Top-down estimation of CO_2 fluxes: lessons learnt and challenges ahead

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Data Sharing for Transverse GEOSS

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TOWARD THE PREDICTION OF GLOBAL CHANGE
Frontier Research Center for Global Change

Plan of the talk

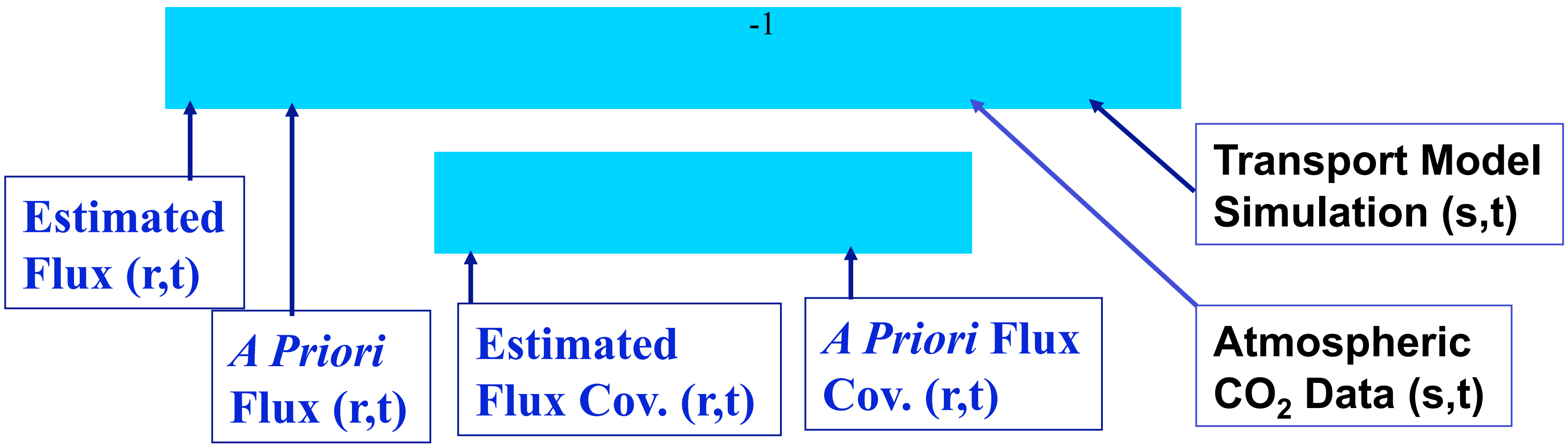
- Introduction
- Inverse/top-down model, and issues with forward transport errors
- Decadal CO_2 flux variability and its controls
- Estimation of absolute flux and example with improved transport model
- Recent developments in observing systems and future analysis perspectives

Basic Equations in the Inverse Model:

Forward model simulation of an atmospheric tracer (e.g. CO_2) mathematically is:

$D_0 = G \, . \, S_0$, where G is a linear operator representing atmospheric transport (no chemistry).

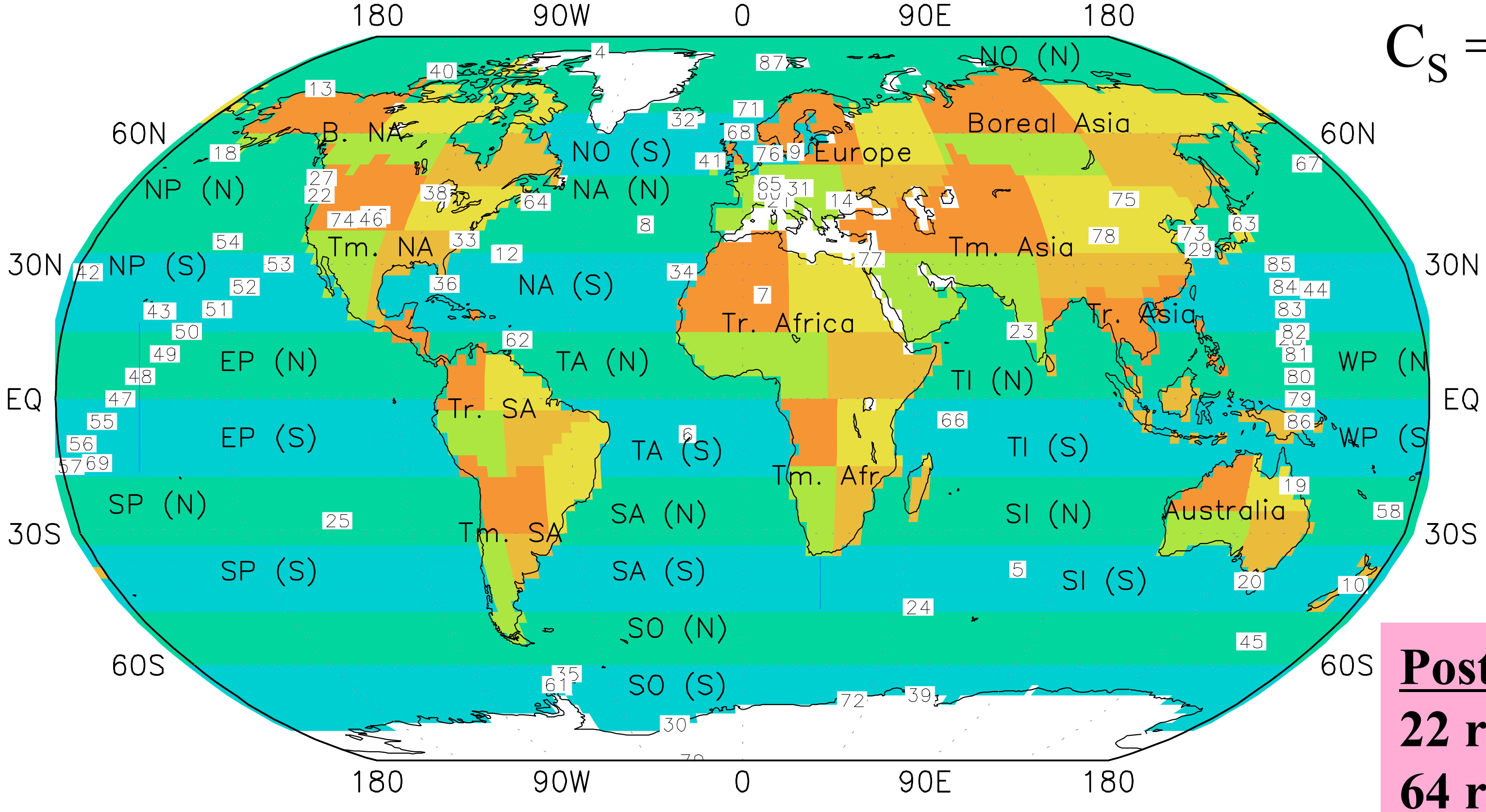
Inverse model equations for CO_2 fluxes and uncertainties:



r: inverse model region, s: observation station, t: time

64-Regions Inverse Model

(using NIES/FRCGC CTM and interannually varying NCEP/NCAR reanalysis meteorology)



$C_S = c_{s1} + c_{s2}\ldots$

Post Inversion c^2	
22 reg	2.15
64 reg	1.11
64+IAV	0.99

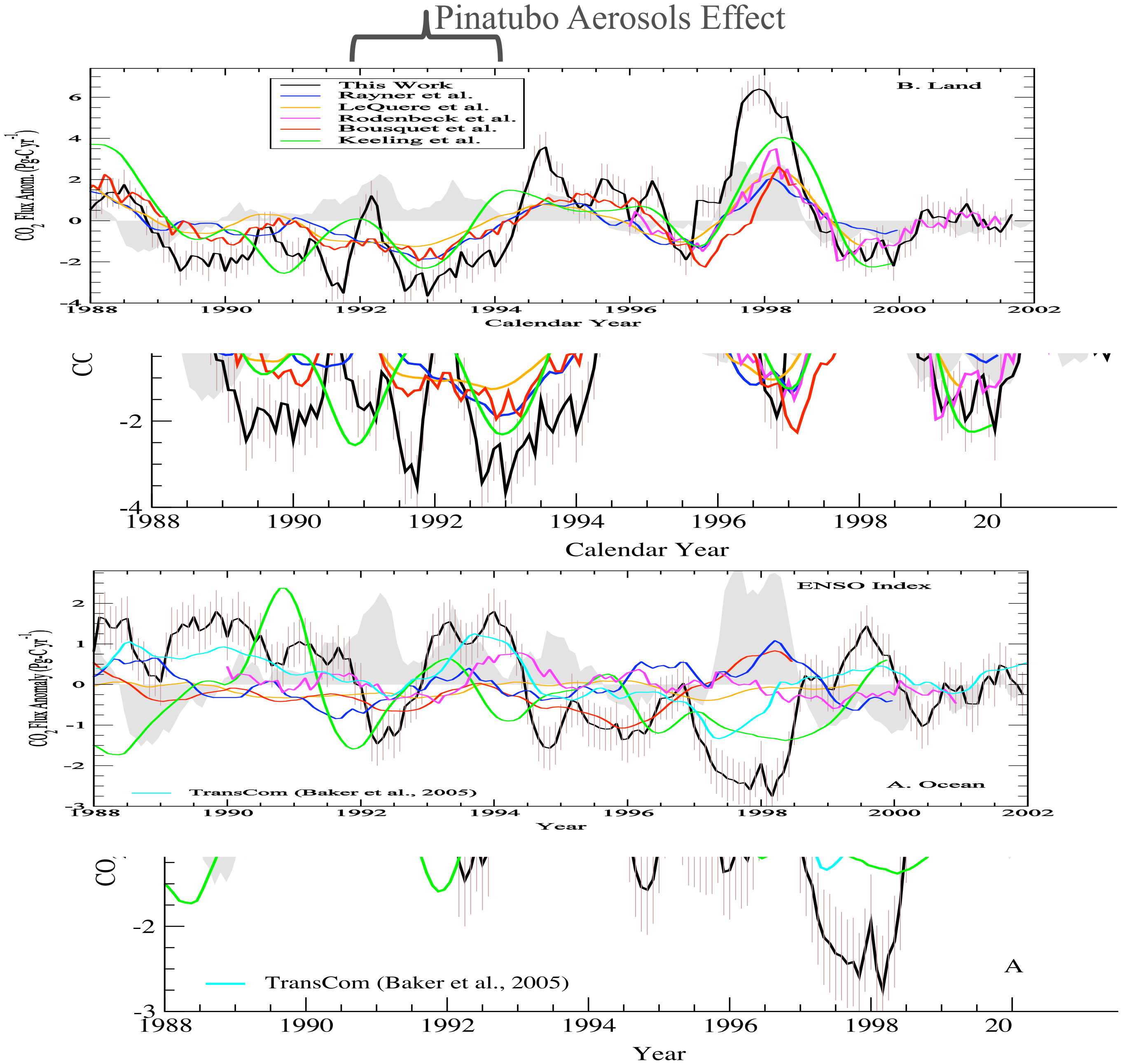
$$\chi^2 = \frac{1}{T}\left[\frac{1}{N}\sum_1^N \left[(D - D_{predicted})^2 / C_D + \frac{1}{M}\sum_1^M (S_0 - S)^2 / C_S\right]\right.$$

Patra et al., Global Biogeochem. Cycles., 2005a,b

Less dependent on transport modelling error, but network size dependent

CO_2 FLUX VARIABILITY AND CLIMATE/ ANTHROPOGENIC ACTIVITIES LINK

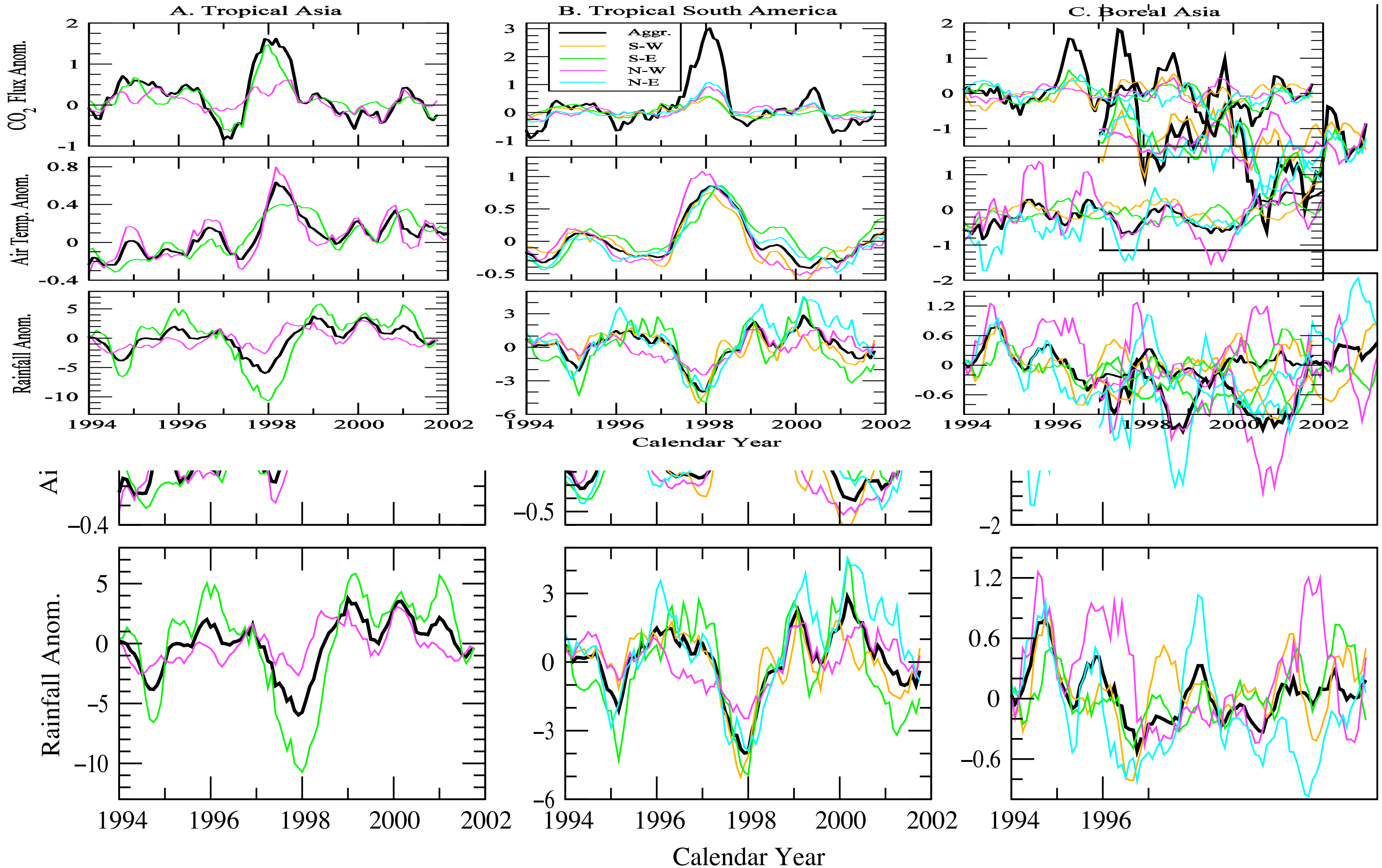
Comparison of CO_2 flux anomalies with other estimates



ANOMALY:
monthly-mean flux timeseries – average seasonal cycle

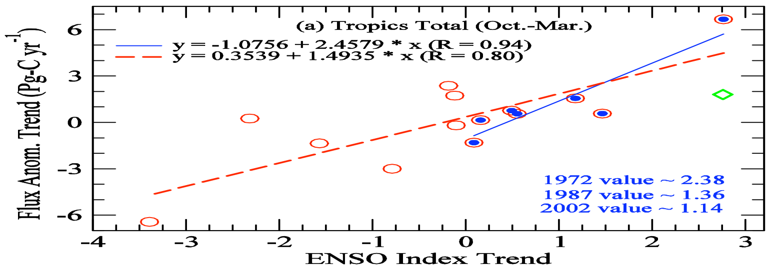
Patra et al., Global Biogeochem. Cycles., 2005a,b

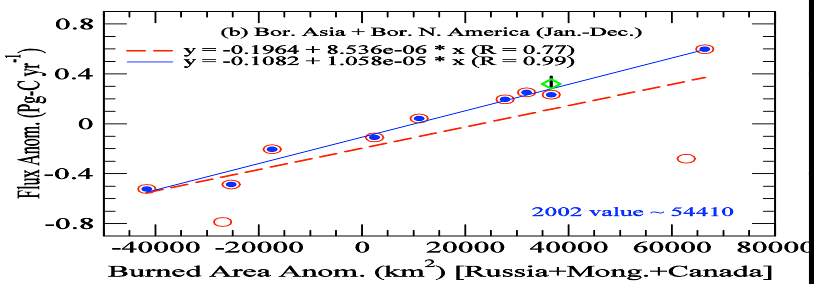
Effect of Drought on Regional Land Fluxes

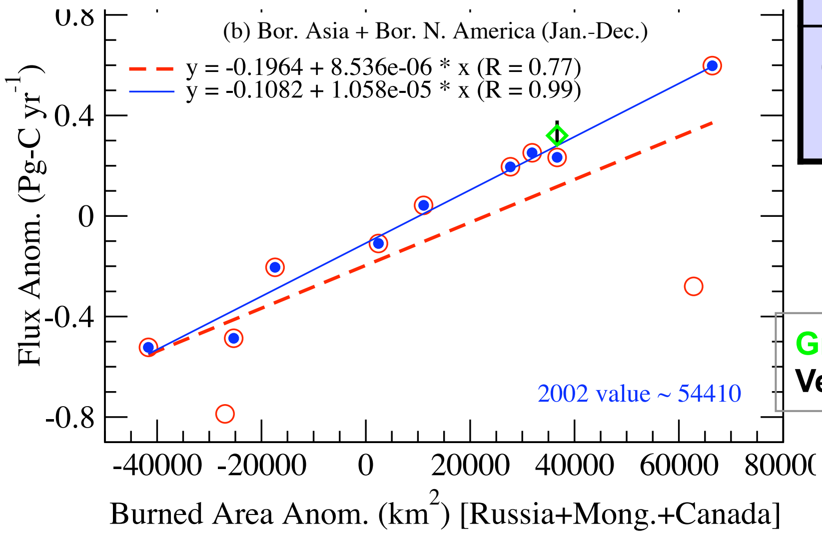


Patra et al., Global Biogeochem. Cycles., 2005b

Simple empirical relations for atmospheric-CO_2 growth rate prediction







Sources/Increase Rates	1971-1972	1986-1987	2001-2002
El Nino (Pg-C)	4.0	2.3	2.1
Boreal Fire (Pg-C)	0.0	0.5*	0.28*
CO_2 Gr. Rate (estimated) (ppm/yr)	1.9	1.6	1.3
CO_2 Gr. Rate (observed) (ppm/yr)	1.8	1.5	1.3

* this flux is confined to NH only

Green diamond: van der Werf et al.
Vertical bar: Kasischke and Bruhwiler

Patra et al., Tellus-B, 2005

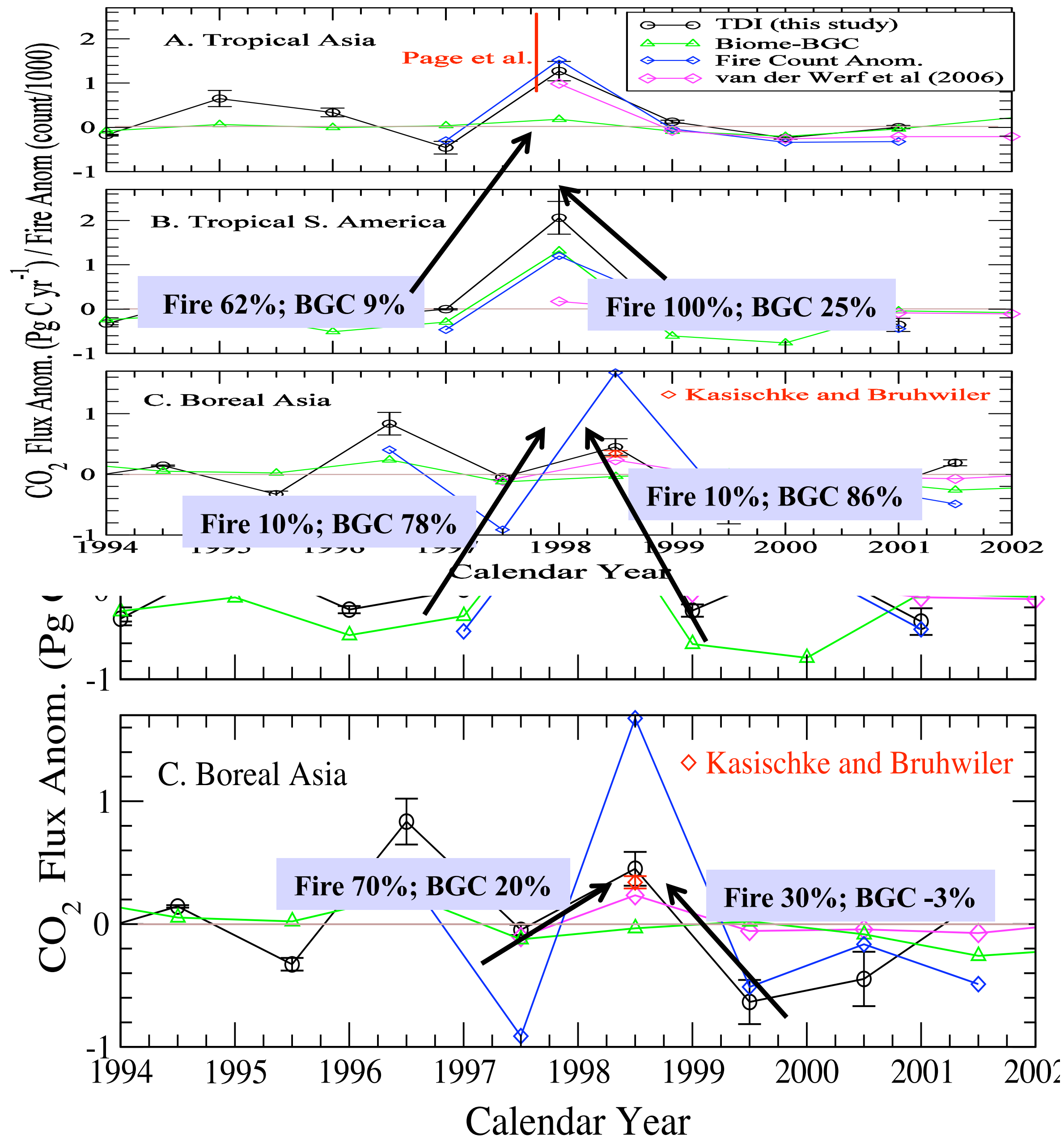
Drivers of CO_2 regional flux anomalies

TDI,

vs.

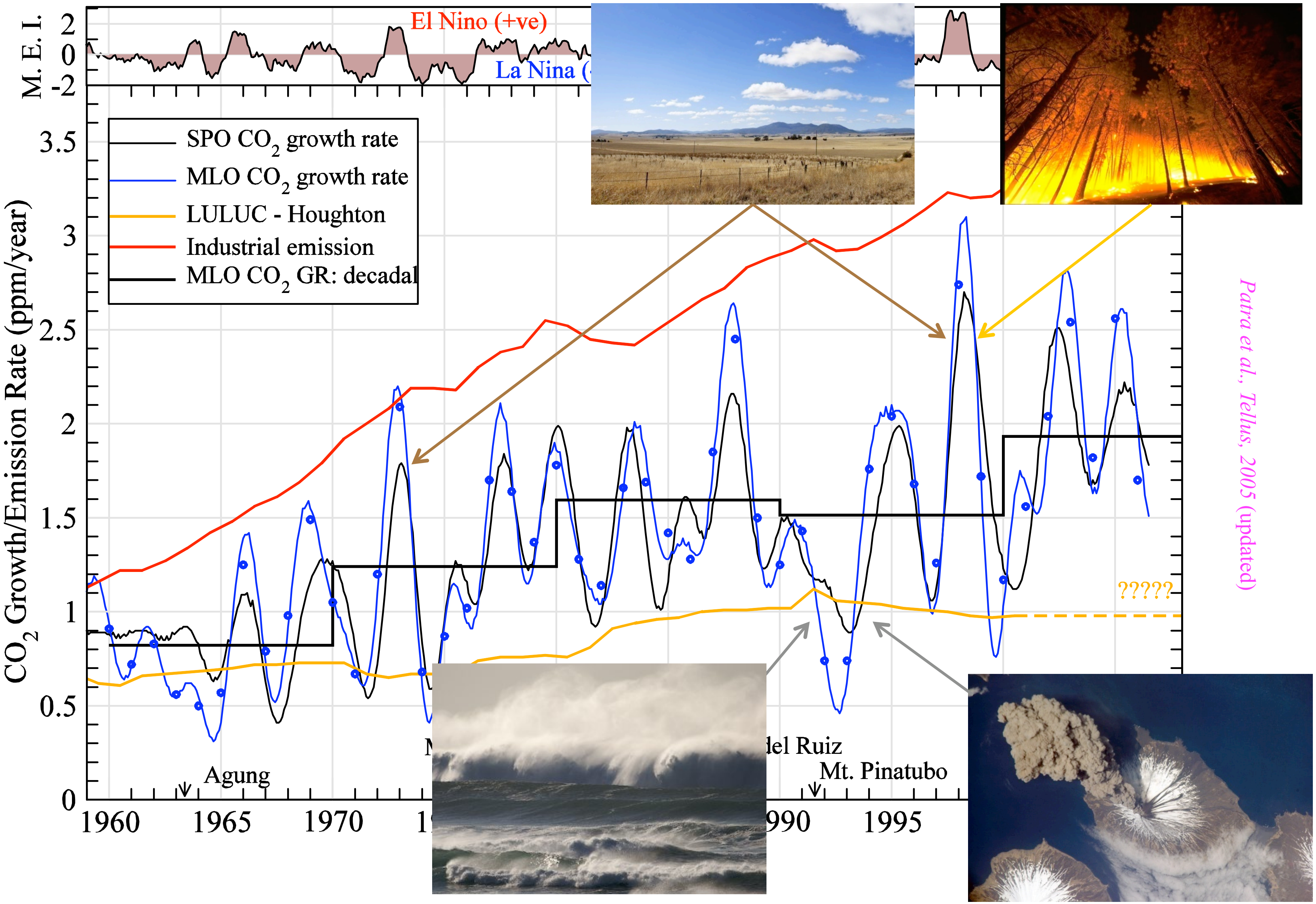
Bottom-up estimates:

1. Biome-BGC (drought)
2. GFEDv2 (fire emission)



Patra et al., Global Biogeochem. Cycles., 2005b (Updated)

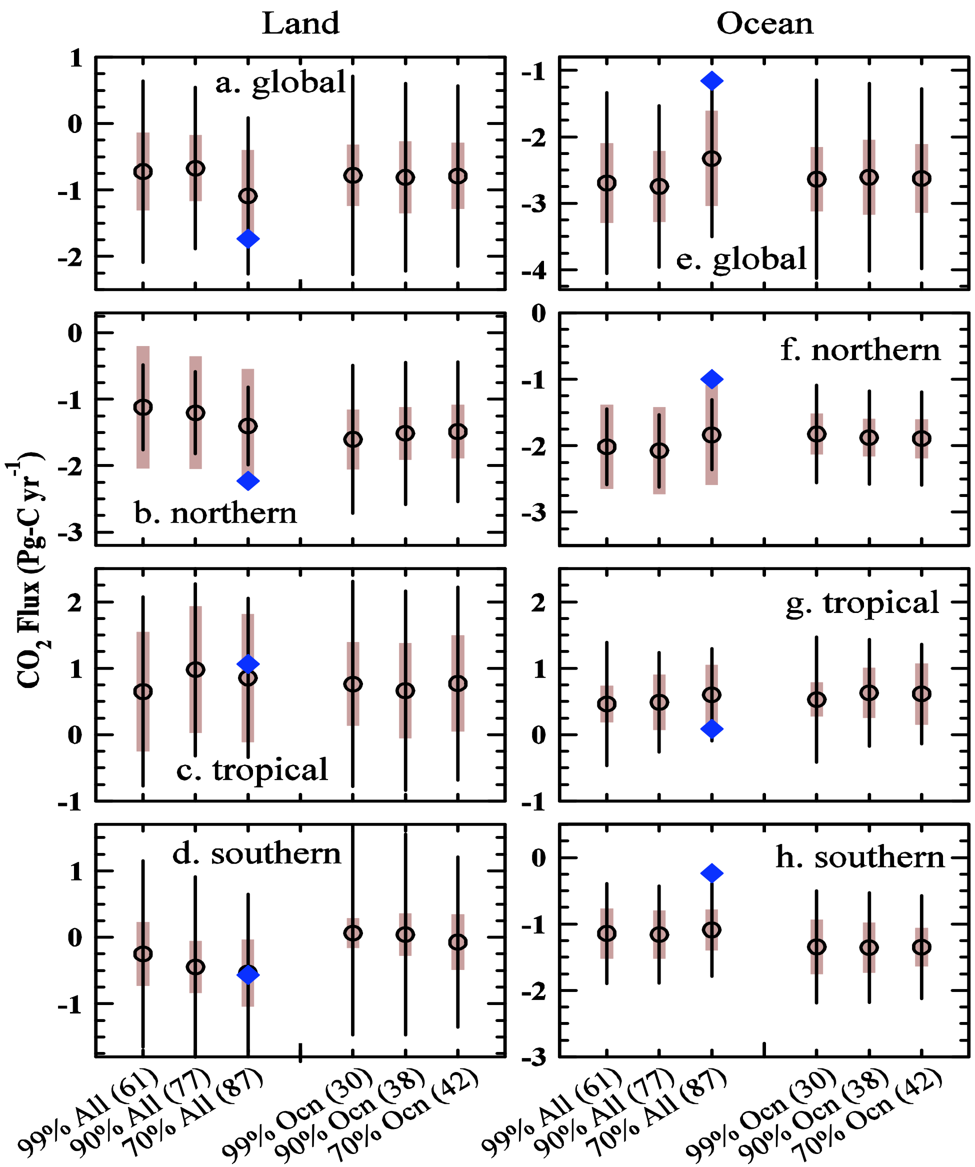
Atmospheric-CO_2 variability and its controls

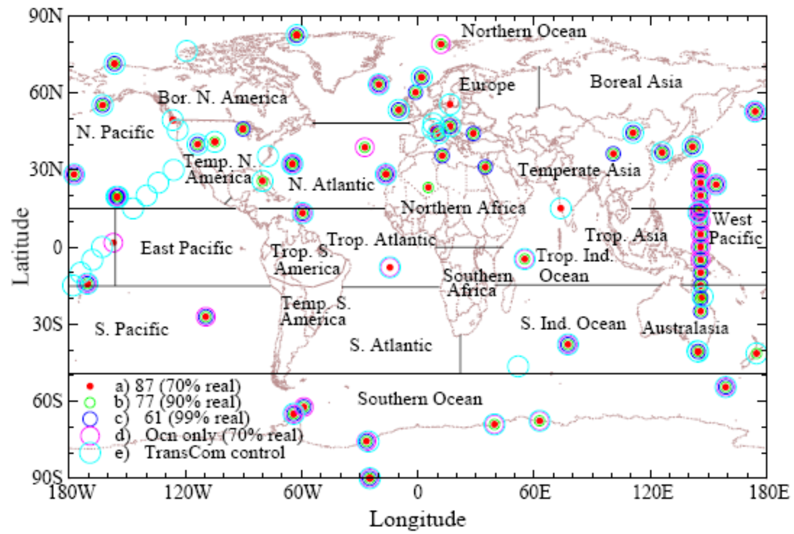


Transport modelling errors and measurement density affecting

ABSOLUTE FLUX DETERMINATION

Global & hemispheric Scale CO2 Fluxes – Network Dependency (Patra et al., GRL, 2006)

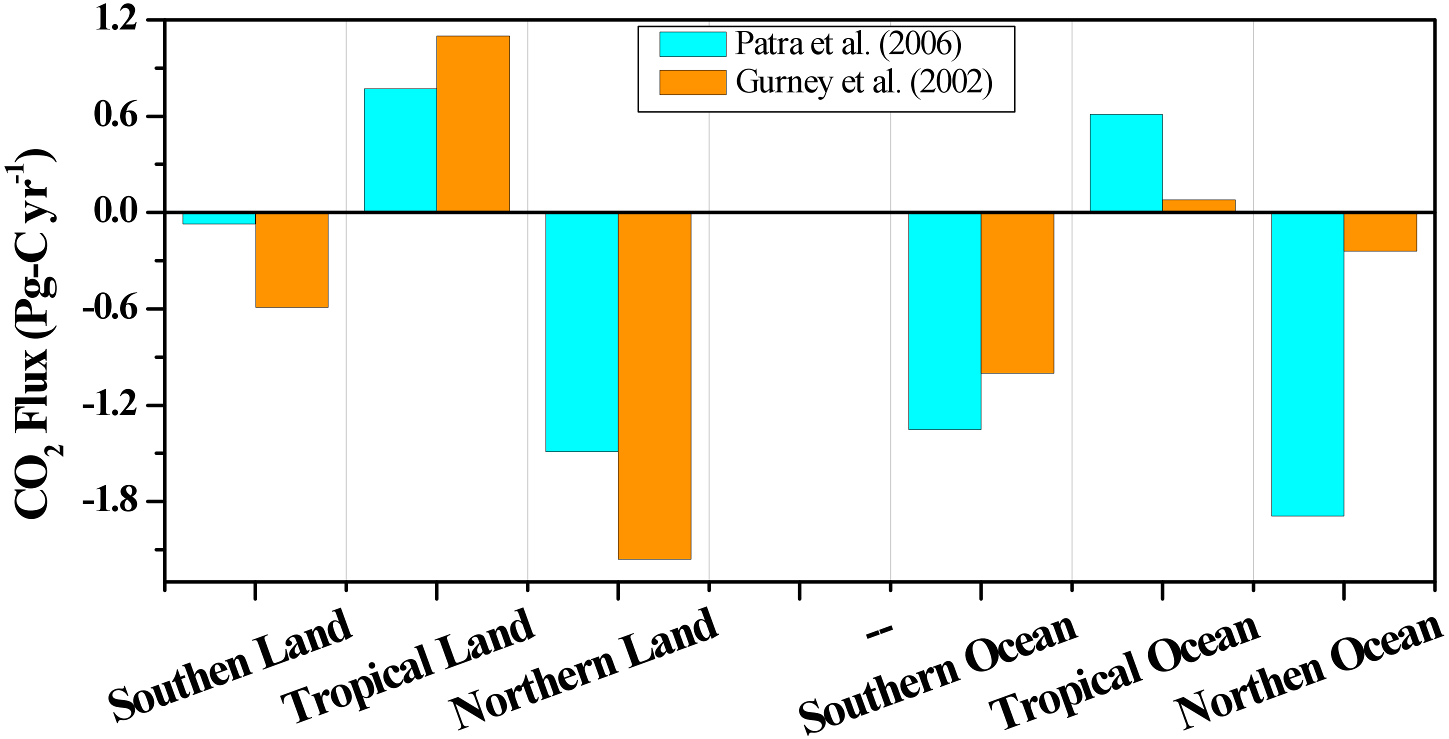




This work suggested that

- Land sites lead to variations in flux estimation – more difficult to model?
- Estimation of Ocean region fluxes is relatively robust
- Improvement in forward transport model is desired, more than the use of multiple models

Land and ocean source/sink distributions: Implications for northern/tropical land sinks



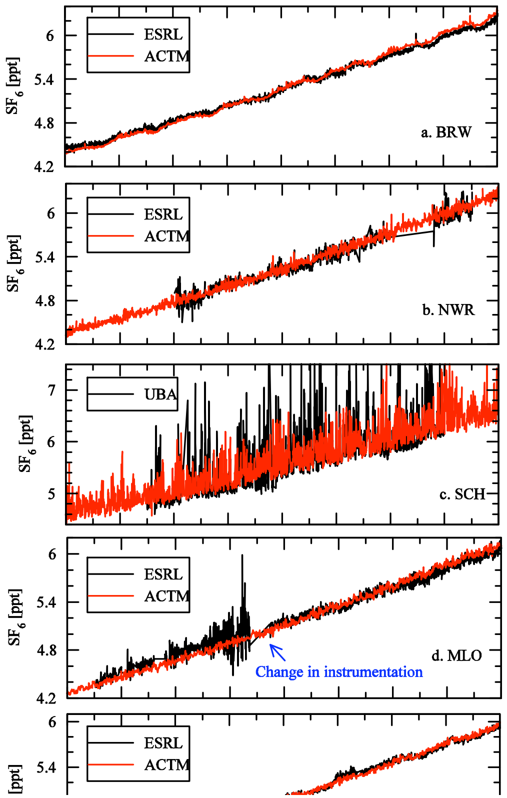
Net ecosystem sink = *inversion estimate - land use/LU change flux* ***(Houghton, 2003)***

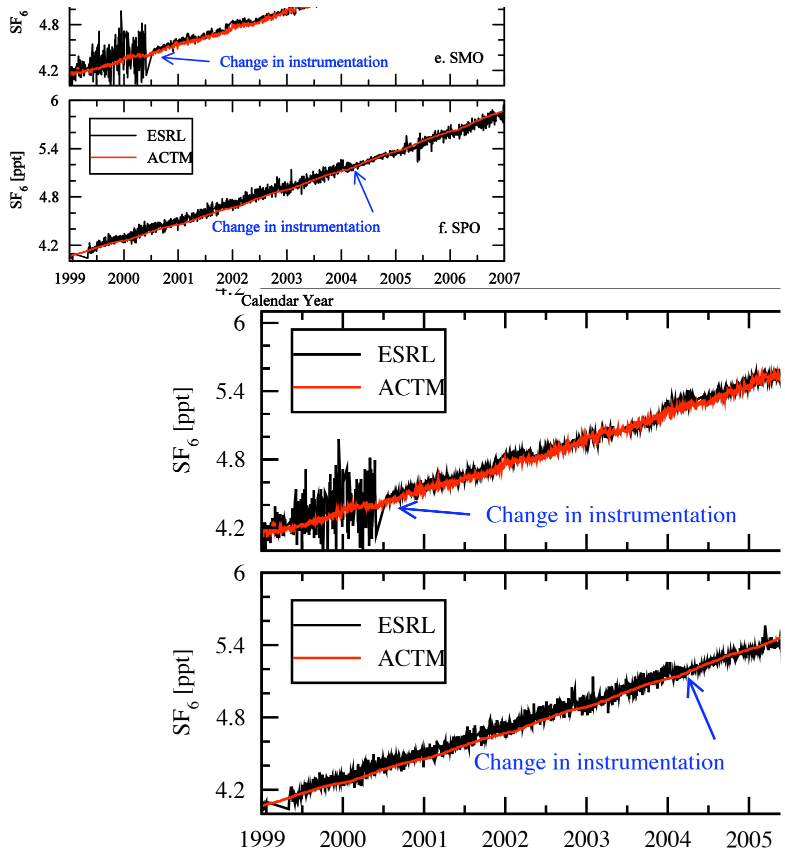
	BEFORE	AFTER
Tropical Land (Pg-C/yr):	1.10-2.20 = **-1.10**	0.85-2.20 = **-1.35**
Northern Land (Pg-C/yr):	-2.16-0.02 = **-2.18**	-1.49-0.02 = **-1.51**

Stronger NH sink Equal NH and TR sink

New transport modelling initiatives:

CCSR/NIES/FRCGC chemistry-transport model (**ACTM**); Validation using SF_6 model-observation comparison





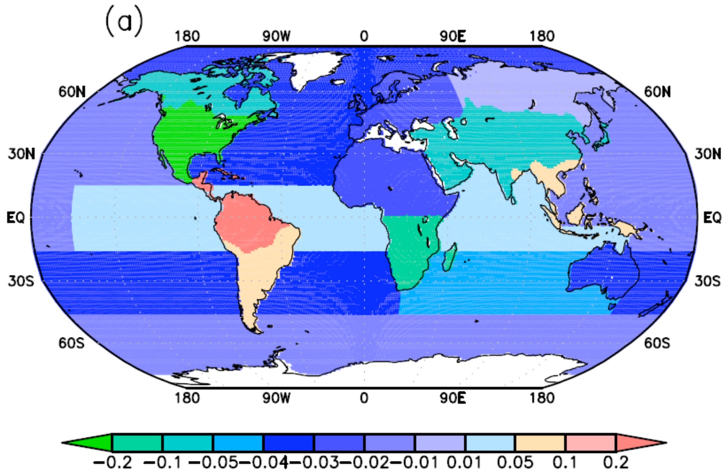
Patra et al., ACP, in press, 2009

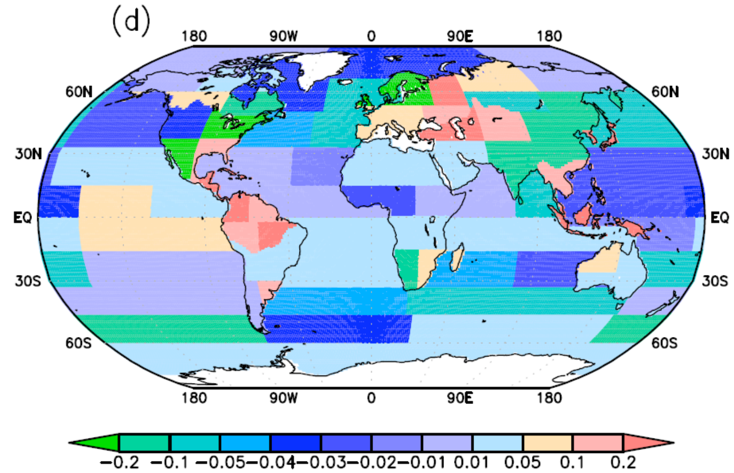
Station ➔	BRW	NWR	SCH	MLO	SMO	SPO
Std. Dev. (ppt) (observed-model)	0.051 (N=1334)	0.077 (N=898)	0.389 (N=1020)	0.056 (N=1402)	0.034 (N=1284)	0.043 (N=1335)

Measurement precision = 0.05 ppt

CO_2 inverse fluxes using ACTM forward simulations – results are appearing to be less biased and prior free

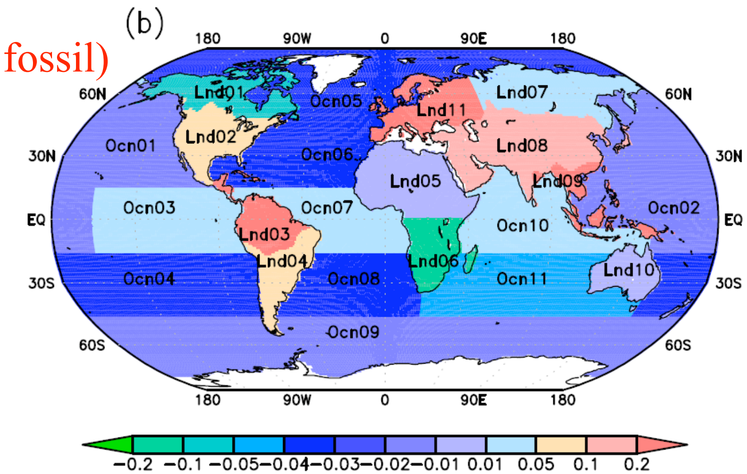
Non-fossil CO_2 flux

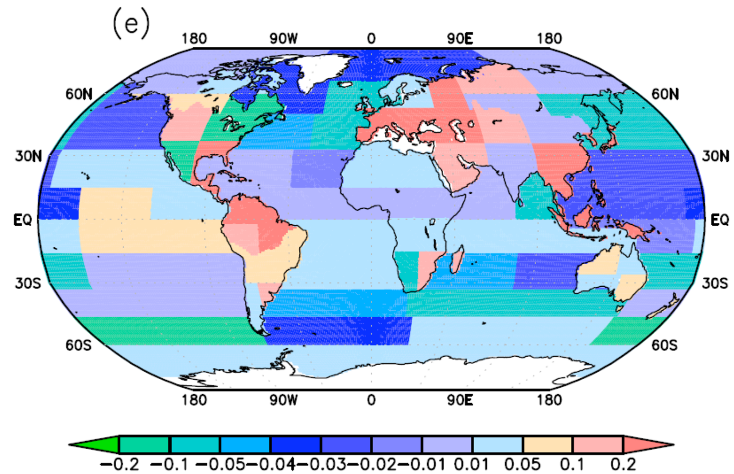




g-C/m2/day

All (incl. fossil) CO_2 flux



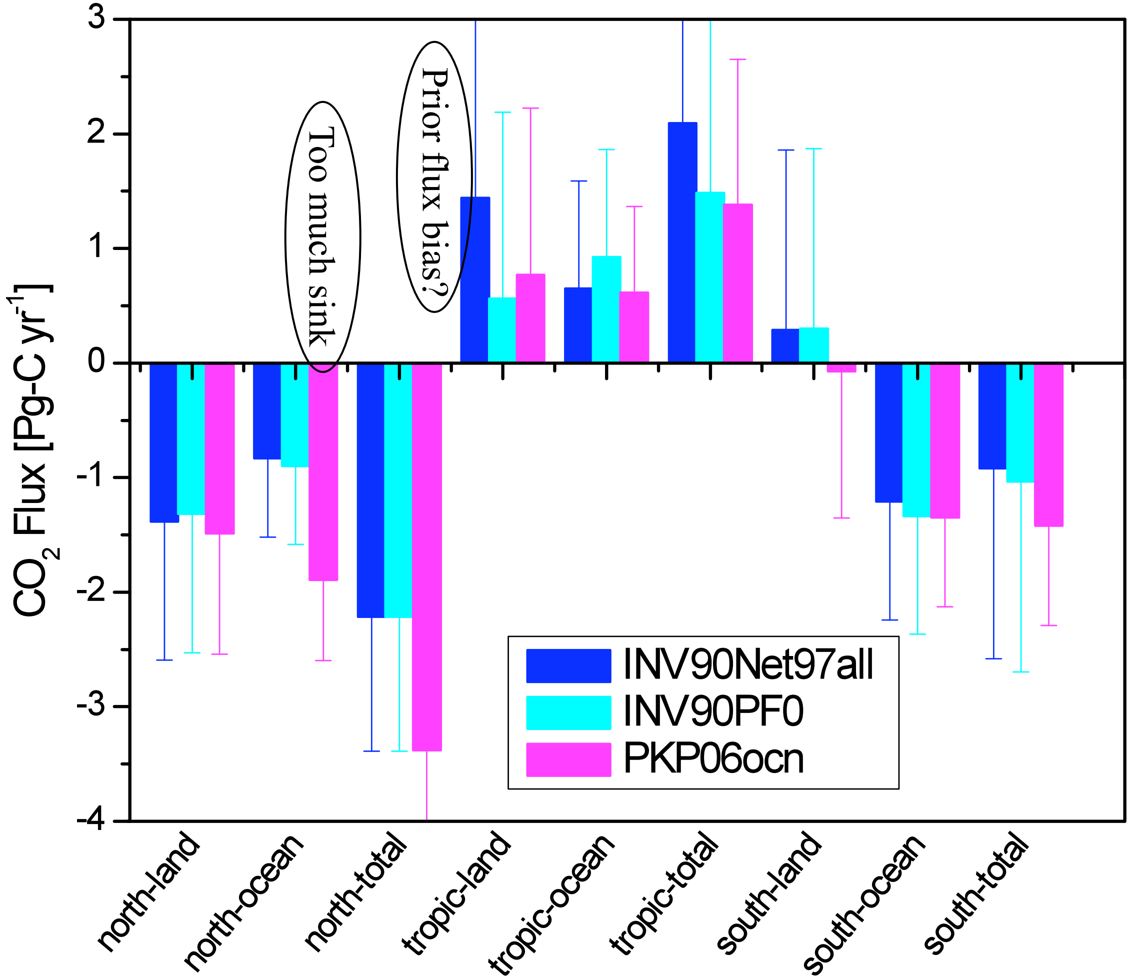


22-region inversion

90-region inversion

Patra et al., *work in progress*

Importance of increased observation network and well validated model transport



INV90Net97all: 90region Inv. mod., 97-site obs. Network, Incl. land & ocean sites

INV90PF0: As above, But with 0 Prior Flux

PKP06ocn: From Patra et al. (GRL, 2006), 22-region Inv. mod., 16 transport mod., Ocean only network

Patra et al., *work in progress*

Looks like, we can ingest data from the both Land & Ocean sites, and Inverse model results can be free of initialization (prior flux)

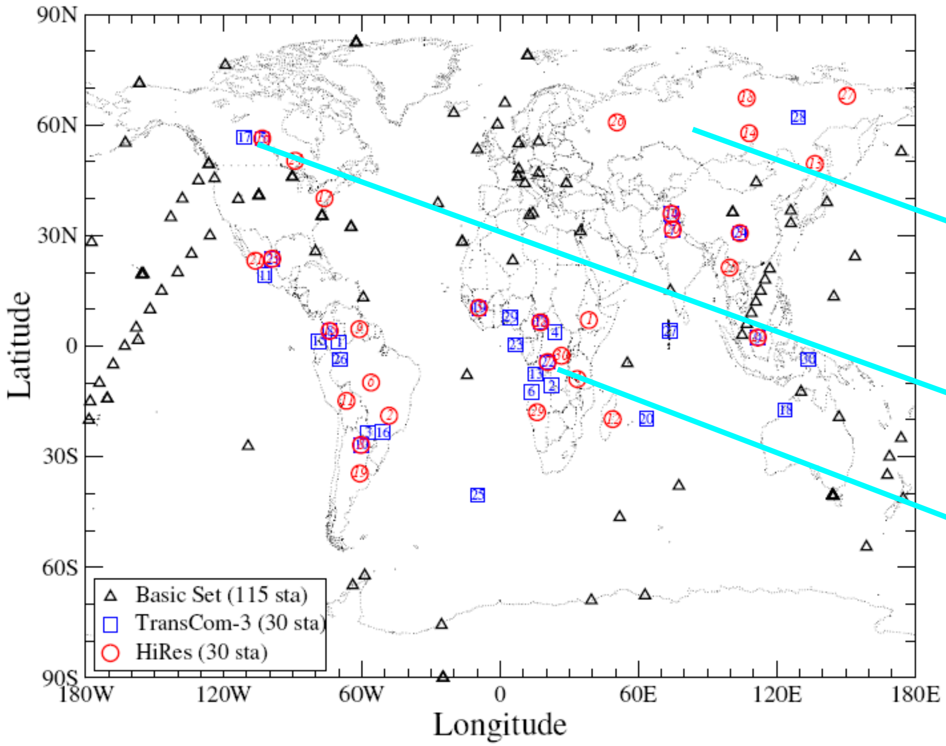
Global land and ocean C-flux partitioning

Method/Period	Land	Ocean	References
1990-1999	1.40±0.7	1.70±0.5	IPCC, 2001/2007
pCO_2, 1995 2000		1.46 - 2.12 1.40±0.7	Takahashi et al., 2002 2009
O_2/N_2 (~1990s)	1.26±0.8 0.70±0.8 1.00±0.6 1.00±0.9	1.86±0.6 2.40±0.7 1.70±0.5 2.10±0.7	Keeling & Garcia, 2002 Plattner et al., 2002 Bender et al., 2005 Tohjima et al., 2008
Atmospheric CO_2 Inversions (~1990s) ~2000s	1.40±0.5 1.60±0.3 1.46±0.6 1.15±0.7 2.09±0.5 0.04-0.45	1.80±0.6 1.70±0.2 1.34±0.6 1.88±0.5 1.06±0.5 1.31 - 1.58	Bousquet et al., 2000 Roedenbeck et al., 2003 Gurney et al., 2004 Patra et al., 2005 Baker et al., 2006 This work (*ACTM; PF=0.0*)
Oceanic pCO_2 Inv., 1970-2000		1.70±0.52	Mikaloff-Fletcher et al., 2006

Past, present and future of CO_2 measurement density

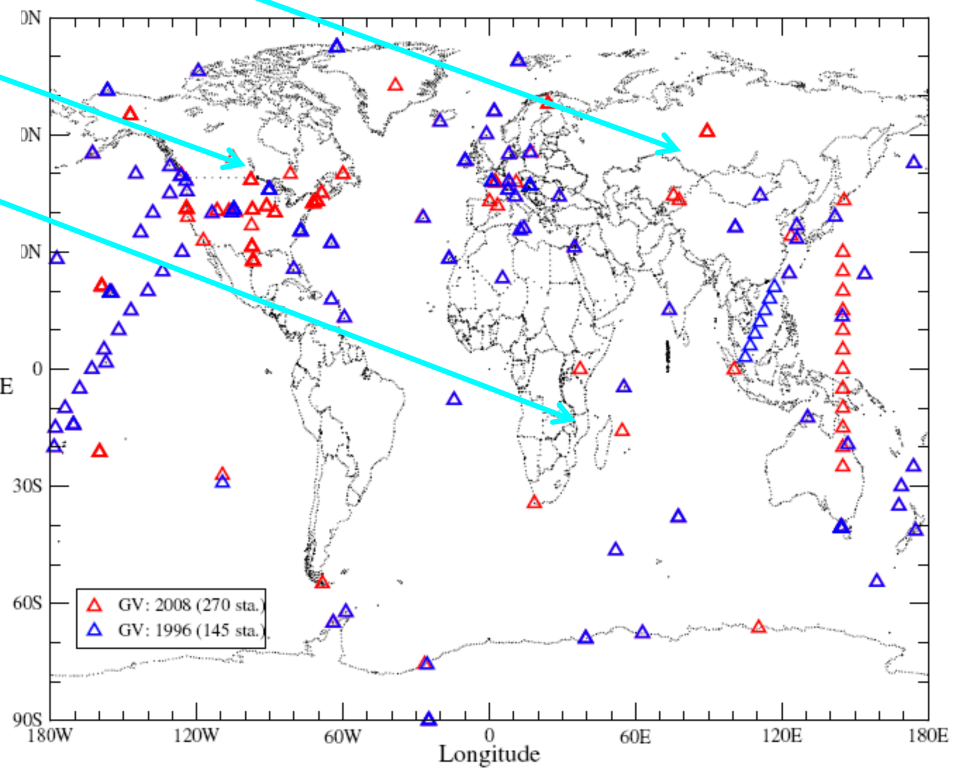
SURFACE, AIRCRAFT, SATELLITE

Surface measurement network is increasing… (from 2 sites in 1960)

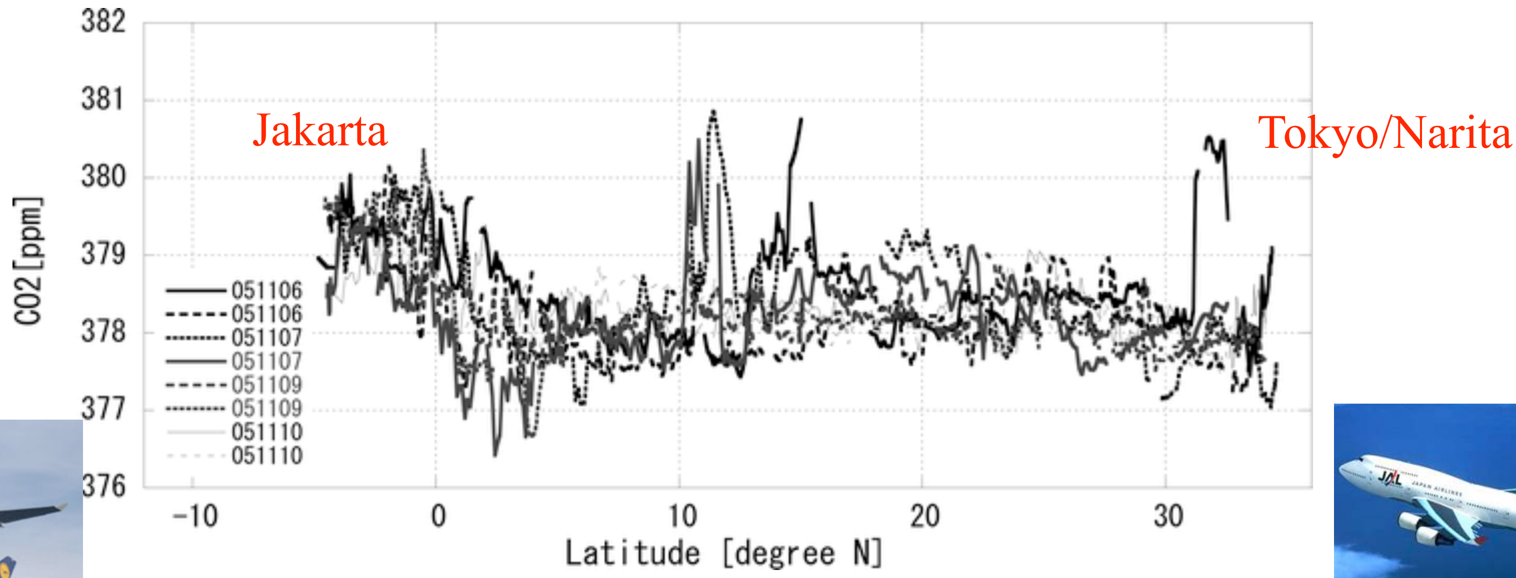


Sites recommended by network optimization (Patra et al., 2003)
Blue: 22 region inv.; Red: 42 region Inv.

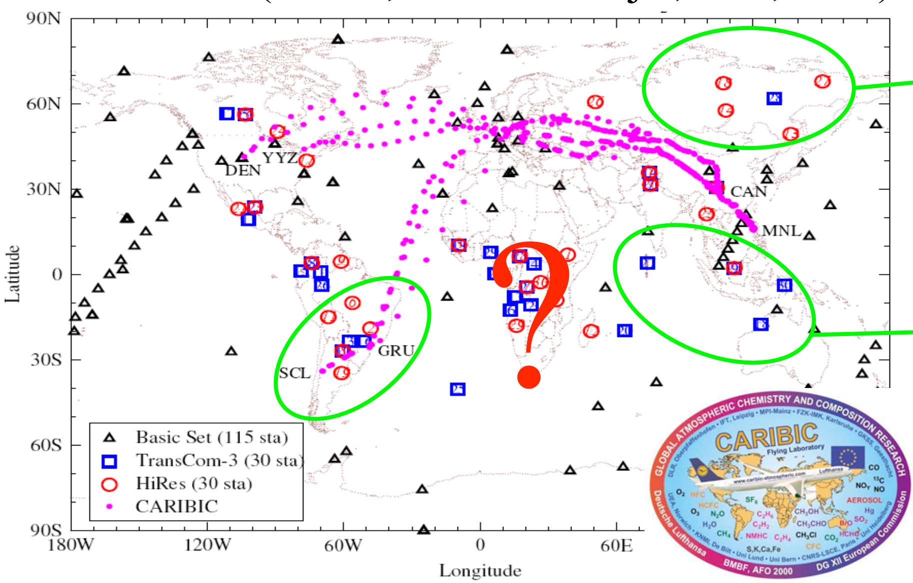
GlobalView-CO_2 (1996, 2008+)



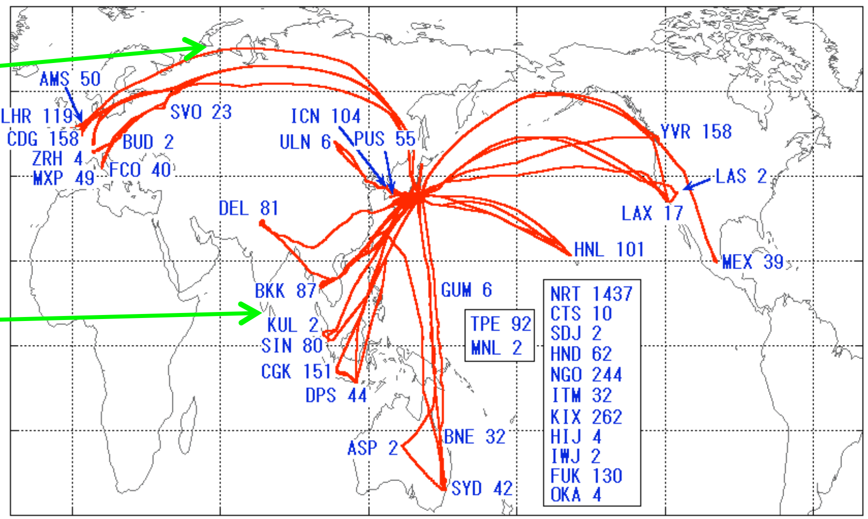
Measurement of CO_2 using aircrafts have been started



CARIBIC (2006--; Brenninkmeijer, ACP, 2007)



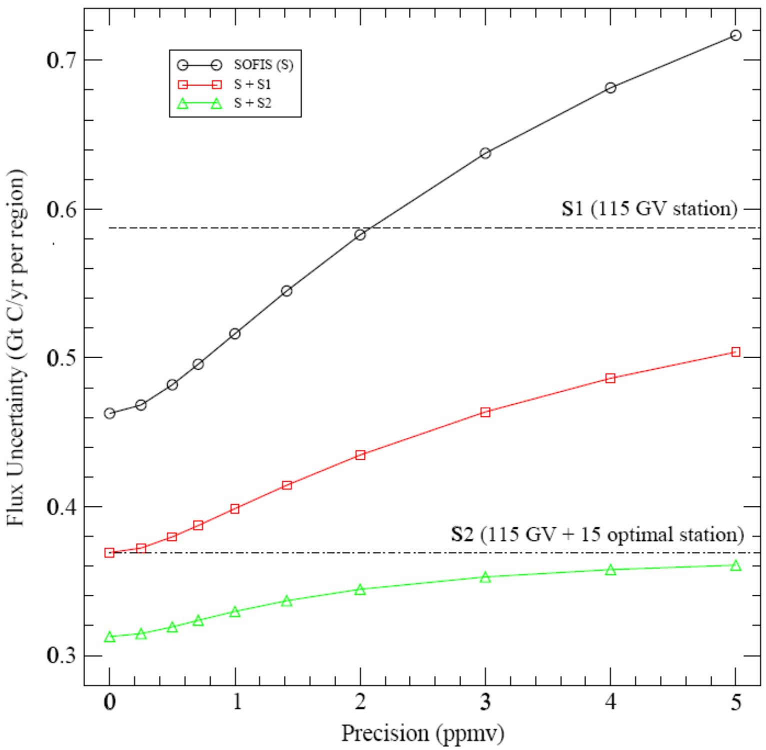
CONTRAIL (2005--; Machida et al., JAOT, 2008)



Surface vs. satellite observations

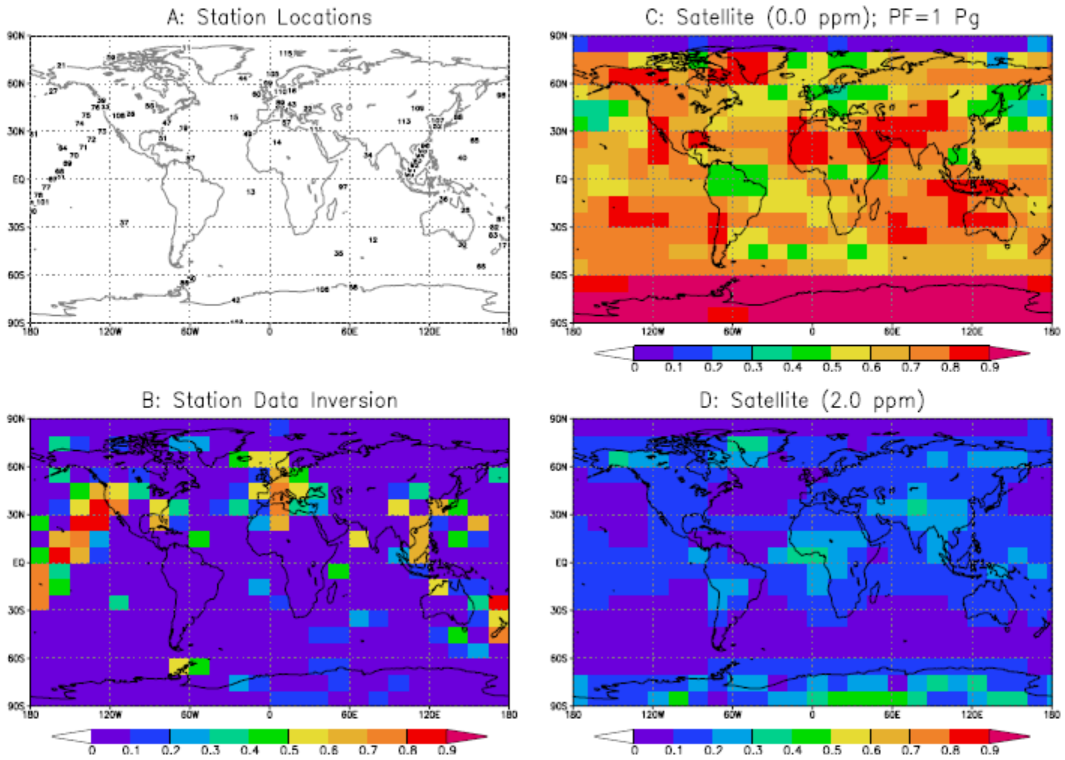
Coarse resolution inversion

(42-regions; Patra et al., 2003)



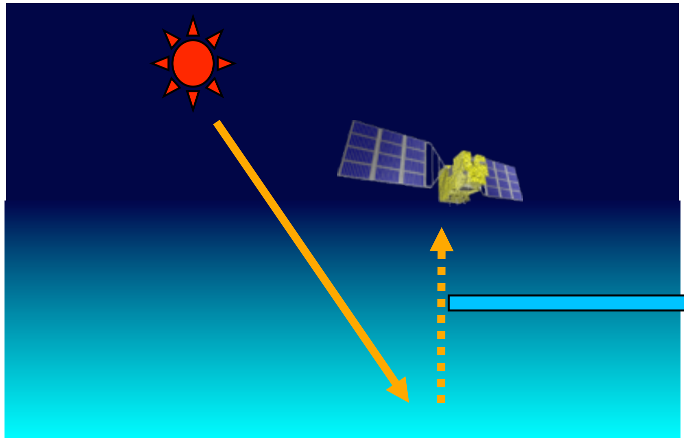
High resolution inversion

(432 regions; Maksyutov et al., 2003)

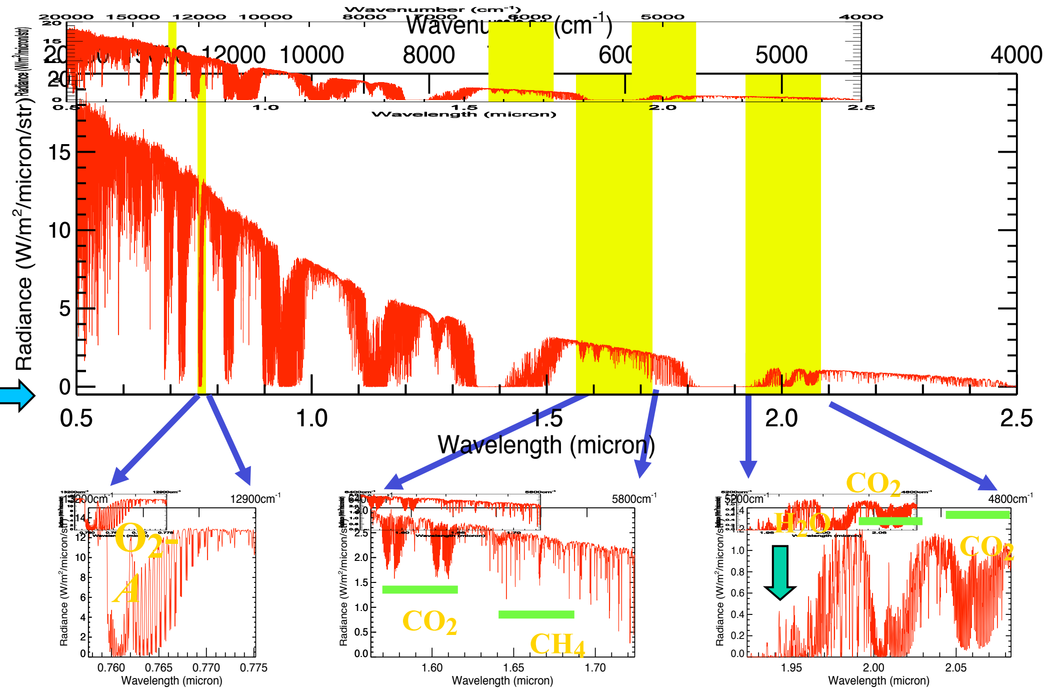


Information content in the surface/aircraft and satellite observations are seemingly different (high quality vs. resolution), but need to be combined

Satellite observations are starting



Yokota et al., JRSSJ, 2008



O_2 *A*-band (0.76 µm)

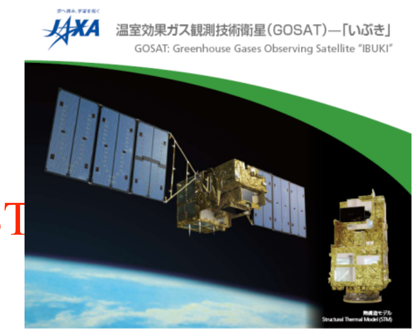
CO_2 1.6 µm and CH_4 1.67 µm band

CO_2 (H_2O) 2.0 µm band

GOSAT Greenhouse gases Observing SATellite

Launched:
23 Jan 2009; 12:54 JST

http://www.jaxa.jp



Launching due:
23 Feb 2009

http://www.jpl.nasa.gov

Conclusions

1. Accuracy of CO_2 flux determination primarily depend on
   - Selection of observational networks (expansion and sustenance of the surface network)
   - Forward model transport (less on techniques)

2. The flux variability over land and ocean are linked to ENSO cycle at global scale, and the NAO, PDO at the regions scale
   - The top-down and bottom-up flux variability can be reconciled
   - This enables us to establish a CO_2 growth rate prediction model based on "climate-carbon" empirical relations

3. We really need more "hands/groups to join" the analysis and modelling activities for extracting meaningful information