A global 3D model for the triple oxygen isotope signature $\Delta^{17}O$ of atmospheric CO_2 in TM5

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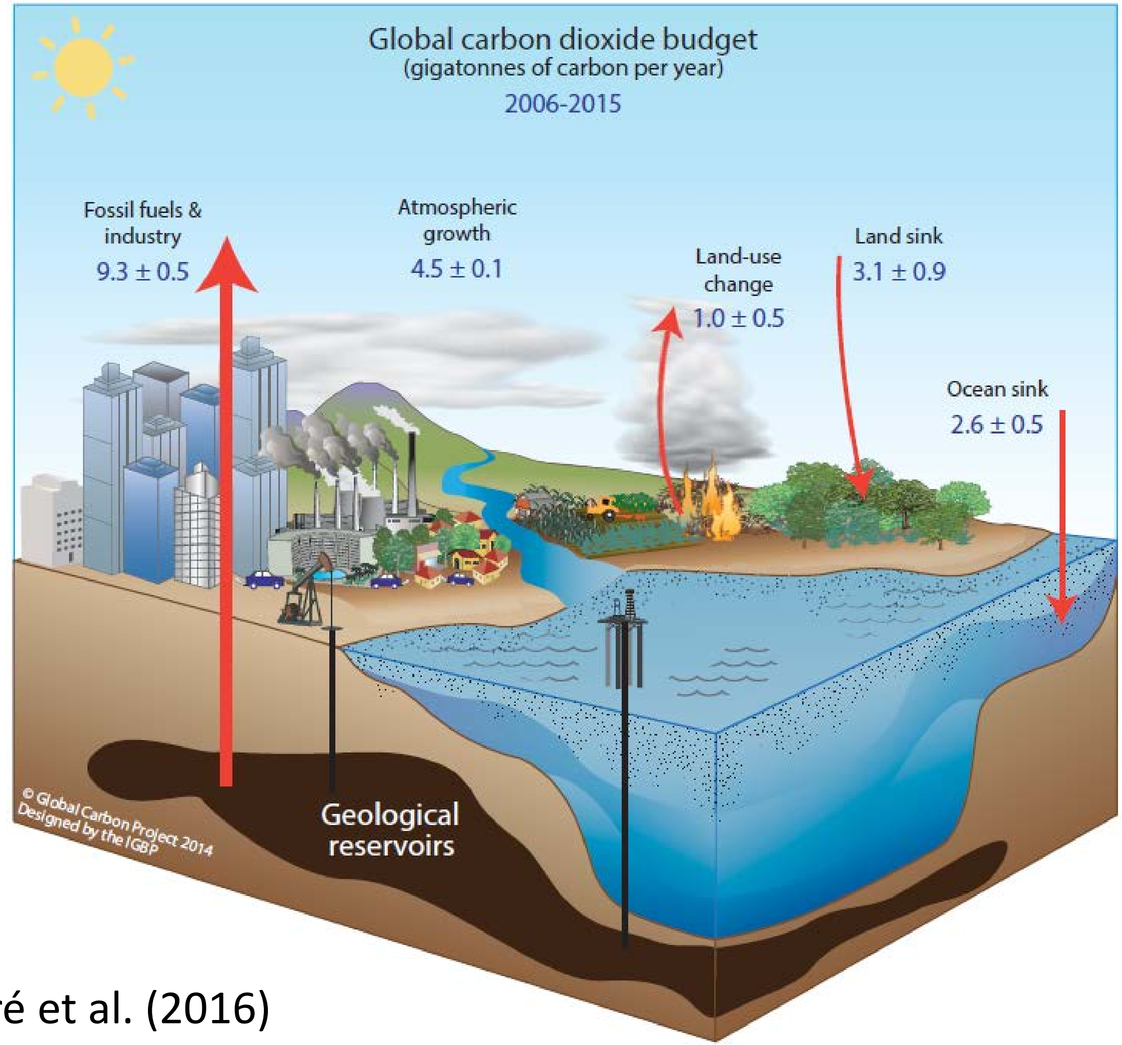
TM5 meeting *- November 21, 2017 - Wageningen*

Airborne Stable Isotopes of Carbon from the Amazon

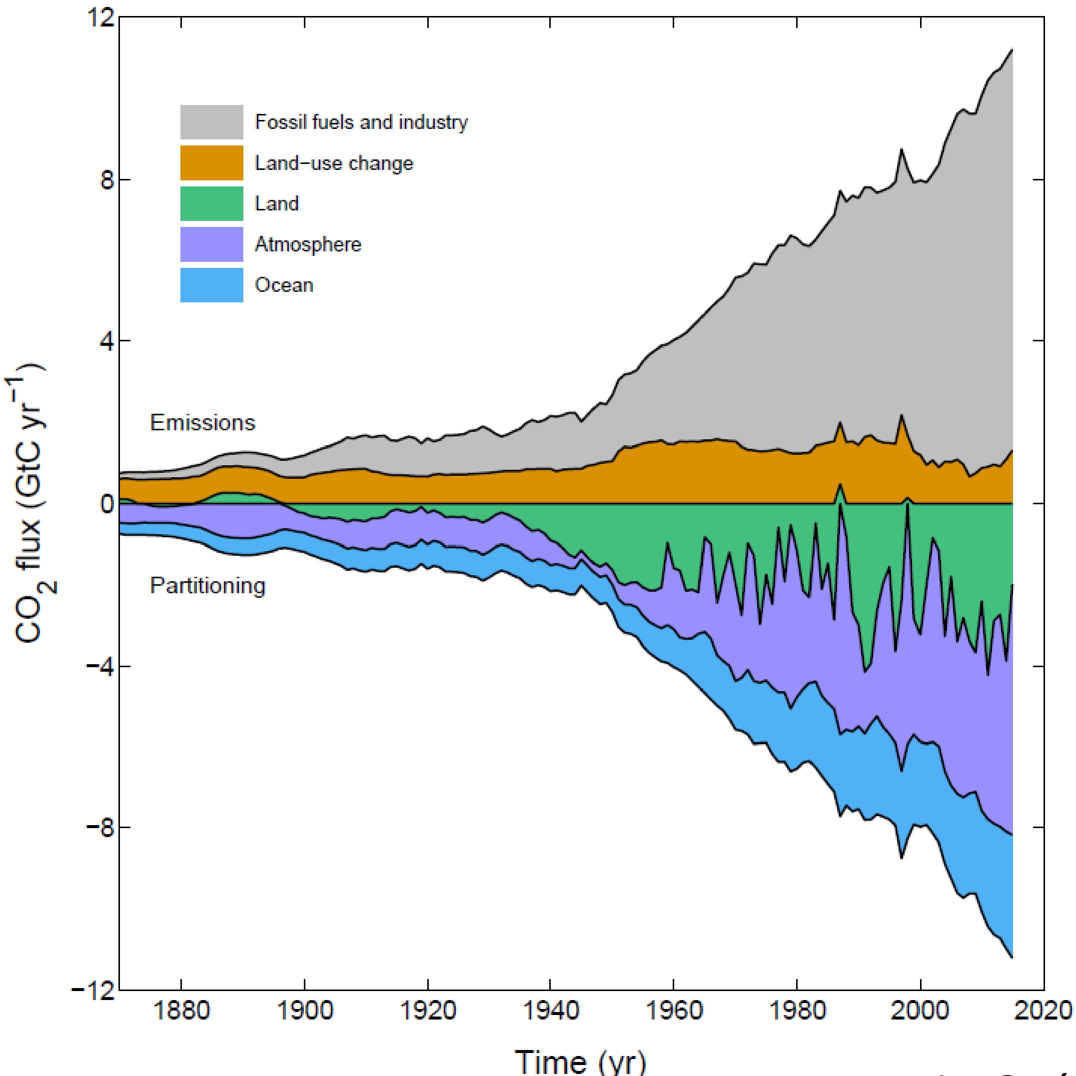
WAGENINGEN UNIVERSITY & RESEARCH

The carbon cycle



Le Quéré et al. (2016)

The carbon cycle



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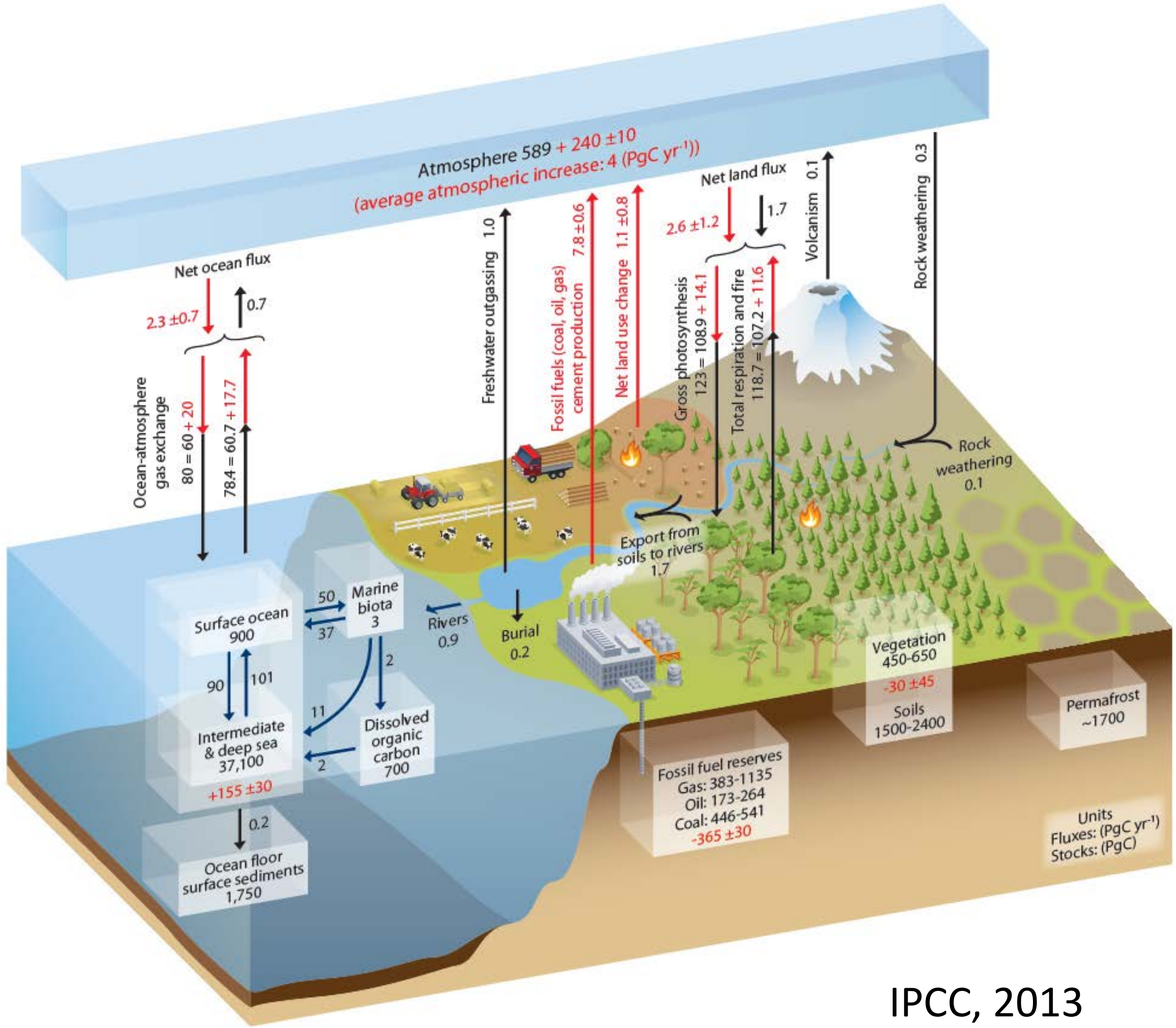


IPCC, 2013

Research motivation

- Global carbon cycle:
  - Vegetation-atmosphere exchange consists of two large opposing fluxes
  - Magnitude of gross primary production (GPP) is uncertain

- Objective:
  - Develop ‘forward’ model framework for $\Delta^{17}O$ in atmospheric CO_2
  - Simulate spatial and temporal patterns of $\Delta^{17}O$ in CO_2

- Follow up:
  - Constrain gross primary production (GPP) with inverse model and measurements of $\Delta^{17}O$ in atmospheric CO_2

Definition of $\Delta^{17}O$ in CO_2

- Definition of $\delta^{n}O$ (n =17 or 18):

$$\delta^{n}O = \frac{[{}^{n}O/{}^{16}O]_{sample}}{[{}^{n}O/{}^{16}O]_{standard}} - 1$$

$\delta^{n}O > 0$: sample enriched in ${}^{n}O$

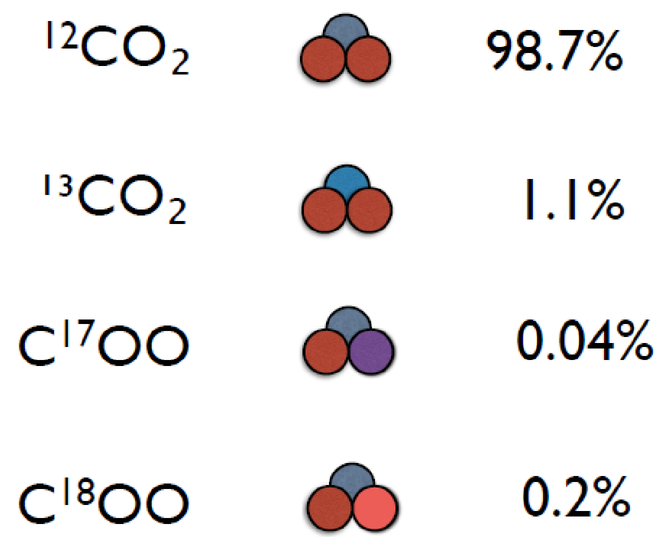
$\delta^{n}O < 0$: sample depleted in ${}^{n}O$

- Definition of $\Delta^{17}O$:

$$\Delta^{17}O = \ln(\delta^{17}O + 1) - 0.5229 \cdot \ln(\delta^{18}O + 1)$$

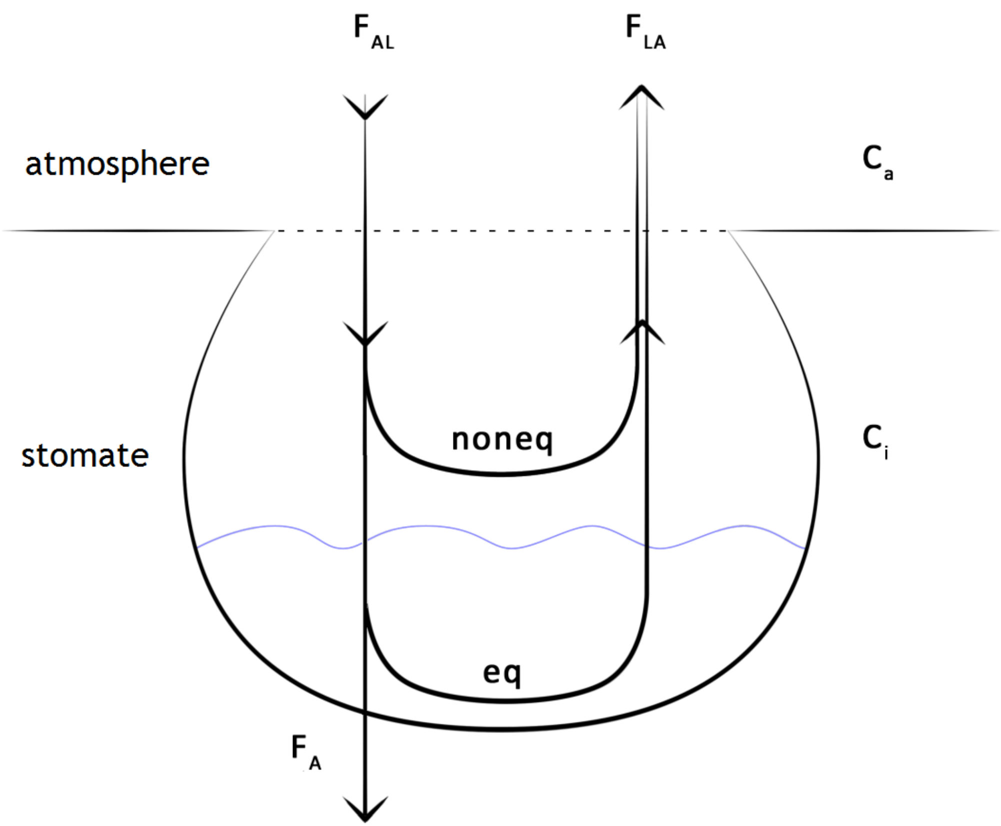
$$\approx \delta^{17}O - 0.5229 \cdot \delta^{18}O$$

- Also known as the ${}^{17}O$-excess



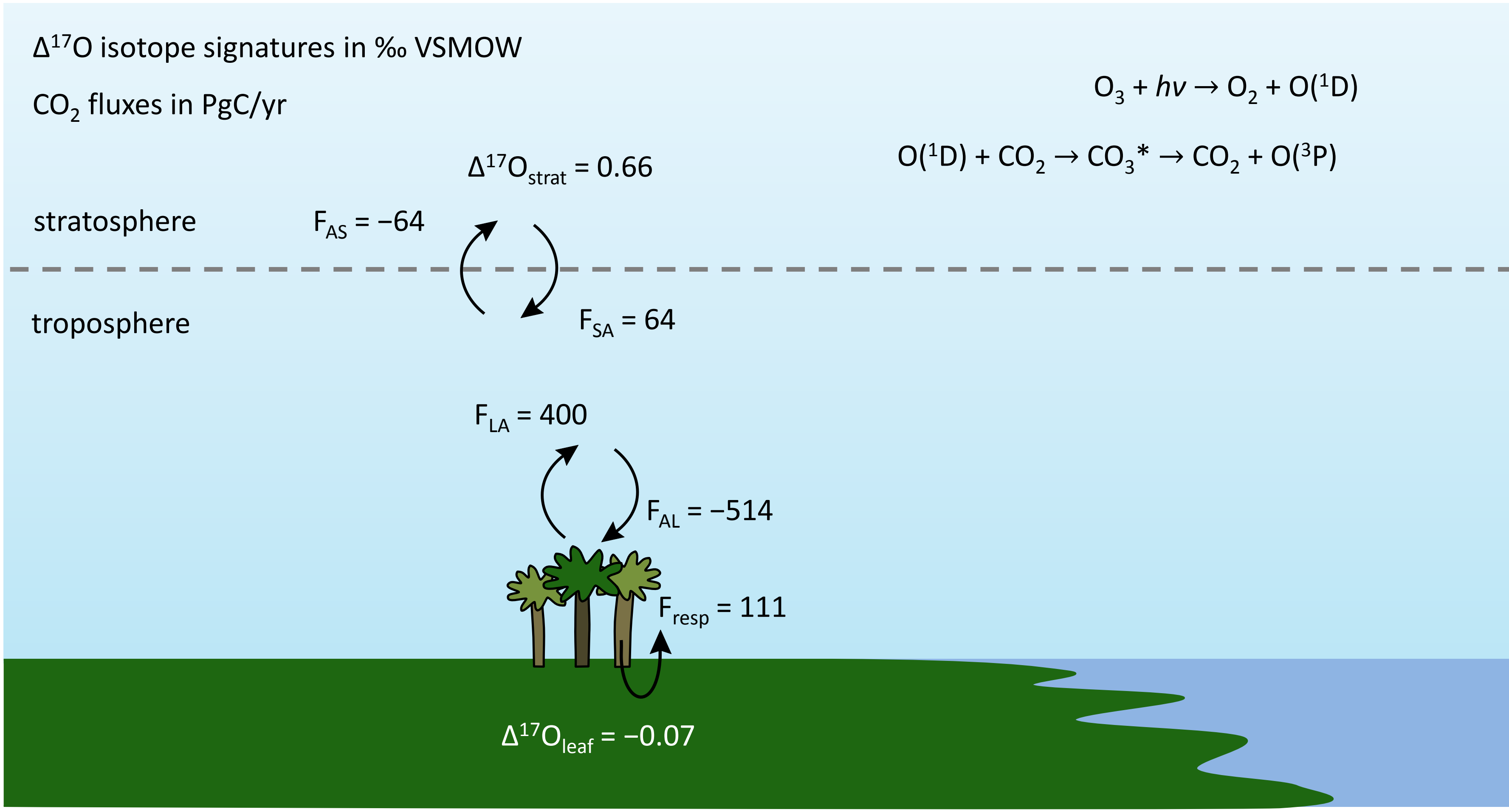
Effect of vegetation on $\Delta^{17}O$ in CO_2

- CO_2 can exchange oxygen isotopes after dissolving into water
- Most exchange of isotopes between CO_2 and water occurs in vegetation
- $\Delta^{17}O$ in atmospheric CO_2 is strongly affected by gross atmosphere leaf exchange
- Internal and external CO_2 concentration C_i and C_a determine gross exchange fluxes F_{AL} and F_{LA}



$$F_{AL} = F_A \frac{c_a}{c_a - c_i}$$

Global budget of $\Delta^{17}O$ in CO_2



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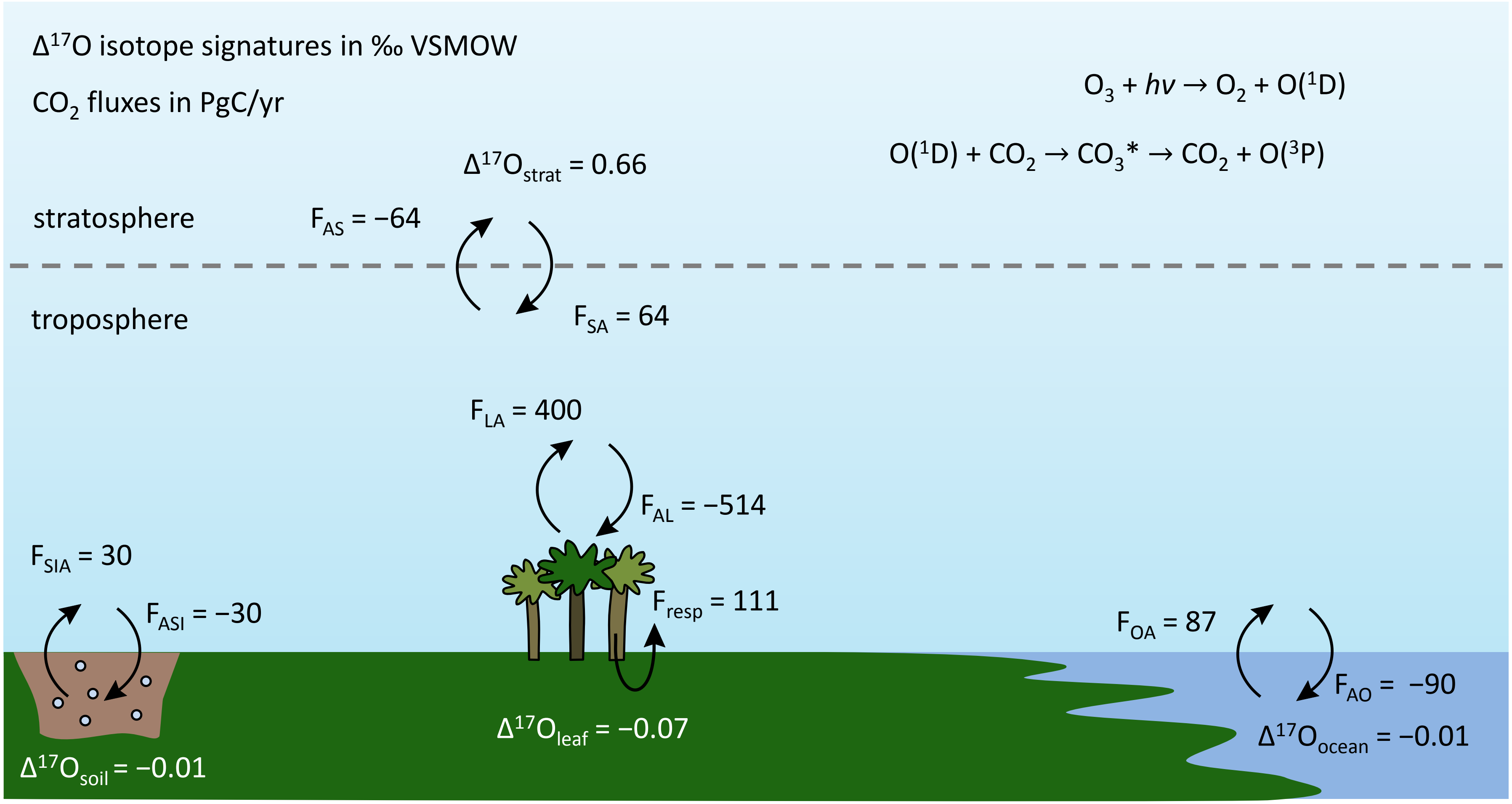

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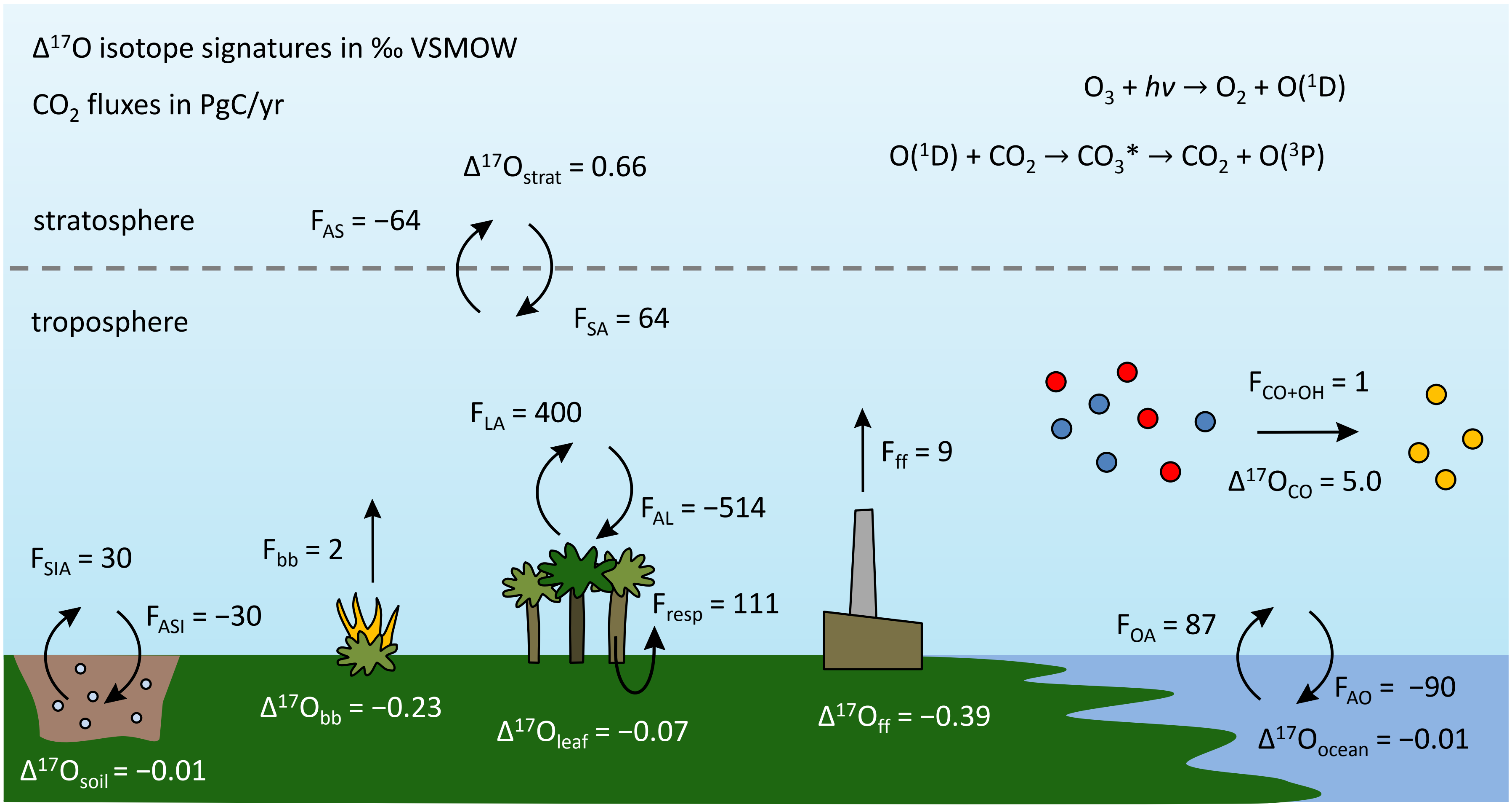
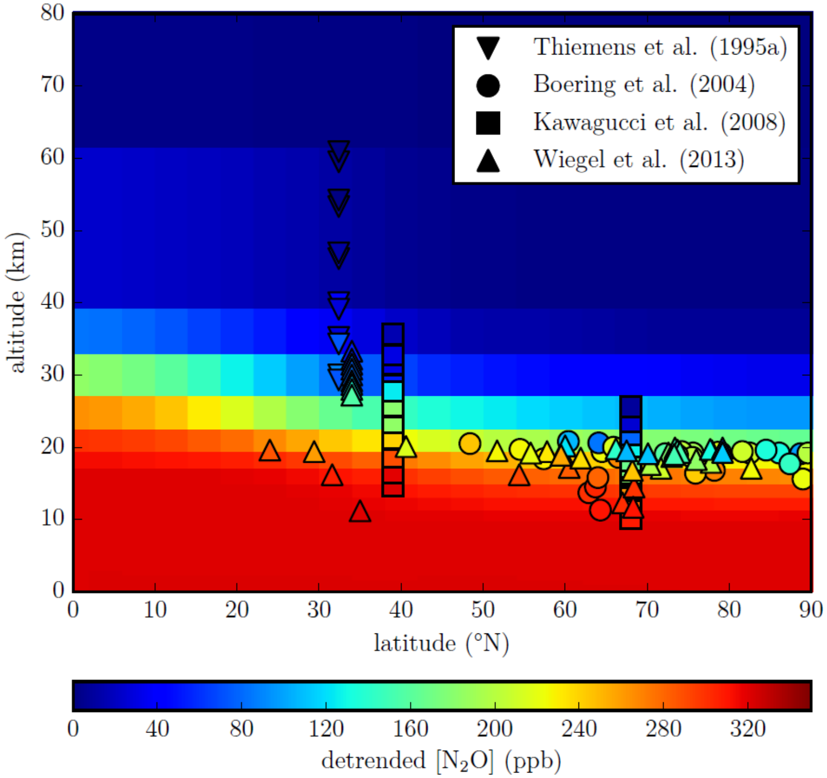
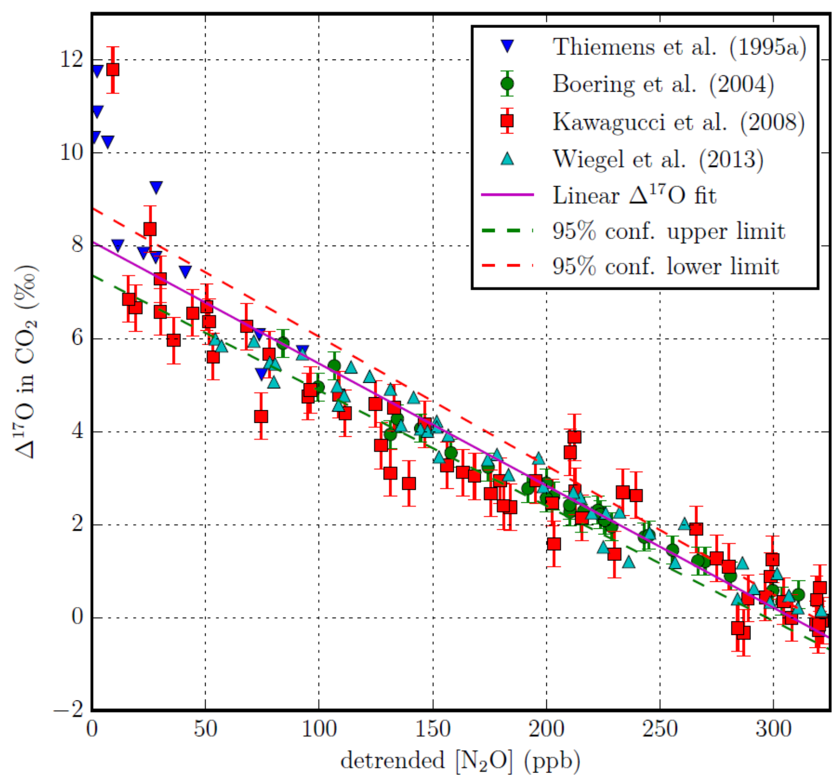


Stratospheric source of $\Delta^{17}O$ in CO_2

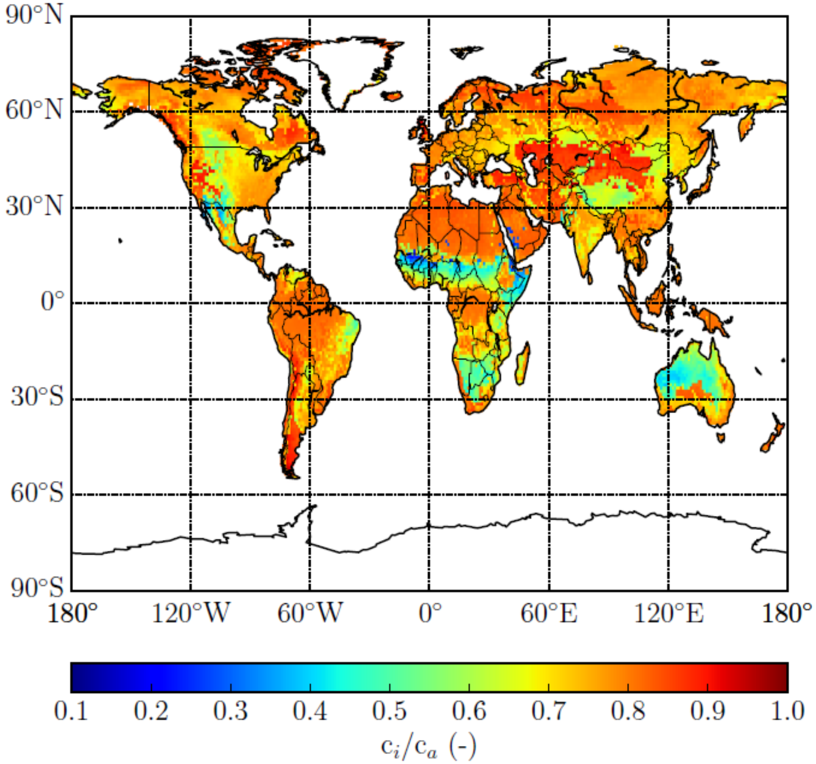


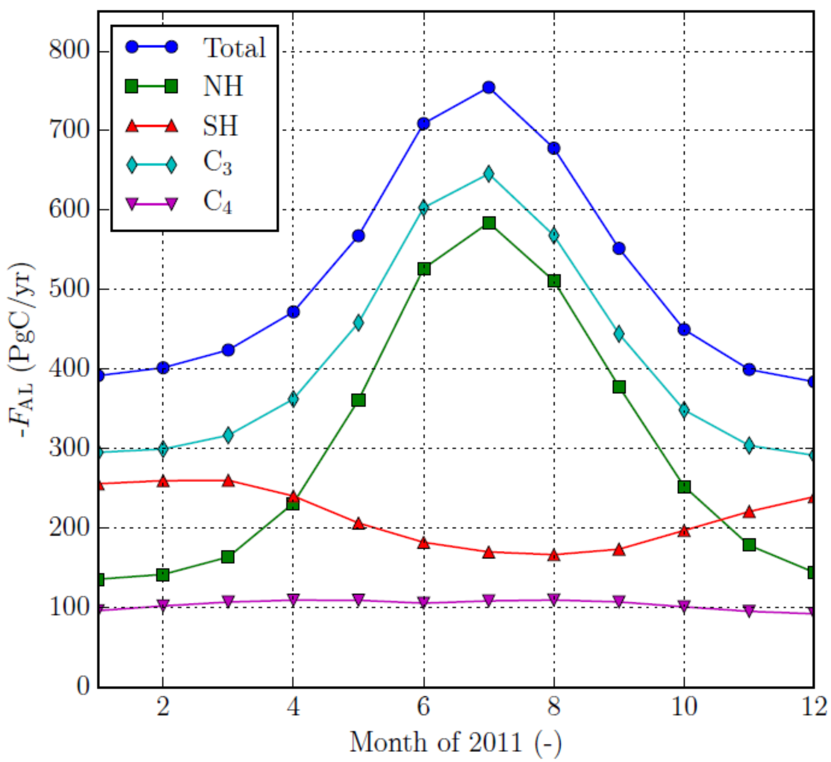


- N_2O and $\Delta^{17}O$ in stratospheric CO_2 are both tracers with a long lifetime and related to photochemistry

- N_2O tracer with optimized surface emissions and stratospheric sinks (data from Bergamaschi et al., 2015)

Biospheric sink of $\Delta^{17}O$ in CO_2

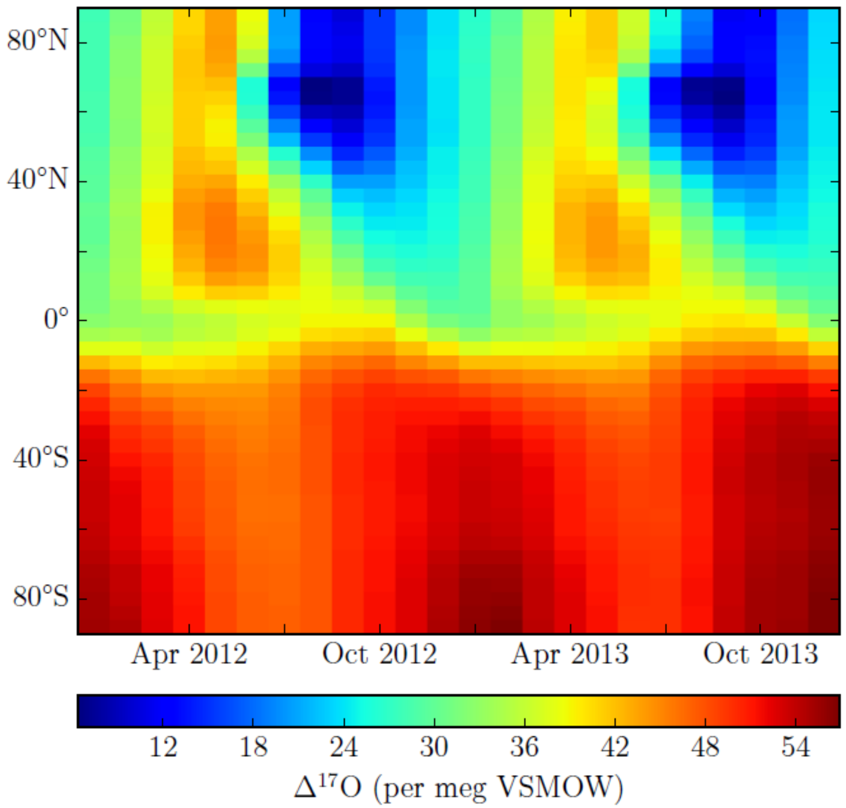


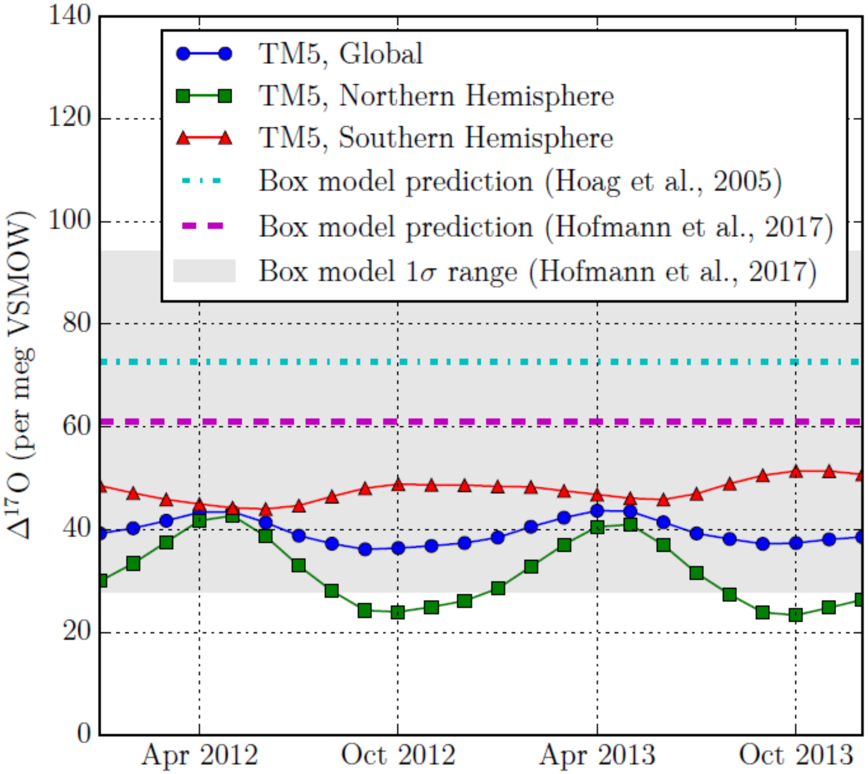


- Vegetation model SiBCASA with C_3 and C_4 vegetation photosynthesis scheme
- Gross atmosphere-leaf flux from c_i / c_a (and $F_A = 0.88 \cdot GPP$)
- Time and space dependent $\Delta^{17}O$ leaf water signature

$$F_{AL} = F_A \frac{c_a}{c_a - c_i}$$

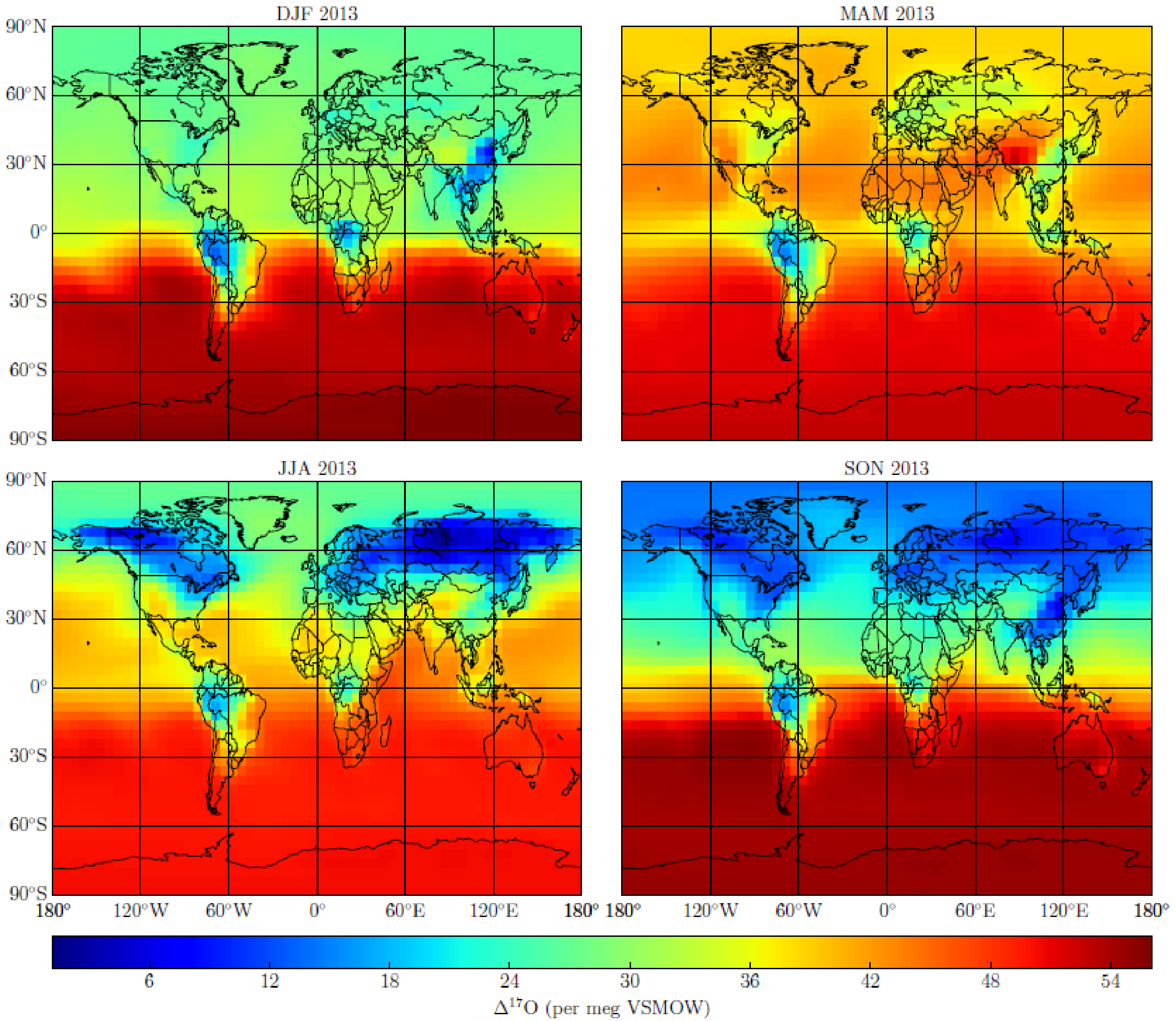
Global time series of $\Delta^{17}O$ in CO_2





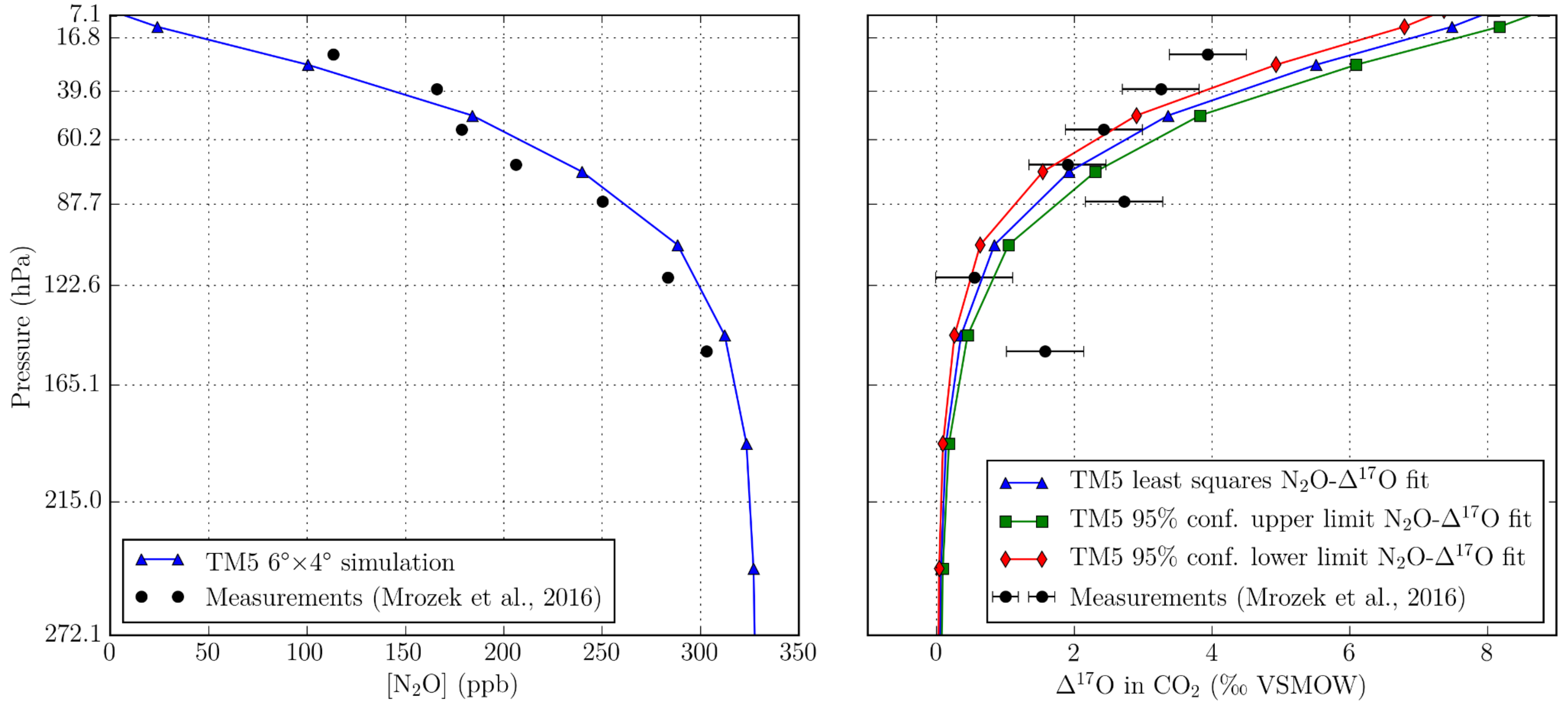
- Decrease of $\Delta^{17}O$ in atmospheric CO_2 during periods of high GPP (with highest amplitude in NH)
- Our TM5 model prediction lower than box models (mainly due to higher F_{AL})

Seasonal maps of $\Delta^{17}O$ in CO_2



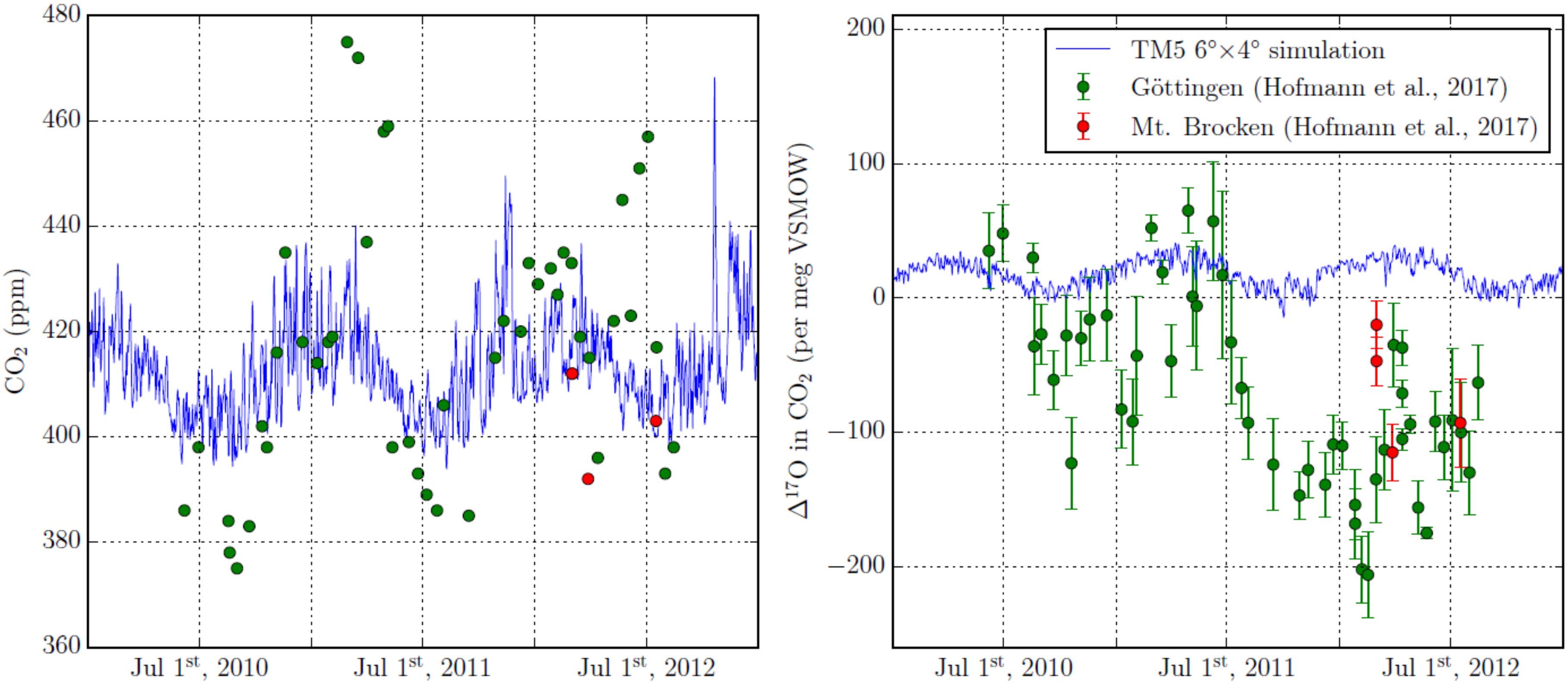
- Lower values of $\Delta^{17}O$ in CO_2 over land area
- During entire year low $\Delta^{17}O$ value above the Amazon
- Large swings in $\Delta^{17}O$ values for NH

Results of $\Delta^{17}O$ in CO_2 over Sodankylä, Finland



- Model predictions for N_2O mixing ratios and $\Delta^{17}O$ in CO_2 agree well with observations from Mrozek et al. (2016) measured with AirCore

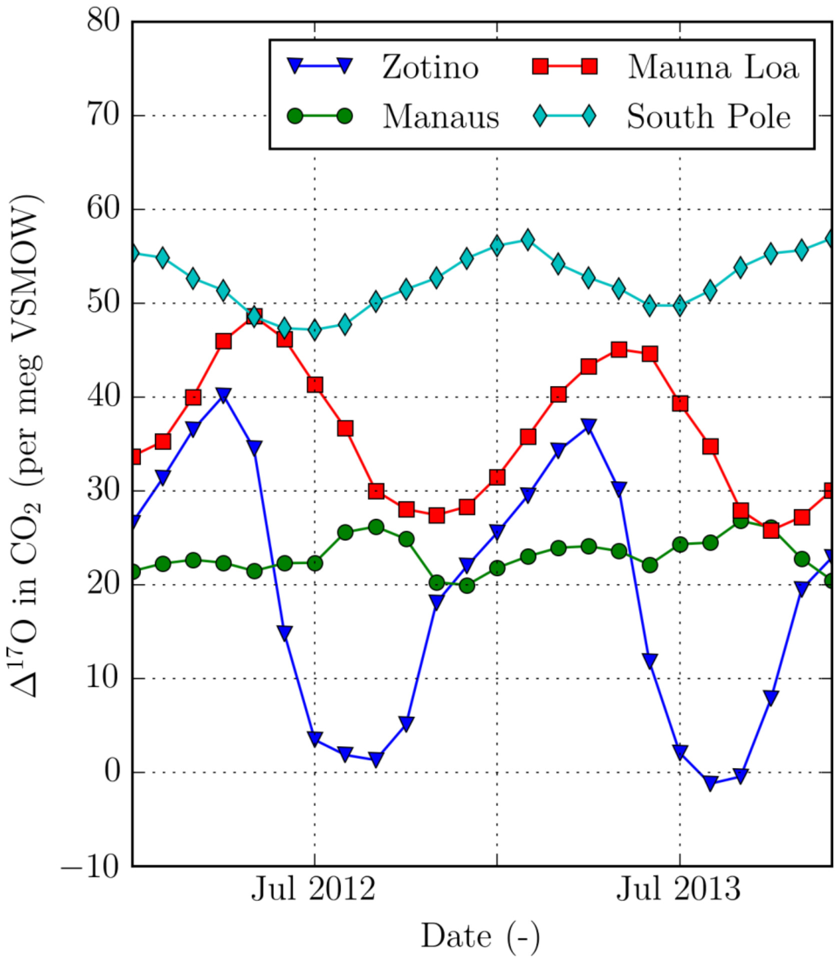
Results of $\Delta^{17}O$ in CO_2 for Göttingen, Germany



- Seasonal cycle in $\Delta^{17}O$ due to seasonality in biosphere
- Large drop in measured $\Delta^{17}O$ in CO_2 for second year cannot be explained

Where should we measure?

- High northern latitude (e.g. Zotino, Russia at 60 °N) for large seasonal cycle
- Northern Hemisphere background (e.g. Mauna Loa, Hawaii, 19.5 °N)
- Southern Hemisphere background location for NS-gradient (e.g. South Pole)
- Amazonia for vegetation induced drop in $\Delta^{17}O$ (e.g. Manaus, 3 °S)



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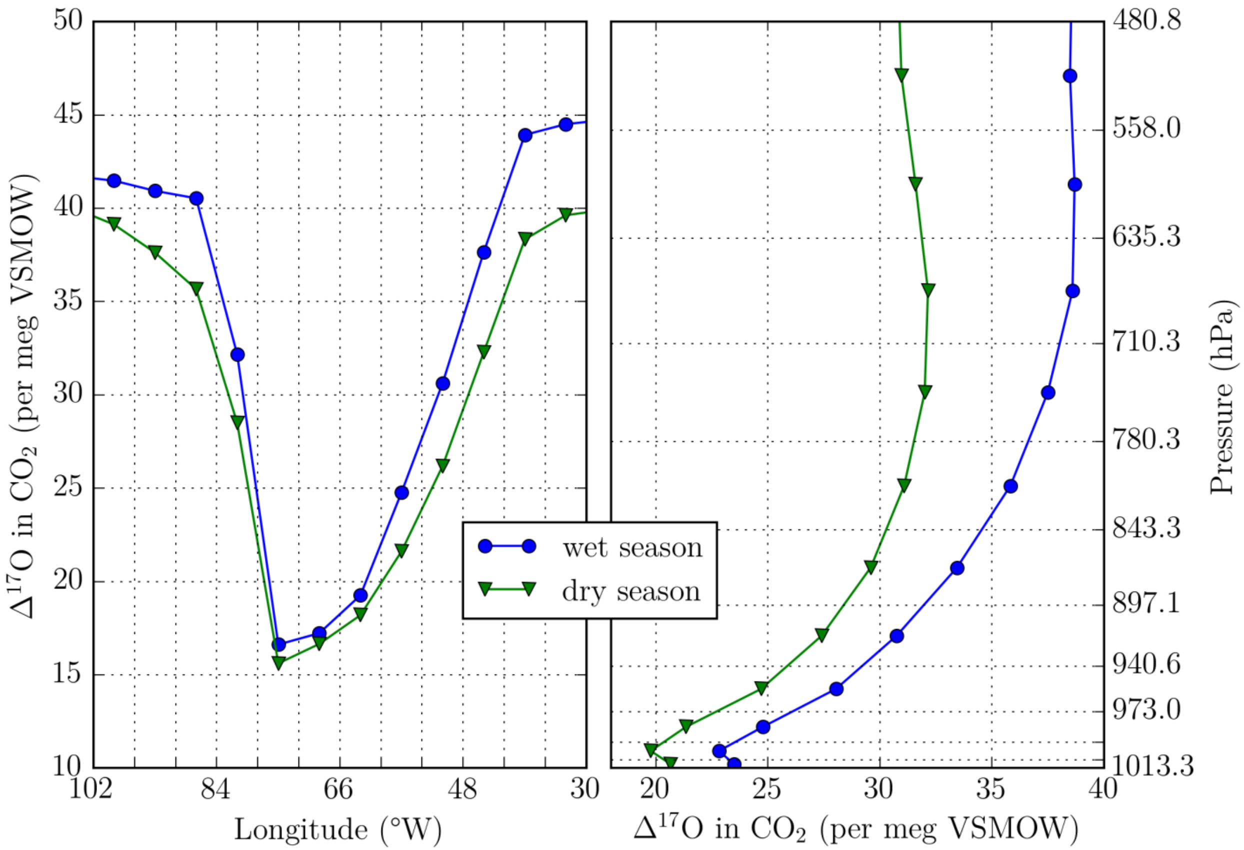

- Longitudinal and vertical gradients in $\Delta^{17}O$ of CO_2 for wet and dry season at Manaus (60 °W)

Conclusions

- First 3D model for $\Delta^{17}O$ in atmospheric CO_2
    - Atmospheric transport model TM5
    - Stratospheric source based on observed N_2O-$\Delta^{17}O(CO_2)$ correlation
    - Gross atmosphere-leaf exchange from vegetation model SiBCASA
- Model results for $\Delta^{17}O$ in CO_2
    - Spatial and temporal pattern agree with vegetation dynamics
    - Average prediction lower than box model predictions
    - Good agreement for profile over Sodankylä, Finland
- More measurements are need to better understand the budget of $\Delta^{17}O$ in CO_2