
TransCom, San Francisco, 1998

Atmospheric Inversions

Estimating fluxes of carbon dioxide and other greenhouse gases

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17 March 2015

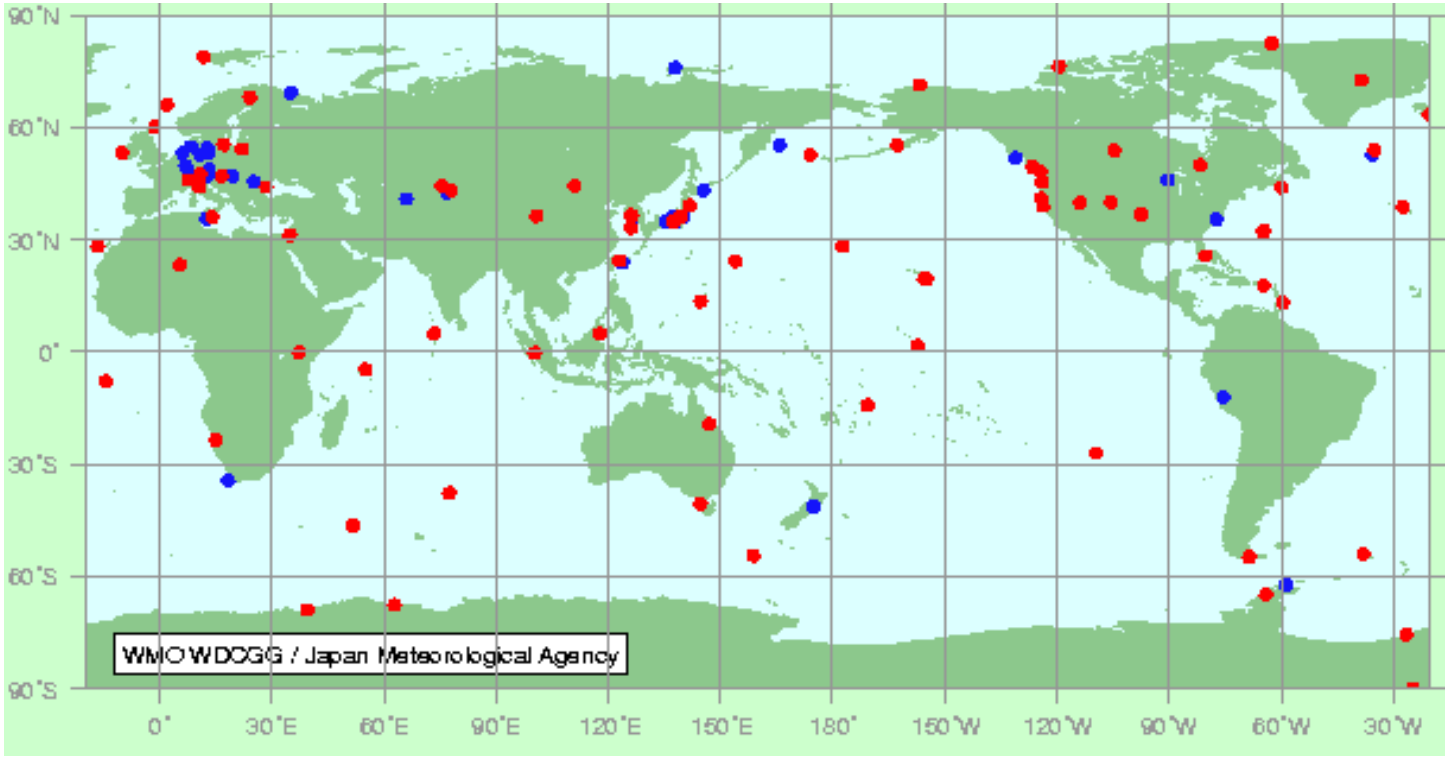
OCEANS AND ATMOSPHERE FLAGSHIP
www.csiro.au

CSIRO

Atmospheric measurements of CO_2

World Data Centre for Greenhouse Gases

http://gaw.kishou.go.jp/wdcgg/



Network biased to remote, clean-air conditions.
Many marine boundary layer or mountains.

Transport links fluxes and mixing ratios

Carbon fluxes

Biosphere, land-use, fossil, ocean

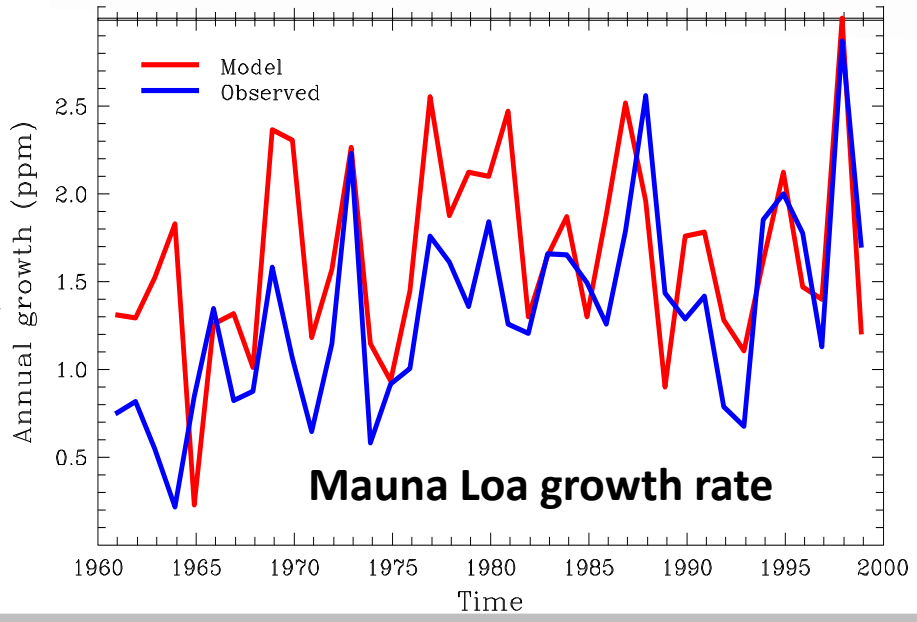
Atmospheric transport

Offline transport or climate model

Atmospheric CO_2

Flasks, in-situ

$$\frac{\partial}{\partial t} m(\mathbf{r}, t) = s(\mathbf{r}, t) + \mathcal{T}[m(\mathbf{r}, t), t] \qquad (1.2.1)$$



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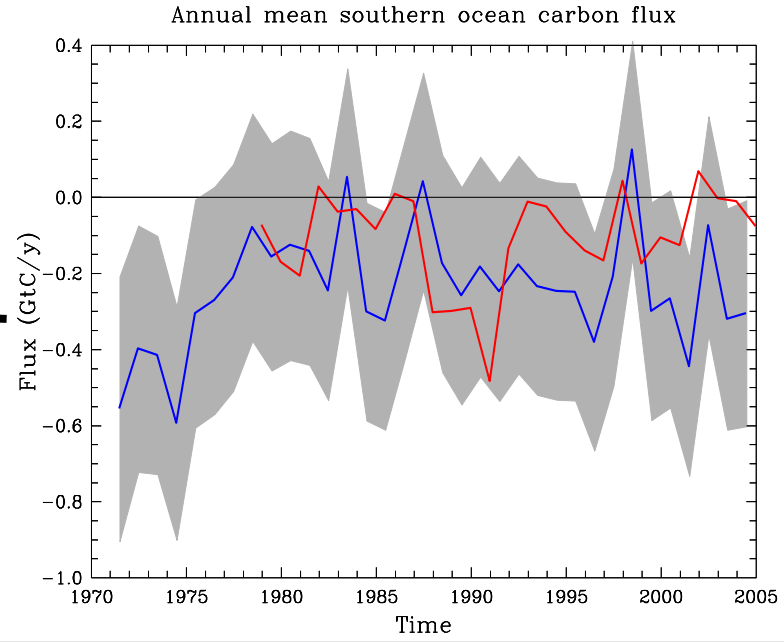


Inversion timeline – Ian's contributions

1985

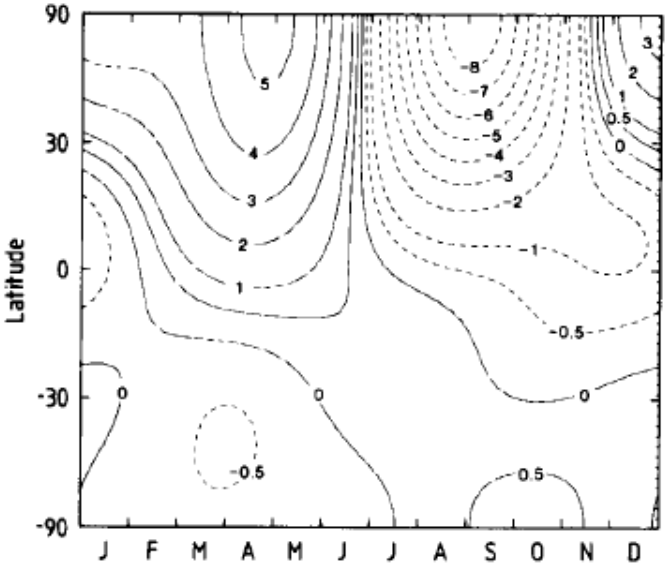
- Principles of Constrained Inversion in the Calibration of Carbon-Cycle Models, Tellus, 37B.
- Green-Functions and response functions in geochemical modeling, Pure and Applied Geophysics, 123.
- A Classification of some inverse problems in geochemical modeling, Tellus, 37B.

1988-1993

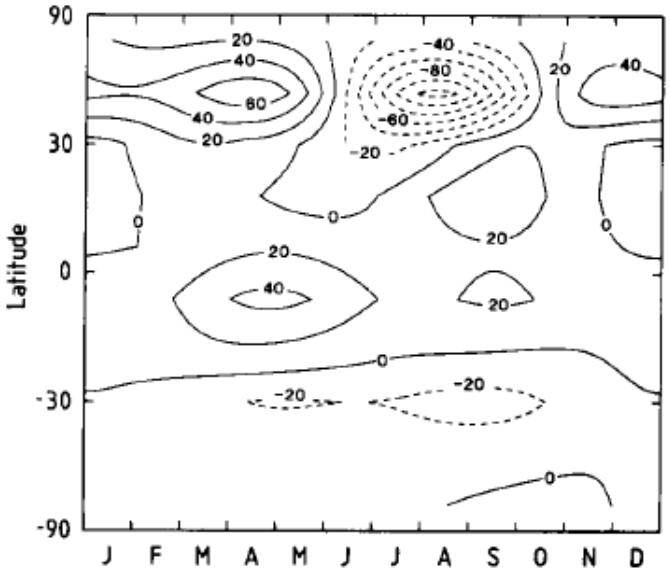
- Inversion problems in atmospheric constituent studies, Inverse Problems
  - Newsam and Enting, 1. Determination of surface sources under a diffusive transport approximation (1988)
  - Enting and Newsam, 2. Sources in the free atmosphere (1990)
  - Enting, 3. Estimating errors in surface sources (1993)

Applications (1)

Enting and Mansbridge, Seasonal sources and sinks of atmospheric CO_2: Direct inversion of filtered data, Tellus, 41B, 1989



CO_2 concentration

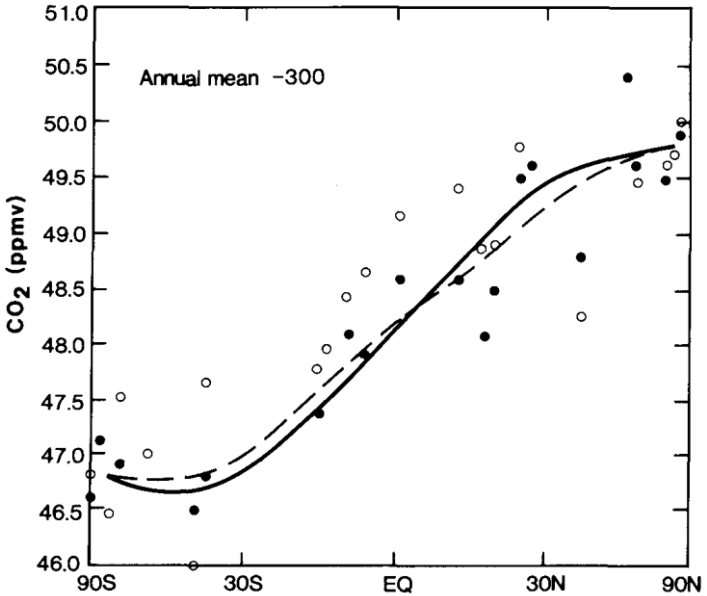


CO_2 source

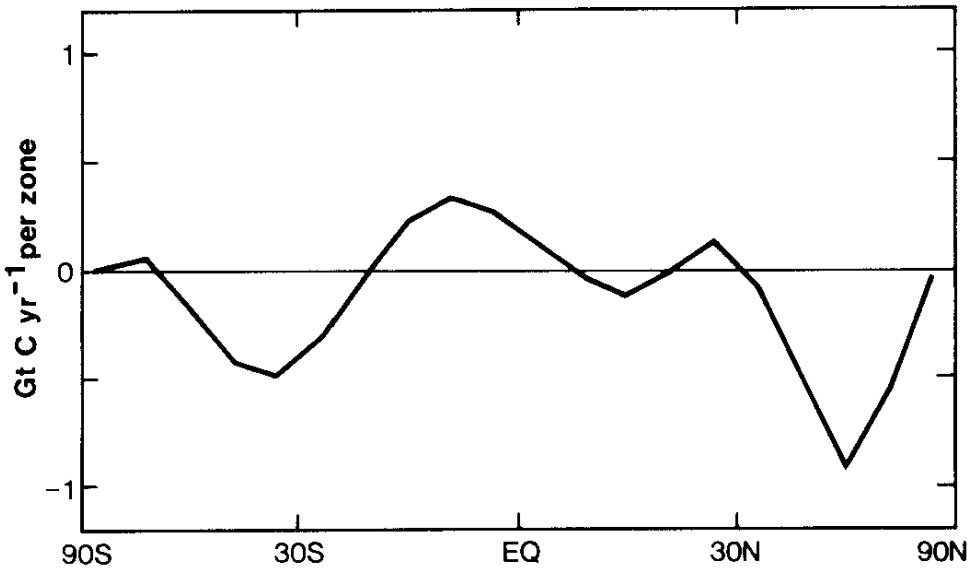
2d transport model. Interpretation of annual mean and seasonality.
71 citations

Applications (2)

Enting and Mansbridge, Latitudinal distribution of sources and sinks of CO2 – results of an inversion study, Tellus, 43B, 1991



CO_2 concentration



Annual mean, non-fossil CO_2 source

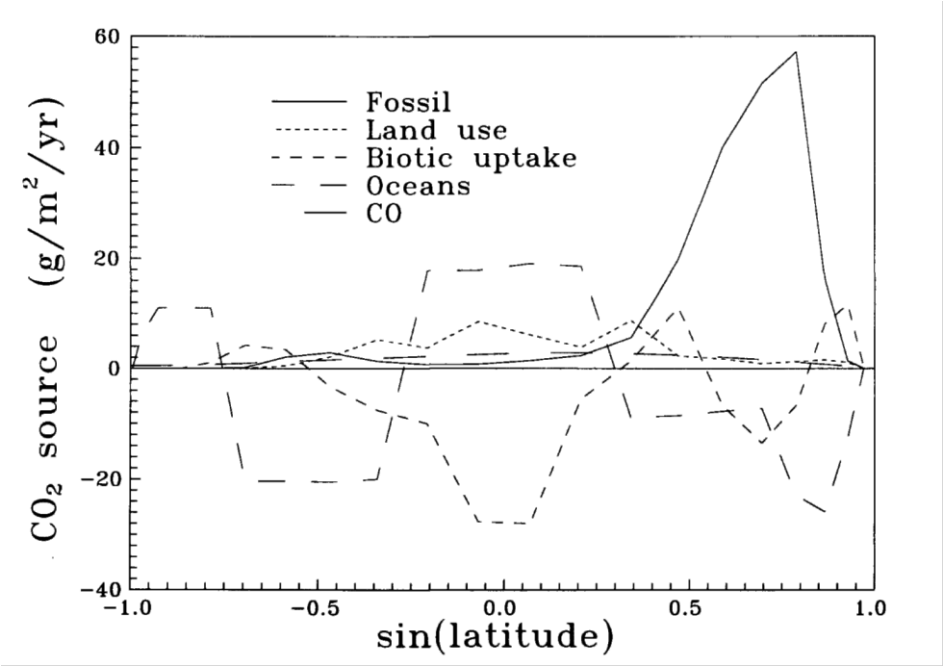
Inclusion of CO, 2d transport model
97 citations

Applications (3)

Enting, Trudinger and Francey, A synthesis inversion of the concentration and $\delta^{13}C$ of atmospheric CO_2, Tellus, 47B, 1995

Presented at 4th International CO_2 conference, Carqueiranne, France, 1993

3d transport
CO_2 isotope – to help distinguish land and ocean sources
Uncertainties
1986-1987 compared to 1989-1990
Limits of quasi-steady state?
235 citations



Cooperative Research Centre for Southern Hemisphere Meteorology

ANNUAL REPORT 1993-1994

Program B - Global Transport Modelling

Objective

To improve the scientific basis for the atmospheric transport modelling used in Australia for input to environmental policy on issues such as greenhouse gas emissions. This requires the development of a versatile 3-D transport model and improved inversion methodologies to infer trace gas sources.

Research Staff

I Enting, R Francey, P Fraser, R Law, L P Steele, I Watterson.

Dr Ian Enting, Program Leader

Tom Wigley, Office for Interdisciplinary Ear

Dr Ian Enting, Program Leader

November 1993: 2nd Workshop on Inverse Modelling Problems in Atmospheric Constituent Transport (WIMPACT-2)

August 1994: Peter Rayner joins CRCSHM

1994-1998: TransCom coordination

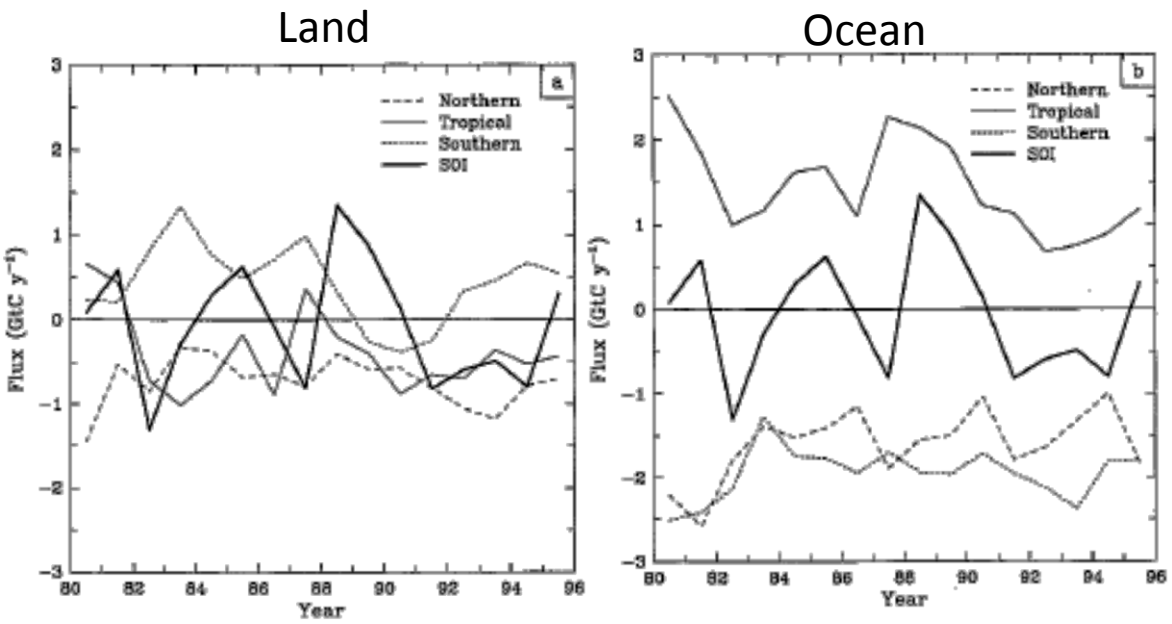
1995/1996: Ian leads ‘B2: Greenhouse Gases’

Applications (4)

Rayner, Enting, Francey and Langenfelds, Reconstructing the recent carbon cycle from atmospheric CO_2, $\delta^{13}C$ and O_2/N_2 observations, Tellus, 51B, 1999

Presented at 5th International CO_2 conference, Cairns, Australia, 1997

3d transport
CO_2 isotope and oxygen – to help distinguish land and ocean sources
Uncertainties
Time-dependent, 1980-1995
Bayesian synthesis inversion
ENSO, Pinatubo
287 citations



Education

Workshops

- Symposium Workshop on Inverse Modeling of Global Biogeochemical Cycles, Iraklion, Greece, 1998
- Enting, Green's function methods of tracer inversion
- In ‘Inverse Methods in Global Biogeochemical Cycles’, Geophysical Monograph Series, 114, 19-31, 2000

The book

- IG Enting, Inverse Problems in Atmospheric Constituent Transport, Cambridge University Press, 2002 (164 citations)

TransCom (Transport Comparison)

1993 CO_2 conference

- Forward simulations, CO_2 fossil and biosphere, SF_6

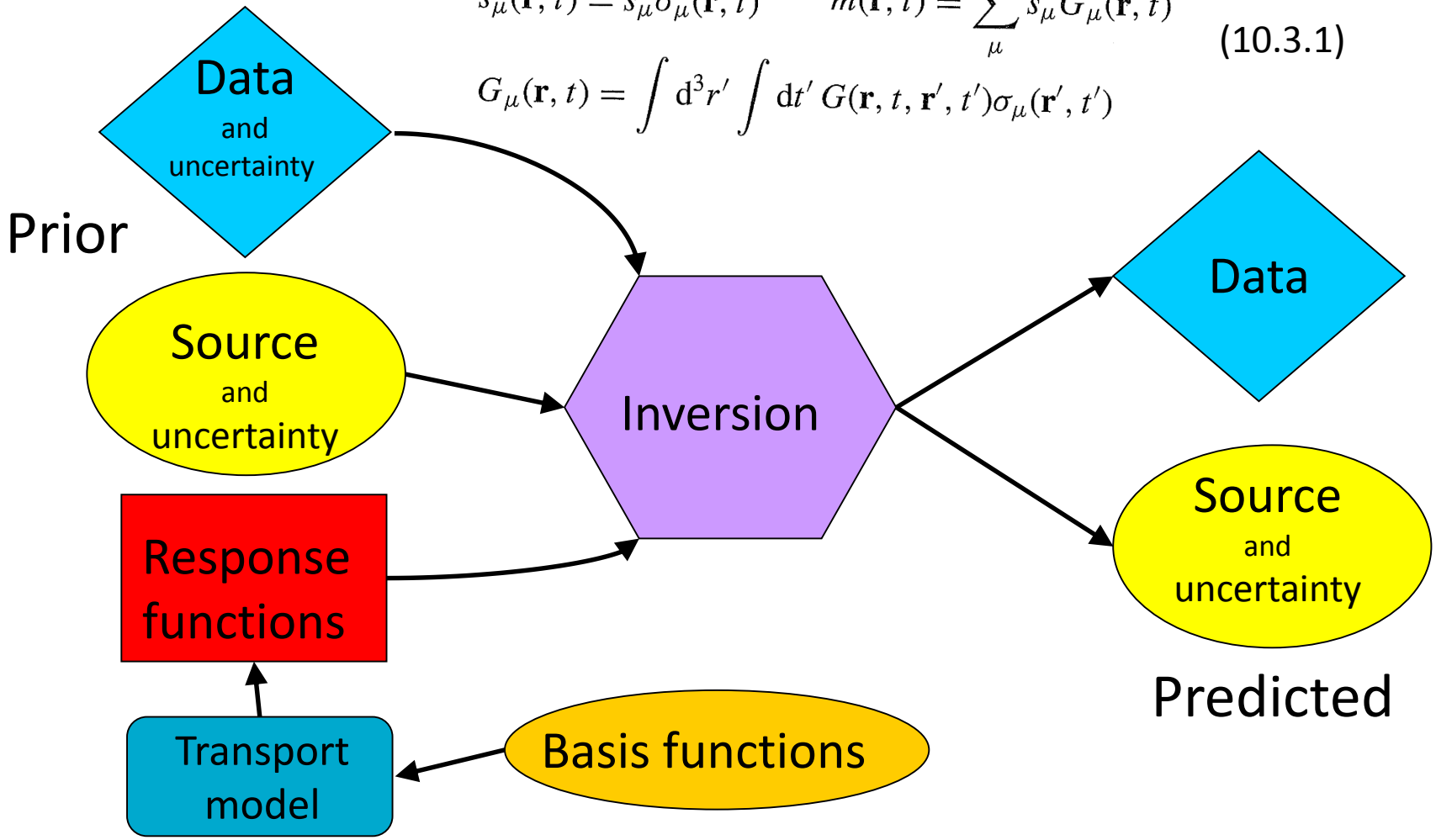
1997 CO_2 conference

- Inversions
- Scott Denning, NSF Grant, funding for coordination and workshops
- Feb 1998, Santa Barbara planning meeting
  (Australian vs GFDL proposals, global vs N American focus)
- Dec 1998, San Francisco,
  kick-off meeting

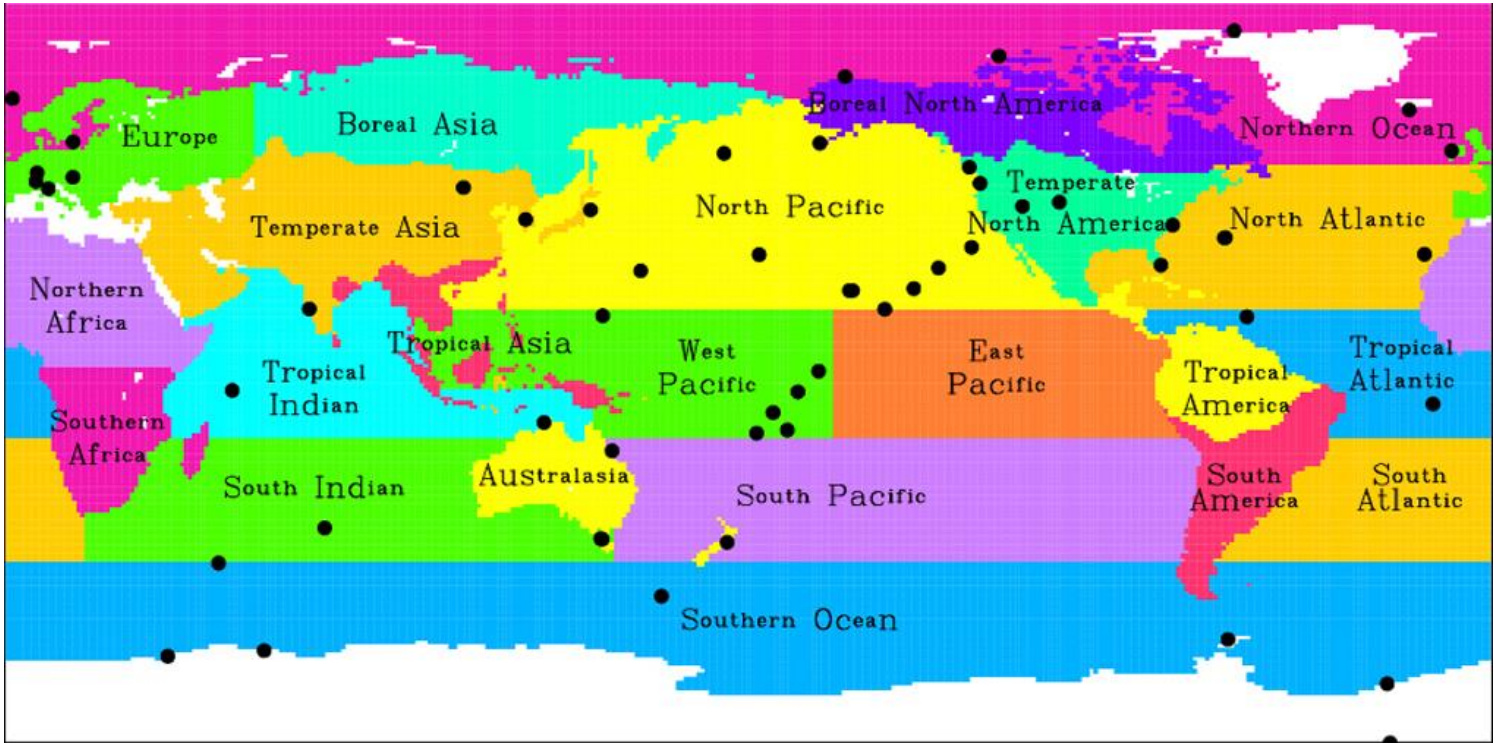
Bayesian synthesis inversion

$$s_\mu(\mathbf{r}, t) = s_\mu \sigma_\mu(\mathbf{r}, t) \qquad m(\mathbf{r}, t) = \sum_\mu s_\mu G_\mu(\mathbf{r}, t)$$

$$G_\mu(\mathbf{r}, t) = \int \mathrm{d}^3 r' \int \mathrm{d}t'\, G(\mathbf{r}, t, \mathbf{r}', t') \sigma_\mu(\mathbf{r}', t') \qquad (10.3.1)$$



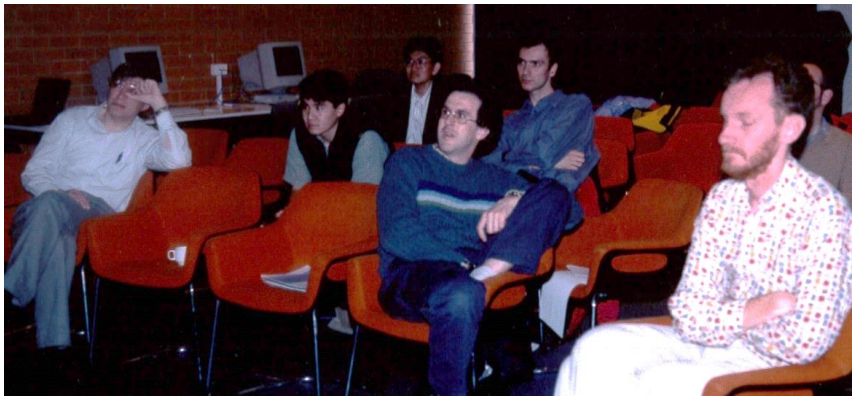
TransCom regions / Basis functions



Background fluxes: fossil fuel, neutral biosphere - ‘rectifier’, air-sea exchange.

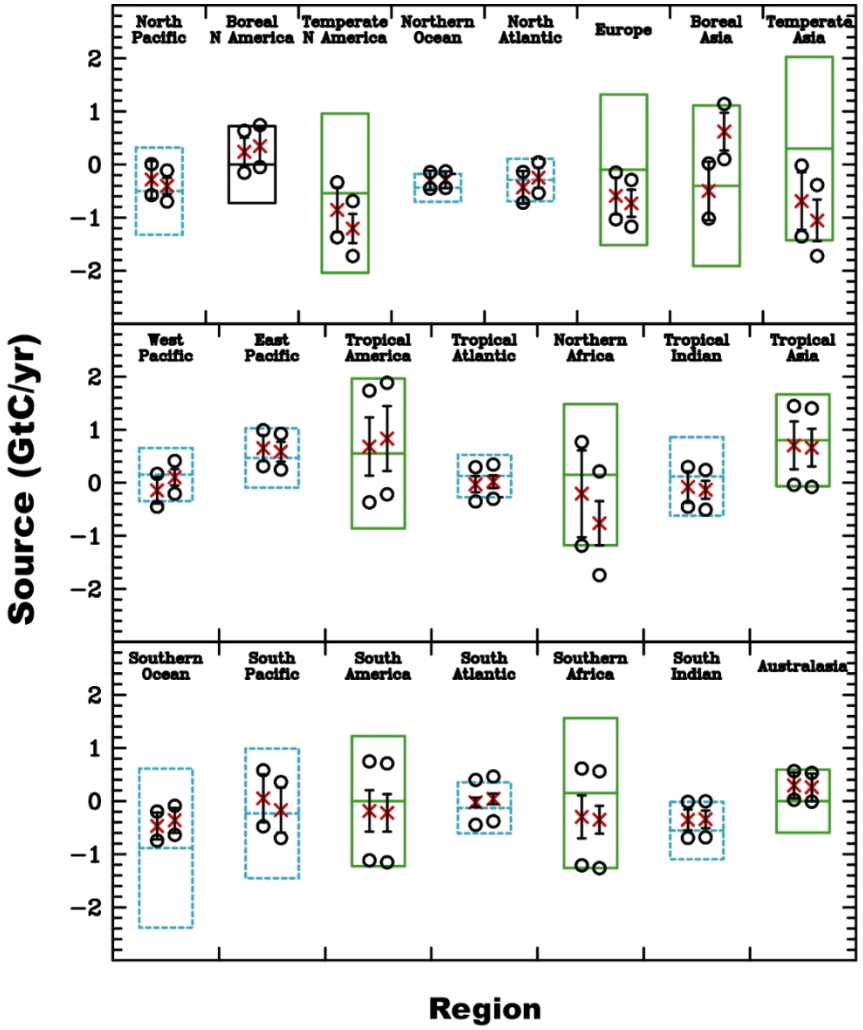
TransCom, Melbourne 2001

"Work on finalizing the Science paper was completed. This contains the annual mean, level 1, control results from the experiment. We are about to submit to Science."



"Many thanks to Ian Enting for hosting a wonderful get together at his home."

TransCom annual mean inversion (1992-1996)



Gurney et al, Nature, 2002, (572)

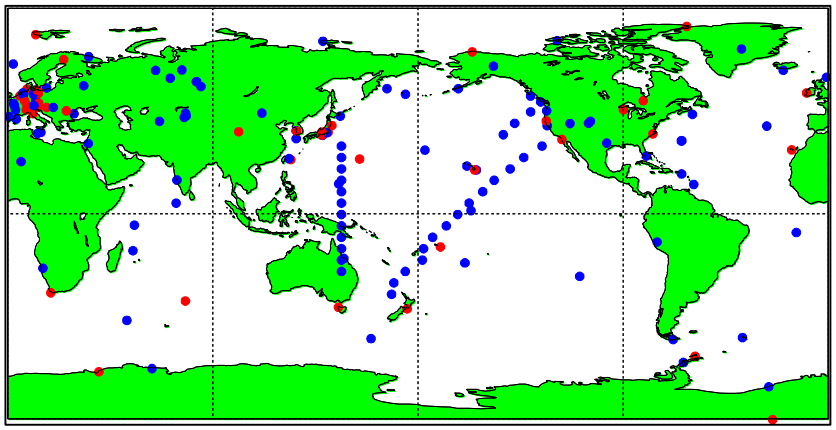
+ more detail, Tellus, 2003 (154, 42)

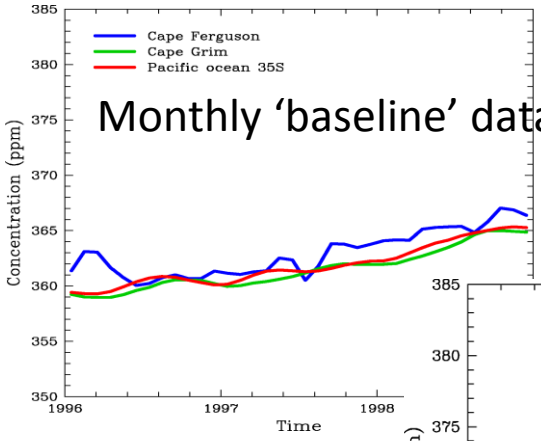
Seasonal cycle: Gurney et al, Tellus, 2004 (162)

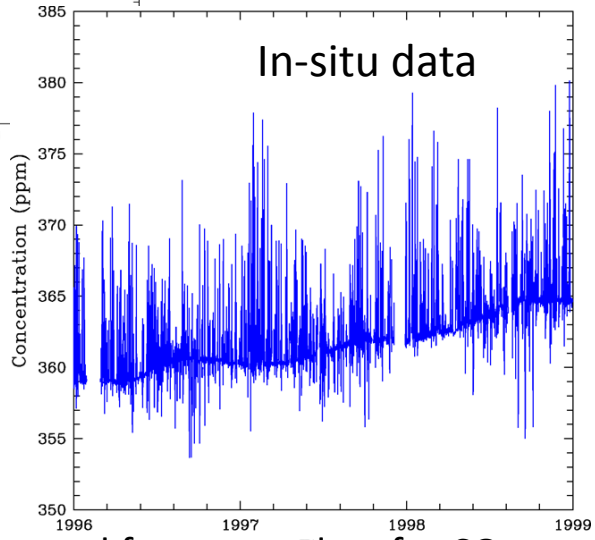
Interannual: Baker et al, GBC, 2006 (69)

Model spread (error bar) mostly similar to predicted uncertainty (determined by data availability and uncertainty)

Making use of in-situ sites with hourly data

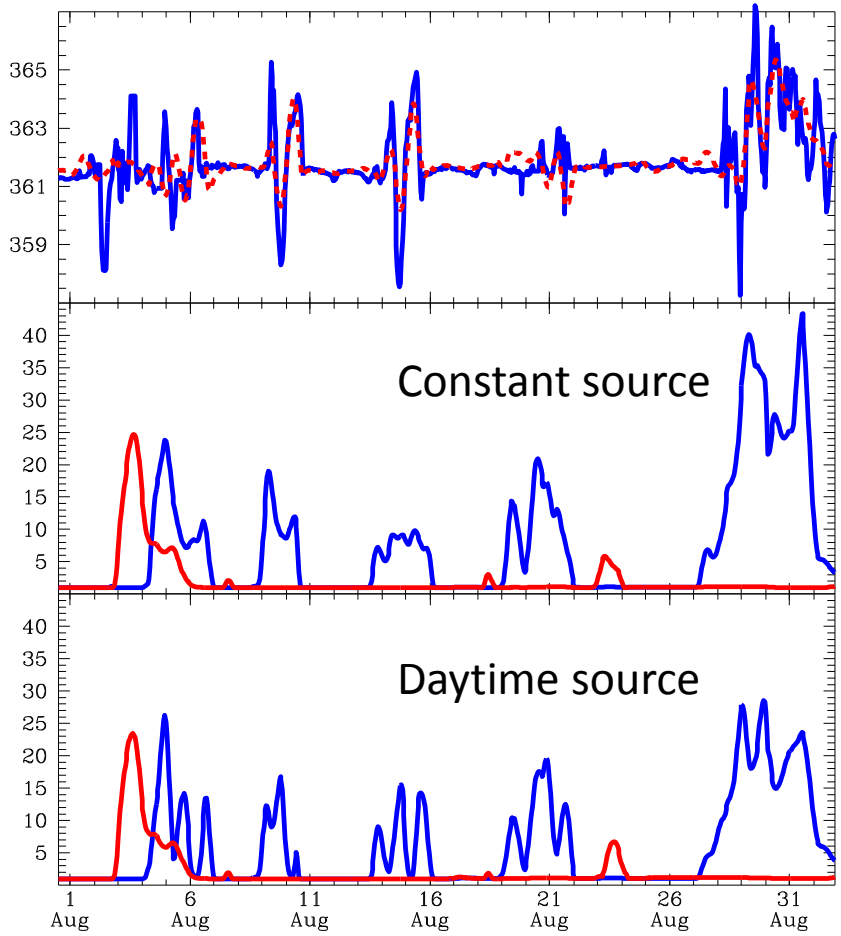






- Law, R.M., P.J. Rayner, L.P. Steele and **I.G. Enting**, 2002: Using high temporal frequency data for CO_2 inversions, *Global Biogeochem. Cycles*, 16(4). 1053. doi:10.1029/2001GB001593.
- Law, R.M., P.J. Rayner, L.P. Steele and **I.G. Enting**, 2003: Data and modelling requirements for CO_2 inversions using high frequency data, *Tellus*, 55B, 512-521, doi:10.1034/j.1600-0560.2003.29.x.
- **Synthetic data**

Real data – transport model limitations



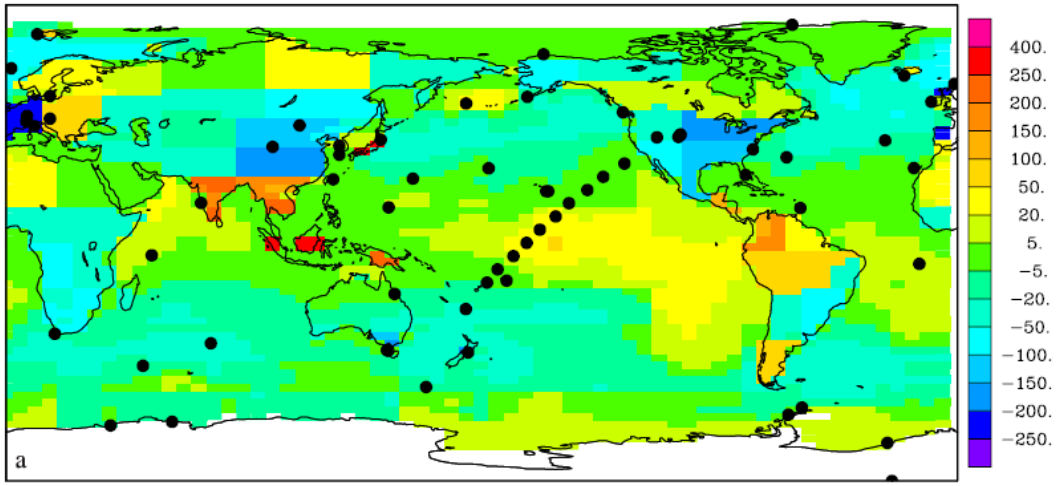
Blue – data

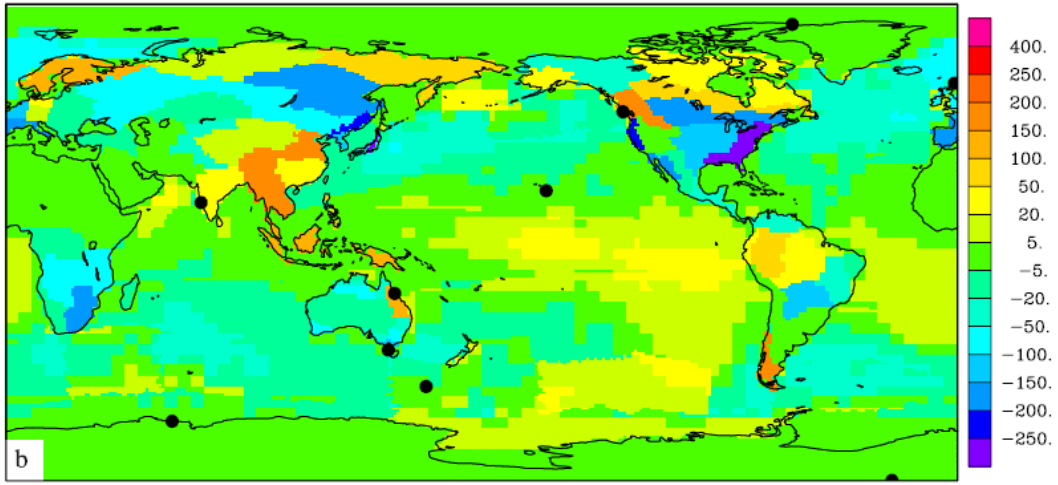
Red – inversion fit

Model responses

Blue – SE Australia

Red - Tasmania





1992-2005 mean flux, colour boundaries on land indicate typical region size

Rayner et al., GBC, 2009

Bayesian synthesis (matrix) inversion set up similarly to T3 (Baker et al., 2006)

MATCH

67 land regions, 49 ocean regions

CCAM

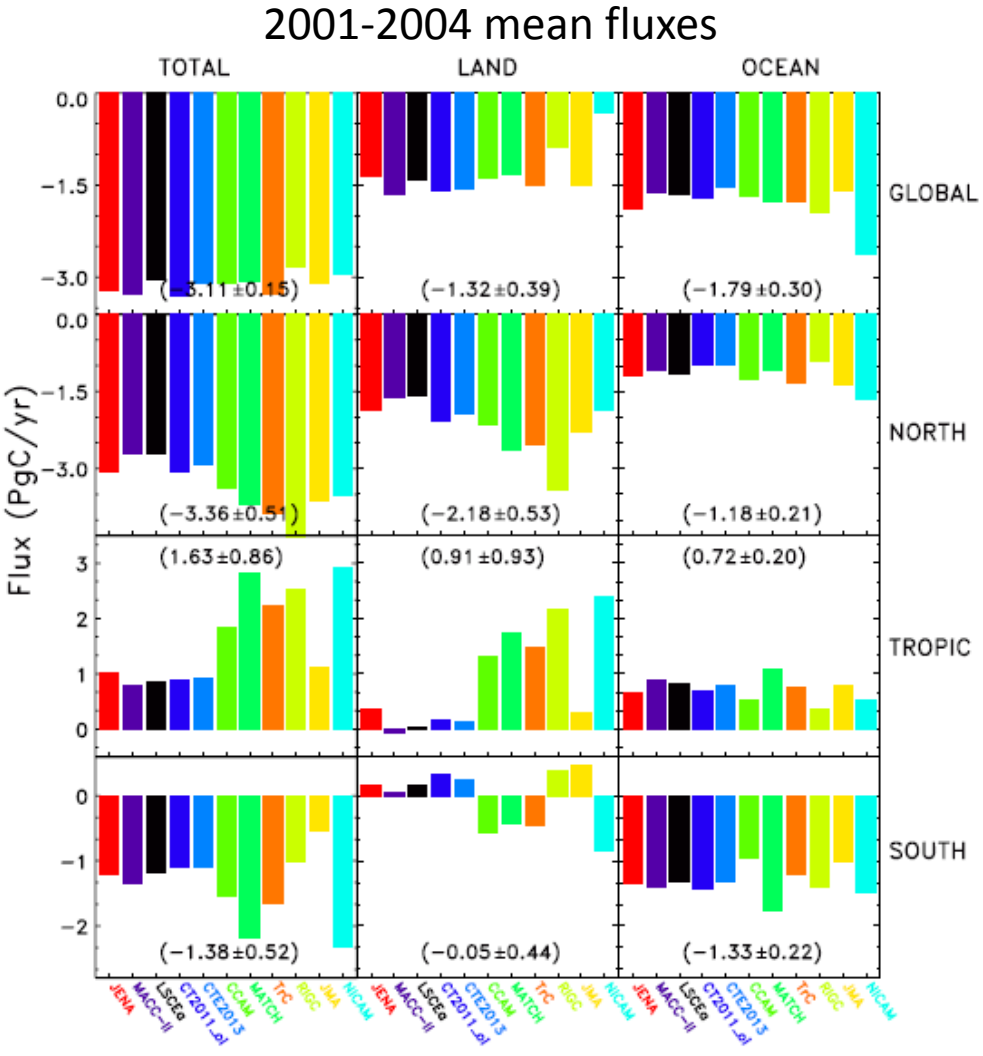
94 land regions, 52 ocean regions

- 67 CO_2 sites
- 10 ^{13}C sites

REgional Carbon Cycle Assessment and Processes (RECCAP)

Peylin et al., Global atmospheric carbon budget: results from an ensemble of atmospheric CO_2 inversions, Biogeosciences, 2013.

- Multiple inversion methods
- Monthly mean data or flasks/in-situ at observing time (mid-afternoon only)



Enting et al: Carbon Cycle Uncertainty in RECCAP
(Biogeosciences, 2012)

Inversions represent cases of indirect inference where the direction of inference is in the opposite direction to real-world causality. Consequently, the dissipative nature of most biophysical systems means that such inverse problems will be ill-conditioned: highly sensitive to both model error and data error.

The RECCAP study is a unique effort in synthesising a large body of quantitative knowledge about the carbon cycle. Experience from comparable exercises in other contexts suggest that as much will be learned about the problems in performing such an exercise for the first time as is learned about the targeted science. Examples from our own experience include:

– The Transcom intercomparison, where initial compromises (e.g. the neglect of reduced carbon, fossil emissions either fixed or with a single global uncertainty) have persisted;

Thank you

Oceans and Atmosphere Flagship
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