Estimation of Surface CO_2 Fluxes with Data Assimilation

(plus latent and sensible heat fluxes)

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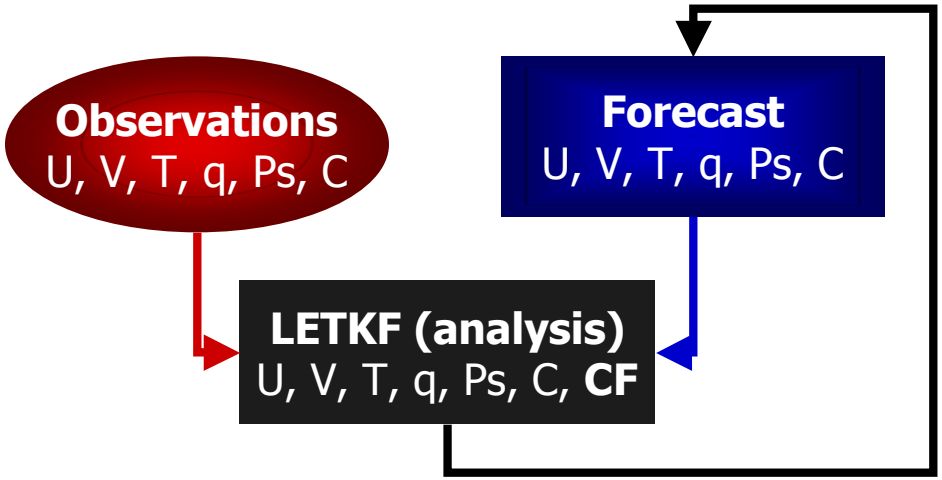
Success!

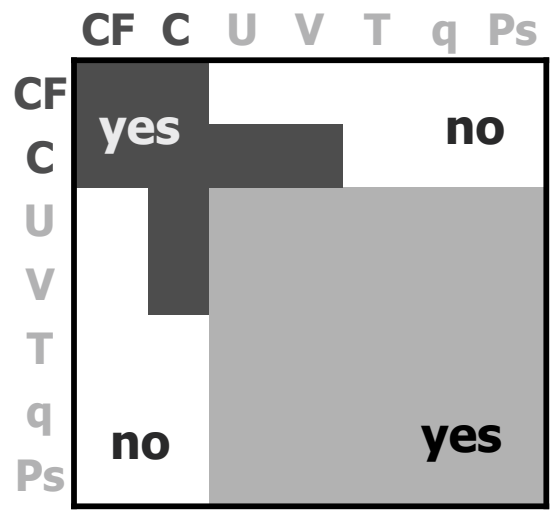
- With an OSSE, we show it is possible to estimate surface carbon fluxes using 6 hour data assimilation and a realistic observing system.
- We use no a priori information.
- We could apply the same advanced methodology to assimilate AIRS retrievals and estimate surface fluxes of heat and moisture.

Surface CO_2 flux estimation: top-down approach

- Top-down approaches
  - Estimate surface fluxes from atmospheric CO_2 obs.
- Carbon Tracker (Peters et al., 2007)
  - One of the most advanced top-down approaches
  - Uses 5 weeks of CO_2 observations: ill-posed problem
  - *A priori* information: CASA, eco-regions, etc.
  - No explicit treatment of transport errors
- Alternative approach: Simultaneous analysis of meteorology and CO_2 using LETKF
  - 6 hours of meteorological and CO_2 observations
  - No a priori information needed for fluxes
  - Transport errors are reflected in CO_2 analysis
  - Observing System Simulation Experiments (OSSEs)

UMD-Berkeley LETKF-C System





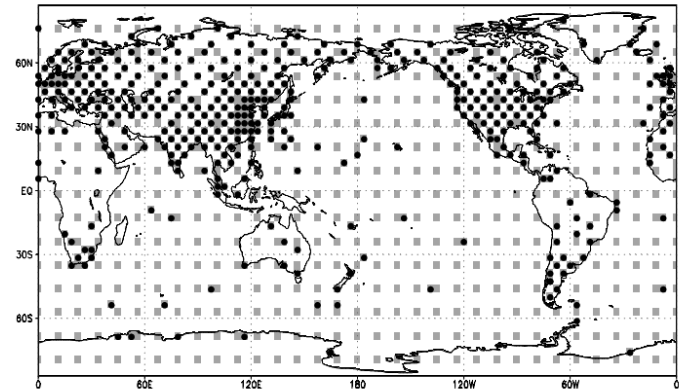
- Simultaneous analysis of carbon and meteorological variables
  - Update all variables at ***every six hours*** (avoids ill-posedness)
  - **Multivariate analysis** with localization of variables (Kang et al., 2011)
  - Advanced LETKF methodologies
    - Adaptive inflation (Miyoshi, 2011) and a vertical localization of column CO_2 satellite data

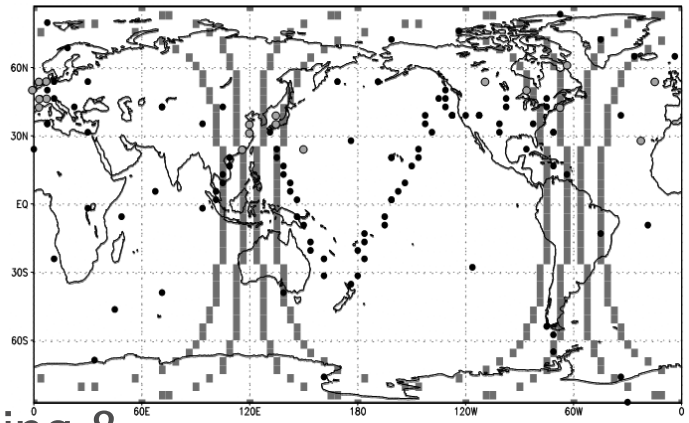
Observing System Simulation Experiments

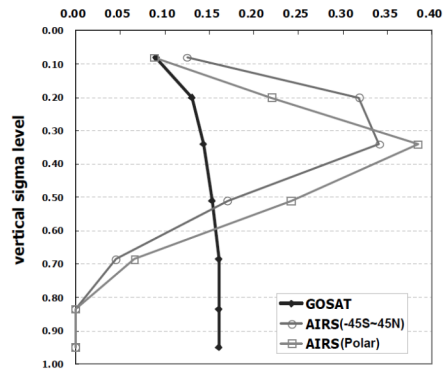
- Nature run (assumed true state in the experiments)
  - SPEEDY-C: the modified version of SPEEDY (Molteni, 2003)
    - AGCM with a trace gas of atmospheric CO_2 (C)
    - Prognostic variables: U, V, T, q, Ps, C
    - No chemical process of carbon and no diurnal cycle
  - **"True" CO_2 fluxes (CF)**
    - A constant fossil fuel emission (Andres et al., 1996)
    - CASA terrestrial CO_2 fluxes (Randerson et al., 1997)
    - Oceanic CO_2 fluxes (Takahashi et al., 2002)
- Forecast model
  - SPEEDY-C with persistence forecast of surface CO_2 fluxes (CF)
    - **CF is updated only by the data assimilation**

Simulated Observations

- Meteorological variables
  - Conventional data
    - U,V,T,q: black dots (every 12 hours)
    - Ps: gray squares (every 6 hours)
- Atmospheric CO_2 concentrations
  - In-situ & flask observations
    - Weekly records: black dots (107)
    - Hourly records: gray dots (18)
  - Satellite data: column mixing ratios
    - GOSAT (gray squares)
    - AIRS (covers half of globe with ascending & descending modes)
- **No direct measurement of surface CO_2 fluxes**

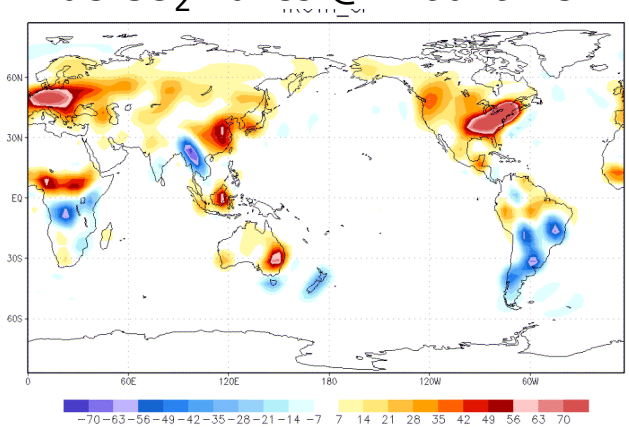




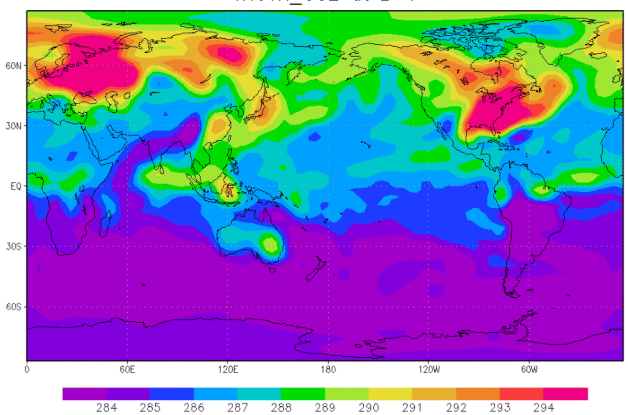


Initial conditions for carbon variables

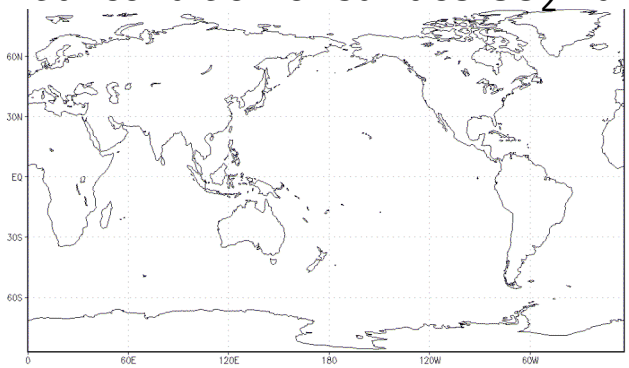
True CO_2 fluxes @ initial time



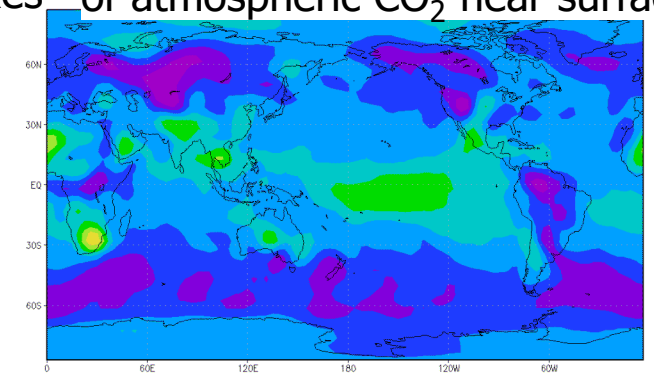
True atmospheric CO_2 near surface @ initial time



Initial condition of surface CO_2 fluxes



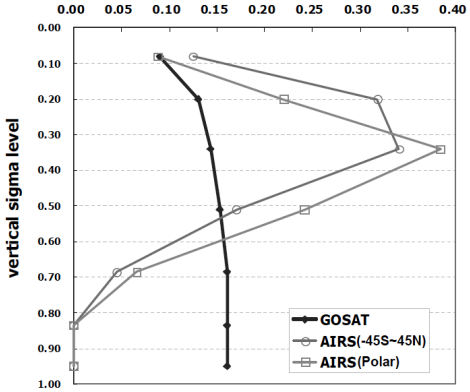
Initial condition of atmospheric CO_2 near surface



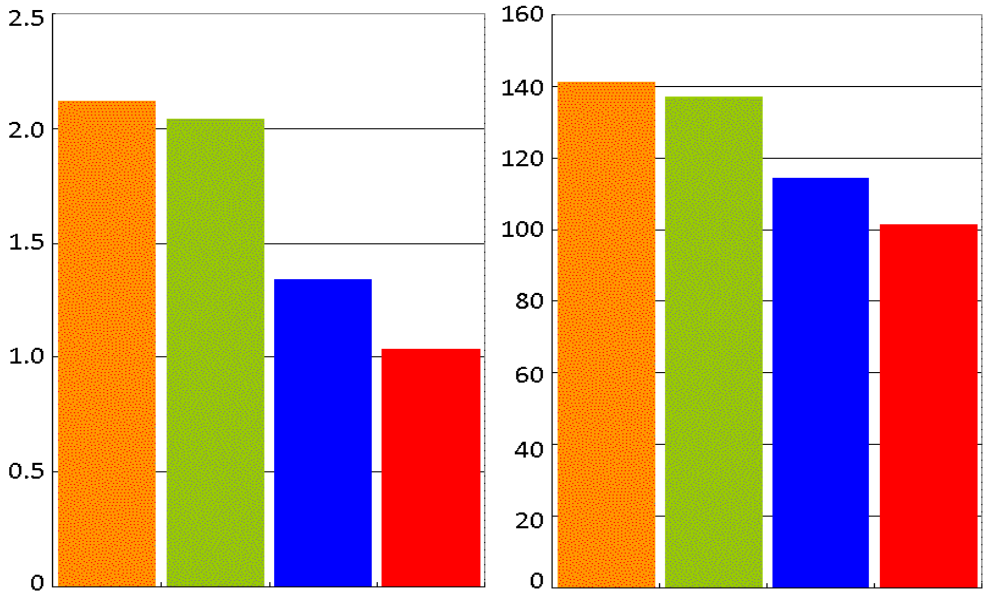
No initial conditions information!
No *a-priori* information!
No surface flux model!

Surface CO_2 flux estimation from LETKF-C

- Impact of CO_2 observations on surface CO_2 flux estimation
  - **SFC**: in-situ flask data
  - **SFC+AIRS**
  - **SFC+GOSAT**
  - **SFC+GOSAT+AIRS**



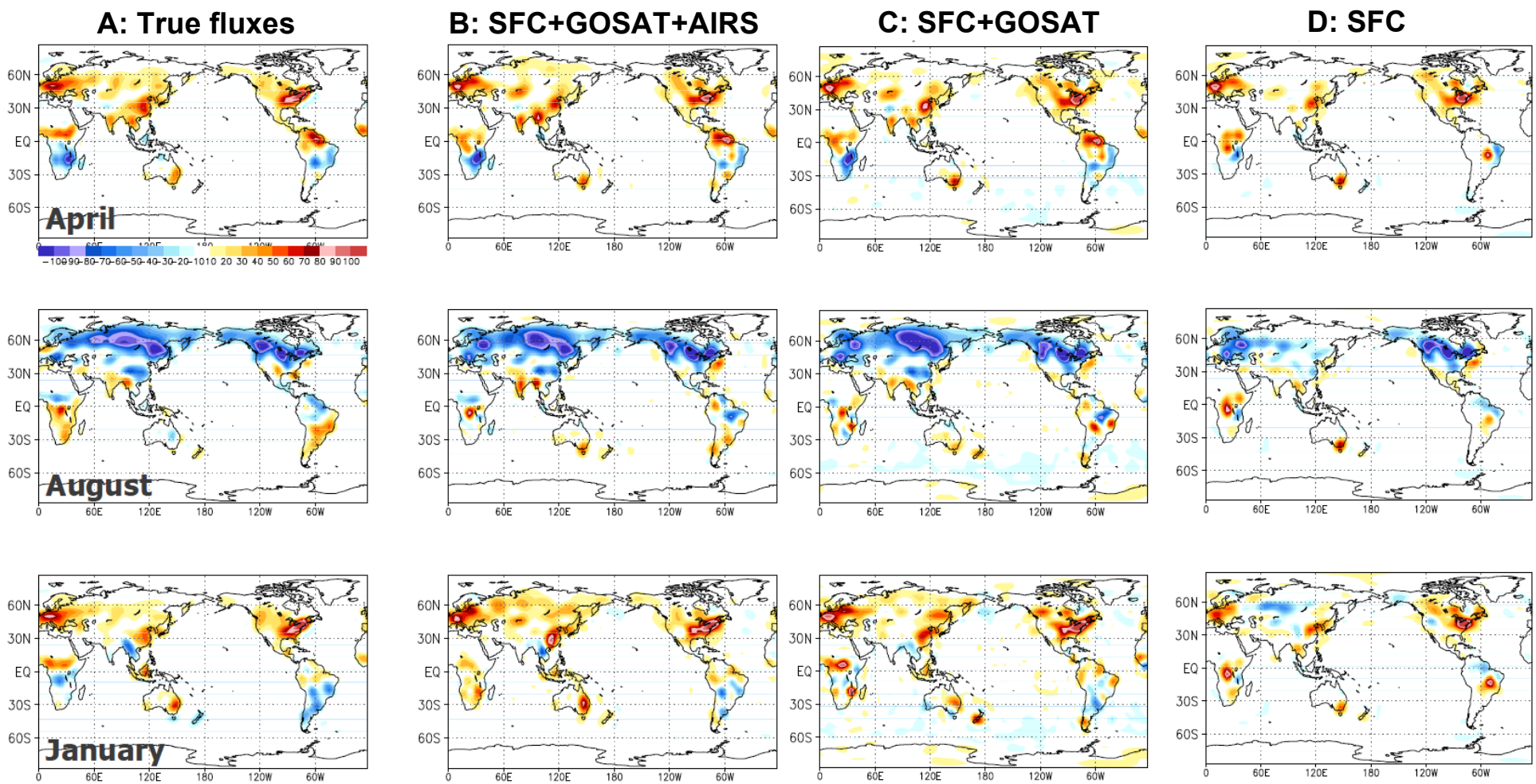
RMSE of surface atmospheric CO_2 (ppmv)



RMSE of surface CO_2fluxes ($gC/m^2/yr$)

Observation impact

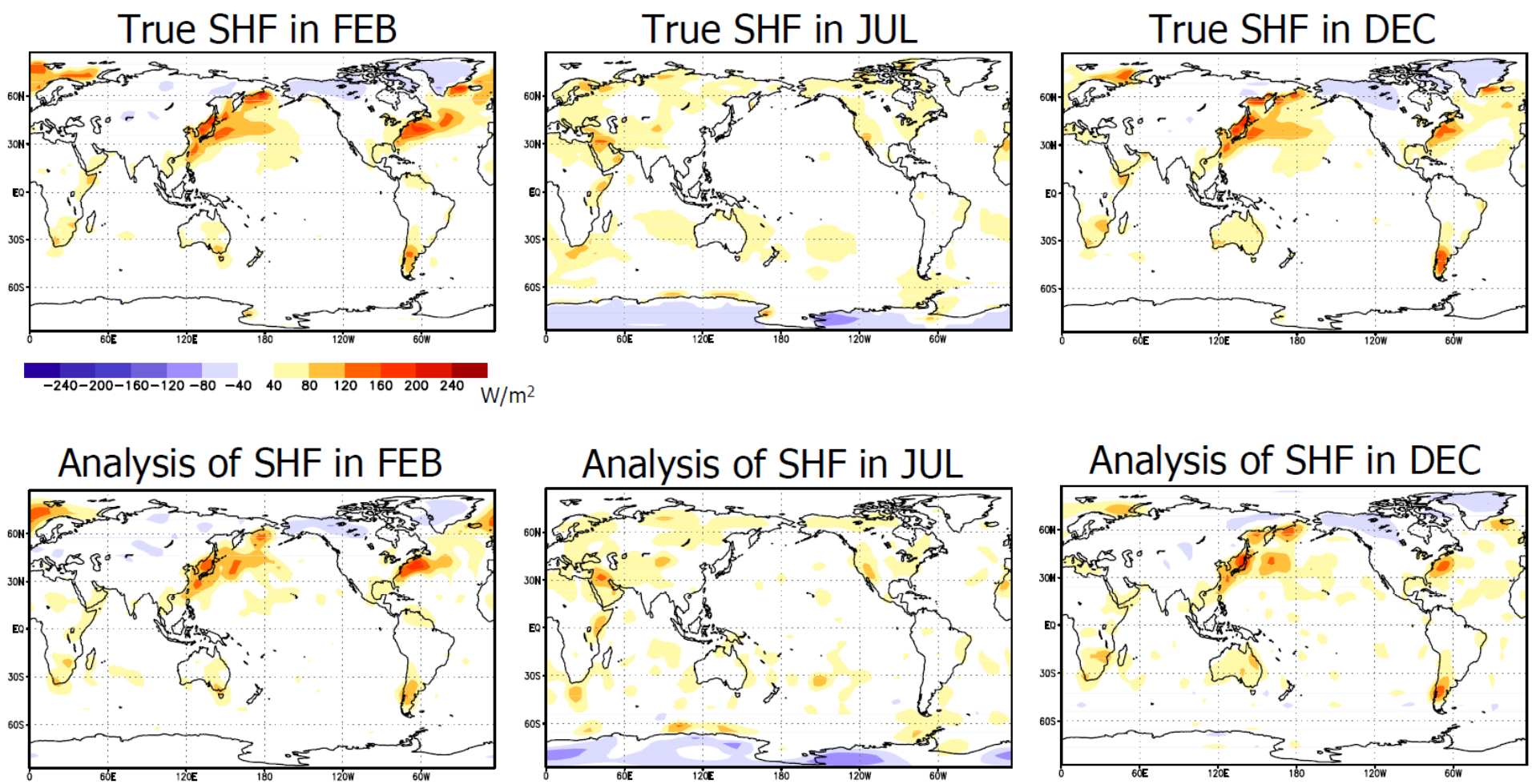
- Global maps of surface CO_2 fluxes in different seasons



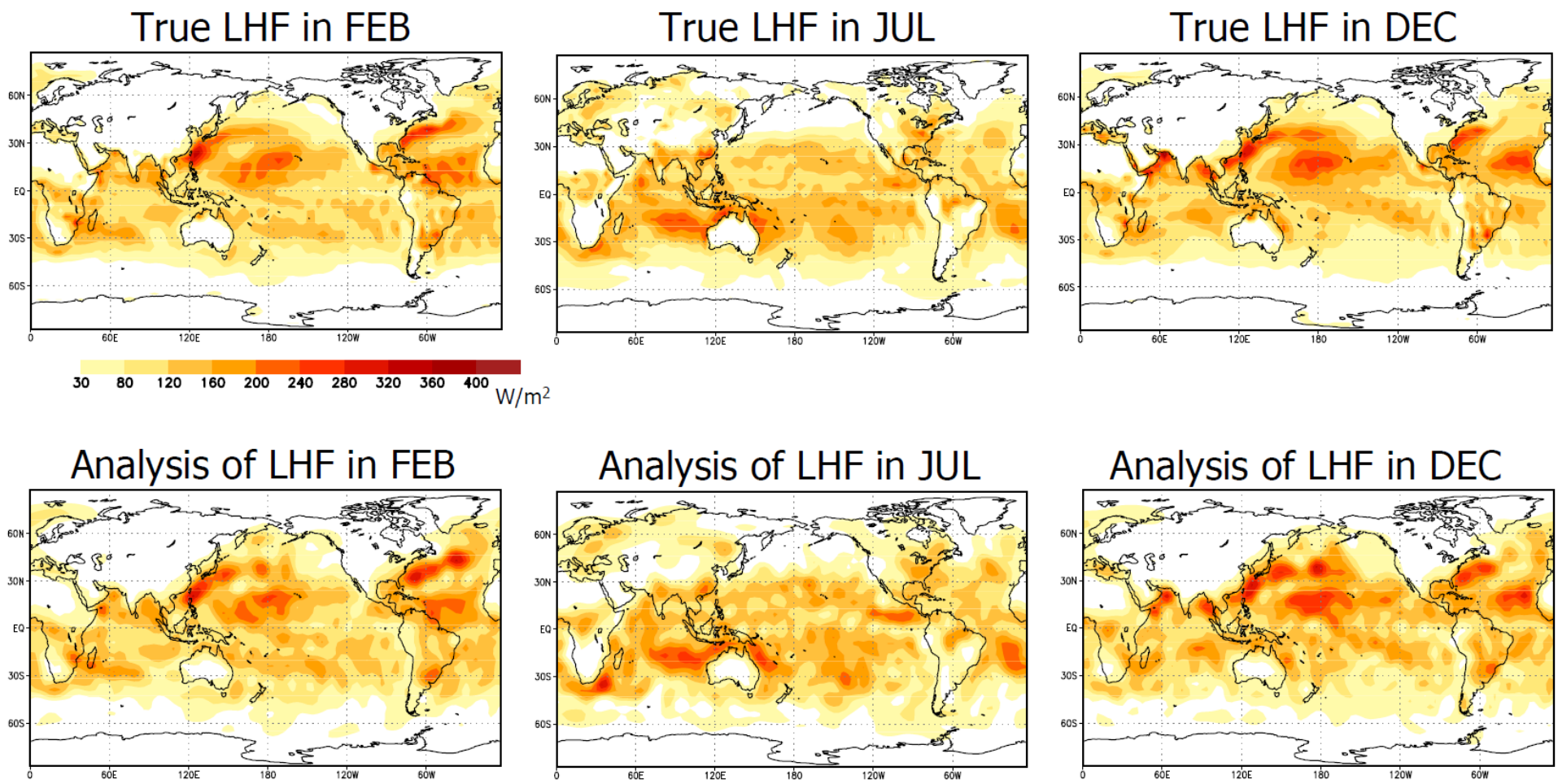
Application to heat/moisture flux estimation

- Can we estimate **surface heat/moisture fluxes** by assimilating atmospheric temperature/moisture observations? *We can use the same methodology!*
- OSSEs
  - Nature run: SPEEDY
  - Forecast model: SPEEDY with **persistence forecast of sensible/latent heat fluxes (SHF/LHF)**
  - Observations: conventional observations of (U, V, T, q, Ps) and AIRS retrievals of (T, q)
  - Initial conditions: random (no *a-priori* information)
  - Fully multivariate data assimilation
  - Analysis: U, V, T, q, Ps + **SHF** & **LHF** every six hours

Result: Analysis of Sensible Heat Flux

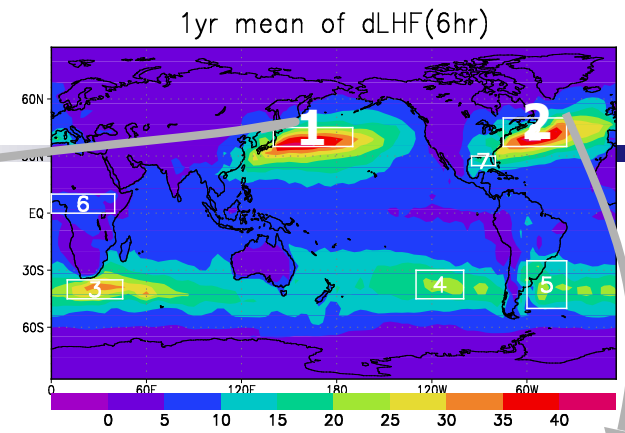


Result: Analysis of Latent Heat Flux

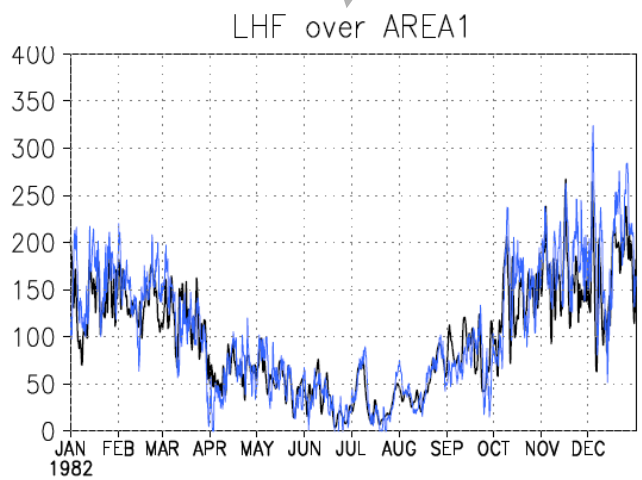


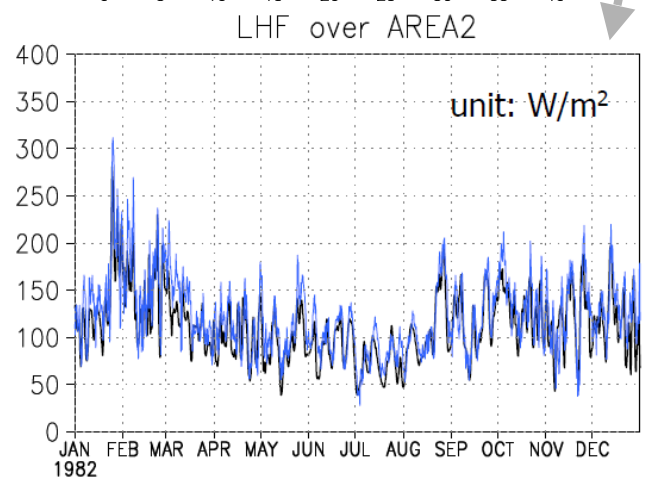
Time series of LHF/SHF

- Black: nature
- Color: analysis of LHF(blue)/SHF(red)

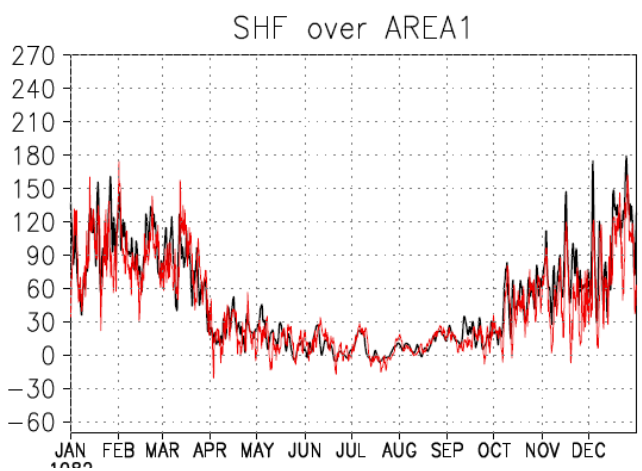


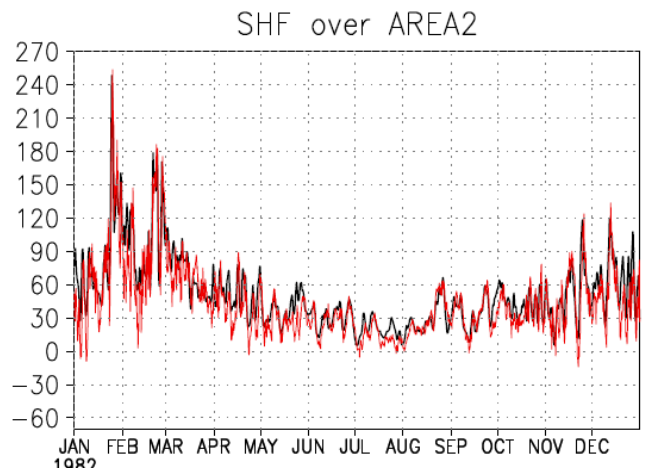
Recall that LHF & SHF are updated only by the data assimilation here!





Promising results from the estimation of "evolving parameters" with data assimilation





Summary

- We succeeded in estimating surface CO_2 fluxes with an advanced LETKF-C system, even without any *a-priori* information (OSSEs)
- Dedicated CO_2 monitoring satellite (GOSAT/OCO-2) contribute to the surface CO_2 flux estimation significantly
- AIRS CO_2 retrievals help CO_2 flux estimation due to better analysis of atmospheric CO_2 circulation
- The same methodology used for carbon cycle data assimilation could be applied to surface heat/moisture flux estimation
- AIRS temperature/moisture profile data make possible to estimate sensible/latent heat fluxes over the globe

Briefly: AIRS forecast impacts

- Li et al (2010): Impact of assimilating AIRS temperature retrievals (positive).
- Liu et al. (2009): Impact of assimilating AIRS moisture retrievals (positive).
- Miyoshi and Kunii (2011): Impact of assimilating AIRS T and q retrievals in forecasting typhoon Sinlaku (positive).

Assimilation of AIRS temperature retrievals

- *System :* NCEP GFS (T62L28) and 4D-LETKF
- *Control Run:* All operational observations except for radiances (Non-radiance data, Szunyogh et al. 2007, Whitaker et al. 2007)
- *AIRS Run:*

Non-radiance plus AIRS temperature retrievals [Chris Barnet (NOAA)]

v5 emulation with 3 deg * 3 deg resolution

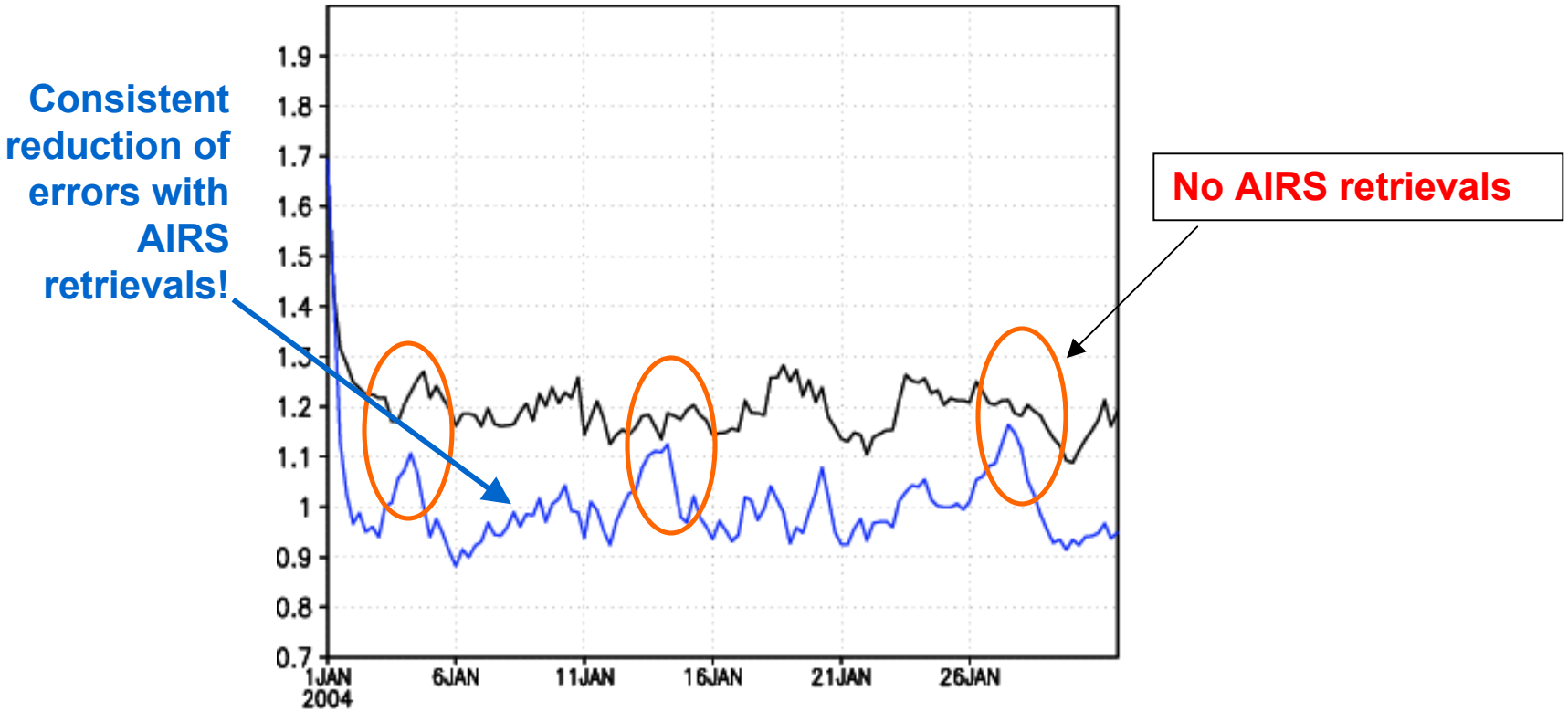
EXP1 : Ignored retrieval error correlations,

but increase the error standard deviation to be 2K

$$R = \begin{bmatrix} 2^2 & 0 & 0 \\ 0 & 2^2 & 0 \\ 0 & 0 & 2^2 \end{bmatrix}$$

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

500 hPa Temperature analysis error averaged over Globe

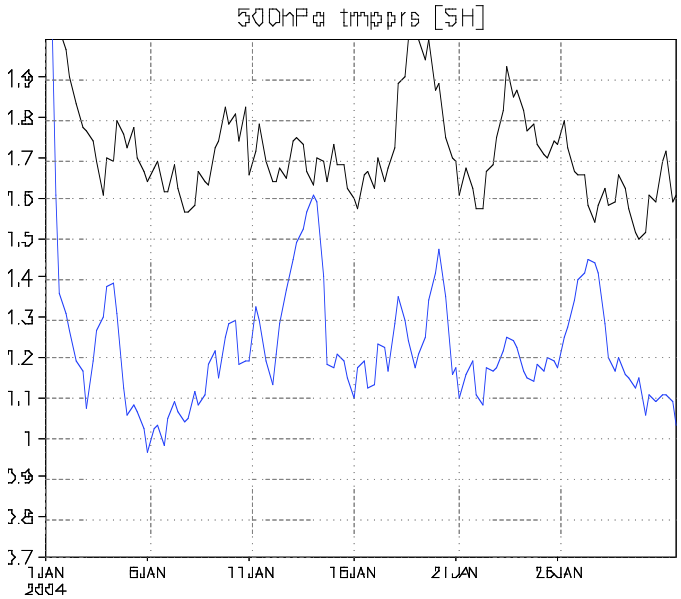


Non-radiances Non-radiances + AIRS temperature retrieval

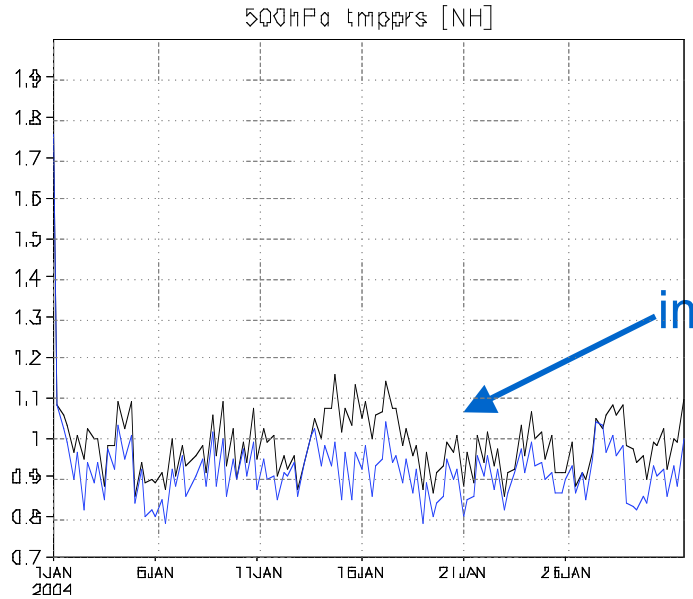
Result are similar to non-radiance when there are no available retrievals

500 hPa Temperature analysis error

SH



NH

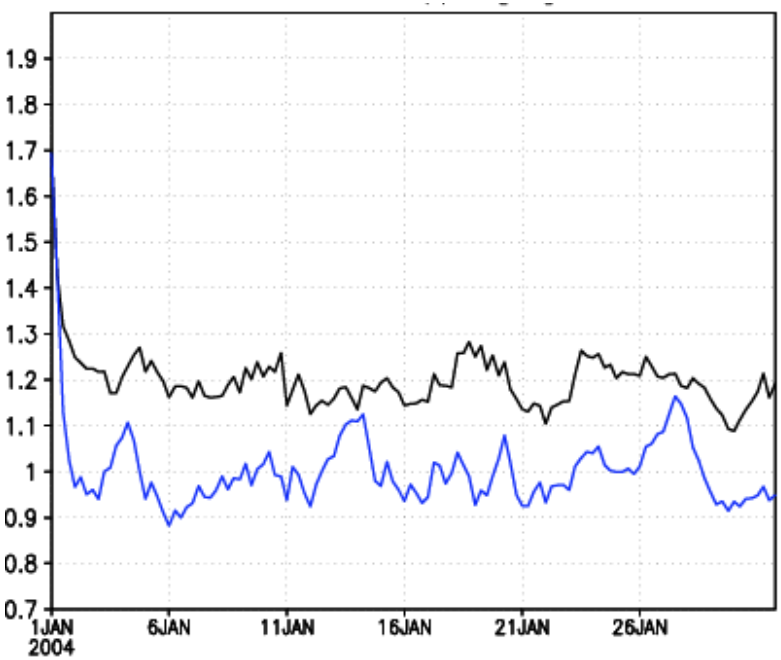


Consistent positive impacts even in the NH!

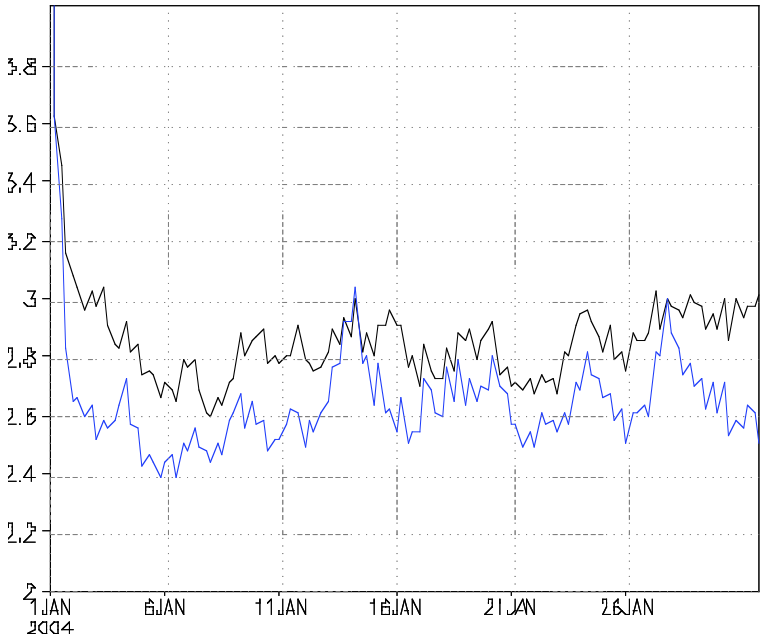
Non-radiances Non-radiances + AIRS temperature retrieval

Impact of AIRS Temperature retrievals on zonal wind

500 hPa Temperature

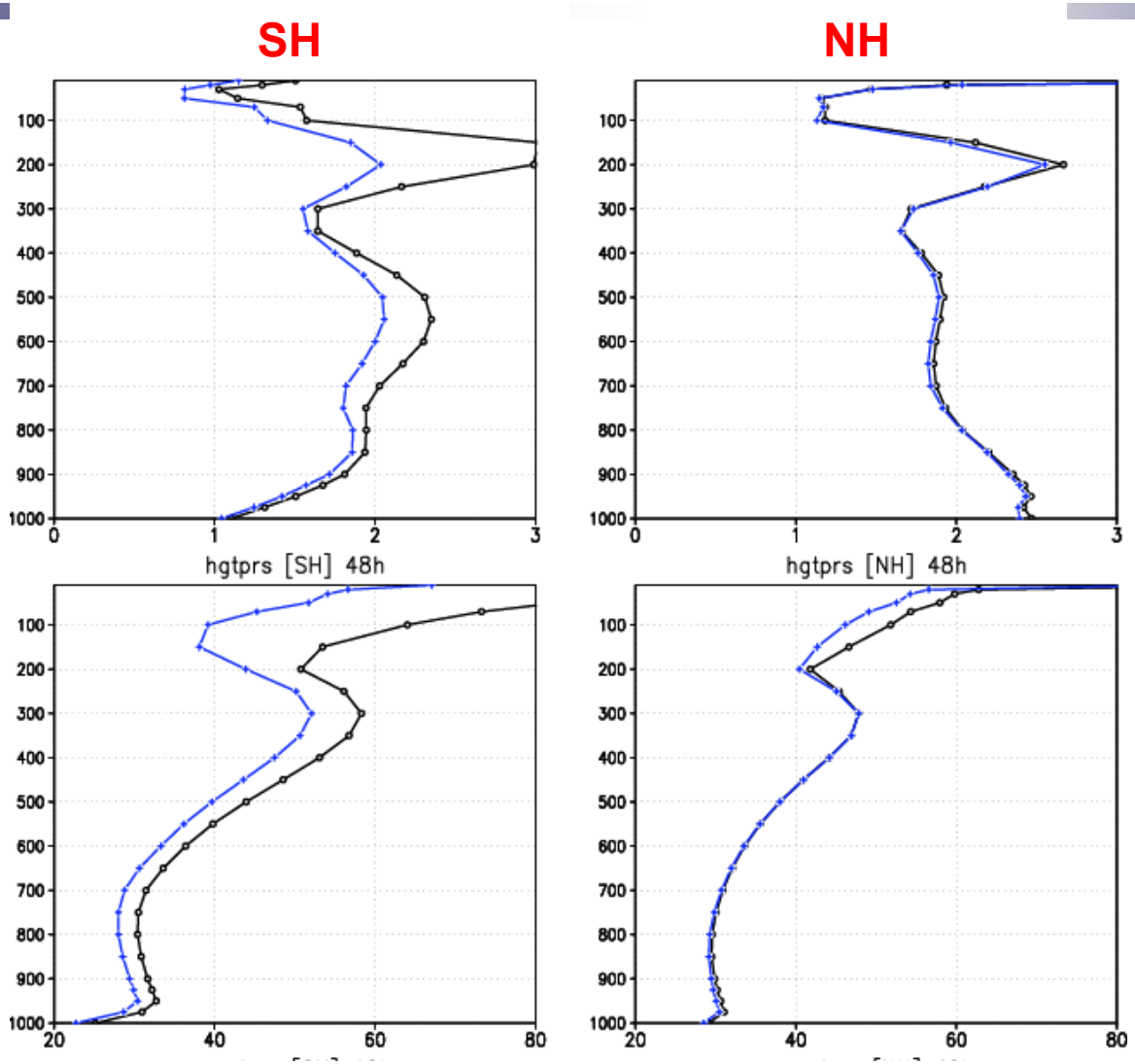


500 hPa zonal wind



AIRS Temperature retrievals also have positive impact on other variables

48 Hour Forecast RMSE

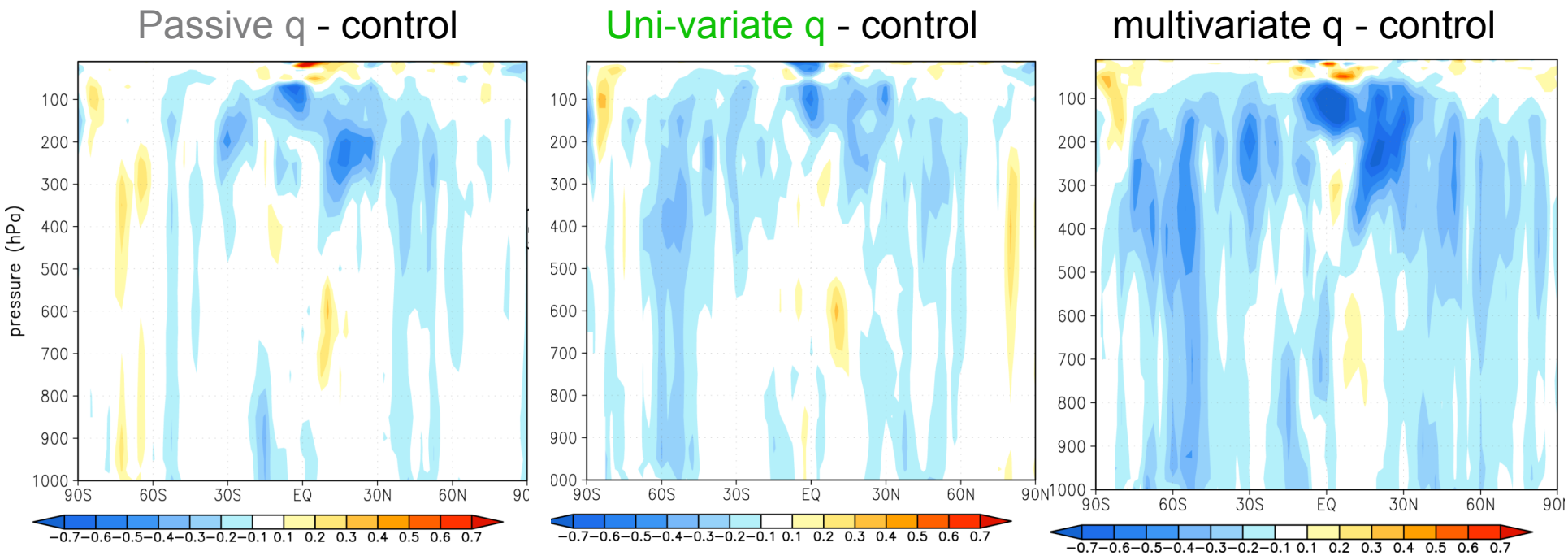


Temperature

Geopotential Height

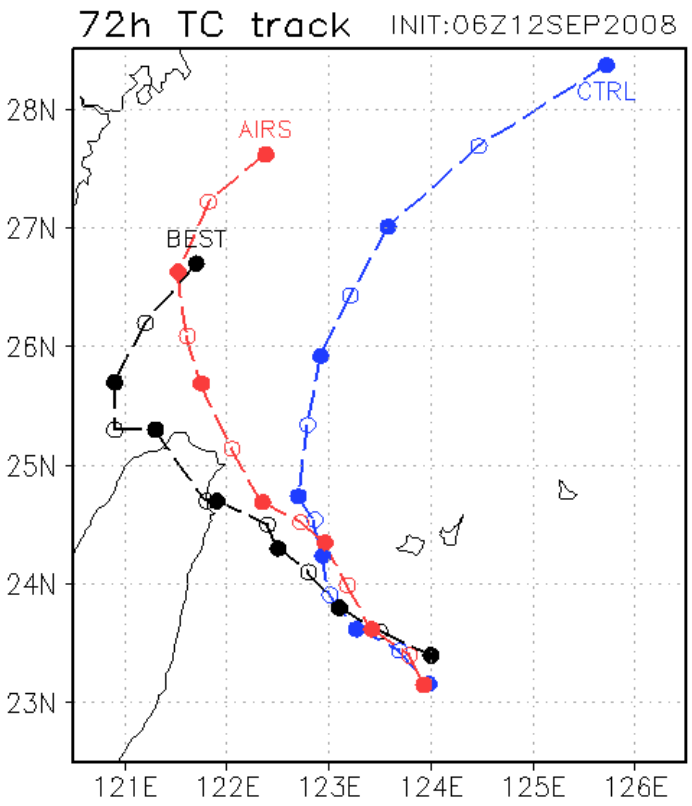
Non-radiances Non-radiances + AIRS temperature retrievals

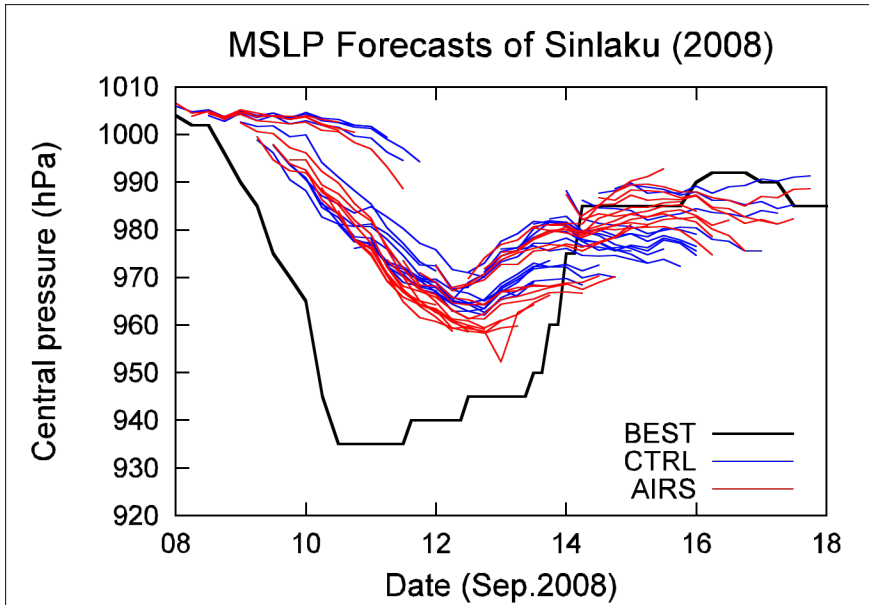
Liu et al: zonal average zonal wind 48-hour forecast RMS error difference between humidity run and the control run



- Uni-variate q has much larger positive impact on 48-hour zonal wind forecast accuracy than passive q (no assimilation)
- Multivariate q has largest positive impact on 48-hour zonal wind forecast accuracy

Miyoshi and Kunii: Impact of AIRS retrievals on forecast of typhoon Sinlaku





AIRS improved significantly track forecast
and to some extent, intensity forecast