Jet Propulsion Laboratory
California Institute of Technology

Using Satellite Observations of Precipitation to Improve Ensemble Hurricane Forecasts

S. Hristova-Veleva [1,2], Hua Leighton [3], Sundararaman Gopalakrishnan [4], Ziad Haddad [1,2], Eun-Kyoung Seo [5],

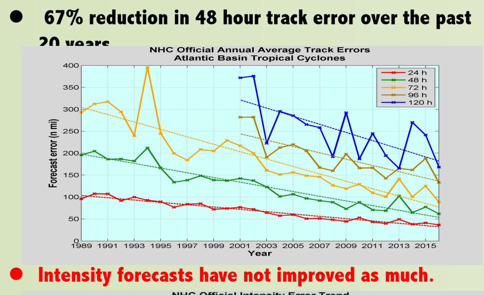
svetla.hristova@jpl.nasa.gov

[1] – Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109   [2] – JIFRESSE, UCLA   [3] Hurricane Research Division/AOML/NOAA/University of Miami, RSMAS   [4] Hurricane Research Division, AOML/NOAA   [5] – Kongju National University

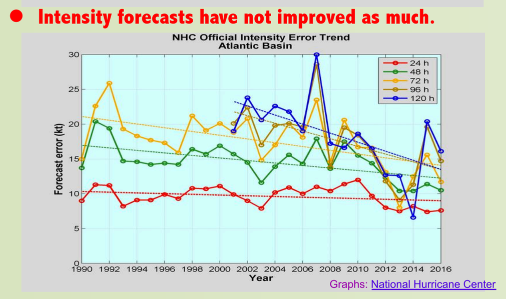
Motivation

Current state-of-the-art hurricane understanding & *prediction*

- 67% reduction in 48 hour track error over the past 20 years



- Intensity forecasts have not improved as much.

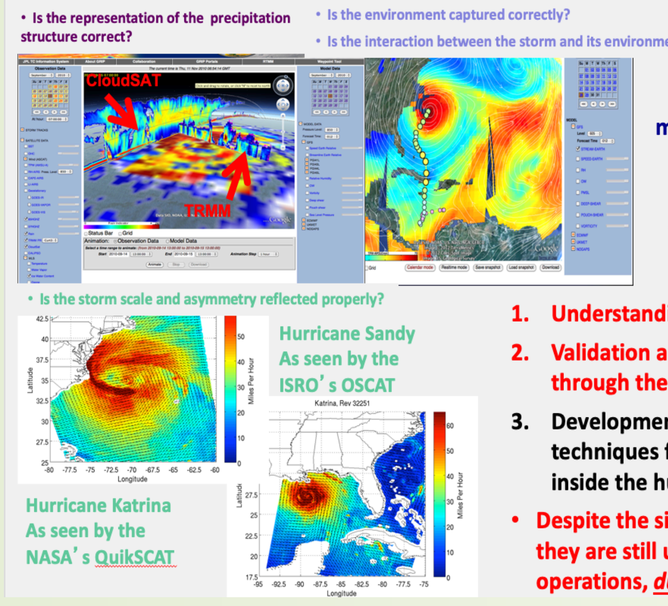


Graphs: National Hurricane Center

- But WHY ???
  - What are the *sources of the intensity errors in the models*?
- 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
- Recognizing an urgent need for more accurate hurricane forecasts, NOAA recently established the multi-agency 10-year Hurricane Forecast Improvement Project (HFIP).

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?
- Is the storm scale and asymmetry reflected properly?



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!

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.*

Our approach:

- Use of **high-resolution ensembles (used HWRF).**
- In a hind-cast – **sub-select** a few of the most realistic forecasts and a few of the least realistic
- Develop metrics for objective comparison of models and simulations based on measures of similarity between the observed and forecasted structures of precipitation, using Wave Number Analysis to reduce the dimensionality of the problem
- Determine whether precipitation structure of the good forecasts is closer to the observations than that of the bad
- Determine the skill of forecasting the track to provide "guidance on guidance"
- Future: analysis of the mutli-scale interactions using the **members** with the best predictive skill

The way forward:

Observations

- provide critical information to evaluate and validate the models
- alone cannot provide full understanding of the multi-scale interactions

Models – provide significant insights on processes and interactions … but only when their forecasts are realistic!

- Deterministic forecasts have limitations due to the uncertainty in the representation of the physical processes and initial conditions.
- Use of high-resolution ensembles is one of the most crucial recent improvements
  - Using different perturbed initial states and different physical parameterizations, cloud-resolving models are used to generate a representative set of outcomes – the members of an ensemble.
- The ensemble members
  - can be used to obtain the **ensemble mean** which provides a more reliable forecast than any of the individual members.
  - The ensemble itself provides also a measure of the uncertainty.
- Yet, the ensemble forecast could be further improved, by keeping only the most realistic members.
- This begs the questions:
  - How to select realizations that are most representative of the complex hurricane processes?
  - Can we use satellite observations to sub-select the most realistic members with the goal to decrease the uncertainty of the forecasts ?

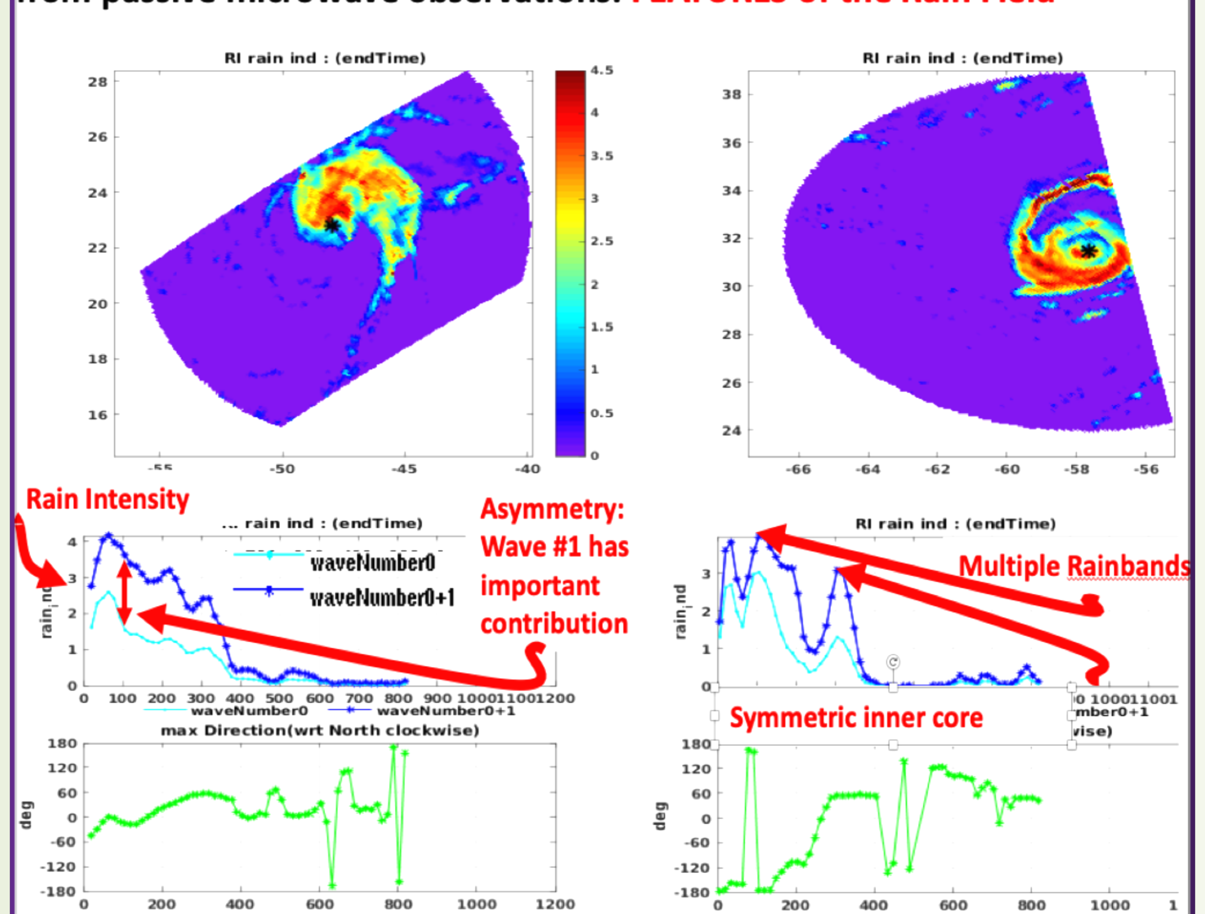
Goals:

To use observations and models to:

- Advance the still-lacking understanding of the governing processes
- Evaluate and improve models

The method for objective comparison

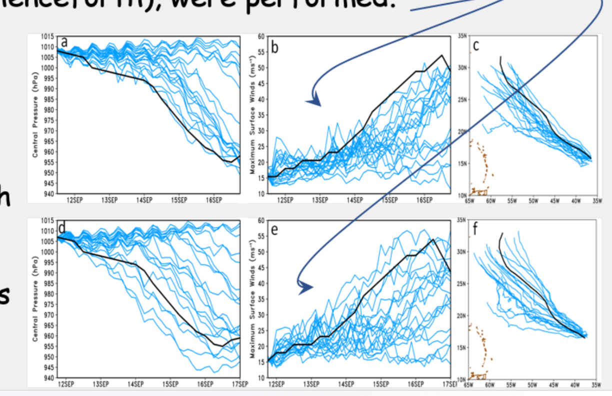
Wave Number Analysis of the Rain Field (as depicted by the Rain Index) from passive microwave observations: **FEATURES of the Rain Field**



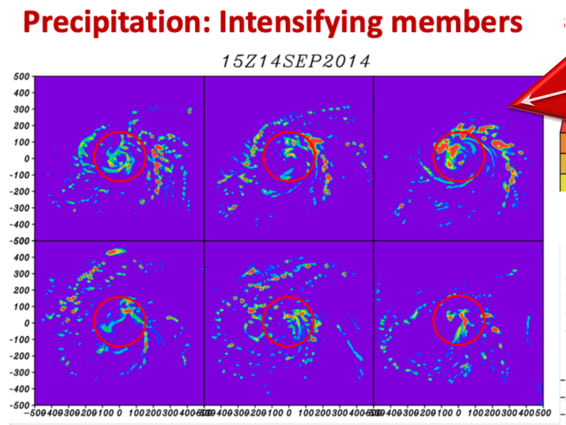
Model Forecasts

High-resolution ensemble forecasts

- Two sets of retrospective HWRF ensemble forecasts of Hurricane Edouard (2014), driven by 20 GEFS members initialized at
  - 1200 UTC (Ens1200 henceforth)
  - and 1800 UTC 11 Sept (Ens1800 henceforth), were performed.
- Here:
  - Six members with the strongest intensification rate and six members with the weakest intensification rate, based on a 24 h pressure drop, were selected from the combined 40 HWRF ensemble forecast members of these two sets of HWRF ensemble forecasts.
  - We then analyzed their signatures

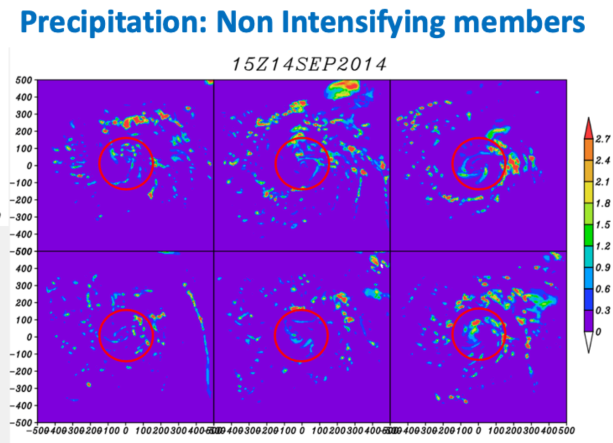


Precipitation: Intensifying members

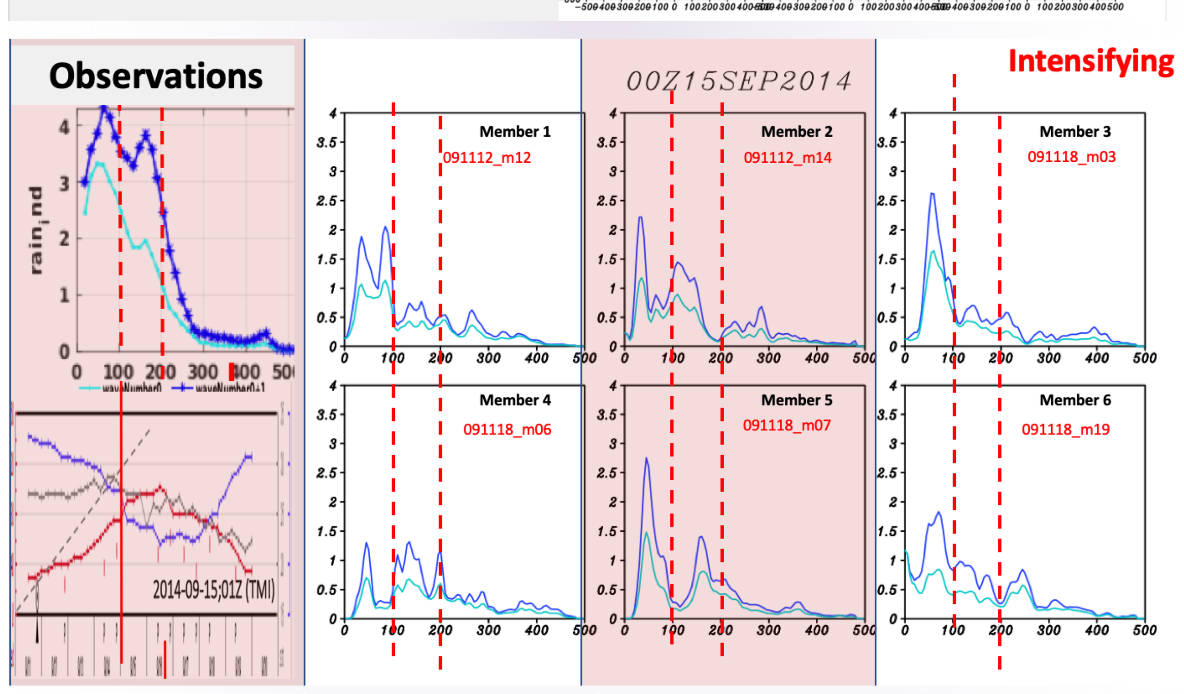


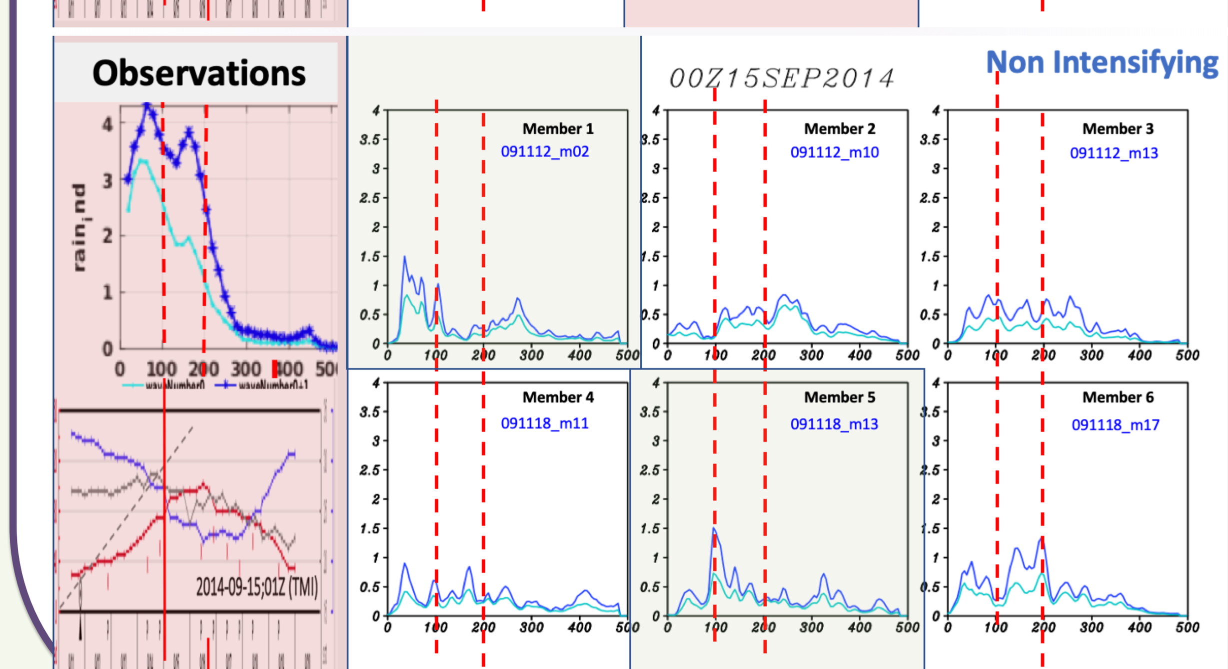
NOTE the similarity!!

Precipitation: Non Intensifying members



Note the difference in the amount of precipitation inside the red circles when comparing the two groups:
The intensifying group has more precipitation closer to the storm center.





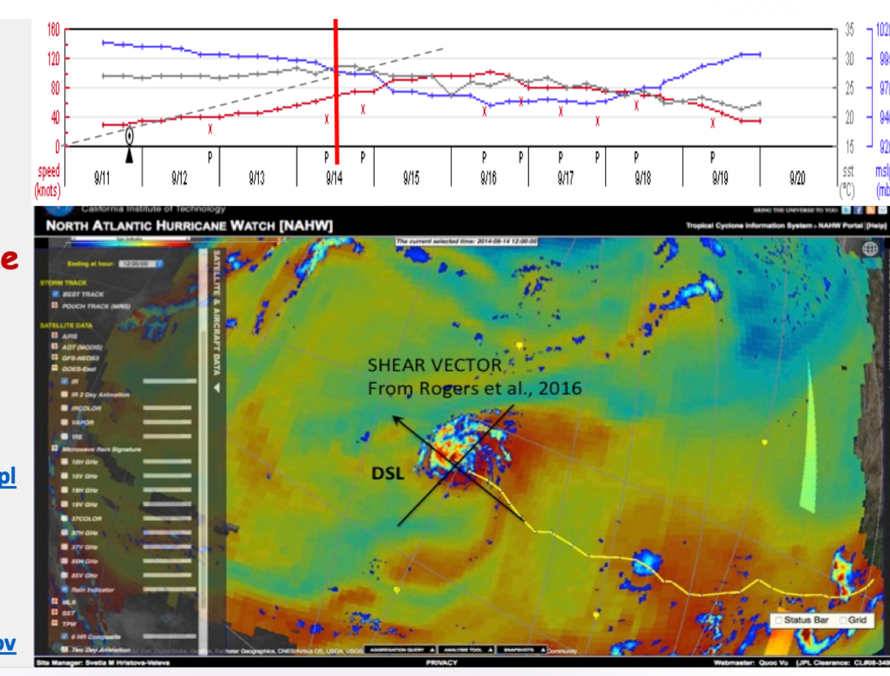
Observations

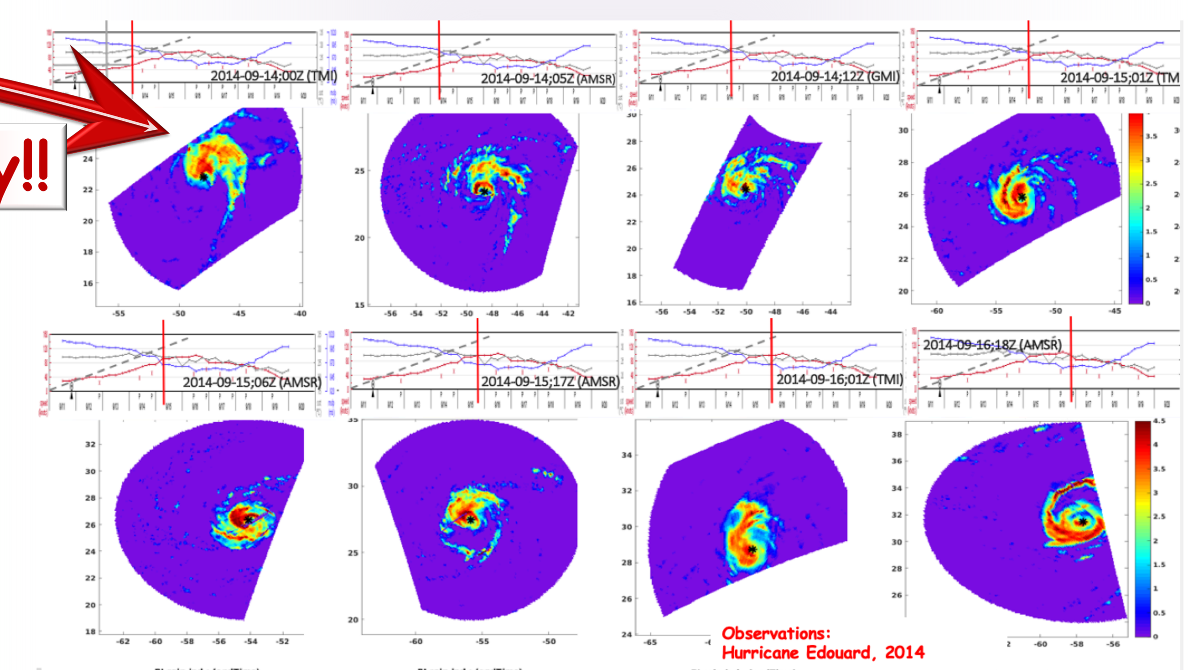
Observations: Hurricane Edouard, 2014

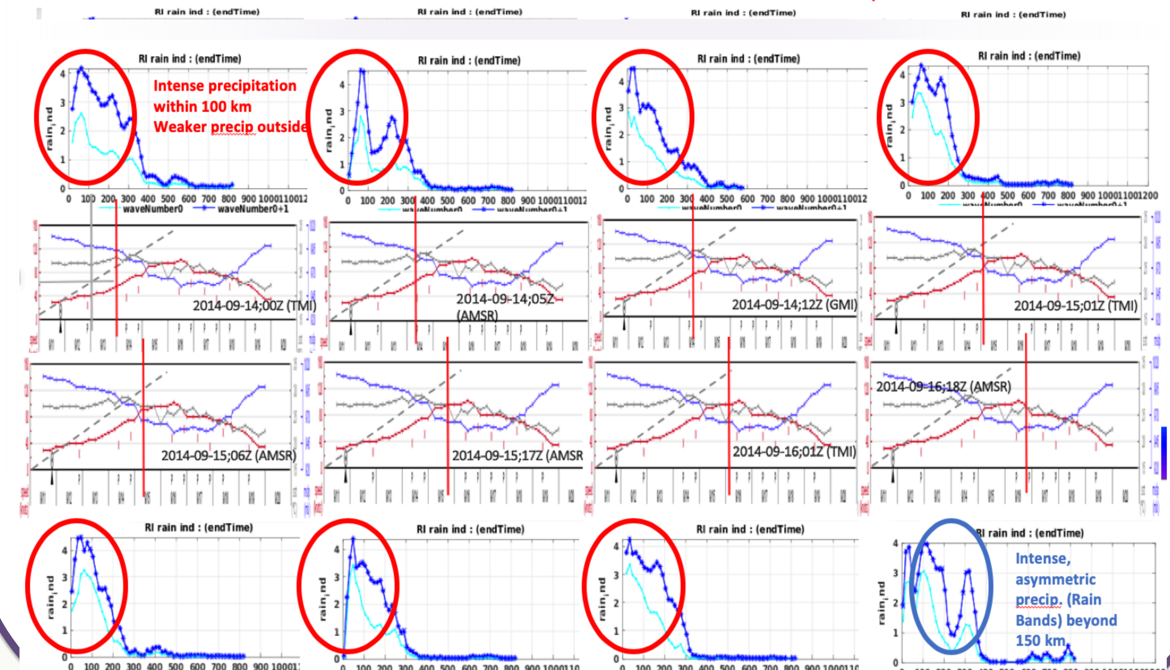
The JPL Tropical Cyclone Information System

https://tropicalcyclone.jpl.nasa.gov

The North Atlantic Hurricane Watch (NAHW)
https://nahw.jpl.nasa.gov







Summary

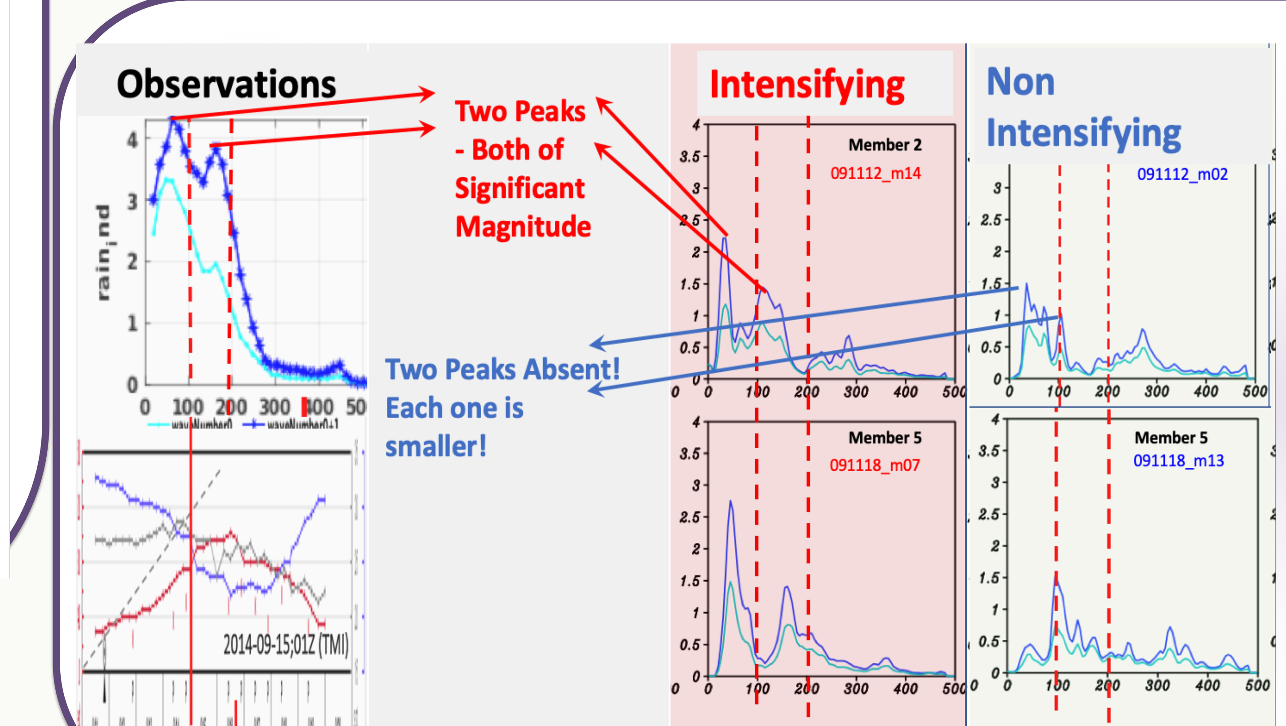
Results

- Determined that the precipitation structure of the more realistic intensity forecasts is closer to the observations than that of the less realistic ones!
- Evaluated the predictive skills in the track.
- Confirmed expectation: the ensemble members with a more-realistic distribution of precipitation have better skill in forecasting not only the intensity but also the track of the storm.

These results suggest that we can use satellite observations of the precipitation structure to determine the more realistic members from an ensemble of model forecasts.

Sub-selecting only those members to generate an ensemble mean would then improve the mean and decrease the uncertainty in the forecast, providing "guidance on guidance".

Comparison and implications



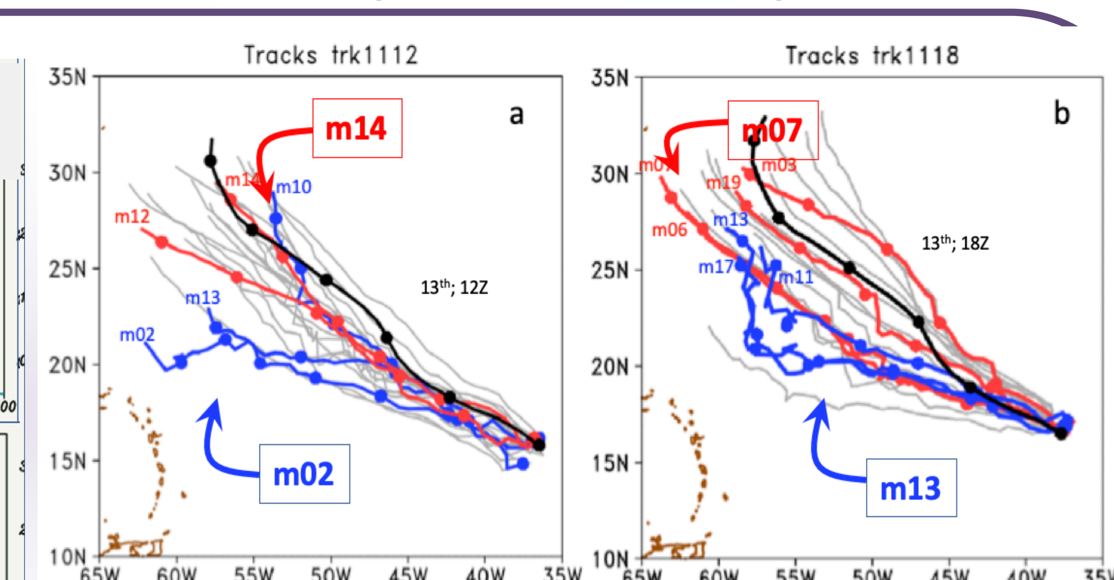


Figure: a) tracks of ens1112 and b) ens1118.

- tracks of the more realistic members (the rapidly intensifying ones) plotted in red
- tracks of the the less realistic members (the non-intensifying) plotted in blue.
- **Black lines denote best track.**

The highlighted tracks are marked every 24 hours.