Radiance Data Assimilation for WRF model: overview and results

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Outline

- Components of radiance assimilation in WRF-Var with demonstrations
- Radiance Assimilation Applications
  - A case study for Hurricane Katrina using RTTOV
  - DATC extended tests
- Cloudy radiance assimilation development using CRTM
- 4DVAR+Radiance

Components of radiance assimilation

- Data Ingestion
  - NCEP radiance BUFR data
    - AMSU-A/B, MHS, HIRS, AIRS
  - SSMIS from AFWA/NRL, UPP produced
- Radiative Transfer Model
  - Both CRTM and RTTOV
- Bias Correction
  - Scan bias and air-mass bias (Harris and Kelly, 2001)
  - Variational Bias Correction (Derber and Wu, 1998)
- Quality Control
- Thinning and Load balancing
- Observation error tuning (Desroziers & Ivanov, 2001)
- Monitoring tool
- Work for 3DVAR/FGAT/4DVAR

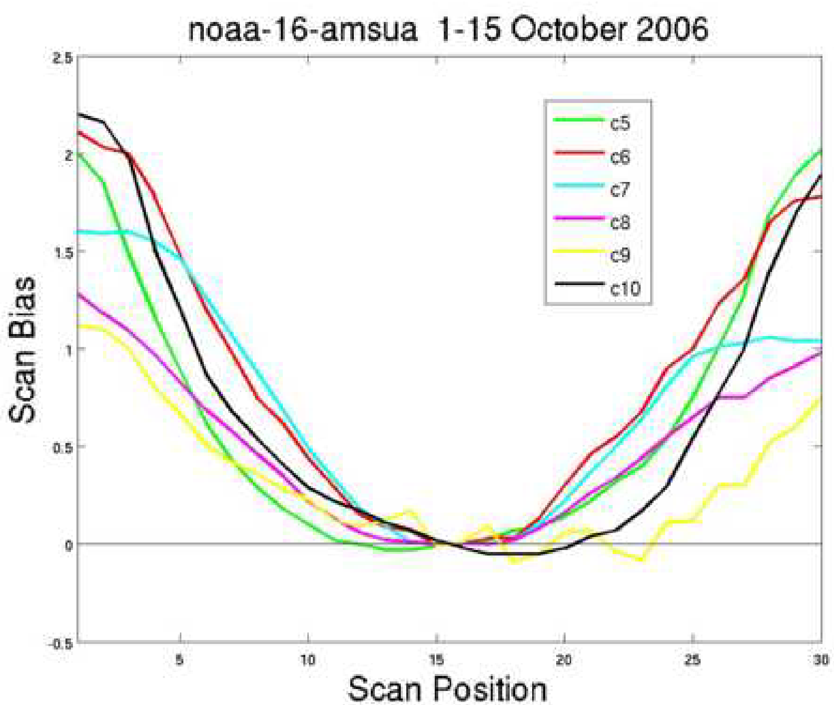
Air-Mass dependent Bias Correction

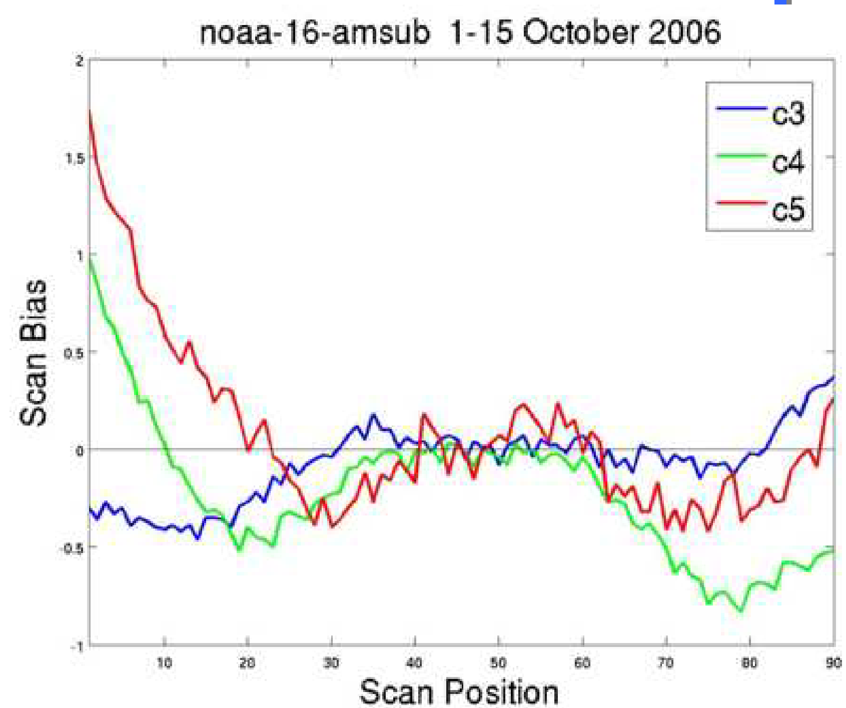
- Harris & Kelly (2001) scheme
  - Bias coefficient calculated offline and fixed
  - Separate total bias into scan bias and air-mass dependent bias
  - Air-mass bias is predicted by some ‘predictors’
    - 1000-300mb thickness
    - 200-50mb thickness
    - surface skin temperature
    - Total column precipitable water

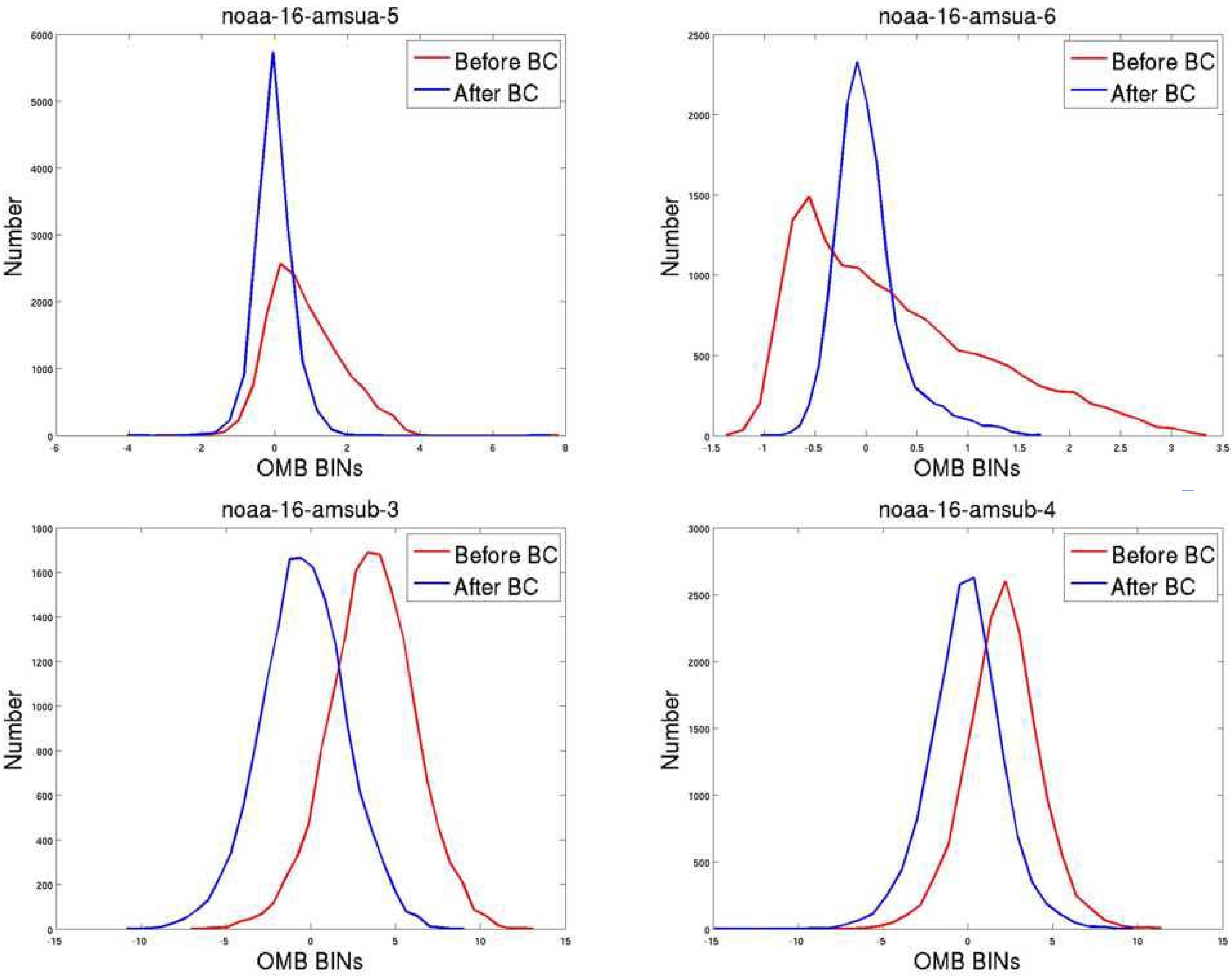
Scan Bias

- Scan Bias = d(limb) - d(nadir)
  - d(.) is departure (omb or oma)
  - This is relative bias between limb and nadir

Scan bias statistics for SWA domain with 15 days data






noaa-16-amsua-5
Before BC
After BC
Number
OMB BINs
noaa-16-amsua-6
Before BC
After BC
Number
OMB BINs
noaa-16-amsub-3
Before BC
After BC
Number
OMB BINs
noaa-16-amsub-4
Before BC
After BC
Number
OMB BINs

Variational bias correction: VarBC

For each instrument/channel, the **biais** is described from (a few) **parameters**
(associated with air-mass and scan predictors).

These parameters can be estimated within the variational assimilation, jointly with the atmospheric model state (Derber and Wu 1998) (Dee 2005)

- Inclusion of the bias parameters in the control vector : $x^T \rightarrow [x, \beta]^T$
- Modification of the observation operator to include the bias : $H(x) \rightarrow H(x,\beta)$

J_b: background term for x — J_o: observation term

$$\mathbf{J(x)} = (\mathbf{x_b} - \mathbf{x})^T \mathbf{B_x}^{-1} (\mathbf{x_b} - \mathbf{x}) + [\mathbf{y} - b - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - b - H(\mathbf{x})]$$

J_b: background term for x — J_o: corrected observation term

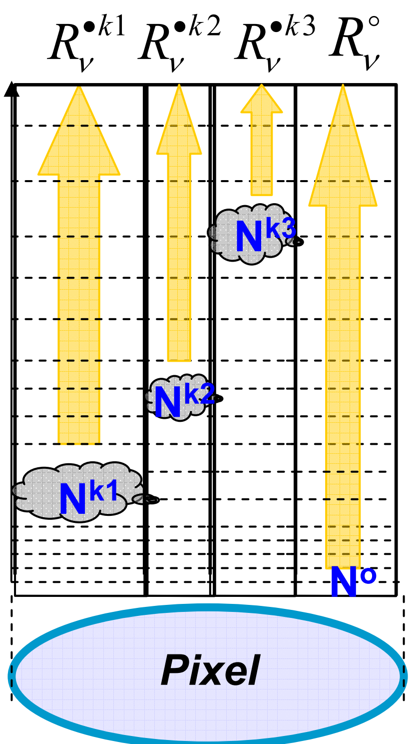
$$\mathbf{J}(\mathbf{x},\beta) = (\mathbf{x_b} - \mathbf{x})^T \mathbf{B_x}^{-1} (\mathbf{x_b} - \mathbf{x}) + [\mathbf{y} - \mathbf{b}(\beta) - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b}(\beta) - H(\mathbf{x})] + (\beta_b - \beta)^T \mathbf{B}_\beta^{-1} (\beta_b - \beta)$$

J_β: background term for β

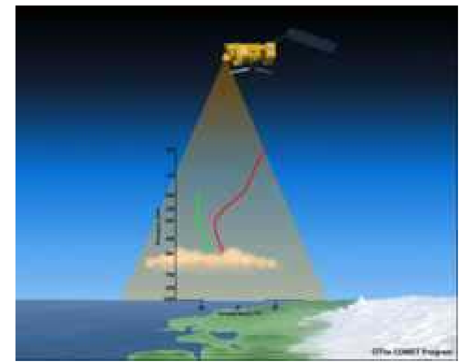
AIRS cloud detection (courtesy T. Auligné)

Cloud detection strategy:

from « hole hunting » (identifying clear pixels)
to identifying clear channels (insensitive to the cloud).



Multivariate Minimum Residual (MMR) scheme



R_ν° Radiance calculated in clear sky

$R_\nu^{\bullet k}$ Radiance calculated for a thin opaque cloud at level k

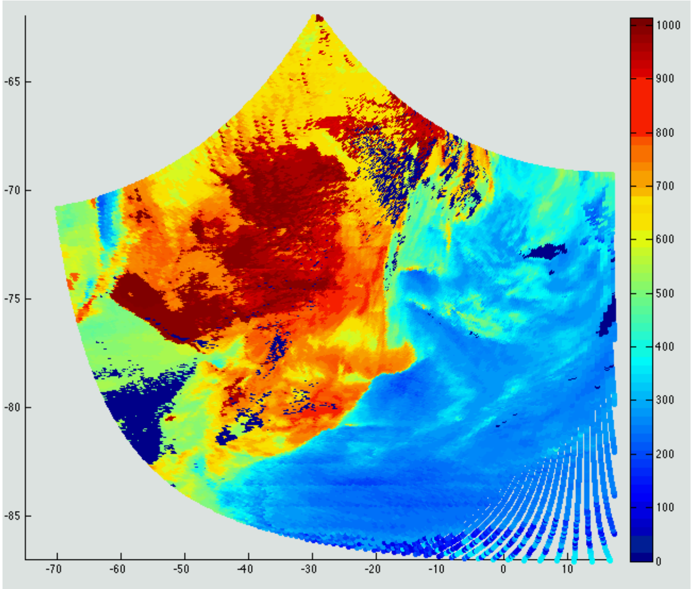
$$R_\nu^{Cld} = \sum_{k=1}^{n} N^k R_\nu^{\bullet k} + N^{\circ} R_\nu^{\circ} \quad \text{with} \quad \begin{cases} 0 \le N^k \le 1, \forall k \in [0, n] \\ N^{\circ} + \sum_{k=1}^{n} N^k = 1 \end{cases}$$

For each pixel, the n cloud fractions N^k are adjusted **variationally** to fit the observed spectrum:

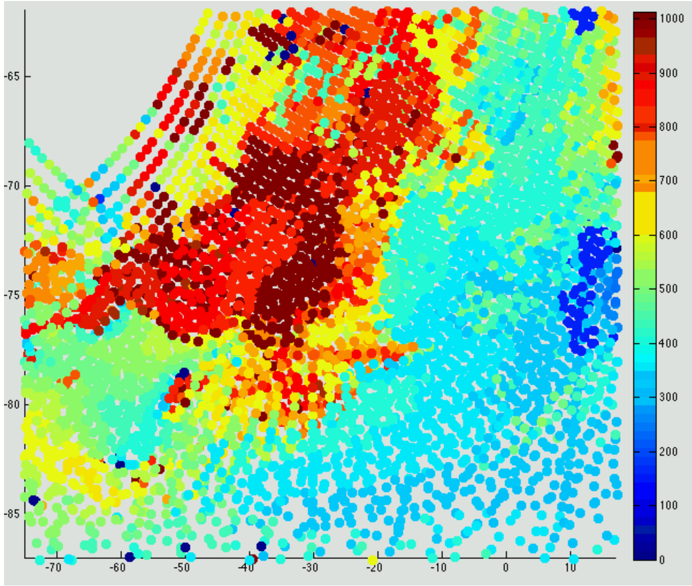
$$J(N) = \frac{1}{2} \sum_\nu \left(\frac{R_\nu^{Cld} - R_\nu^{Obs}}{R_\nu^{\circ}} \right)^2$$

Cloud Detection: comparison with MODIS

Retrieved Cloud Top (hPa)



MODIS



AIRS

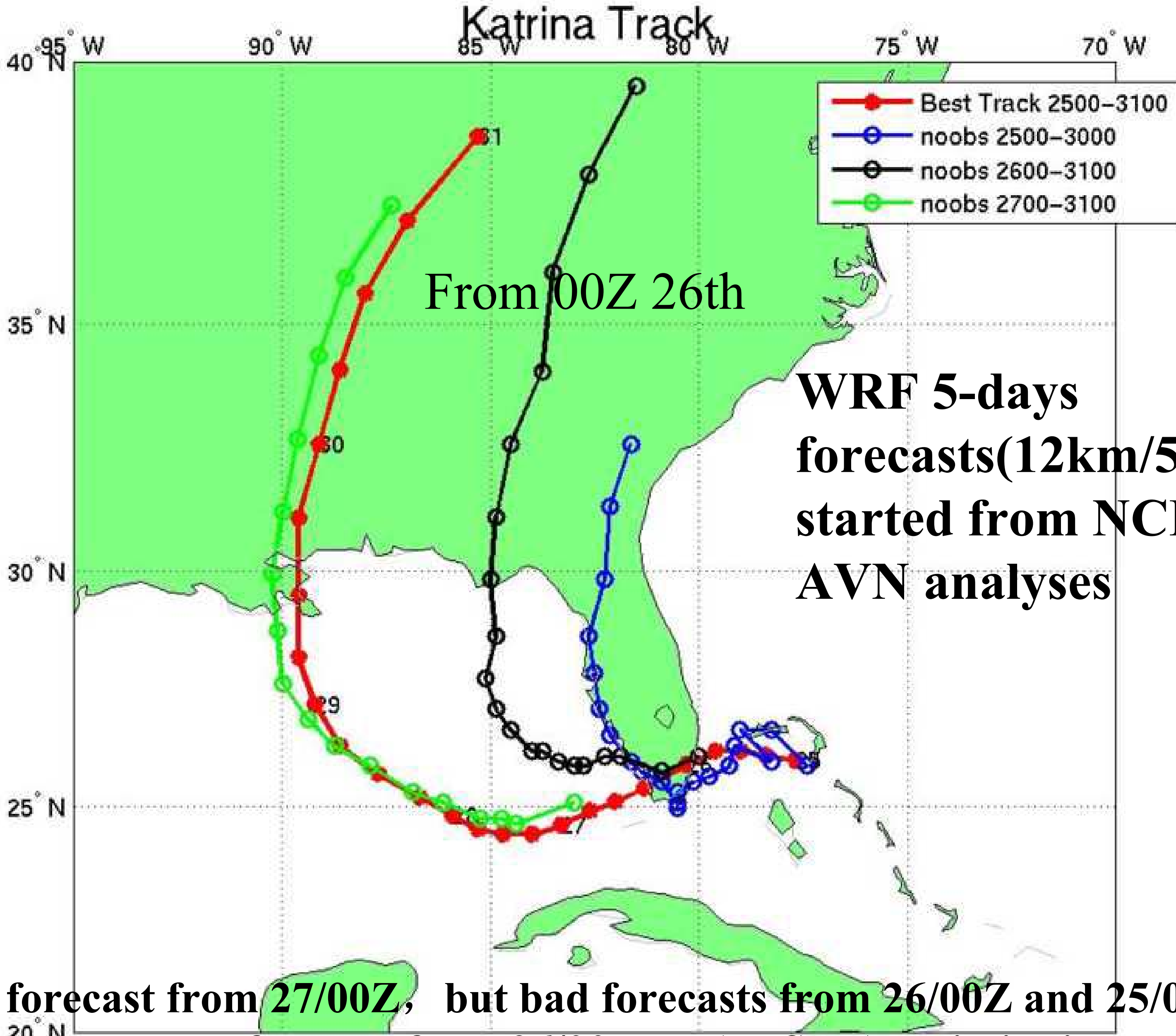
(courtesy T. Aulligné)

Application to Katrina Case with WRF-ARW (Liu et al., to be submitted)

Use RTTOV

Assimilate only AMSU-A
Channels 1~4 over sea
Channels 5~10 both over sea and land
Pixels over precipitating area rejected

12km51L, model top 10mb (limited by NCEP GFS product)



WRF 5-days forecasts(12km/51L） started from NCEP AVN analyses

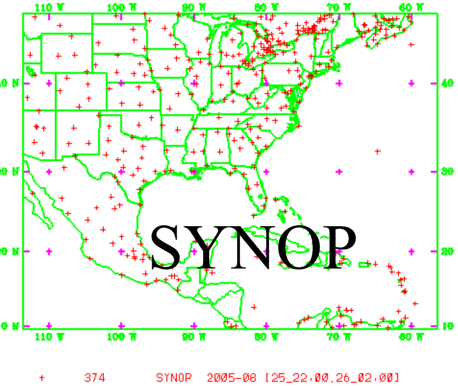
Good forecast from 27/00Z， but bad forecasts from 26/00Z and 25/00Z try to improve the forecast from 26/00Z by AMSU-A assimilation.

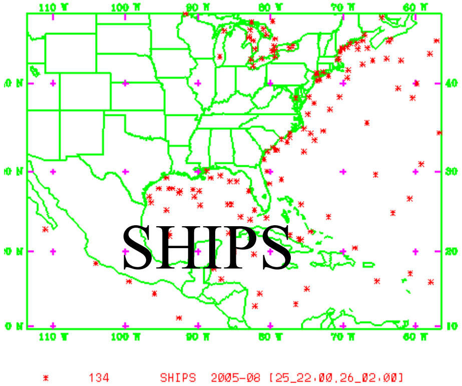
4 Assimilation Experiments at 00Z 26th

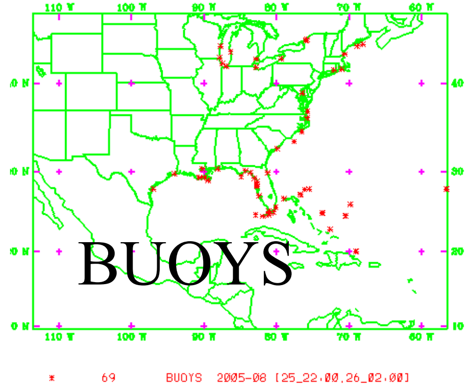
Background is a WRF 6h forecast from 18Z 25th

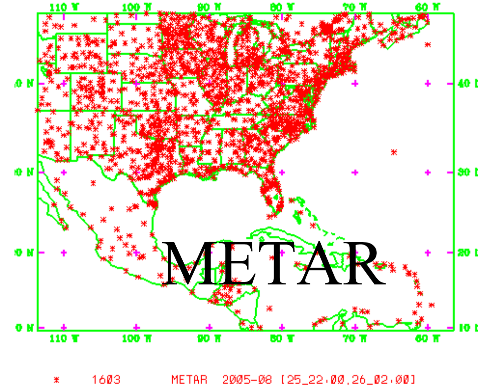
- GTS
  - only use conventional data
- AMSUA
  - only use AMSUA radiance
- GTS+AMSUA
  - conventional plus AMSUA radiance
- AMSUA+SLP
  - AMSUA radiance plus one single SLP located at center of Hurricane

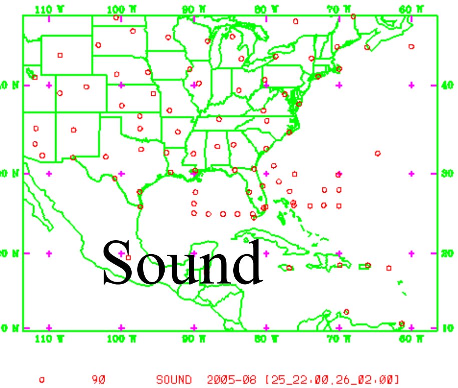
Followed by a 5-day forecast

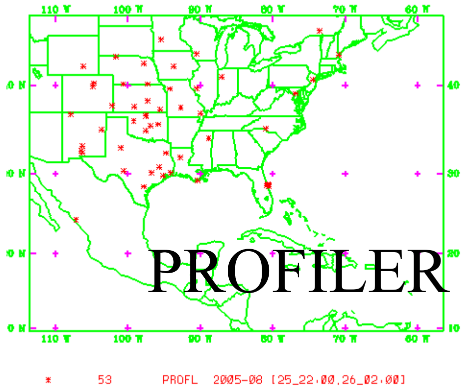


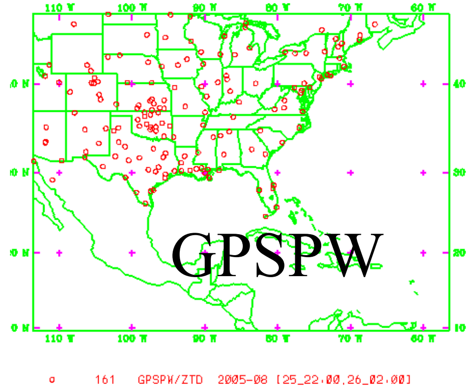


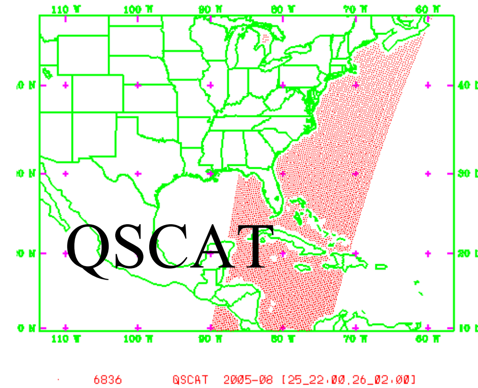


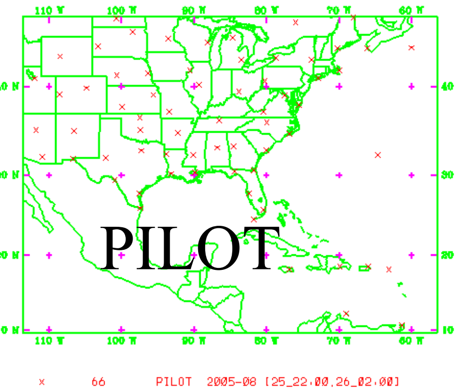


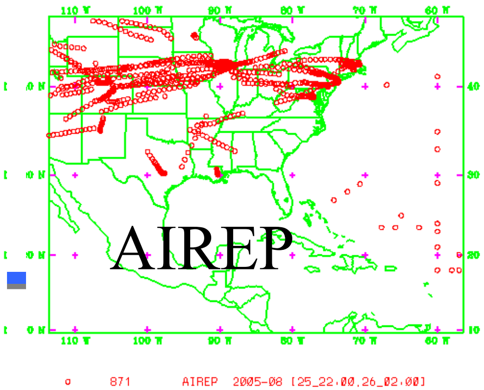






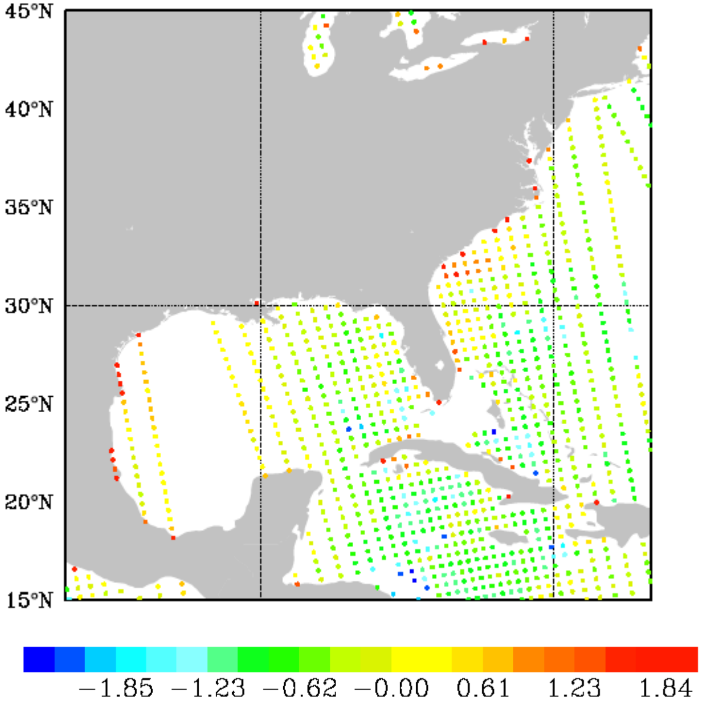




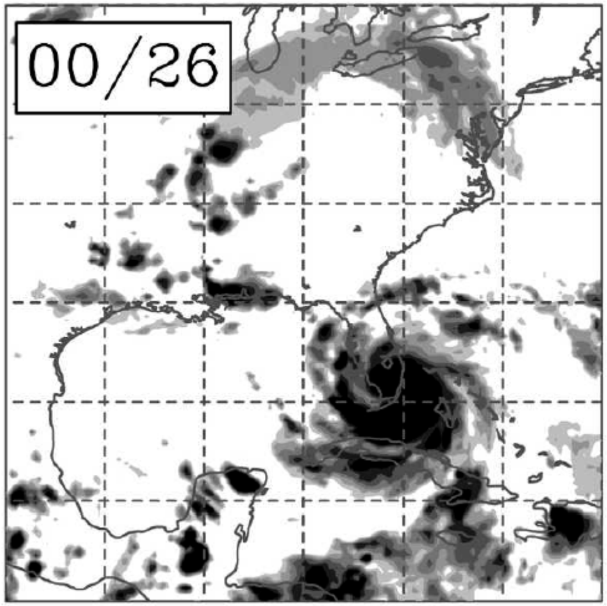


Conventional data coverage at 00Z 26th August

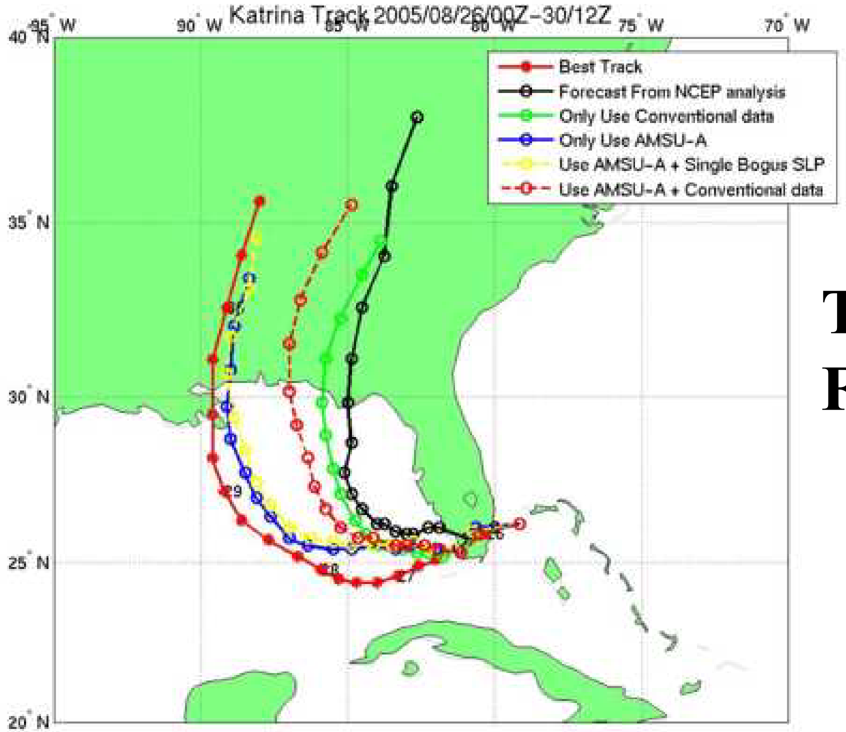
Satellite Observations



OMB of NOAA-15 AMSU-A channel 4 after Quality Control



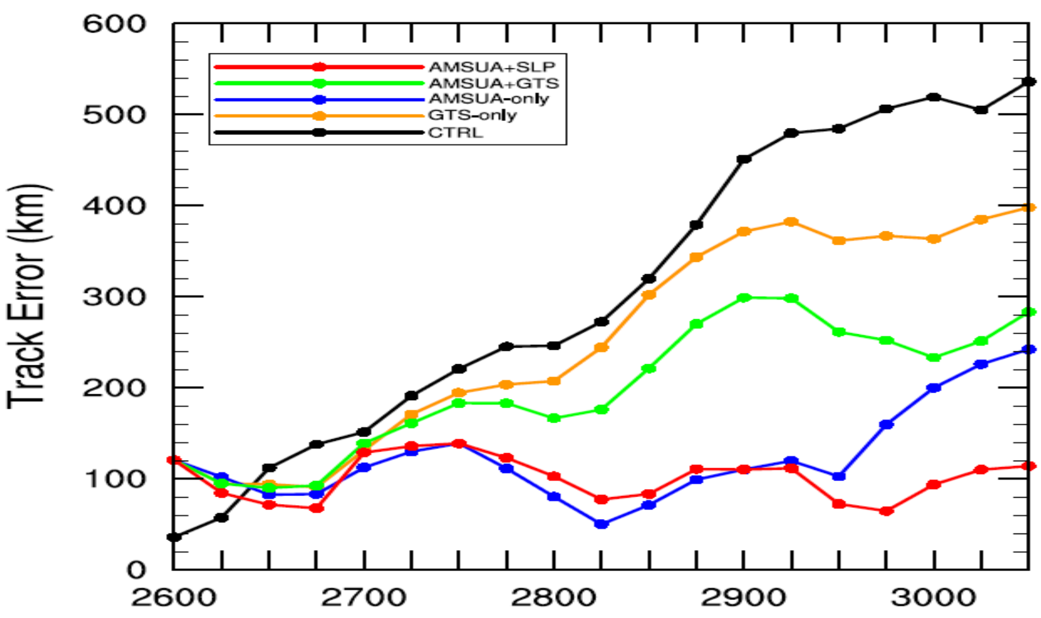
GOES IR image

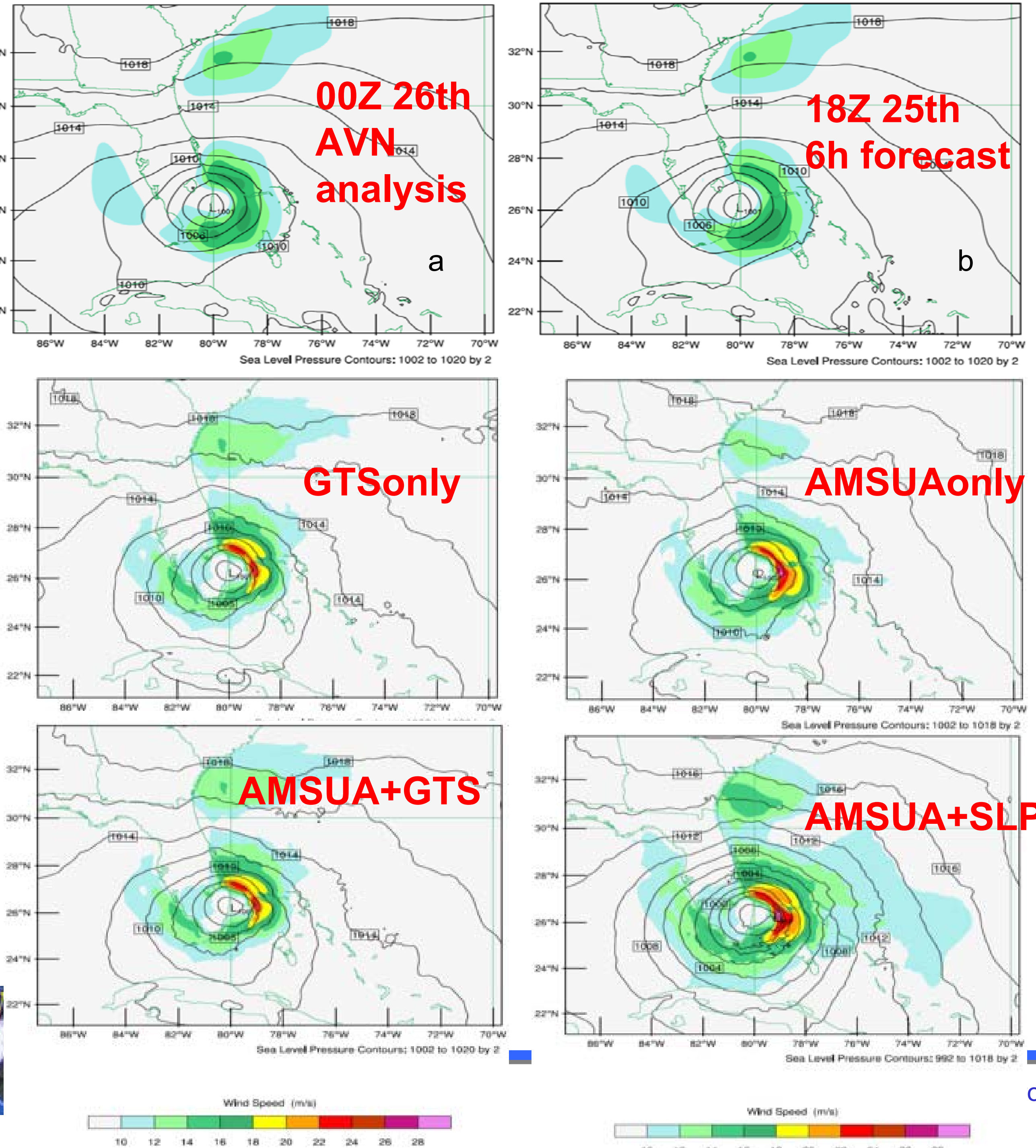


Track

Track improvement mainly From AMSU-A assimilation

Track Error





Best track:
983 hPa, 35 m/s

MWS 16~18m/s

AMSU-A affect wind analysis through background error covariance constraint

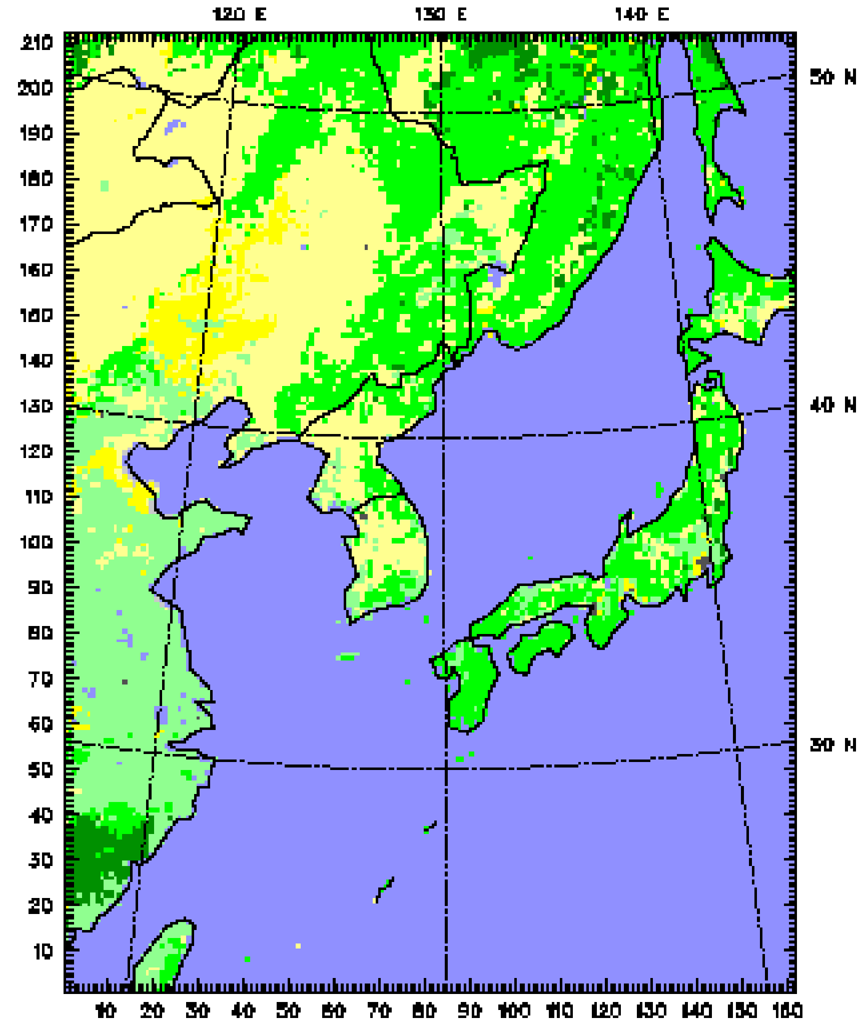
MWS increased to 24~26m/s with WRF-Var

DATC extended tests

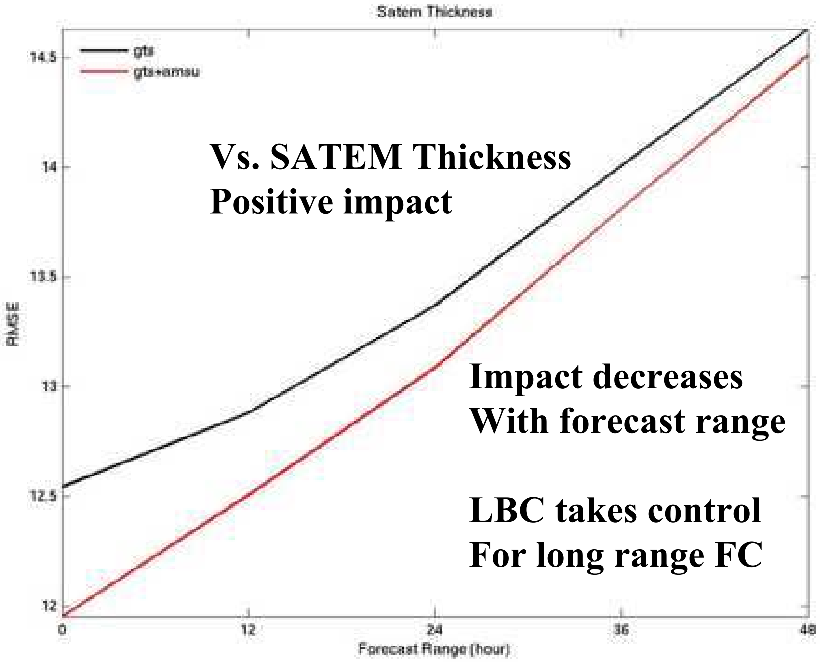
- DATC: Data Assimilation Testbed Center
  - Parallel with DTC (Developmental Testbed Center, which focuses on tests for model part)
- Testbeds for radiance impact
  - East Asia
  - Atlantic

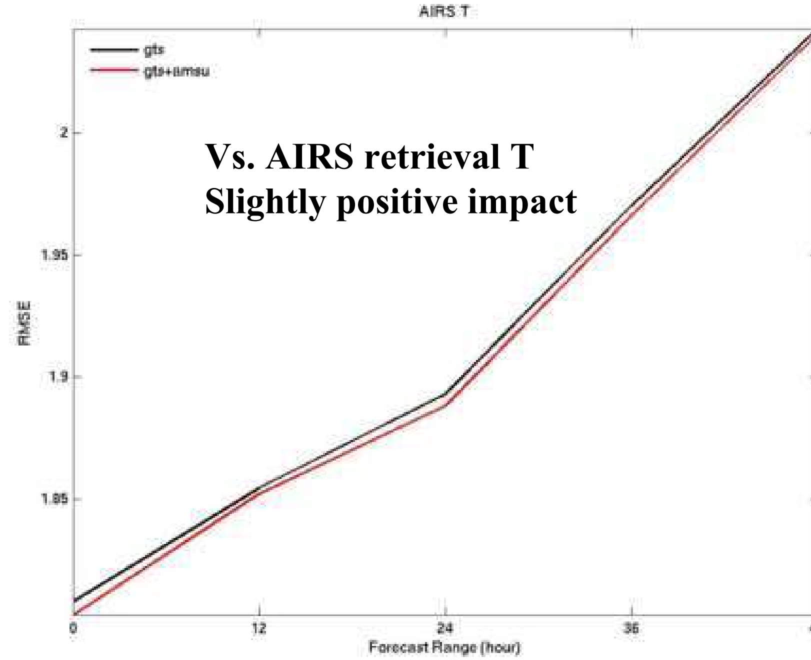
DATC: East Asia Testbed

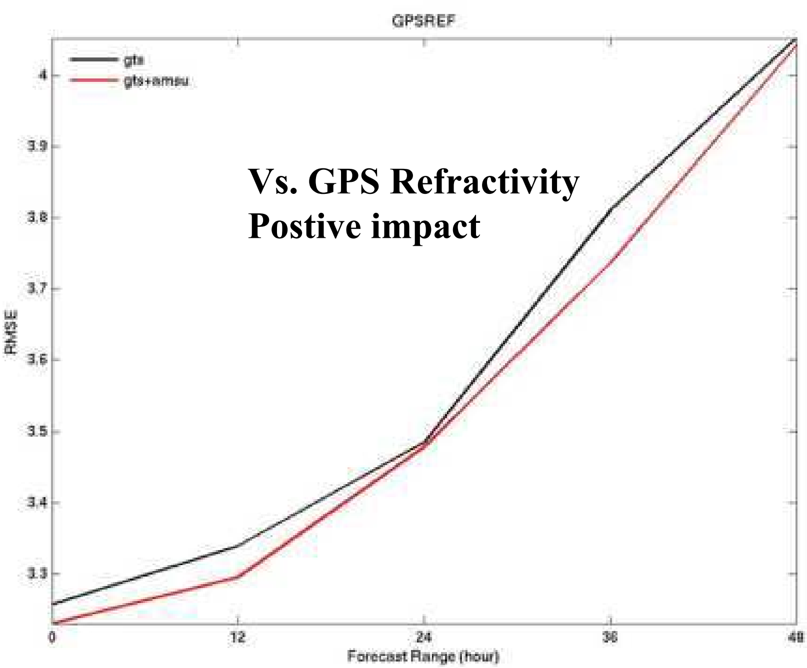
- **162*212*42L, 15km**
- **model top: 50mb**
- **Full cycling exp. for a month**
  - **1 ~ 30 July 2007**
- **GTS+AMSU**
  - **NOAA-15/16, AMSU-A/B from AFWA**
  - **AMSU-A: channels 5~9 (T sensitive)**
  - **AMSU-B: channels 3~5 (Q sensitive)**
  - **Radiance used only over water**
  - **thinned to 120km**
  - **+-2h time window**
  - **Bias Correction (H&K, 2001)**
- **Compare to GTS exp.**
  - **Only use GTS data from AFWA**
- **48h forecast, 4 times each day**
  - **00Z, 006, 12Z, 18Z**

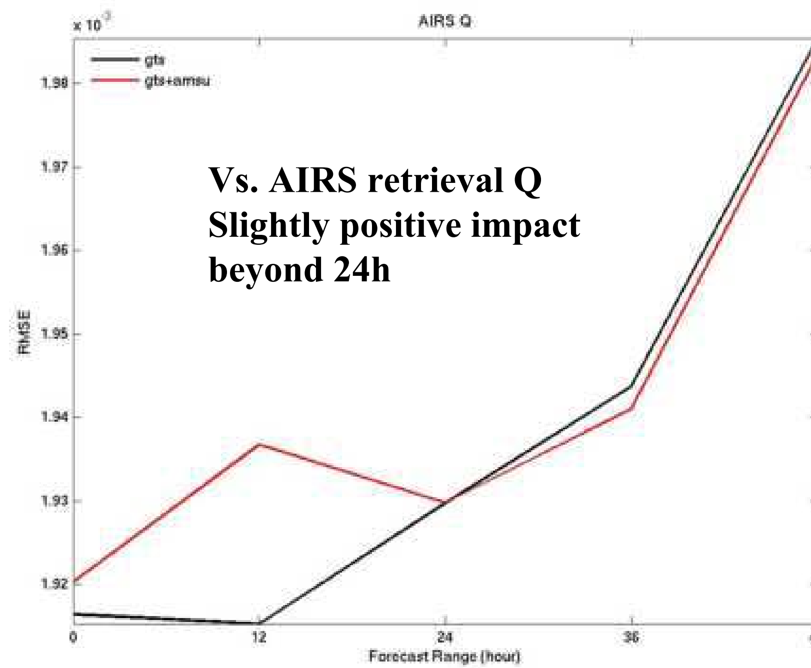


Land Use Category


Satem Thickness
gts
gts+amsu
RMSE
Forecast Range (hour)
Vs. SATEM Thickness
Positive impact
Impact decreases
With forecast range
LBC takes control
For long range FC

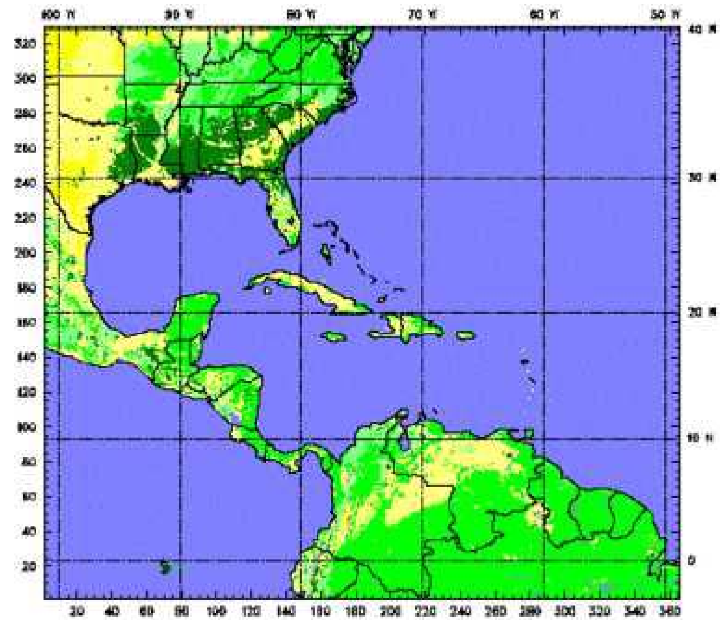

AIRS T
gts
gts+amsu
RMSE
Forecast Range (hour)
Vs. AIRS retrieval T
Slightly positive impact


GPSREF
gts
gts+amsu
RMSE
Forecast Range (hour)
Vs. GPS Refractivity
Postive impact

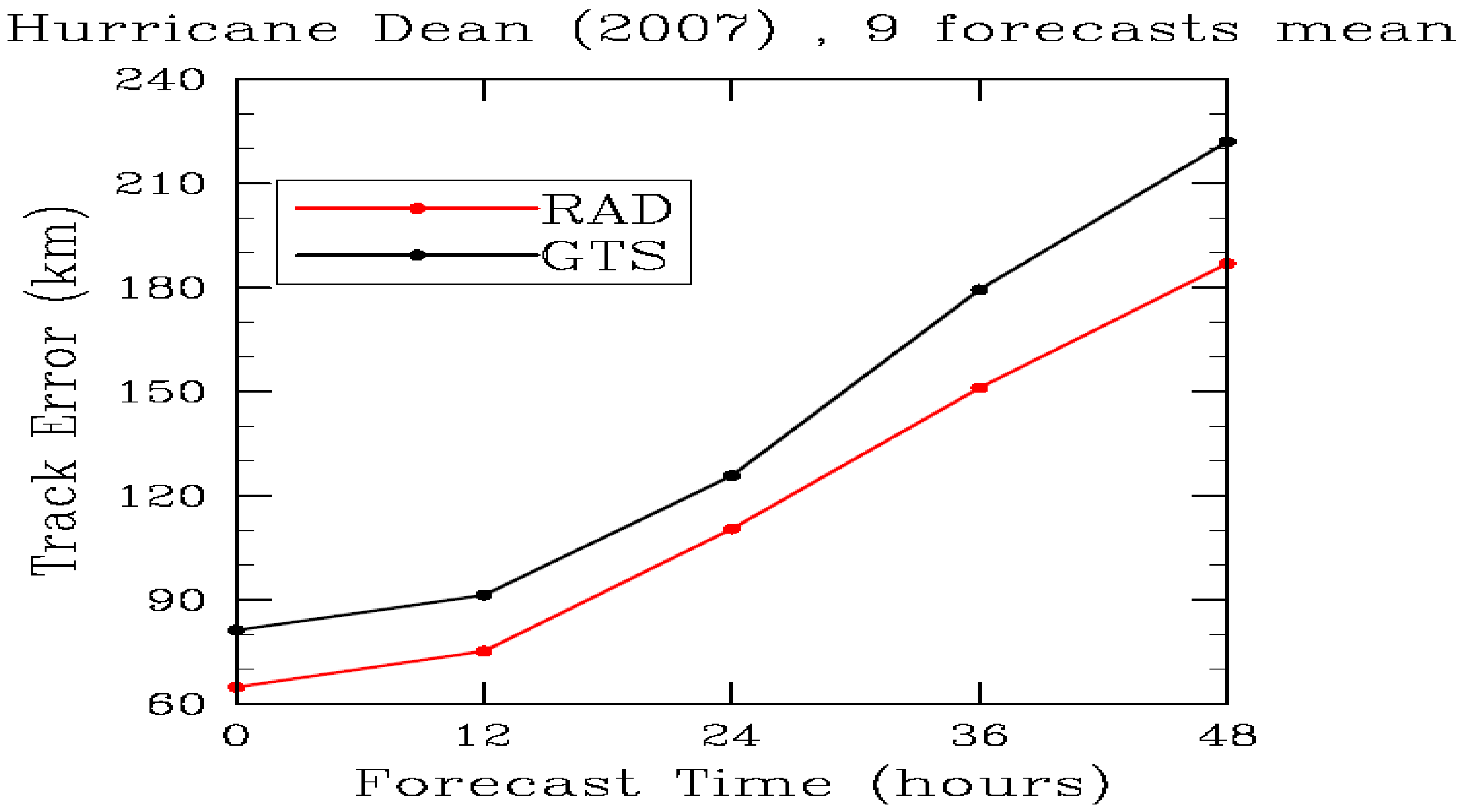

AIRS Q
gts
gts+amsu
RMSE
Forecast Range (hour)
Vs. AIRS retrieval Q
Slightly positive impact
beyond 24h

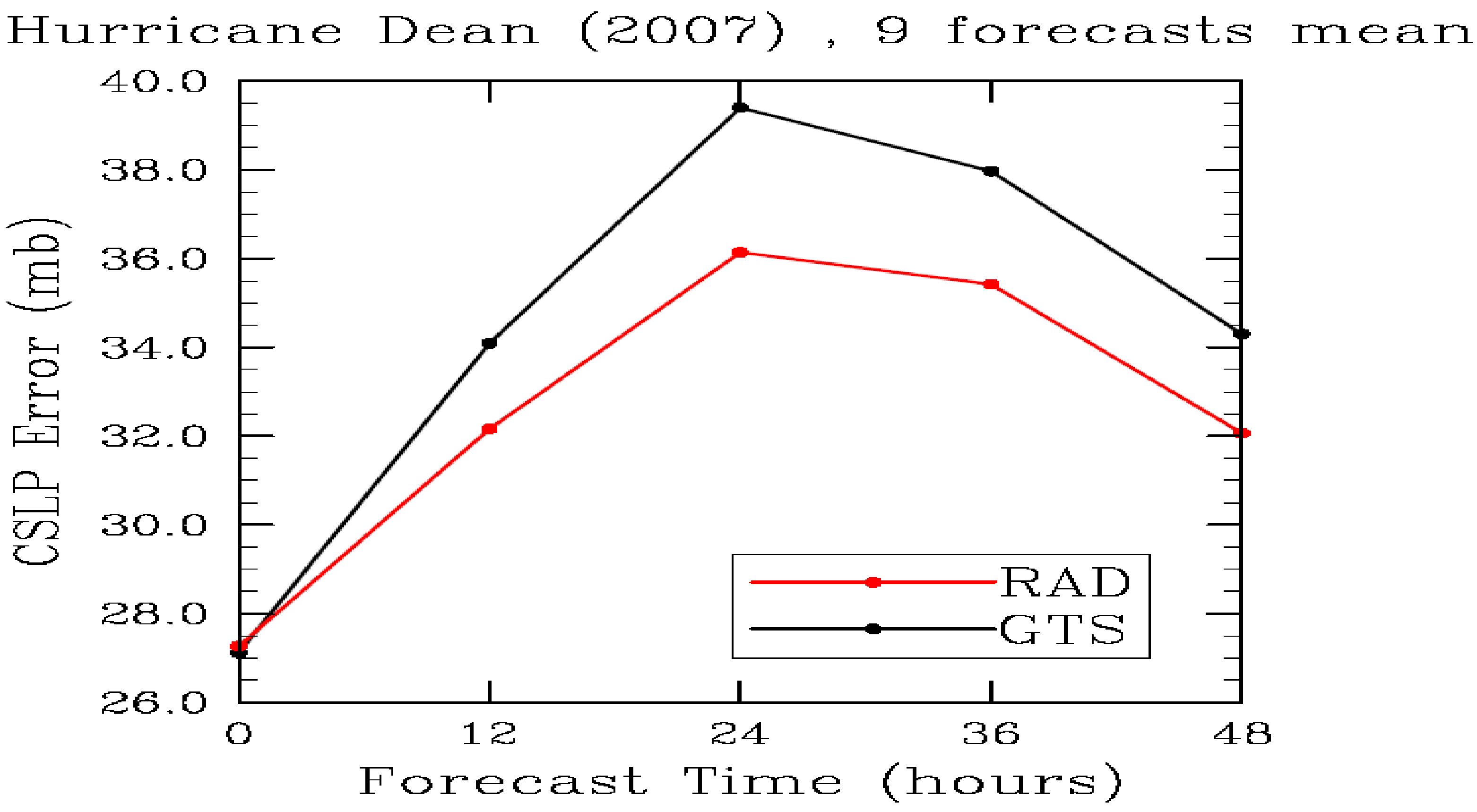
DATC: Atlantic Testbed

- 361*325*57L, 15km
- model top: 10mb
- Full cycling exp. for 6 days
  - 15 ~ 20 August 2007
- GTS: assimilate NCAR conventional obs
  - Select similar data type used by AFWA
- GTS+AMSU+MHS (use NCEP BUFR rad.)
  - NOAA-15/16/18, AMSU-A, ch. 5~10
  - NOAA-15/16/17, AMSU-B, ch. 3~5
  - NOAA-18, MHS (similar to AMSU-B)
  - Radiance used only over water
  - thinned to 120km
  - +-2h time window
  - Bias Correction (H&K, 2001)
- 48h forecast twice each day
  - 00Z, 12Z
- Might not optimal to use all sensors/satellites at the first try, but I want to test the robustne ss of the system with all Microwave sensors which can be assimilated in WRF-Var now.

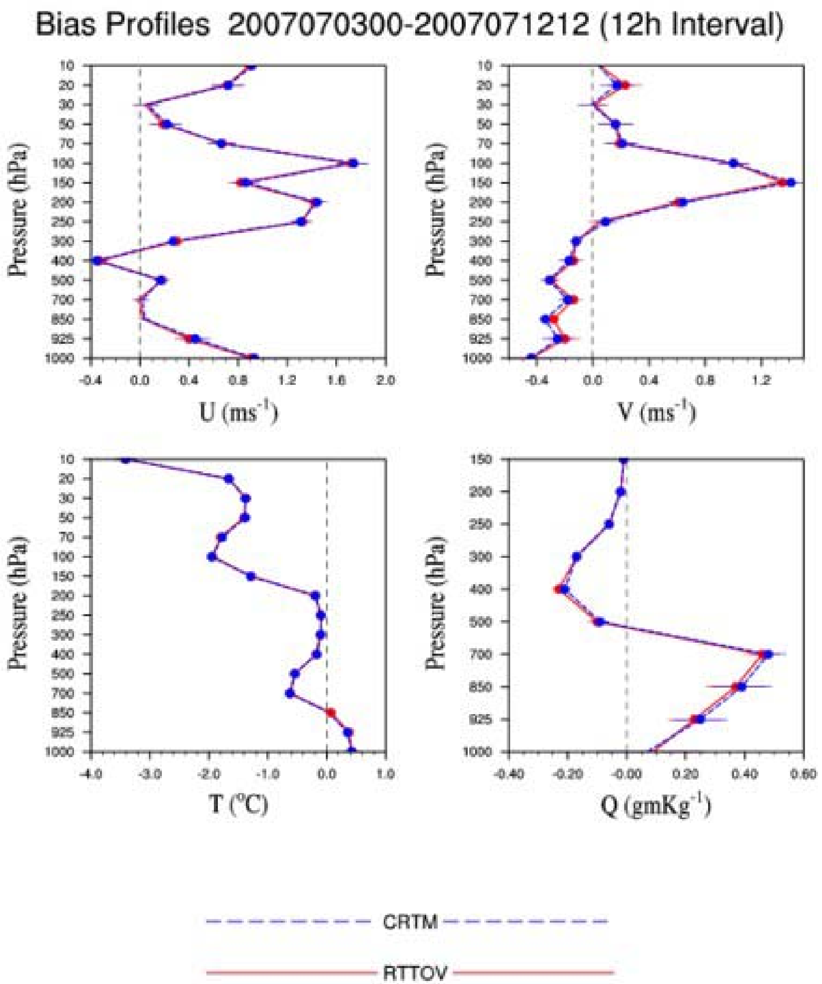


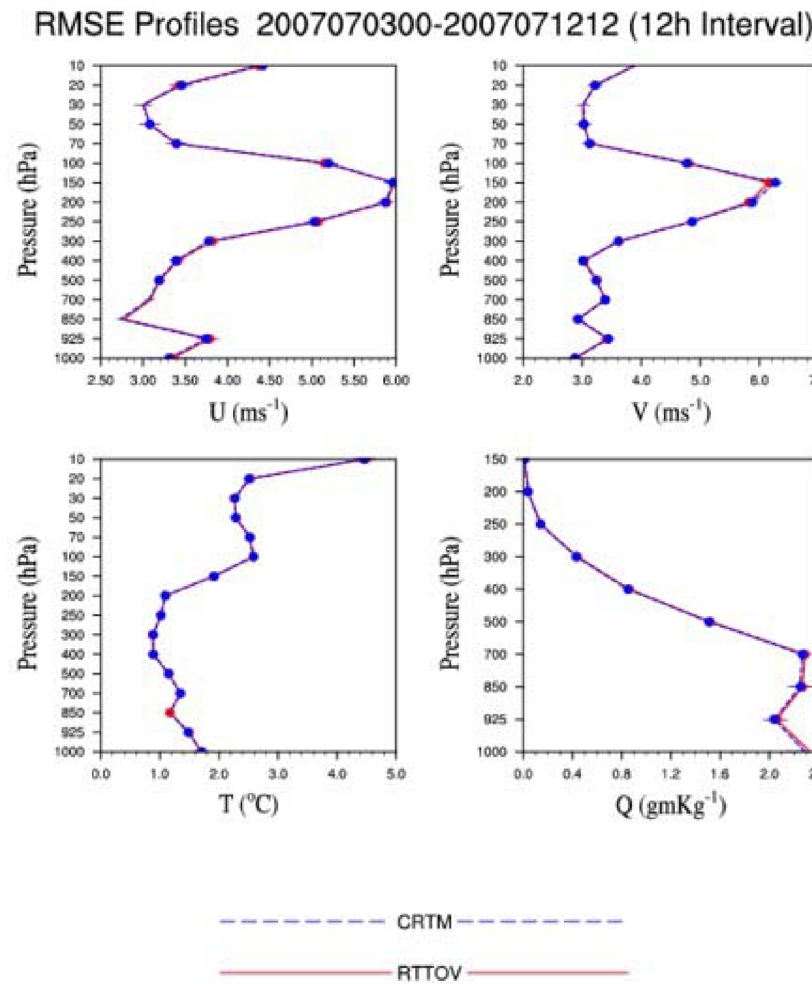
Land Use Category


Hurricane Dean (2007) , 9 forecasts mean
Track Error (km)
240
210
180
150
120
90
60
0
12
24
36
48
Forecast Time (hours)
RAD
GTS


Hurricane Dean (2007) , 9 forecasts mean
CSLP Error (mb)
40.0
38.0
36.0
34.0
32.0
30.0
28.0
26.0
0
12
24
36
48
Forecast Time (hours)
RAD
GTS

CRTM vs. RTTOV (48h FC vs. GTS obs) with a model resolution of 45km

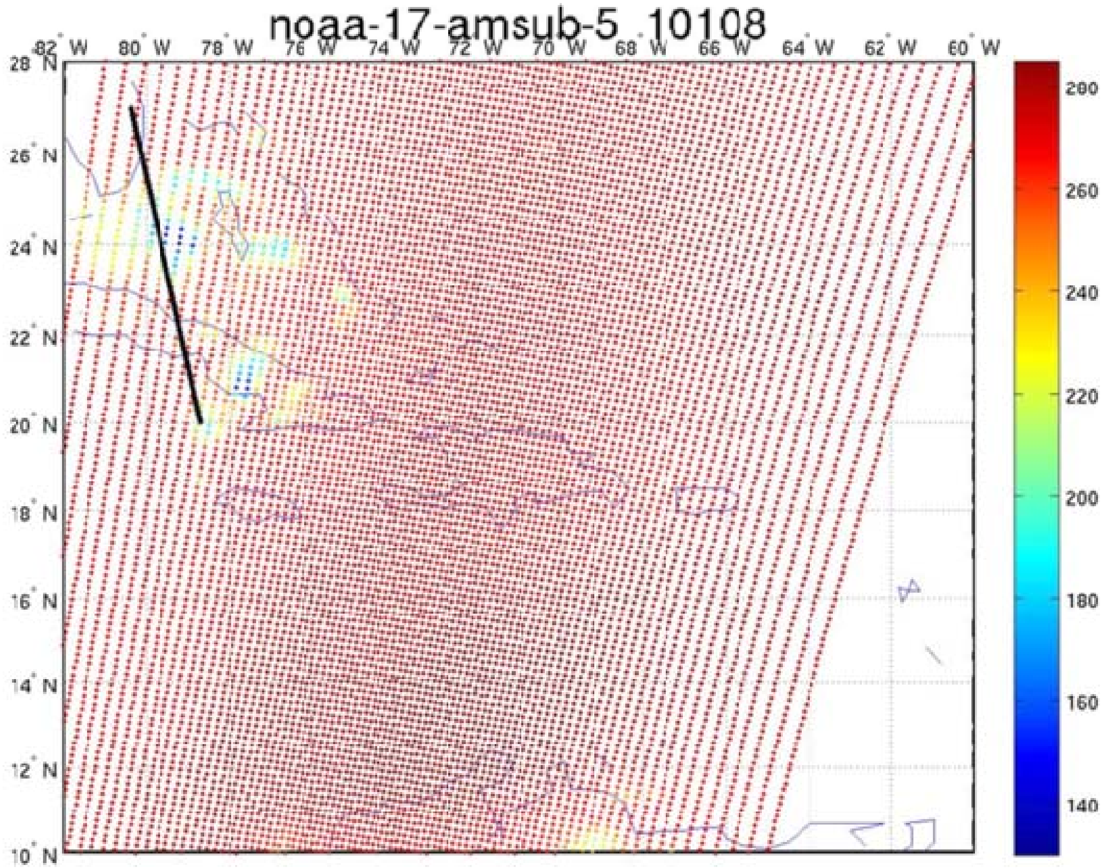




Cloudy radiance Assimilation

- CRTM cloudy radiance Forward/TL/AD calculation interface implemented
  - Input: hydrometeors profiles and particle radius
- Particle size is diagnosed from cloud water content (Bauer, 2001)
- No hydrometeor control variables available in WRF-3DVAR, instead Total Water (Qt) as control variable, and a warm-rain process' TL/AD is used to partition Qt into cloud water and rain (Xiao et al., 2007) in 3DVAR
  - Warm-rain process limits the application
- Initial test with WSM3 microphysics scheme for hydrometeors forecast with a 4km resolution
  - Include cloud water/ice, rain/snow, no mixture phase

AMSU-B cloudy radiance (Ernesto storm)

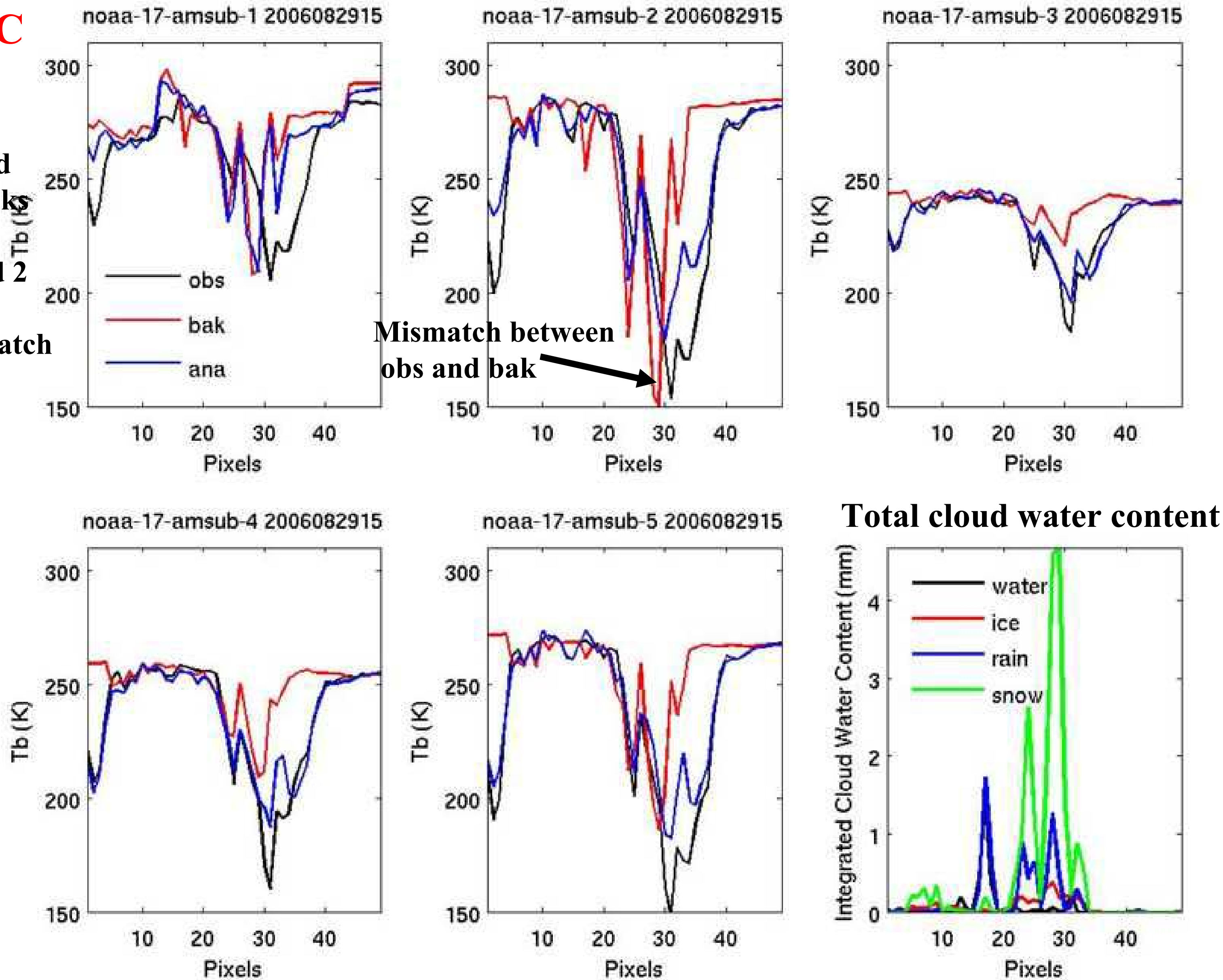


OBS time around 2006-08-29-15:23
Select pixels near CloudSat Path

NOAA-17-AMSUB Tb along CloudSat path

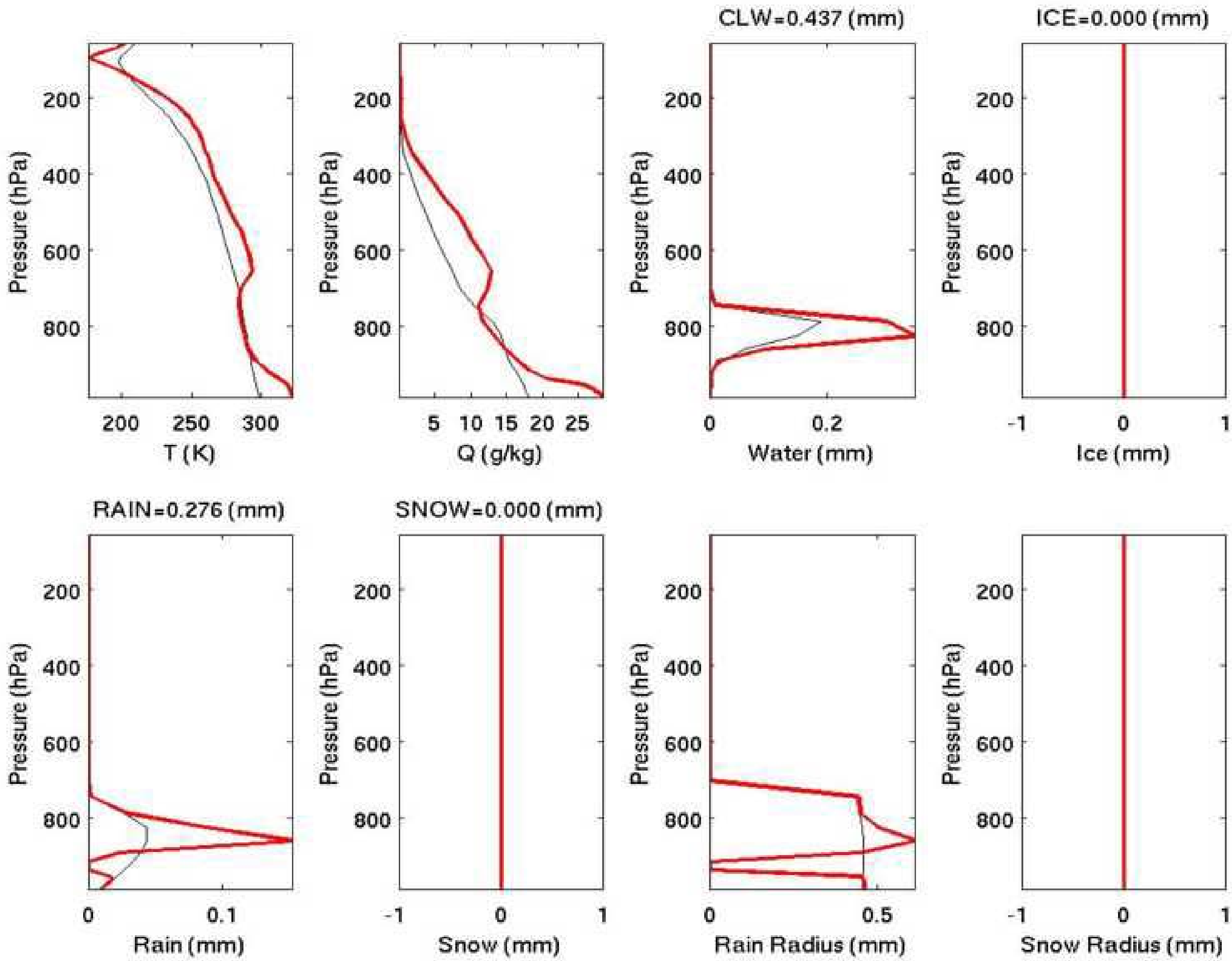
NO ANY QC

CRTM forward Calculation looks quite good for Channels 1 and 2 Regardless of Location mismatch

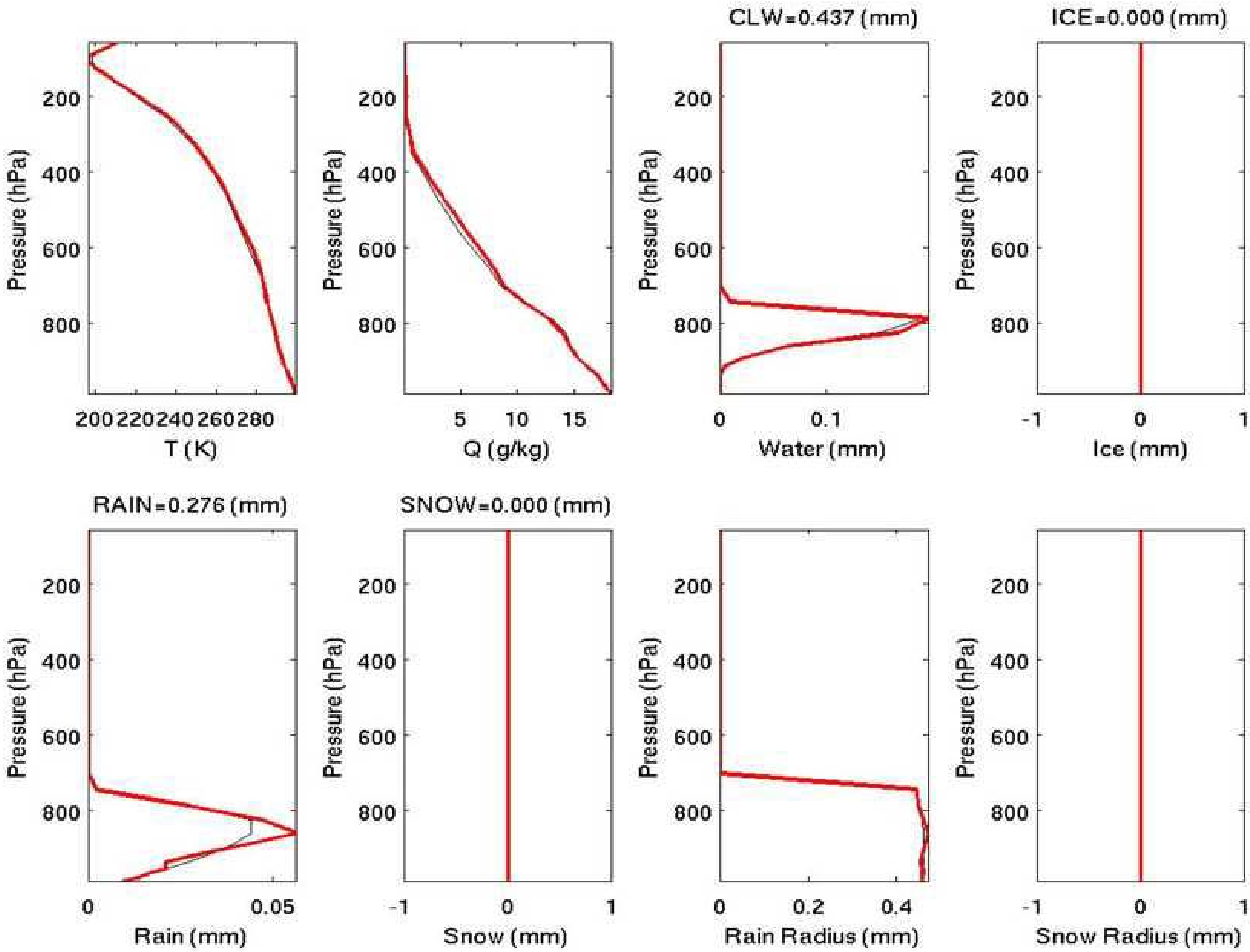


Profile 16, red line: analysis (no any QC)

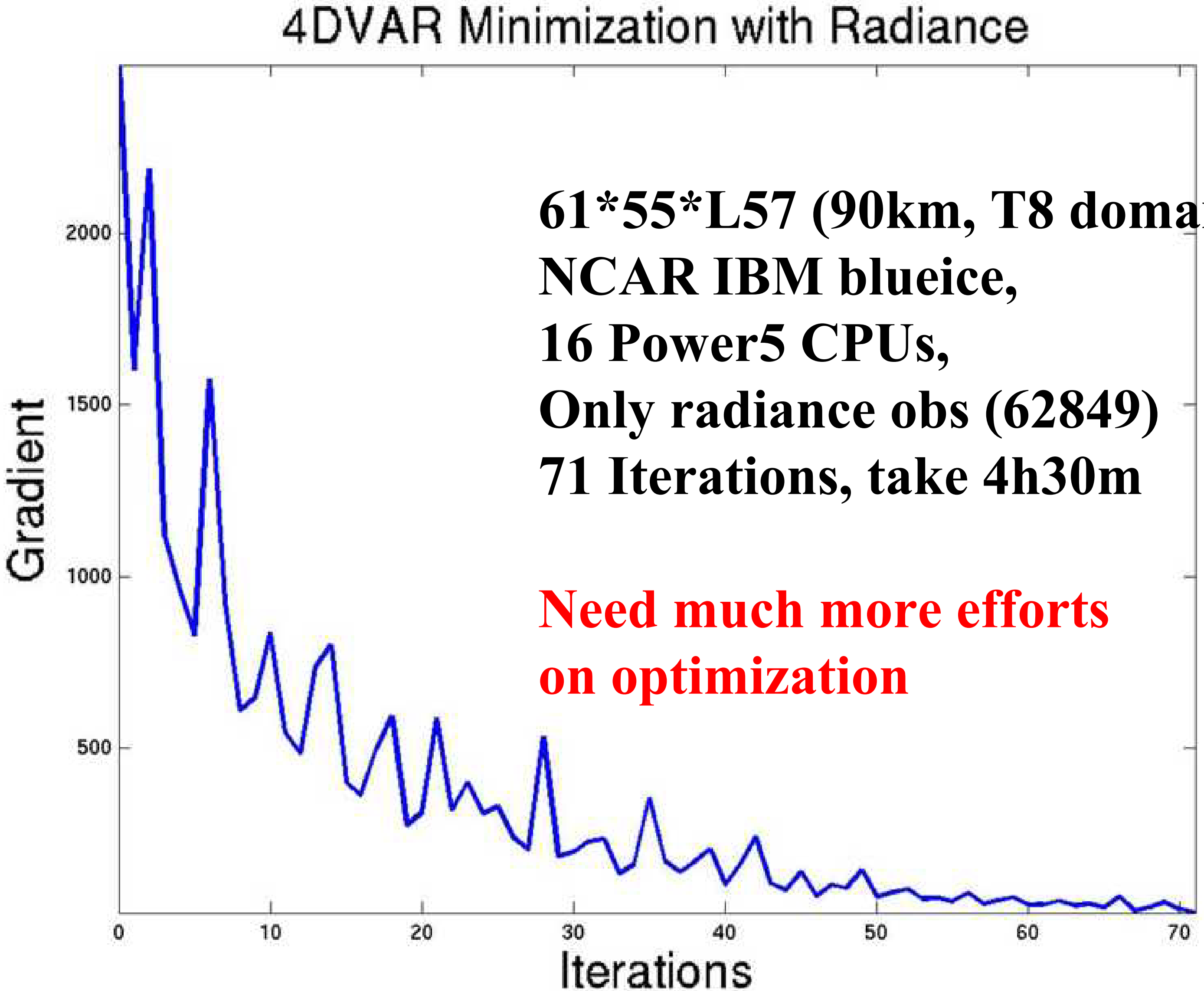
Large analysis increment for T, Q, CLW, Rain



Profile 16, red line: analysis (with simple QC)



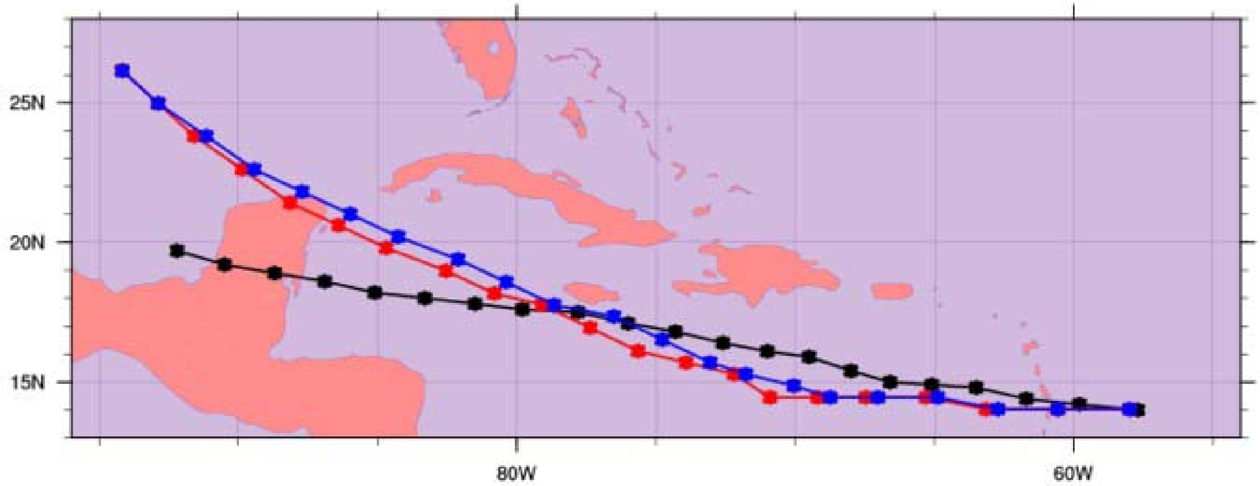
4DVAR+Radiance

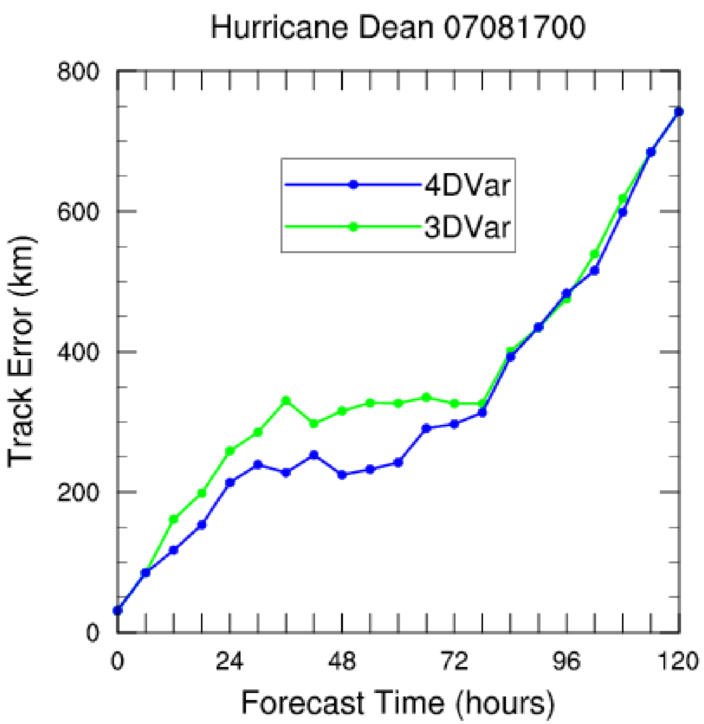


61*55*L57 (90km, T8 domain)
NCAR IBM blueice,
16 Power5 CPUs,
Only radiance obs (62849)
71 Iterations, take 4h30m

Need much more efforts on optimization

4DVAR vs. 3DVAR





45km resolution

model top = 10mb

Only assimilate radiance data (AMSU/MHS), 6h time window

Future plans

- Extended tests over Atlantic testbed in DATC
  - AMSU, SSMIS, AIRS
- Assist AFWA's operational implementation for radiance assimilation (planed this year)
  - Initial implementation will focus on microwave sensors (e.g., AMSU/MHS from NOAA platforms)
- Add more instruments
  - e.g., HIRS, IASI, GOES platforms, future NPP/NPOESS sensors
- Tune the system for various testbeds
- Further developments for cloudy radiance assimilation and 4DVAR+radiance
- Explore ensemble-based radiance assimilation