The ability of satellite-based CO2 measurements to constrain carbon cycle science: from GOSAT to OCO-2

Chris O'Dell[1] & Hannakaisa Lindqvist[1]

[1] Colorado State University, Fort Collins, CO, USA

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- ACOS Team (JPL, CSU)
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- CarbonTracker Model Output (NOAA)
  - Andy Jacobson et al.
- MACC Model Data (LSCE)
  - Frederic Chevallier
- Univ. of Edinburgh Model Data (UoE)
  - Liang Feng, Paul Palmer

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The utility of remotely sensed CO_2 concentration data in surface source inversions

P. J. Rayner

Cooperative Research Centre for Southern Hemisphere Meteorology and CSIRO Atmospheric Research, Aspendale, Victoria, Australia

D. M. O'Brien

CSIRO Atmospheric Research, Aspendale, Victoria, Australia

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Precision requirements for space-based X_{CO_2} data

C. E. Miller,[1] D. Crisp,[1] P. L. DeCola,[2] S. C. Olsen,[3] J. T. Randerson,[4] A. M. Michalak,[5,6] A. Alkhaled,[5] P. Rayner,[7] D. J. Jacob,[8,9] P. Suntharalingam,[8,9] D. B. A. Jones,[10] A. S. Denning,[11] M. E. Nicholls,[11] S. C. Doney,[12] S. Pawson,[13,14] H. Boesch,[1] B. J. Connor,[15] I. Y. Fung,[16] D. O'Brien,[11] R. J. Salawitch,[1] S. P. Sander,[1] B. Sen,[1] P. Tans,[17] G. C. Toon,[1] P. O. Wennberg,[18] S. C. Wofsy,[8] Y. L. Yung,[18] and R. M. Law[19]

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XCO2 precisions of 1 – 2 ppm are needed on regional scales to improve our knowledge of carbon cycle phenomena

2009: Greenhouse Gases Observing SATellite (GOSAT)

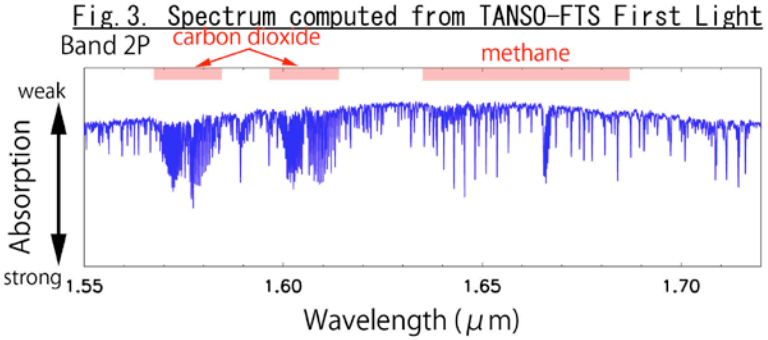
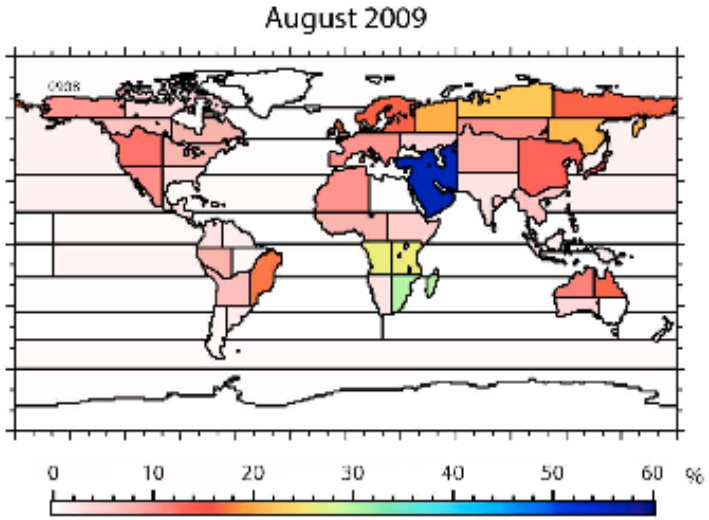


Fig. 3. Spectrum computed from TANSO-FTS First Light

*Redbar shows gas absorption band.

1. Unbiased GOSAT retrievals should help constrain CO2 sources & sinks

- Theoretical work shows that *bias-free* GOSAT observations reduce surface carbon flux uncertainties.
- Chevallier et al. (2011) found uncertainty reductions of 20-60% over land using OSSEs, including the effects of transport model uncertainty.
- Maksyutov et al. (2013) found uncertainty reductions of 15-50% over many land areas relative to GLOBALVIEW, for real GOSAT observations.



Percent Uncertainty reduction in surface fluxes brought by GOSAT relative to surface observations (GLOVALVIEW) alone. From Maksyutov et al. (2013).

2. Biases in GOSAT data can lead to large errors on inverted fluxes.

- Basu et al. (2013) found that a 0.8 ppm bias between land and ocean in GOSAT retrievals was enough to turn the global lands from a sink to a source.
- Chevallier et al. (2014) looked at inversions of ACOS and UoL GOSAT data, using mutiple inversions systems, found that both satellite biases and transport errors can lead to unrealistic inferred surface fluxes.
- **As a result, very few consistent flux inversion results have resulted from GOSAT XCO_2 observations so far.**

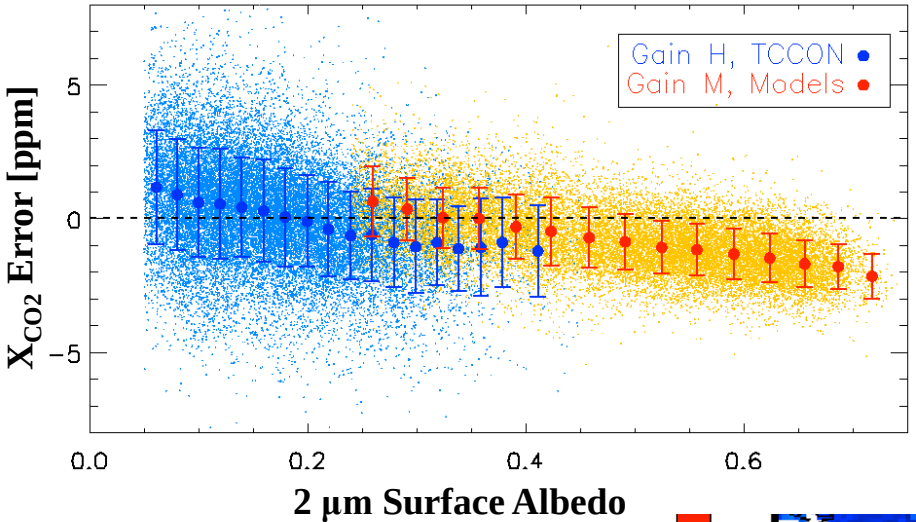
SO…

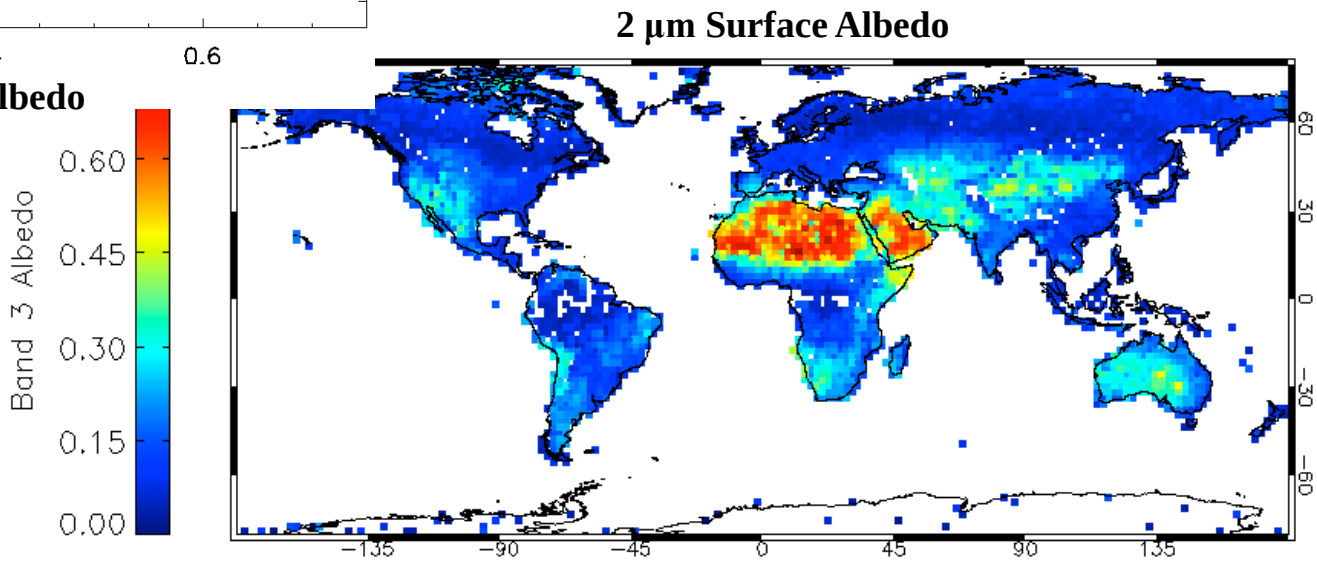
1. How large are errors in **raw** GOSAT retrievals?

2. How large are the errors after bias correction?

RAW GOSAT XCO2 Errors

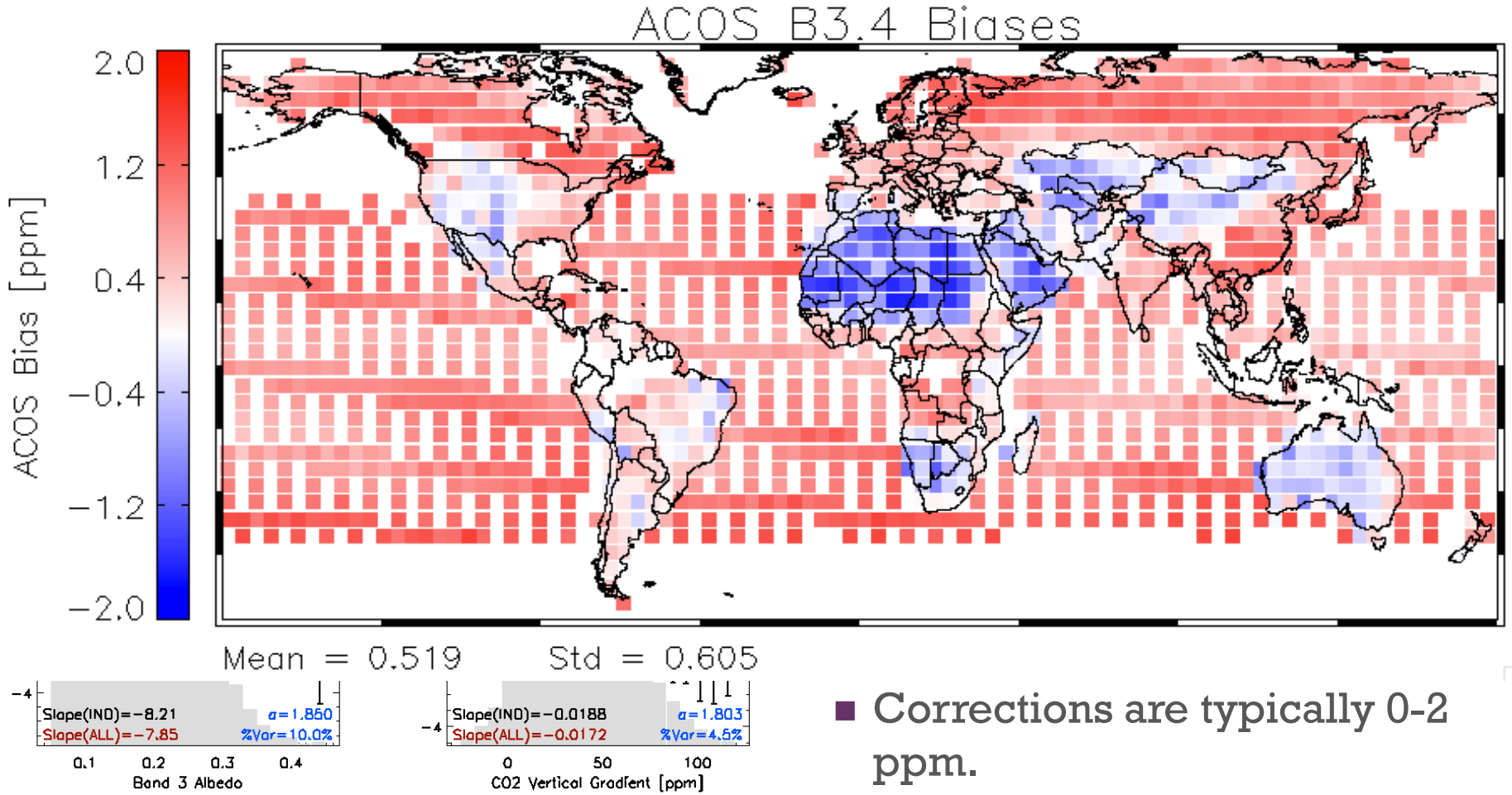
- Raw GOSAT errors can be many ppm, and are often correlated with geophysical parameters such as surface albedo.





+ ACOS Bias Correction Approach

Error vs. Models (Land gain H)



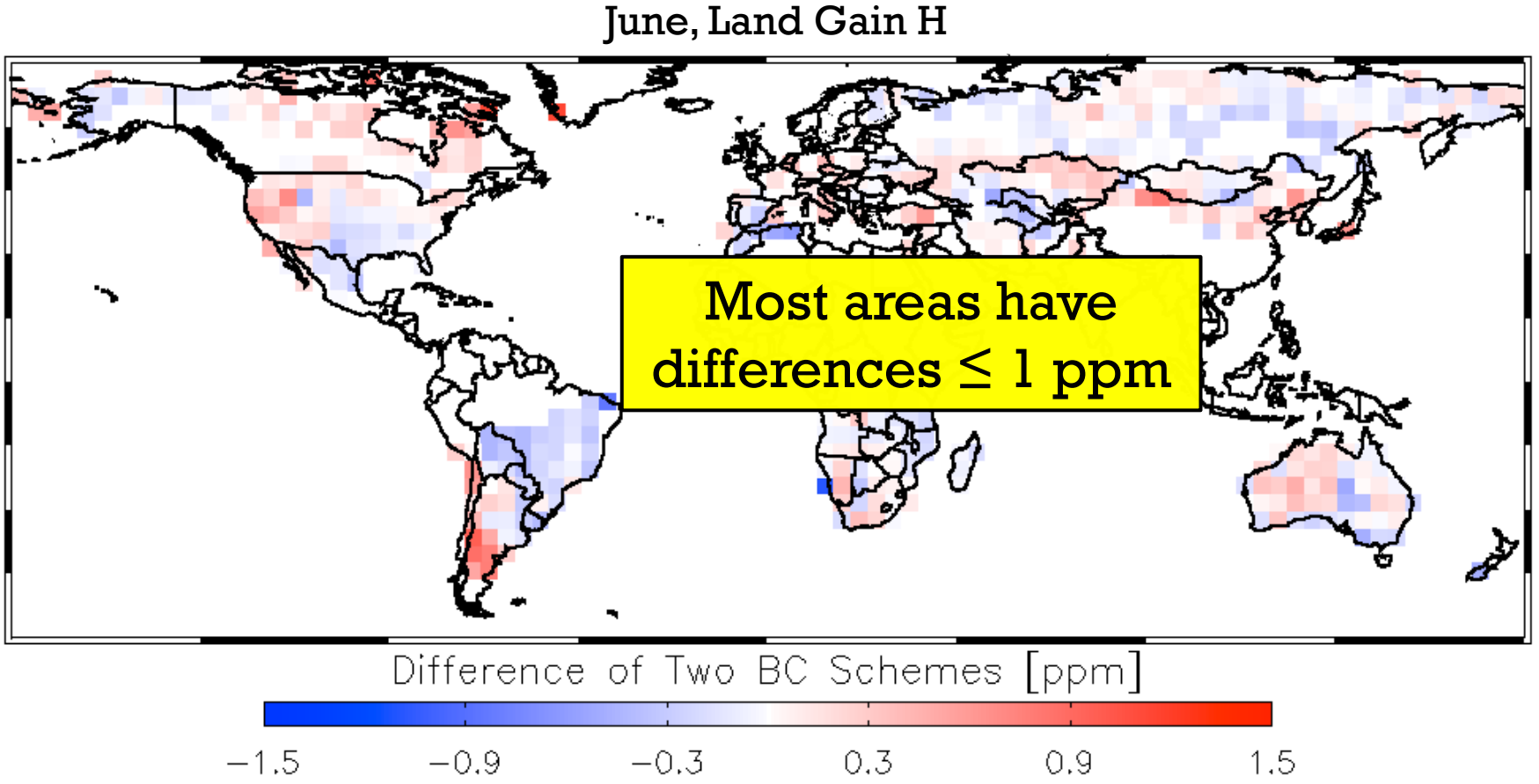
- Corrections are typically 0-2 ppm.

2. How large are the remaining biases?

Method 1: Different regressions

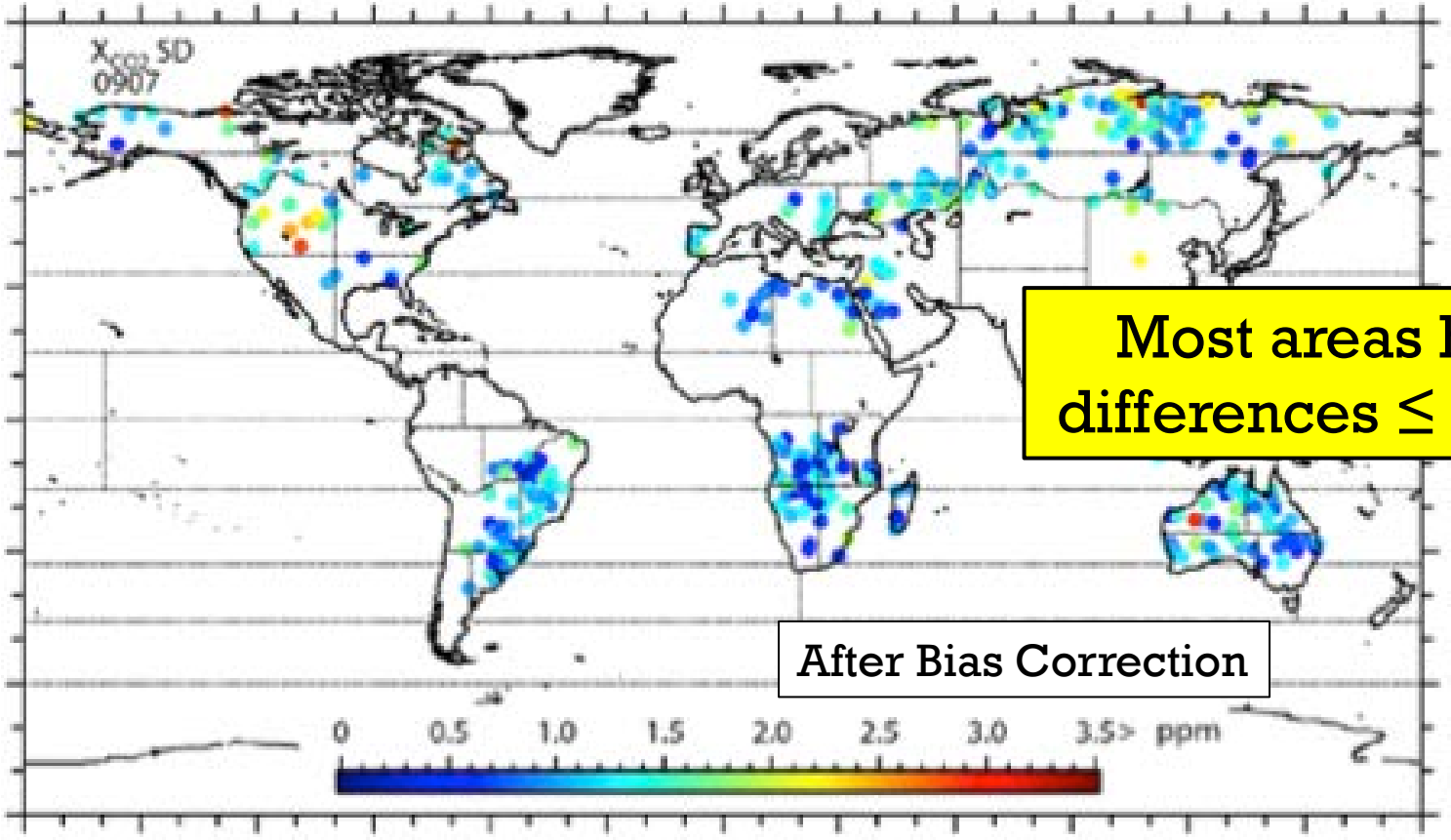
Scheme 1: Albedo_3, Fs, CO2 Vertical Gradient

Scheme 2: Sig3/Sig1, Fs, CO2 Vertical Gradient



How large are the remaining biases?

Comparing different algorithms



Most areas have differences ≤ 2 ppm

July 2009 Inter-algorithm Standard Deviations for 5 GOSAT algorithms:
(RemoTeC, NIES, PPDF-S, UoL, ACOS)

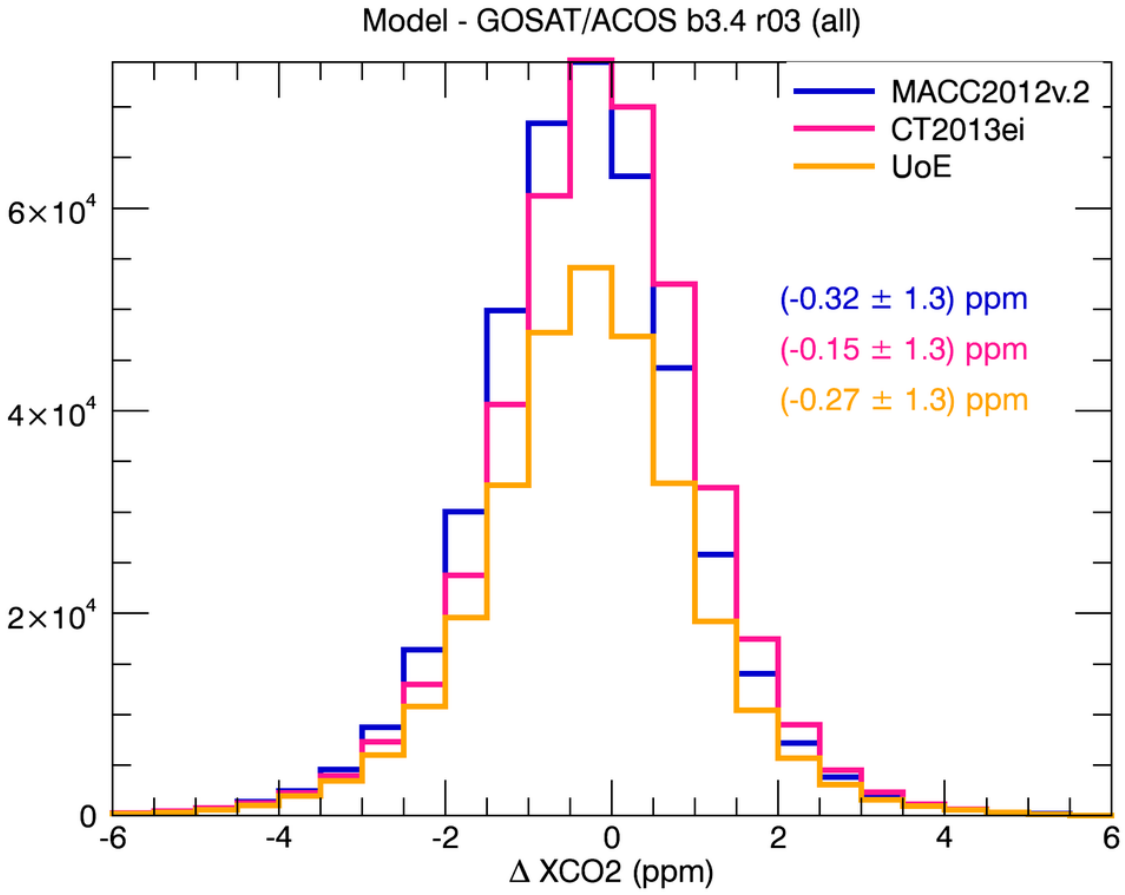
From Takagi et al. (2014)

XCO2 comparisons to models

- Compare retrieved XCO2 to models **directly**
- Only use modelled XCO2 values from fluxes optimized against surface data
- Large (> 1-2 ppm) systematic differences are probably NOT from data biases!
- These diffferences are what inversions will use to change fluxes.

Model	Biosphere/ Fires	Transport	Inversion Type
CarbonTracker 2013ei	CASA/GFED	TM5/ECMWF	EnKF
MACC v12.2	ORCHIDEE	LMDZ/ECMWF	Variational
Univ. Edinburgh	CASA/GFED 3	GEOS-CHEM/GEOS5	EnKF

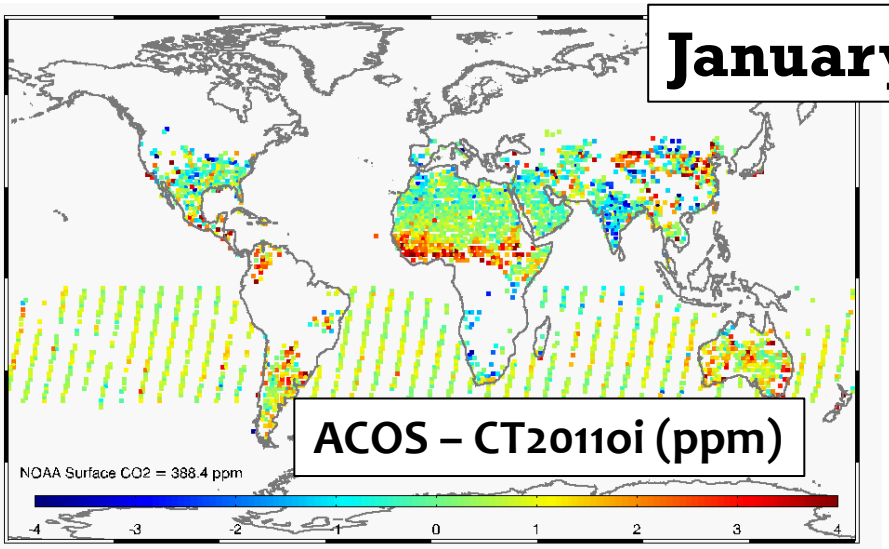
All sounding statistics: Tells us little

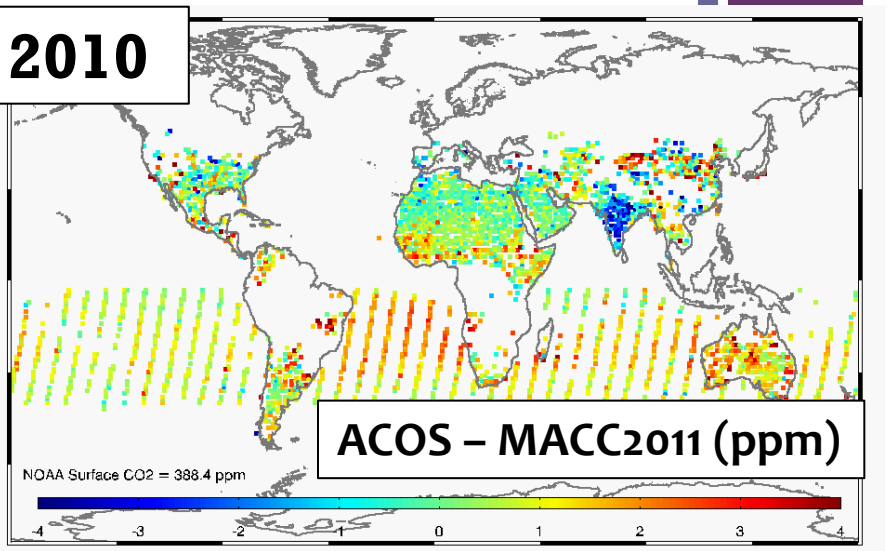


On average:

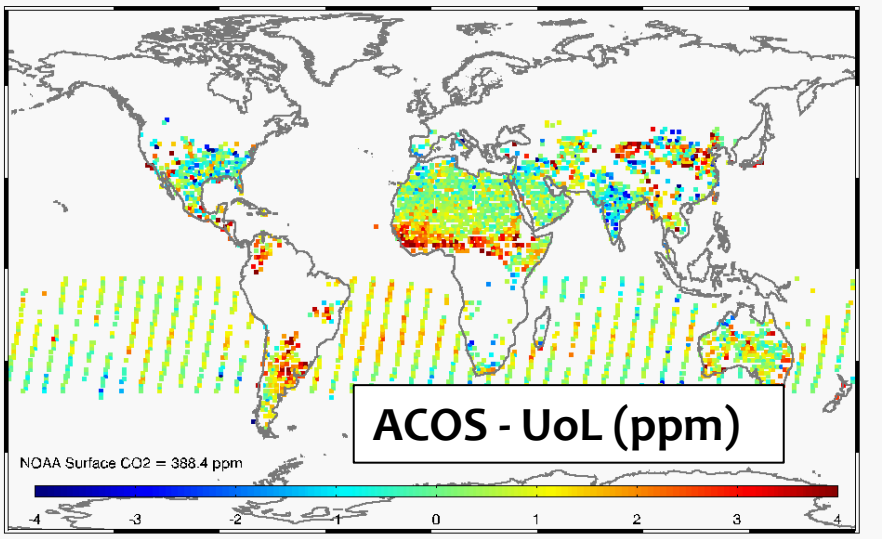
- models give lower values compared to ACOS*
  (ACOS overall level set via TCCON comparisons)
- Don't learn much otherwise

+ Monthly Averages



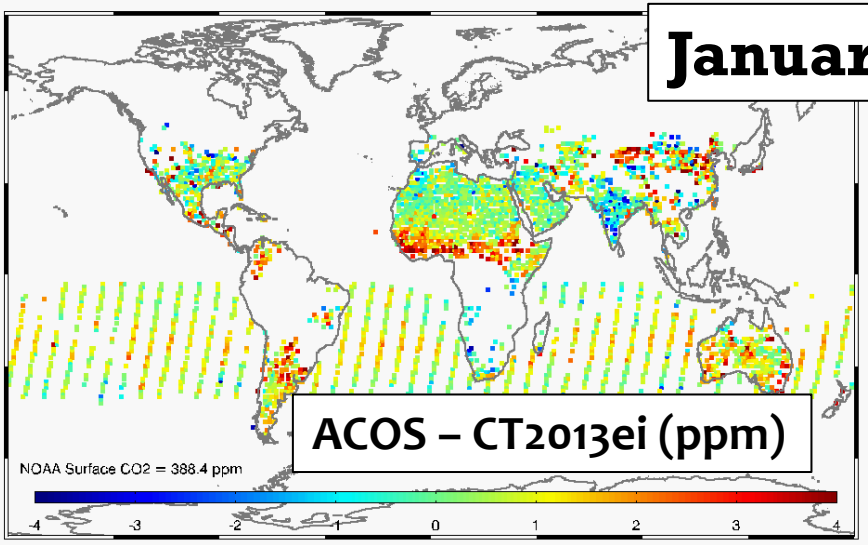


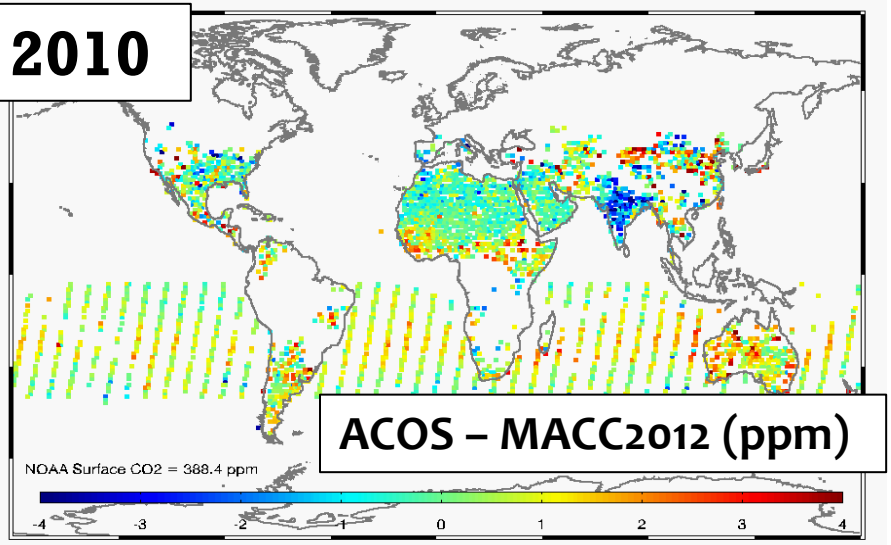
- CT2011_oi not enough positive flux in Equatorial Africa
- Problematic MACC fluxes over India, appear linked to seasonal cycle of uptake & respiration.
- MACC has too strong S.H. sinks? (seen via ocean data)

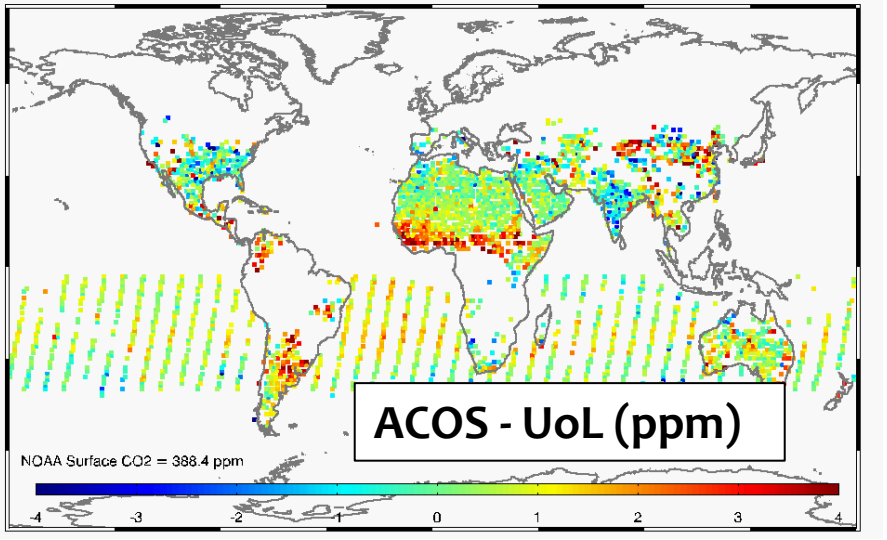


+ Monthly Averages

January 2010







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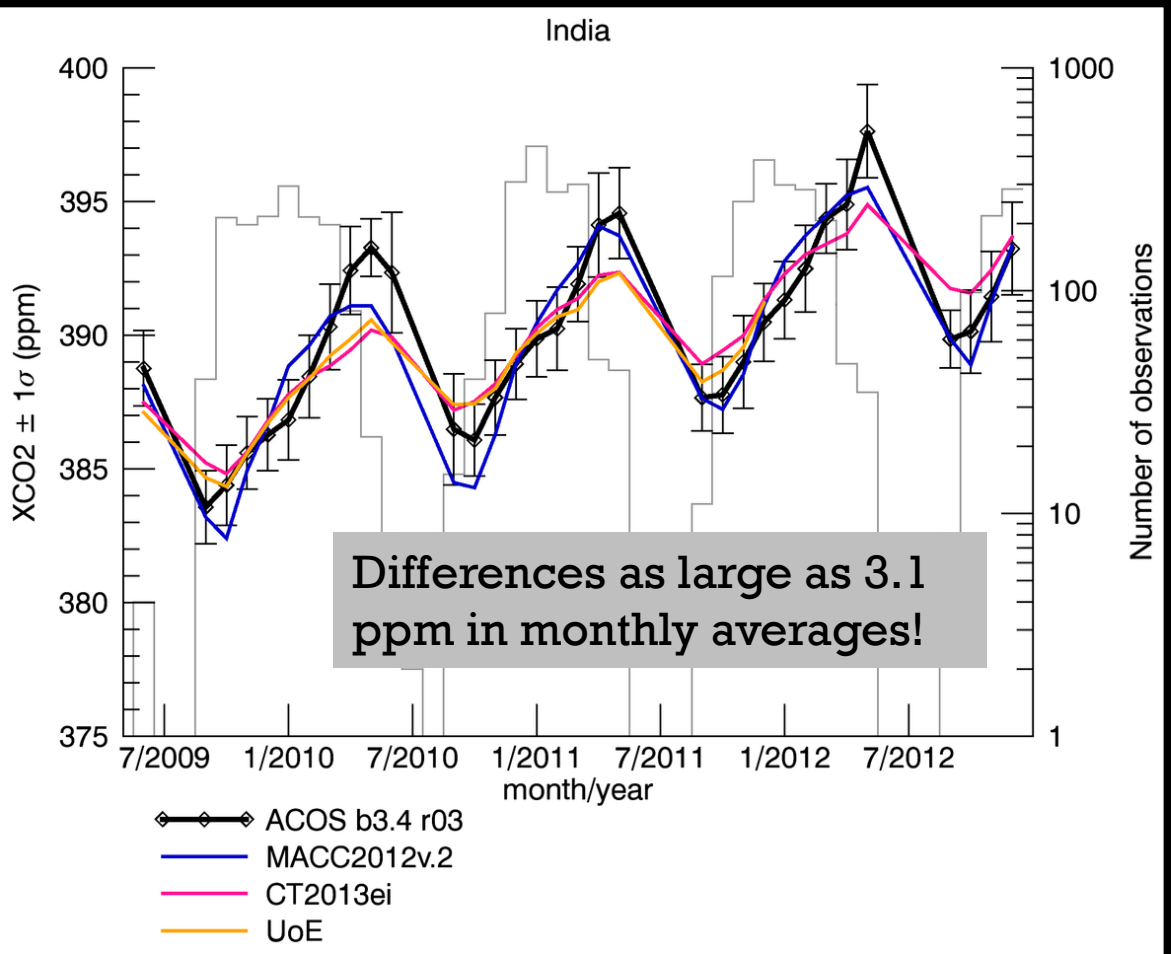
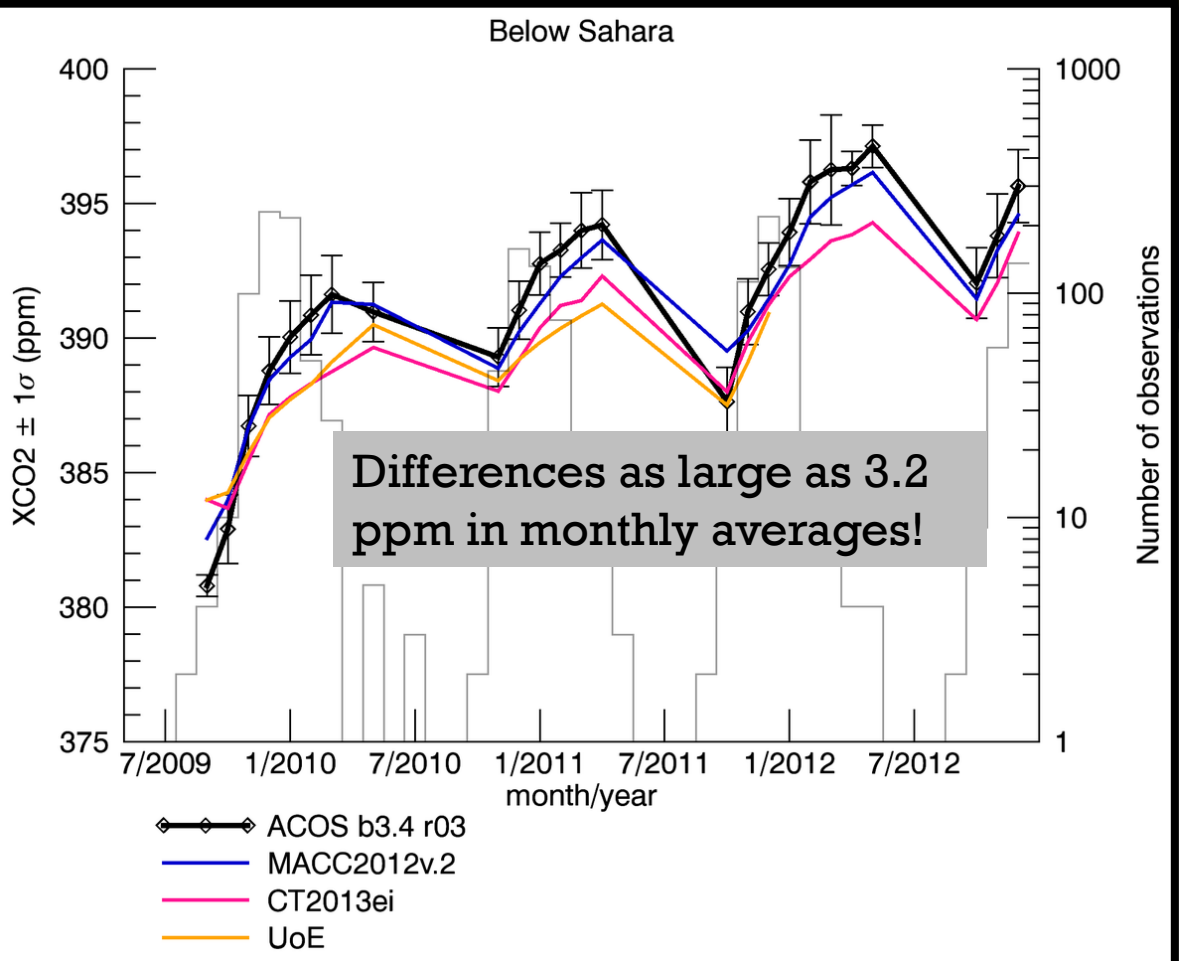
India



Differences as large as 3.1 ppm in monthly averages!

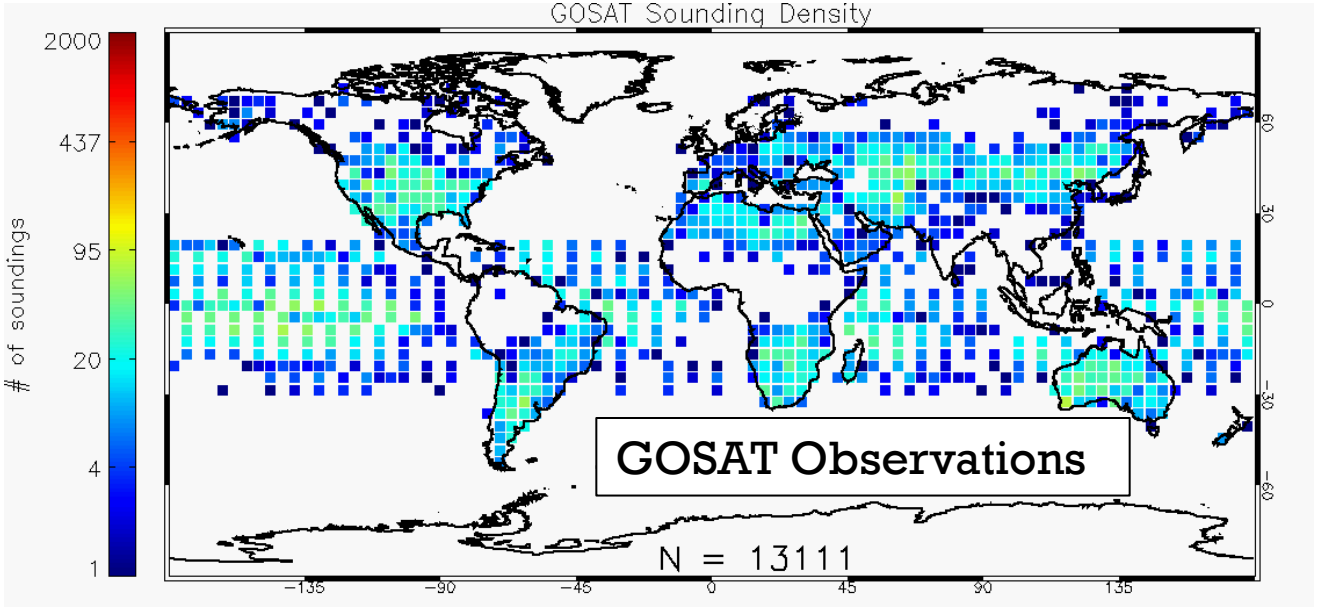
- Clear amplitude problem with CASA seasonal cycle vs. obs.
- MACC seasonal cycle better amplitude, but phasing problem.

African Sahel



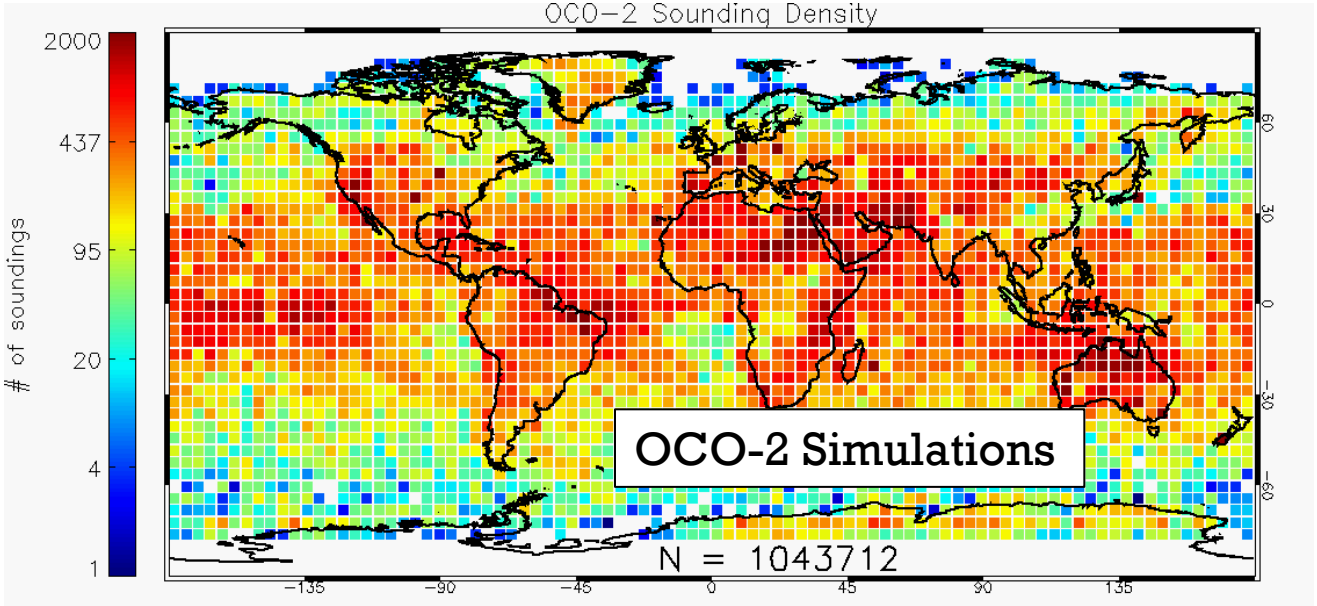
- Large differences, missing respiration signal or biomass burning in Dec-Feb.
- MACC shows generally better agreement.
- No obs. April-October!

OCO-2 vs. GOSAT data density



32 day repeat Cycle
September 2010

4x4 degree boxes



Summary

- Direct inversions with GOSAT XCO2 are hampered by both model issues and observation biases.
- Direct comparison of XCO2 between Models and Observations is potentially useful to diagnose both model issues and observation biases.
- Retrieval biases tend to be ~ 1 ppm. **Significantly larger model/observation differences point to model deficiencies.**
- Several potential model weaknesses seen :
  - Poor model seasonal cycle characterization in India
  - Poor model representation of African Sahel (esp CT+UoL)
  - See Poster P-26 (Lindqvist/Schuh) for detailed model/ACOS comparisons.

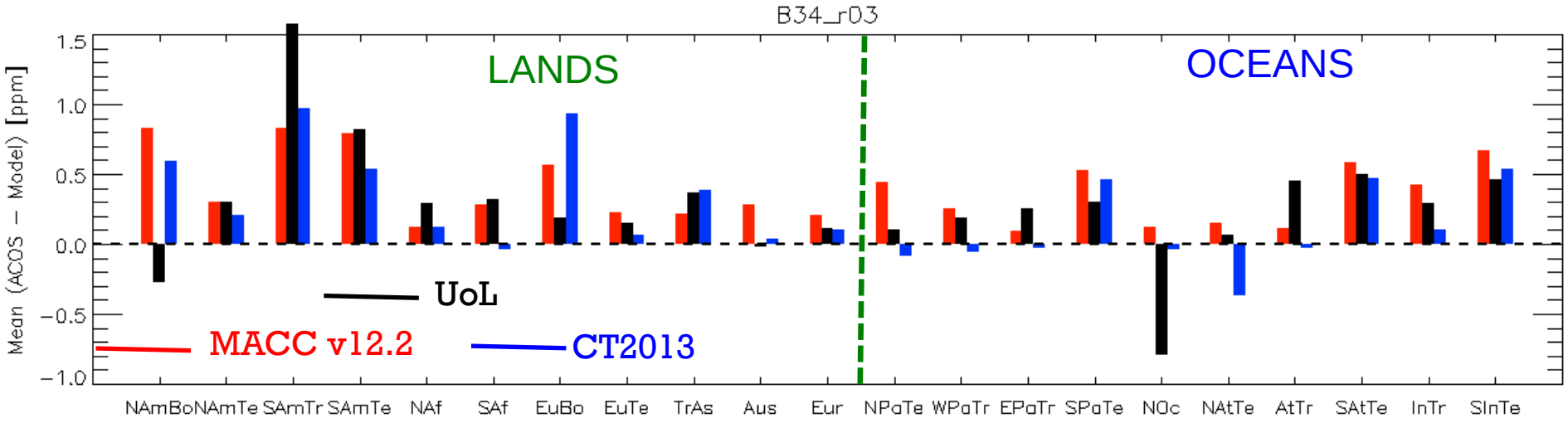
Open Questions

- How can we best use some of these robust model-observation differences?
  - **Push simultaneous assimilation of GROUND and SPACE-BASED observations (e.g., CarbonTracker!)**
  - **Work to improve the biosphere priors directly?**

- Observational data gaps leave us blind in many regions and times of year – how much will OCO-2 mitigate this?

Backup

On Transcom Regions: Getting better…



- Larger regional differences between GOSAT & Models
- Substantial differences between the three Models in certain regions.
- Largest Land differences over South America, Boreal regions
- Smaller differences over ocean

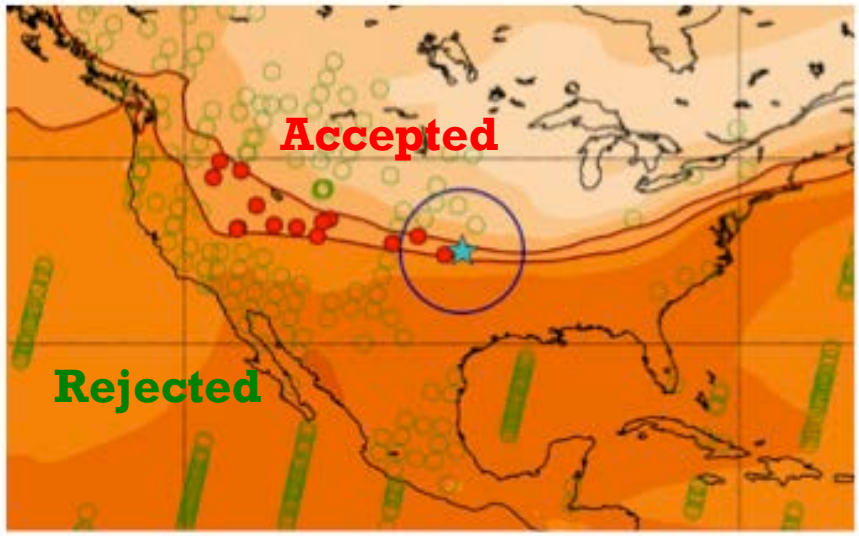
ACOS Truth Proxies: TCCON & Models

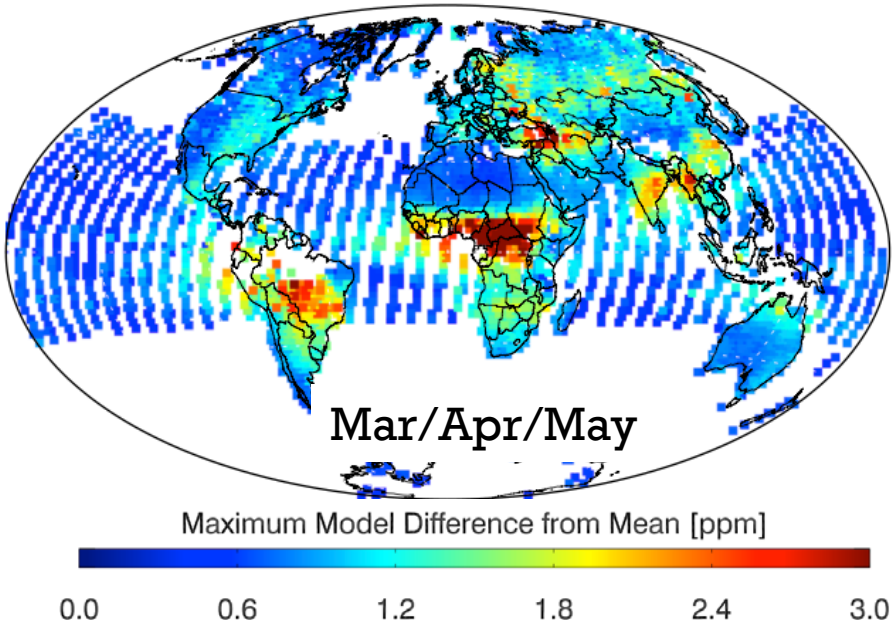
TCCON:

- SRON/KIT/Basu Colocation
- Described in Guerlet et al., 2013
- Yields larger number of accurate colocations
- Data from 2009-2012, 15+ stations

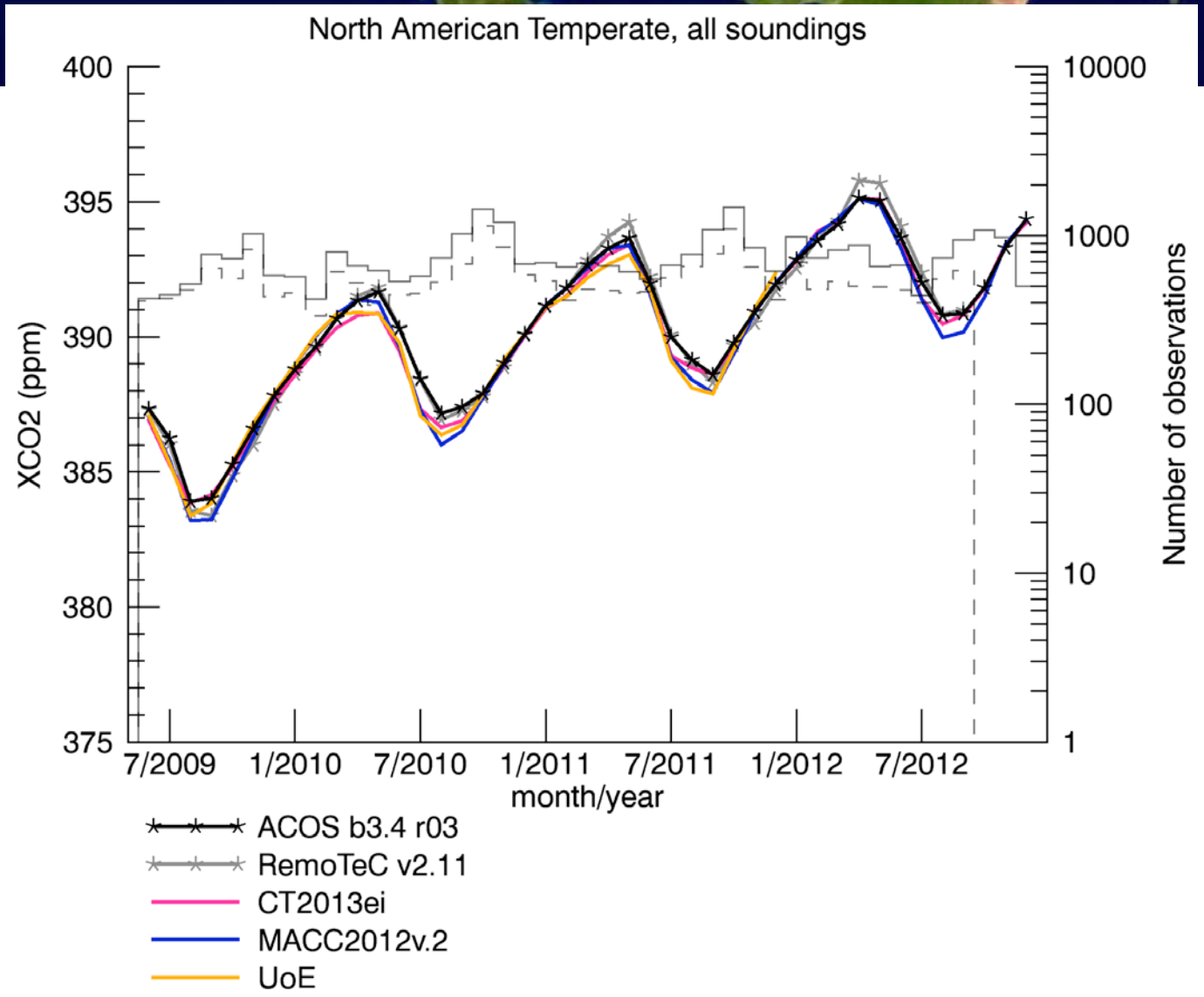
Models:

- Use soundings where all models agree to within ~1 ppm.
- Model mean is best guess.
- Models: MACC, CT2011_oi, U. Edinburgh (x2), NIES (x2), D. Baker TM5





Temperate North America



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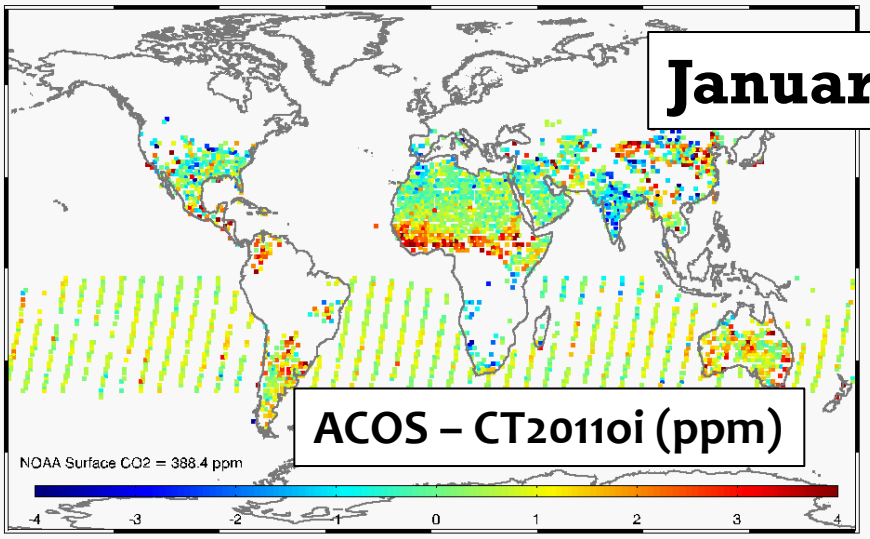

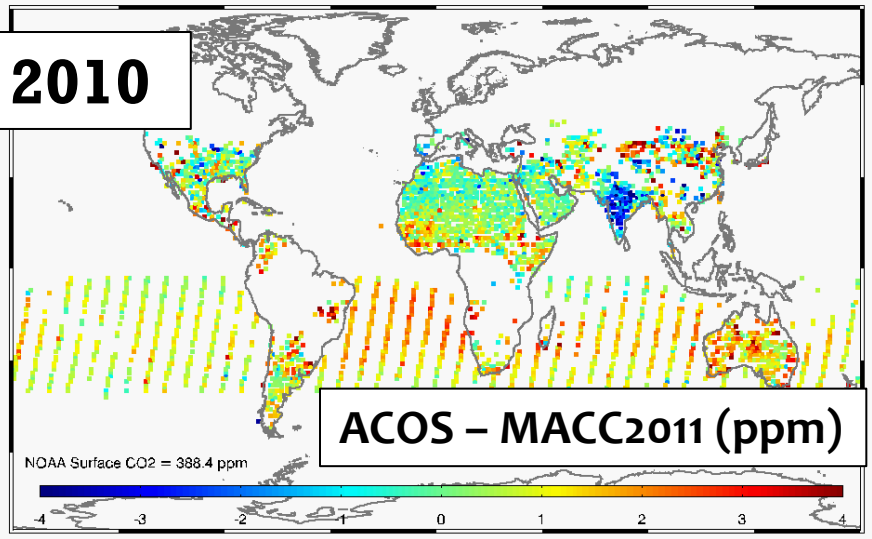

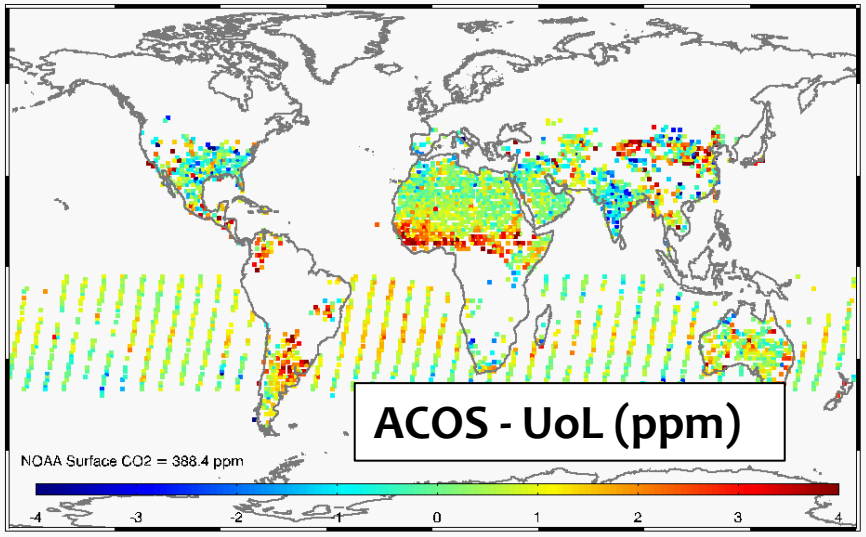

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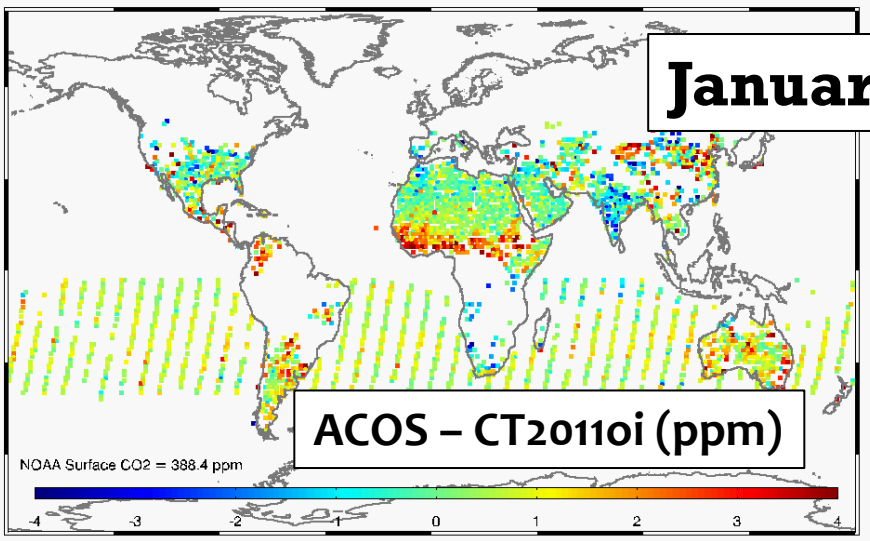

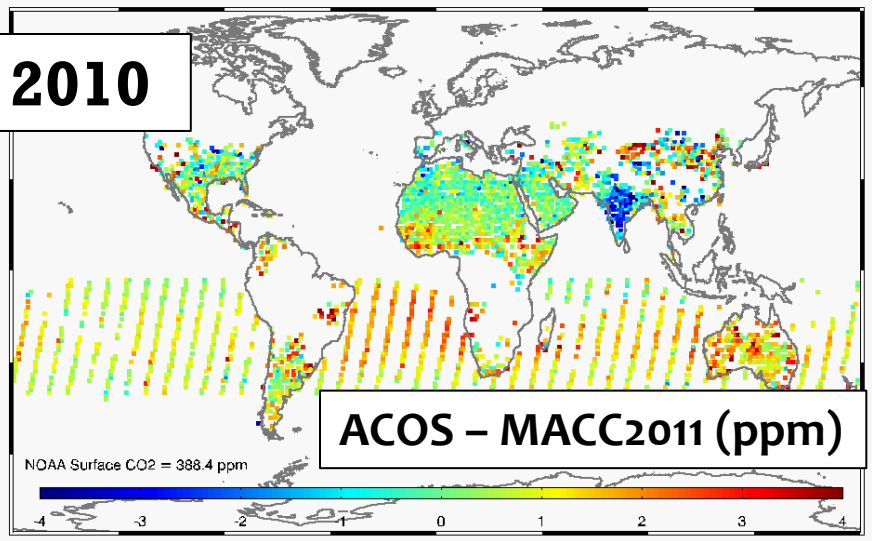

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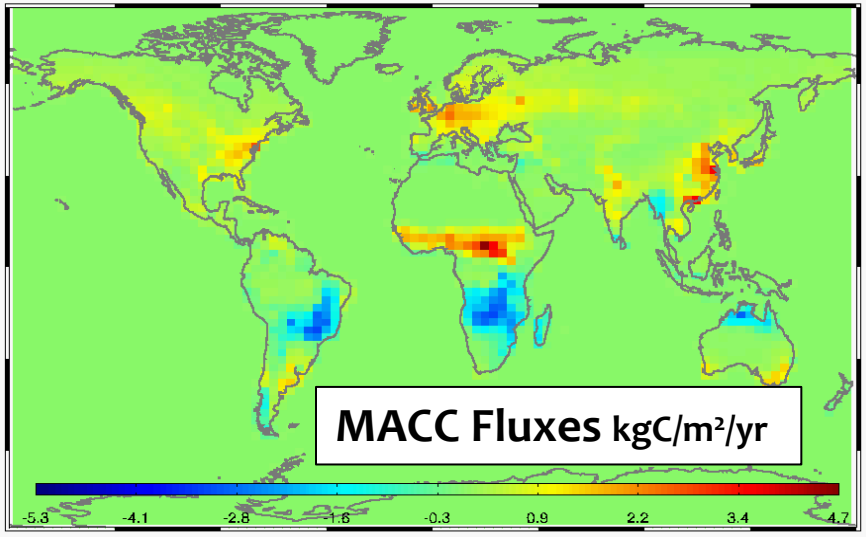

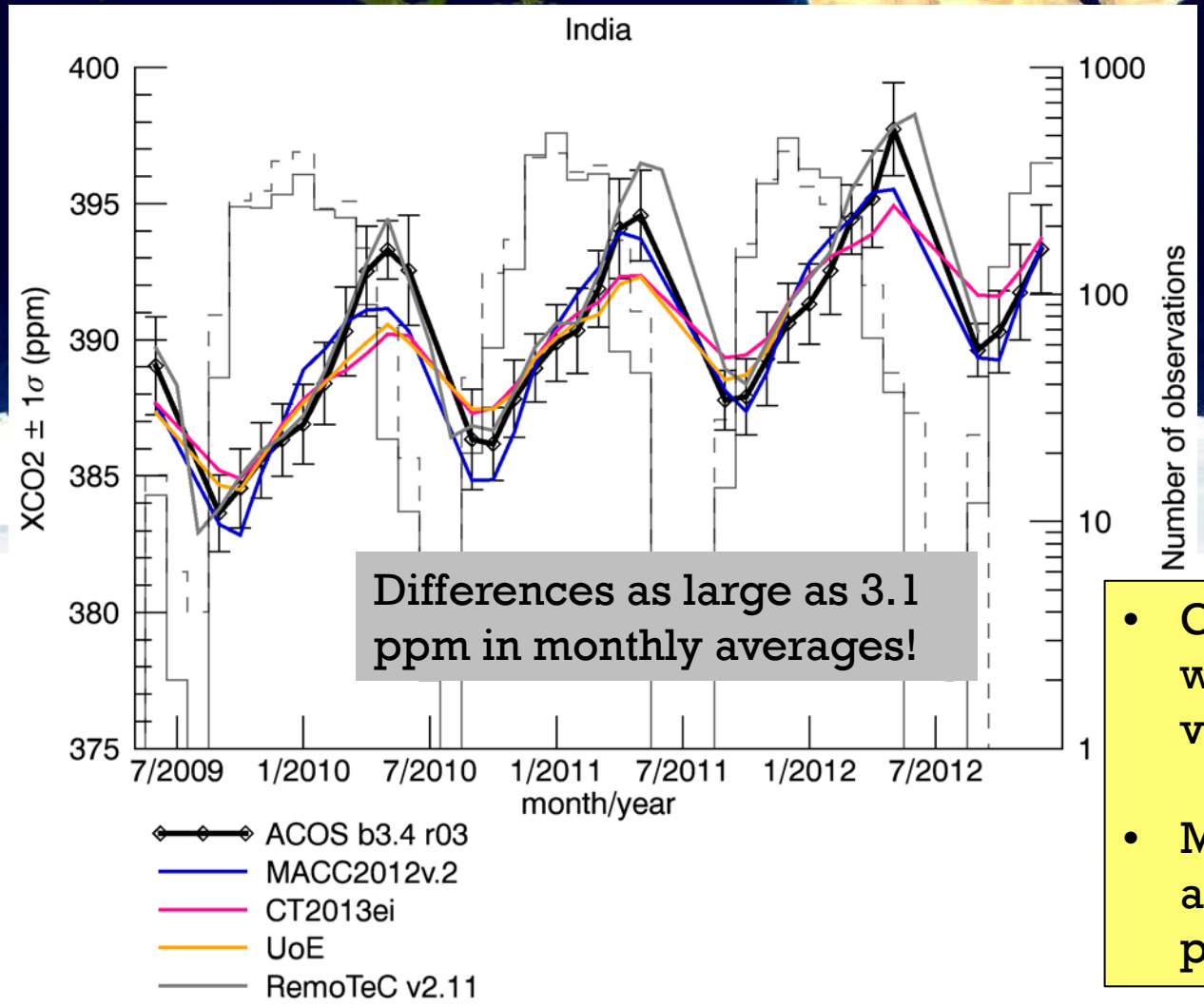

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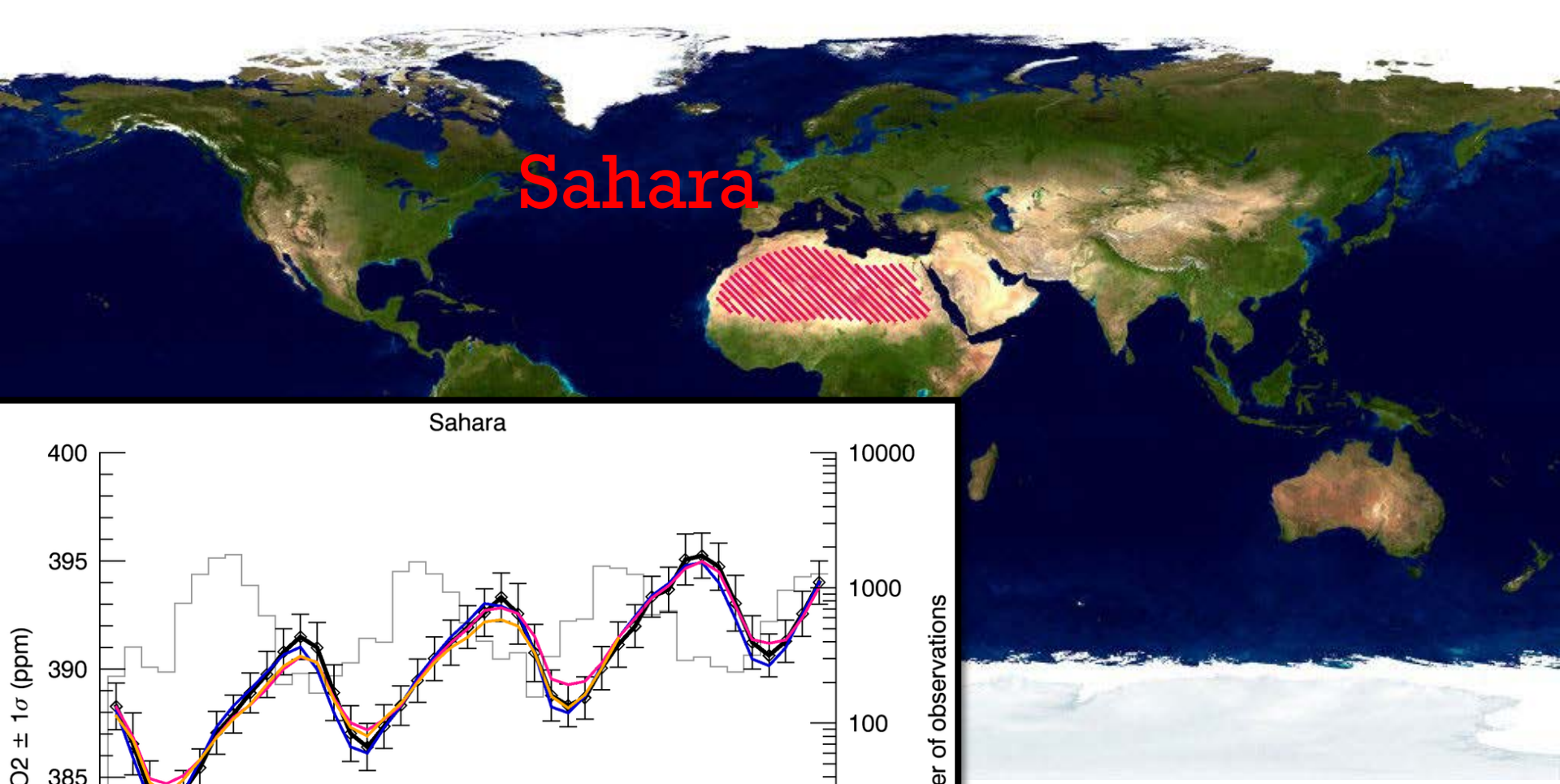
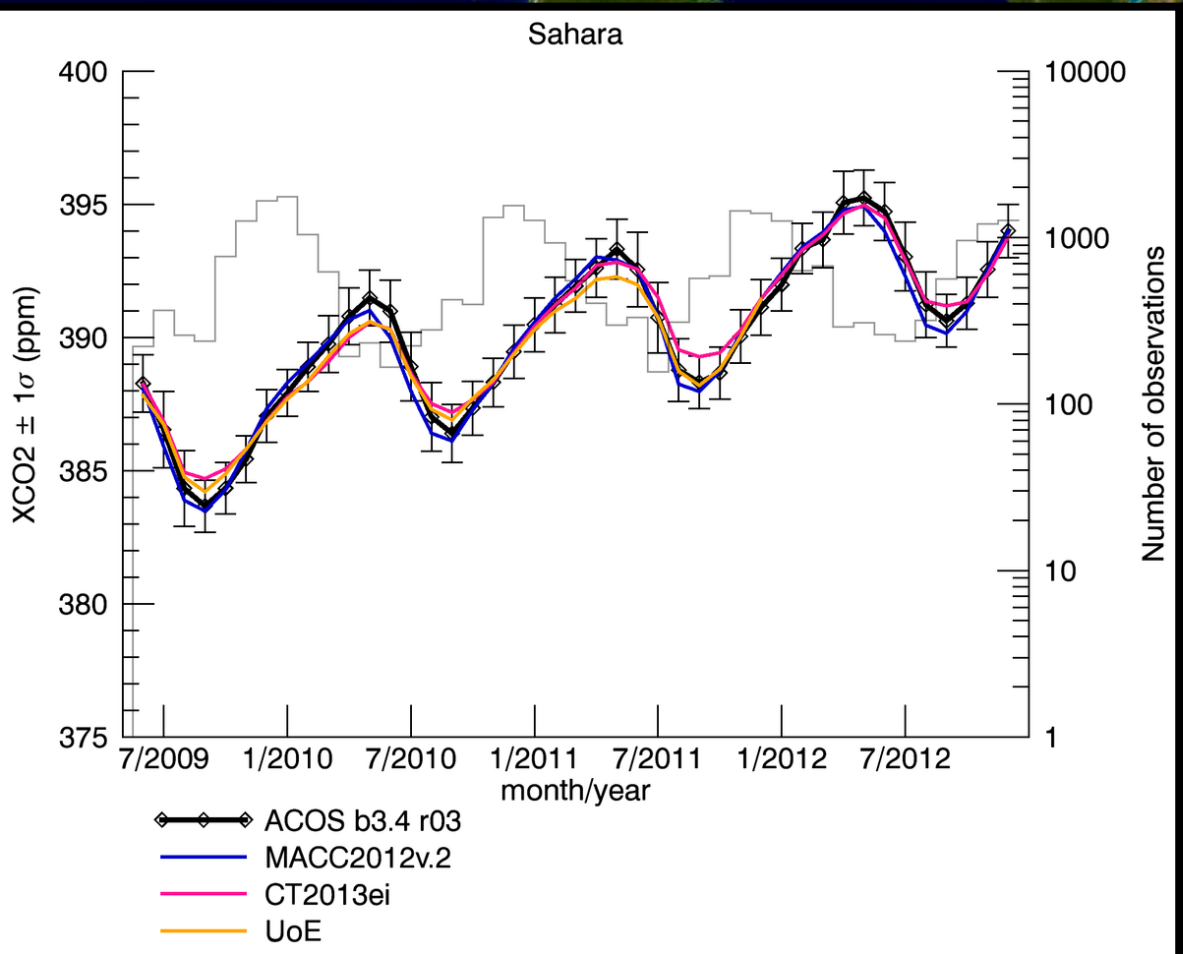
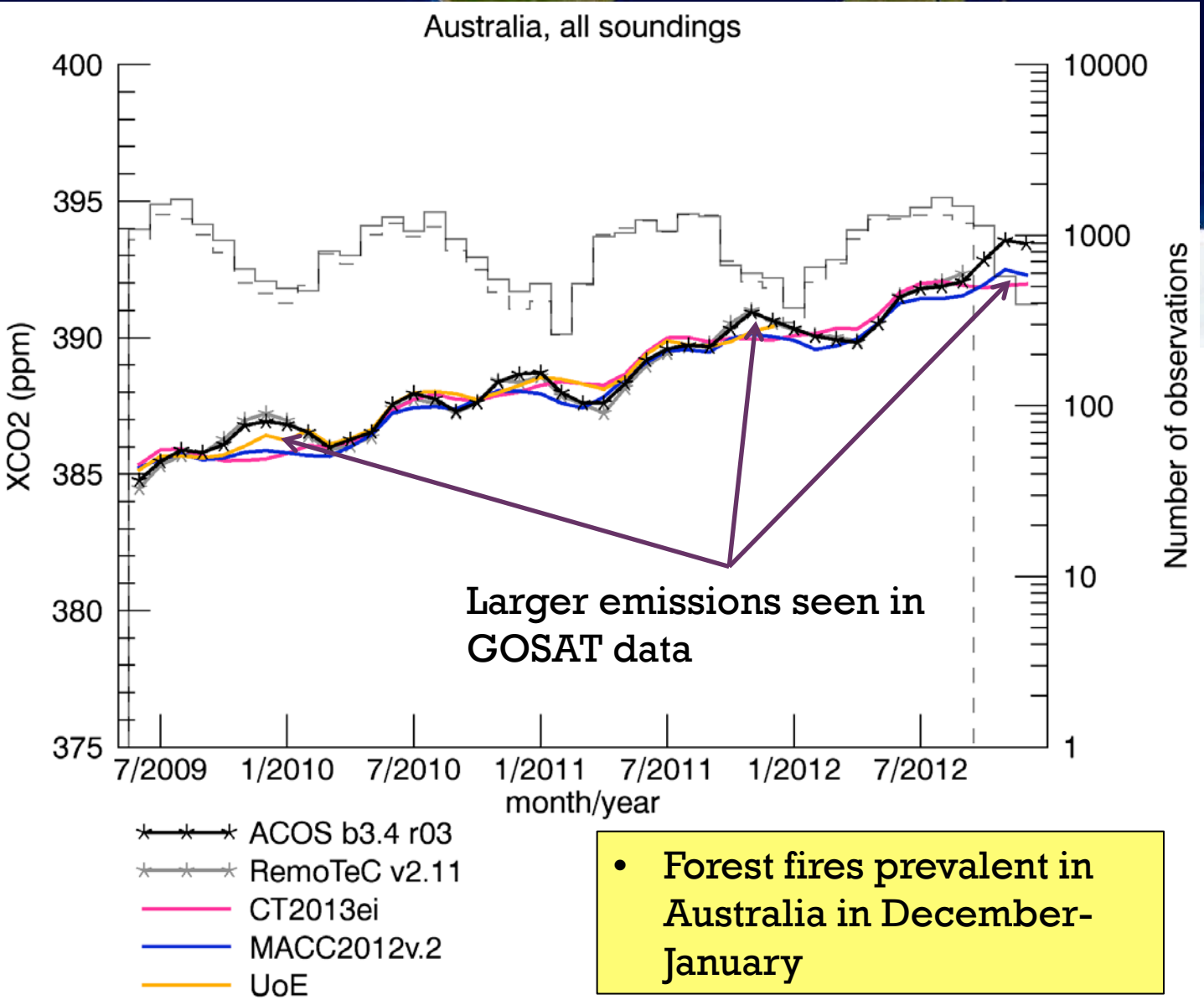




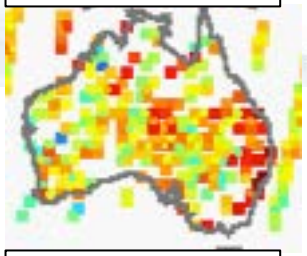
For comparison: the Saharan region

Australia

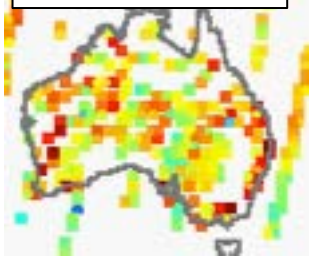


- Forest fires prevalent in Australia in December-January

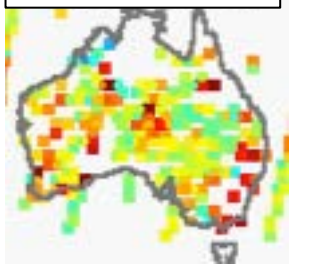
Nov 2009



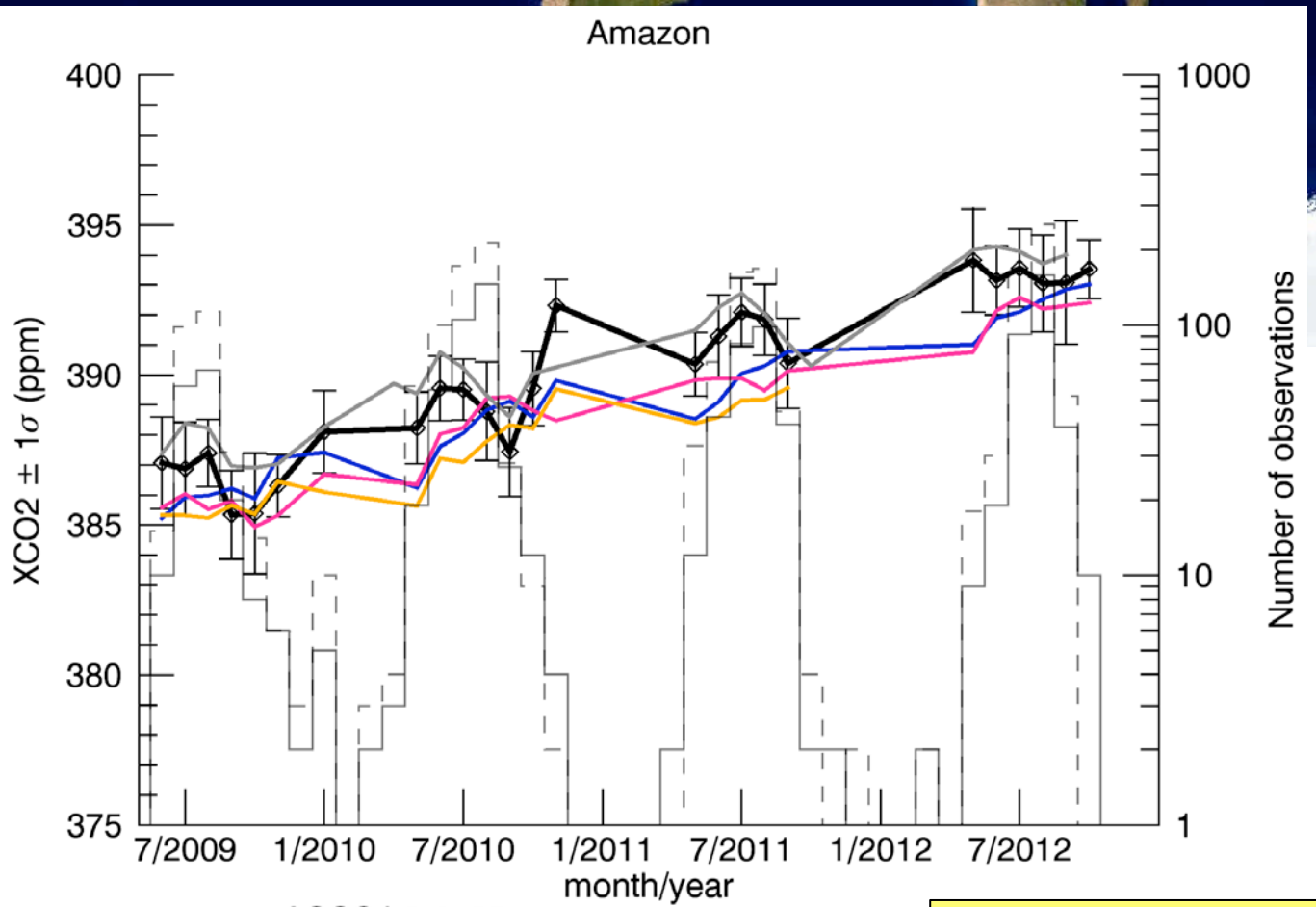
Dec 2009



Jan 2009



Amazon



- Large bias between models & obs!
- GOSAT retrievals or model issue?
- Potential causes?
- Data gaps leave us blind ½ the year!

Regional differences generally don't align with Transcom-3 regions!