Using aircraft observations to evaluate satellite column CO_2 observation: OCO-2 B8 vs. B7

Junjie Liu

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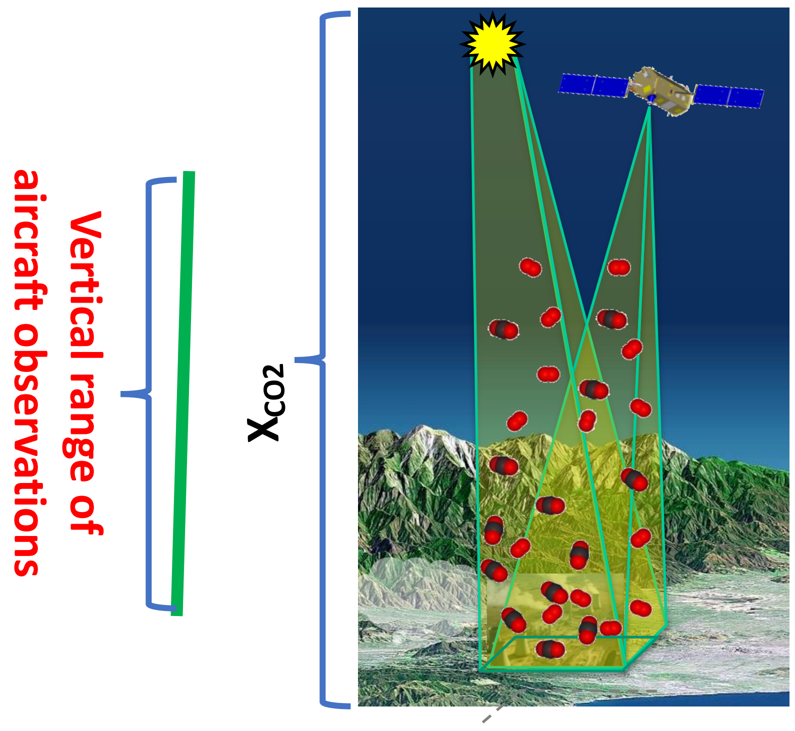
Outline

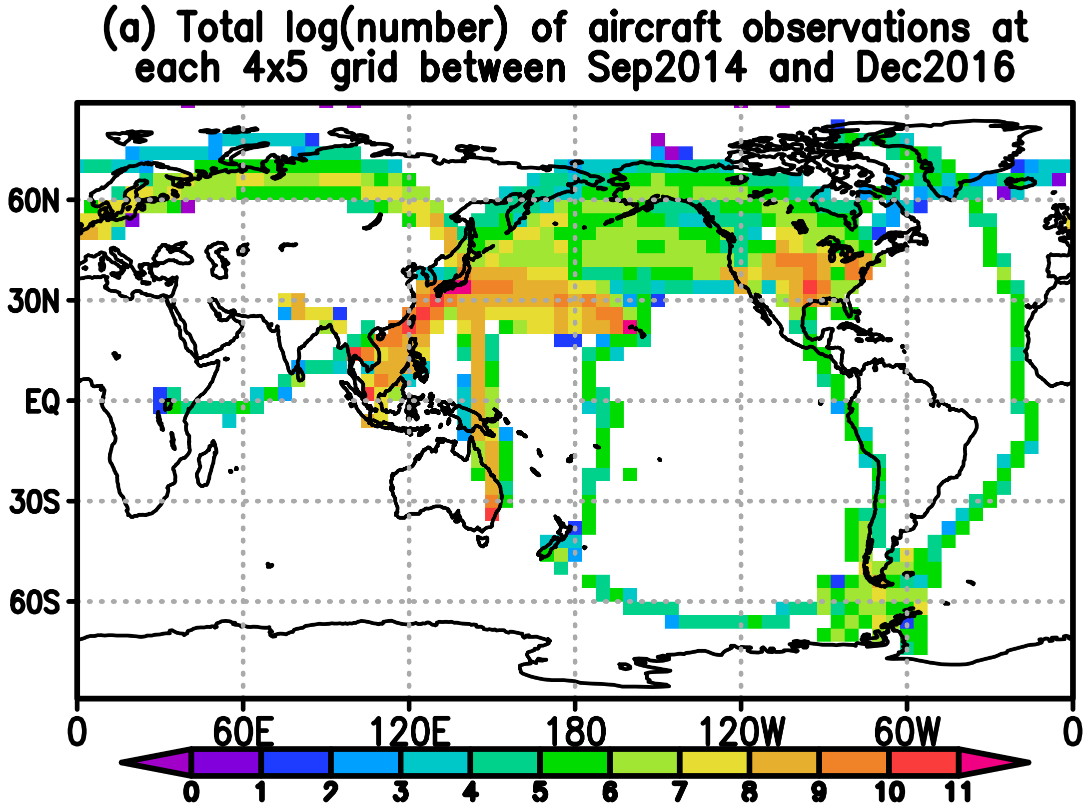
- **Direct comparison between aircraft observations and satellite column CO2 (XCO2) observations**
- **Compare aircraft observations to posterior CO2 concentrations constrained by satellite XCO2**
  - ❑ **Linkage between posterior CO2 errors and the accuracy of underlying fluxes**
  - ❑ **Linkage between posterior CO2 errors and the accuracy of the assimilated satellite observations**

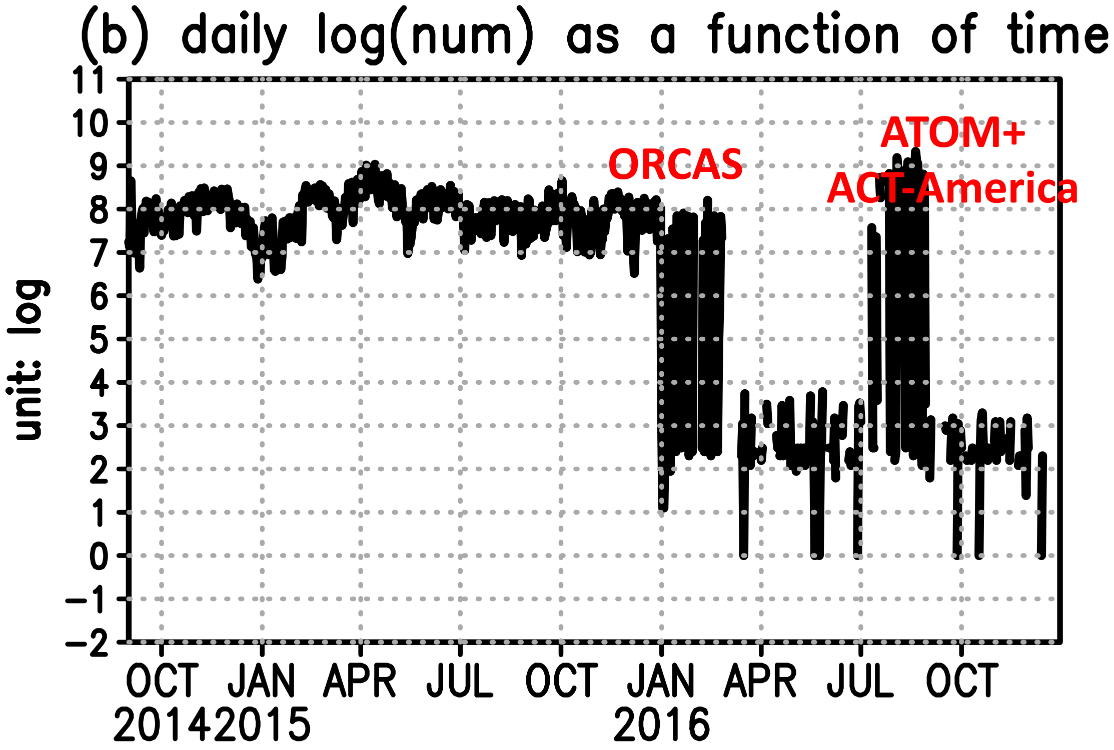
Directly comparison between aircraft and satellite X_{CO2} observations

- **Aircraft observations only observe partial column**
  - **Fill the rest of the column with simulated CO2 observations from transport model**
  - **Criteria: at least 10 vertical levels in the bottom 20 model levels have aircraft observations**
- **Colocations between aircraft profile and OCO2**
  - **Within 2.5 hours, and within 3º in both longitude and latitude**
  - **Apply OCO-2 averaging kernel to the (aircraft + model) profiles**



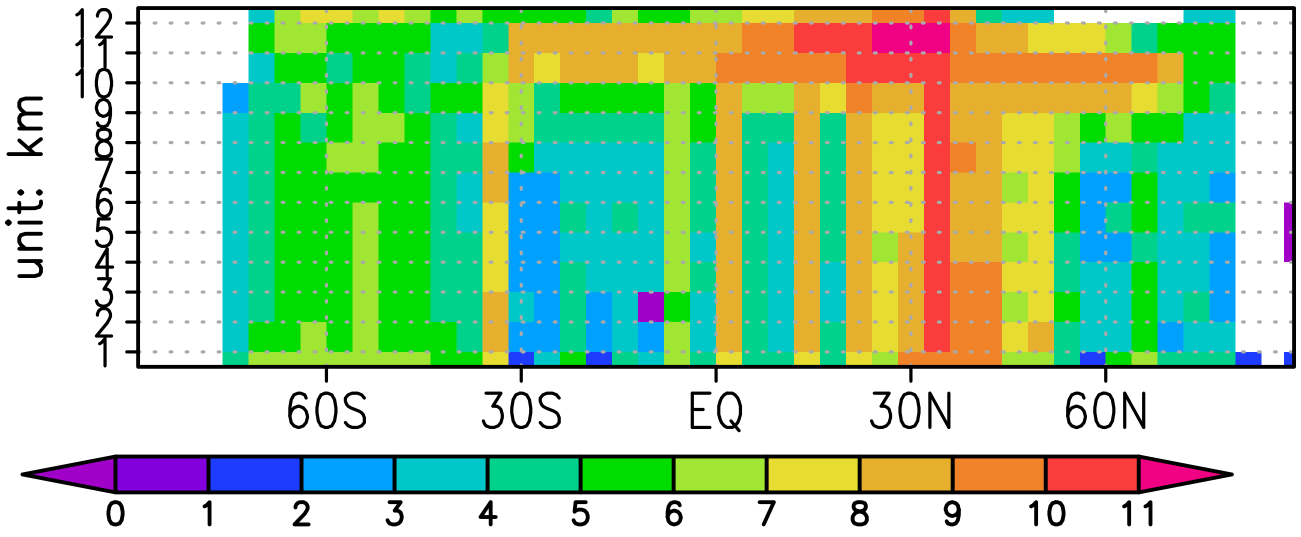
Locations and the number of aircraft observations as a function of time



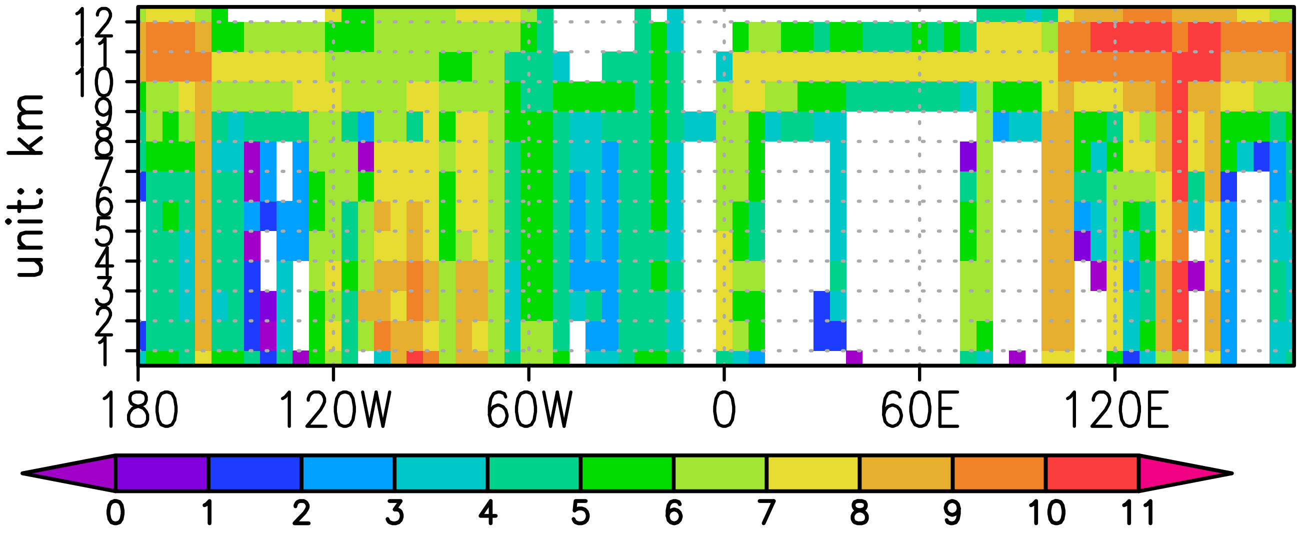


Amount of aircraft observations

(c) log(num) as a function of lat and height

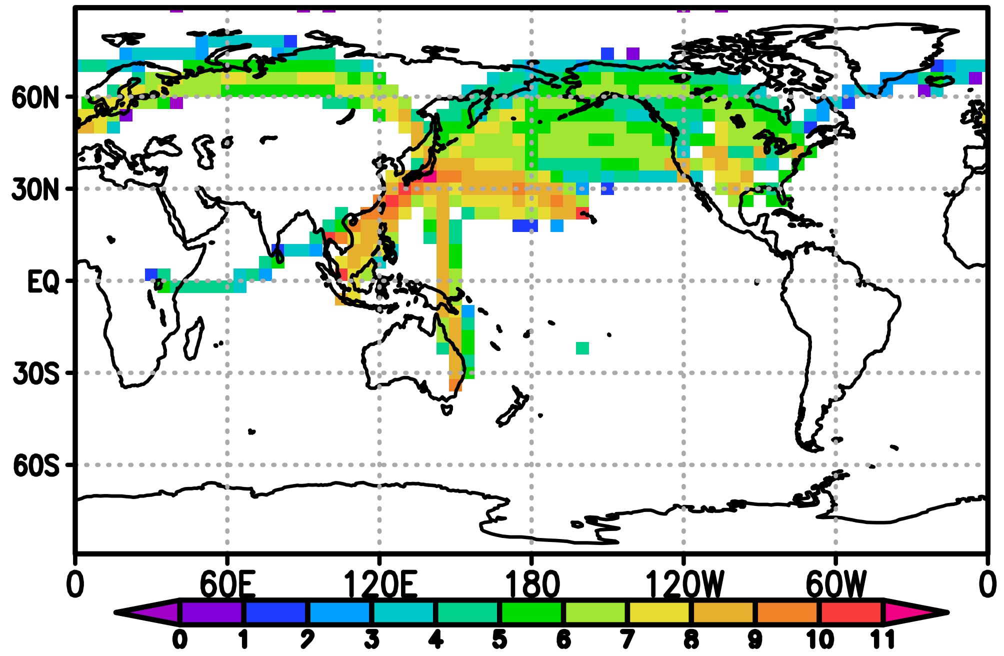


(d) log(num) as a function of lon and height

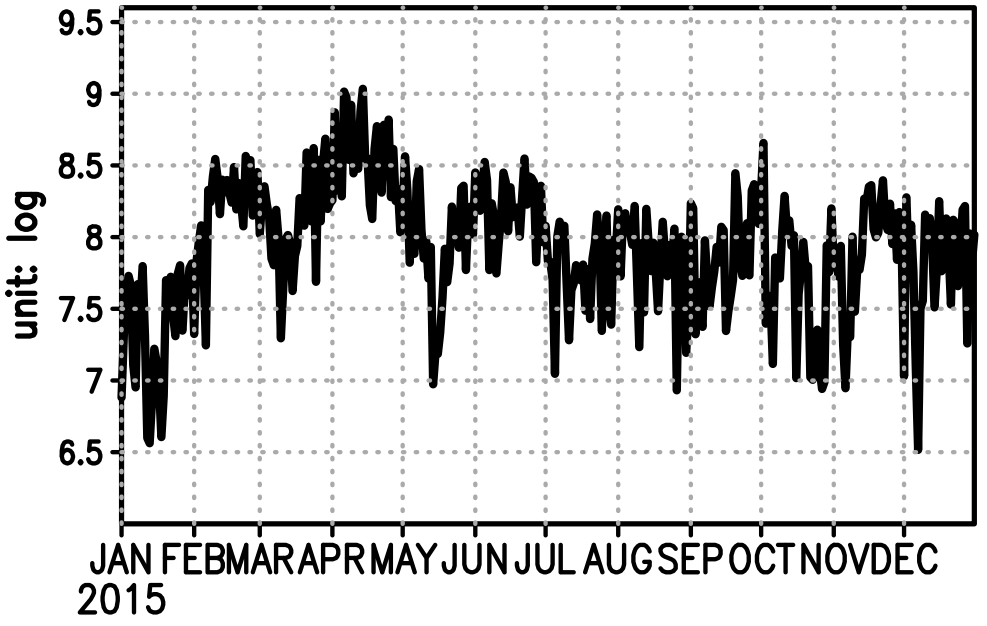


2015

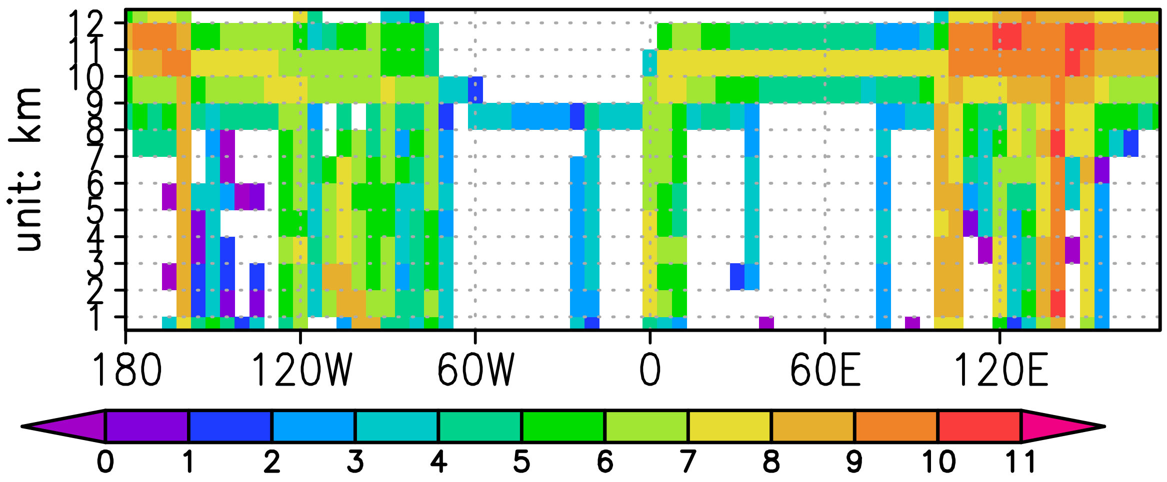
(a) Total log(number) of aircraft observations at each 4x5 grid between Jan2015 and Dec2015



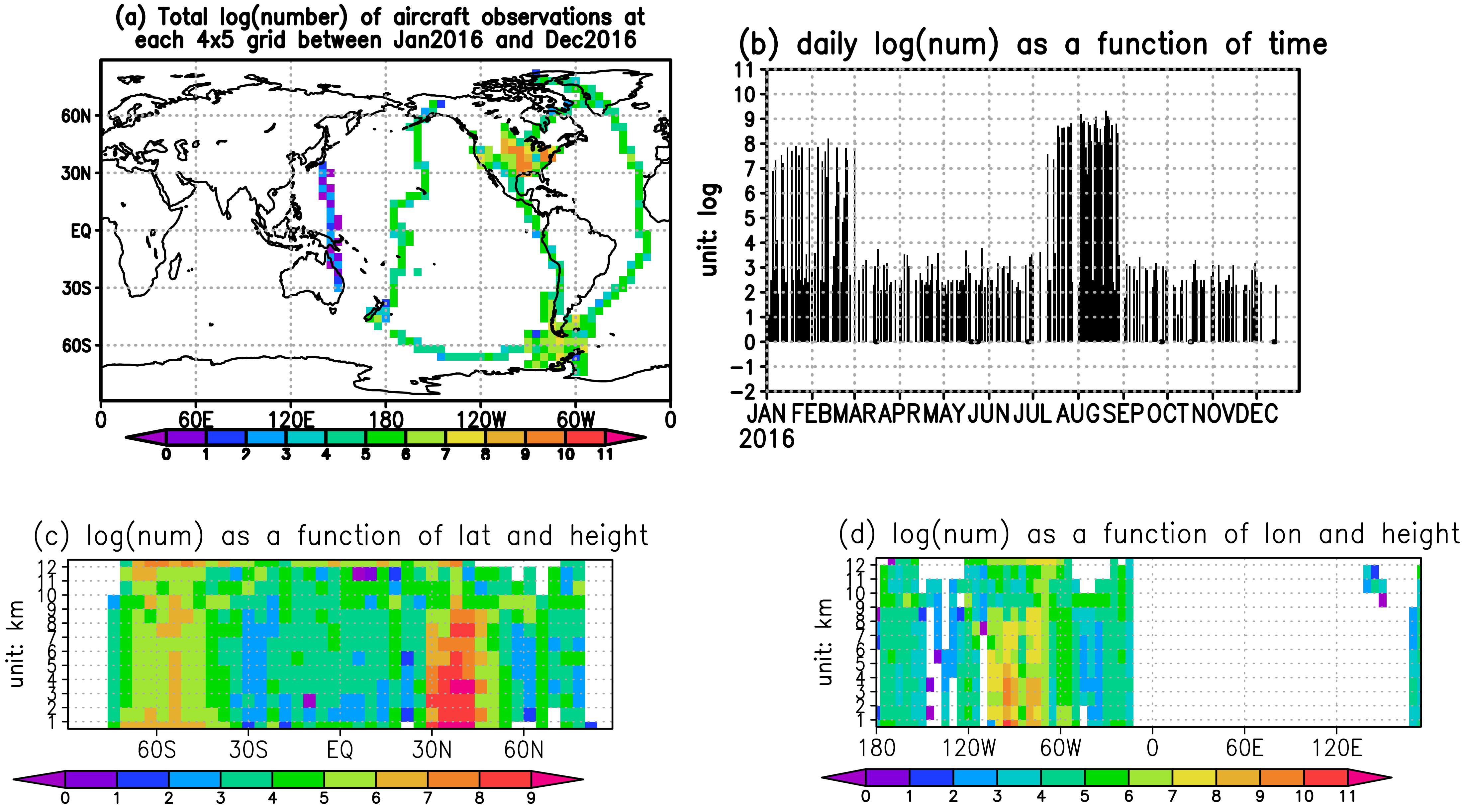
(b) daily log(num) as a function of time



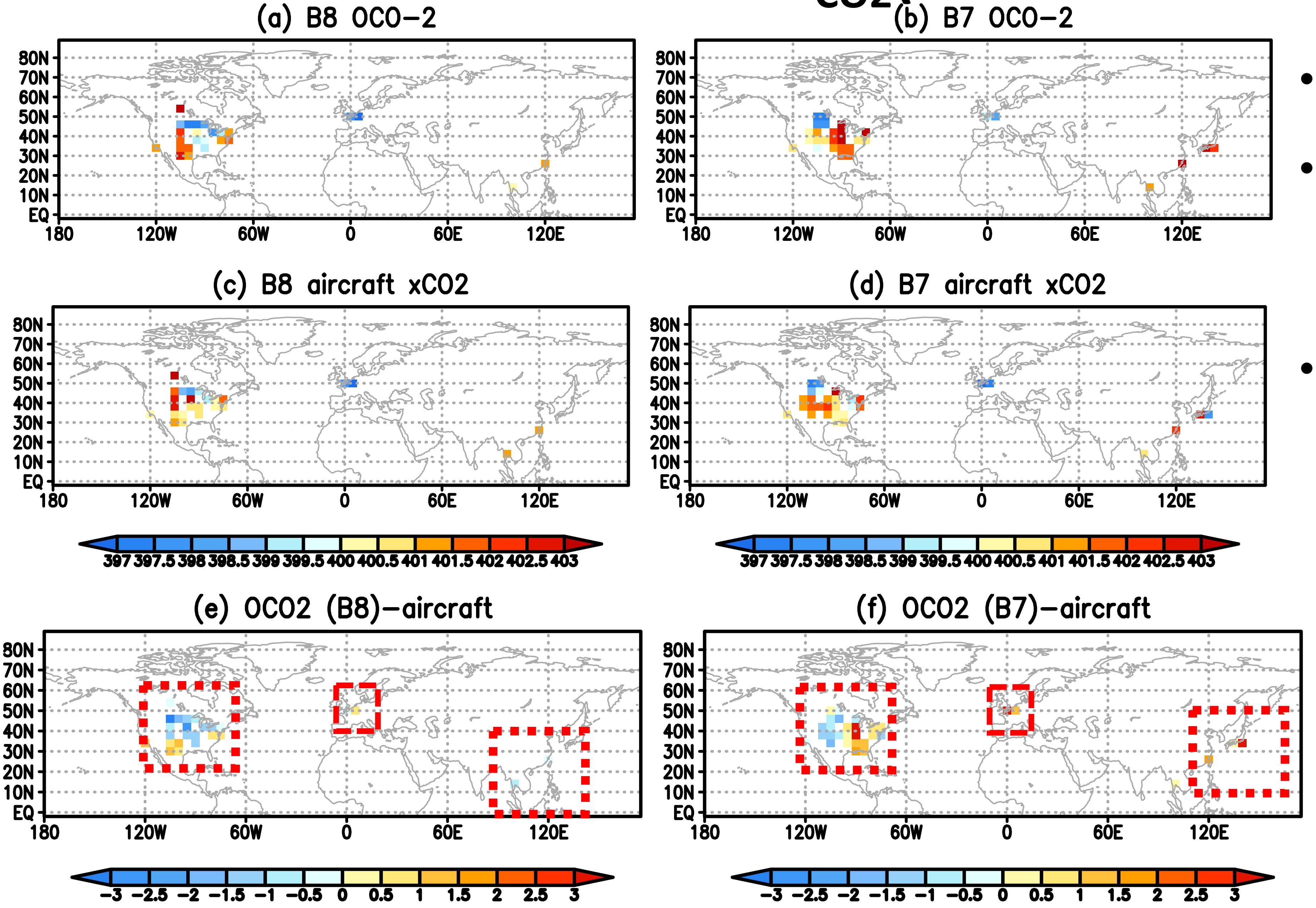
(d) log(num) as a function of lon and height



2016

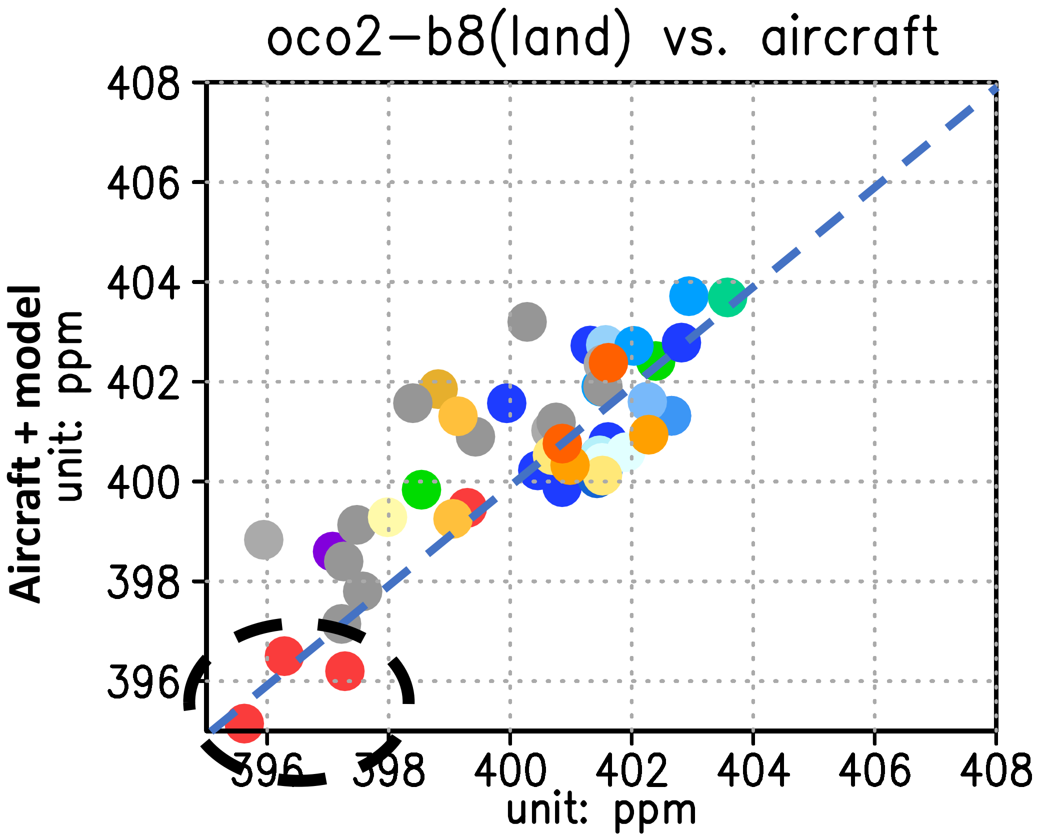

(a) Total log(number) of aircraft observations at each 4x5 grid between Jan2016 and Dec2016
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
0
0 1 2 3 4 5 6 7 8 9 10 11
(b) daily log(num) as a function of time
unit: log
11 10 9 8 7 6 5 4 3 2 1 0 -1 -2
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
2016
(c) log(num) as a function of lat and height
unit: km
12 11 10 9 8 7 6 5 4 3 2 1
60S 30S EQ 30N 60N
0 1 2 3 4 5 6 7 8 9
(d) log(num) as a function of lon and height
unit: km
12 11 10 9 8 7 6 5 4 3 2 1
180 120W 60W 0 60E 120E
0 1 2 3 4 5 6 7 8 9 10 11

Mean OCO-2 vs. X_{CO2}(aircraft + model)

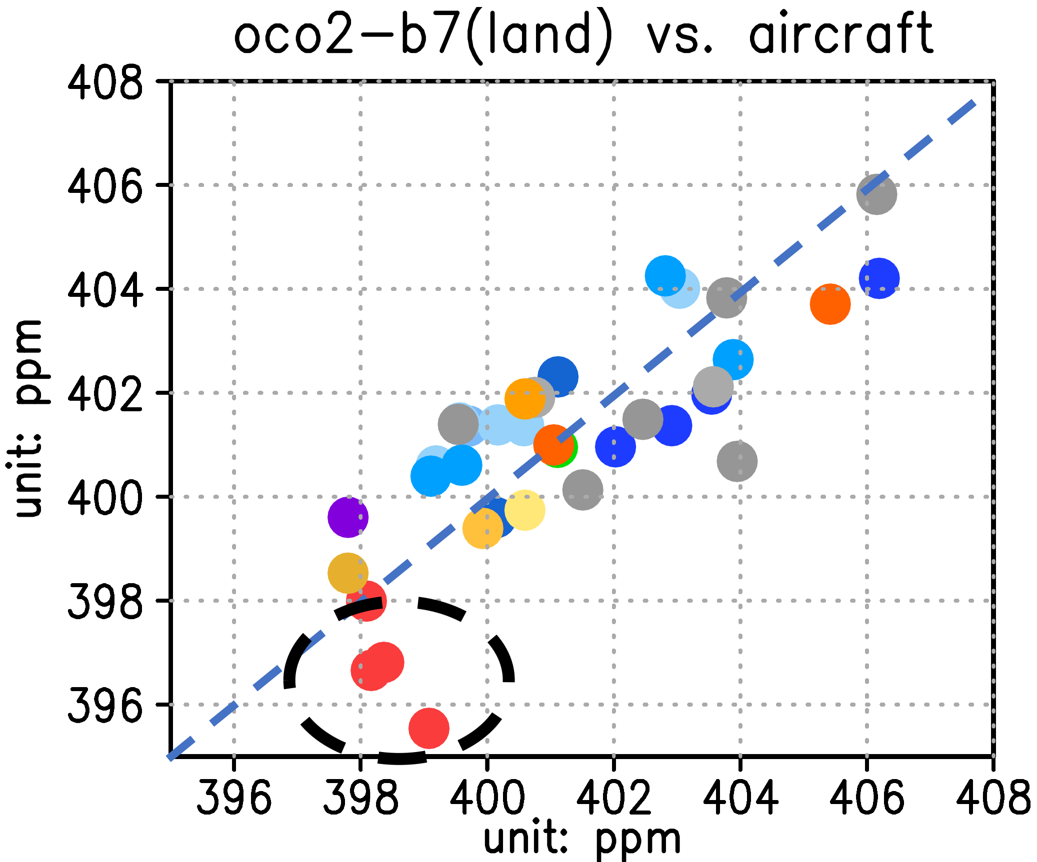


- Limited spatial coverage
- B8 is relative low than ”aircraft+model” over NA
- But much better performance over EU

Scatter plot between X_{CO2}(OCO-2) and X_{CO2}(aircraft + model)



OCO-2 (b8)



OCO-2 (b7)

RMS=1.19 ppm
Bias=-0.25 ppm

RMS=1.84ppm
Bias=0.61ppm

Red: Europe, green: South-East Asia, blue: East Asia; light blue – dark blue: Southwest-US, grey-purple: mid-west US , yellow-orange: northeast US

Challenges

- Very few aircraft observations are underpass OCO-2 track
- Top and bottom levels are from model simulated values

Alternative method

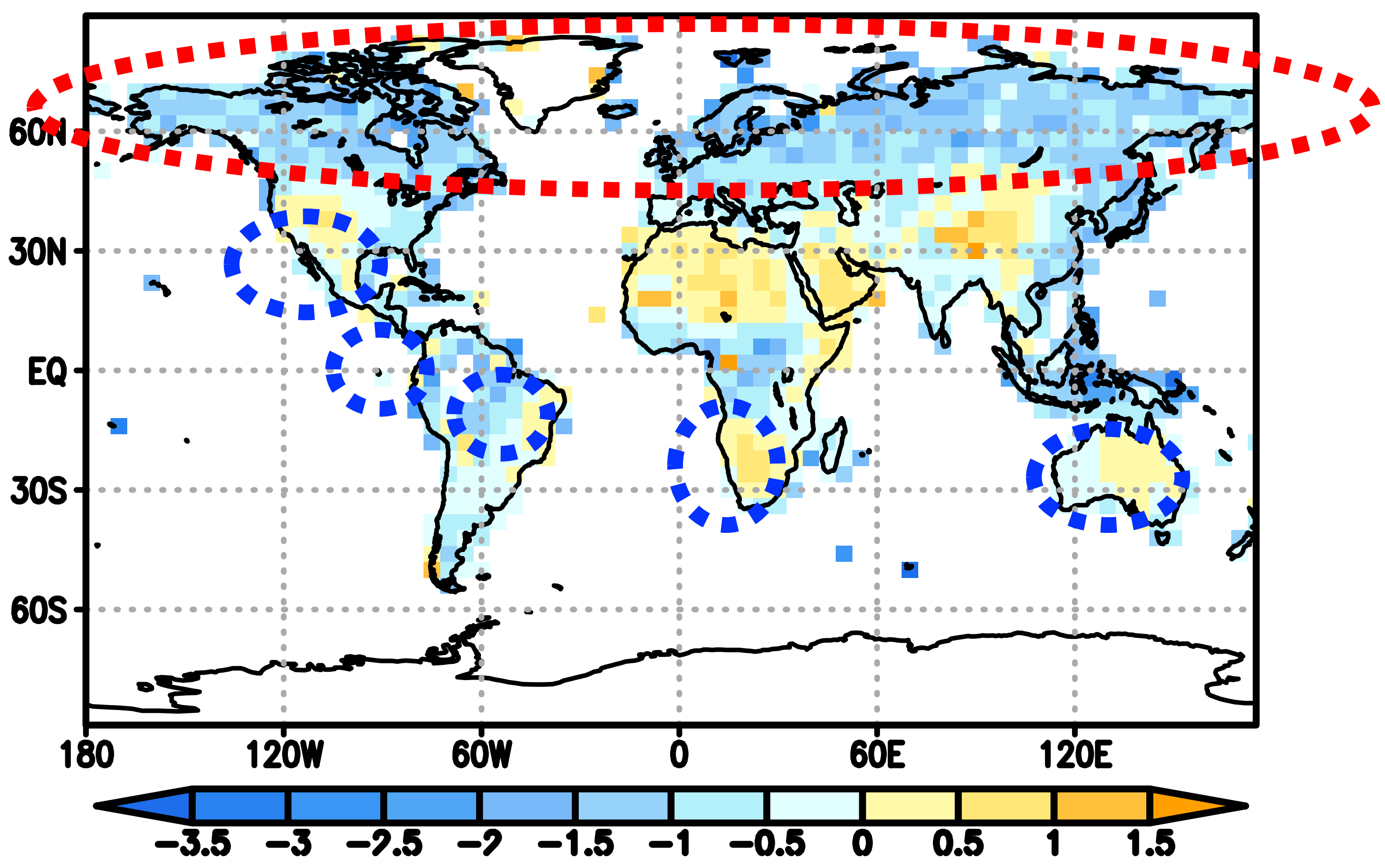
- Constrain surface CO_2 fluxes with OCO-2 observations
- Compare posterior CO_2 concentrations with aircraft observations
  - Can use all the available aircraft observations

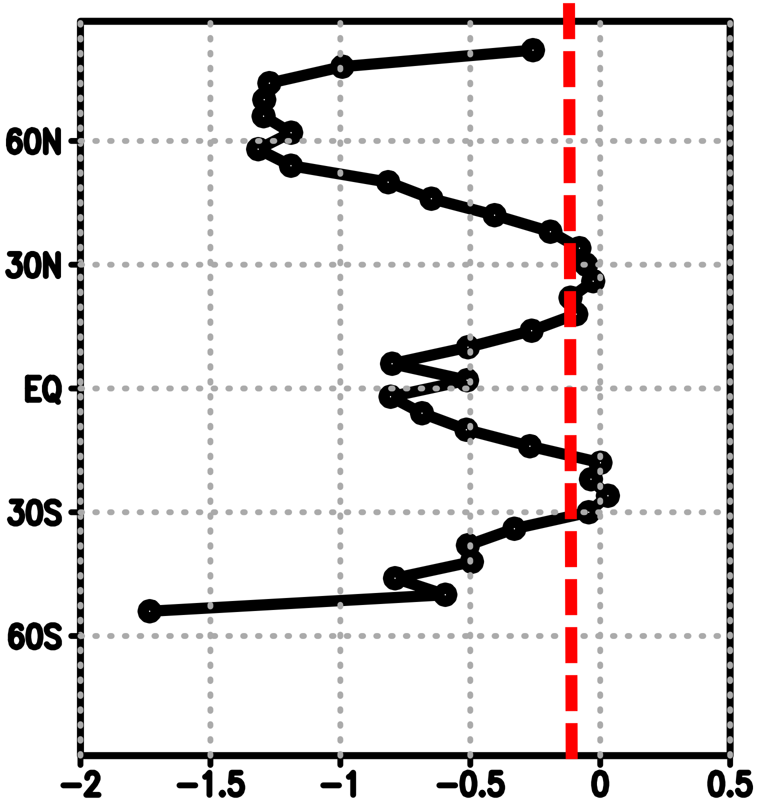
Experimental design

- CMS-Flux inversion system with GEOS-Chem adjoint model
- Optimize monthly biosphere and ocean carbon fluxes at 4 x 5 resolution
- Assimilate OCO-2 B7 and B8 nadir observations separately
- Compare posterior CO2 with aircraft observations

- What does the comparison to aircraft observations indicate about the quality of underlying fluxes?
- Is the comparison between posterior CO_2 and aircraft sufficient to inform the quality of assimilated observations?
- What additional steps do we need to identify where and when B8 is more/less accurate than B7?

2015 B8 and B7 X_{CO2} differences





- B8-B7=-0.33 ppm
- B8 X_{CO2} are much lower than B7 over NH high latitudes

B8 inversion has larger total sink than B7 inversion

2015

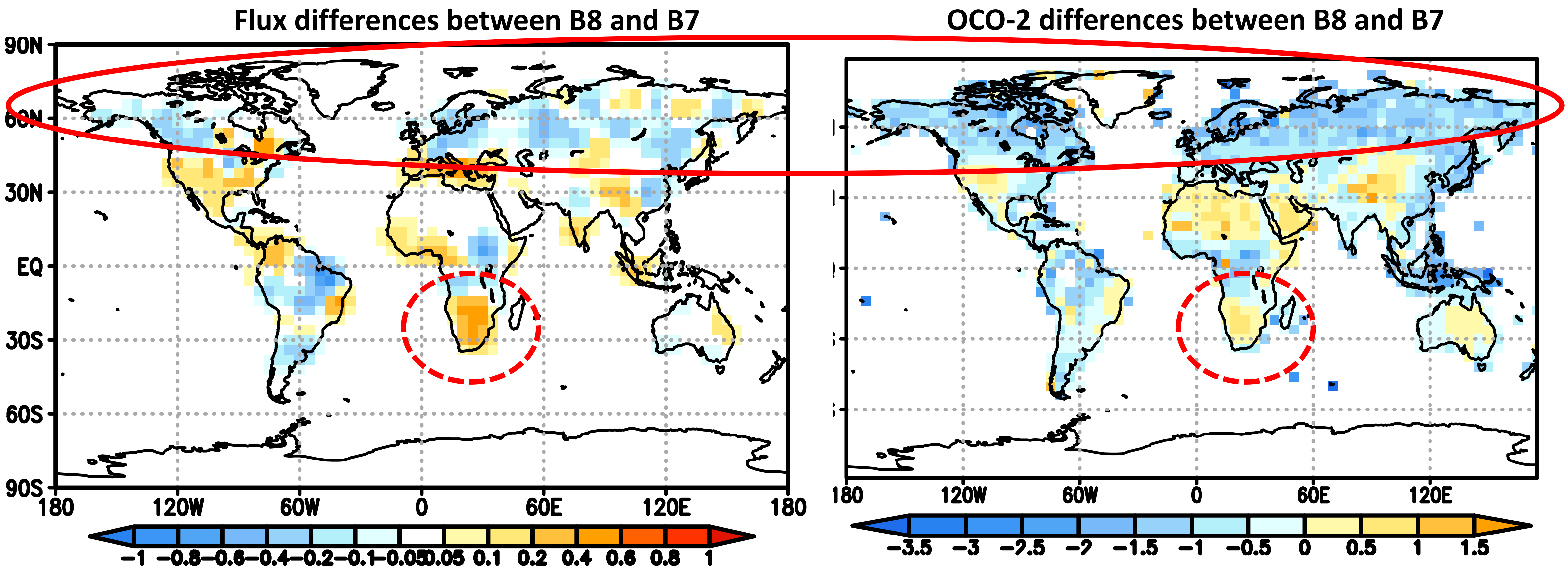
	Total biosphere	Ocean	FF	Atmospheric Growth	NOAA CO2 derived growth rate
Land nadir b7	-1.00	-2.88	9.85	6.00+-0.53	6.30+-0.2
Land nadir b8	-1.50	-2.80	9.85	5.6	

2016

	Total biosphere	Ocean	FF	Atmospheric Growth	NOAA CO2 groth rate
Land nadir b7	-0.77	-2.95	9.85	6.06+-0.53	6.08+-0.2
Land nadir b8	-2.09	-3.08	9.85	4.68	

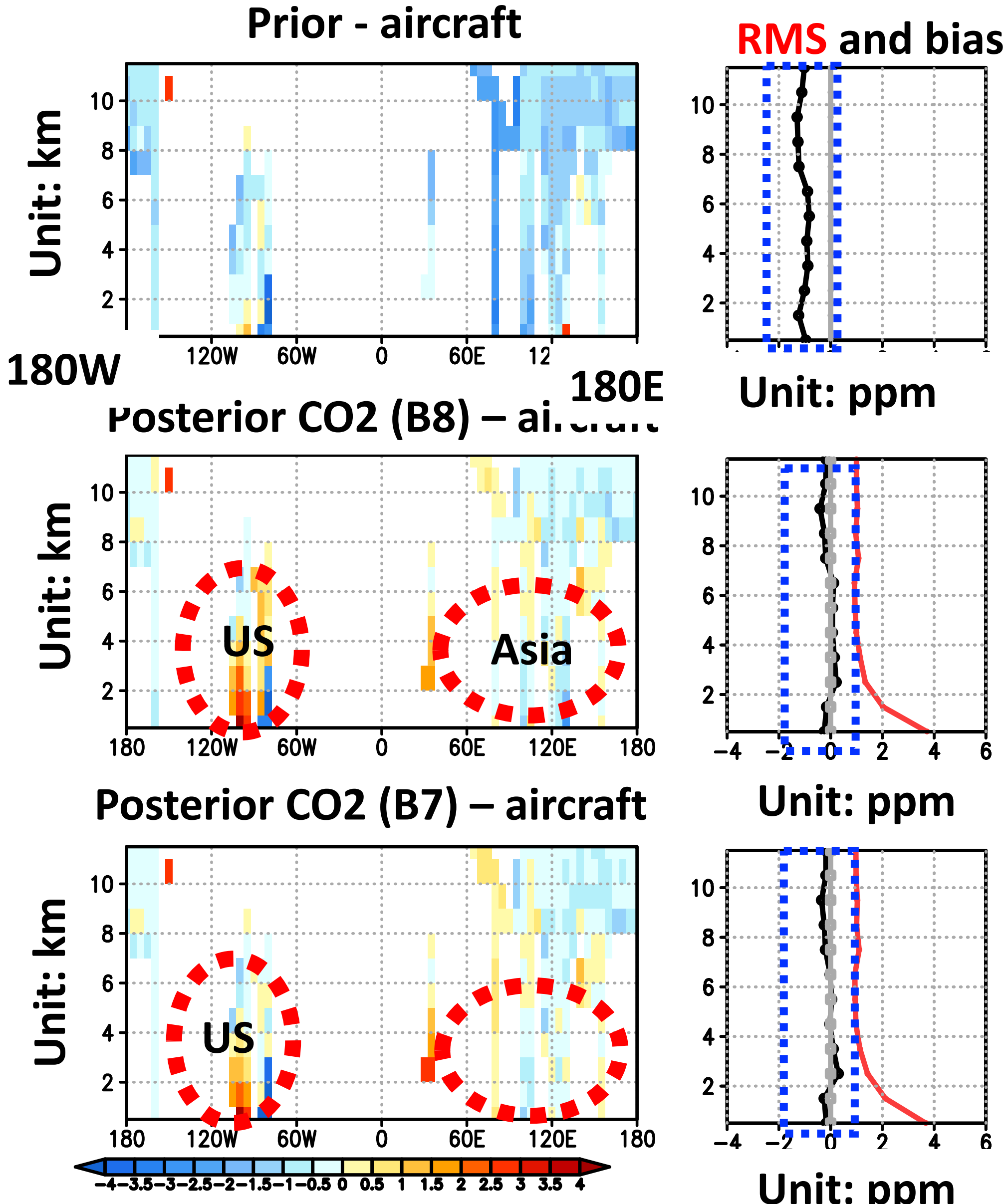
- B7 inversion results agree better with the observed atmospheric CO2 growth

Posterior flux differences between B8 and B7 land nadir inversions for 2015

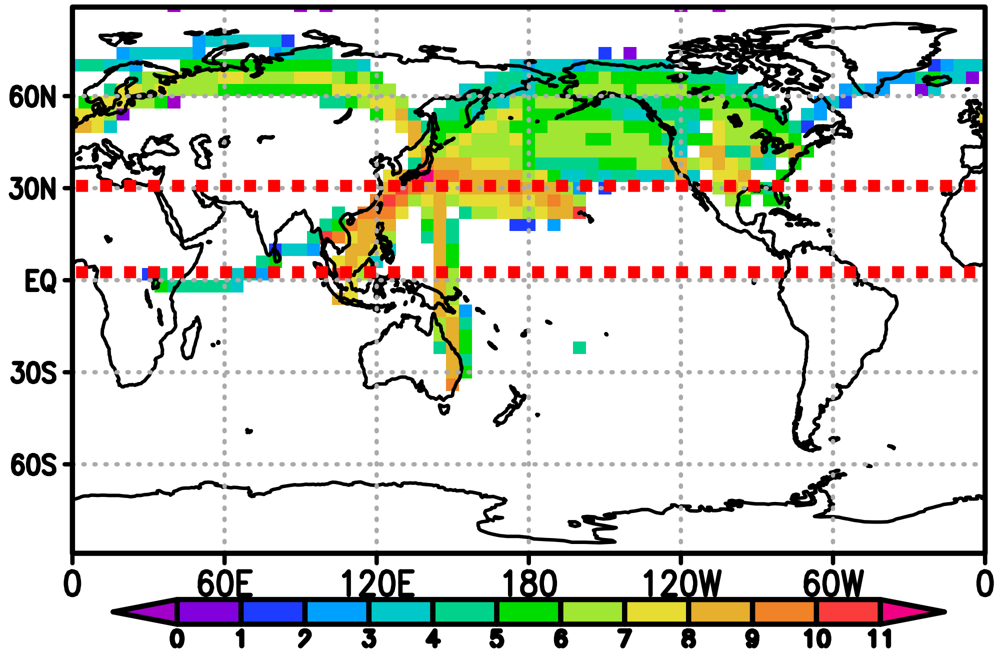


- The large differences are over the NH high latitudes
- The flux differences respond to the B8 and B7 land nadir observation differences

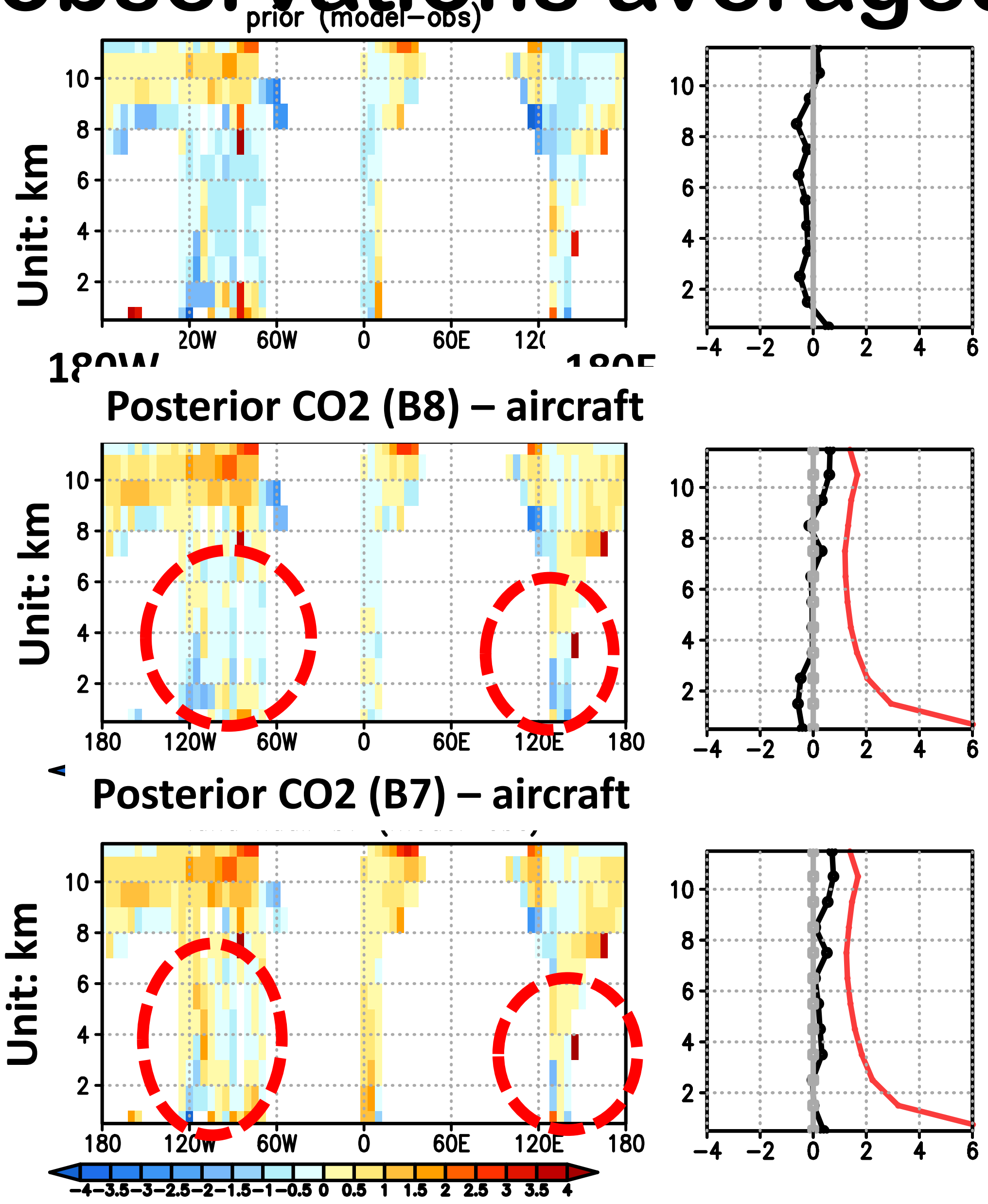
Mean differences between posterior CO2 and aircraft obs averaged between equator and 30N in 2015



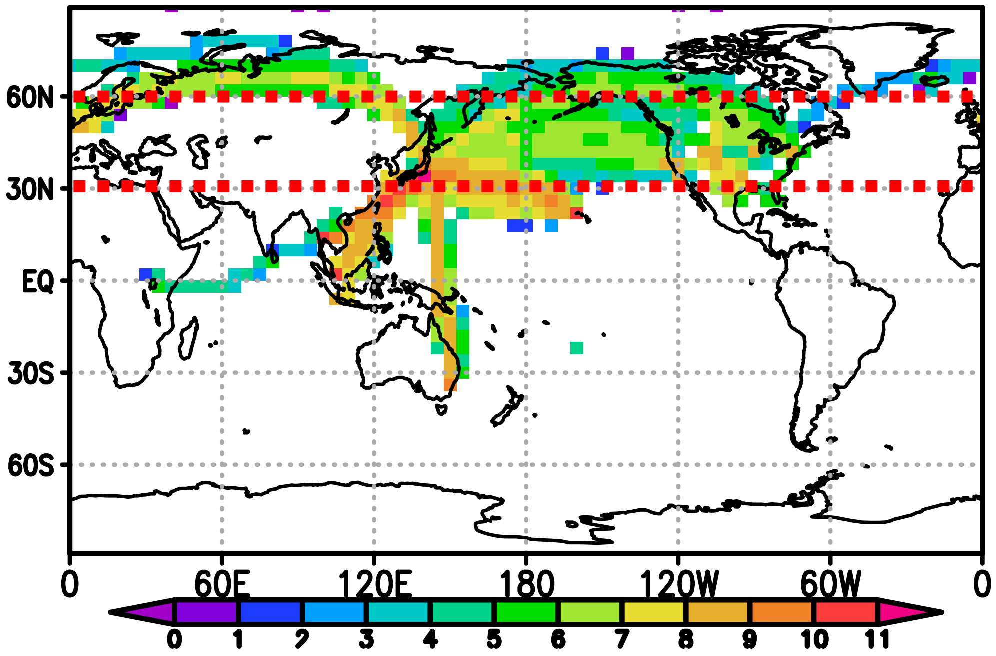
- Posterior CO2 concentrations are significantly improved relative to the prior.
- The mean differences are close to zero.
- B8 has slightly higher positive bias over US, and higher negative bias over Asia



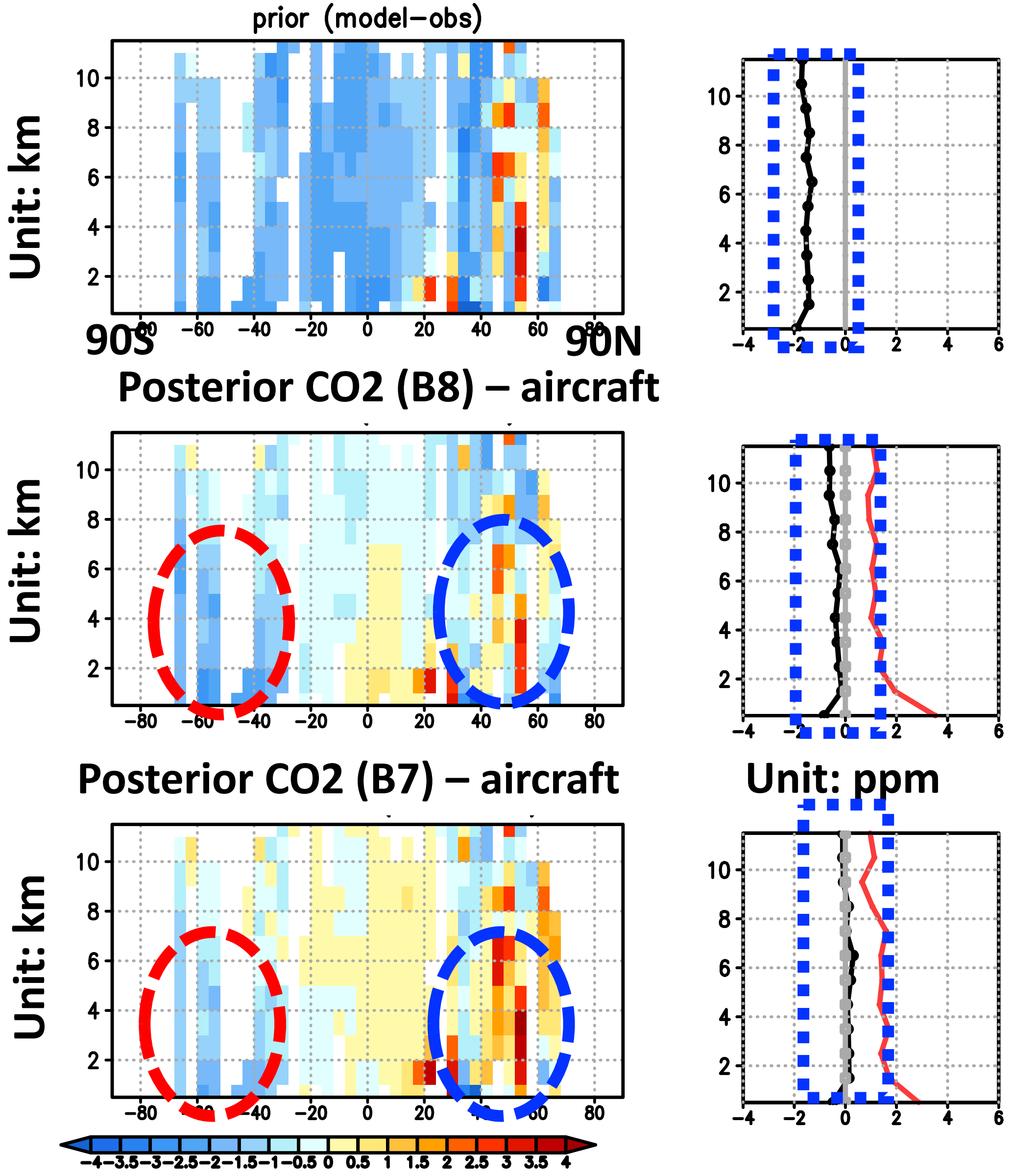
Mean differences between posterior CO2 and aircraft observations averaged over 30°N and 60°N in 2015



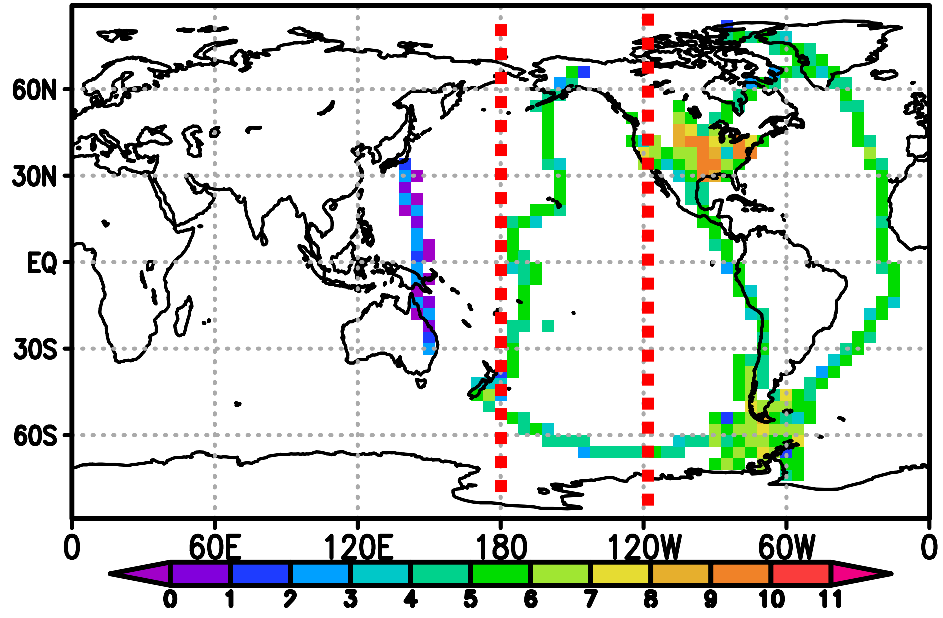
- Posterior CO2 concentrations are significantly improved relative to the prior
- B8-posterior CO2 errors are smaller than b7-posterior over NA.



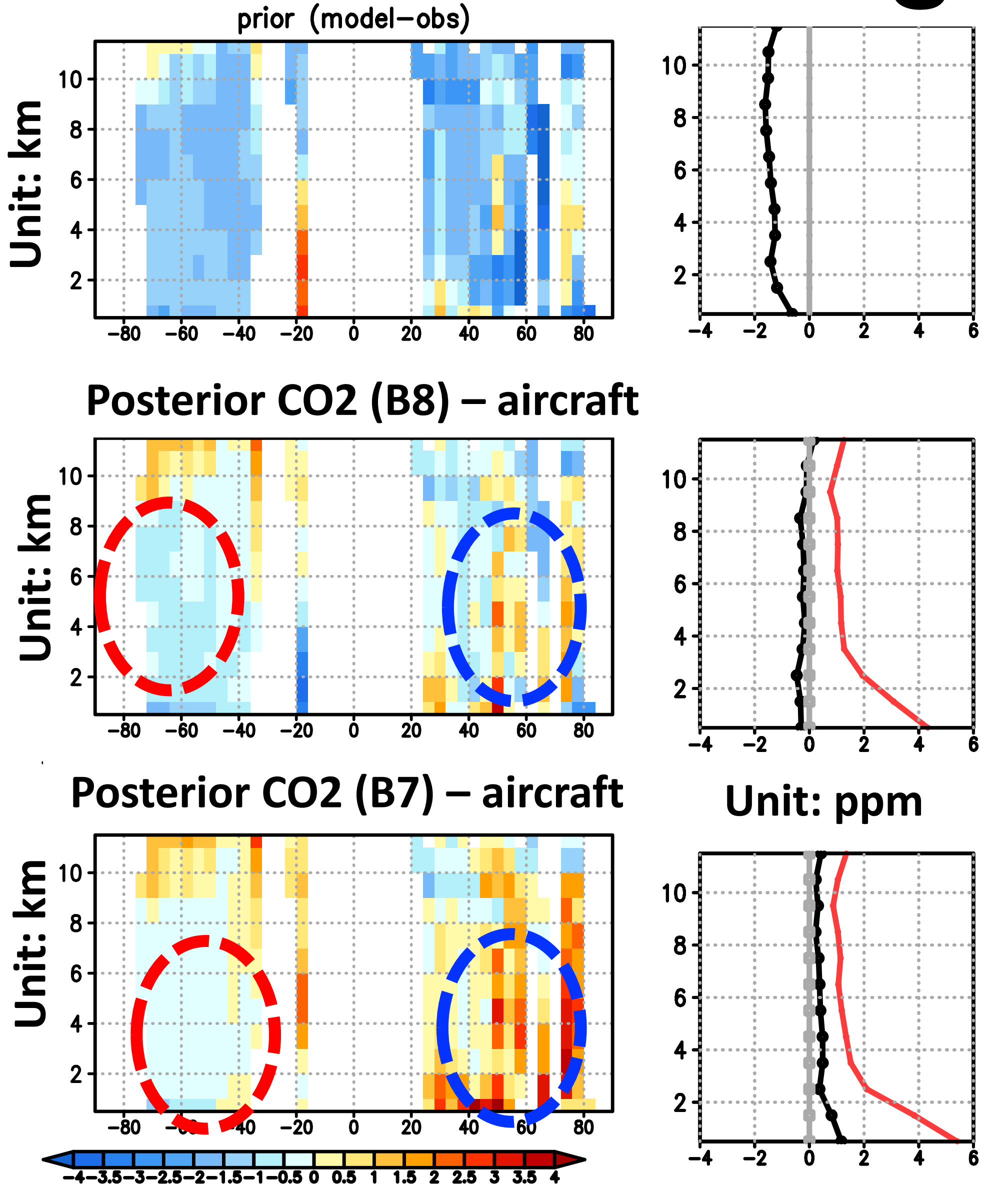
Mean differences between posterior CO2 and aircraft observations averaged over 180W-120W in 2016



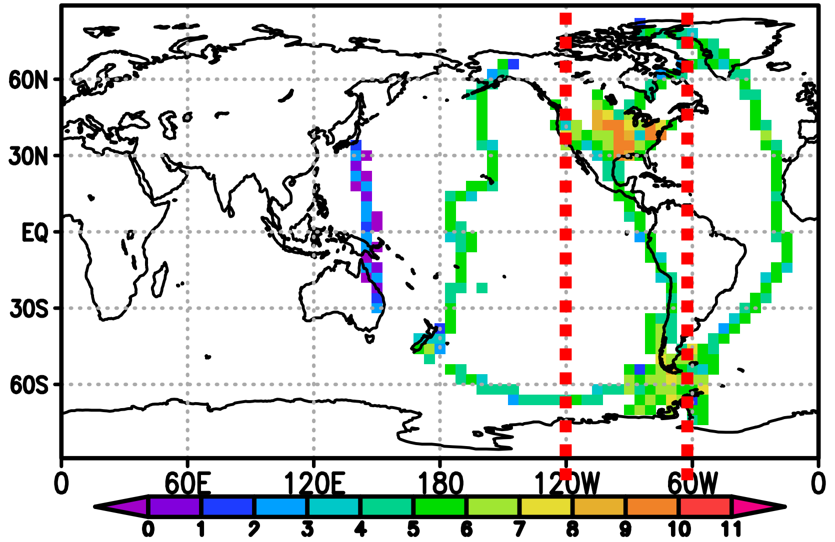
- Posterior CO2 concentrations are significantly improved relative to the prior
- B8 may have low biases over SH high latitudes
- The high biases over the NH high latitudes are much smaller in B8



Mean differences between posterior CO2 and aircraft obs averaged over 120W-60W in 2016

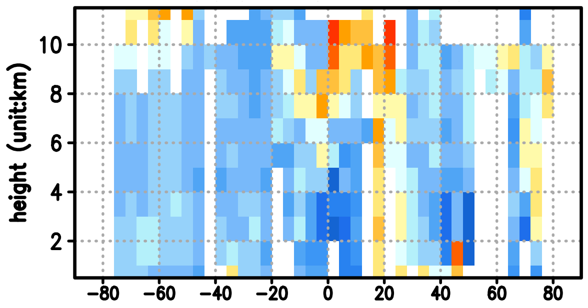


- Posterior CO2 concentrations are significantly improved relative to the prior
- The high bias over the NH high latitudes in 2016 are much smaller in B8
- B8 may have low bias over SH high latitudes

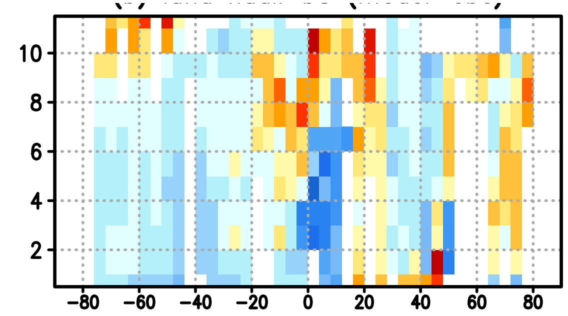


Mean differences against aircraft observations averaged over 60W-0 in 2016

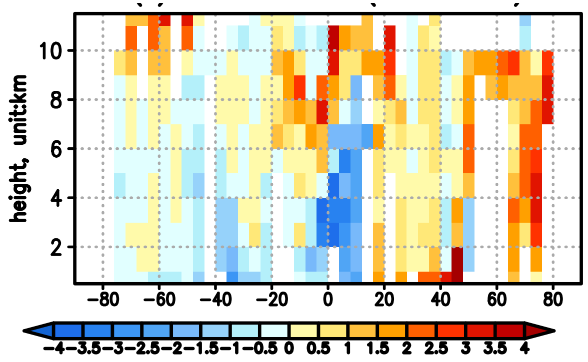
Prior (model) – aircraft

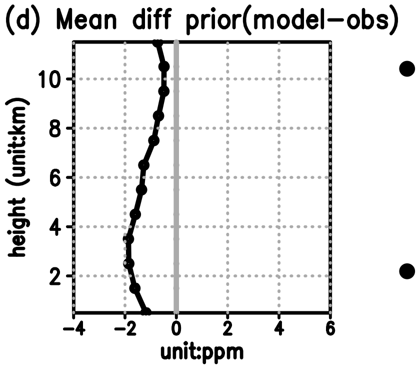


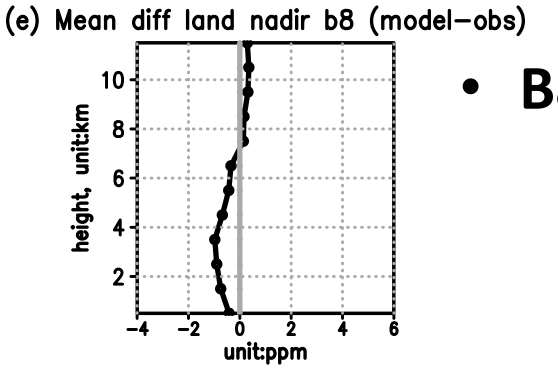
Posterior CO2 (B8) – aircraft

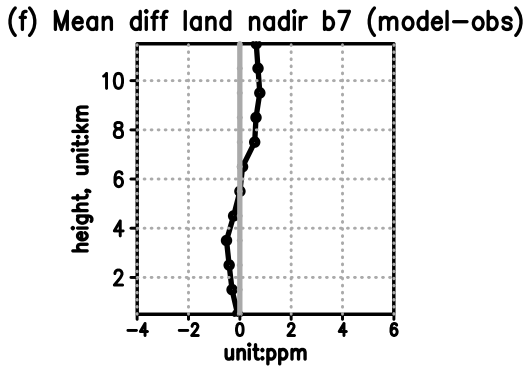


Posterior CO2 (B7) – aircraft

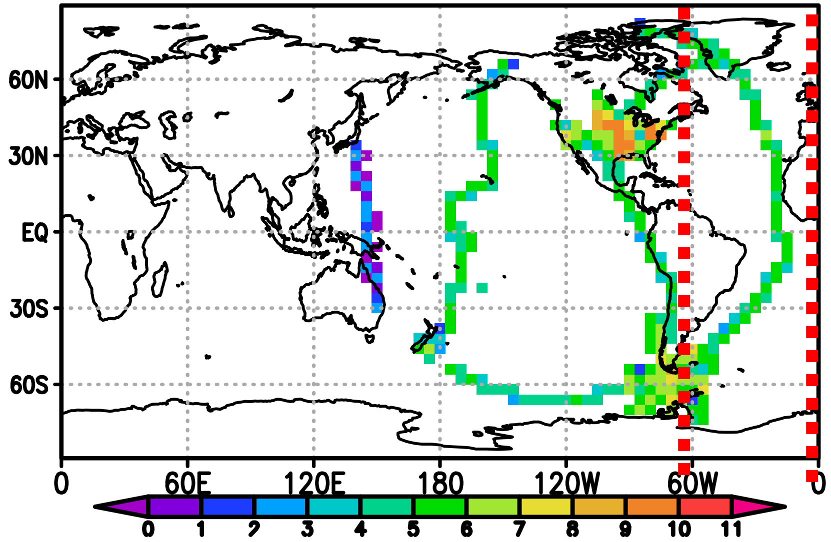








- Posterior CO2 concentrations are significantly improved relative to the prior
- The high bias over the NH high latitudes in 2016 are much smaller in B8
- B8 may have low bias over SH high latitudes



Linkage between the accuracy of posterior CO2 and the accuracy of underlying fluxes

We first define two functions that measure the RMS errors of posterior CO_2 (C_{post}) relative to independent observations (O):

$$J_{B8} = (\mathbf{C}_{B8}-\mathbf{O})^T (\mathbf{C}_{B8}-\mathbf{O})$$

$$J_{B7} = (\mathbf{C}_{B7}-\mathbf{O})^T (\mathbf{C}_{B7}-\mathbf{O})$$

Liu and Bowman, 2016

Linkage between posterior CO2 accuracy and the accuracy of underlying fluxes (continued)

- **We then define the difference between these functions:**

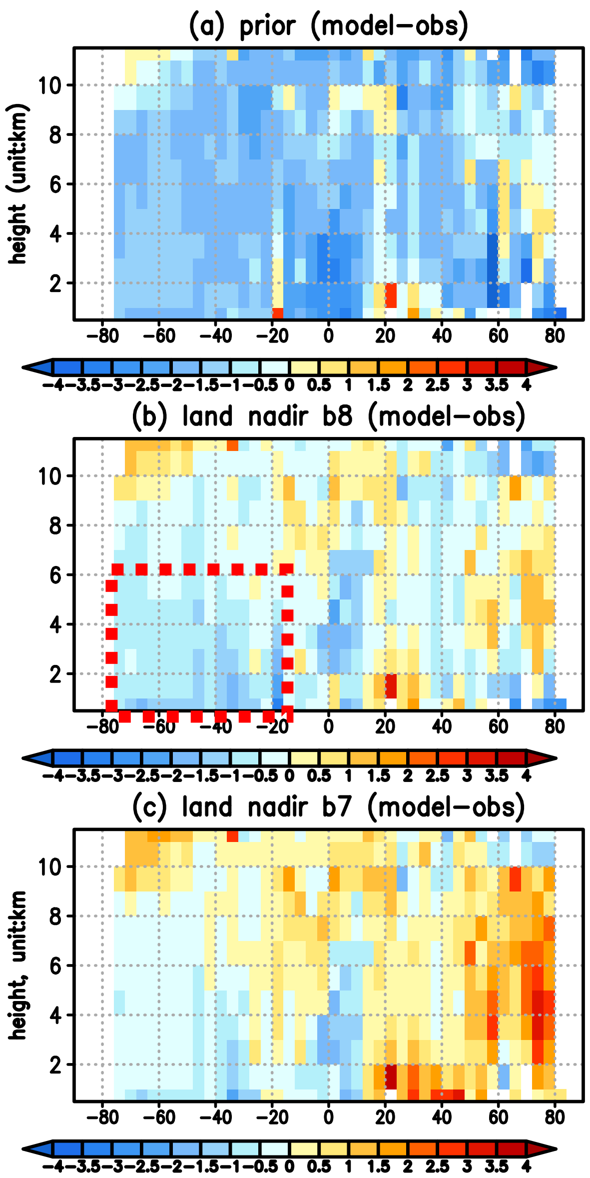
$$\Delta \boldsymbol{J} = \boldsymbol{J}_{\boldsymbol{B8}} - \boldsymbol{J}_{\boldsymbol{B7}}$$

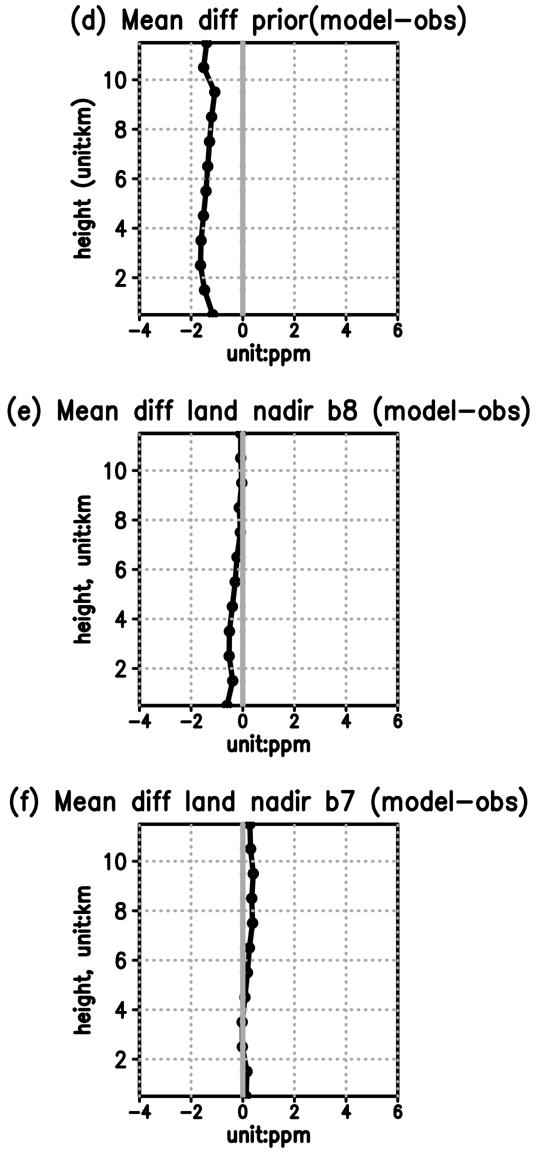
- **It can be rewritten as:**
- $\Delta \boldsymbol{J} = \left\langle (\boldsymbol{f}_{\boldsymbol{B8}} - \boldsymbol{f}_{\boldsymbol{B7}}), \mathrm{M}^{\boldsymbol{T}} (\boldsymbol{C}_{\boldsymbol{B8}} - \boldsymbol{O} + \boldsymbol{C}_{\boldsymbol{B7}} - \boldsymbol{O}) \right\rangle$

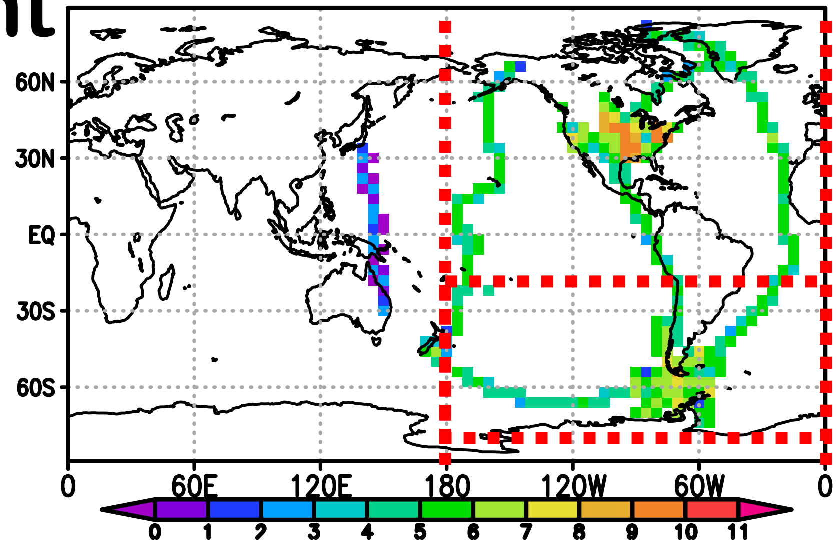
where $\boldsymbol{f}_{\boldsymbol{B8}}$ and $\boldsymbol{f}_{\boldsymbol{B7}}$ are the posterior fluxes constrained by B8 and B7 observations respectively, and M^{T} is the adjoint of the transport model. The above equation calculates changes of ΔJ from the changes of fluxes (i.e., $(\boldsymbol{f}_{\boldsymbol{B8}} - \boldsymbol{f}_{\boldsymbol{B7}}),$)at every grid point and time.

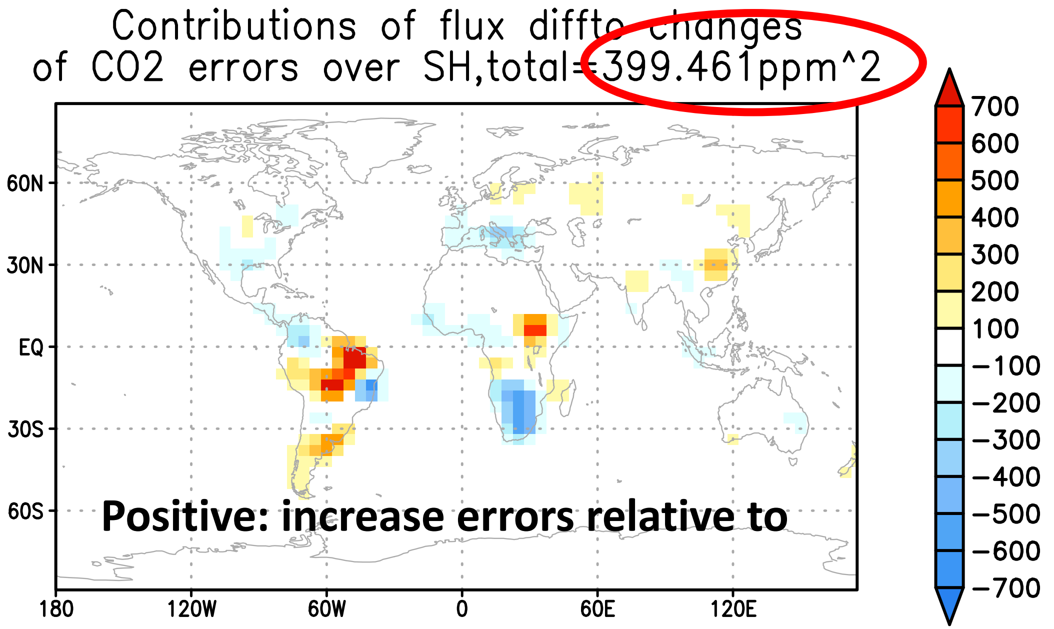
Liu and Bowman, 2016

Change of CO2 errors over SH due to flux differences at every grid point

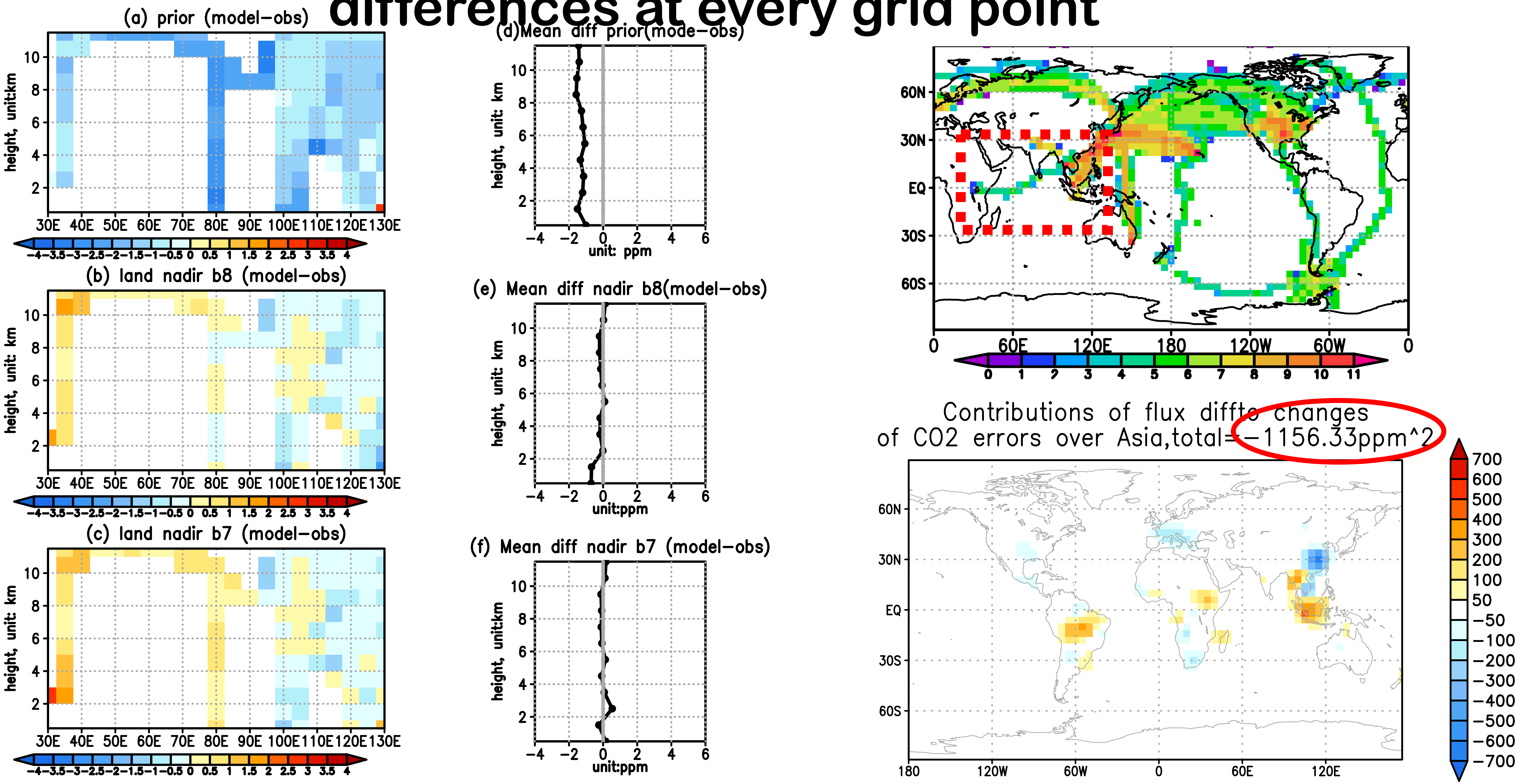




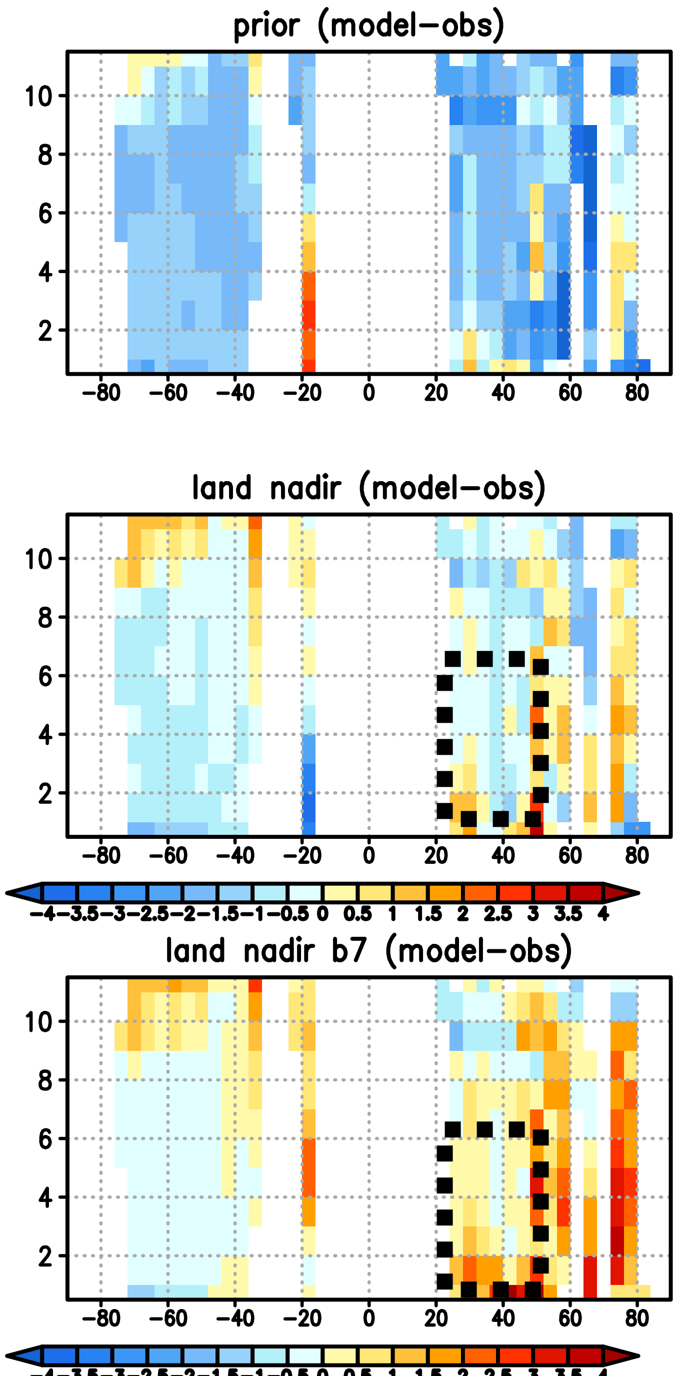


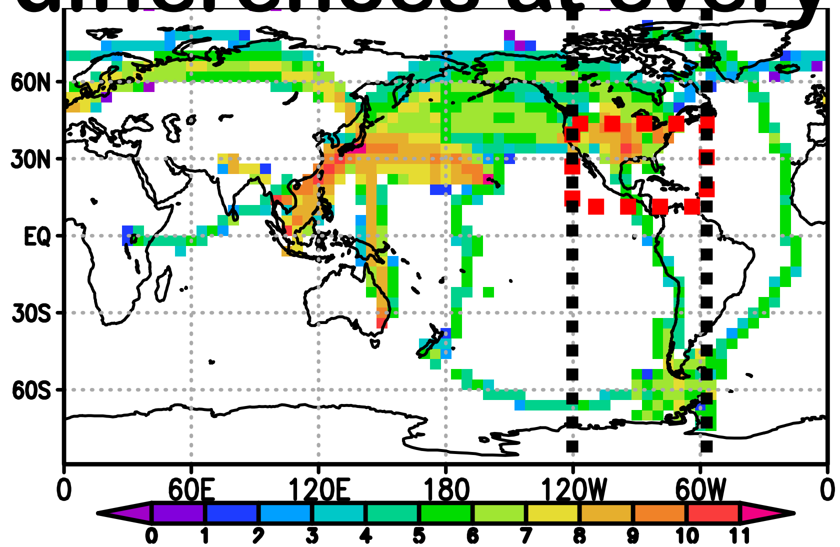


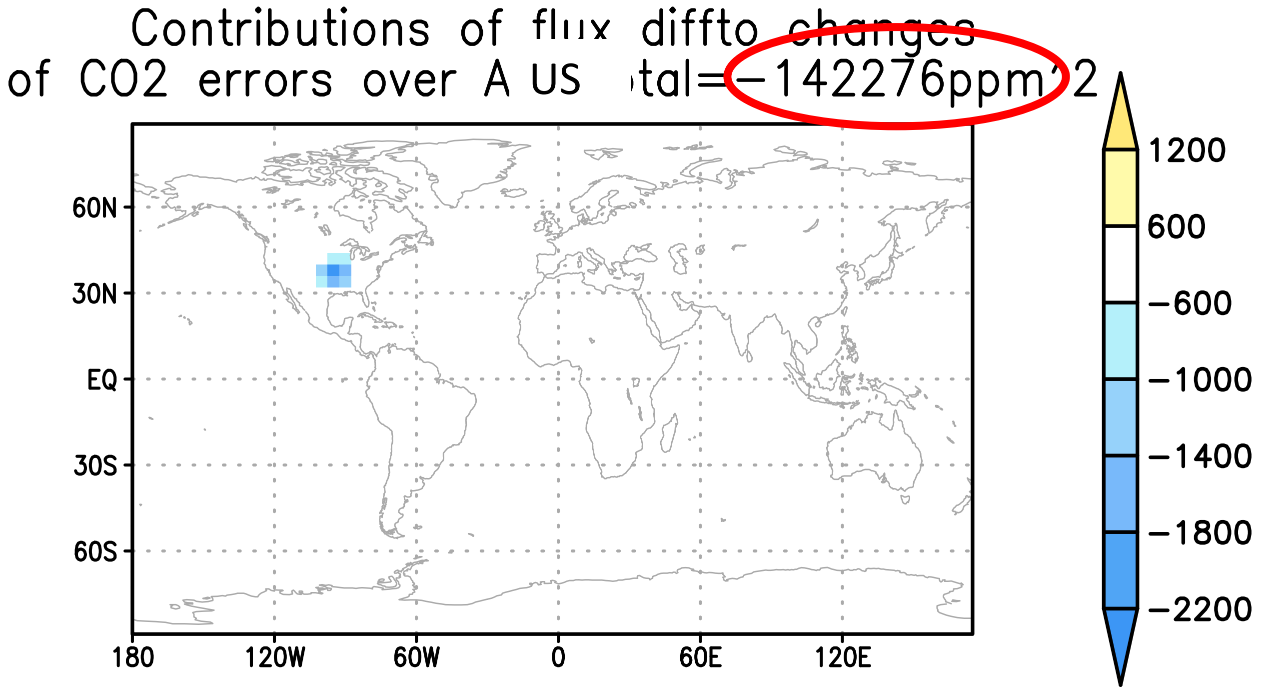
Change of CO2 errors over Asia due to flux differences at every grid point



Change of CO2 errors over NA due to flux differences at every grid point







Linkage between the accuracy of posterior CO_2 and the accuracy of the assimilated satellite observations

- $\Delta J = \left\langle (\boldsymbol{f}_{\boldsymbol{B8}} - \boldsymbol{f}_{\boldsymbol{B7}}), \mathrm{M}^{T}(\boldsymbol{C}_{\boldsymbol{B8}} - \boldsymbol{O} + \boldsymbol{C}_{\boldsymbol{B7}} - \boldsymbol{O}) \right\rangle$ **(1)**

The changes of posterior CO2 errors due to posterior flux differences at each grid point

- $\Delta \boldsymbol{f} = (\boldsymbol{f}_{\boldsymbol{B8}} - \boldsymbol{f}_{\boldsymbol{B7}})$ **(2)**

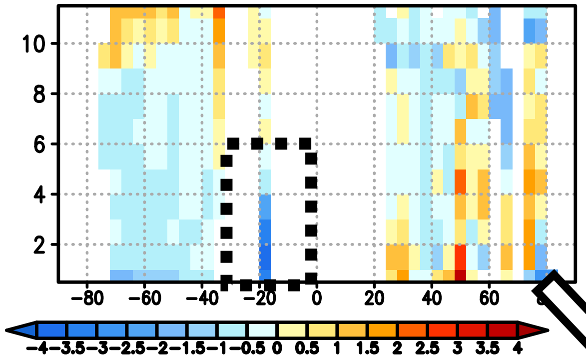
Posterior flux differences

- $\Delta \boldsymbol{C} = \boldsymbol{F}(\Delta \boldsymbol{f})$ **(3)**

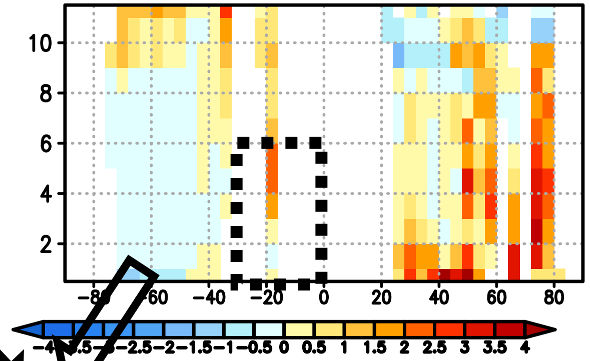
Forward sensitivity experiments to pinpoint the satellite observations that cause the posterior flux differences.

Comparison to aircraft=>the quality of satellite X_{CO2}

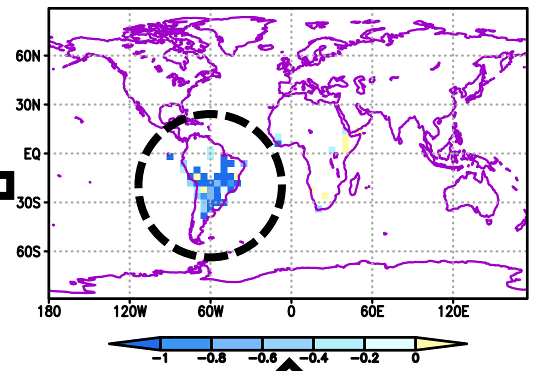
CO2(B8)-aircraft



CO2(B7)-aircraft



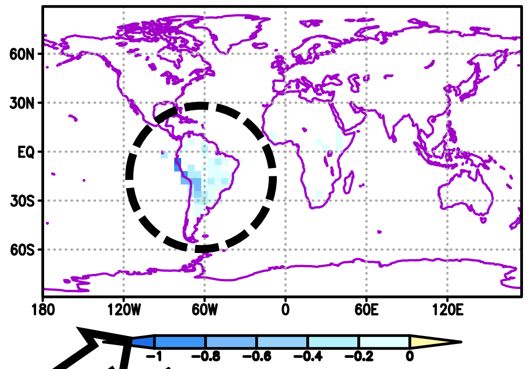
Δ XCO2$_{(B8-B7)}$



Why

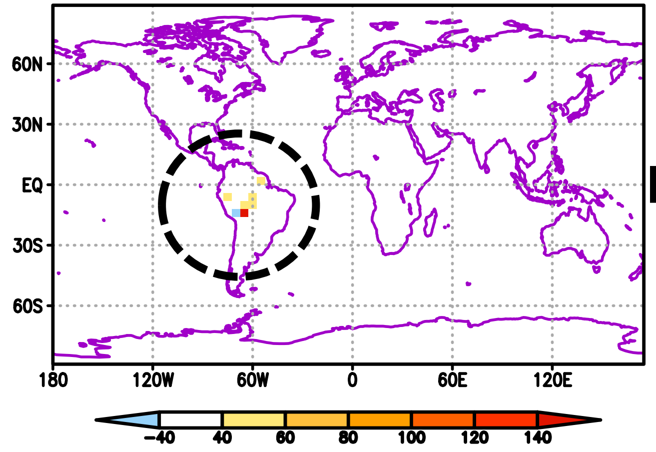
$$\Delta J = J_{B8} - J_{B7}$$

Δ(XCO2)$_{fpost(B8)-fpost(B7)}$

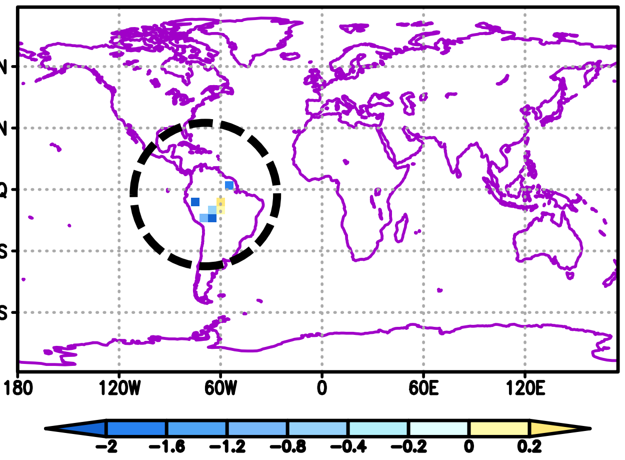


$$\Delta\tilde{J} = \langle (\mathbf{f}_{post(B8)} - \mathbf{f}_{post(B7)}, \mathbf{M}^T(\mathbf{C}_{post(B8)} - \mathbf{O} + C_{post(B7)} - \mathbf{O}) \rangle$$

Changes $\Delta\tilde{J}$ of from $f_{post(B8)}$-$f_{post(B7)}$



$f_{post(B8)}$ - $f_{post(B7)}$



Forward model

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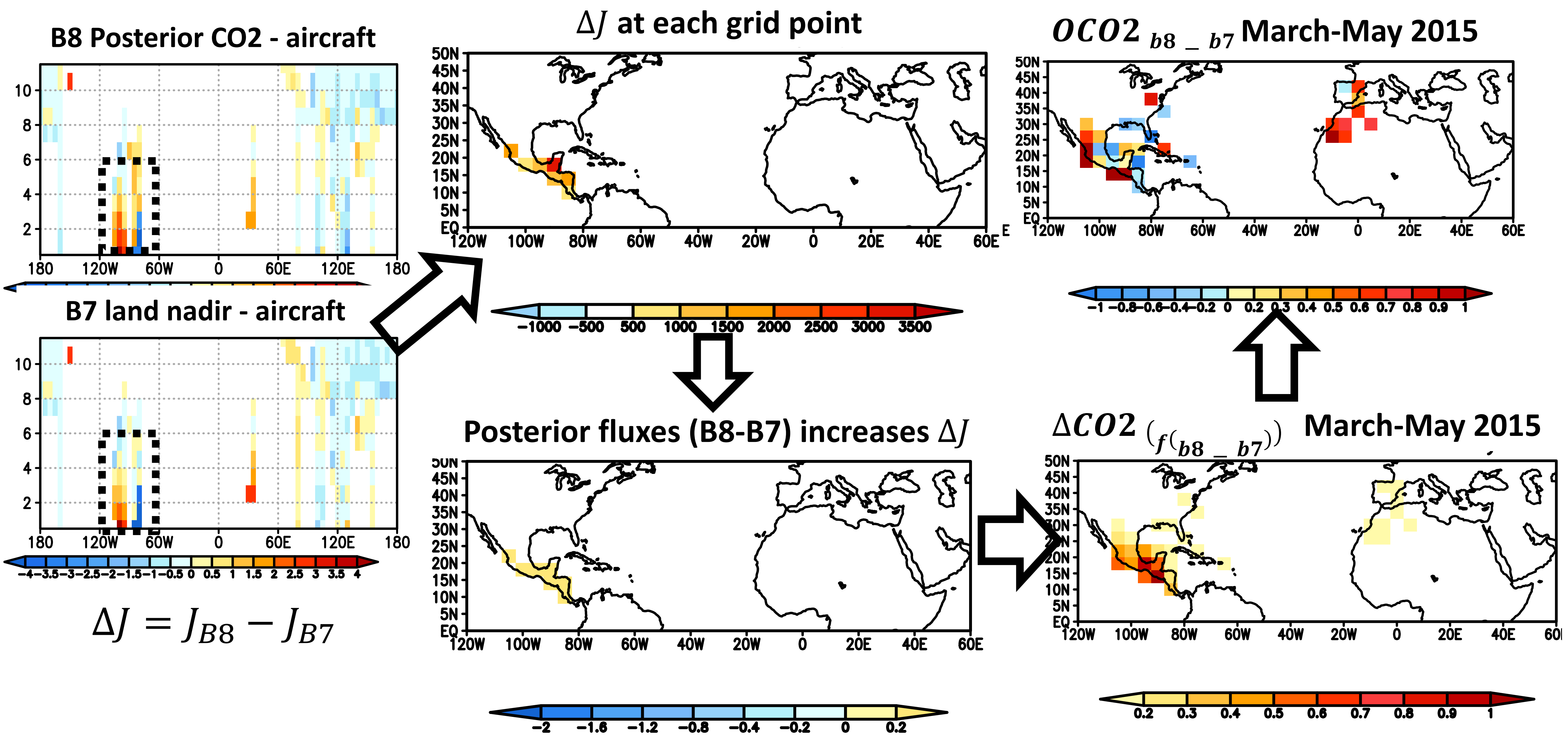
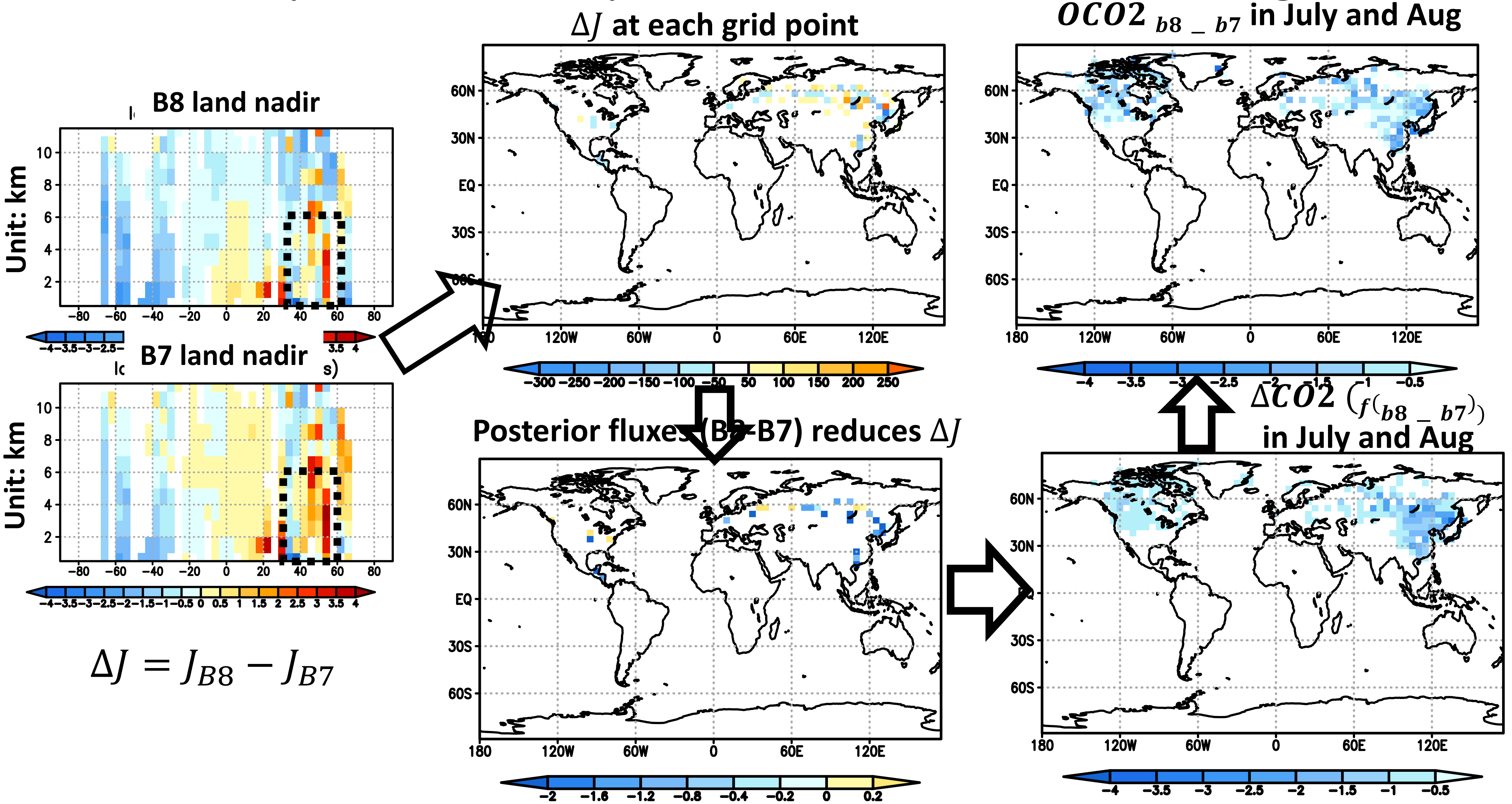
B8 X_{CO2} might be too high over Central America in March-April



An example: b8 improves CO2 accuracy



$$\Delta J = J_{B8} - J_{B7}$$

Summary and Conclusions

- **Methods:**
  a) **comparison to aircraft observations;**
  b) **compare posterior CO2 concentrations to aircraft observations;**
  c) **Project CO2 concentration errors to fluxes => sensitivity test => CO2 observations**
- **Directly comparing to aircraft observations shows that B8 has smaller random errors and biases than B7**
- **B7 inversion results agree better with the observed atmospheric CO2 growth**
- **The accuracy of posterior CO_2 concentrations relative to aircraft observations depends on region and season: e.g.,**
  a) **B8 is more accurate than B7 over NH high latitudes during summer;**
  b) **B8 is less accurate than B7 over central America during March-May 2015;**
  c) **B8 seems to have low bias over SH high latitudes in 2016**