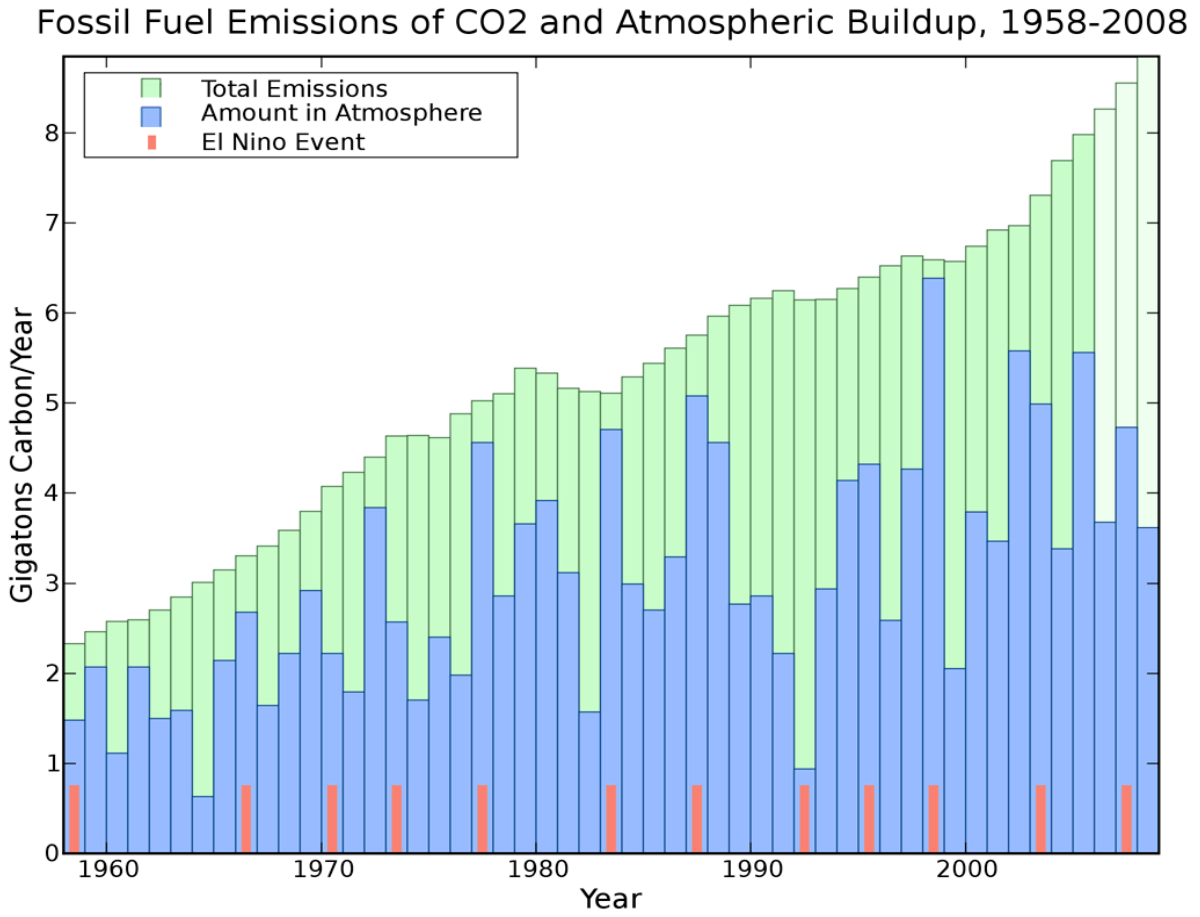
Assimilation of AIRS CO_2 Observations with the LETKF in a Carbon-Climate Model

[1]Junjie Liu, [2]Eugenia Kalnay, [1]Inez Fung,
[3]Moustafa T. Chahine and [3]Edward T. Olsen

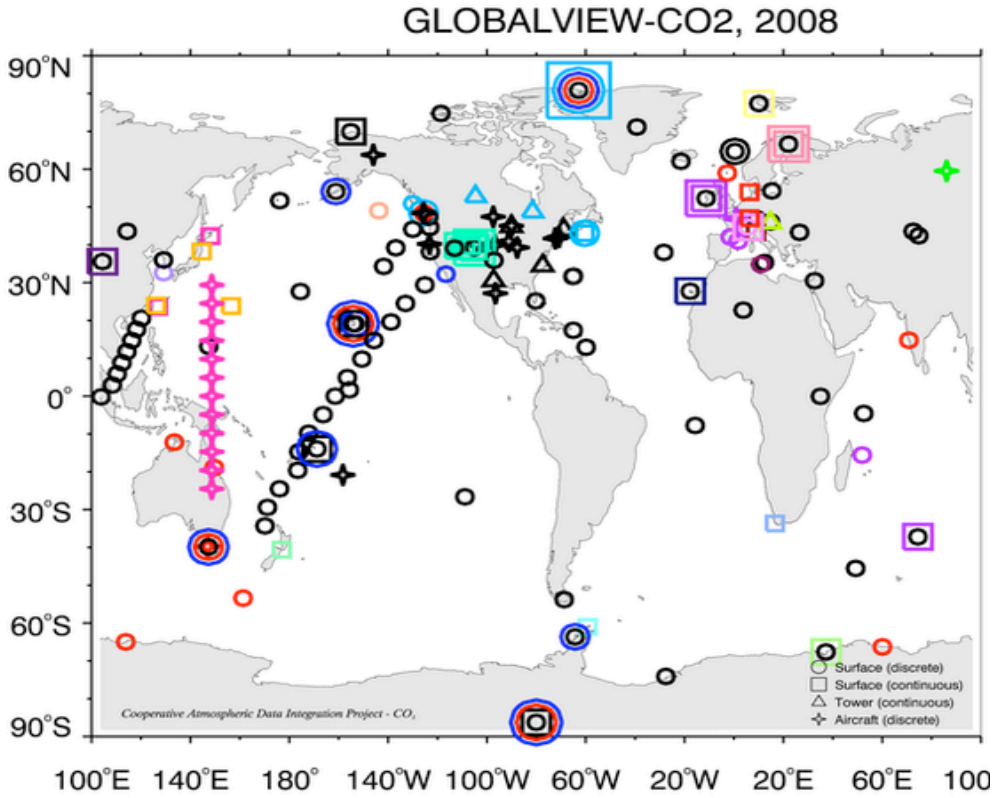
[1]University of California, Berkeley; [2]University of Maryland;
[3] Jet Propulsion Lab (JPL), NASA

Big Problem: The Elusive Carbon Sink

- **Only half of the CO_2 produced by human activities is remaining in the atmosphere.**
- **Where are the *sinks* that are absorbing about 50% of the CO_2 that we emit?**
  - **Land or ocean?**
  - **Eurasia/North America?**
- **How will CO_2 sinks respond to climate change?**



Background: Top-down Approach & Conventional CO2 Observation Coverage

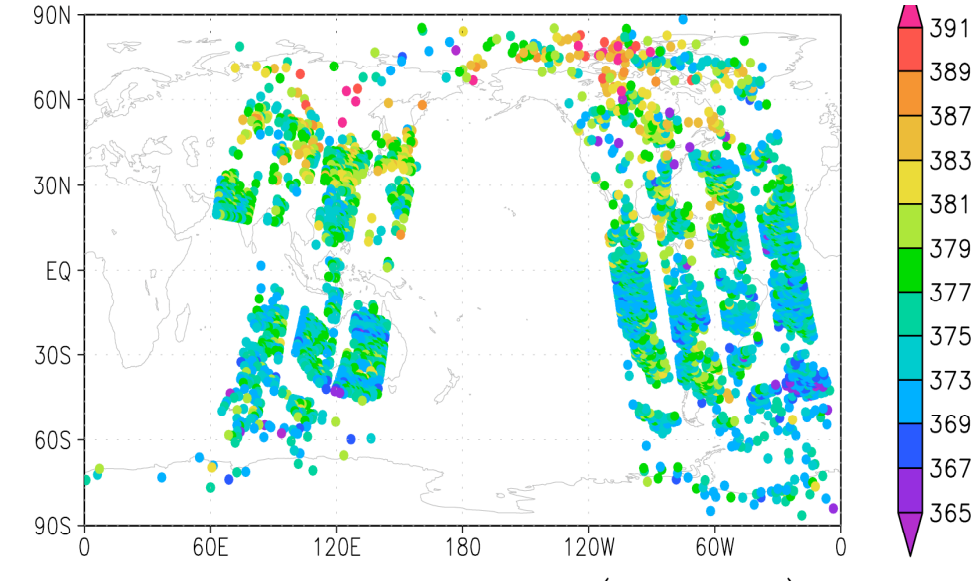


NOAA/ESRL

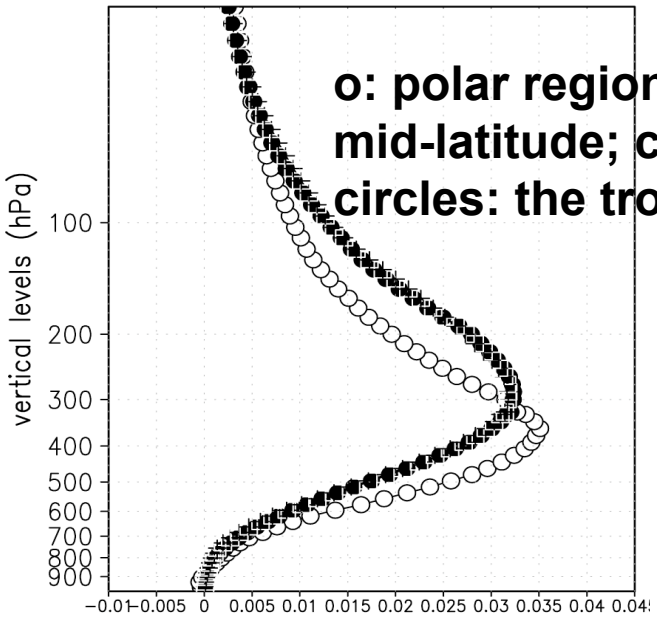
- **Top-down approach: CO2 concentrations->carbon flux**
- **Carbon flux estimation has been constrained by limited observation coverage.**

AIRS CO2 Observations & Research Goals

AIRS CO2 at 18Z01May2003 (+/-3hour)



AIRS averaging kernel



o: polar region; +: mid-latitude; closed circles: the tropics.

- **Generate CO_2 vertical profiles**
- **Preliminary results on surface carbon flux estimation.**

Carbon-Climate Model

- Community Atmospheric Model 3.5 (CAM 3.5) coupled with Community Land Model 3.5 (CLM 3.5)
  - Finite Volume dynamical core
  - 2.5°x1.9° horizontal resolution, with 26 vertical levels up to 3.5hPa.
- CO_2 is transported as a tracer in CAM 3.5
- Carbon surface fluxes:
  - Fossil fuel emission (yearly average value for 2003)
  - Ocean C fluxes (monthly means, interpolated between months; Takahashi et al., 2002)
  - Land C flux (6-hourly carbon flux from CASA)
- Initial CO_2 is the spin-up after 3 years.
- Assimilation time period: 01Jan2003-30June2003

CO_2 Observation Operator

- Model forecast x^b is CO_2 vertical profile;
- AIRS CO_2 is column-weighted Volume Mixing Ratio (vmr);

=> observation operator: interpolate x^b to obs location & calculate model forecast column-weighted CO_2 vmr.

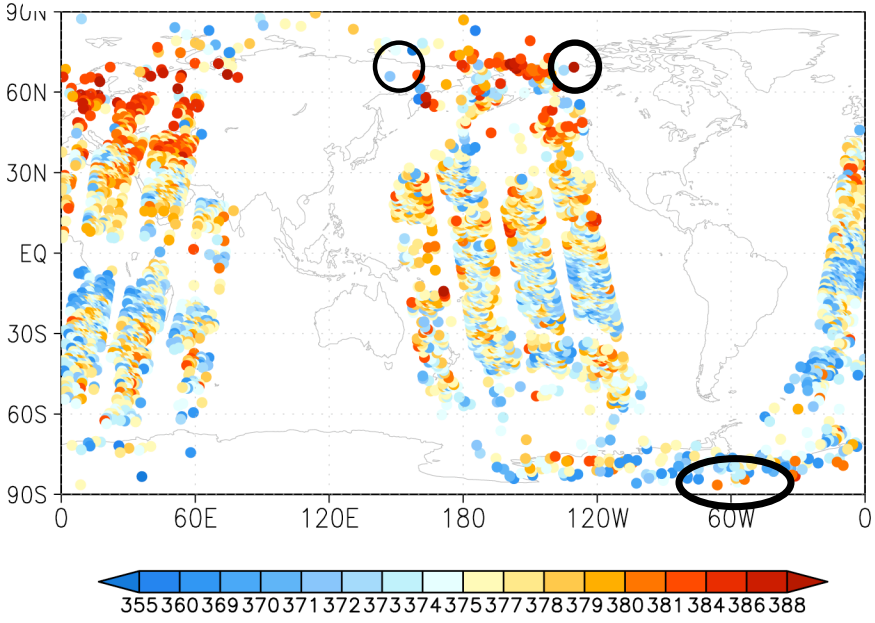
$$\underbrace{\mathbf{y}^b}_{\text{model forecast "obs"}} = \underbrace{\underbrace{\mathbf{A}}_{\text{avg kernal}}{}^T \left(\underbrace{S}_{\text{spatial interpolator}} \left(\underbrace{\mathbf{x}^b}_{\text{model forecast}} \right) \right)}_{\text{obs operator}}$$

Quality Control: Buddy Check

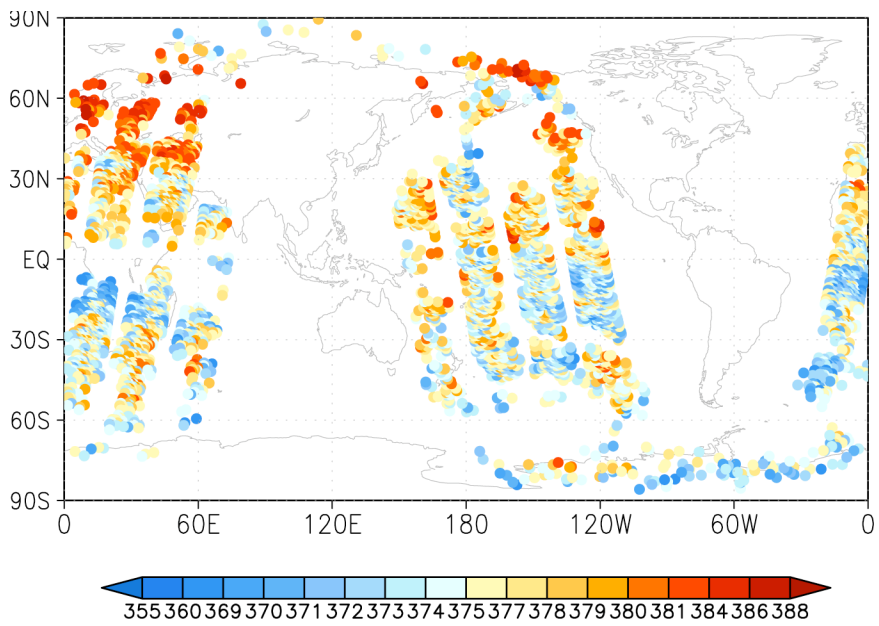
Buddy check: compare each obs to the mean of the adjacent obs

AIRS CO2 within 6 hours

Before buddy check



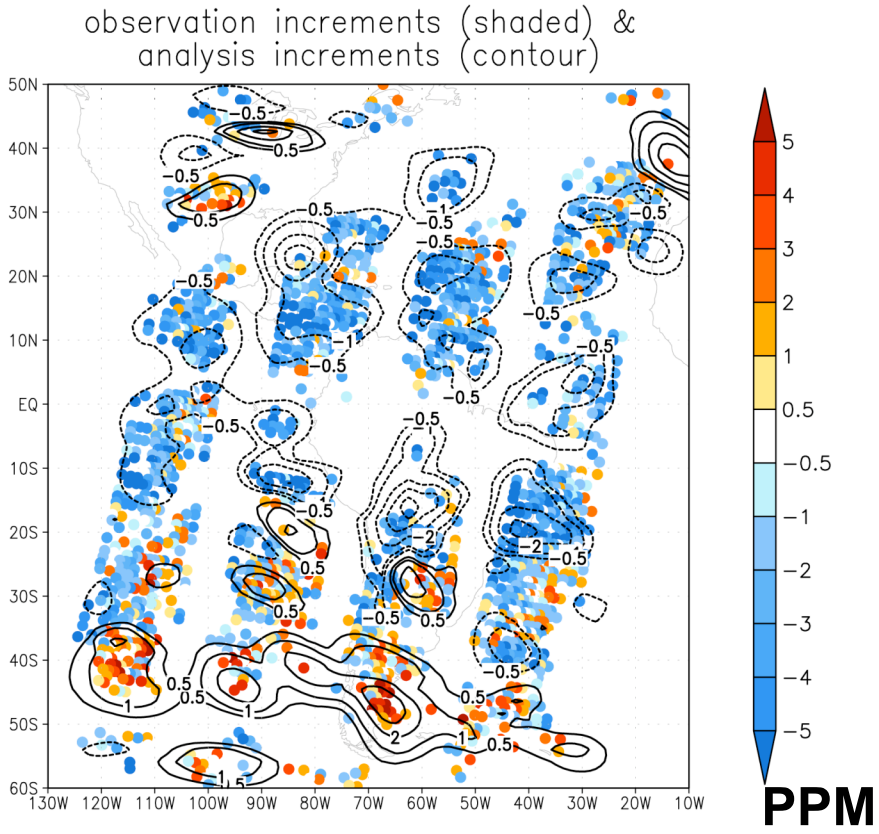
After buddy check



The quality of the rejected obs is not necessarily bad by itself!

- **8% of AIRS CO2 observations were deleted in this way**

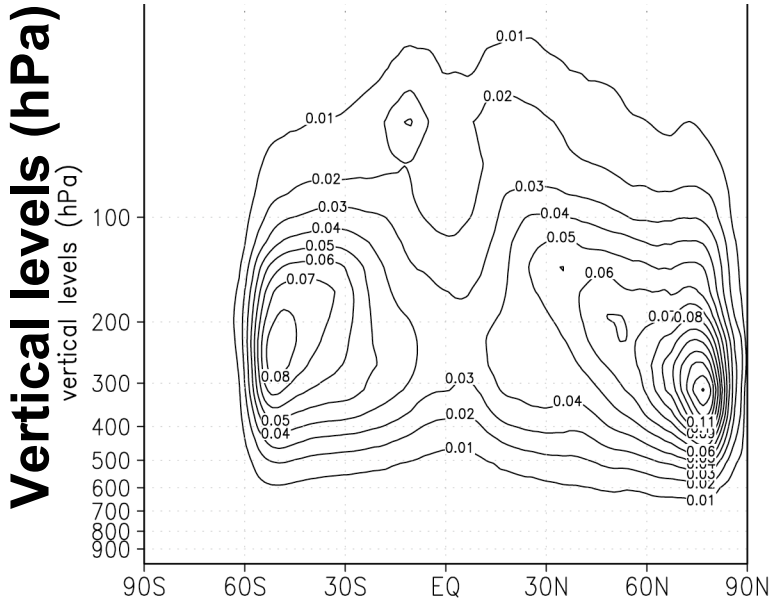
Analysis Increments (contour) & Observation Increments (shaded) At One Assimilation Cycle



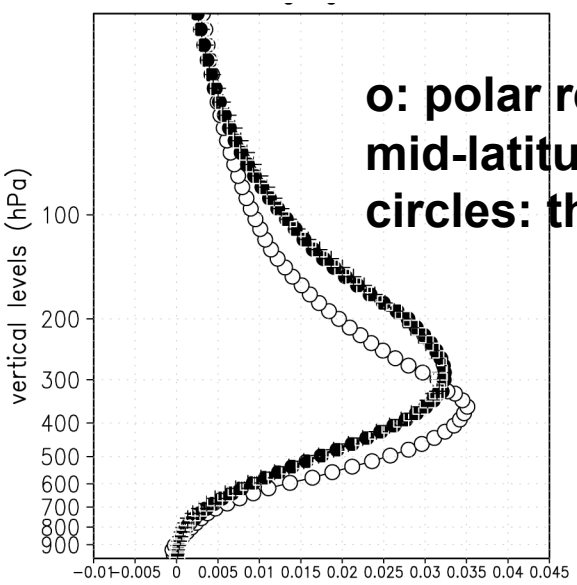
- **Analysis increments agree with observation increments**

Time-averaged Absolute Analysis Increments

Time-averaged absolute analysis increments



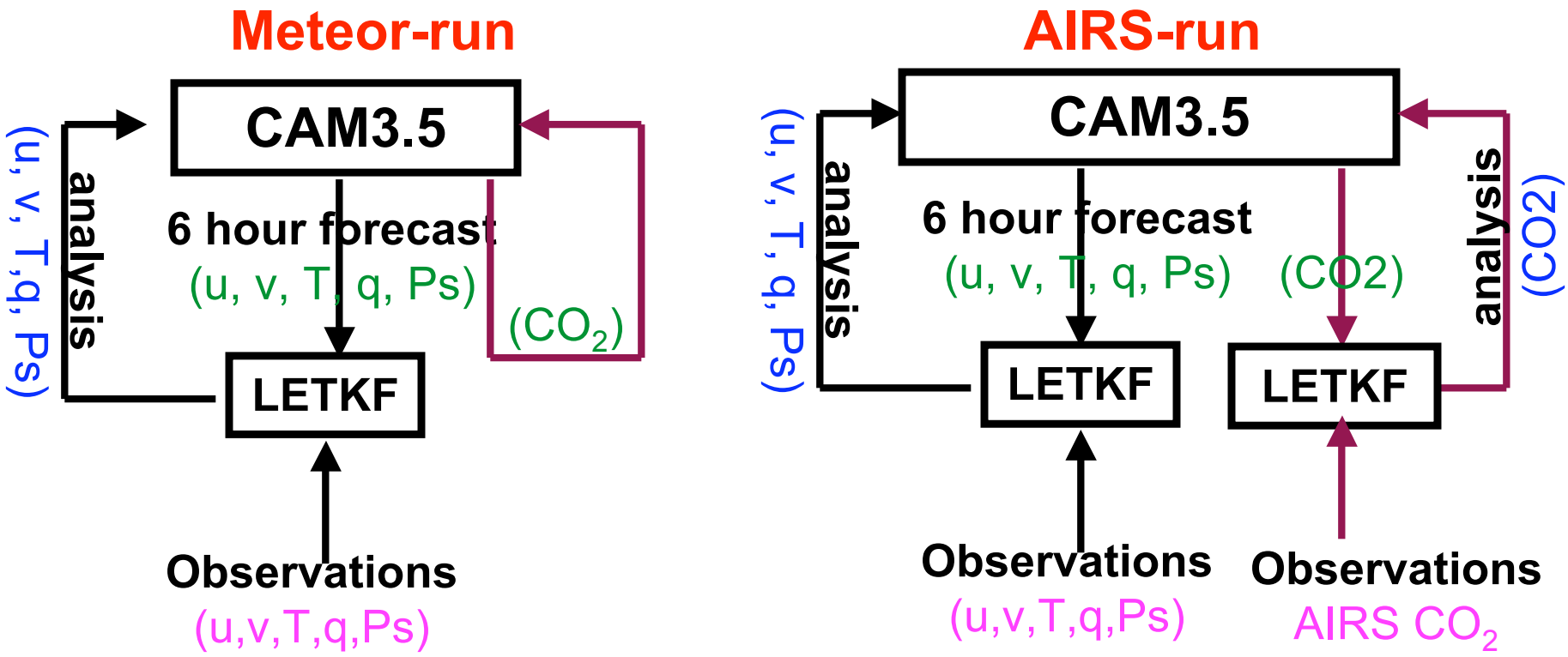
Averaging Kernel



o: polar region; +: mid-latitude; closed circles: the tropics.

- **Obtain CO_2 vertical profiles from column weighted CO_2; no AIRS CO2 observations beyond 60ºS.**
- **Analysis increments peak at the similar levels of the peak of the averaging kernels.**

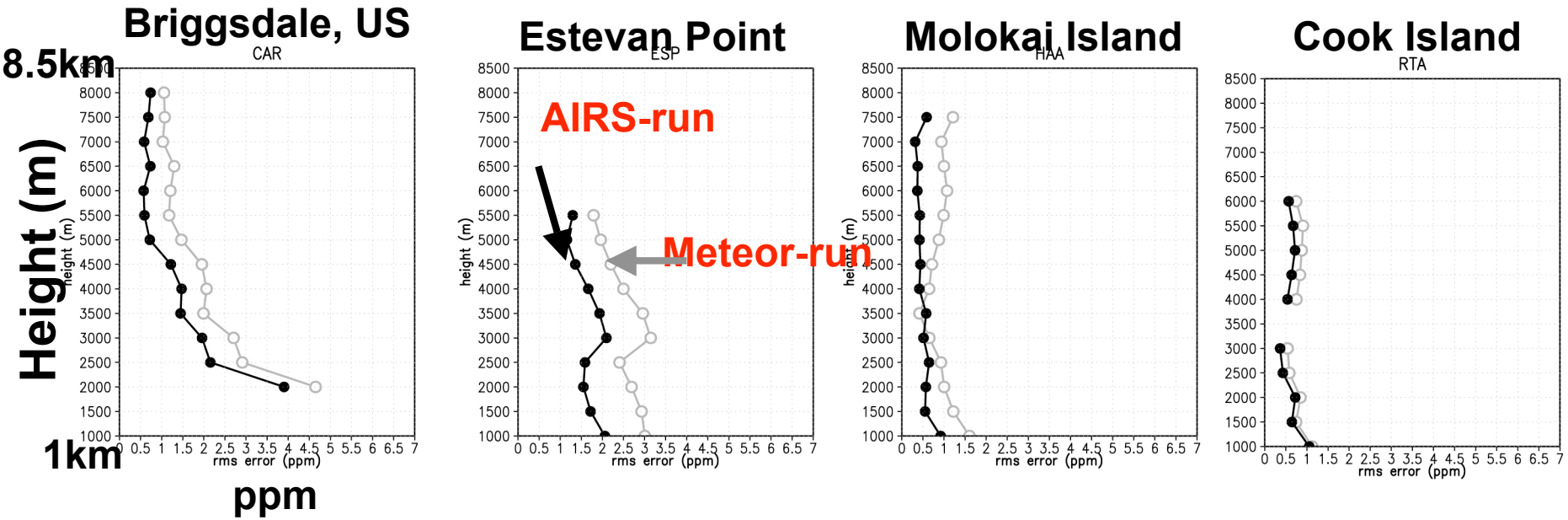
The Impact of AIRS CO_2 Assimilation



LETKF: Local Ensemble Transform Kalman Filter (Hunt et al., 2007)

- **Assimilate meteorological observations along with AIRS CO_2**

Verified Against Independent Aircraft CO_2

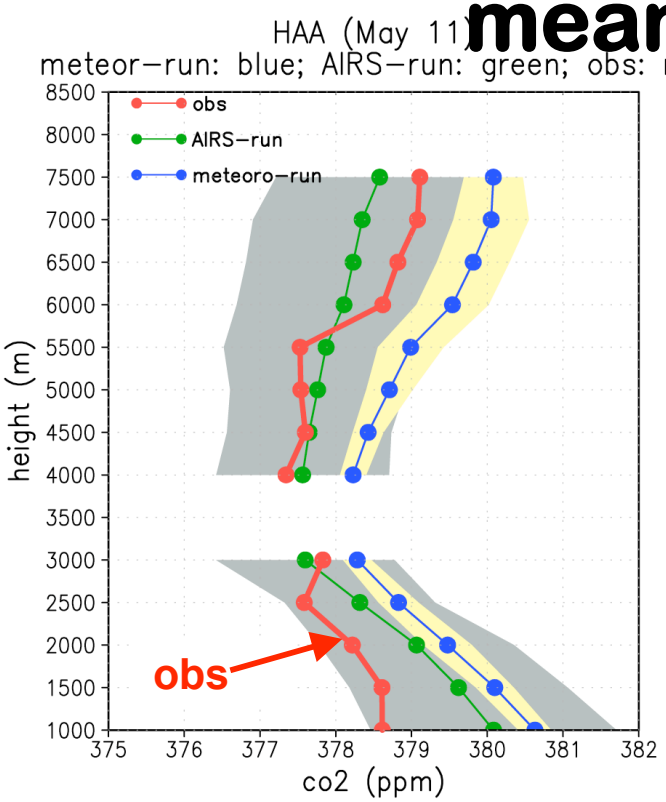


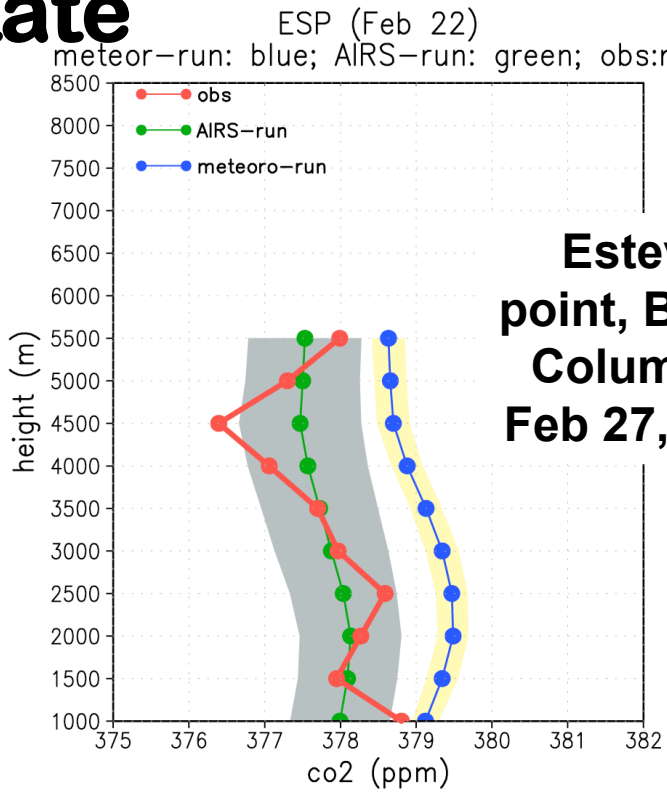
Time average of all the cases between 01Jan2003-30June2003

- **Grey: meteor-run; black: AIRS-run.**
- **CO_2 vertical profiles from the AIRS-run can be about 1 ppm more accurate that those from the meteor-run.**

Analysis ensemble spread along with the mean state

Molokai Island, Hawaii. May 11, 2003

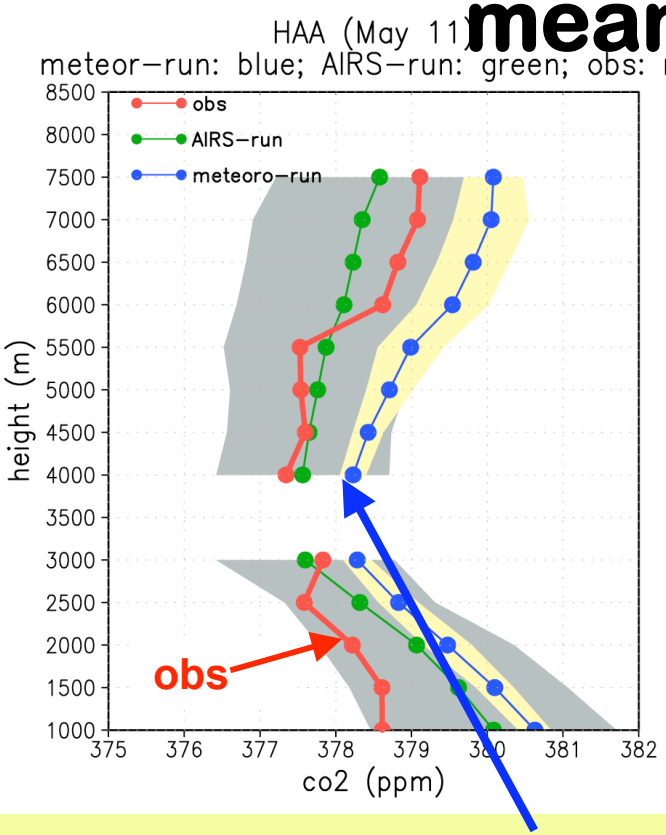


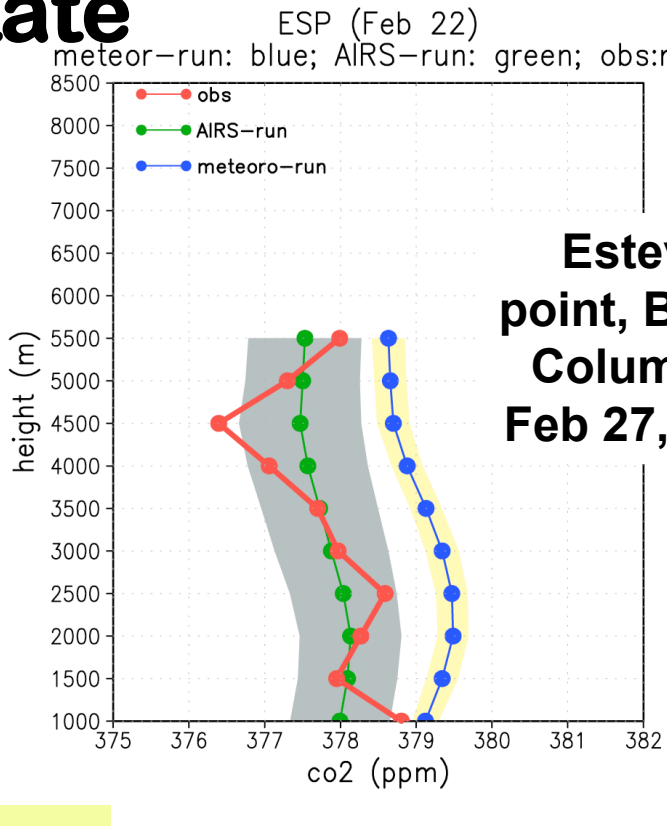


Estevan point, British Columbia, Feb 27, 2003

Analysis ensemble spread along with the mean state

Molokai Island, Hawaii. May 11, 2003



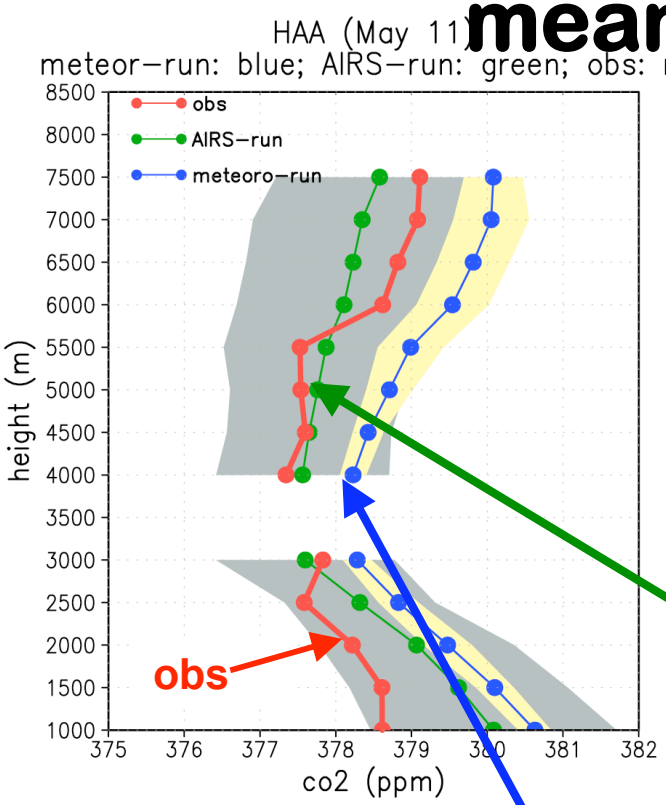


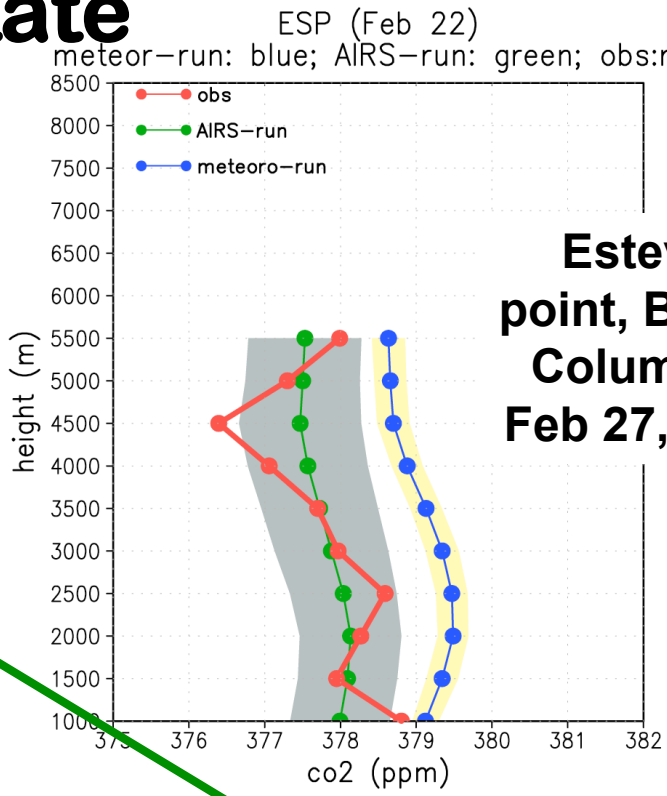
Estevan point, British Columbia, Feb 27, 2003

- **Meteor-run: CO2 tracer transported by 64-member ensemble meteorological analyses generated every 6hr --> "precision" of CO2 "forecast" by model**

Analysis ensemble spread along with the mean state

Molokai Island, Hawaii. May 11, 2003





Estevan point, British Columbia, Feb 27, 2003

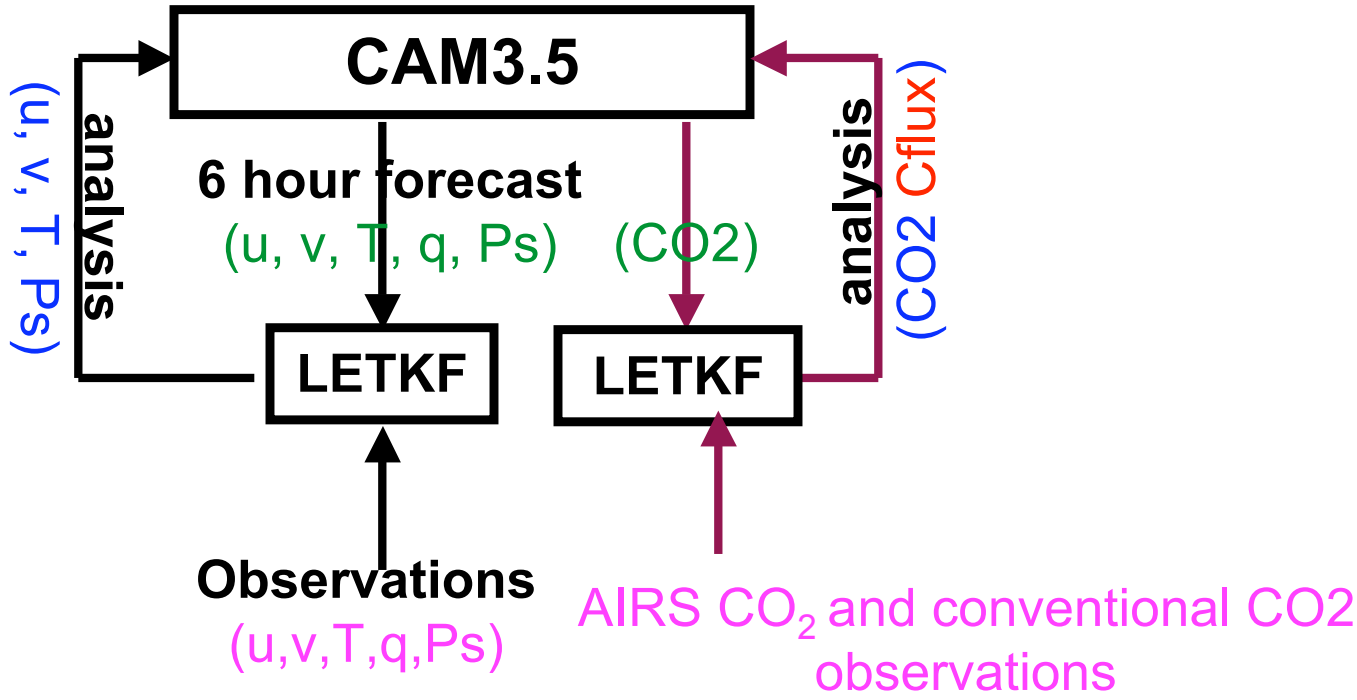
- Meteor-run: CO2 tracer transported by 64-member ensemble meteorological analyses generated every 6hr --> "precision" of CO2 "forecast" by model

- AIRS-run: CO2 assimilated along with meteorological obs.

- Ensemble CO2 analyses (grey shaded) bracket aircraft obs

Preliminary results on surface carbon flux estimation by assimilating AIRS CO2

The impact of AIRS CO2 assimilation



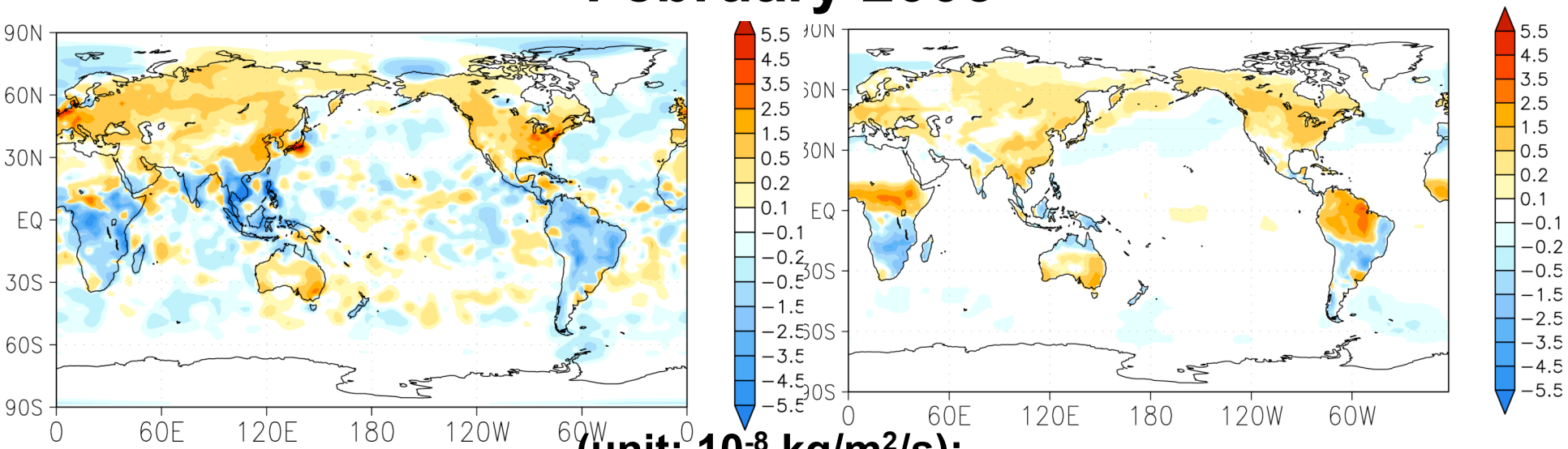
LETKF: Local Ensemble Transform Kalman Filter (Hunt et al., 2007)

• The carbon flux analysis acts as boundary forcing for the forecast of next time step.

• Three-month assimilation cycles (01Jan2003-31March2003).

Carbon Flux Analysis:Data Assim (left)
Carbon Flux (CASA (land)+Takahashi (ocean)(right)

February 2003

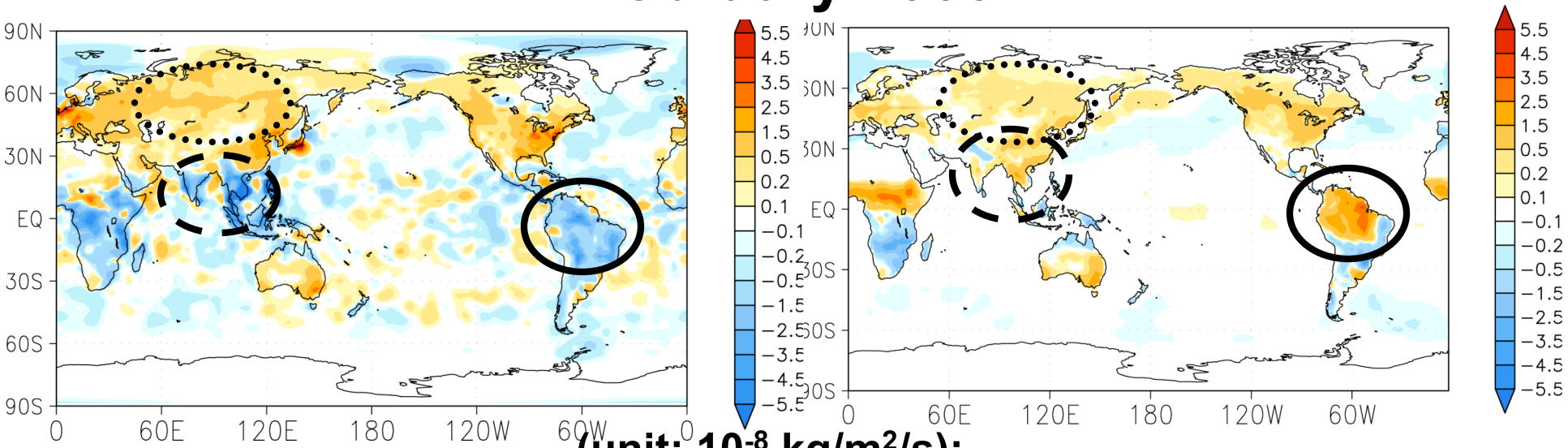


(unit: 10^{-8} kg/m^2/s):

- Stronger source in the NH winter
- Stronger sink in the tropics and SH subtropics
- Noisy over ocean compared to Takahashi

Carbon Flux Analysis:AIRS CO2 Data Assim (left) Carbon Flux (CASA (land)+Takahashi (ocean)(right)

February 2003

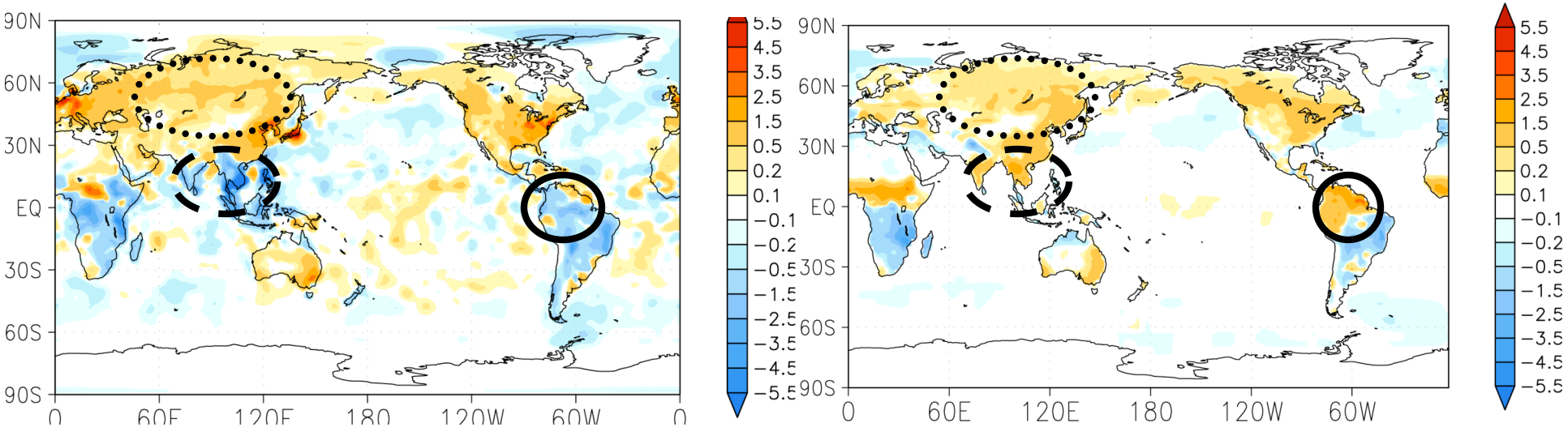


(unit: 10^{-8} kg/m^2/s):

- Stronger source in the NH winter
- Stronger sink in the tropics and SH subtropics
- Noisy over ocean compared to Takahashi

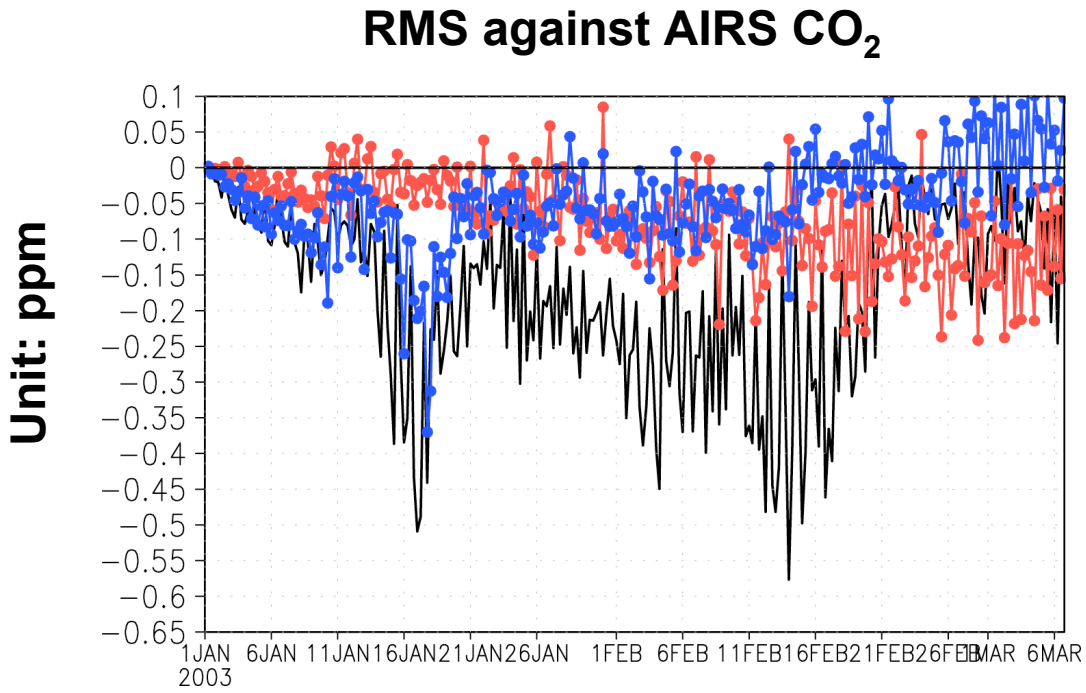
Carbon flux analysis (left) and carbon flux (CASA+Takahashi)(right) (unit: 10^{-8} kg/m^2/s): Mar

March 2003



- **Stronger source in the NH winter**
- **Stronger sink in the tropics and SH subtropics**
- **Noisy over ocean compared to Takahashi**

RMSE Difference Between CO2 Analyses From Carbon Flux Analysis and those from Fixed Carbon Flux



Black: NH; Red: SH; Blue: Tropics

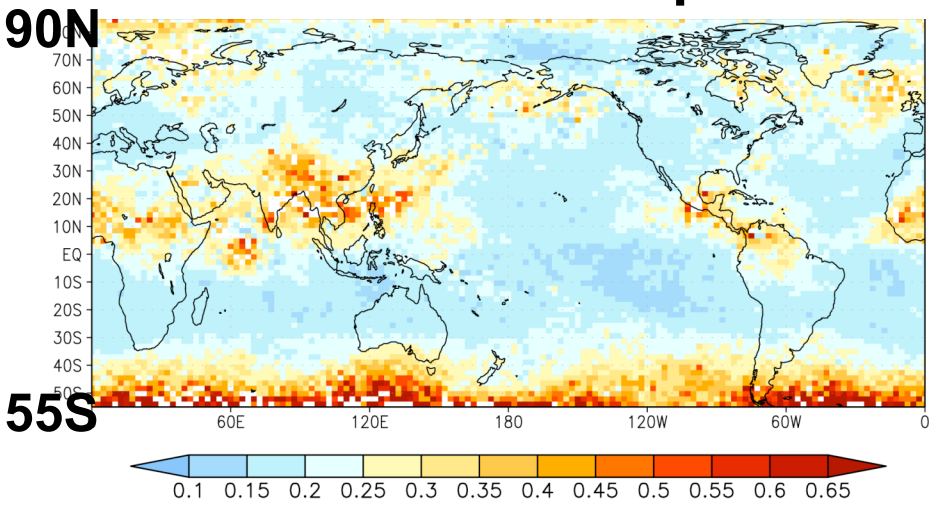
- **Negative: carbon flux analysis is more accurate than fixed carbon flux when verified against AIRS CO_2.**
- **Stronger fluxes drive CO2 to better agreement with AIRS CO_2!**

Summary and future direction

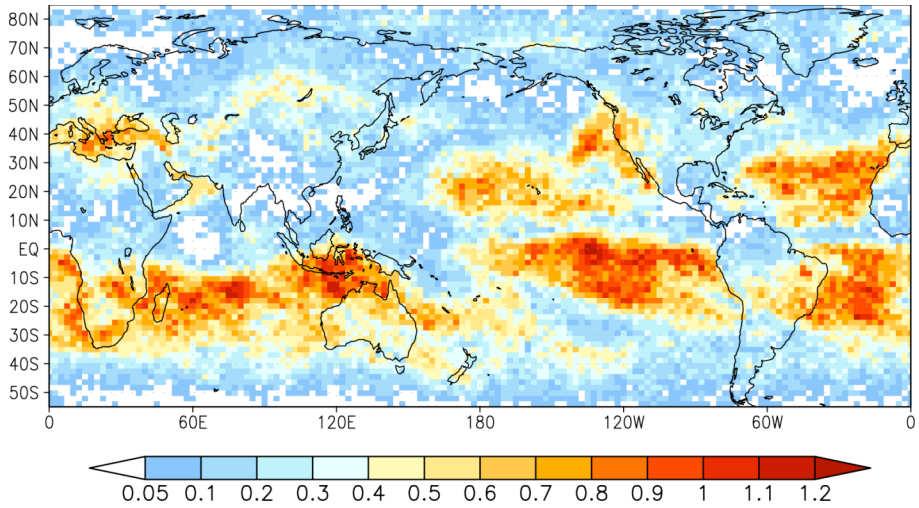
- **Assimilation of CO2 observations have improved the CO_2 vertical profiles;**
- **The ensemble analyses encompasses the aircraft CO_2 vertical profiles.**
- **The preliminary surface carbon flux estimation from assimilating AIRS CO_2 and conventional CO_2 observations are encouraging! Needs more sophisticated verification and bias correction method.**

Relationship Between Analysis Ensemble Spread and Observation Coverage

CO_2 analysis ensemble spread at observation space



Average number of AIRS CO_2 observations within 6-hour



- **Analysis ensemble spread is anti-correlated with the the CO_2 observation coverage**