Comparing two inversions of ACOS GOSAT column CO_2 measurements: flux estimates and uncertainties

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Outline

- Comparison of flux uncertainty from two similar GOSAT flux inversions (2010-2011)
- Comparison of flux estimates from same two inversions
- Impact of other assumptions (2009-2014)
  - Subset of GOSAT data used
    - High- and medium-gain nadir data over land
    - Glint data over ocean
  - Prior fluxes used

Uncertainty in estimates of C storage

The challenge: many approaches to characterizing uncertainty – details are important when comparing

Example -- compare two closely-related quantities from CMS flux and biomass projects:

- Biomass projects: carbon stored in trees
  - only above-ground biomass
  - only in sampled "forested" areas
- Flux projects: carbon cycling through continents, as inferred from top-down atmospheric inversions. Includes:
  - C that runs off into ocean via rivers
  - C stored in grasslands, scrublands, wetlands, etc.
  - C stored below ground in roots/soils
  - C stored in sediments behind dams

Uncertainty estimates from OSSEs

- In past, flux uncertainties taken from *a posteriori* covariance matrix given by flux inversion
- For large problems, matrices get too large to use traditional batch inversion
- More efficient methods, like variational data assimilation ("4Dvar"), required -- they obtain their efficiency by jettisoning the full covariance calculation
- Uncertainties calculated instead with observing system simulation studies (OSSEs):
  - A set of "true" fluxes is chosen, run through transport model to get "true" concentrations
  - Random measurement errors added on to get "true" measurements
  - These measurements are assimilated into a global CO_2 flux inversion system, starting from a (different) initial guess of fluxes, to get a final flux estimate
  - The final flux estimate is compared to the know "true" fluxes to calculate the flux errors from the inversion
  - This may be done multiple times with different draws of noise for the measurement errors and the prior-truth flux errors
  - Uncertainty statistics calculated from the posterior – truth flux differences

Comparison of flux uncertainties from two similar OSSEs using GOSAT atmospheric CO_2 data

David Baker, CIRA/CSU

- 4DVar data assimilation
- PCTM transport model
- MERRA met drivers
- Surface CO_2 fluxes estimated:
  - weekly
  - on 4.5°x6° (lat/lon) grid
  - both land and ocean areas
- GOSAT X_{CO2} retrievals used:
  - both H- & M-gain over land
  - glint over ocean
- Uncertainty calculation:
  - monte carlo, $N = 1$
  - prior, true fluxes from two different carbon models

Junjie Liu, NASA/JPL

- 4DVar data assimilation
- GEOS-Chem transport model
- MERRA met drivers
- Surface CO_2 fluxes estimated:
  - monthly
  - on 4°x5° (lat/lon) grid
  - land areas only
- GOSAT X_{CO2} retrievals used:
  - H-gain over land
- Uncertainty calculation:
  - monte carlo, $N = 60$
  - random prior-truth flux differences consistent with P_o assumed in inversion

GOSAT soundings used

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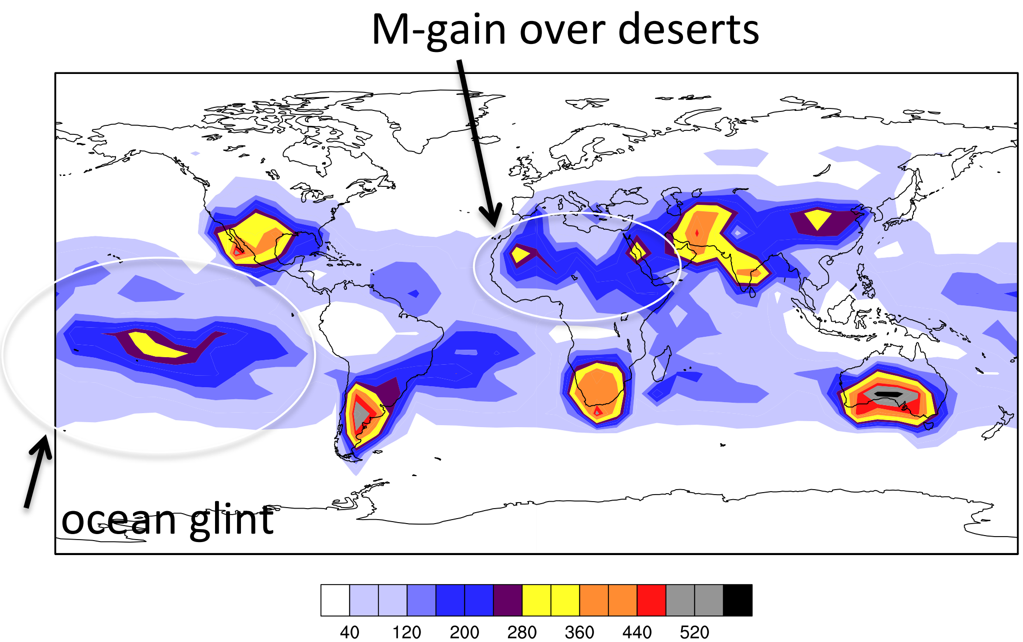
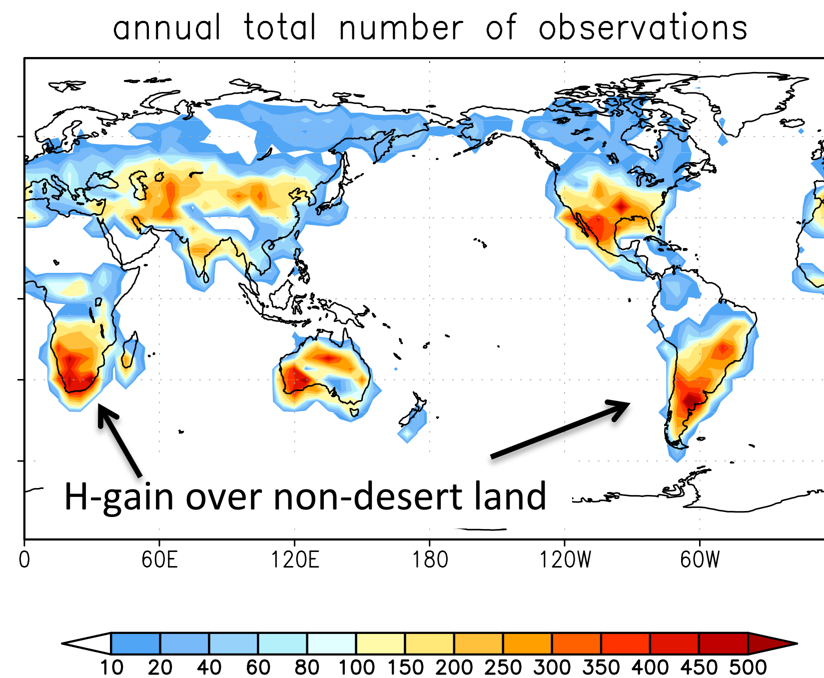


Both H- & M-gain data over land
Glint data over oceans

Liu



H-gain data over land

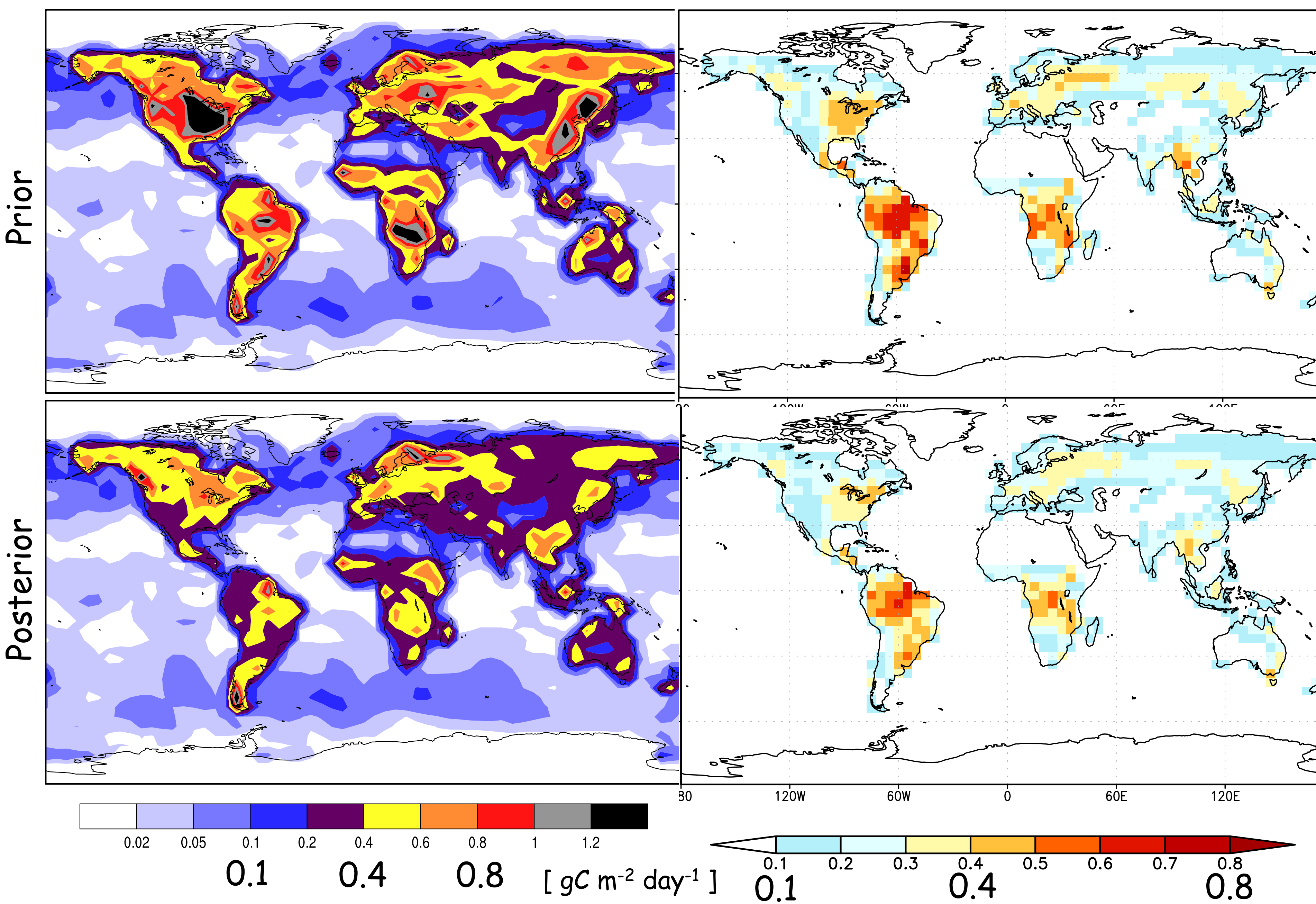
Measurement uncertainties assumed:

- 1.7 ppm (1σ) -- H-gain land
- 1.5 ppm (1σ) -- M-gain land
- 1.0 ppm (1σ) -- ocean glint

Measurement uncertainties assumed:

- 1.0 – 2.5 ppm (1σ) -- H-gain land (using the actual uncertainties calculated for each ACOS retrieval)

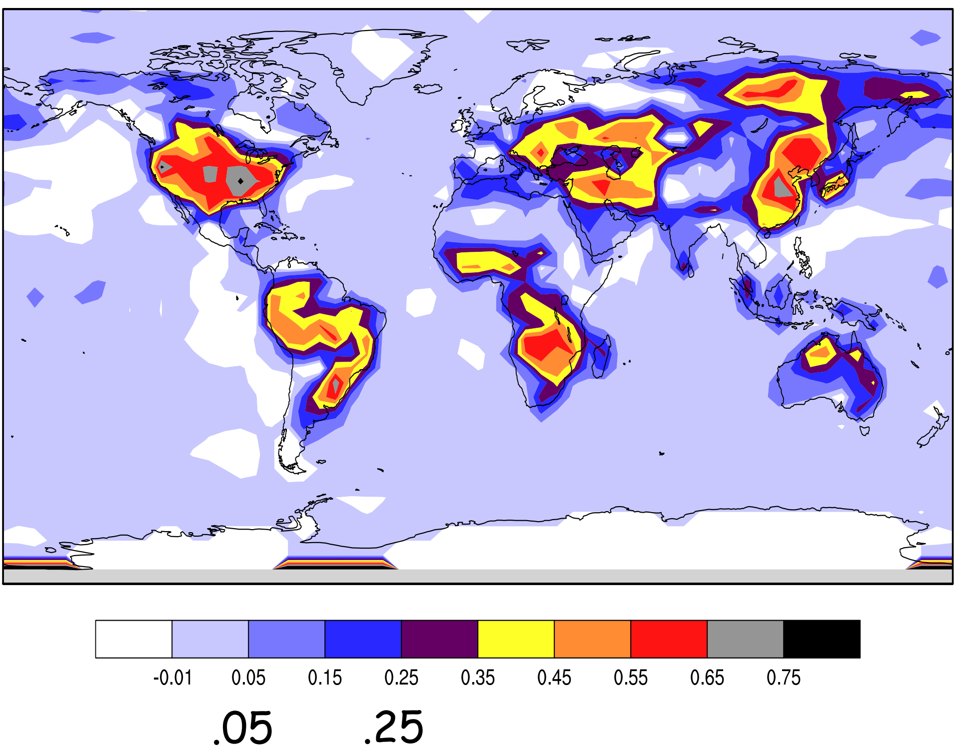
Flux uncertainties from OSSEs



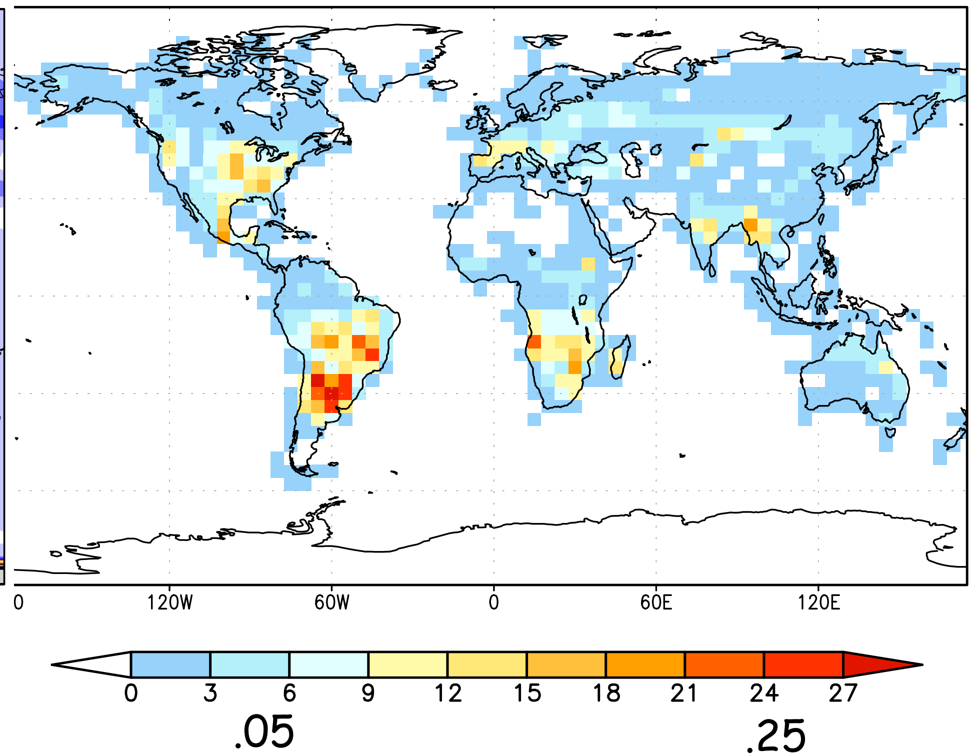
Uncertainty reduction statistic

$$R = (\sigma_{prior} - \sigma_{post}) / \sigma_{prior}$$

Baker



Liu



- Uncertainty reductions largest where initial errors largest
- Patterns of *a priori* uncertainty assumed are quite different
- Overall uncertainty reduction differs by factor of 3
- Final uncertainties for Liu lower, due to tighter prior

Conclusions – flux uncertainty

- Even when two groups are trying to solve for the same thing, large differences may occur due to assumptions
- Here, largest differences due to:
  - Assumed prior-truth flux differences
  - Volume/type of GOSAT data used
  - Measurement uncertainties assumed
  - Monte carlo approach used
    - Prior-truth flux differences
    - Number of draws of random errors

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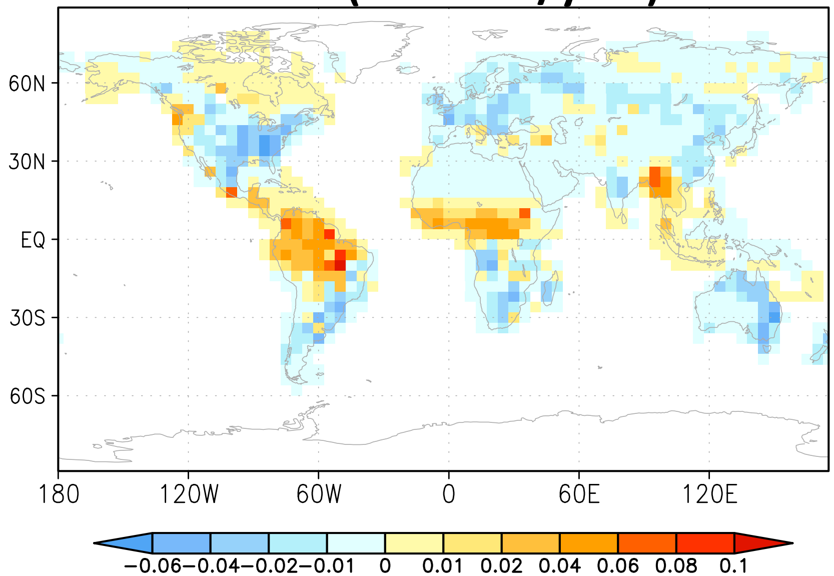
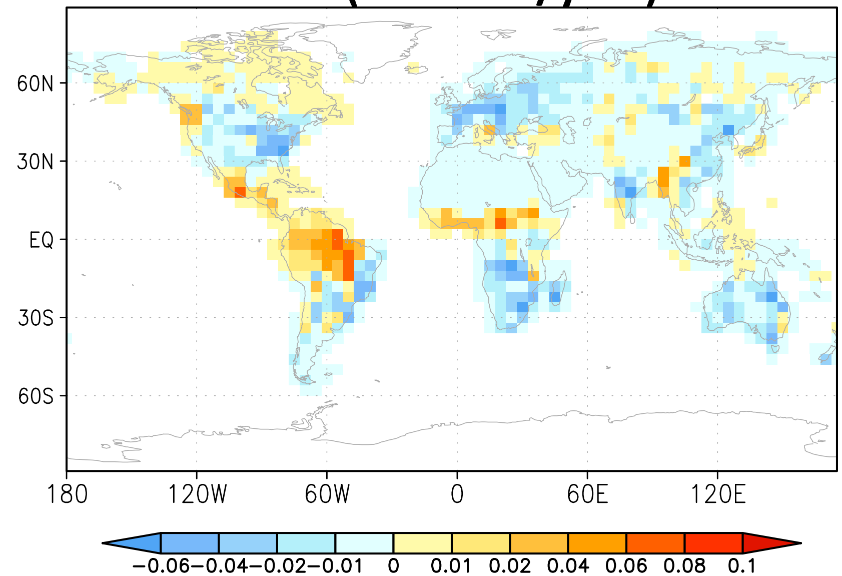
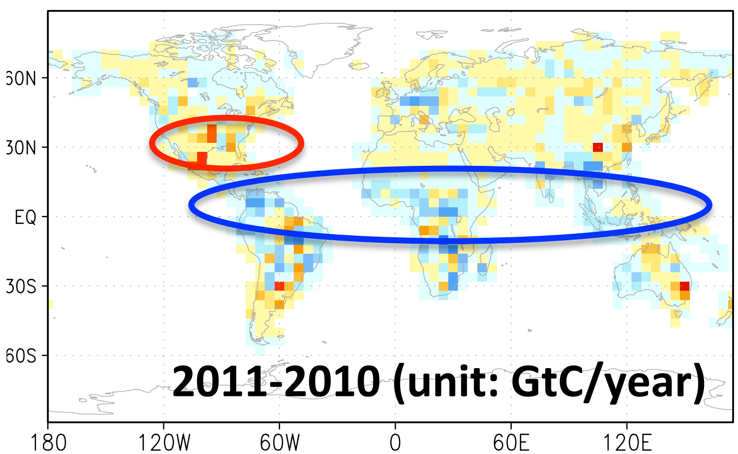
Liu CMS net biospheric flux (including fire) estimated for 2010 and 2011

2010 (unit: GtC/year)



2011 (unit: GtC/year)

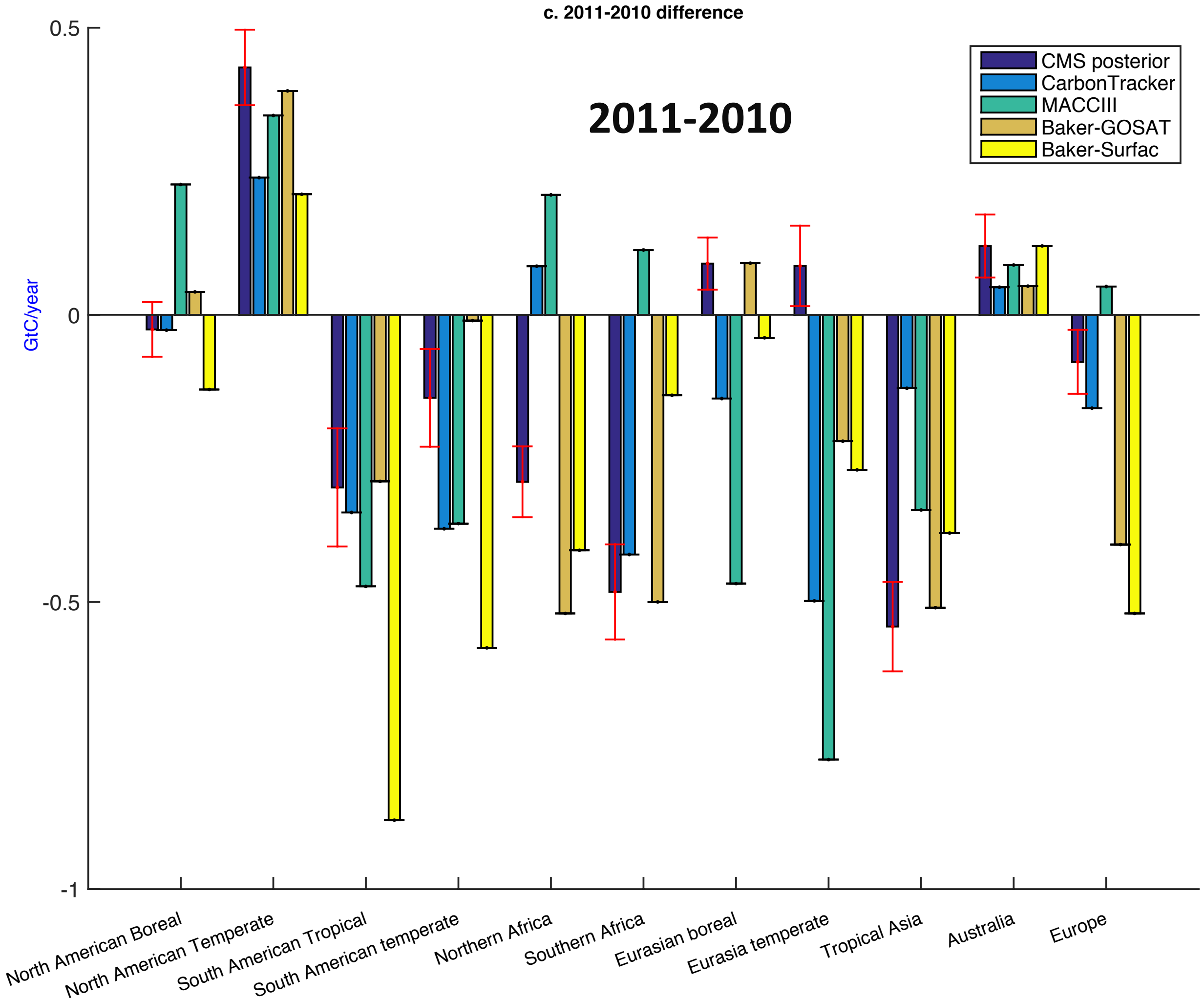




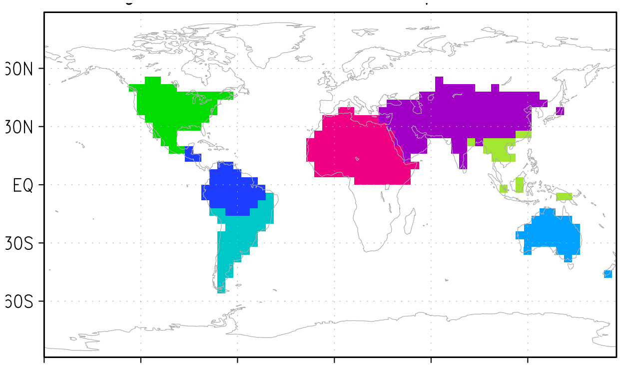
- Source strength is reduced in 2011 in tropics
- Sink becomes weaker in NA

- Mid to high latitudes absorb CO_2 from the atmosphere
- Tropics release CO_2 in both years

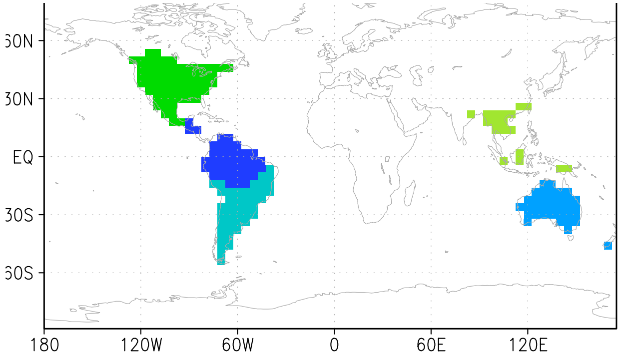
Flux changes (2011-2010): Liu & Baker GOSAT inversions, MACCIII, and CarbonTracker



Flux changes from CT and MACC with the same sign

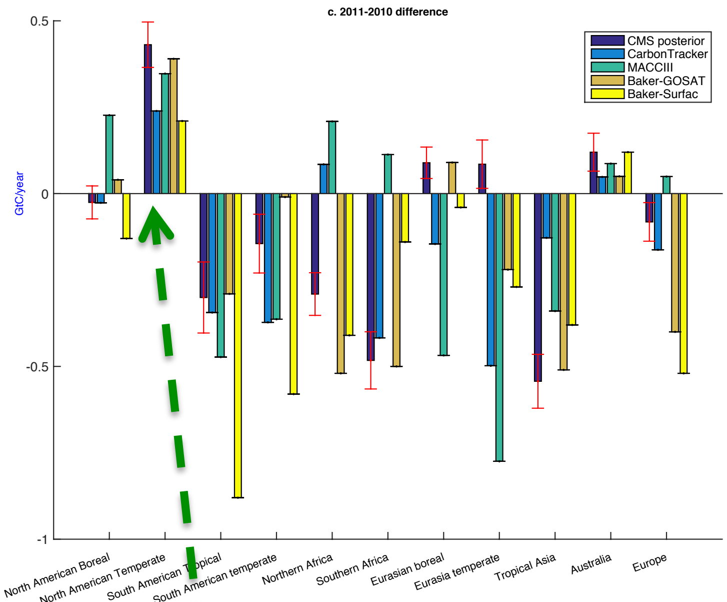


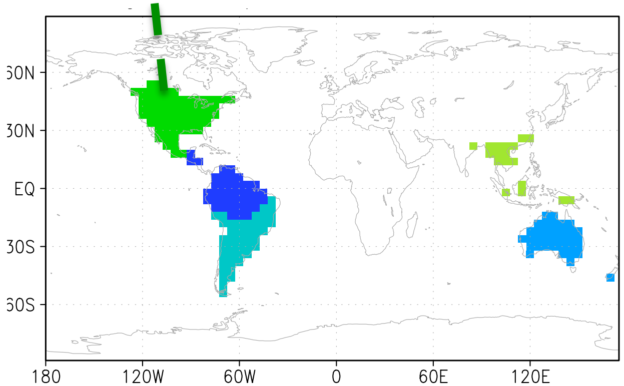
Flux changes from CT, MACC, CMS-Flux, and Baker with the same sign



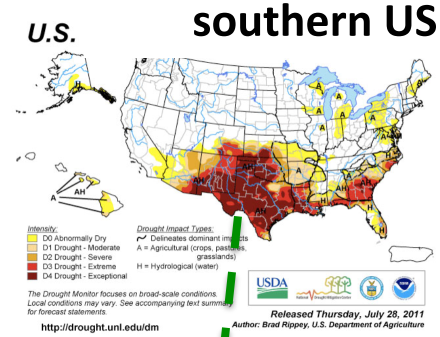
- **MACCIII (ECMWF) and CarbonTracker (NOAA) both constrained by surface CO_2 obs, only**
- **RMS(CT-MACC)=0.25 GtC;**
- **RMS(CMS-MACC)=0.27 GtC; RMS(CMS-CT)=0.41 GtC**

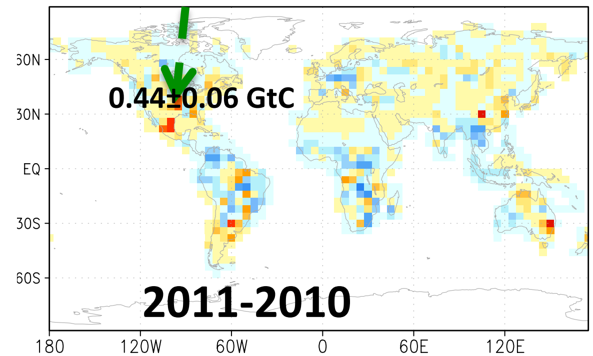
Possibly correct flux change signals from CMS-Flux





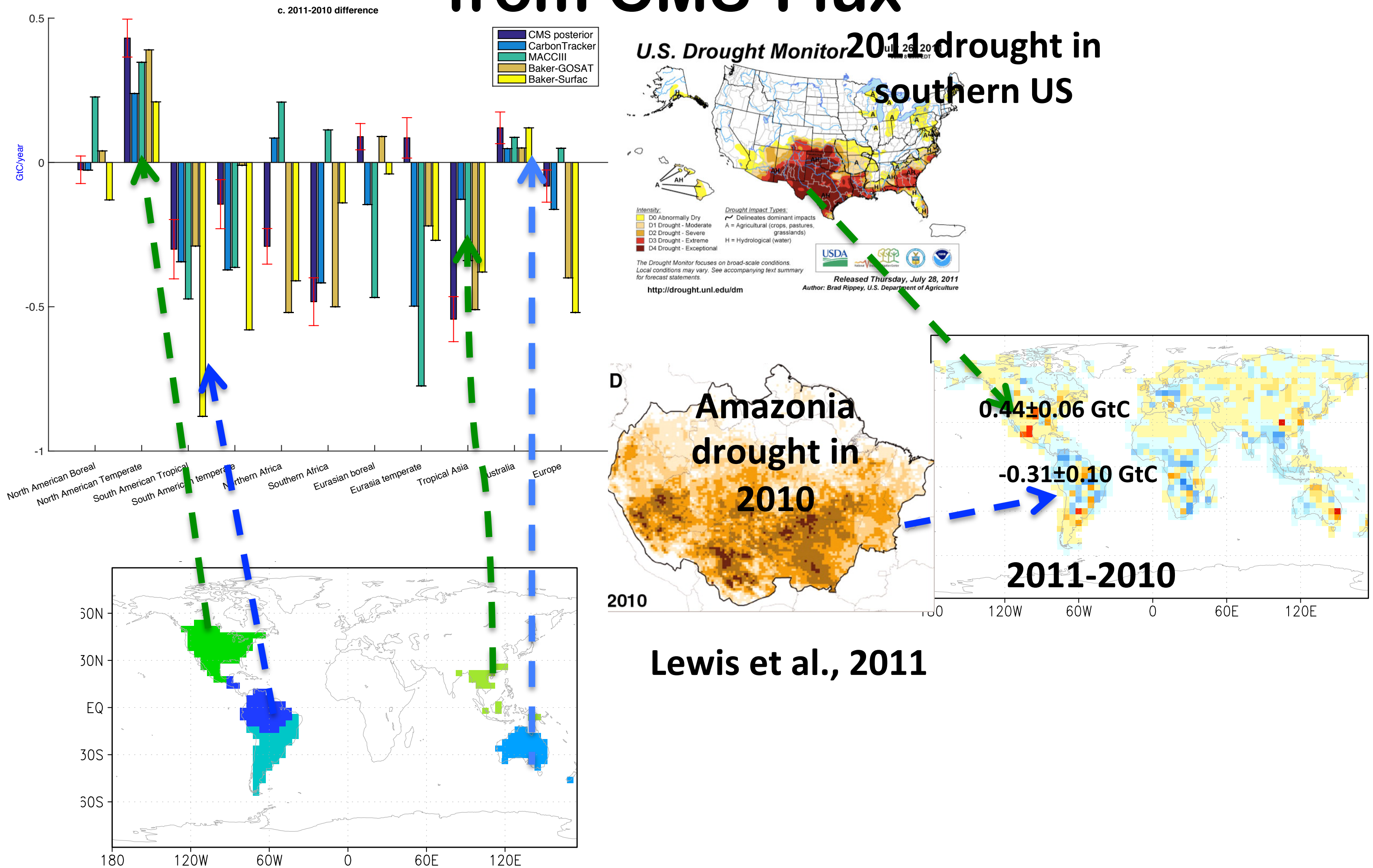
2011 drought in southern US





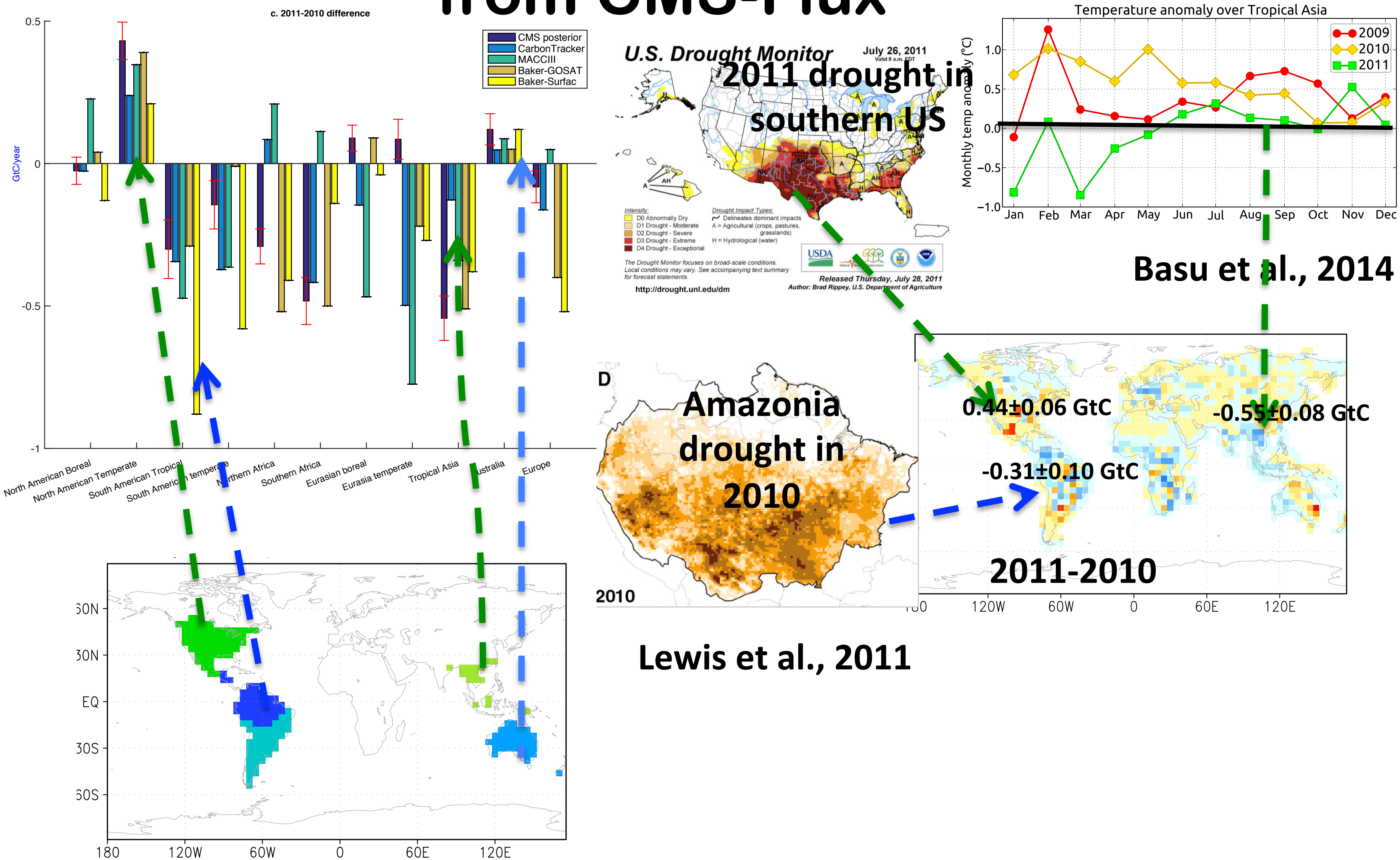
- Flux changes from CMS-Flux detect the impact of 2011 southern drought on CO_2 fluxes

Possibly correct flux change signals from CMS-Flux



- Flux changes from CMS-Flux detect the relative impact of 2010 Amazonia drought

Possibly correct flux change signals from CMS-Flux



- **Anomaly high temperature in 2010 produces large source in Tropical Asia (Basu et al., 2014)**

Possibly correct flux change signals from CMS-Flux

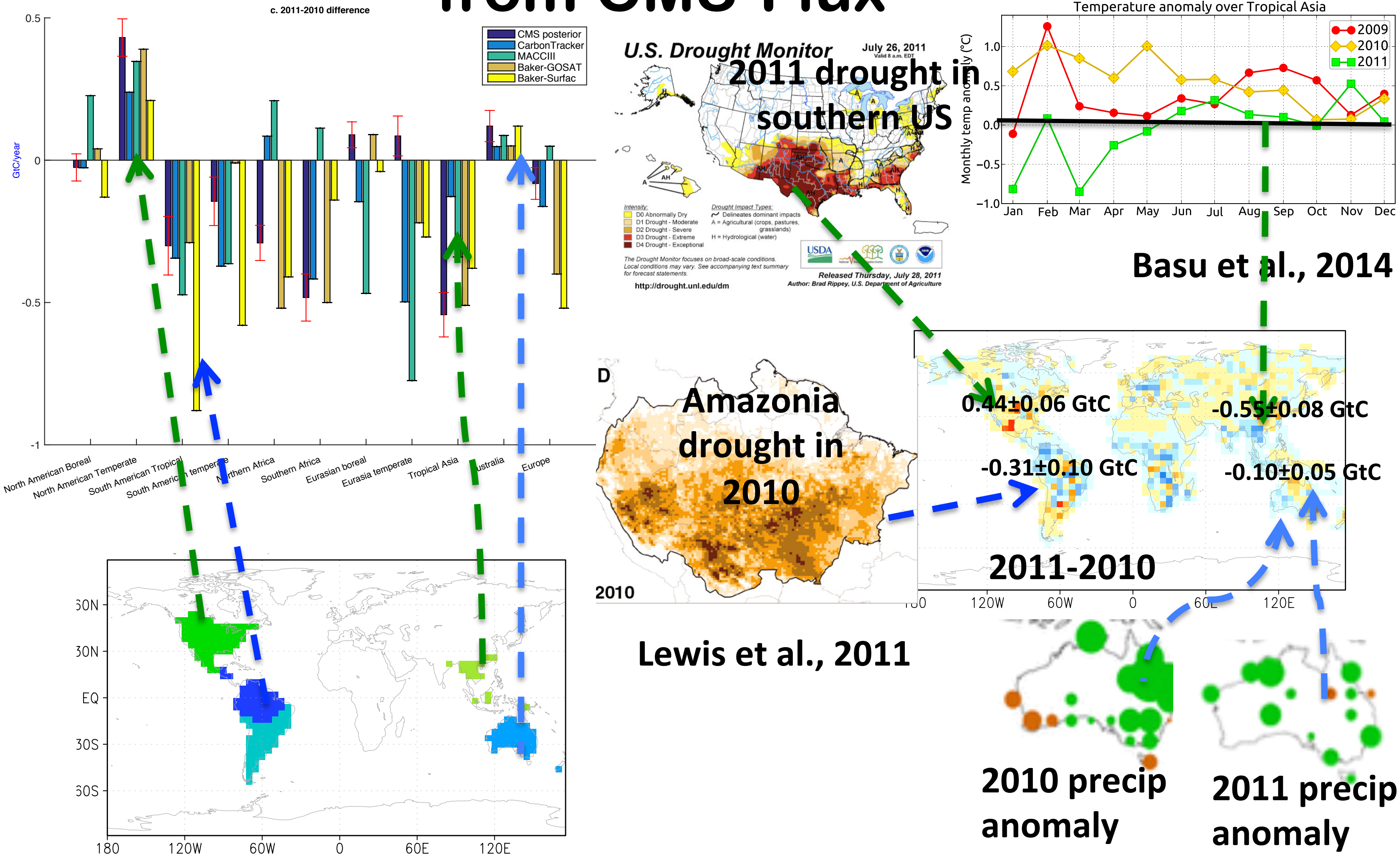
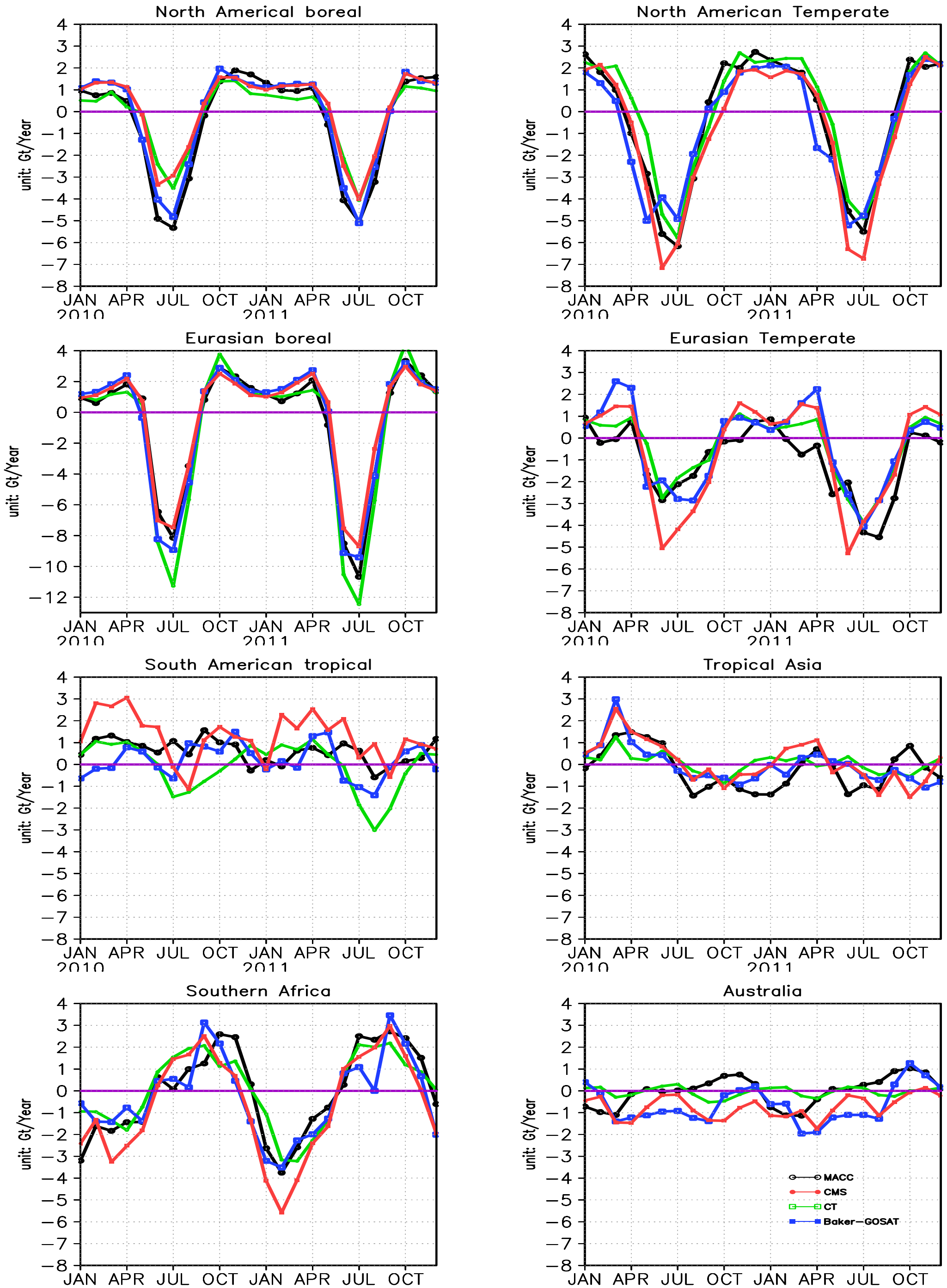
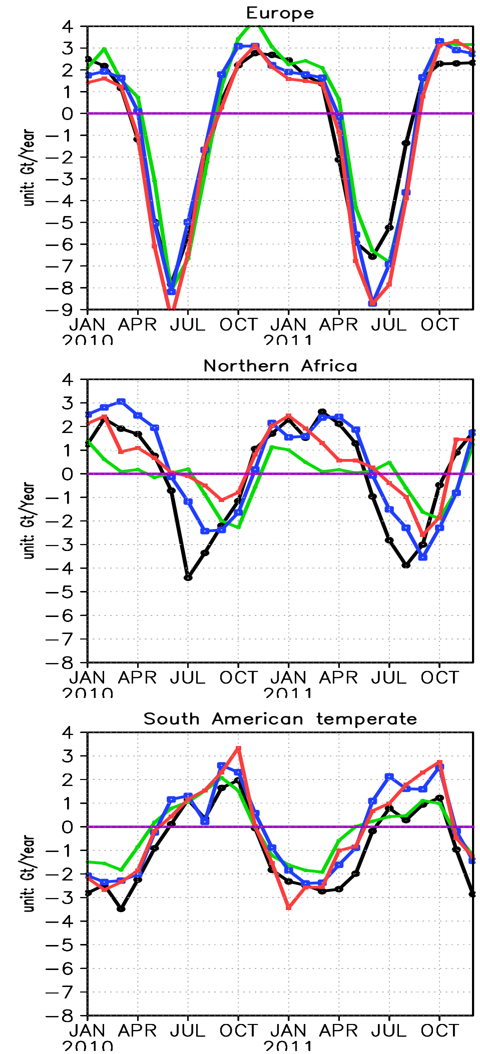


Figure credit: NOAA

- **Flux changes from CMS-Flux detect the flux changes due to precipitation anomaly in Australia**





Liu - GOSAT
Baker-GOSAT
MACC-III
CarbonTracker

Monthly flux estimates 2010-2011

Conclusions – flux estimates

- Liu and Baker GOSAT inversions give similar results, for shift in flux from 2010 to 2011
- Less agreement at monthly time scale
- GOSAT data drive fluxes towards different values than *in situ* data do – filling in gaps, or adding biases?

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ACOS b3.5 GOSAT X_{CO2}, 2009-2014

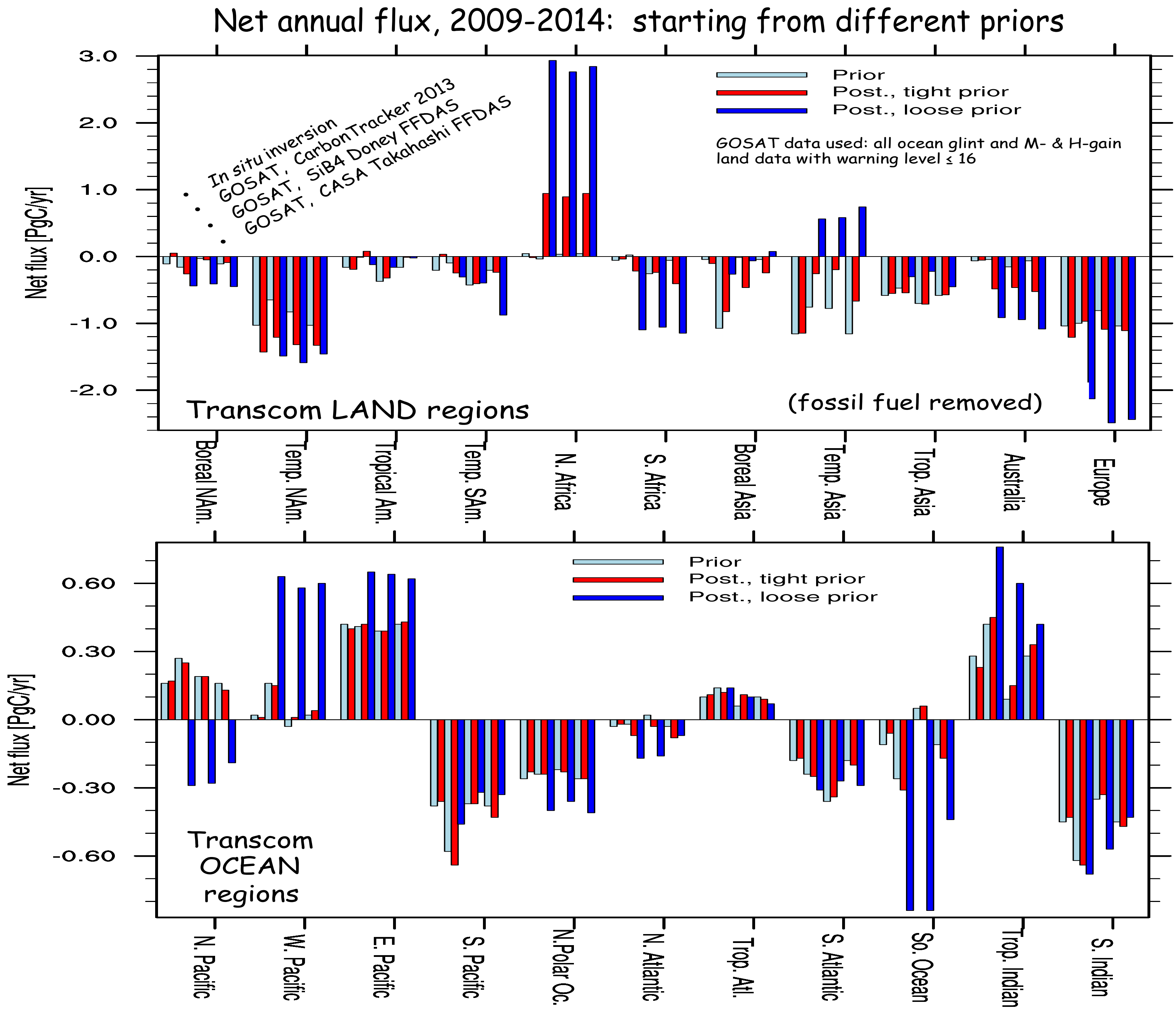
- Chris O'Dell's "lite" Level 2 product, with these additional data screened out:
  - south of 60° S and north of 75°N
  - retrieved X_{CO2} uncertainty of ≥ 1.5 ppm
  - "warn levels" of 17-19
- Number of scenes passing these screening criteria:
  - ~444,000 land, high-gain (non-desert areas)
  - ~87,000 land, medium-gain (desert areas)
  - ~420,000 ocean glint
- Chris O'Dell's standard bias corrections applied
- Measurement uncertainty in inversion taken to be 60% higher than uncertainty given by retrieval
- Outliers greater than 3σ from prior are deweighted

RMS mismatch to the GOSAT data [ppm], pre-inversion

			all data	ocean glint data >20° N	ocean glint data Tropics	ocean glint data <20° S	M-gain land N of Eq	M-gain land S of Eq	H-gain land >20° N	H-gain land <20° N
		Shots	952 K	60 K	280 K	81 K	69 K	18 K	252 K	192 K
CASA	FFDAS hourly	NOBM	1.862	1.384	1.252	1.238	1.689	1.239	2.577	1.895
CASA	FFDAS hourly	Doney	1.857	1.397	1.268	1.241	1.696	1.238	2.552	1.909
CASA	FFDAS hourly	Takahashi	1.861	1.376	1.265	1.249	1.684	1.222	2.571	1.903
CASA	CDIAC monthly	NOBM	1.862	1.371	1.247	1.238	1.684	1.240	2.576	1.890
CASA	CDIAC monthly	Doney	1.852	1.381	1.260	1.240	1.690	1.238	2.550	1.902
CASA	CDIAC monthly	Takahashi	1.857	1.362	1.257	1.248	1.679	1.222	2.572	1.897
SiB4	FFDAS hourly	NOBM	1.960	1.367	1.278	1.333	1.667	1.213	2.792	1.797
SiB4	FFDAS hourly	Doney	1.924	1.369	1.277	1.323	1.659	1.202	2.746	1.801
SiB4	FFDAS hourly	Takahashi	1.941	1.353	1.283	1.349	1.657	1.207	2.783	1.802
SiB4	CDIAC monthly	NOBM	1.974	1.364	1.282	1.337	1.667	1.216	2.797	1.798
SiB4	CDIAC monthly	Doney	1.933	1.363	1.278	1.328	1.657	1.204	2.750	1.800
SiB4	CDIAC monthly	Takahashi	1.951	1.350	1.285	1.354	1.656	1.210	2.788	1.802
SiB3	FFDAS hourly	NOBM	1.930	1.406	1.193	1.289	1.739	1.308	2.665	1.912
SiB3	FFDAS hourly	Doney	1.896	1.417	1.189	1.284	1.734	1.300	2.627	1.927
SiB3	FFDAS hourly	Takahashi	1.901	1.390	1.185	1.296	1.725	1.283	2.651	1.917
SiB3	CDIAC monthly	NOBM	1.939	1.392	1.192	1.283	1.738	1.305	2.668	1.903
SiB3	CDIAC monthly	Doney	1.900	1.400	1.184	1.279	1.731	1.297	2.628	1.916
SiB3	CDIAC monthly	Takahashi	1.906	1.376	1.181	1.291	1.723	1.280	2.655	1.907
Carbon Tracker 2013		Miller/ODIAC	1.794	1.229	1.191	1.230	1.689	1.289	2.455	1.884
Carbon Tracker 2013		FFDAS	1.800	1.238	1.195	1.229	1.694	1.288	2.453	1.888
Carbon Tracker 2013		CDIAC	1.793	1.228	1.187	1.228	1.691	1.288	2.455	1.879

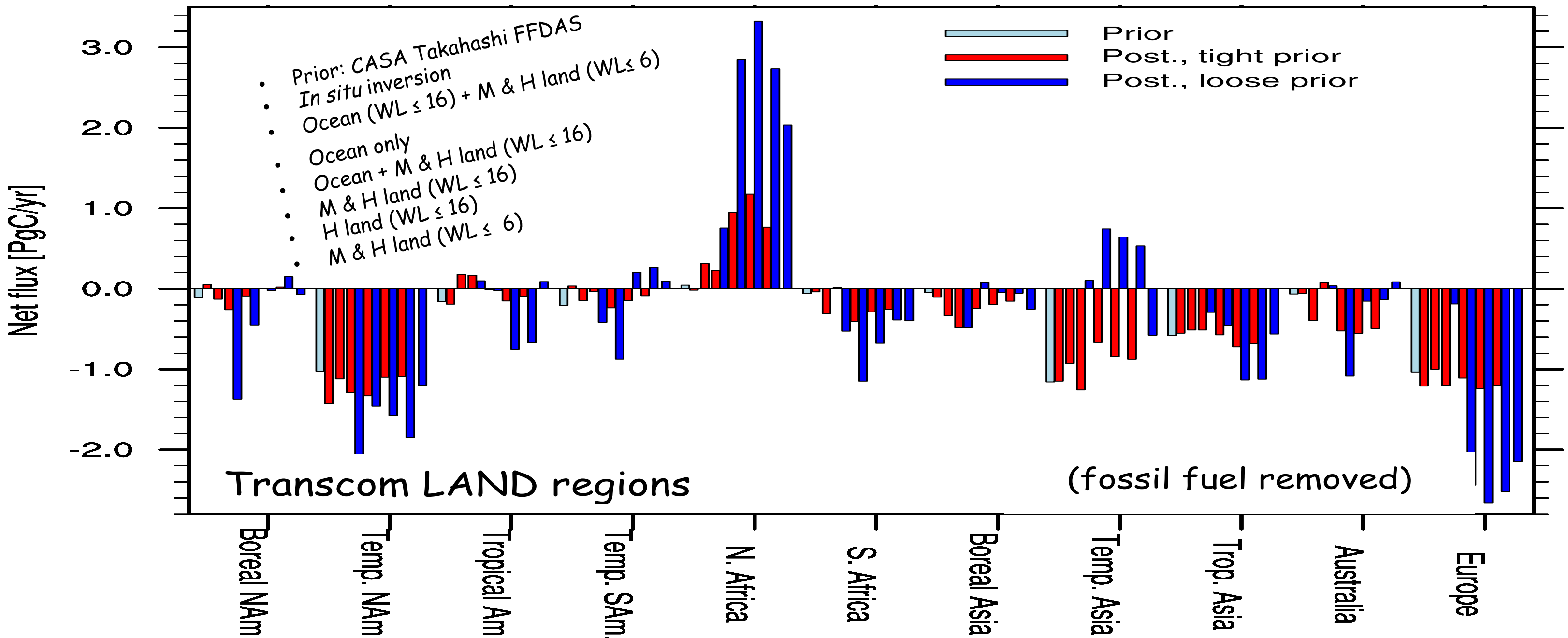
CarbonTracker, which incorporates information from *in situ* CO_2 measurements, fits the GOSAT data better overall than the free-running flux models, but not for all GOSAT data types

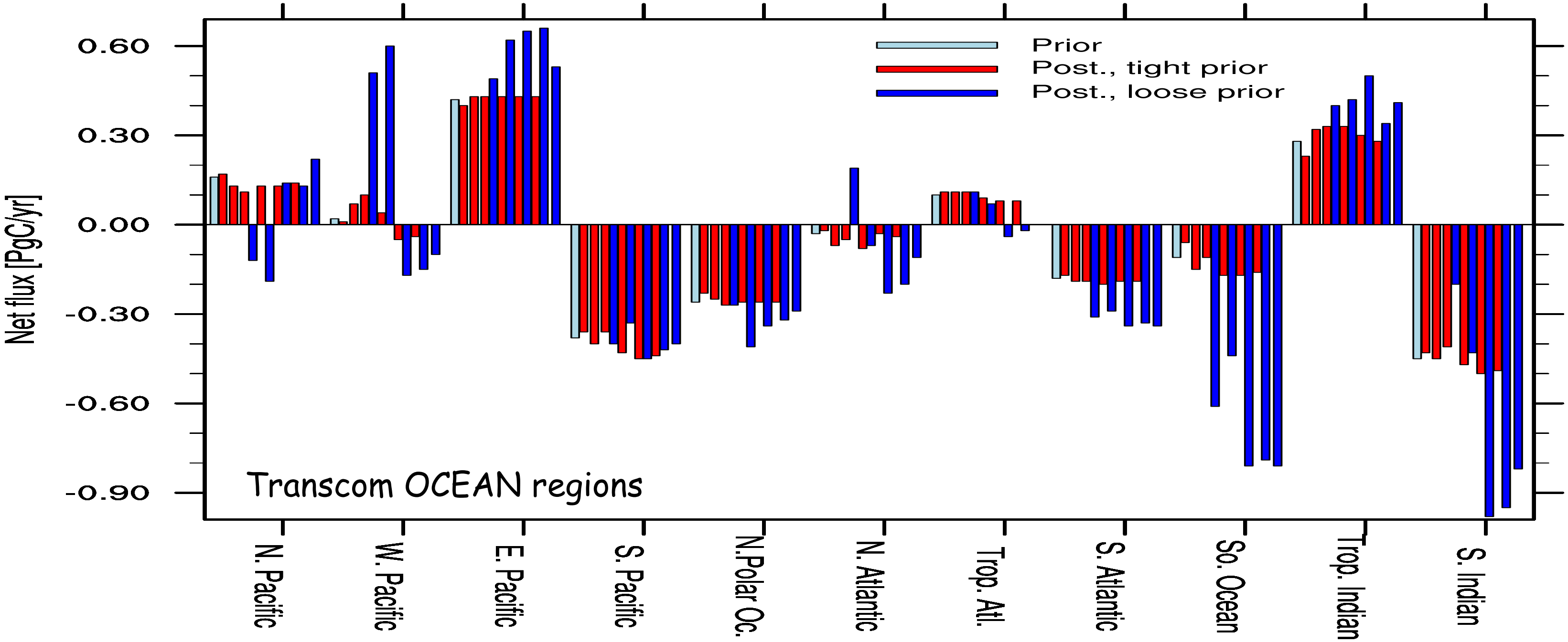
No one land biosphere model or combination of prior fluxes is obviously better than another at fitting the GOSAT data: which model is best depends on the type of GOSAT data.



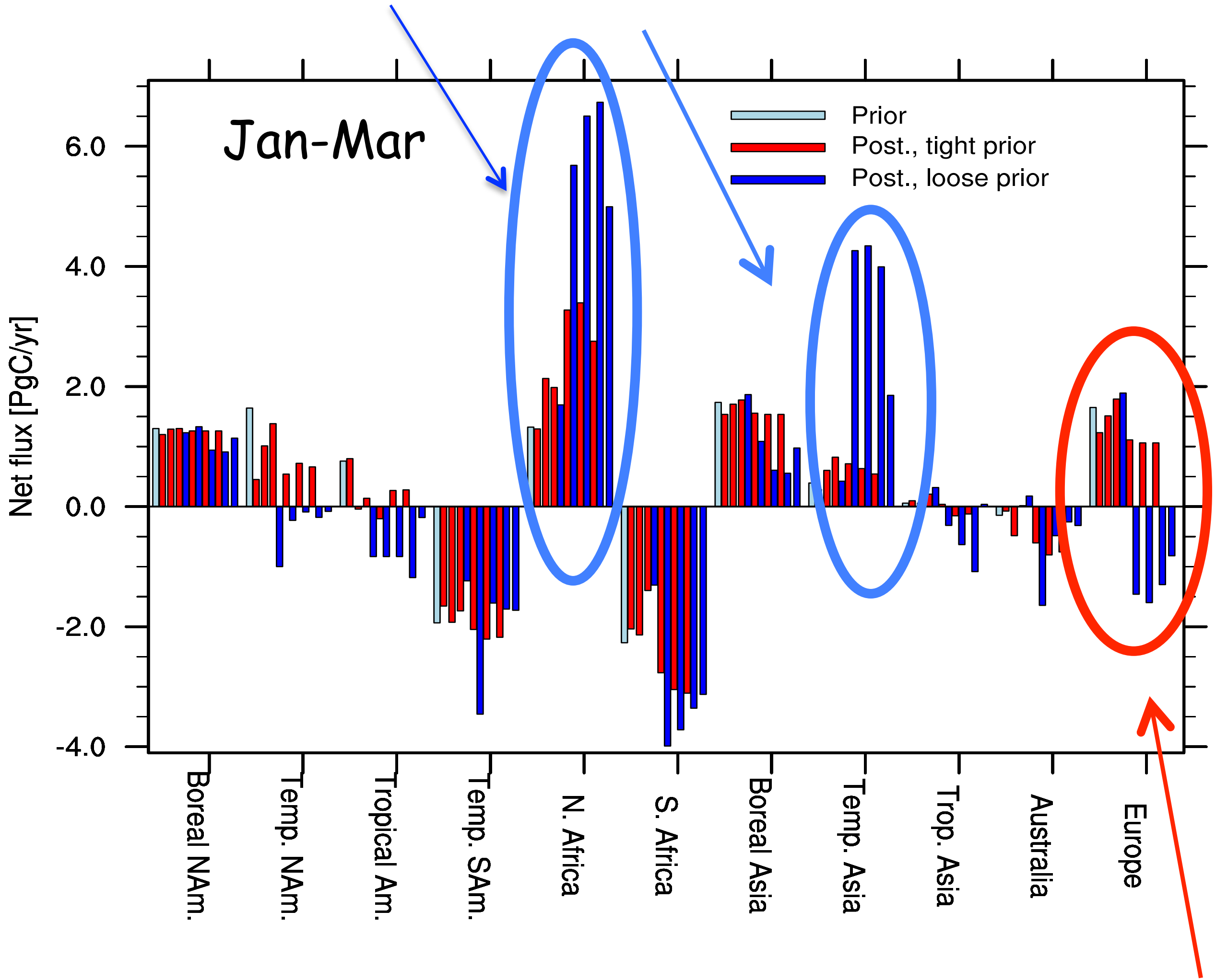
Net annual flux, 2009-2014: starting from different priors
Prior
Post., tight prior
Post., loose prior
GOSAT data used: all ocean glint and M- & H-gain
land data with warning level ≤ 16
In situ inversion
GOSAT, CarbonTracker 2013
GOSAT, SiB4 Doney FFDAS
GOSAT, CASA Takahashi FFDAS
Net flux [PgC/yr]
3.0
2.0
1.0
0.0
-1.0
-2.0
Transcom LAND regions
(fossil fuel removed)
Boreal NAm.
Temp. NAm.
Tropical Am.
Temp. SAm.
N. Africa
S. Africa
Boreal Asia
Temp. Asia
Trop. Asia
Australia
Europe
Prior
Post., tight prior
Post., loose prior
Net flux [PgC/yr]
0.60
0.30
0.00
-0.30
-0.60
Transcom
OCEAN
regions
N. Pacific
W. Pacific
E. Pacific
S. Pacific
N.Polar Oc.
N. Atlantic
Trop. Atl.
S. Atlantic
So. Ocean
Trop. Indian
S. Indian

Net annual flux, 2009-2014: using different GOSAT data subsets





The GOSAT-driven outgassing in North Africa and Temp. Asia, is centered during the NH winter.

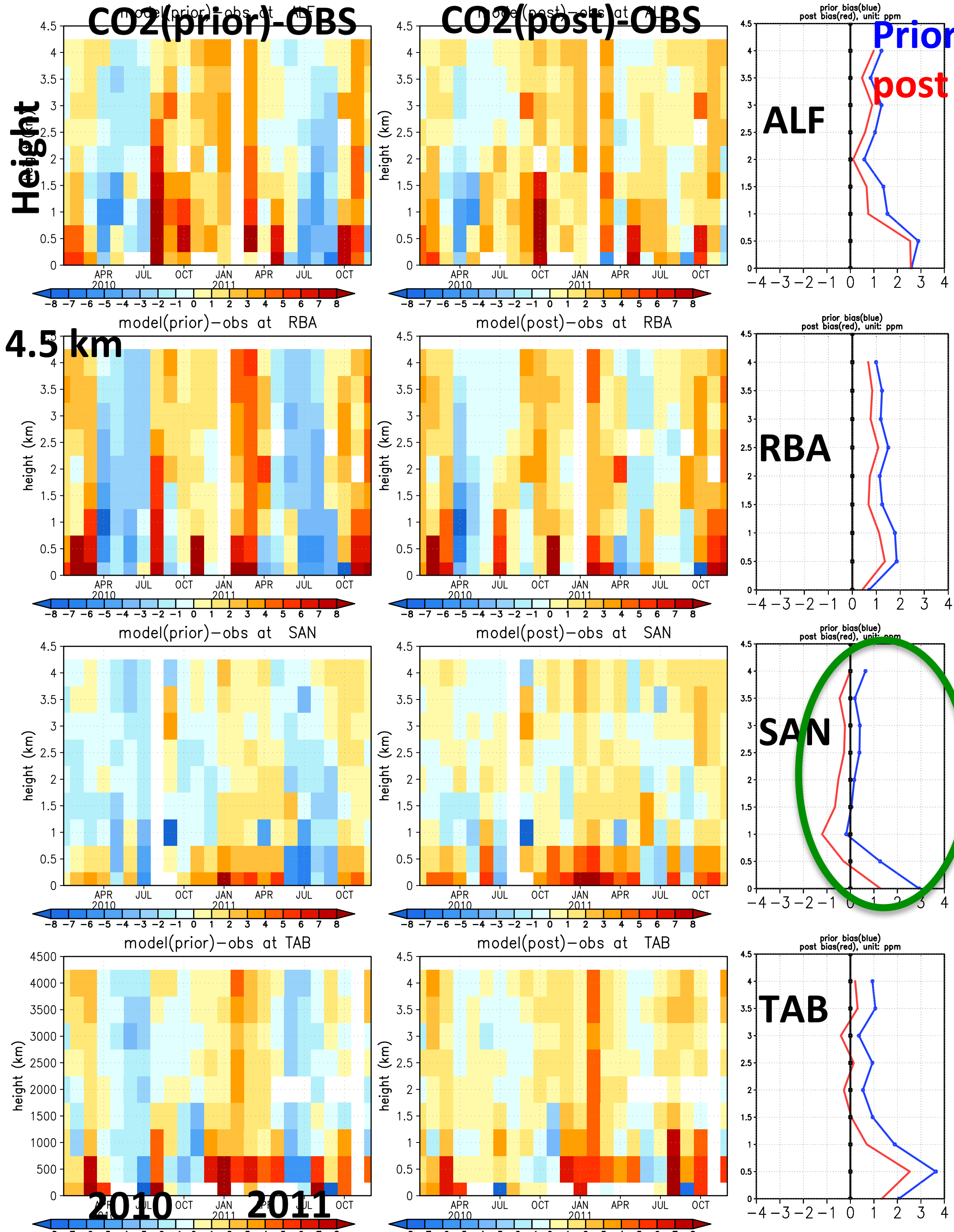


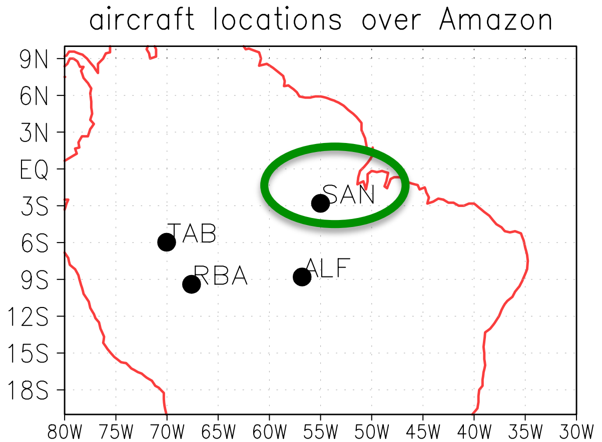
The GOSAT data want to drive Europe towards a large uptake of CO_2 in the NH winter – unphysical !!

Thoughts on ACOS b3.5 GOSAT data, inversions

- Results depend less on the prior, more on the subset of GOSAT data used
- GOSAT M- and H-gain land data have biases that drive winter CO_2 outgassing in North Africa & Temp. Asia, with balancing uptake in Europe and elsewhere
- Using ocean glint data, and a reasonably-tight flux prior, mitigate the worst of this
- Warn-level filtering of M- and H-land data only partly successful: an improved bias correction needed for GOSAT land data
- GOSAT land data provide information not contained in ocean data – should be used, but bias-corrected first
- Comparison to independent data can guide the bias-correction

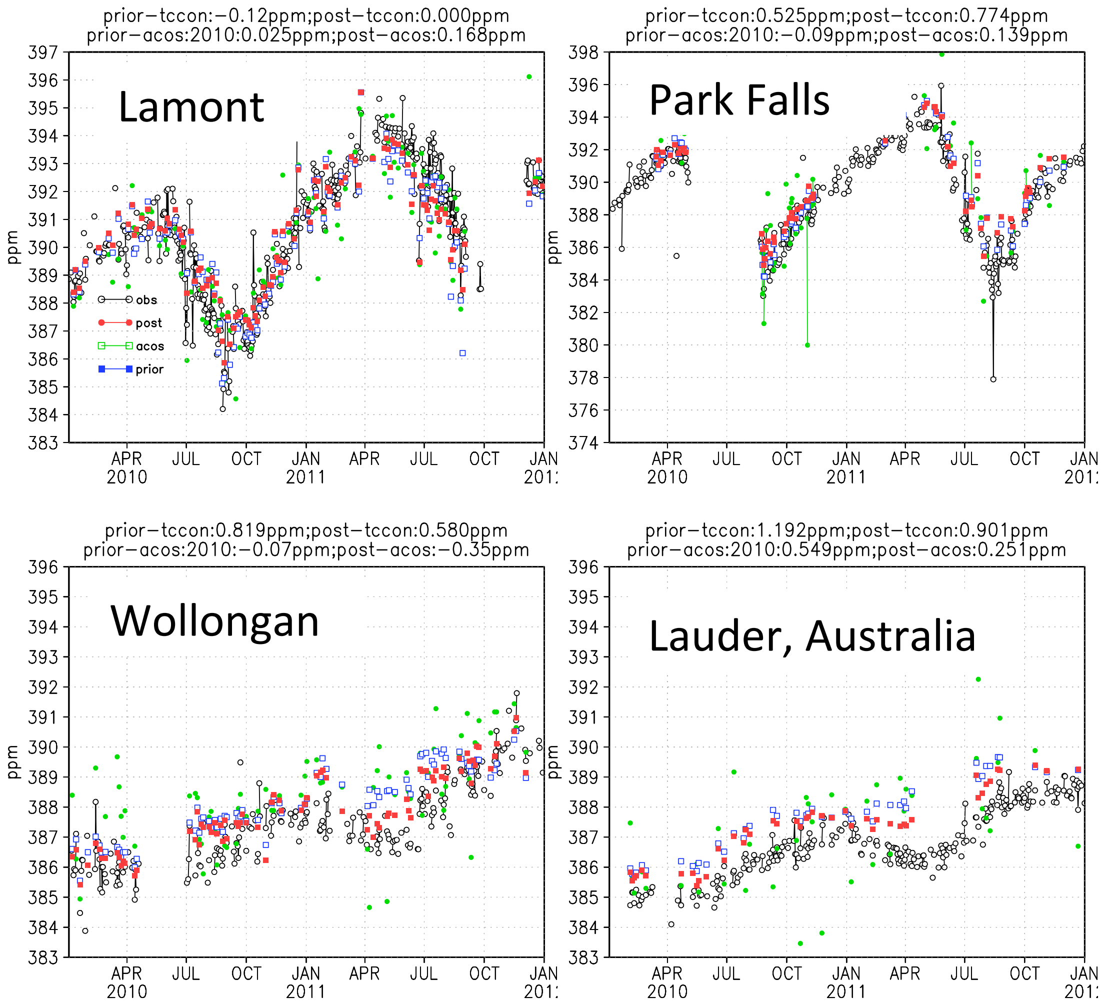
Verification against aircraft observations over Amazonia





- The mean posterior CO_2 bias is less than 1 ppm above 1 km.
- The posterior CO_2 bias is smaller than the prior CO_2 bias except in SAN

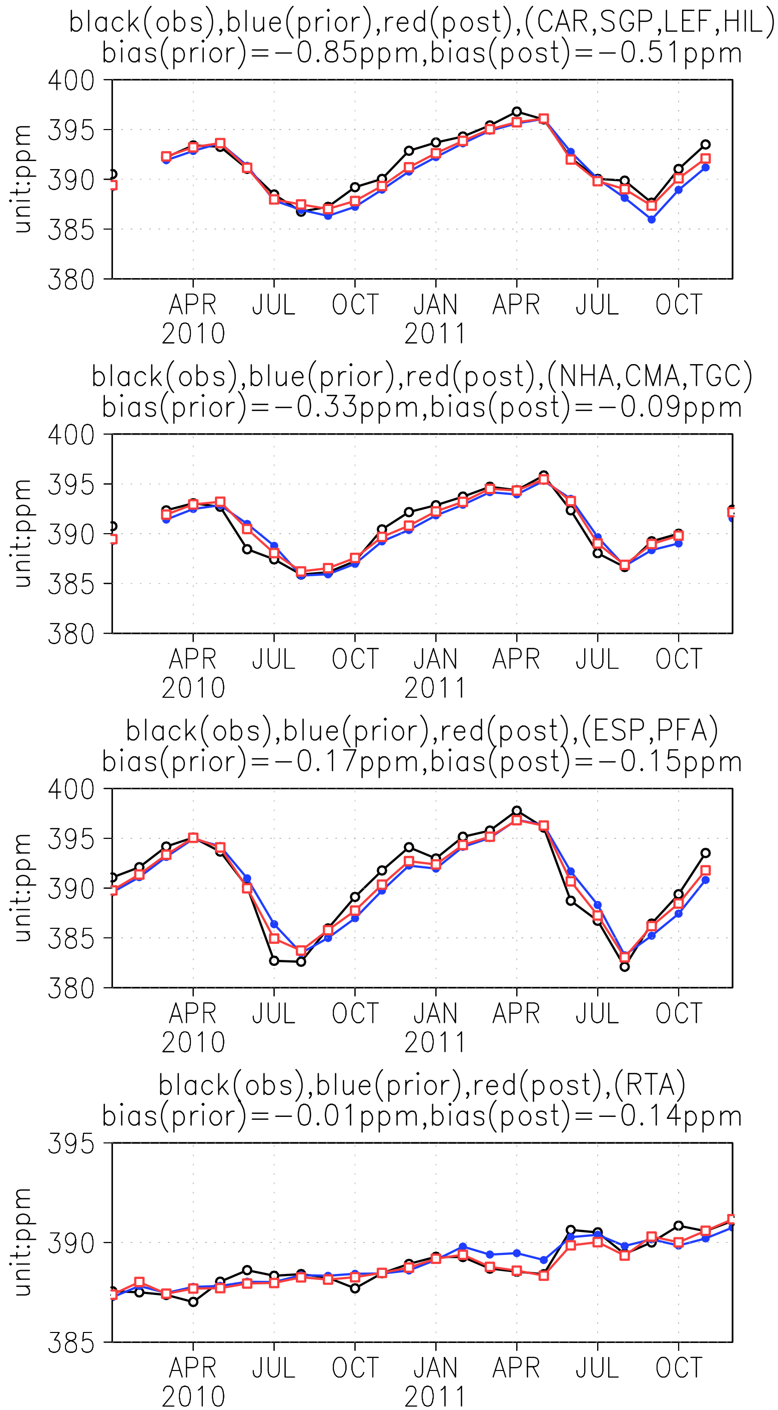
Verification against TCCON X_{CO2} observations

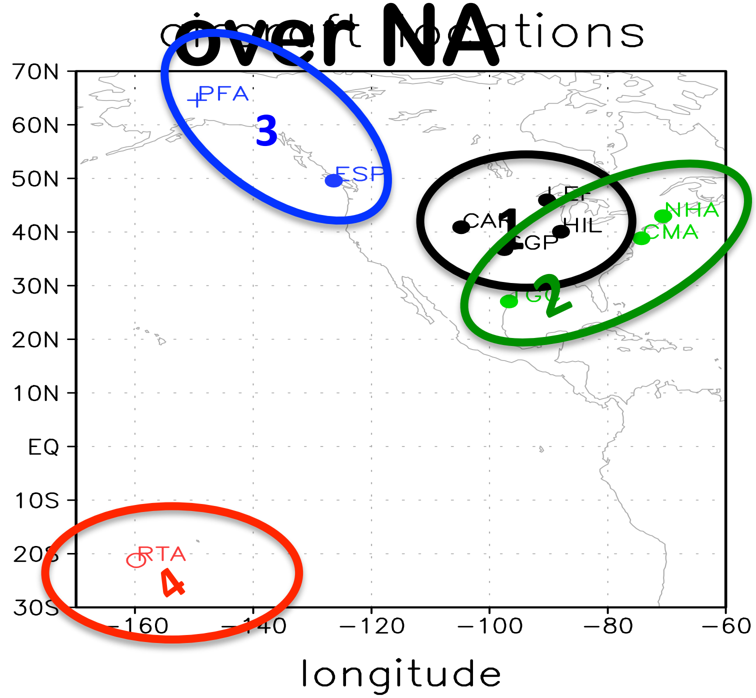


Black: TCCON
Green: ACOS
Blue: prior
Red: posterior

- **The overall bias between posterior modeled X_{CO2} and TCCON X_{CO2} is less than 1 ppm.**
- **Assimilating ACOS observations has improved the fitting to TCCON X_{CO2} observations.**

Verification against aircraft observations over NA





- The posterior CO_2 seasonal cycle has been improved and the bias becomes smaller.