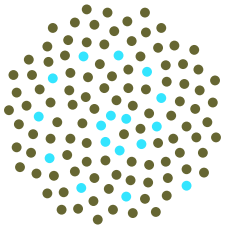

Forty years of global CO_2 inversions: what have we learned?

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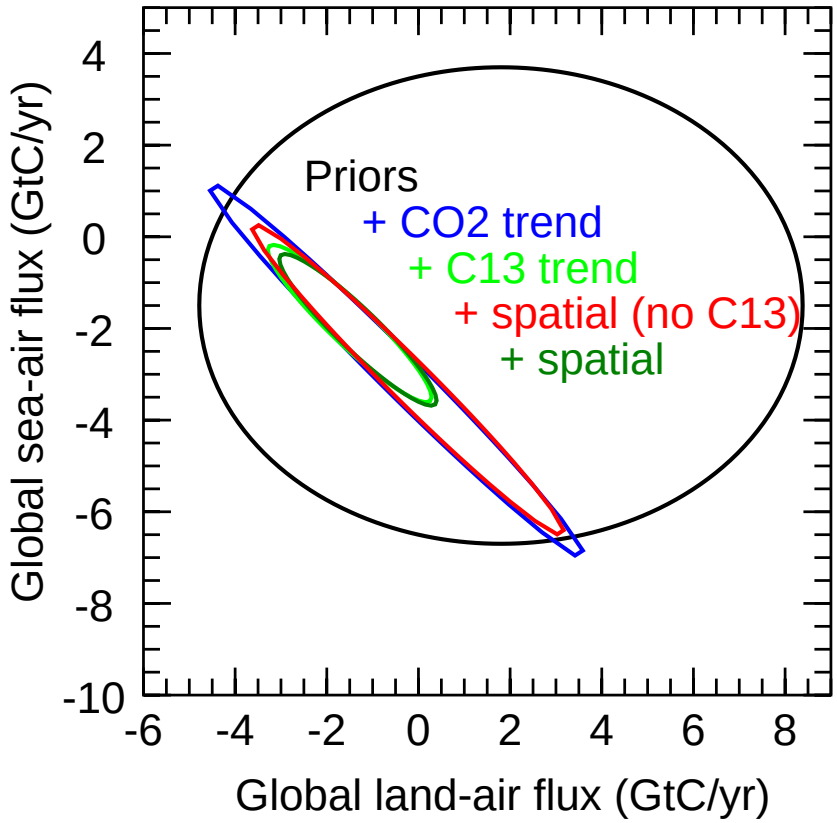
Overview

- Objectives
  - Budgets $\longrightarrow$ Processes $\longrightarrow$ projections
- Inverse Problems
  - Estimations $\longrightarrow$ Resolution
- Cases:
  - Tropical source
  - Ocean sink
  - Northern sinks
  - Internannual variability

Objectives of inversion



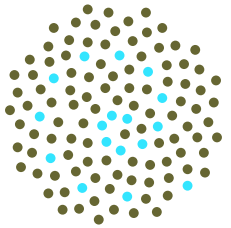
- Understand budgets
- Better projections

but

- Most global information is in global trends
- N-S is poor proxy for air-sea

Philosophy is an attempt to transmit all we know into what we would like to know. (Valery).

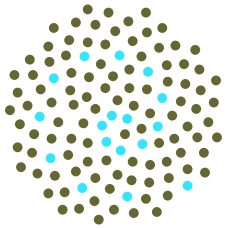
Evolving views of carbon cycle



- circa 1975: models calibrated by ^{14}C reveal "missing sink"
- 1990: conflicting estimates of ocean sink, from inversions
- 1992: conflicting estimates of ocean sink from isotopes
- 1995: conflicting isotopic estimates of interannual variability
- circa 2000: concern about feedbacks, increased focus on processes

(more in book, chapter 14, concept from R Francey)

Consistency requirements



Time :

- Time
- Averaging: period and type of smoothing

Space :

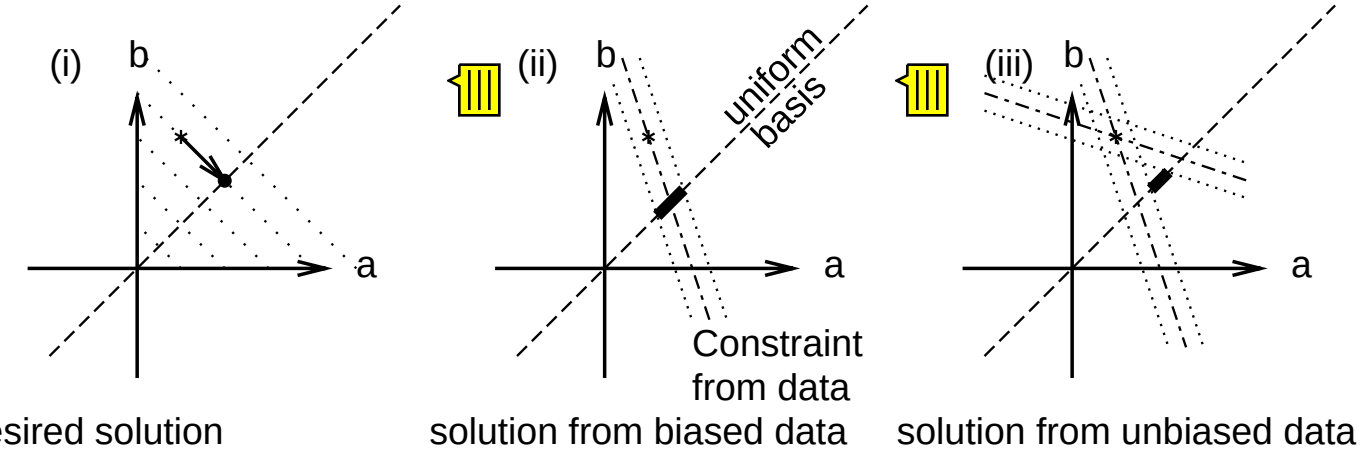
- Location
- Form and scale of averaging

Process :

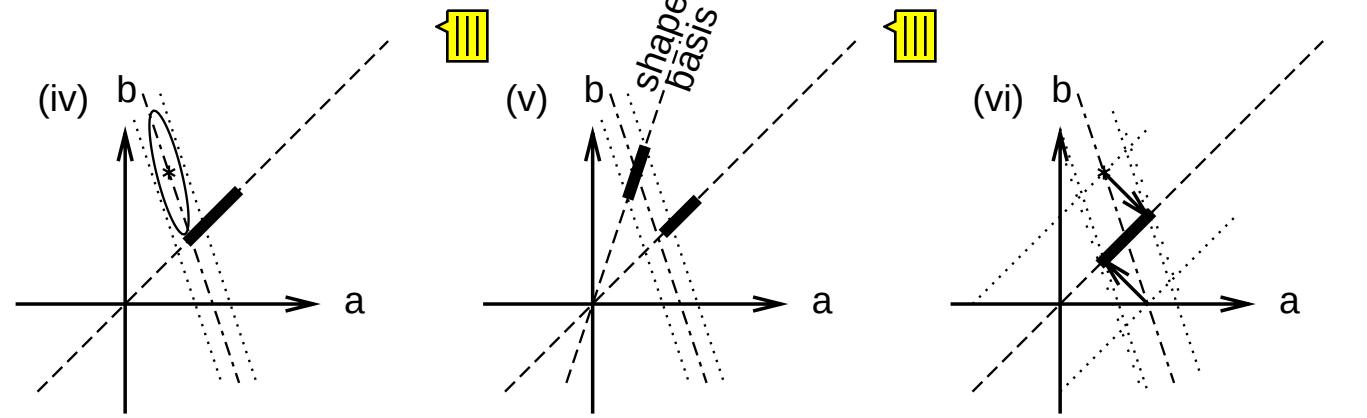
- CO_2 vs. carbon fluxes
- Flux vs. storage budgets.

Truncation error: idealised

Seeking projection • from unknown 'true' value *



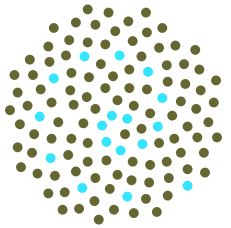
desired solution | solution from biased data | solution from unbiased data



project from full space | work in target space | apply truncation error to data

i objective
ii the risk
iii the hope
iv Wunsch
v Strong prior
vi correction

Ill-conditioning



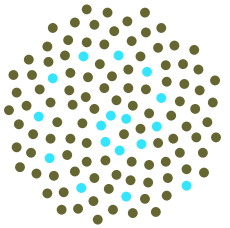
Bolin and Keeling, 1963:"*no details of the sources and sinks are reliable*"

Junge and Czeplak, 1967: "*It seems hardly likely that detailed information could be obtained on the latitudinal dependence of K and the CO_2 source function from atmospheric CO_2 observations, even if the number and quality of the data were very considerably increased*."

Pearman (WMO report, 1980): "*over 100 stations to determine air-surface exchange within regions with significant anthropogenic influence*"

- Use Bayesian estimation to stabilise inversion.

Inversion as estimation



- Inversion should be process of statistical estimation
  - or hypothesis testing, if detecting discrepancies!
- Only limited number of modes can be estimated (or detected):
  - these need to be determined by data (Backus Gilbert,Wunsch and Minster)
  - use non-parametric statistics to avoid building in the solution (Evans and Stark)

Autocorrelation in estimates

Zones 90S to 48S to 12S to 12N to 48N to 90N

$$\begin{bmatrix} 0.21 & -0.37 & 0.22 & -0.06 & 0.01 \\ -0.37 & 1.04 & -0.53 & -0.04 & -0.07 \\ 0.22 & -0.53 & 1.75 & -1.37 & 0.00 \\ -0.06 & -0.04 & -1.37 & 2.43 & -0.86 \\ 0.01 & -0.07 & 0.00 & -0.86 & 0.94 \end{bmatrix}$$

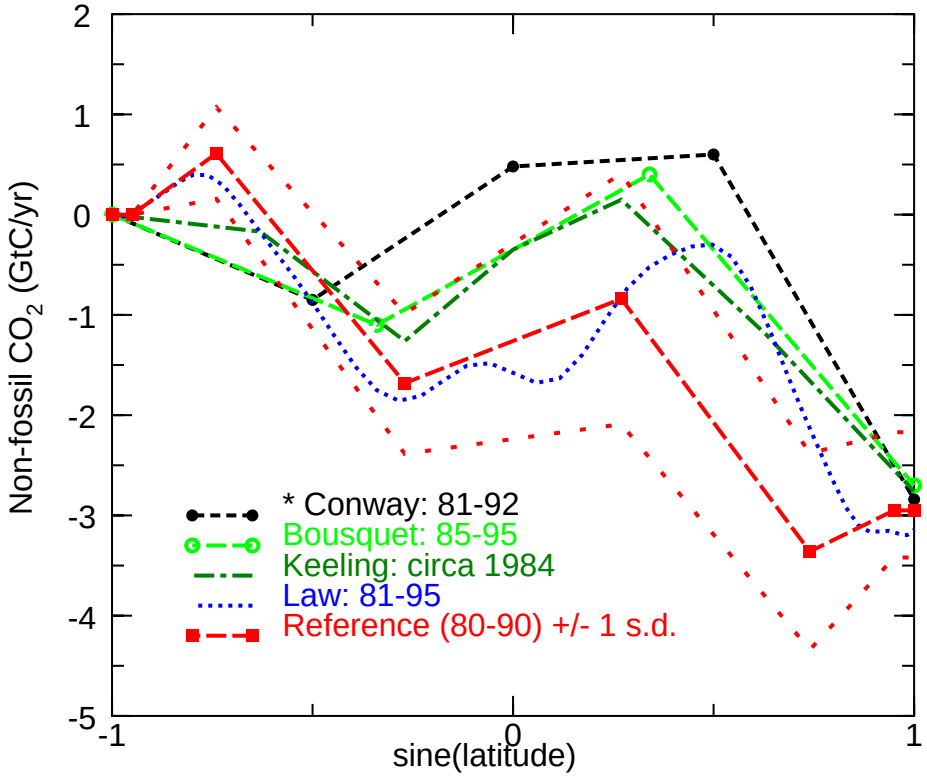
covariance of zonal flux

$$\begin{bmatrix} 0.21 & -0.16 & 0.06 & 0.00 & 0.01 \\ -0.16 & 0.50 & 0.18 & 0.09 & 0.03 \\ 0.06 & 0.18 & 1.64 & 0.16 & 0.10 \\ 0.00 & 0.09 & 0.16 & 1.12 & 0.20 \\ 0.01 & 0.03 & 0.10 & 0.20 & 0.23 \end{bmatrix}$$

covariance of integrated flux

Circumventing autocorrelation

Cumulative CO_2 flux, integrated south to north

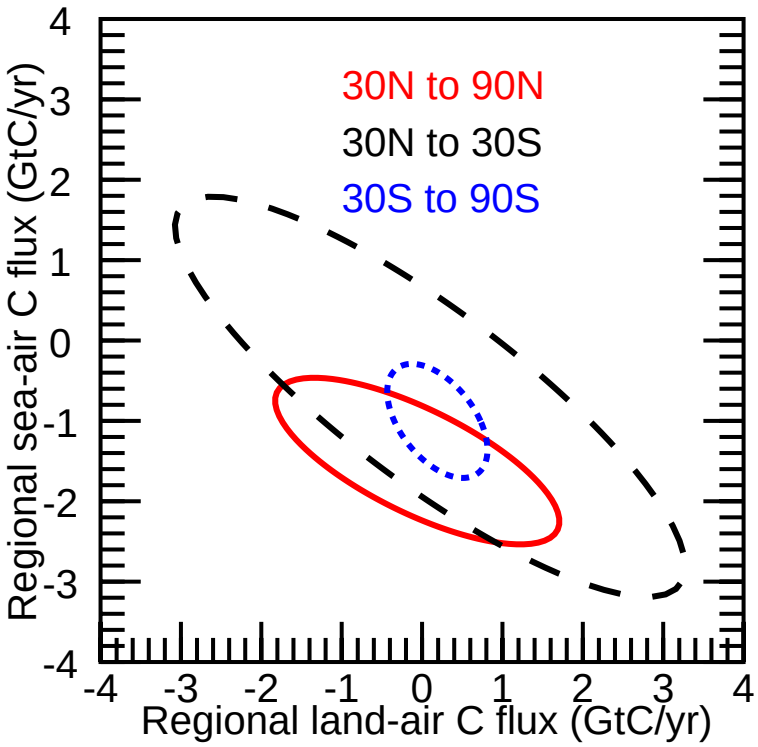


- Compare different discretisations using integrated fluxes.

and

- Illustrates robust features that are obscured when considering each region separately.

Tropical CO_2 fluxes

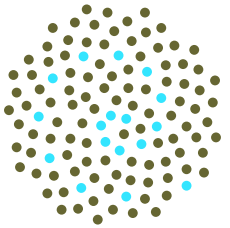


- Tropical fluxes are important, but poorly determined by inversions

due to

- Sparse observing network
- Circulation transports 'signal' vertically, away from observing sites.

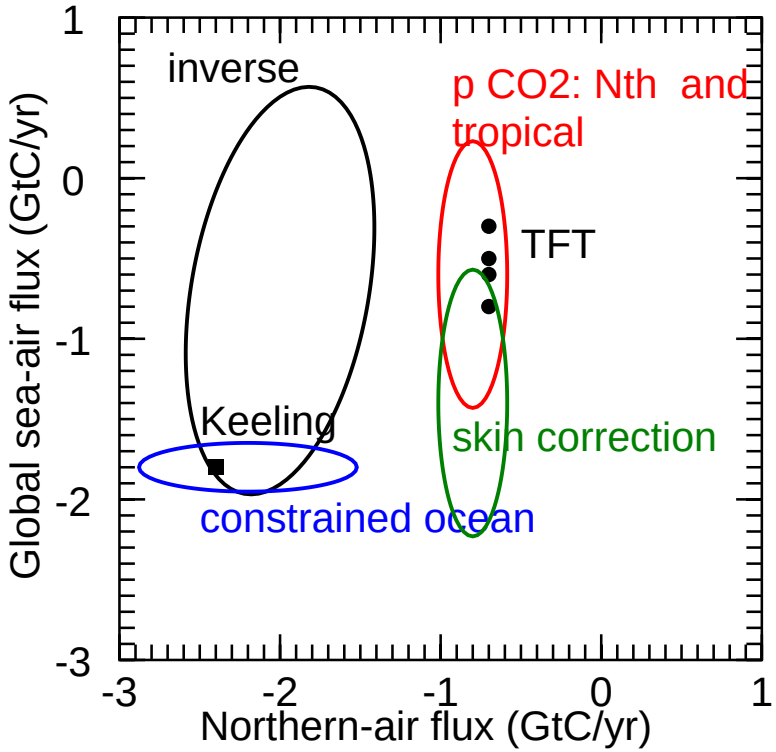
Tropical fluxes



Tropical fluxes are hard to estimate from inversion **but**

- tropical flux seems less than expected from ocean outgassing plus deforestation (Tans et al., 1989, plus most subsequent studies)
- Ocean p_{CO2} can provide constraint on ocean contribution
- there is a strong ENSO effect in the ocean flux (and possibly terrestrial flux)

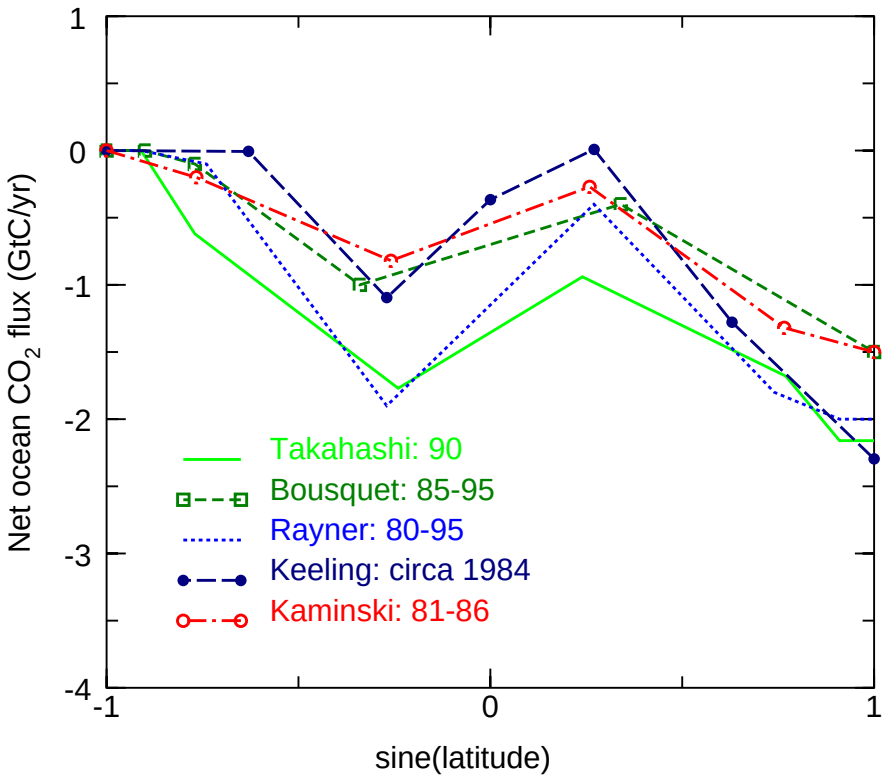
Oceans: 1990 perspective



Conflicting views of ocean flux: high vs. low uptake

- inversions alone are weak constraint
- global ocean constraint achieved by high Nth uptake
- direct constraint from p_{CO2} favours low uptake.
- correction for p_{CO2} skin effect reduces discrepancy

Ocean fluxes

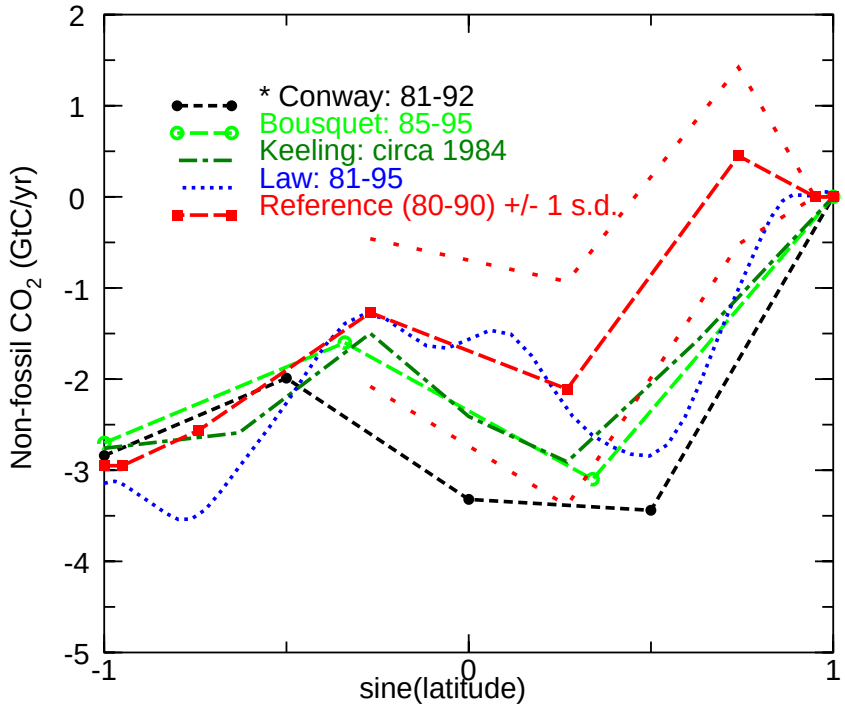


- Global isotopic budgets also split between low (Tans et al) and high (Quay et al) ocean uptake
- Resolved by flux vs. storage distinction (and skin effect and CO)
- Inversions often have same assumptions as global budgets

Most inversions give smaller SH sink than implied by (sparse) p_{CO2} data.

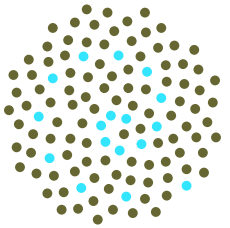
Northern sink

Cumulative CO_2 flux, from north to south



- Northern sink is robust feature
- Attribution to ocean (Keeling) driven by global budget
- Identified as terrestrial (Ciais, 95, also using ^{13}C)
- Attributed to Nth American biota (Fan et al)
- More even America–Eurasia split in most other inversions.

Interannual variability

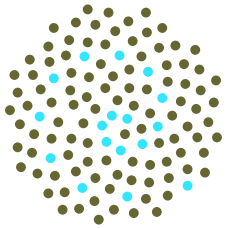


- Joint global budgets of CO_2 and $^{13}CO_2$ indicate high interannual variability of CO_2 fluxes.
- SIO and CSIRO budgets disagree (mainly in early years) attributable to calibration

but

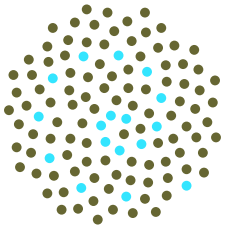
- For surface sources, variability of surface mean is greater than variability of atmospheric mean.
- time-dependent inversions give interannual variability closer to direct estimates

The role of TransCom



- Model error is comparable to data error
  - Tarantola says this is normal
- Therefore, in the absence of model improvement, adding data may not reduce real uncertainties
- Most ‘synthetic data’ experiments carry the assumption of an ideal model
  - This may be acceptable if one is evaluating data streams well in advance of actual availability

Notes for internet version



- Prof. Enting's attendance at TransCom-Tsukuba was funded by the Global Carbon Program.
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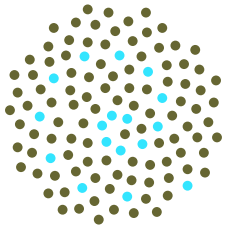
- This presentation was prepared in LaTeX, using the prosper class with a hack of the gyom style. All graphics are hand-coded postscript.

Some references



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