AMSU-A Cloudy Radiance Data Assimilation in NCEP NWP Models

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Introduction

- **Large numbers of radiance data contain cloud and precipitation signal.**
- **If cloudy radiances can be properly used, potential for significant improvements in forecasts of temperature, wind, moisture, and cloud fields.**
- **Initially addressing simpler problem with AMSU-A microwave radiance data in the oceanic region with non-precipitating clouds.**
- **Planned for initial operational implementation in the next NCEP global data assimilation system upgrade. (Spring-Fall 2013)**

NCEP Global Data Assimilation System(GDAS)

* NCEP Global Data Assimilation System (GDAS)
  - Gridpoint Statistical Interpolation (GSI) system
  - Global Forecast System (GFS) model
  - Community Radiative Transfer Model (CRTM)

$$J = (x-x_b)^T B^{-1}(x-x_b) + (H(x)-y_0)^T R^{-1}(H(x)-y_0)$$

x= Analysis,
x_b= background ,
B= Background error covariance ,
H= Observation operator,
y_0= Observations
R = Observation error covariance

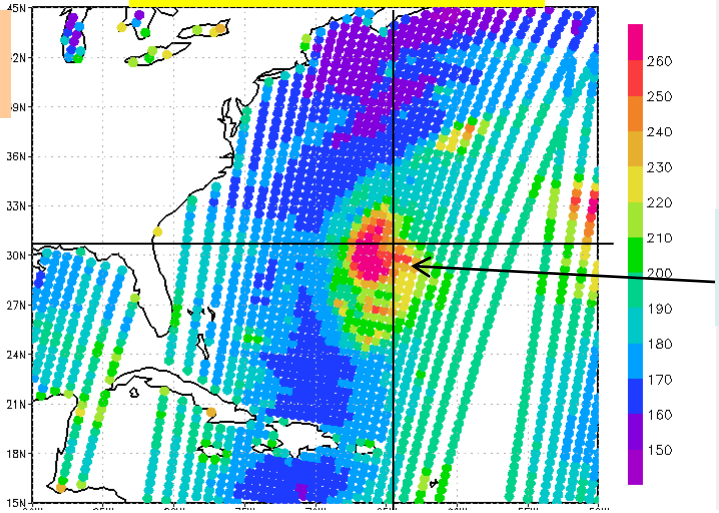
Observation operator

Community Radiative Transfer Model (CRTM)

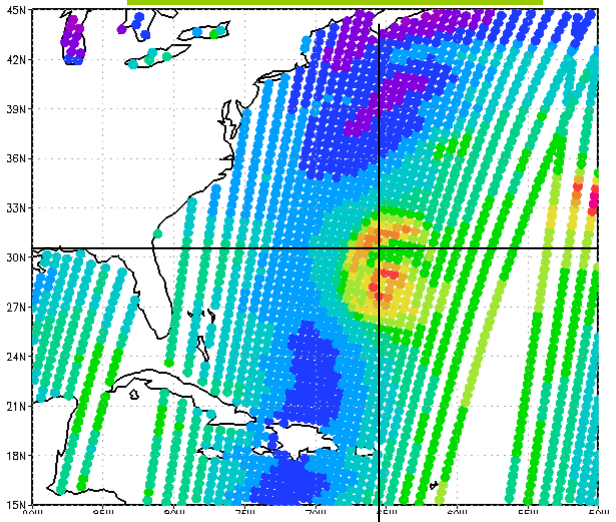
AMSU-A Observed Tb

First-Guess Tb

CH 2
31.4 GHz

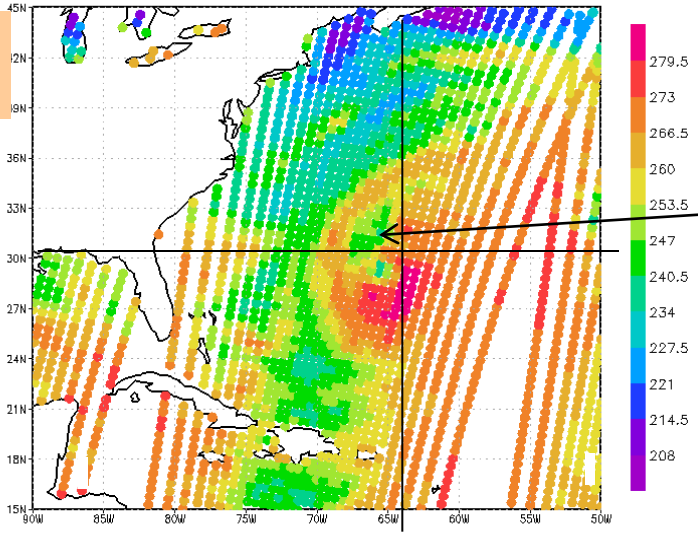


Much warmer than FG

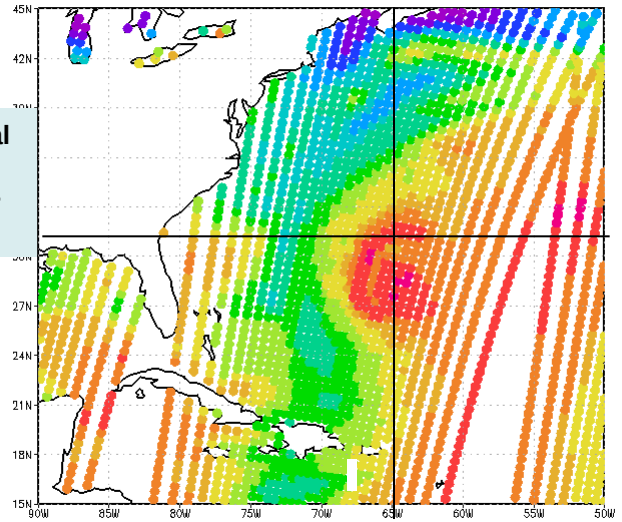


CH 2
31.4 GHz

CH 15
89.0 GHz



Scattering signal in observations. ➔Precipitation+ ice clouds



CH 15
89.0 GHz

Necessary modifications for cloudy radiances

- ❑ Observation operator: Simulate cloudy radiances (CRTM)
- ❑ **Define quality control (currently only doing non-scattering clouds)**

  ➔ Screening retrieved averaged CLWP > 0.5kg/m^2 over the ocean

- ❑ Define observation errors
- ❑ Develop forward for cloud physics
  - Tangent linear model
  - Adjoint model
- ❑ Define control variable(s) for clouds
- ❑ Define background error for control variable(s)

Necessary modifications for cloudy radiances

- Simulate cloudy radiances (CRTM)
- Define quality control (currently only doing nonscattering clouds)
- Define observation errors

  (1) Function of model cloud or observed cloud?

  ➔ Following Geer et al. 2010 (ECMWF) , obs. errors are defined using mean of observed and modeled cloud liquid water path (CLWP).

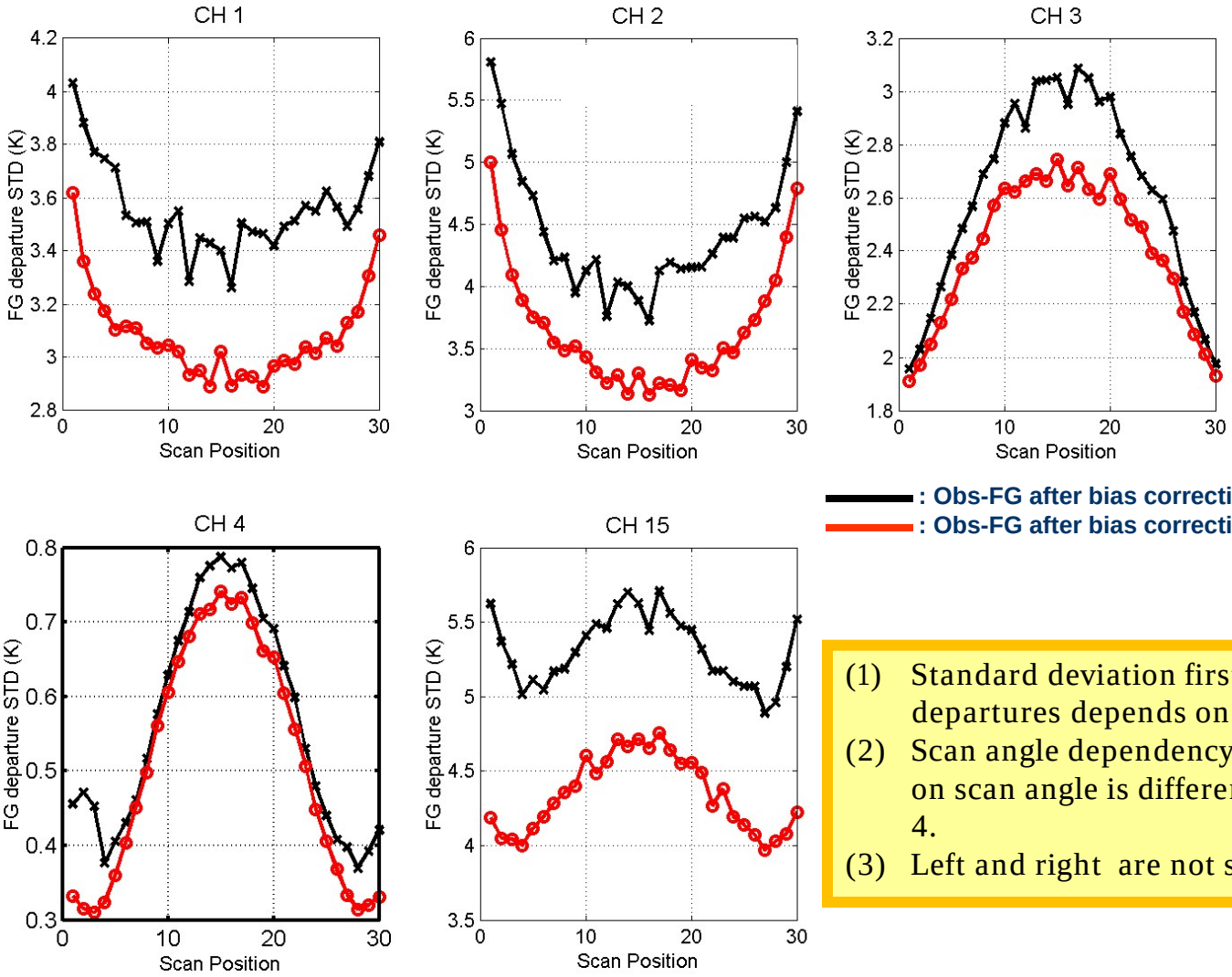
  (2) Do they depend on AMSU-A scan angle?
- Develop forward for cloud physics

  - Tangent linear model
  - Adjoint model
- Define control variable(s) for clouds
- Define background error for control variable(s)

Observation Error

: Does it depend on AMSU-A Scan Angle?

Standard Deviation (STD) of First-guess Departure (NOAA-18 AMSU-A)



: Obs-FG after bias correction

: Obs-FG after bias correction and QC passed

(1) Standard deviation first-guess departures depends on scan angle.

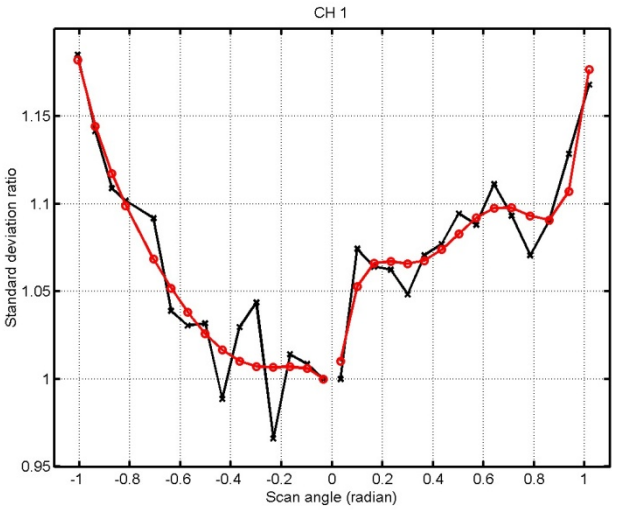
(2) Scan angle dependency pattern of Ch1,2 on scan angle is different from Ch 3 and 4.

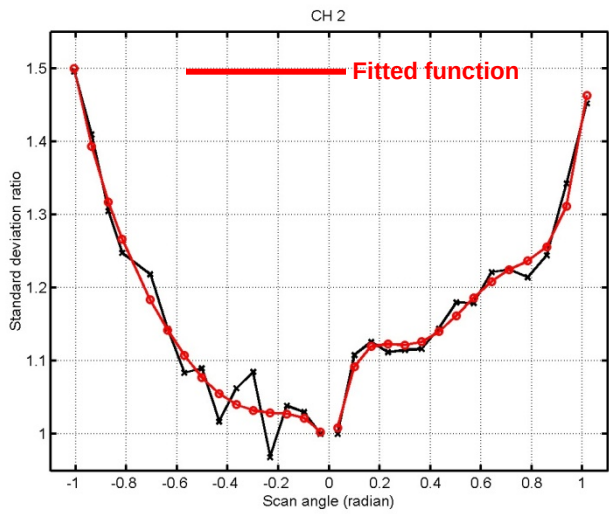
(3) Left and right are not symmetric.

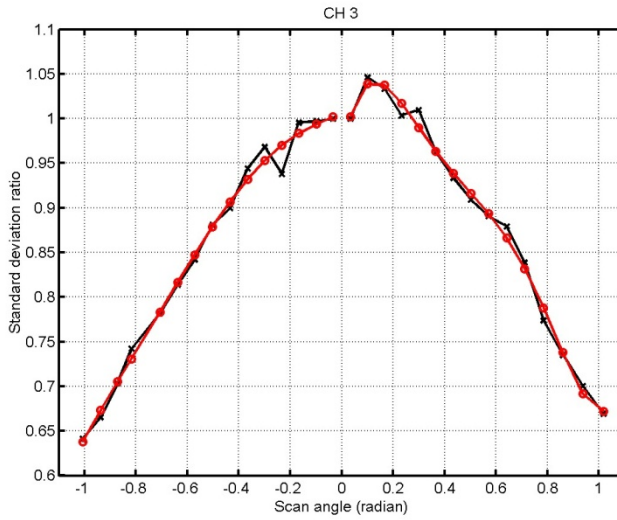
Observation Error

: How to include AMSU-A scan angle dependency?

std ratio: STD ratio= $\frac{STD(each\ scan\ position)}{STD\ (nadir)}$







Example: for channel 1

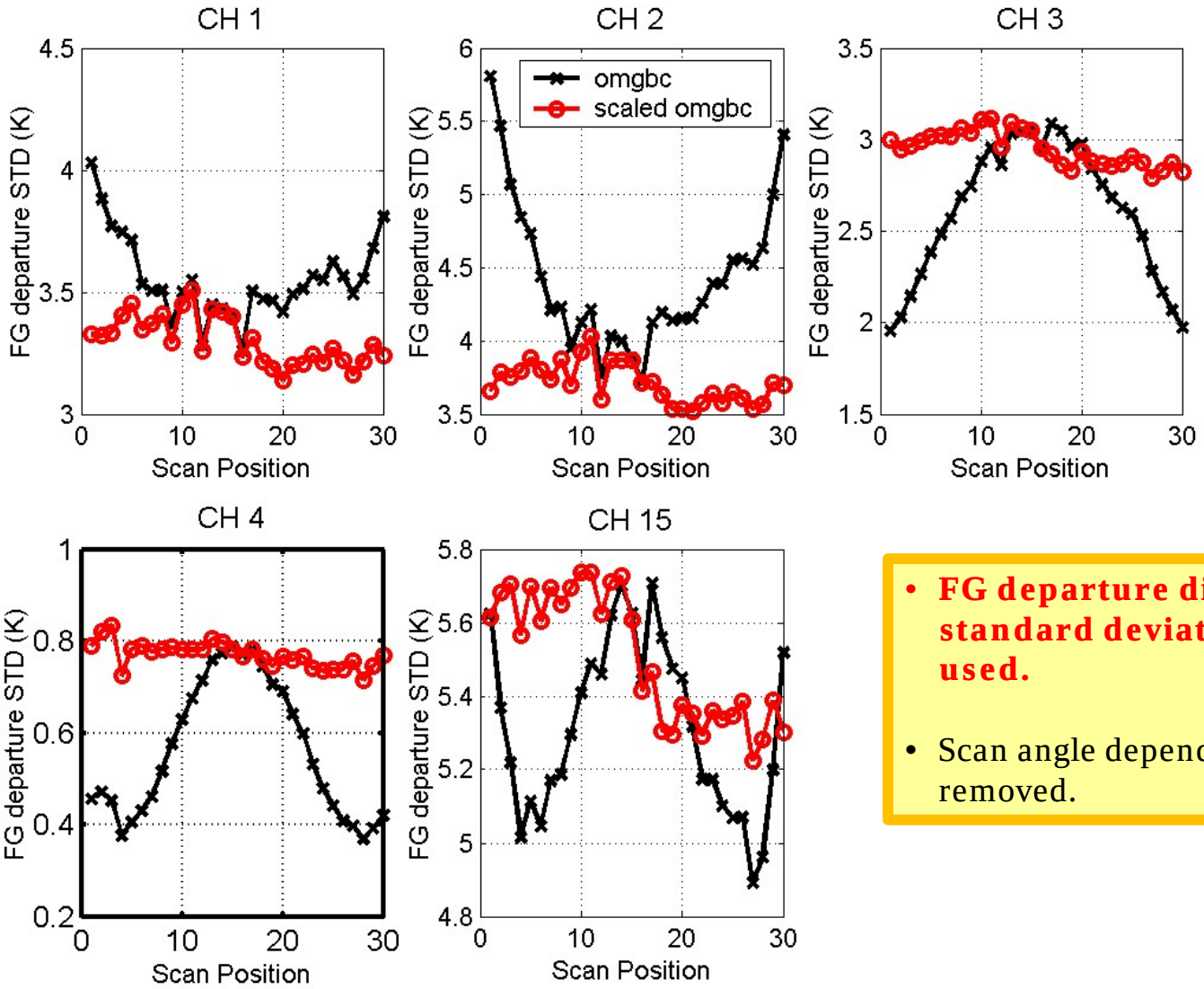
Scan position 1-15 $std\ ratio = 0.2256x^5 + 0.3811x^4 - 0.1201x^3 - 0.1331x^2 - 0.0638x + 0.9986$

Scan position 16-30 $std\ ratio = 6.0783x^5 - 15.638x^4 + 15.027x^3 - 6.7122x^2 + 1.4404x + 0.9677$

x: scan angle in radian

Observation Error

: How to include AMSU-A scan angle dependency?

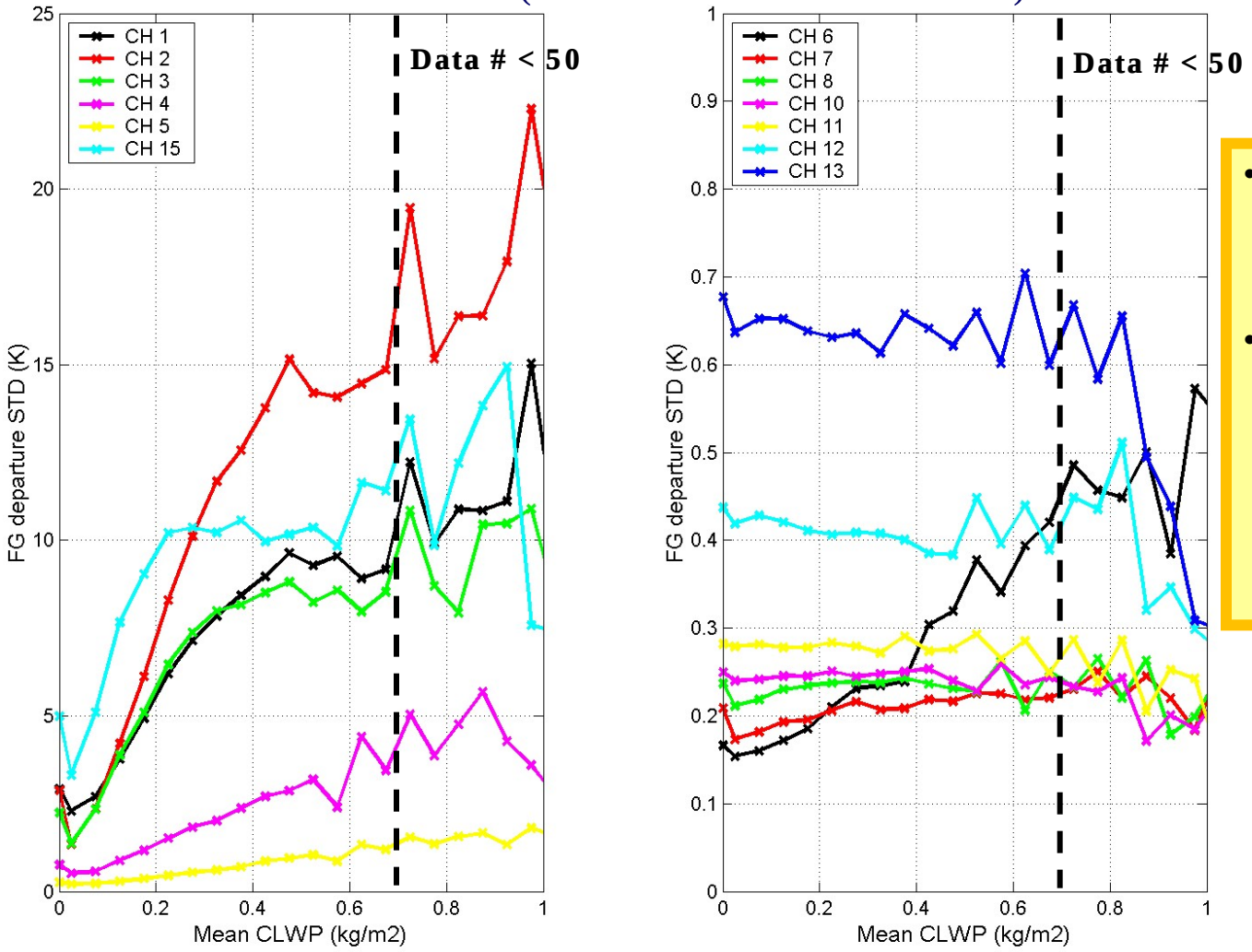


- **FG departure divided by standard deviation ratio were used.**
- Scan angle dependencies got almost removed.

Observation Error

: Function of Mean Cloud Liquid Water Path (CLWP)

Mean CLWP=0.5×(observed CLWP + model CLWP)



- FG departure divided by std ratio were used to get STD in these plots.
- Once observation errors are defined as function of CLWP, the error value will be rescaled by multiplying with std ratio depending on scan position.

Necessary modifications for cloudy radiances

- **Simulate cloudy radiances (CRTM)**
- **Define quality control (currently only doing nonscattering clouds)**
- **Define observation errors**

  (1) Function of model cloud or observed cloud?

  ➔ Following Geer et al. 2010 (ECMWF) , obs. errors are defined using mean of observed and modeled cloud liquid water path (CLWP).

  (2) Do they depend on AMSU-A scan angle?

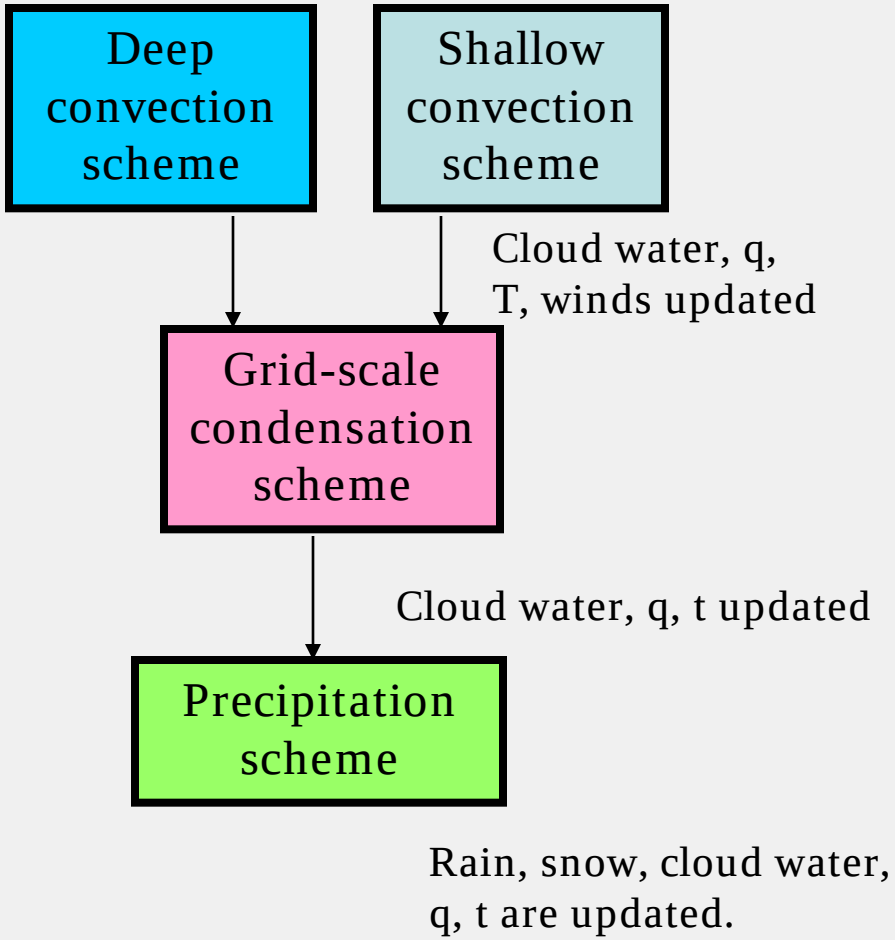
- **Develop forward for cloud physics**

  - Tangent linear model
  - Adjoint model

- **Define control variable(s) for clouds**
- **Define background error for control variable(s)**

Moisture Physics Models

NCEP GFS moisture physics schemes



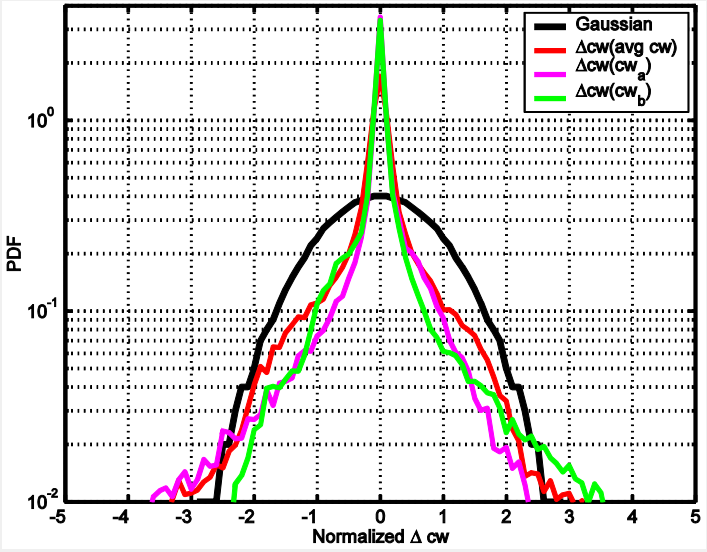
- **NCEP Global Forecast System(GFS) moisture physics schemes are composed of**
  (1) Simplified Arakawa-Schubert (SAS) convection scheme,
  (2) a shallow-convection scheme,
  (3) a grid-scale condensation scheme, and (4) a precipitation scheme.

- **The Tangent-linear and adjoint codes for (1), (3), and (4) have been developed and currently being tested in GSI for cloudy radiance data assimilation**.

Moisture Control Variable

: What differentiates GSI analysis results when different configurations for moisture control variables are used?

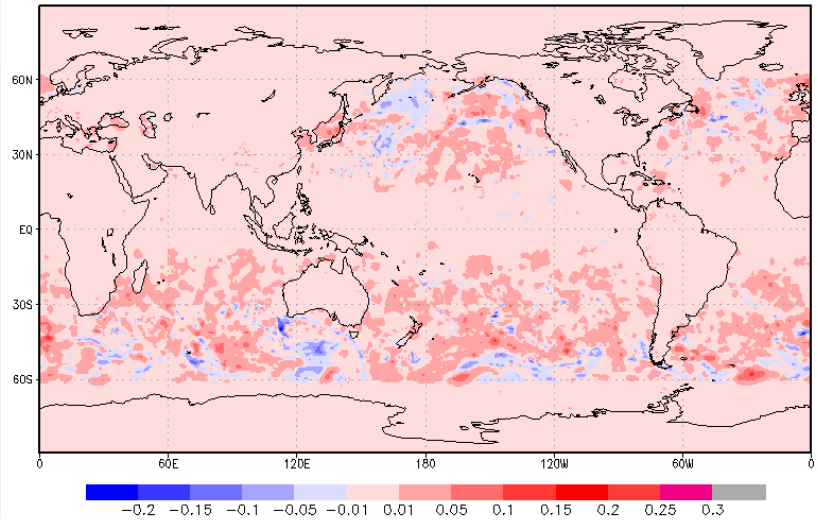
Cloud water error statistics show "non-Gaussian" distribution.



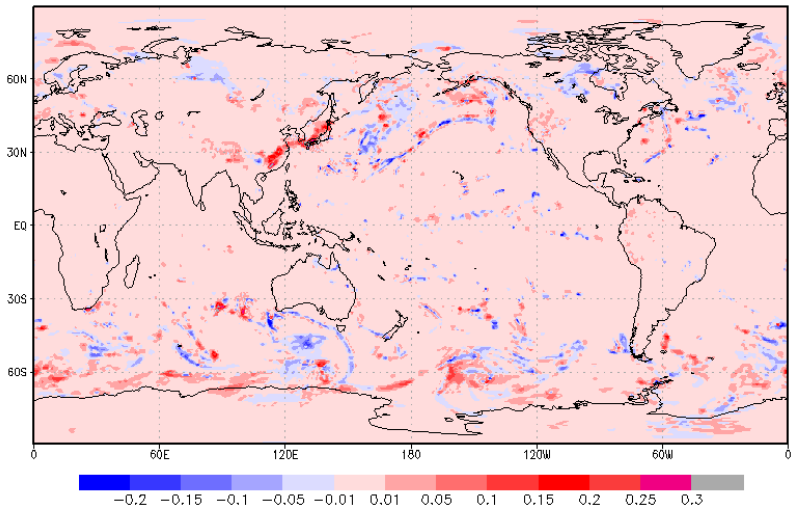
	Moisture input for observation operator (CRTM)	Moisture Control variable
Control	q	Normalized RH
Experiment 1	q, ql, qi	Normalized RH, cw(=ql+qi)
Experiment 2	q, ql, qi, rain, snow	Normalized RH
Experiment 3 **(In progress by Emily Liu)**	q, ql, qi	Normalized Total Relative Humidity (RH Total=ql+qi+cw)
Experiment 4 **(In progress)**	q, ql, qi	Different forms of cw (e.g. cw/qs, cw/N where N is cloud coverage and qs is saturated mixing ratio)

Cloudy Analysis Increments

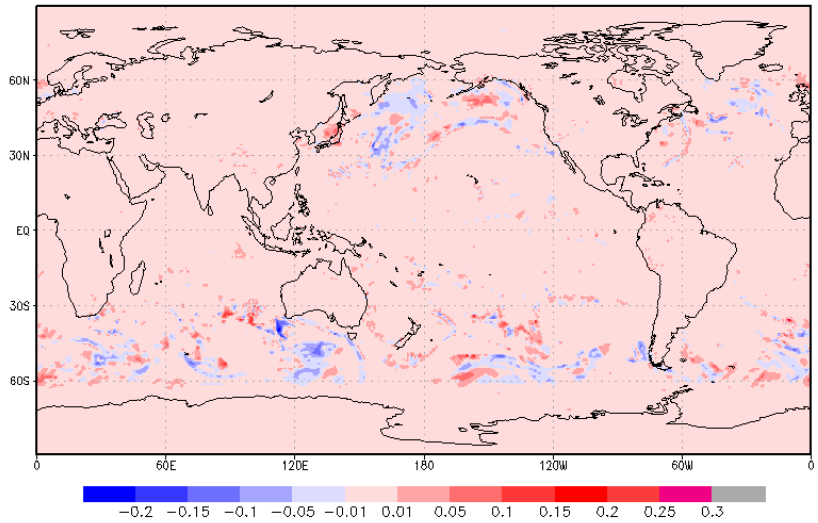
CW, without Moisture Physics



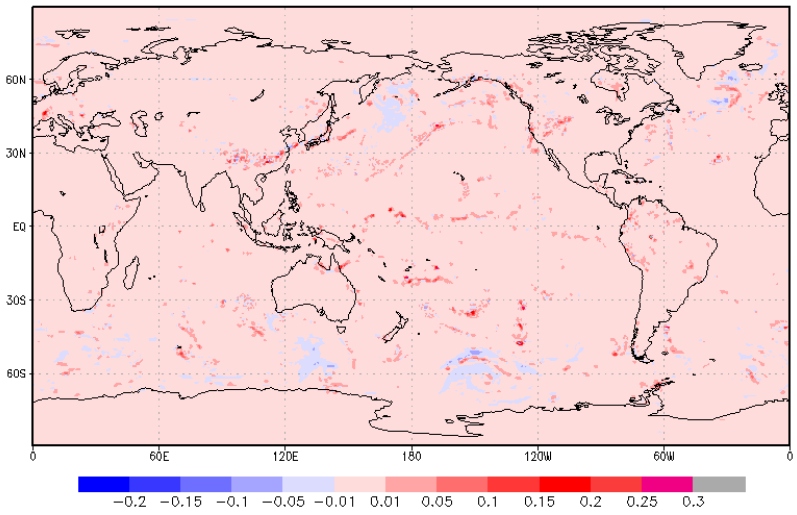
RHtot, with Moisture Physics



CW, with Moisture Physics



Moisture physics in the outer loop only



Conclusions

1. There has been great progress in assimilating AMSU-A cloudy radiance data in NCEP Global Data Assimilation System (GDAS).

2. New observation errors and quality control methods, which are applicable for clear and cloudy sky conditions, have been developed.

3. Testing/comparing different options for moisture control variables are in progress.

4. Preliminary results from case studies show that cloud fields are now being actively assimilated and cloud analysis fields get much closer to the retrieved values.

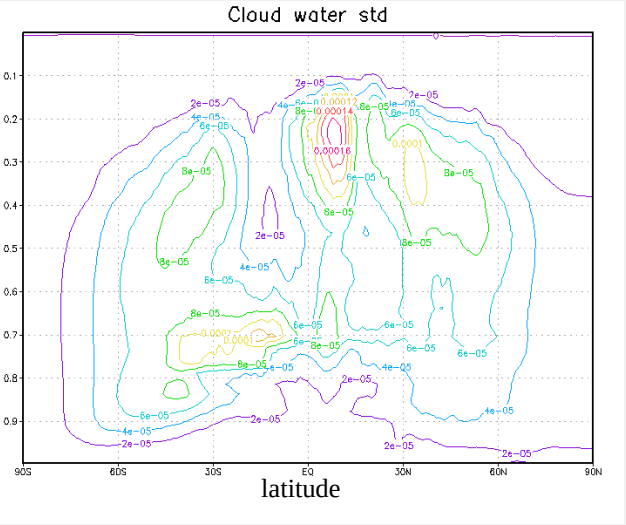
5. Comparisons of static background error covariance with ensemble background error covariance for hybrid GSI system are under way.

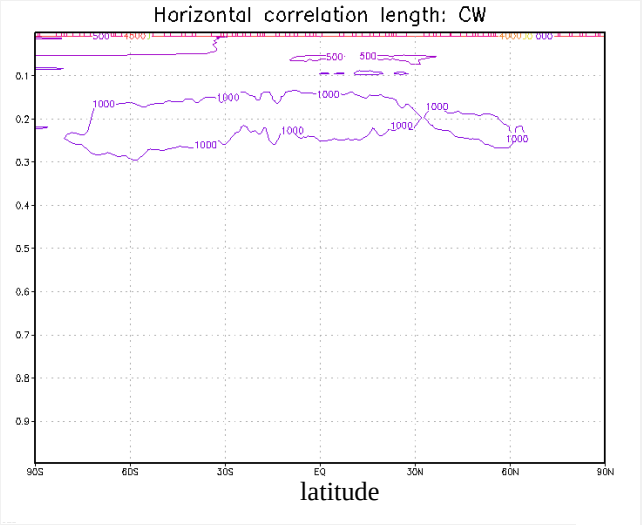
6. Testing impacts on GFS model forecasts and HWRF model forecasts skill scores.

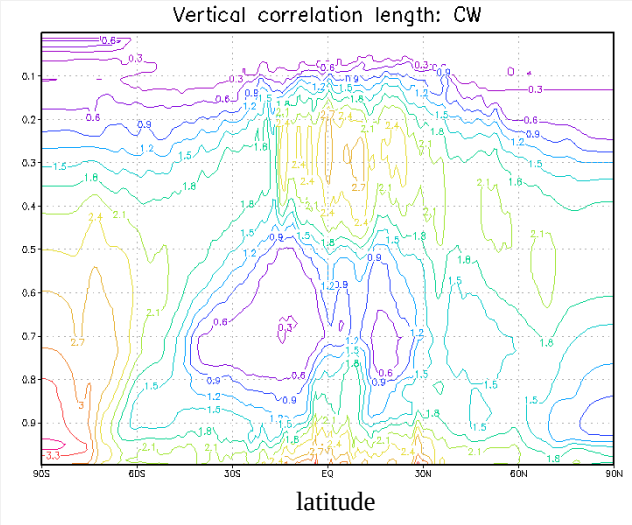
BACK-UP SLIDES

Background Error Covariance

Background error covariance for clouds are from NMC method.







Large standard deviations in the region of convections near tropics and midlatitude frontal systems

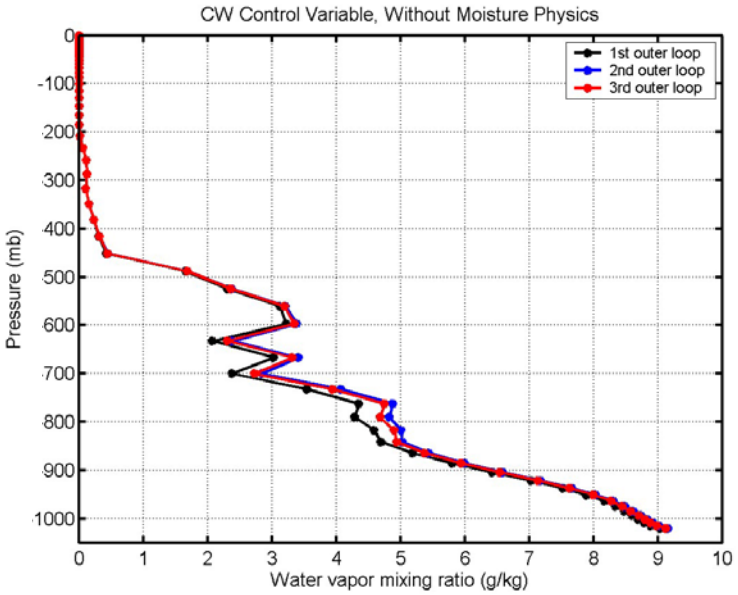
Not much horizontal correlation for cloud

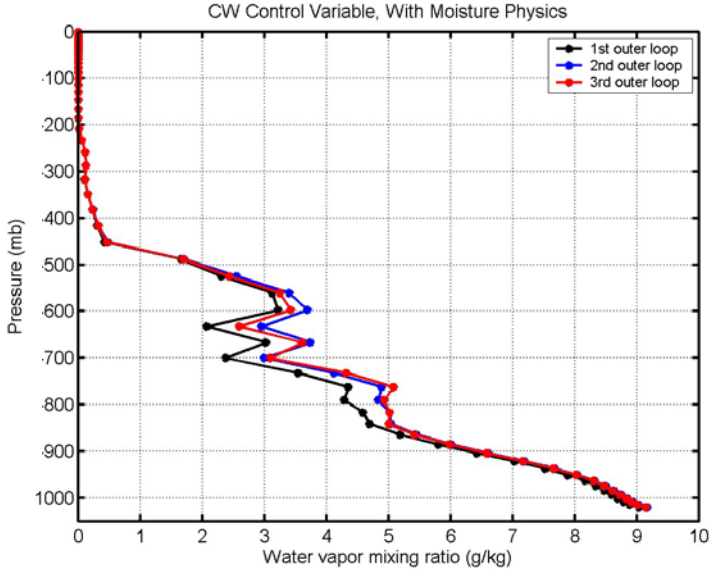
Larger correlation in vertical than in horizontal

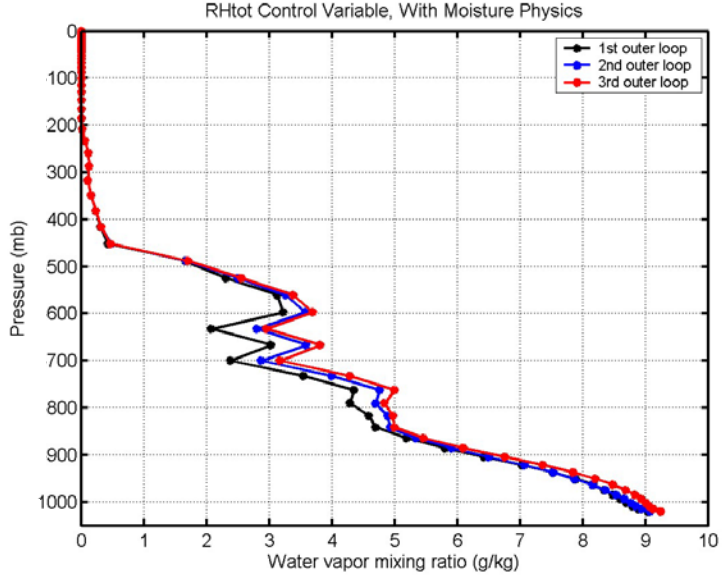
Comparisons of static background error covariance with ensemble background error covariance for hybrid GSI system are under way.

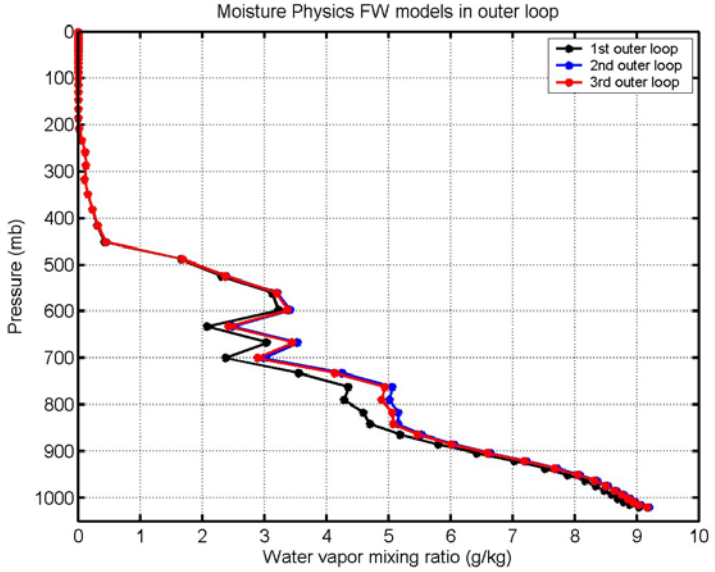
Single Obs Test Results

: Water vapor profiles



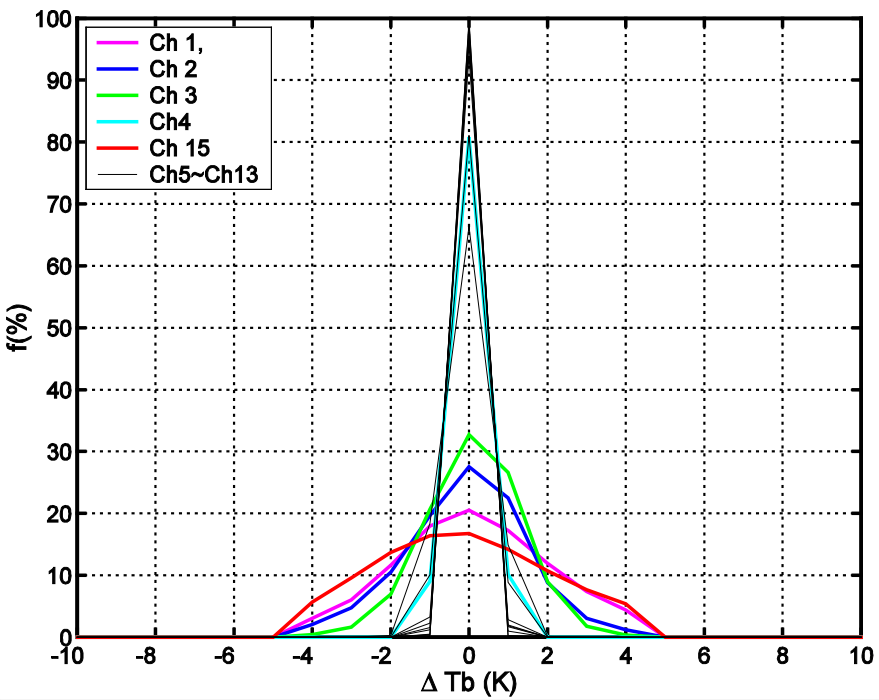




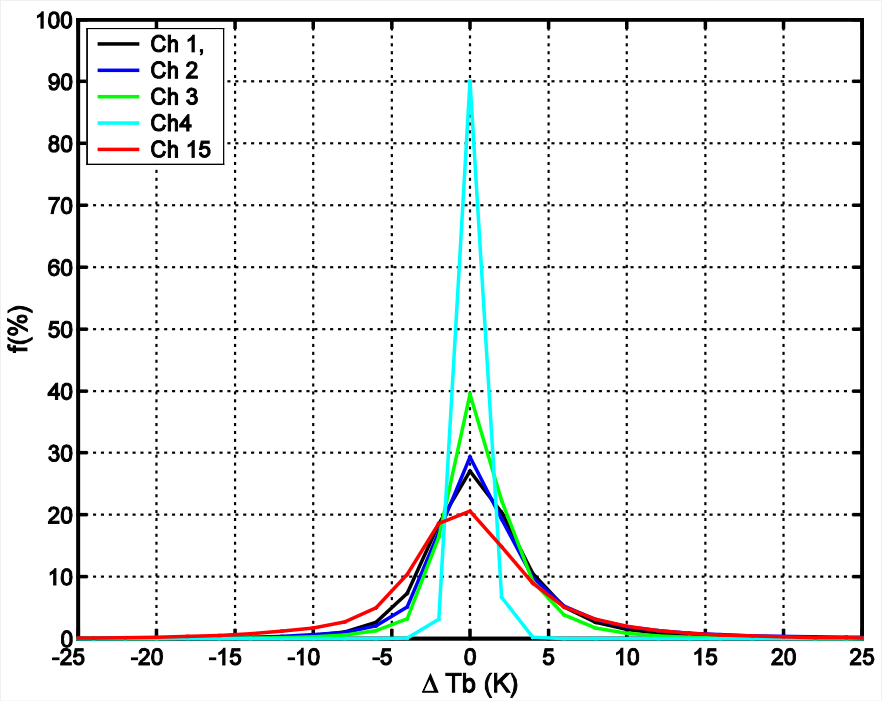


Observation vs. First-Guess

Original GSI: clear sky over the ocean



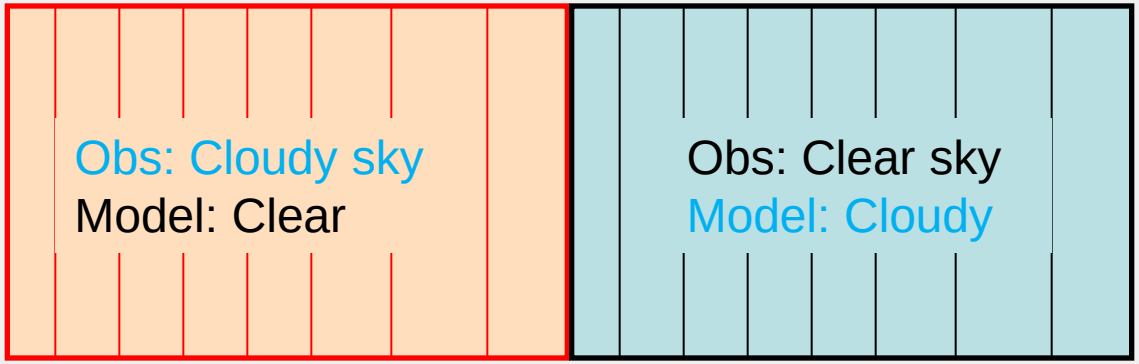
All-Sky GSI: clear sky for all surface+ nonprecipitating cloudy sky over the ocean



Observation Error

: Function of observed cloud or model cloud ?

Method learned from Geer et al. (2010) @ ECMWF



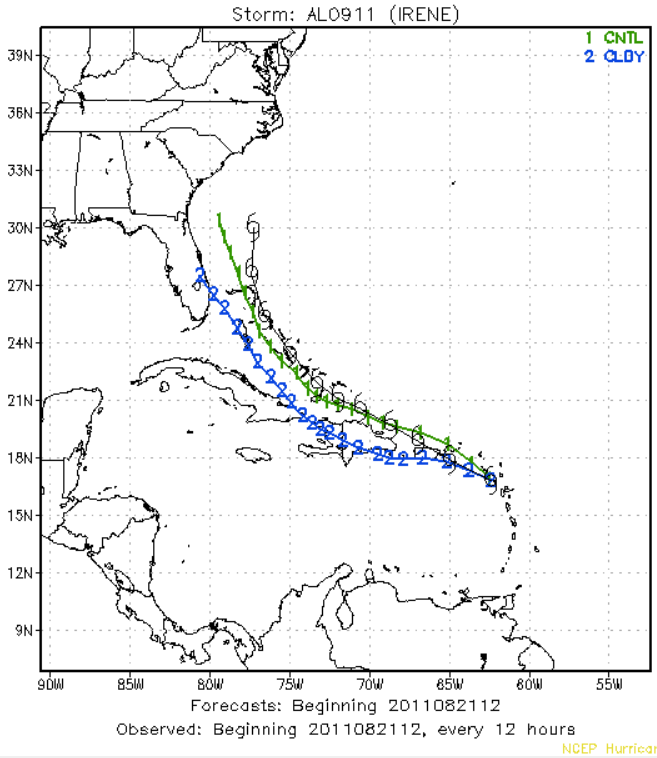
Obs error function of Obs cloud → Large obs error (Small weight) → Small obs error (Large weight) → Dry model atmosphere

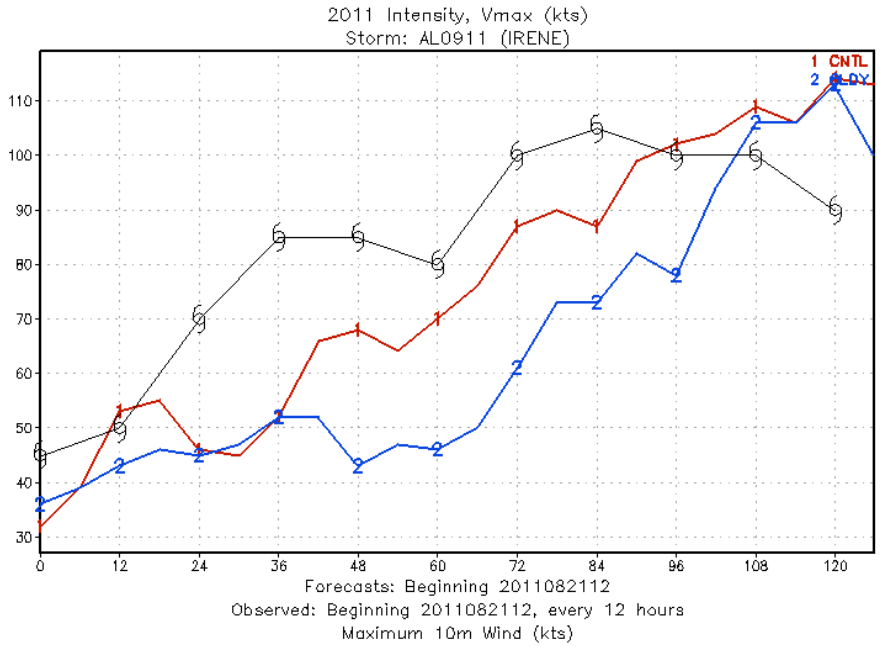
Obs error function of Model cloud → Small obs error (Large weight) → Large obs error (Small weight) → Moisten model atmosphere

Observation error = function of $\frac{\text{Cloud}_{\text{MODEL}} + \text{Cloud}_{\text{OBSERVED}}}{2}$

Preliminary Assessment :

Hurricane forecast: IRENE (21 August 2011, 12Z)





- Initial test run shows that track and intensity forecasts got worse compared with control run.
- We are in the middle of diagnosis for improvements.
- Experiments with other moisture control variables shown in Table 1 are in progress.

GSI without cloud radiances

Data thinning = 145 km for AMSU-A

User input & initializations

Read in & distribute Observations, guess fields background error (T, q, sfc P, u, v, ozone)

Additional initializations

Outer loop

a) Calculate radiances and jacobians with CRTM,

b) Applying bias corrections

c) Screening observation with QC processes

d) Set up right hand side of analysis equation

e) Call inner loop

i. Compute gradient information

ii. Apply background error

iii. Compute search direction

iv. Compute step size

v. Update analysis increment

f) Update outerloop analysis increments

Write analysis & related output

GSI without cloud radiances

Data thinning = 145 km for AMSU-A

User input & initializations → **Read in & distribute Observations, guess fields background error (T, q, sfc P, u, v, ozone, clouds)** → **Additional initializations**

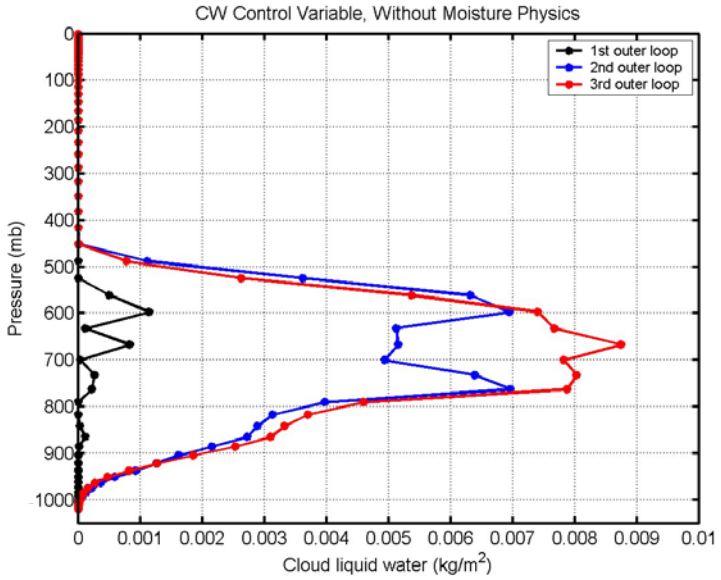
Outer loop **(add cloud analysis control variable)**

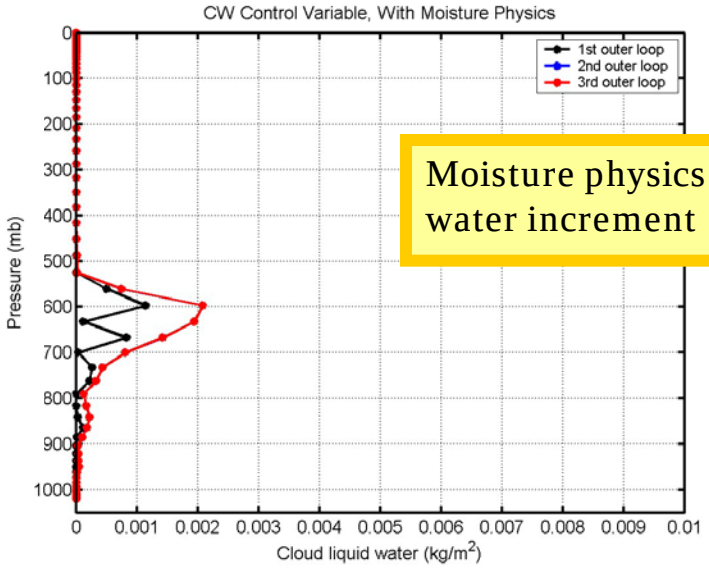
- **a) Calculate radiances and jacobians with CRTM,** **(clear and cloudy radiances)**
- **b) Applying bias corrections** **(revised for cloudy radiances)**
- **c) Screening observation with QC processes** **(remove radiances we cannot simulate)**
- **d) Set up right hand side of analysis equation** **(include cloud forcing)**
- **e) Call inner loop**
  - i. Compute gradient information **(through TL and AD model of moisture physics)**
  - ii. Apply background error **(including cloud control variable)**
  - iii. Compute search direction
  - iv. Compute step size **(including cloudy radiances)**
  - v. Update analysis increment **(through linearization of physics)**
- **f) Update outerloop analysis increments**

→ **Write analysis & related output**

Single Obs Test Results

: Cloud liquid water profiles





Moisture physics regulates the cloud water increment