NCEP Operational HWRF: Progress and Challenges in Satellite Data Assimilation for Regional Hurricane Modeling

Vijay Tallapragada, Banglin Zhang, Mingjing Tong and Emily Liu

Environmental Modeling Center,
NOAA/NWS/NCEP, NCWCP, College Park, MD 20740.

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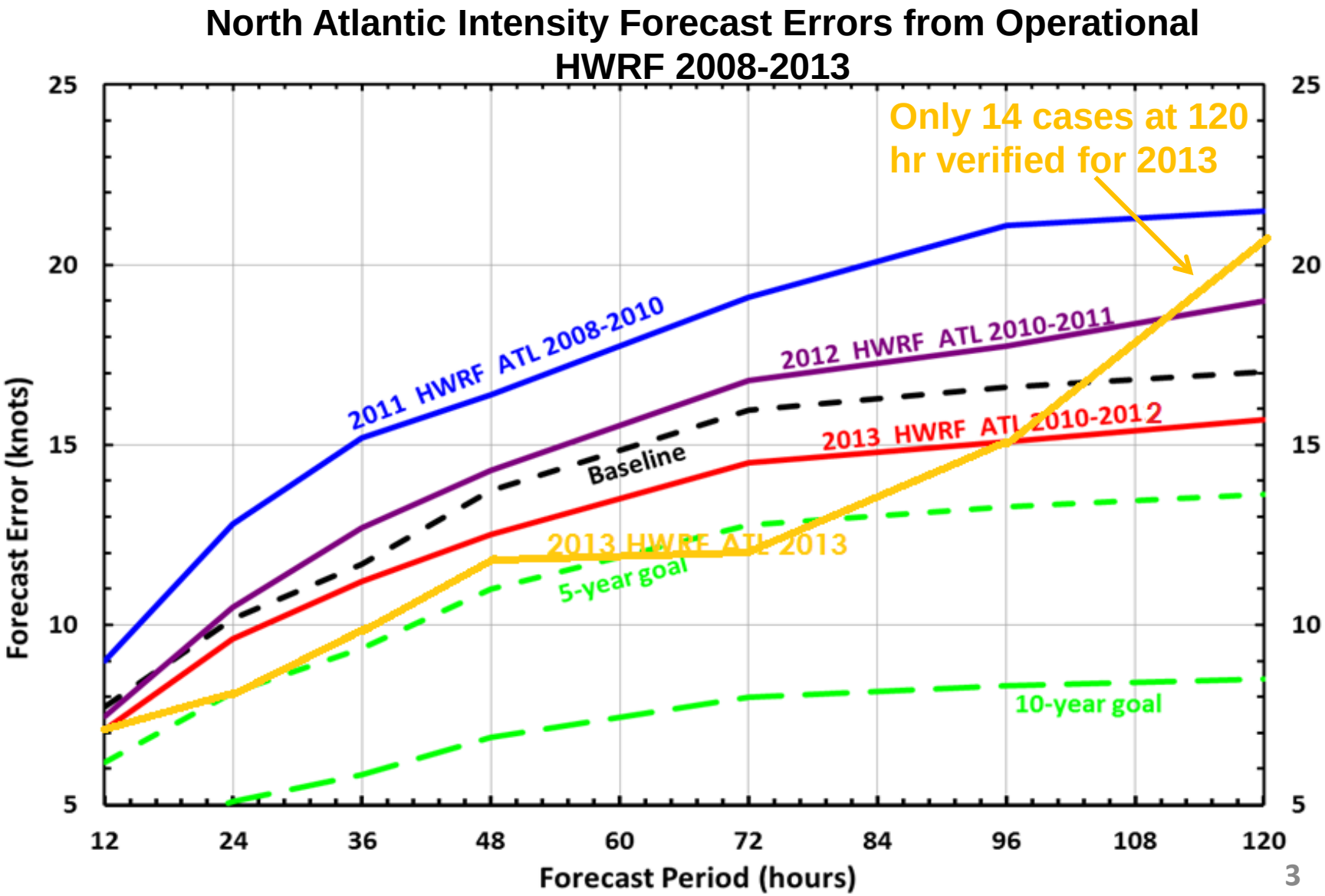
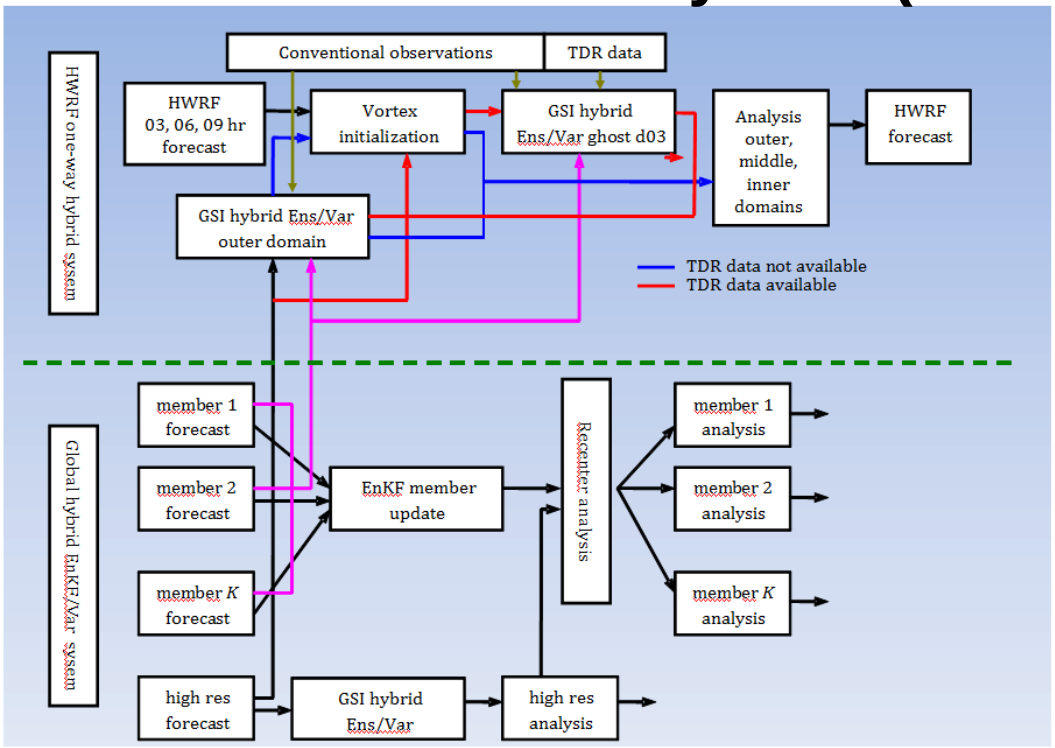
Outline

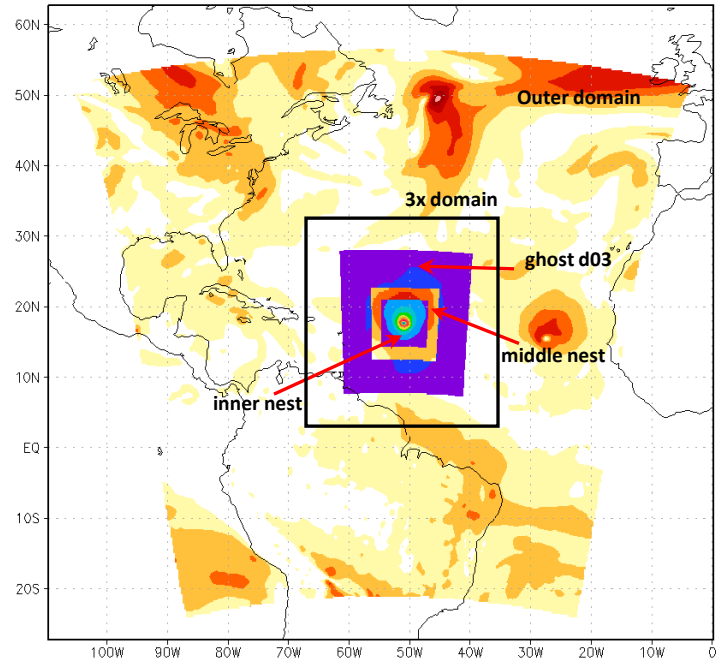
- HWRF's evolution as an important dynamical model guidance tool for hurricane forecasts
- Advancements to Hurricane Data Assimilation System (HDAS) for operational HWRF
- Ongoing Satellite Data Impact Experiments
- Challenges and issues with assimilation of satellite data for regional hurricane modeling

NCEP Operational HWRF showing systematic improvements in Atlantic intensity forecasts



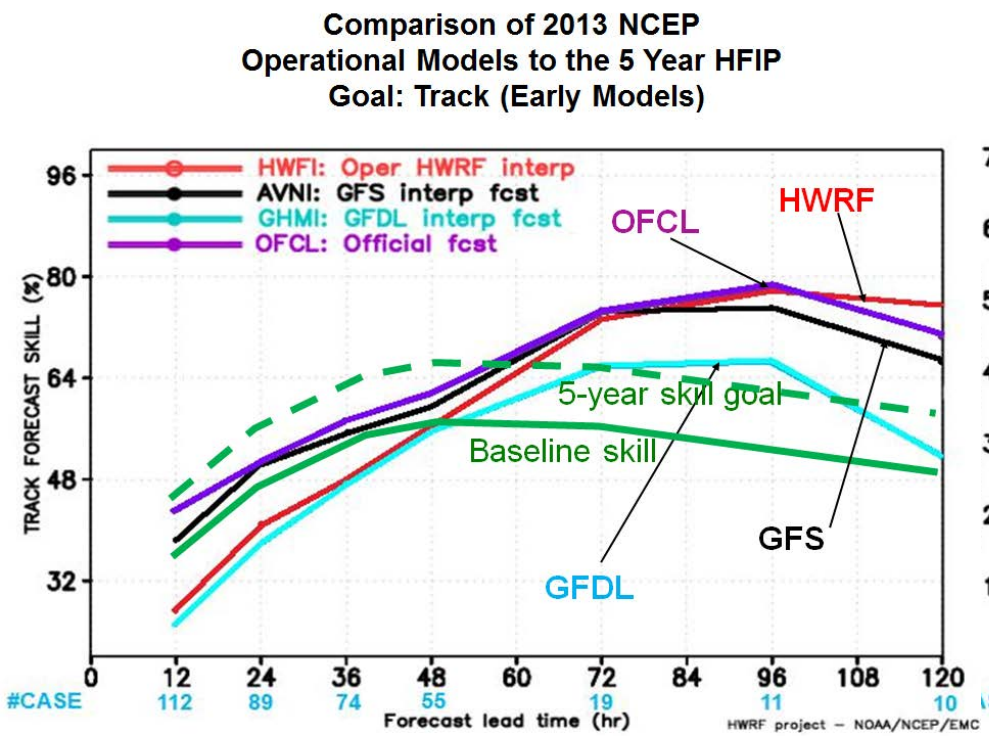
2013 Operational HWRF Data Assimilation System (HDAS)

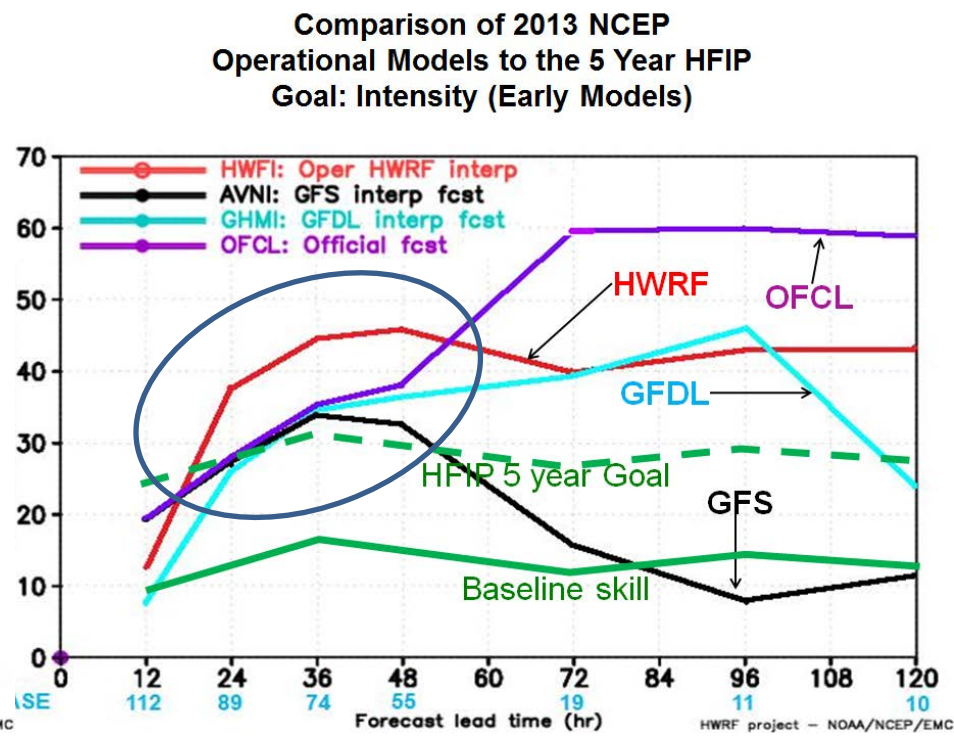




- Data assimilation performed on outer domain. When TDR data are available, data assimilation also performed on ghost d03 after vortex initialization. Vortex initialization performed on 3x domain prior to the DA.
- GSI hybrid analysis using global 80 EnKF ensemble member at T254L64.
- First guess
  - TC environment cold start from GDAS forecast
  - TC vortex cycled from HWRF forecast
  - First Guess at Appropriate Time (FGAT)
- Observational data
  - outer domain: conventional data (radiosondes, dropsondes, aircraft reports, surface ship and buoy observations, surface observations over land, pibal winds, wind profilers, VAD wind, scatterometer winds, GPS-derived integrated precipitable water)
  - ghost d03: conventional data and TDR data
  - satellite radiance, satellite derived wind and GPS RO data are **not** assimilated in the 2013 operational HWRF.

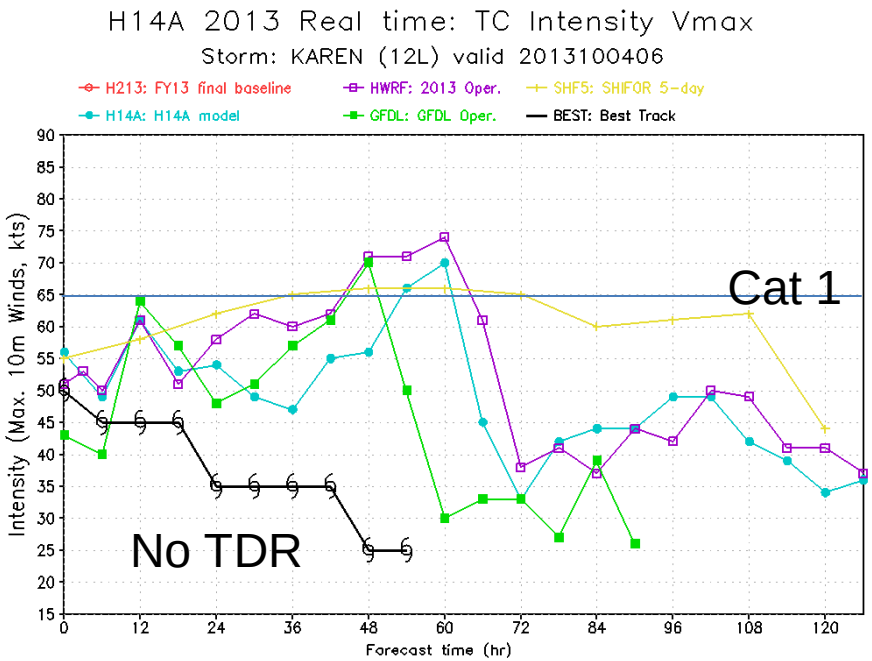
Performance of NCEP Models for 2013 North Atlantic Basin

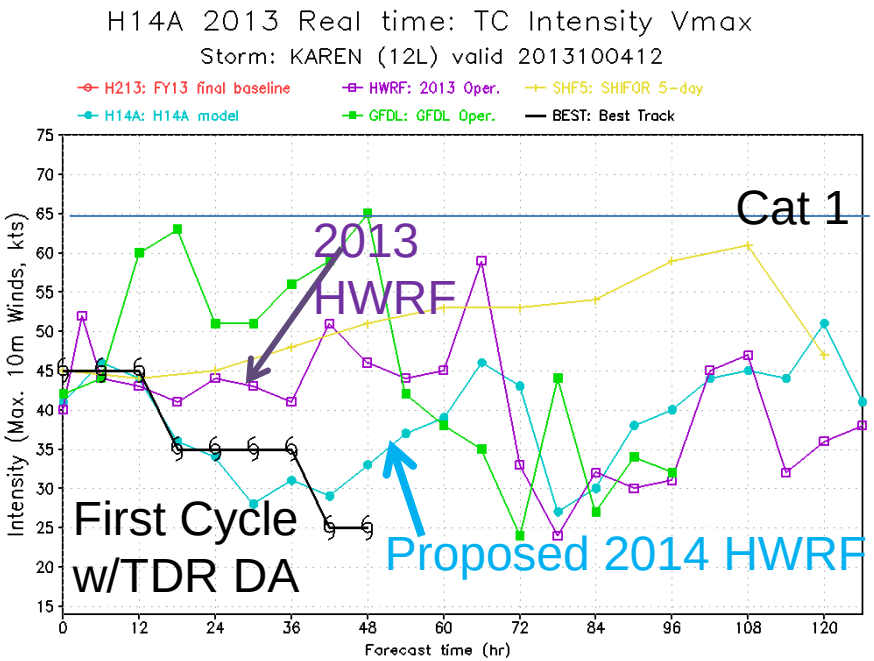




HWRF Model Real-Time Performance for 2013 Atlantic intensity forecasts match the expectations from the pre-implementation T&E

Impact of TDR DA on operational HWRF for TS Karen:





Real-time assimilation of NOAA P3 TDR DA for operational HWRF – A First in many years of flying.

- Conduct experiments to maximize the effective utilization of inner core data for 2014 HWRF implementation

Impact of HWRF forecasts with TDR DA on NHC Operational Forecasts

NHC Forecast Discussion on October 4, 5 PM:

- **THE 12Z HWRF RUN SHOWED CONSIDERABLY LESS INTENSIFICATION WITH KAREN COMPARED TO PREVIOUS RUNS AFTER ASSIMILATING DATA FROM THE FROM THE NOAA P-3 TAIL DOPPLER RADAR. THIS MARKS THE FIRST TIME DOPPLER RADAR DATA HAVE BEEN ASSIMILATIED INTO AN OPERATIONAL HURRICANE MODEL IN REAL TIME.**

-- Forecaster Brennan

Ongoing Efforts for Assimilation of Satellite Data into Operational HWRF

- **Key Priority Areas for HFIP:**
  - Increased use of observations in high-resolution regional hurricane modeling systems with special emphasis on satellite data
  - Advancement of Data Assimilation Techniques for both large-scale and vortex scale circulations

- **HFIP Satellite DA Tiger Team efforts during 2013 hurricane season:**
  - Current issues and the solutions for satellite data assimilation in HWRF
  - Configuration for Stream 2.0 experiment (HDA0)

- **Pre-implementation configurations for 2014 HWRF**
  - Four data assimilation configurations for 2014 HWRF pre-implementation tests (H14A, H14B, H14C and T14C)
  - The final baseline configuration for 2014 HWRF (T14C)

- **Collaborative efforts with community involvement**
  - JPSS PG collaboration with JCSDA and FSU (Fuzhong Zhang & Xiaolei Zou)
  - HFIP AO and other funding opportunities
  - GOES-R PG collaboration with U. Wisc. for assimilation of high-resolution hourly AMVs (Chris Velden)

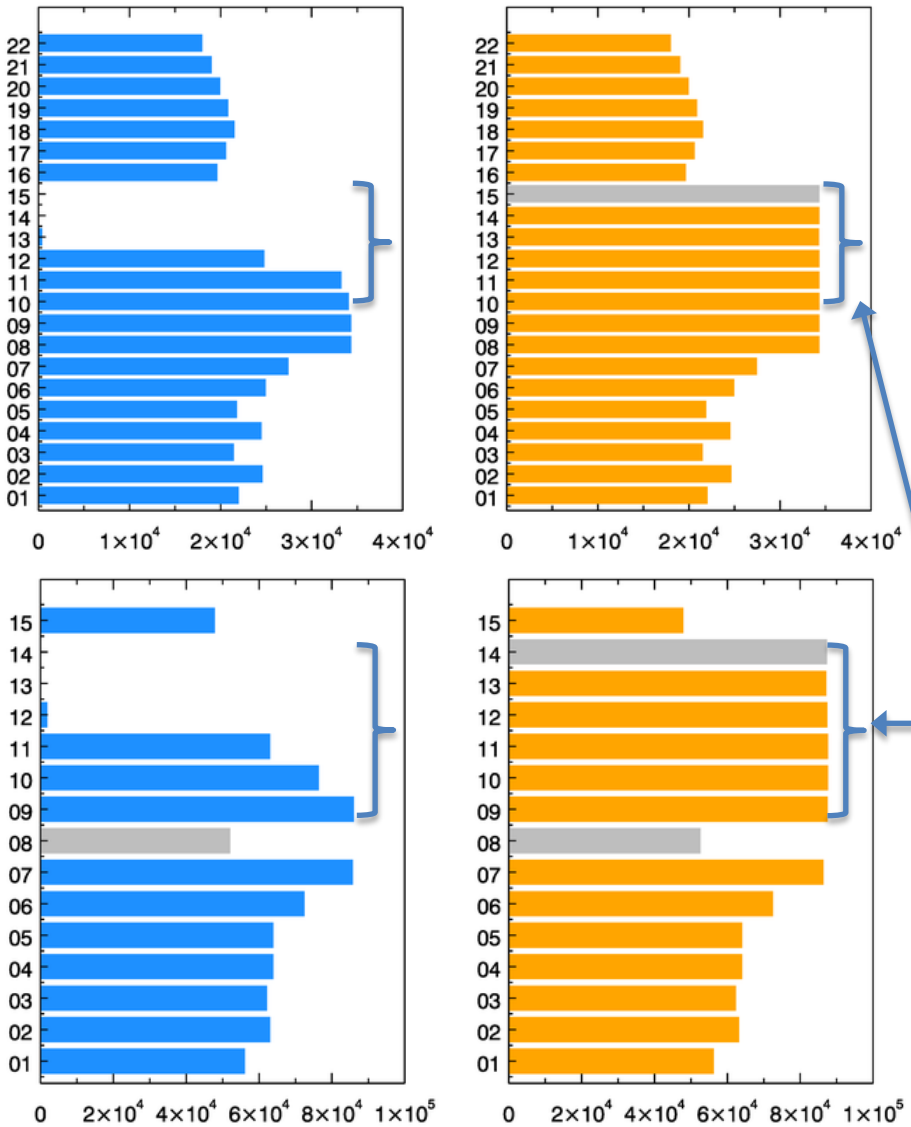
Current issues and proposed solutions for assimilation of satellite data in HWRF

- **Current Issues**
  - Short cycling period and variable sample size make the spin up of bias correction problematic
  - Lower model top makes the use of high peaking channels difficult
  - No ozone profiles in HWRF background and this may lead to biases in the simulated brightness temperature, especially for IR instruments
- **Solutions**
  - Use global-regional blended vertical coordinate to obtain better vertical resolution in stratosphere and extend the model top up to 0.3 hPa
  - Use bias correction estimation from GFS
  - Use ozone profiles from GFS in HWRF

Benefits of using global-regional blended vertical coordinate

ATMS NPP

AMSU-A N19

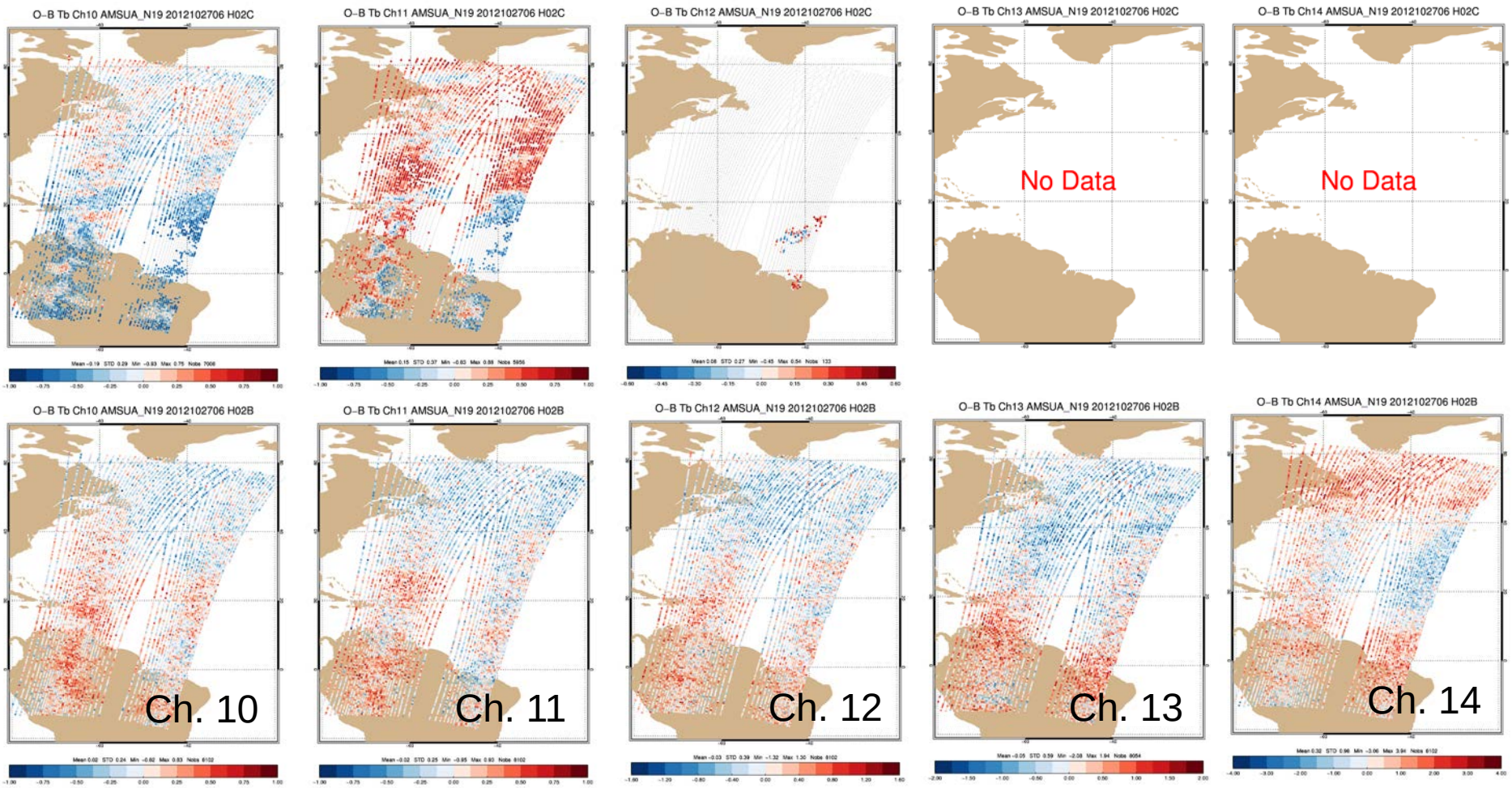


61 levels; model top at 2 hPa
75 levels; model top at 0.3 hPa
Channel not assimilated

- Data passed QC in the analysis for all ATMS NPP and AMSU-A NOAA-19 during the entire life cycle of Hurricane Sandy

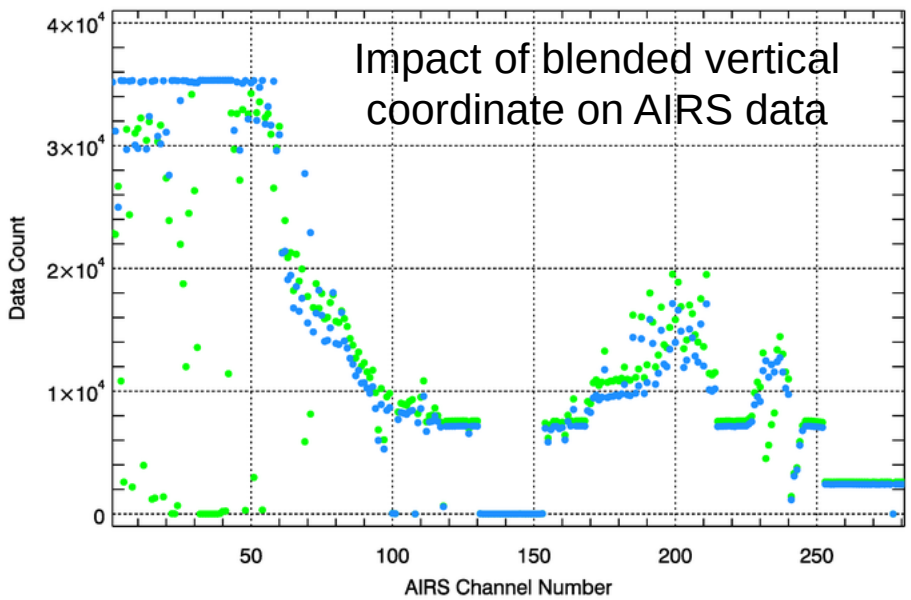
- More data in the stratosphere and above are assimilated when blended vertical coordinate is used

Upper panel: 61 levels; model top at 2 hPa
Lower panel: 76 levels; model top at 0.3 hPa



- Data coverage and model fit to the observation are significantly improved when blended vertical coordinate is used in the analysis

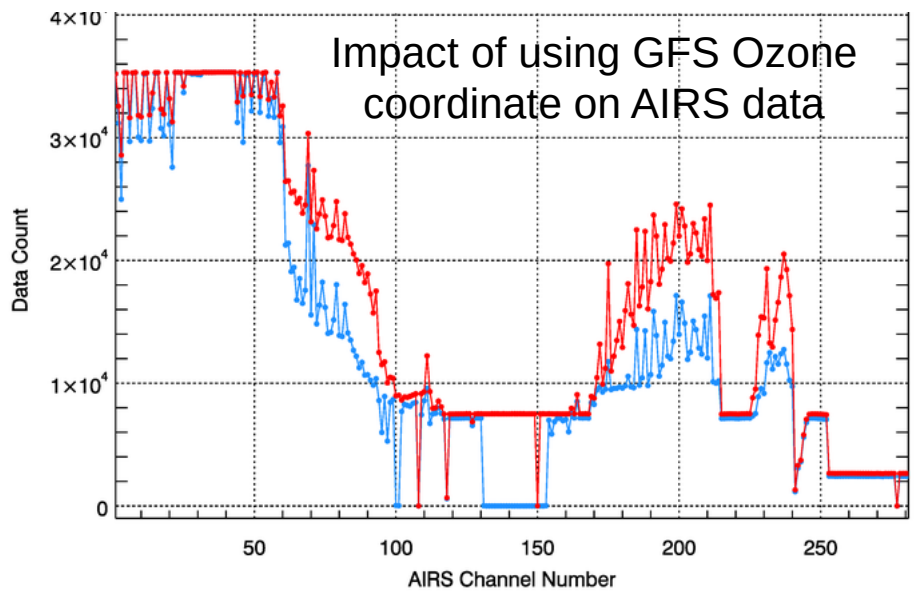
Benefits of using GFS Ozone profiles



AIRS data passed QC

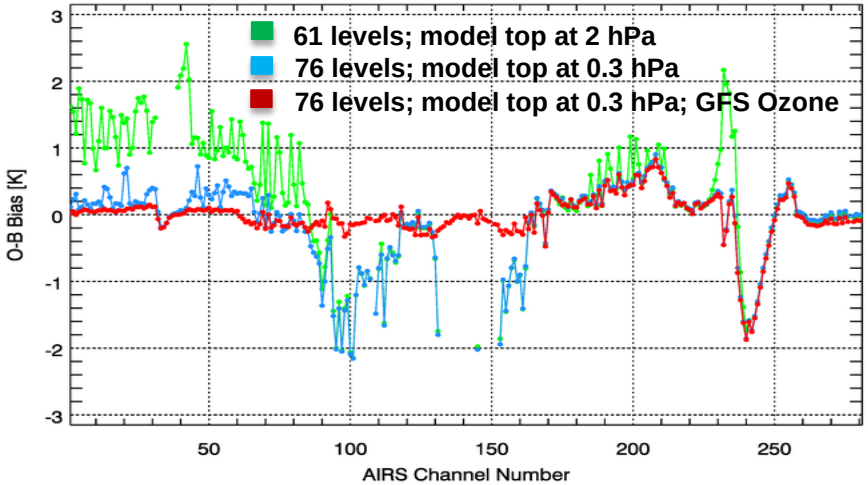
- **61 levels; model top at 2 hPa**
- **76 levels; model top at 0.3 hPa**
- **76 levels; model top at 0.3 hPa; GFS Ozone**

- Data passed QC is significantly increased for channels peaking in the stratospheric and above with increased vertical levels and blended vertical coordinate

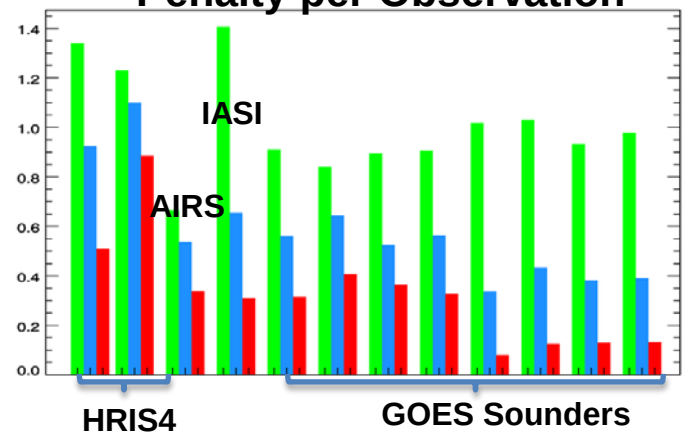


- Data passed QC is significantly increased for almost all AIRS channels across the spectrum

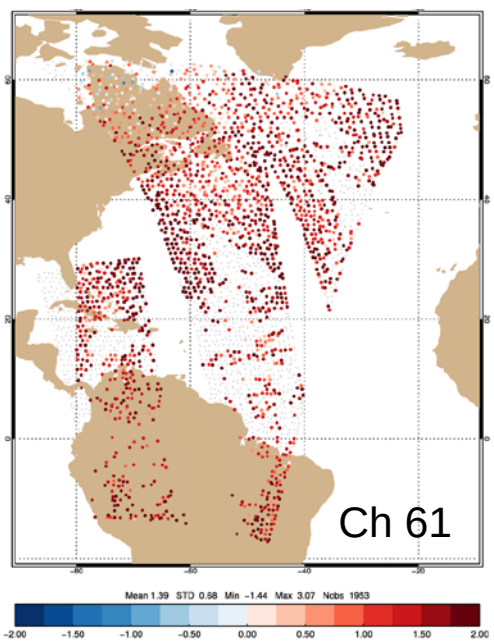
AIRS O-B Bias



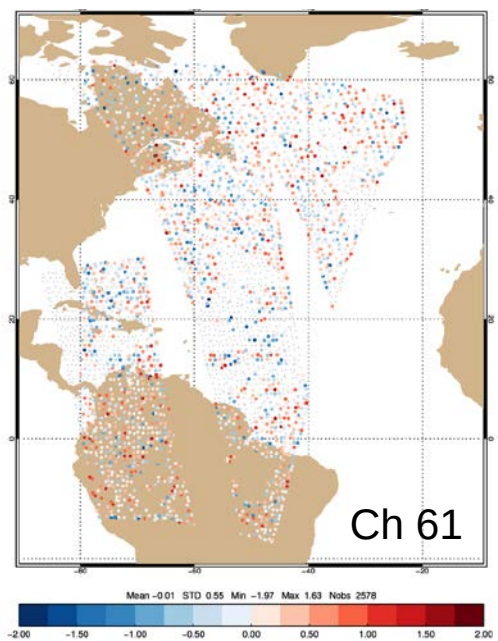
Penalty per Observation



61 levels; model top at 2 hPa



76 levels; model top at 0.3 hPa; GFS Ozone



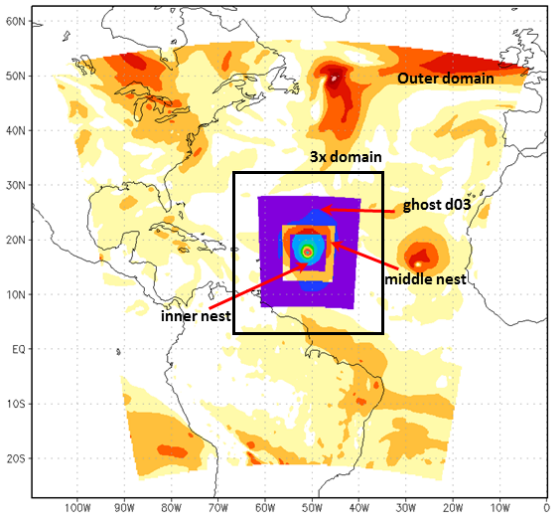
Benefits of blended vertical coordinate and GFS ozone in the analysis:

- AIRS biases are greatly reduced when blended vertical coordinate and GFS ozone are used in the analysis
- Cost function for IR instruments reduced more than 50%

HFIP Stream 2 Demo Experiments for 2013 Hurricane Season

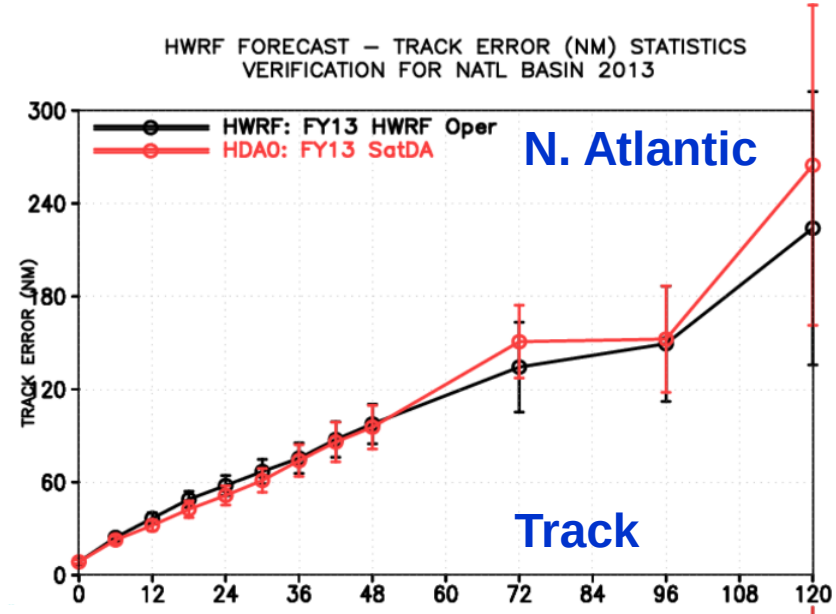
- **Objective** – **to test the impact of satellite data for HWRF initialization**

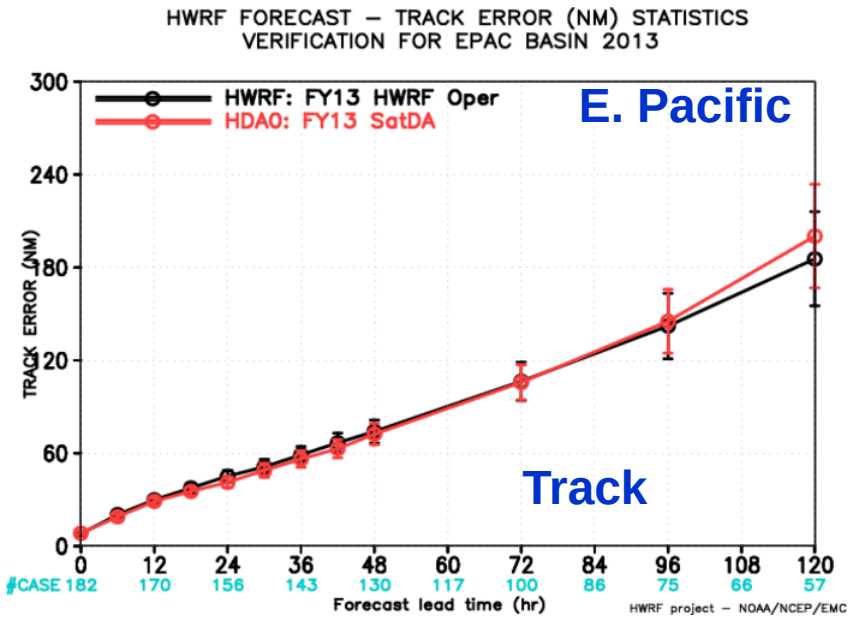
- **Configuration**
- **Forecast model** based on 2013 operational model, but with the following upgrade:
- **Raised model top from 50 hPa to 2 hPa**
- **Model levels increased from 43 to 61 levels**
- **GSI Analysis**
- GSI analysis on both outer and ghost d03 domains
- First Guess at Appropriate Time (FGAT)
- **GFS-HWRF blended vertical coordinate (76 levels)**
- Radiance bias correction estimations from global analysis
- **GFS ozone profiles**
- Satellite thinning box: 90 km for IR instruments and 45 km for MW instruments

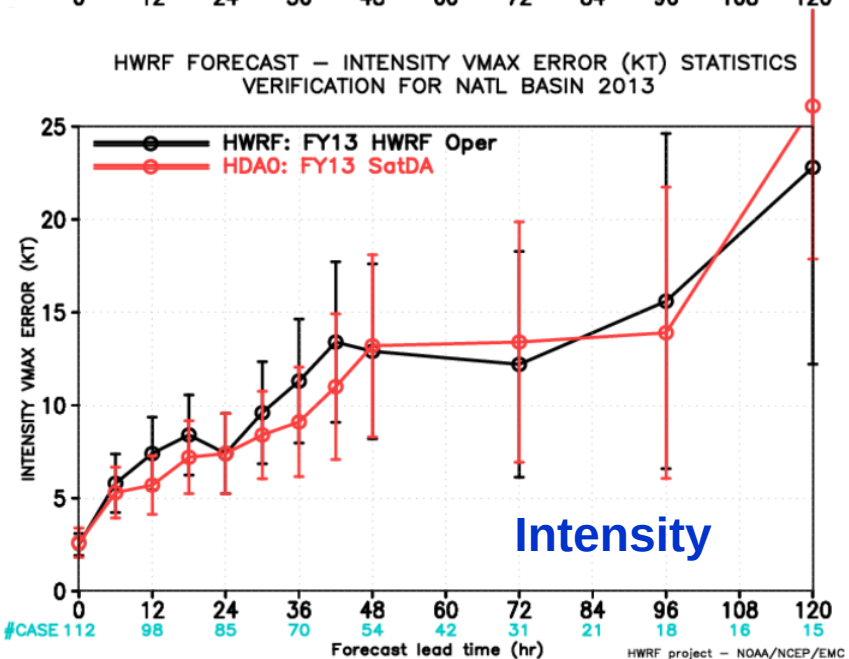


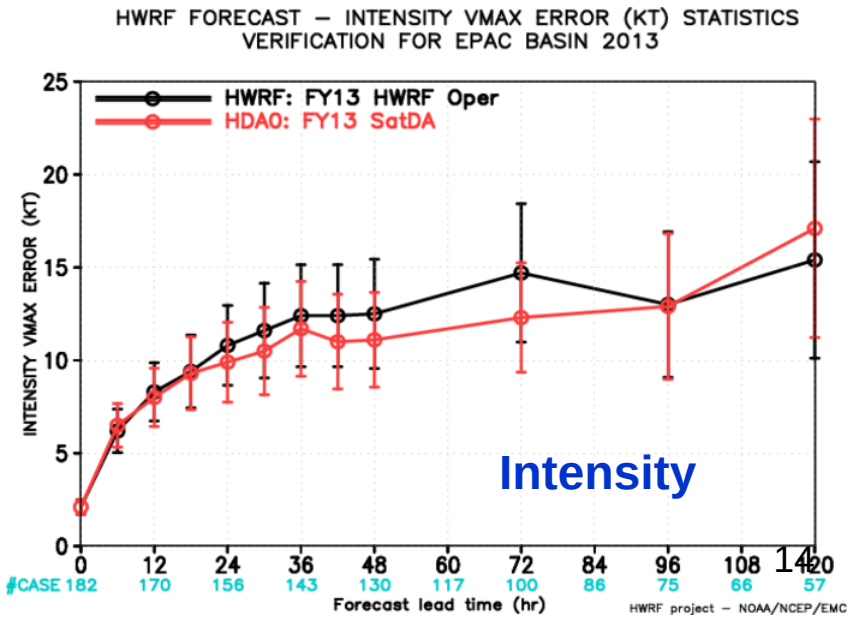
- Data assimilated: (in both outer and ghost domains)
  - Conventional data and TDR
  - **Blending angle from GPS Radio Occultation (GPSRO)**
  - **Radiances from IR instruments (HIRS, AIRS, IASI, GOES Sounders)**
  - **Radiances from MW instruments (AMSU-A, MHS, ATMS)**
  - **Satellite derived wind (IR/VIS cloud drift winds, water vapor winds)**

Verification of Real-Time Results for 2013

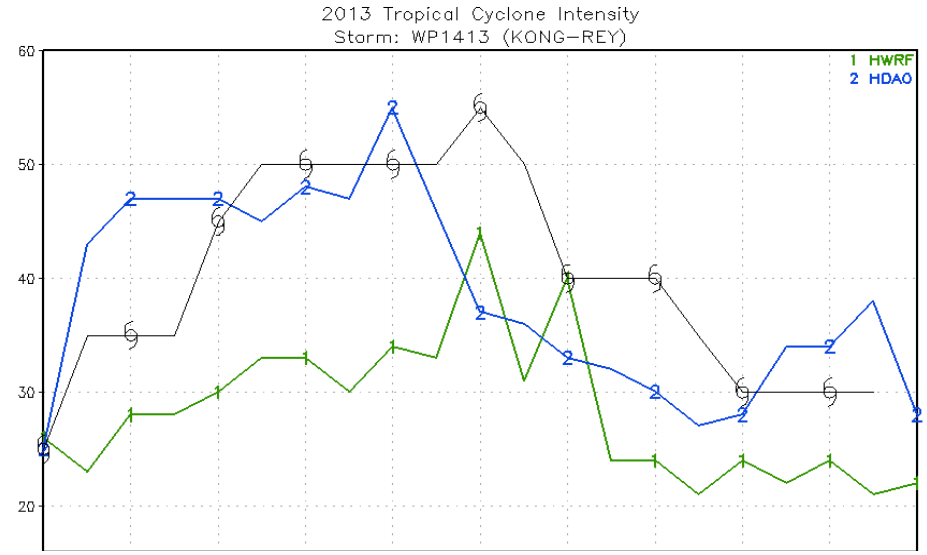


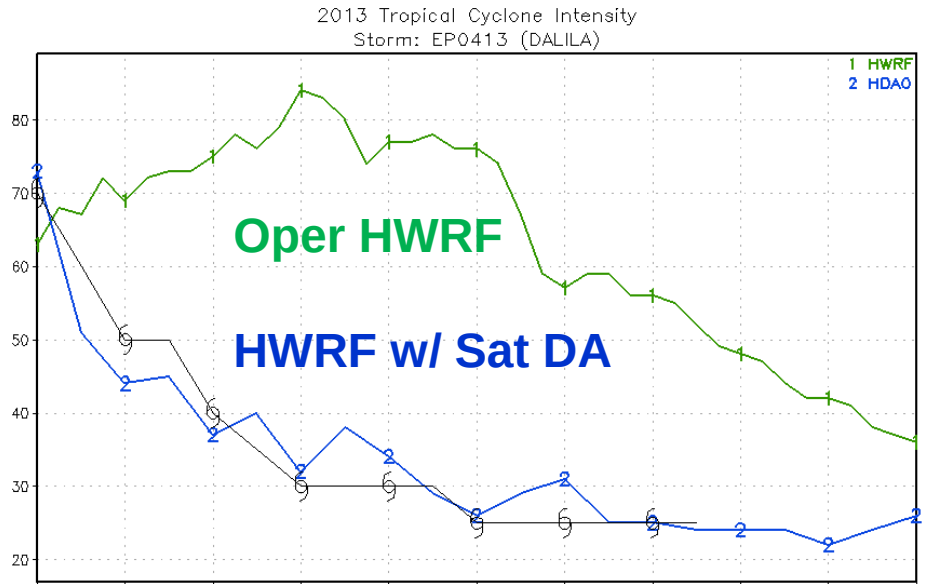


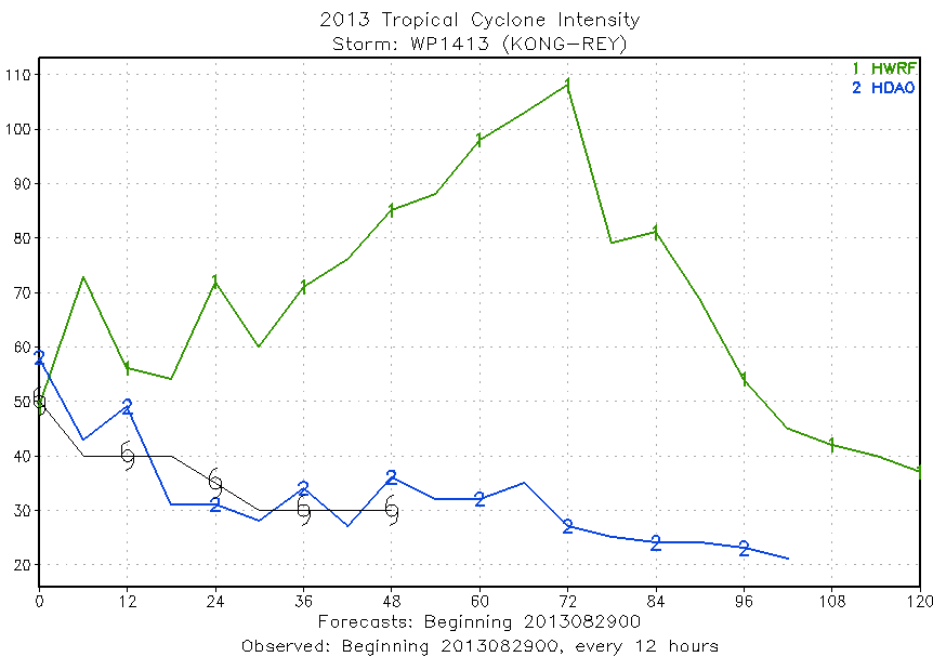


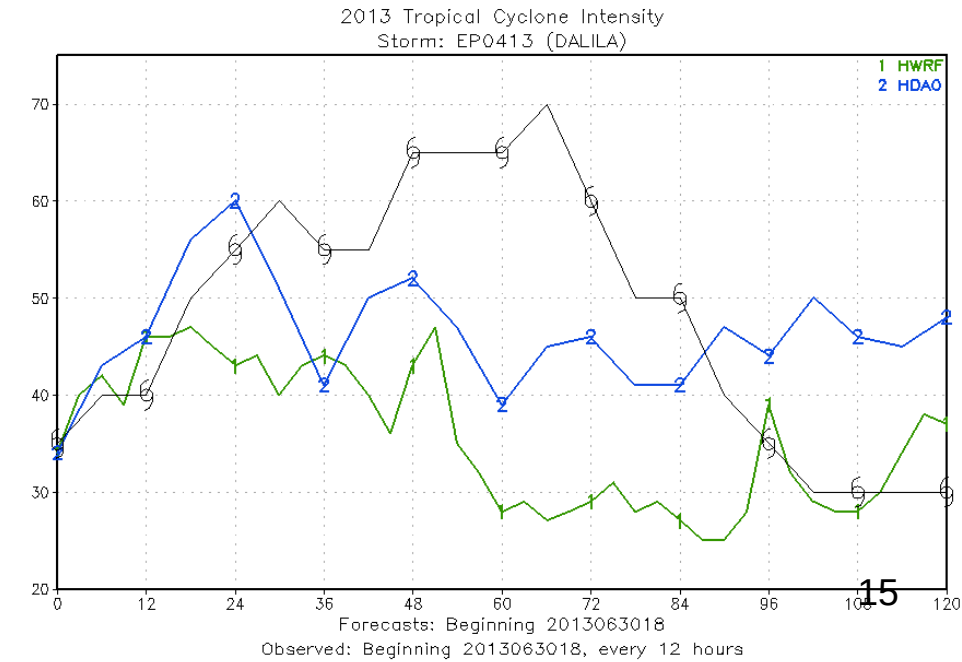


Positive impact on HWRF intensity forecasts

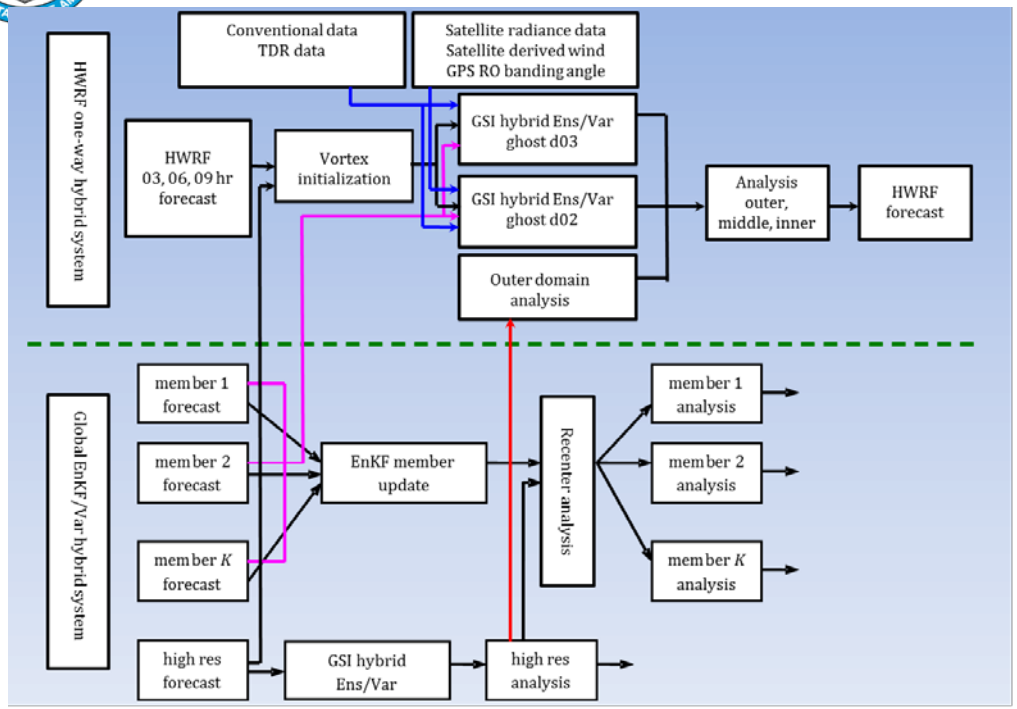


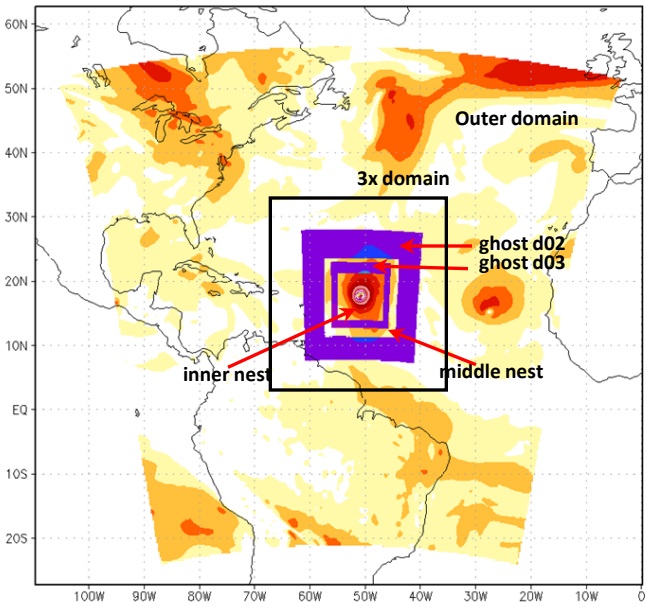






HDAS Upgrades for 2014 Implementation





- Data assimilation performed on ghost d02 (20°x20°, 9km) and ghost d03 (10°x10°, 3km) after vortex initialization. GFS analysis is used in outer domain. No DA for outer domain.
- GSI hybrid analysis using global EnKF 80 ensemble member.
- First guess:
  - TC environment cold start from GDAS forecast
  - TC vortex cycled from HWRF forecast
  - First Guess at Appropriate Time (FGAT)
- Observational data:
  - ghost d02: conventional data (including dropsonde data), TDR data and Satellite Data
  - ghost d03: conventional data (including dropsonde data) and TDR data (no satellite data for 3km analysis)

Satellite radiance assimilation for 9km (ghost_d02) domain:

- use GFS-HWRF blended vertical coordinate (75 levels)
- use bias correction estimations from global analysis
- use GFS ozone profiles

Satellite Data:

Radiances from IR instruments (HIRS,AIRS, IASI, GOES Sounders), Radiances from MW instruments (AMSU-A, MHS, ATMS), Satellite derived wind, GPS RO bending angle

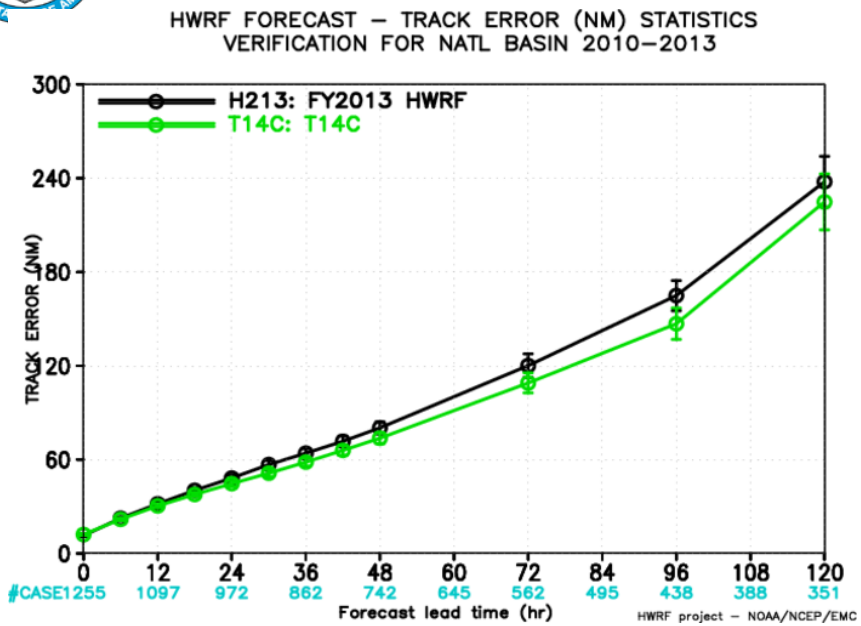
T14C configuration for 2014 HWRF pre-implementation tests

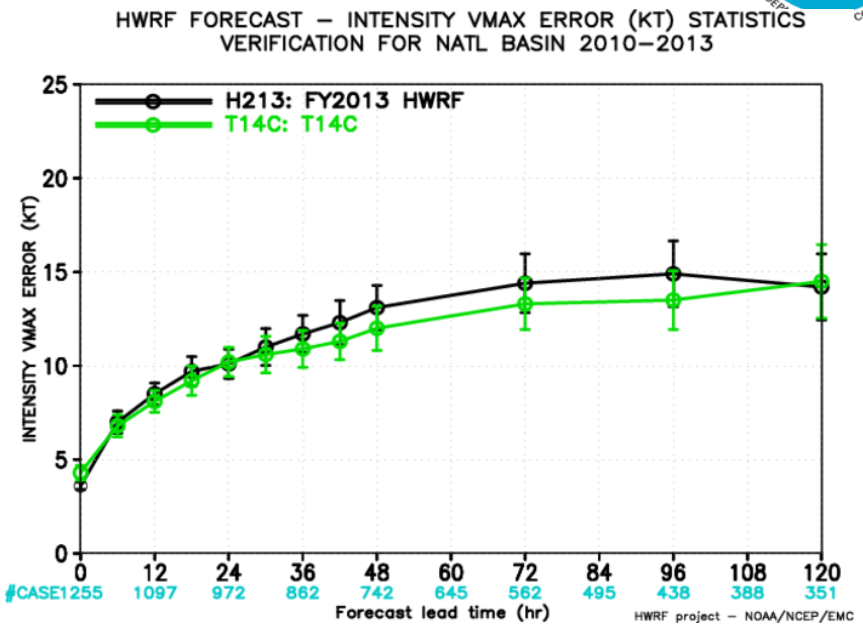
Motivations:

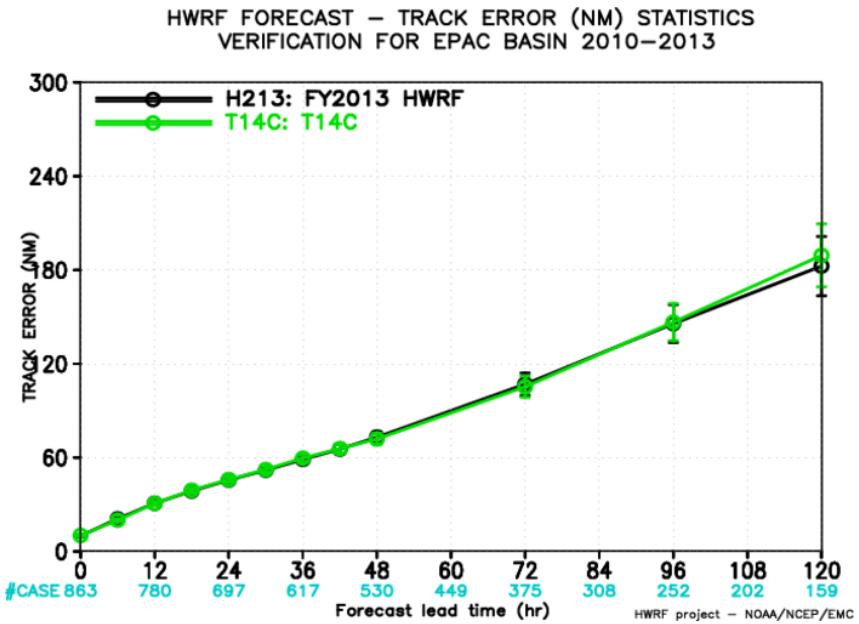
- Save resource and running time without sacrificing new capability for better use of satellite data – using GFS-HWRF blended coordinate
- Barely see benefit of regional analysis over global analysis for large scale TC environment
- More focus on vortex scale analysis

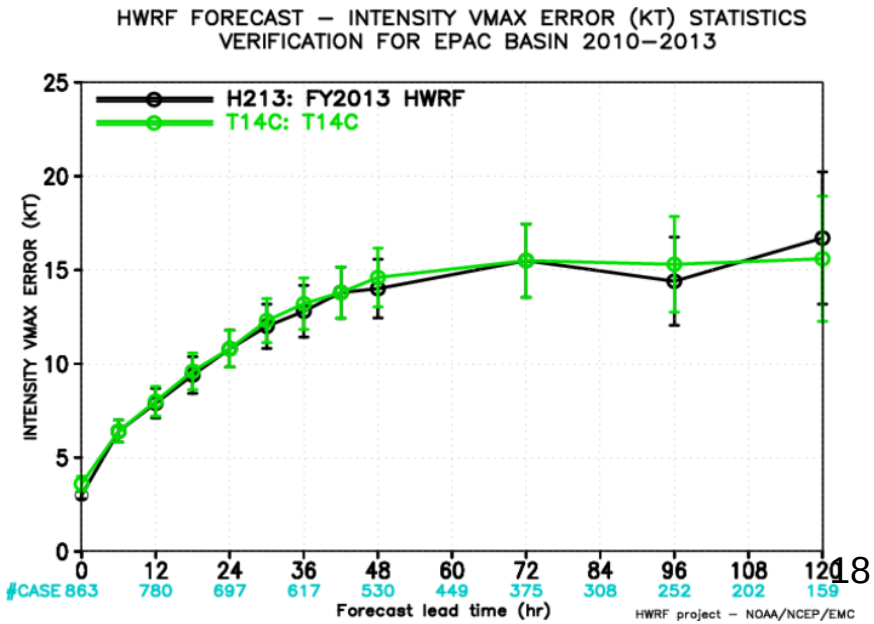
domains	D01 (27km)	ghost_d02 (9km)			ghost_d03 (3km)		
T14C	Using GFS analysis	20°x20°	4 nodes	11 min	10°x10°	8 nodes	12 min
		Conventional data, TDR Data, satellite radiance, satellite wind, GPS RO, on GFS-HWRF blended coordinate (75 vertical levels)			Conventional data and TDR data		

Preliminary Results from FY14 HWRF Configuration with DA upgrades 2010-2013 ATL/EP basins

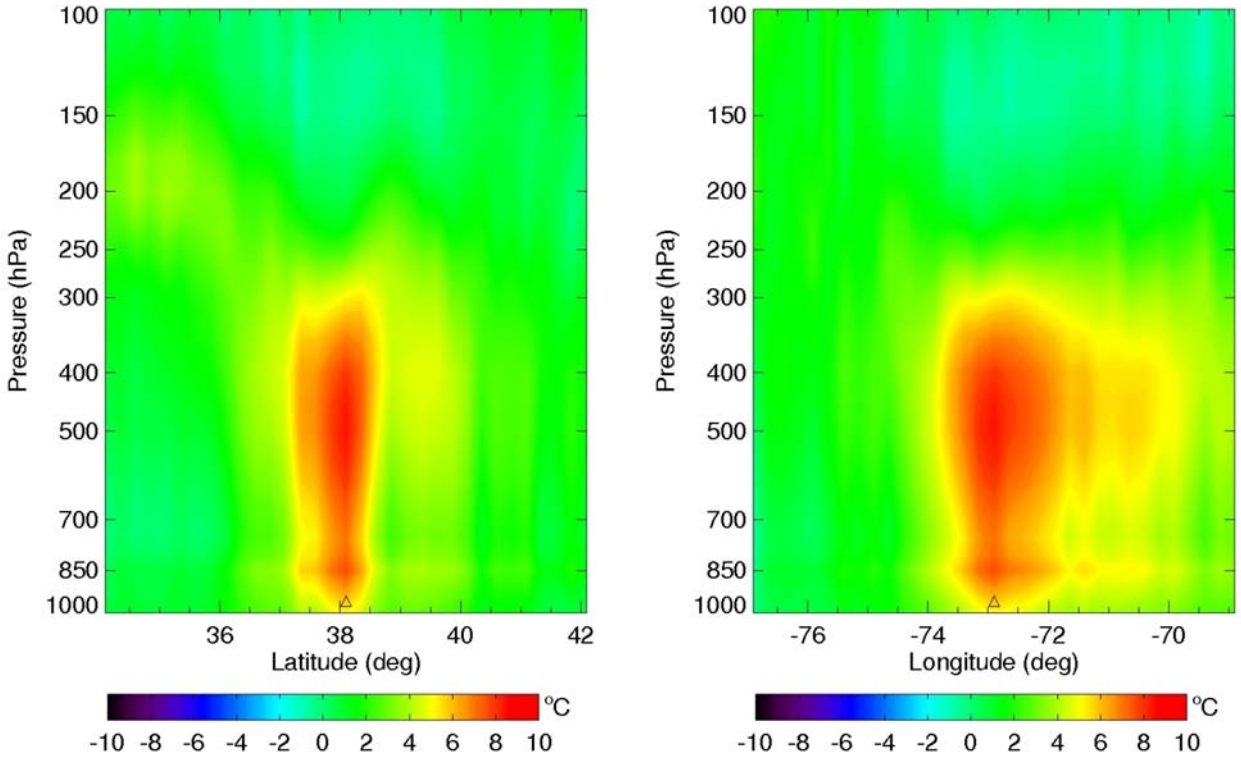








Applications of Satellite Data in Vortex Initialization for HWRF



Vertical cross section of Hurricane Sandy warm core structures retrieved from ATMS observations on 1730 UTC 29 October. (a) Cross section along Longitude 72.9 W, (b) Cross section along Latitude 38.1 N.

Impact of ATMS data on Hurricane Forecasts

Using HWRF Model

- A consistent FOV distribution between temperature and humidity channels on ATMS makes the cloud detection easy to implement

- A higher model top allows more upper-level microwave and infrared channels to be assimilated into HWRF, resulting improved atmospheric steering and track forecasts

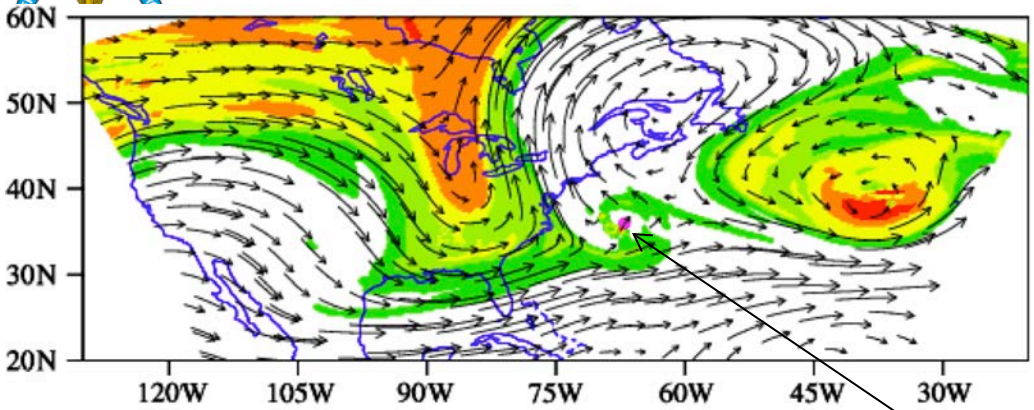
- ATMS data assimilation in GSI/HWRF results in a consistent positive impact on the track and intensity forecasts of the four landfall hurricanes in 2012

- Hurricane Sandy's forecasts are significantly improved after ATMS data assimilation when verified with independent GOES and POES observations

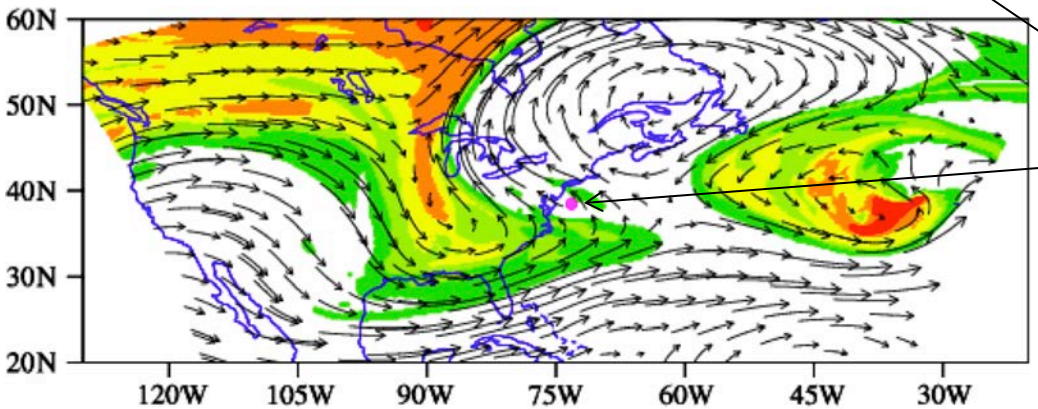
Zou et al., JGR 2014

PV and Wind at 200 hPa for Hurricane Sandy

HWRF 84-h forecast valid at 0000 UTC Oct. 30 (no ATMS)

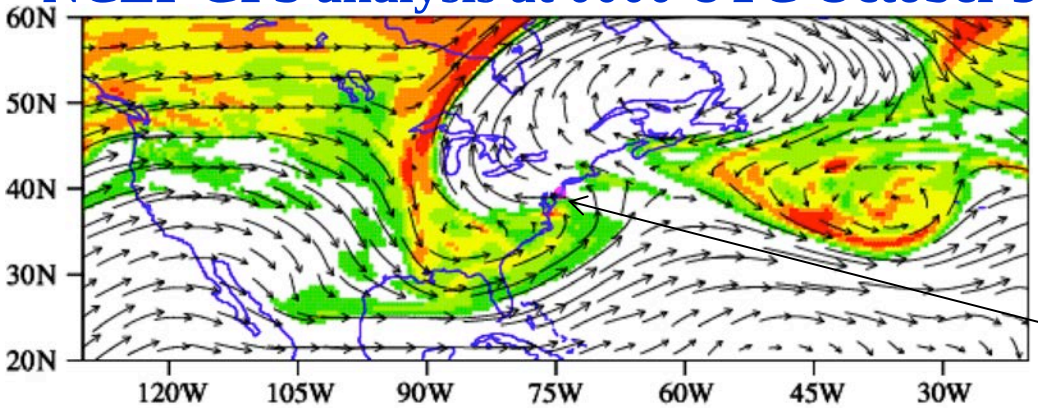


HWRF 84-h forecast valid at 0000 UTC Oct. 30 (ATMS)



Model-Predicted Sandy's location

NCEP GFS analysis at 0000 UTC October 30



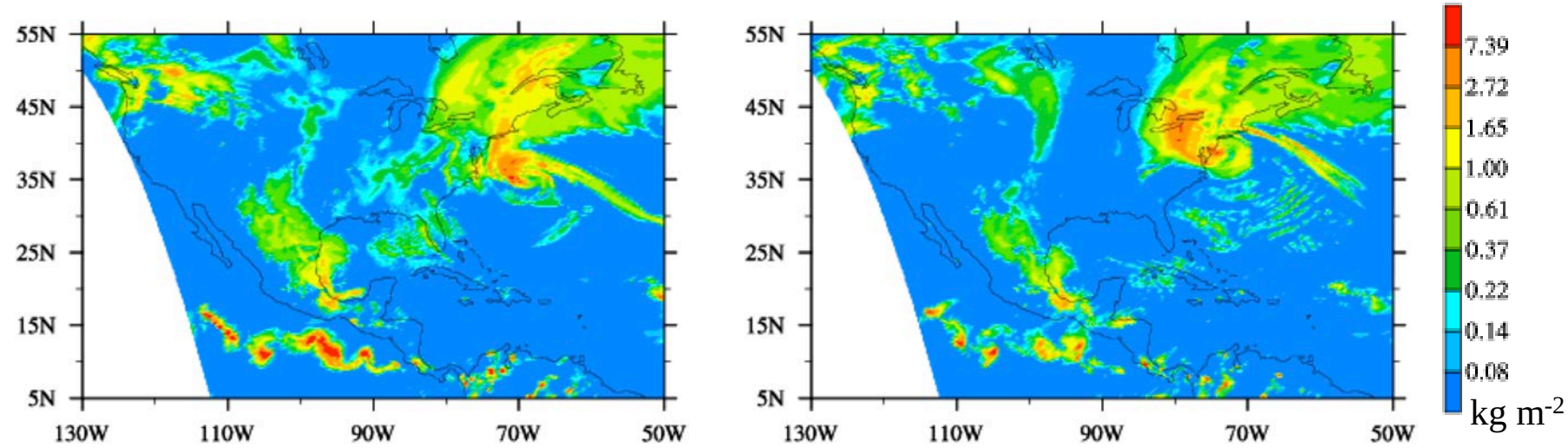
Sandy's observed location

ATMS data assimilation resulted an improved prediction of Sandy's track (purple dots) and a middle latitude ridge northeast of hurricane Sandy.

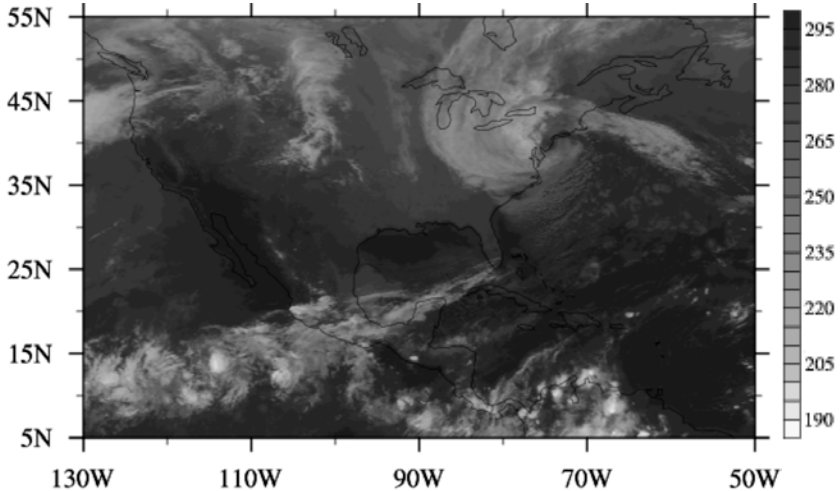
Zou et al., JGR 2014

84-h Forecasts of Cloud Liquid Water Valid at 0000 UTC 30 October 2012

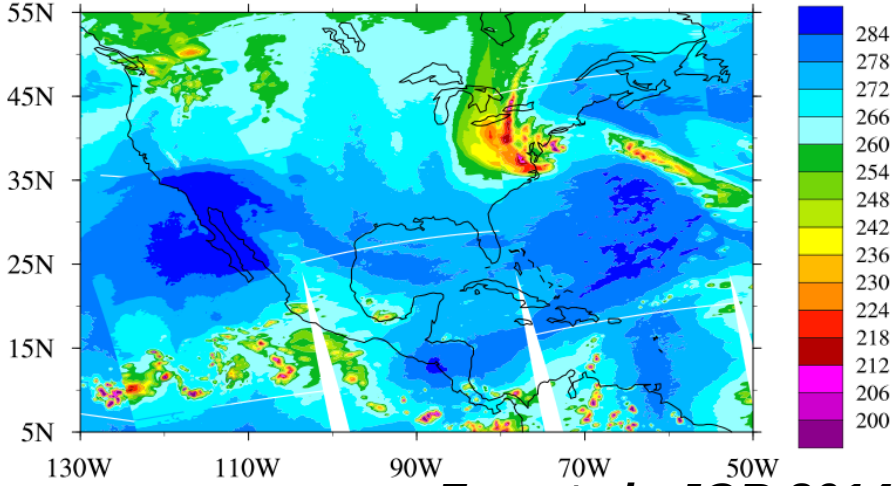
Without ATMS | **With ATMS**



GOES-13 $T_{b,4}$ for Verification

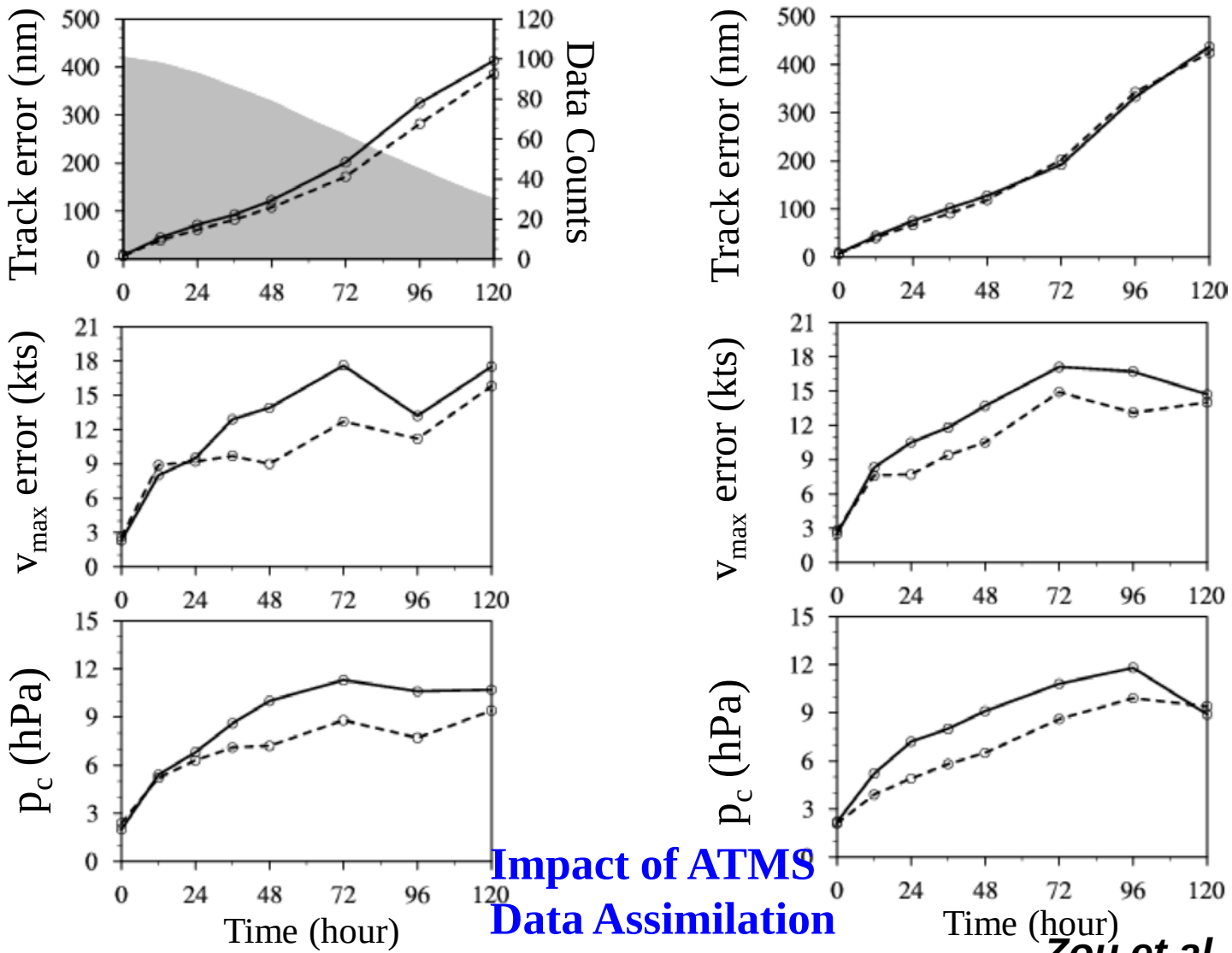


ATMS $T_{b,18}$ at 1727 UTC 10/29/12



Zou et al., JGR 2014

Mean Forecast Errors for Four 2012 Atlantic Land- falling Hurricanes



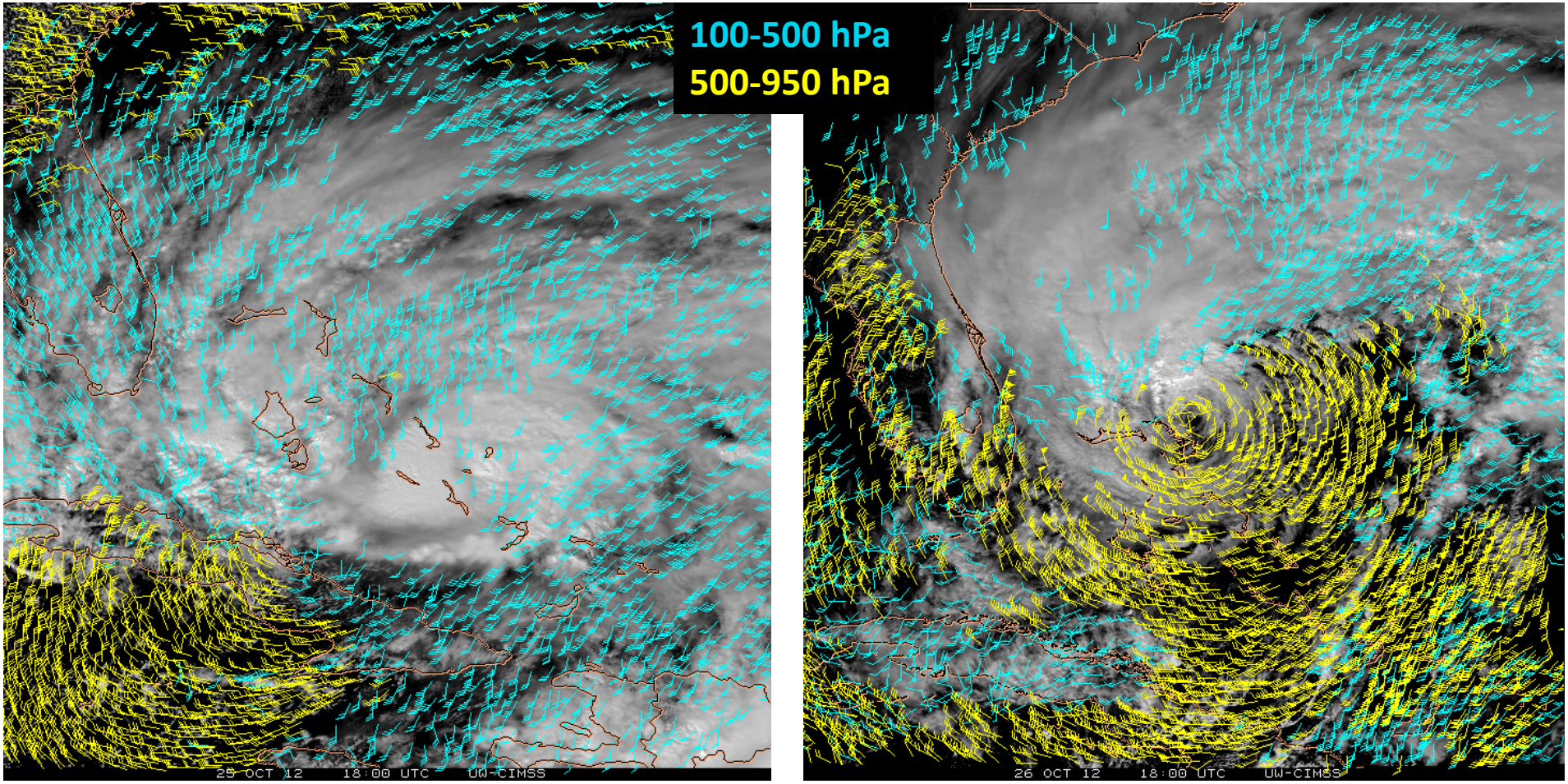
Impact of ATMS Data Assimilation

Zou et al., JGR 2014

Atmospheric Motion Vectors from GOES-R

Proxy: AMVs from special GOES-14 super-rapid-scan ops during *Hurricane Sandy*

1800 UTC 25 Oct, 2012 | 1800 UTC 26 Oct, 2012

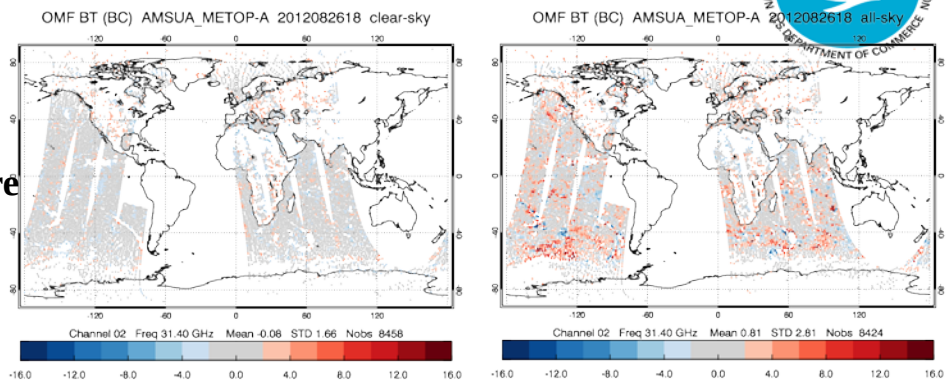


ABOVE: VIS/IR AMVs from 5-min image intervals derived using the current CIMSS/NESDIS AMV algorithm

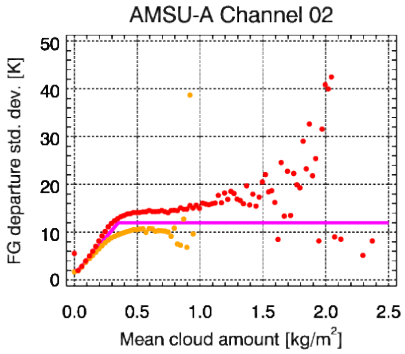
- **Tests using the new GOES-R tracking algorithm are underway (with NESDIS/STAR)**
- **DA and HWRF model forecast impact experiments are planned w/support from HFIP/GOES-R PG**
- **Low hanging fruit???**

C. Velden (CIMSS)

Future: All-sky assimilation of AMSU-A observations



- **Objectives**
  - **Extend data coverage in cloudy and rainy regions.**
  - **Observations sensitive to precipitation and cloud are assimilated directly, with the modeled cloud and precipitation match closely**
- **Issues and Challenges**
  - **Forecast model**
    - Rain and cloud modeling is less, resulting in large innovation statistics
  - **Observation operator**
    - Require accurate representation of the radiative effects such as absorption and scattering from hydrometeors
    - Larger representativeness error of background profiles at observation location
    - More non-linear in all-sky than in clear sky condition
  - **Analysis**
    - Need proper inflation in observation error to account for the uncertainties in background fields, observation operator, and representativeness.
    - Need proper ensemble spread to better characterize background error covariance in cloudy/rainy regions
- **Current efforts**
  - Assimilation of cloud-affect, non-precipitating AMSU-A observations are being considered first.
  - Observation error under all-sky condition is modeled as a function of averaged cloud liquid water path estimated from background and observation.
  - Preliminary results showed neutral to slight positive forecast skill in both Hemispheres; **<u>however, the wind and temperature forecast are worsen in the tropics.</u>**
  - The accuracy of observation operator for all-sky condition is currently under investigation.
  - Tuning ensemble spread through stochastic physics (e.g. boundary layer, convection) in the ensembles to give more realistic representation of background error in cloudy and rainy region is under way



Summary and the future plans

- Summary
  - The results of the stream 2.0 experiment indicate that the first time direct assimilation of satellite radiances produced overall neutral or positive impacts on the tropical cyclone forecasts.
  - Comparing with the 2013 operational HWRF, both track and intensity forecast errors of the 2014 baseline are improved in Atlantic basin.
  - The retrieved temperatures from ATMS have been used to monitor the hurricane warm core. Correcting the vortex structure in the hurricane inner core region for HWRF vortex initialization will be next step in the near future.
- The future plans in the 2-5 years
  - The data assimilation method needs to be enhanced, for example, improving background error covariance and exploring different techniques to improve balance in the analysis.
  - The cloudy radiance analysis has to be developed to account for the cloud effects near hurricane eye wall.
  - The satellite bias estimation and correction scheme also need to be interactively incorporated within HWRF model.
  - Further experiments to study the impact of each instrument type are necessary to enhance the use of satellite data for storm initialization in HWRF.
  - To attack the HWRF spin-down problem, IAU scheme could be used to incrementally add the forcing derived from intermediate data assimilation.

Real-time and pre-implementation T&E HWRF products:

http://www.emc.ncep.noaa.gov/gc_wmb/vxt/index.html

Thanks for your attention

Questions?

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