AIRS data assimilation with LETKF: temperature, humidity retrievals, preliminary results assimilating radiances, and multivariate assimilation of CO2

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Outline

- Review AIRS temperature retrievals assimilation in our LETKF system (Li et al., 2007)
- Assimilation of AIRS humidity retrievals in addition (Liu et al., submitted to MWR): Improved both humidity and wind fields
- (AIRS retrievals provided by Chris Barnett and students)
- Preliminary results assimilating radiances within LETKF
- Multivariate assimilation of CO2 simulations (OCO+AIRS)

Assimilation of AIRS temperature retrievals

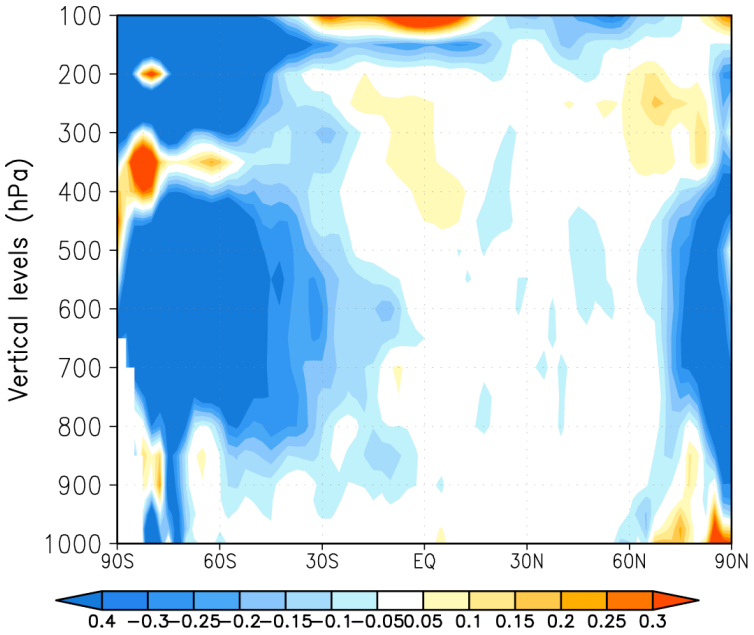
- *System :* NCEP GFS (T62L28) with 4D-Local Ensemble Transform Kalman Filter (4D-LETKF, Hunt et al., 2007, Szunyogh et al., 2007)
- *Experimental design:*

Experiments	*Observations*
Control run	Non-radiance operational observation data
AIRS T run	Non-radiance + AIRS temperature retrievals

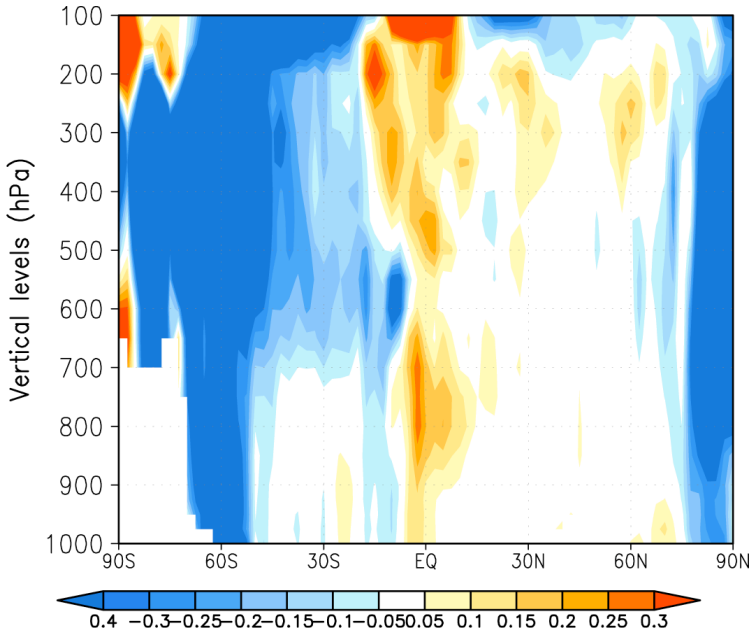
- *Verification:* Operational NCEP analysis at T254L64, assimilating all operational observations. (Not "truth"!).

Zonal average analysis RMS error difference between AIRS T run and control run

Temperature



Zonal wind



Blue means AIRS run is better, Red means AIRS is worse

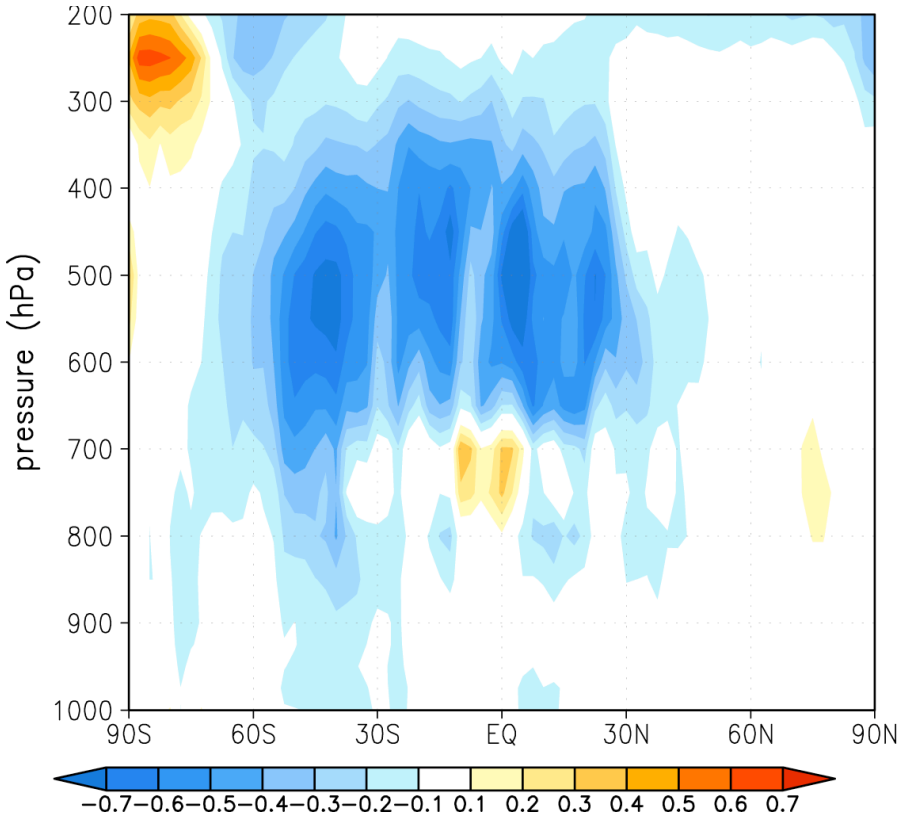
AIRS Temperature retrievals have significant positive impact in both NH and SH, and little impact on the tropics.

Assimilation of AIRS humidity retrievals on NCEP GFS with the LETKF

Experiments	*Observations*
Control run	Non-radiance + AIRS T retrievals
AIRS q run	Non-radiance + AIRS T + q retrievals

- Assimilating pseudo-RH ($\frac{q^o}{q^b_{st}}$, Dee and da Silva, 2003)
  - more Gaussian than q (assimilating of q makes u, v, t, Ps worse)
  - have no correlation with T observations (unlike relative humidity)
- Fully coupled error covariance with u, v, T, ps during data assimilation (multivariate)
- *Verification*: Operational NCEP analysis at T254L64, assimilating all operational observationsn *(not truth!)*.

Specific humidity RMS error difference between AIRS q run and control run

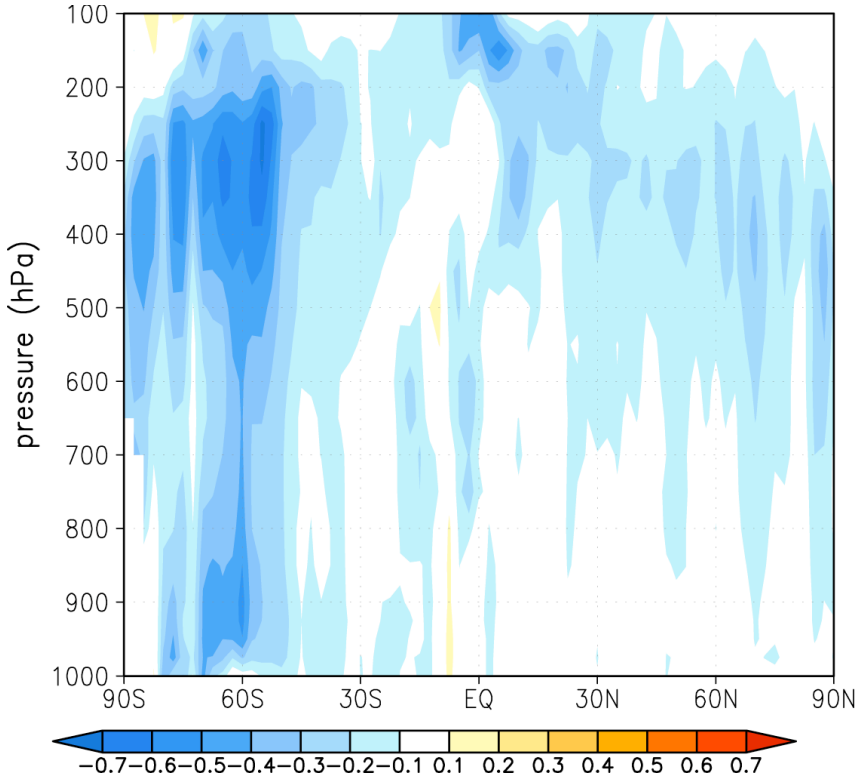


Blue means AIRS run is better, Red means AIRS is worse

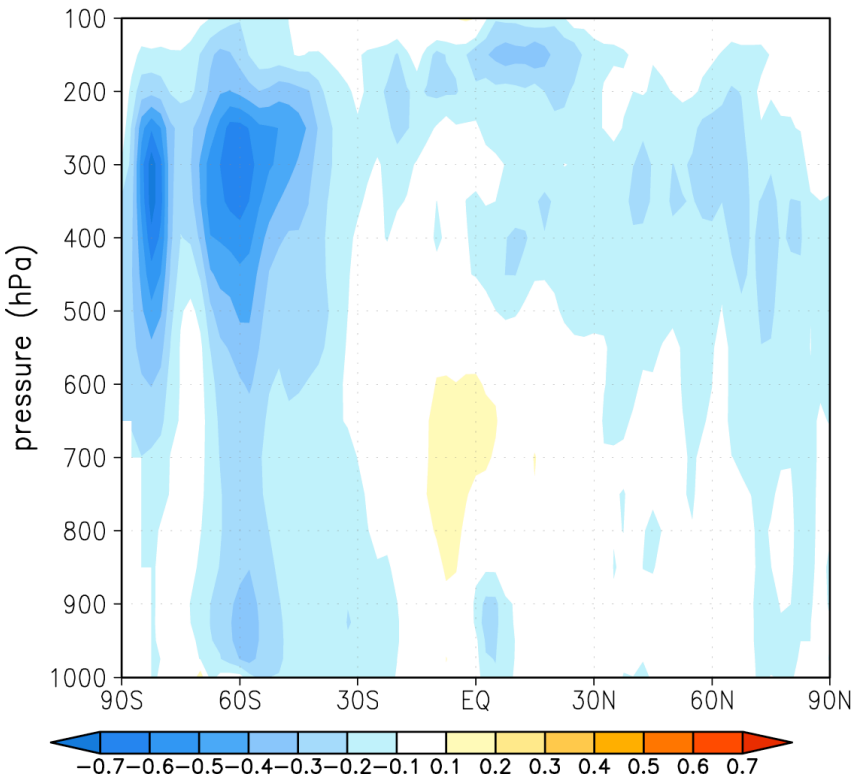
- Positive impact in most of the area

Analysis RMS error difference between humidity run and control run

Zonal wind

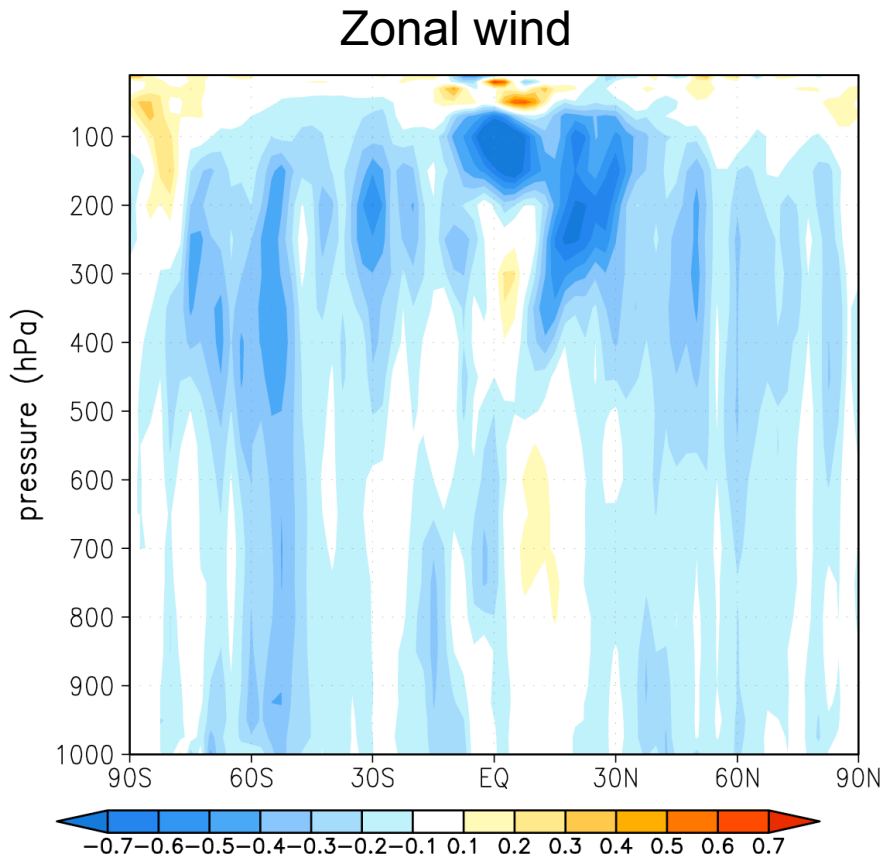


Meridional wind



- Positive impacts on both zonal wind the meridional wind.

48hr zonal wind forecast RMS error difference between humidity run and control run

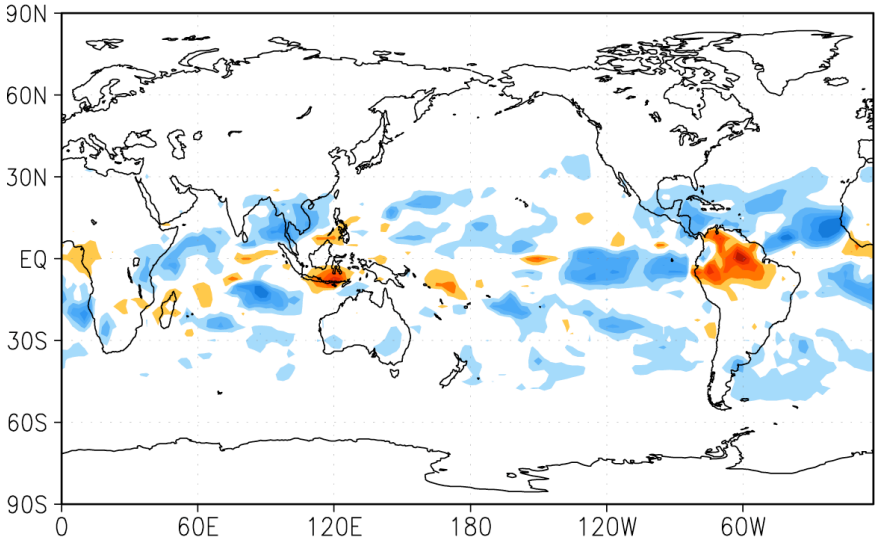


48-hour forecast keeps the advantage of assimilating humidity retrievals.

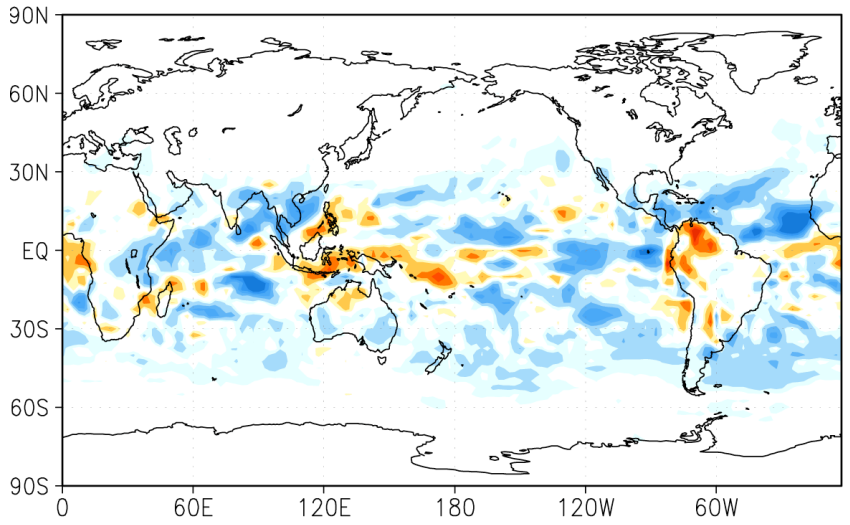
The center of larger improvement moves northward.

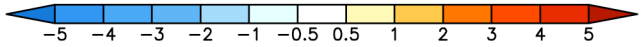
Total column precipitable water 6 hour forecast rms error difference between humidity run and the control run

Univariate q - control run



Multivariate q - control run





- Improved humidity analysis improves the 6-hour total column precipitable water forecast for both univariate-*q* and multivariate-*q* experiments.
- Multivariate q has larger improvement

Summary of AIRS retrieval assimilation

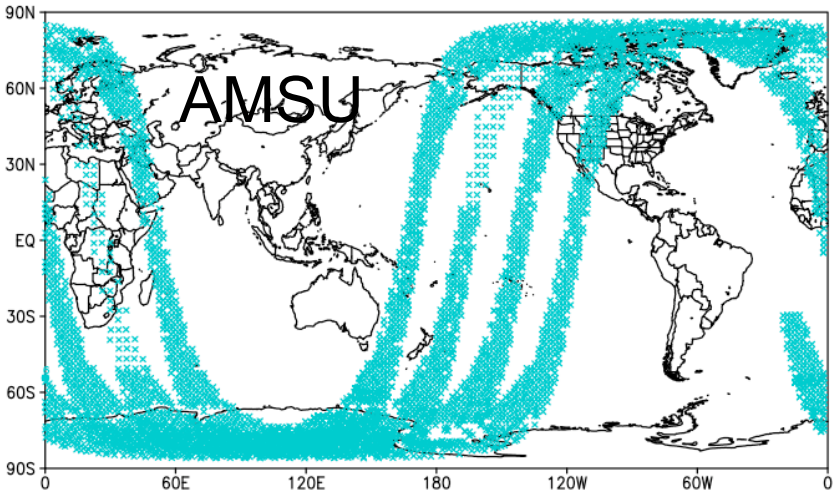
- *Improved analysis accuracy from assimilating both AIRS temperature retrievals and humidity retrievals.*
- *With pseudo-RH assimilation, it improves not only humidity analysis, but also wind analysis.*
- *As far as we know, this is the first time that multivariate assimilation of humidity has been shown to improve wind fields.*
- *It also improved precipitable water.*

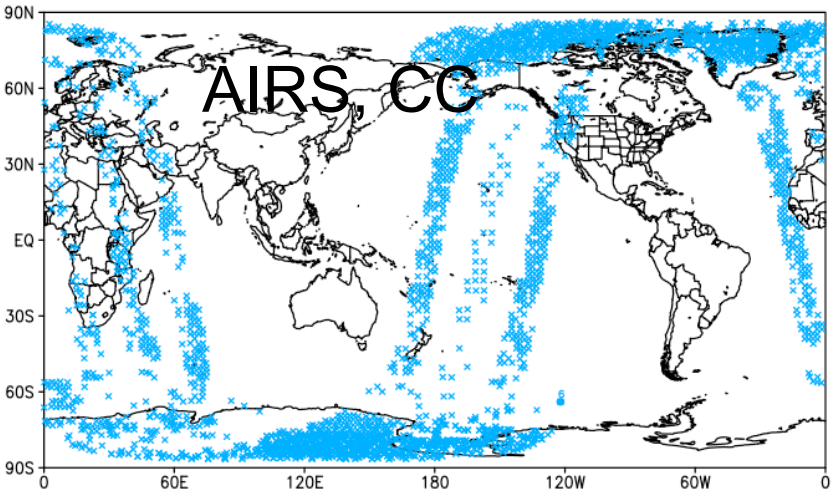
Assimilation of AMSU & Cloud Cleared AIRS radiances with LETKF

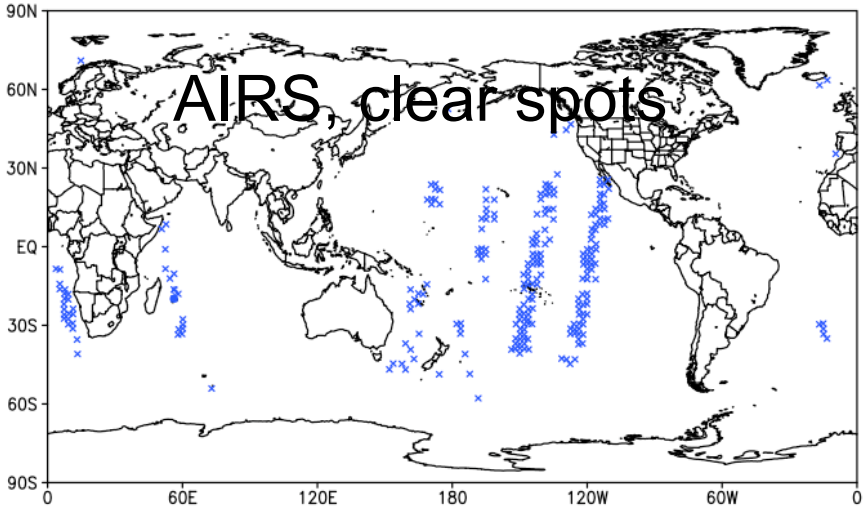
Preliminary results

Jose Aravequia (CPTEC, Brazil) Istvan Szunyogh, Elana Fertig and Eugenia Kalnay

Observations

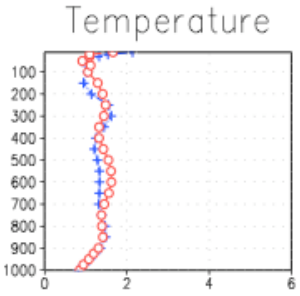


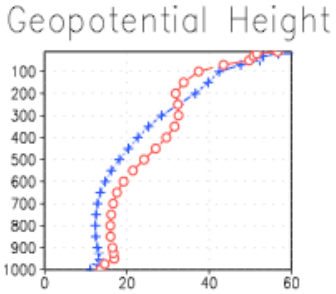


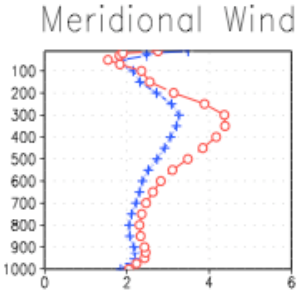


Level 2 AIRS cloud cleared radiances (blue) and non radiance (red) data 1-31 Jan2004 analysis and 48 hr forecast: **some positive impact in SH**

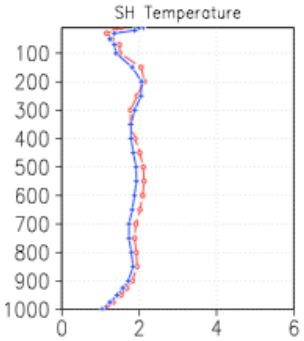
Analysis

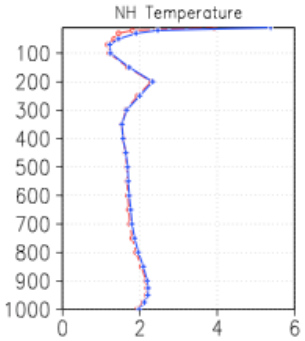


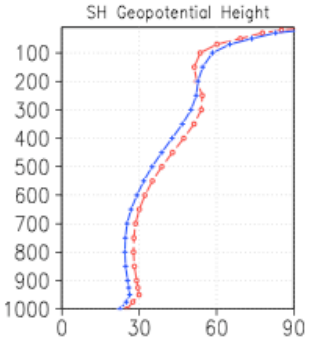


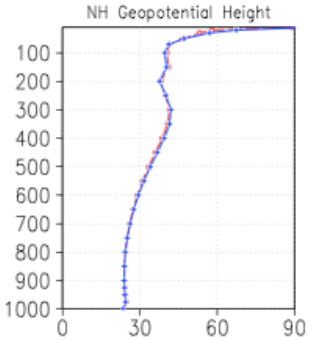


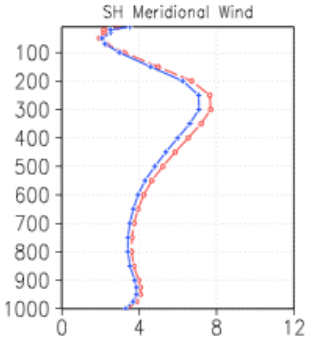
48 hour forecast

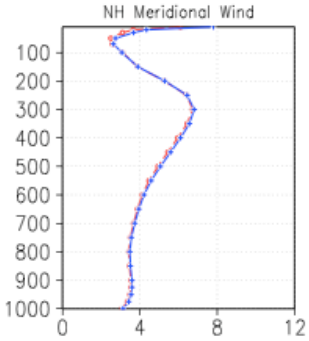






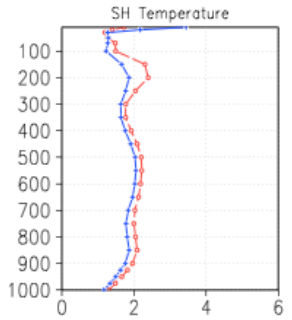


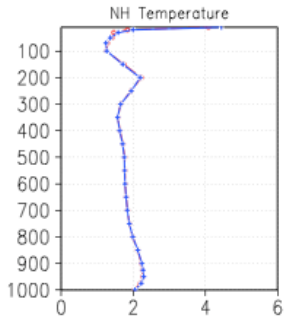


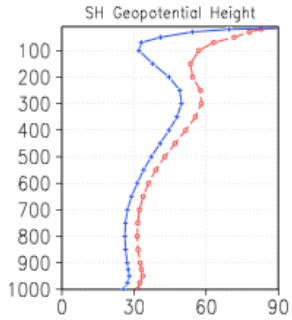


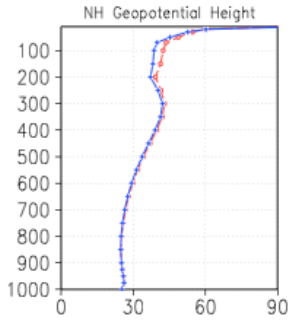
Impact over 48 hour forecasts: the impact comes from AMSU

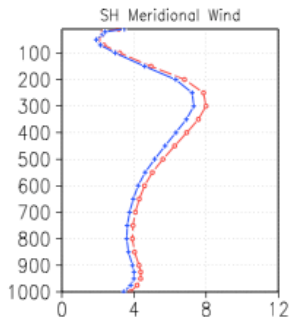
AMSU

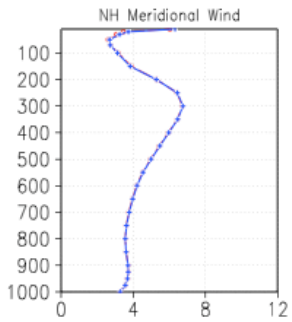




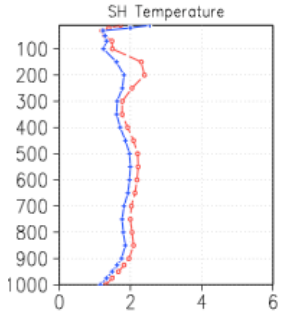


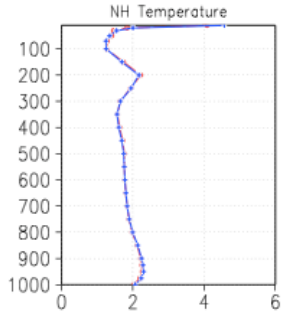


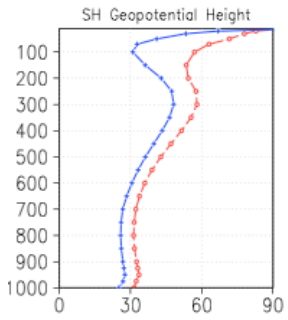


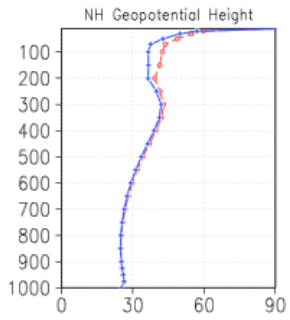


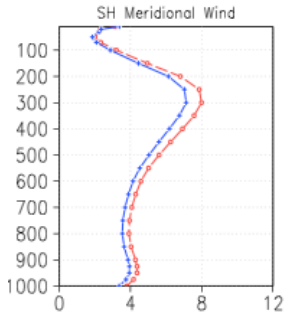
AMSU+AIRS clear spots

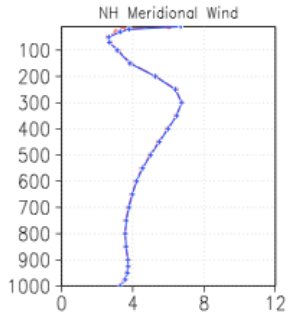












Preliminary results for assimilation of radiances within the LETKF

- The good news:
  - The system for assimilating radiances works
  - AIRS cc radiances give a positive impact

- The not so good news:
  - we only used 20 channels
  - the impact comes from AMSU
  - we still have to work on the bias correction (system has sampling errors)

- The LETKF is going operational in Brazil
- They would like to assimilate retrievals (T & q).
  Are they available in time?

Multivariate CO_2 data assimilation with the LETKF: simulations with SPEEDY model

Ji-Sun Kang and Eugenia Kalnay
UMD
(Junjie-Liu and Inez Fung
UC Berkeley)

Why multivariate assimilation of CO2?

So far:

- All estimations of CO2 and surface fluxes, including inversions, ECMWF, Peters et al. EnKF have been done **univariately**.
- This means CO2 is advected by the wind, but the CO2 and wind errors are uncorrelated

Proposed:

- Use LETKF that allows multivariate error covariance $\boldsymbol{P}^b$.
- This should improve the CO2 analysis and provide estimates of errors.
- Also estimate model parameters.

SPEEDY-C (global, PE model with CO2)

- SPEEDY (F. Molteni, 2003)

  (Simplified Parametrizations, primitivE-Equation DYnamics)

  – General Circulation Model of the Atmosphere
  – Spectral model with T30 resolution (96X48)
  – Seven layers in the vertical
  – Prognostic variables: U, V, T, q, Ps
  – Adapted for 6hr assimilation cycle by T. Miyoshi
  – **Added an additional prognostic variable, C^{atm}**
    - No feedback between the integrated CO_2 and radiative properties & No chemical processes in SPEEDY

$$\frac{\partial C}{\partial t} + \underbrace{\Im(C)}_{Atm\_transport+mixing} = \underbrace{S|_{z=0}}_{SourcesSinks} + \cancel{P}_{Chem\ Prod}$$

S = Fossil Fuel emission + ~~Land Use~~ + ~~Ocean Flux~~ + ~~Land sfc Flux~~

Experimental design

- Nature [Perfect Model Assumption]
  - SPEEDY_C model
- Forecast
  - SPEEDY_C model
- Simulated Observations
  - U, V, T, q, Ps: rawinsonde distribution (9% coverage)
  - Atmospheric carbon dioxide concentration: at every other grid point (25% coverage)
  - First all levels, then at level 1 (“OCO”) and level 5 (“AIRS”)
  - ***No Observation of CO_2 flux on the surface***
  - ***No prior information***
- Analysis (every 6 hours): LETKF(Hunt et al., 2007)

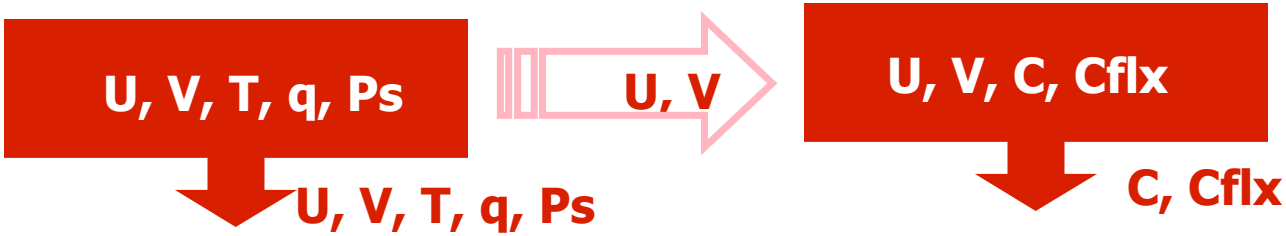
Test 3 types of CO2 Data Assimilation

- Univariate Data Assimilation [Uncoupled]
  - Forecast errors of (Catm, Cflux) have NO effect on errors of u,v,T,q, and vice versa (only method used so far)

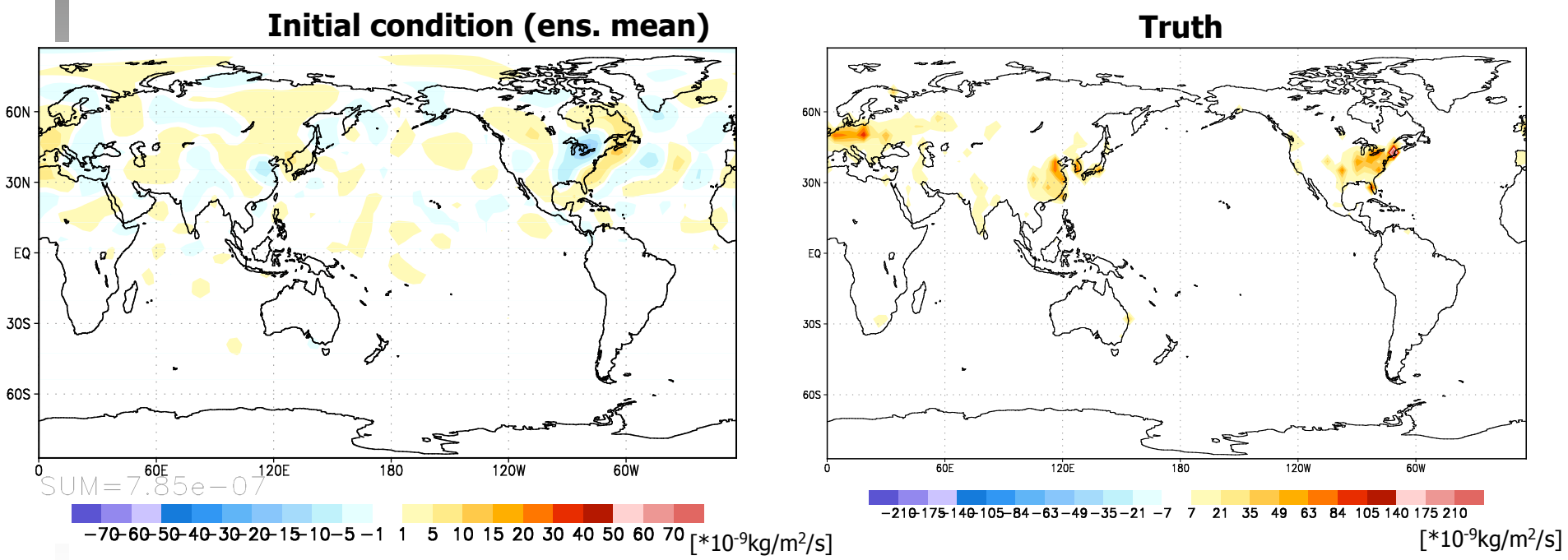
- Multivariate Data Assimilation
  - Errors of all variables are coupled

U, V, T, q, Ps, Catm, Cflx

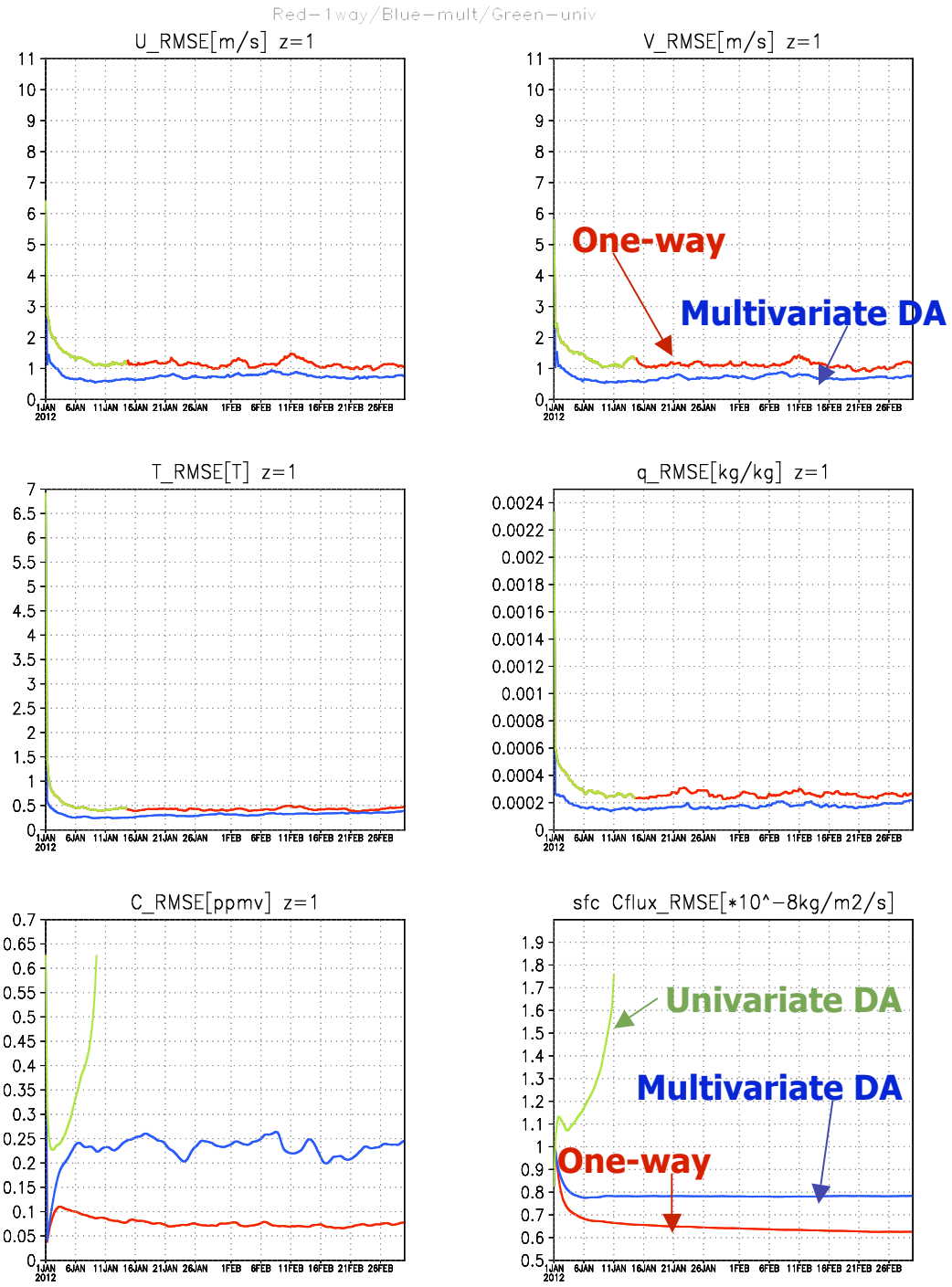
- One-way Multivariate Data Assimilation



Initial Condition of Surface CO_2 Fluxes



- **Unlike the inversion methods, the initial condition of surface CO_2 flux used for this study is very poor in terms of the magnitude and the spatial distribution**
- **No a-priori information**



Globally averaged analysis errors

- **Red - 1-way multivariate DA**
- **Blue - Multivariate DA**
- **Green - Univariate DA**

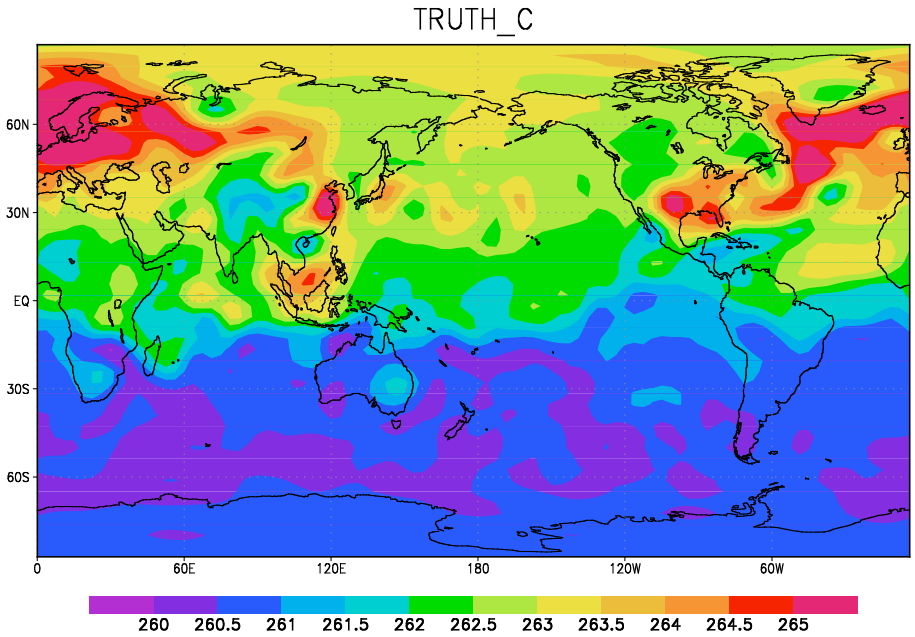
Remarkably, **multivariate DA** is slightly better for atmospheric variables (u,v,T,q) but **1-way multivariate DA** is better for CO2 fluxes (sampling errors).

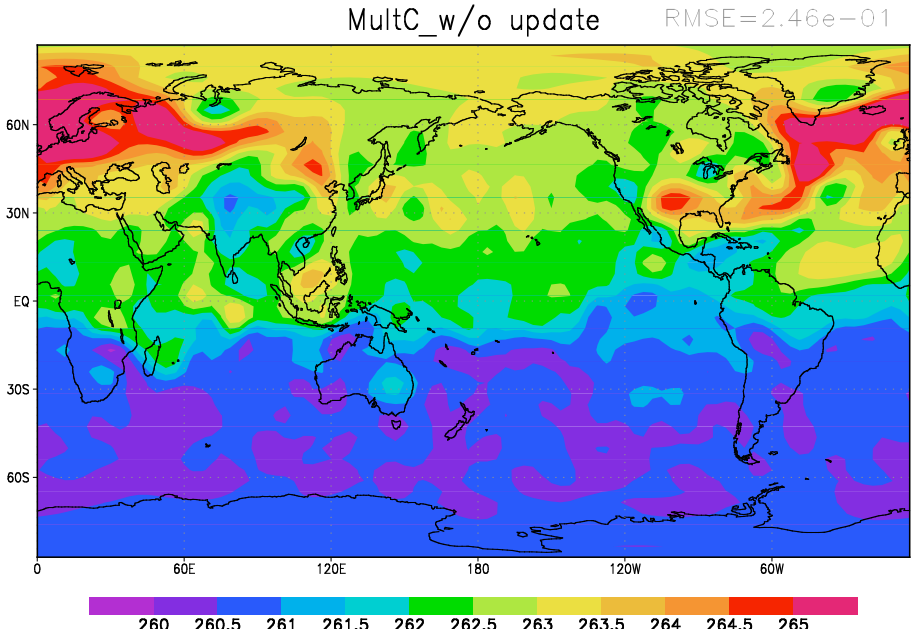
Univariate DA cannot compete (blows up after 2 weeks)

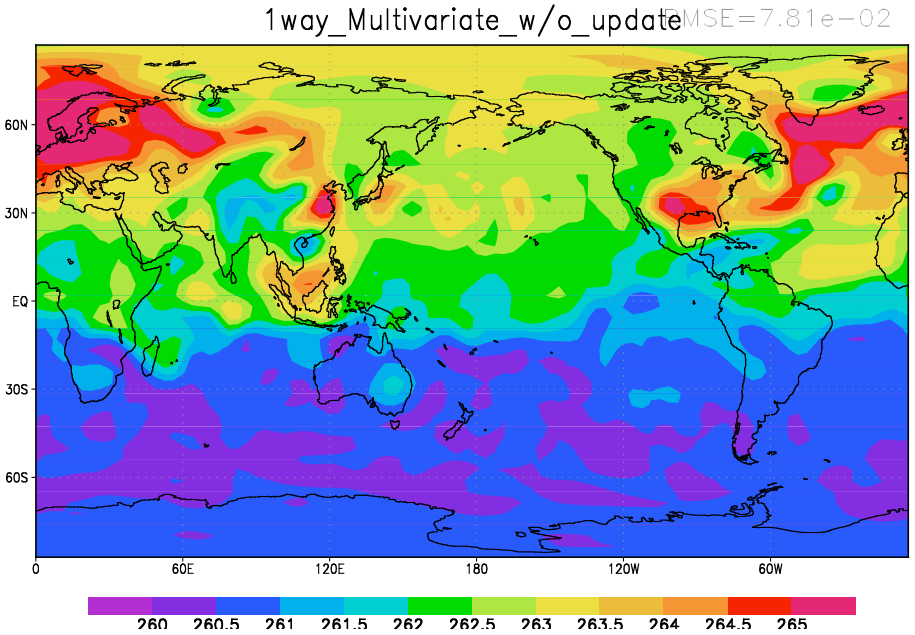
CO2 at level 1

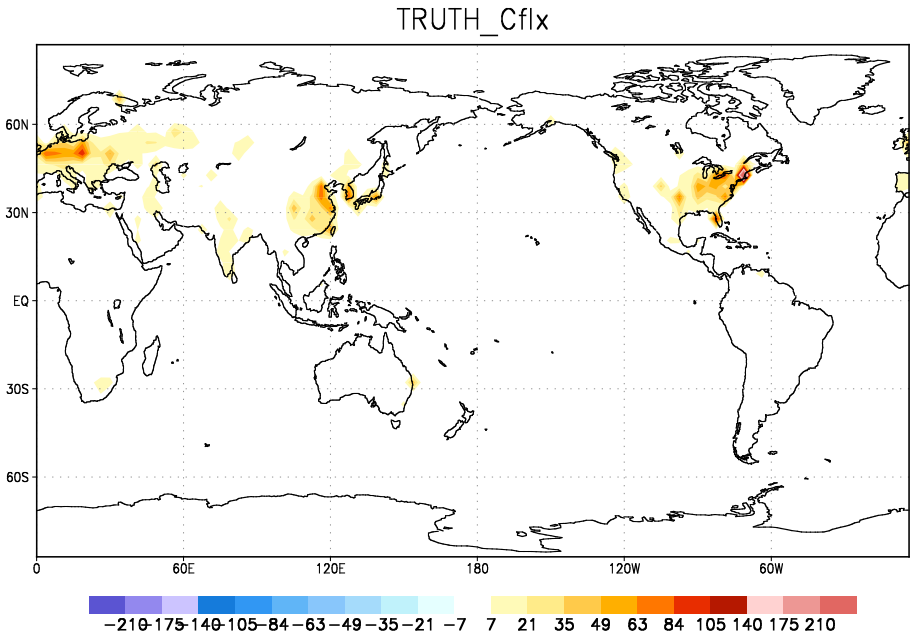
Time= 1 March

After a few days both multivariate runs capture well the CO2 distribution





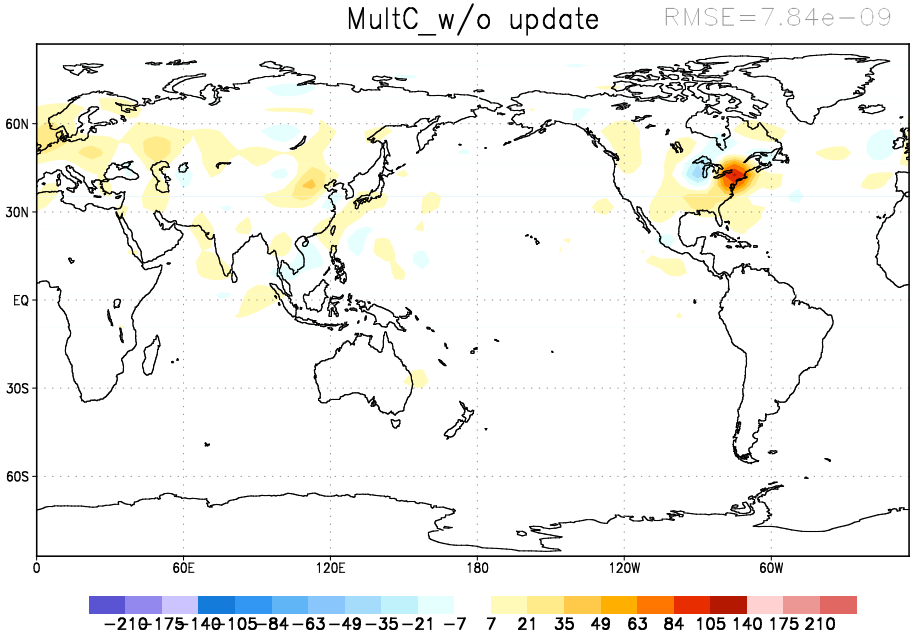


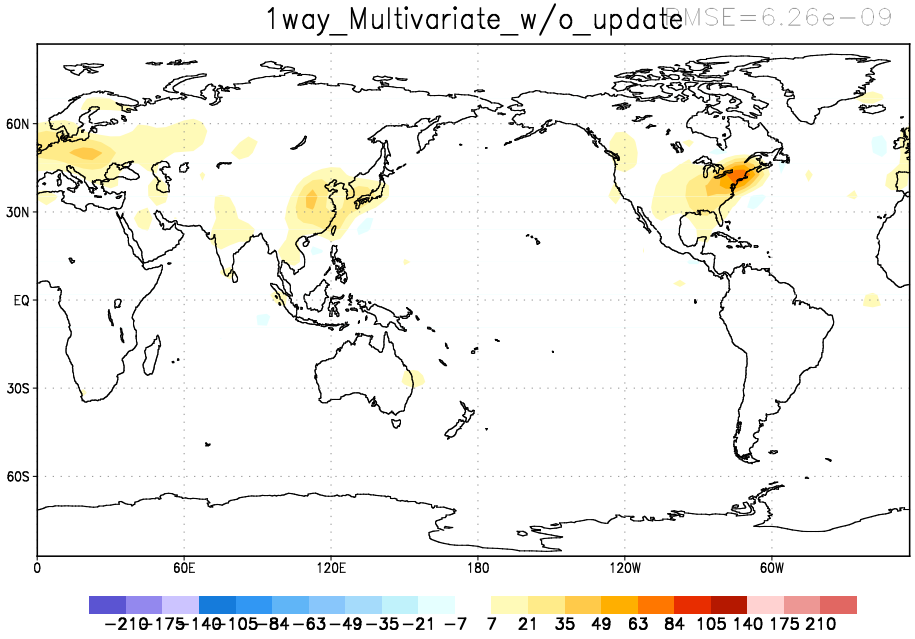


Surface fluxes of CO2

Time= 1 March

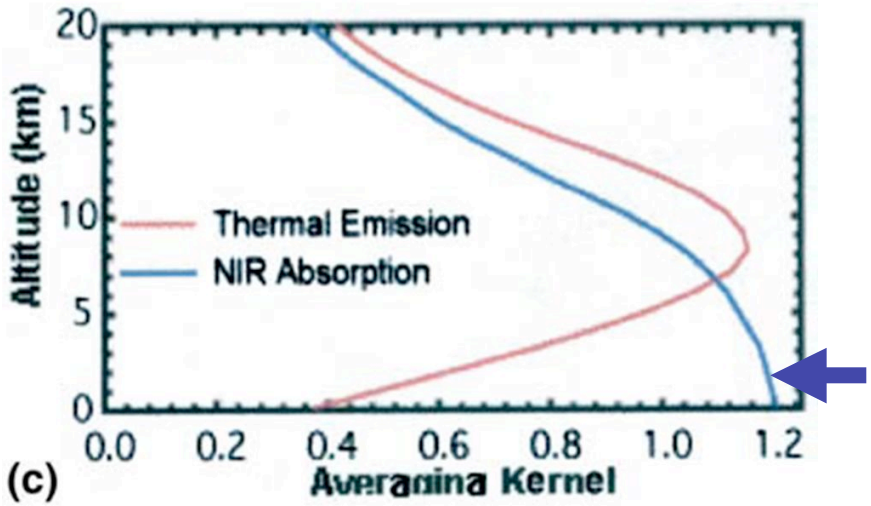
After 2 months both multivariate runs capture the surface flux of CO2 but 1-way multivariate is better.





“OCO” and “AIRS” experiments

- So far we assumed we had complete profiles of CO2 (to make life simple).
- We now assume we have OCO-derived CO2 obs in level 1 and AIRS-derived obs in level 5.



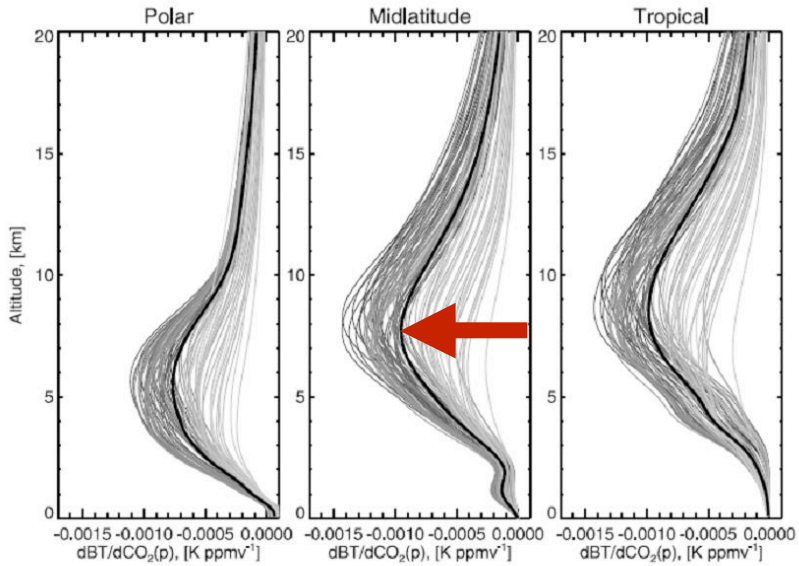
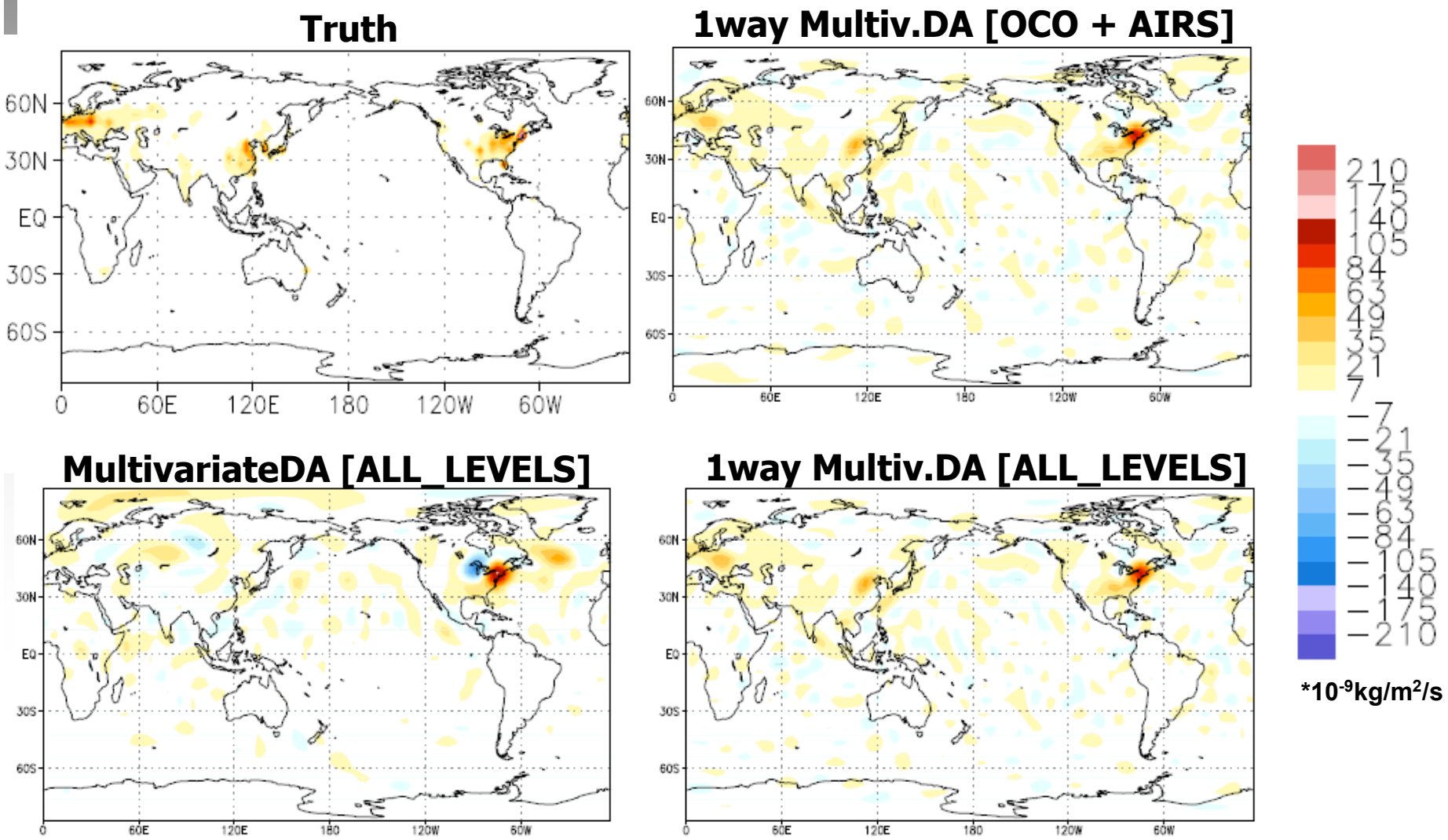


Figure 1. CO_2 Jacobians for a 1 ppmv layer perturbation for the 69 AIRS channels used in the NOAA retrieval. Polar, midlatitude, and tropical situations shown to illustrate the effect of H_2O displacement on the peak altitude. The average Jacobian over all channels is shown as the thick black line.

Analysis of CO_2 surface fluxes



After 2 month of DA

Conclusions from SPEEDY/LETKF simulation experiments

- Multivariate DA with error covariances of CO2 coupled with winds works much better than Univariate CO2 DA (the method used so far).
- Updating "Cflx observations" (neglecting transport errors) works very well when background CO2 is zero but not when it is realistic. So we cannot use it! (not shown)
- One-way Multivariate DA gives best result for CO2, but Multivariate DA still works well (has more sampling errors for CO2 error covariance).
- Using only 2 levels of observations (1 and 5) "OCO" plus "AIRS" works also fairly well.

Acknowledgements

- We are very grateful for the AIRS support and interaction.
- We developed the LETKF which is now considered the leading Ensemble Kalman Filter
- LETKF has now all the good properties of 4D-Var, but it is simpler, cheaper and better.
- Under testing by JMA, will be operational in Brazil.
- Elana Fertig, Hong Li and Junjie Liu have all finished their doctorates and published several papers each.