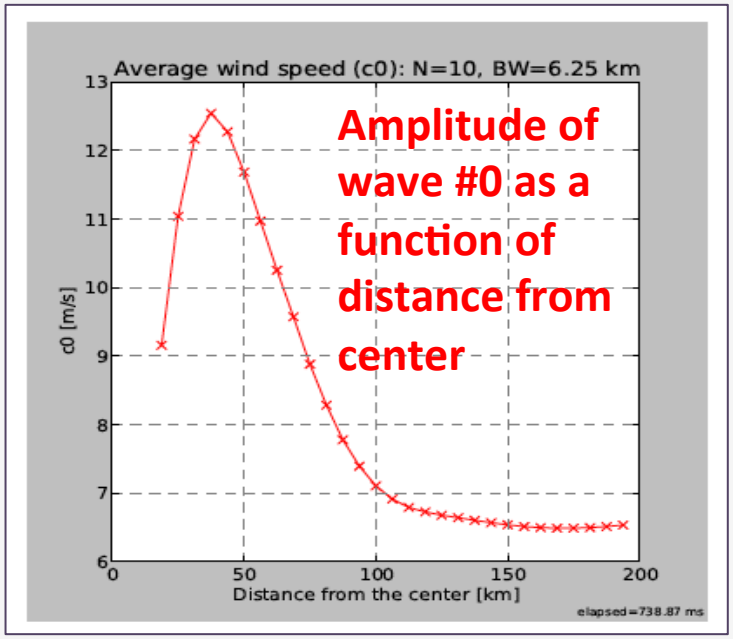
- **PERFORM:**

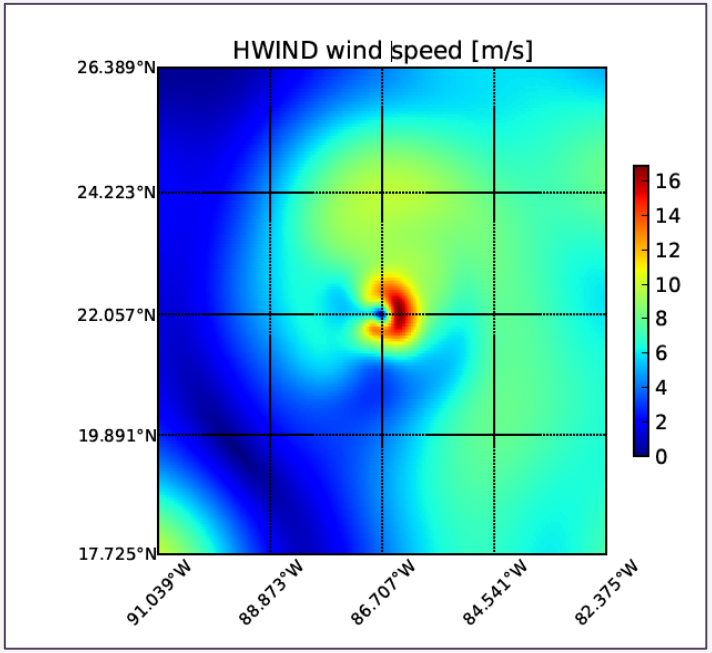
- Statistical evaluation
  - EOFs, Joint PDFs
  - Azimuthal averages
- Storm Structure
  - Storm Size/ Asymmetry
  - Storm Center - ARCHER
  - Convective/ Stratiform
- Environment
  - Vertical Slices On-demand
- Analysis Visualization

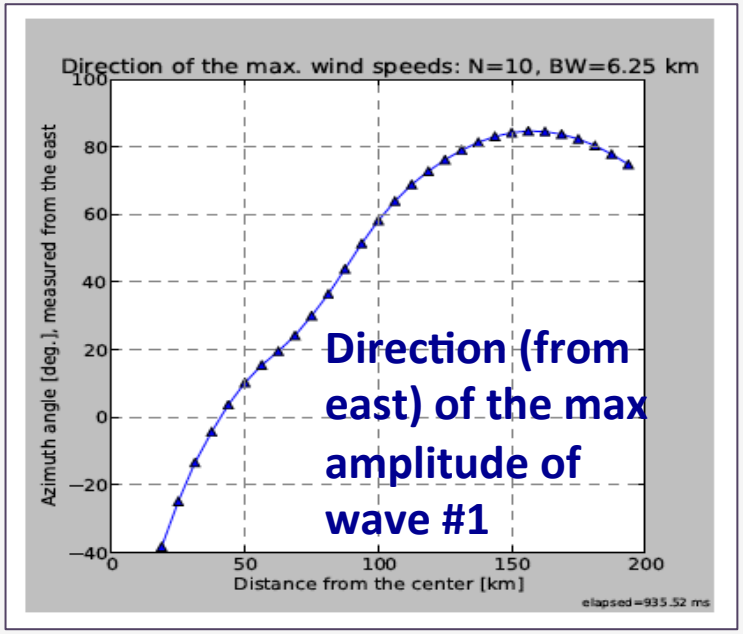
Analysis of the Storm Structure
The Wave Number Analysis Tool
Potential for Intensification

Wavenumber analysis tool

- **First adopted by NOAA/HRD**







Satellite Observations

- To investigate the 2D structure of the precipitation, we use multi-channel passive microwave observations from a number of different instruments (TMI, AMSR-E, SSMI and SSMIS, all available at TCIS).
  - In particular, the rain is inferred from the Rain Index (Hristova-Veleva et al., 2013) that combines the emission and scattering signals from the multi-channel information (19 GHz –to 89 GHz) to present a cohesive depiction of the rain and the graupel above.
  - Previous comparisons to NexRad observations show that the Rain Index looks a lot like radar reflectivity and has a resolution on the order of 15-20km.
- The wind estimates come from scatterometer observations made by ASCAT and RapidScat. Both instruments post their retrievals at 12.5km. However, the actual resolution is closer to 20 km.

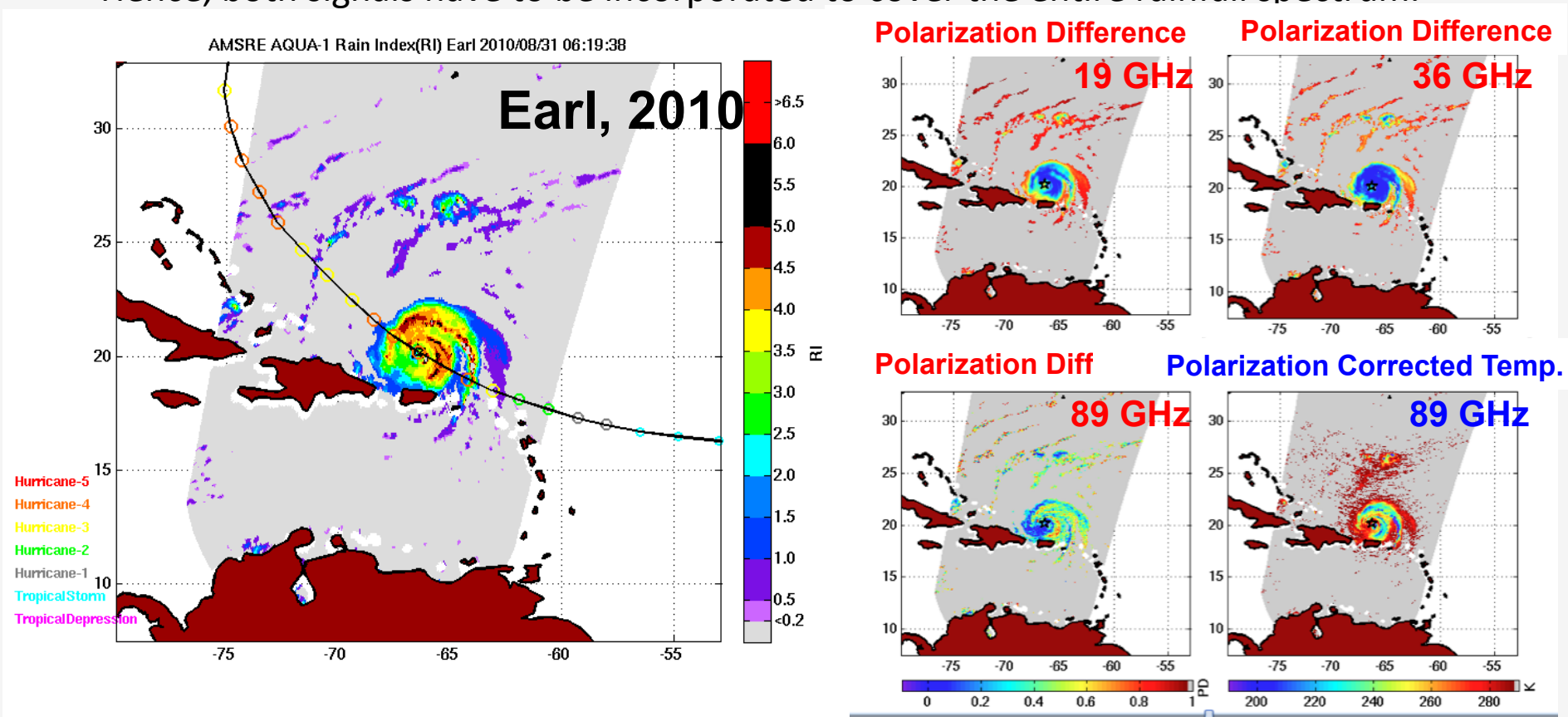
- The Rain Indicator – a multi-channel depiction of the storm structure

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

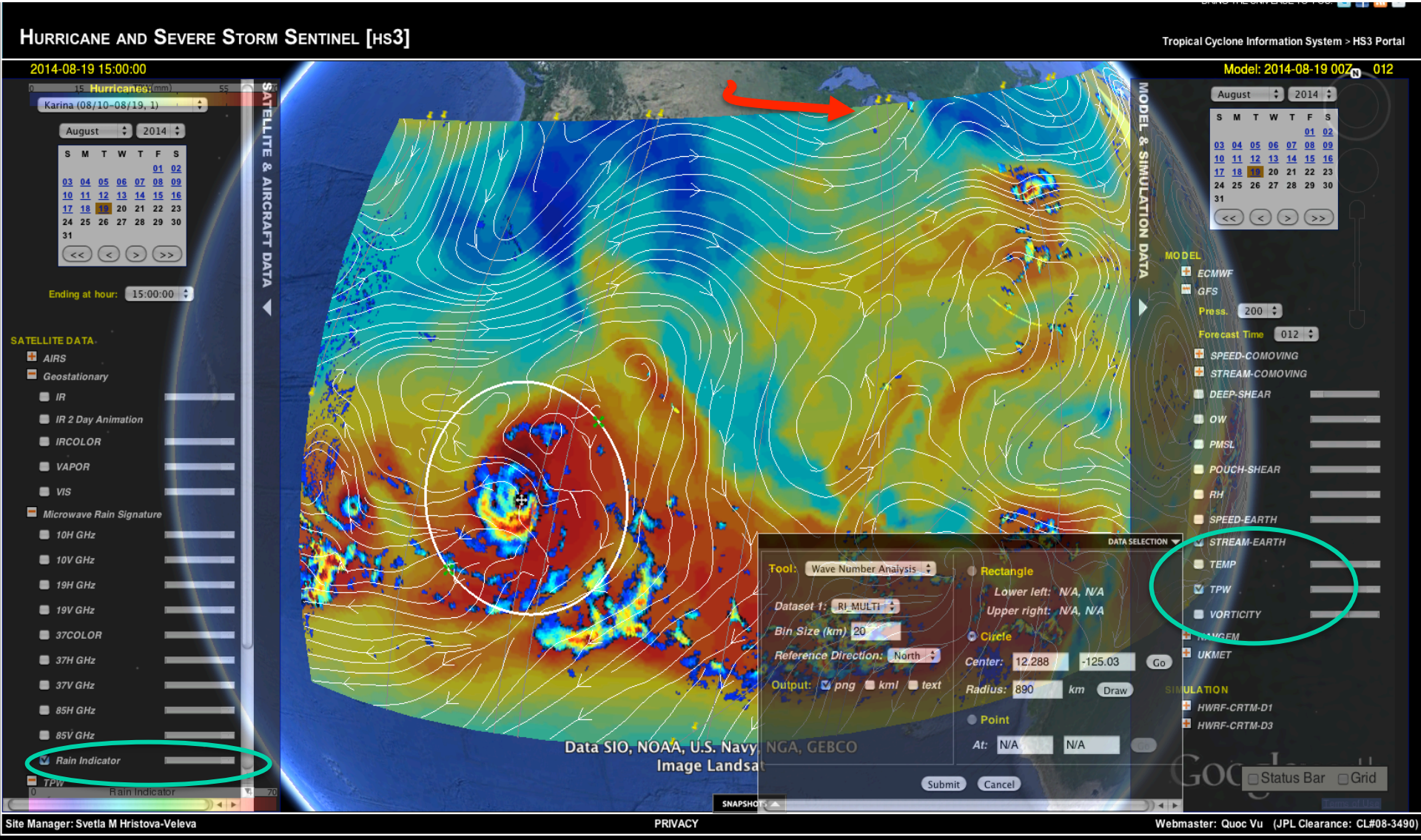
Microwave signals at the top of the atmosphere can be classified into two categories:

- **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**

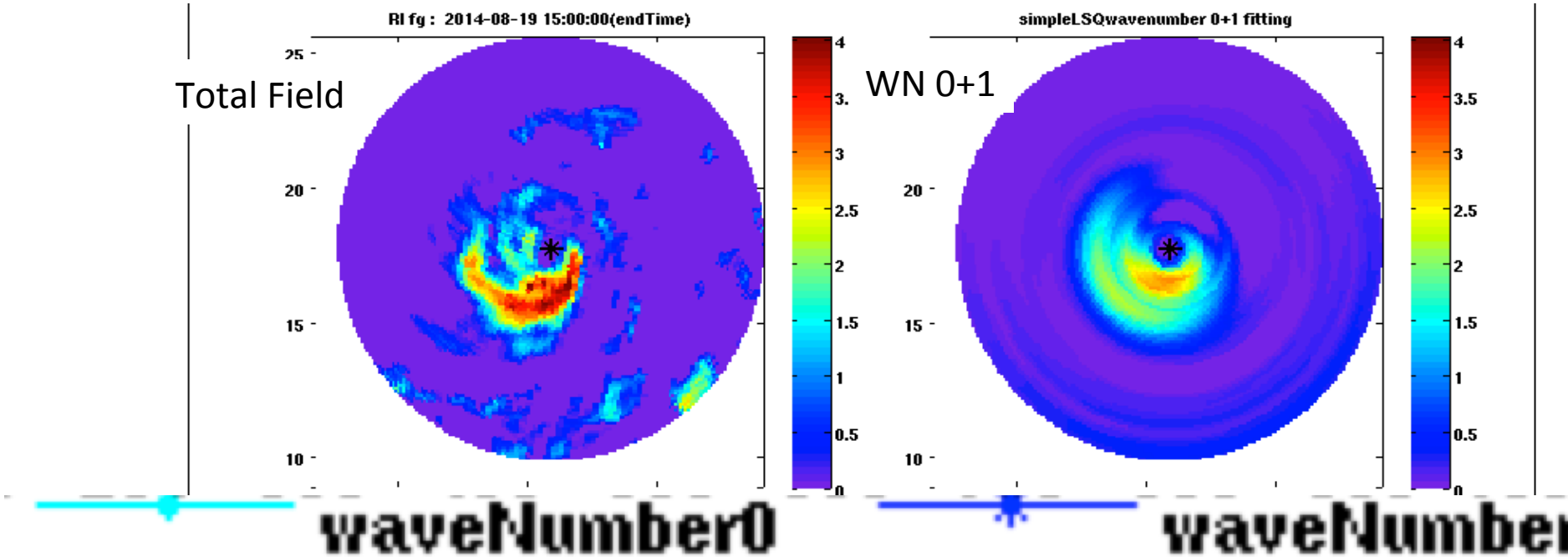
- Hence, both signals have to be incorporated to cover the entire rainfall spectrum.

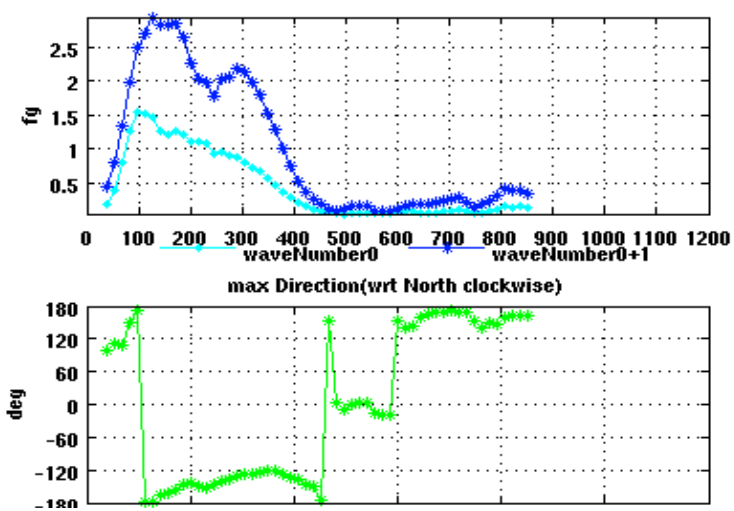


The Observed Rain Index (in contrasting colors); GFS 12h forecast of the TPW (in pastel colors) and the 200 mb flow

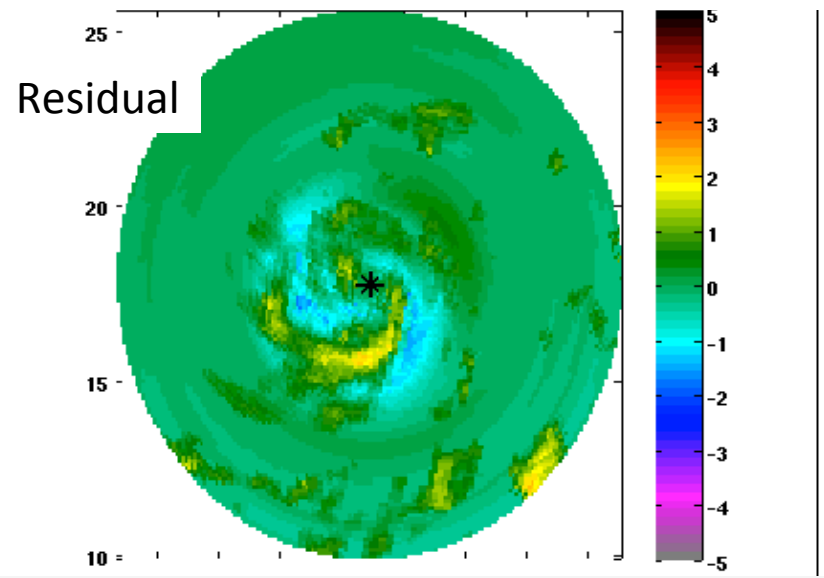


Wave Number Analysis of the Rain Field (as depicted by the Rain Index) passive microwave observations

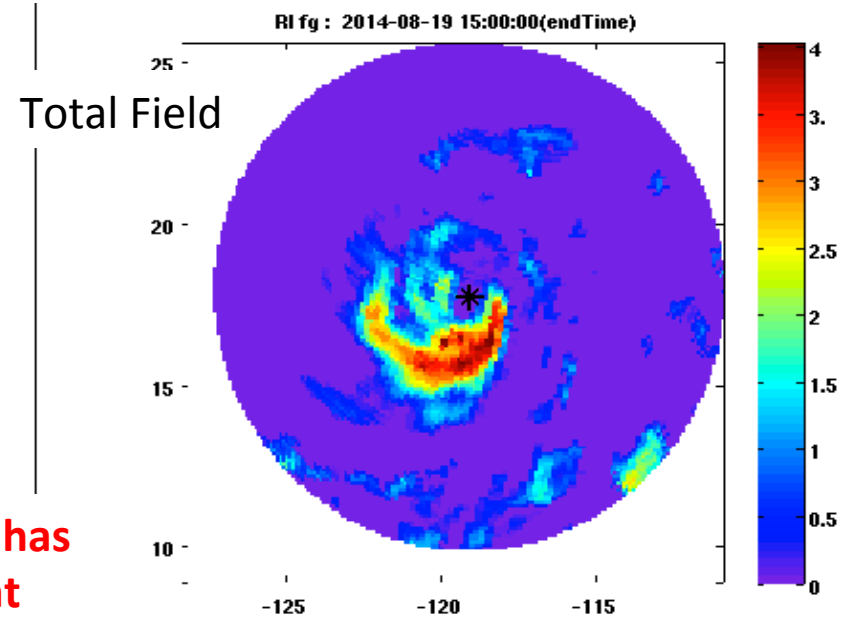


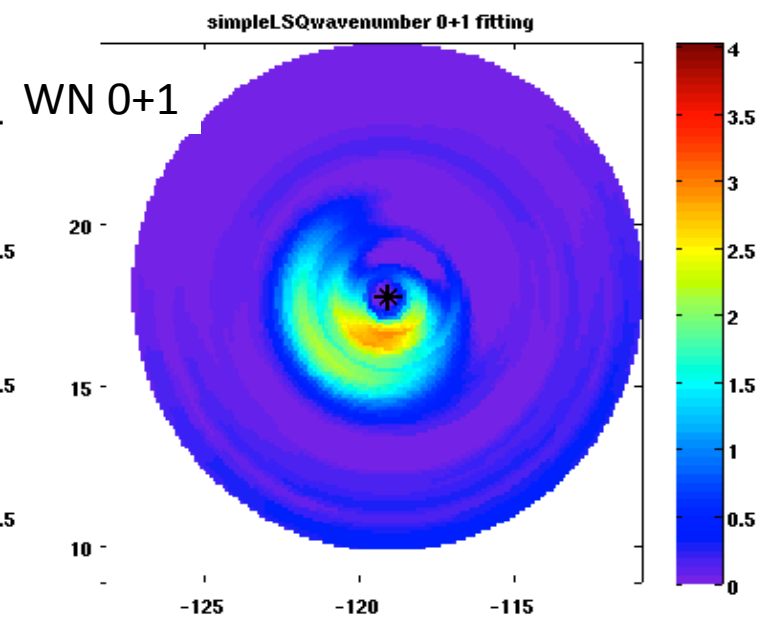


Radial Distance from Storm Center

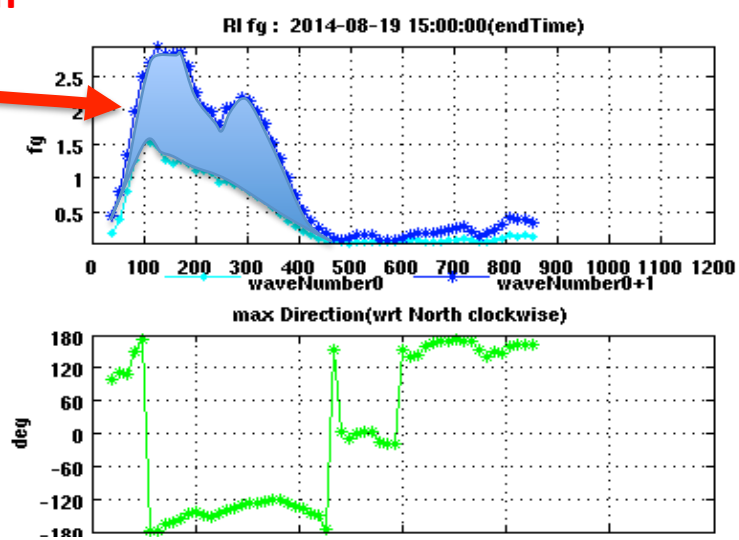


Wave Number Analysis of the Rain Field (as depicted by the Rain Index) passive microwave observations

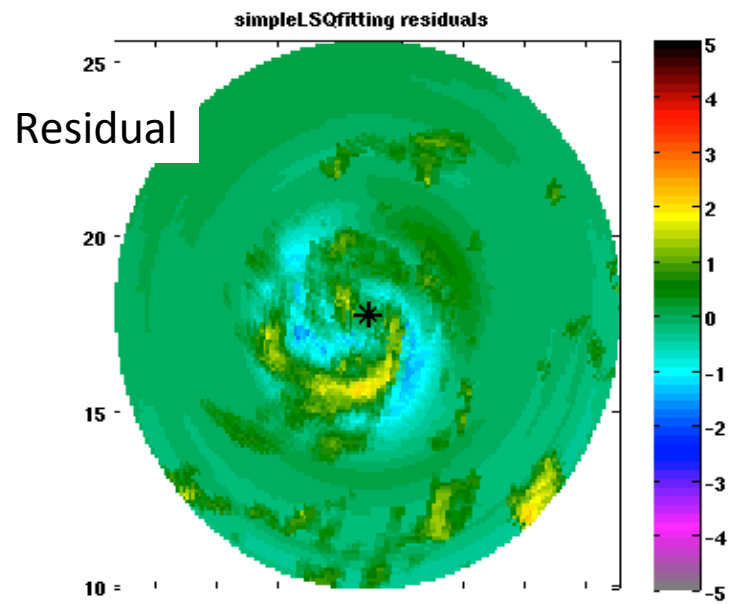




Wave #1 has important contribution



Radial Distance from Storm Center



Hurricane Humberto

(2013)

The Wave Number Analysis

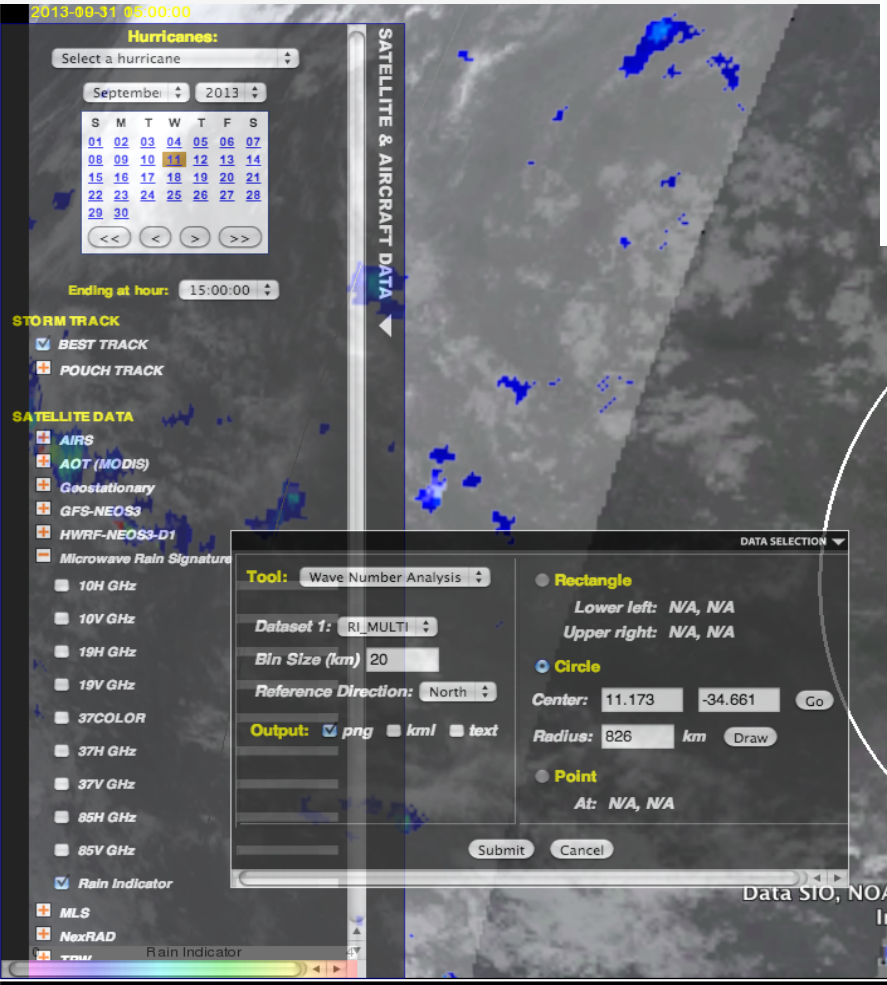
Potential for Intensification

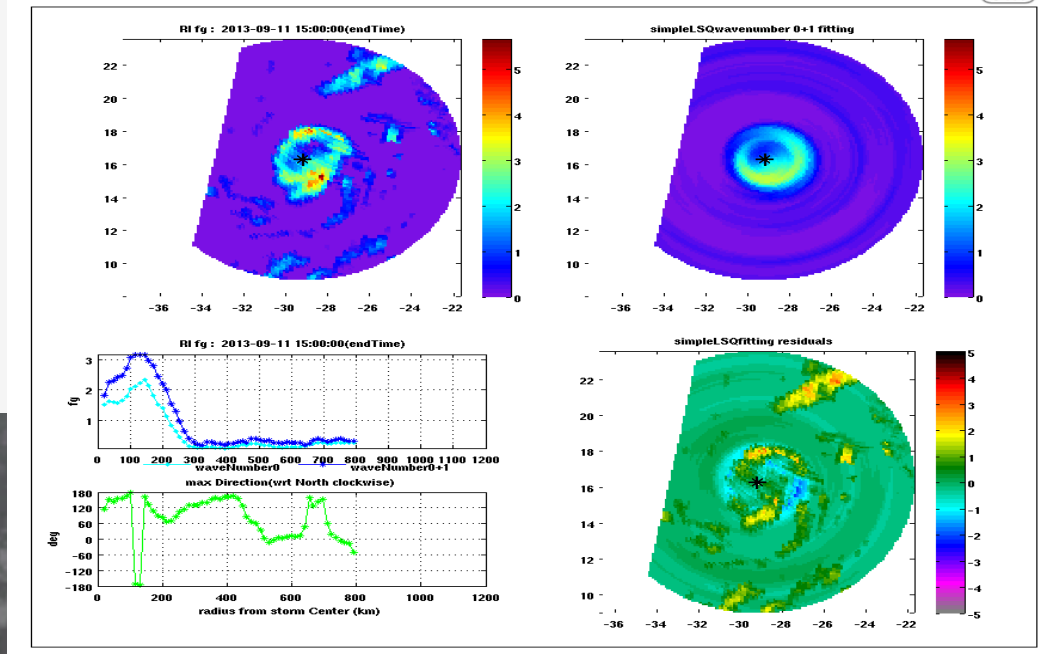
Storm structure Tool:

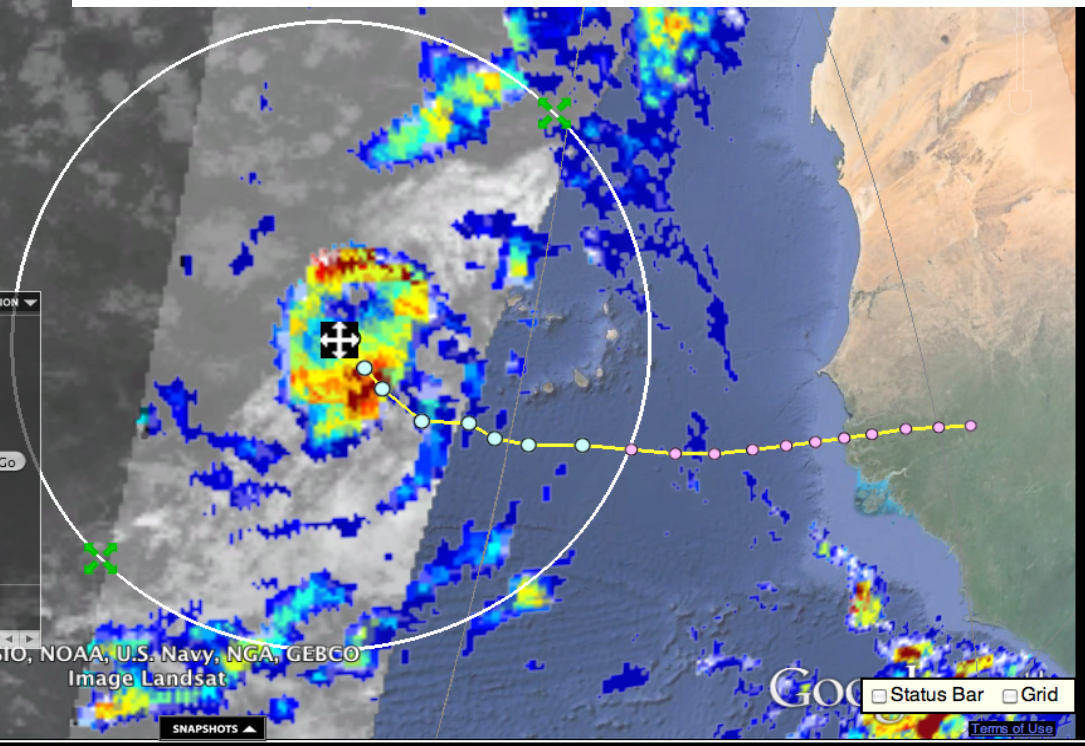
Observations: Rain

Storm Size and Asymmetry: *The Wave Number Analysis Tool using the Rain Index*

Hurricane Humberto -09/11/2013: 15Z





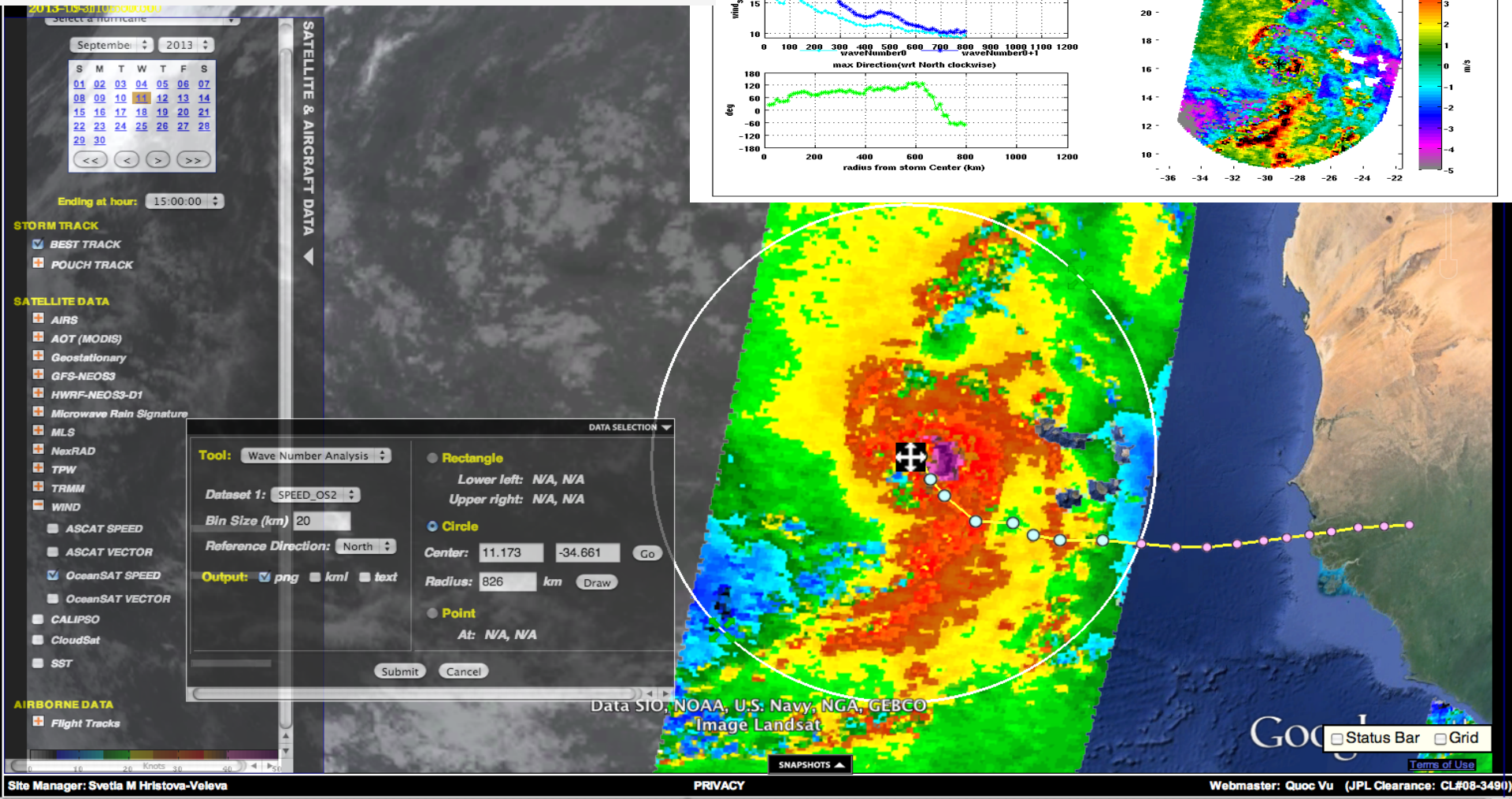


Storm structure Tool:

Observations: Wind from OSCAT

Storm Size and Asymmetry: ***The Wave Number Analysis Tool using the Rain Index***

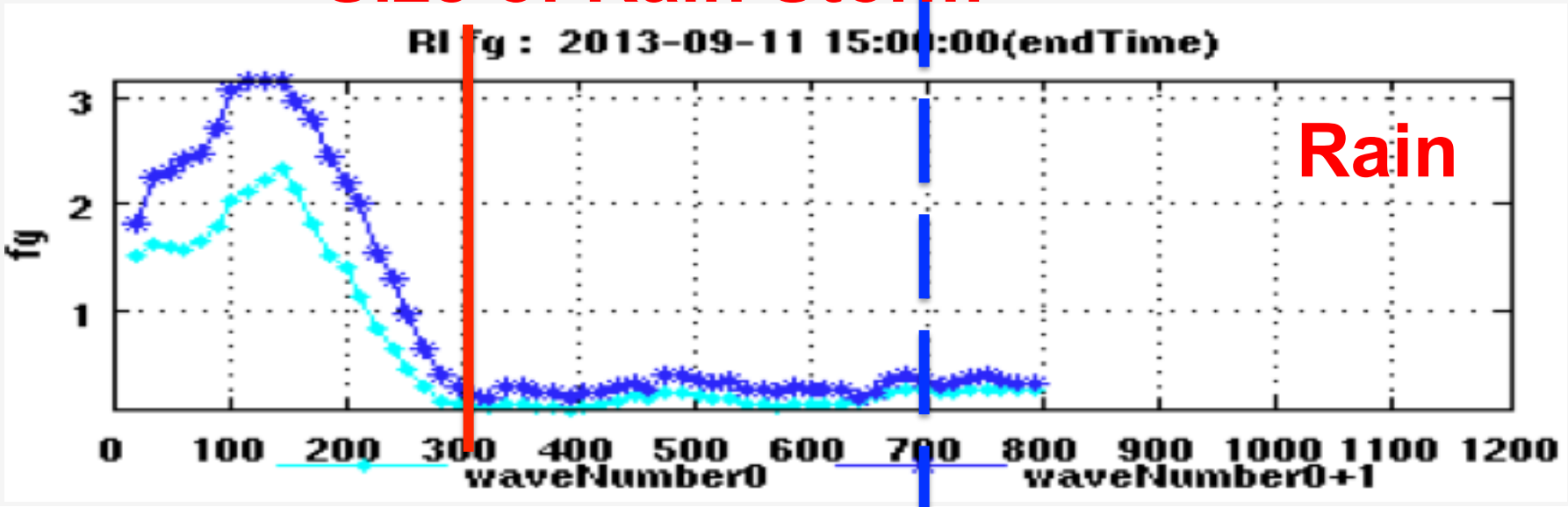
Hurricane Humberto -09/11/2013: 15Z

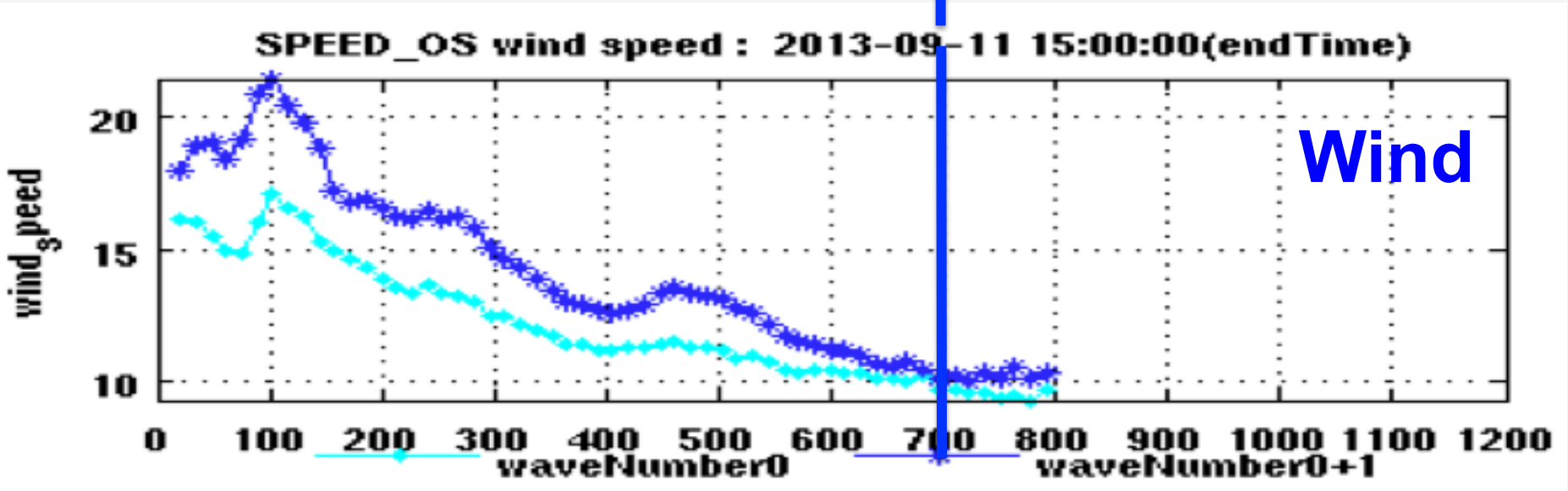


Size of precipitation is much smaller than the size of the wind field

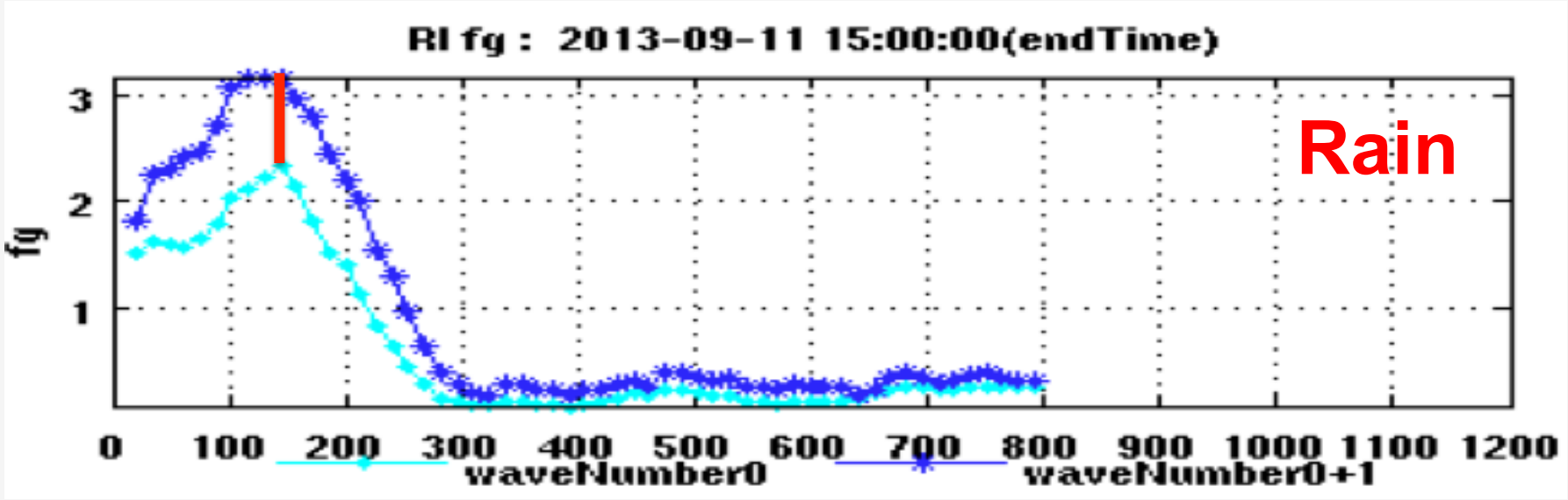
Size of Wind Storm

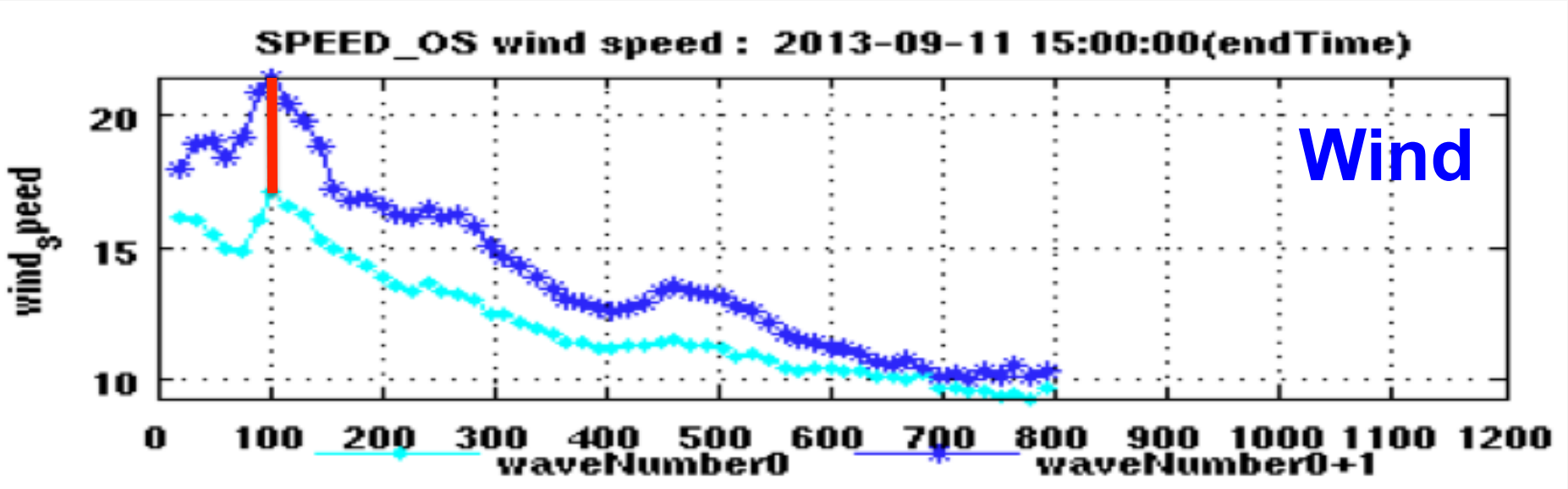
Size of Rain Storm





The storm is quite asymmetric in both wind and rain

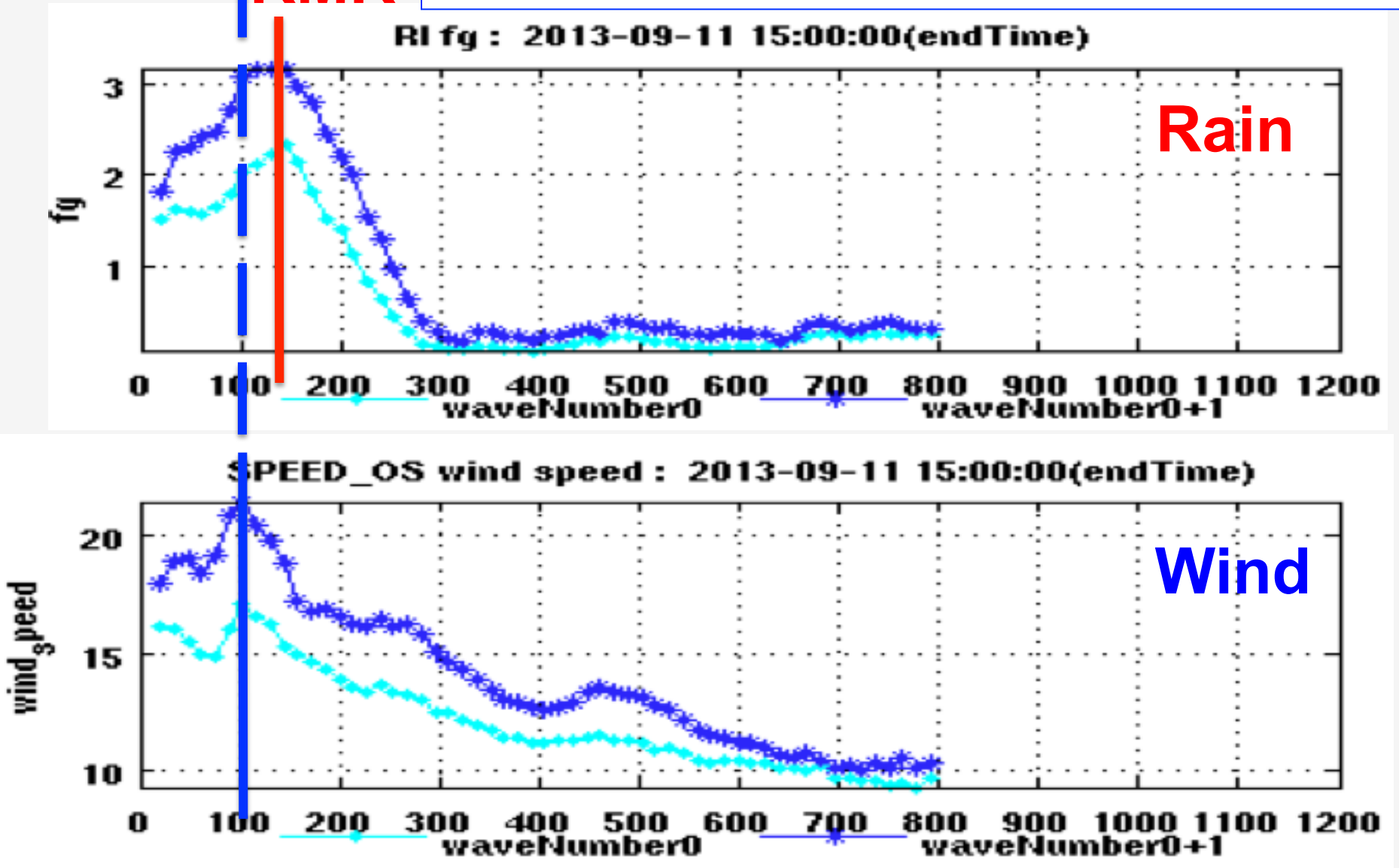




The storm is quite asymmetric in both wind and rain

Radius of Max Wind (RMW) is smaller than the Radius of Max Rain (RMR).

Conditions are not conducive to Rapid Intensification.

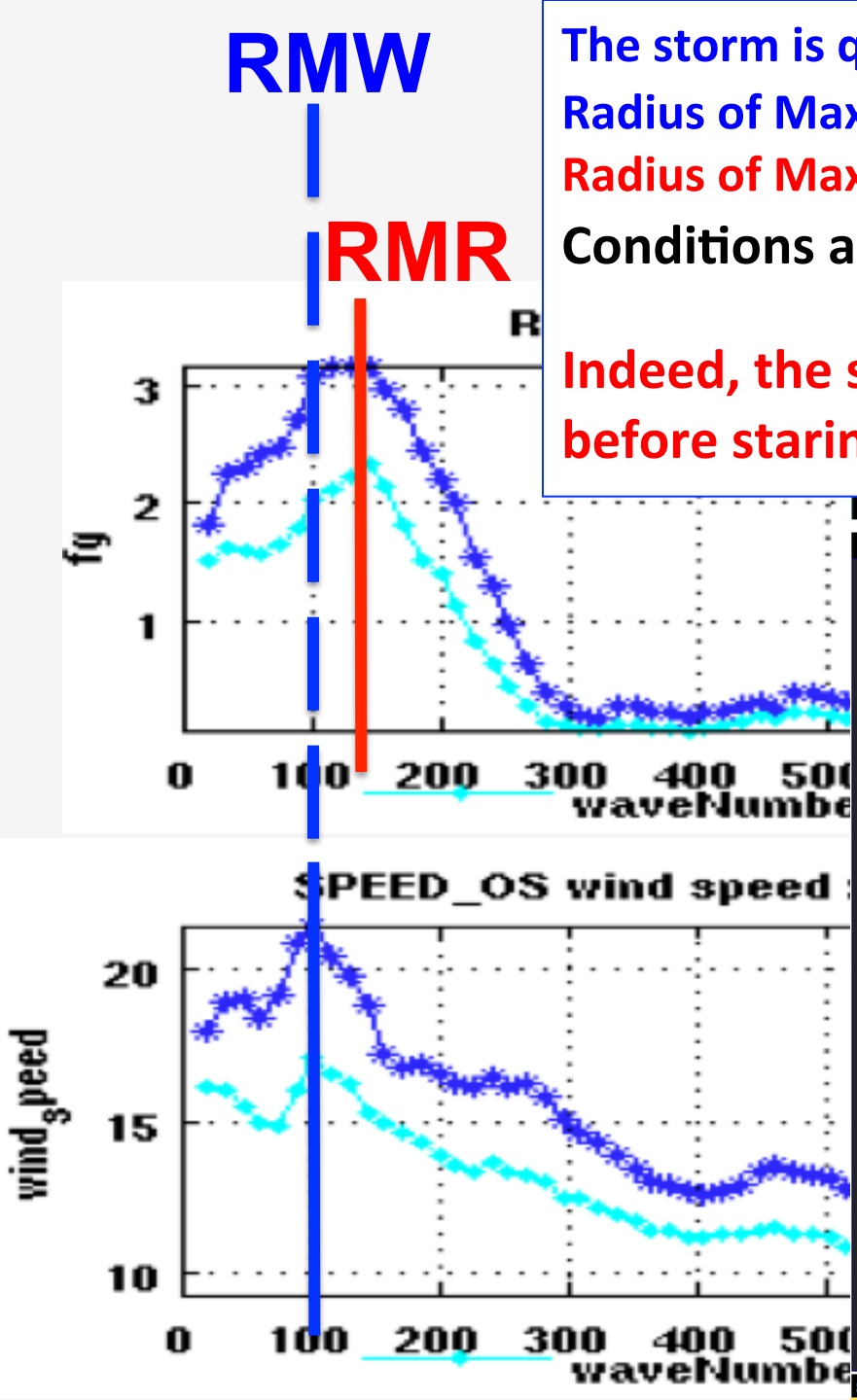


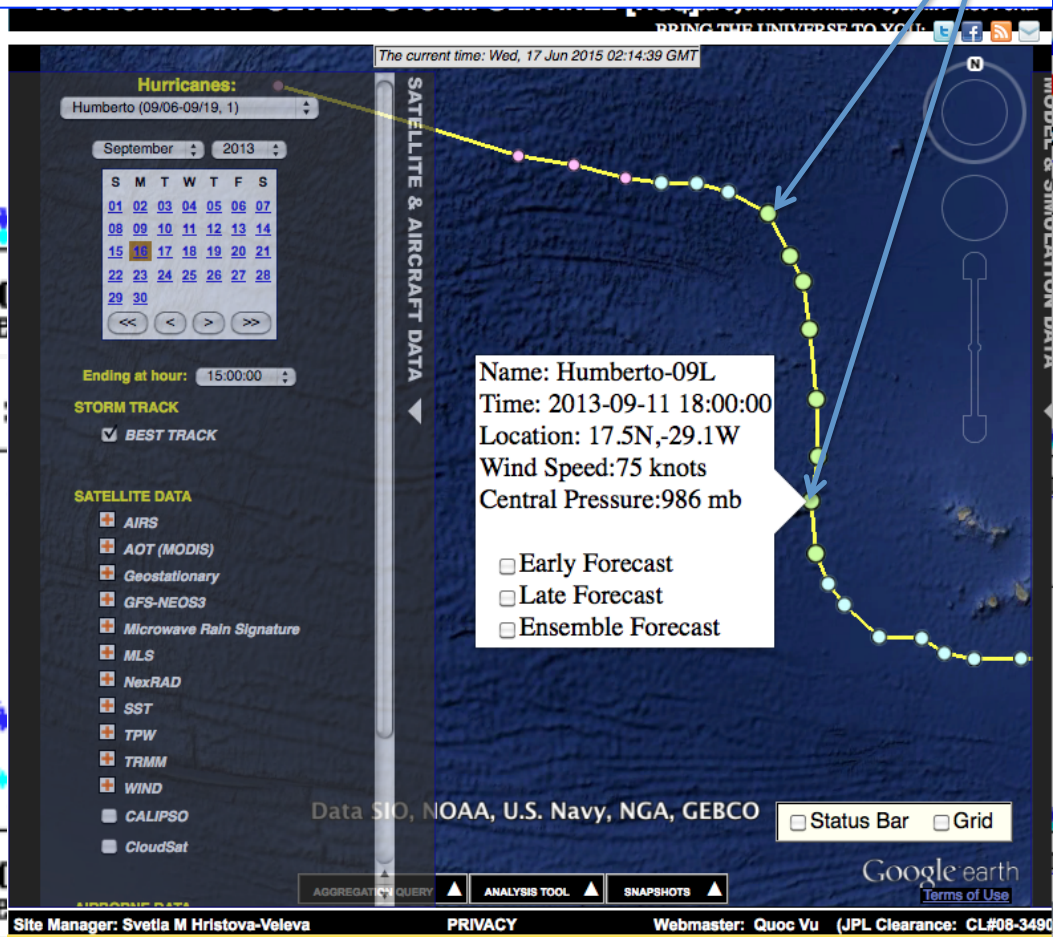
The storm is quite asymmetric in both wind and rain

Radius of Max Wind (RMW) is smaller than the Radius of Max Rain (RMR).

Conditions are not conducive to Rapid Intensification.

Indeed, the storm remained very steady for 36 hours, before staring to weaken on 09/13/2013 at 06Z





Joaquin 2015

What is the current storm structure telling is?

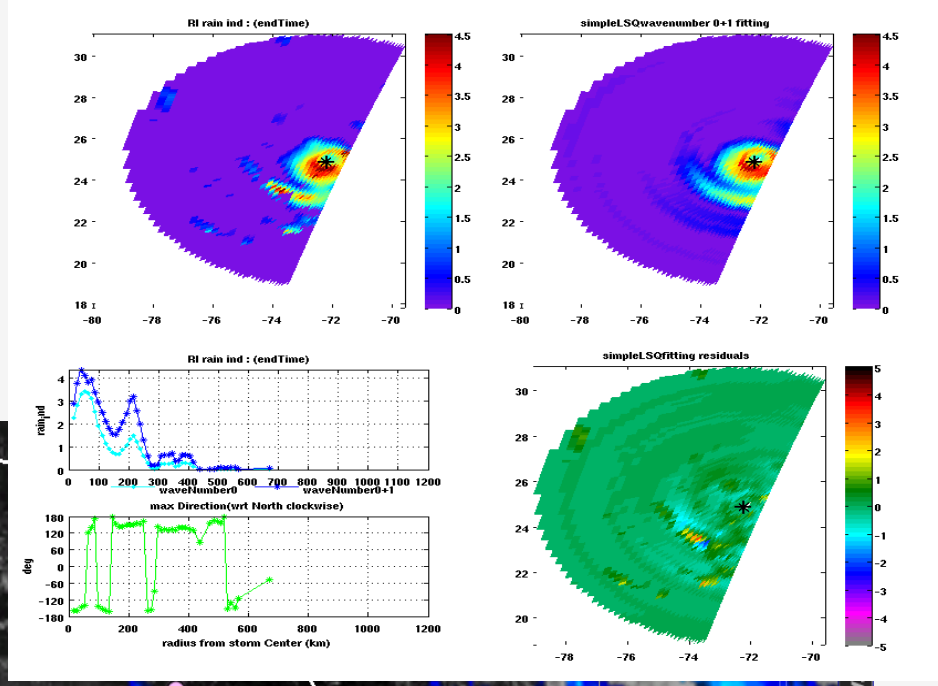
11L – Atlantic Hurricane Joaquin
09/30/2015; 13Z-16Z
Wave Number Analysis

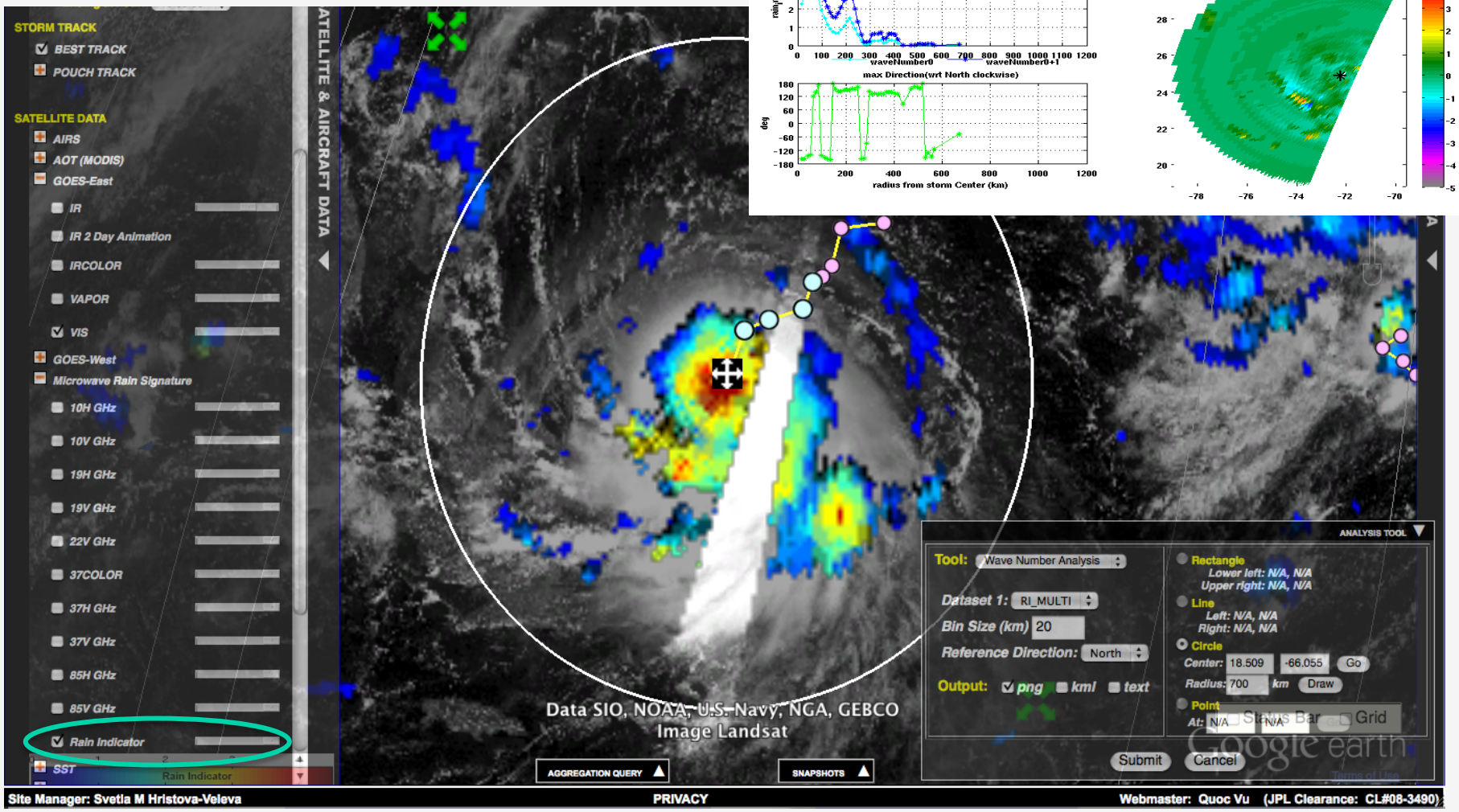
Storm structure Tool: Observations

Storm Size and Asymmetry:

The Wave Number Analysis Tool using the Rain Indicator (Rain Index)

AL Hurricane Joaquin -09/30/2015: 13Z (12:50Z)

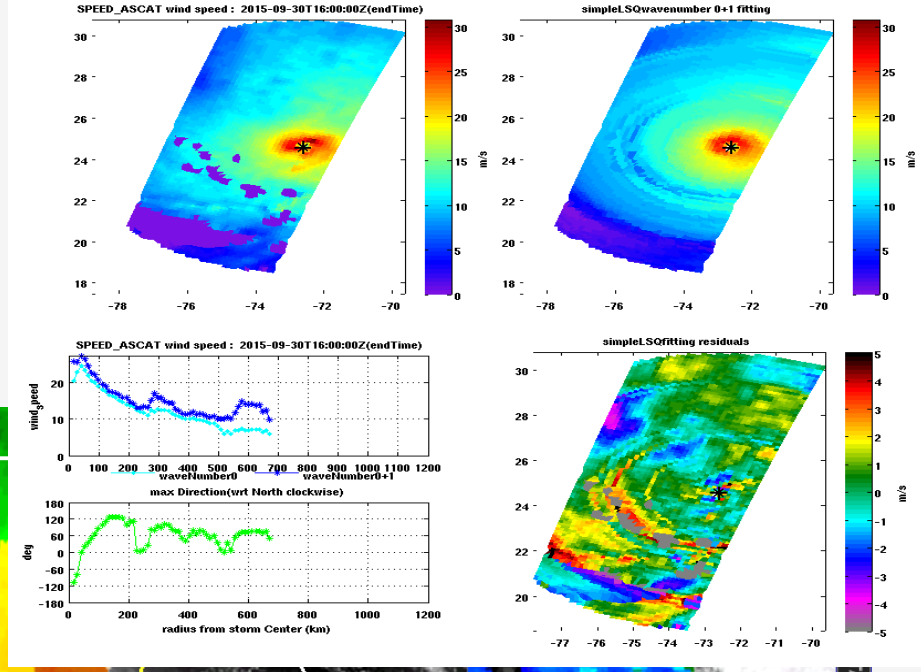


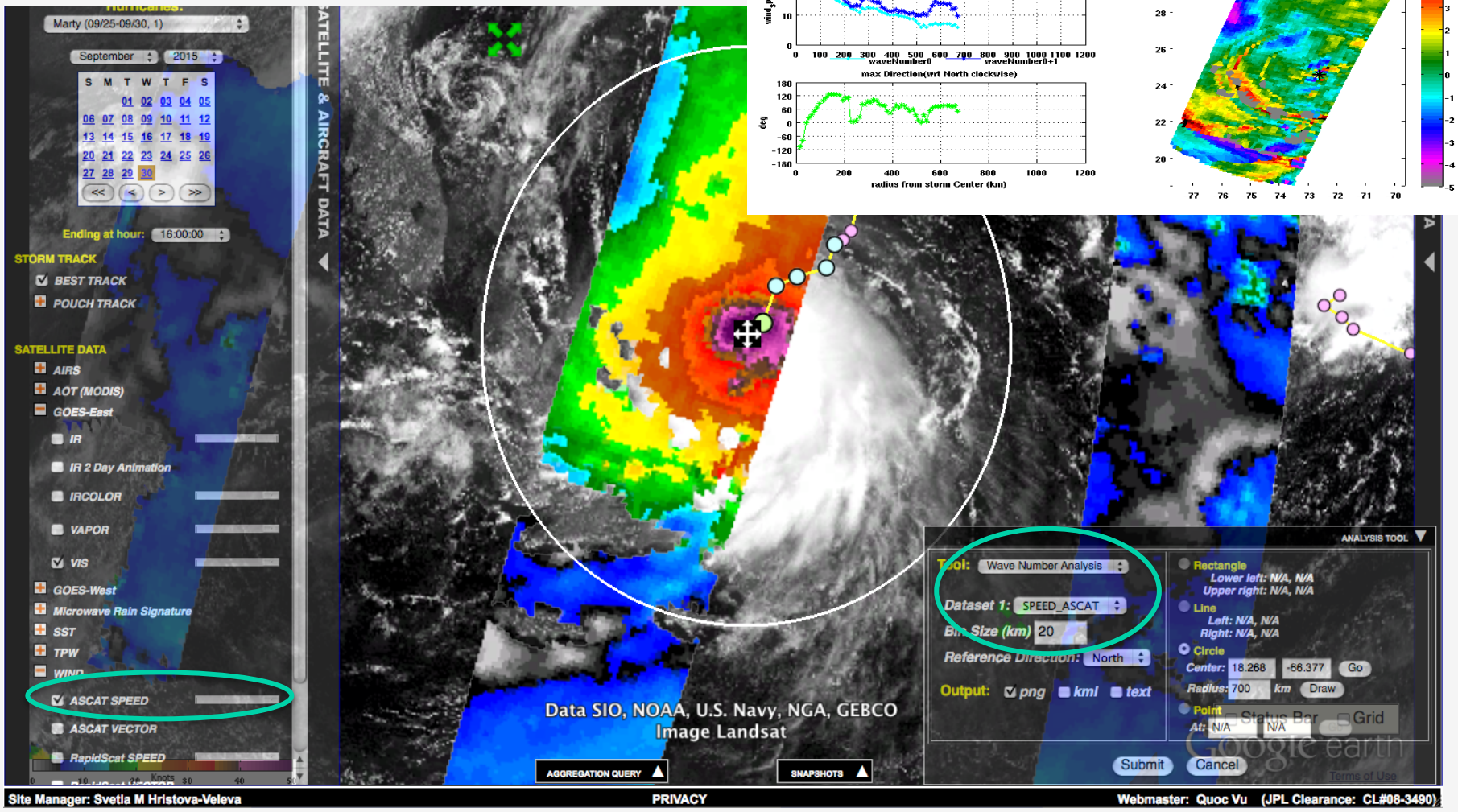


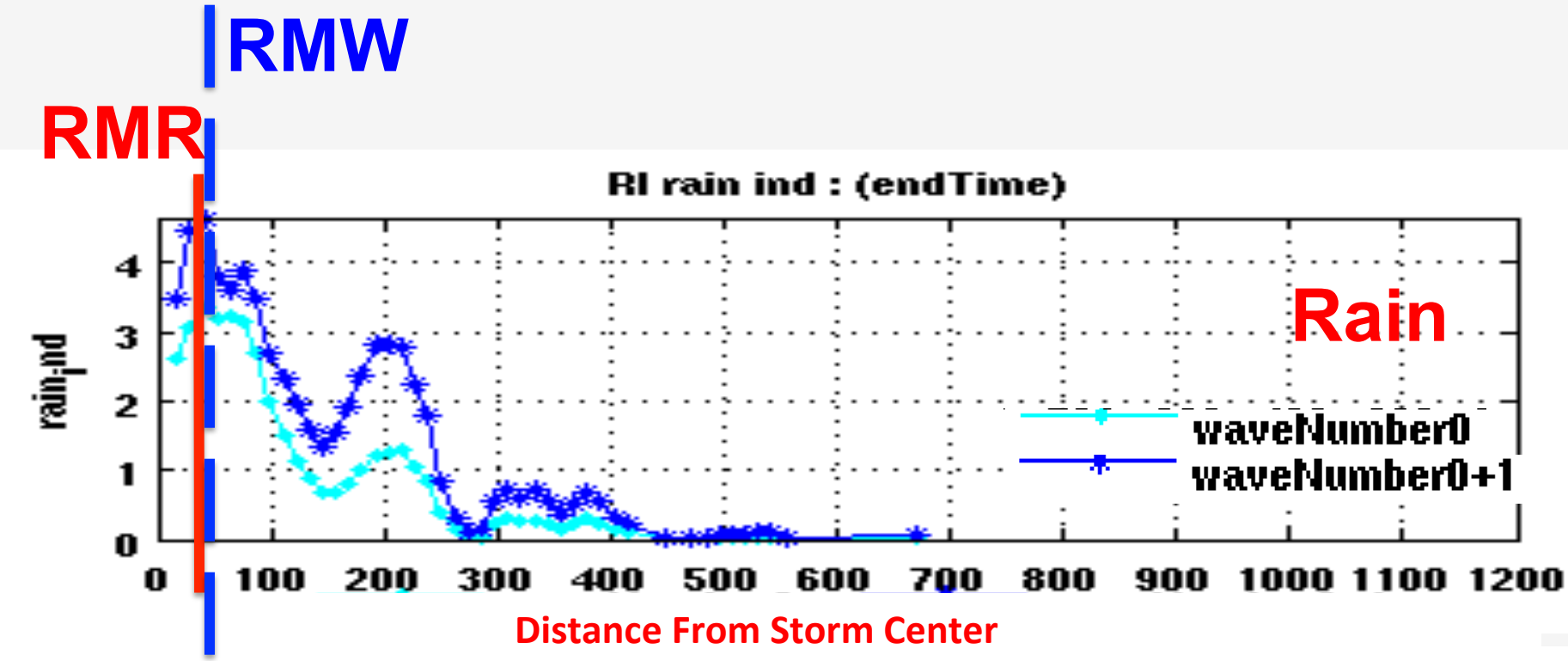
Storm structure Tool: Observations

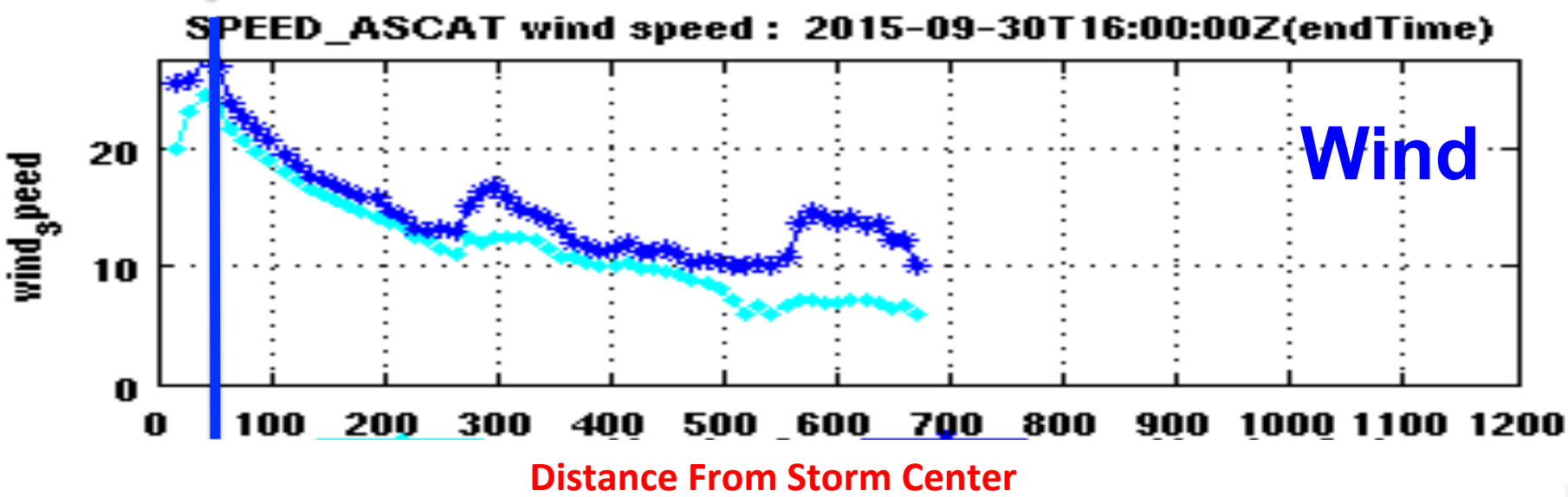
Storm Size and Asymmetry: *The Wave Number Analysis Tool using the ASCAT winds*

AL Hurricane Joaquin -09/30/2015: 13Z (15Z-16Z)






RMW
RMR
RI rain ind : (endTime)
rain_ind
Rain
waveNumber0
waveNumber0+1
0
1
2
3
4
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Distance From Storm Center

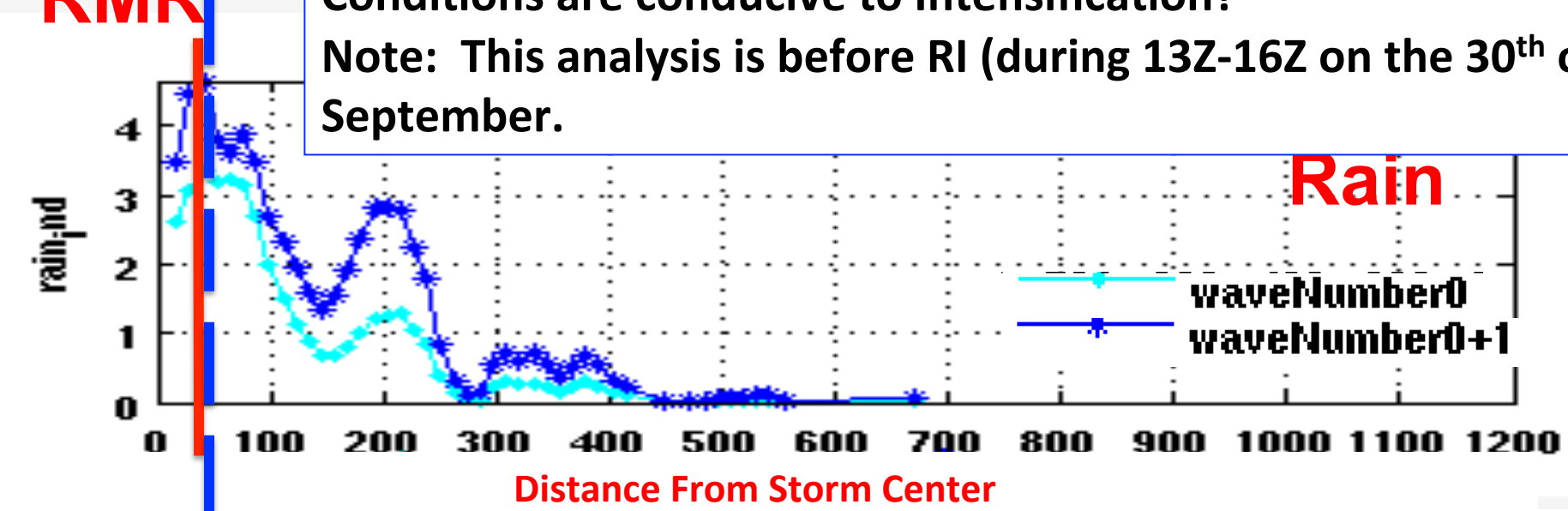

SPEED_ASCAT wind speed : 2015-09-30T16:00:00Z(endTime)
wind_speed
Wind
0
10
20
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Distance From Storm Center

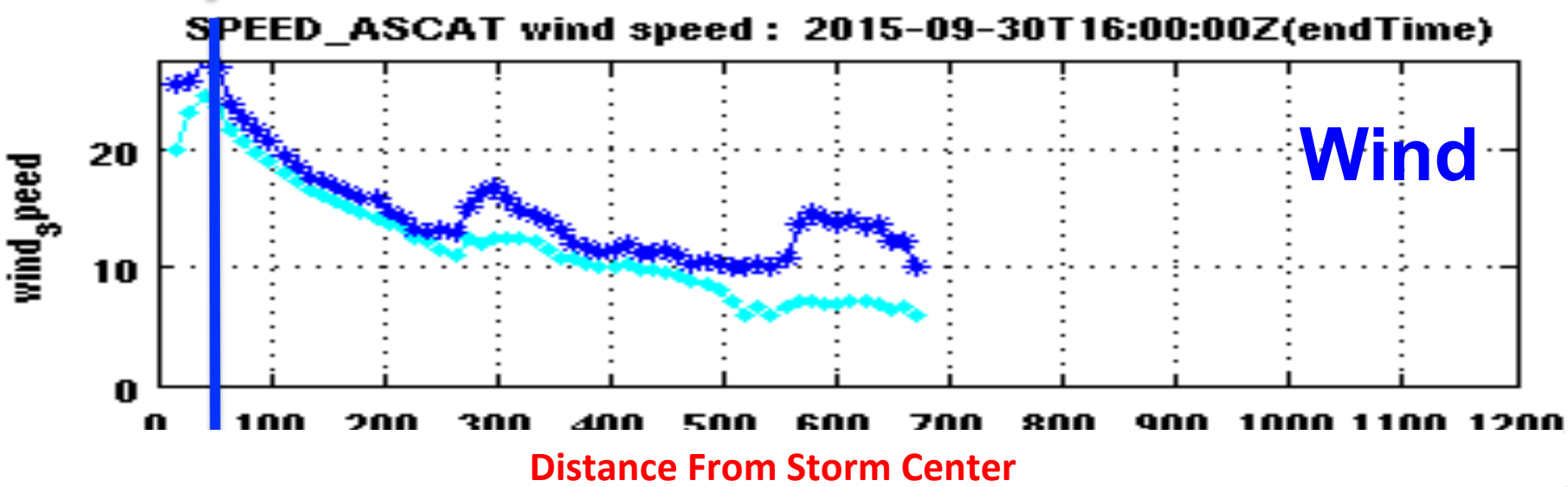
The storm is more asymmetric in rain than in wind

Radius of Max Wind (RMW) is just a bit larger than the Radius of Max Rain (RMR). Significant Precipitation inside RMW.

Conditions are conducive to Intensification?

Note: This analysis is before RI (during 13Z-16Z on the 30th of September.



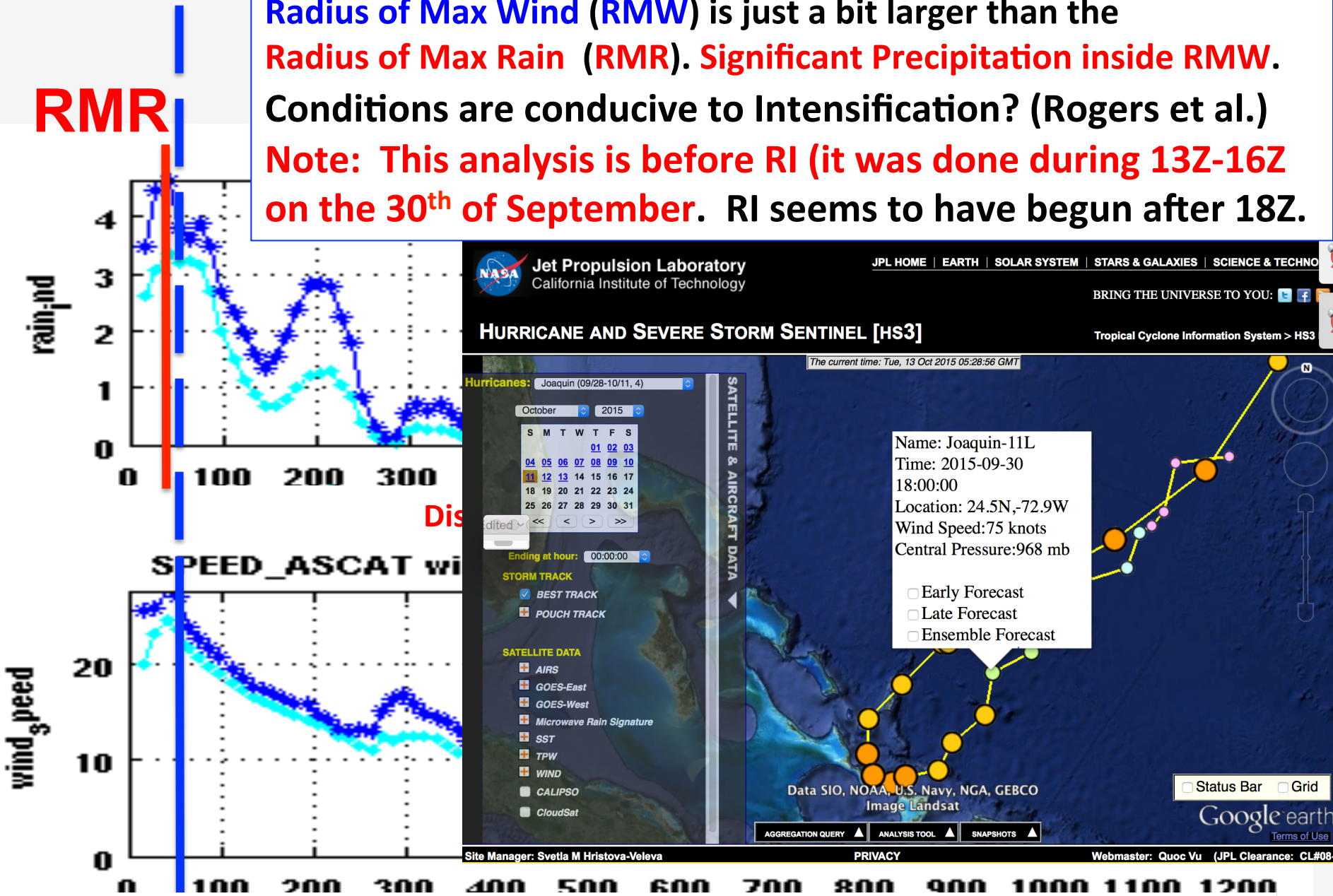


The storm is more asymmetric in rain than in wind

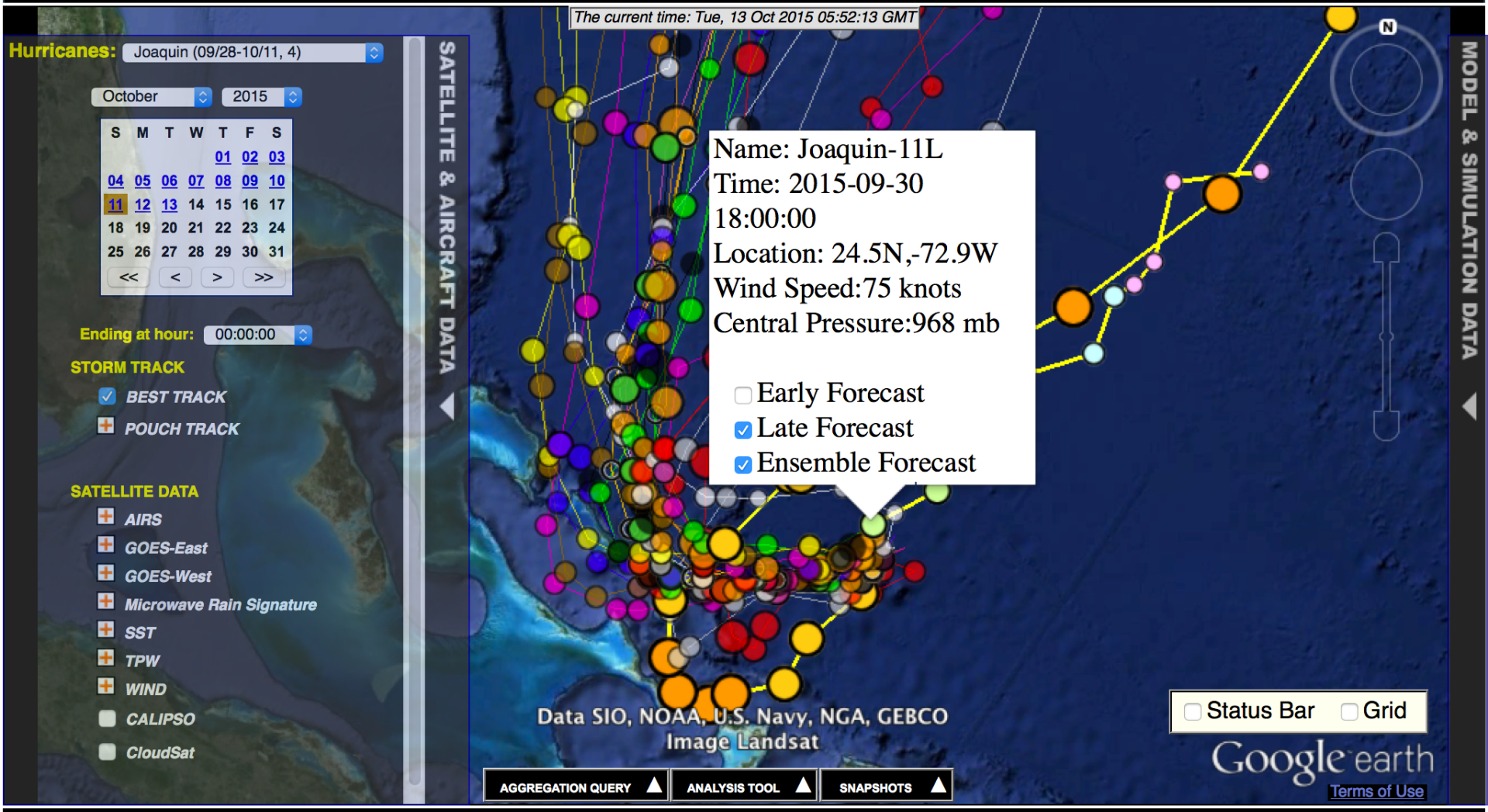
Radius of Max Wind (RMW) is just a bit larger than the Radius of Max Rain (RMR). Significant Precipitation inside RMW.

Conditions are conducive to Intensification? (Rogers et al.)

Note: This analysis is before RI (it was done during 13Z-16Z on the 30th of September. RI seems to have begun after 18Z.



HURRICANE AND SEVERE STORM SENTINEL [HS3]



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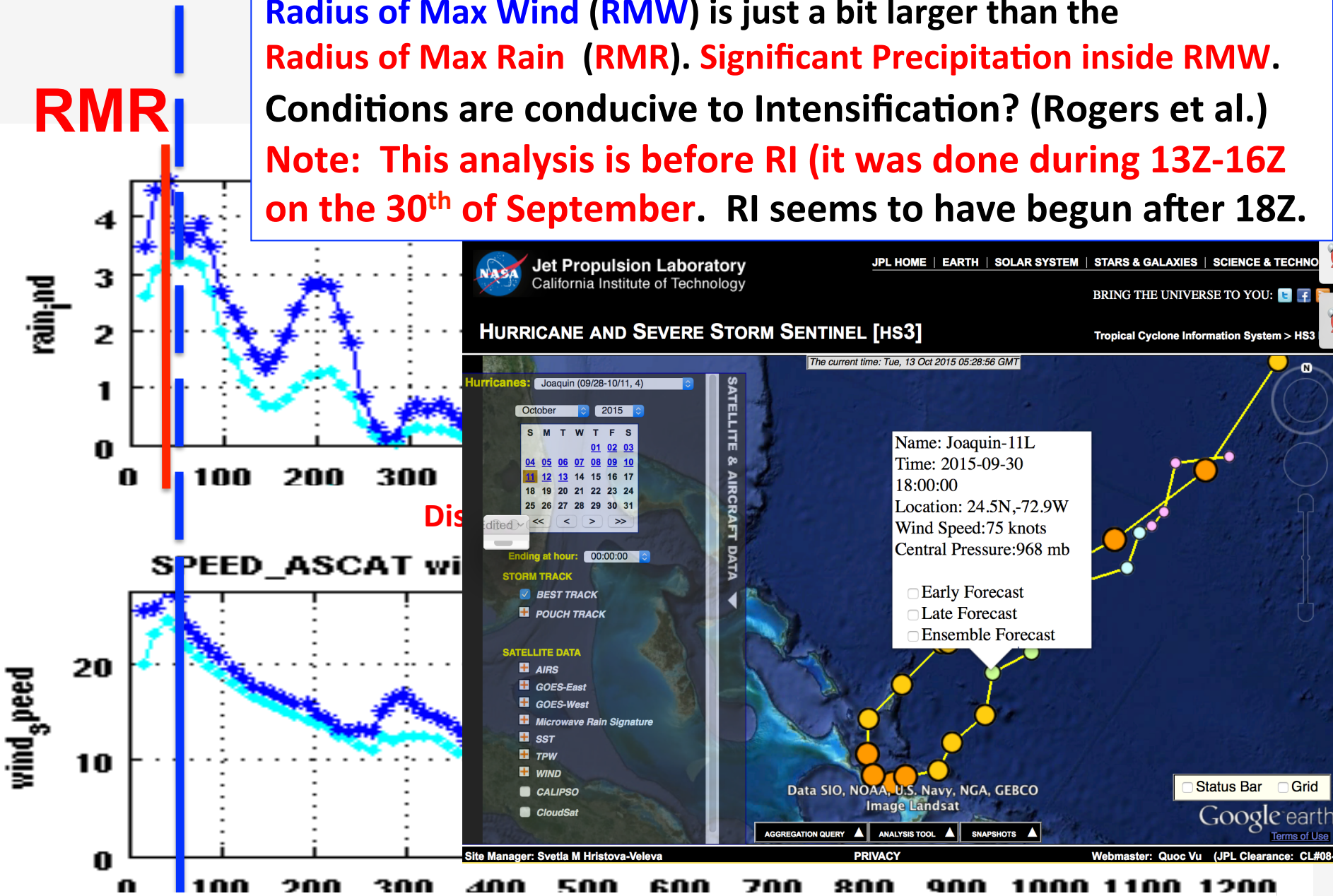
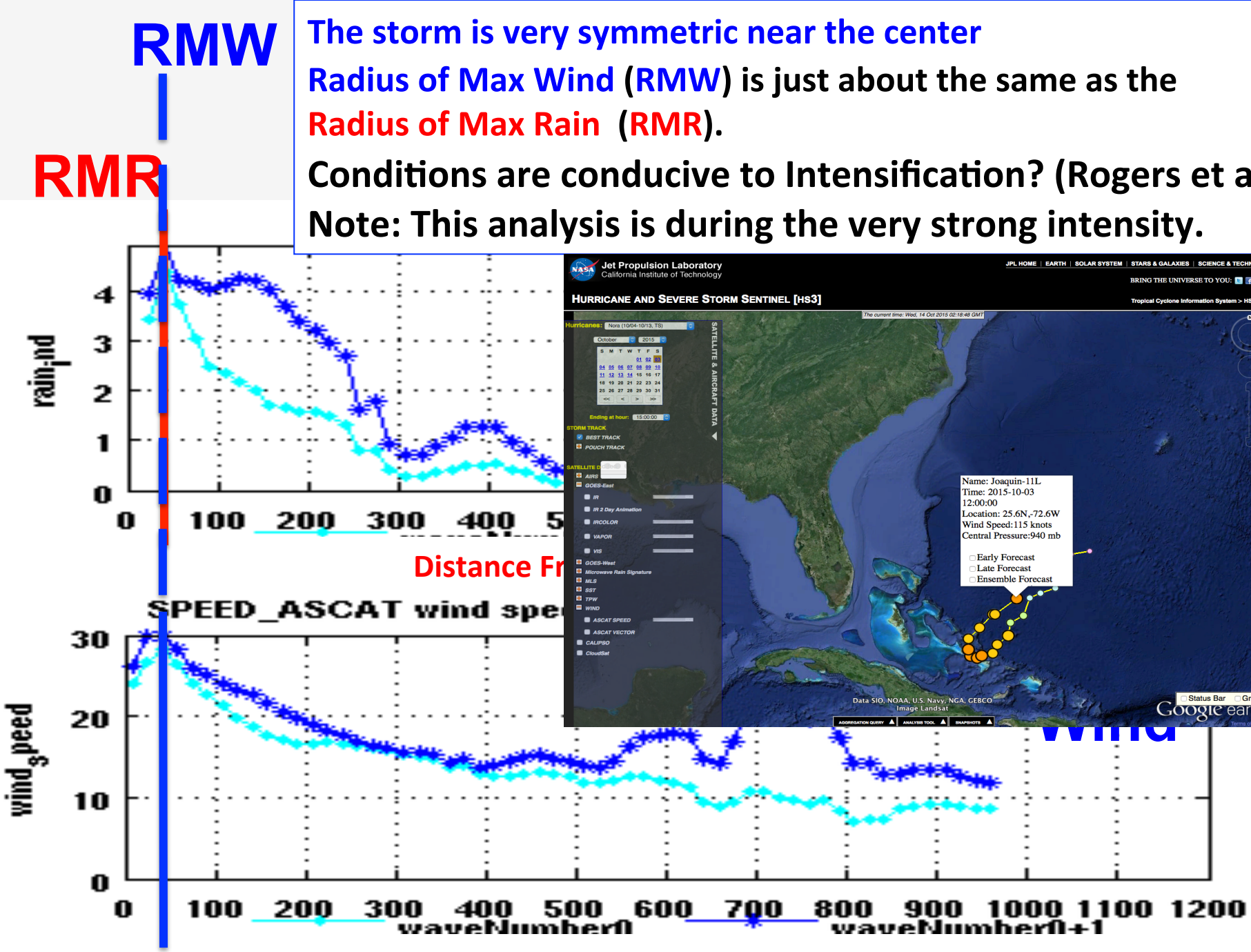


The storm is very symmetric near the center

Radius of Max Wind (RMW) is just about the same as the Radius of Max Rain (RMR).

Conditions are conducive to Intensification? (Rogers et al.)

Note: This analysis is during the very strong intensity.

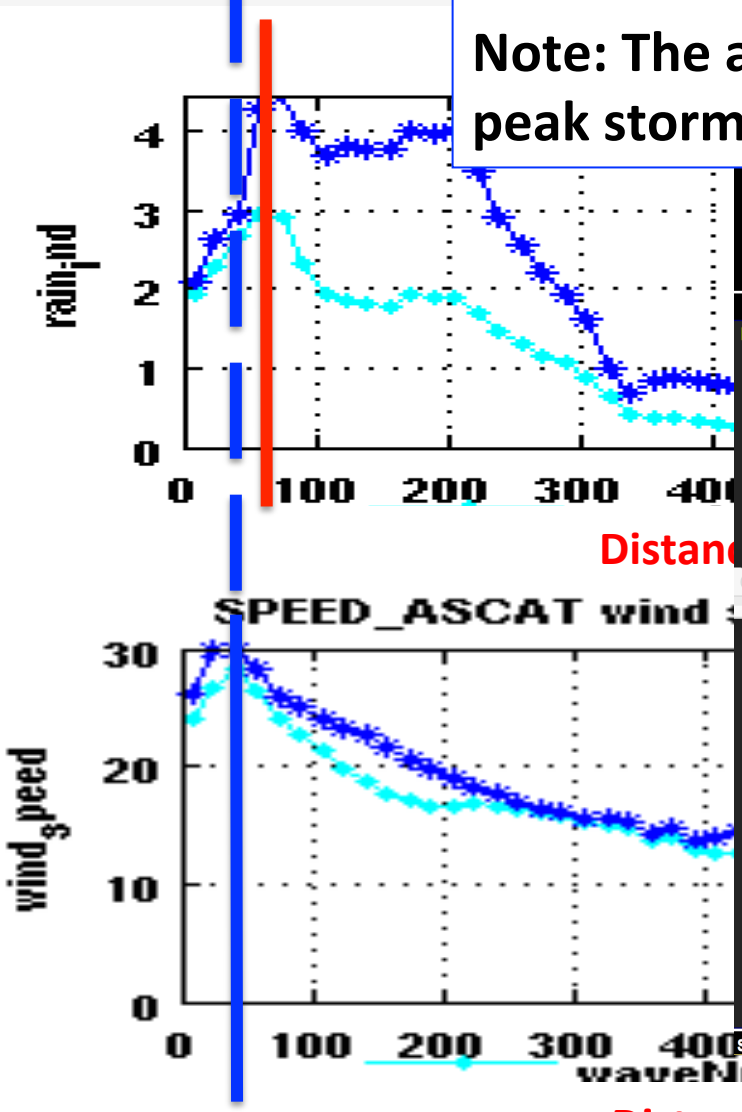


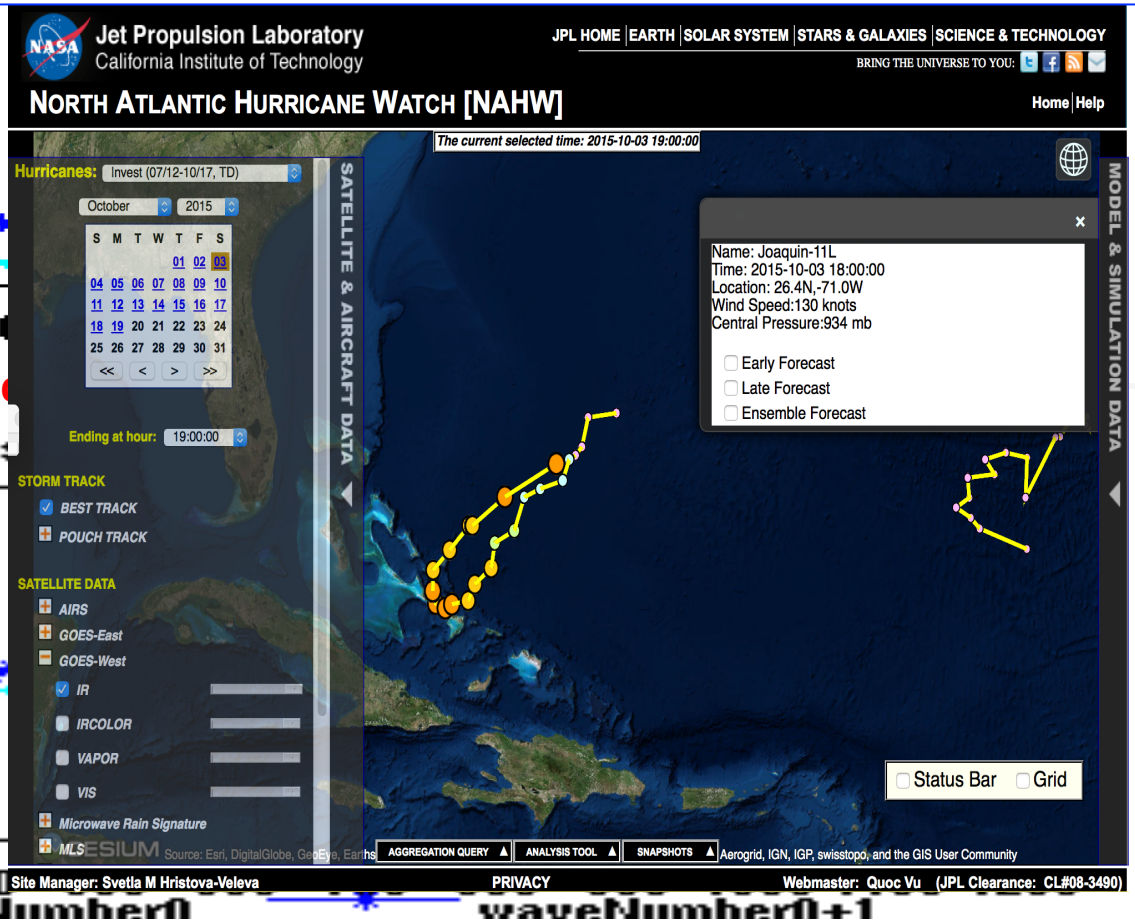
The storm is becoming very asymmetric away from the center

Radius of Max Wind (RMW) is inside the Radius of Max Rain (RMR).

Conditions are NOT conducive to Intensification?

Note: The analysis of the Rain field is at the end of the peak storm intensity.





RMW

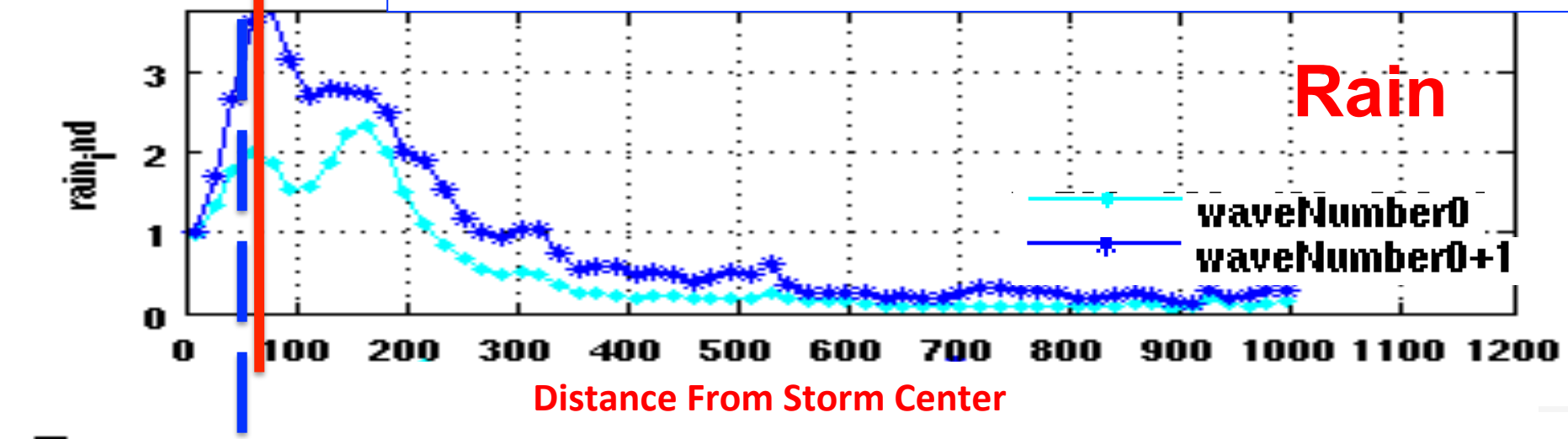
RMR

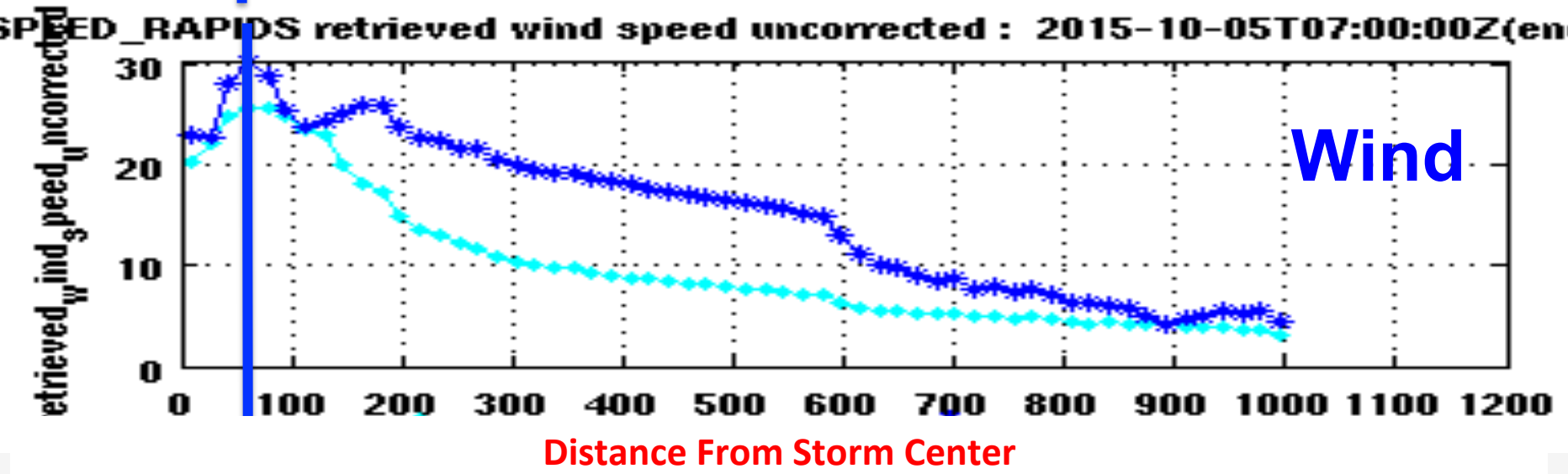
The storm is more asymmetric in rain than in wind

Radius of Max Wind (RMW) is just a bit smaller than the Radius of Max Rain (RMR).

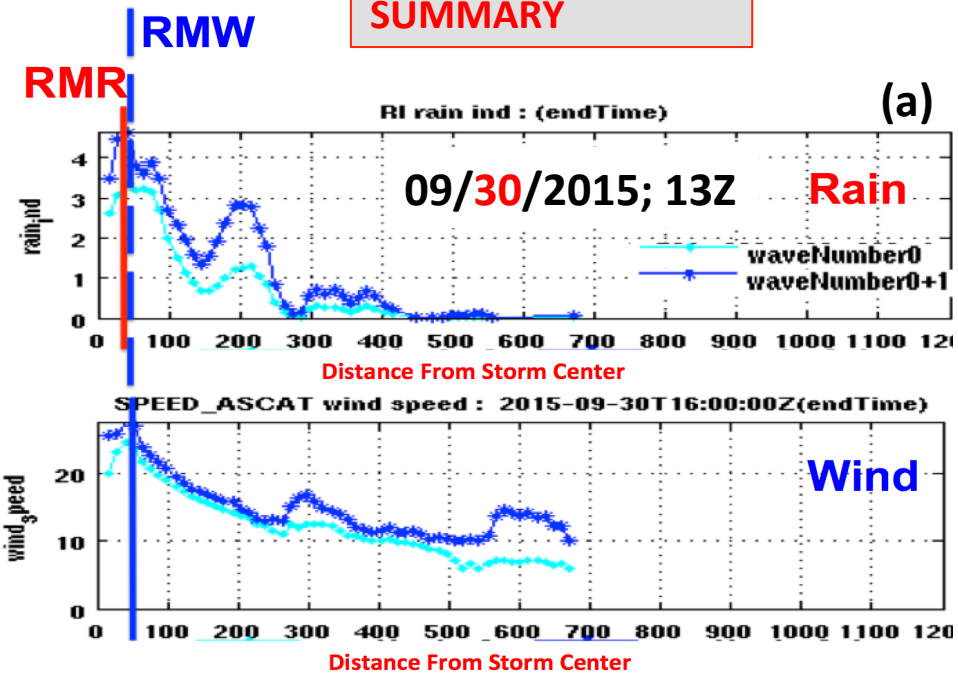
Rain inside RMW is much less intense

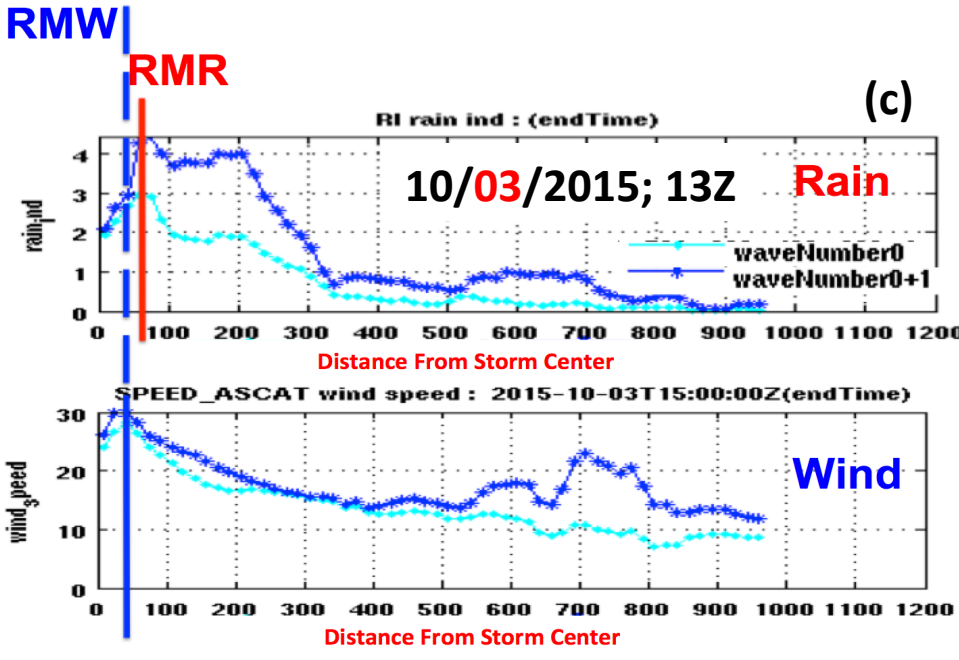
Conditions are not conducive to Intensification.

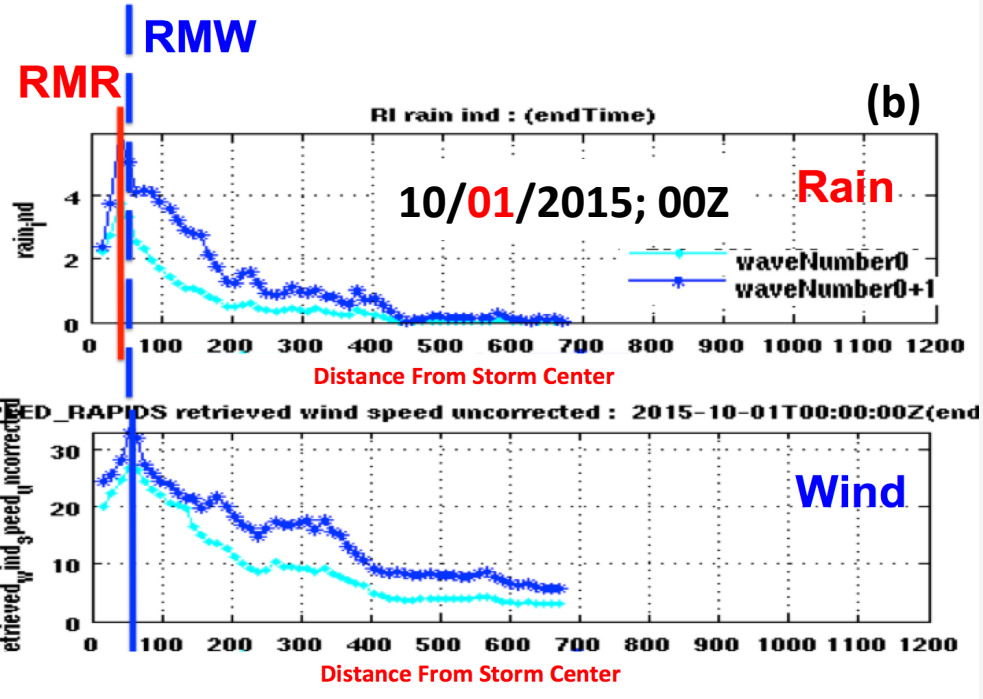


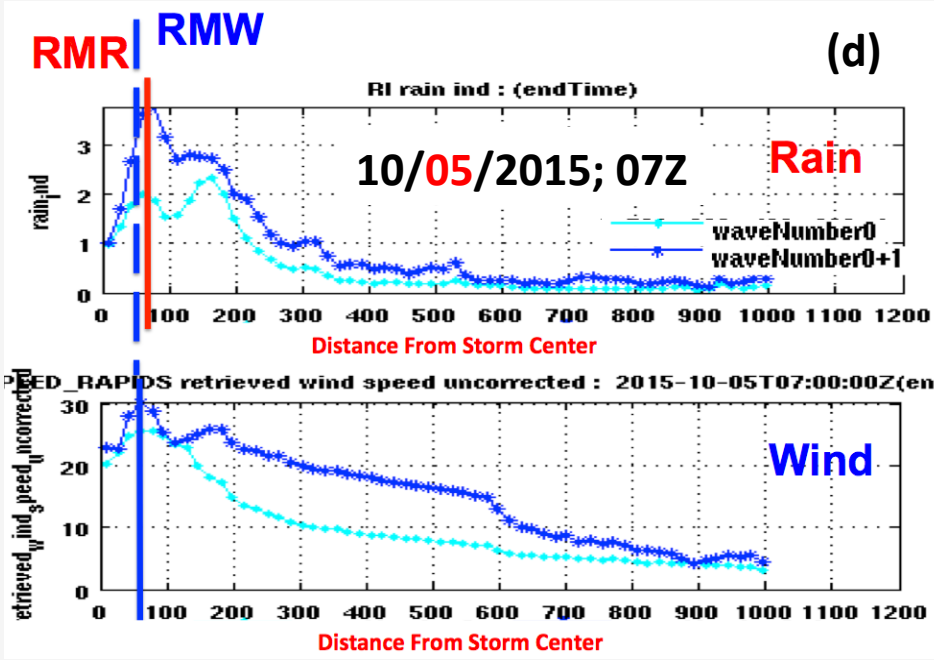


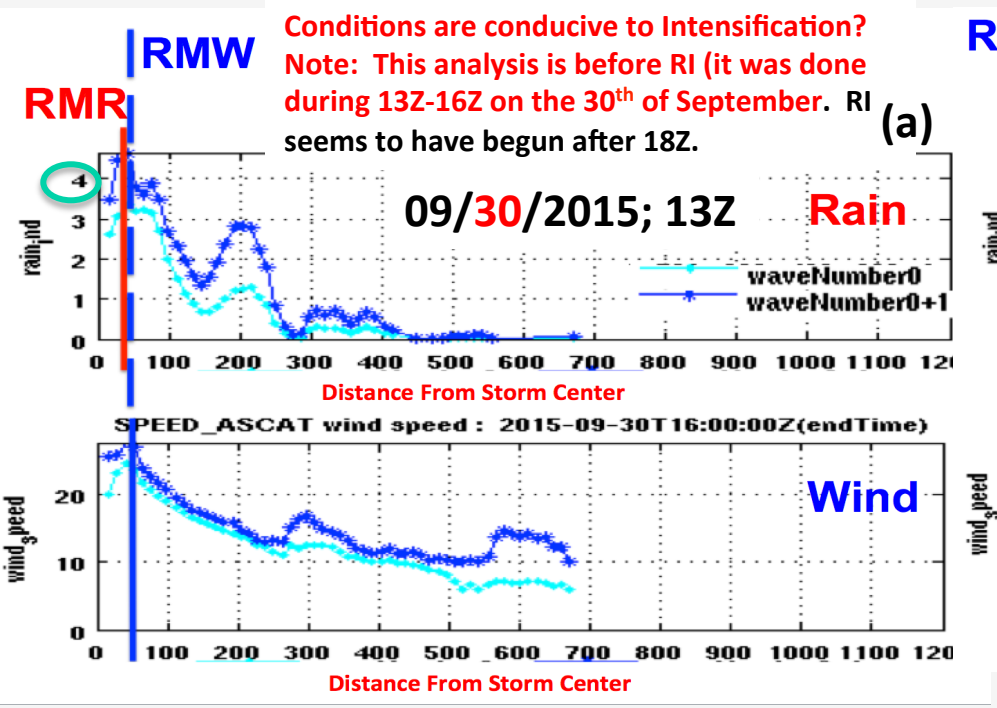
SUMMARY

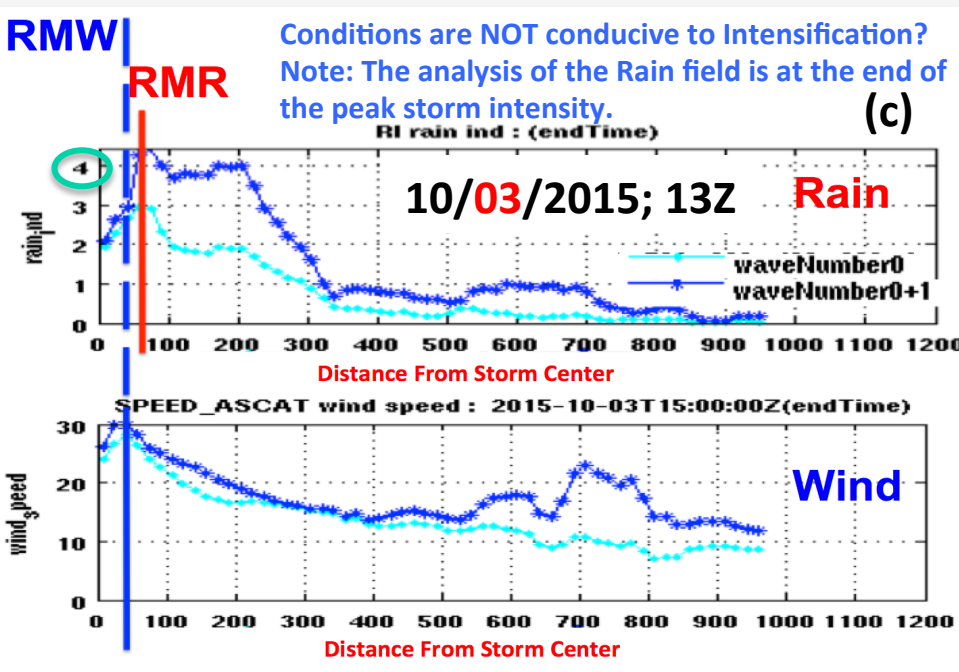

RMW
RMR
(a)
RI rain ind : (endTime)
09/30/2015; 13Z
Rain
waveNumber0
waveNumber0+1
rain_ind
Distance From Storm Center
SPEED_ASCAT wind speed : 2015-09-30T16:00:00Z(endTime)
Wind
wind_speed
Distance From Storm Center

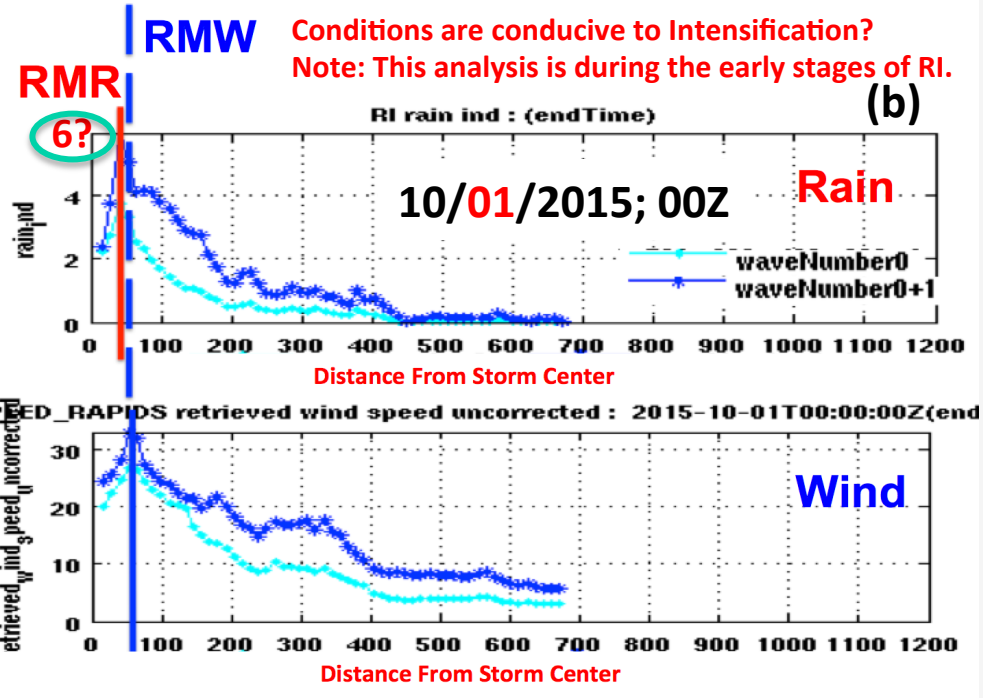

RMW
RMR
(c)
RI rain ind : (endTime)
10/03/2015; 13Z
Rain
waveNumber0
waveNumber0+1
rain_ind
Distance From Storm Center
SPEED_ASCAT wind speed : 2015-10-03T15:00:00Z(endTime)
Wind
wind_speed
Distance From Storm Center

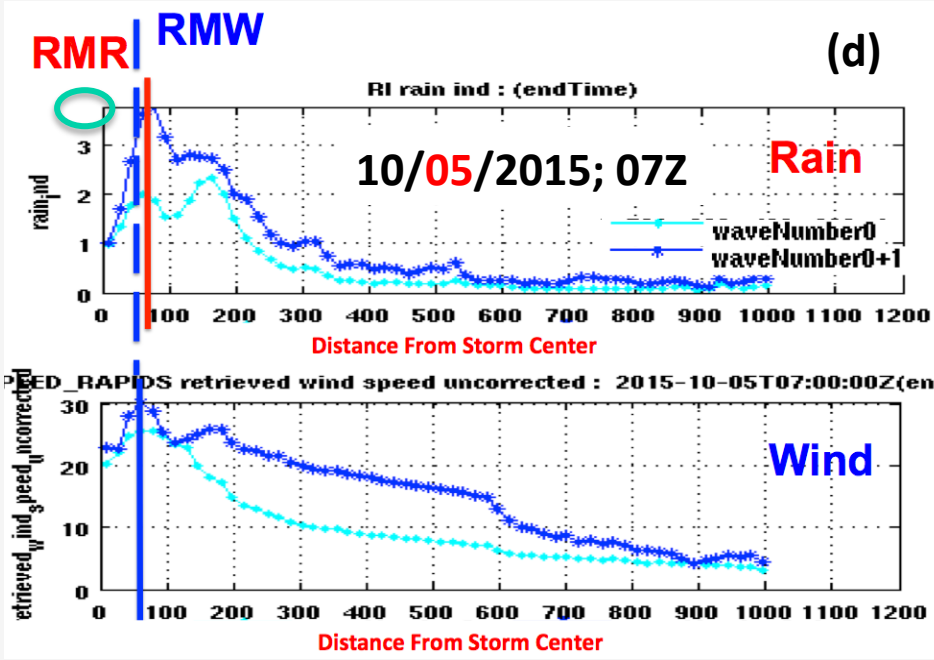

RMW
RMR
(b)
RI rain ind : (endTime)
10/01/2015; 00Z
Rain
waveNumber0
waveNumber0+1
rain_ind
Distance From Storm Center
ED_RAPIDS retrieved wind speed uncorrected : 2015-10-01T00:00:00Z(end
Wind
Distance From Storm Center


RMR
RMW
(d)
RI rain ind : (endTime)
10/05/2015; 07Z
Rain
waveNumber0
waveNumber0+1
rain_ind
Distance From Storm Center
ED_RAPIDS retrieved wind speed uncorrected : 2015-10-05T07:00:00Z(en
Wind
Distance From Storm Center


RMW
RMR
Conditions are conducive to Intensification?
Note: This analysis is before RI (it was done during 13Z-16Z on the 30th of September. RI seems to have begun after 18Z.
(a)
09/30/2015; 13Z
Rain
waveNumber0
waveNumber0+1
Distance From Storm Center
SPEED_ASCAT wind speed : 2015-09-30T16:00:00Z(endTime)
Wind
Distance From Storm Center


RMW
RMR
Conditions are NOT conducive to Intensification?
Note: The analysis of the Rain field is at the end of the peak storm intensity.
(c)
RI rain ind : (endTime)
10/03/2015; 13Z
Rain
waveNumber0
waveNumber0+1
Distance From Storm Center
SPEED_ASCAT wind speed : 2015-10-03T15:00:00Z(endTime)
Wind
Distance From Storm Center


RMW
RMR
6?
Conditions are conducive to Intensification?
Note: This analysis is during the early stages of RI.
(b)
RI rain ind : (endTime)
10/01/2015; 00Z
Rain
waveNumber0
waveNumber0+1
Distance From Storm Center
SPEED_RAPIDS retrieved wind speed uncorrected : 2015-10-01T00:00:00Z(end
Wind
Distance From Storm Center


RMR
RMW
(d)
RI rain ind : (endTime)
10/05/2015; 07Z
Rain
waveNumber0
waveNumber0+1
Distance From Storm Center
SPEED_RAPIDS retrieved wind speed uncorrected : 2015-10-05T07:00:00Z(en
Wind
Distance From Storm Center

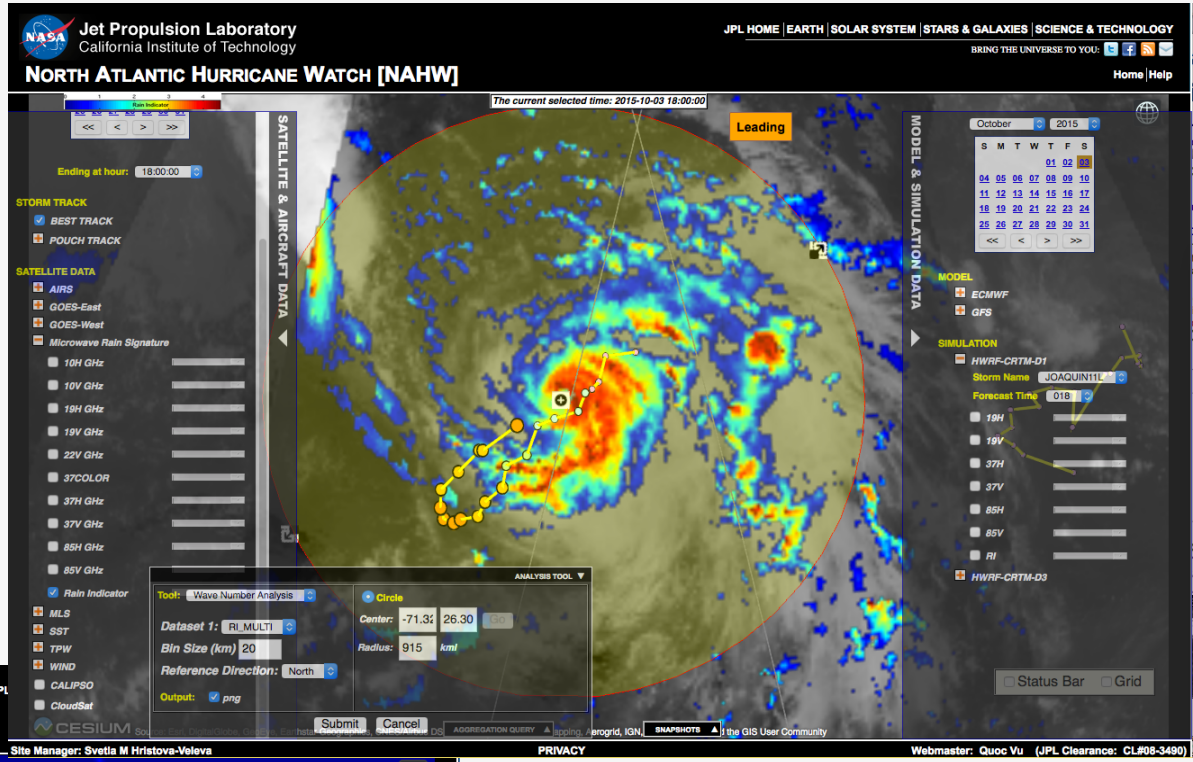
Comparing the Storm Structure in HWRF and in Observations

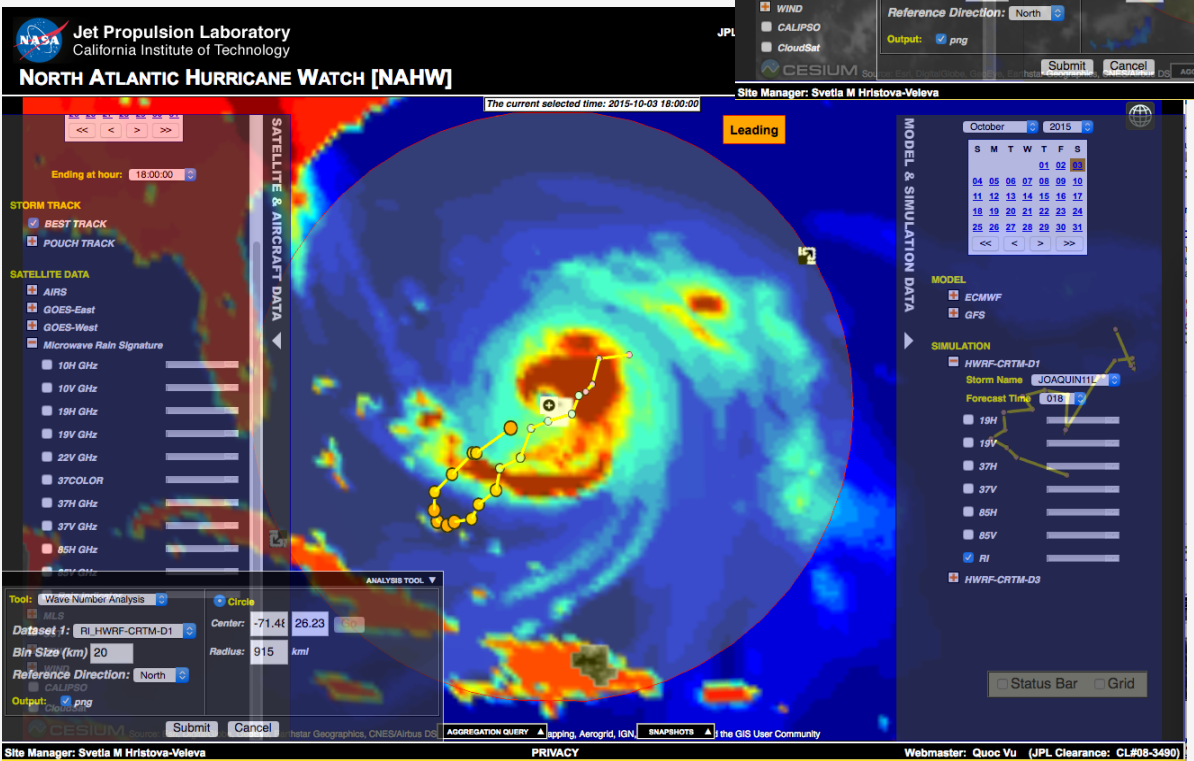
Evaluating HWRF Forecast; *(Hurricane Joaquin)*

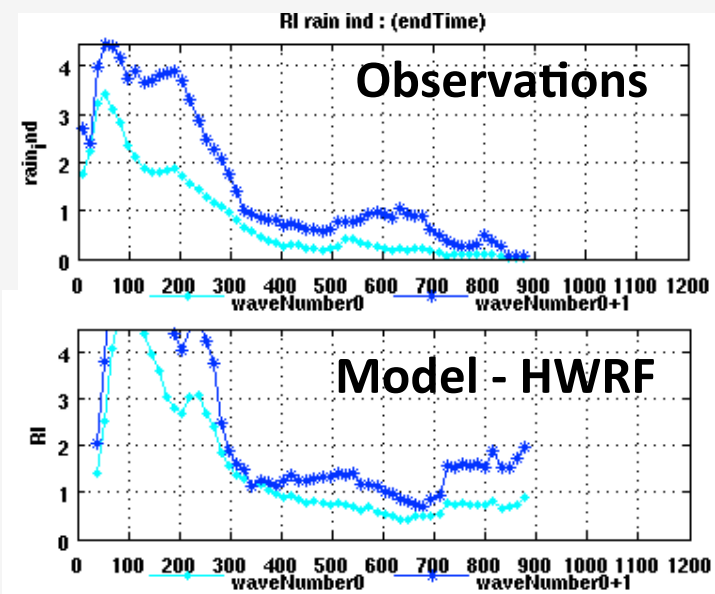
18h forecast starting on October 3rd, 00Z

Looking at the Rain Index

- **Overall – a very good comparison in the shape of the precipitation**





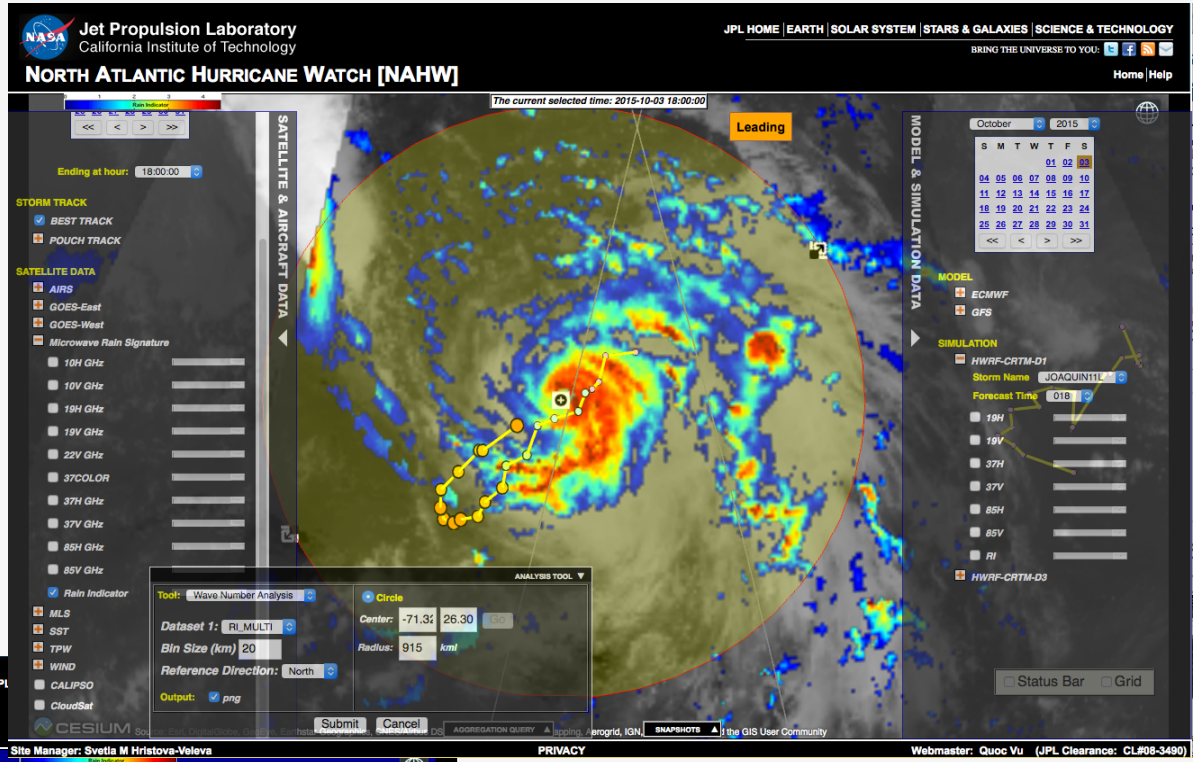


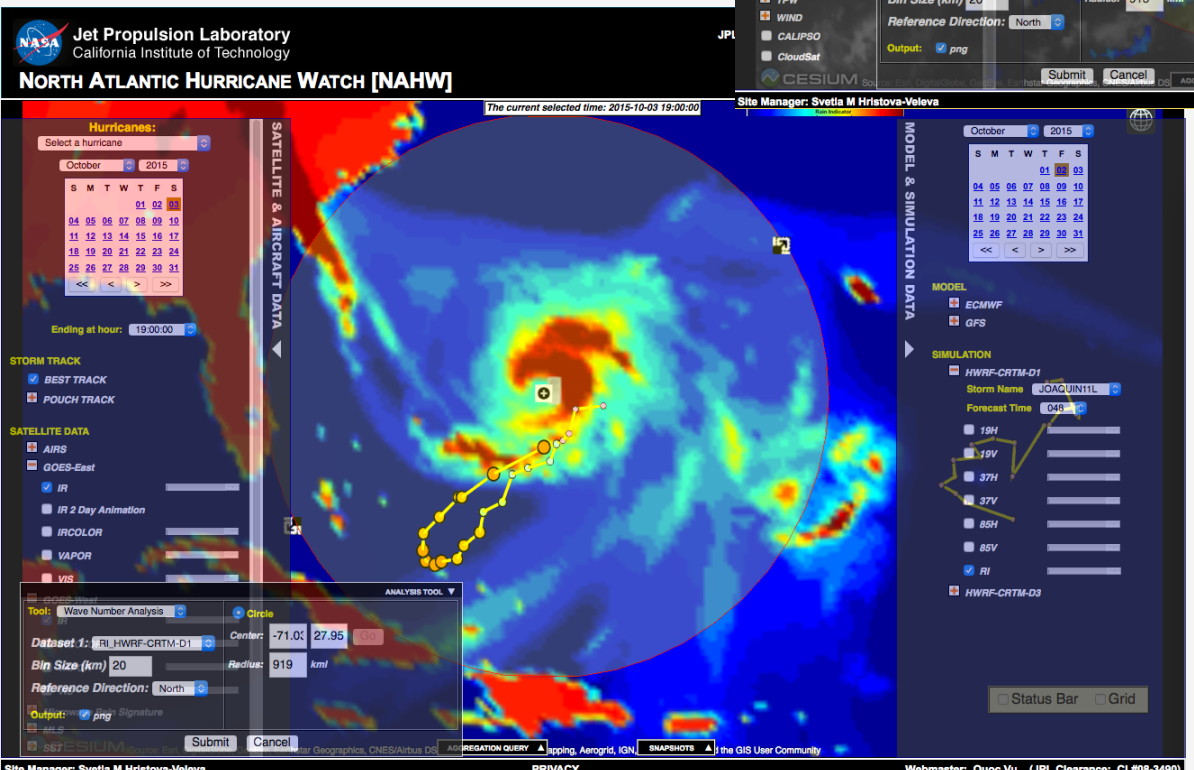
Evaluating HWRF Forecast; *(Hurricane Joaquin)*

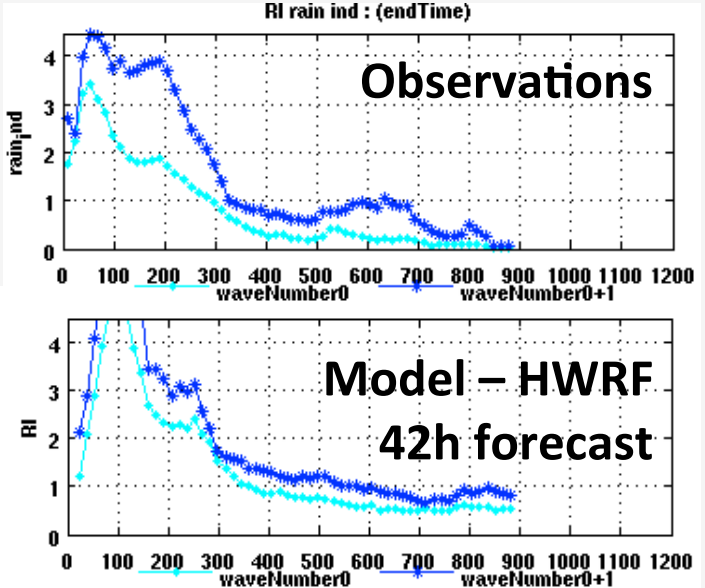
42h forecast starting on October 2nd, 00Z

Looking at the Rain Index

- **Overall – a very good comparison in the shape of the precipitation**
- **Center is off**







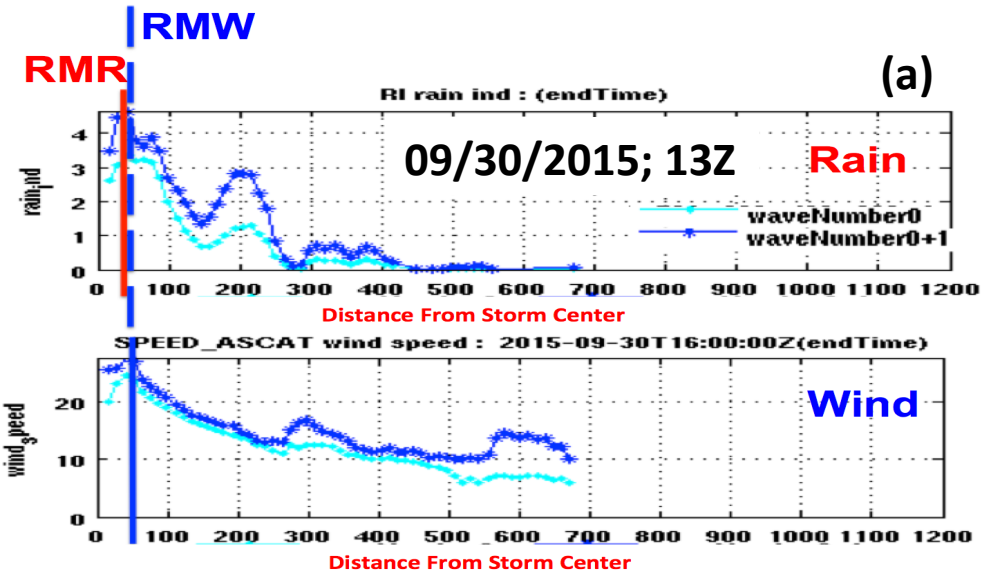
Summary

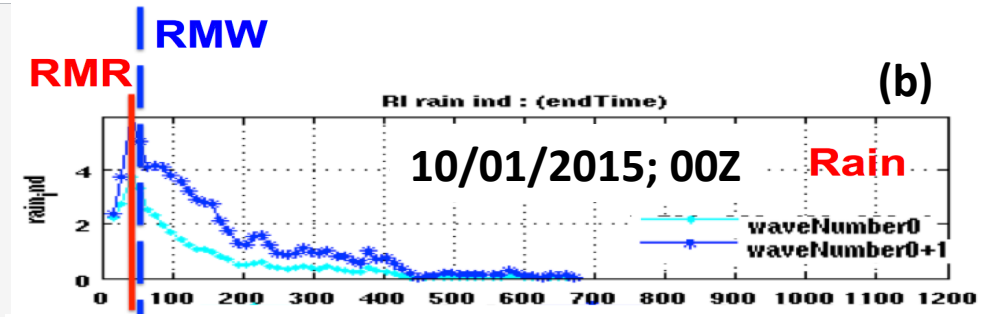
- Accurate forecasting of hurricane rapid intensification, while very desired, still remains problematic
- Observational studies and theoretical considerations point to the need to understand the evolution of the 2D-precipitation structure un relation to the vortex structure as defined by the radius if maximum wind.
- Following Vukicevic et al. (2013), we analyze the 2D distribution of the wind and rain fields using Wave Number Analysis (WNA).
  - A WNA tool is available on-line at the North Atlantic Hurricane Portal (NAHW portal -http://mwsci.jpl.nasa.gov/nahw).
  - WNA can be used to evaluate the degree of storm symmetry that is related to its intensity.
  - Very importantly, it can also be used to evaluate the radial distribution of precipitation/wind, as the wave number decomposition is performed in several 20km- annuli, at distances that are progressively further away from the storm center.
- We performed WNA of nearly-simultaneous wind and rain observations. In particular, we analyzed observations of hurricane Joaquin (2015) and hurricane Humberto (2013).
- We find that the proposed joint WNA of satellite observations has potential predictive capabilities.
- We have a comprehensive set of observations, covering 10 years of global satellite observations

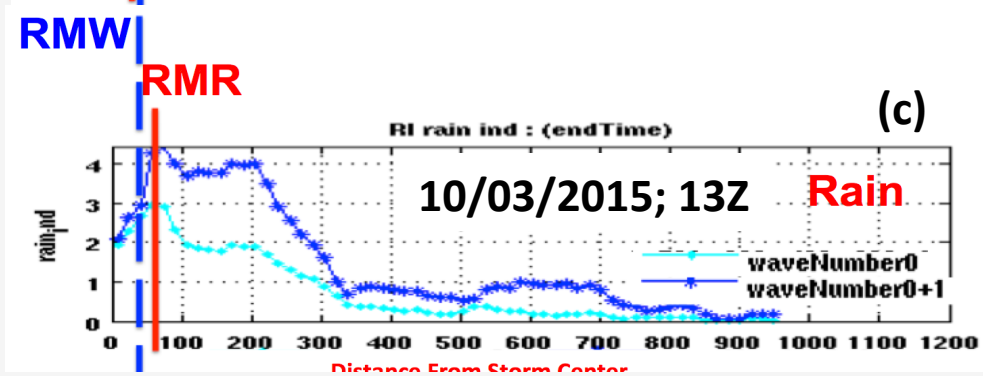
Next Steps

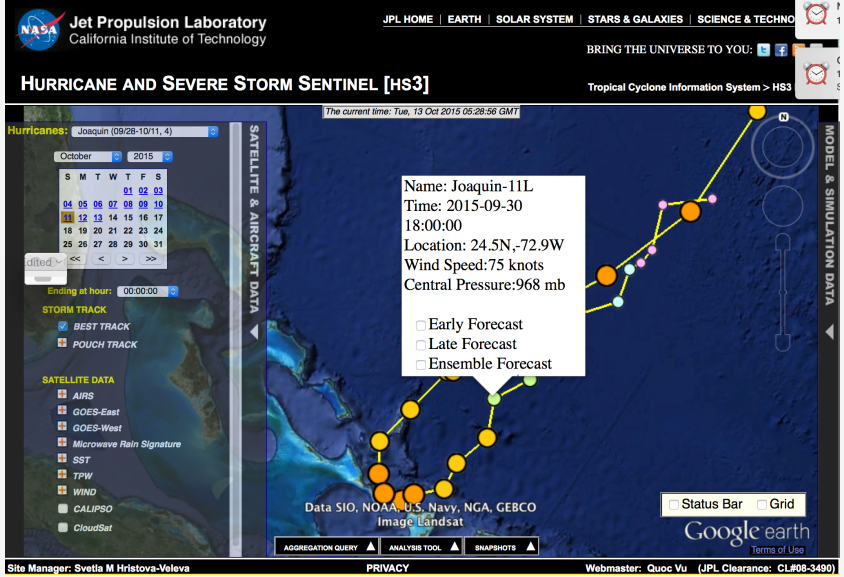
- We have a comprehensive set of observations, covering 10 years of global satellite observations, all available from the JPL TCIS Data Archive
- We are now poised to apply machine learning techniques to uncover the details in the relationship between the evolution of the 2D precipitation field as related to the vortex size
- It is expected that such studies will facilitate the forecasting of rapid intensification based on satellite observations alone.
- Furthermore, such relationships between the wind and precipitation structures will present a new way to evaluate models and will provide insights as to the circumstances under which the forecasts of rapid intensification fail.

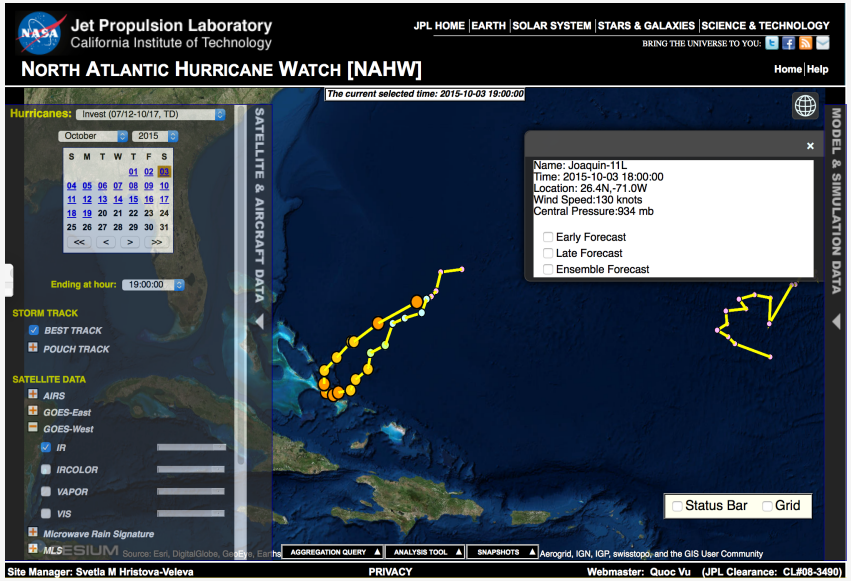
Backup


RMW
RMR
(a)
RI rain ind : (endTime)
09/30/2015; 13Z
Rain
rain_ind
waveNumber0
waveNumber0+1
Distance From Storm Center
SPEED_ASCAT wind speed : 2015-09-30T16:00:00Z(endTime)
Wind
wind_speed
Distance From Storm Center


RMW
RMR
(b)
RI rain ind : (endTime)
10/01/2015; 00Z
Rain
rain_ind
waveNumber0
waveNumber0+1


RMW
RMR
(c)
RI rain ind : (endTime)
10/03/2015; 13Z
Rain
rain_ind
waveNumber0
waveNumber0+1


Jet Propulsion Laboratory
California Institute of Technology
HURRICANE AND SEVERE STORM SENTINEL [HS3]
Hurricanes: Joaquin (09/28-10/11, 4)
Name: Joaquin-11L
Time: 2015-09-30
18:00:00
Location: 24.5N,-72.9W
Wind Speed:75 knots
Central Pressure:968 mb
Early Forecast
Late Forecast
Ensemble Forecast
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat
Google earth
Site Manager: Svetla M Hristova-Veleva
PRIVACY
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)


Jet Propulsion Laboratory
California Institute of Technology
NORTH ATLANTIC HURRICANE WATCH [NAHW]
Hurricanes: Invest (07/12-10/17, TD)
Name: Joaquin-11L
Time: 2015-10-03 18:00:00
Location: 26.4N,-71.0W
Wind Speed:130 knots
Central Pressure:934 mb
Early Forecast
Late Forecast
Ensemble Forecast
Site Manager: Svetla M Hristova-Veleva
PRIVACY
Webmaster: Quoc Vu (JPL Clearance: CL#08-3490)