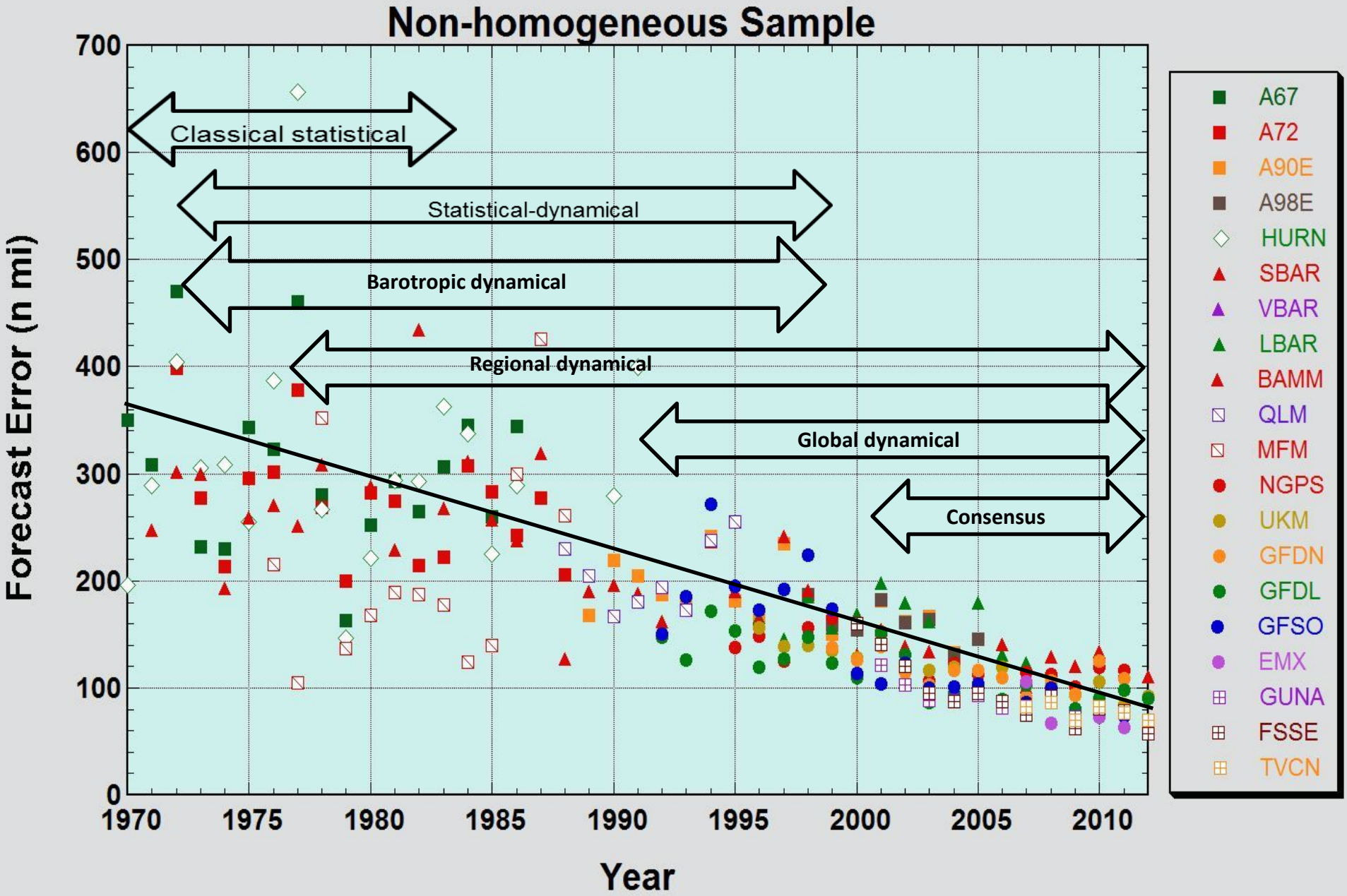
Tropical Cyclone Satellite Data Assimilation Discussion

Joint JPSS-GOES-R Seminar

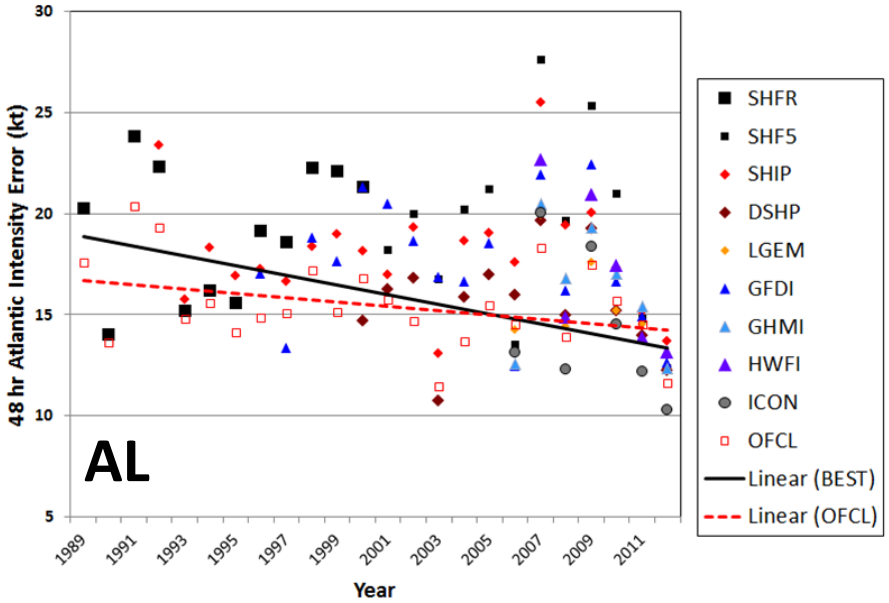
November 18, 2013

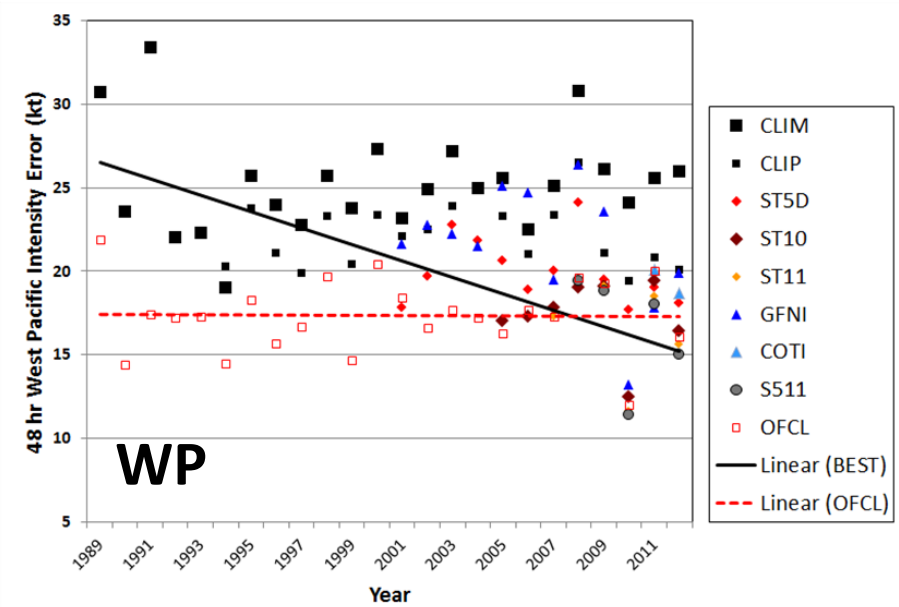
Outline

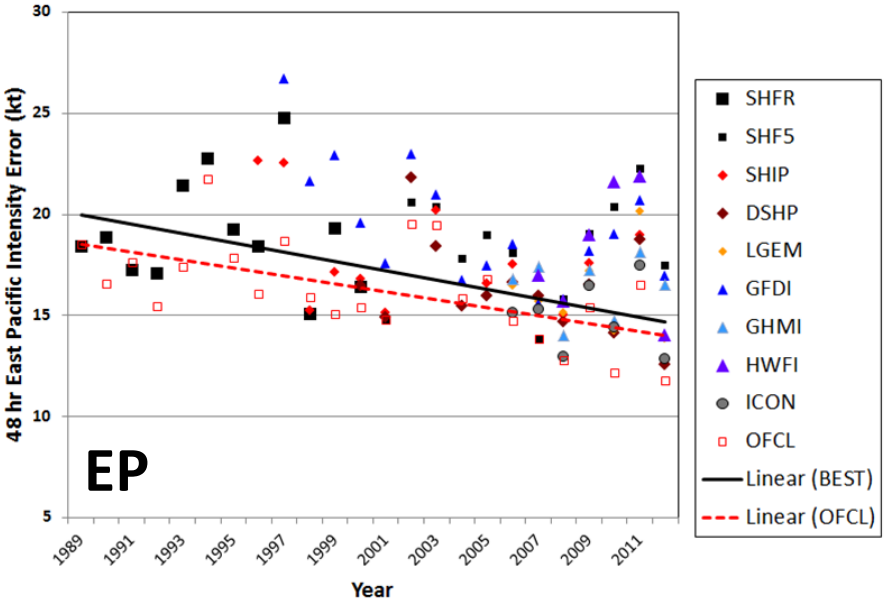
- Introduction and CIRA projects (5 min)
  - Mark DeMaria, NESDIS/STAR, Milija Zupanski, CIRA/CSU
- Satellite data assimilation in HWRF (20 min)
  - Fuzhong Weng, NESDIS/STAR
- Assimilating High Resolution AMVs (10 min)
  - Chris Velden, UW/CIMSS
- Near-real time forecast system for satellite data assimilation (10 min)
  - Jun Li, UW/CIMSS
- Near-real time forecast system and OSSEs for satellite and aircraft data assimilation (15 min)
  - Tomislava Vukicevic, NOAA/OAR/HRD
- Wrap-up (5 min)
  - Mark DeMaria

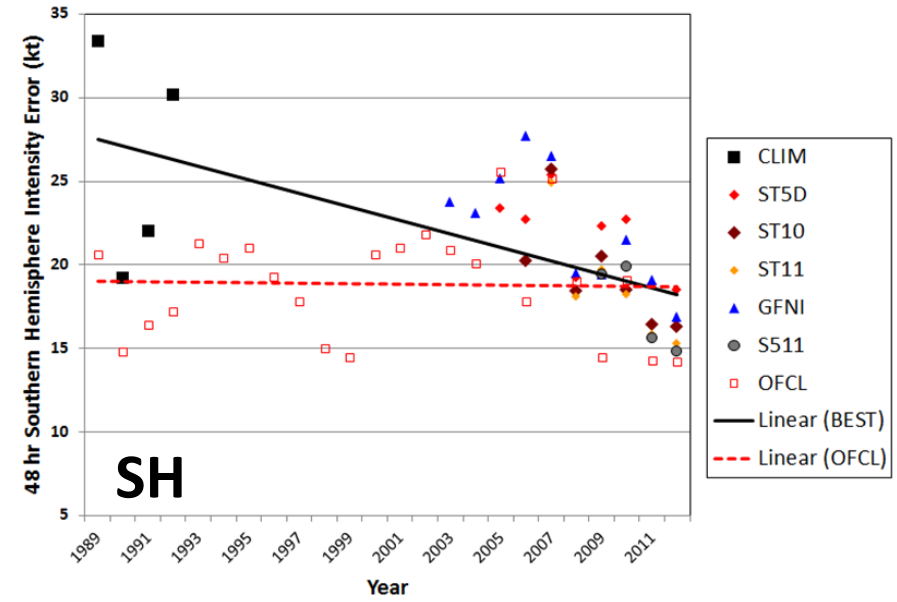

48-h Track Errors - Model Guidance
Atlantic Basin Tropical Storms and Hurricanes
Non-homogeneous Sample
Forecast Error (n mi)
Year
Classical statistical
Statistical-dynamical
Barotropic dynamical
Regional dynamical
Global dynamical
Consensus
A67
A72
A90E
A98E
HURN
SBAR
VBAR
LBAR
BAMM
QLM
MFM
NGPS
UKM
GFDN
GFDL
GFSO
EMX
GUNA
FSSE
TVCN

48 hr Intensity Guidance Errors 1989-2012









Methods for Improving TC Forecasts with Satellite Data

- Improve TC analysis
  - Estimation of initial position, intensity, structure
- Improve statistical-dynamical and statistical post-processing techniques
- Assimilate data into numerical models

CIRA JPSS and GOES-R Projects

- Automated center fixing with ATMS and VIIRS
- Initial intensity and storm size estimation from ATMS warm core analysis
  - Joint JPSS/PGRR project with CIMSS
- Improve statistical-dynamical intensity models using ATMS and proxy GLM, ABI data
- Advanced assimilation methods (M. Zupanski)

CIRA data assimilation for GOES-R:
Tropical Cyclone Core applications

- **Hybrid ensemble-variational data assimilation system (MLEF)**
  - uncertainty information from ensembles
  - iterative minimization of cost function

- **Model:** NOAA HWRF (operational in 2011, 27km/9km)

- **Observation capability:**
  - All-sky infrared satellite radiances (MSG SEVIRI as a proxy for GOES-R ABI)
  - Lightning flash rate (WWLLN as a proxy for GOES-R GLM)
  - NOAA operational observations (conventional and clear-sky radiances)

- **Observation operators:**
  - forward component of GSI
  - forward component of CRTM
  - lightning

- **New development:**
  - simultaneous assimilation of GOES-R ABI and GLM measurements
  - inclusion of static error covariance

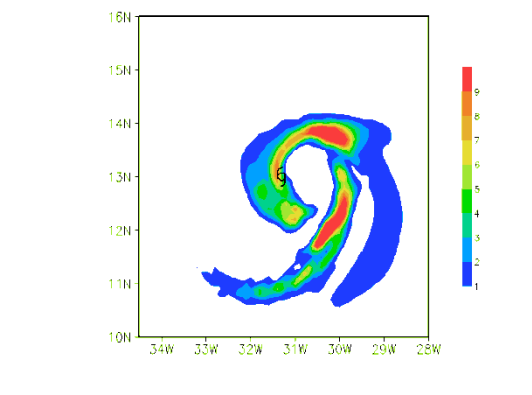
Assimilation of all-sky MSG SEVIRI radiances: Hurricane Fred (2009)

- **Results for TC core area (inner nest) at 9 km resolution**
- **Observations:** SEVIRI all-sky radiances (10.8 ⌠m)
- **Data assimilation interval:** 1 hour
- **Number of ensembles:** 32

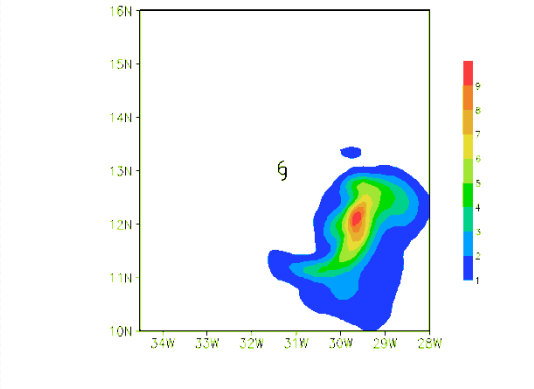
Total cloud condensate (cwm)

Valid 0600 UTC 9 Sep 2009

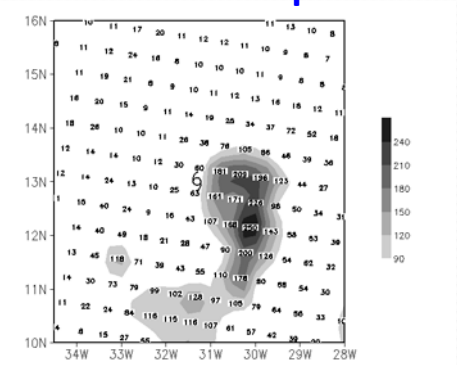
Clear-sky radiance assimilation



All-sky radiance assimilation



Verification: AMSU-A NOAA-16 retrieved cloud liquid water



[from M. Zhang et al. (2013)]

Assimilation of all-sky infrared radiances is able to improve clouds in TC core

Improve Hurricane Forecasts through Satellite Data Assimilation in HWRF:

JPSS Proving Ground and GOES-R3 Jointly Funded Project

Fuzhong Weng
Satellite Meteorology and Climatology Division
NOAA Center for Satellite Applications and Research

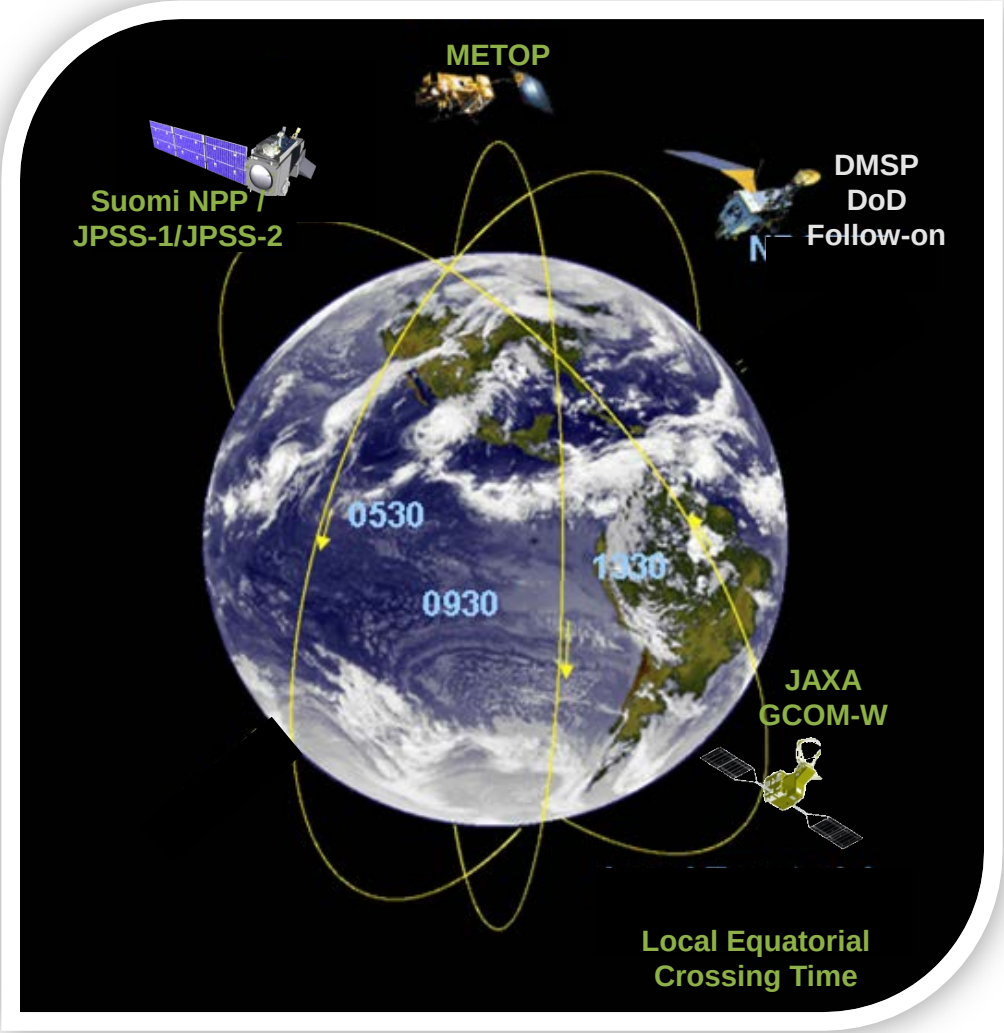
Our Focus on Uses of Satellite Data in HWRF

- New satellite data streams
- HWRF model top issues
- Quality control and bias correction
- Data assimilation experiments
- Summary and conclusion

New Satellite Data Stream

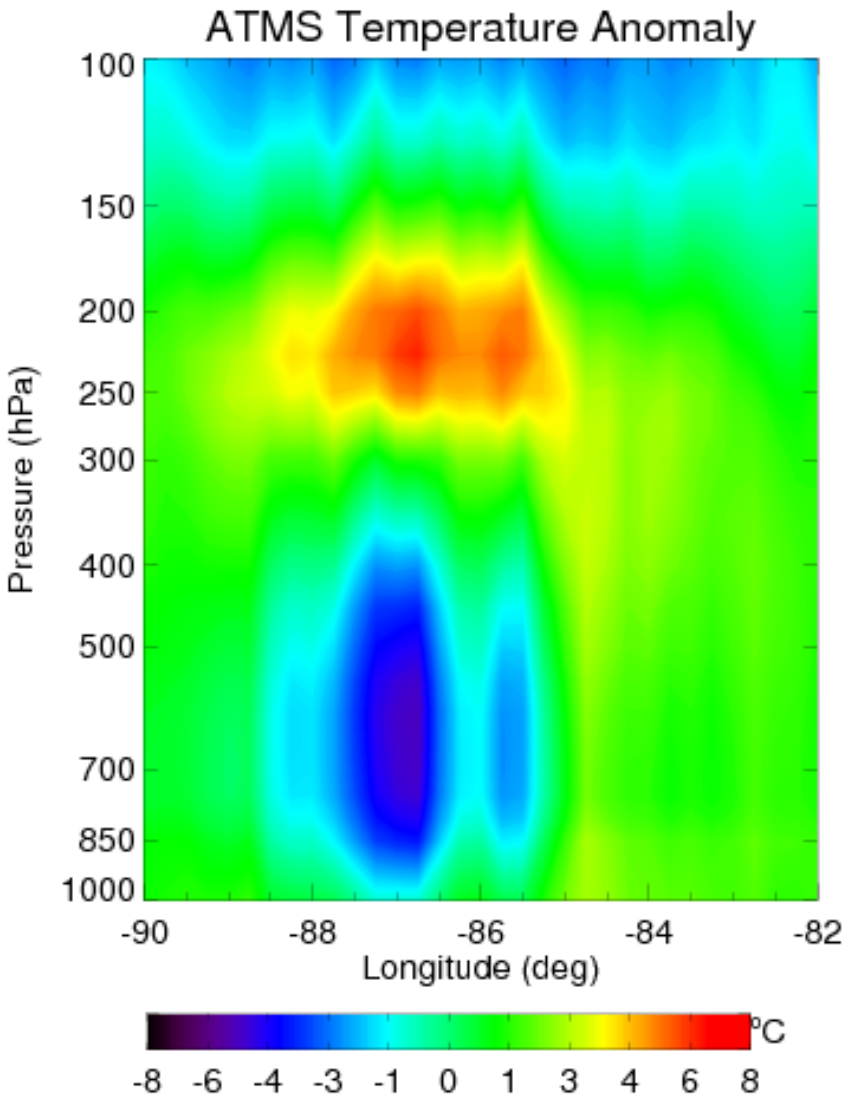
METOP, JPSS/JAXA and DMSP Integral to 3-Orbit Global Polar Coverage

JPSS implements US civil commitment, interagency and international agreements to afford 3-orbit global coverage.

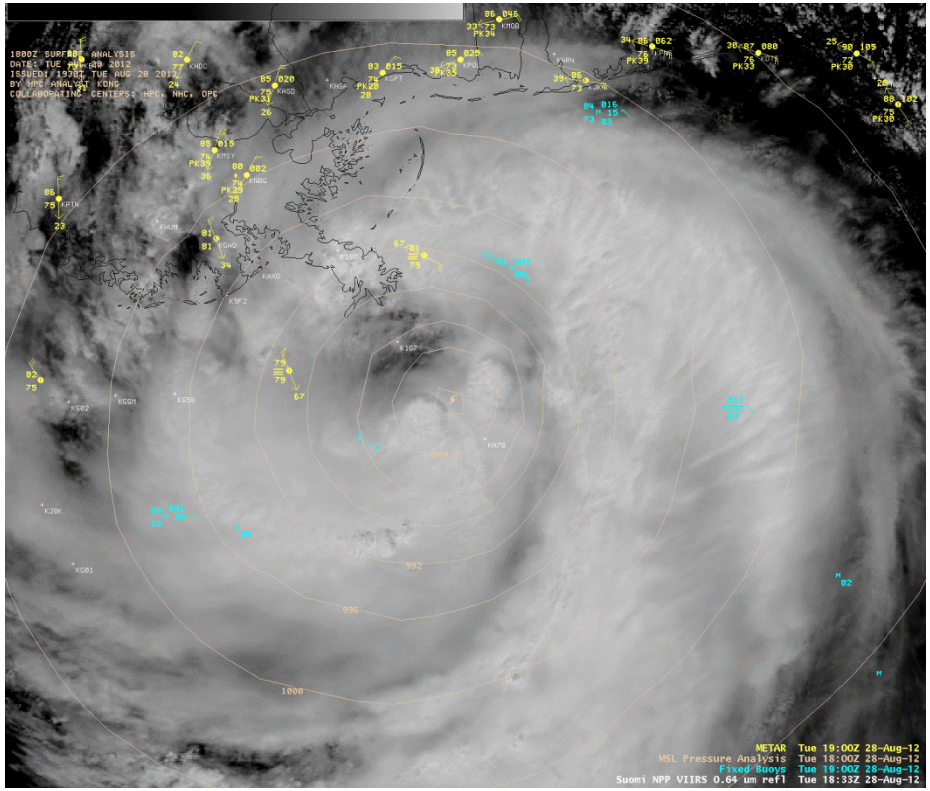


NPP ATMS and VIIRS Imager and Products

Warm Core Cross section along 26.0 N



VIIRS 0.64 µm visible and 11.45 µm IR images at 18:33 UTC, 28 Aug 2012

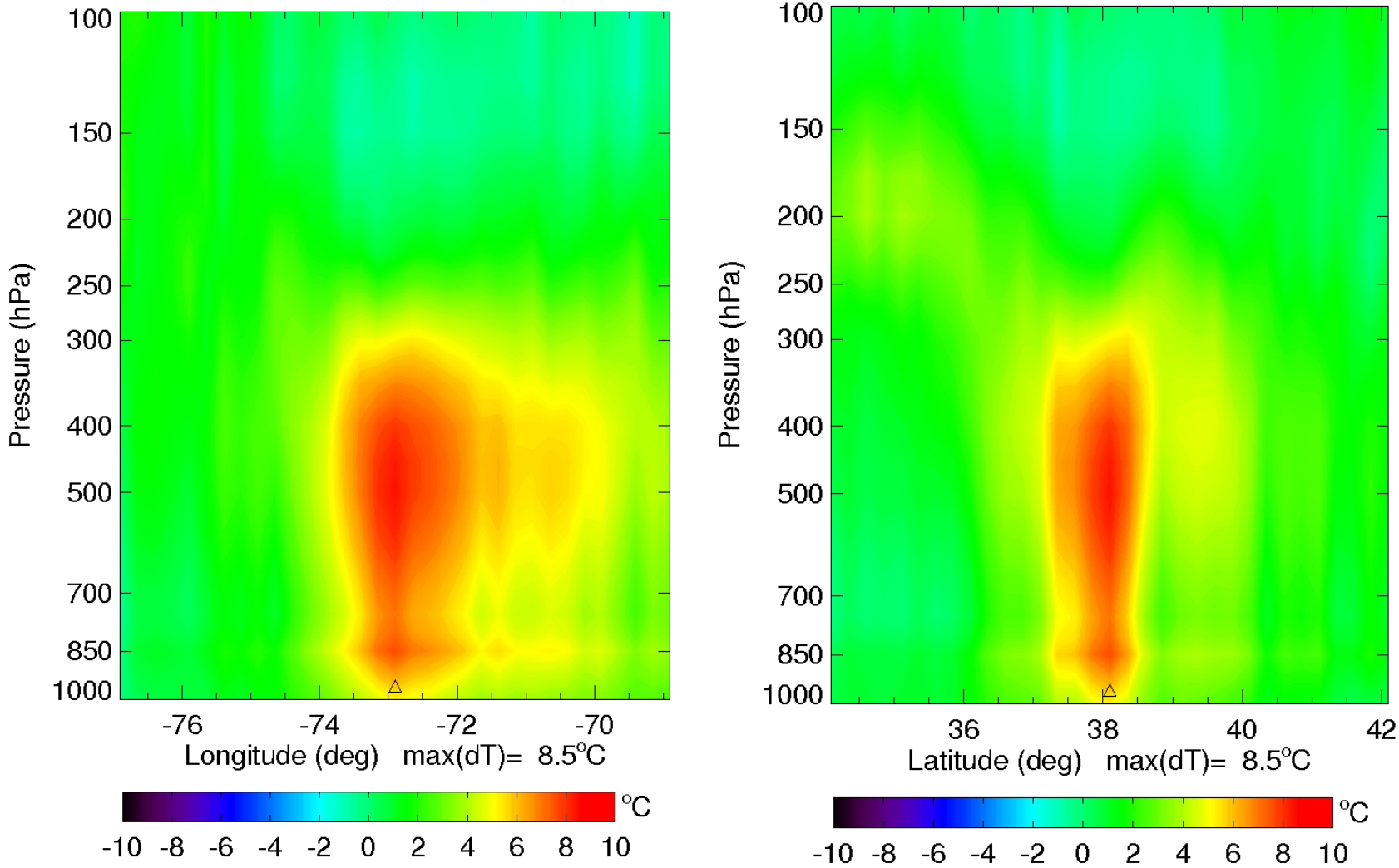


METAR, MSL Pressure, and Buoys information included

Zhu and Weng, 2013, GRL

Hurricane Sandy Warm Core Anomaly Ascending 1730 UTC, 29 October 2012

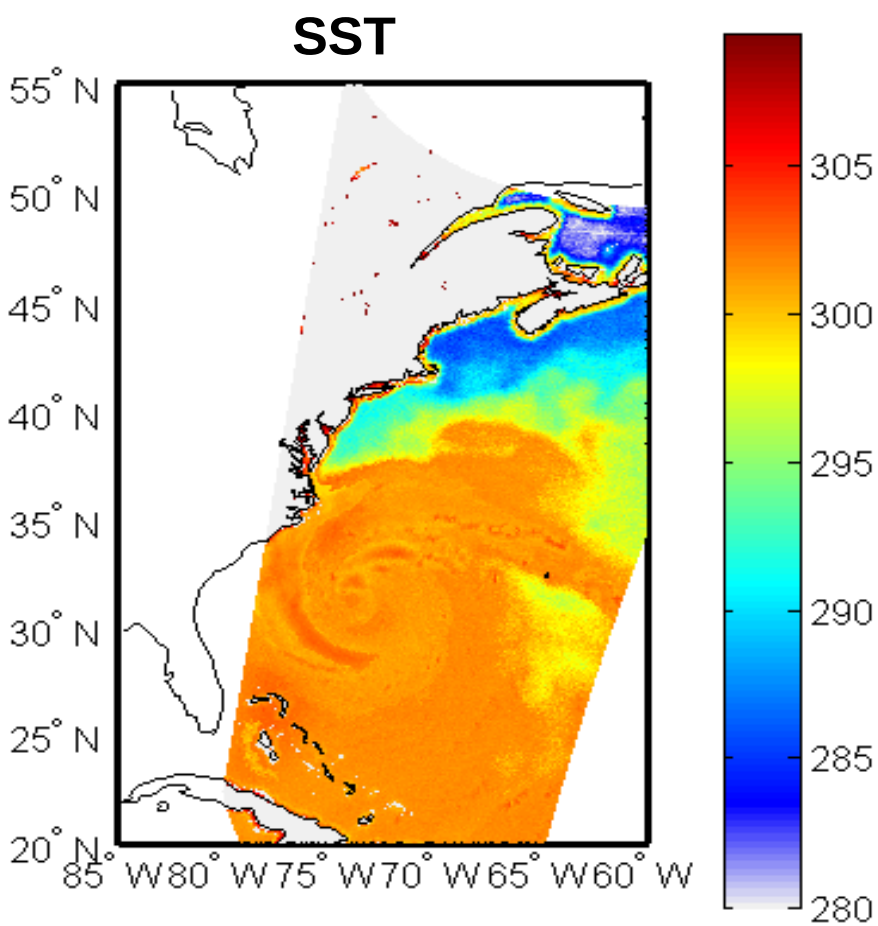
At 1800 UTC Oct 29 Max Wind: 90 MPH, Min Pressure: 940 hPa

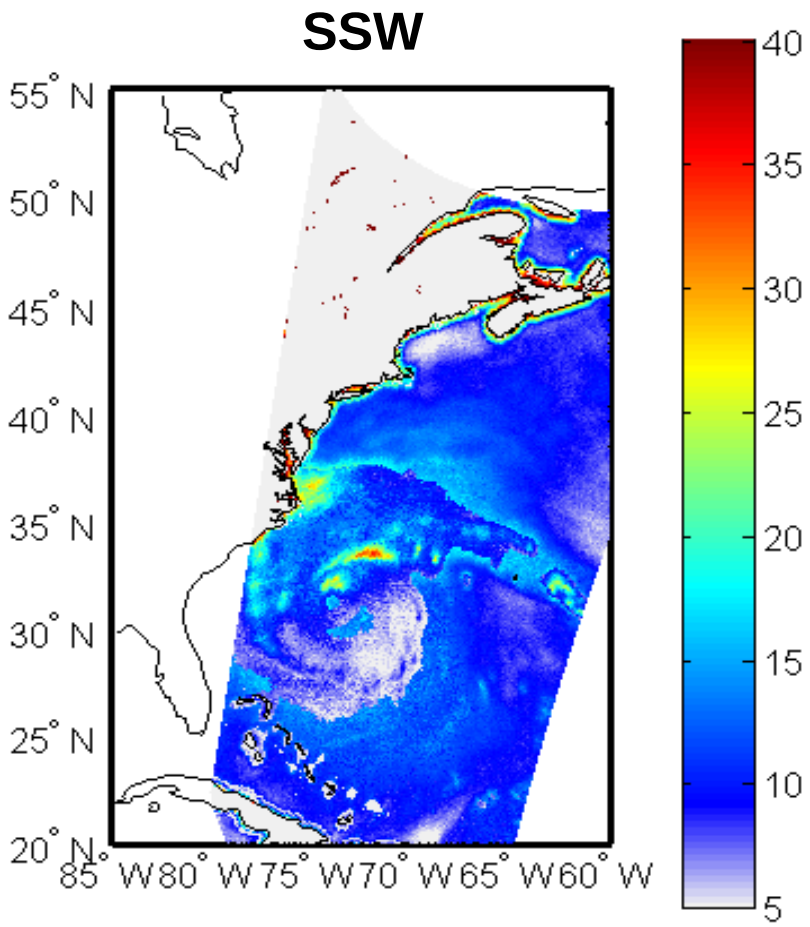


Cross section along Latitude 38.1 N **Cross section along Longitude 72.9 W**

Zhu and Weng, 2013, GRL

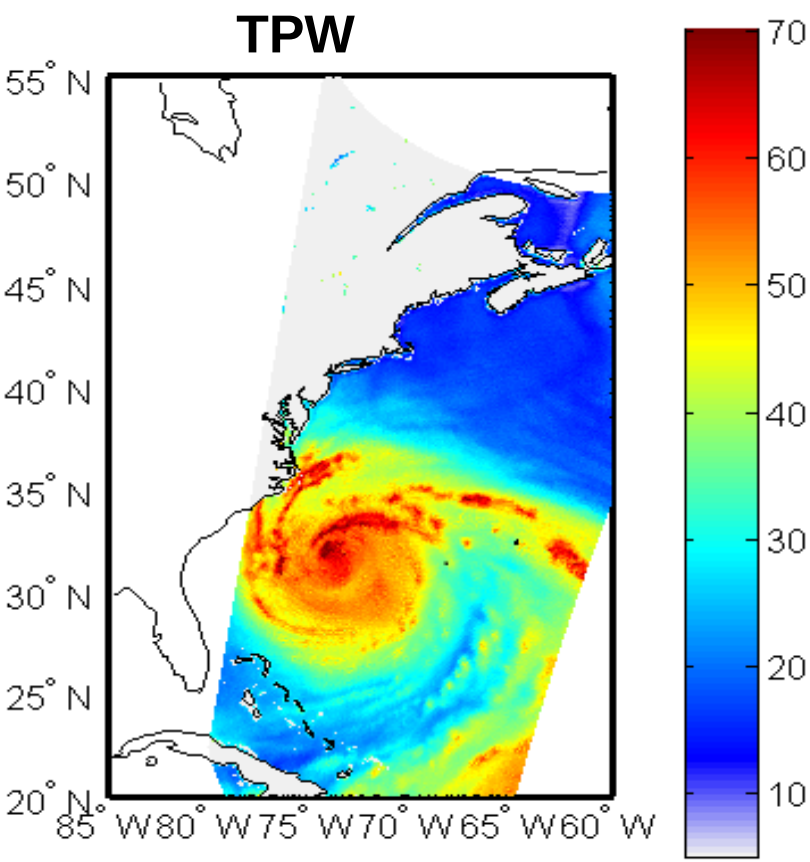
Information Content from GCOM-W1 AMSR2
Hurricane Sandy-10-28-2012 06 UTC

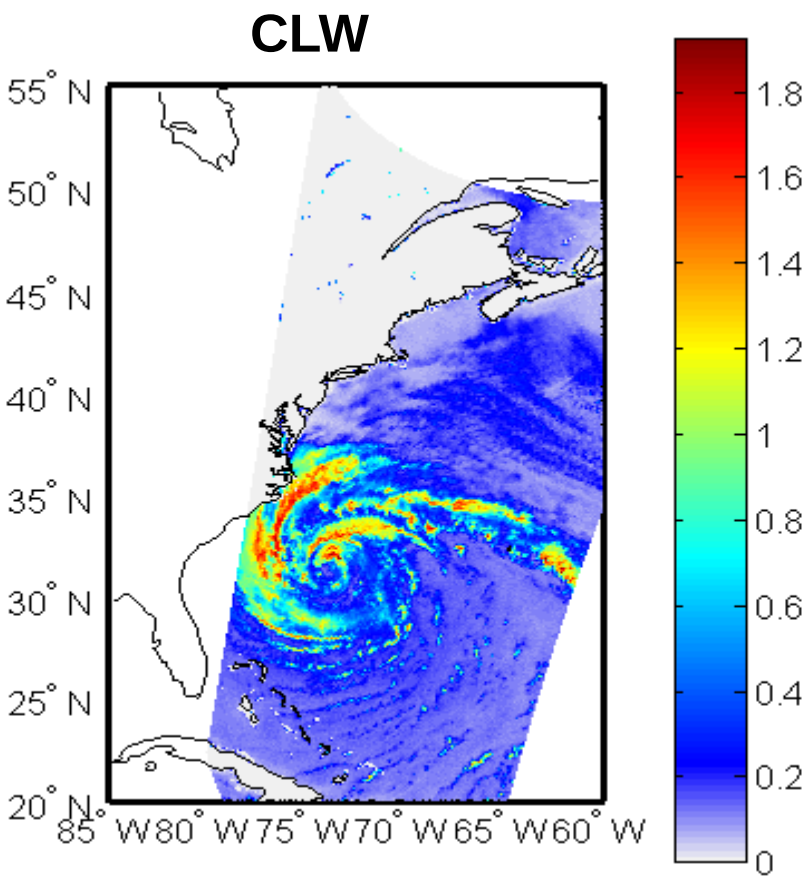




JAXA launched GCOM-W1 on Oct 18, 2011 with AMSR2 on board and NESDIS is developing NOAA unique AMSR2 products for user community.

Information Content from GCOM-W1 AMSR2
Hurricane Sandy-10-28-2012 06 UTC

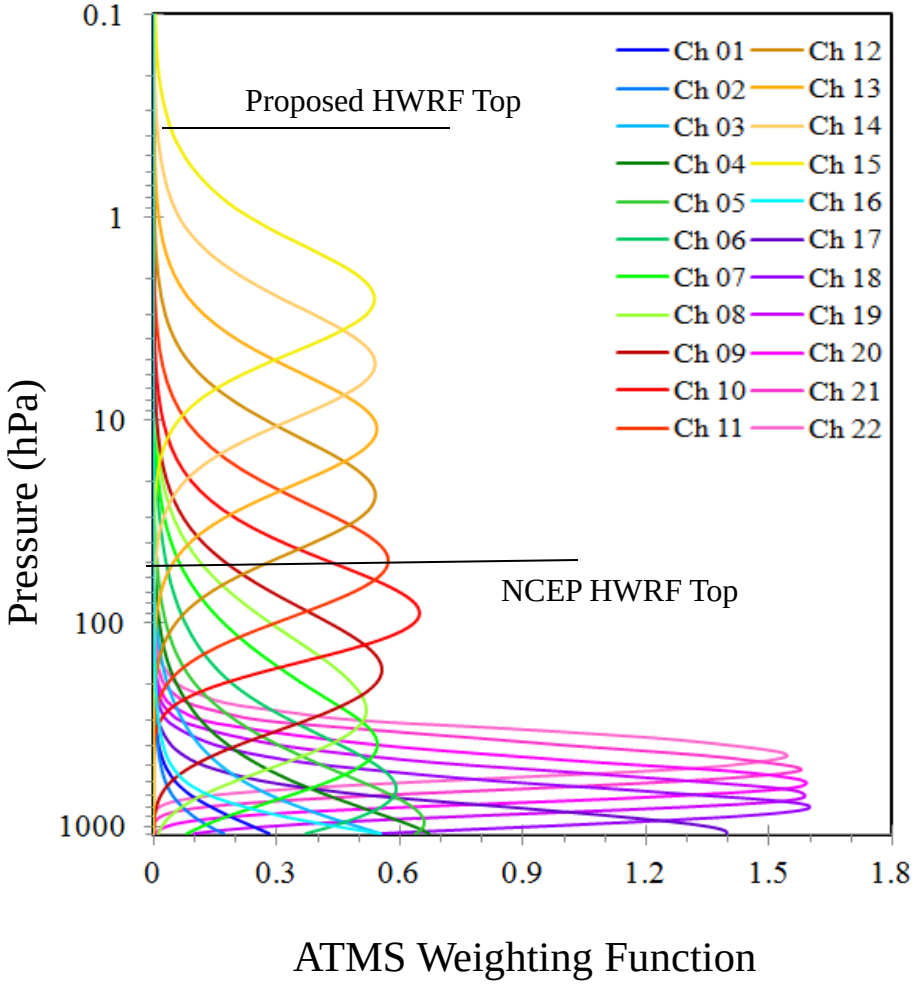




JAXA launched GCOM-W1 on Oct 18, 2011 with AMSR2 on board and NESDIS is developing NOAA unique AMSR2 products for user community.

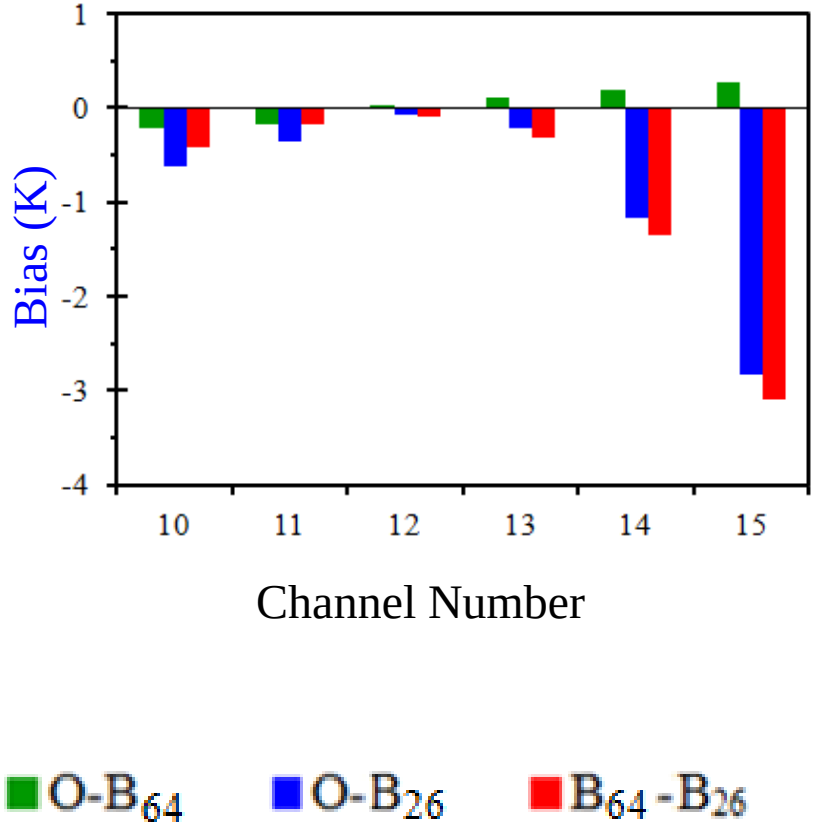
HWRF Model Top Issues

ATMS Weighting Functions



Our approach: Raise the model top to allow for more satellite data assimilated into hurricane forecast model with better analysis fields throughout atmosphere

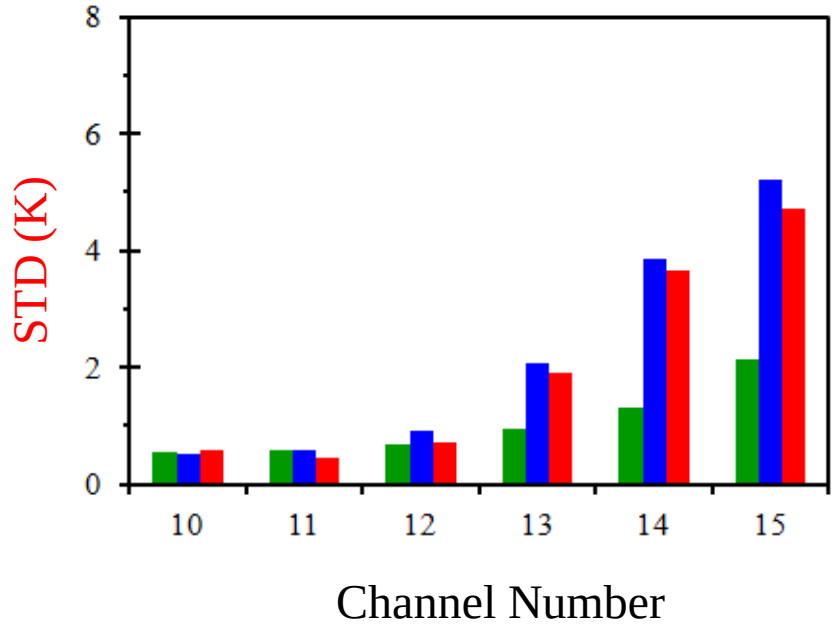
Comparison of GFS 64-level and 26-level Data



Model top level pressure

GFS 64: 0.01hPa

GFS 26: 10hPa



20-27 December 2011

Quality Control and Bias Correction

Quality Control (QC) for SSMIS Imager Channels

Current HWRF/GSI

(1) If $\left|T_{b,i}^{o} - T_{b,i}^{m}\right| \geq 3.5$ K, cloud is detected over both ocean and land. The ith channel will be rejected.

(2) If $WVP < 0$, outliers are detected. All channels will be rejected over ocean.

(3) If $LWP_{comp} > LWP_{i,threshold}$ over ocean, the ith channel will be rejected. (not activated)

(4) If $\left|T_{b,2}^{o} - T_{b,2}^{m} - b_{2,j}\right| \geq 1.5$K, cloud is detected over land. Channels12-16 are rejected.

(5) Data over a mixed surface are removed.

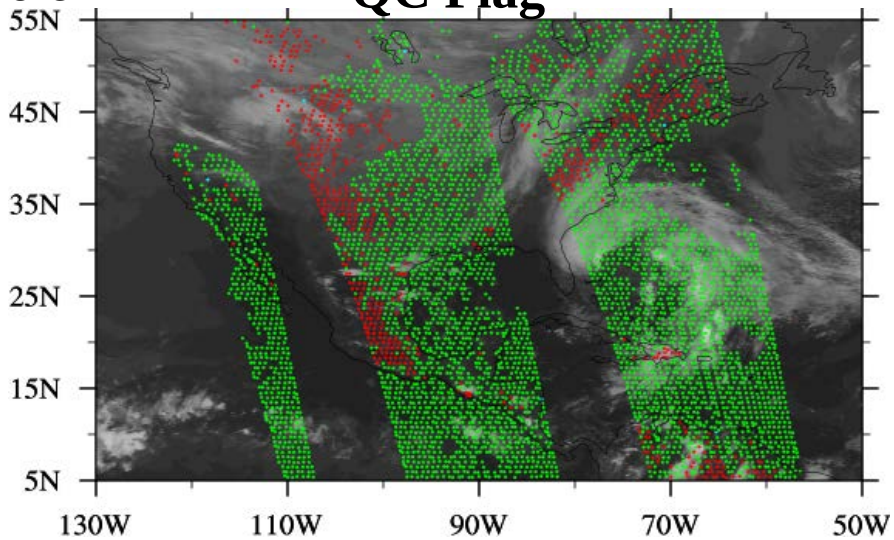
Modifications to current HWRF/GSI

1. Turn on the cloud liquid water (CLW) quality control (QC) in GSI;
2. Use LWP_{91H} instead of LWP_{37V} when water vapor path (WVP) is less than 60 mm in the composite CLW algorithm;
3. Tune the threshold of LWP to 0.02 mm for imager channels;
4. Toss away the data over land.

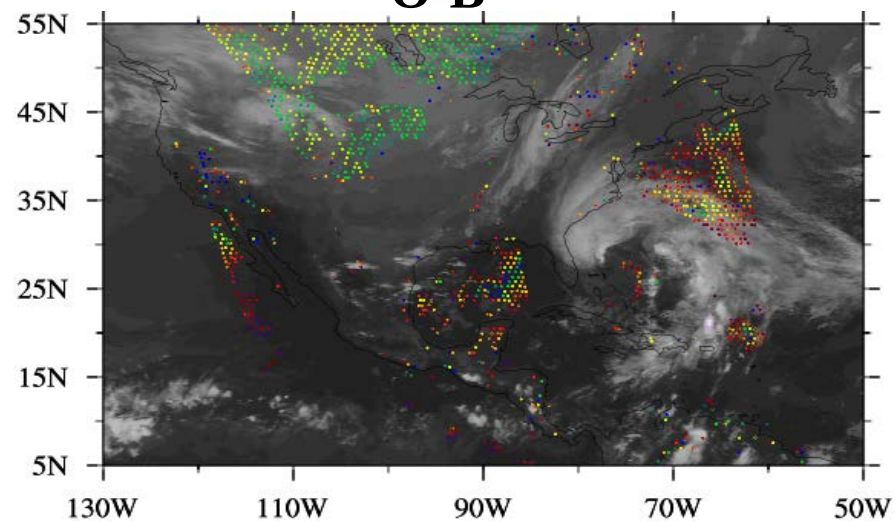
QC Flag and O-B of Channel 12 (19.35H) before/after modifications

before

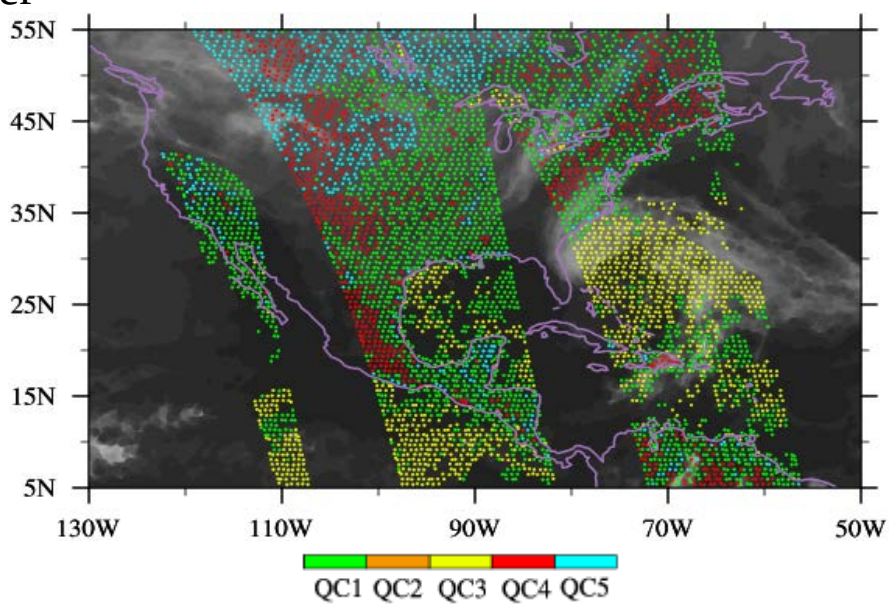
QC Flag

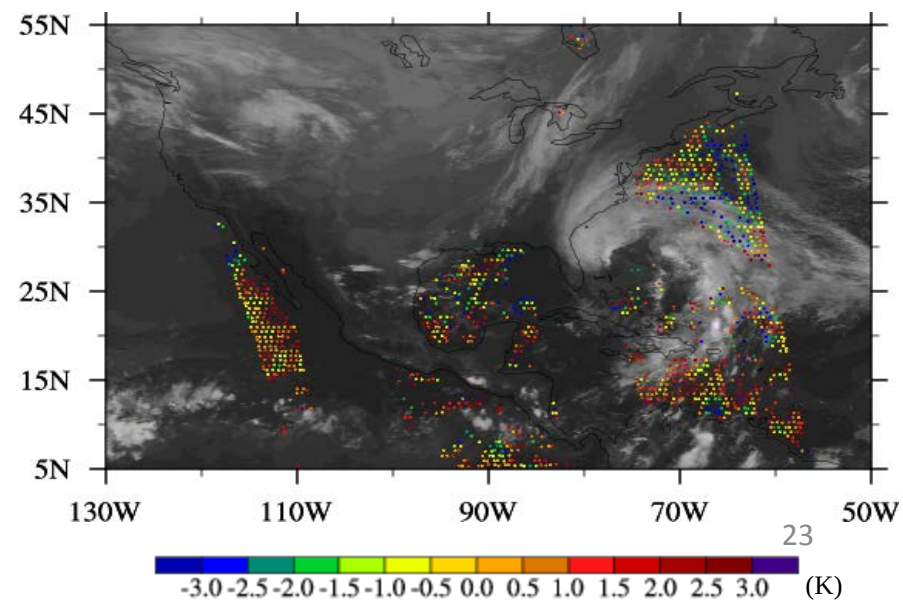


O-B



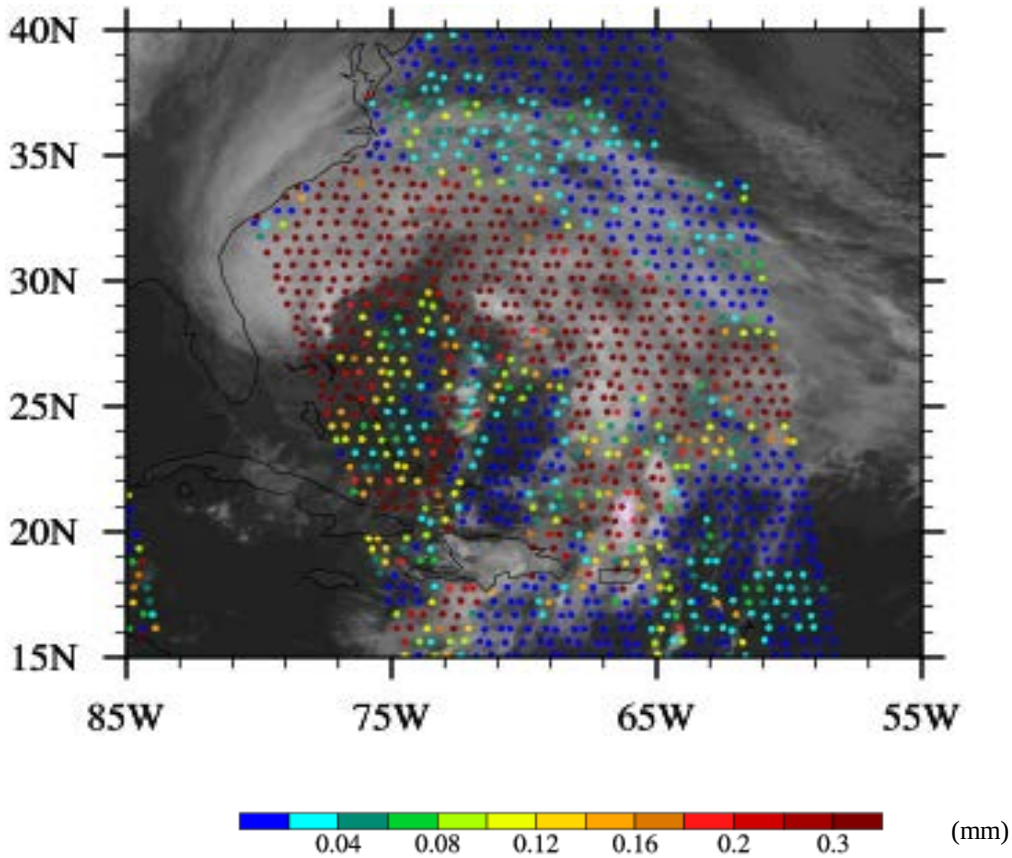
after





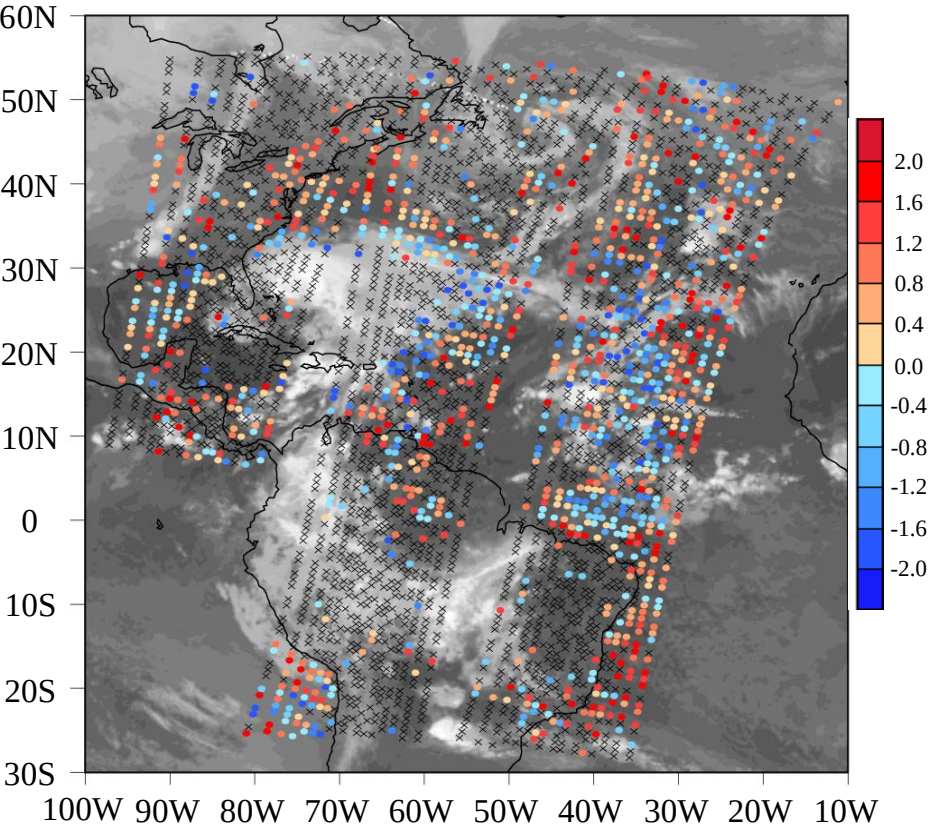
SSMIS Imaging Channel Quality Control Using Cloud Liquid Water Algorithm

$$LWP_{comp} = \begin{cases} LWP_{19v}, & LWP_{19v} > 0.7\ mm \\ LWP_{37v}, & LWP_{37v} > 0.28\ mm\ or\ WVP \geq 60\ mm \\ LWP_{91h}, & otherwise \end{cases}$$

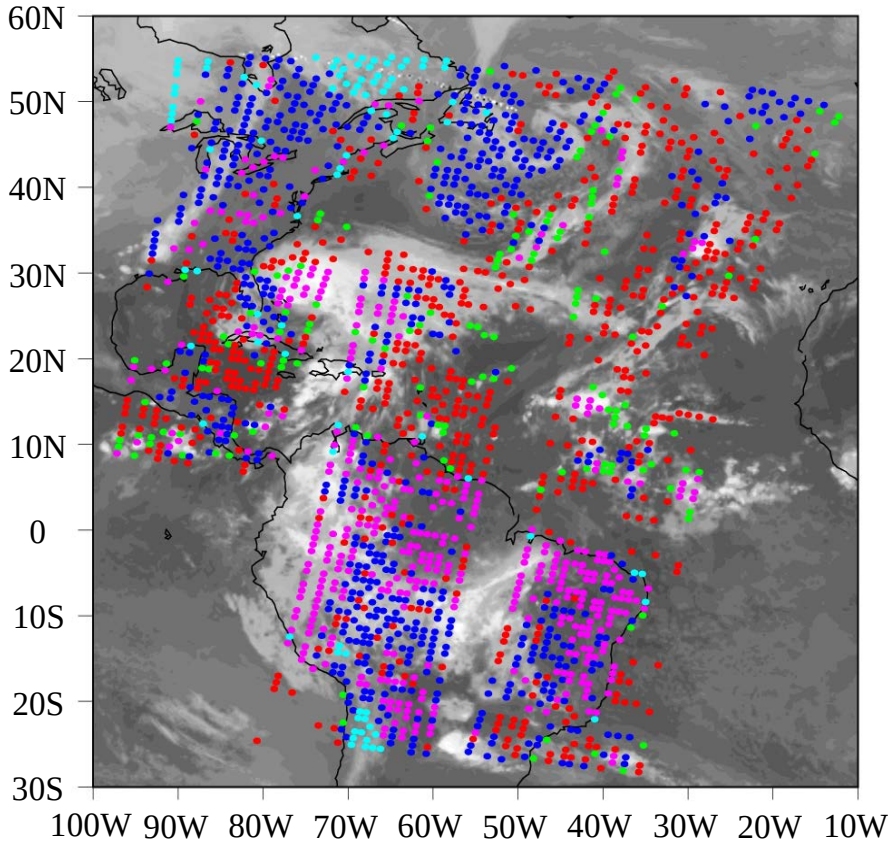


Quality Control of ATMS Data

ATMS ch 19 passing QC



ATMS ch 19 data rejected by various QC indices



Zou, X., F. Weng, B. Zhang, L Lin, V. Talapragada,, 2013, JGR

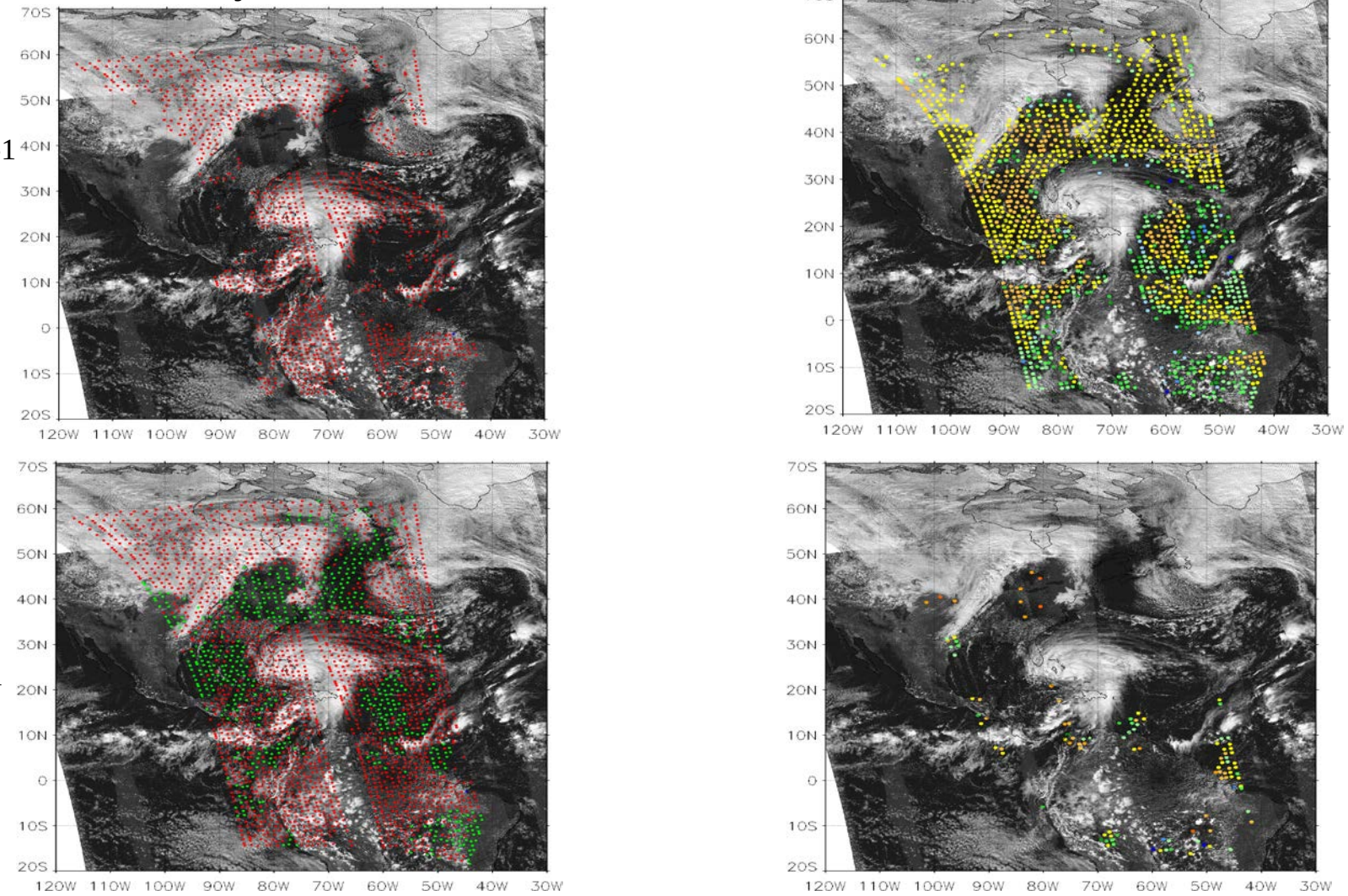
Quality Control of CrIS Data

Rejected Data

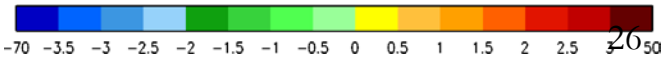
Pass QC

713 cm^{-1}

750 cm^{-1}

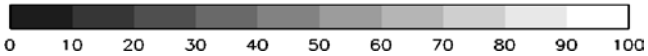


Cloud Mask Near Surface Test O-B Test



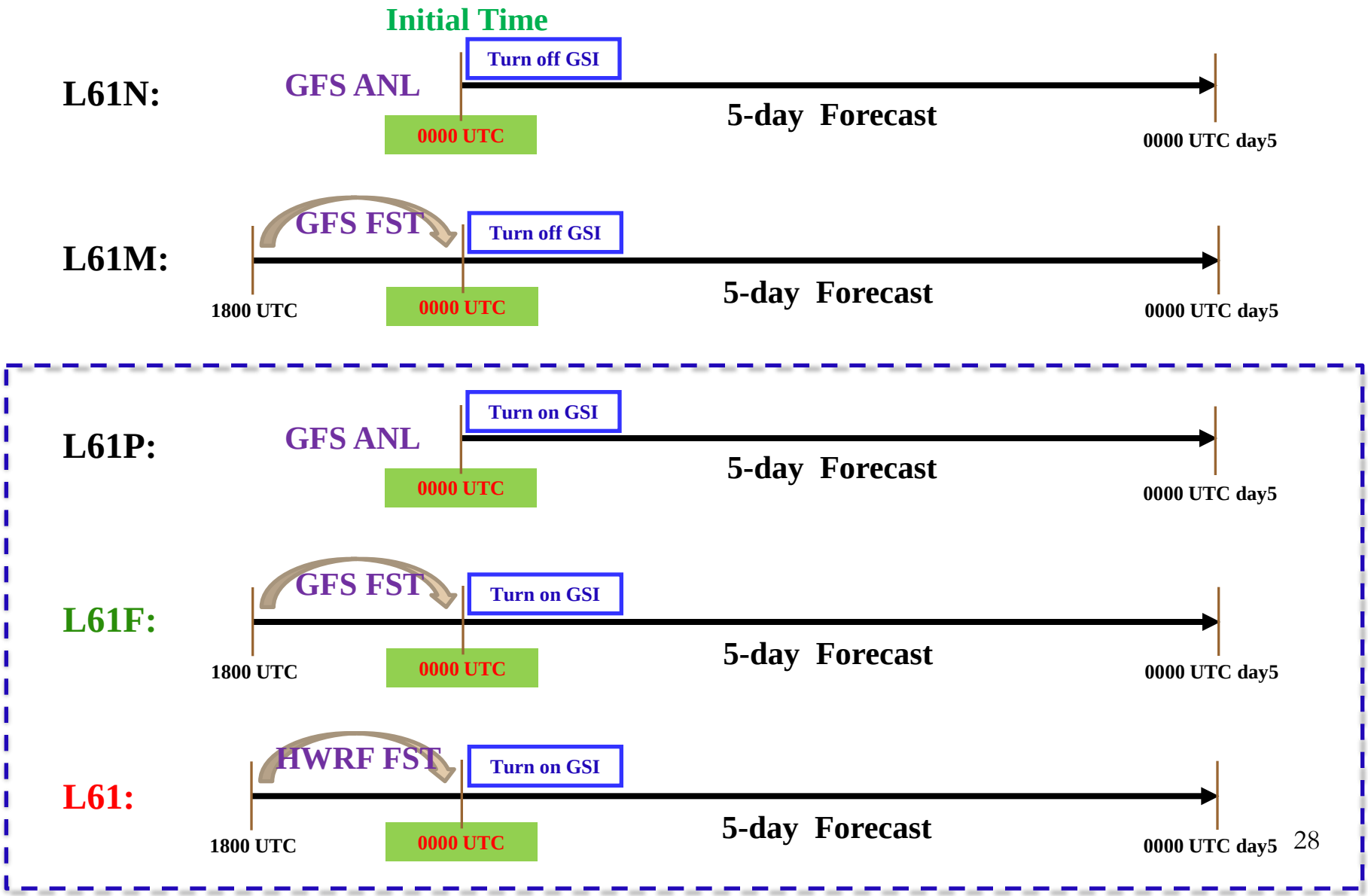
O-B

$ref^{VIIRS}_{0.64\mu m}$



HWRF Satellite Data Assimilation Experiments

HWRF Initialization and Data Assimilation

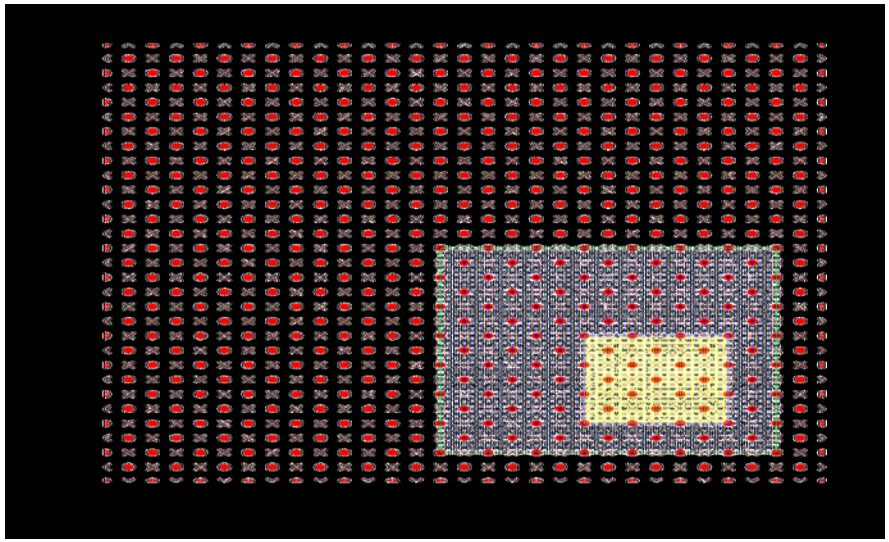


HWRF Model and Data Assimilation System

HWRF Model:

- 2012 NCEP-Trunk version 934
- Three telescoping domains:

Outer domain: 27km: 75x75°;
Inner domain: 9km ~11x10°
Inner-most domain: 3km inner-most nest ~6x6°



Revised Model Level and Top:

- Vertical levels: 61
- Model top: 0.5 hPa

Data Assimilation System:

- HWRF 6 hour forecasts
- GSI (3DVAR)

•The Hurricane Weather Research and Forecasting (HWRF) Model dynamical core is designed based on the WRF model using NCEP Non-Hydrostatic Mesoscale Model (NMM) core with a movable high-resolution nested grid (telescopic)
•Regional-Scale, Moving Nest, Ocean-Atmosphere Coupled Modeling System. Horizontal resolution: 27 km outer grid, 9 km inner grid, 42 vertical levels
•Non-Hydrostaticsystem of equations formulated on a rotated latitude-longitude, Arakawa E-grid and a vertical, pressure hybrid (sigma_p-P) coordinate.
•Advanced HWRF 3D Variational analysis that includes vortex relocation, correction to winds, MSLP, temperature and moisture in the hurricane region and adjustment to actual storm intensity.
•Uses SAS convection scheme, GFS/GFDL surface, boundary layer physics, GFDL/GFS radiation and Ferrier Microphysical Scheme.
•Ocean coupled modeling system (POM/HYCOM).

Data Assimilation Sensitivity Tests

1. **L61 (0.5mb) vs. L43 (50mb)** ***(Completed)***
2. **L61+ATMS** ***(Completed)***
3. **L61+CrIS** ***(Completed)***
4. **L61+IASI** ***(Completed)***
5. **L61+GOES imager radiance** ***(Completed)***
6. **L61+CrIS/VIIRS (on going)**
7. **L61+SSMIS imaging channels (on going)**
8. **L61 + AMSR2 (on going)**
9. **L61 + Combined AMSU-A/MHS data steam (on going)**

Control Experiment – L61

Conventional Data:

Radiosondes, aircraft reports (AIREP/PIREP, RECCO, MDCRS-ACARS, TAMDAR, AMDAR), Surface ship and buoy observations , Surface observations over land, Pibal winds,Wind profilers, VAD wind, Dropsondes

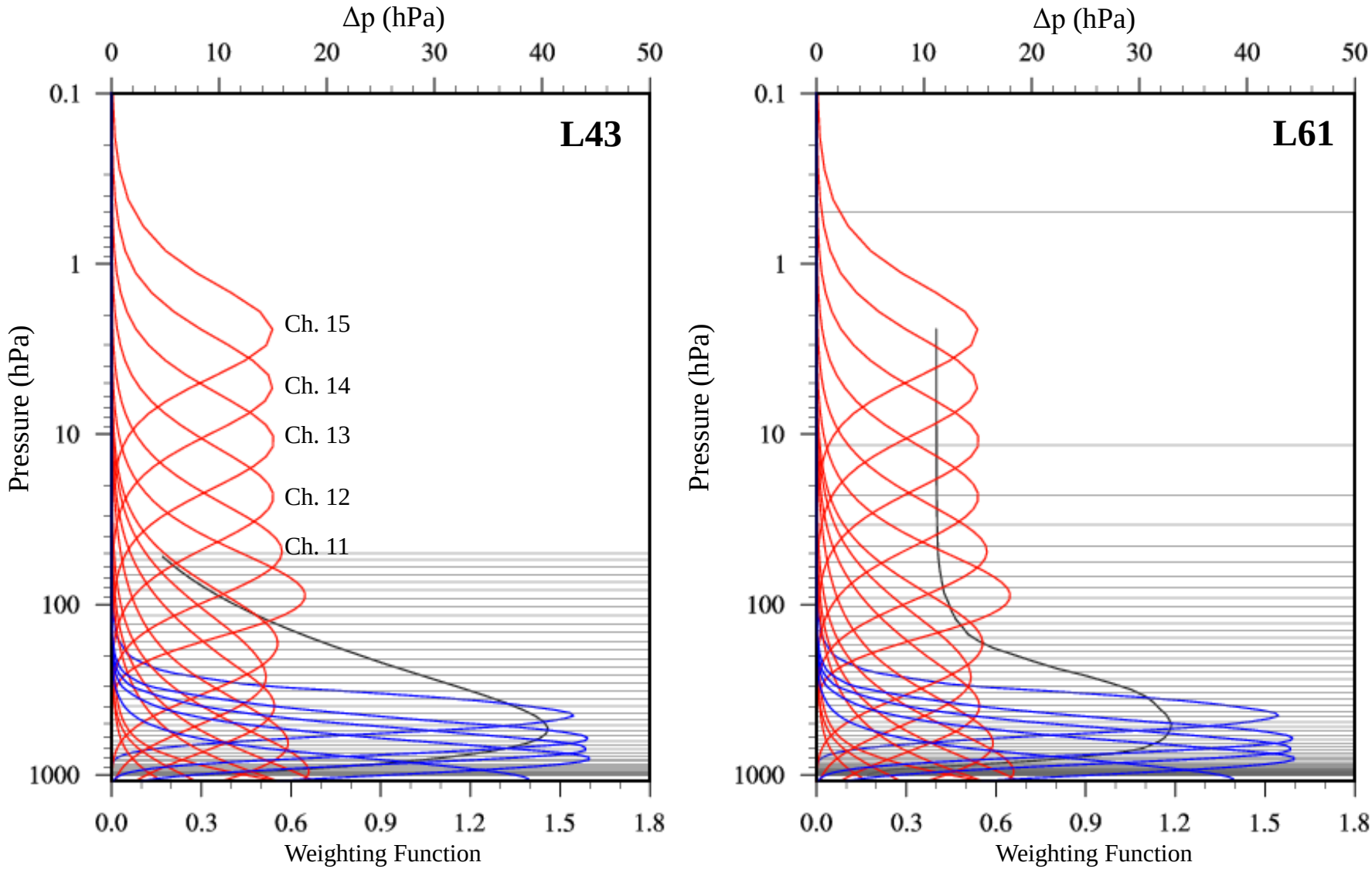
Satellite Instrument Data:

- AMSU-A (channel 5-14) from NOAA, NOAA and METOP
- HIRS from NOAA-19 and METOP-A
- AIRS from EOS Aqua
- ASCAT from METOP-A
- GPSRO from GRAS/COSMIC

Model Top Experiment Setup

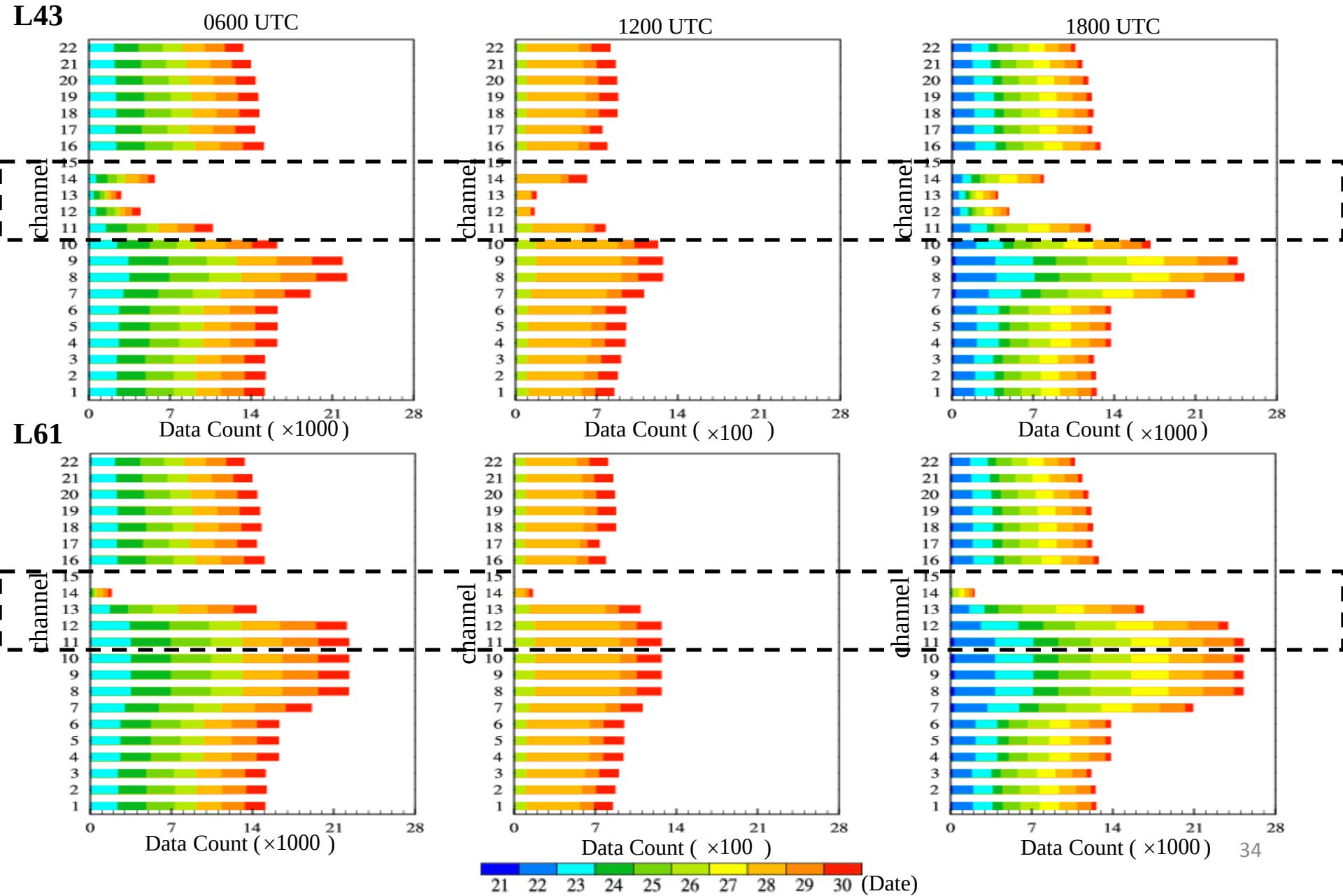
- Model: 2012 HWRF (triple-nested, warm start)
- Satellite Data: GPS, ASCAT, AMSU-A (N18, N19, and MetOp-A), AIRS (Aqua), HIRS (N19 and MetOp-A)
- Control: L43 (43 levels, model top 50 mb)
- Sensitivity: L61 (61 levels, model top 0.5 mb)
- Forecasts of Hurricane Isaac

Weighting Functions for ATMS Channels



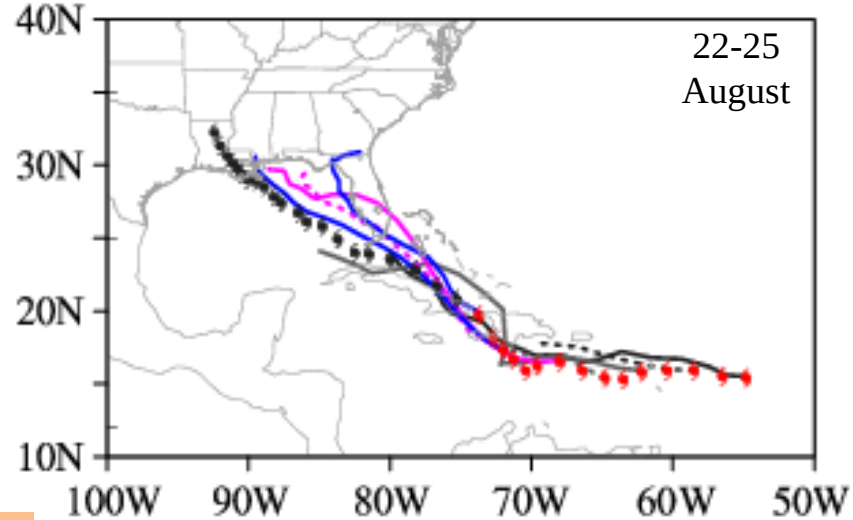
Zou et al. (2013)

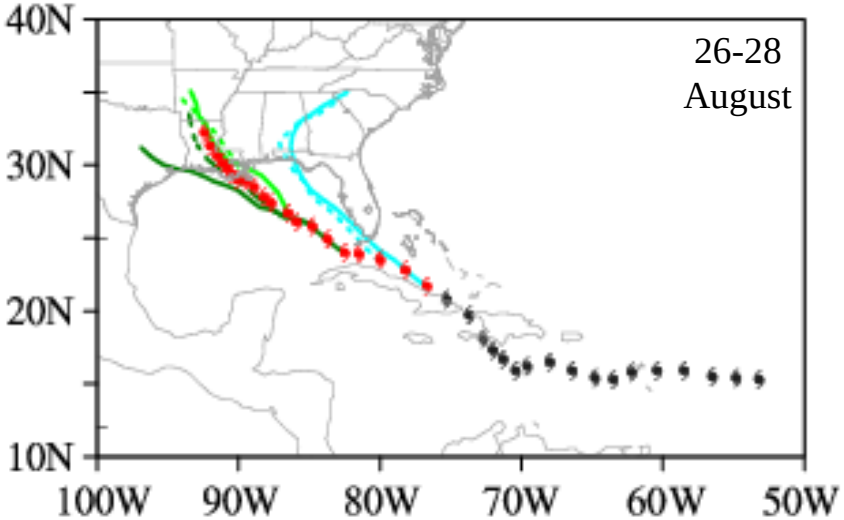
Data Counts of ATMS Radiance Data Assimilated for Hurricane Isaac



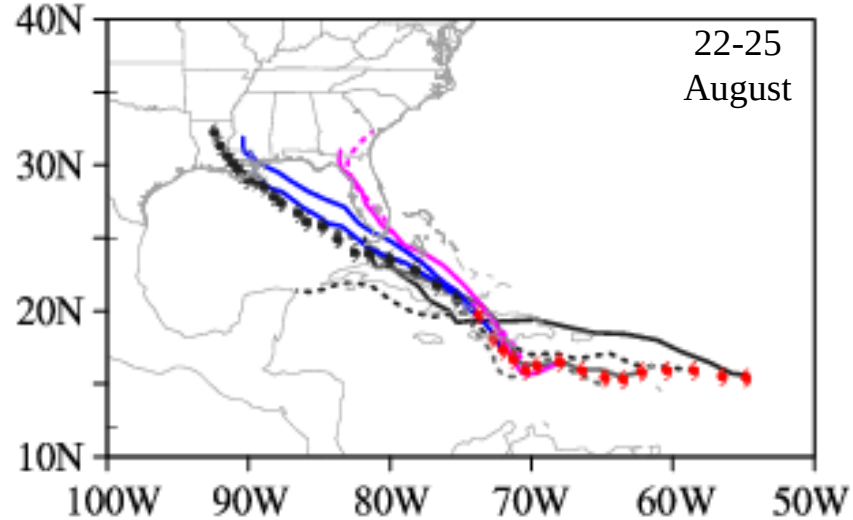
Forecast Tracks of Hurricane Isaac

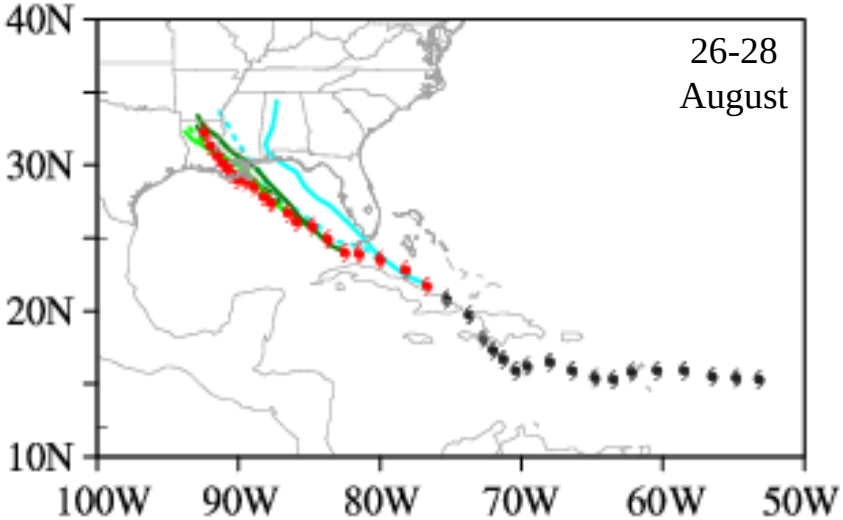
L43





L61

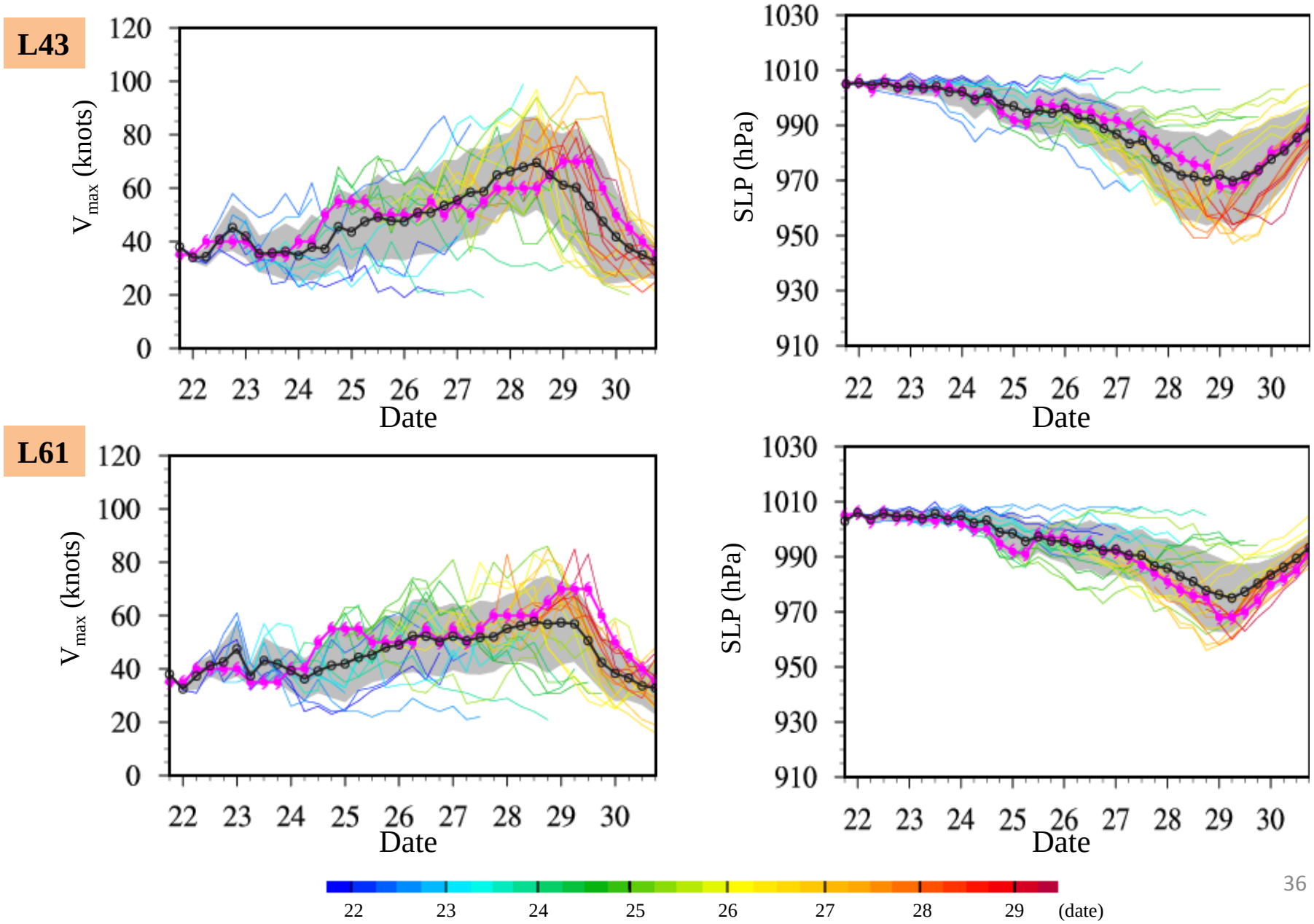




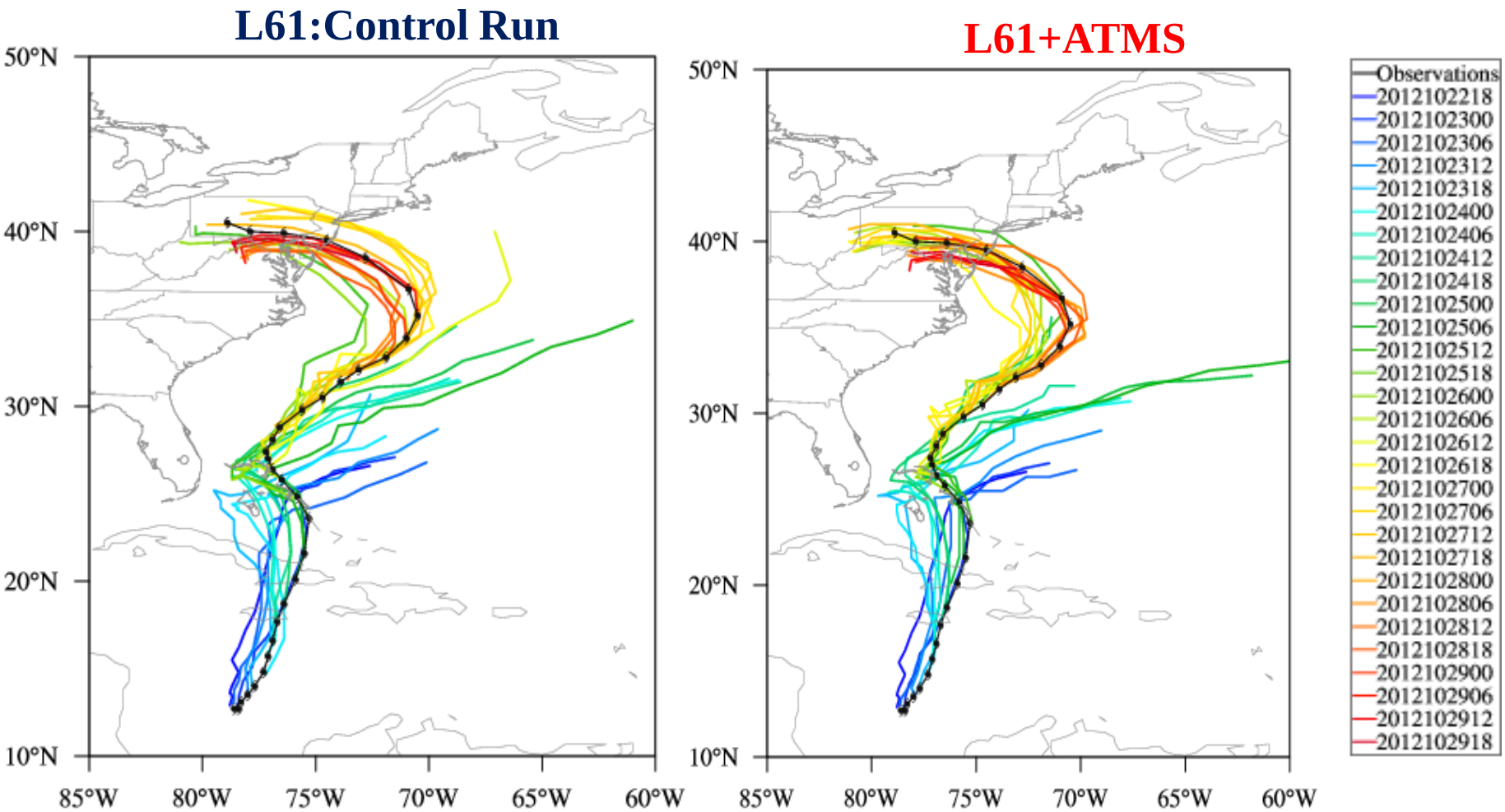
22 23 24 25 26 27 28 (date)

0000 UTC 1200 UTC

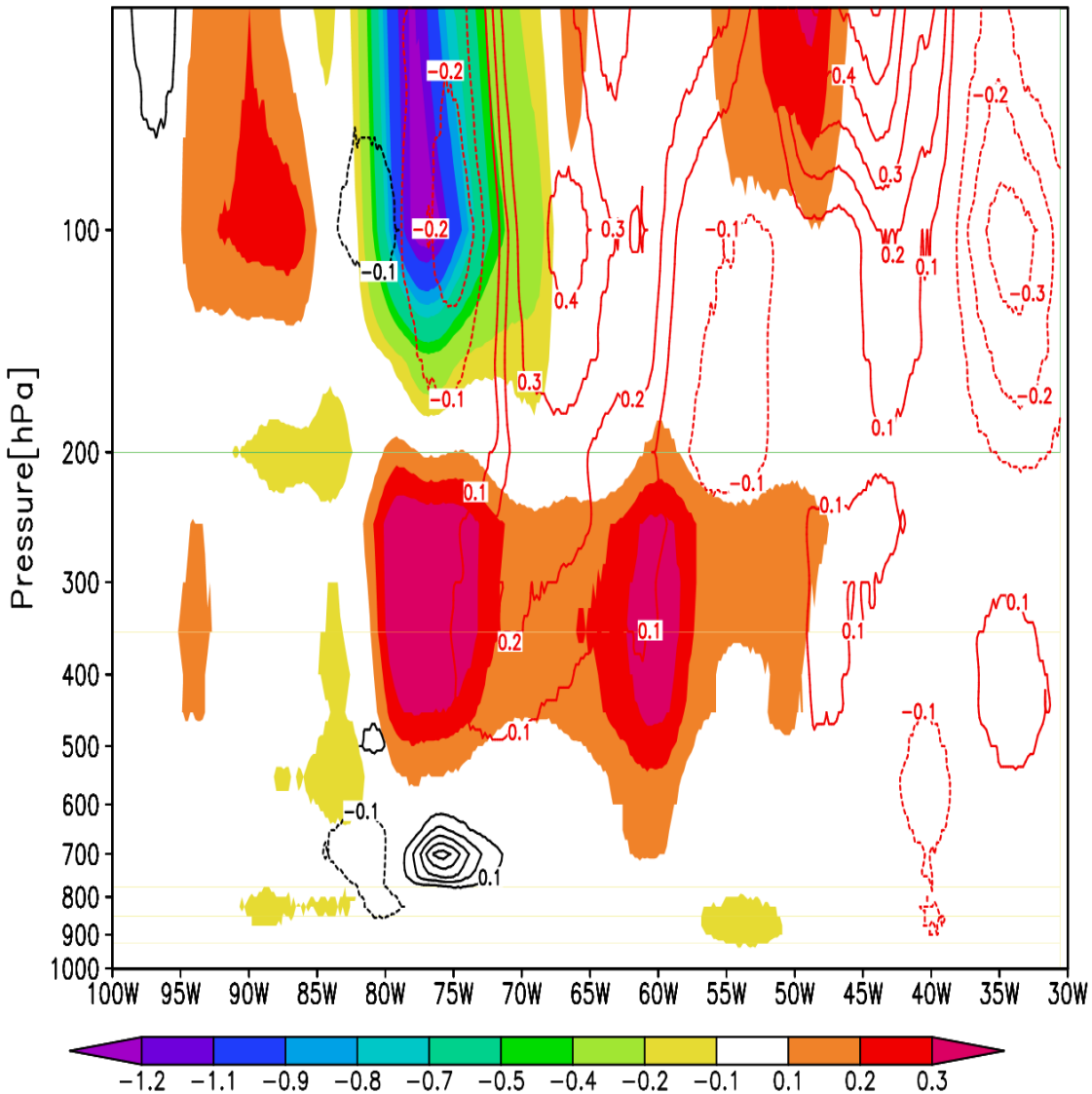
Forecast Intensities of Hurricane Isaac



Impacts of Direct Assimilation of Suomi NPP ATMS Radiances on Hurricane Sandy's Track



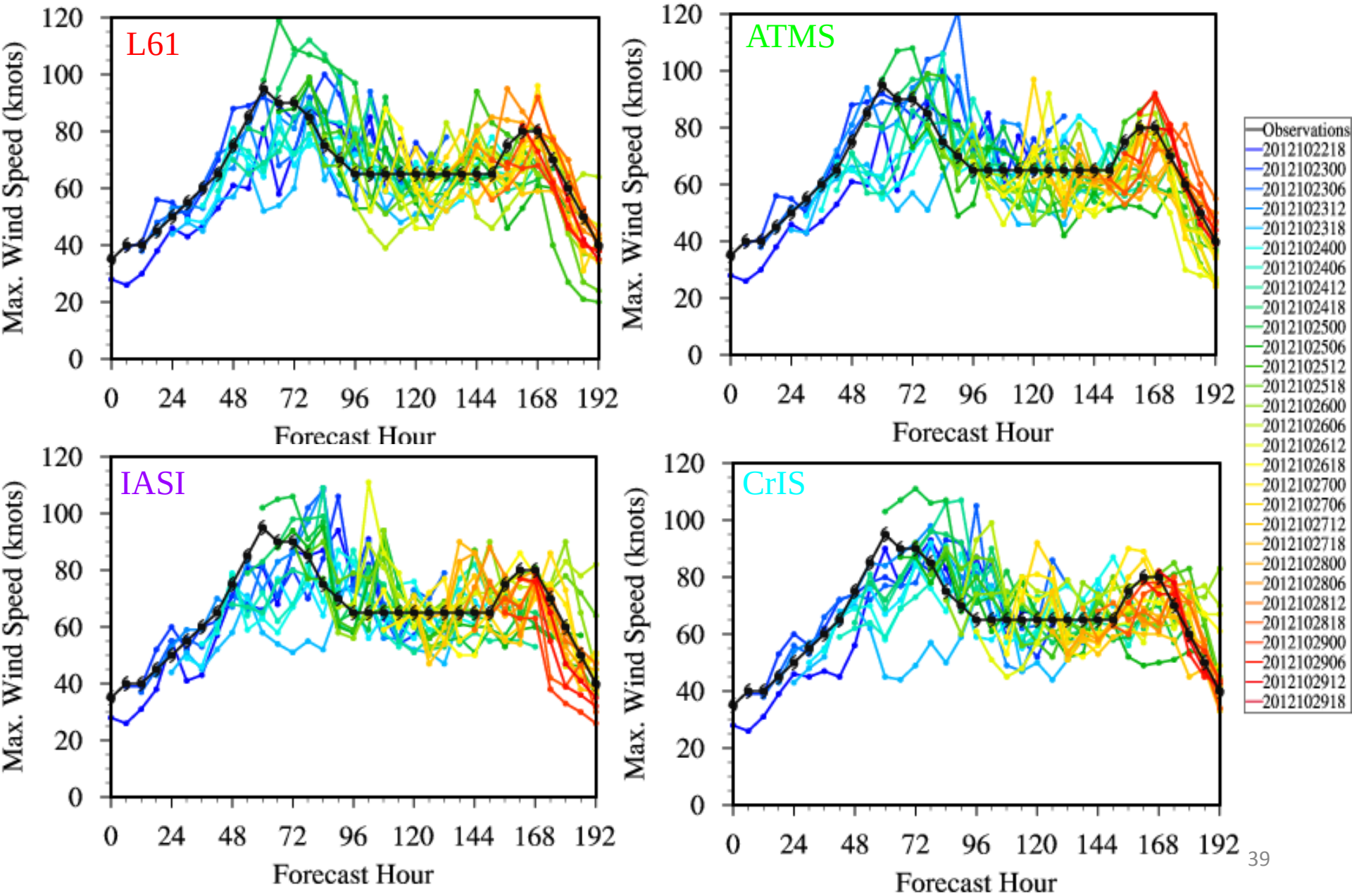
Comparison of Temperature Increments from ATMS and AMSU-A



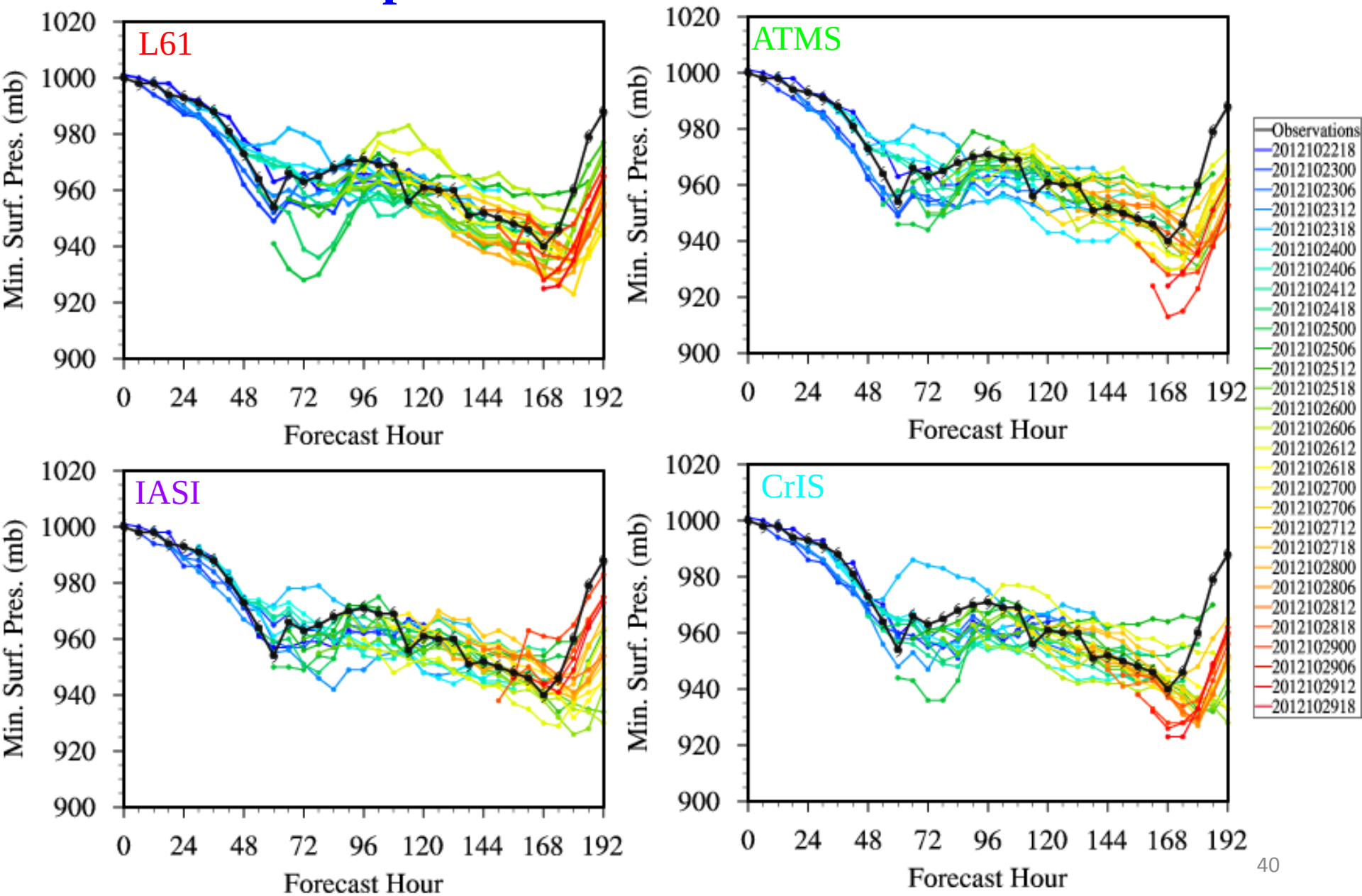
Shaded: ATMS
Red contour: AMSU-A
Black contour: Conventional

ATMS and AMSU-A (NOAA-19) produce largest temperature innovation in storm regions in similar magnitudes and complementary in spatial coverage

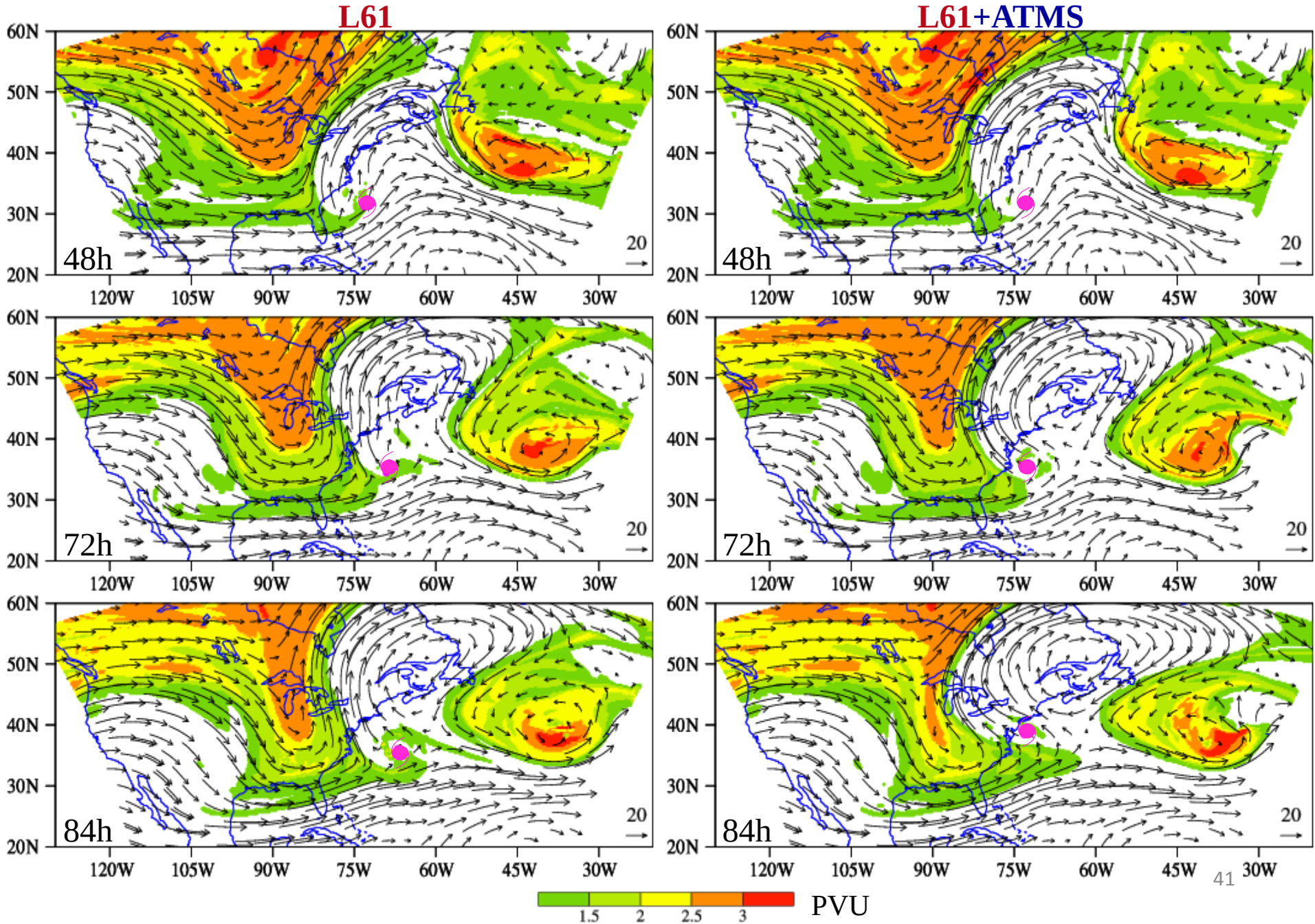
Multiple Forecasts of Max. Wind Speed for Hurricane Sandy



Multiple Forecasts of Min. Surf. Pres.

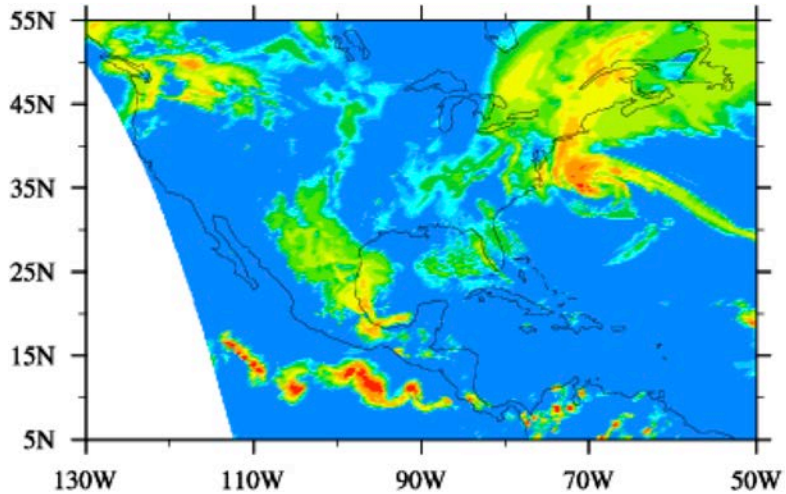


200 mb PV and wind for 48h, 72h and 84h forecast

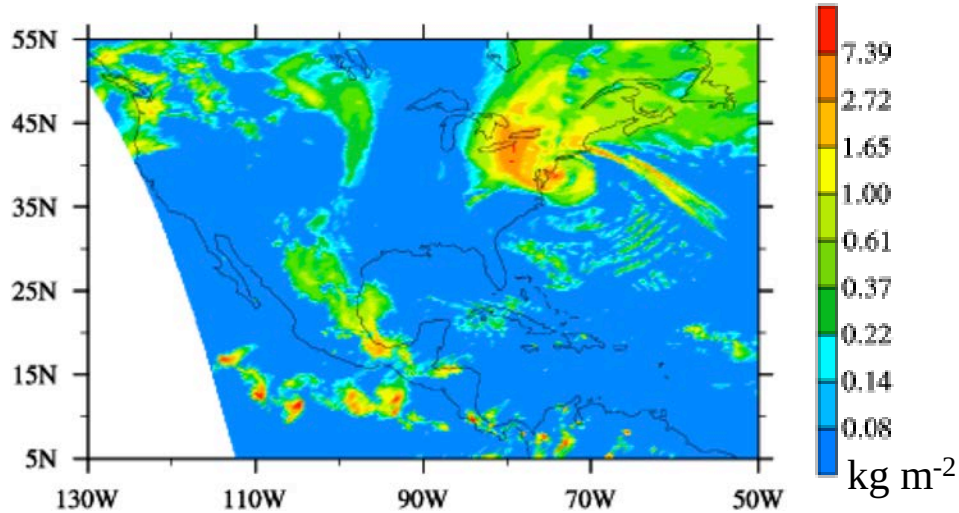


84-h Forecasts of Cloud Liquid Water Valid at 0000 UTC 30 October 2012

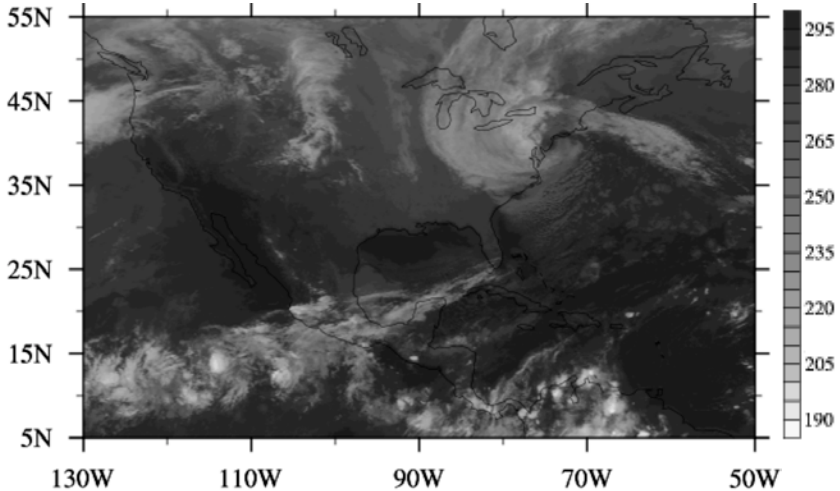
Without ATMS



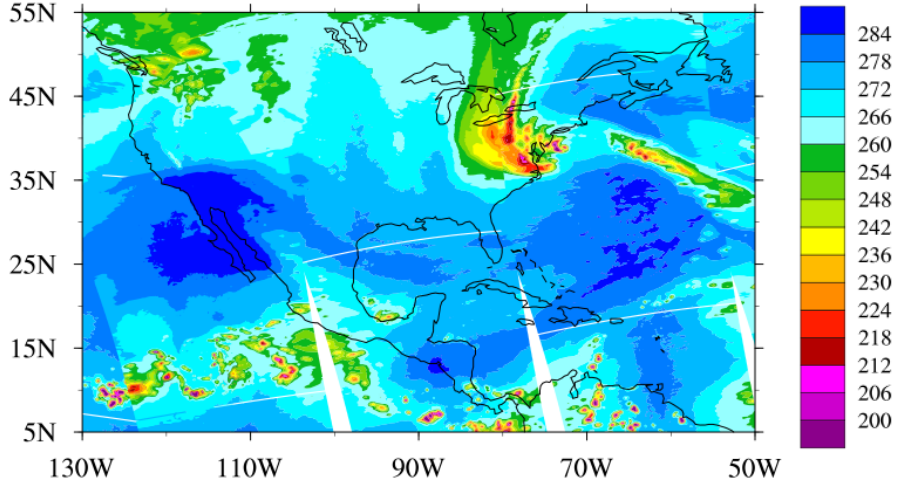
With ATMS



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

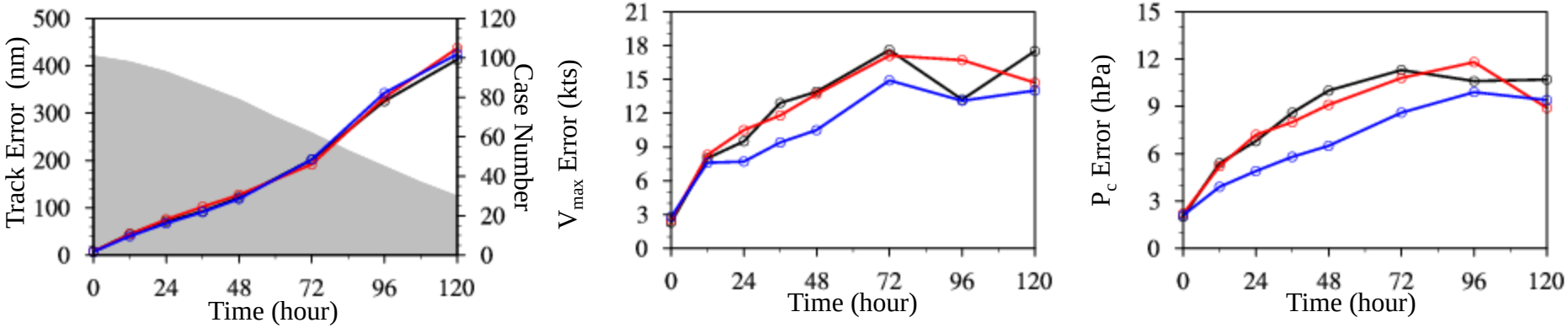


ATMS $T_{b,18}$ at 1727 UTC 10/29/12

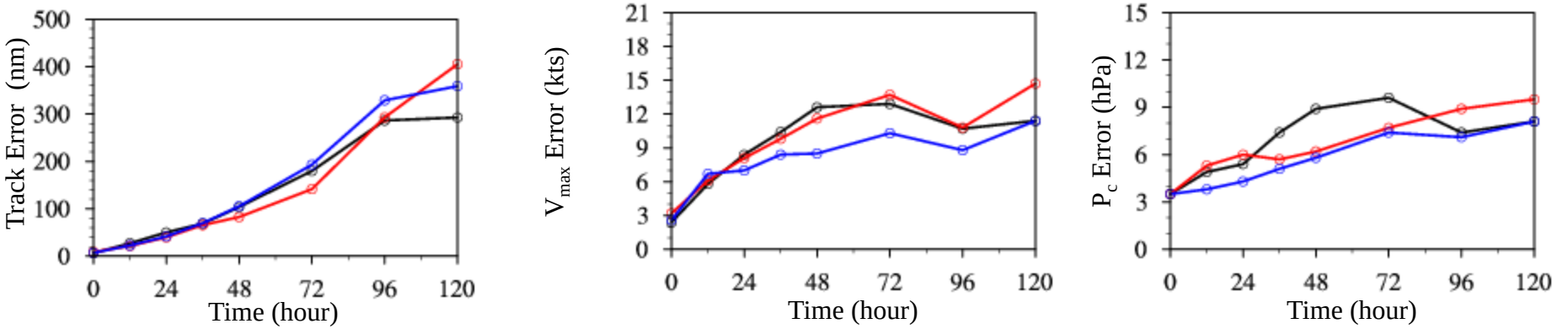


2012 Statistics of Hurricane Forecast Errors

Mean



Std. Dev.



CONV SAT ATMS

Summary

- HWRF/GSI model is re-configured to include more vertical layers and higher model top for more effective uses of satellite sounding data in the analysis

- For 2012 hurricane cases, assimilation of satellite data in HWRF improves the storm intensity forecast in terms of both maximum wind and minimum pressure. The impact on track forecast is positive up to forecast day 3,

- Improvements in the GSI quality control for new instruments (e.g. CrIS and AMSR2/SSMIS imaging channels) remain critical. Sensitivity tests show SSMIS imaging channels have some impacts on hurricane forecasts.

- Control and sensitivity experiments show uses of ATMS in HWRF improve the hurricane forecasts in both intensity and track.

- Characterization of observation error covariance in cloudy conditions is developed for future tests of cloudy radiances assimilation

References

- Zou, X., Qin. Z., and F. Weng, 2012: Improved Coastal Precipitation Forecasts with Direct Assimilation of GOES 11/12 Imager Radiances, *Mon. Wea. Rev*., **10**.1175/MWR-D-10-05040.1
- Yan, B. and F. Weng, 2012: Assimilation of F16 Special Sensor Microwave Imager/Sounder Data in the NCEP Global Forecast System, *Weather and Forecast*, **27**, 700-714.
- Zou, X., Qin Z., and F. Weng, 2013: Improved quantitative precipitation forecasts by MHS radiance data Assimilation with a newly added cloud detection algorithm, *Mon. Wea. Rev*., DOI: 10.1175/MWR-D-13-00009.1
- Zhu, T. and F. Weng, 2013**:** Hurricane Sandy warm-core structure observed from advanced Technology Microwave Sounder, *Geophys. Res Lett.*, **40**, 3325–3330, doi:10.1002/grl.50626
- Zou, X., F. Weng, B. Zhang, L, Lin, Z. Qin, and V. Tallaparada**:** 2013**:** Impacts of assimilation of ATMS data in HWRF on track and intensity forecasts of 2012 four landfall hurricanes, *J. Geophys. Res.*, **118**, 1-19, doi:10.1002/2013JD020405

Influence of Deriving and Assimilating High-Resolution Satellite-Derived Winds on Mesoscale Analyses and Forecasts of Tropical Cyclones in the GOES-R Era

Christopher Velden

University of Wisconsin-CIMSS

GOES-R Risk Reduction Webinar Series

November 18, 2013

Introduction

Improving forecasts of tropical cyclone (TC) track and intensity remains a challenge in numerical weather prediction. This is partially due to the difficulty in prescribing accurate initial conditions of the TC structure and its surrounding environment. Since a TC spends most of its lifetime over the ocean, initial conditions are crucially dependent on the accurate assimilation of data from satellites. Given the increasing space and time resolution of satellite data becoming available, it is necessary to seek optimal methods to exploit the use of these datasets in data assimilation systems. One type of satellite data that is expected to improve in quality and coverage in the GOES-R era is Atmospheric Motion Vectors (AMVs).

In this presentation we will briefly show current work being done to ascertain the impact that high-resolution AMVs (currently achieved by rapid-scan sampling) can have on TC analyses through optimized effective data assimilation in mesoscale numerical hurricane analysis and forecast systems. This demonstration work sets the stage for the types of routine AMV datasets that will become available after the launch and activation of GOES-R.

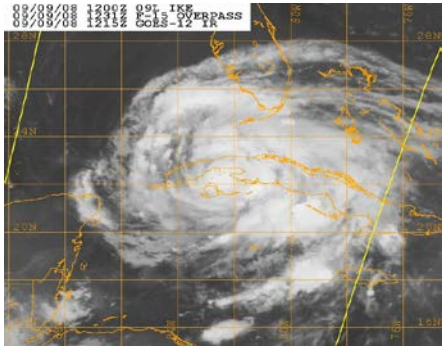
Background

- Recent studies have begun looking at the impact of high-resolution AMVs derived from GOES rapid-scan data on hurricane model analyses and forecasts.
  (Wu, T.C., H. Liu, S. Majumdar, C. Velden and J. Anderson, 2013: Influence of assimilating satellite-derived atmospheric motion vector observations on numerical analyses and forecasts of tropical cyclone track and intensity. Mon. Wea. Rev.)
- The presumption is that the AMVs can help define the smaller-scale flow features in the TC vortex and near-environment that may be important to improving model initial conditions and forecasting of short-term intensity and track changes.
- Improving data assimilation schemes allow the increased information content of the high-density AMV observations, but must be tested and tuned to optimize positive impacts.

Methodology

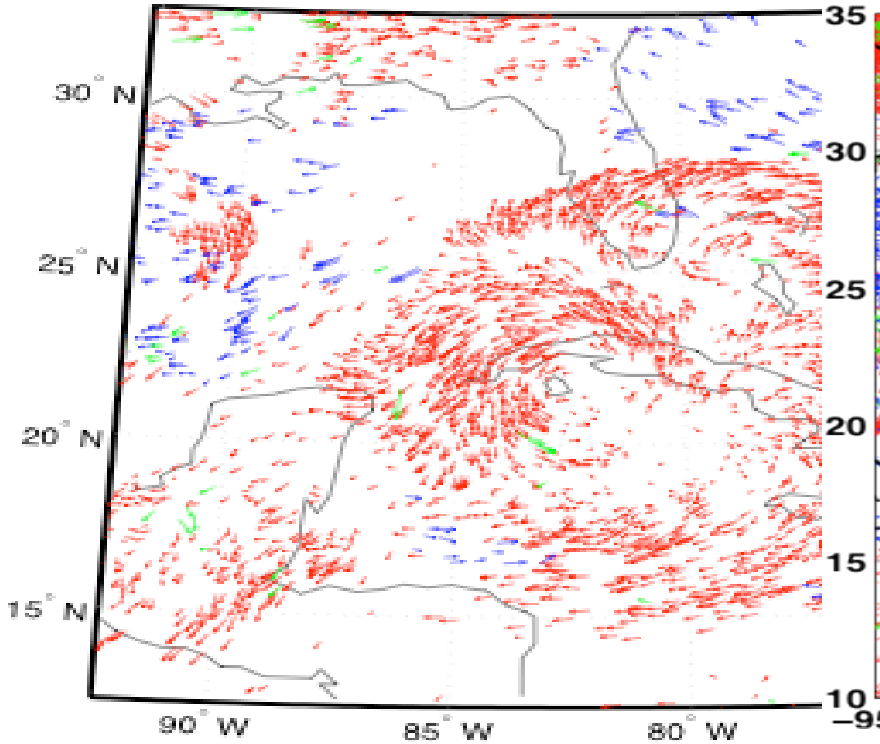
- Traditionally, AMVs are derived operationally for global NWP analyses to aid in the depiction of synoptic and large scale flow patterns. Vector densities and QC are set with this in mind.
- For smaller high-impact weather events such as TCs that are defined on much smaller scales, we can employ different AMV processing strategies, such as the use of more frequent imaging that allows for improved cloud tracer selection/tracking and mesoscale flow depiction.
- It is important to demonstrate this potential impact now, as GOES-R will provide 5-15 minute imaging routinely, and 1-minute sequences on demand.

As a proxy for GOES-R 5-min. imagery, GOES-East rapid-scan imagery (7-min.) is used to derive AMVs.

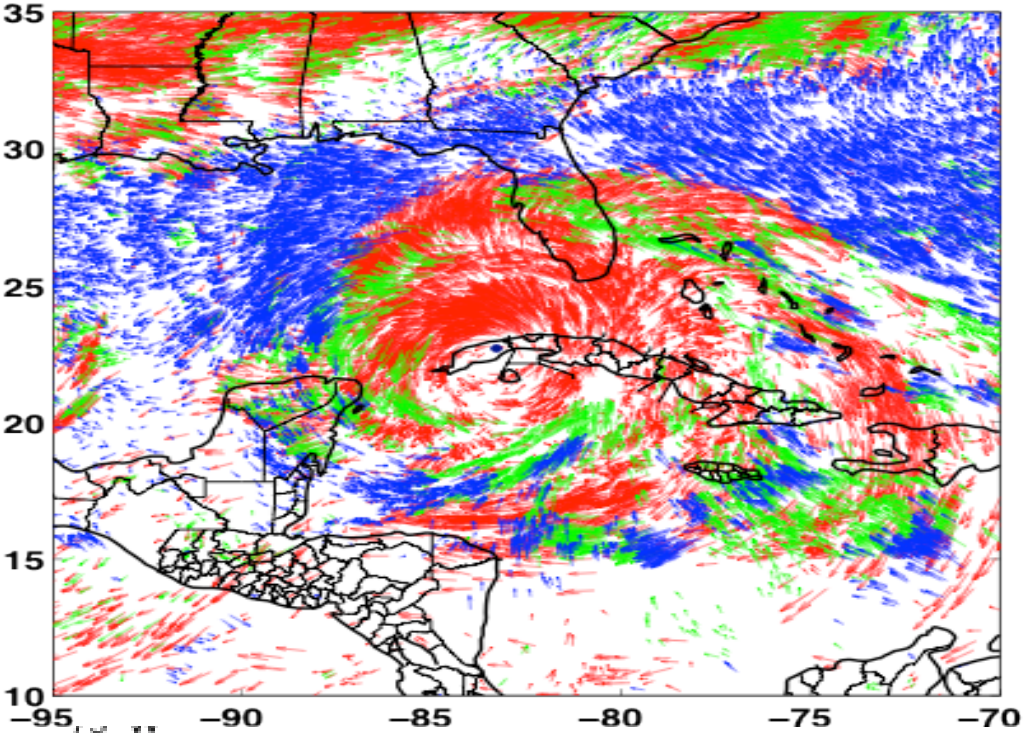


-- Example: Hurricane Ike (2008) --

Operational Coverage (15/30 min. images)



IKE:2008/09/09 1800Z Rapid–Scan



AMV heights: P ≤ 350 hPa 350 < P ≤ 800 hPa P > 800 hPa

The AMV coverage vs. normally-available winds is substantially increased over and around Hurricane Ike when using the rapid-scan imagery.

Impact Study

Conduct data enhancement experiments to assess the impact of adding the GOES Rapid-Scan AMVs to assess hurricane model initial intensity analyses of TC Ike, and subsequent forecasts.

Model:

WRF-ARW v3.1.1: 9km moving nest grid (198 x 198 x 36) with feedback to 27km grid (215 x 205 x 36). Provides 3-hr forecast fields for analysis boundary conditions.

Assimilation system:

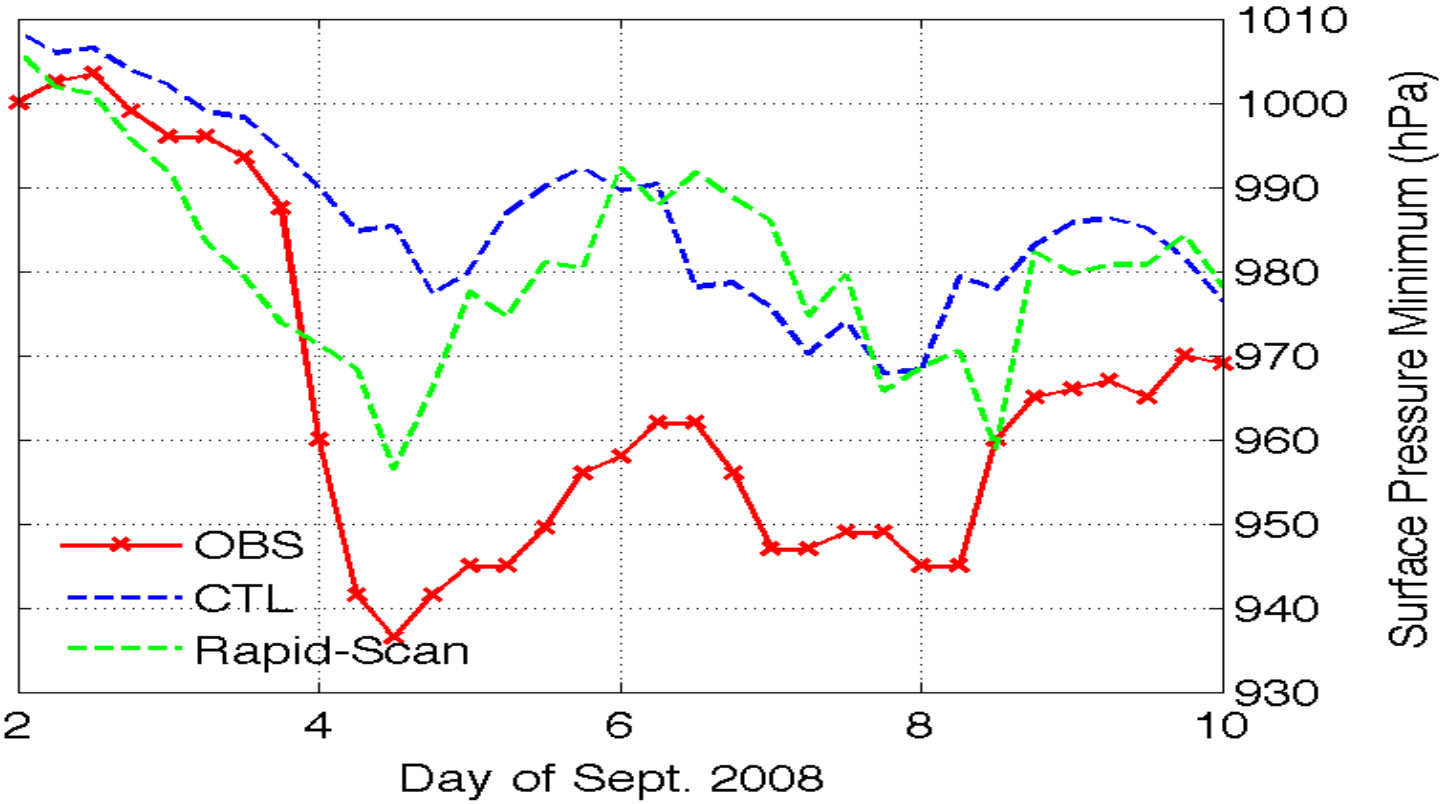
NCAR DART: Ensemble Adjustment Kalman Filter (EAKF) with 84 members.

Experiments:

- **Assimilate hourly GOES R/S AMVs into DART using a 3-hr cycle (with +/- 1-hr assimilation window) during Hurricane Ike.**
- **Compare DART analyses & WRF forecasts with and w/o the R/S AMVs.**

Results

Hurricane Ike Intensity Analyses

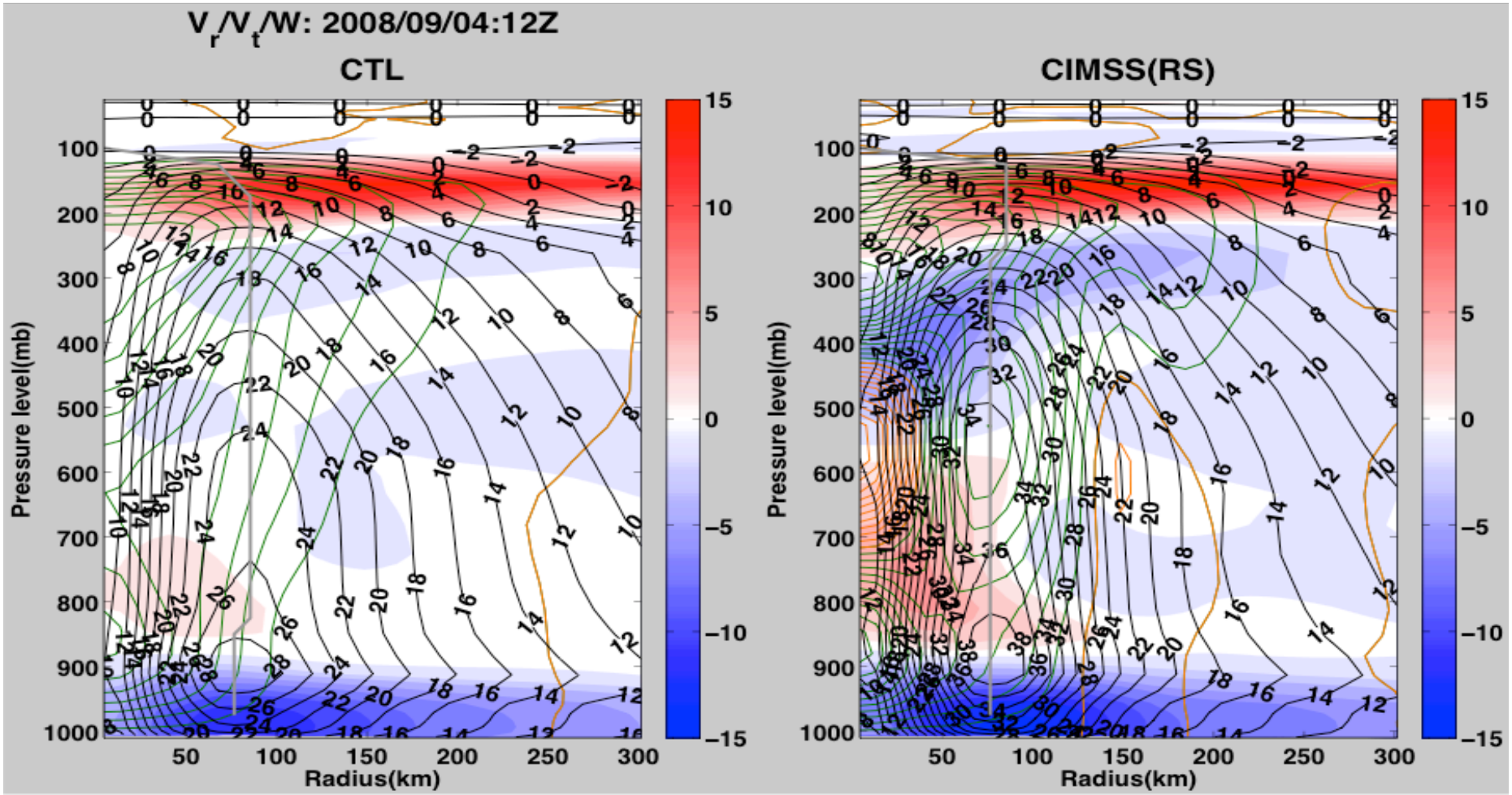


Assimilation of the GOES rapid-scan AMVs into the mesoscale DART/WRF system --- initial analyses of Hurricane Ike's intensity (OBS) vs. a Control (CTL) without the R/S winds.

Results

Hurricane Ike Vortex Structure Analyses

1200 UTC 04 Sep 2008

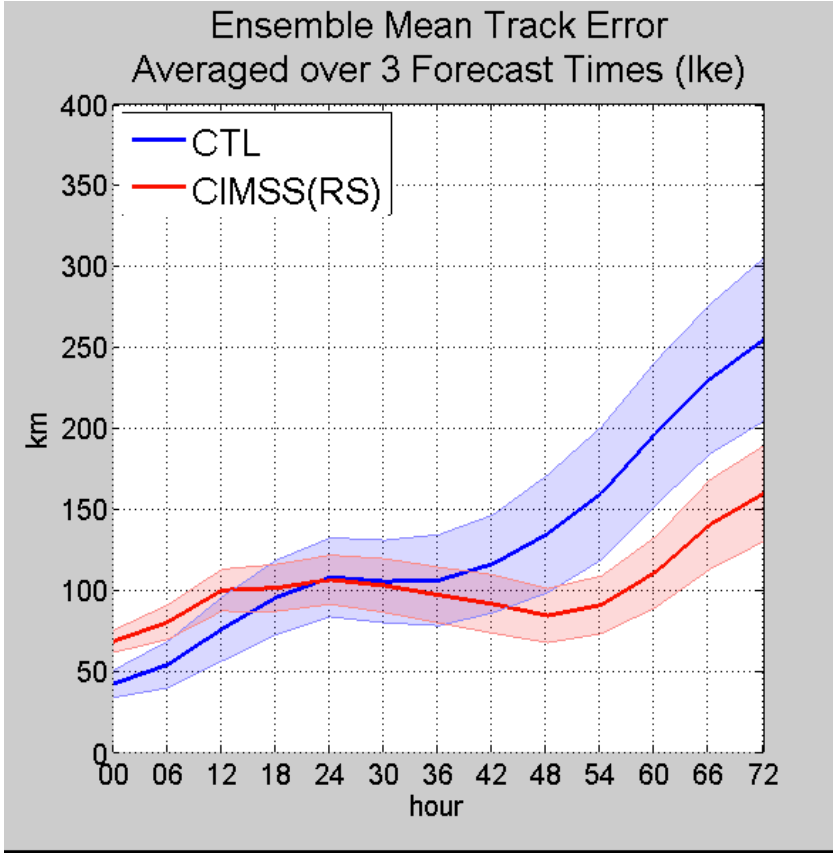


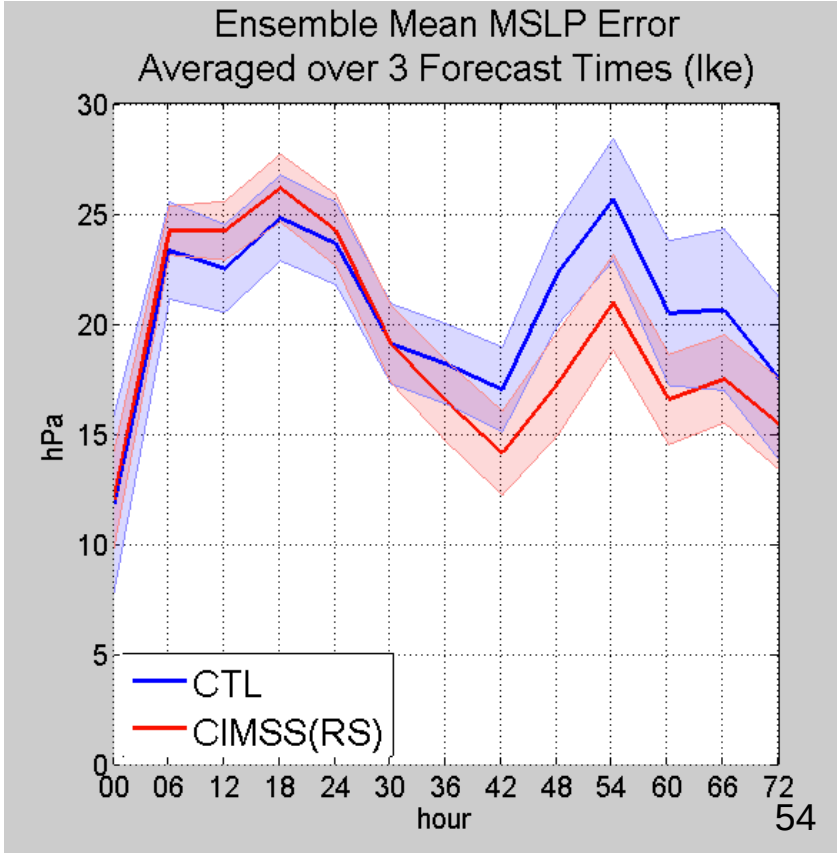
Axisymmetric tangential wind (black contour, 2 ms^{-1} int.), radial wind (shading), vertical motion (green upwards, orange downwards, contour int. = 0.05 ms^{-1}).

Results

Hurricane Ike Track and Intensity Forecasts

WRF-ARW Model Ensemble (84mem) -- CTL vs. CIMSS(RS)
For 3 forecast times: 00UTC on Sept. 2/4/6





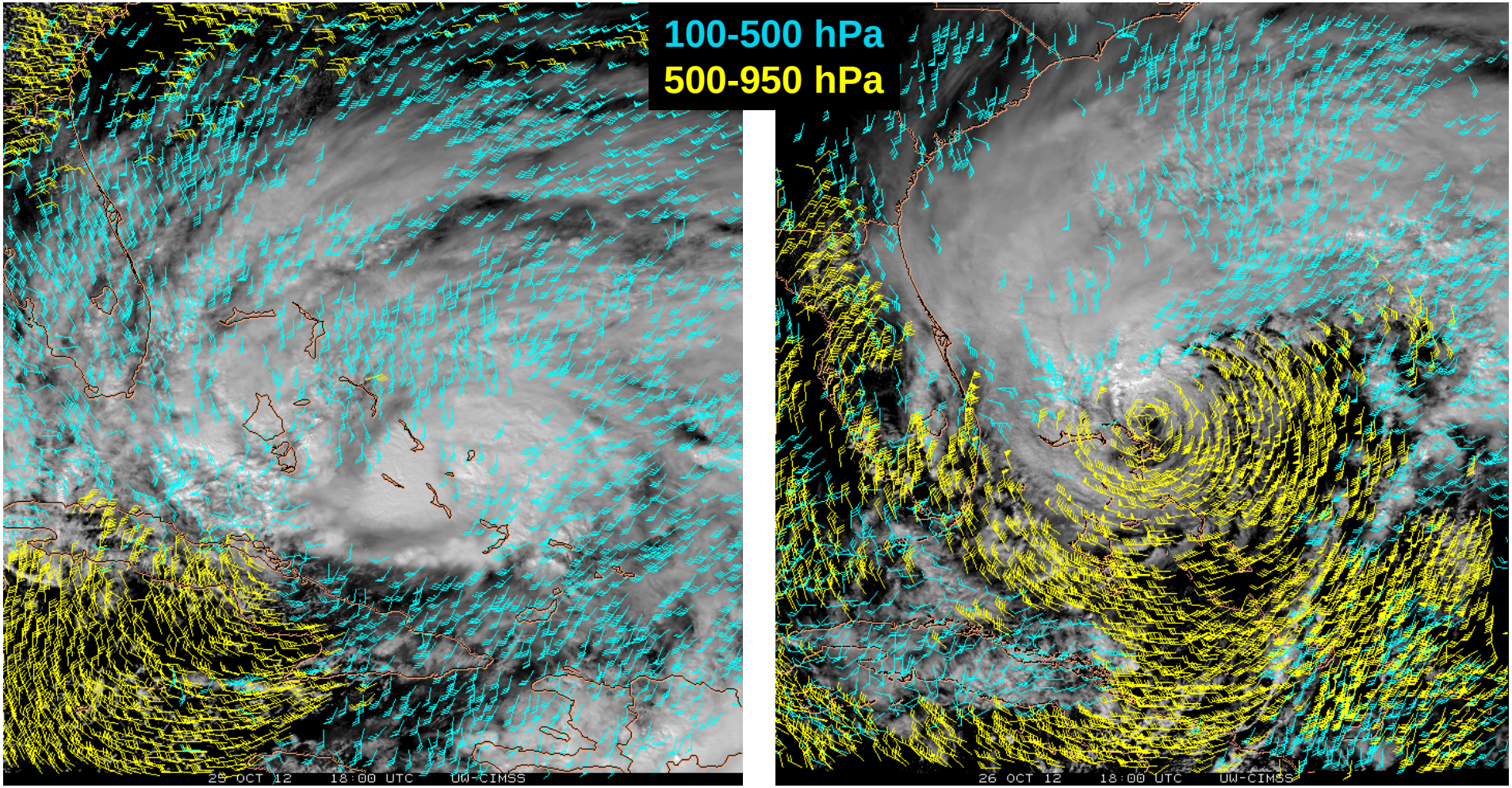
Future Plans & Possible Path to Operations

- These initial studies using the DART/WRF system are demonstrating the potential of enhanced AMVs from GOES to impact TC analyses and forecasts.
- NOAA/HRD is also testing AMV datasets provided by CIMSS for impacts (Tomi Vukicevic).
- Plans are to further test rapid-scan AMV assimilation and impacts in the operational NCEP HWRF and RAP mesoscale model systems in collaboration with EMC and ESRL (GOES-R “Day-1” product readiness).
- A study will be conducted using rapid-scan imagery obtained during Hurricane Sandy. These investigations will employ the GOES-R AMV processing algorithms (AWG and R3 projects).

Near-Future Plans

AMVs from GOES 5-min. rapid-scans during Hurricane Sandy

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



VIS/IR cloud-tracked winds from 5-min image intervals derived using the current NESDIS operational AMV algorithm. Tests using the new GOES-R tracking algorithm in conjunction with data assimilation and model forecast impact experiments are planned.

A near real time JPSS/GOESR data assimilation system

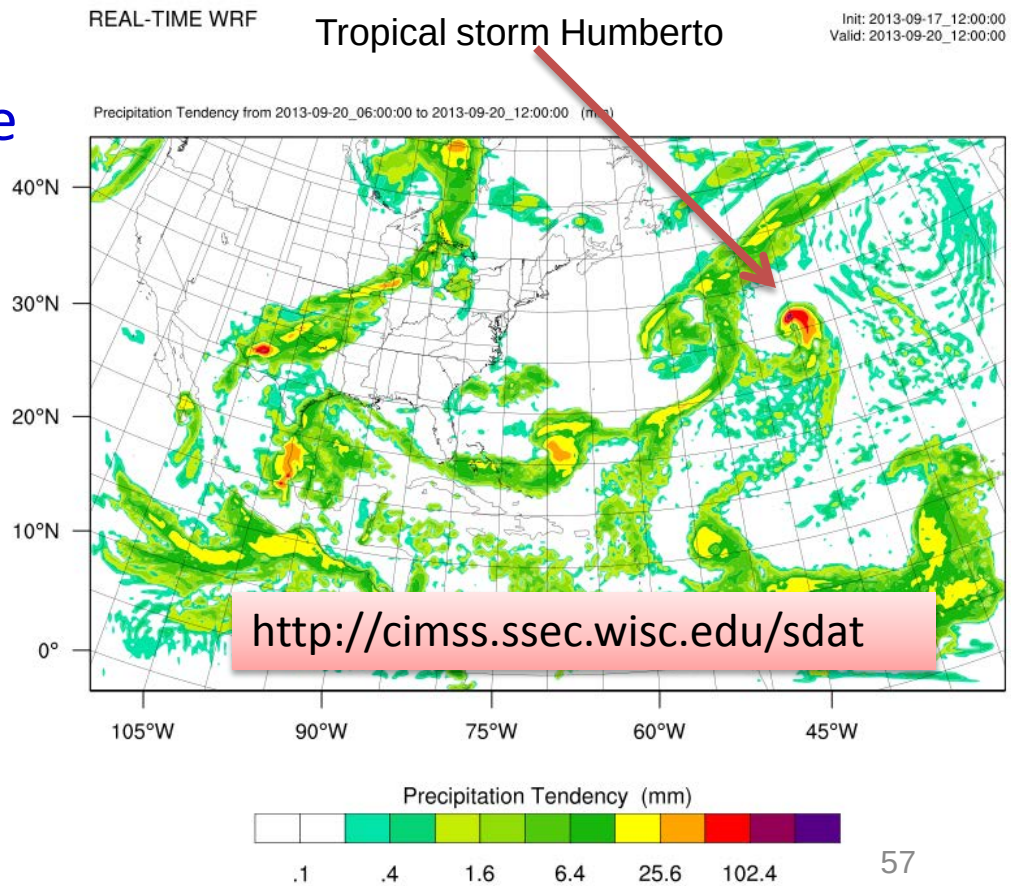
Jun Li@, Jinlong Li@ , Pei Wang@, Tim Schmit&, Zhenglong Li@ , Chris Velden@

@CIMSS/UWn-Madison; &STAR/NESDIS/NOAA

In collaboration with: **Mark DeMaria, John L. (Jack) Beven, Fuzhong Weng etc.**

Acknowledgement: **JPSS PGRR Program, GOES-R HIW Program, JCSDA S4 computer, SSEC Data Center**

- Research to better use of JPSS/GOES-R data in a mesocale NWP model for applications;
- Accelerate the R2O transition
  - offline case studies followed by online demonstration
  - Transfer research progress (e.g., handling clouds, way to use moisture information etc.) to operation with collaborating with NCEP team

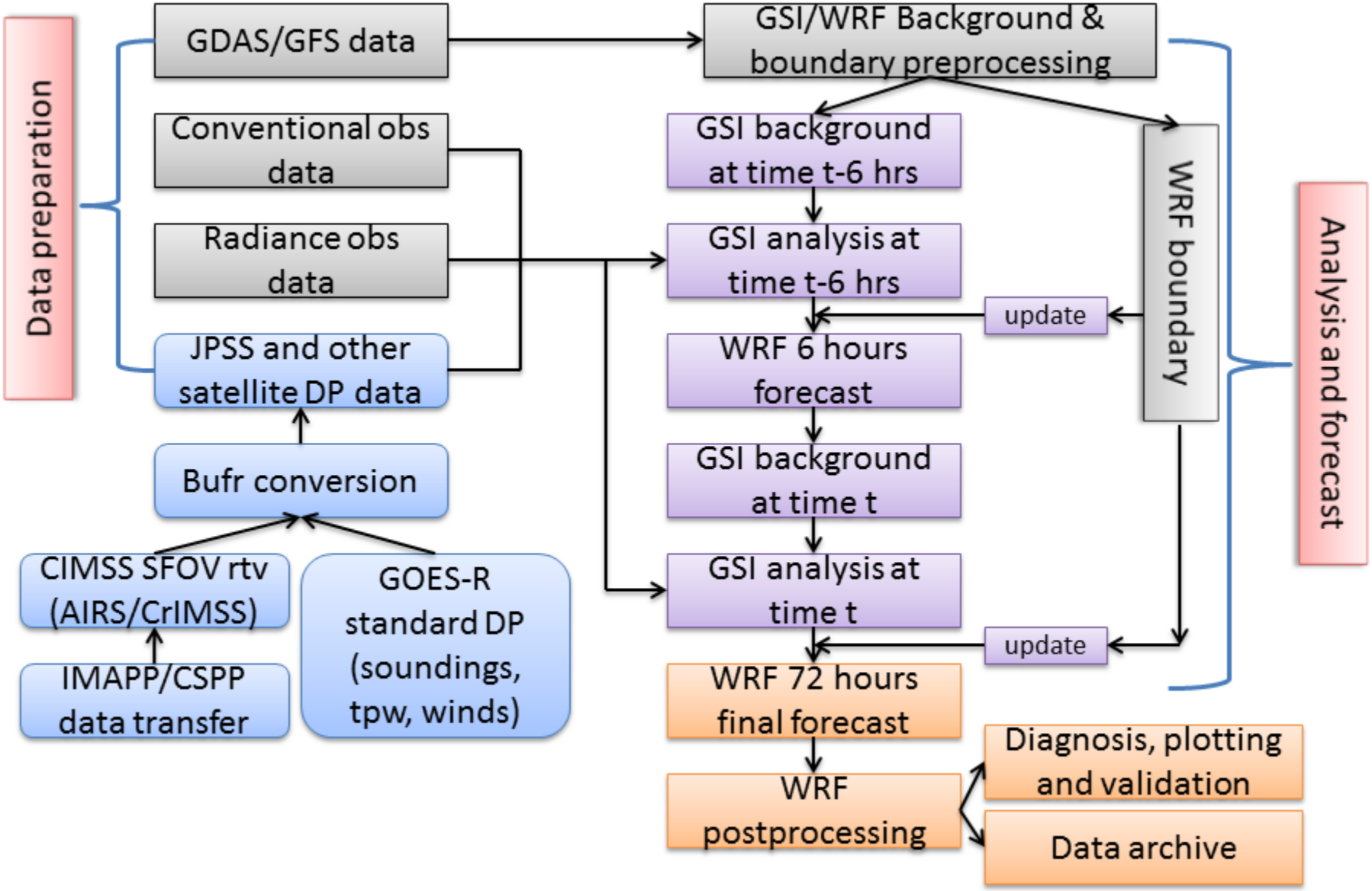


Recent progress

- **A regional Satellite Data Assimilation system for Tropical storm forecasts (SDAT) has been developed and running in near real time (NRT) at CIMSS since August 2013, analysis and evaluation of SDAT are ongoing;**
  - **Based on WRF/GSI;**
  - **Conventional and satellite including AMSU-A (N15, N18, N19, metop-a, aqua), ATMS (Suomi-NPP), HIRS4 (N19, metop-a), AIRS (aqua), IASI (metop), and MHS (N18, N19, metop).**
- **“Tracker" program was implemented since October 2013 for post process;**
- **Layer Precipitable Water (LPW) forward operator has been developed within GSI for assimilating GOES-R water vapor information;**
- **Research progress has been made using SDAT on**
  - **radiance assimilation versus sounding assimilation;**
  - **handling clouds when assimilating radiances.**

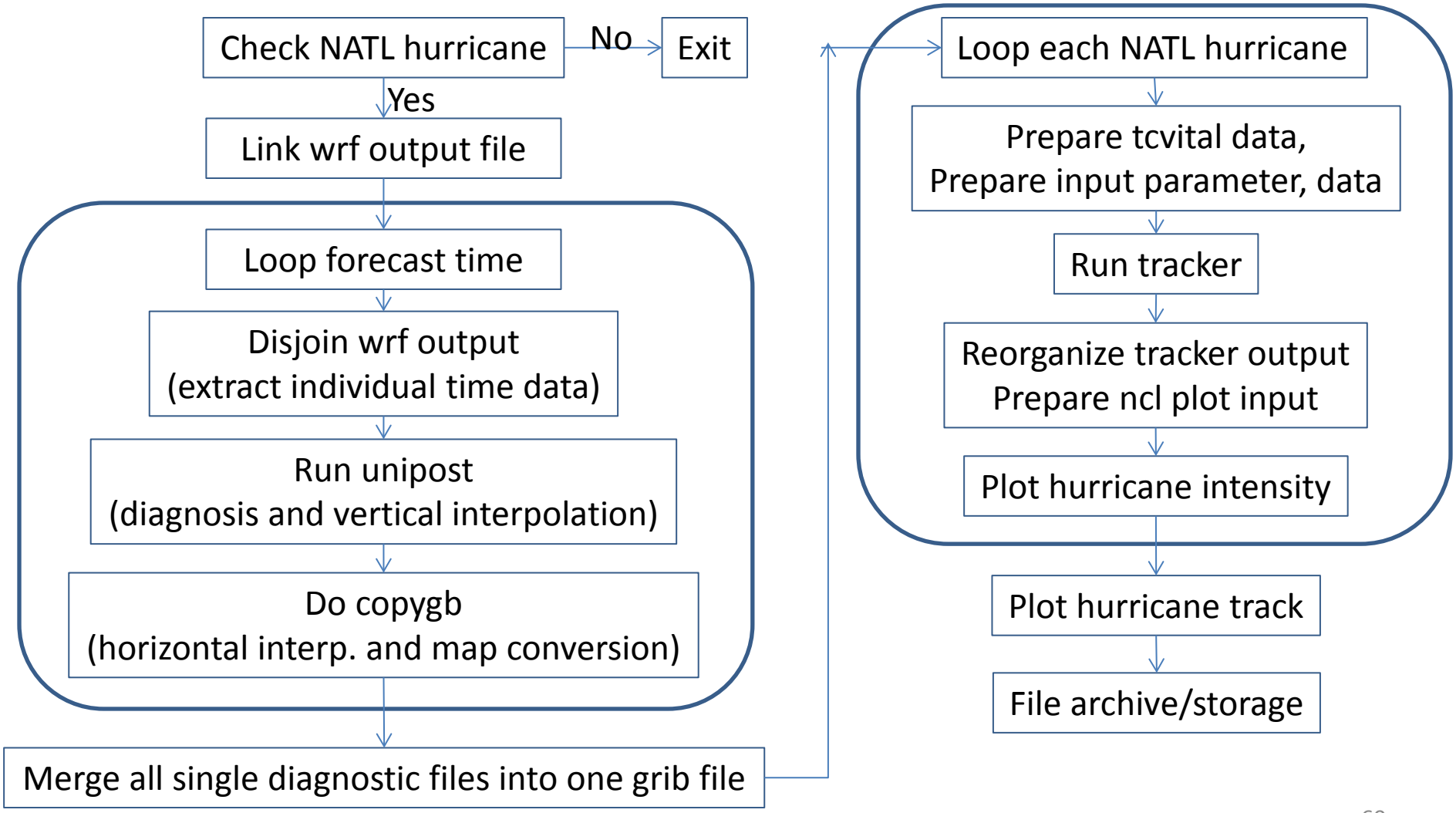
Satellite Data Assimilation for Tropical Storms (SDAT) – A real time system based on WRF/GSI

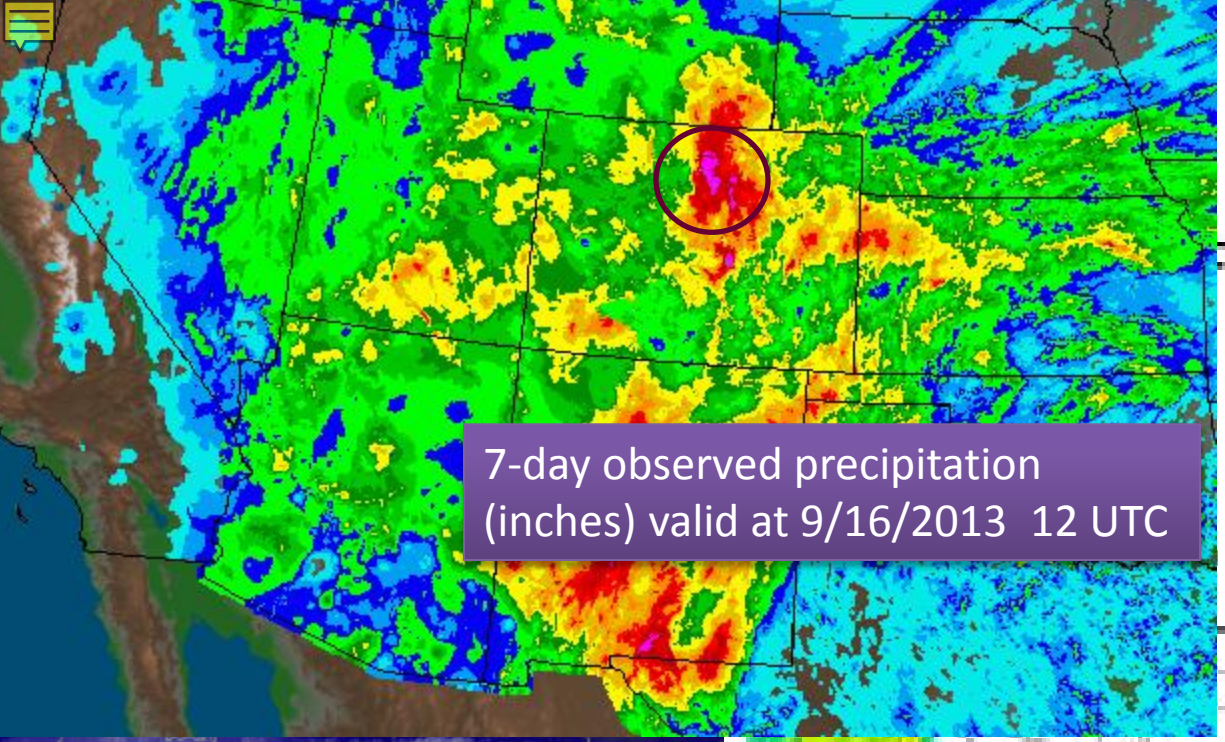
http://cimss.ssec.wisc.edu/sdat



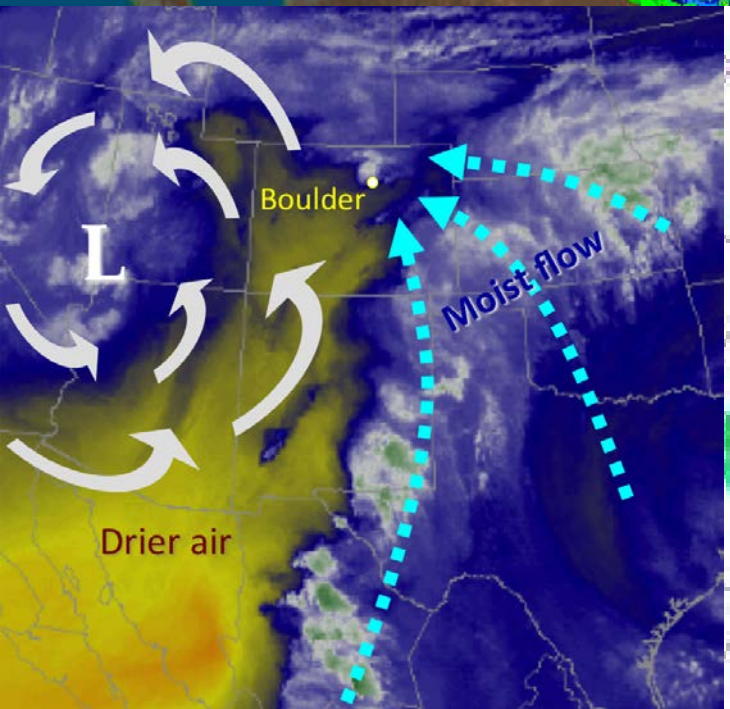
GFDL vortex tracker v3.5b (released Sept. 16, 2013) was implemented in SDAT

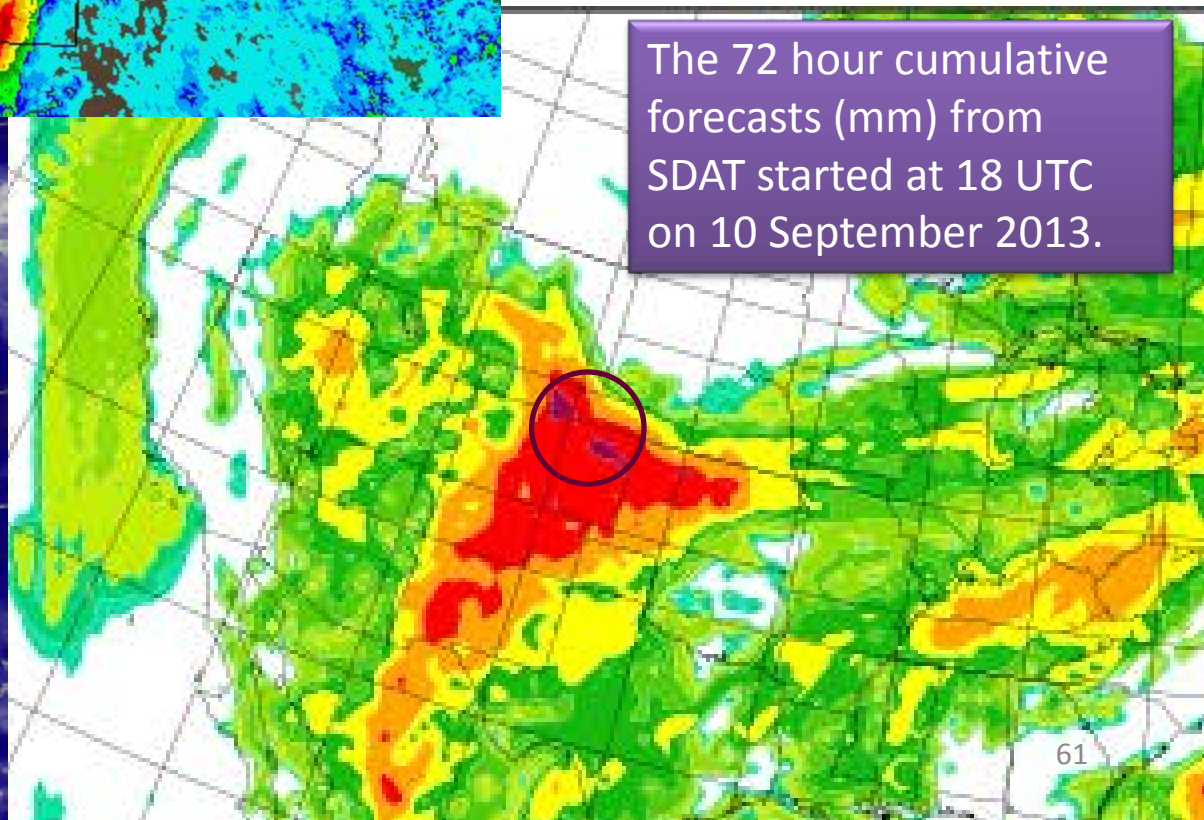
(Flow chart to run tracker)

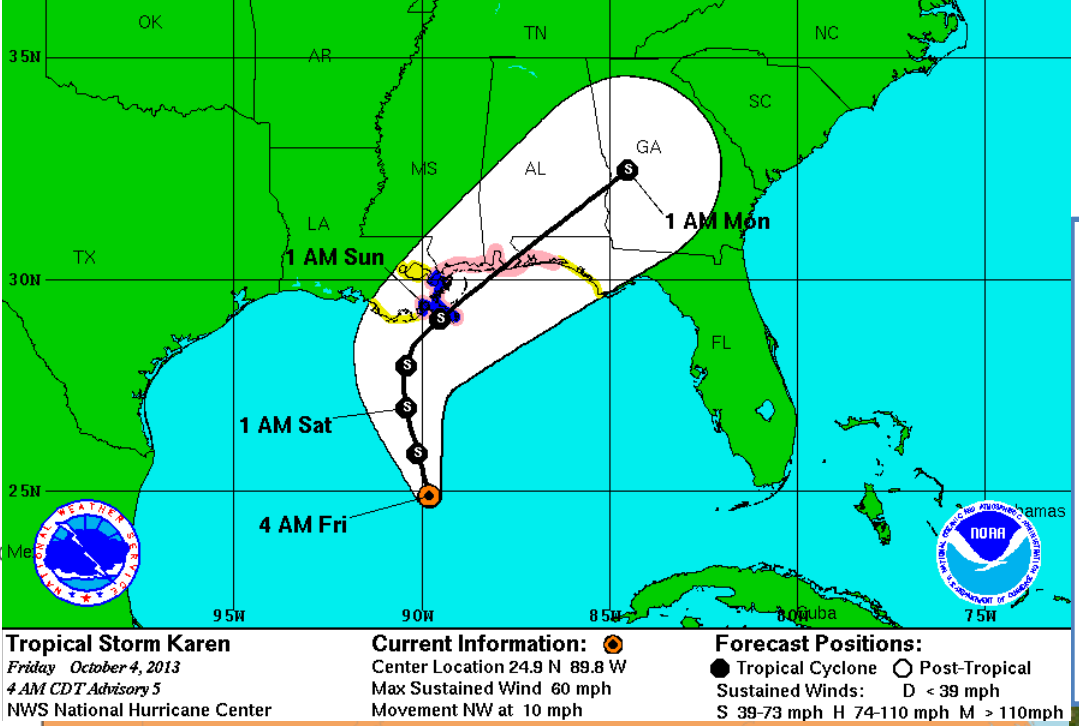




During the week starting on September 9, 2013, a slow-moving cold front stalled over Colorado, clashing with warm humid monsoonal air from the south. This resulted in heavy rain and catastrophic flooding along Colorado's Front Range from Colorado Springs north to Fort Collins. The situation intensified on September 11 and 12. Boulder County was worst hit, with 9.08 inches (231 mm) recorded September 12 and up to 17 inches (430 mm) of rain recorded by September 15, which is comparable to Boulder County's average annual precipitation (20.7 inches, 525 mm).



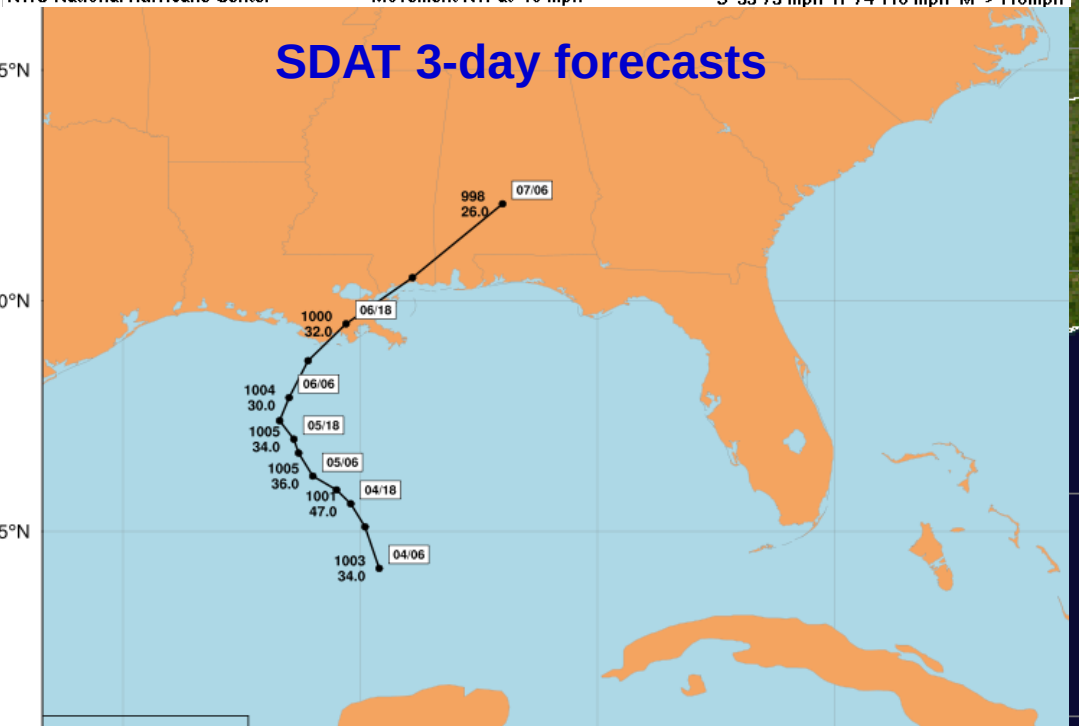


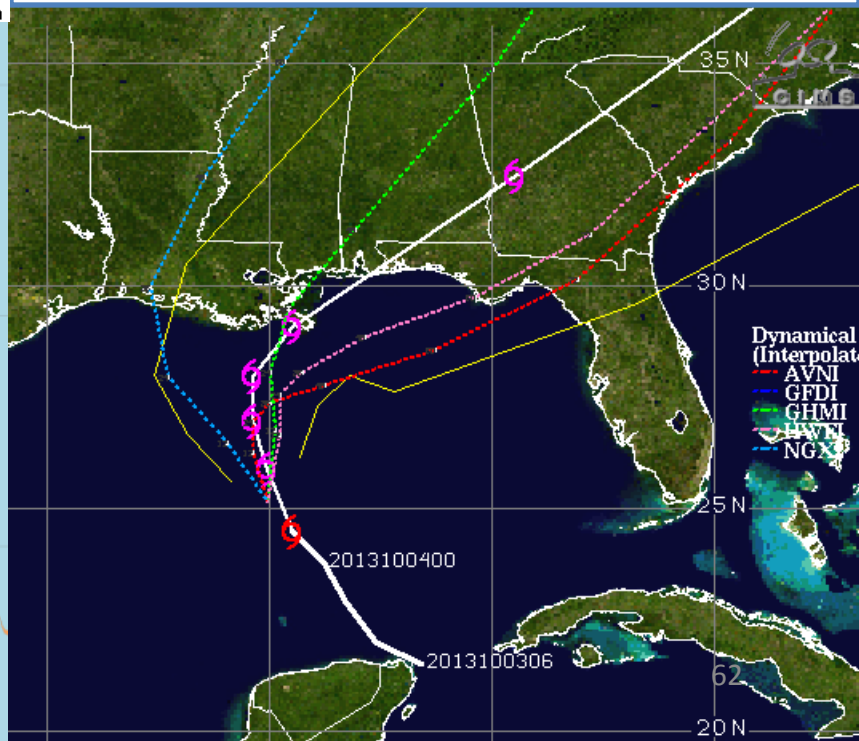


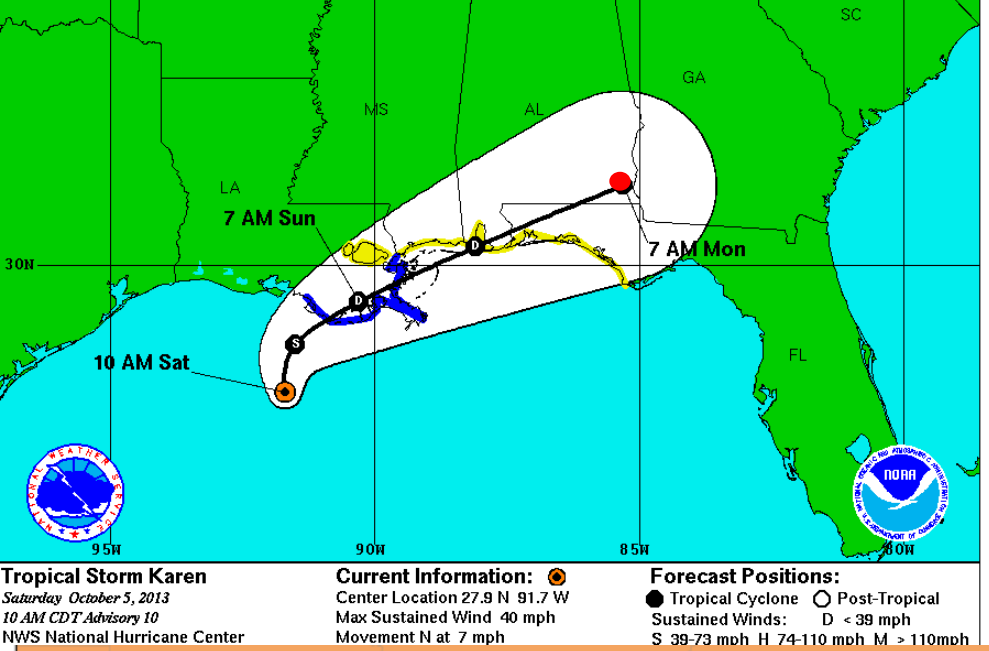
Upper Left: NHC 4 AM CDT Advisory (Friday 04 October 2013)

Lower left: SDAT track forecasts started at 06 UTC 04 October valid 06 UTC 07 October 2013)

Lower right: Other dynamic models



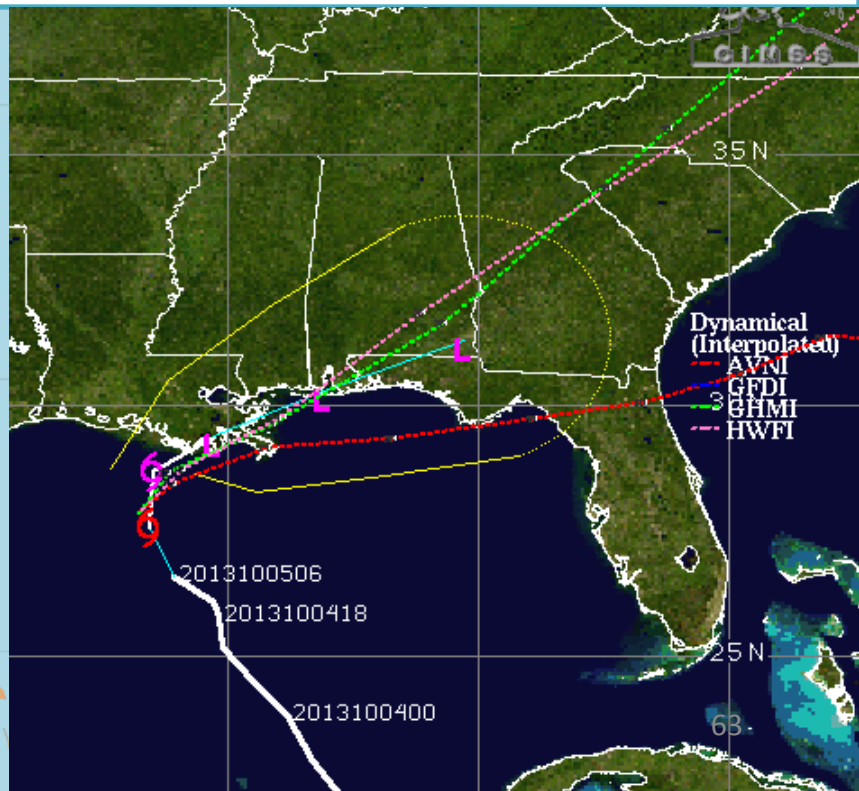




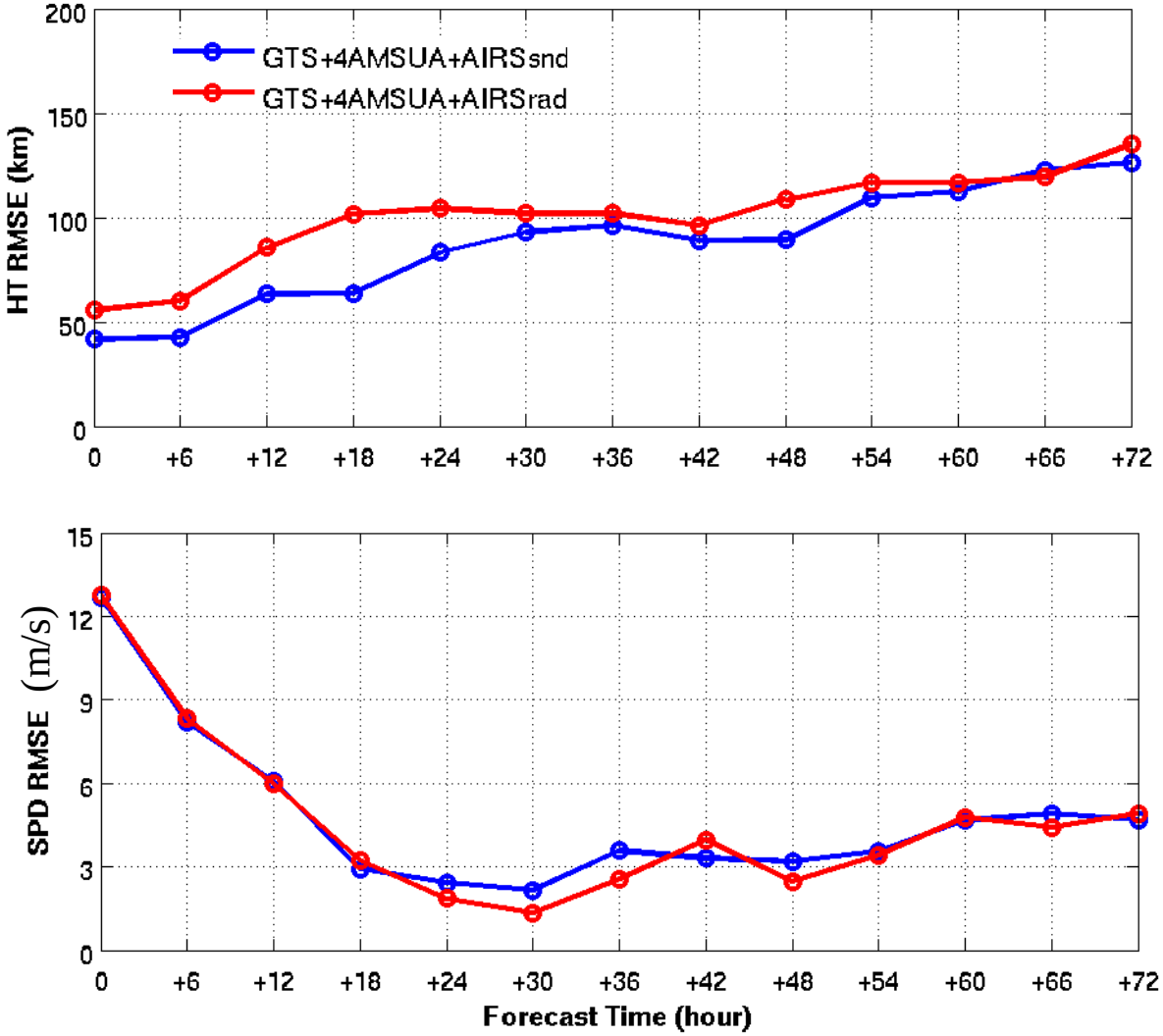
Upper Left: NHC 10 AM CDT Advisory (Saturday 05 October 2013)

Lower left: SDAT track forecasts started at 12 UTC 05 October valid 12 UTC 08 October 2013)

Lower right: Other dynamic models



Radiance assimilation versus sounding assimilation – Sandy (2012) forecast experiments

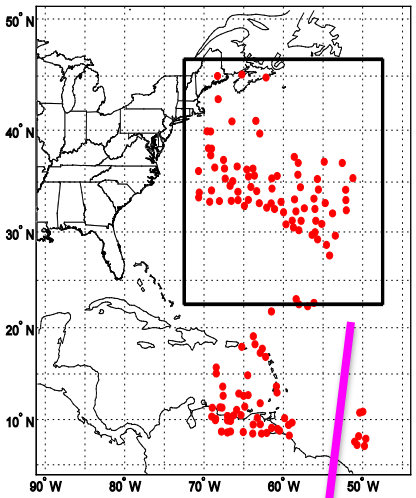


"On the Equivalence between Radiance and Retrieval Assimilation"

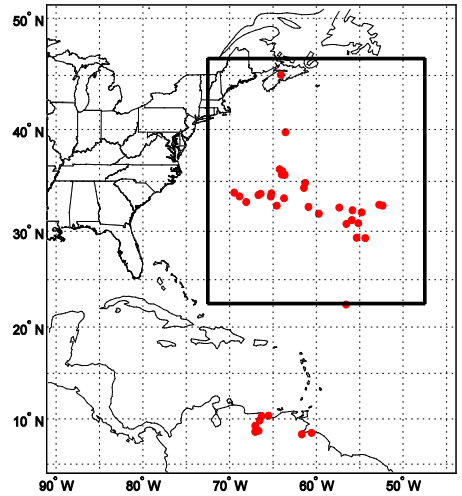
By Migliorini (2012) (University of Reading) – *Monthly Weather Review*

"Assimilation of transformed retrievals may be particularly advantageous for remote sounding instruments with a very high number of channels or when efficient radiative transfer models used for operational assimilation of radiance measurements are not able to model the spectral regions (e.g., visible or ultraviolet) observed by the instrument."

AIRS stand-alone cloud detection

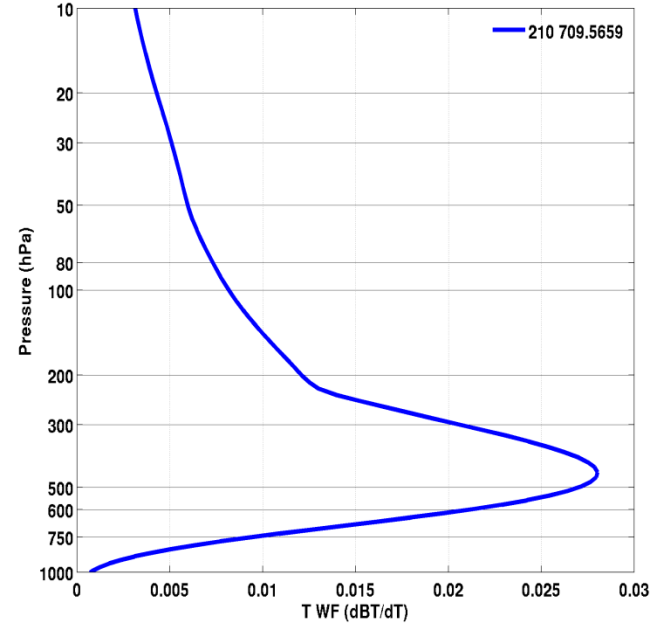


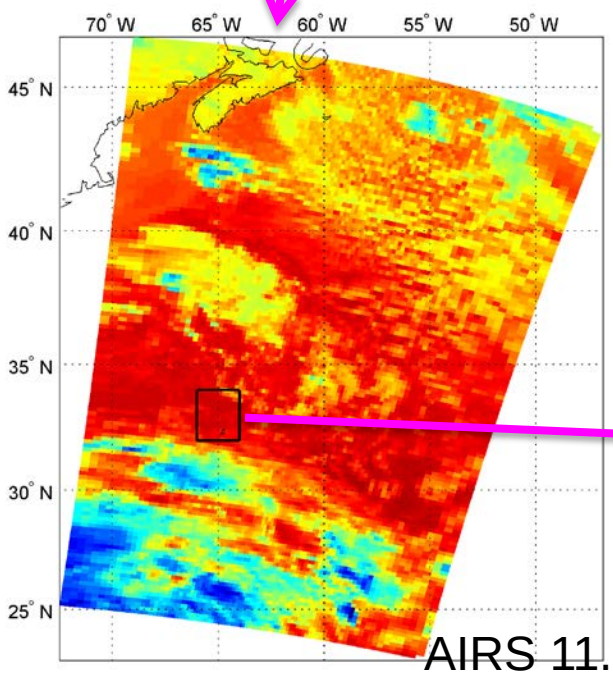
MODIS cloud detection



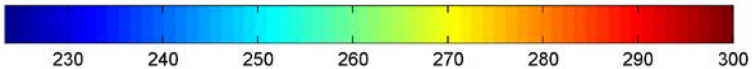
AIRS data at 06 UTC 25 October 2012 (Sandy)

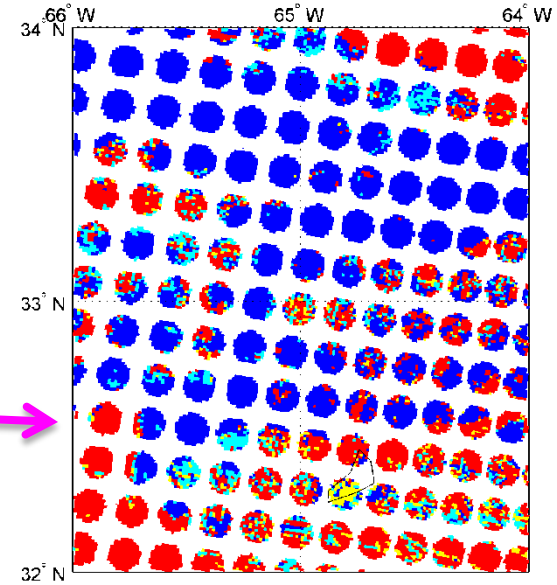
Channel Index 210, Wave number 709.5659





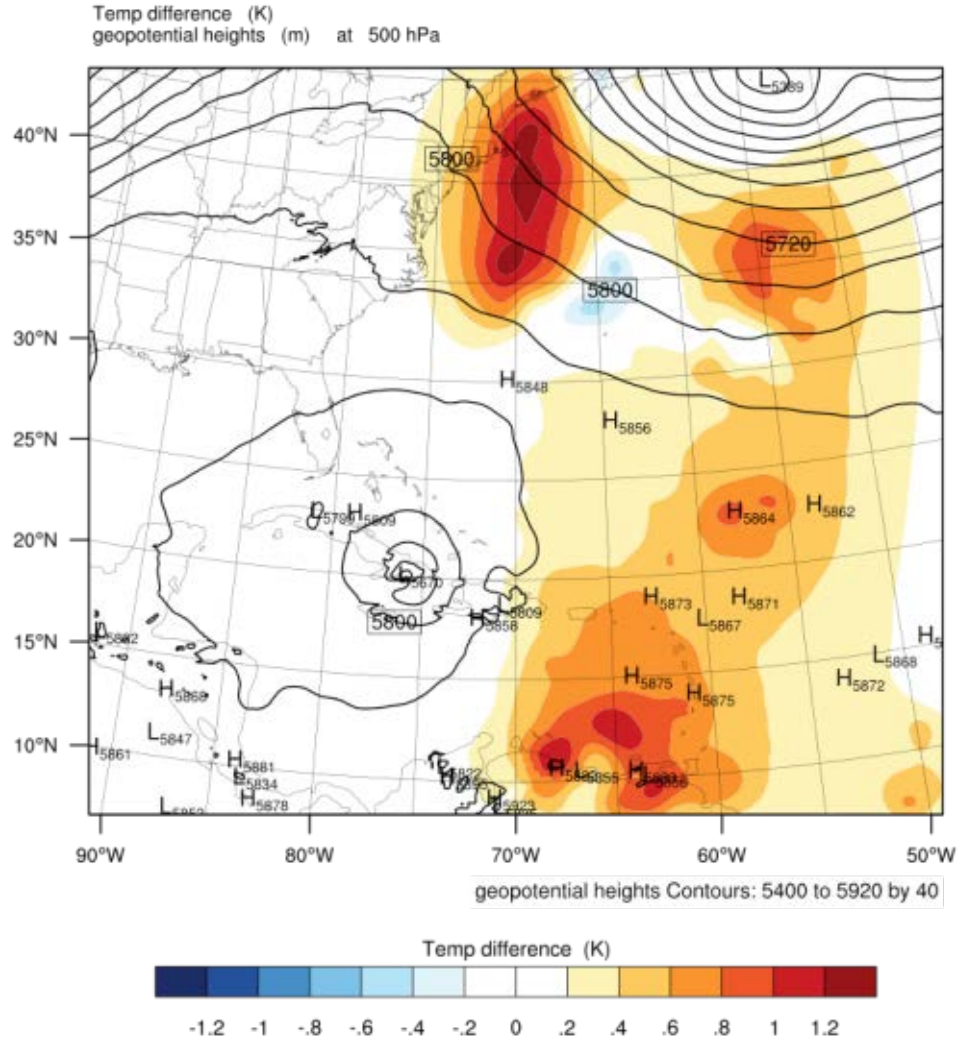
AIRS 11.3 µm BT (K)

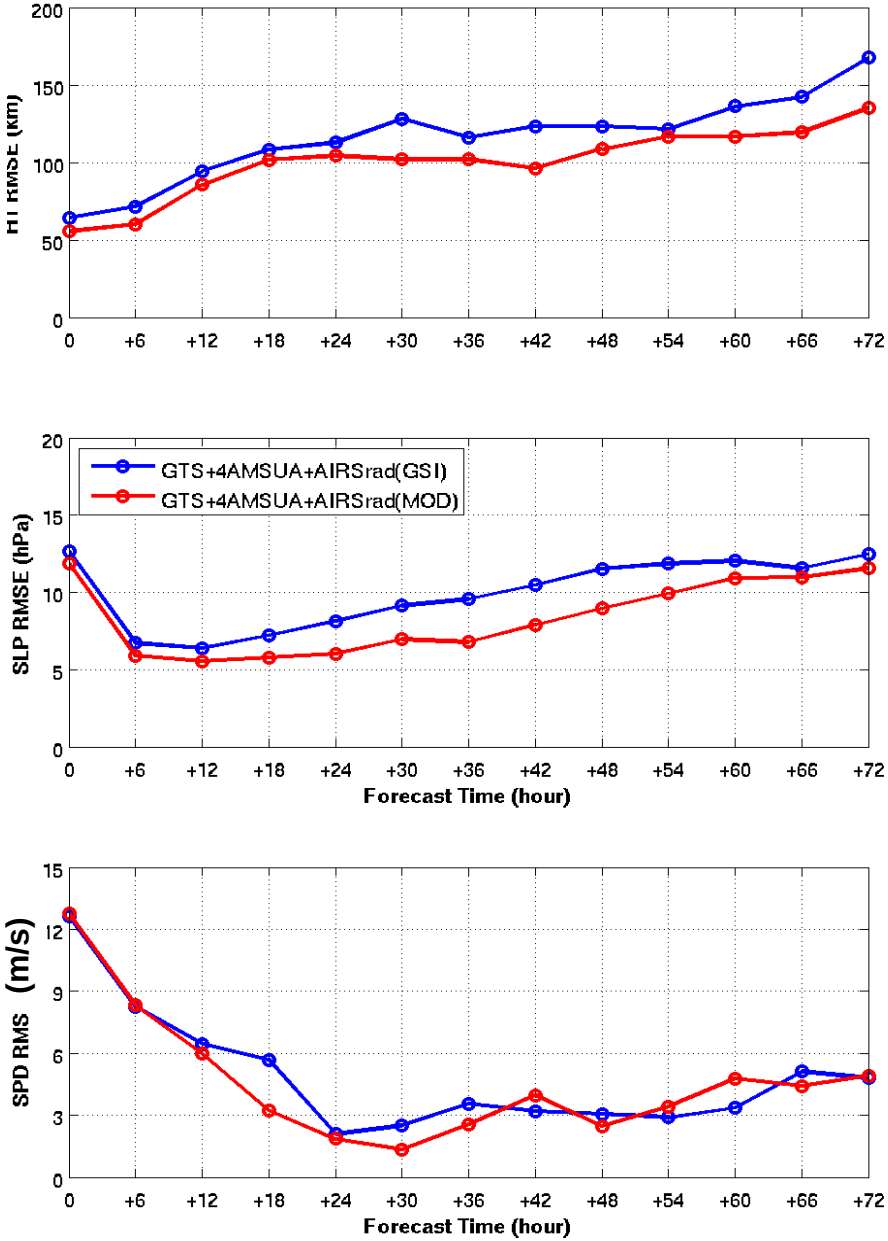




AIRS sub-pixel cloud detection with MODIS

Hurricane Sandy (2012) forecast RMSE





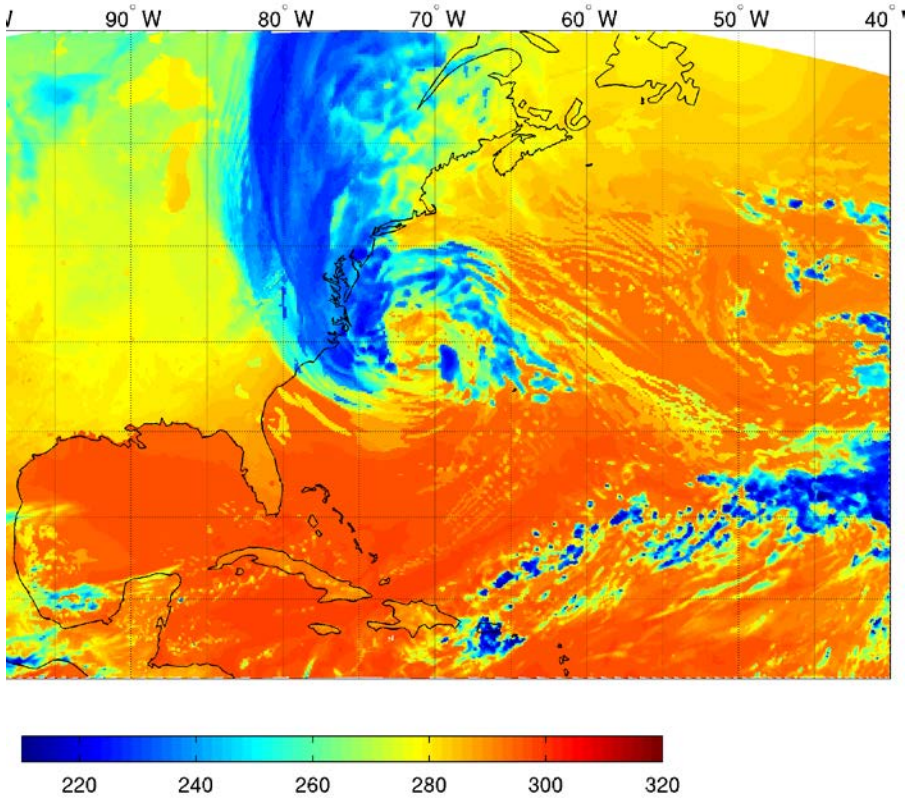
500 hPa temperature analysis difference

(AIRS(MOD) - AIRS(GSI))

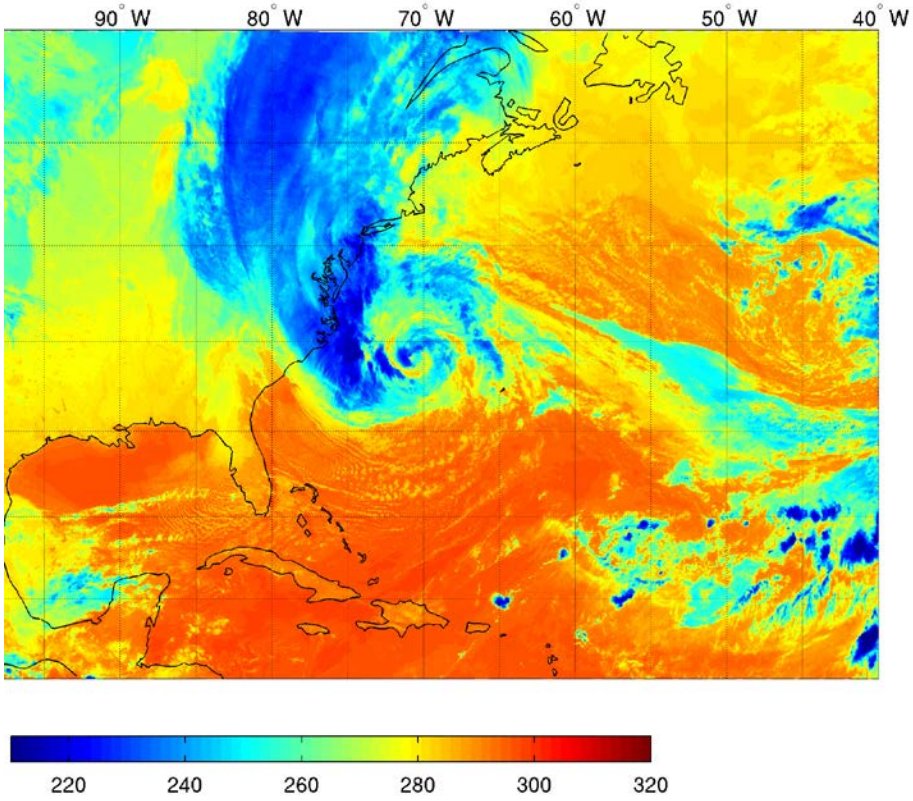
72-hour forecasts of Sandy from 06z 28 to 00z 30 Oct, 2012

Sandy forecast verification

This verification with GOES Imager will be in NRT soon in SDAT



Simulated GOES-13 Imager 11 µm BT from SDAT experimental forecasts



GOES-13 Imager 11 µm BT observations

Future work

- Implement PW assimilation in SDAT and get ready for GOES-R;
- Continue research on handling clouds, using AMVs and high temporal moisture information;
- Simulated GOES imager (11 and 6.7 μm) from forecasts in real time;
- Applications (collaborating with CIRA etc.)
  - Proving ground next hurricane season to get the track/intensity information in the Automated Tropical Cyclone Forecast (ATCF) system that NHC uses;
  - Potential use of SDAT products in CIRA's statistical model.
- R2O transition (collaborating with EMC on using hybrid GSI and HWRF etc.)

Tropical Cyclone Data Assimilation Research at AOML/HRD

Tomislava Vukicevic

Robert Atlas, Altug Aksoy,
Sim Aberson, Lisa Bucci, Bachir Annane, Javier Delgado, Xuejin Zhang and Sundararaman Gopalacrishnan

Collaboration with JCSDA, NASA-GFSC, NOAA-ESRL, JPL and CIMSS

Major DA research activities at AOML

- Vortex-scale data assimilation using HEDAS (HWRF Ensemble Data Assimilation System) with airborne and satellite observations
  - Impact of high resolution airborne observations and satellite-based data products within TC core region on HWRF forecasts

- Regional OSSEs with different DA options for study of
  - Relative impact of alternative concepts for space-based lidar winds
  - Relative impact of alternative concepts for polar and geostationary hyperspectral sounders
  - Potential impact of unmanned aerial systems
- DA options include: GSI, GSI-hybrid and HEDAS algorithms

Focus on improving HWRF forecasts

- Operational HWRF modeling system is used
- Model configuration in terms of nest size, number of nests and spatial resolution depends on specific requirements of DA experiment
- These configurations are typically more advanced than the current operational configuration
- HWRF model version in terms of physical parameterizations is set as close as possible to the operational version

VORTEX SCALE DA

VORTEX-SCALE HURRICANE DATA ASSIMILATION
NOAA/AOML/HRD's
HURRICANE ENSEMBLE DATA ASSIMILATION SYSTEM (HEDAS)

- An ensemble-based **EnKF** data assimilation system **interfaced with NOAA's HWRF model (2012 version, no ocean)**
- Ran **near real time in 2013** on NOAA's Jet supercomputer (supported by **NOAA HFIP project**)
- Focuses on **data assimilation in the hurricane inner core** (in a 3-km inner nest)
- **Assimilates aircraft data** (radar, dropsonde, flight level, SFMR surface wind speed) from NOAA P-3 and G-IV, Air Force Reserve C-130, and NASA Global Hawk aircraft, **and satellite AMVs, AIRS and GPS-RO retrieved T/Q profiles**
- Published papers: Aksoy et al. (MWR, 2012 & 2013); Aksoy (MWR, 2013); Vukicevic et al. (MWR, 2013)

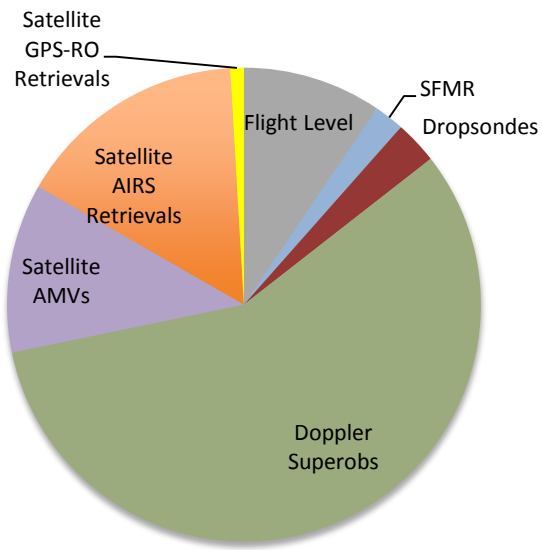
HEDAS implementation

- Near real time experimental analysis and forecast during hurricane season since 2010
- Assimilation of satellite-based data since 2013 season
- Retrospective multi-season DA experiments

2013 HEDAS
ASSIMILATED OBSERVATIONS – SUMMARY BY PLATFORM

Platform	Num. Obs.	Num. Cases	Avg. Num. Obs.
Flight Level	75,826	36	2,106
SFMR	15,459	34	455
Dropsondes	21,420	33	649
Doppler Superobs	267,310	21	12,729
Satellite AMVs	112,749	44	2,562
Satellite AIRS Retrievals	80,589	23	3,504
Satellite GPS-RO Retrievals	4,992	24	208
Total	**578,345**	**44**	**13,144**

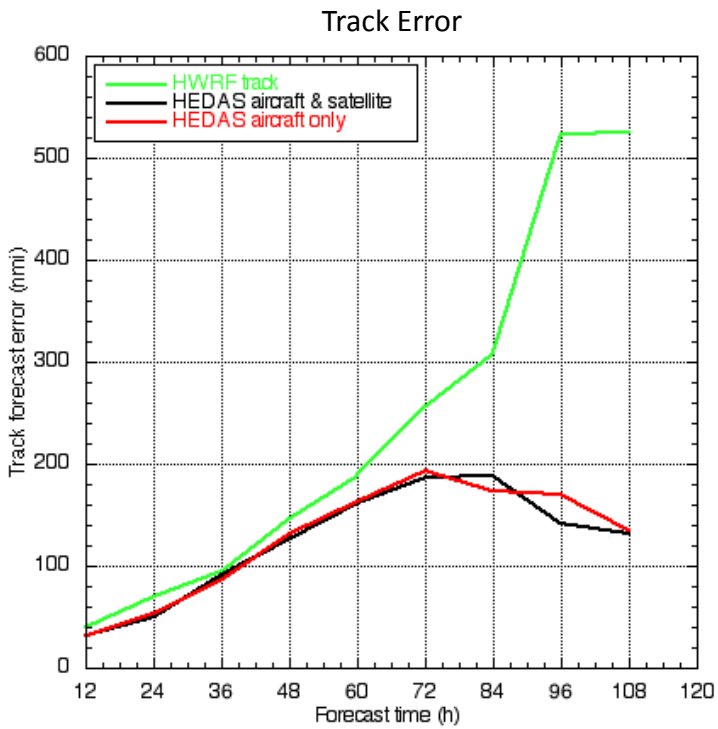
Case-Averaged Num. of Observations

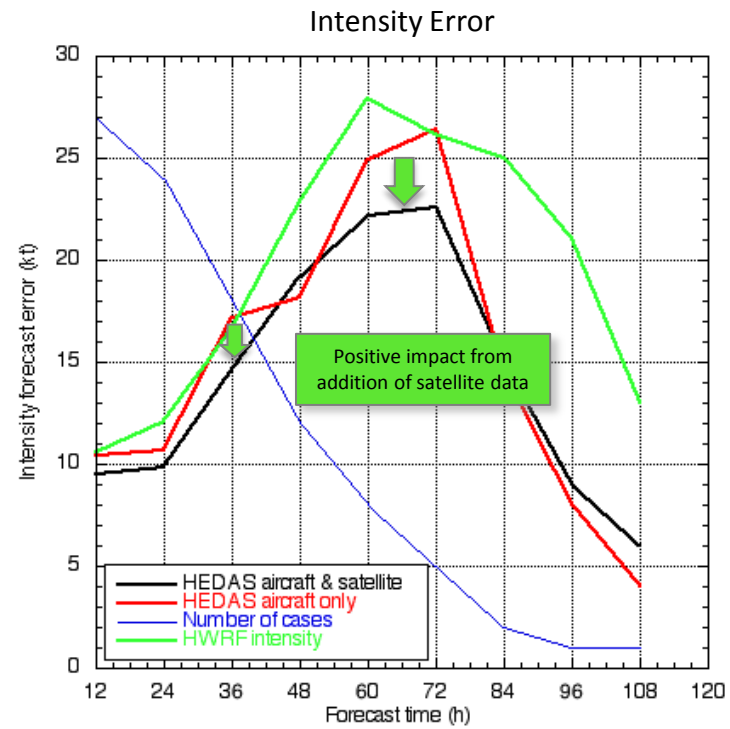


- Doppler wind superobs the majority of data, but only when P-3 or G-IV missions underway, which is less than half of the total cases.
- **AMVs not only provide a good number of data points, but they were also available in *all* of the cases.**
- **Although not as readily available, AIRS retrievals provide more thermodynamic observations than dropsondes when available.**

By Altug Aksoy (NOAA/AOML/HRD & U. Miami/CIMAS)

IMPACT OF SATELLITE OBSERVATIONS
ALL DATA (AIRCRAFT + SATELLITE) vs. AIRCRAFT ONLY





- In 2013, HWRF forecasts initialized with the HEDAS vortex analyses outperformed operational HWRF forecasts both for track and intensity.
- The addition of satellite data to aircraft data improves forecasts especially for intensity for the first 72 h.
- Another positive impact not reflected in the statistics is that with satellite data, the model inner nest was better able to follow the storms.

By Sim Aberson (NOAA/AOML/HRD) and Altug Aksoy (NOAA/AOML/HRD & U. Miami/CIMAS)

Regional OSSE system

REGIONAL OBSERVING SYSTEM SIMULATION EXPERIMENT OBJECTIVES FOR TCs

1. Evaluate the potential impact of new (proposed) observing systems on hurricane track and intensity predictions.

2. Evaluate tradeoffs in the design and configuration of proposed observing systems (e.g. coverage, resolution, accuracy and data redundancy).

3. Optimize sampling strategies for current and future airborne and space-based observing systems.

4. Evaluate and improve data assimilation and vortex initialization methodology for hurricane prediction.

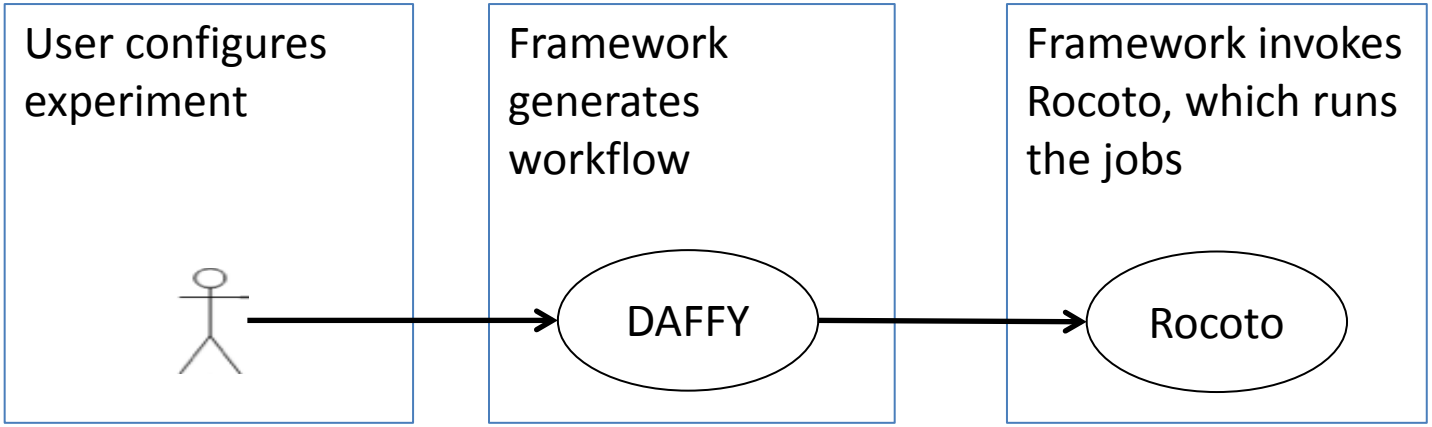
AOML's REGIONAL TC OSSE/OSE SYSTEM

Nature run: WRF ARW embedded within ECMWF T511 Global nature run

- **Numerical Assimilation and Forecast Model:**
  - NOAA's Hurricane Weather Research and Forecasting (HWRF) Model
    - Operational TC forecast model
    - WRF-NMM dynamical core with storm-following grid nesting
- **3 options for data assimilation:**
  - 3DVAR with NOAA Gridpoint Statistical Interpolation (GSI)
    - Assimilation of conventional and satellite observations
    - Satellite radiances are used only in cloud-clear conditions
    - Grid-point-based static background errors
    - Need new development for assimilation of airborne and cloudy radiance observations
  - Hybrid 3DVAR with NOAA's GSI-Hybrid data assimilation system
    - Same capability for observations as GSI
    - Applies weighting between ensemble-based and static background errors
    - Ensemble perturbations updated by an EnKF
    - Need new development for assimilation of airborne and cloudy radiance observations
  - Ensemble Kalman Filter with NOAA/AOML/HRD Hurricane Ensemble Data Assimilation System (HEDAS)
    - EnKF
    - Developed in AOML as a research tool to study assimilation of TC airborne observations
    - Need new development for assimilation of satellite radiance observations

Advanced OSSE system software configuration

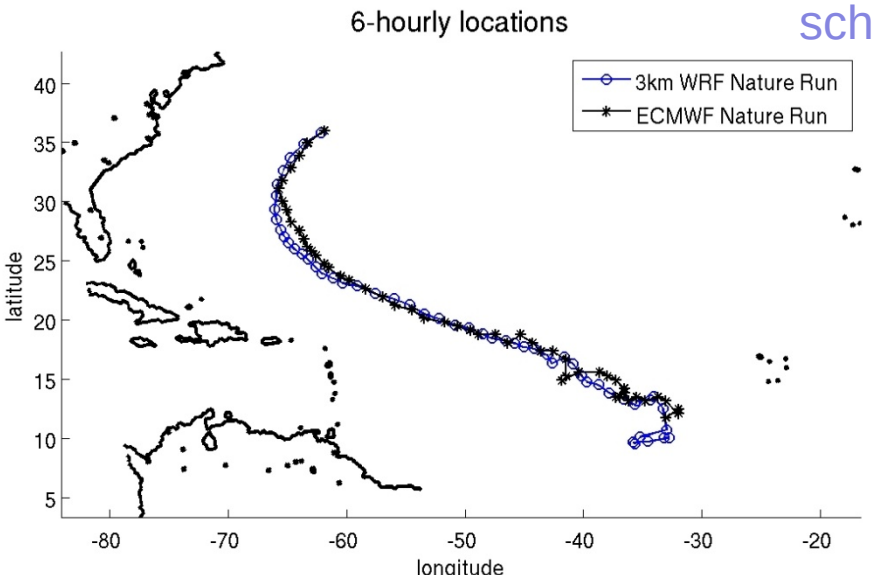
- The workflow engine (Rocoto) is used to manage the workflow (i.e. runs tasks/jobs once dependencies are met)
- DAFFY (Data Assimilation Framework For You) creates the workflow definition and provides the scripts that perform each task

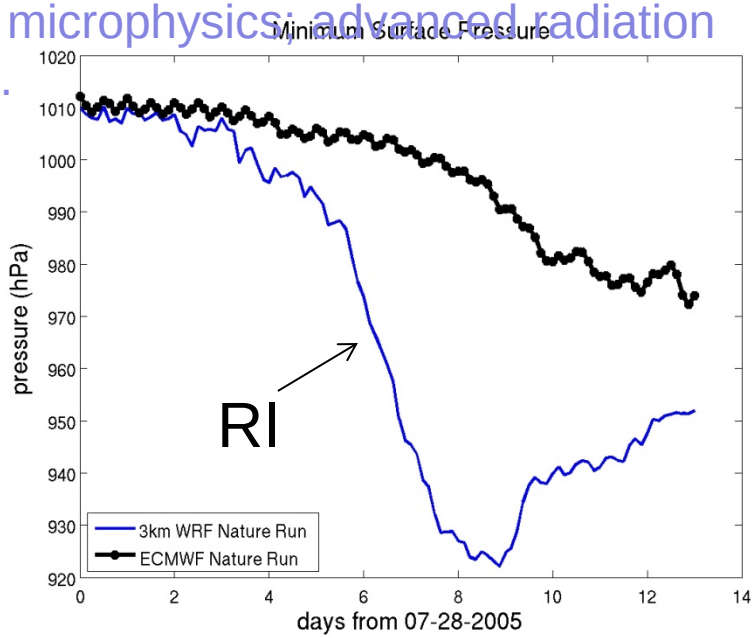


Rocoto: http://rdhpcs.noaa.gov/rocoto

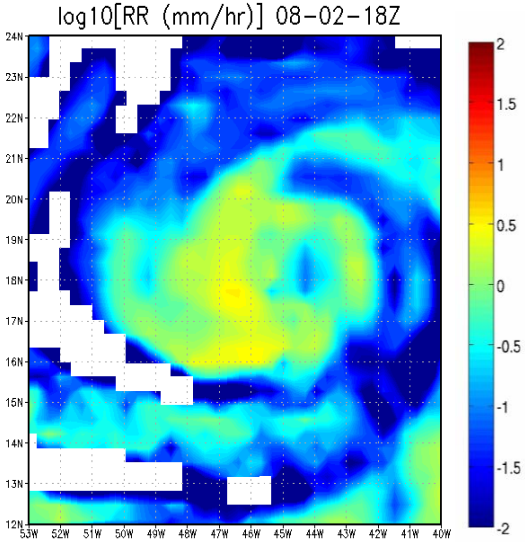
High Resolution Hurricane Nature Run: WRF Simulation Embedded Inside the ECMWF Nature Run

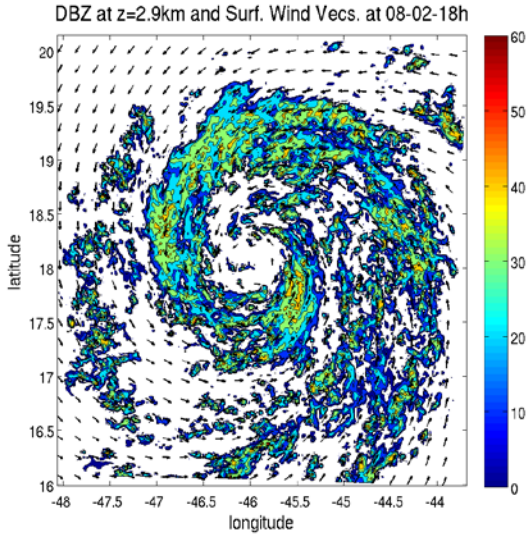
60 levels; 1km resolution; double-moment microphysics; advanced radiation schemes.





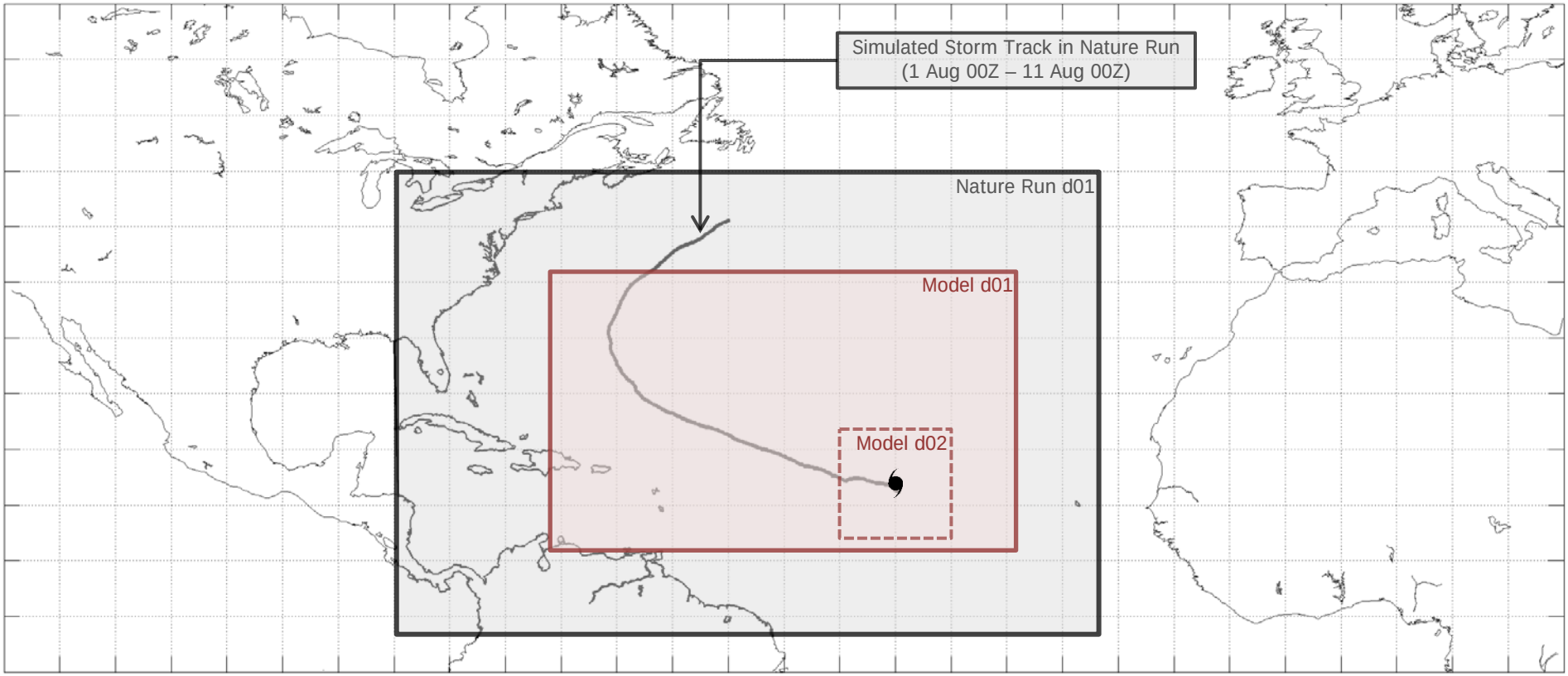
ECMWF T511 Nature Run





1 km WRF-ARW Nature Run

MODEL DOMAIN CONFIGURATION IN OSSEs

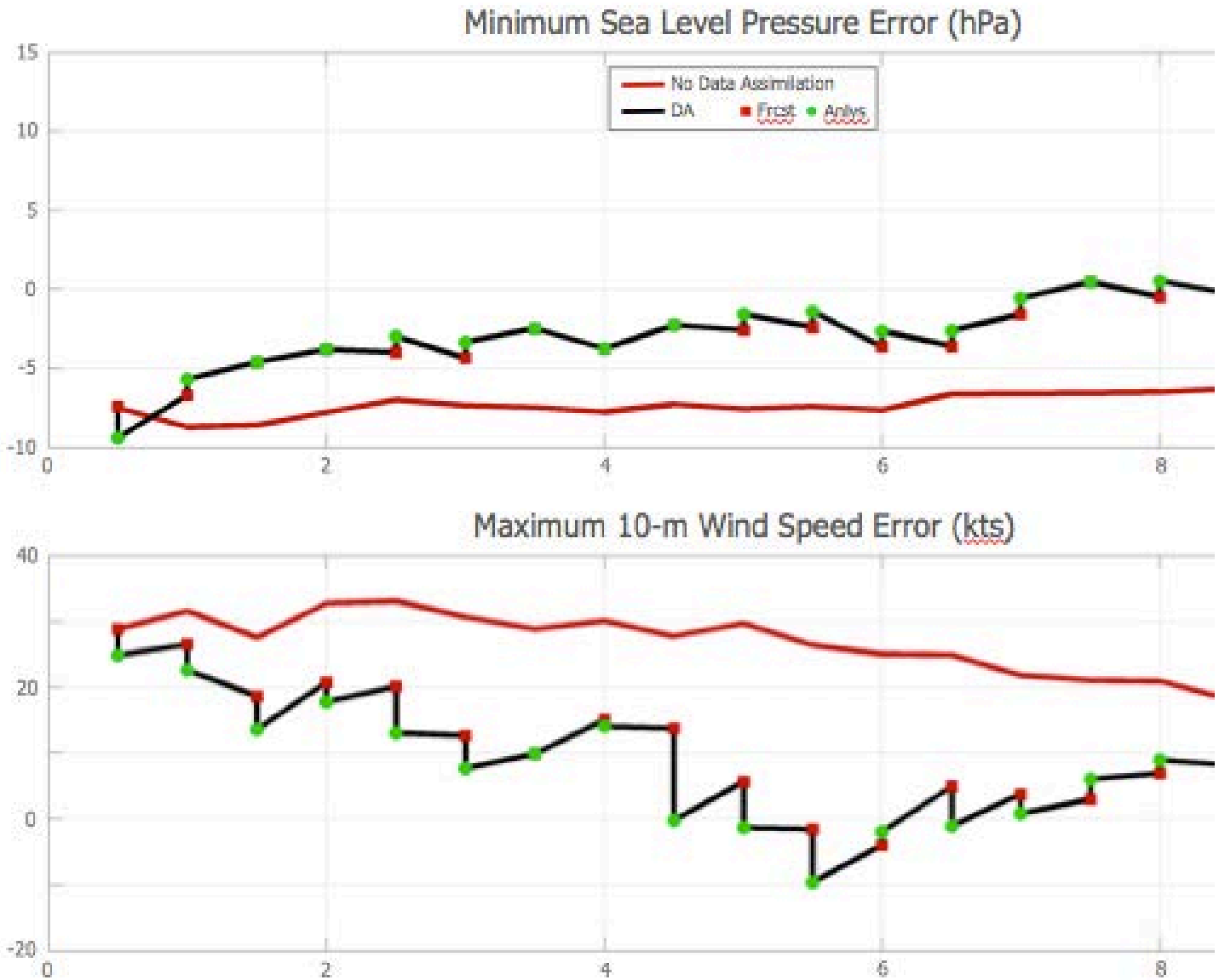


- **Outer domain (d01):**
  - Analysis domain
  - Fits within the Nature Run outer domain & tries to capture most of storm life cycle
  - 9 km horizontal grid spacing (708x412 grid points)
  - 61 vertical levels
- **Inner domain (d02):**
  - Only active during forecasts
  - Storm-following moving nest
  - 3 km horizontal grid spacing (352x340 grid points, ~10°x10°)
  - 61 vertical levels

Recent and ongoing OSSEs

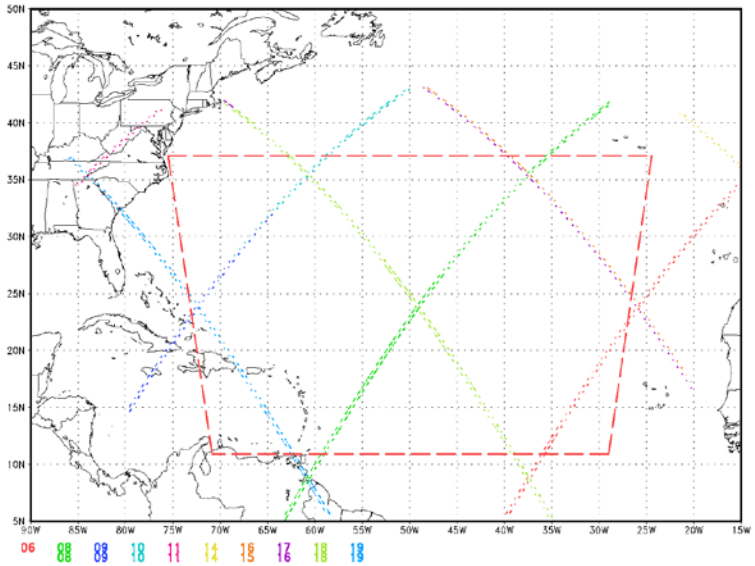
- GeoStorm – hyperspectral retrievals
- Space-based wind lidar
- Gestationary hyperspectral radiances (GeoAIRS)

Preliminary results: Impact of GeoStorm data on TC analysis

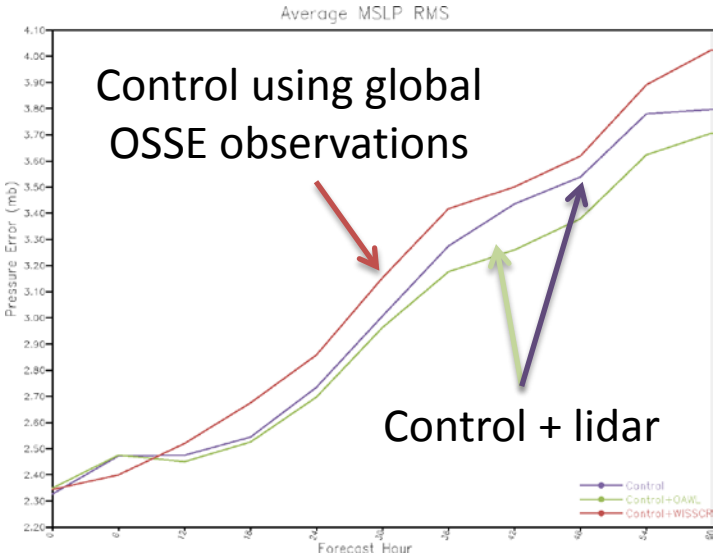


Impact of lidar winds using GSI (AOWL and WISSCR)

Observation tracks



MSLP forecast errors



Summary

- Results are encouraging but there is lots more to do
- Optimize DA options
  - Global ensemble DA data needed for LBCs
  - Background and observation error statistics
- Validate the OSSE system
  - Lack of the standard current TC DA system to compare to
- Develop capability for radiance assimilation in all sky conditions: cloudy and clear

Overall Summary

- Considerable effort underway to assimilate Geo and Leo satellite data in regional-scale hurricane models
- Funding from JPSS, GOES-R, HFIP, NESDIS-base, OAR-base, + others
- Coordination needed to insure that new capabilities are transitioned to NCEP operations