Regional flux estimates of CO2 and CH4 inferred from GOSAT XCH4:XCO2 ratios

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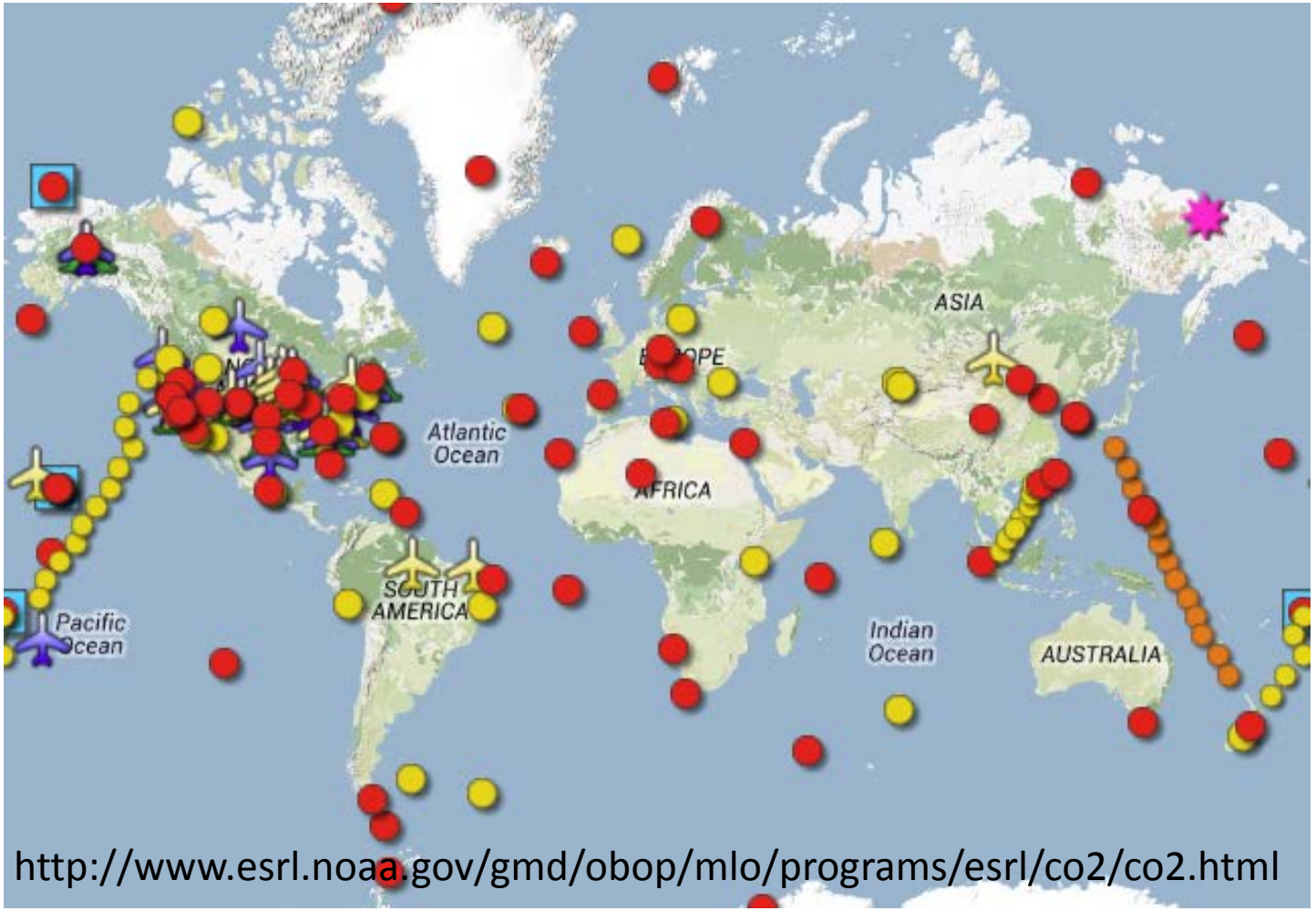
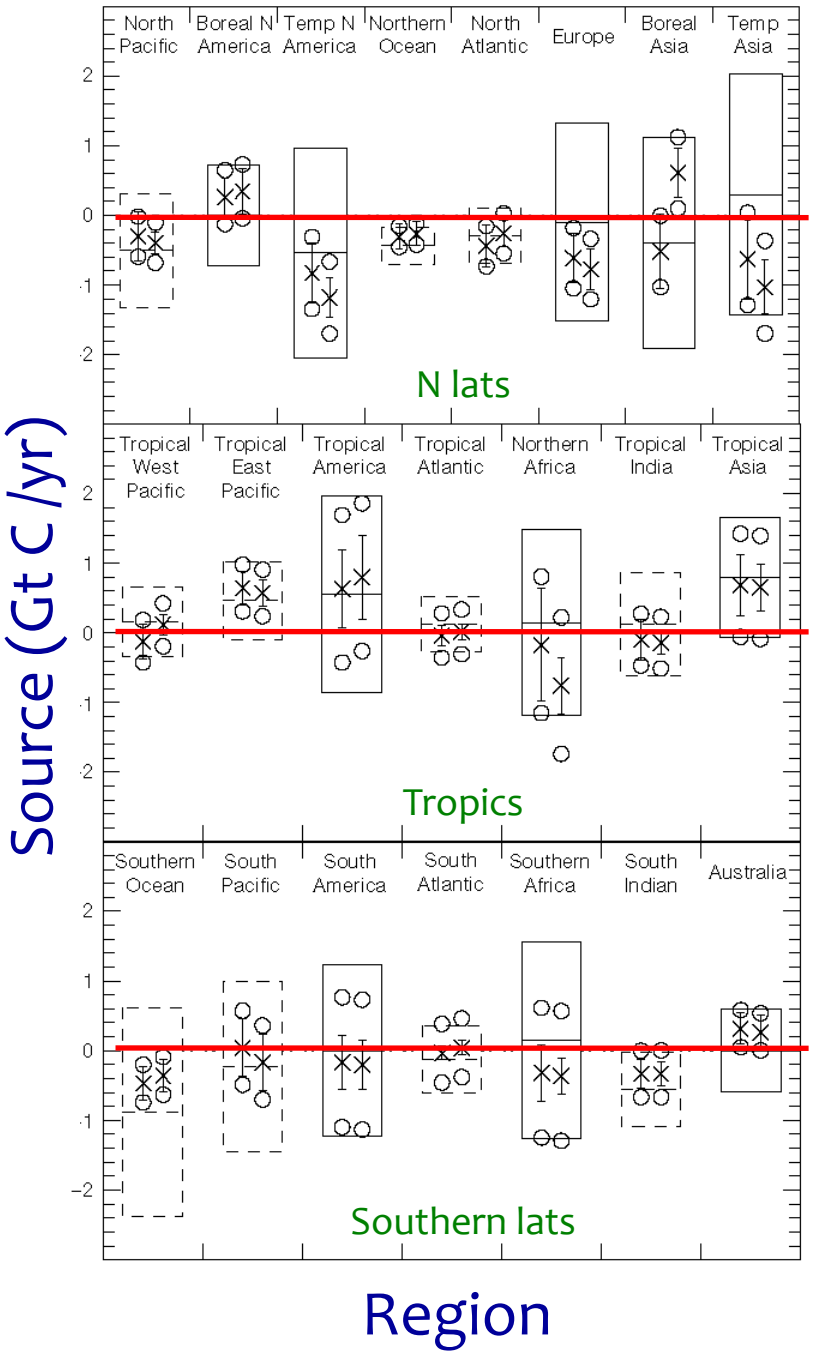
NERC SCIENCE OF THE ENVIRONMENT

Surface in situ CO_2 mole fraction measurements have provided useful insights on large-scale surface fluxes.

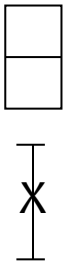


But the measurement network is sparse with particular gaps at higher (e.g., Siberia) and tropical latitudes. This has implications.

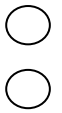
Gurney et al, 2002



CO2 flux estimates have not been significantly improved for 10-15 years



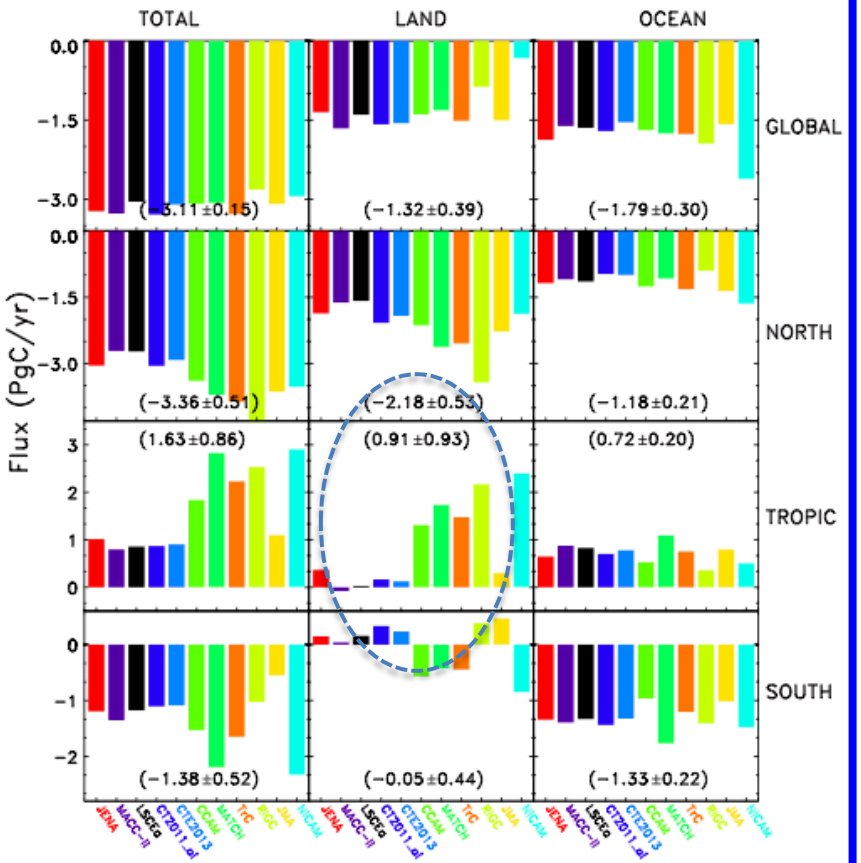
$\mu_k^{prior} \pm \sigma_k^{prior}$



Mean ($\sigma_{mk}^{posterior}$)

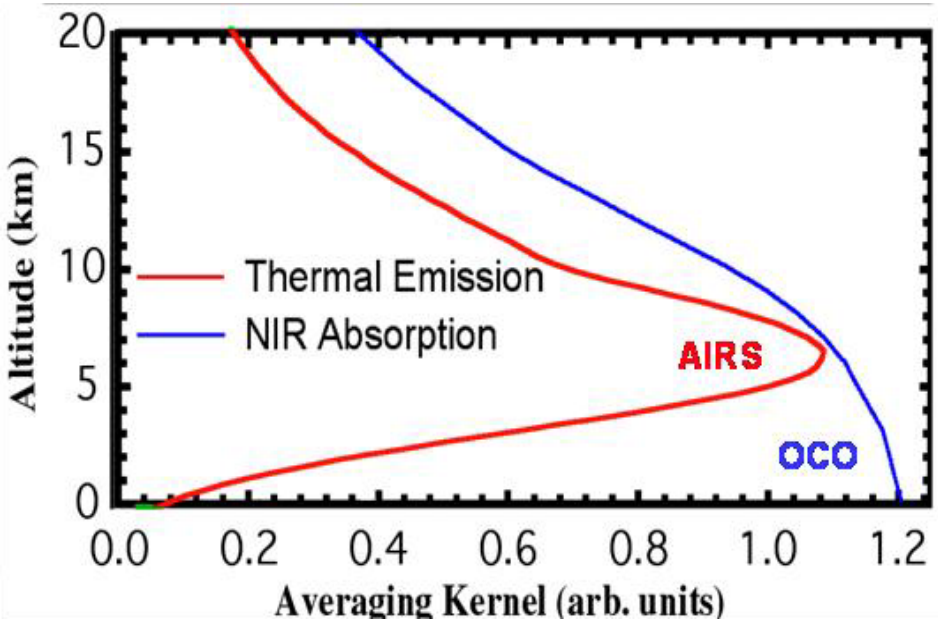
Mean, std_dev ($\mu_{mk}^{posterior}$)

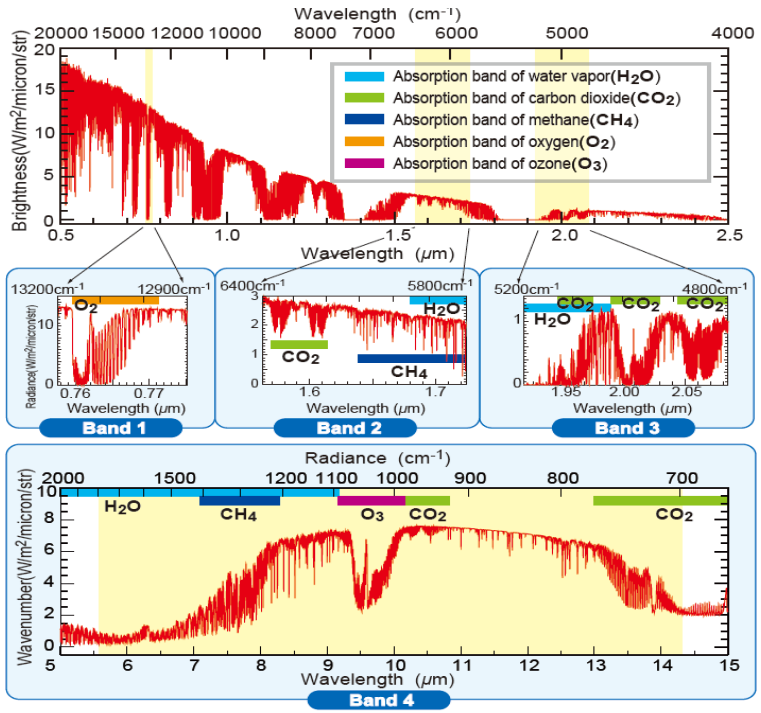
Peylin et al, 2013



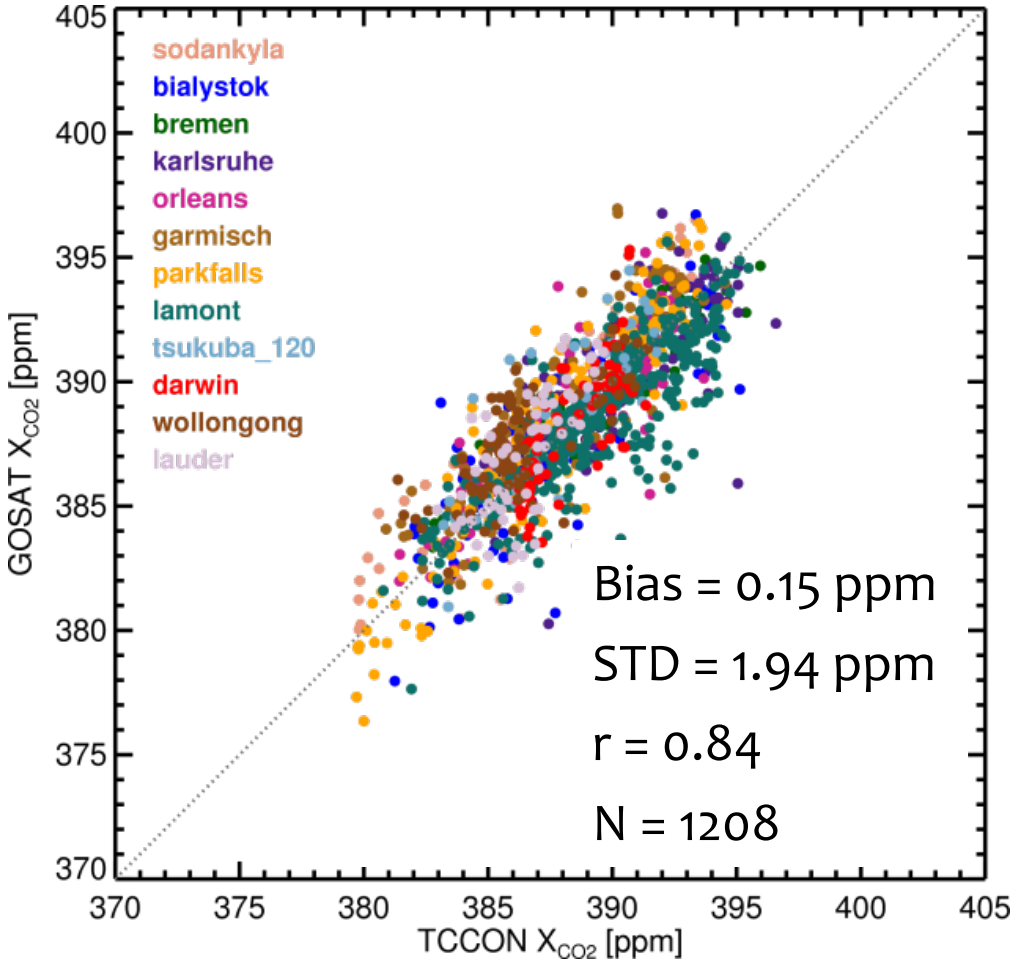
Greenhouse gases Observation SATellite (GOSAT): space-borne GHG data show great promise

- Designed to measure dry-air CO2 and CH4 columns to a precision necessary for flux estimation.
- Launched January 23, 2009 in sun-synchronous orbit.





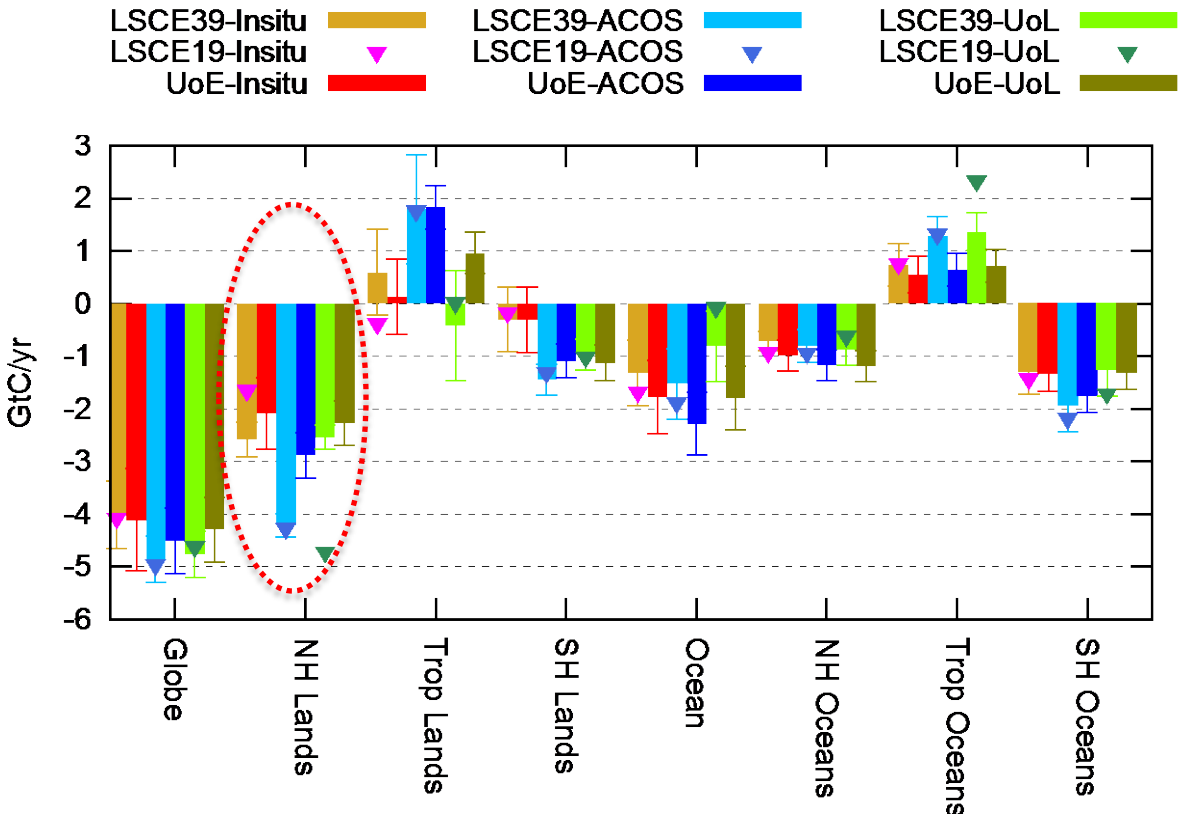
Quality of GOSAT XCO2 retrievals has steadily improved.



Comparison of UoL v4 XCO2 with TCCON *(Parker et al., 2014)*

For our analysis we use bias-corrected H-gain ACOS v3.3 and UoL v4 .0 XCO2 Retrievals.

However, uncharacterized bias compromises GOSAT XCO2



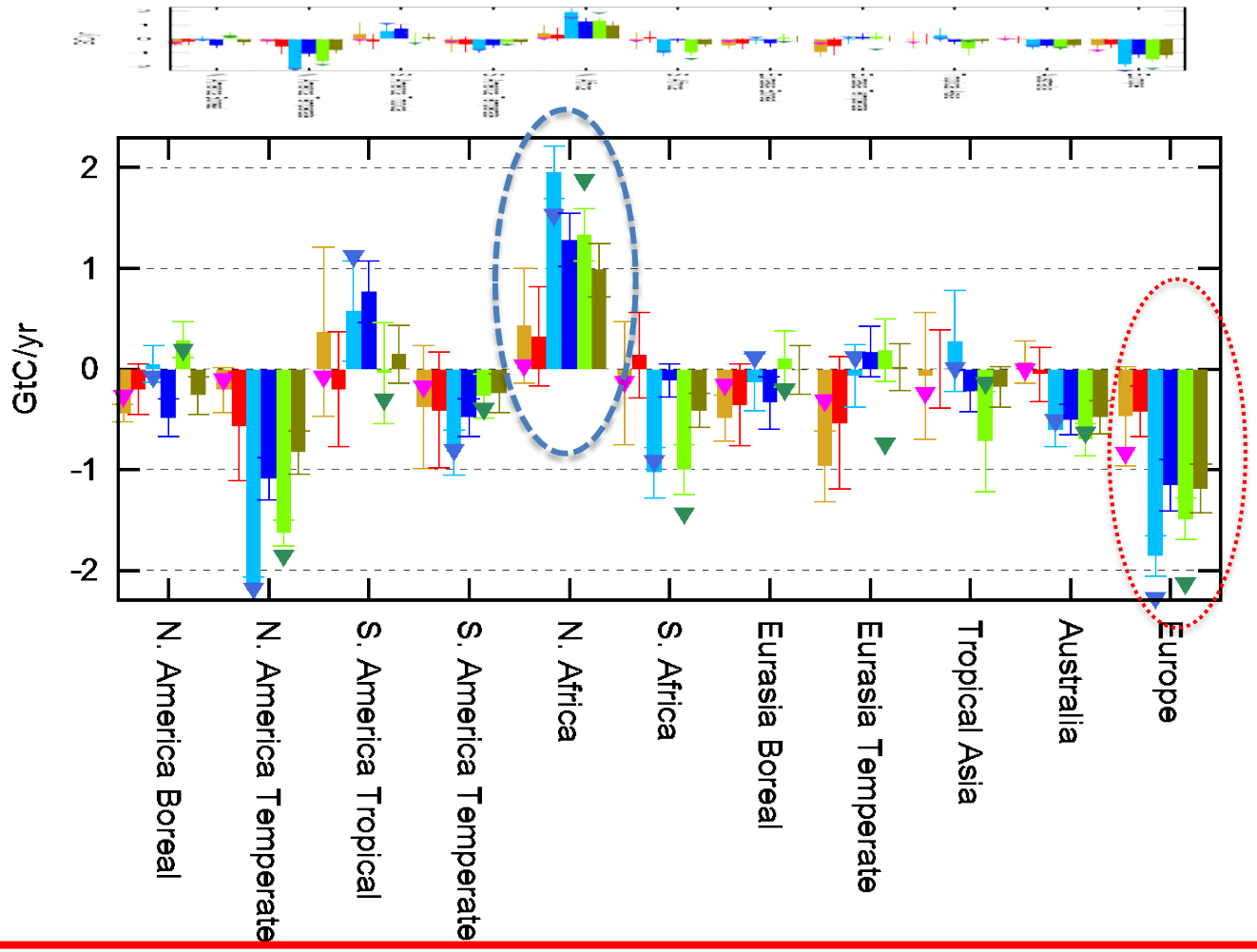
- Two independent models (+related model)
- EnKF and 4D-Var
- Two versions of GOSAT data.
- One version of in situ data

Large spatial scale (annual scales):

- Good agreement between in situ data inferred estimates (except where there is little data!)
- Significant disagreements between the various GOSAT-inferred CO2 fluxes; some of them are **far beyond the 1-sigma level.**

Chevallier, Palmer, Feng et al, 2014

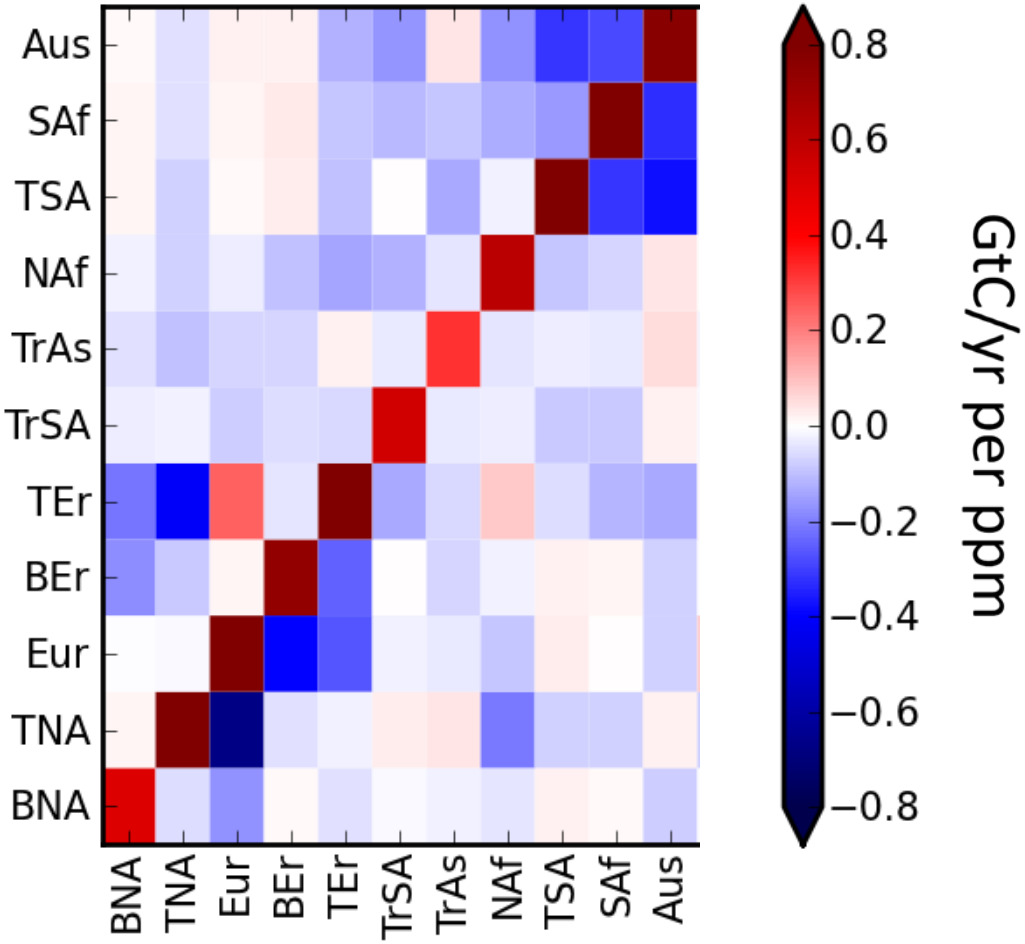
Bias over one region impacts others by mass balance



- Generally, less of a clear message once we consider continental scale geographical regions.
- Like in-situ inversions, model transport errors have significant adverse impacts.
- There are also issues particularly related to GOSAT inversions.

Option #1 (of 2): estimate regional bias

- The Goldilocks principle of bias
- Non-trivial to determine the effect of regional bias



The bias sensitivity matrix (EnKF):

Regional flux sensitivity to systematic perturbation of regional bias

- widely spread ('magnified' by atmospheric transport).
- highly correlated.
- different from posterior error correlation for random errors.

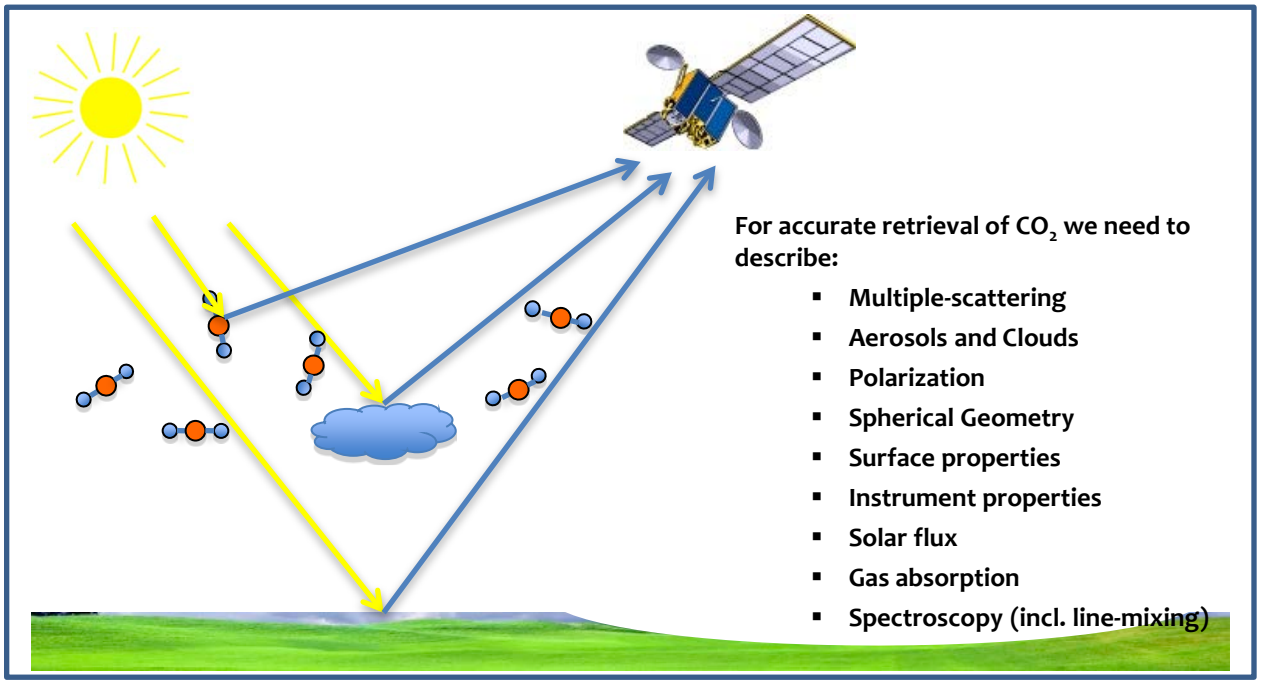
Feng, Palmer et al, *in prep*

Option #2 (of 2): use a new GOSAT data product

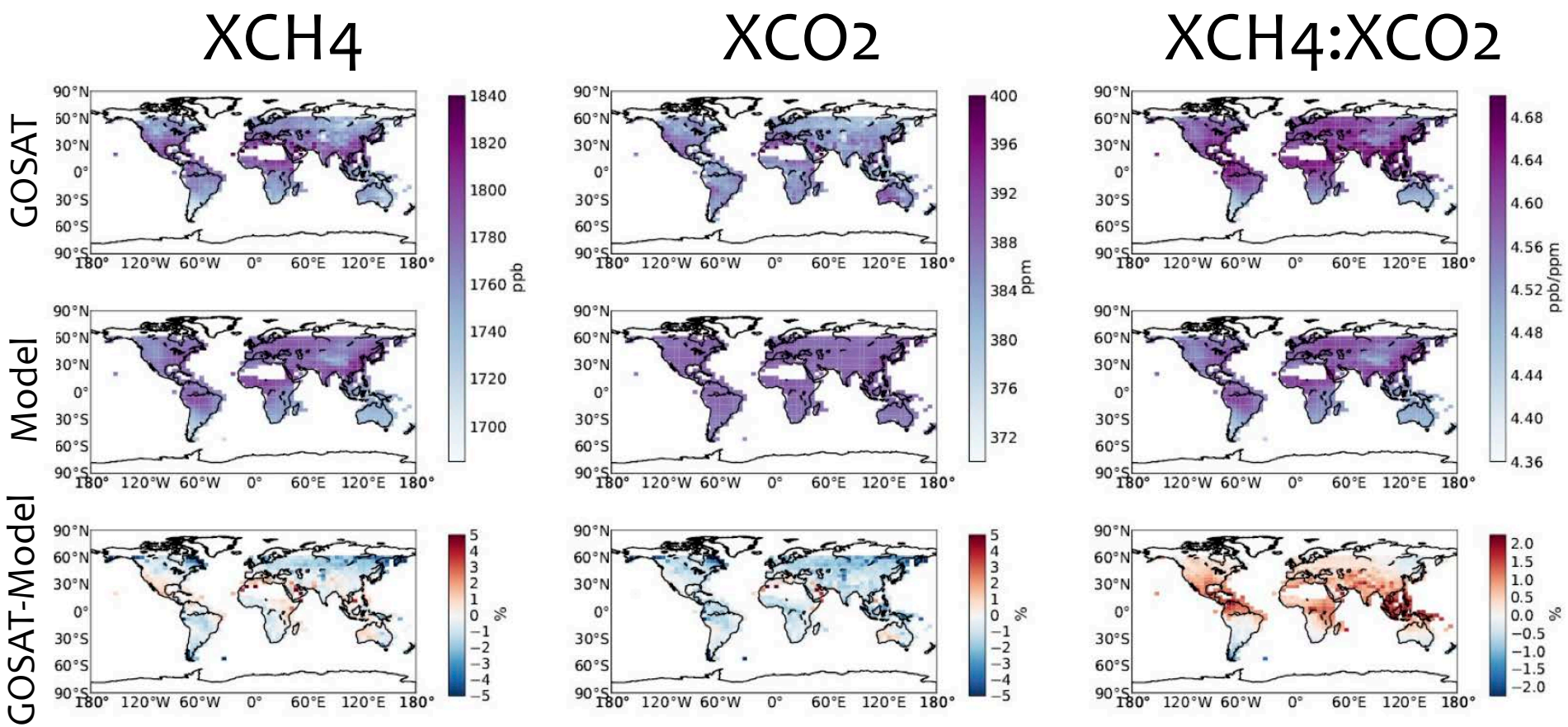
- We can directly use a XCH4/XCO2 data product
- Fits CO2 band at 1.61 mm & 1.65 mm CH4
- Key assumption: clouds and aerosols affect both gases the same way
- **Advantages:**

⌘ Product more bias-free, but subject to error from high cirrus clouds

⌘ Lots more data than the full-physics approach

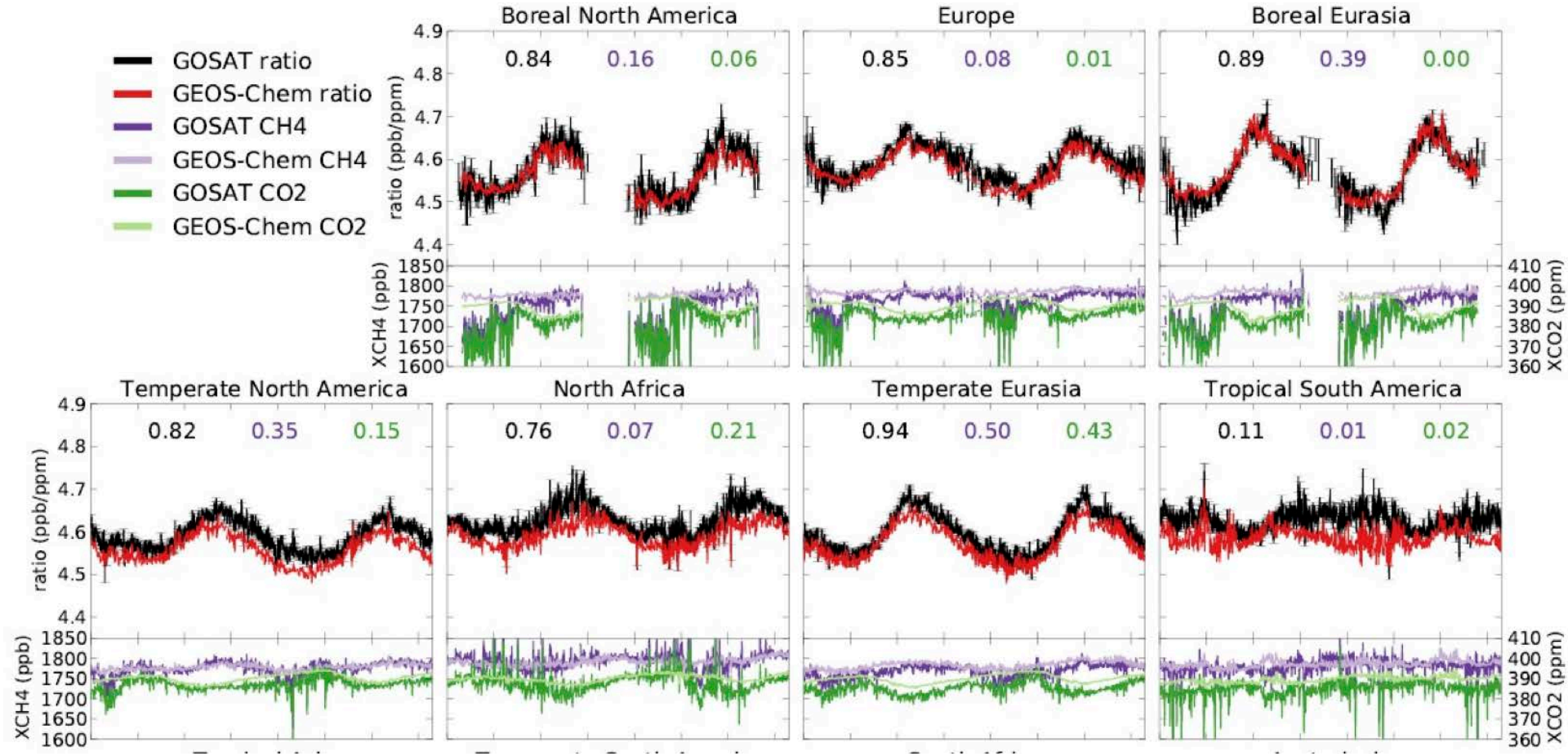


Good agreement in the XCH4:XCO2 ratio!



Fraser, Palmer, Feng et al, 2014

Regional time series show the importance of the ratio



- Clearly identify regions with large model bias
- It is possible to reconcile the data using either CO2 or CH4 but a mix is more likely

Fraser, Palmer, Feng et al, 2014

The efficacy of the MAP approach relies on correctly modelling the covariance between CH4 and CO2

Posterior state vector

Observation operator

State vector covariance

$$\mathbf{x} = \mathbf{x}_a + (\mathbf{H}^T\mathbf{R}^{-1}\mathbf{H} + \mathbf{P}^{-1})^{-1}\mathbf{H}^T\mathbf{R}^{-1}(\mathbf{y}_{obs} - \mathbf{H}\mathbf{x}_a)$$

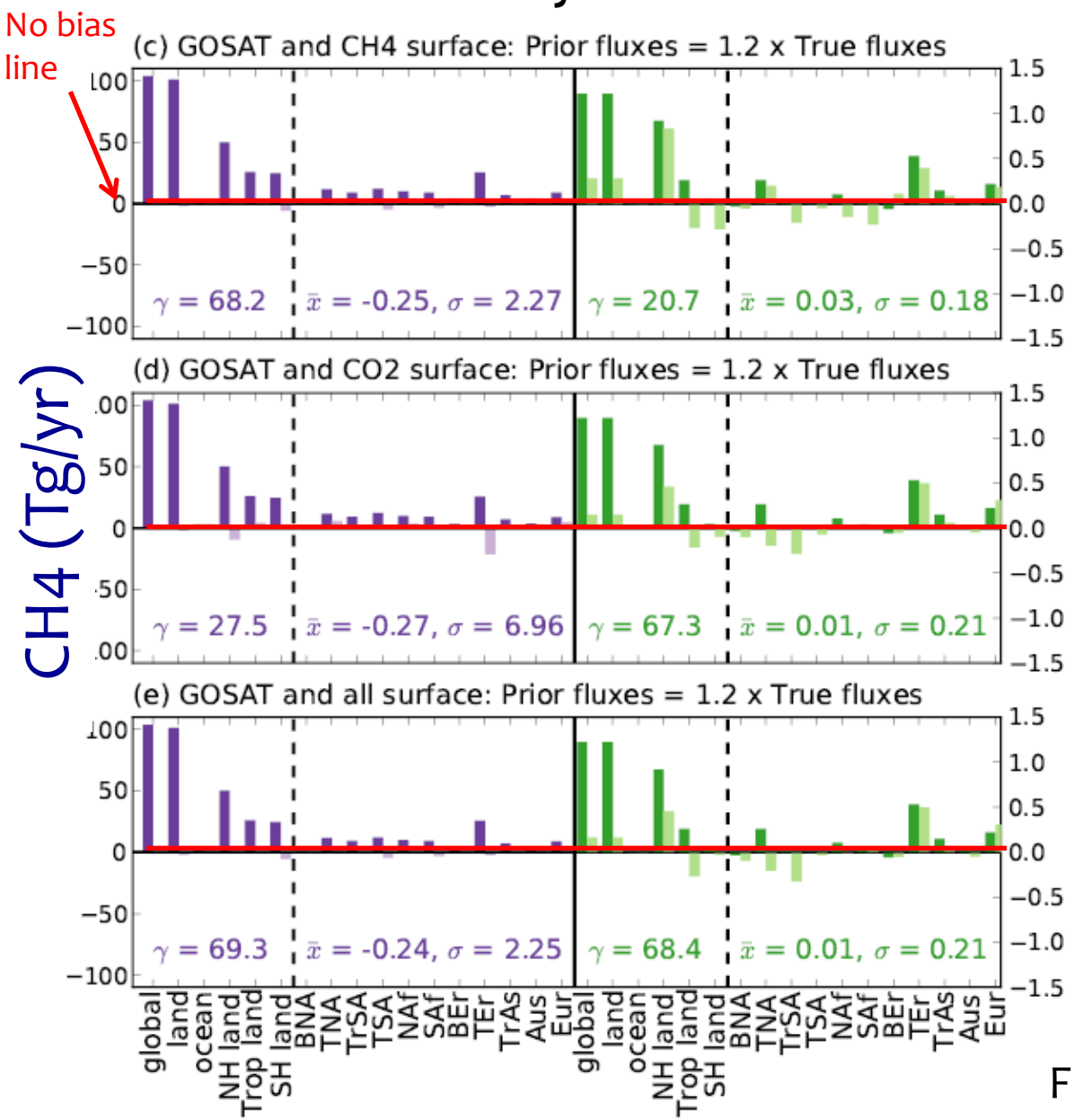
Prior state vector

Obs covariance

Observations

- Weak covariance in the prior sources: biomass burning is the only common source
- We have to yet to introduce a transport model error
- To improve the CH4/CO2 effectiveness on CO2 we also fit independent surface measurements of CH4 mole fraction from NOAA
- We have ignored minor sources of error from spectroscopy, …

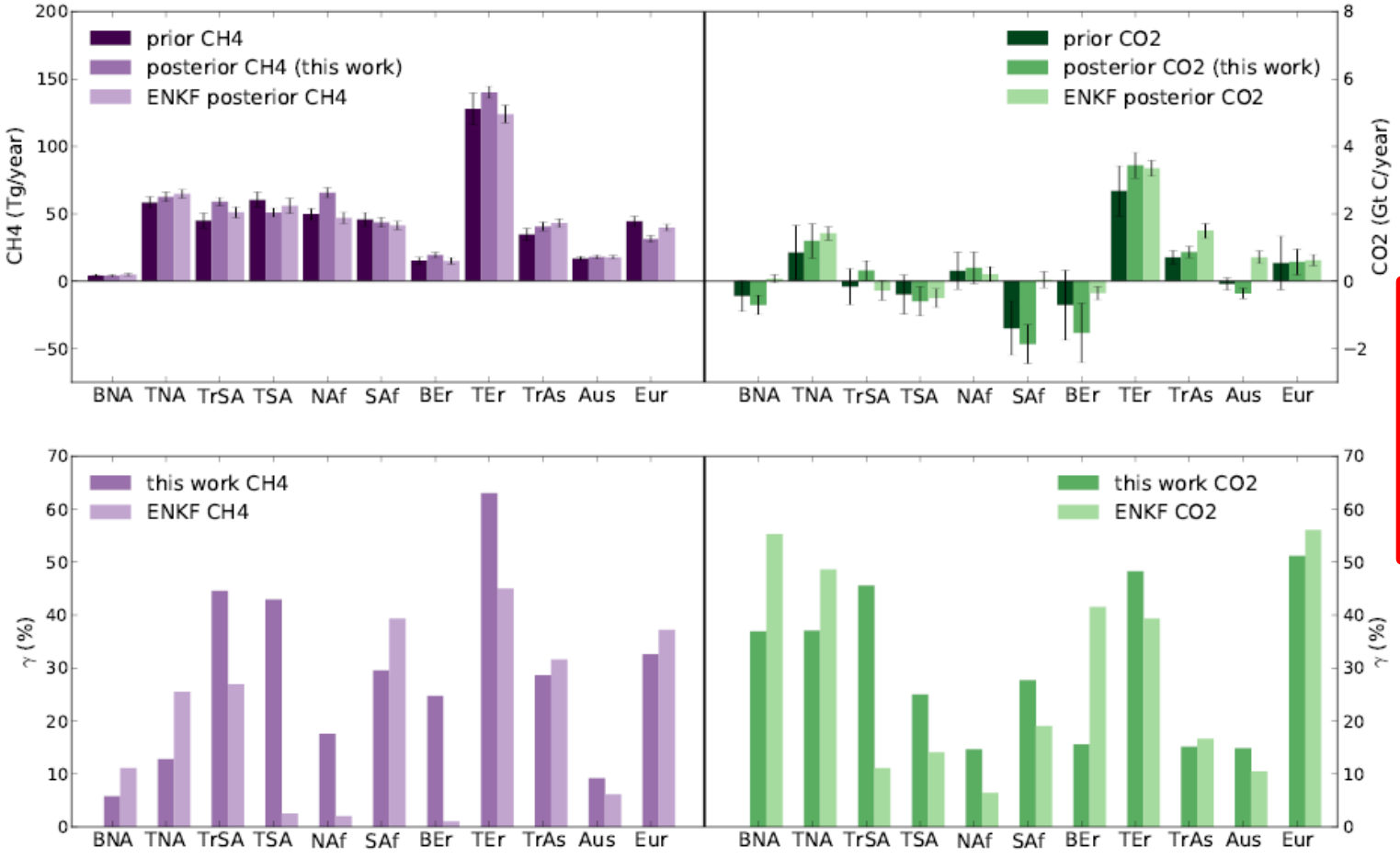
OSSEs show the method is able to simultaneously estimate CO2 and CH4 fluxes



- Control, perfect knowledge run works
- Simultaneously fitting in situ data improved the effectiveness of the CO2 flux estimation
- In theory, our method works…

Fraser, Palmer, Feng et al, 2014

CO2, CH4 fluxes inferred from GOSAT XCH4:XCO2 data are more robust than those inferred from XCO2 or XCH4 data



$$\gamma = 1 - \frac{\hat{S}}{S_a}$$

New method generally leads to greater reductions in uncertainty

Summary

- Uncharacterized GOSAT XCO_2 bias (1,000—10,000 km) compromises their ability to estimate regional CO_2 fluxes.
- We have addressed this:
  ① By estimating regional bias (not shown)
  ② Using a new XCH_4:XCO_2 data product
- The XCH_4:XCO_2 proxy product is less biased and less sparse than the full-physics XCO_2 product.
- We have developed a method to assimilate the XCH_4:XCO_2 data to simultaneously estimate CH_4 and CO_2 regional fluxes
- Results are encouraging and qualitatively consistent with recent work over the Amazon basin, for instance.
- In **future work** we will:
  - Extend the analysis for the length of the GOSAT record
  - Explore how the XCH_4:XCO_2 ratio can be used with other tracers (e.g., CO from IASI or HCHO from GOME-2)

  [GPU technology will improve the speed of this analysis]