Tropical Cyclone Mesoscale Data Assimilation

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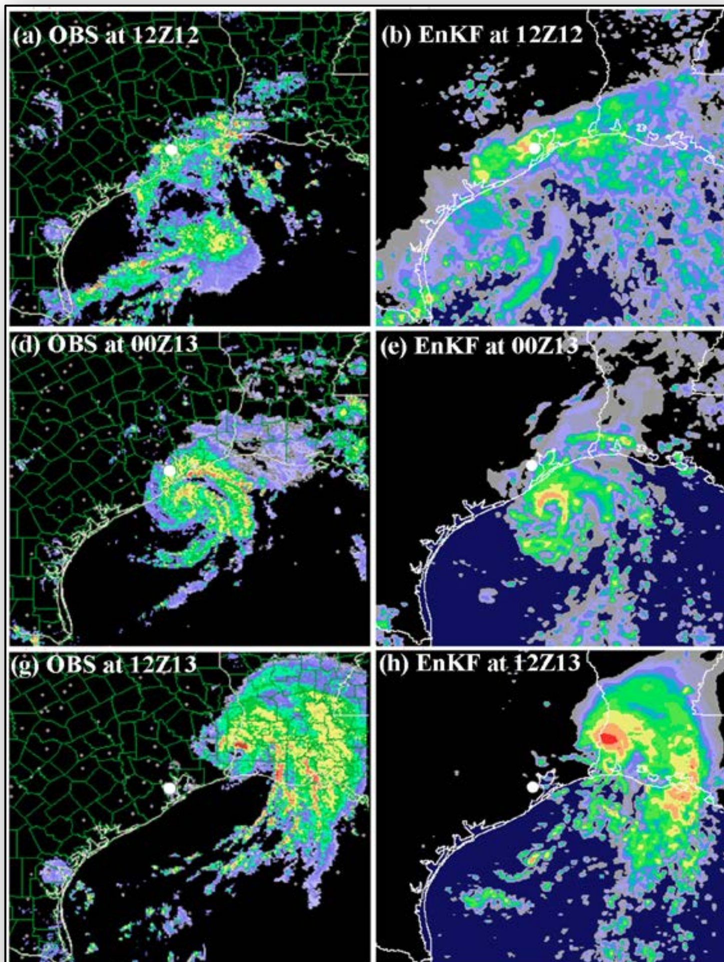
Motivation

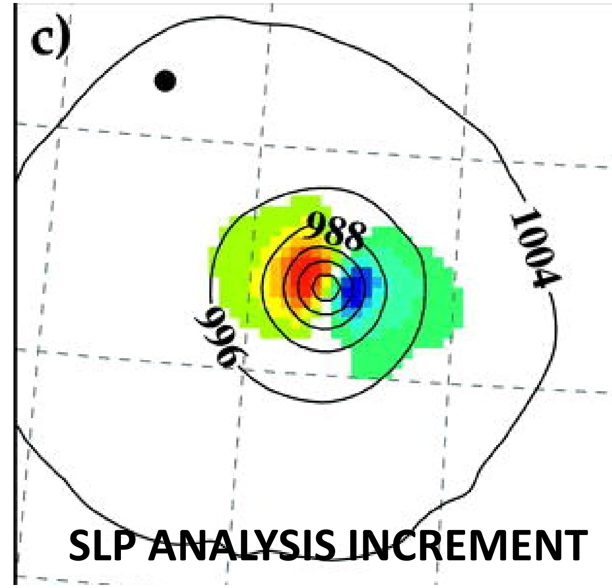
- **Forecasts of tropical cyclone (TC) track have improved steadily over the past 2 decades.**
- **However, forecasts of intensity, structure, flooding, storm surge etc have not kept pace.**
- **TC inner-core dynamics contributing to intensity change are largely mesoscale and convective-scale.**
- **Past 5 years: new focus on effort in mesoscale TC DA, particularly in the USA and in east Asia.**
  - **Concentrate on observations sampled *within* TC, as well as its near environment.**
  - **Many case studies and cycling experiments, mostly using EnKF (highly flow-dependent error covariance in TCs).**

Outline

- Recent assimilation studies
  - Radar and conventional observations
  - Aircraft-based inner-core
  - Satellite datasets
- Summary of results-to-date and challenges
- Future opportunities

Assimilation of radar Vr improves TC structure (Zhang et al. 2009, MWR)

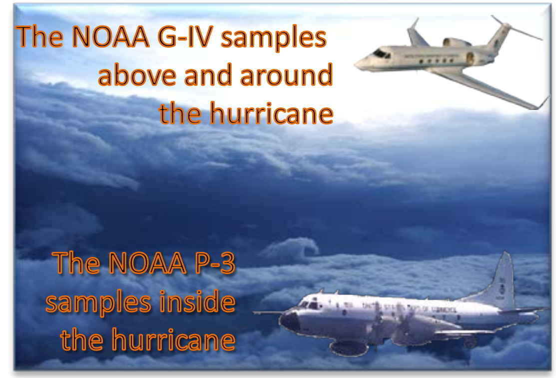




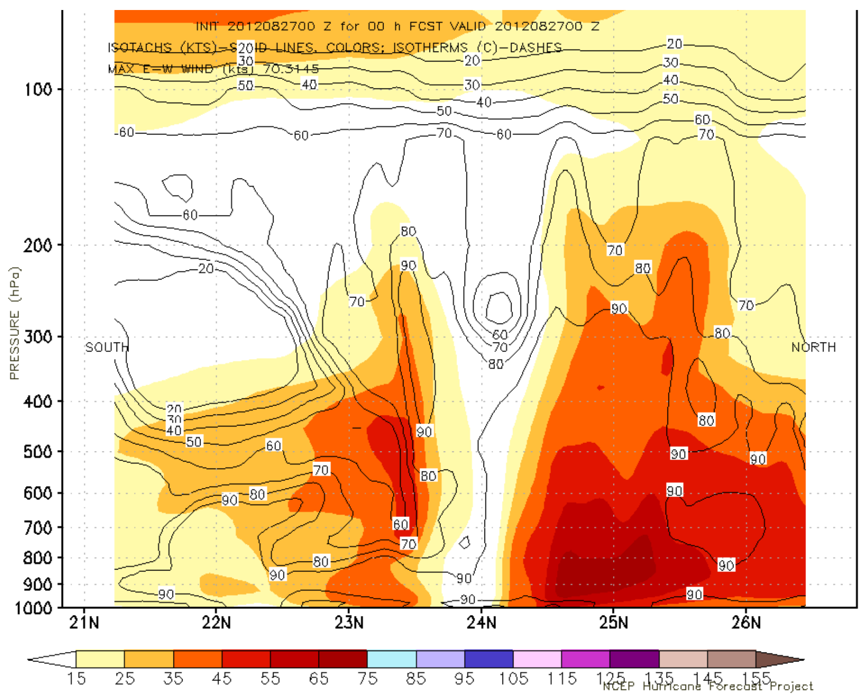
Analysis increment is dominated by position shift

(Torn and Hakim 2009, MWR)

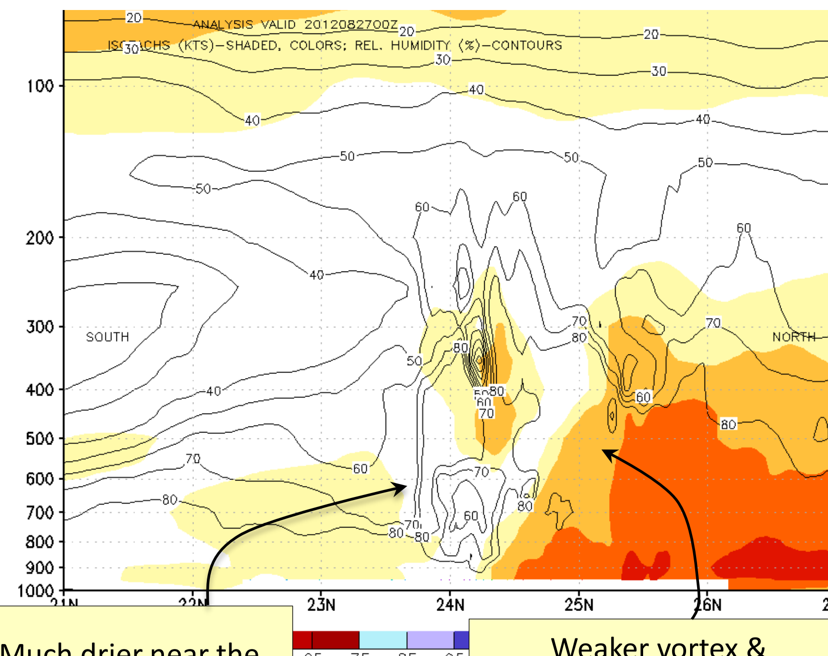
Data assimilation using aircraft radar and dropwindsonde data (NOAA/HRD)



ISAAC Initial vortex (wind + RH)
Operational HWRF (No Data Assimilation)



ISAAC Initial vortex (wind + RH)
with assimilation of observations



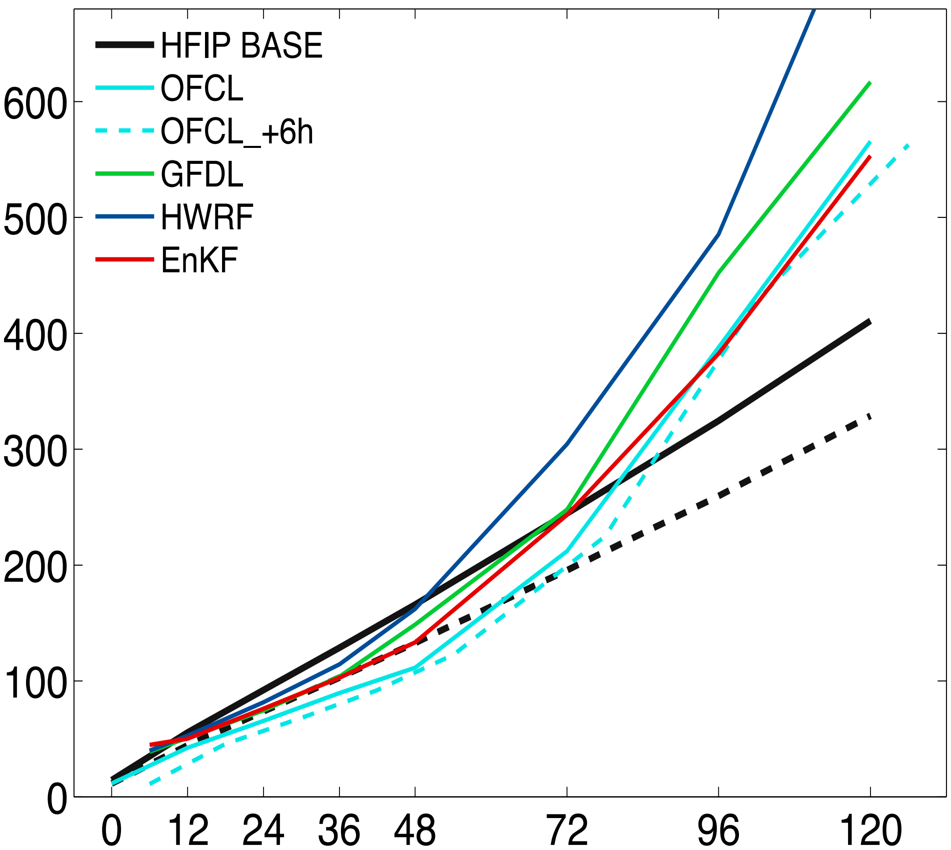
Much drier near the vortex

Weaker vortex & Distinct vortex tilt & Distinct vortex asymmetry

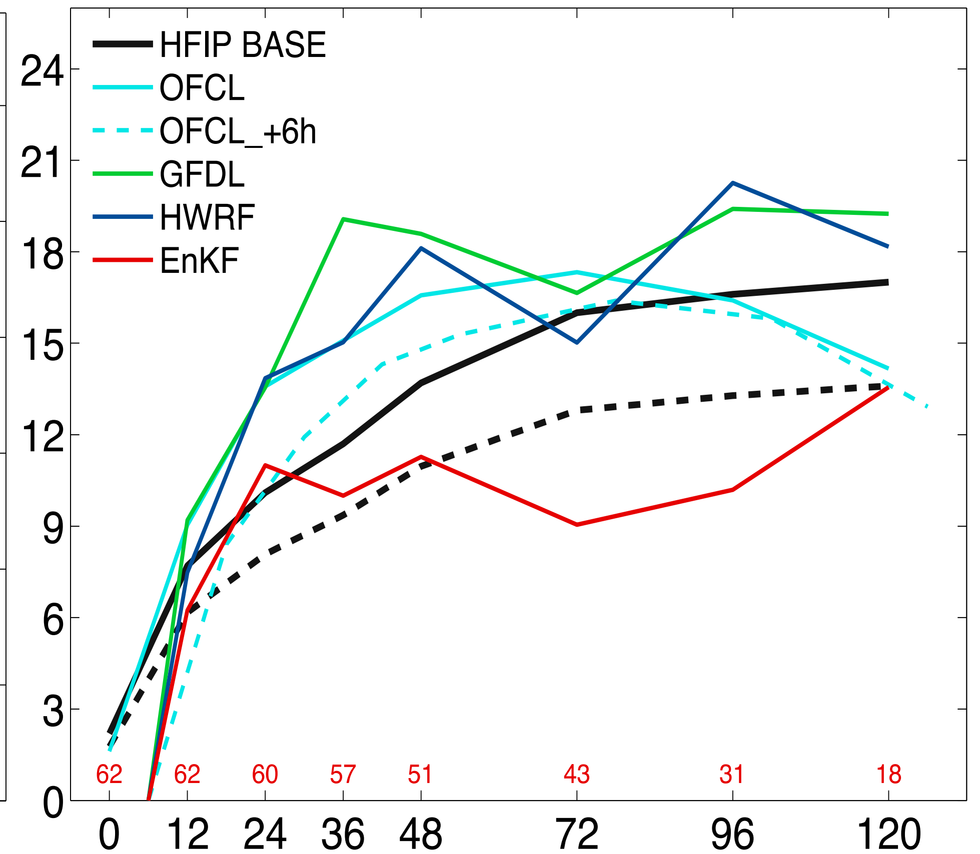
A. Aksoy

EnKF Performance Assimilating Airborne Radar OBS

Mean Absolute Error for 74 P3 TDR missions during 2008-2011



Position Error (km)



Intensity Error with Bias-correction (kt)

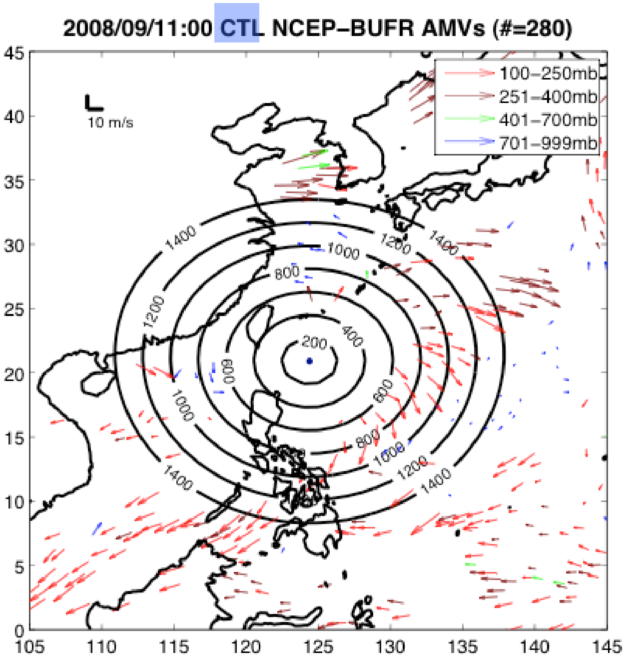
F. Zhang

Mesoscale TC Data Assimilation – Satellite Datasets

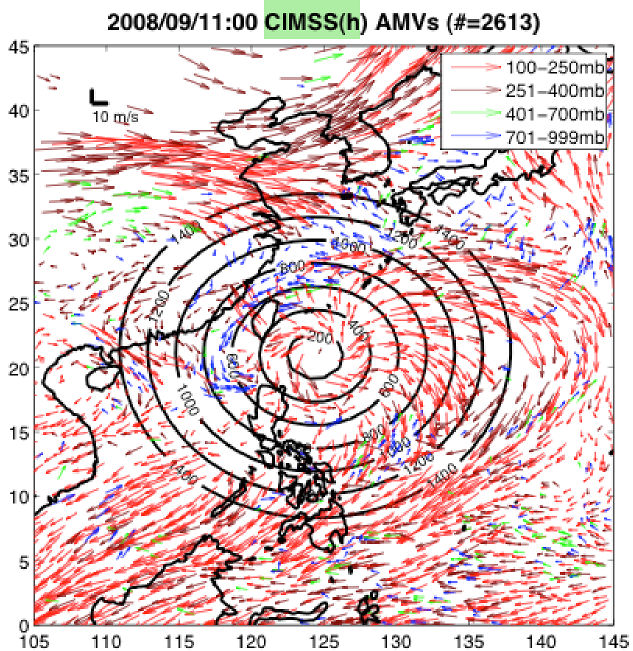
- **Use multiple satellite data sets at their highest resolution to build up an advanced analysis/forecast system for tropical cyclones and their environments.**
- **Seek an optimal assimilation strategy for integrated satellite data, under WRF-DART EnKF framework.**

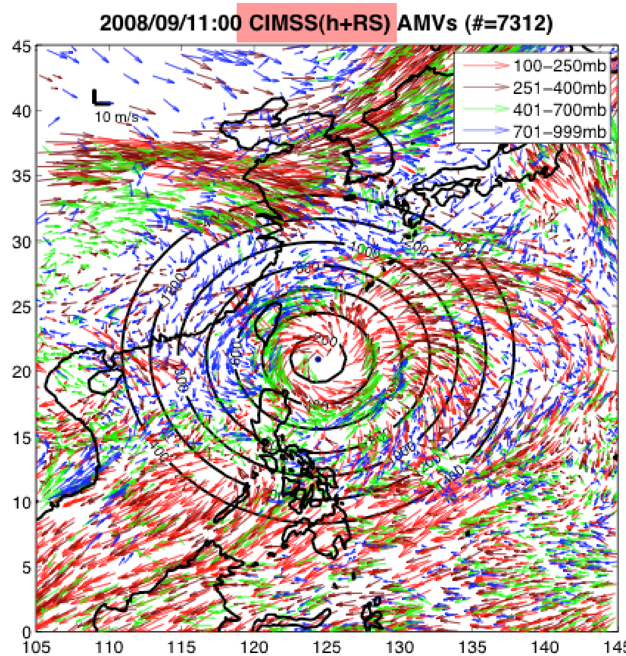
NOPP
National Oceanographic Partnership Program

Satellite data: Dynamic (AMVs, SCAT)

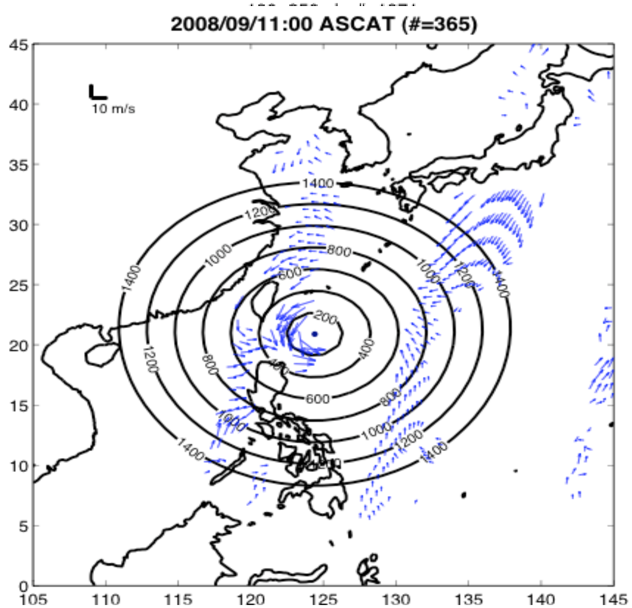


100-250mb: #=145
251-400mb: #=82
401-700mb: #=7
701-999mb: #=45



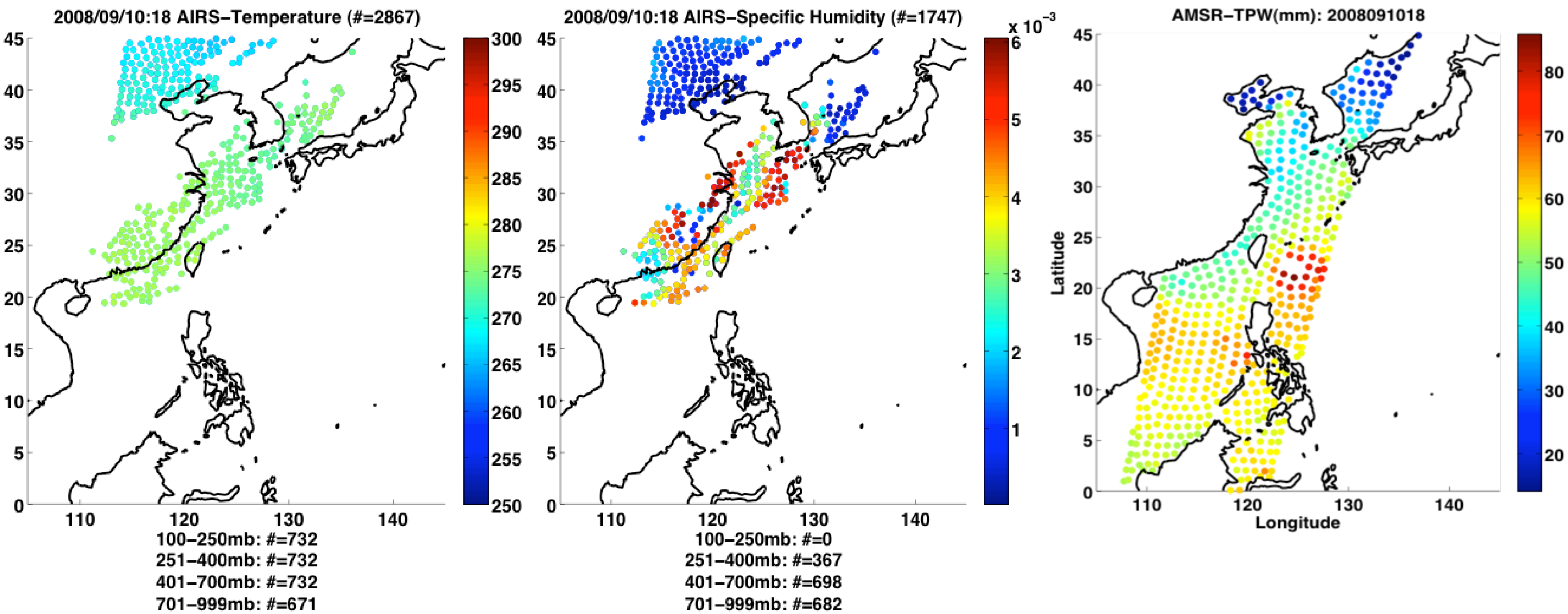


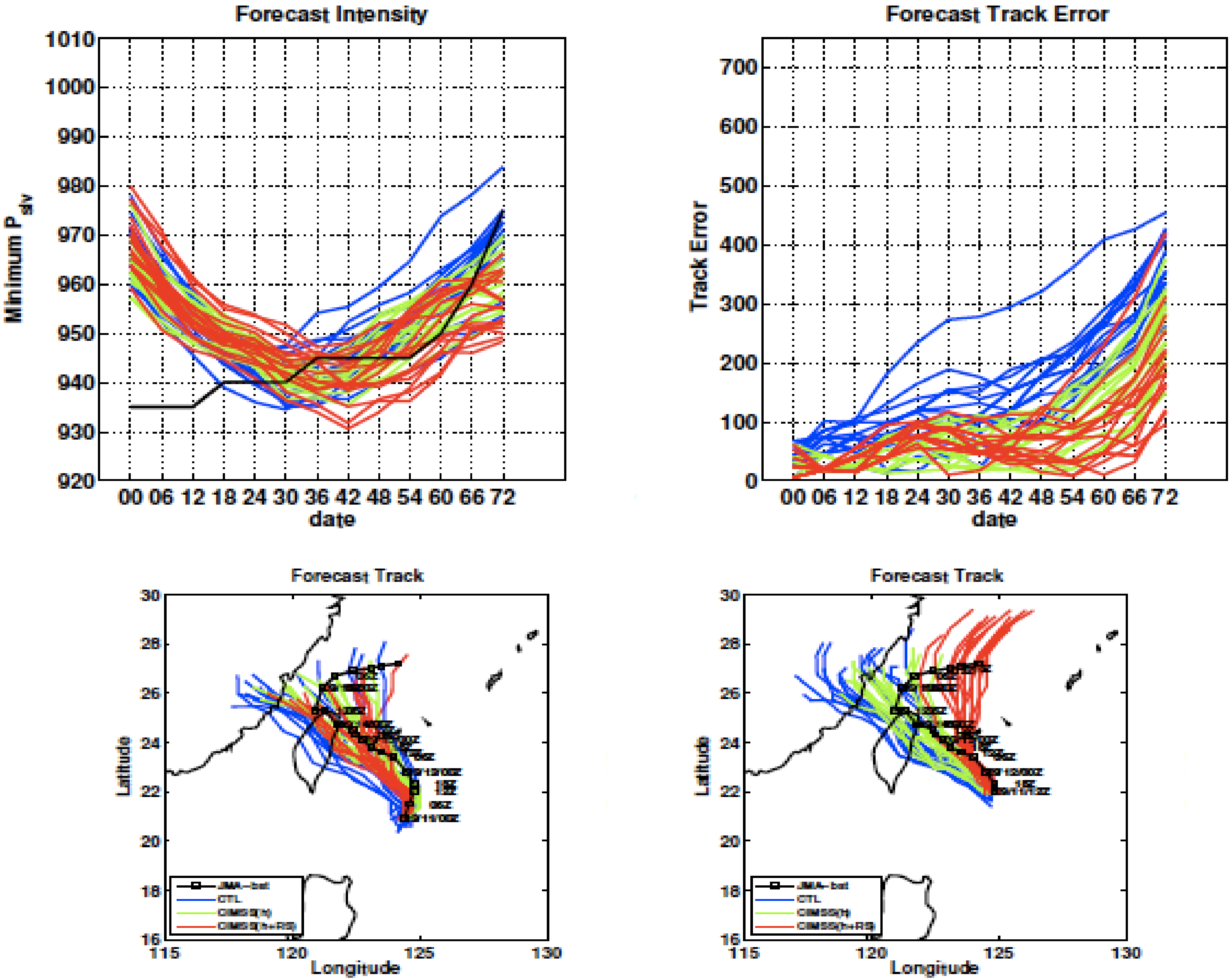
100-250mb: #=1639
251-400mb: #=1820
401-700mb: #=1953
701-999mb: #=1892



Contour every 200km

Satellite data: Thermodynamic (AIRS, TPW)

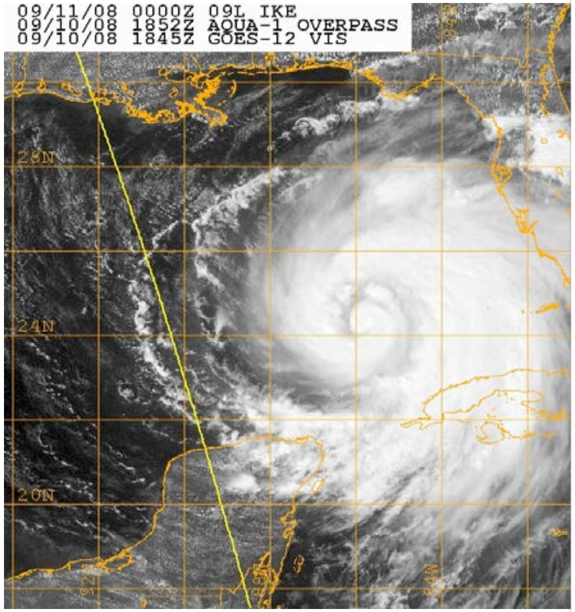


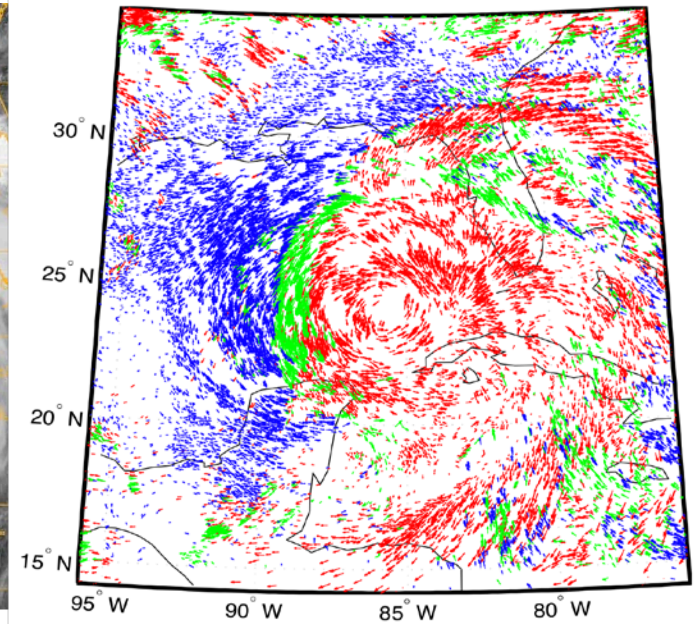

Forecast Intensity
Minimum P_{slv}
1010
1000
990
980
970
960
950
940
930
920
00 06 12 18 24 30 36 42 48 54 60 66 72
date
Forecast Track Error
Track Error
700
600
500
400
300
200
100
0
00 06 12 18 24 30 36 42 48 54 60 66 72
date
Forecast Track
Latitude
30
28
26
24
22
20
18
16
115
120
125
130
Longitude
JMA−bst
CTL
CIMSS(h)
CIMSS(h+RS)
Forecast Track
Latitude
30
28
26
24
22
20
18
16
115
120
125
130
Longitude
JMA−bst
CTL
CIMSS(h)
CIMSS(h+RS)

(a) (b)

TC Meso DA: Bogus Initialization Experiments

Hurricane Ike 10 Sep 18 UTC





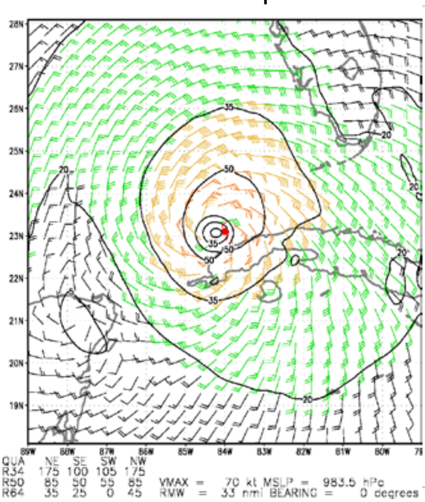
P ≤ 350 hPa   350 < P ≤ 800 hPa   P > 800 hPa

TC intensity, size and outflow asymmetries are all important parameters to properly initialize a model.

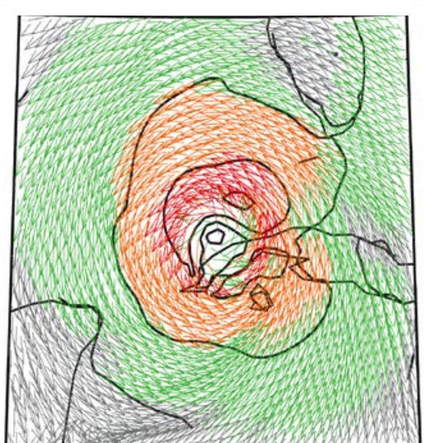
Enhanced AMVs depict properties of the core outflow, as well as inflow at lower levels.

An ensemble of bogus vortices is used to initialize GSI-Hybrid / WRF DA, thereby representing background uncertainty with respect to intensity and size.

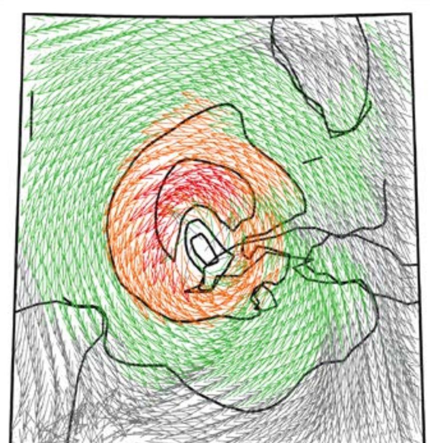
CIRA Multiplatform



CTL



EXP3HR



AMV assimilation using a 3-hrly cycle produces better fit to CIRA surface wind analysis (truth) relative to Control (PREPBUFR obs only)

Courtesy: Will Lewis (UW/SSEC)

Advances

- **More effective assimilation of inner-core observations, particularly of radar and dropwindsonde data.**
- **Demonstrated that inner-core assimilation is superior to no inner-core assimilation in terms of model forecasts.**
- **Use of full-res satellite data in and near the inner-core demonstrates promise.**
- **Progress towards unifying DA that is used with all other meteorological phenomena.**

Some common negative findings

Short-term forecast bias

- Short-term spin-down tendency for high intensity cases reduces impact of inner-core wind observations

Model physics affects assimilation

- Model representation of secondary circulation is affected by the model PBL structure

Lack of vertical motion in the analysis

- Initial imbalance; vortex adjustment

Challenges

- Non-Gaussian background errors in TCs.
- Analysis increments tend to be dominated by position corrections, not structural corrections. Explore storm-centered coordinates?
- Model error and bias is a critical issue
  - Further model development required
  - Develop schemes consistent with observations in TCs
- Nesting issues
  - Inconsistency between nest positions
  - Regional model tracks worse than parent global model

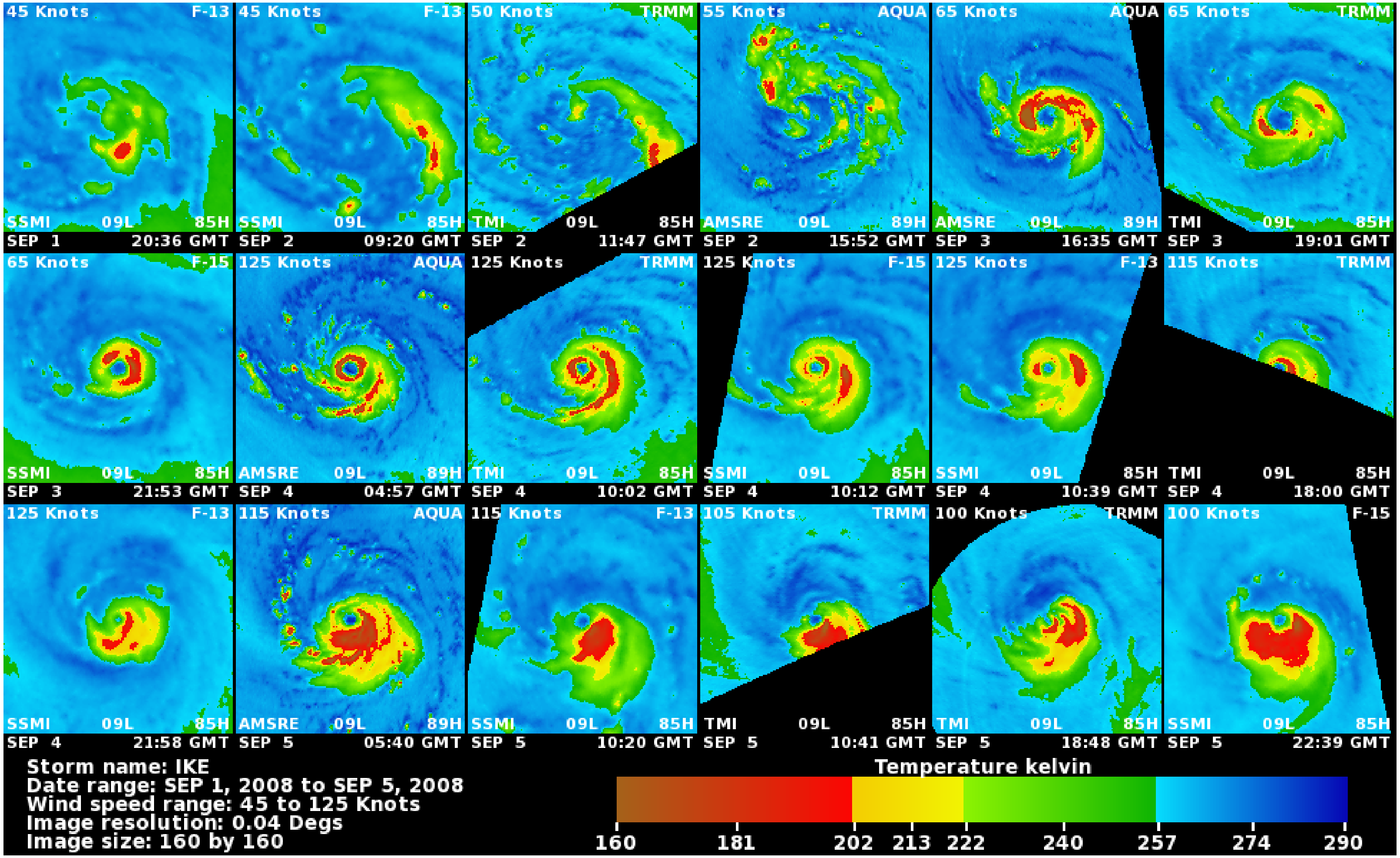
Future goals

- **Advance DA: 4d-EnKF / account for non-Gaussianity**
- **Quantify the intrinsic predictability of metrics relevant to TC structure and intensity**
  - **Focus only on Wavenumber 0 and 1?**
- **Continue to investigate the issue of initialization with or without bogussing techniques**
- **Quantify which observations are the most important**
- **OSSEs and OSEs**
  - **Optimize aircraft flight tracks**
  - **Real and Simulated data from Global Hawk (NASA 2012-14)**
  - **Experiments with assimilating other types of satellite data such as microwave imager radiances and hyperspectral sounders**
  - **Less thinning of conventional satellite observations; finer decorrelation length scale**

Promising satellite datasets not yet fully exploited in TC DA

Microwave Imagers -- TC Structure Time Series

Hurricane Ike

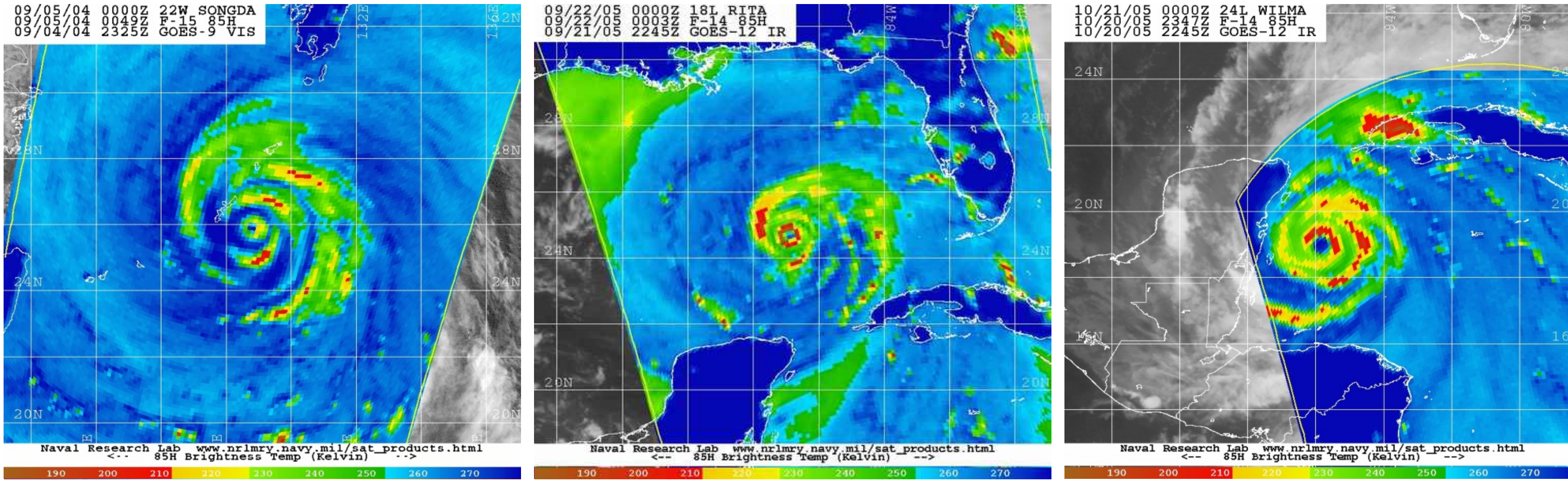


➢ **Multi-satellite MW sensors enable enhanced temporal sampling needed to observe rapid convective/precip structure and organization changes.**

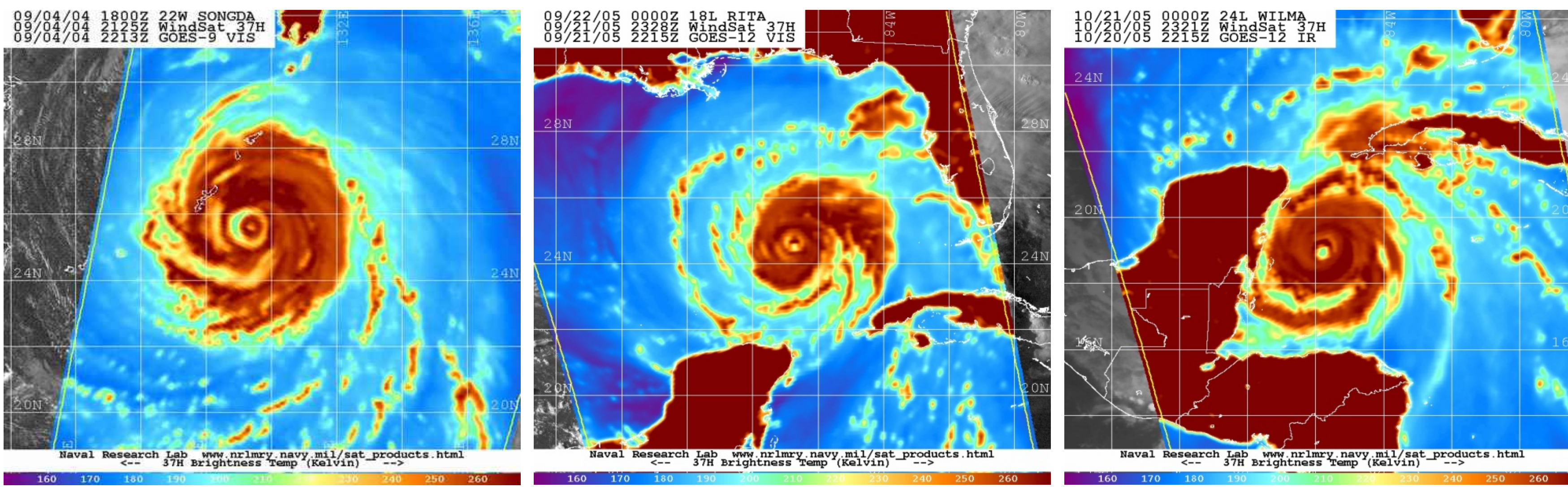
Promising satellite datasets not yet fully exploited in TC DA

Radiances from multiple MW frequencies indicate precip patterns, depth and hydrometeor phase

85 GHz H-Pol



37 GHz H-Pol



Promising satellite datasets not yet fully exploited in TC DA

Megha Tropiques - MADRAS

Sensor: **Passive Microwave Conical Scanner**
Spacecraft: **Mega-Tropiques**
Launched: **Oct. 12, 2011**
Heritage: **TRMM/TMI**

Channels: **18.7, 23.8, 36.5, 89, 157 GHz**
~40, 40, 40, 10, 6 km

Swath: 1700 km

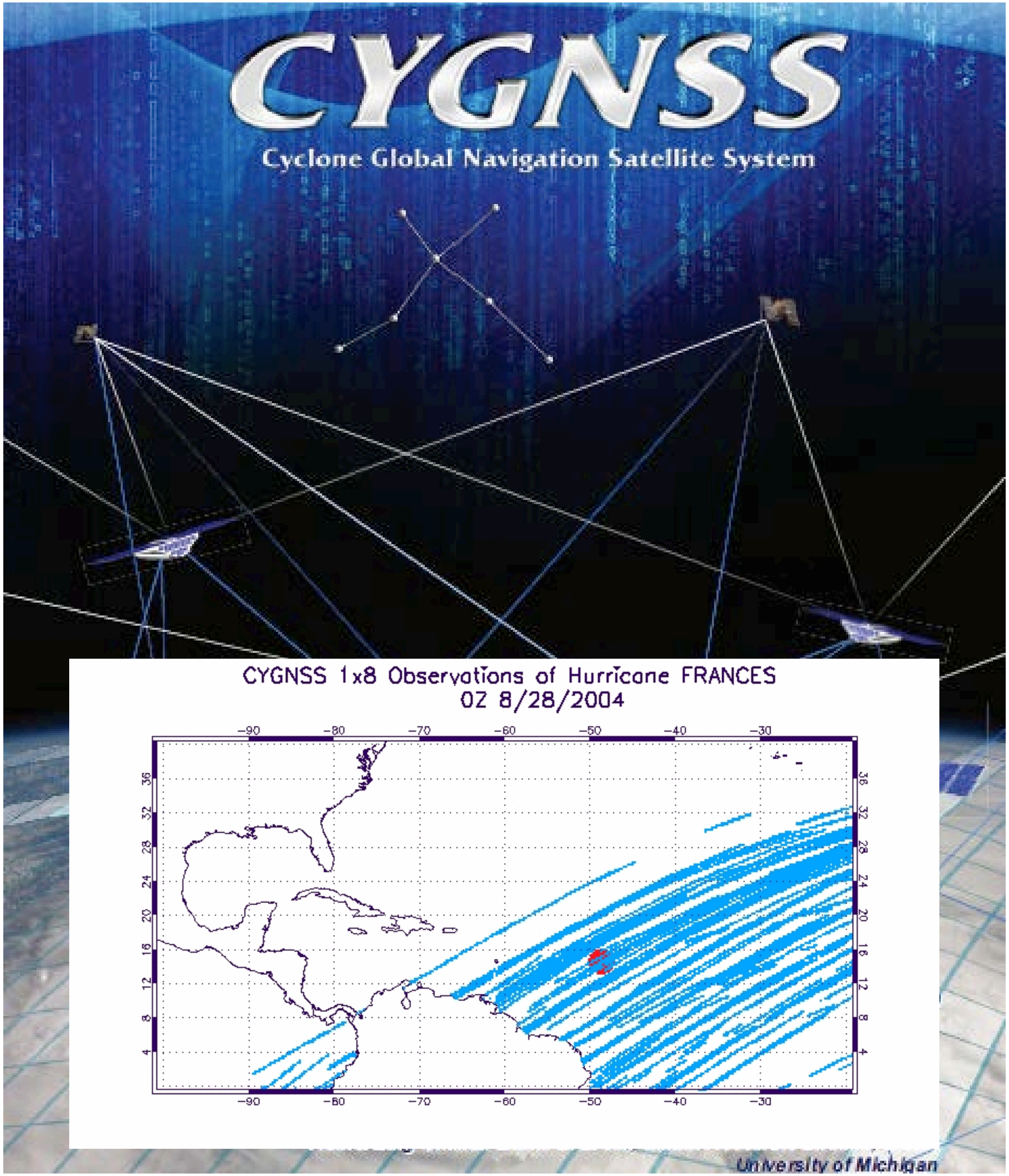
Enhancements for TC Applications:

(1) Tropical inclination (20 deg),
(2) 3-5 overpasses/day for TCs +/- 23 deg Lat

Source: N. Karouche, CNES

Data may start flowing in Jan 2013 timeframe.

Web Link: http://meghatropiques.ipsl.polytechnique.fr/


CYGNSS
Cyclone Global Navigation Satellite System
CYGNSS 1x8 Observations of Hurricane FRANCES
0Z 8/28/2004
-90
-80
-70
-60
-50
-40
-30
4
8
12
16
20
24
28
32
36
University of Michigan

Z. Jelenak