Climatological depiction of hurricane structure from passive microwave and scatterometer observations: Using the 12-year JPL Tropical Cyclone Information System (TCIS) to create composites and establish reliable statistics.

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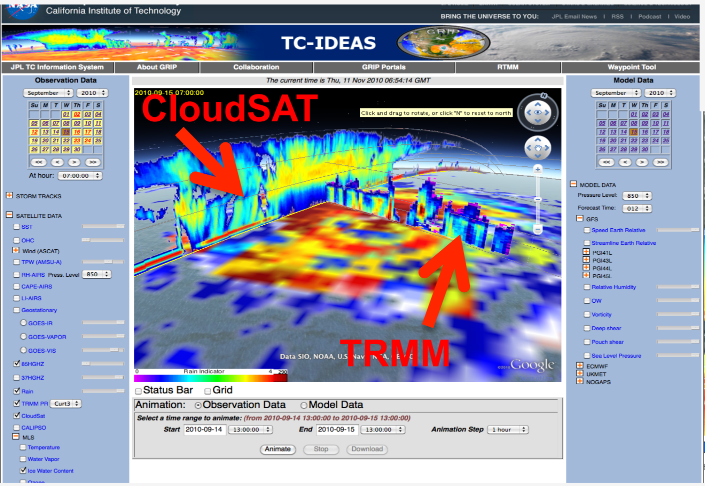
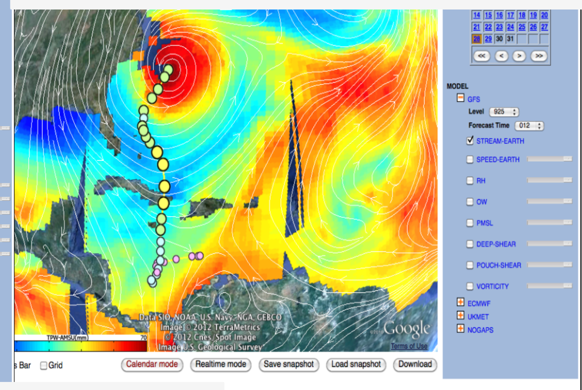
31st Conference on Hurricanes and Tropical Meteorology
April 3rd, 2014

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

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



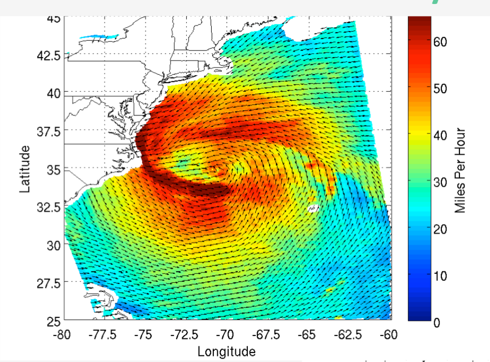
- **Is the environment captured correctly?**
- **Is the interaction between the storm and its environment realistic?**



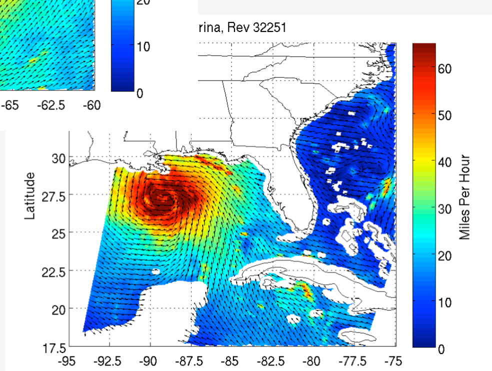
To improve Hurricane Intensity forecasts, **we need to understand how well the models reflect the physical processes and their interactions.**

Satellite observations can help in 3 important ways!

- **Is the storm scale and asymmetry reflected properly?**



Hurricane Sandy As seen by the ISRO's OSCAT



Hurricane Katrina As seen by the NASA's QuikSCAT

1. **Understanding the physical processes**
2. **Validation and improvement of hurricane models through the use of satellite data**
3. **Development and implementation of advanced techniques for assimilation of satellite observations inside the hurricane core.**

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

The JPL Tropical Cyclone Information System (TCIS)

http://tropicalcyclone.jpl.nasa.gov

Objective of the TCIS

To provide a one-stop place that facilitates fusion of multi-parameter, multi-instrument observations (satellite, airborne and in-situ) and model output, relevant to both the large-scale and the storm-scale hurricane processes. These observations pertain to:

- **the thermodynamic and microphysical structure of the storms;**
- **the air-sea interaction processes;**
- **the larger-scale environment**

Goal:

- help understand the physical processes that determine hurricane genesis, intensity, track and impact on large-scale environment

- help improve hurricane forecast accuracy by facilitating validation and improvement of hurricane models through comparison with observations and development of new data assimilation techniques

- enable studies aimed at developing new algorithms, sensor systems and missions.

The JPL TCIS – Tropical Cyclone Information System

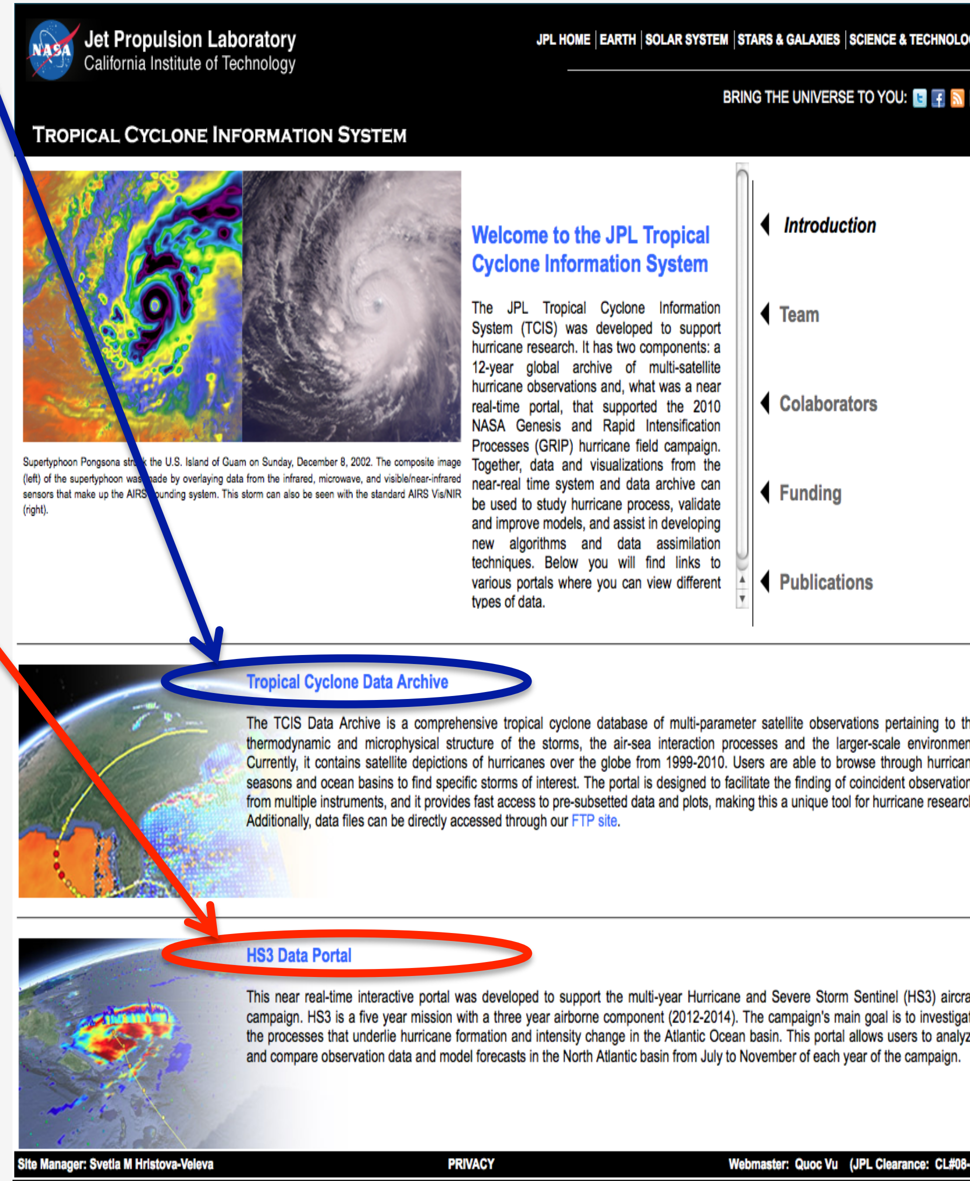
http://tropicalcyclone.jpl.nasa.gov

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.



The 12-year Global Data Archive

- A wide variety of data types
- Organized by year, basin, storm - no need to search!
- DATA and imagery
- Large-scale and storm scale
  - Large-scale (over the ocean basins; +2 days on either side)
    - SST (Sea Surface Temperature)
    - Scatterometer winds (ASCAT)
    - TPW (Total Precipitable Water) from AMSU
    - Thermodynamic atmospheric structure from AIRS
  - Storm scale
    - 2000 x 2000km regions centered on the "Best Track" that was interpolated to the time of the satellite observation
    - Geostationary IR: GOES, MTSAT, FY2, Meteosat, MSG (HURSAT Version 5)
    - Multi-frequency brightness temperatures from TRMM-TMI, AMSR-E, SSMI
    - full set of radar observations from TRMM-PR and CloudSAT
    - QuikSCAT and OSCAT surface winds – new JPL product (Stiles et al., 2013)
    - MLS, OMI

JPL TCIS – The Tropical Cyclone Data Archive

JPL

- Satellite depictions of hurricanes over the globe
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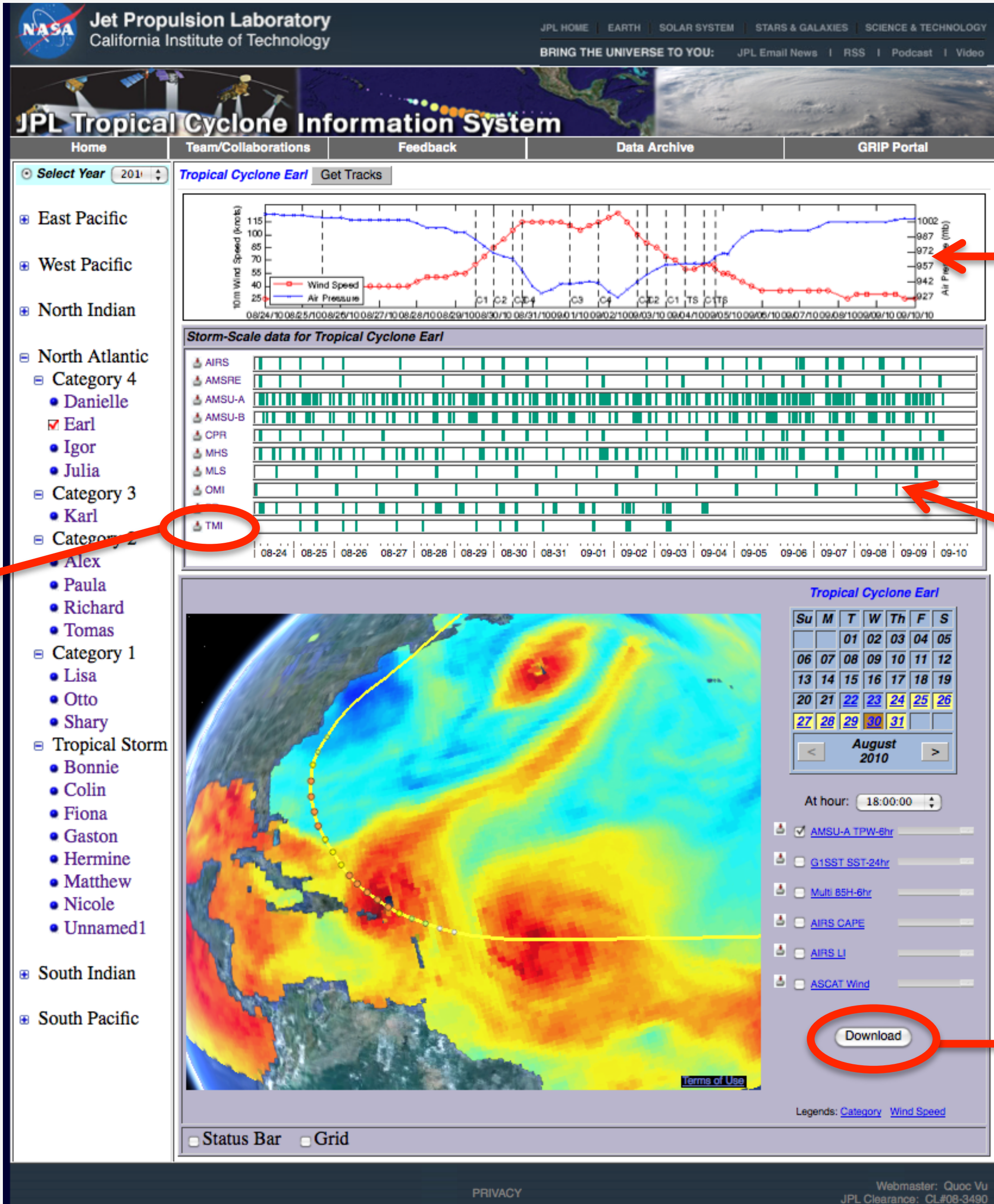


Timeline

View and download Storm-scale data

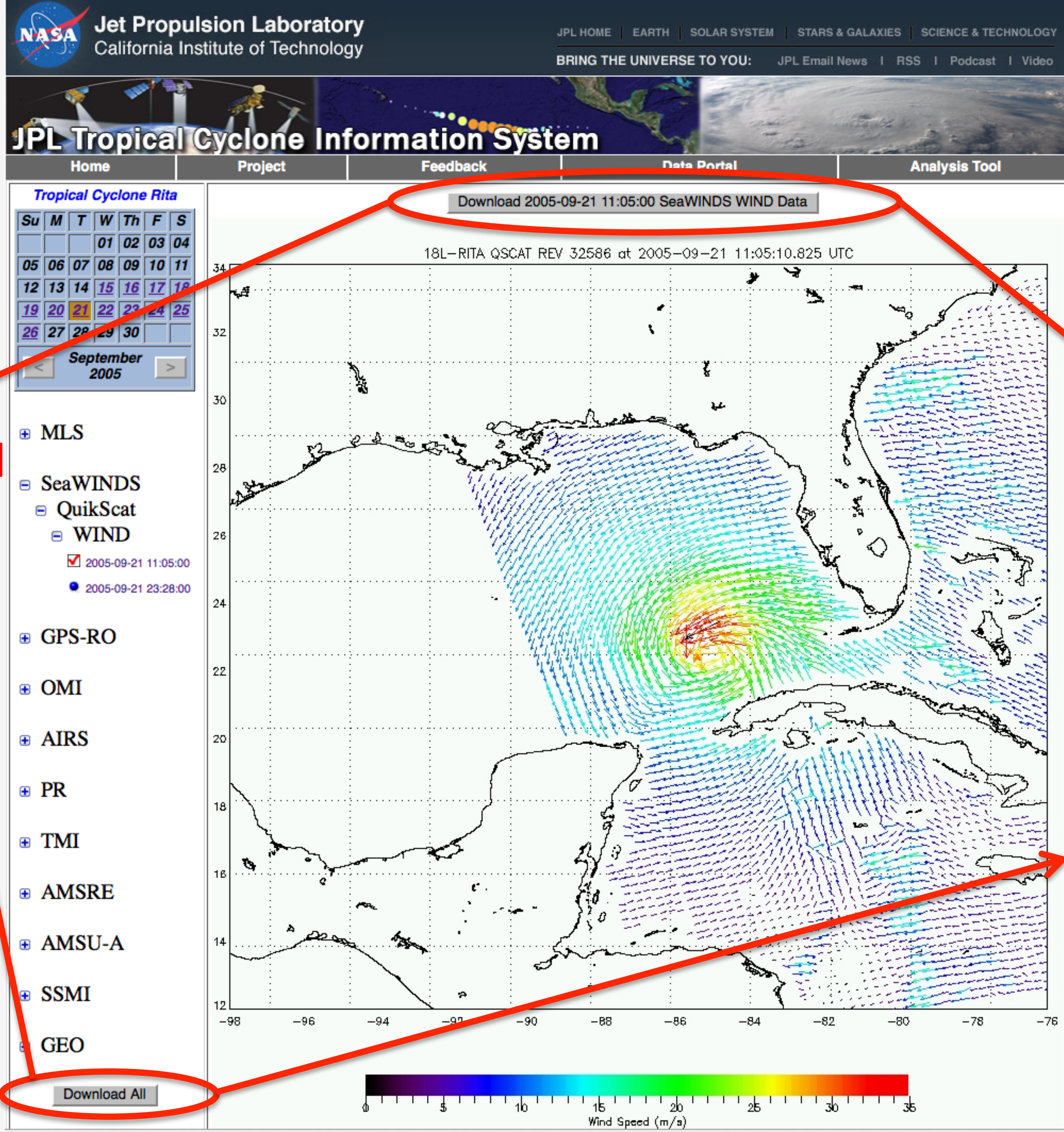
Earl, 2010

Download all data from this Instrument (TMI)

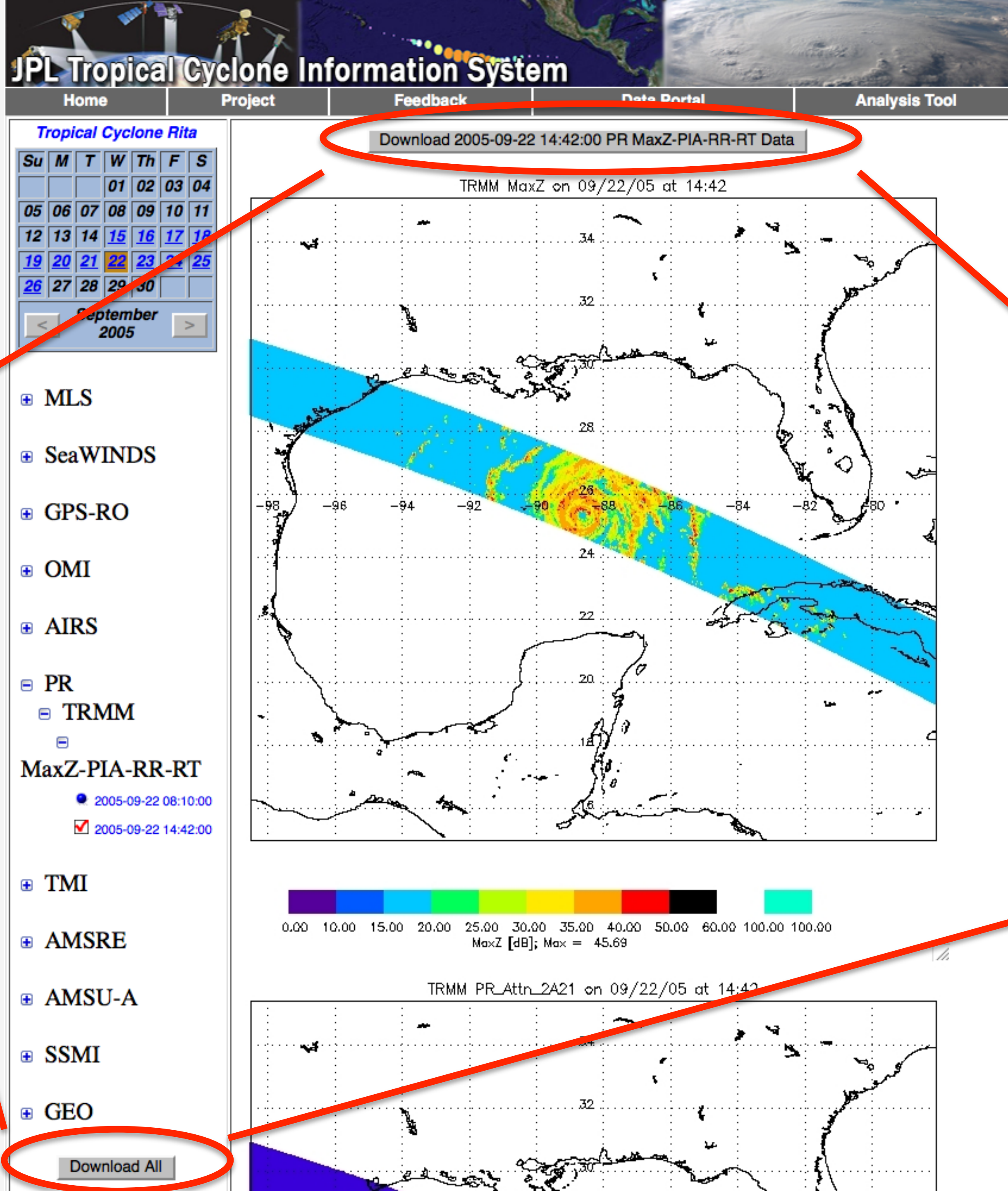
Download Selected large-scale data from this day

At this time

Download NetCDF



All data on this day



At this time

Download NetCDF

All data on this day

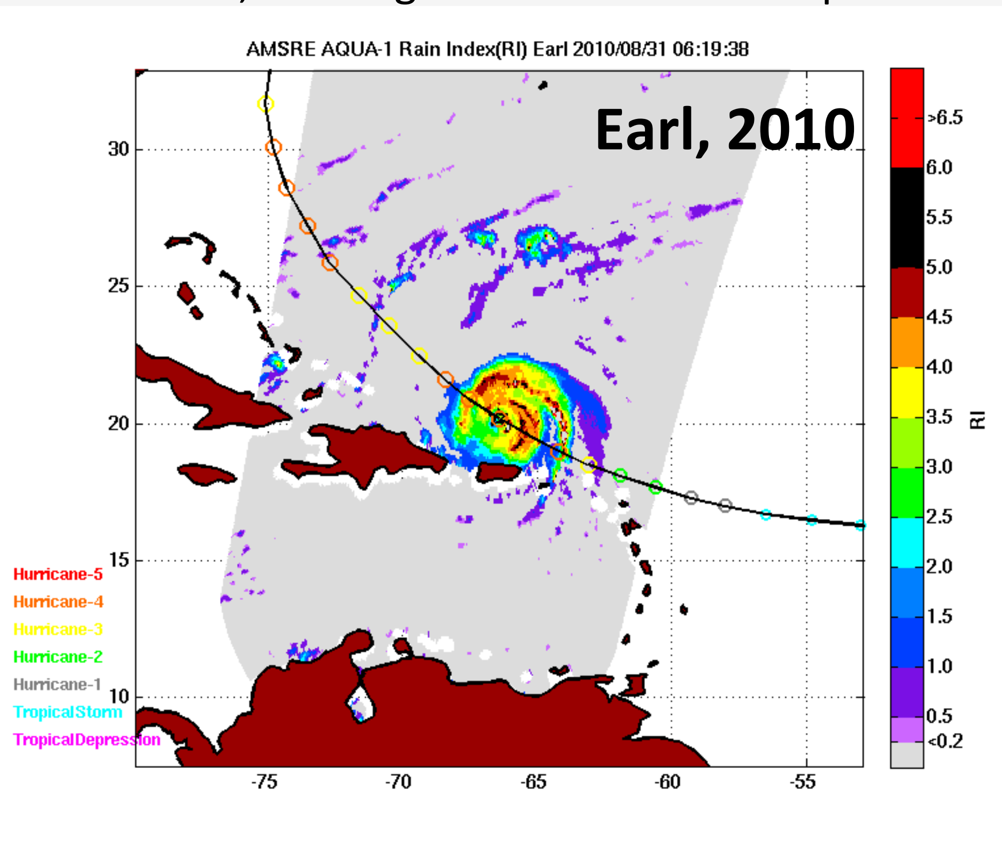
The Rain Indicator – a multi-channel depiction of the storm structure

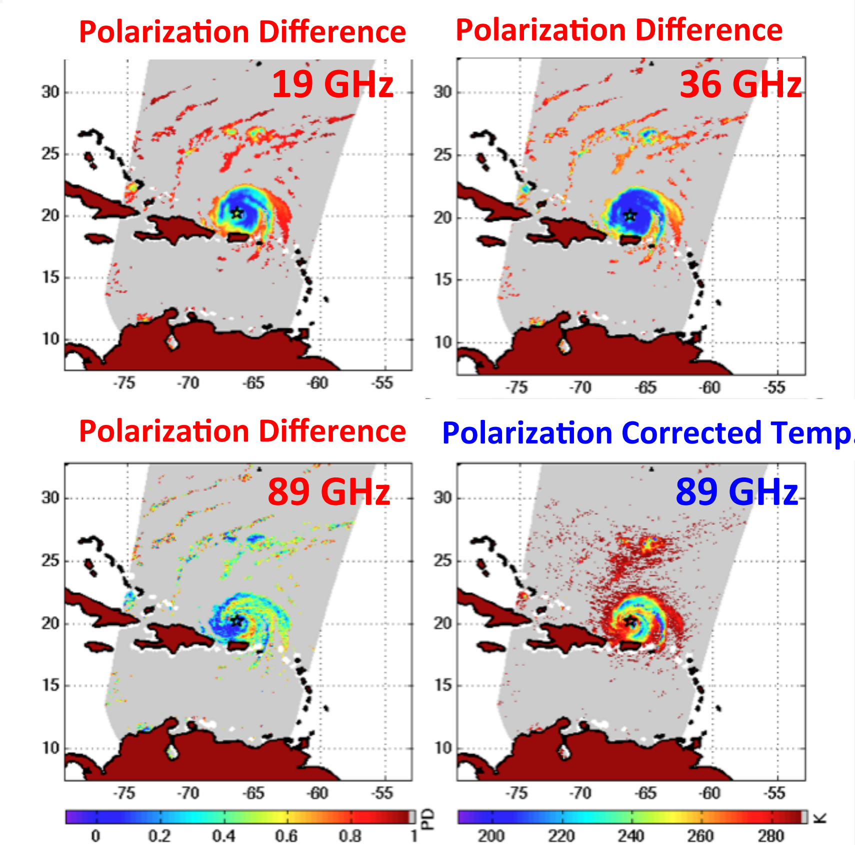
Hristova-Veleva et al., 2013**: "Revealing the Winds Under the Rain. Part I. Passive Microwave Rain Retrievals Using a New, Observations-Based, Parameterization of Sub-Satellite Rain Variability and Intensity: Algorithm Description", **2013, JAMC 52, 2828–2848

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

- **emission signal** - dominant at lower frequencies; **warming**; **better for light rain**. ***Strong emission in the atmosphere reduces the polarization difference (PD) in the ocean surface radiation. Hence, PD is representative of the atmospheric emission.***
- **scattering signal** -dominant at higher frequencies; **cooling; better for heavy rain; PCT**

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





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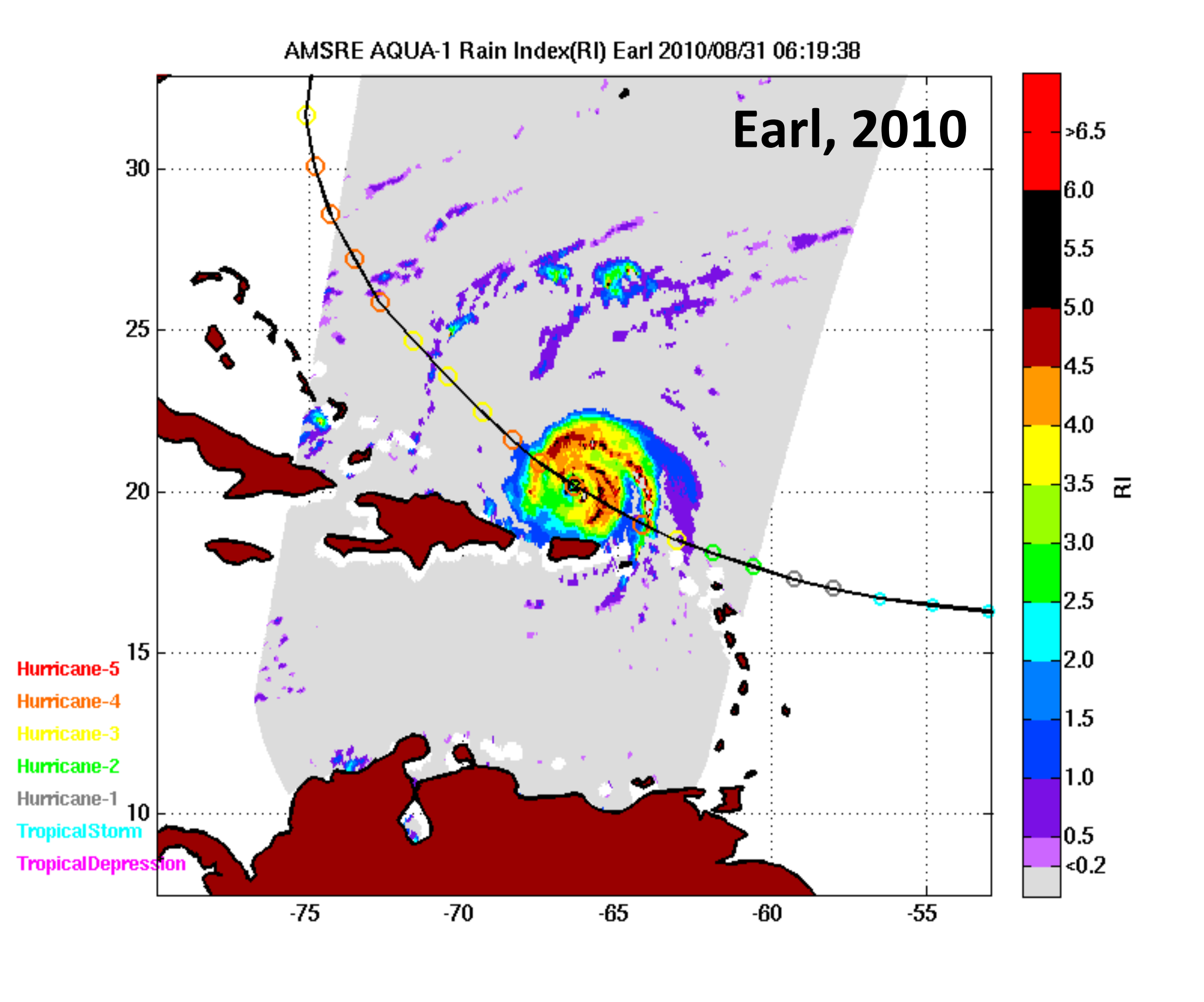


Advantages of Using the Rain Indicator over single passive microwave channels

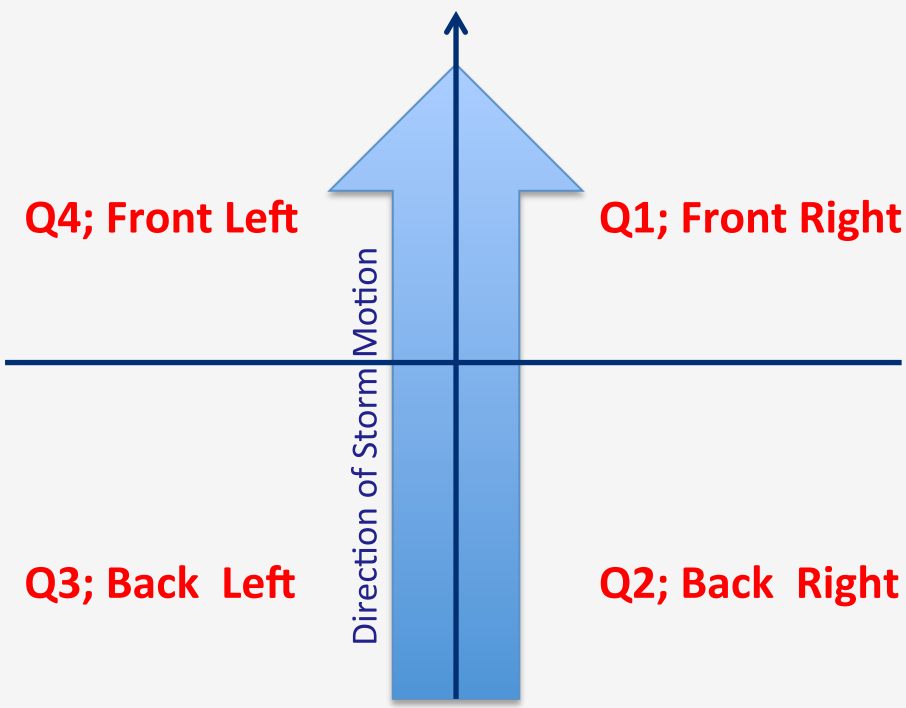
- combines the emission and scattering signals from the **multi-channel information to present a cohesive depiction of the rain and the graupel above**, covering the precipitation spectrum
- Uses polarization difference. Hence, it is **less affected by calibration accuracy**.

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.

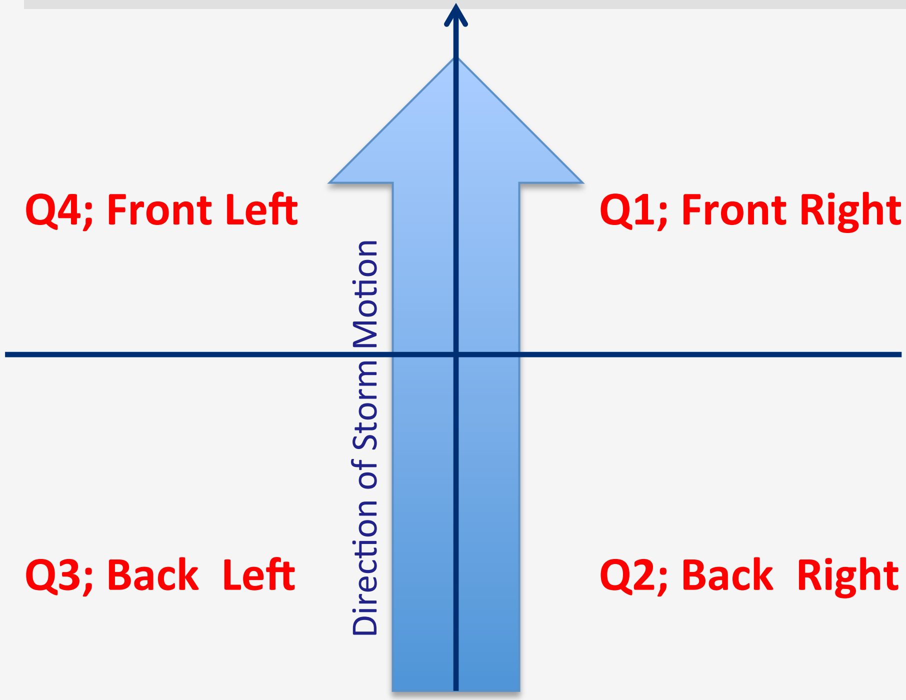
Many others.

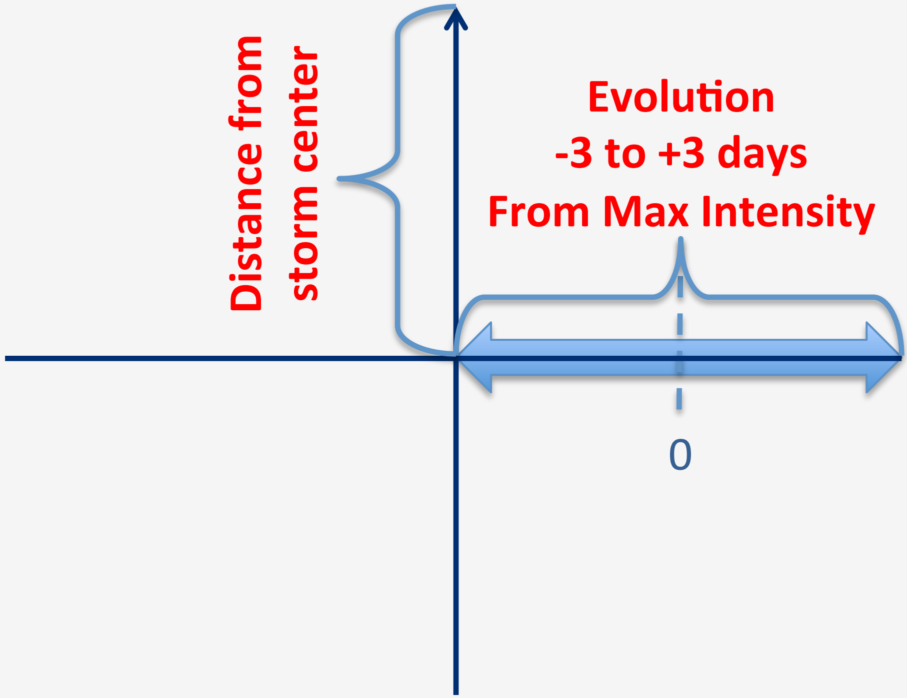
Asymmetry and Evolution

Statistics from observations ; North Atlantic Hurricanes

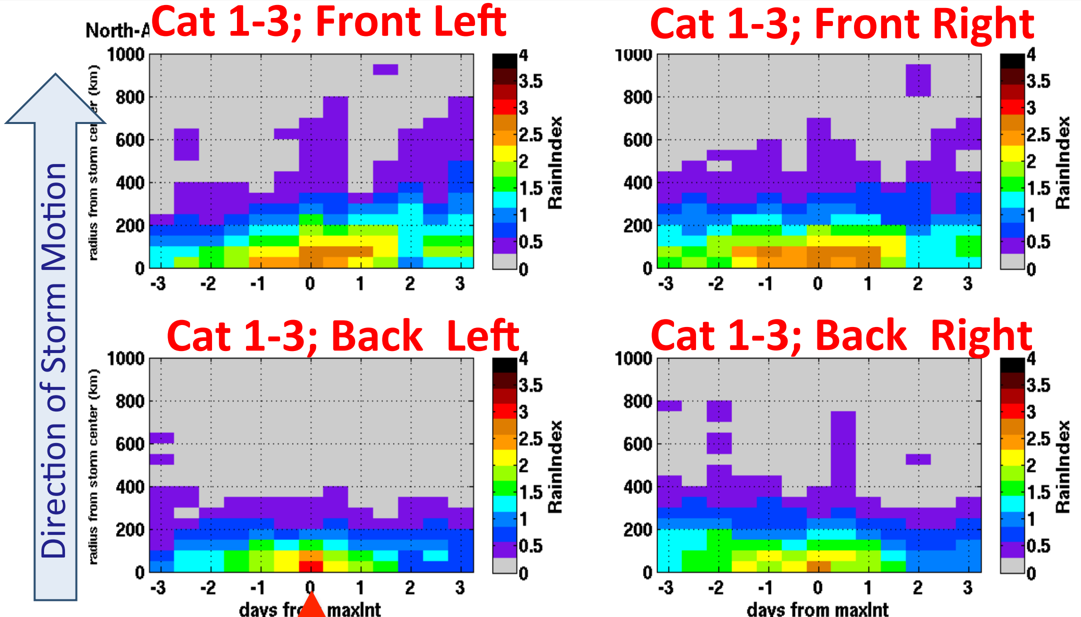
Parameter as a function of:

- 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

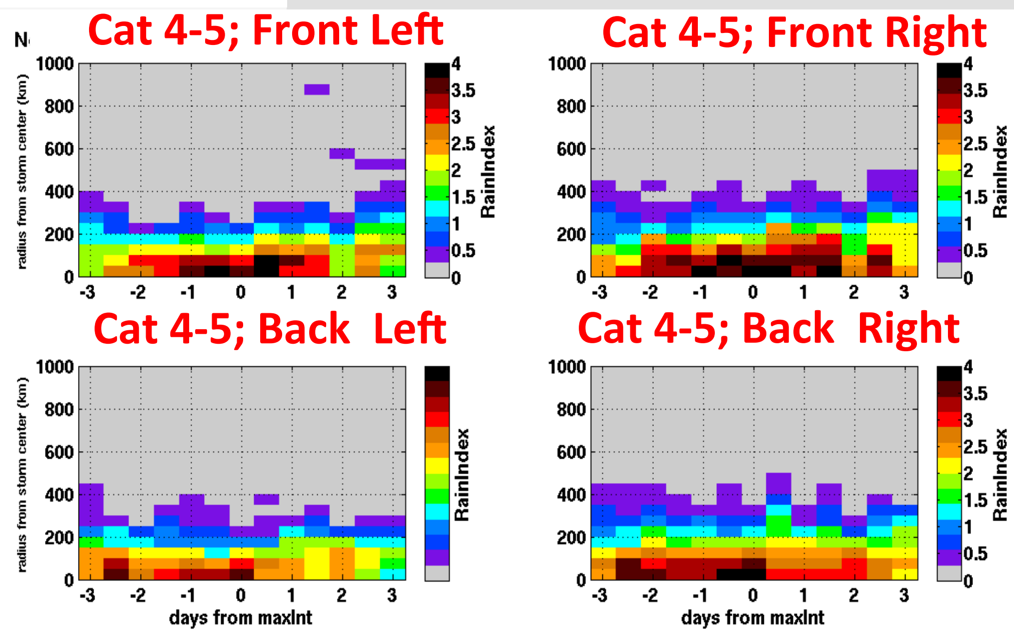
Cat3: 12 cases

Total Cat1-3 = 52 cases

Cat4: 18 cases

Cat5: 7 cases

Total Cat4-5 = 25 cases



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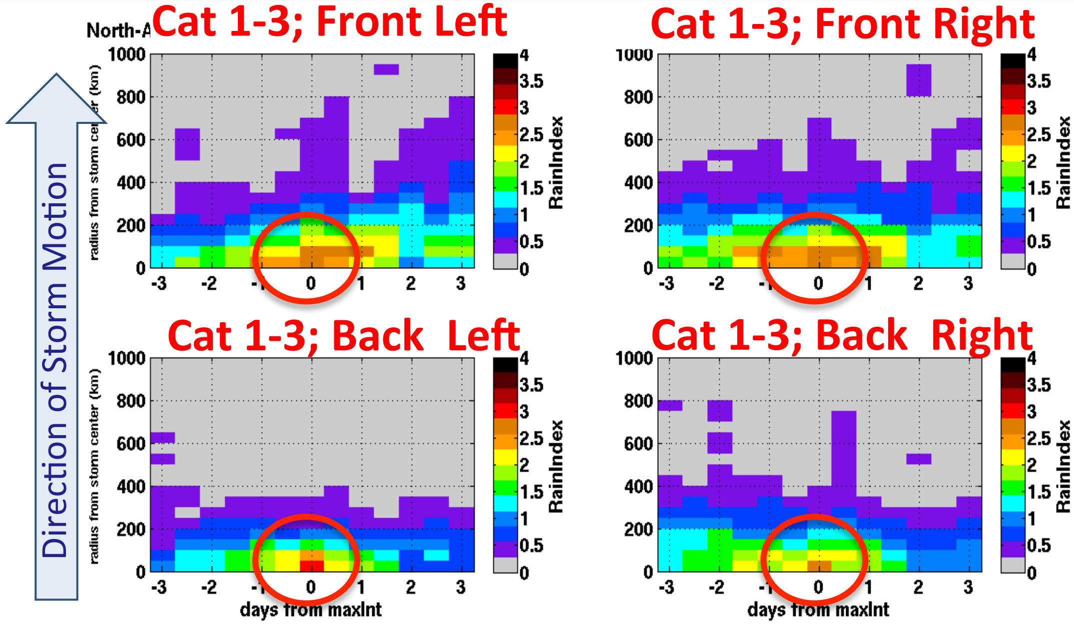

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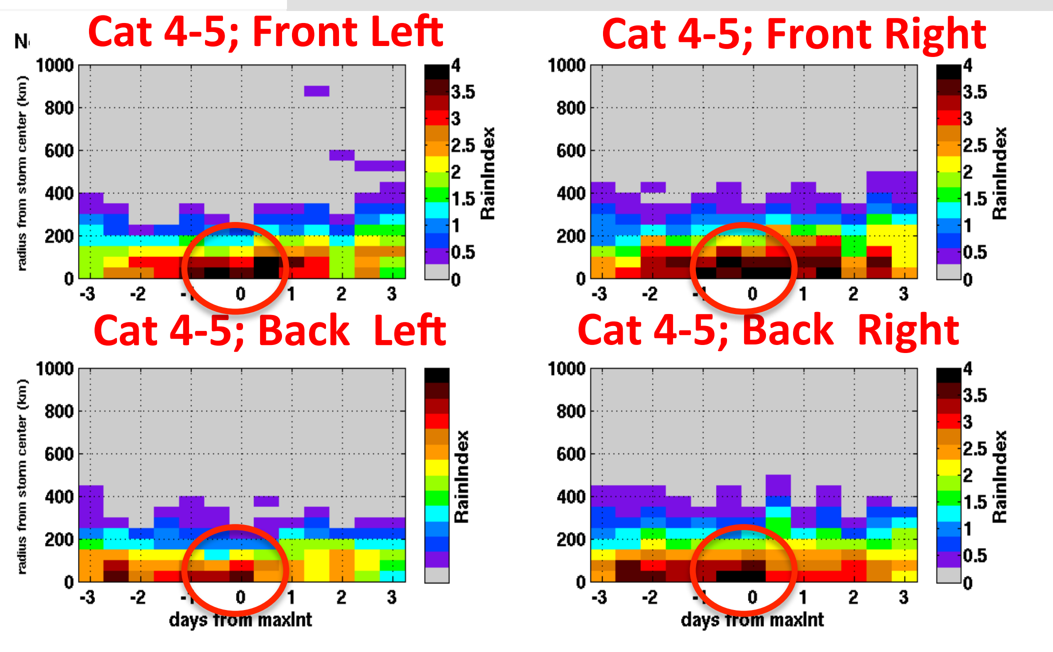
Cat 1-3 have rain fields that are larger, weaker and less symmetric in:

- **Space**
  - More intense precipitation is in the front 2 quadrants



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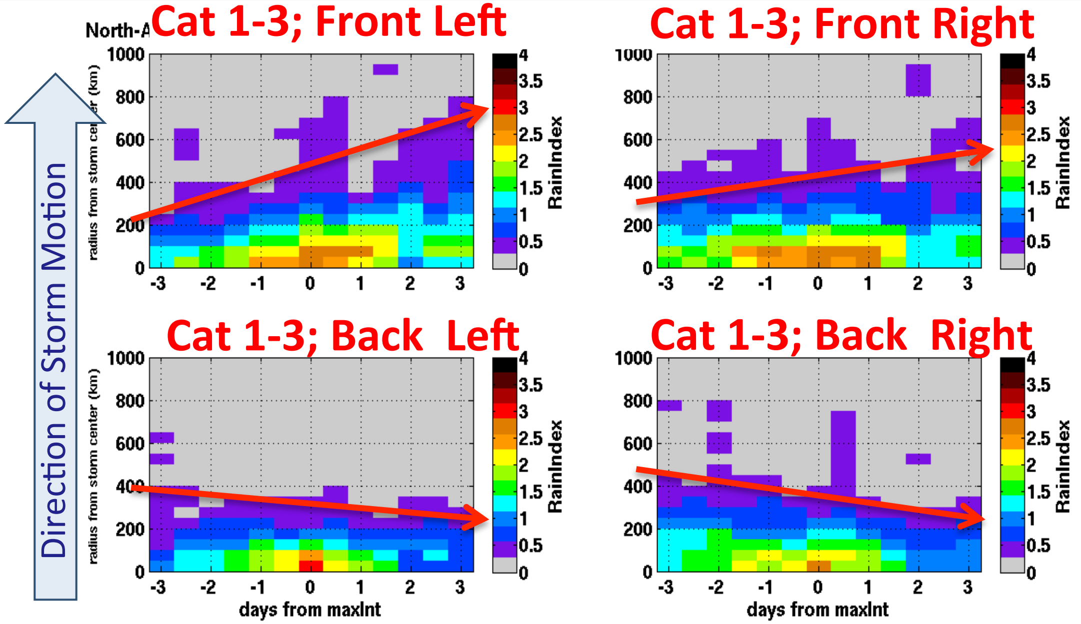

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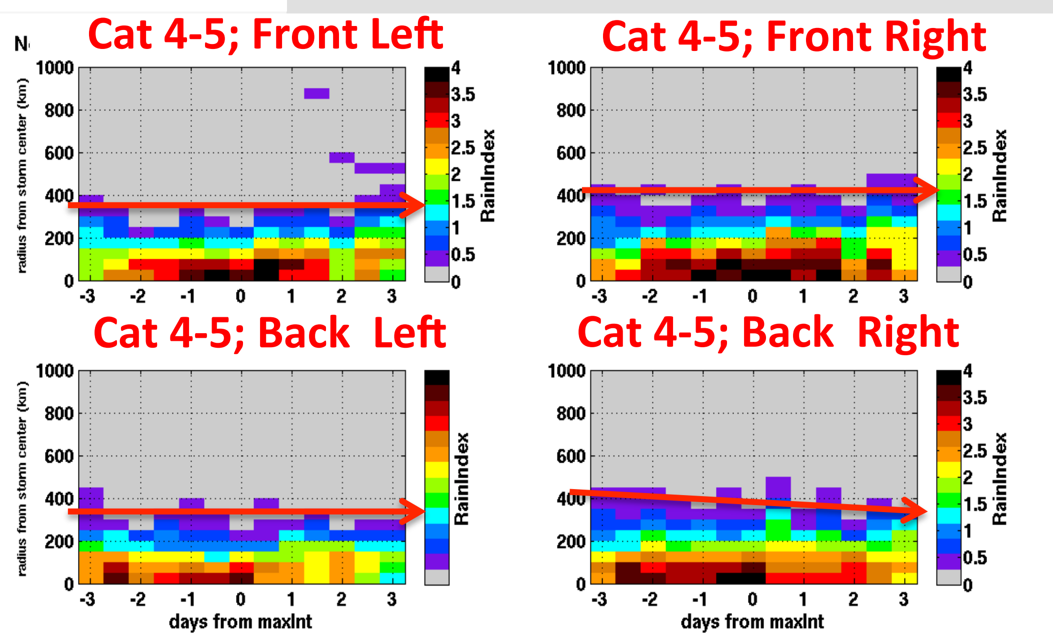
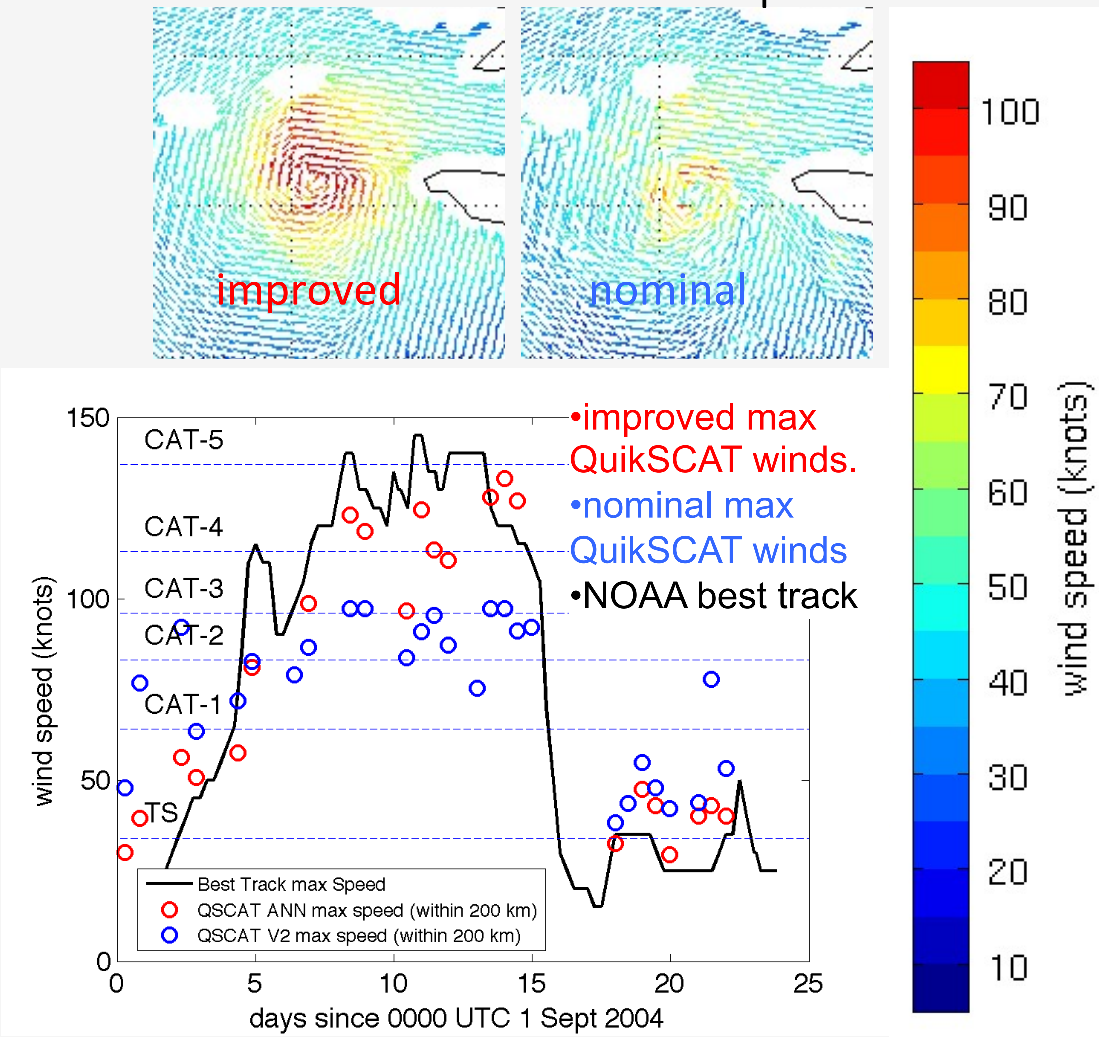
- **Time**
  - Tendency for radial expansion of precipitation after the peak of the storm. Only in the front 2 quadrants.
  - Increase in asymmetry



Improved QuikSCAT Hurricane Winds

Stiles, B.W., *R. E. Danielson, W. Lee Poulsen, M. J. Brennan, S. Hristova-Veleva, T.-P. J. Shen, and A. G. Fore, "Optimized Tropical Cyclone Winds from QuikSCAT: A Neural Network Approach," accepted IEEE TGARS, 2013.*

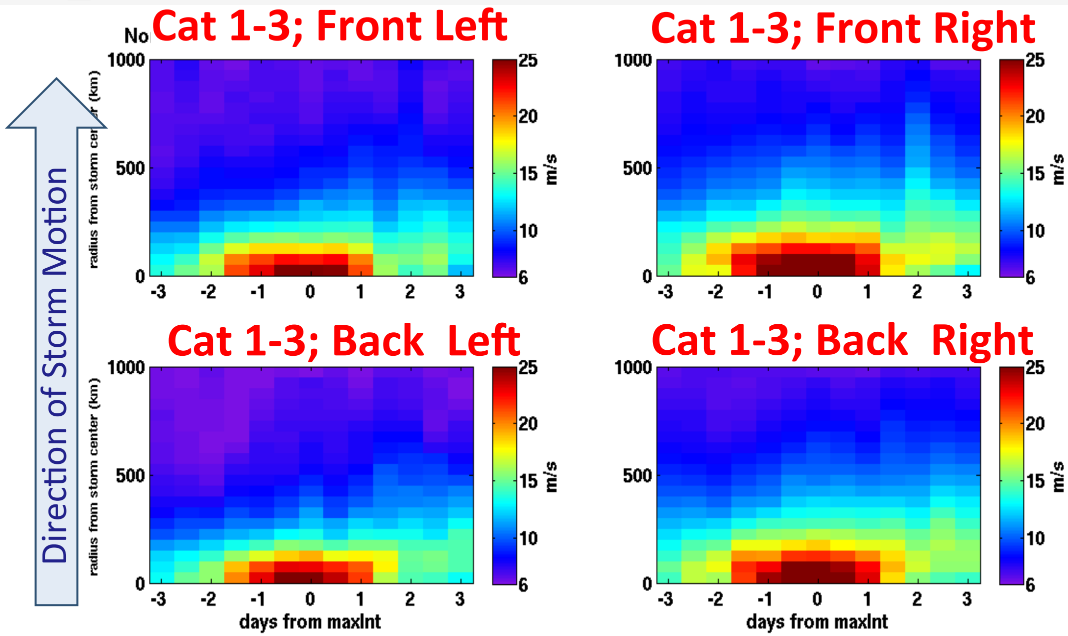
Hurricane Ivan 23:37 UTC 11 Sept. 2004



- Improved QukSCAT tropical cyclone (TC) wind speed fields
  - –10,000 storm scenes over 10 years
  - –Validated vs. hurricane analysis fields and aircraft overflight measurements.
- **Problem:** Scatterometer winds are corrupted by rain and use empirical retrievals not optimized for high winds.
- **Solution:** Neural network retrieval method trained specifically for TC winds.
- Developing similar datasets for OceanSAT-2 (ISRO) and ASCAT (ESA) scatterometers.

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

10-year statistics from QuikSCAT observations North Atlantic Hurricanes; 2000-2009



Evolution of asymmetry

Azimuthal/Range Distributions of

WIND speed

Cat1: 38 cases

Cat2: 11 cases

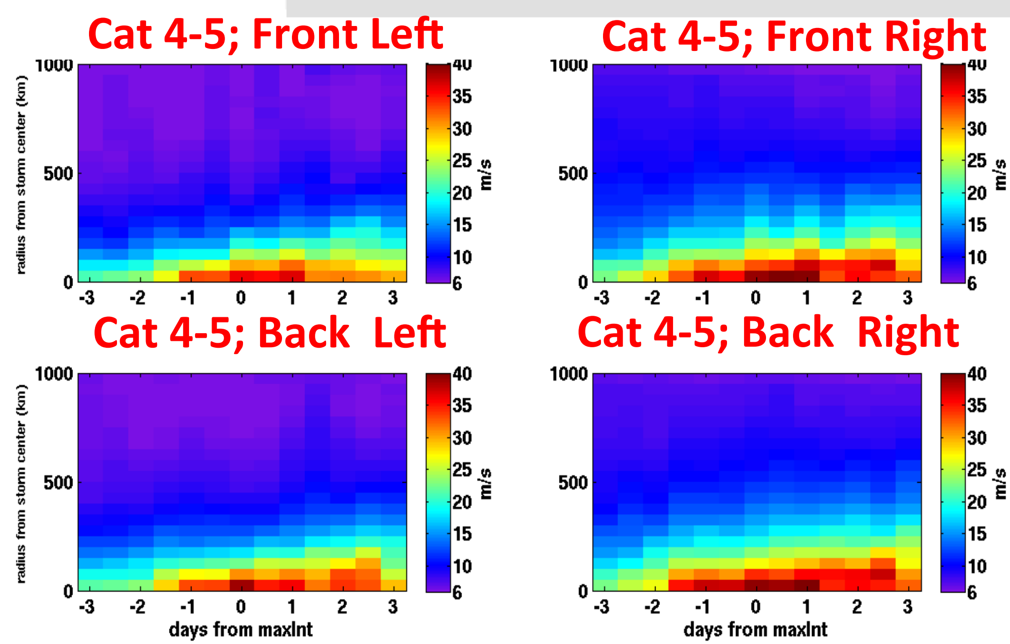
Cat3: 17 cases

Total Cat1-3 = 66 cases

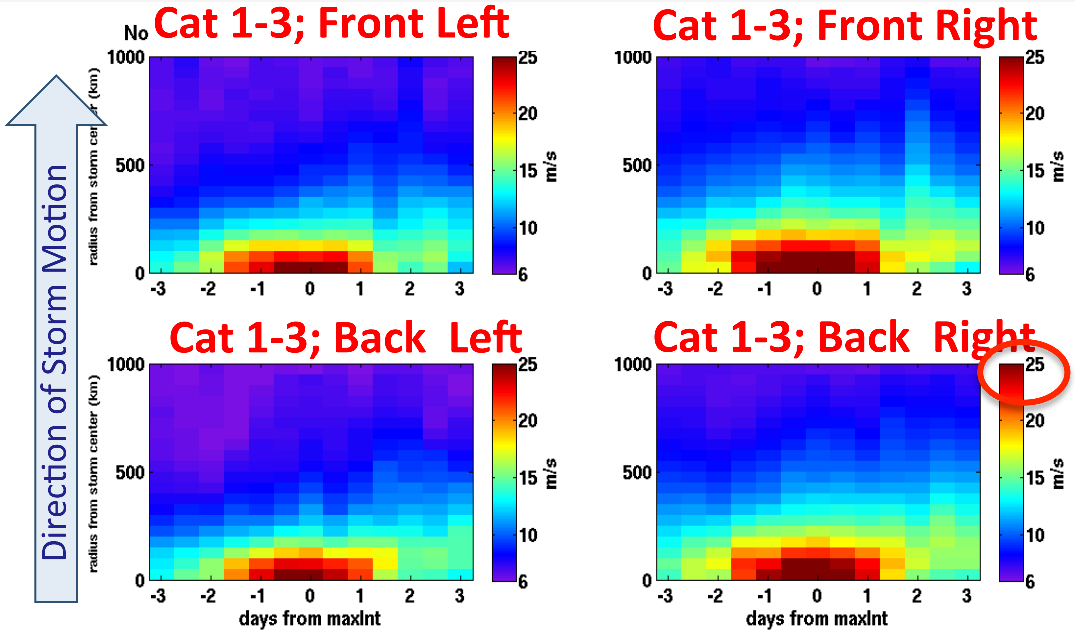
Cat4: 21 cases

Cat5: 7 cases

Total Cat4-5 = 28 cases



10-year statistics from QuikSCAT observations North Atlantic Hurricanes; 2000-2009



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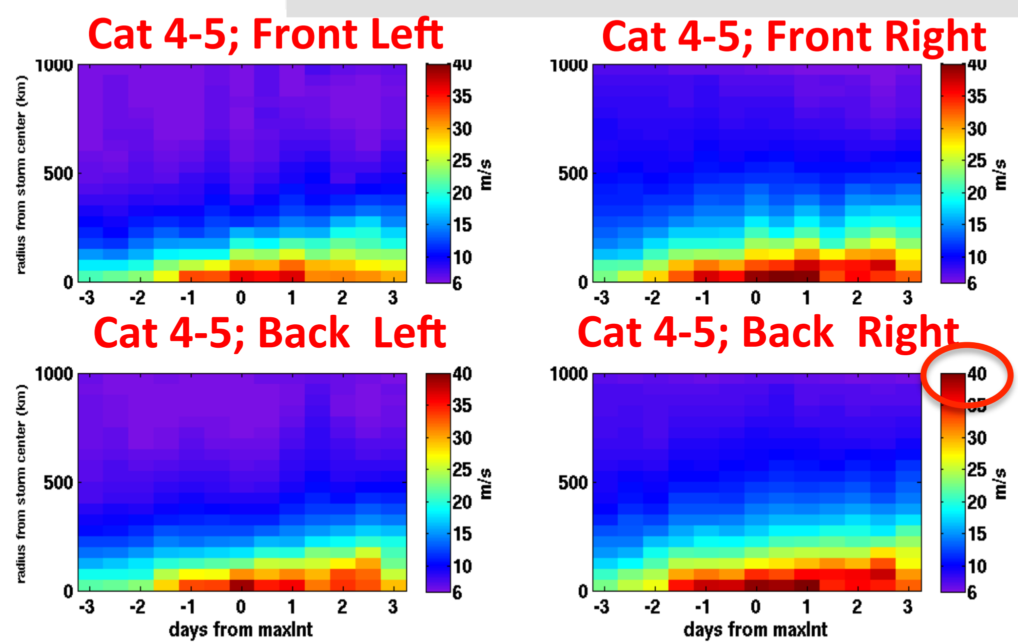
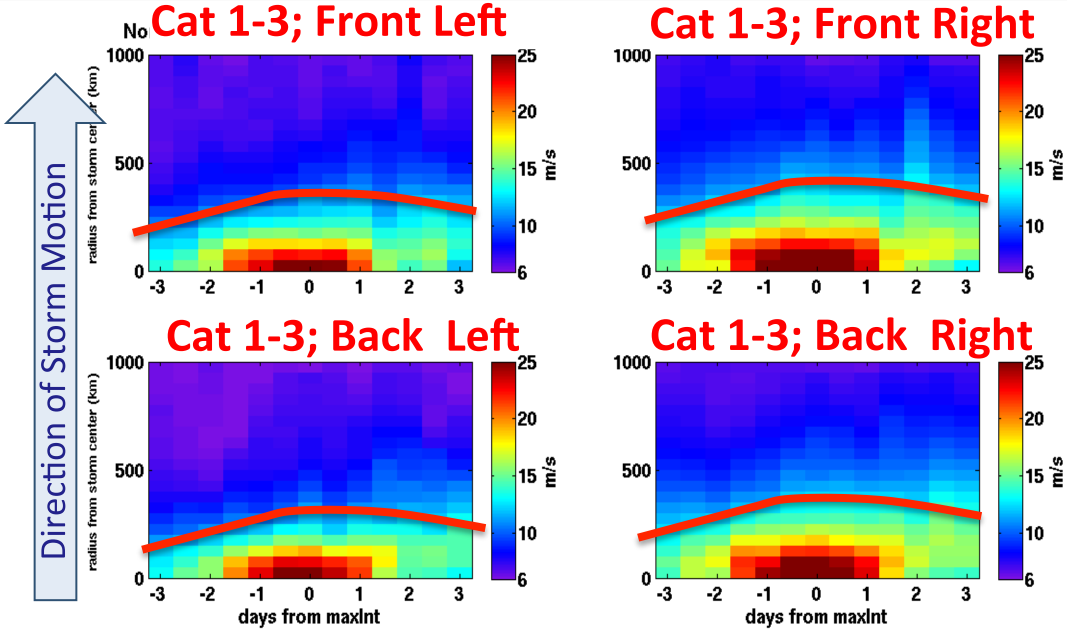
Cat 4-5 have wind fields that are larger and less symmetric in:

- Space
  - More intense winds in the right 2 quadrants



10-year statistics from QuikSCAT observations North Atlantic Hurricanes; 2000-2009



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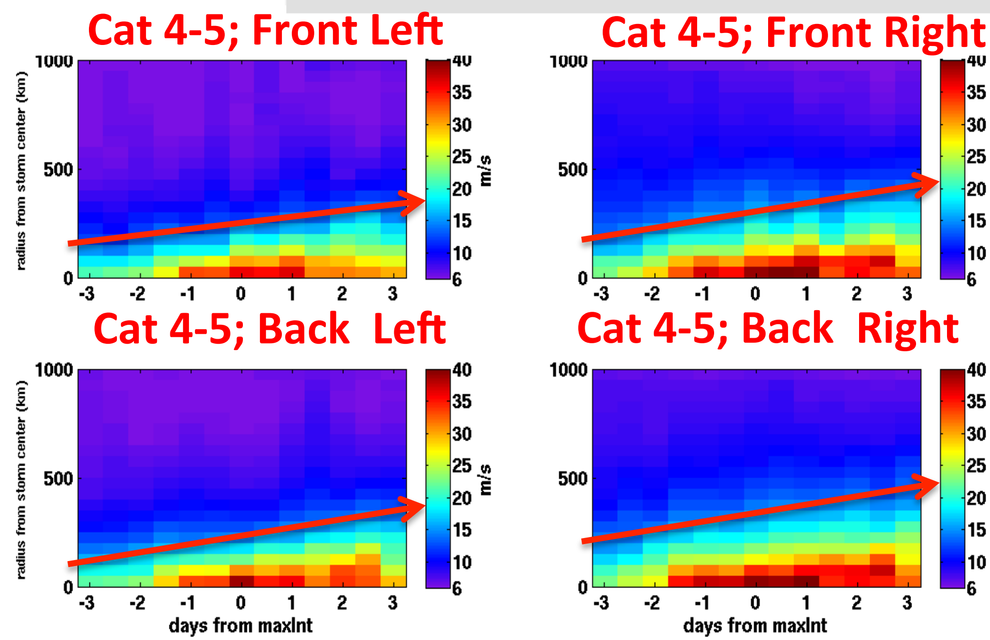
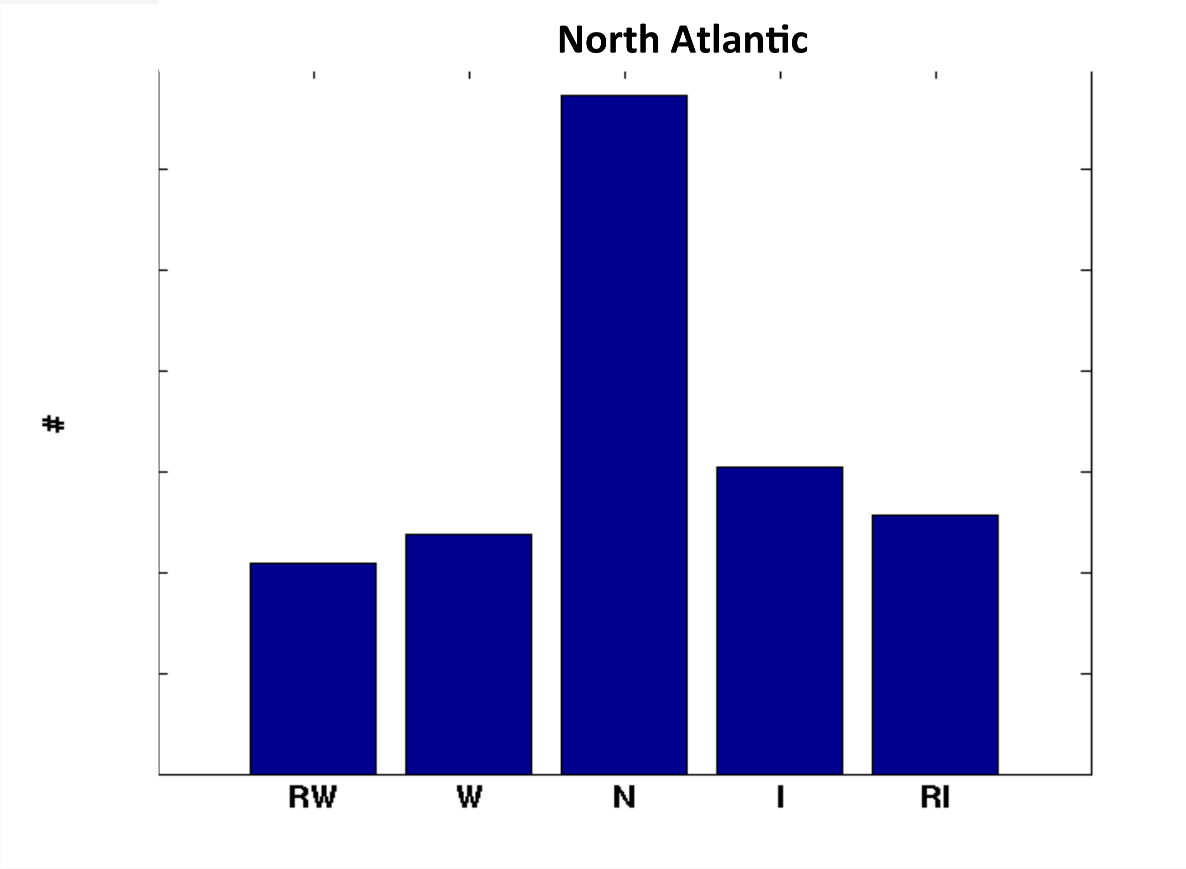
  - Increase in asymmetry



Classifying by Intensity change



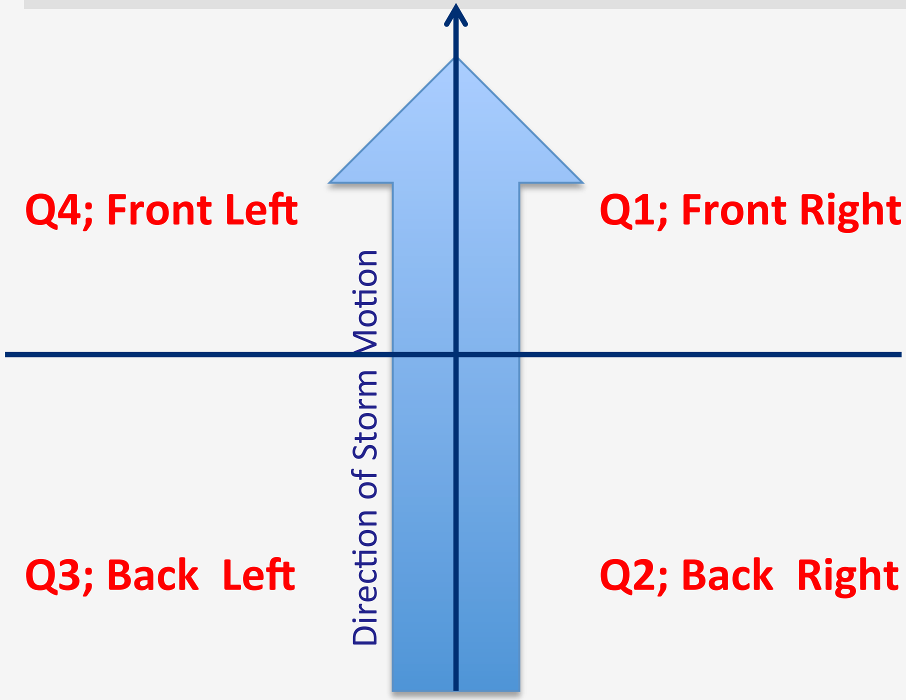
RW= Rapidly Weakening		DeltaSpeed	< - 4.75 m/s per 6hr (-37.0kt per 24h)
W= Weakening	-4.75 m/s per 6hr <	DeltaSpeed	< - 0.75 m/s per 6hr (- 5.8kt per 24h)
N= No change	-0.75 m/s per 6hr <	DeltaSpeed	< 2.25 m/s per 6hr (+17.5kt per 24h)
I= Intensifying	2.25 m/s per 6hr <	DelatSpeed	< 4.75 m/s per 6hr (+37.0kt per 24h)
RI= Rapidly Intensifying		DeltaSpeed	> 4.75 m/s per 6hr (+37.0kt per 24h)

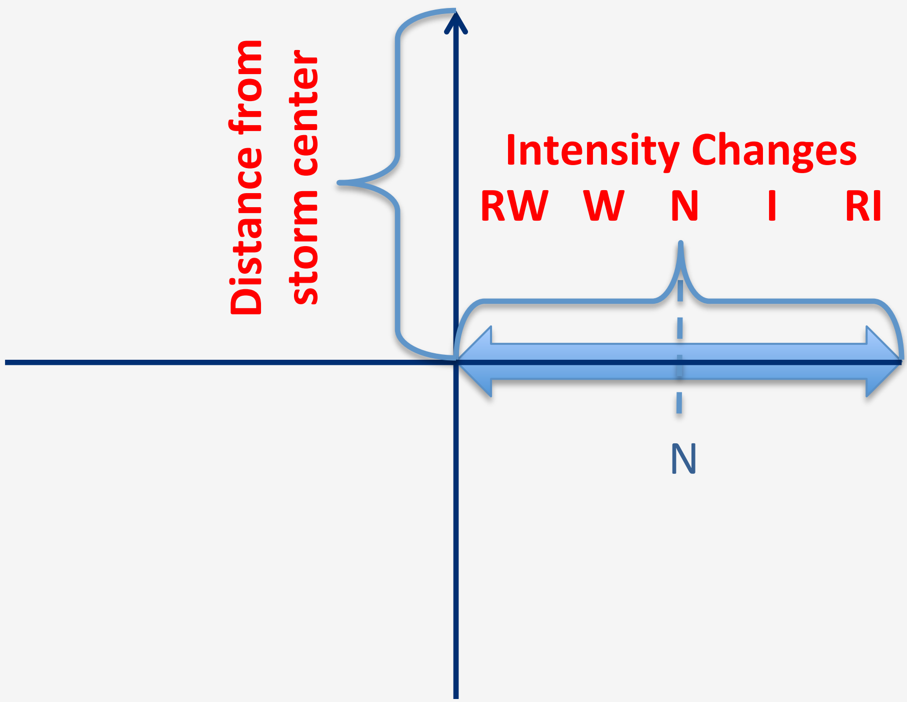
Asymmetry and Intensity Changes

Statistics from observations ; North Atlantic Hurricanes

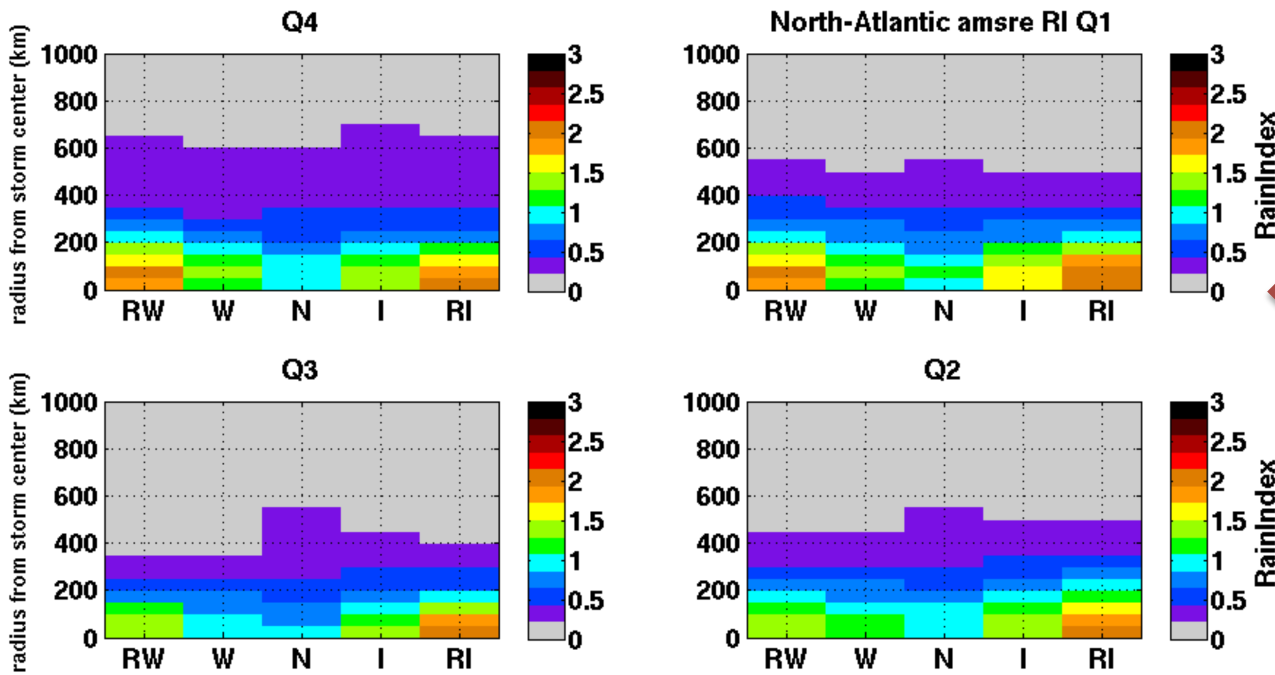
Parameter as a function of:

- Quadrant wrt storm motion
- distance from storm center (y-axis)
- days from maximum intensity (x-axis)

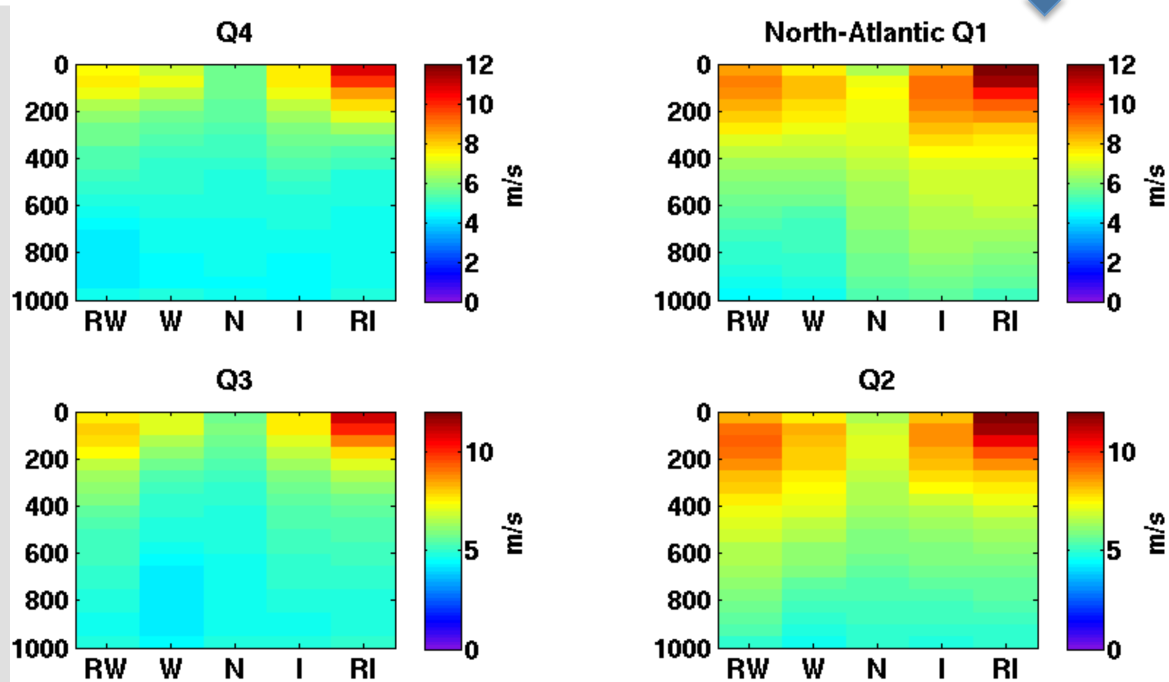




AMSR-E Rain Index



QuikSCAT wind



- RI storms have most symmetric wind and rain fields
- RW storms have most asymmetric wind and rain
  - Stronger rain in the 2 forward quadrants
  - Stronger wind in the 2 right quadrants
- I and W storms are similar in asymmetry with the I storms being somewhat stronger
- N storms have the weakest fields

Summary

- To facilitate hurricane research, we developed the JPL Tropical Cyclone Information System (TCIS) of multi-parameter multi-instrument observations (satellite, airborne and in-situ) pertaining to:
  - the thermodynamic and microphysical structure of the storms;
  - the air-sea interaction processes;
  - the larger-scale environment.
- One of the two main components of the JPL TCIS is an archival database of satellite observations (http://tropicalcyclone.jpl.nasa.gov/hurricane/gemain.jsp)
  - It presents the satellite depiction of hurricanes
    - over the globe
    - during the period 1999-2011
    - ***offering both data and imagery***
  - It provides a one-stop place to obtain an extensive set of multi-parameter data from multiple observing systems, making the TCIS-archival Database a unique source to support hurricane research, forecast improvement and algorithm development.

Summary (cont.)

- We analyzed the rain and wind fields of the Atlantic hurricanes during the last decade
- Looked at **two new products**
  - The Rain Indicator – a multi-channel passive microwave measure
  - New hurricane–specific surface wind product (from QuikSCAT) that provides reliable wind estimates under rain and in high-wind conditions typical for hurricanes
- Investigated
  - the storm **asymmetry and its evolution** as a function of storm intensity (Cat1-3 versus Cat4-5)
  - the **storm asymmetry and its relationship to the storm intensity changes**
    - **R**apidly **W**eakening, **W**eakening, **N**eutral, **I**ntensifying, **R**apidly **I**ntensifying

Summary (cont.)

- **We find that:**
  - Category 1-3 hurricanes show different evolution of the storm asymmetry than Cat 4-5.
  - Rain and Wind fields show different evolution of the asymmetry
    - **Rain: Cat 1-3 fields are larger and less symmetric in both space and time** (more intense precipitation is in the **front 2 quadrants**; Radial expansion of precipitation after the storm peak (**front 2 quadrants**). Increase in asymmetry
    - **Wind: Cat 4-5 fields are larger and less symmetric in both space and time** (stronger winds in the **right 2 quadrants**; Radial expansion of high winds after the peak of the storm. More pronounced in the **right 2 quadrants**; Increase in asymmetry)
    - Of course, in both cases (rain and wind) Cat4-5 have more intense fields.
  - Rapidly Intensifying (**RI**) and Rapidly Weakening (**RW**) storms show structures that make them distinguishable from the other storms.
    - **RI storms have most symmetric wind and rain fields**
    - **RW storms have most asymmetric wind and rain**
      - **Stronger rain in the 2 forward quadrants**
      - **Stronger wind in the 2 right quadrants**
- Looking at the **statistics of multiple variables** (rain and wind) provides **a more complete view of the storm structure and evolution**.

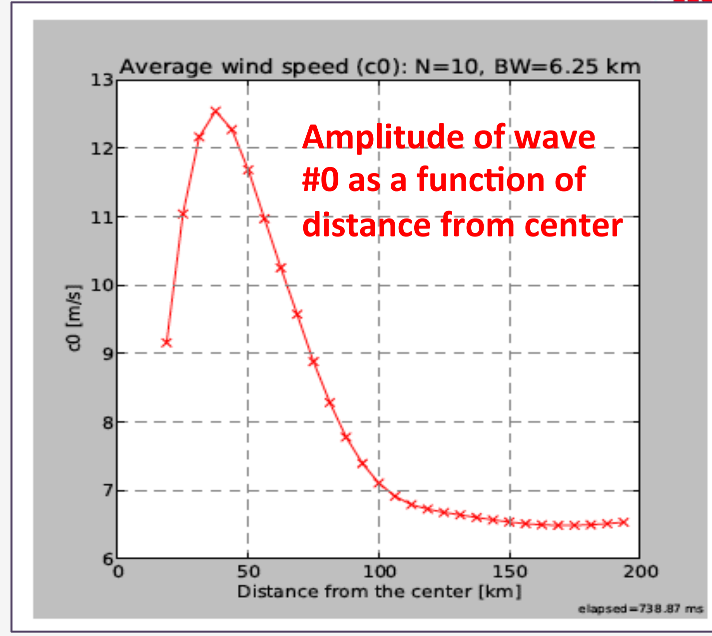
Backup

The NRT Interactive PORTALS

- Two near-real-time (NRT) web portal
- Developed to facilitate the hurricane field campaigns:
  - GRIP in 2010 – http://grip.jpl.nasa.gov
  - HS3 in 2012-2014 – http://hs3.jpl.nasa.gov
- Integrates model forecasts with satellite observations from a variety of instruments and platforms.
- The unique features of the portal allow users to interrogate 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.
- By including a diverse set of satellite observations and model forecasts, it provides a good spatial and temporal context for the high-resolution, but limited in space and time, airborne observations.
- Such knowledge is essential for the experiment design, providing critical input for the flight planning and serving as a very rich source of information in the analysis stage of the airborne experiment

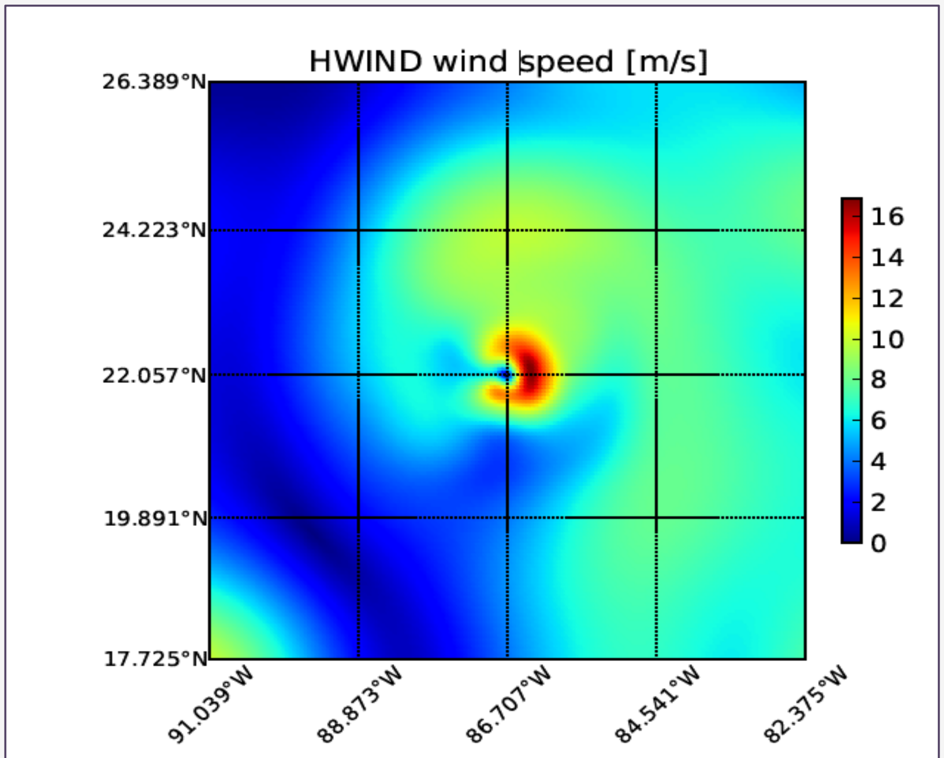
Analysis tools to allow interrogation of a large number of atmospheric and ocean variables

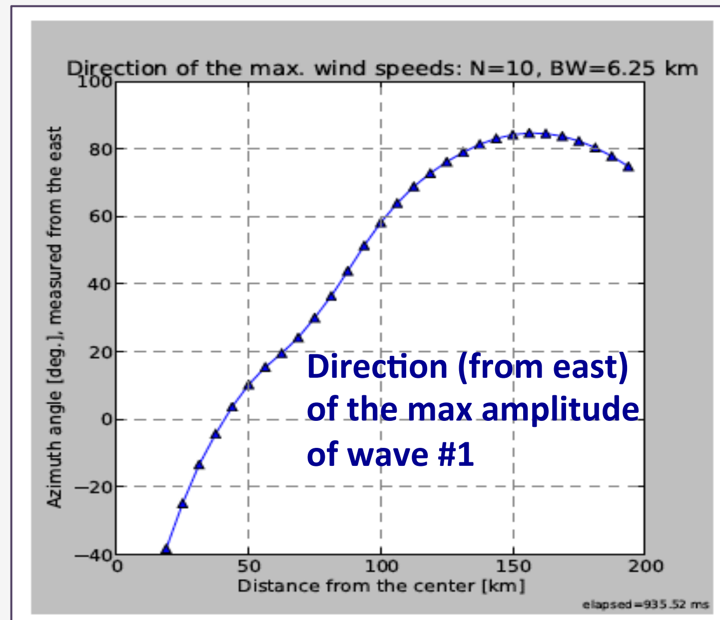
- To evaluate and improve models
- To better understand the large-scale and storm-scale processes and their interaction



Wavenumber analysis tool

- First adopted and used by NOAA/AOML/HRD
- Developed for us by Z. Haddad and N. Niamsuwan

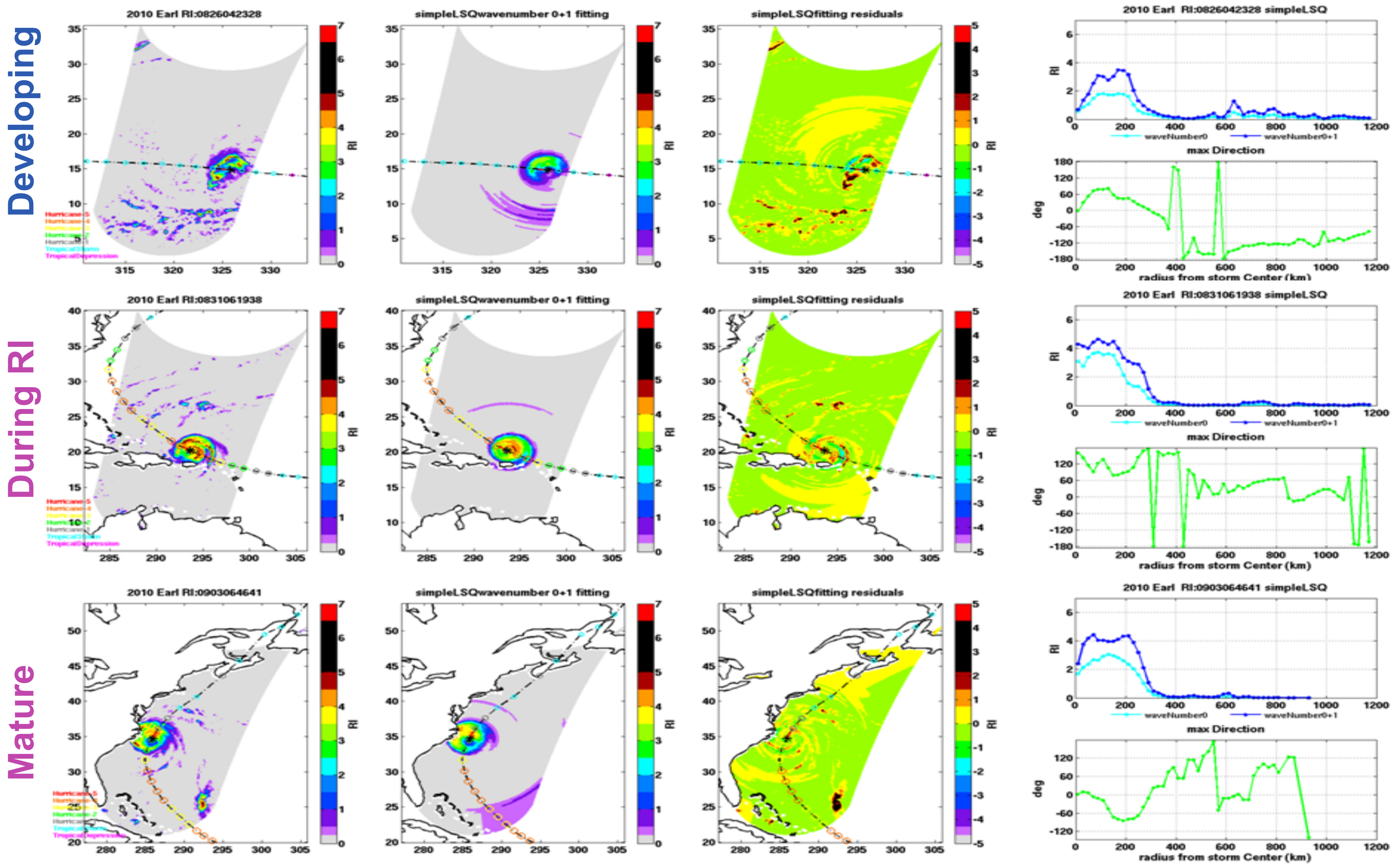




Storm structure Tool: Storm Size and Asymmetry

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



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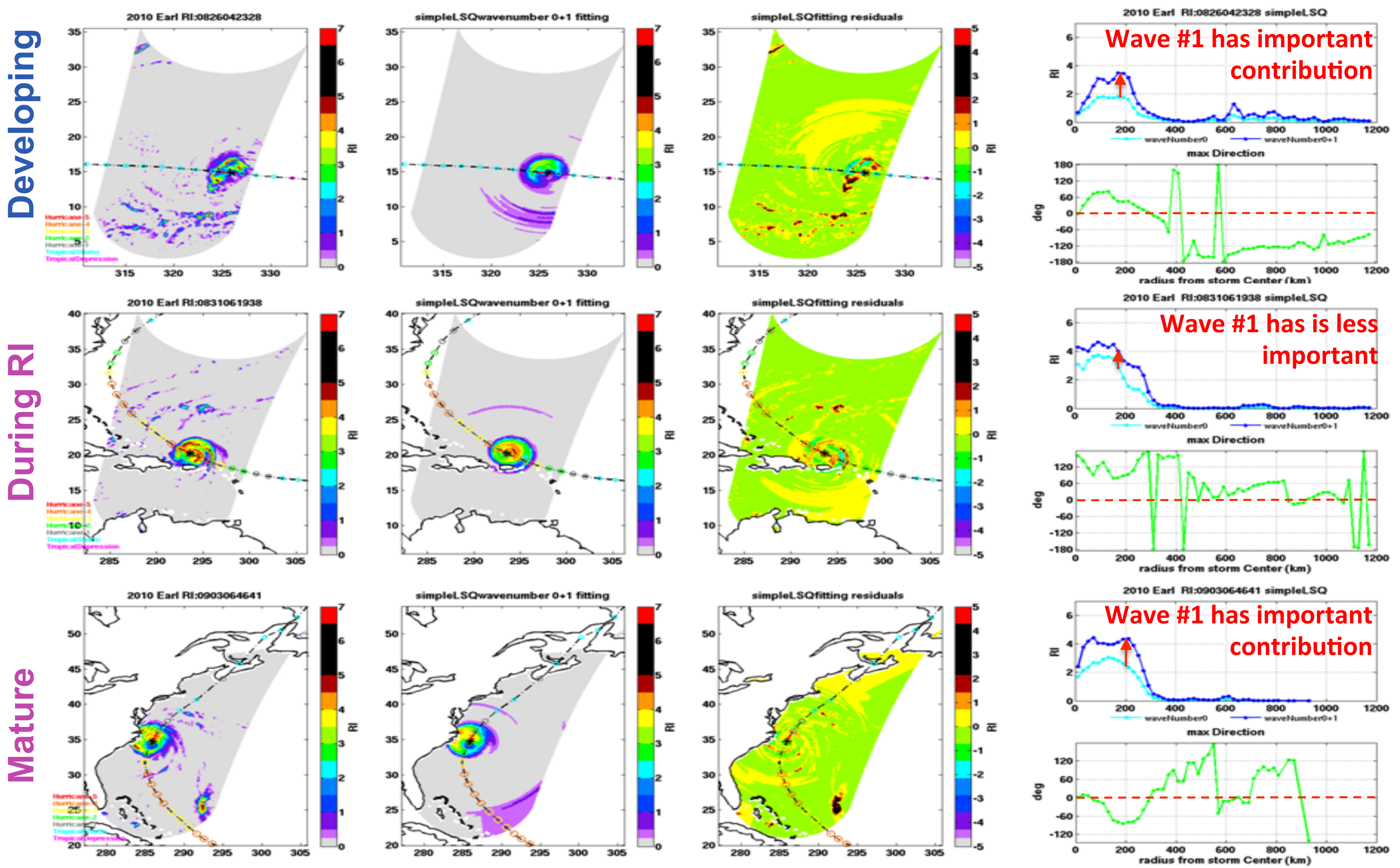
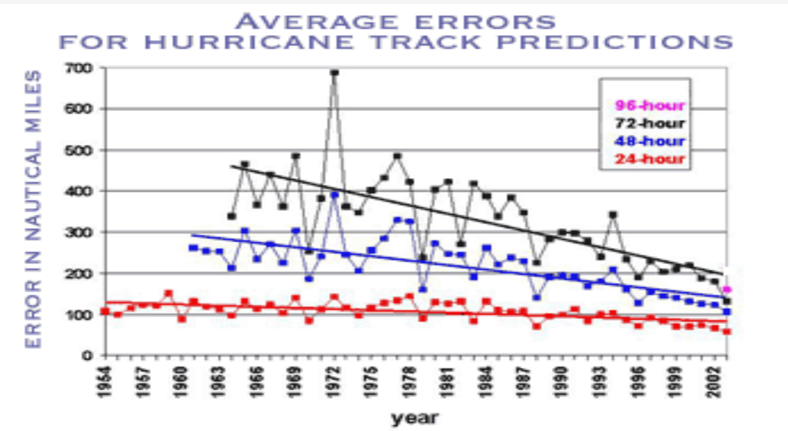
The Wave Number Analysis Tool using the Rain Index (multi-channel PMW index)

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

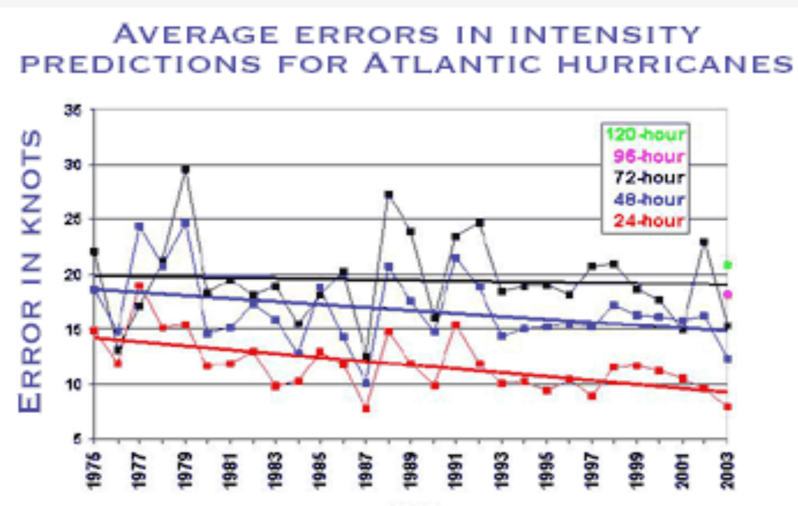


Current state-of-the-art hurricane prediction

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



- Intensity forecasts have not improved.



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).