Environment and Climate Change Canada / Environnement et Changement climatique Canada

Canada

On the spatial scales informed by surface and GOSAT CO_2 observations

Saroja Polavarapu, Feng Deng[2], Brendan Byrne[2]
Dylan Jones[2], Michael Neish

Climate Research Division, CCMR, ECCC
[2]Dept. of Physics, U Toronto

IWGGMS 14, 9 May 2018

Motivation

- In carbon flux estimation, analysis increments are on fluxes.
- What can we learn by looking at 3D atmospheric concentrations and how they are affected by surface flux updates? i.e. CO_2 analysis increment
  - Consider 2 different observing systems
  - Focus: Vertical propagation of flux perturbation

Posterior Atmospheric Adjustment

$$\Delta c_n = T\left(x^a_{0,n-1}, c^a_0, s^a_{0,n-1}\right) - T\left(x^b_{0,n-1}, c^b_0, s^b_{0,n-1}\right)$$

Transport model → T; Initial CO_2 → c^b_0; meteorology → $x^b_{0,n-1}$; fluxes → $s^b_{0,n-1}$; Posterior atmospheric adjustment (PAA) → Δc_n

- Our initial CO_2 is not adjusted with fluxes during inversion.
- But allow for imperfect meteorology.

$$\Delta c_n = T\left(x^a_{0,n-1}, c^a_0, s^a_{0,n-1}\right) - T\left(x^a_{0,n-1} - \varepsilon_{0,n-1}, c^a_0, s^a_{0,n-1} - \Delta s_{0,n-1}\right)$$

Met uncertainty → $\varepsilon_{0,n-1}$; Flux increments → $\Delta s_{0,n-1}$

To first order: $\Delta c_n \cong \Delta c^s_n + \Delta c^x_n$

PAA PAAF PAAM

$$\Delta c^s_n = T\left(x^a_{0,n-1}, c_0, s^a_{0,n-1}\right) - T\left(x^a_{0,n-1}, c_0, s^b_{0,n-1}\right) = PAAF$$

$$\Delta c^x_n = T\left(x^a_{0,n-1}, c_0, s^a_{0,n-1}\right) - T\left(x^b_{0,n-1}, c_0, s^a_{0,n-1}\right) = PAAM$$

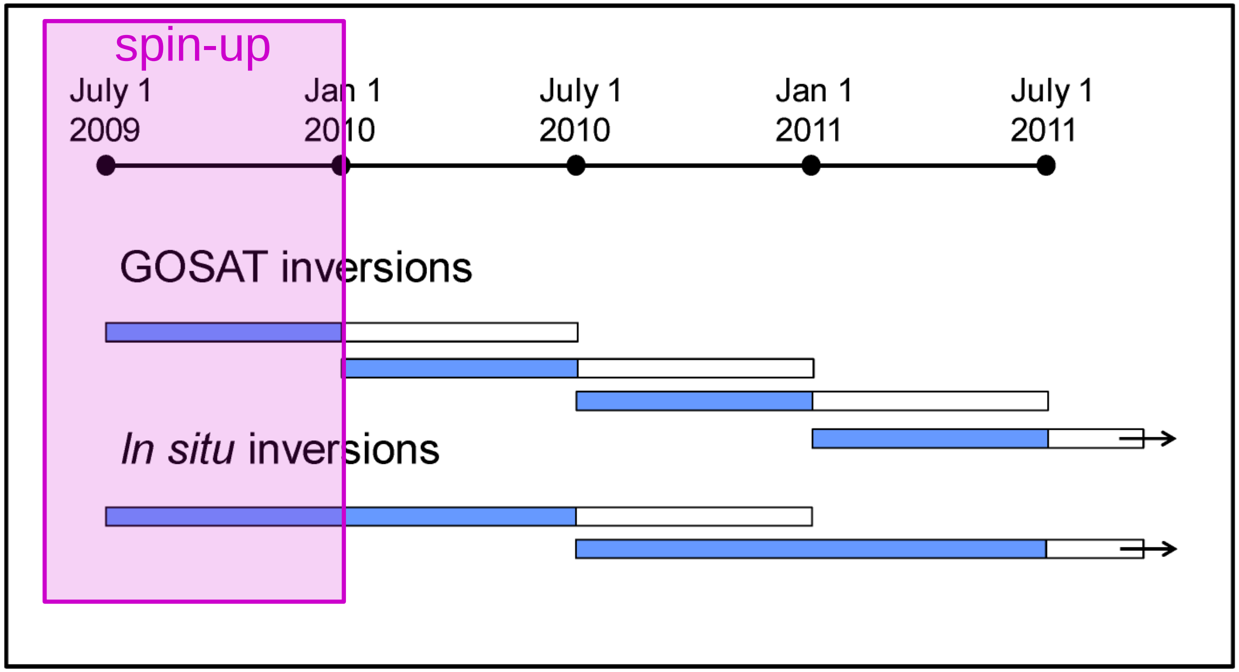
Canada

Posterior Atmospheric Adjustment

- Posterior Atmospheric Adjustment has two components:
  1. CO_2 changes due to flux increments (PAAF)
  2. CO_2 changes due to imperfect meteorology (PAAM)
- Which is the dominant component?
  - Will depend on time, location, scales (temporal, spatial)

To compute PAAF we need flux increments

GEOS-Chem 4D-Var inversion system

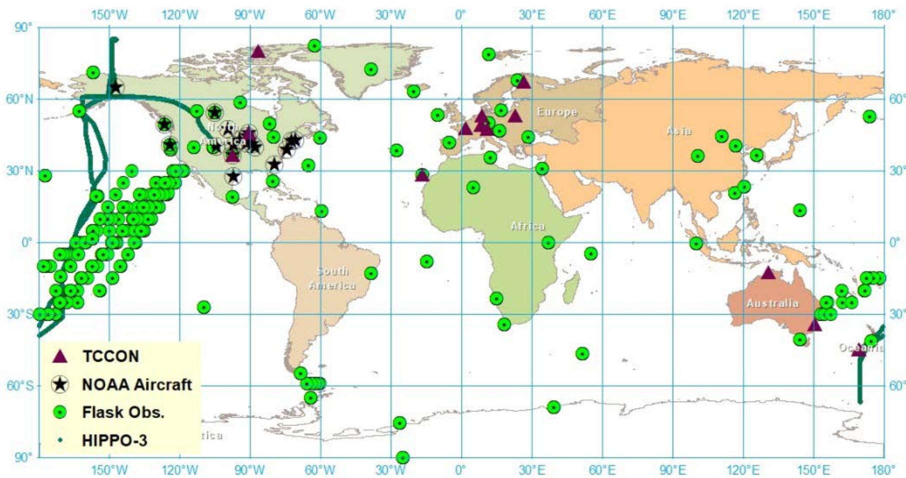


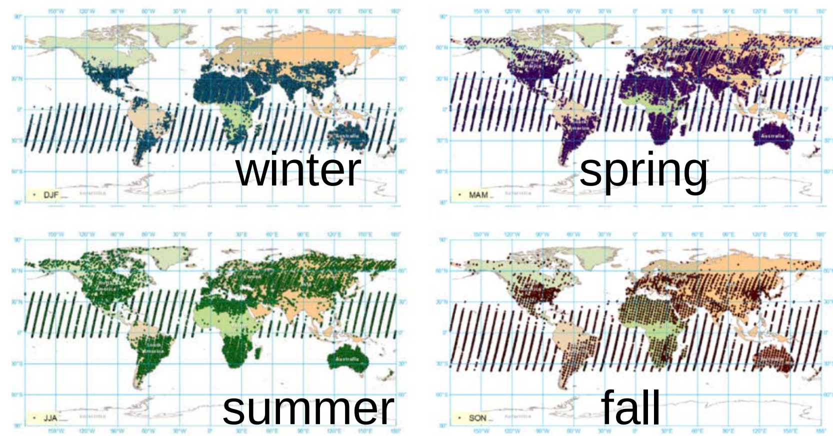
- GOSAT b3.4 ACOS data, as in Deng et al. (2016)
- In situ obs (72 NOAA, 6 ECCC sites), as in Deng et al. (2014)

Two observation “networks”

In situ observations:
sparse, accurate

GOSAT observations:
Dense, less accurate,
seasonal variation





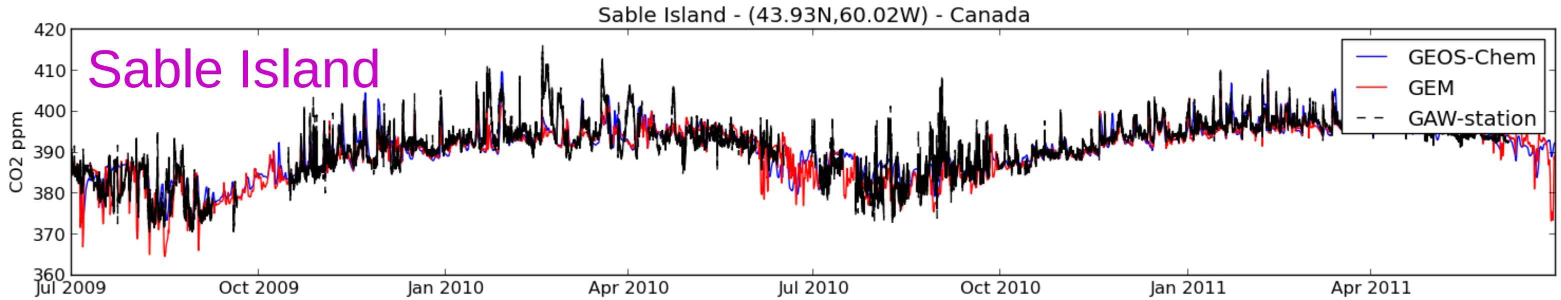
Surface continuous, TCCON,
HIPPO3, NOAA aircraft used
for validation only

Posterior CO_2 adjustment: Two models

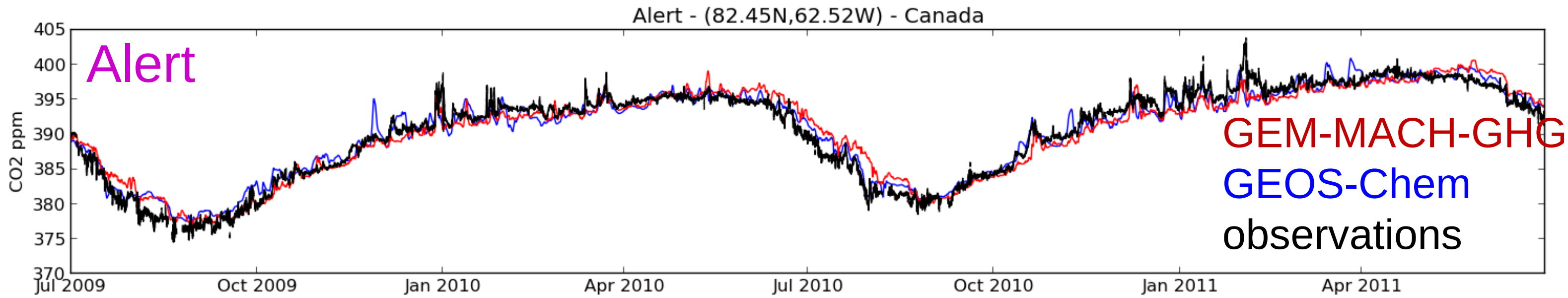
Model Name	Grid	Lid	Vertical levels	Meteorology
GEOS-Chem	4°×5°	0.1 hPa	47	GEOS5
GEM-MACH-GHG	0.9°×0.9°	0.1 hPa	80	CMC oper.

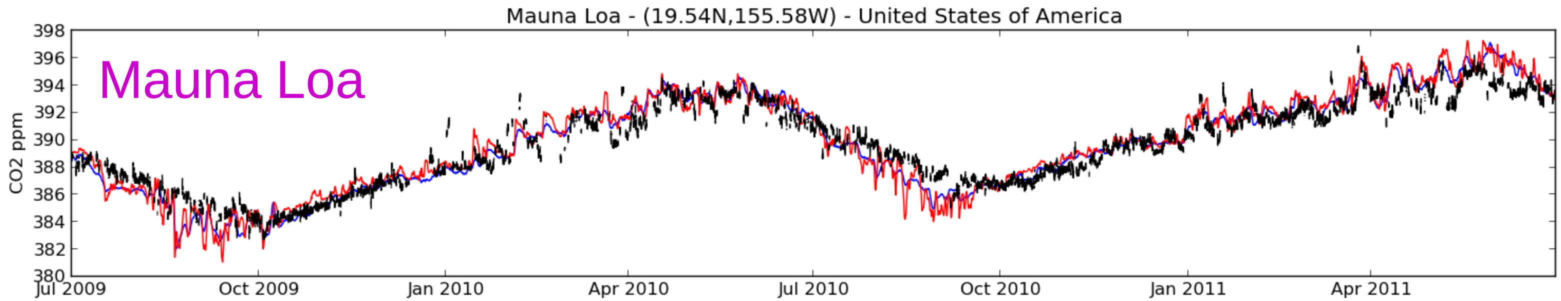
- To test sensitivity of results to transport error
- Model 1 = GEOS-Chem
- Model 2 = GEM-MACH-GHG with online tracer transport (Polavarapu et al. 2016, ACP).
  - Allow uncertainty estimation due to wind field errors (PAAM)
  - This will convolve transport error from 2 models.

GEM-MACH-GHG CO_2 with GEOS-Chem in situ posterior fluxes



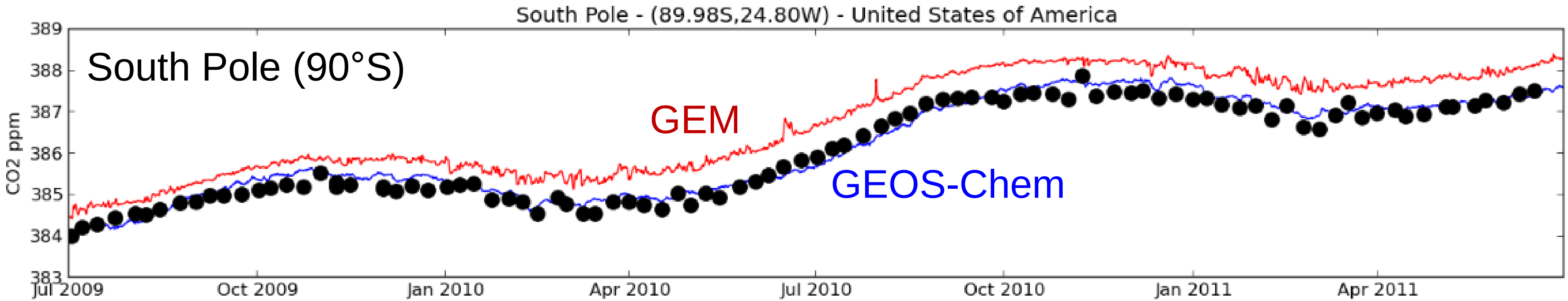
Good agreement with independent observations using both GEOS-Chem posterior fluxes on synoptic and long time scales.



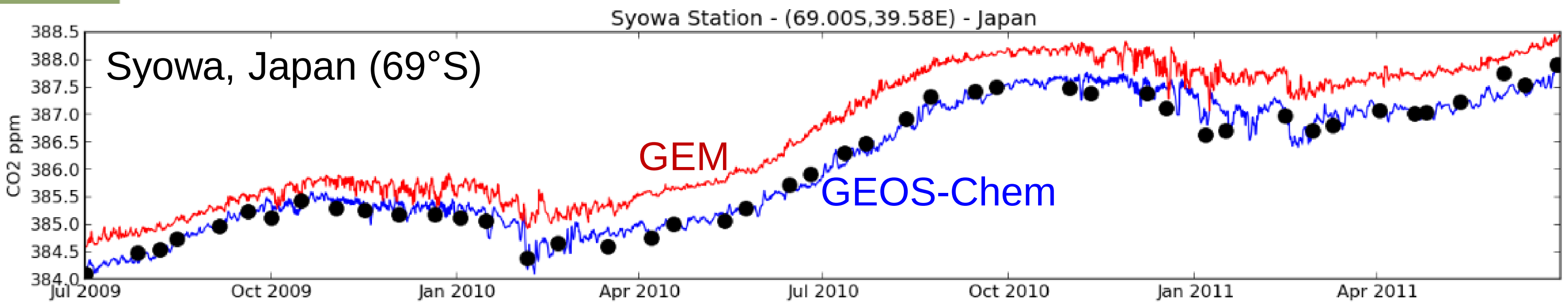


ada

Evidence of convolution of transport errors between GEOS-Chem and GEM

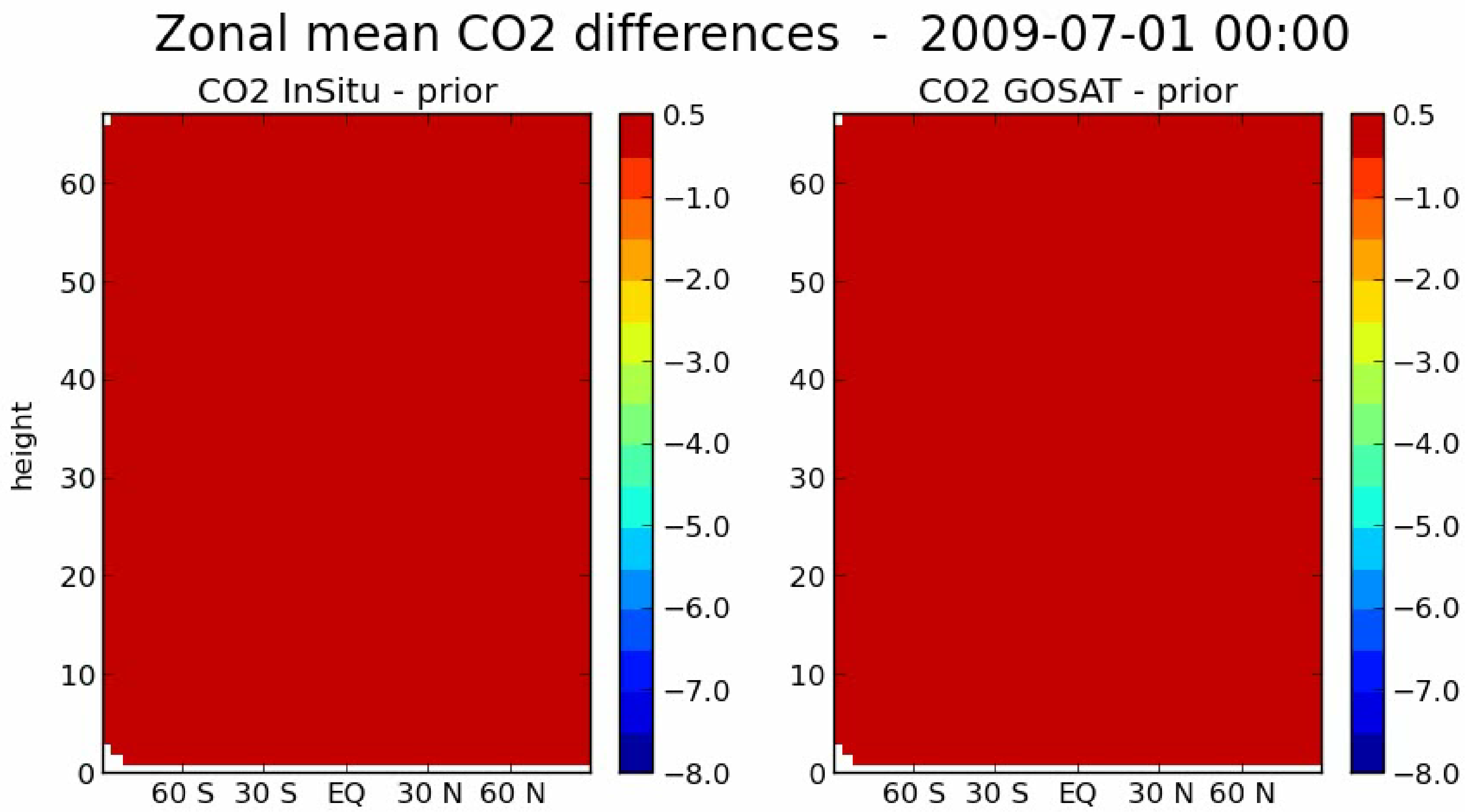


- GEM-MACH-GHG starts with a bias in southern hemisphere.
- This bias gets a bit worse with time. Too much CO_2 means departure from prior CO_2 is not fast enough. GEOS-Chem posterior fluxes are obtained assuming faster transport to the southern hemisphere.



Compare PAAF with 2 obs networks

Both PAAFs use GEOS-Chem



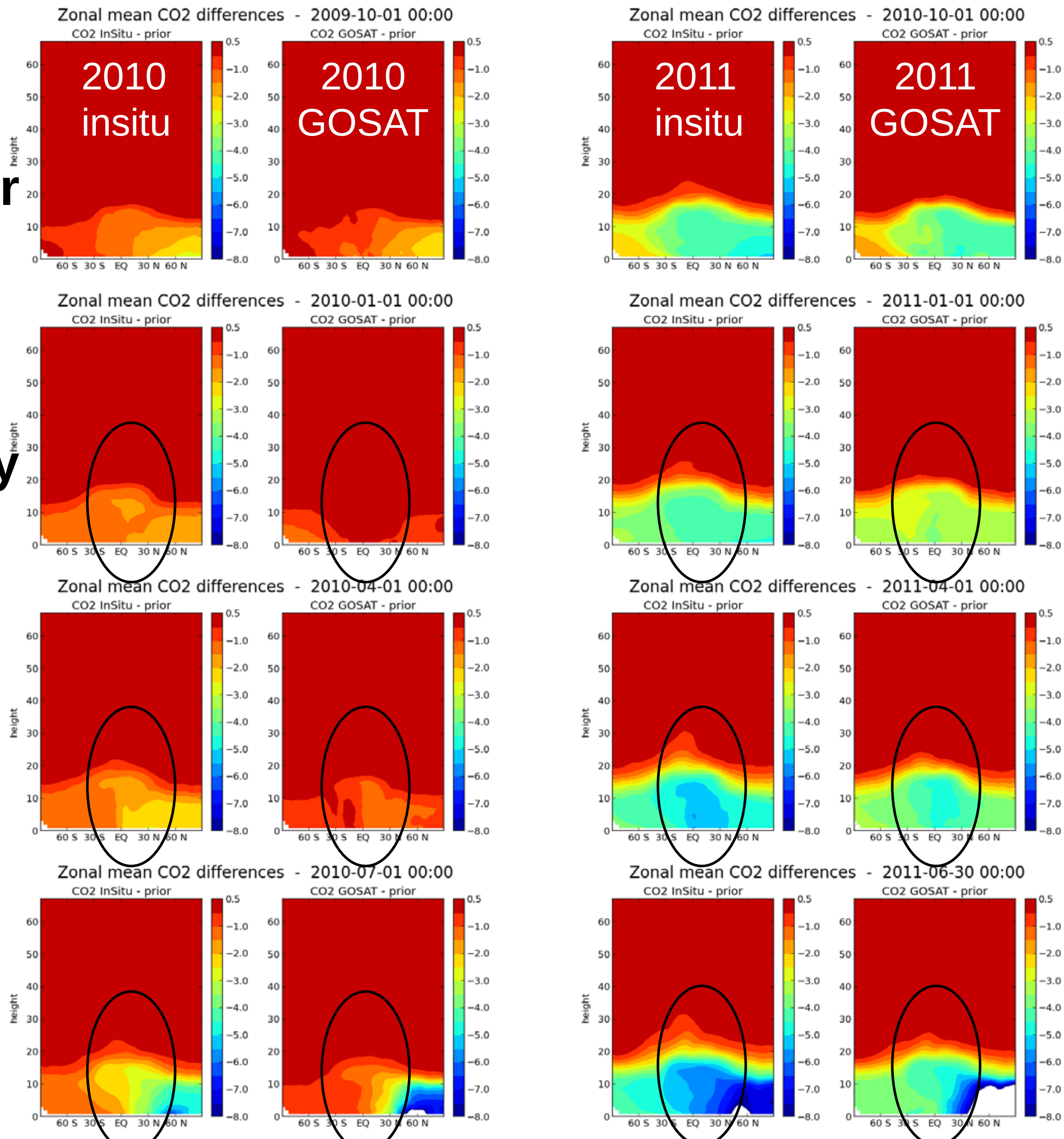
Note the differences in the tropics.

October

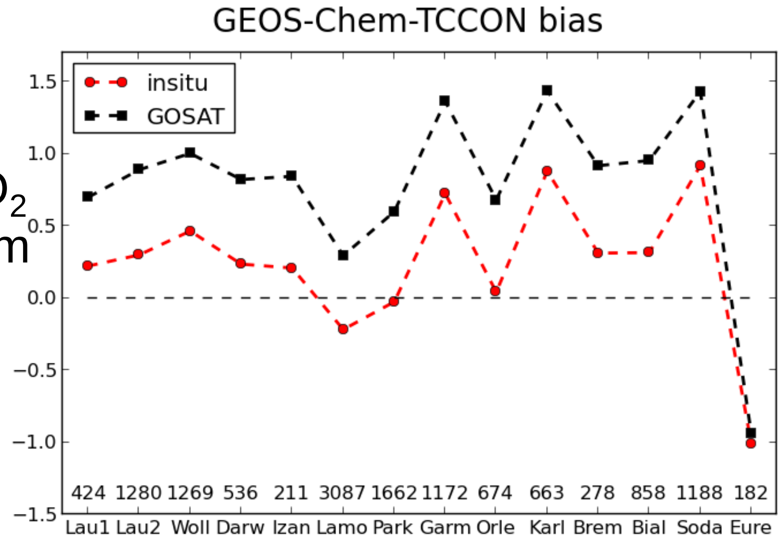
January

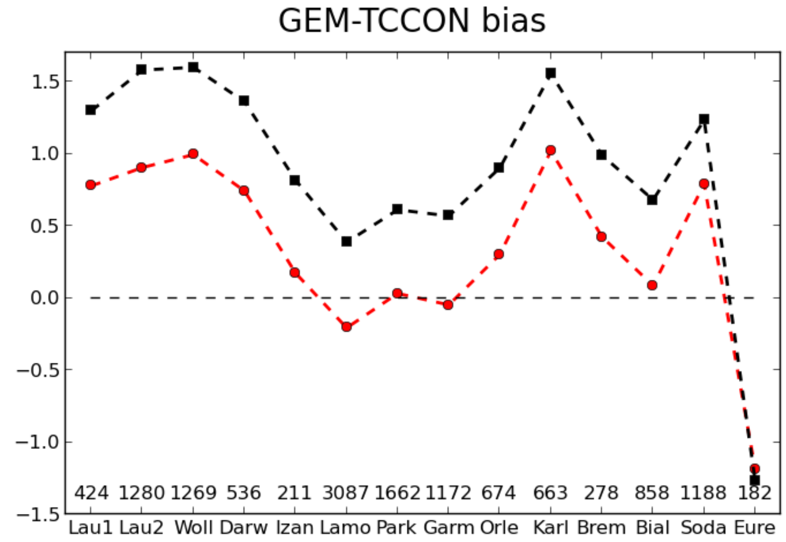
April

July



Long time means of (model-obs)





CO_2 ppm

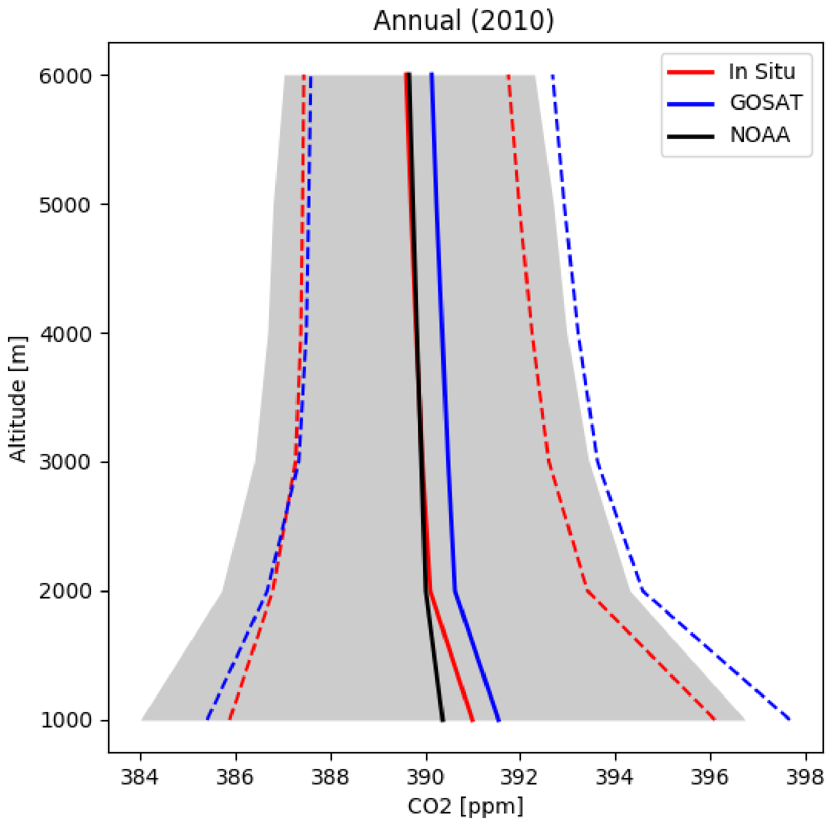
TCCON site TCCON site

Dec 2009 – May 2011

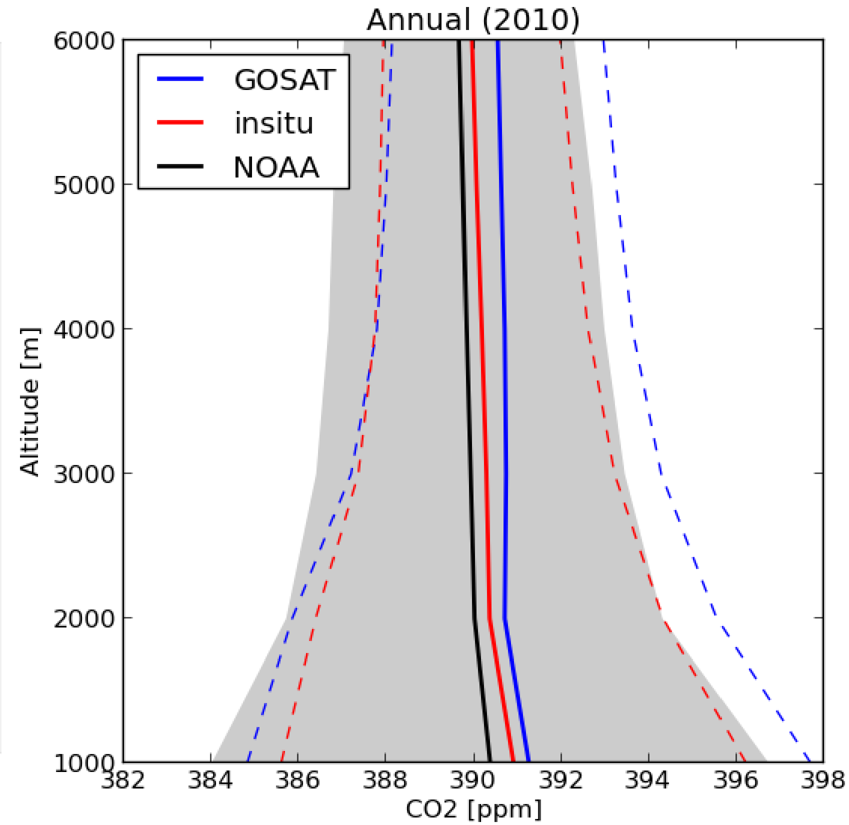
in situ posterior better matches TCCON by ~0.5 ppm except at Eureka, for both models.

Compare to NOAA aircraft profiles

GEOS-Chem CO_2

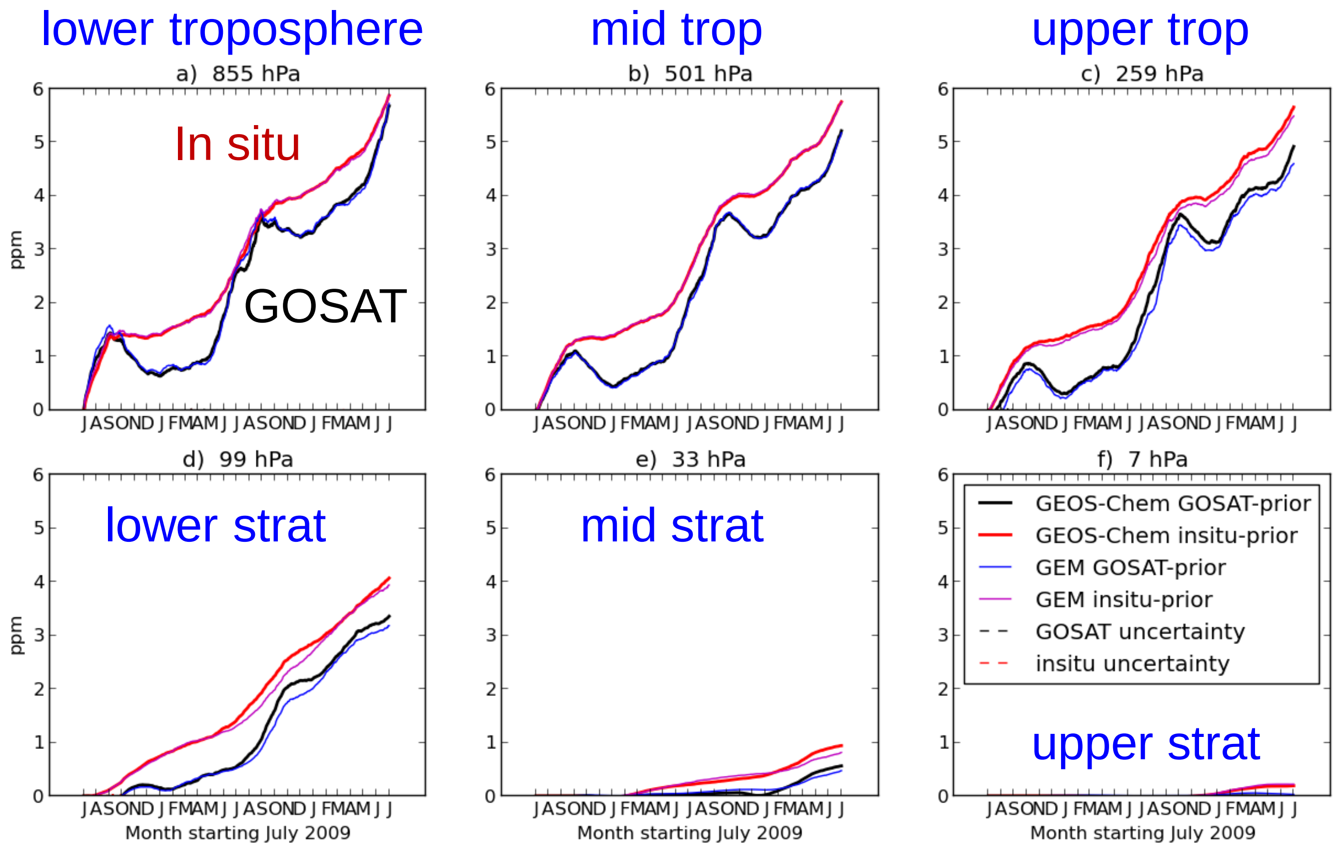


GEM-MACH-GHG CO_2



In situ-derived fluxes agree better with aircraft profiles over 2010

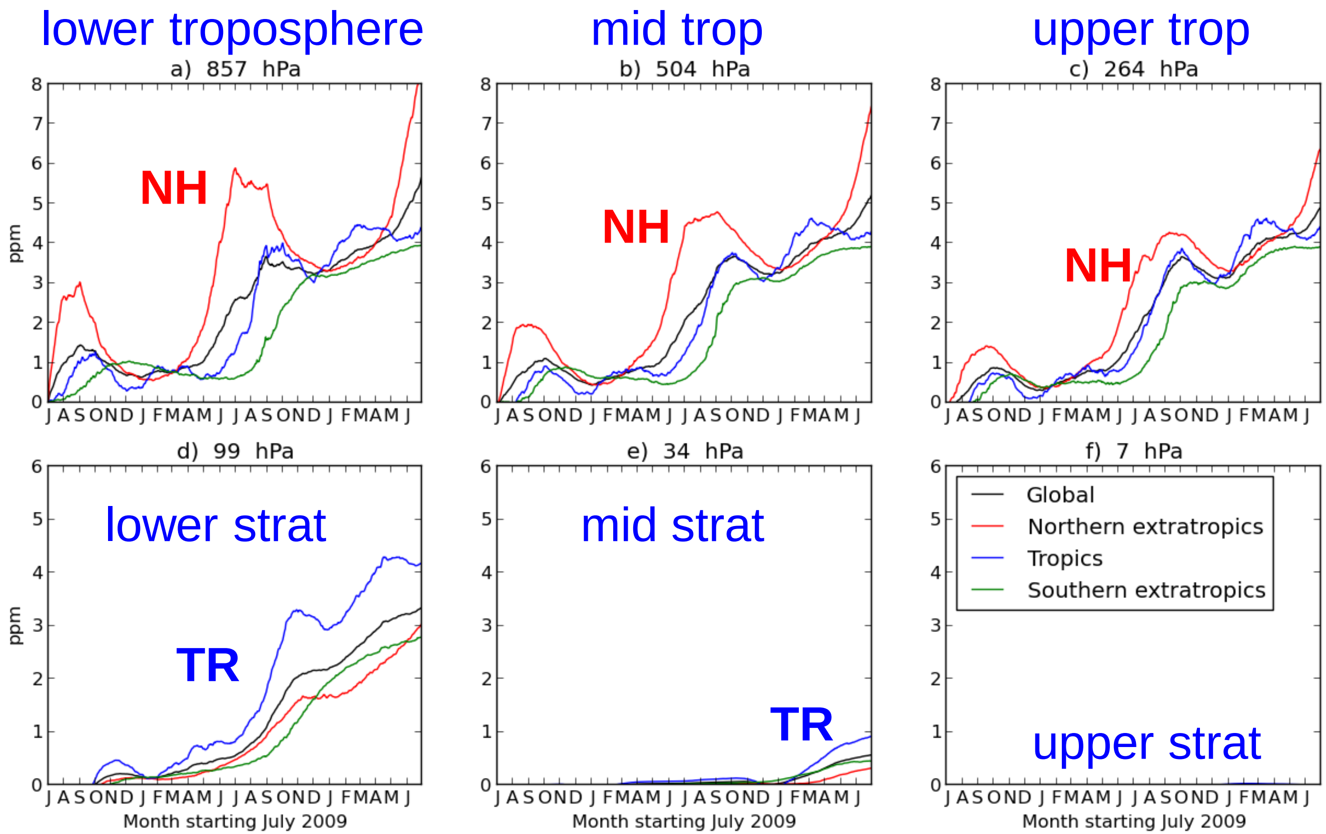
Time series of global mean PAAF



- Insitu data contributes to global burden more consistently throughout the year. GOSAT data affects global burden mainly in boreal summer.
- Both models produce very similar PAAF despite transport error differences

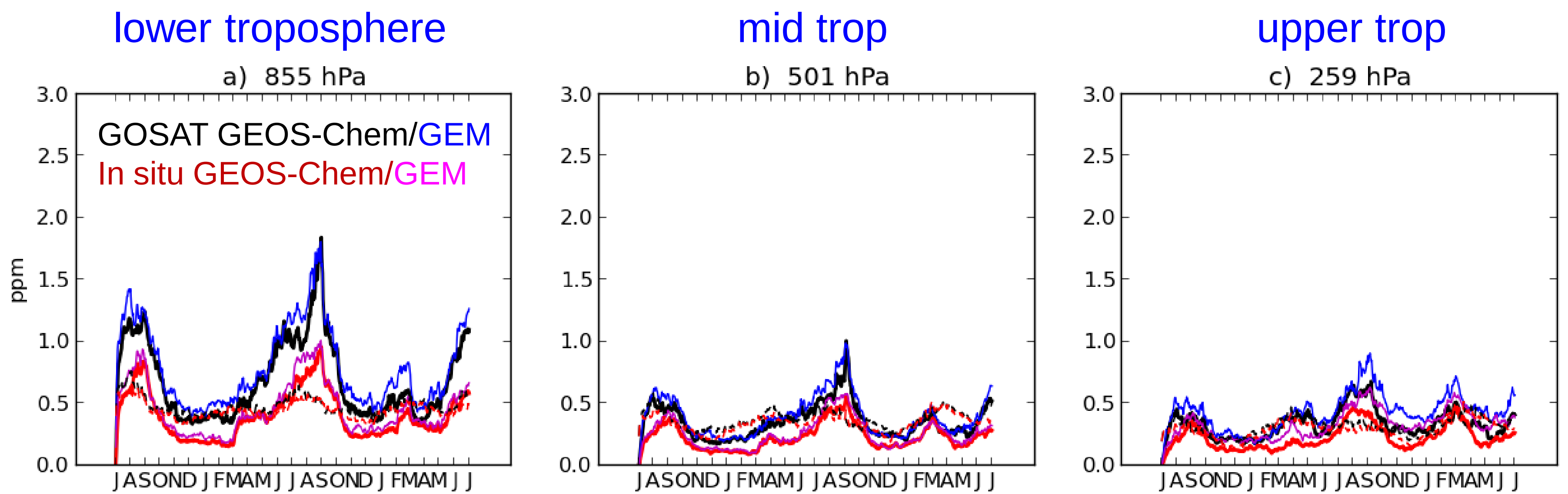
PAAF(GOSAT): contributions

GEOS-Chem was integrated



Troposphere: Northern extratropics dominate contributions to global mean
Stratosphere: Tropics dominate contributions to global mean

Zonal std.dev. flux signals: Troposphere



Once the flux signal has diffused to large-scale structures (~3 months in troposphere), there will be no contribution to zonal std-dev. So zonal std-dev reflects shorter time scales than zonal mean.

- PAAF(GOSAT) exceeds PAAM except in boreal winter in lower trop.
- PAAF(insitu) exceeds PAAM(insitu) only in boreal summer in lower trop.

Conclusions

- Posterior atmospheric adjustment is a function of the model and the prior flux. Comparing PAAF and PAAM is useful.
- GOSAT data produce zonally asymmetric structures that exceed adjustments due to imperfect meteorology in the tropics year round and in the northern extratropics except during boreal winter.
- In the lower troposphere, zonal asymmetries in the flux signal exceed that arising from meteorological uncertainties only in boreal summer, when in situ data constrain posterior fluxes.
- The GEOS-Chem flux inversion constrained by in situ data better agrees (by 0.5 ppm) with independent observations on the global annual scale compared to the inversion constrained with GOSAT observations *but the inversion with GOSAT data better captures the seasonal cycle of* CO_2 *at northern extratropical sites (not shown).*

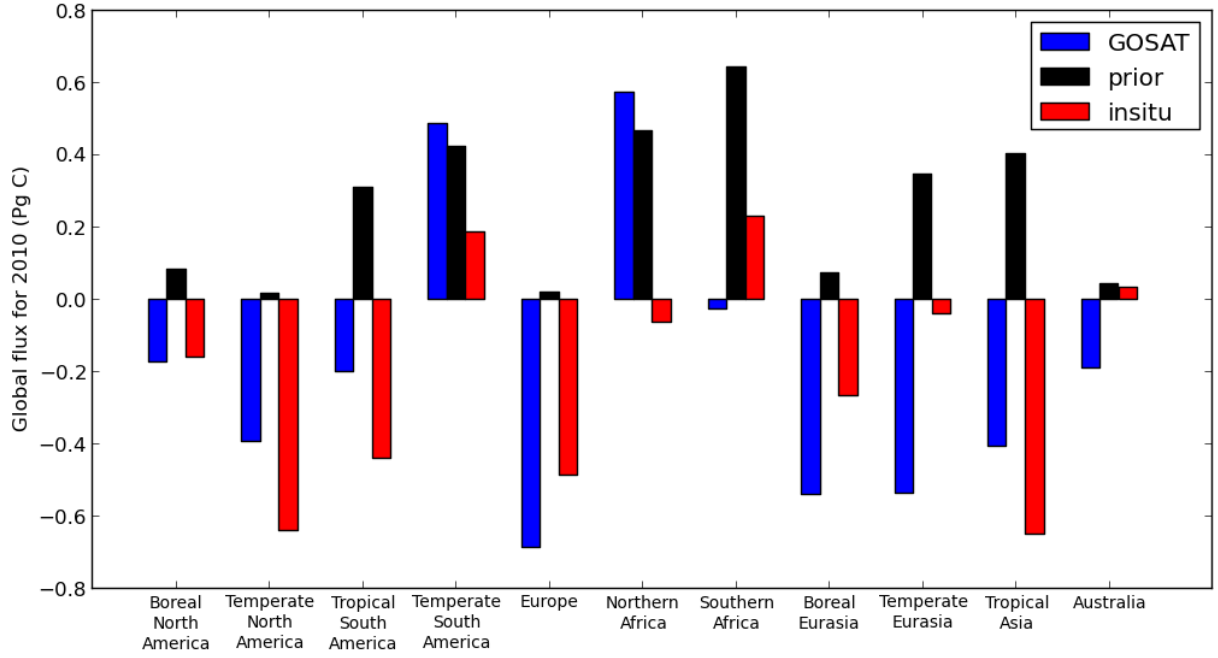
Acknowledgements

- Funding for U Toronto work was from the Canadian Space Agency, ECCC and NSERC.
- ACOS/OCO-2 were from co2.jpl.nasa.gov. Thanks to JPL and GOSAT project.
- TCCON from http://tccon.ornl.gov/. We thank TCCON PIs Paul Wennberg, Caltech (Lamont, Park Falls), David Griffith, University of Wollongong (Darwin and Wollongong), Justus Notholt, University of Bremen (Bremen), Nicholas Deutscher, University of Bremen (Bialystok), Thorsten Warneke, University of Bremen (Orleans), Dave Pollard, NIWA (Lauder), Ralf Sussmann, IMKIFU (Garmisch), Kimberly Strong, University of Toronto (Eureka), Rigel Kivi, FMI (Sodankylä), Frank Hase, KIT (Karlsruhe), and Matthias Schneider, KIT (Izaña).
- NOAA Aircraft profiles from ObsPack2013. Thanks Colm Sweeney.
- NOAA surface obs. Thanks Ken Masarie. obspack_co2_1_PROTOTYPE_v1.0.4_2013-11-25) from http://dx.doi.org/10.3334/OBSPACK/1001.
- HIPPO (http://hippo.ucar.edu). NSF, NOAA. Thanks Steve Wofsy.

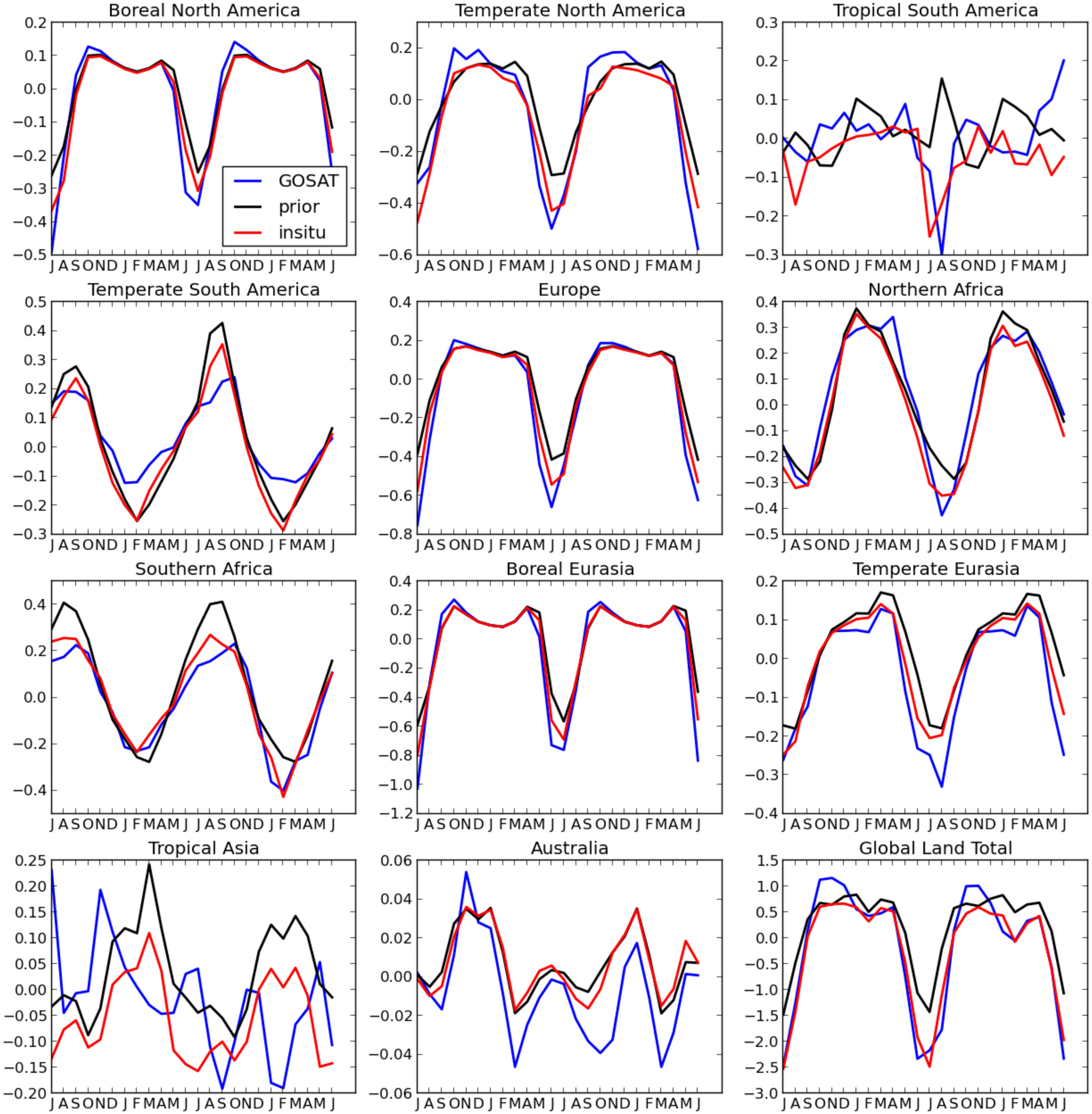
EXTRA SLIDES

GEOS-Chem posterior fluxes for TransCom regions

Annual fluxes for 2010 for the 11 TransCom land regions



- Prior and insitu similar to Deng et al. (2014)
- GOSAT Looks like fig. 8 of Deng 2016
- Insitu v GOSAT: insitu has more uptake in Americas but GOSAT has more uptake in Europe/Asia. Insitu has more uptake in tropics (Asia, S.Am)



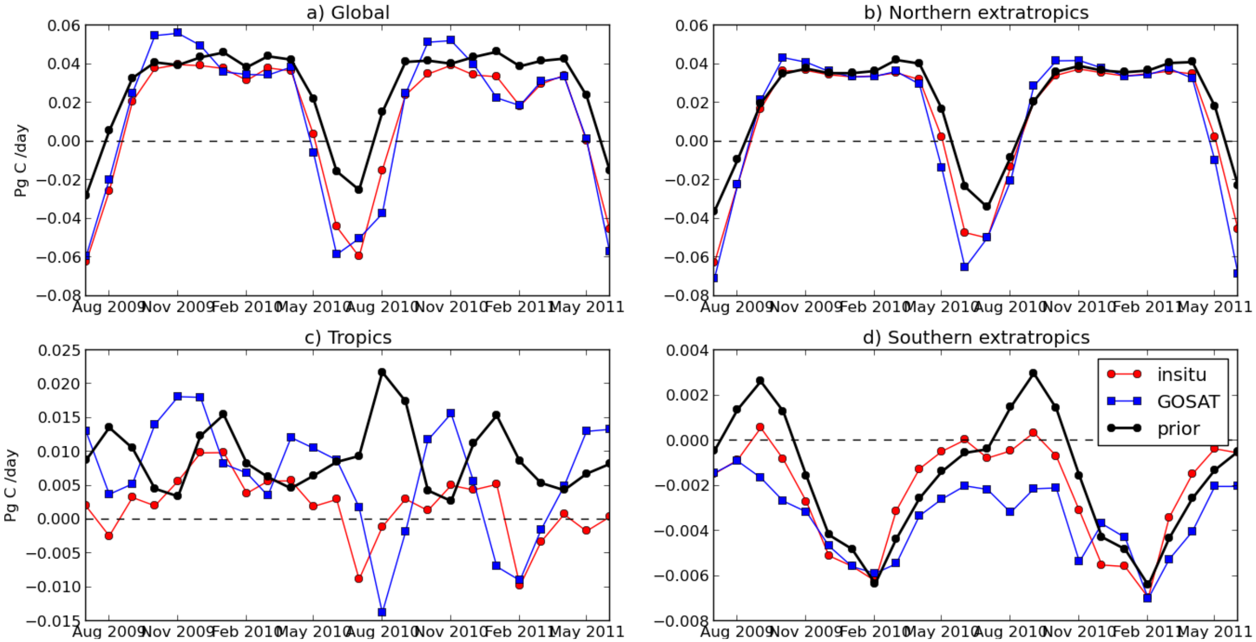
GEOS-Chem posterior Monthly fluxes for July 2009 – June 2011

- As in 2010 annual, insitu lowers prior fluxes in tropical regions (Asia, S.Am.)
- GOSAT lowers uptake over prior in SH (Australia, S.Africa)
- GOSAT has more uptake than insitu in NH summer
- GOSAT has more outgassing in N.Am. fall

Canada

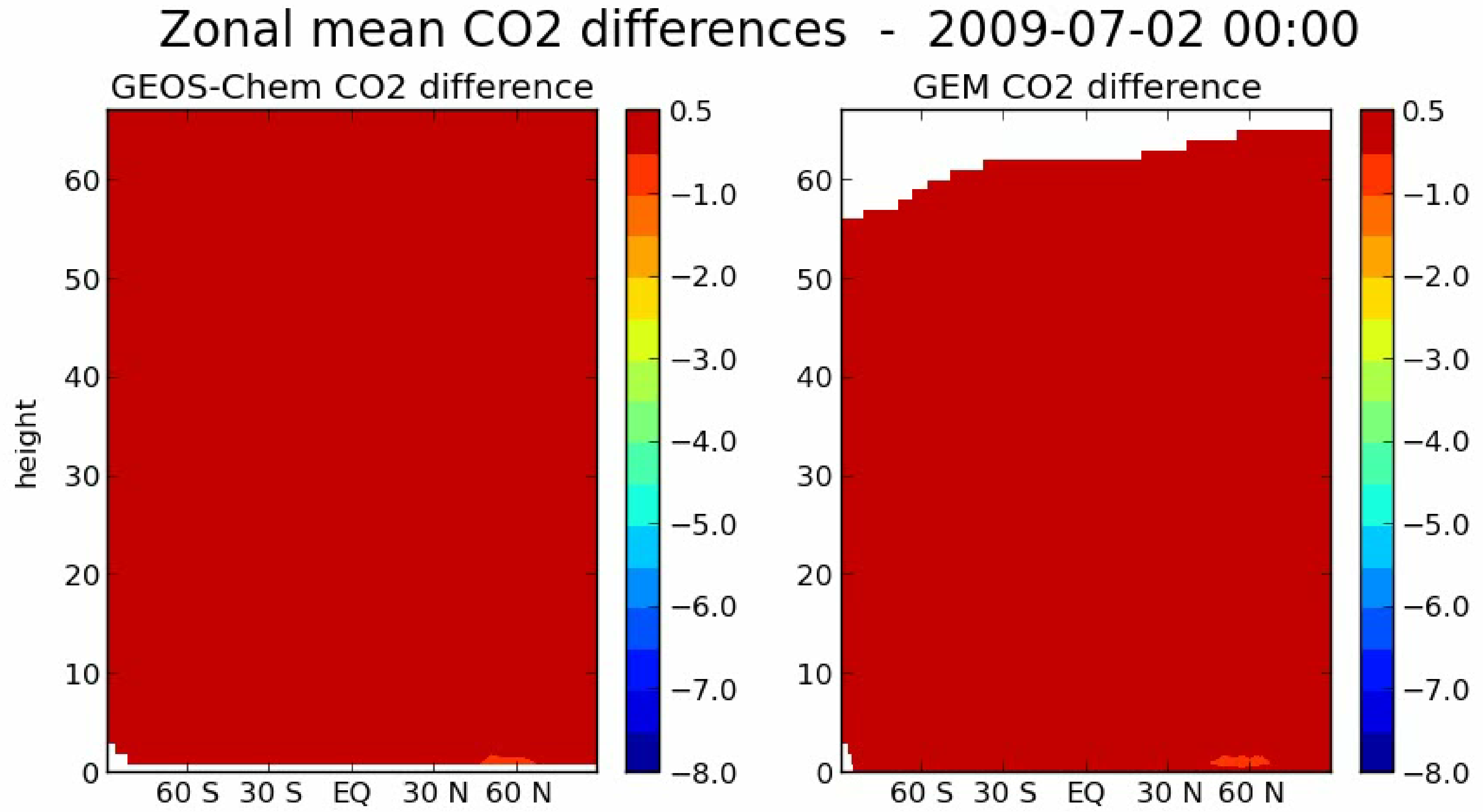
Time series of retrieved global fluxes and contributions from 3 latitude bands

Prior and posterior monthly fluxes area weighted and regionally averaged for July 2009 to June 2011.



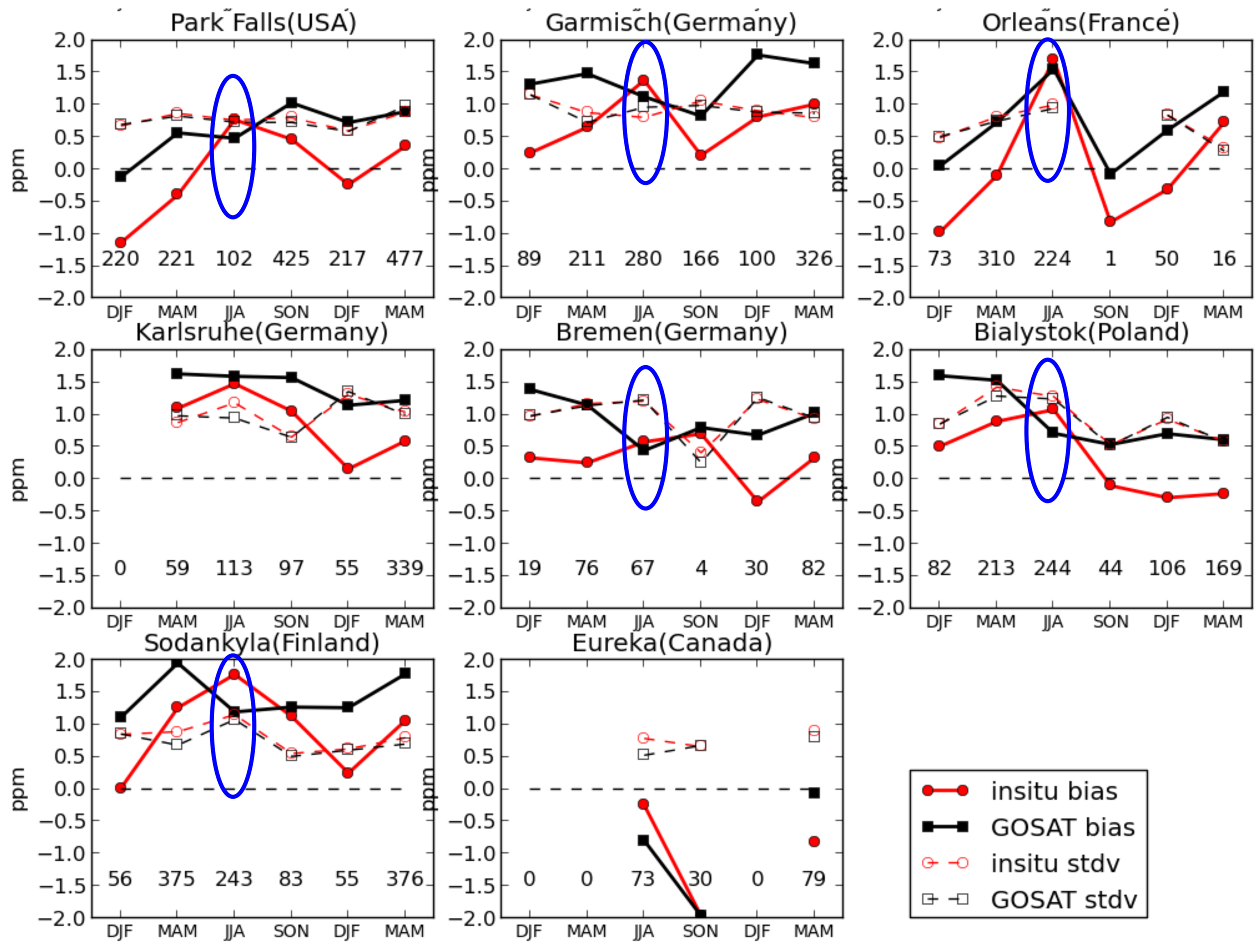
- In boreal summer, both posterior fluxes reduce CO_2 by 0.04 PgC/day (panel a). This is primarily due to northern extratropics (panel b).
- GOSAT increases CO2 in Nov-Dec over that obtained with prior fluxes due to NH, TR
- GOSAT always reduces SH over prior. Insitu larger than prior in Spring
- Annual mean tropical flux is lowered by insitu data.

Mismatch of transport times to SH



Watch for summer 2010

Compare to TCCON data



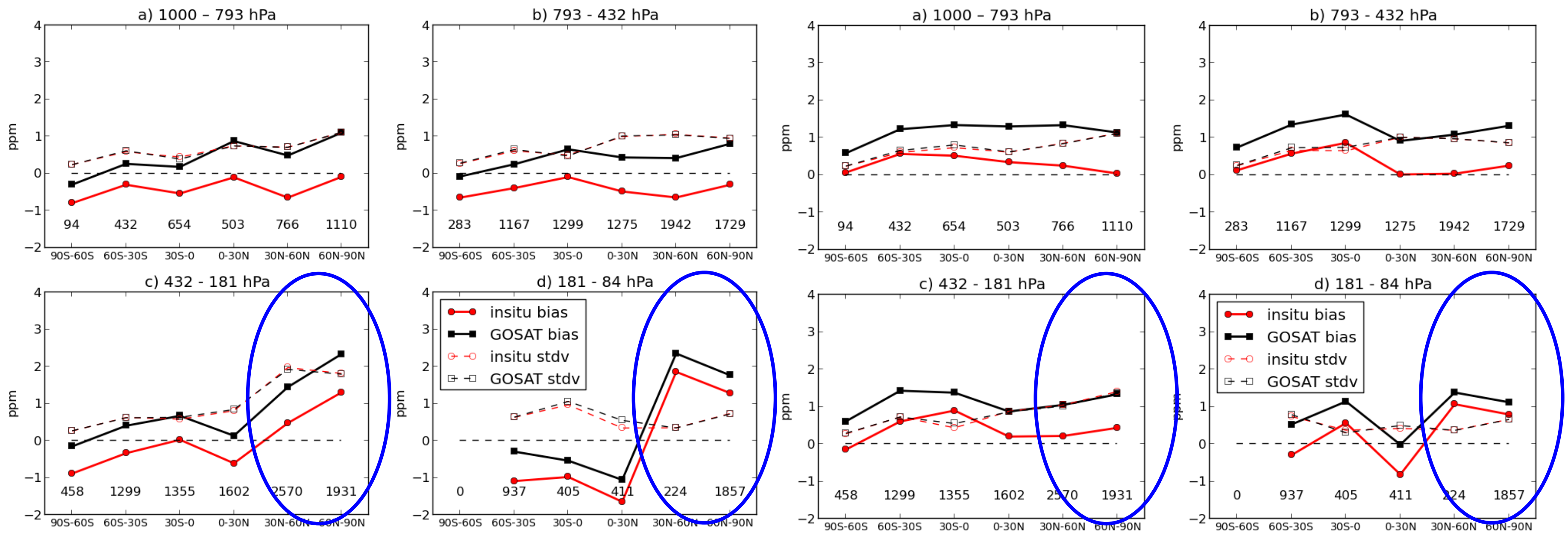
CO_2 with GOSAT-based fluxes is better in northern extratropics in summer

Seasonal cycle is better with GOSAT data

Compare to HIPPO3 aircraft data

24 March to 16 April 2010

GEOS-Chem | GEM-MACH-GHG
HIPPO3-GC | HIPPO3-GM



- In situ posterior always produces lower CO_2. This is a good thing in northern extratropics in upper troposphere and stratosphere.
- GEM has too much CO_2 in the southern hemisphere.

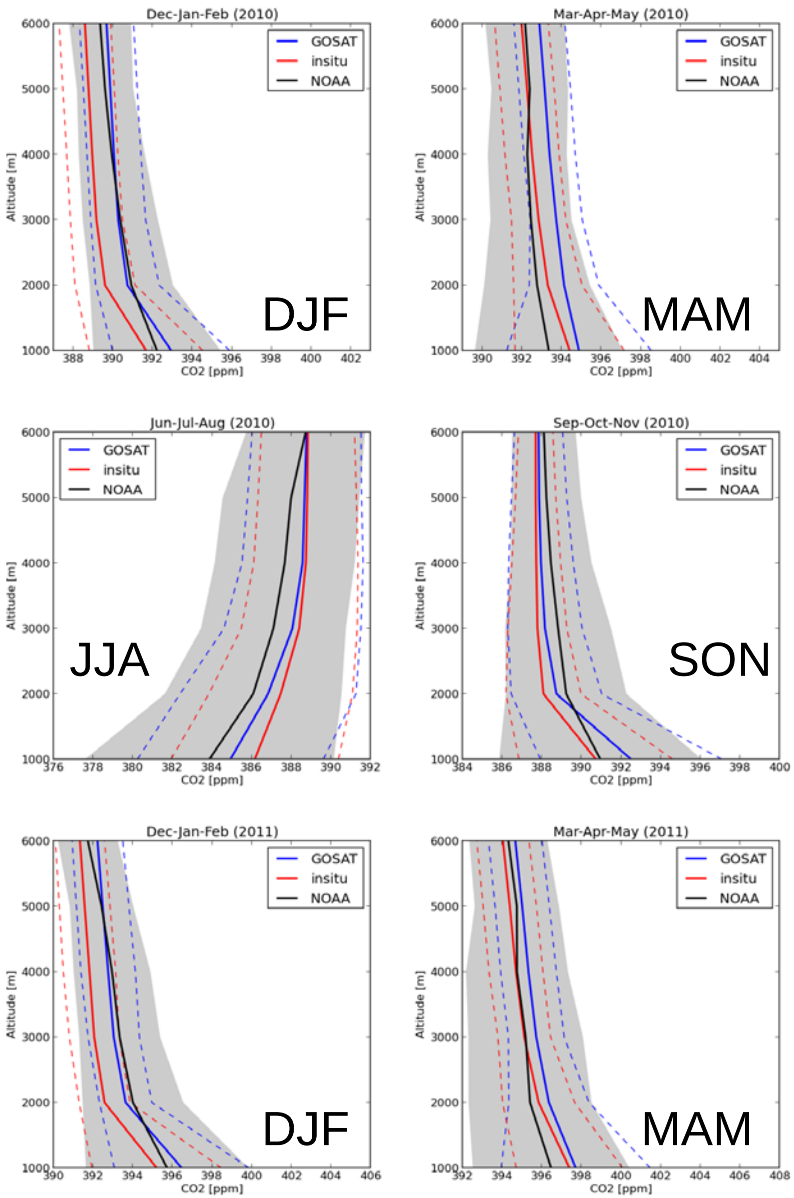
Comparison of GEOS-Chem and GEM-MACH-GHG CO_2 to TCCON observations.

Station	<prior>	<in situ>	<GOSAT>	<|prior'|>	<|in situ'|>	<|GOSAT'|>	No. obs
Lauder 1	3.02	0.78	1.30	0.99	0.19	0.17	424
	2.46	0.22	0.70	0.96	0.13	0.20	
Lauder 2	3.30	0.90	1.58	1.27	0.19	0.15	1280
	2.67	0.30	0.89	1.34	0.23	0.17	
Wollongong	3.52	0.99	1.60	1.28	0.29	0.33	1269
	3.00	0.46	1.00	1.35	0.30	0.40	
Darwin	4.02	0.74	1.36	1.11	0.13	0.18	536
	3.46	0.23	0.82	1.09	0.09	0.18	
Izana	3.31	0.17	0.82	0.98	0.57	0.56	211
	3.49	0.21	0.84	1.04	0.28	0.21	
Lamont	2.98	-0.21	0.39	0.90	0.53	0.44	3087
	3.03	-0.22	0.29	0.99	0.45	0.25	
Park Falls	3.26	0.03	0.61	1.57	0.65	0.33	1662
	3.38	-0.03	0.60	1.58	0.56	0.29	
Garmich	3.16	-0.05	0.57	1.55	0.77	0.52	1172
	4.25	0.72	1.36	1.26	0.35	0.27	
Orleans	3.72	0.30	0.90	1.49	0.71	0.45	674
	3.58	0.04	0.68	1.57	0.78	0.48	
Karlsruhe	4.83	1.02	1.55	0.74	0.41	0.24	663
	4.85	0.88	1.44	0.68	0.40	0.20	
Bremen	3.75	0.42	0.99	1.11	0.31	0.24	278
	3.75	0.31	0.92	1.05	0.24	0.27	
Bialystok	3.36	0.09	0.68	0.93	0.57	0.29	858
	3.76	0.31	0.95	0.74	0.51	0.41	
Sodankyla	4.18	0.79	1.23	1.31	0.47	0.34	1188
	4.47	0.92	1.43	1.23	0.52	0.29	
Eureka	3.25	-1.19	-1.27	0.63	0.64	0.72	182
	3.56	-1.01	-0.94	0.62	0.63	0.68	

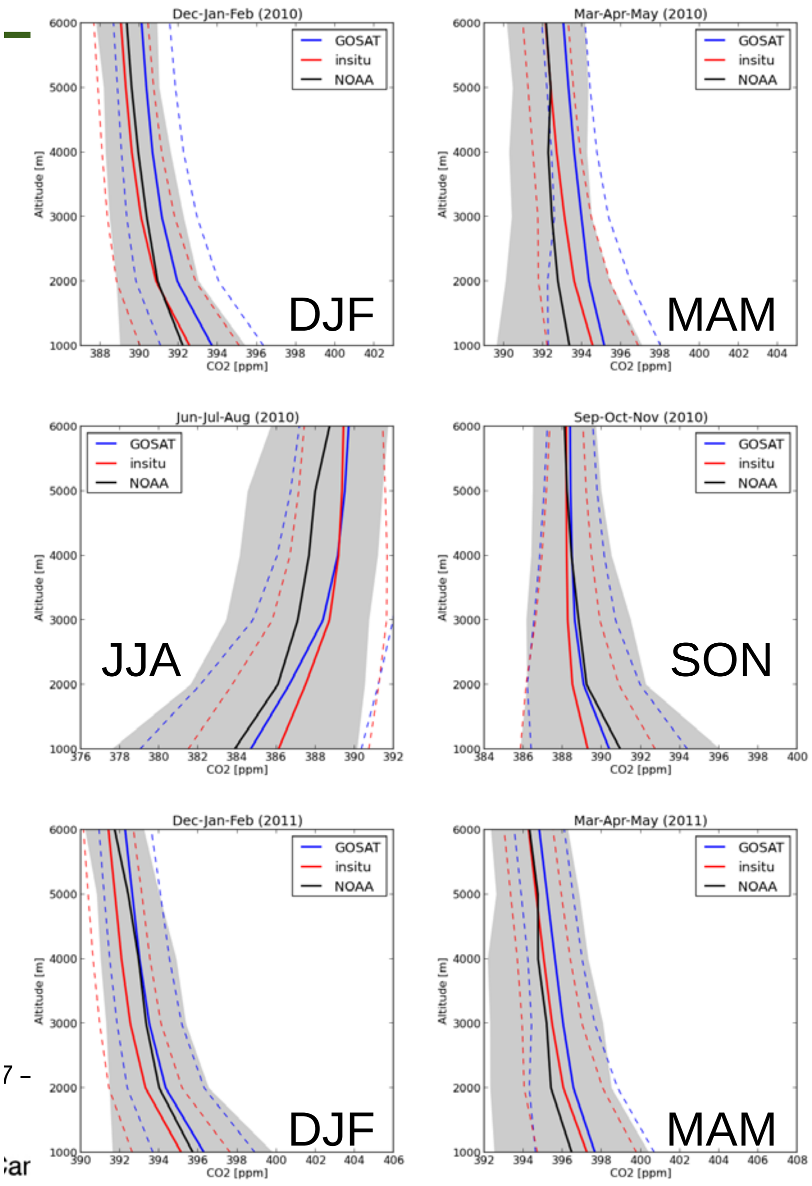
The mean absolute departures of seasonal means from this time average are shown in columns 5-7. This statistic is a measure of the "flatness" of the curves seen in TCCON figures. For each statistic, the top value corresponds to the GEM-MACH-GHG results with bottom corresponding to the GEOS-Chem results. Two different instruments are Lauder are used.

Compare to NOAA aircraft profiles

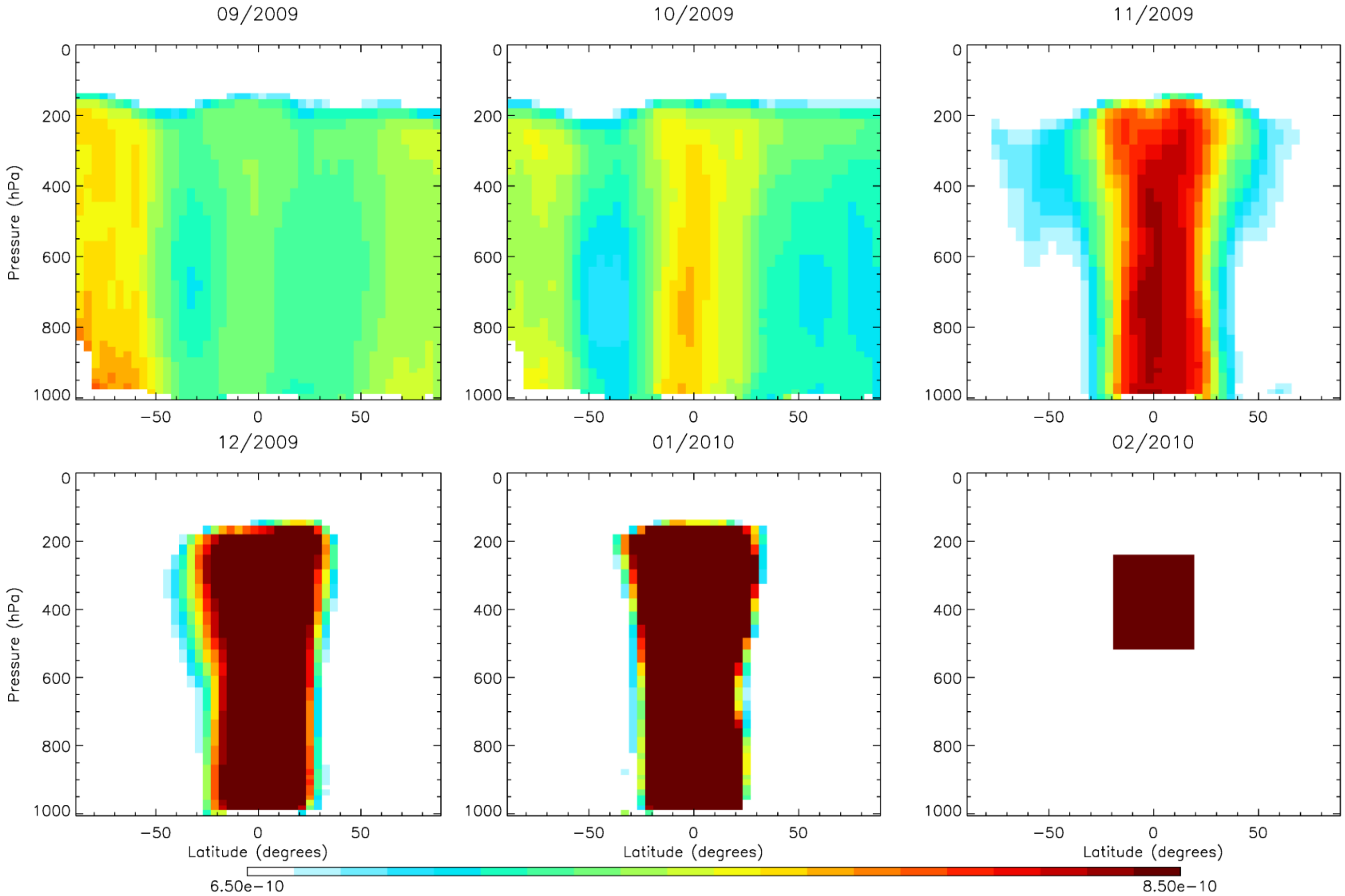
GEOS-Chem



GEM-MACH-GHG

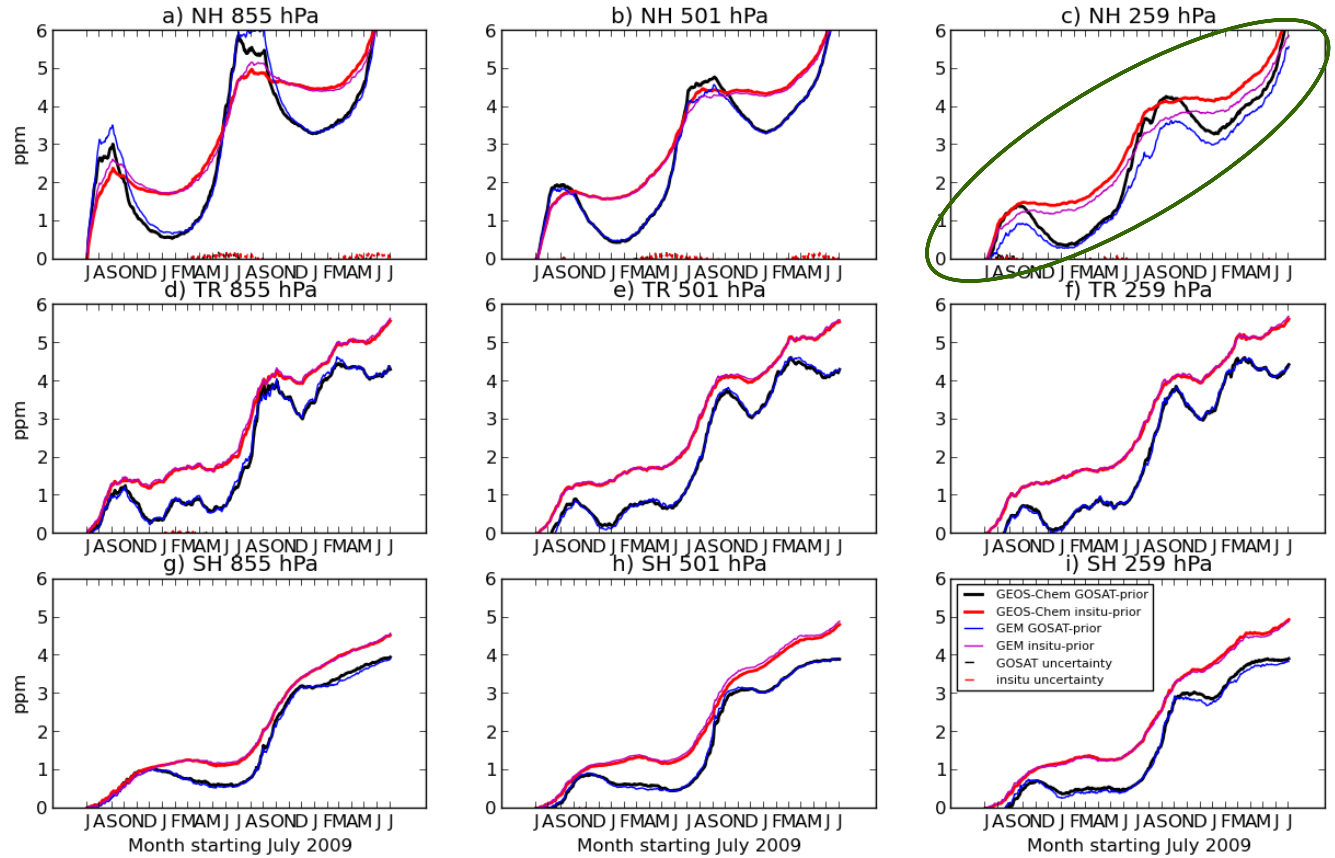


Adjoint sensitivity of tropical upper troposphere to 3D state



Regional contributions to PAAF(in situ) and PAAF(GOSAT)

3 times Regional contributions to the global mean CO_2 flux signal for 1 July 2009 to 30 June 2011.



NH

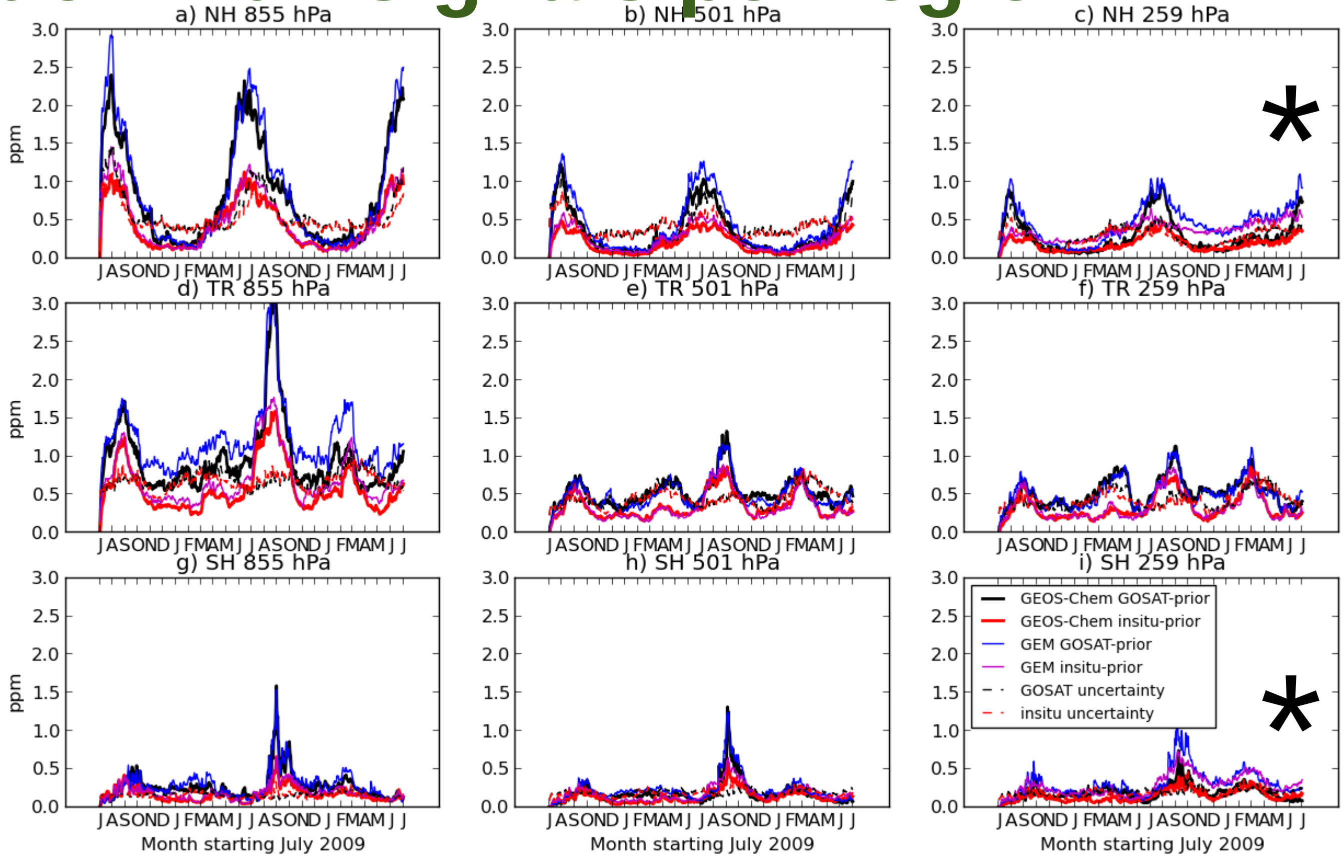
TR

SH

The two models differ most in the Northern Extratropical upper troposphere

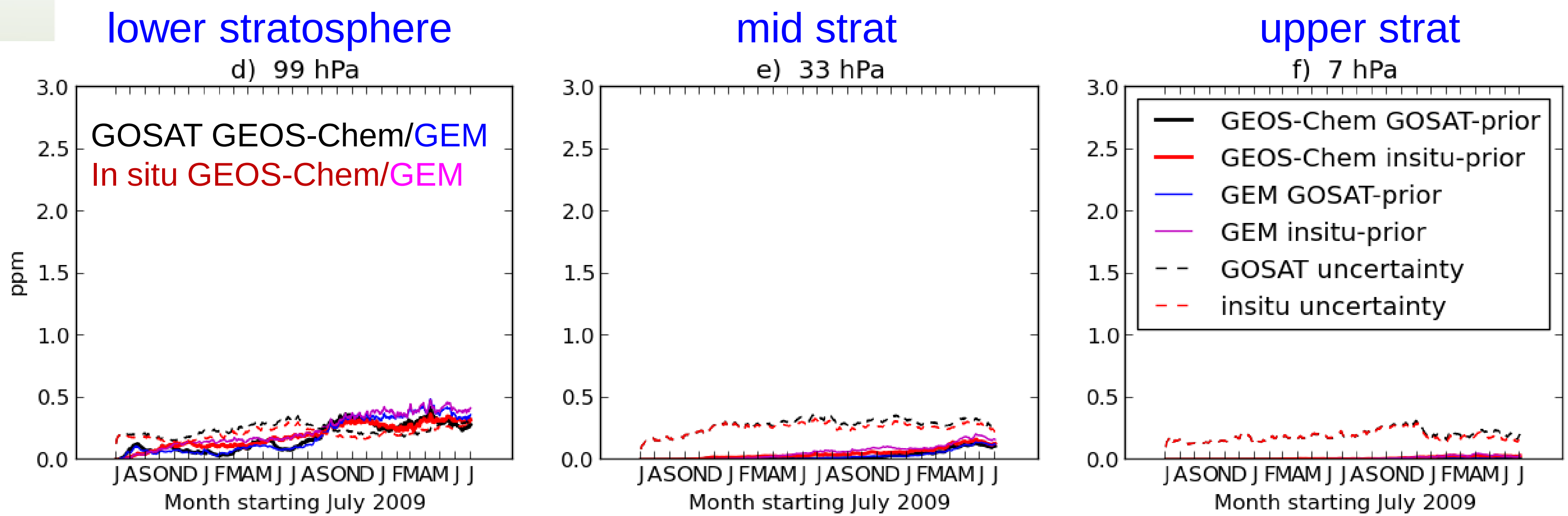
Uncertainty in CO_2 is estimated for each integration by perturbing the meteorological analyses and computing the difference from the unperturbed integration.

Compare in situ and GOSAT zonal std.dev. flux signals per region



- **NH**: We can trust GOSAT zonal structure May-Oct near the surface and June-Sept in lower troposphere. With insitu obs, zonal info not trustable except in JAS near the surface.
- **Tropics**: Zonal structure is evident for GOSAT near the surface. For insitu, zonal structure trustable only in JAS near the surface and lower troposphere.
- GOSAT has larger zonal stdev in tropics even though mean incr is larger for flask outside of summer
- The two models differ most in the extratropical upper troposphere. See *.

Zonal std.dev. flux signals: Stratosphere

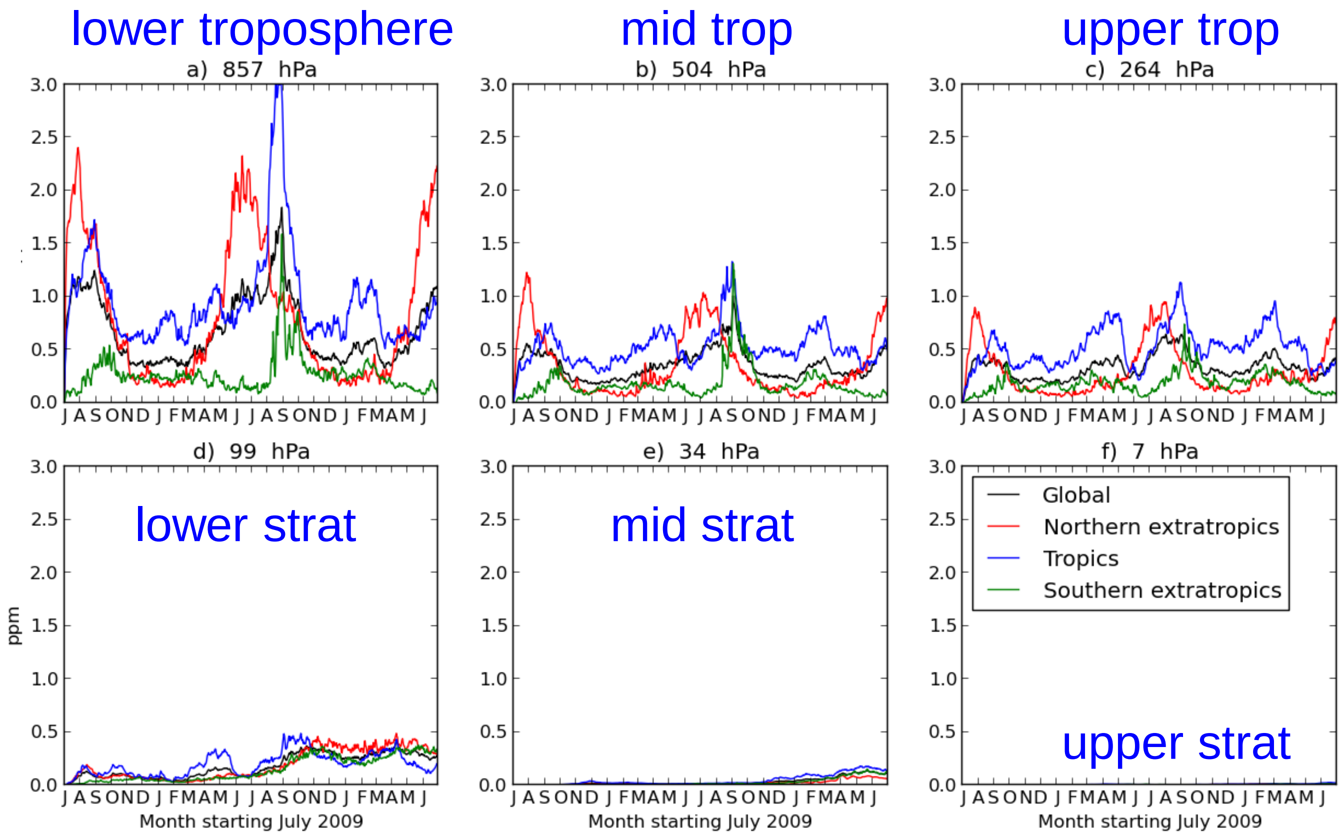


The flux signal takes a long time to reach stratosphere (>1 year)

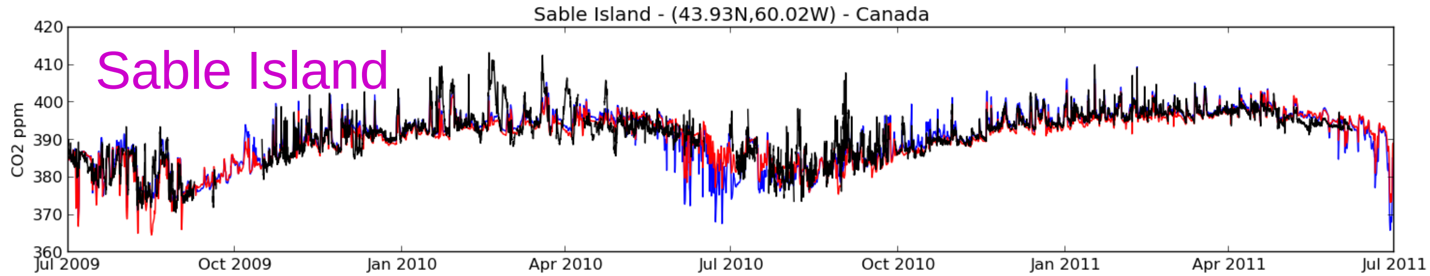
- We cannot trust zonal structures in the stratosphere except after 1 year, in the lower stratosphere.
- GEM has larger values than GEOS-Chem in lower stratosphere

Flux signal zonal standard deviation: Spatial contributions

GEOS-Chem was used to compute GOSAT-posterior CO_2 minus prior CO_2.

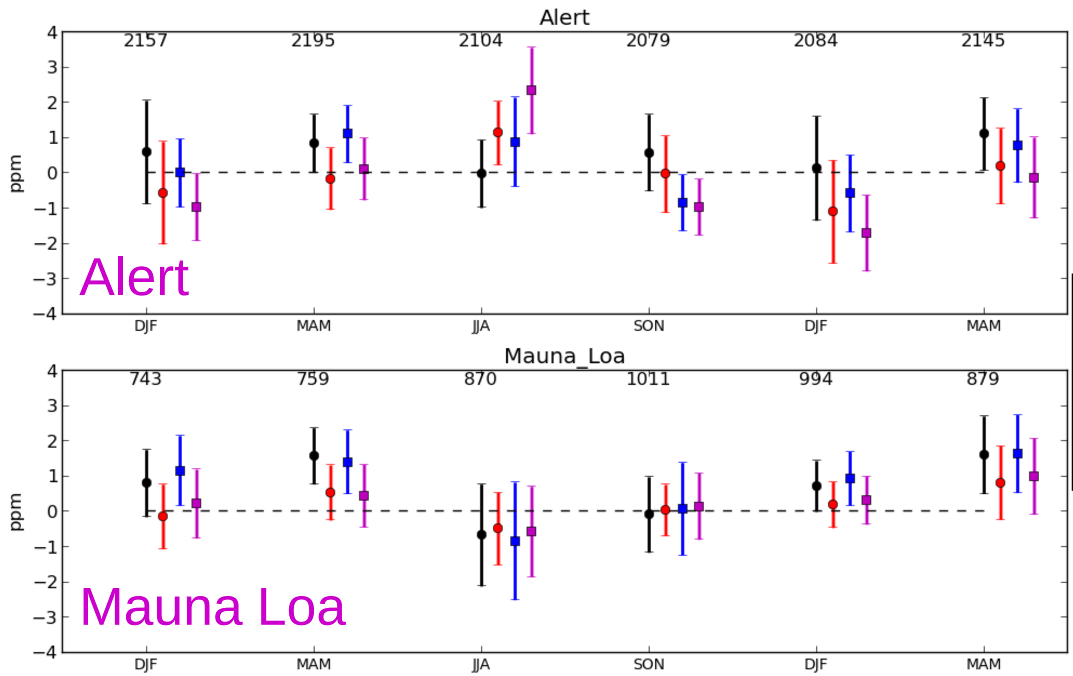


GEM-MACH-GHG CO_2 with GEOS-Chem posterior fluxes



In situ
GOSAT
obs

Good agreement with independent observations using both GEOS-Chem posterior fluxes on synoptic and long time scales.



GEM GOSAT
GEM in situ
GEOS-Chem GOSAT
GEOS-Chem insitu

Seasonal mean errors are qualitatively similar for a given posterior

Statistics use day and night time obs

Canada