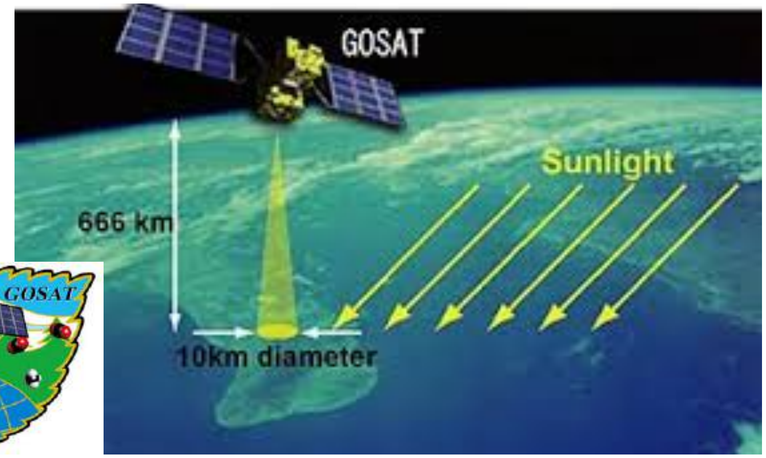
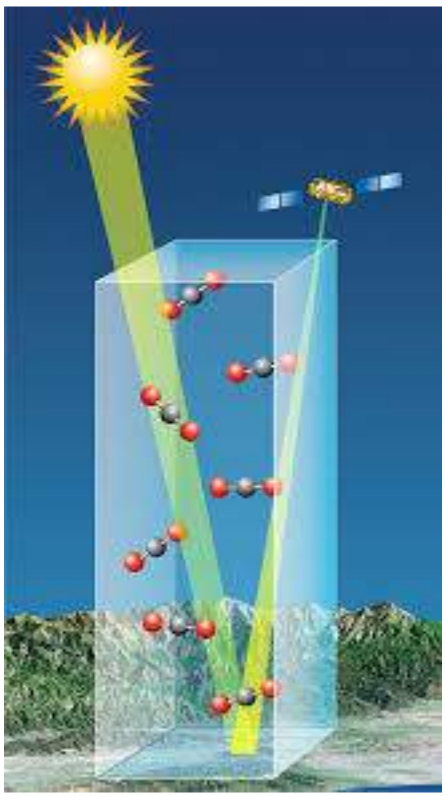


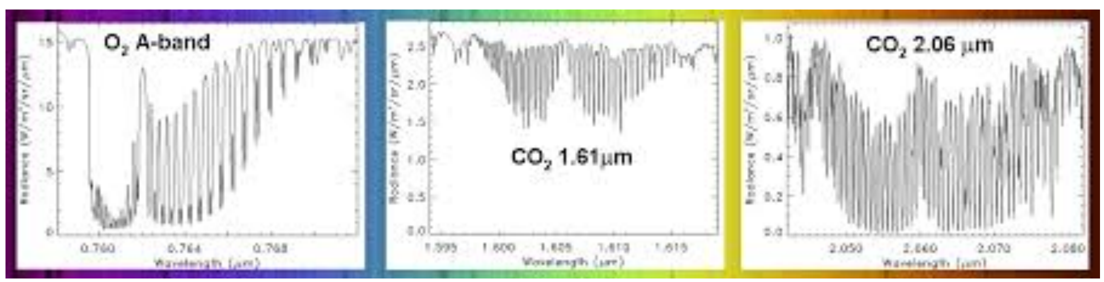
What have we learned about the global carbon cycle from GOSAT and OCO-2 ?



David Baker, Andy Jacobson, & Sean Crowell
CIRA/CSU CIRES/CU Univ. of Oklahoma

May 24, 2017

NOAA/ESRL Global Monitoring Annual Conference

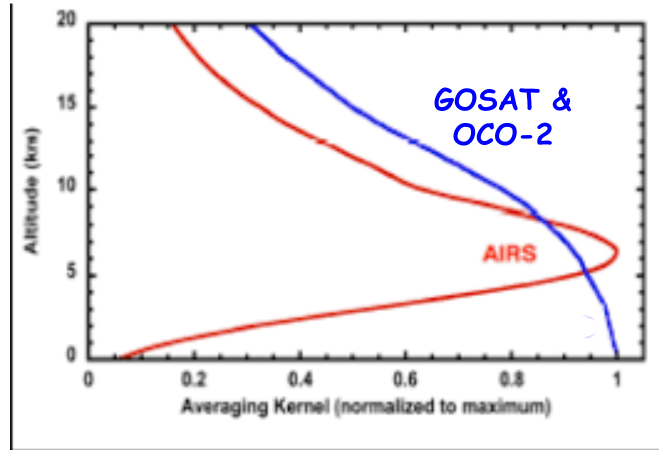


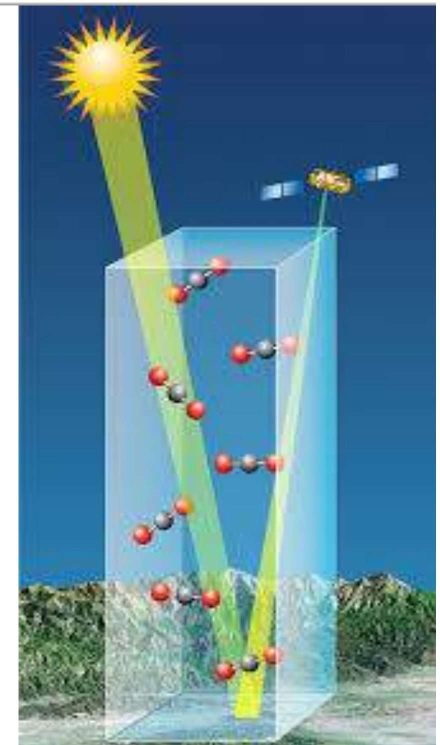
Outline

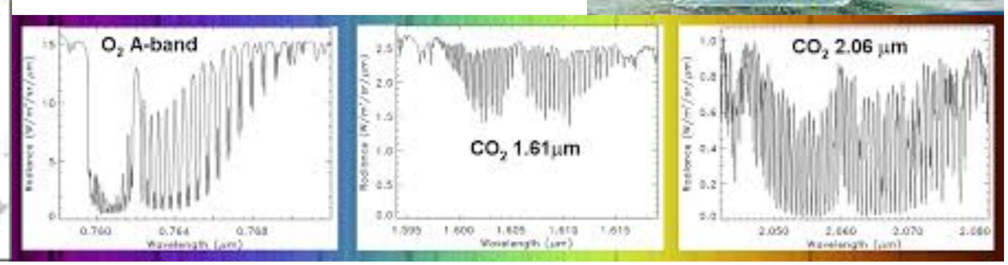
- CO_2 from space – GOSAT and OCO-2
  - Benefit: spatial coverage, esp. over tropics
  - Drawback: systematic errors
  - Drawback & benefit: full-column vs. surface
- Tropical land biosphere:
  - Its role in the interannual variability of global CO_2
  - Is it a net source or sink?
    - Implications for impact of CO_2 fertilization

GOSAT & OCO-2 measurements

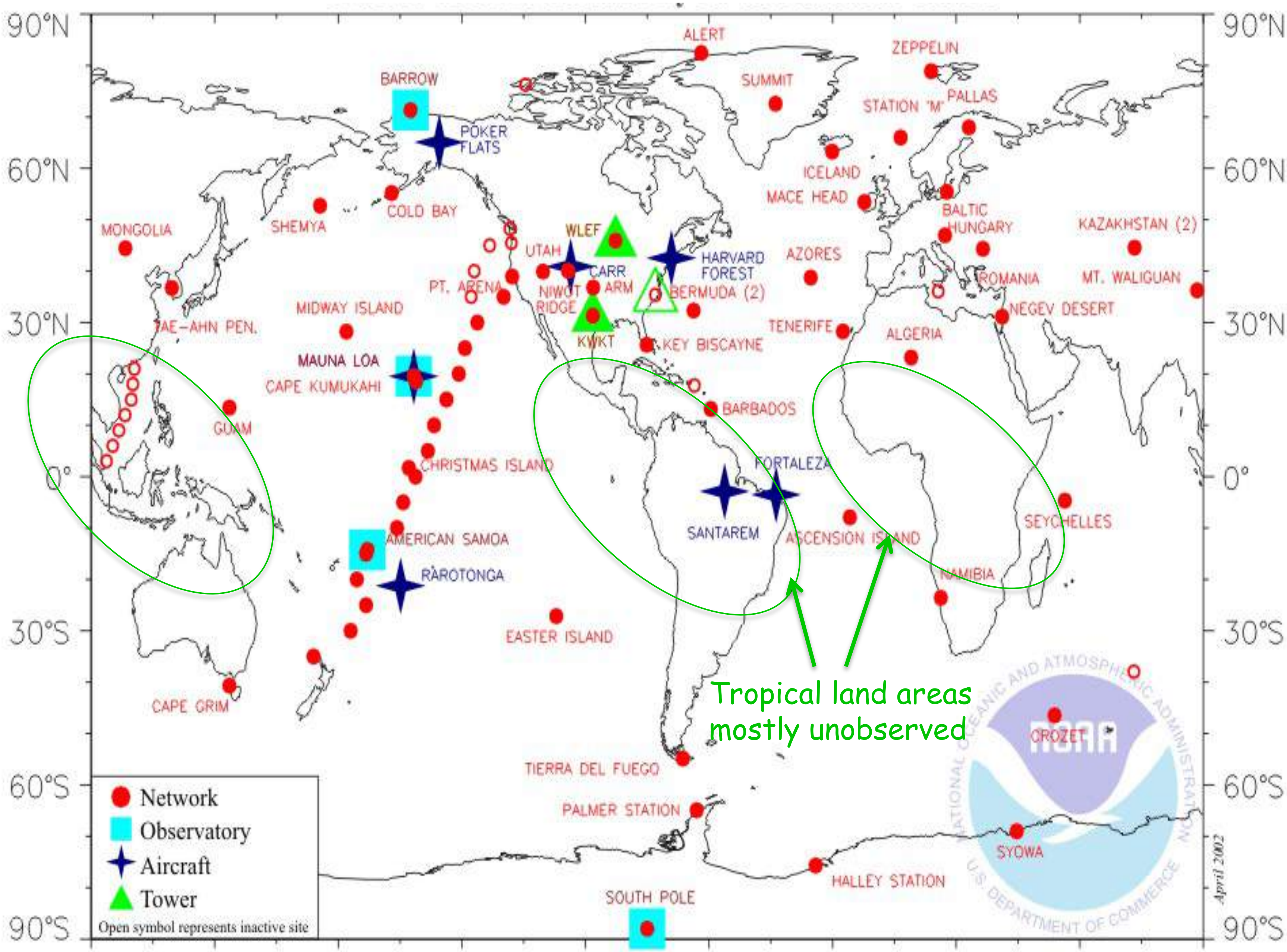
- Measure reflected solar rays to get sensitivity to surface
- Look at sun glint spot over ocean
- Throw out cloudy scenes
- Model full radiative transfer
  - Solve for aerosol amount, four types
  - Solve for surface pressure
  - Certain fixes to spectroscopy
- Solve for dry air CO_2 mixing ratio on 20 levels
- Report the pressure-weighted column integral, X_{CO2}
- Bias correct this after the fact, vs. TCCON, etc.



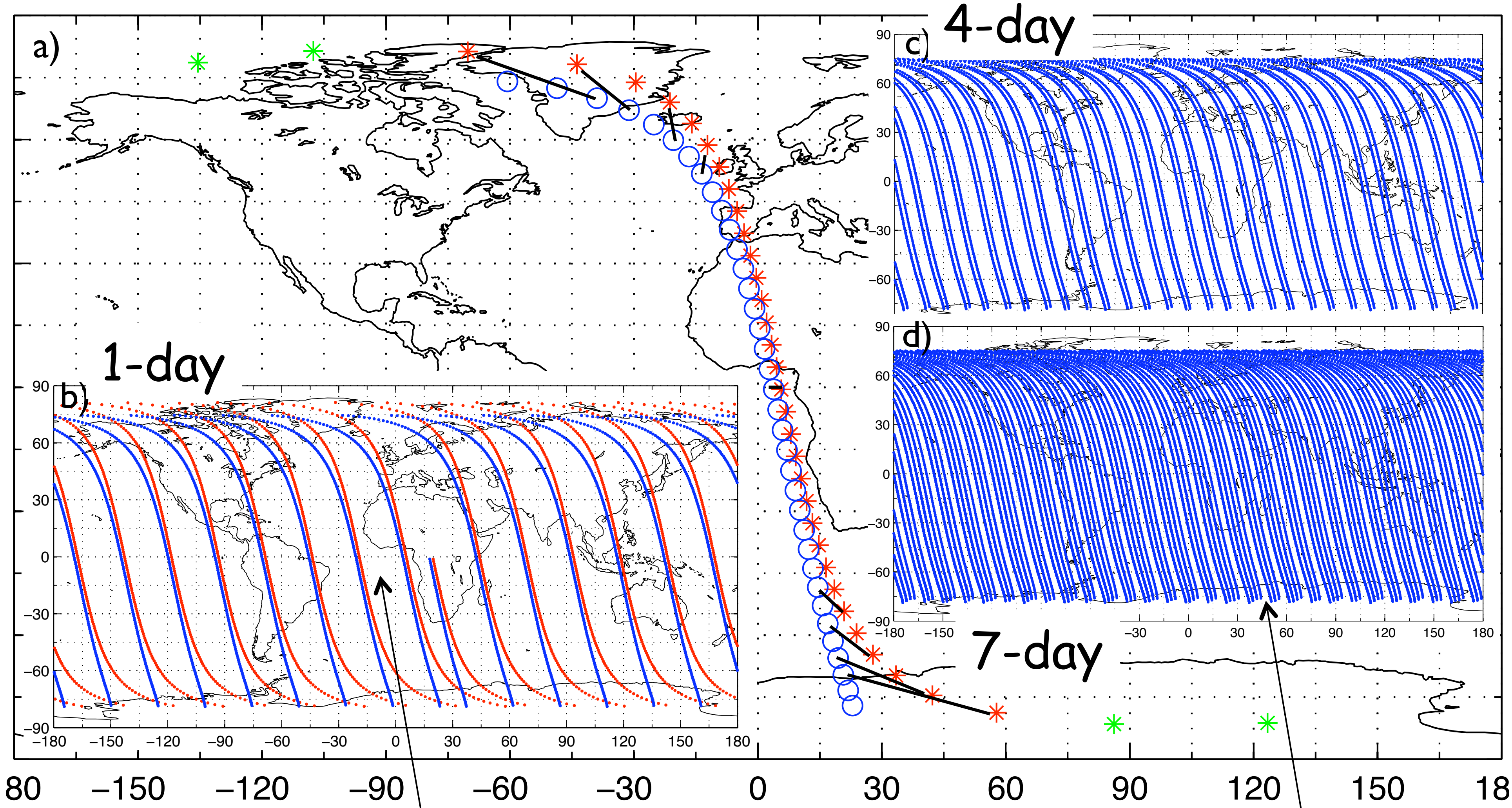




Coverage from the *in situ* network

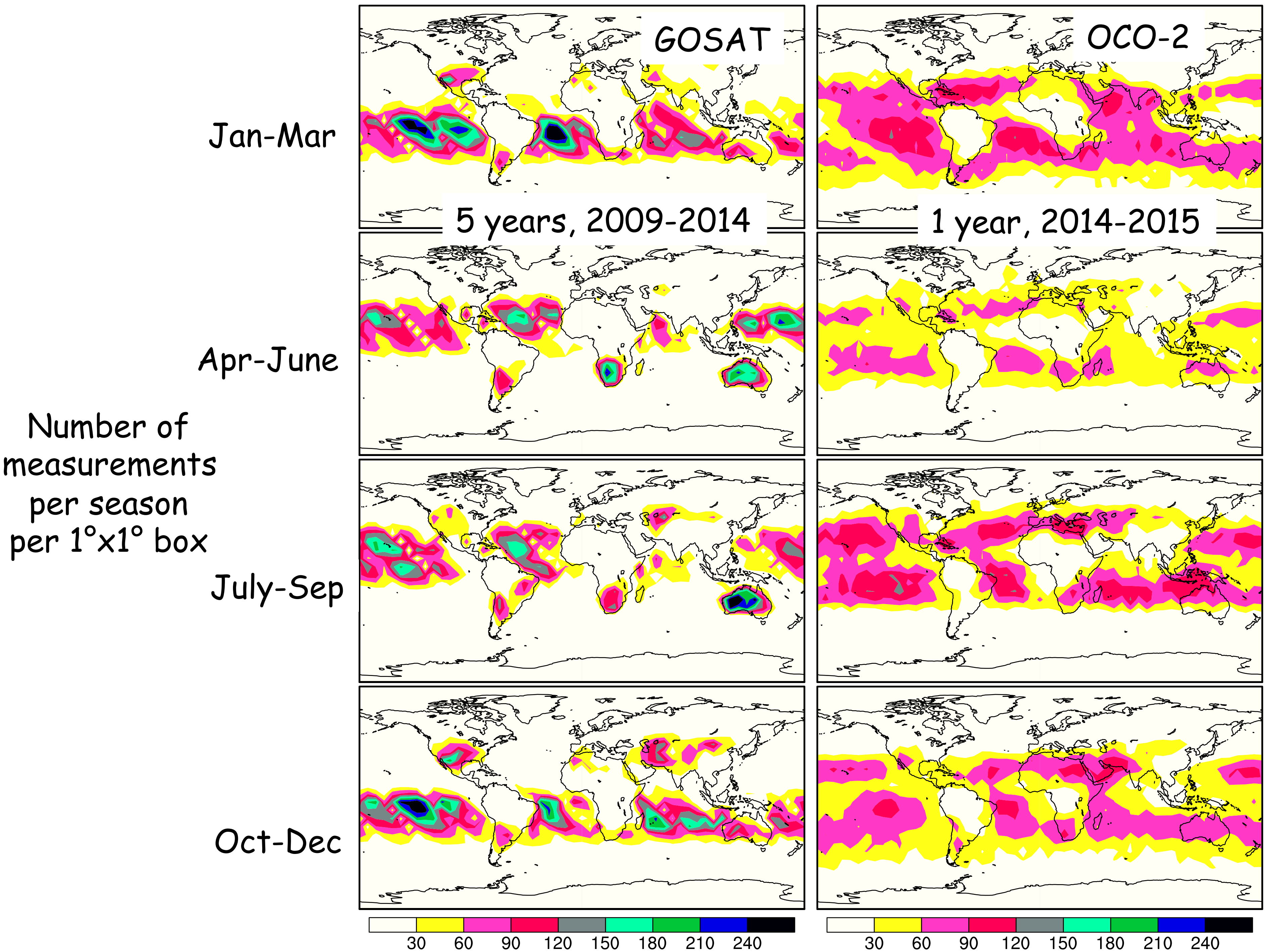


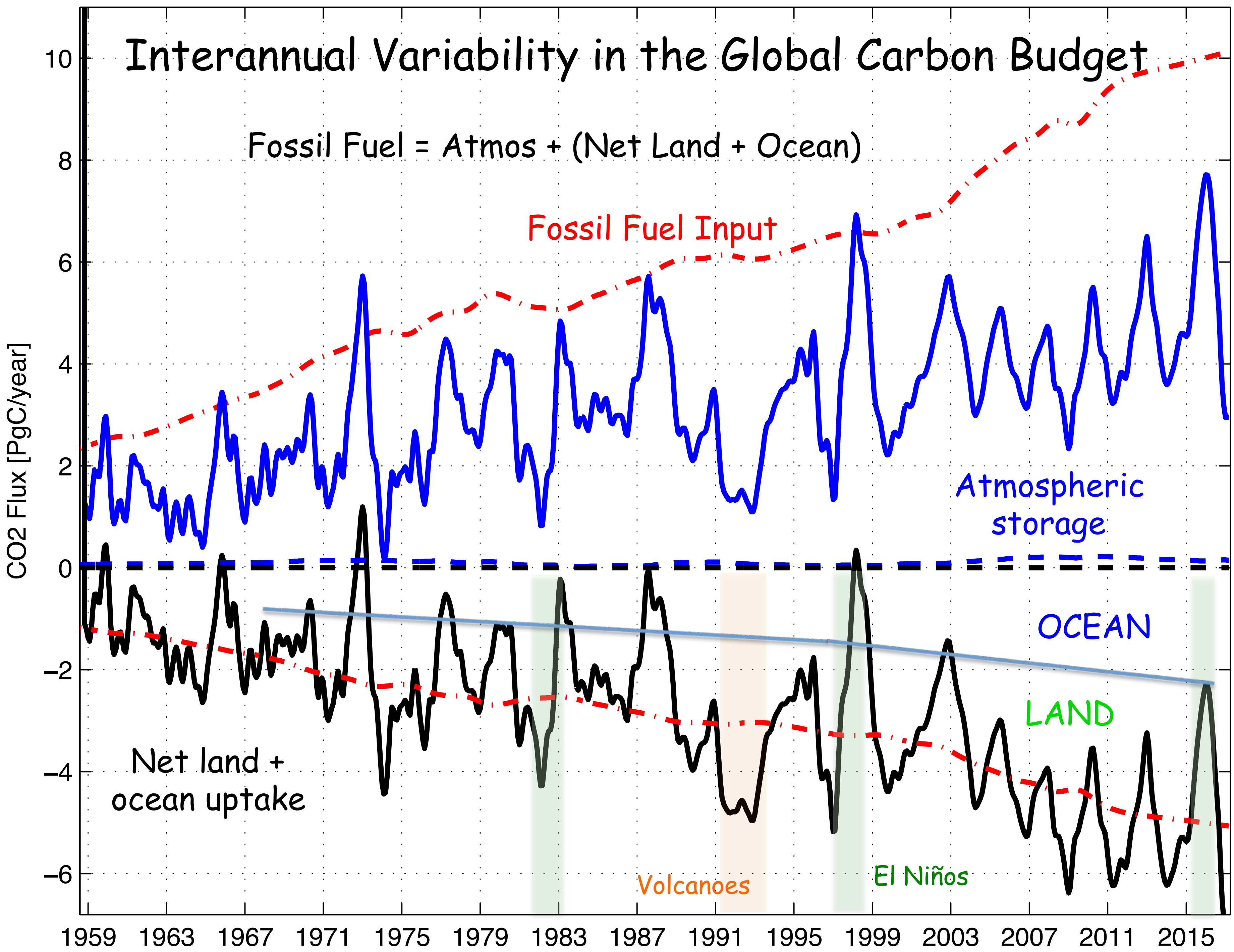
Coverage from OCO-2



~25° spacing in longitude

~3.5° spacing in longitude

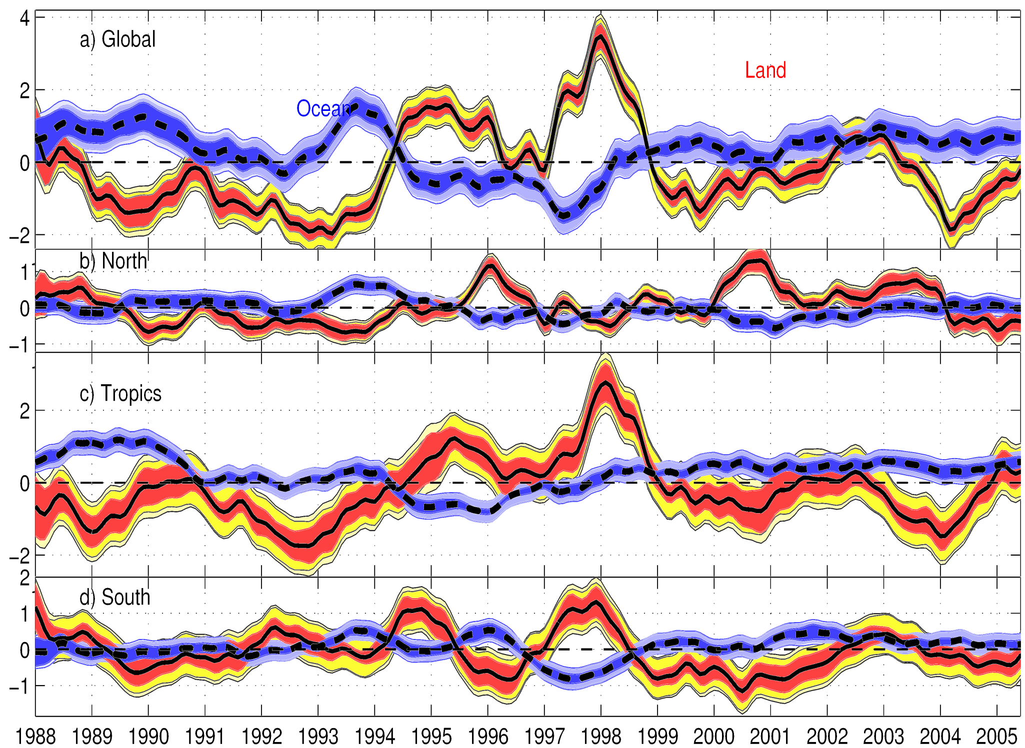

GOSAT
OCO-2
Jan-Mar
5 years, 2009-2014
1 year, 2014-2015
Apr-June
Number of measurements per season per 1°x1° box
July-Sep
Oct-Dec
30 60 90 120 150 180 210 240
30 60 90 120 150 180 210 240

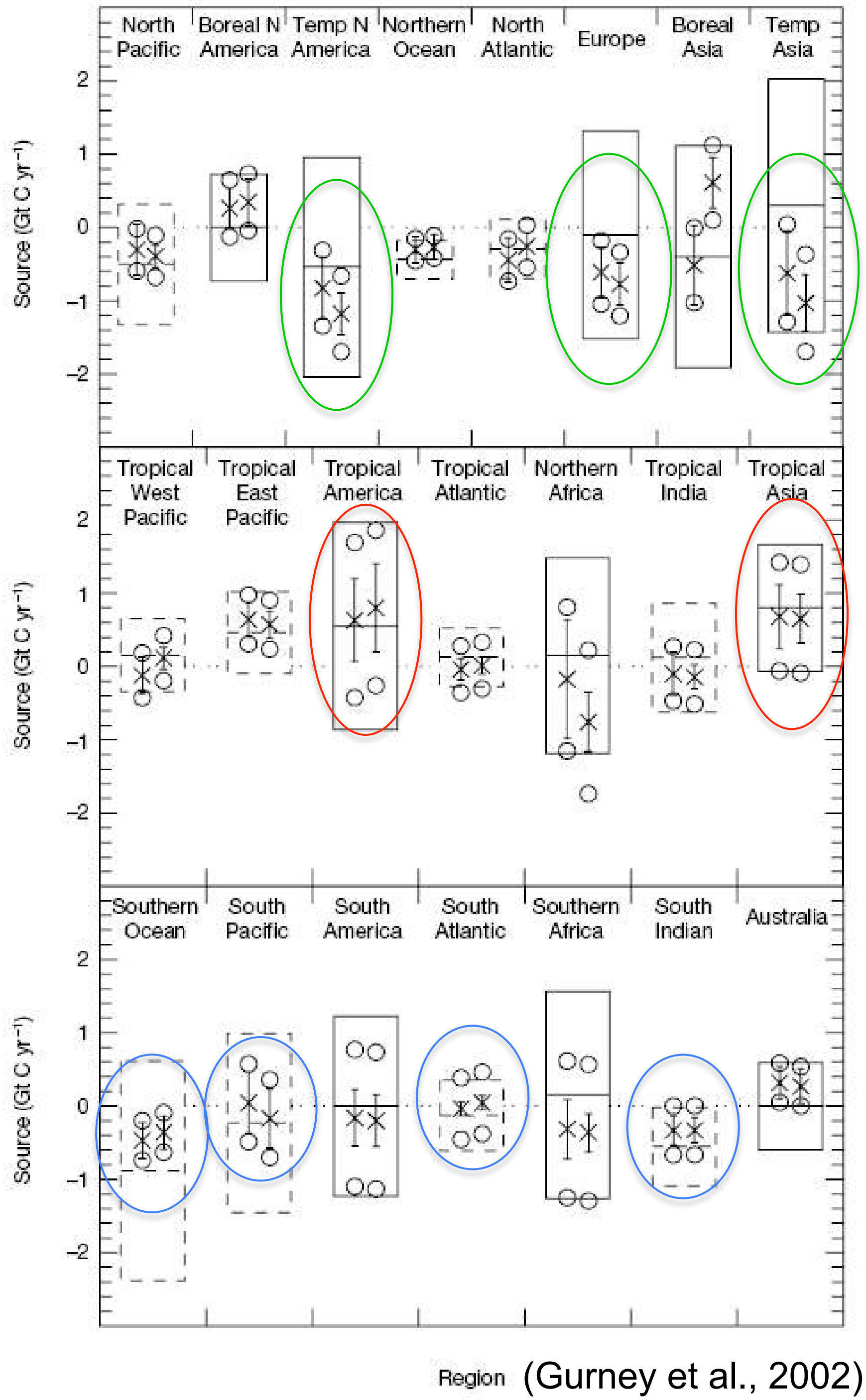


Interannual Variability in the Global Carbon Budget
Fossil Fuel = Atmos + (Net Land + Ocean)
Fossil Fuel Input
Atmospheric storage
OCEAN
LAND
Net land + ocean uptake
Volcanoes
El Niños
CO2 Flux [PgC/year]
10
8
6
4
2
0
−2
−4
−6
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999
2003
2007
2011
2015

TransCom3

- Less uptake by southern oceans
- Strong uptake by NH land bio …
- … balanced by outgassing from tropical land
- Most of IAV due to tropical land





(Gurney et al., 2002)

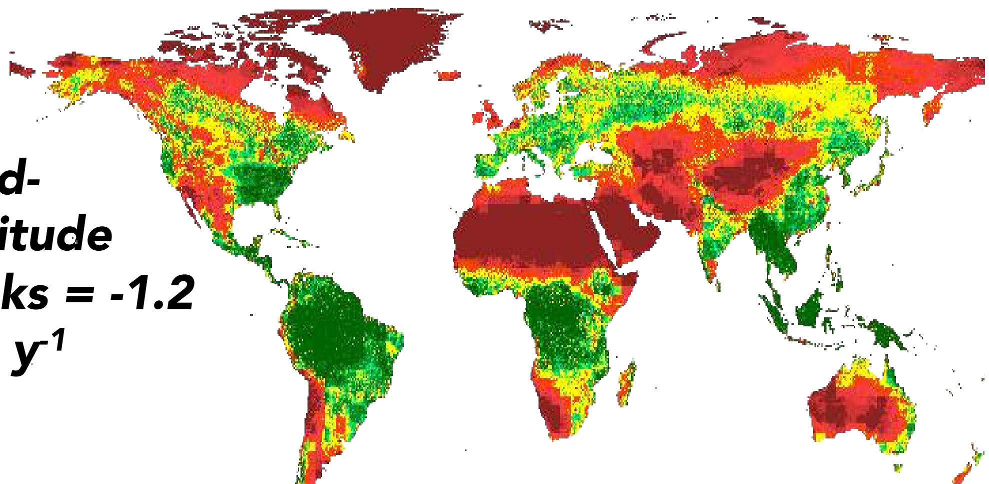
Increased CO_2 uptake due to higher $[CO_2]$

= "CO_2 effect"

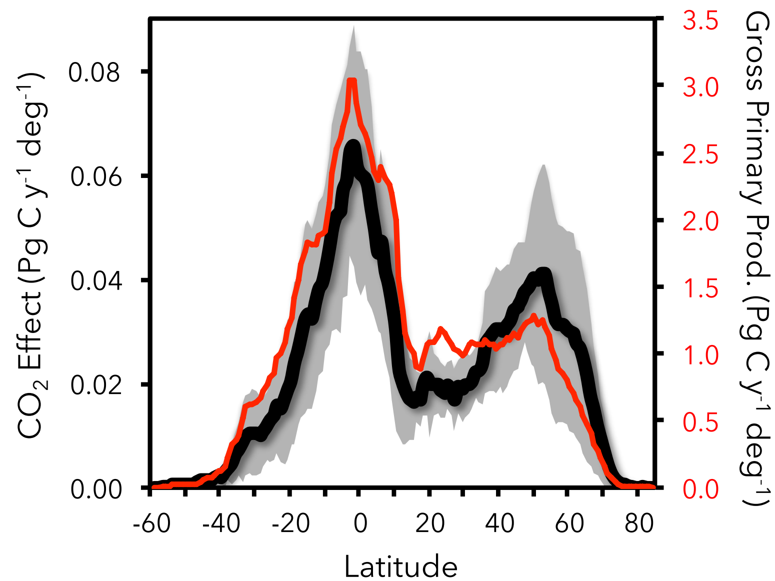
(Friedlingstein *et al* 1995)

(Slide courtesy of D. Schimel and P. Friedlingstein)

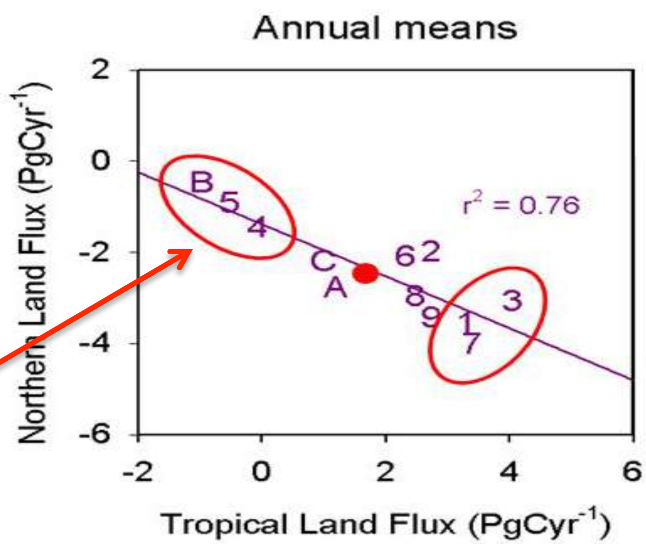
Mid-latitude sinks = -1.2 Pg y^{-1}



Tropical sinks = -3 Pg y^{-1}



Stephens et al (2007) say transport is to blame, these models are right

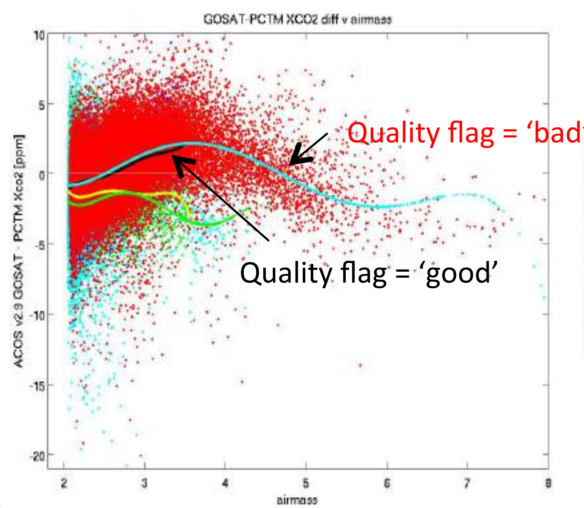


See Schimel, Stephens, & Fisher, *PNAS*, 2015, for argument for significant tropical land sink

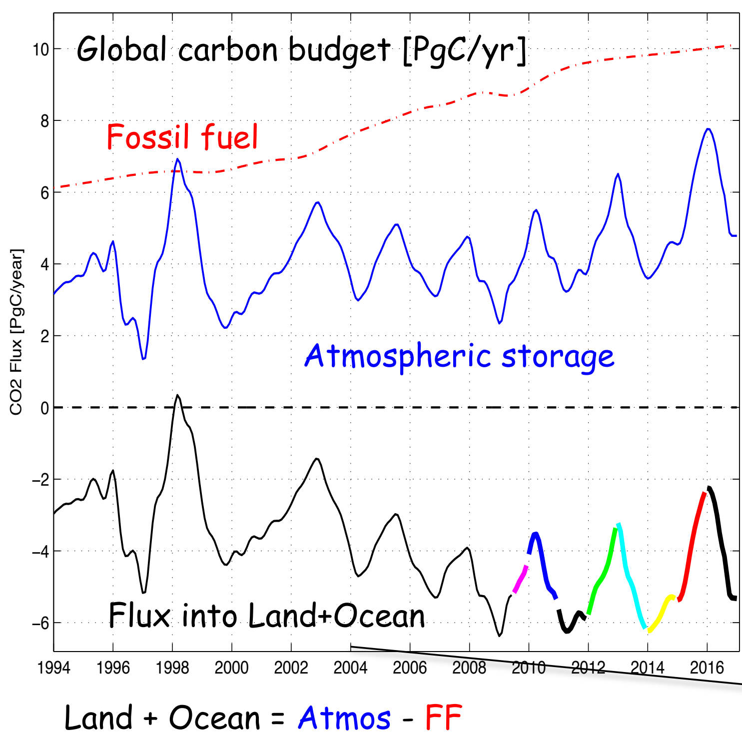
Satellite CO_2 data coverage could help pin down the magnitude of the effect

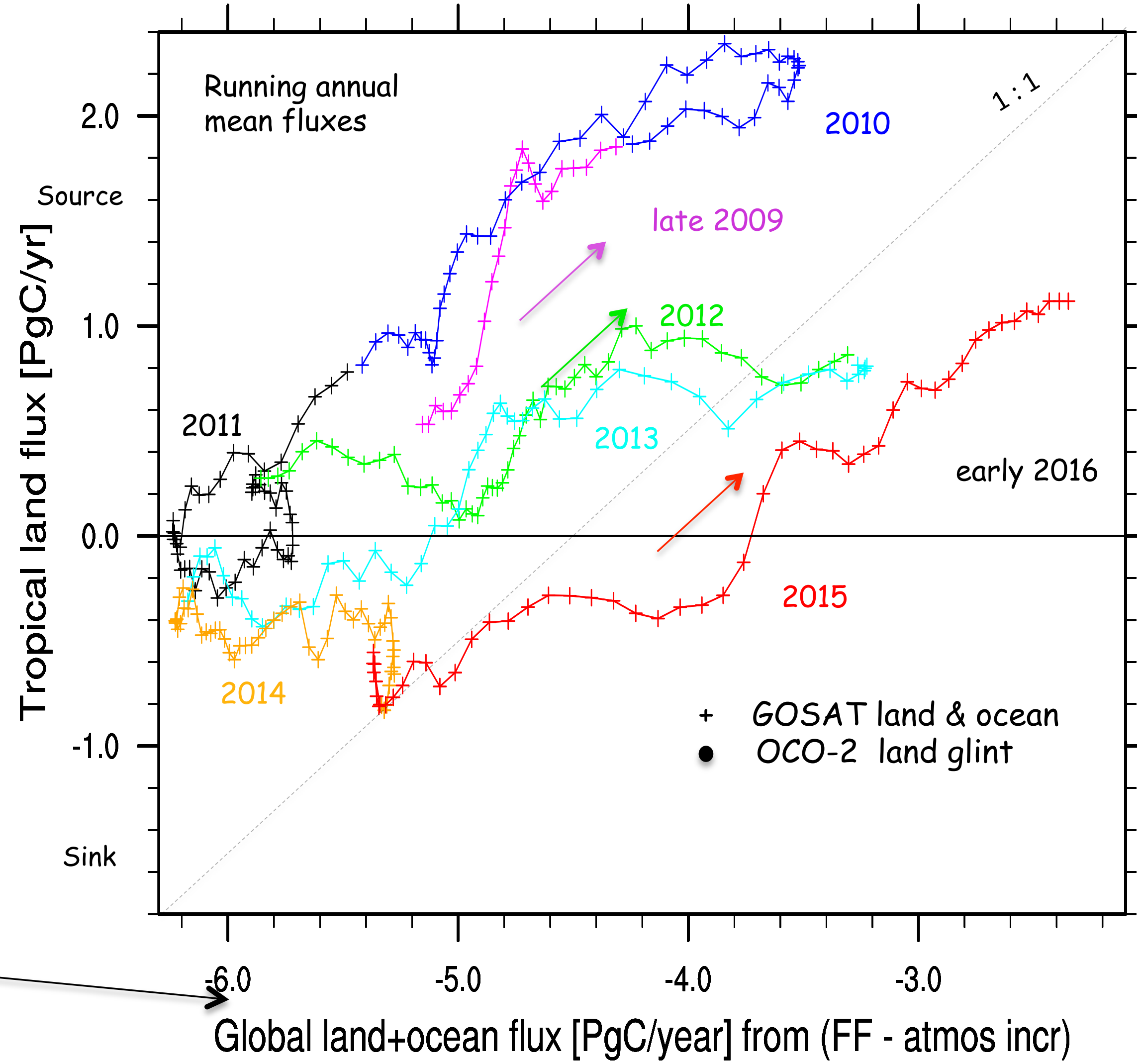
Details of my inversion setup

- PCTM off-line tracer transport model
- 4Dvar data assimilation scheme
- Weekly fluxes estimated across 2009-2016
- Forward runs at 2° x 2.5° (lat/lon)
- Inverse corrections at 6.7°x6.7° (lat/lon)
- Inversions starting from 4 different priors:
  - CASA + NOBM ocean + ODIAC FF
  - CASA + NOBM ocean + FFDAS FF
  - CASA + Takahashi ocean + ODIAC FF
  - CASA + Takahashi ocean + FFDAS FF
- GOSAT v7.3 data (2009-2016)
- OCO-2 v7b data: LN, LG, OG run separately
- Additional OCO-2 bias corrections applied:
  - LN: s31 (albedo) and .997/.9955 ratio
  - LG: s31
  - OG:
    - an airmass-based one
    - using only scenes with airmass ≤ 2.4



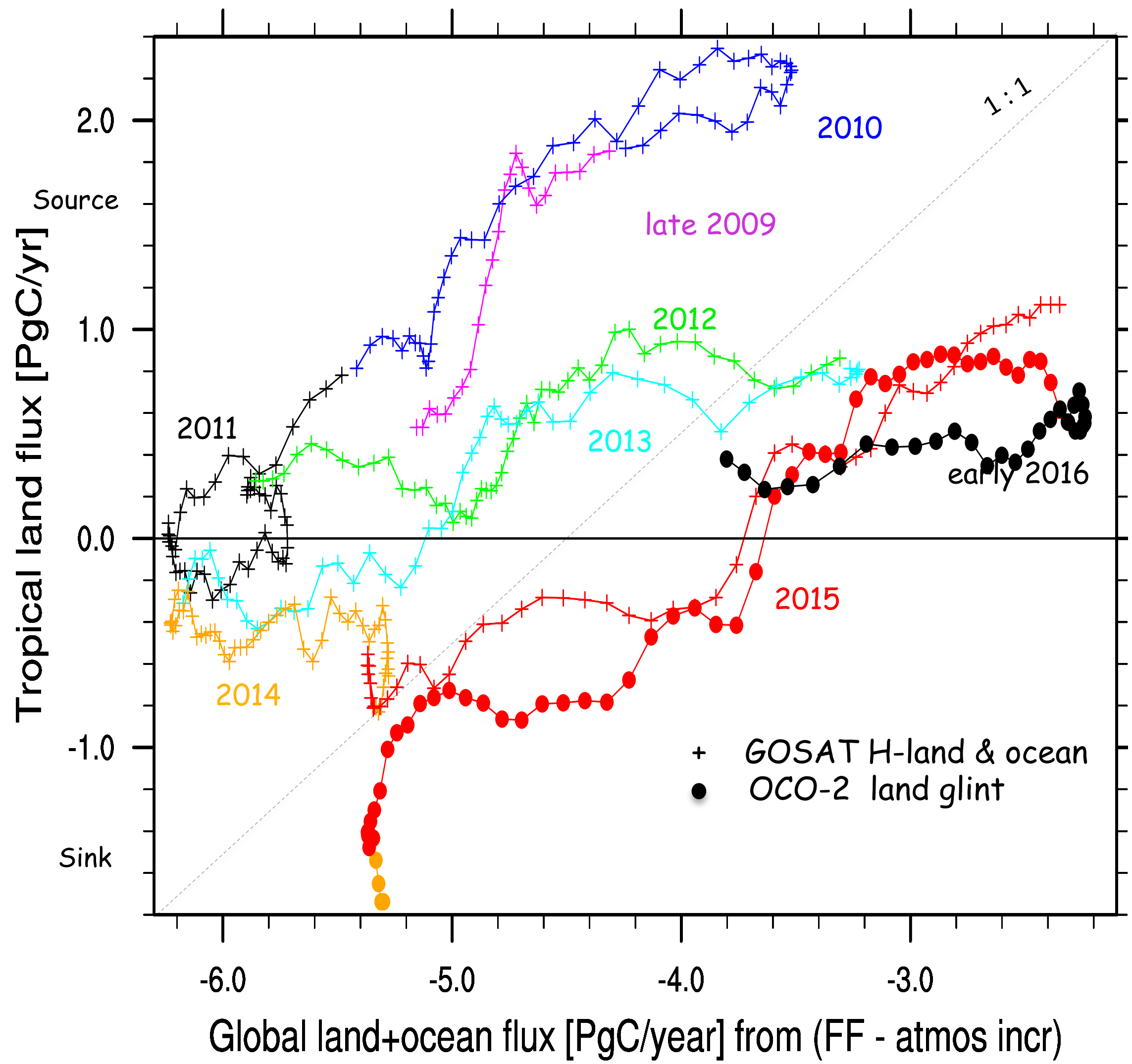
Phase plot of net tropical land flux from GOSAT inversion vs. global land+ocean uptake from *in situ* data



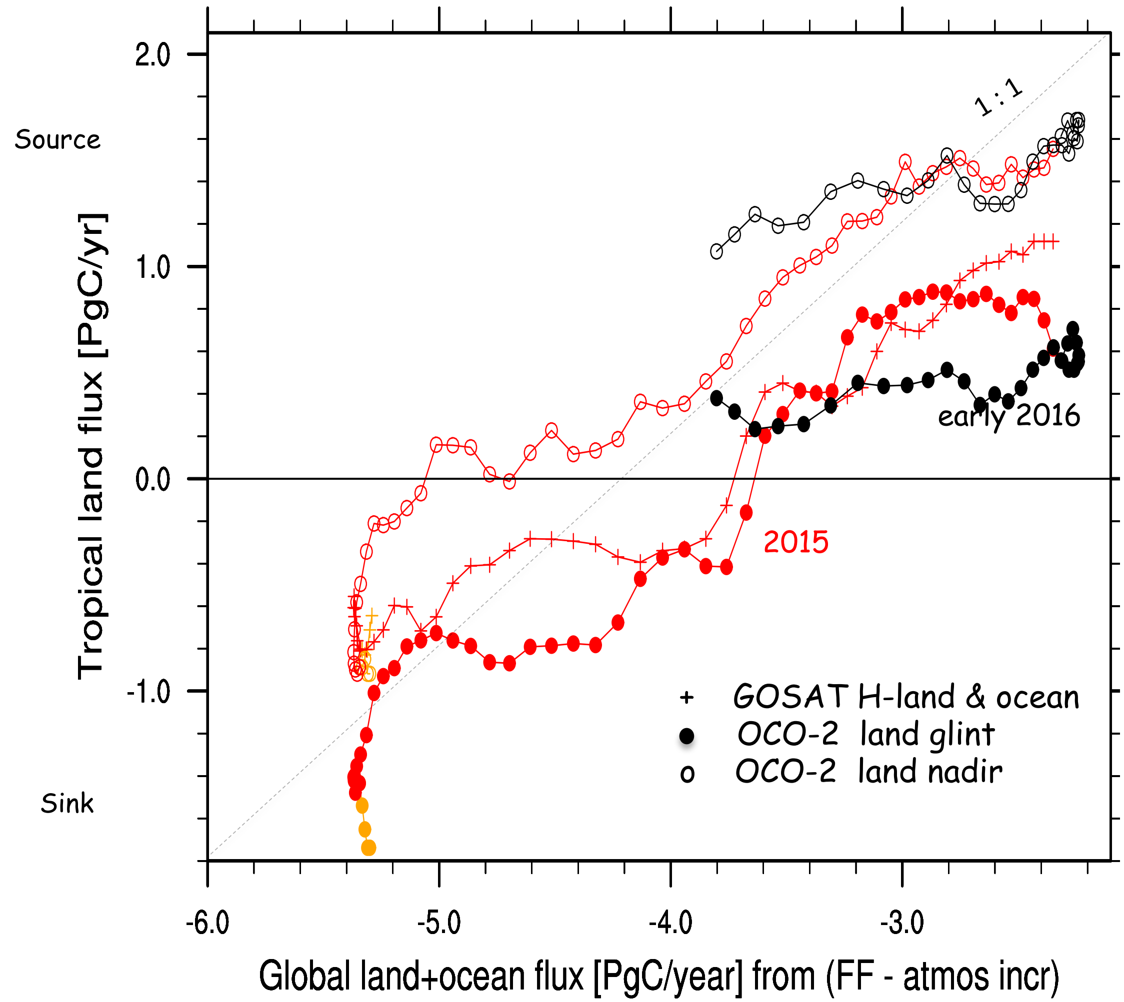


- GOSAT: tropical land regions the main driver of global CO_2 IAV since 2009
- ➔ Dense satellite data confirm the result obtained 15+ years ago from inversion of *in situ* CO_2 data but never really believed

OCO-2 land glint data,
when used in inversions,
gives almost the same
time history of flux
for the tropical
land as GOSAT



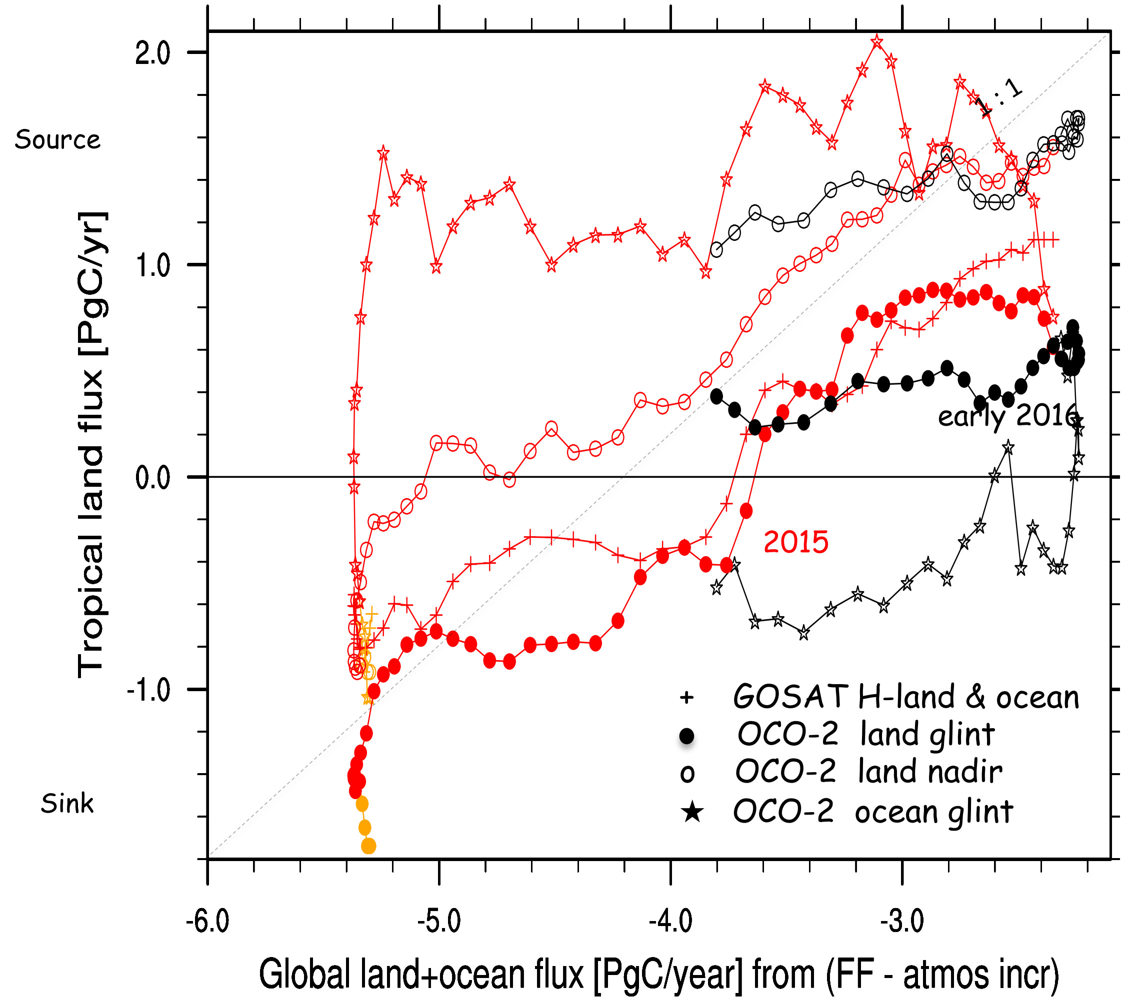
OCO-2 land nadir data,
gives a nearly identical
time history of flux
as the OCO-2 land glint
data …
but with a ~ +1 Pg/yr offset



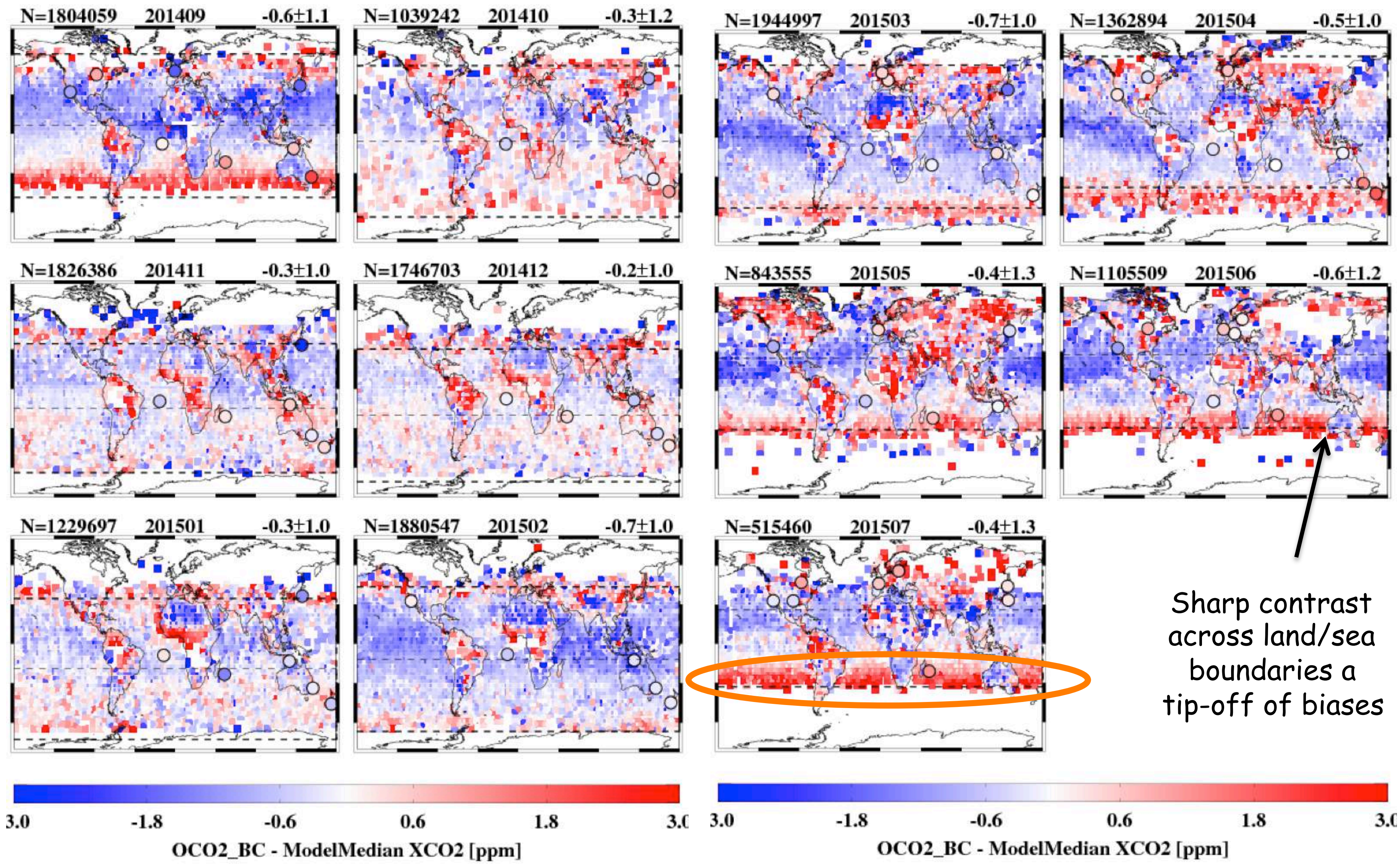
What about the ocean glint data? …

OCO-2 ocean glint data gives a different view than the other three...

Reason to believe that OCO-2 OG suffers more serious biases, though...



Positive bias on southern fringe in ocean glint mode



Sharp contrast across land/sea boundaries a tip-off of biases

(Slide from Chris O'Dell)

Also, an albedo-dependent bias over land (remove with “s31” correction)

Factors influencing inverted fluxes

- Retrieval bias: LN / LG / OG
- Prior fluxes used
- Prior flux covariance assumed
  - Spatial/temporal pattern of errors
  - Overall tightness of land vs. ocean
- Differences in pure transport
  - Vertical mixing
  - Advection
- Other transport model differences
  - Resolution
- Inversion setup differences
  - Data span, data selection, data errors
  - Spin up period
- Inversion method differences
  - 4Dvar vs enKF
  - Control parameters: NEE vs NPP + RESP

➔ Need to quantify these to understand what is causing the spread

➔ Modeling errors seem to contribute at least as much as retrieval errors

OCO-2 flux inversion MIP

Goal: separate OCO-2 retrieval errors from modeling errors/choices with controlled experiments:

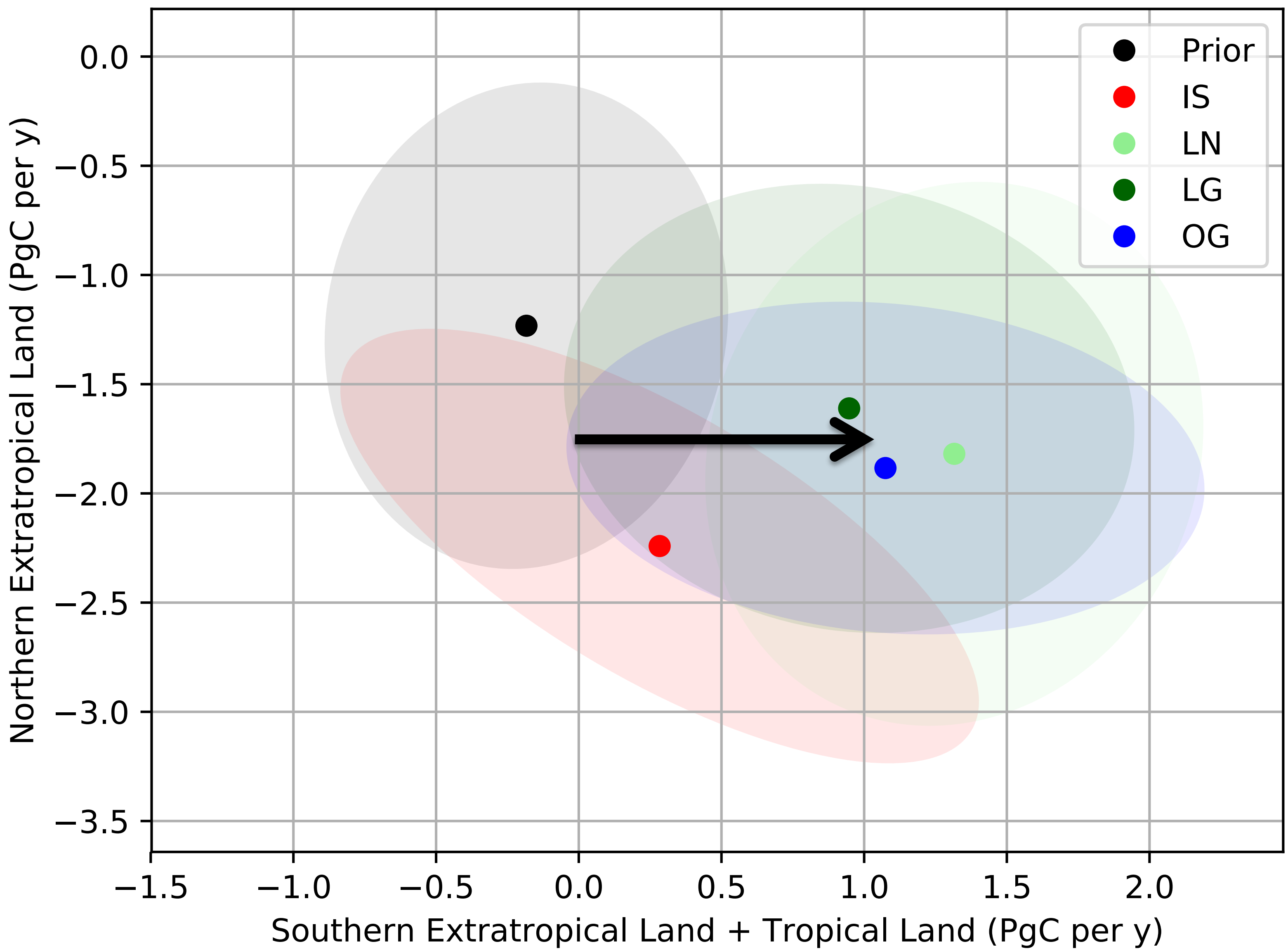
Inversion results from:

- A. Schuh, GEOS-Chem, matrix
- J. Liu, GEOS-Chem, 4Dvar
- A. Jacobson, CT-NRT, EnKF
- L. Feng, GEOS-Chem, EnKF
- F. Deng, GEOS-Chem, 4Dvar
- S. Crowell, TM5, 4Dvar
- F. Chevallier, LSCE, 4Dvar
- S. Basu, TM5, 4Dvar
- D. Baker, PCTM, 4Dvar

Data to invert	Science Experiments		Tier 1					
	Sat	Sat + in situ	Sensitivity btw data types					
	SE	SEi	OG	LN	IS	TCi	TC	LG
Ocean glint	✔	✔	✔					
Land nadir	✔	✔		✔				
Land glint								✔
In situ		✔			✔	✔		
TCCON		✔				✔	✔	

All groups use same data and data uncertainties; satellite data as 10-sec avgs

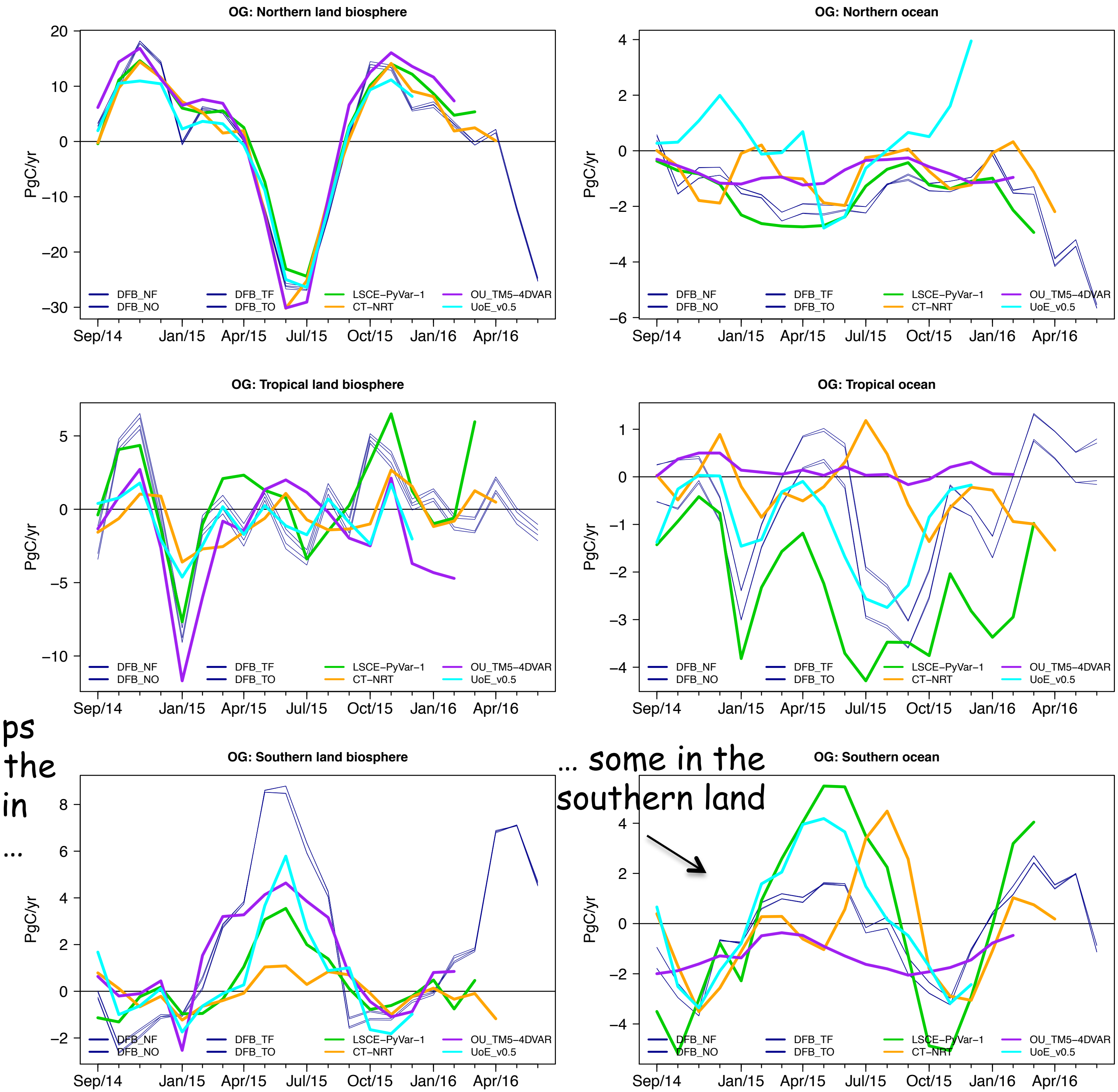
Across multiple models, the OCO-2 data points to the tropical/SH land being a source in 2015



Conclusions

- GOSAT and OCO-2 land data confirm that the tropical land biosphere is the main driver of observed CO_2 inter-annual variability
- Systematic differences between OCO-2 viewing modes (retrieval biases?) make it difficult to estimate robust annual means, but…
- Tropical land biosphere does not seem to be a significant long-term net sink of CO_2
  - Suggests CO_2 fertilization effect not the whole story
- Modeling assumptions also an issue
  - Prior flux distribution
  - Pattern and overall tightness of assumed prior flux uncertainties
- Team of inverse modelers working on understanding model and retrieval errors, in collaboration with OCO-2 retrieval team

Fluxes estimated using OCO-2 ocean glint data (only)



Some modeling groups place the impact of the SH ocean glint bias in the southern ocean …

Observational Constraints on the Global Atmospheric CO_2 Budget

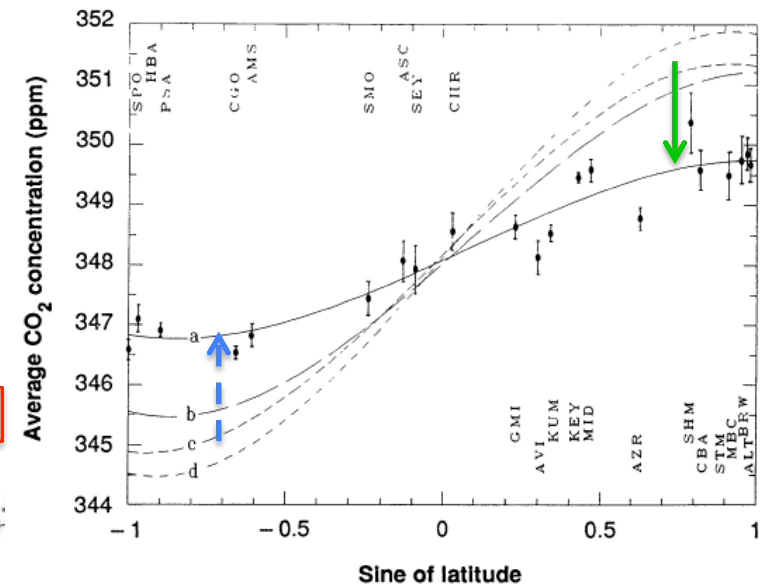
(1990, *Science*)

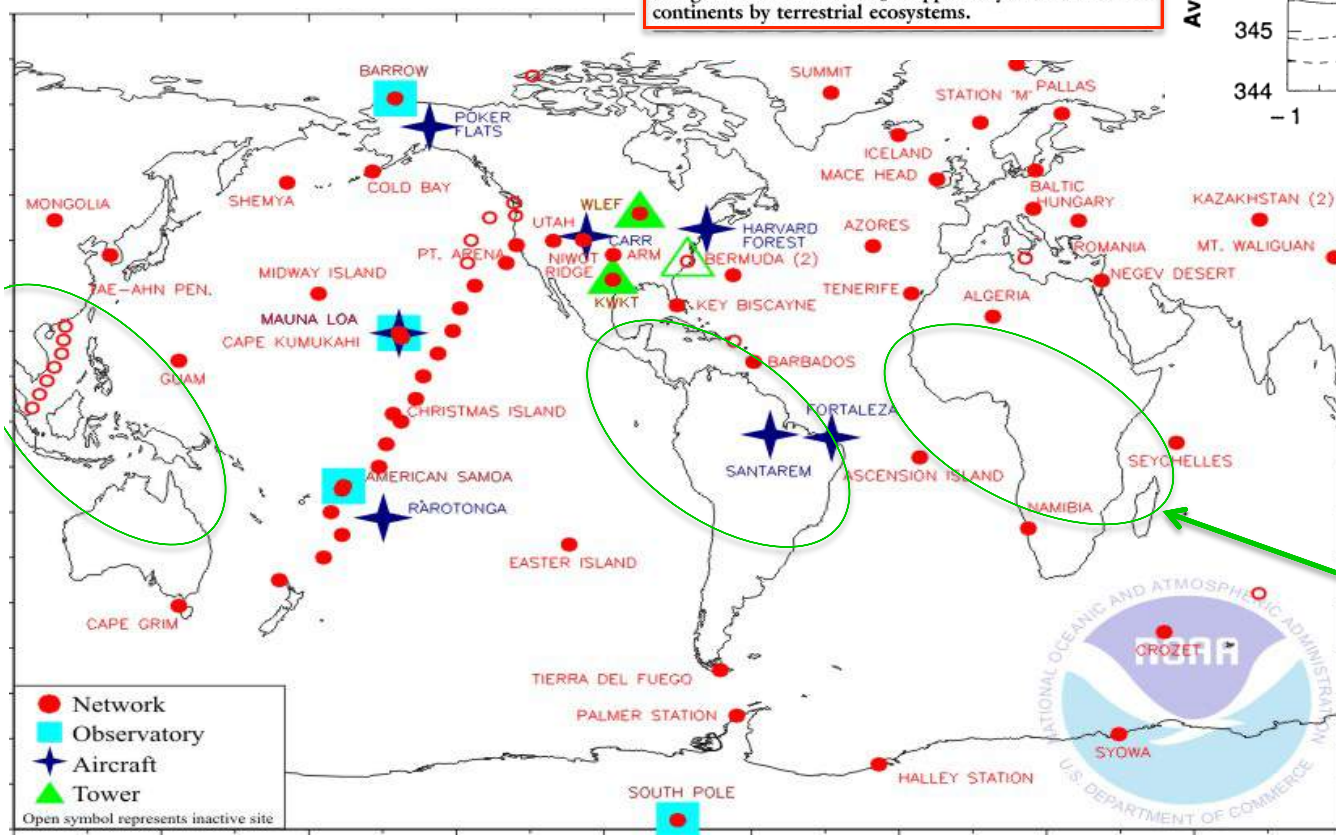
Pieter P. Tans, Inez Y. Fung, Taro Takahashi

Spatially-distributed atmospheric CO_2 measurements
+
atmospheric transport model

= spatially-variable flux estimates

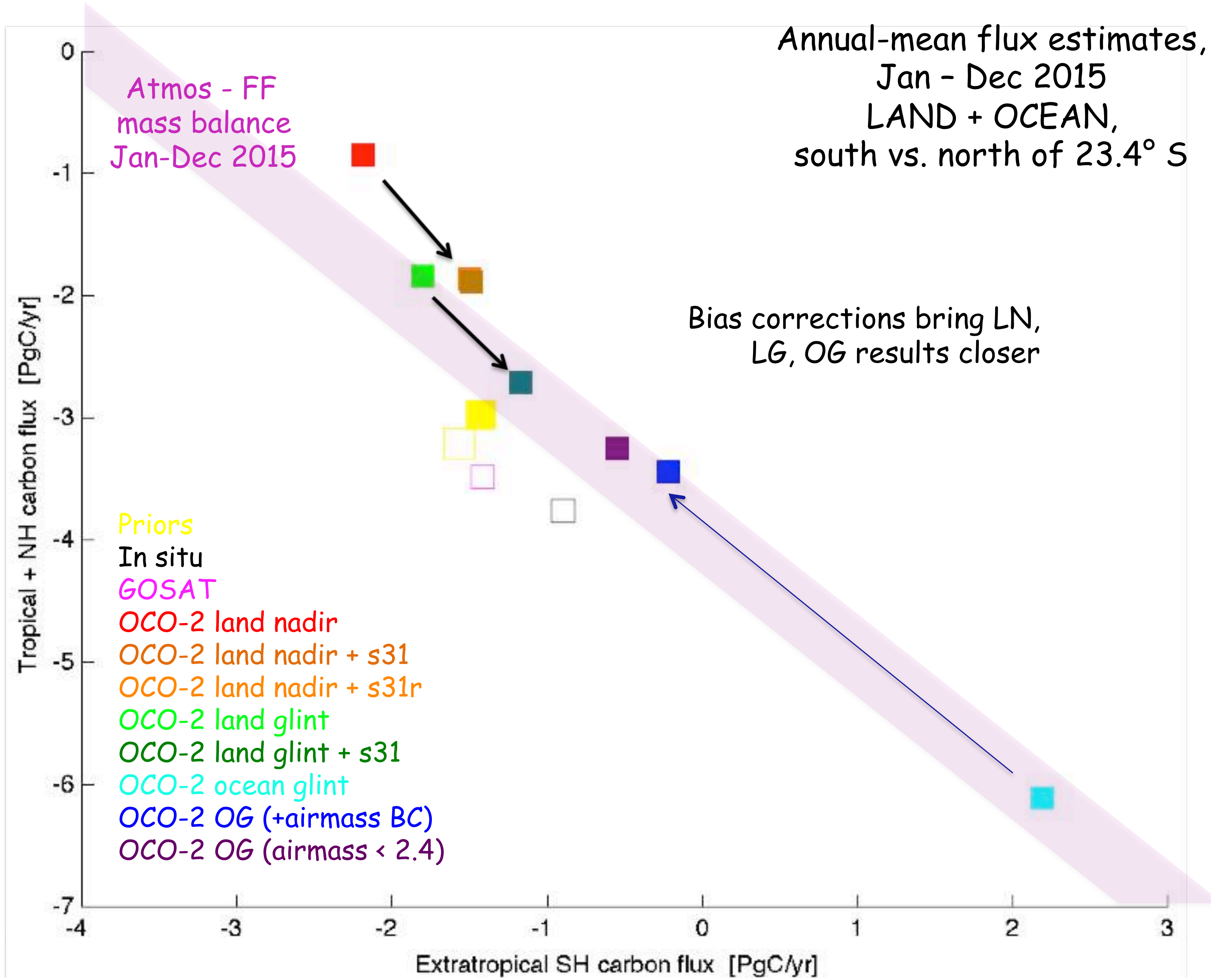
Observed atmospheric concentrations of CO_2 and data on the partial pressures of CO_2 in surface ocean waters are combined to identify globally significant sources and sinks of CO_2. The atmospheric data are compared with boundary layer concentrations calculated with the transport fields generated by a general circulation model (GCM) for specified source-sink distributions. In the model the observed north-south atmospheric concentration gradient can be maintained only if sinks for CO_2 are greater in the Northern than in the Southern Hemisphere. The observed differences between the partial pressure of CO_2 in the surface waters of the Northern Hemisphere and the atmosphere are too small for the oceans to be the major sink of fossil fuel CO_2. Therefore, a large amount of the CO_2 is apparently absorbed on the continents by terrestrial ecosystems.





Disagreement on the location of the northern land sink:
Fan et al (1998),
Bousquet et al (1998)

Tropical land regions mostly unobserved


Annual-mean flux estimates,
Jan – Dec 2015
LAND + OCEAN,
south vs. north of 23.4° S
Atmos - FF
mass balance
Jan-Dec 2015
Bias corrections bring LN,
LG, OG results closer
Priors
In situ
GOSAT
OCO-2 land nadir
OCO-2 land nadir + s31
OCO-2 land nadir + s31r
OCO-2 land glint
OCO-2 land glint + s31
OCO-2 ocean glint
OCO-2 OG (+airmass BC)
OCO-2 OG (airmass < 2.4)
Tropical + NH carbon flux [PgC/yr]
Extratropical SH carbon flux [PgC/yr]
0
-1
-2
-3
-4
-5
-6
-7
-4
-3
-2
-1
0
1
2
3