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All-sky satellite radiance assimilation using NOAA operational HWRF and a regional Hybrid Ensemble-Variational Data Assimilation system

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1. Motivation

- Over the past two decade, TC intensity and inner-core convective structure forecasts remain a challenge for most operational NWP models.
- Evaluate the impact of all-sky satellite observations assimilation in TC inner-core area analysis and forecast.
- Use a prototype hybrid variational-ensemble data assimilation system (HVEDAS) developed at CIRA/CSU to have an early assessment of the future operational HVEDAS.
- Prepare for merging current satellite observations with the future GOES-R measurements (Advanced Baseline Imager and Geostationary Lightning Mapper).

2. A regional HVEDAS components

Hybrid DA algorithm

- Maximum Likelihood Ensemble Filter (MLEF: Zupanski, 2005;Zupanski et al., 2008)
  - A hybrid DA method seeking nonlinear solution;
  - It employs an iterative minimization of a cost function, similar to variational methods;
  - An important advantage of iterative solution method is in application with *nonlinear observation operators*;

NWP model

- The ATMOS portion of NOAA operational HWRF (with the NMM core)
  - HWRF outer domain has a grid spacing of 27 km;
  - the inner domain of about 6°×6° has a grid spacing of 9 km and moves along with the storm

Observation forward operators

- Gridpoint Statistical Interpolation (GSI)
  - Exclude GSI B.E.s, the adjoint model, and minimization
- Community Radiative Transfer Model (CRTM)

Zupanski 2005, *MWR*, **133**, 1710-1726; Zupanski et al. 2008, *QJRMS*, **134**, 1039-1050

MLEF-HWRF flowchart

▪*Forecast step:*

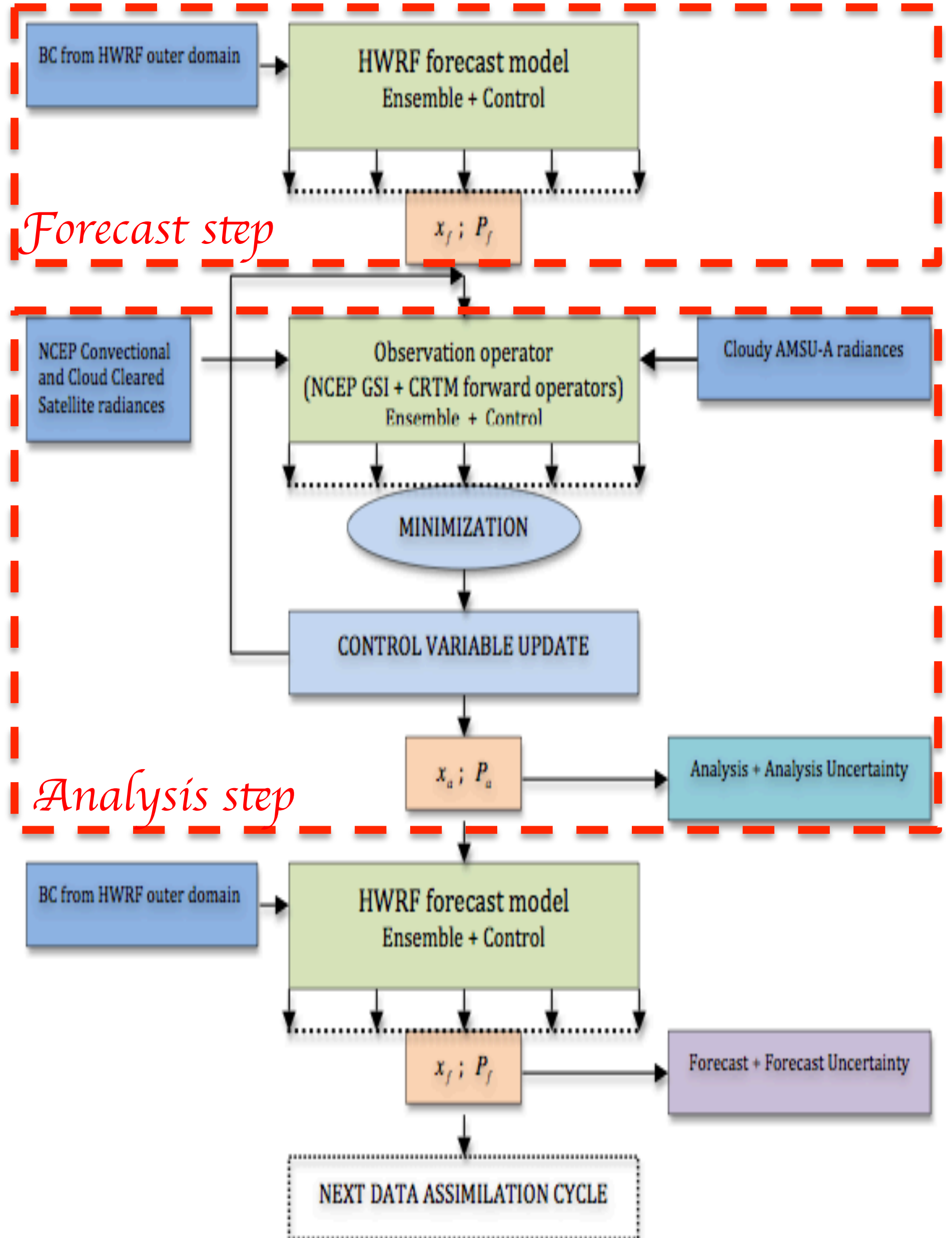
- MLEF calls subroutines to make HWRF ensemble forecasts to next analysis time
- Ensemble forecasts are transformed to MLEF state vectors

▪*Analysis step:*

- Forward model run for all obs, all members
- Observation operator includes forward component of the GSI and CRTM

▪Provide: optimal state + uncertainty

- **Optimal state**: Maximum a posteriori PDF estimate as function of obs and forecast
- **Uncertainty**: Ensemble-based uncertainty estimate *(flow-dependent error covariance)*



3. Direct assimilation of all-sky AMSU-A radiance in TC inner core

- Background
- Operational clear-sky radiance (CSR) approach
- Key elements of the all-sky radiance (ASR) approach
- Hurricane Danielle (2010)

Background

❒ Operational HWRF practice (2011)

- GSI is only used if the observed storm is deep (TCVitals).
- DA is performed using GSI in the storm environment with static B.E. covariance.
- High-resolution observational data in TC inner-core area are not operationally ingested in HWRF.
- The impact of using GSI with operational HWRF is small.

❒ Assimilating data into TC inner-core

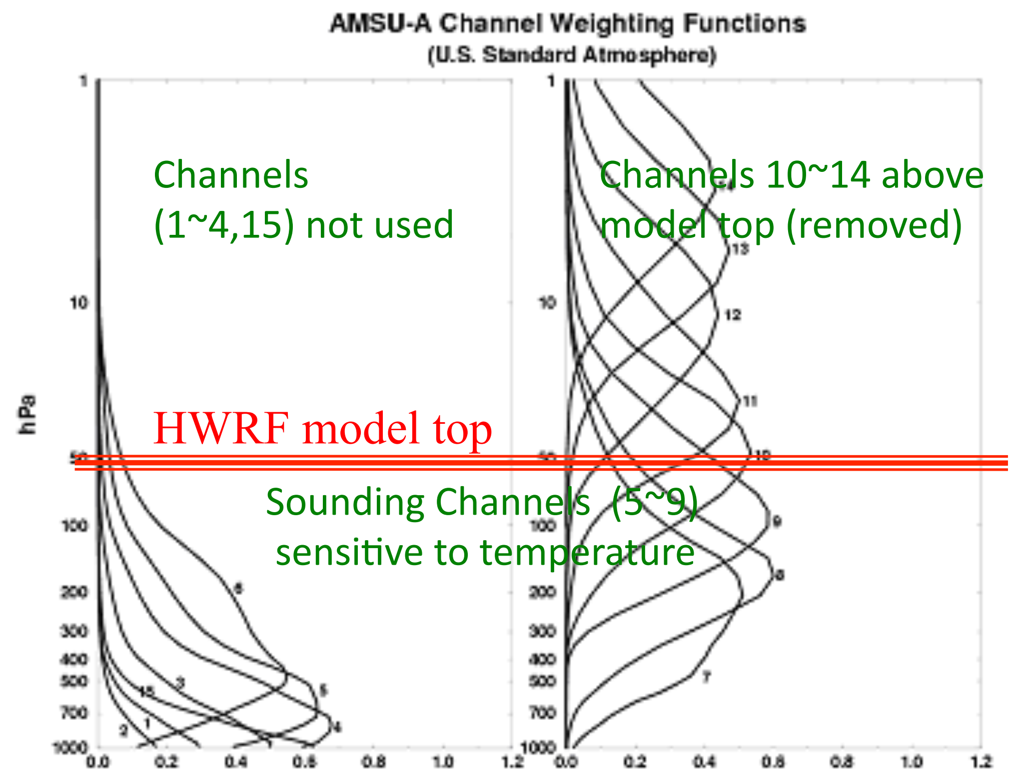
- Observations from Airborne Doppler Radar and satellite-derived inner-core observations (e.g. MTCSWA) are currently tested on experimental basis.
- Several advanced DA techniques are being explored, such as EnKF, 4DVar, and a hybrid method.

(Zhang et al., GRL, 2011; Gordon 2011, Open Access Theses; Weng and Zhang, MWR, 2012, in press)

Data

- AMSU-A: the Advanced Microwave Sounding Unit-A; also known as "temperature sounding"
- The AMSU-A radiances assimilated into HWRF on both domain includes:
  - *NOAA-18*
- The AMSU instrument employs a cross-track scanning strategy with a ground resolution near nadir of 45 km
- Thinning box: 60 km

Channel selection



Sounding Channels (5-9) sensitive to temperature
Ch5: 500-700mb
Ch6: 400-500mb
Ch7: 200mb
Ch8: 200mb
Ch9:100mb (monitor)

A statistical bias correction approach

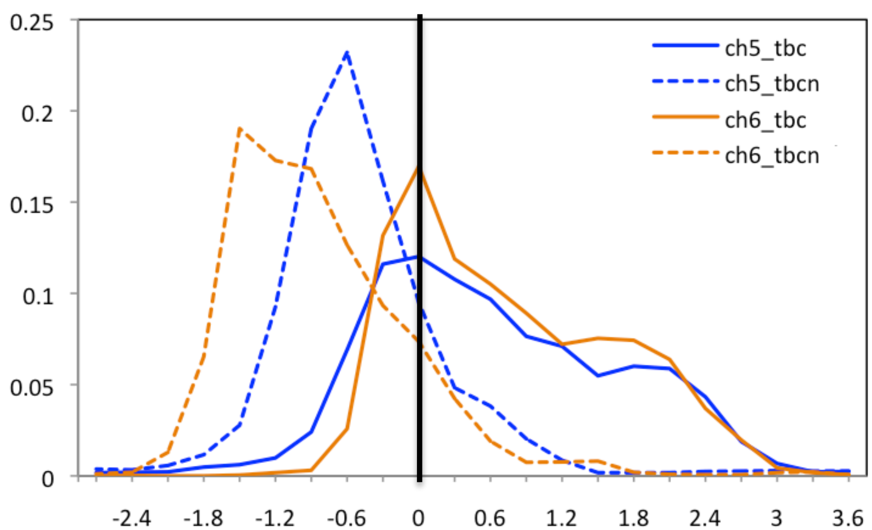
(Derber and Wu, 1998)

NOAA-18 **AMSU-A 2010082418 in HWRF outer domain**

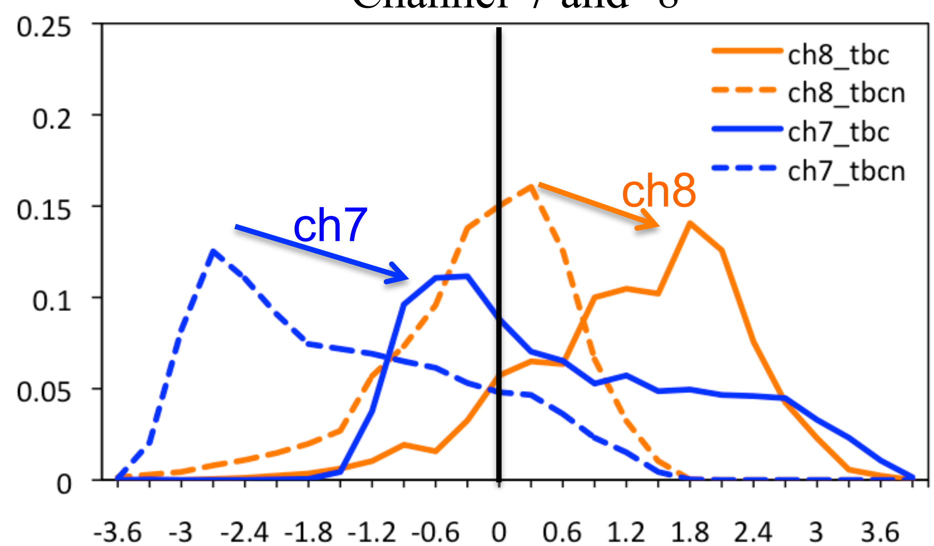
(nobs=4577; tbc-*with* bias correction; tbcn-*without* bias correction)

$$\left[T_b^{obs} - H(x^b)\right]$$

Channel-5 and -6



Channel-7 and -8



✓ Channel 5

✓ Channel 6

Channel 7

× Channel 8

Quality Control Methods for AMSU-A Radiance

(Operational clear-sky DA in GSI)

1. Cloud/precipitation detection procedures
2. AMSU-A radiance over ocean surface
3. Topography effect: reduce QC bounds over higher topography (Zsfc>2 km)
4. Transmittance at the top of the model less than 1

   - inflating observation error
5. Sensitivity to surface temperature/emissivity

   - inflating observation error
6. Background innovation check

$$\frac{\left|\Delta Tb_{ich}\right|}{\sigma_{ich}} > 3 \qquad \sigma_{ich}\ : \text{inflating observation error}$$

Key elements of the ASR approach in MLEF-HWRF

1. Extending the analysis control variables for clouds

   - i.e. total cloud condensate in HWRF

2. Inclusion of cloud information in first guess

   - A prognostic cloud scheme, see Hou et al.2002

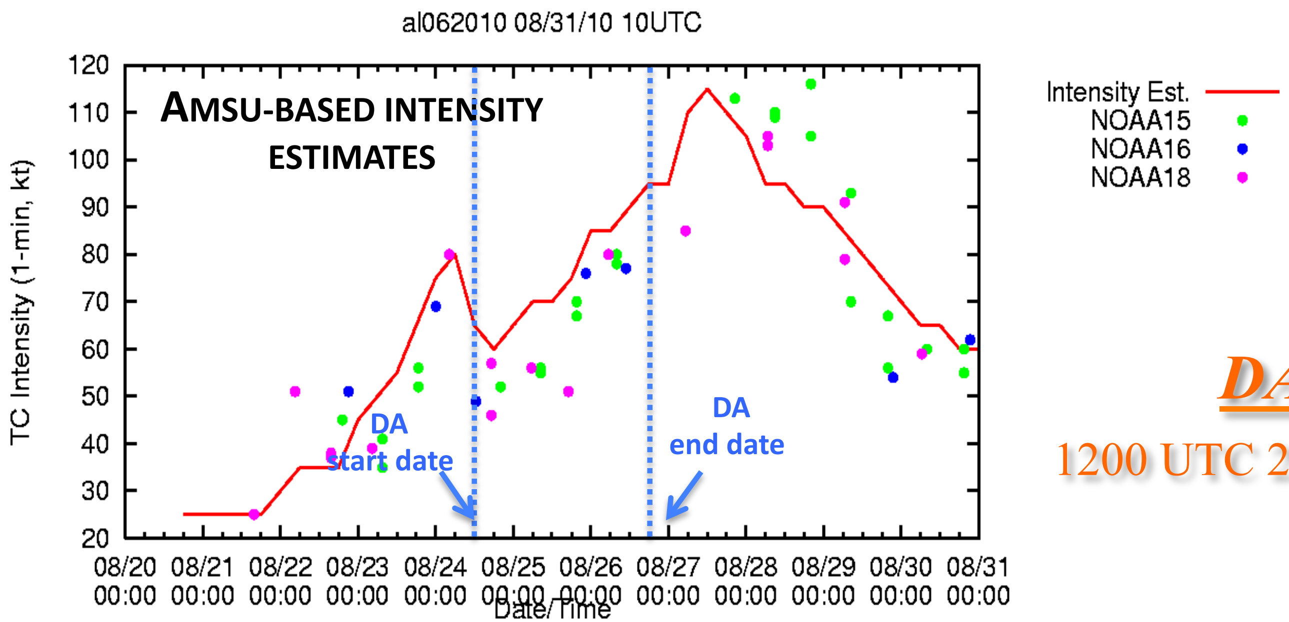
3. Selection of all-sky AMSU-A radiance data and quality control

   - no prior cloud/precipitation detection is used
   - selectively ‘correcting’ bias on certain channels (i.e. ch8 in our case)

The ASR approach provides a weaker observational constraint on cloud analysis compared to operational CSR setting.

Hou et al. 2002, NCEP OFFICE NOTE 441.

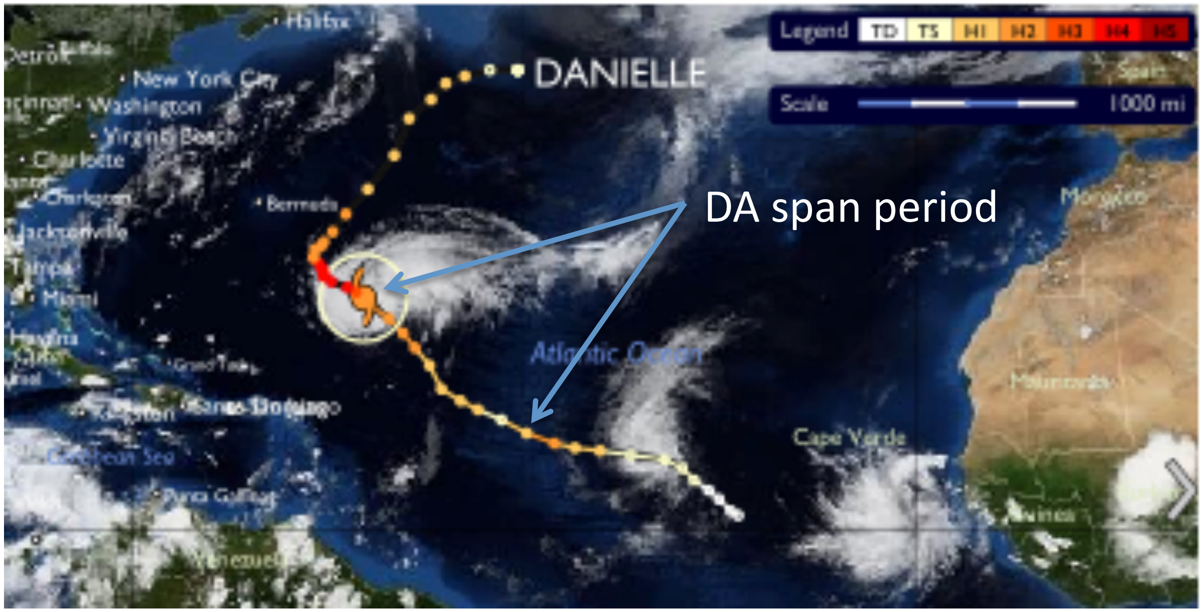
HURRICANE DANIELLE
(21-30 August 2010)



DA span period:

1200 UTC 24 ~1800 UTC 26 Aug 2010

(0-9 cycle)



Experimental design

- MLEF-HWRF cycling system:
  - produce 9-km analysis in HWRF inner domain every 6-hr;
  - **Control variables** include the following 6 components: wind components (**U, V**); specific humidity (**Q**); temperature (**T**); hydrostatic pressure depth (**PD**); total cloud condensate (**CWM**)
- ENSEMBLE SIZE is 32 members
- Other Tuning measures
  - Error covariance localization (Yang et al.2009)
  - Vortex initialization at cycle0

Yang et al. 2009, *QJRMS*,**135**,251-262

Experiments

1. CSR: clear-sky AMSU-A radiance assimilation

- Mimics the operationally clear-sky radiance framework;
- Except for

  - *assimilating only AMSU-A radiances in HWRF inner domain*

  - *using MLEF flow-dependent B.E.s*

2. ASR: as in CSR, but with *new features*:

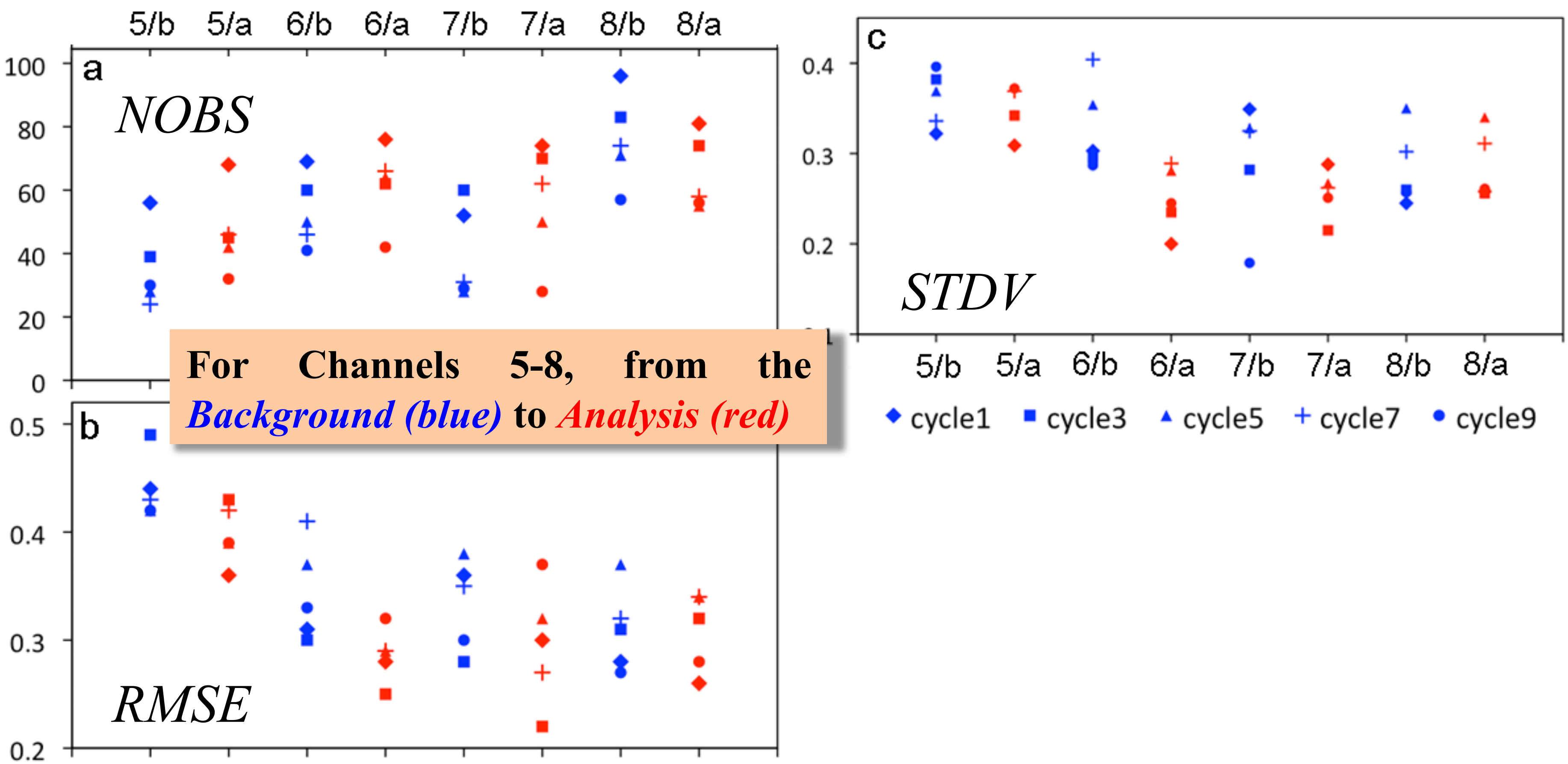
- Including cloud/rain computation in first guess;
- No prior cloud/precipitation detection;
- No bias correction scheme was applied on Channel 8

3.CTL: pure MLEF-HWRF cycling run w/o observation assimilated

• All experiments extend from 1200 UTC 24 Aug to 1800 UTC 26 Aug 2010 (1-9 cycles)

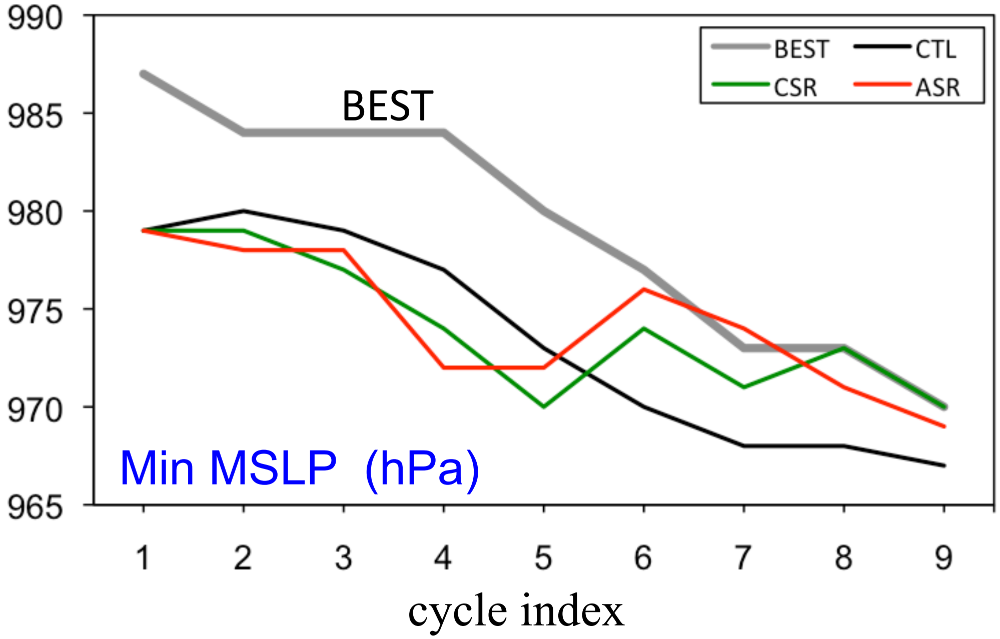
Background/Analyses fit to observations

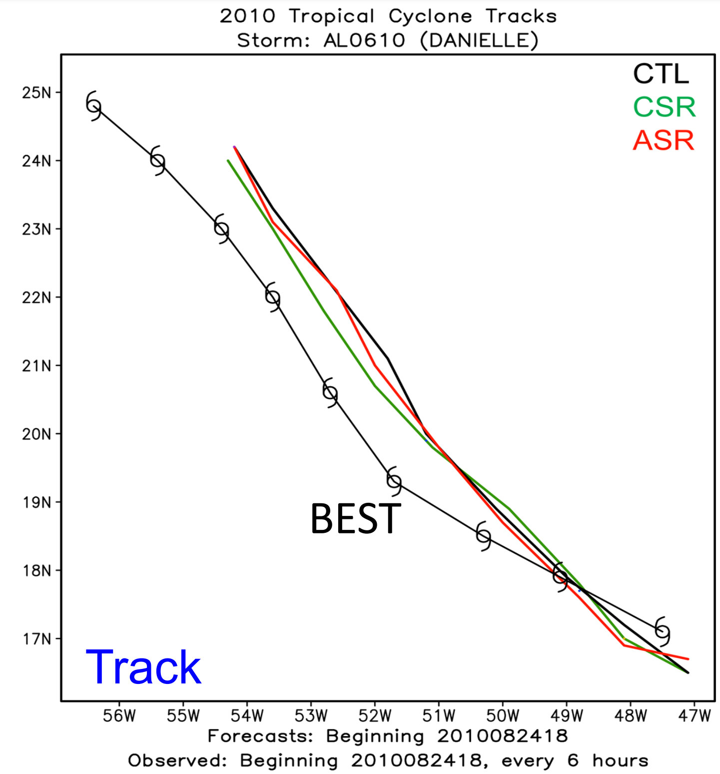
*(**ASR**: cycle 1-9 in HWRF inner domain)*



- The assimilated observation count increases
- The RMS error and standard deviation reduces almost for all cycles
- Similar results could be found in CSR experiments

Verification with NHC best track data

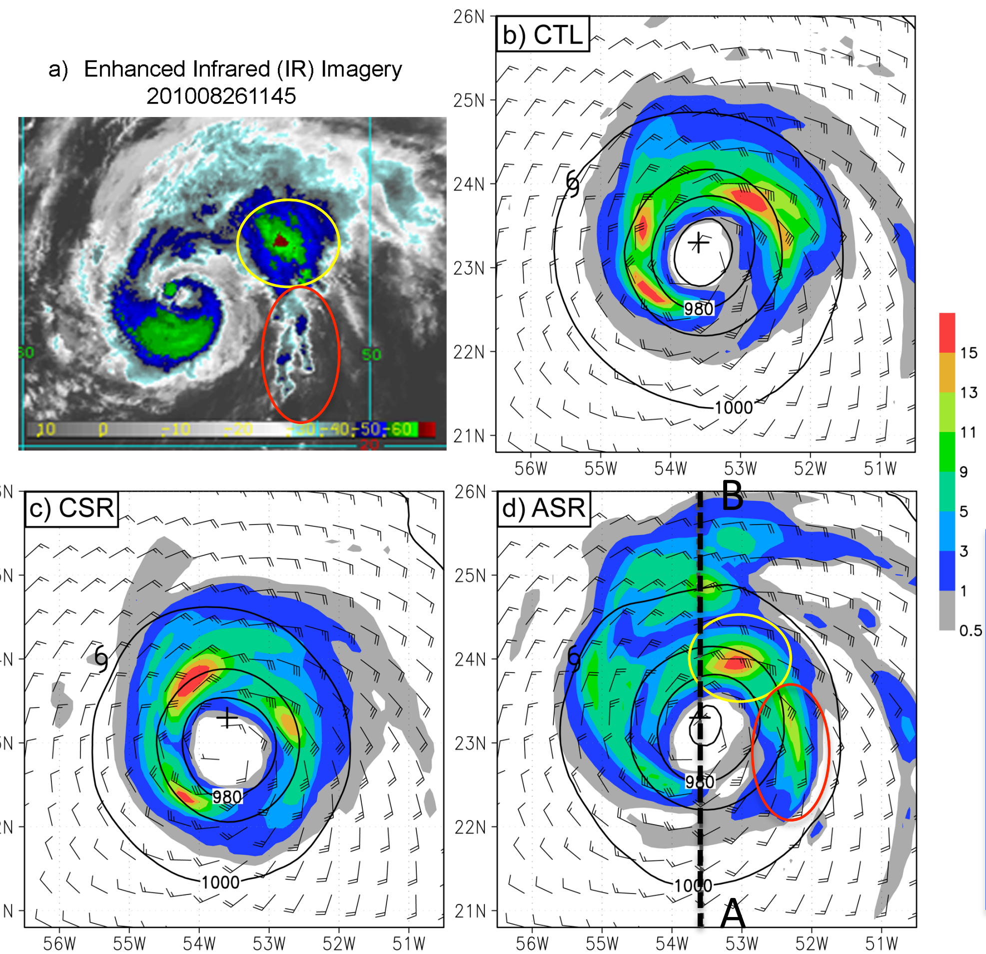




- CTL: produced a stronger storm with less than 10 hPa of min MSLP error due to the use of vortex initialization at cycle0
- CSR & ASR: After 1-day warm-up period, AMSU-A radiance assimilation in TC inner core consistently reduces errors in TC intensity, but not in position.
- ASR: catch up with the observed TC intensity quickly after cycle 5

Verification with satellite imagery

Cycle 8: 1200 UTC 26 Aug 2010



- *The total cloud condensate* (Colored; kg m^{-2})
- *Mean-sea level pressure* (Solid, hPa)
- *10-m above ground wind barbs* (A full barb is 5 m s^{-1})

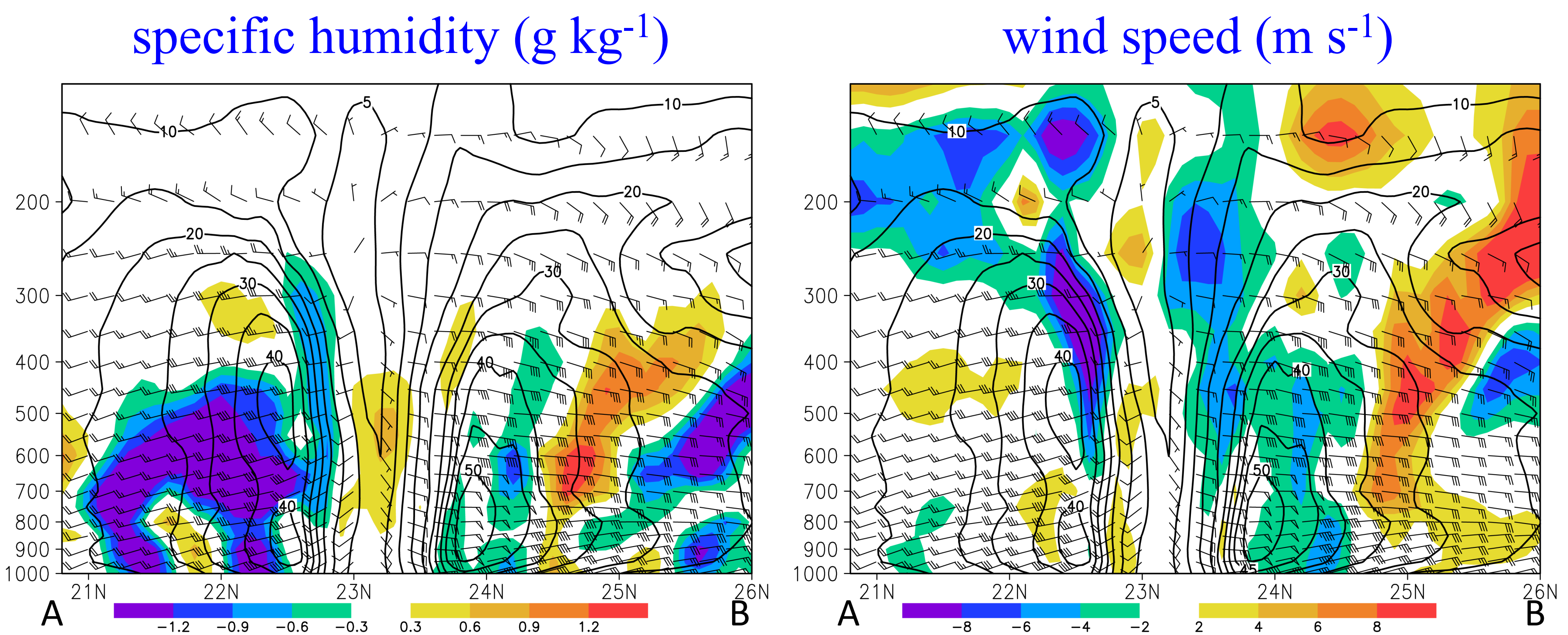
d) ASR reproduced pronounced asymmetries across the storm:

- TC eyewall is semi-circle in shape;
- An outward spiral rainbands in the northern quadrant;
- And many other features in common

Significant improvement of TC inner-core convective description in ASR is due to the unique information content of all-sky satellite radiances

Shadings: analysis increments $x_{ASR}^{a,cyc8} - x_{CTL}^{a,cyc8}$ In north-south vertical cross section

Contours and wind barbs are x_{CTL}^{a}



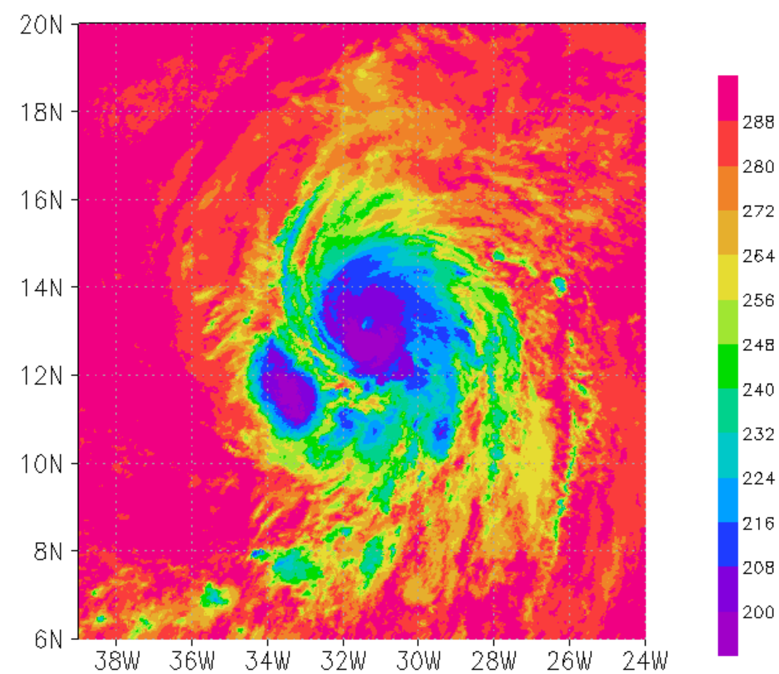
The correction is notable in both moisture and dynamic variable fields within the troposphere and dominated by changes in storm asymmetries

4. Towards assimilating GOES-R measurements

***Background**: Two new instruments will be on the GOES-R satellite: the Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM)*

- All-sky satellite radiance assimilation capability has been implemented in MLEF-HWRF.
- A pilot study by Zupanski et al. (2011) successfully assimilated synthetic GOES-R ABI radiances in cloudy scenes in a severe weather case study through combining MLEF with WRF-ARW.
- Assimilation of GOES-R proxy data in MLEF-HWRF is underway.
  - **SEVIRI**
    - Onboard: MSG
    - Spectral Channels: 12
    - Sampling Frequency: 15 min
    - Spatial resolution: 3km@nadir
  - An observation forward operator for MSG SEVIRI has been developed at CIRA. (Grasso et al. 2008)

Hurricane Fred (2009)
MSG SEVIRI Channel-9 TBs
0615 UTC 09 Sep 2009



Zupanski et al. 2011,*IJRS*, **32**, 9637-9659
Grasso et al. 2008. *IJRS*, **29**, 4373-4384

❑ Summary

- First application to Danielle case shows encouraging results.

  The ASR approach is indeed beneficial for TC inner-core analyses and forecasts with respect to the improvement of QPF and severe wind warning if the storm is about to landfall.

- The hybrid system is applicable to operational HWRF ensemble data assimilation, and promising for the future operational HVEDAS.

❑ Future plan

- Combined assimilation of GOES-R ABI, MSG SEVIRI, GLM proxies (NLDN, WWLLN), AIRS SFOV retrievals and current microwave radiances.
- To address the maximum information content extraction through all-sky satellite measurements.