The isotopic composition of oxygen in atmospheric CO_2 and El Niño: a new constraint on global productivity

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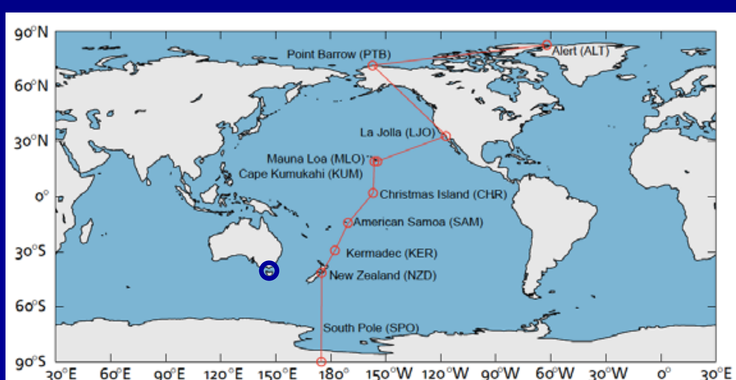
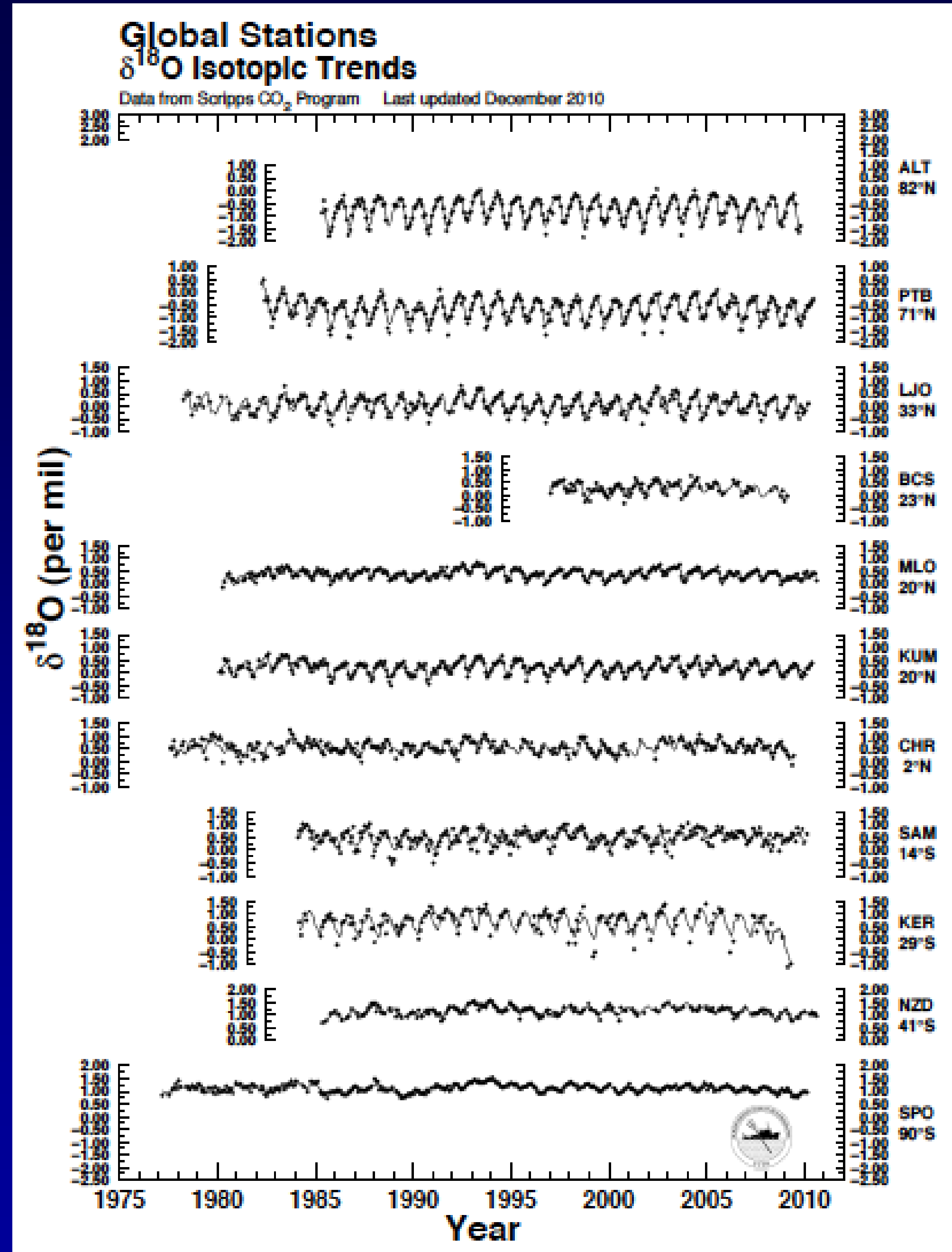
$^{18}O/^{16}O$ in CO_2

- No long term trend like CO_2 and $^{13}C/^{12}C$
- Seasonal cycle and interhemispheric gradient
- Interannual variability



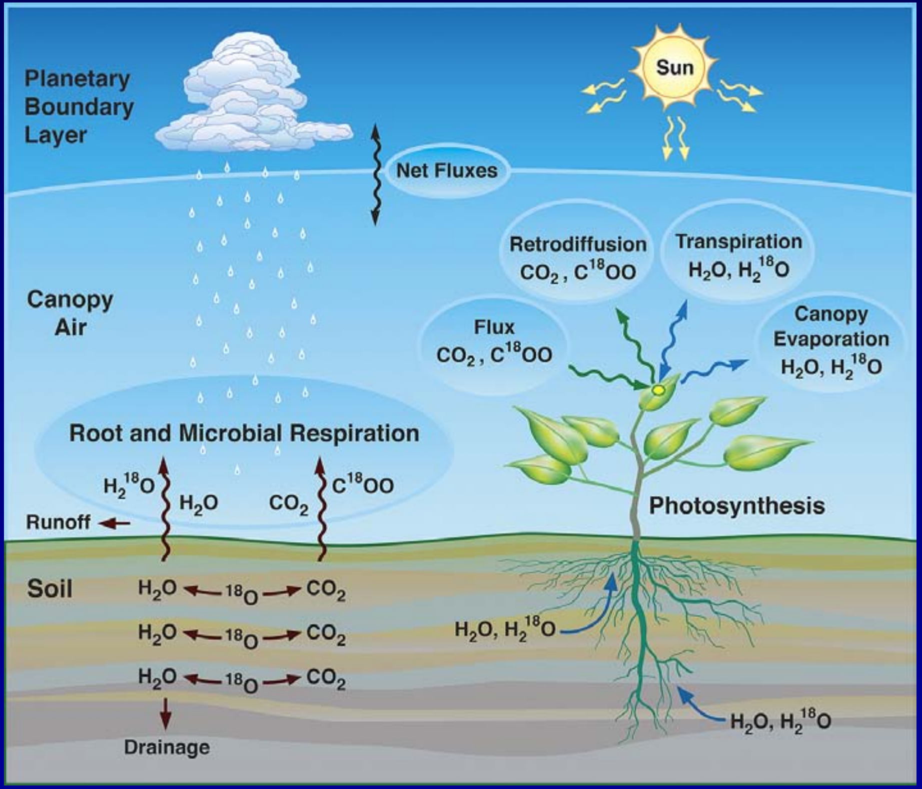


http://scrippsco2.ucsd.edu/

What is $\delta^{18}O$ of CO_2 good for?

- It is a record of CO_2 exchange with water in the ocean and leaf and soil water in the terrestrial biosphere (Farquhar et al., 1993)

- It has the potential to quantify the gross CO_2 fluxes, photosynthesis and respiration, because leaf and soil water are isotopically distinct (e.g. Ciais et al., 1997; Cuntz et al., 2003)

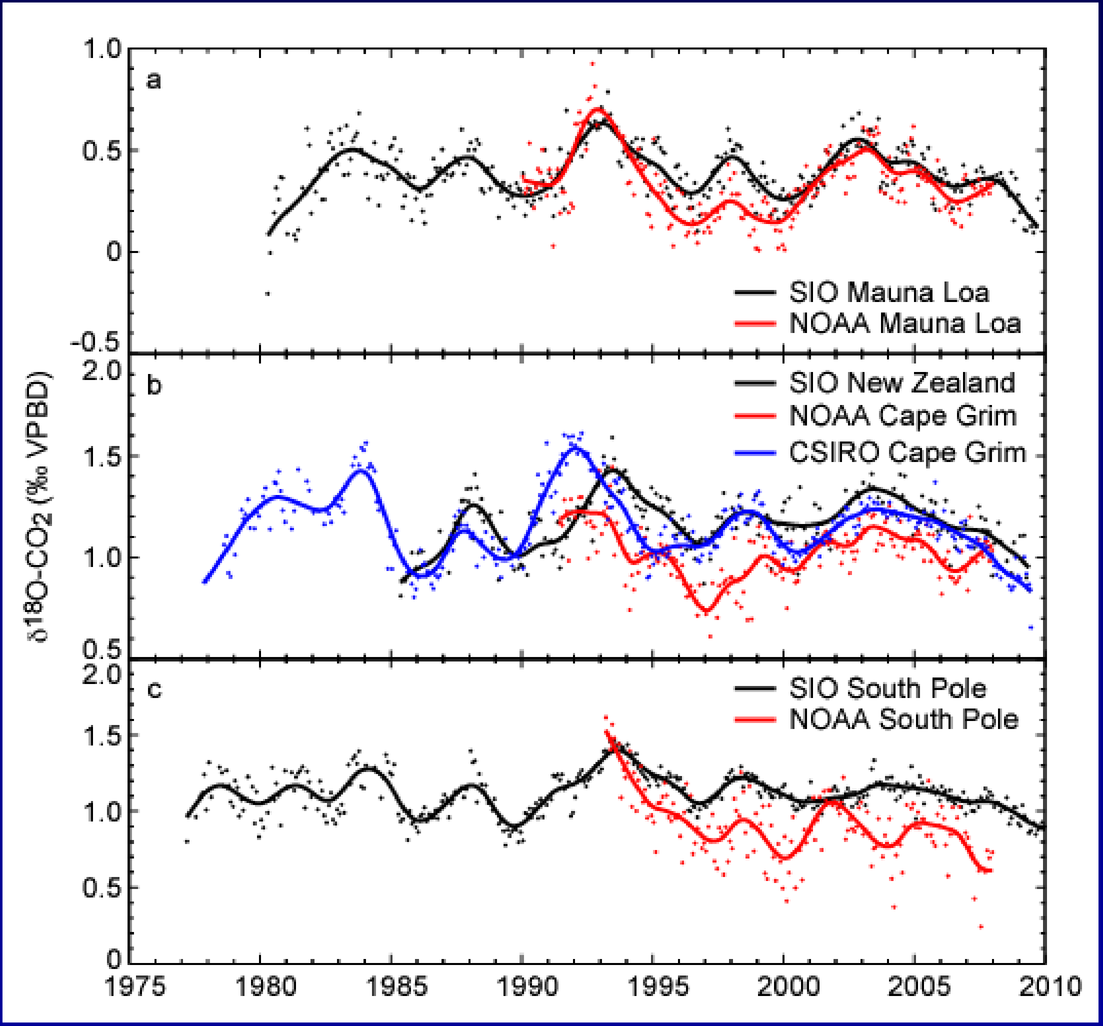


IsoLSM

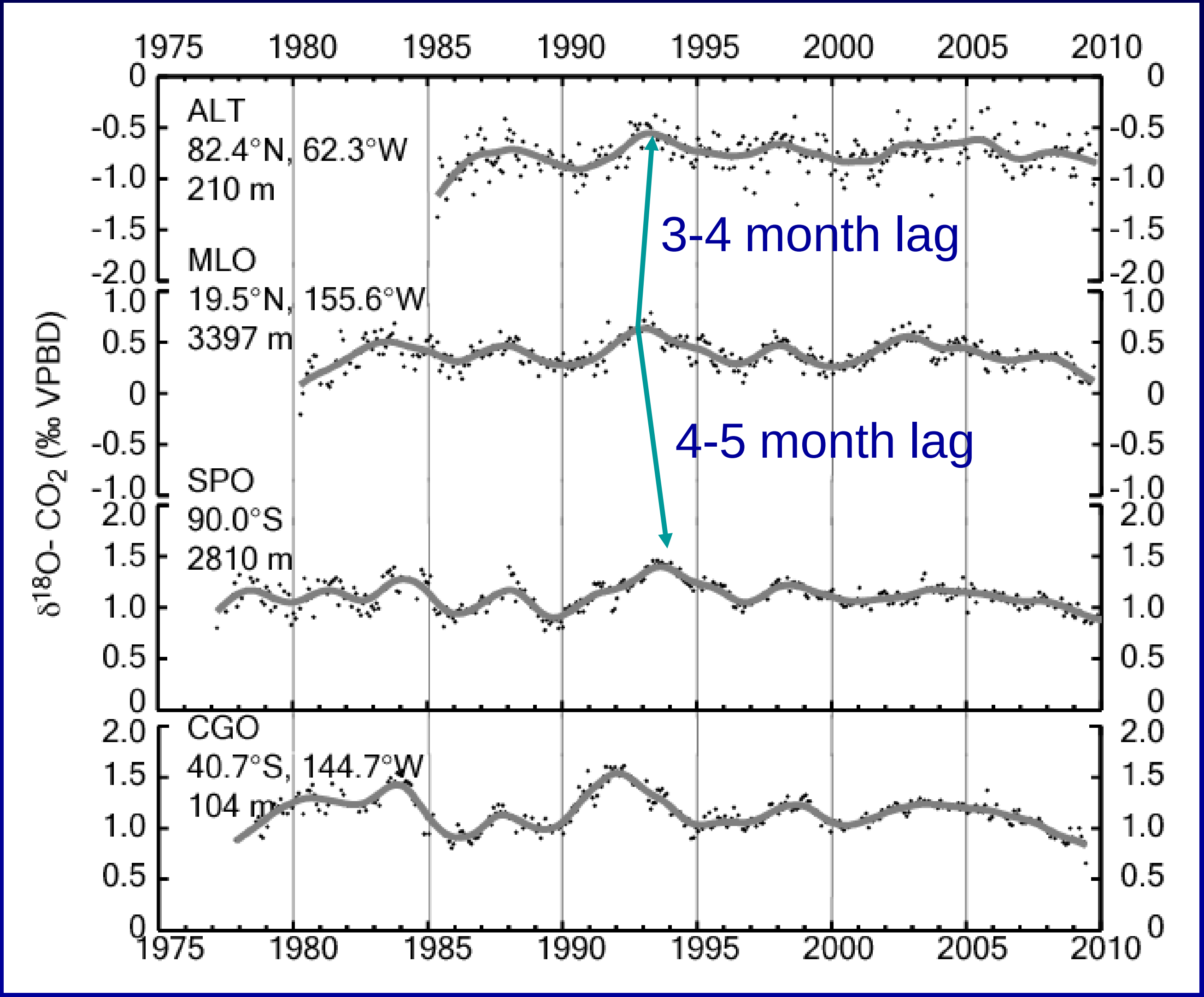
$\delta^{18}O$ in CO_2 flux partitioning

1. Requires detailed spatial and temporal knowledge of the $\delta^{18}O$ of leaf and soil water pools which are highly variable
2. Requires bottom-up process models of the isotopic fractionation and exchange associated with gross CO_2 fluxes
3. Fits modeled fluxes to the latitudinal gradients and seasonal cycles in $\delta^{18}O$-CO_2 flask observations
4. It's not easy… We believe we have a new approach that constrains mean global gross primary production (GPP).

Interannual variability
Seasonal cycles removed



Low latitude process?



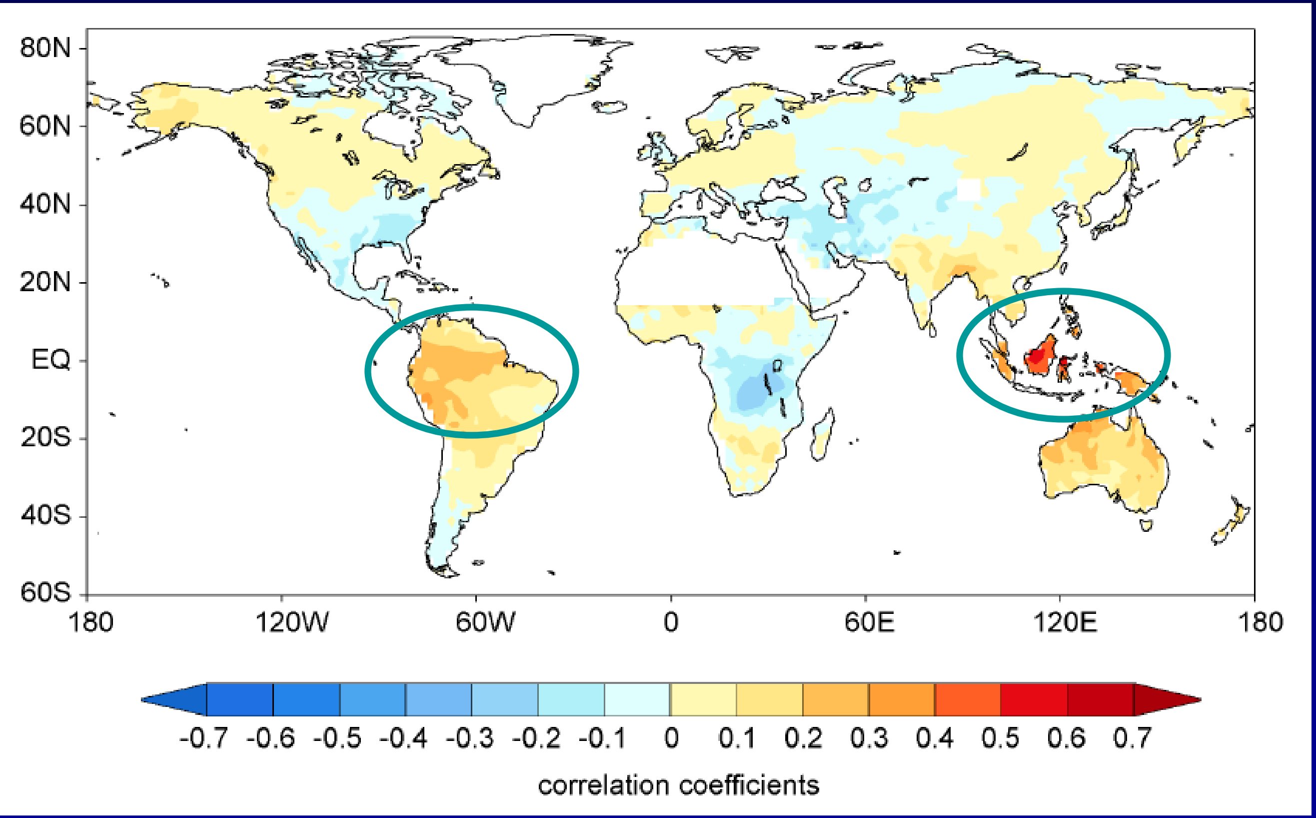
Common patterns emerging across laboratory networks

- SIO, CSIRO and NOAA measurements are ALL significantly correlated with:
  1. ENSO index (see also Zakem)
  2. $\delta^{18}O$ of precipitation and relative humidity at low latitudes (see also Buenning)

Zakem and White (poster at this meeting) Oxygen-18 of atmospheric CO_2: decadal trends and climate variability.

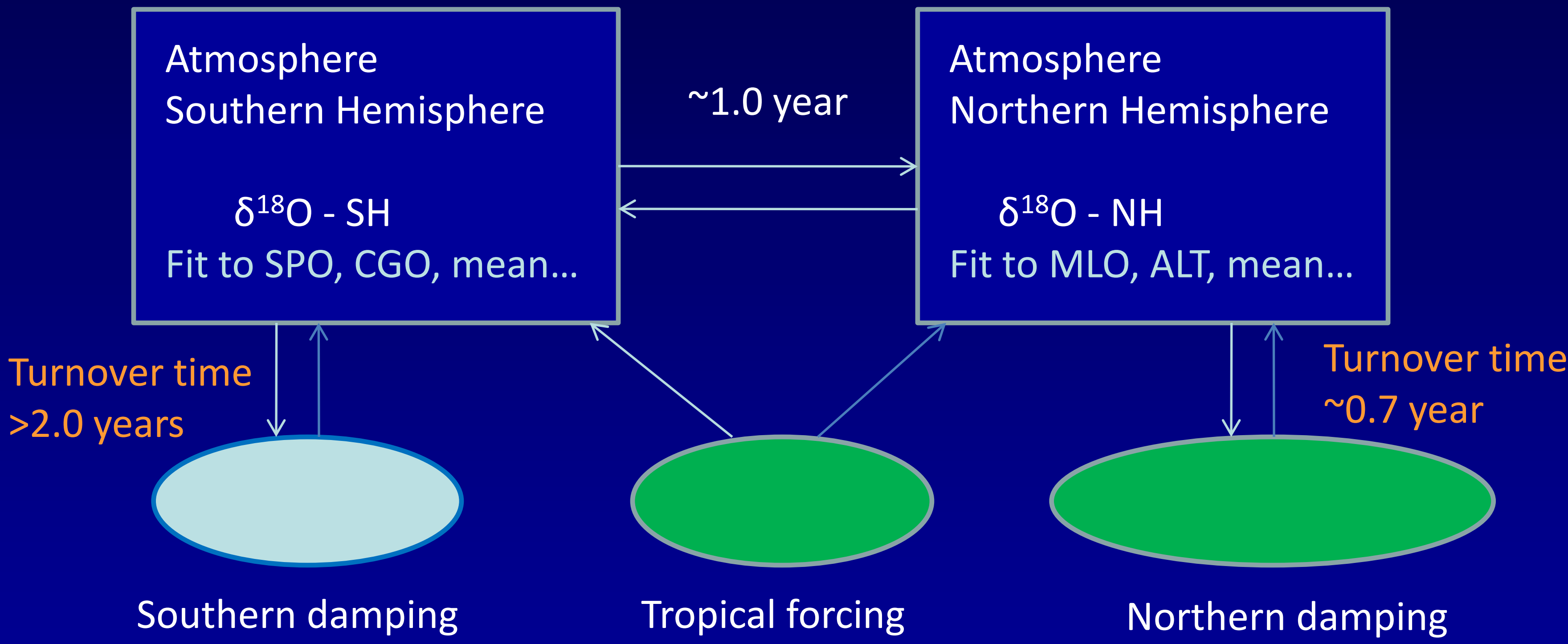
Buenning et al. (in review at JGR-Biogeo) Influences of the hydrological cycle on observed inter-annual variations in atmospheric $CO^{18}O$.

$\delta^{18}O$ of precipitation increases during El Niño



- Correlation between ENSO precipitation index (ESPI) (Curtis & Adler, 2000) and $\delta^{18}O$ of precipitation predicted from IsoGSM (Yoshimura et al., 2008)

2-box model



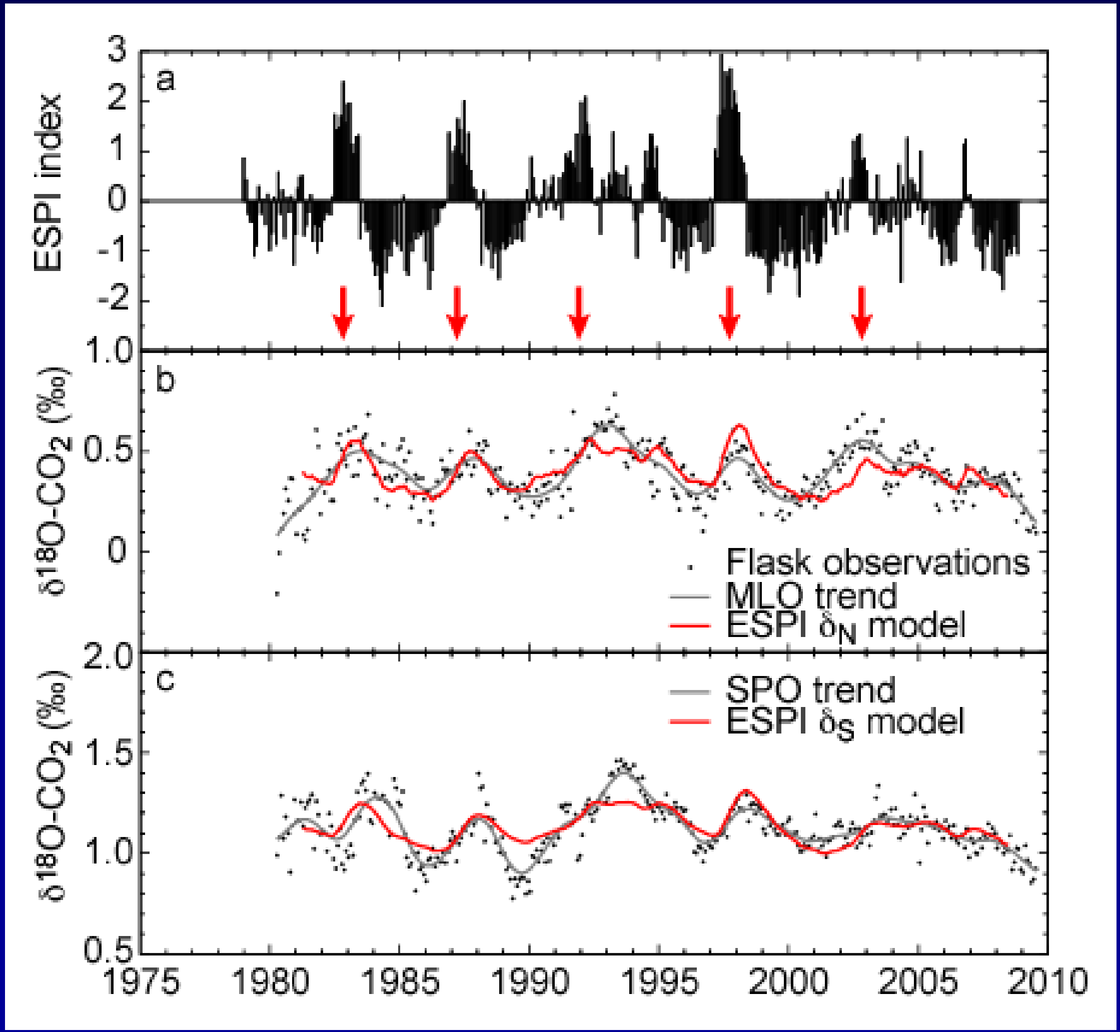
ENSO(t - lag) * scale factor
fraction in each hemisphere

Model results

ENSO

NH box

SH box



Passed autocorrelation test

$R = 0.520$

$p\text{-value} < 0.001$

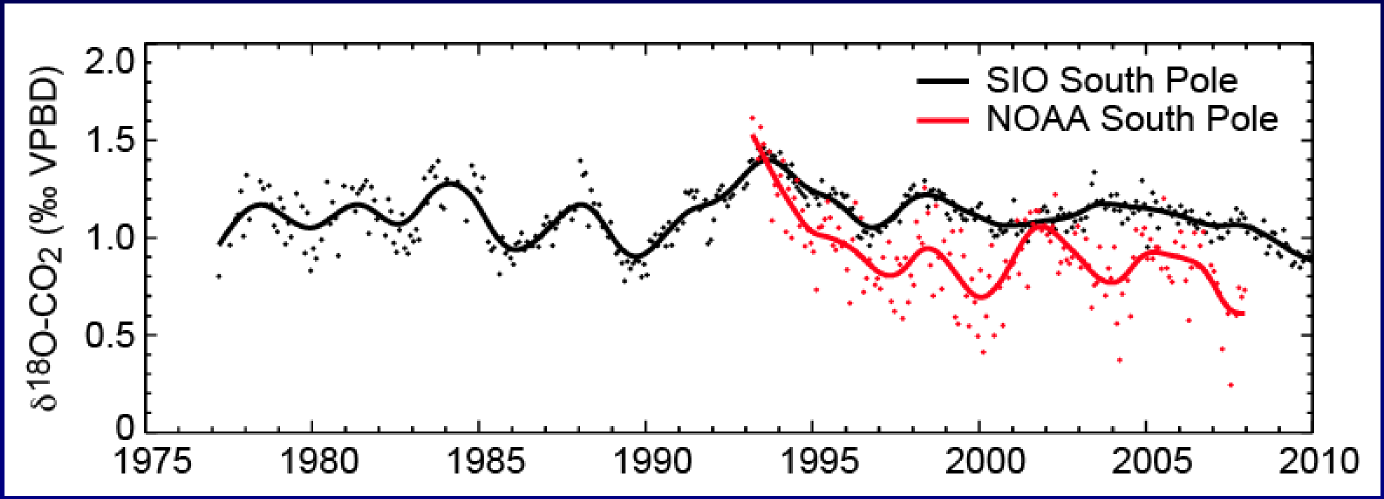
$R = 0.656$

$p\text{-value} < 0.002$

New method for estimating GPP

- Turnover time for O in CO_2 quantifies the isotopic fluxes that 'wash out the ENSO anomalies'
  - Global (include stratosphere mass): 1.1 to 1.7 yr
  - First global estimate based on atmospheric data
- Related to GPP after accounting for back flux of CO_2 out of leaves, air-sea gas exchange, and soil CO_2 invasion
- Global GPP based on ^{18}O turnover = 150-175 Pg C yr^{-1}
  - Larger than the widely used value, GPP = 120 Pg C yr^{-1}
- Does NOT require detailed knowledge of the $\delta^{18}O$ of surface water pools in leaves and soils

Importance of complementary long-term records



- Southern hemisphere records are very influential to the parameter fits even though most of the isotopic exchange occurred in the northern hemisphere.
- For this application, the more ENSO 'wiggles' the better constrained the parameter fits will be.

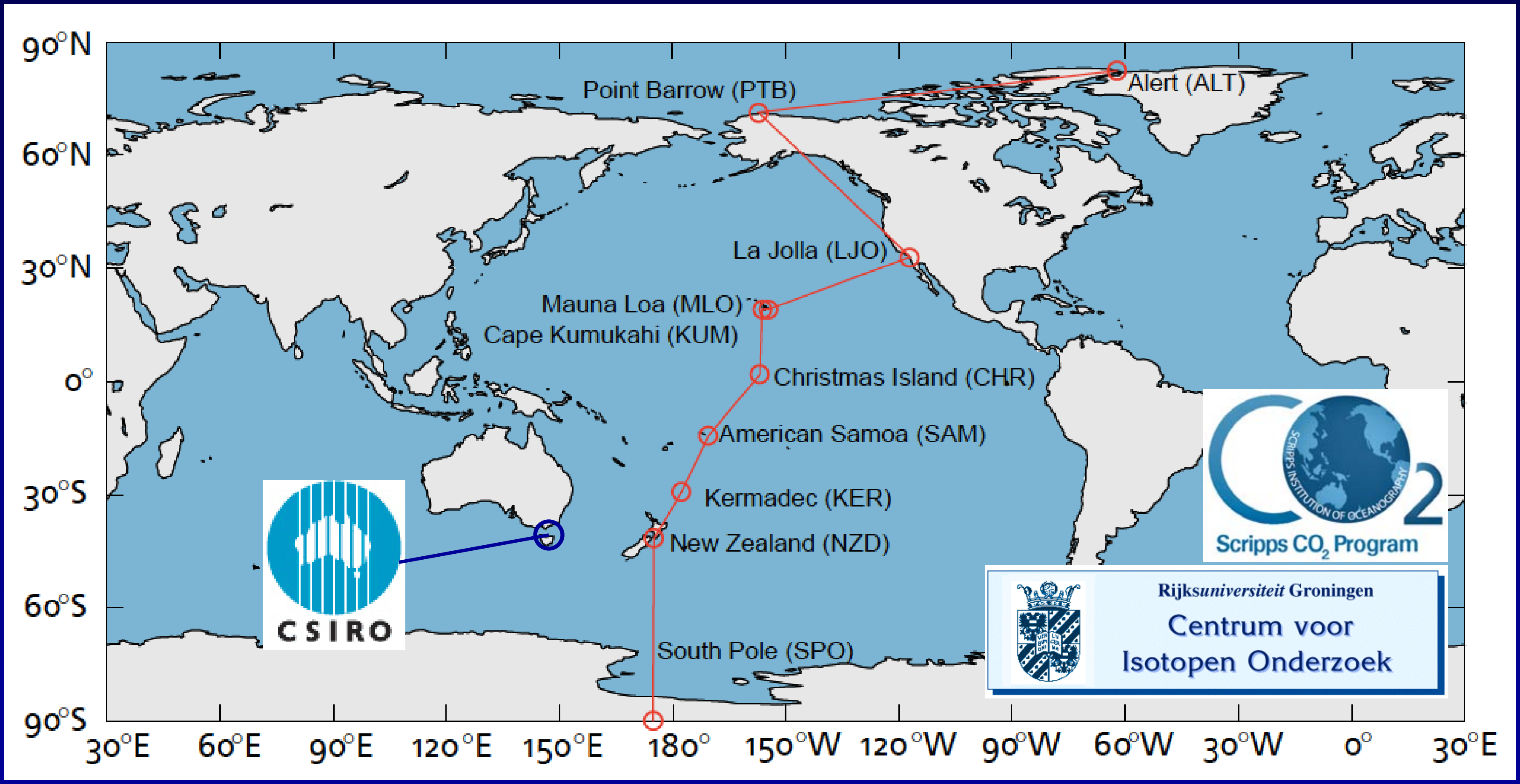
Summary

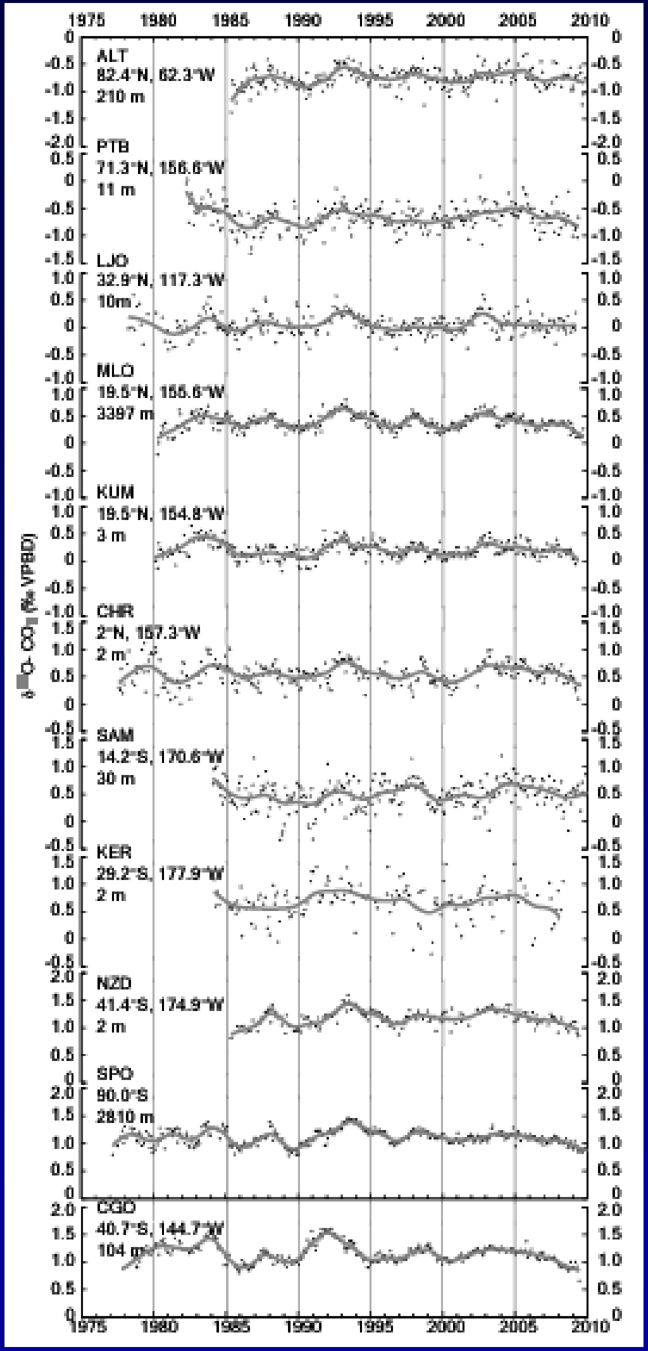
- New approach to using $\delta^{18}O$ of atmospheric CO_2 to understand C-cycling of the terrestrial biosphere
- Damping of the ENSO signal suggests global GPP may be revised upwards to 150-175 Pg C yr^{-1}
- 1-number constraint for biospheric models of carbon cycle based on atmospheric observations
- Long records over multiple El Niño events provide the best constraint

- Next steps…
- Data online at http://scrippsco2.ucsd.edu/

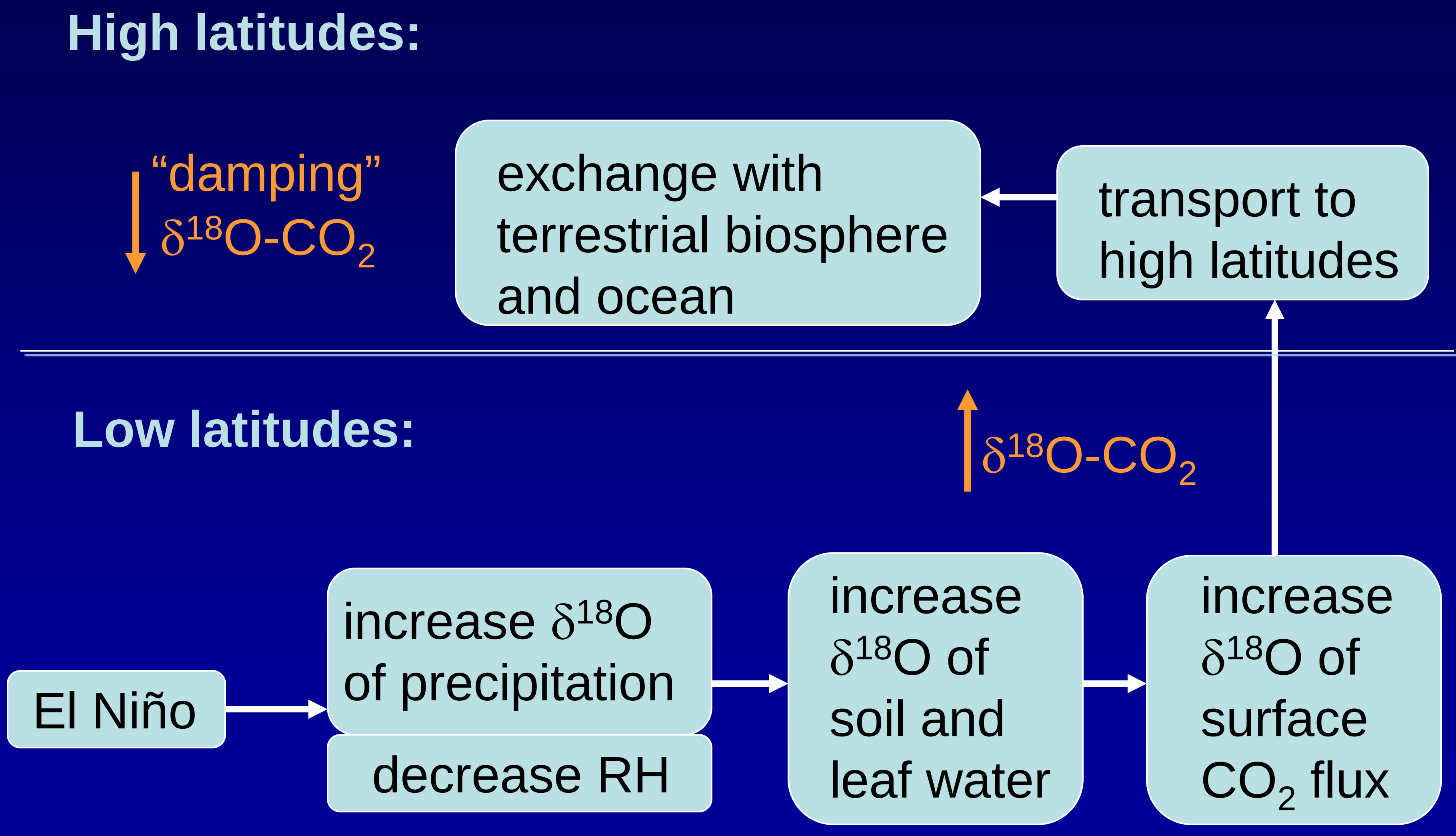
Questions?

Flask sampling




1975 1980 1985 1990 1995 2000 2005 2010
ALT
82.4°N, 62.3°W
210 m
PTB
71.3°N, 156.6°W
11 m
LJO
32.9°N, 117.3°W
10m
MLO
19.5°N, 155.6°W
3397 m
KUM
19.5°N, 154.8°W
3 m
CHR
2°N, 157.3°W
2 m
SAM
14.2°S, 170.6°W
30 m
KER
29.2°S, 177.9°W
2 m
NZD
41.4°S, 174.9°W
2 m
SPO
90.0°S
2810 m
CGO
40.7°S, 144.7°W
104 m
δ18O- CO2 (‰ VPBD)

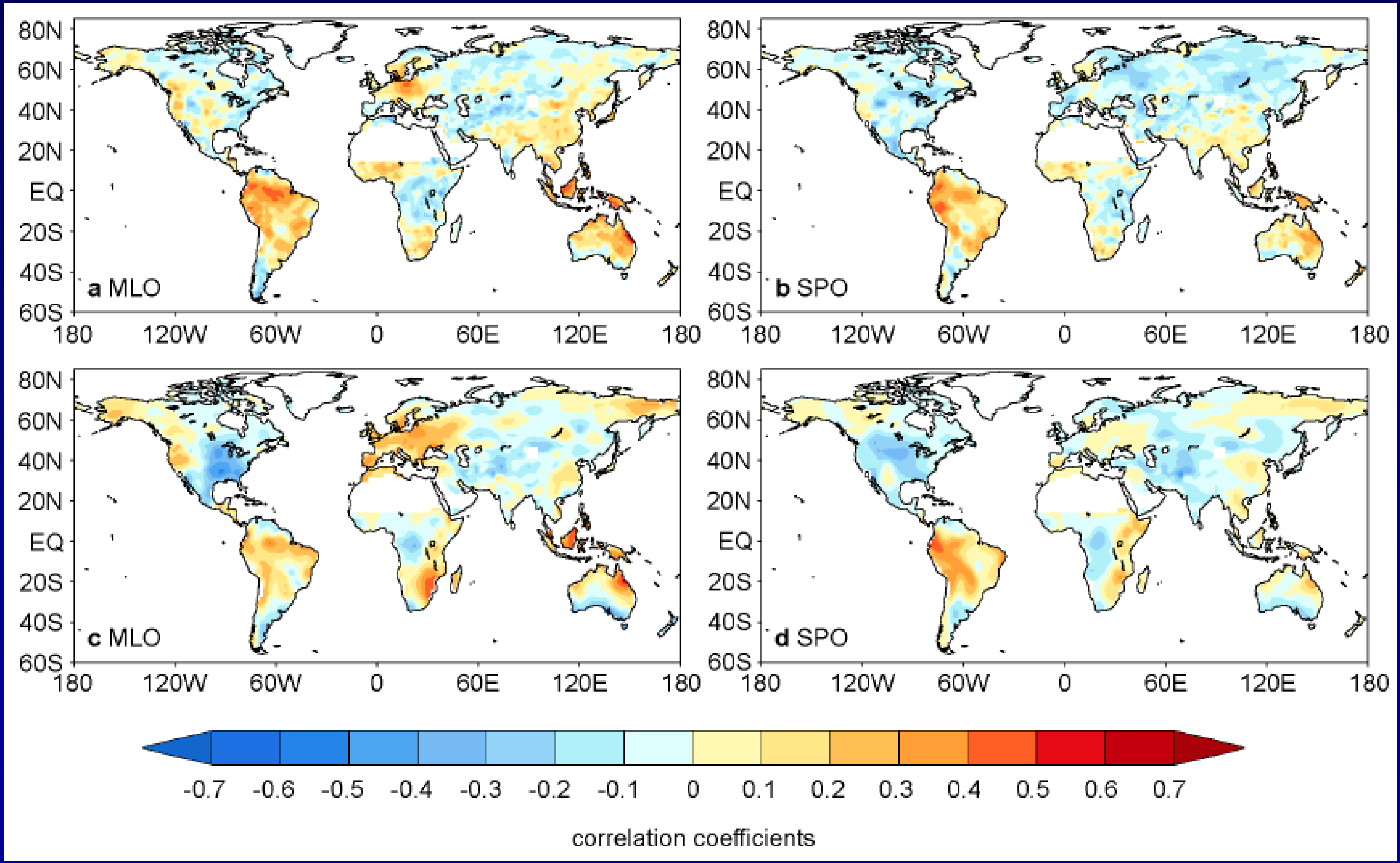
Proposed mechanism



Correlation between IsoGSM and flask observations

$\delta^{18}O$ of precip

RH



Parameter fits and implications

Scale factor

- We compared model fit to a bottom-up scale analysis and found ENSO-related changes in the d18O of precipitation and relative humidity to be the dominant processes

Turnover times

- Global (include stratosphere mass): 1.1 to 1.7 yr
- First global estimate based on atmospheric data
- Similar to previous bottom-up estimates of 1.7 yr (Cuntz et al., 2003; Keeling, 1995)
- This suggests that the turnover time for O atoms in CO_2 may be shorter than we thought…

GPP calculation

$$F_{GPP} = \frac{M_a \left(1/\tau_{globe} + 1/\tau_{ocean} + 1/\tau_{invasion} \right)}{\theta_{eq}\kappa_c + 1}$$

2-box model

ENSO forcing

(A, f_n, lag)

Northern hemisphere τ_N

$$\frac{d\delta_N'}{dt} = f_N \cdot A \cdot ENSO'(t - lag) - \frac{\delta_N'}{\tau_N} + \frac{\delta_S' - \delta_N'}{\tau_{mix}}$$

δ_N = MLO or ALT

τ_{mix} = 1 yr

Southern hemisphere τ_S

$$\frac{d\delta_S'}{dt} = (1 - f_N) \cdot A \cdot ENSO'(t - lag) - \frac{\delta_S'}{\tau_S} + \frac{\delta_N' - \delta_S'}{\tau_{mix}}$$

δ_S = SPO or CGO

Parameter fits and implications
1. Scale factor (*A*)

- Model fit: A = 0.26 to 0.36‰ ESPI^{-1} yr^{-1}
  1-sigma <0.06‰ ESPI^{-1} yr^{-1}

- Bottom up scale analysis:

$$A = \frac{\delta'_{soil}\left(\overline{\theta_{eq}} \cdot \overline{F_{out}} + \overline{F_R}\right) + \Delta'_e \cdot \overline{\theta_{eq}} \cdot \overline{F_{out}} + \ldots}{ESPI \cdot M_{atm}}$$

- 3.8‰ increase $\delta^{18}O$ of precipitation → A = 0.24‰ ESPI^{-1} yr^{-1}
- 10% decrease RH (IsoGSM) → A = 0.16‰ ESPI^{-1} yr^{-1}
- Affecting 40% of land surface fluxes (20°S to 20°N)

Parameter fits and implications
2. Turnover times, τ

- Northern hemisphere: 0.6-0.8 yr, 1-sigma = 0.4 yr
- Southern hemisphere: > 2 yr

$$\frac{1}{\tau_{globe}} = \frac{1}{\tau_N} + \frac{1}{\tau_S}$$

- Global (include stratosphere mass): 1.1 to 1.7 yr
- First global estimate based on atmospheric data
- Similar to previous bottom-up estimates of 1.7 yr*
- This suggests that the turnover time for O atoms in CO_2 may be shorter than we thought…

*Cuntz et al (2003) and Keeling (1995)