Modeling the triple oxygen isotope $\Delta^{17}O$ in CO_2

Gerbrand Koren, Linda Schneider, Magdalena Hofmann, Wouter Peters

TM5 meeting SRON - January 16th, 2017

Airborne Stable Isotopes of Carbon from the Amazon

WAGENINGEN
UNIVERSITY & RESEARCH

What is the triple oxygen isotope $\Delta^{17}O$?

- 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

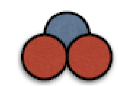
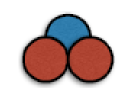
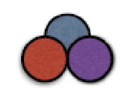
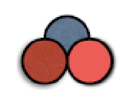
$\delta^{n}O < 0$: sample depleted in ^{n}O

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

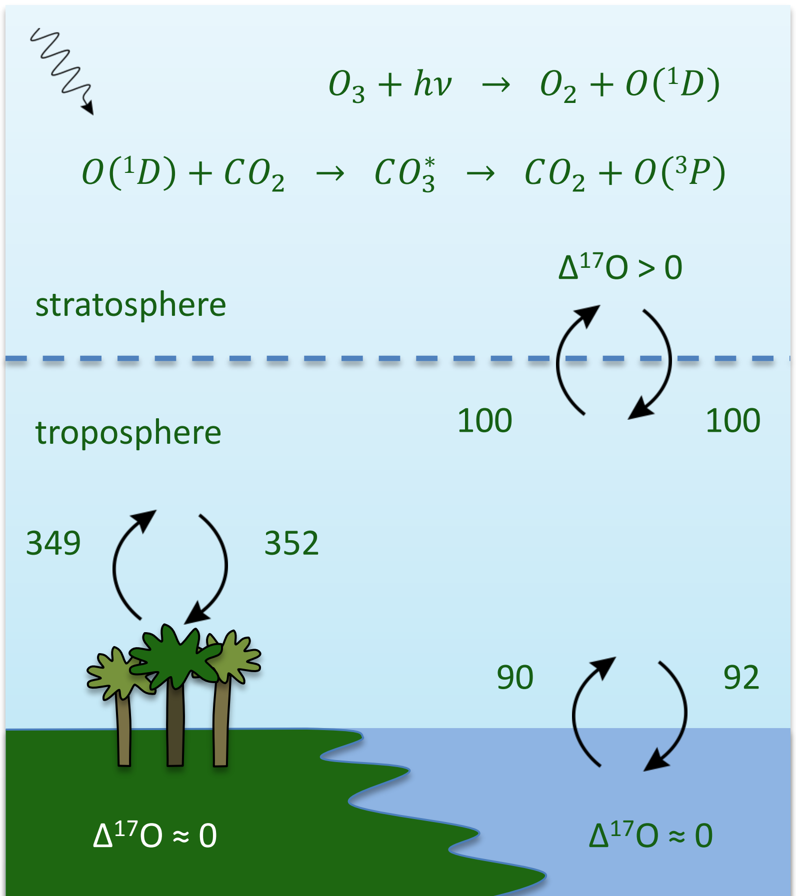
$$\Delta^{17}O = \ln(\delta^{17}O + 1) - 0.5229 \cdot \ln(\delta^{18}O + 1)$$

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

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

$^{12}CO_2$		98.7%
$^{13}CO_2$		1.1%
$C^{17}OO$		0.04%
$C^{18}OO$		0.2%

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

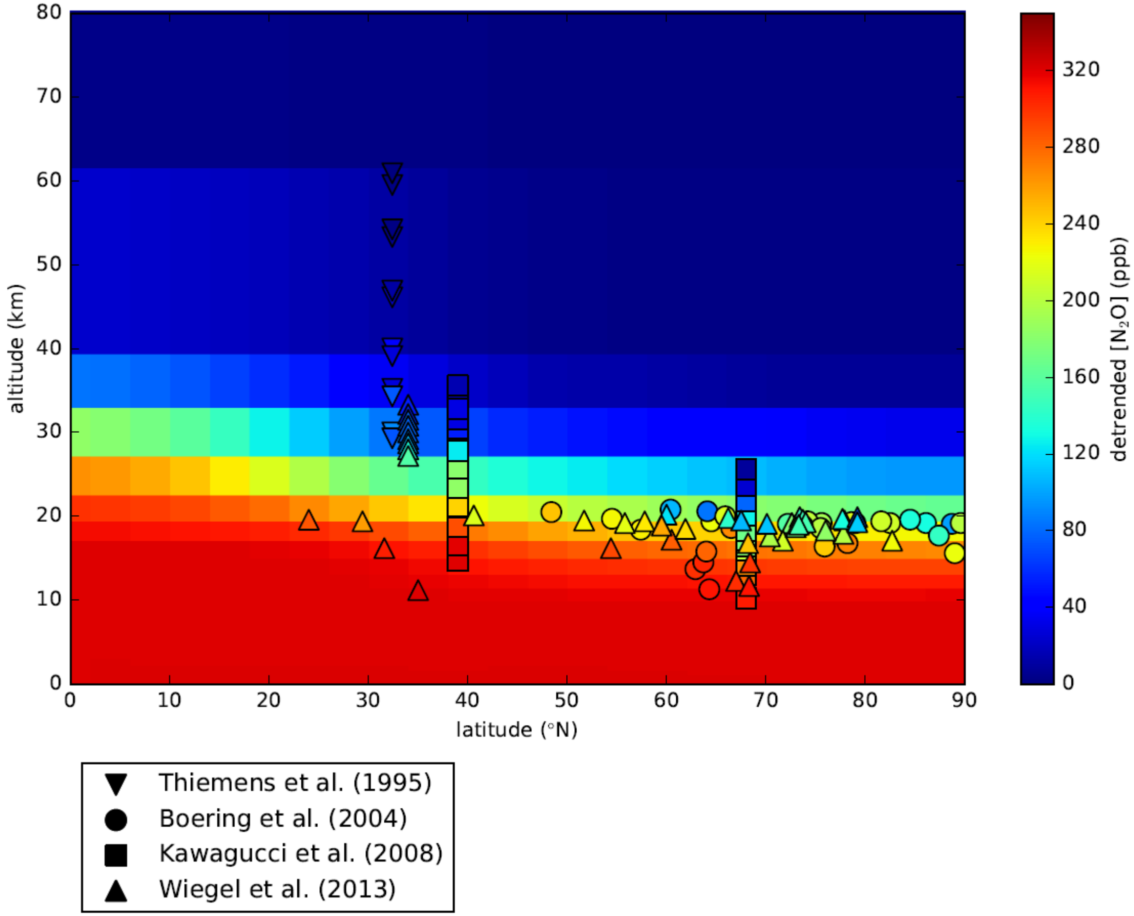


- Budget from 1D box model with fluxes in PgC/yr (Hofmann et al., 2017)
- Source of $\Delta^{17}O$ is in the stratosphere
- Vegetation is main sink of $\Delta^{17}O$ → tracer of gross primary production (GPP)
- Other sinks of $\Delta^{17}O$:
  - oceans
  - soil invasion
  - biomass burning
  - fossil fuel combustion
- Objective: build 3D model for $\Delta^{17}O$

Overview of TM5 model setup

- Model setup:
  - offline 3 hrly ERA-Interim meteorology
  - offline SiBCASA vegetation model results
  - slopes advection scheme
- Active tracers:
  - CO_2
  - $C^{17}OO$
  - N_2O (Bergamaschi et al., 2015)
- Model resolution:
  - 6° x 4° horizontal resolution
  - 25 vertical layers
  - 1 hr time step
- Platforms:
  - cartesius (SURFsara)
  - capegrim (WUR)

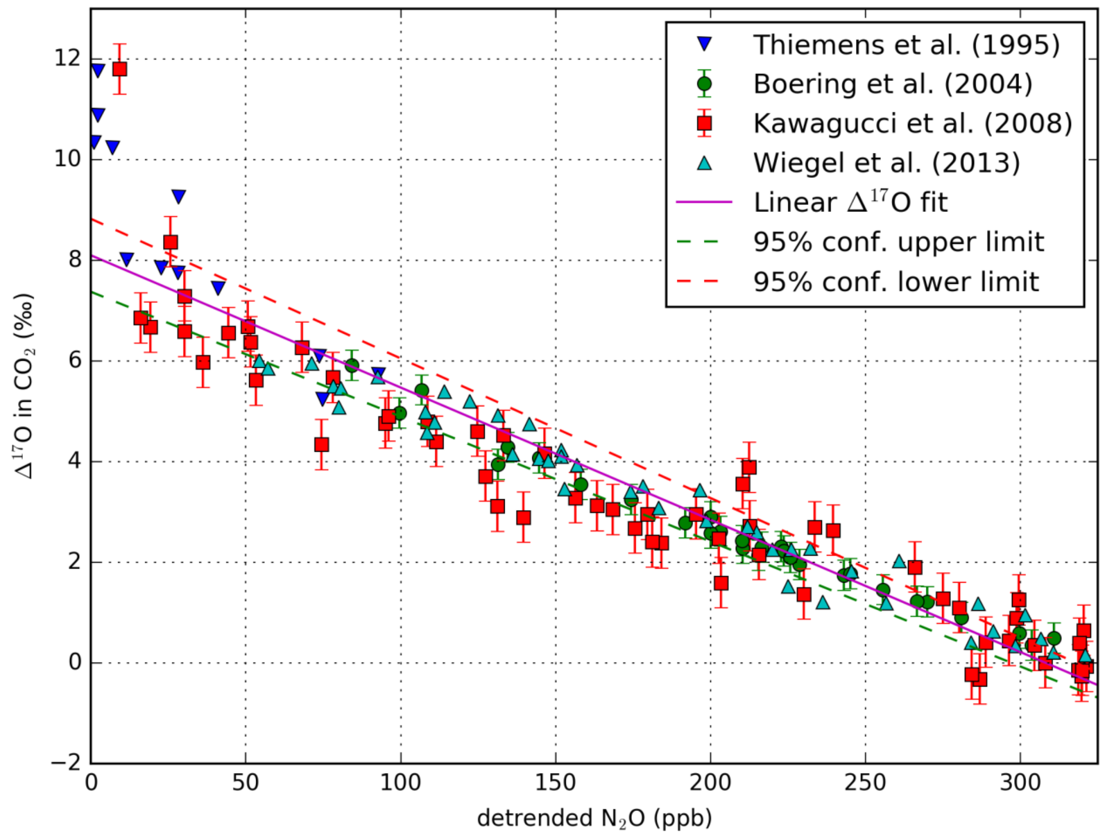
TM5 simulations of N_2O tracer



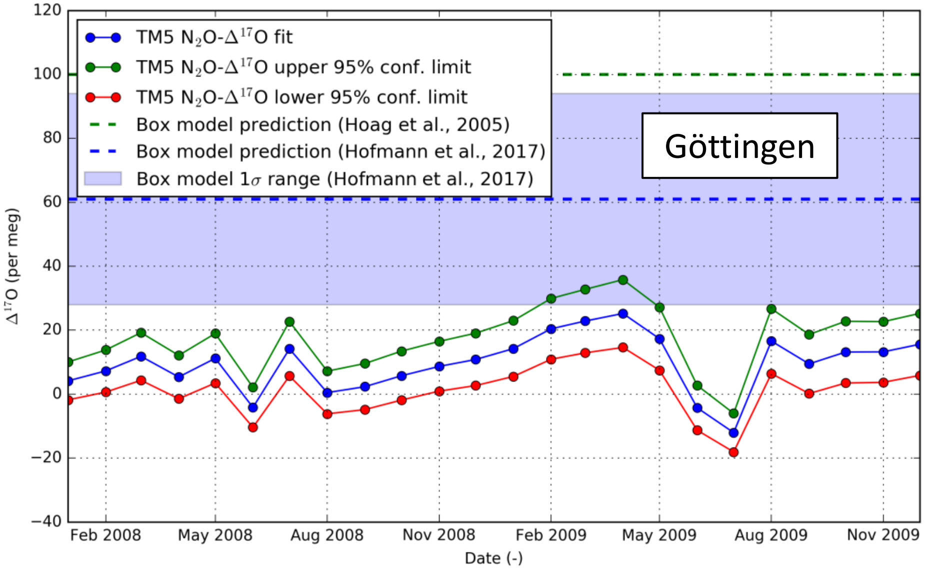
- Stratospheric N_2O sinks and optimized surface fluxes (Bergamaschi et al., 2015)
- Comparison of TM5 simulated N_2O 'climatology' (average over 2007) vs observed N_2O
- N_2O observations detrended with atmospheric growth rate for N_2O

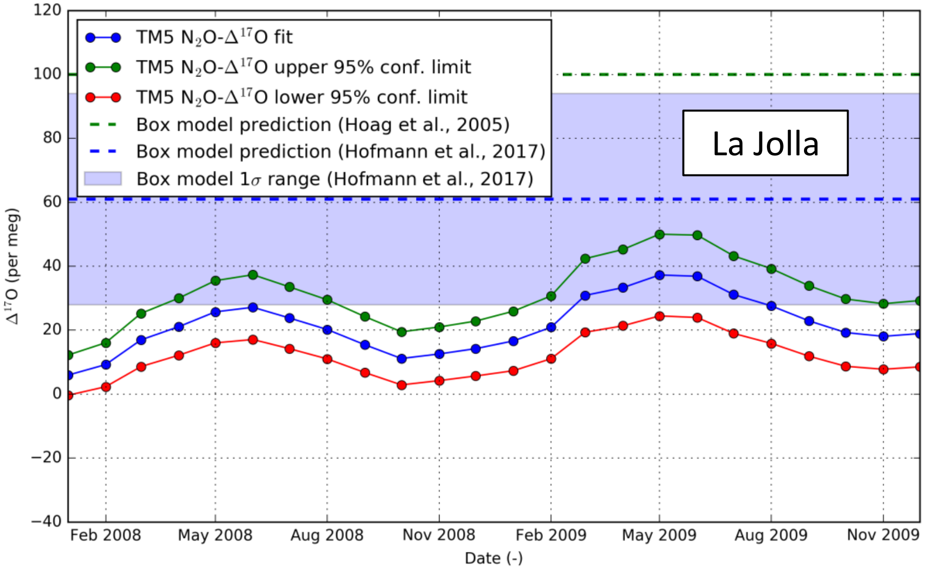
Linear N_2O-$\Delta^{17}O$ correlation

- Stratospheric source of $C^{17}OO$ determined from N_2O tracer and N_2O-$\Delta^{17}O$ fit
- Sensitivity analysis for different fits
- Domain of application for fit:
  - N_2O threshold
  - level threshold



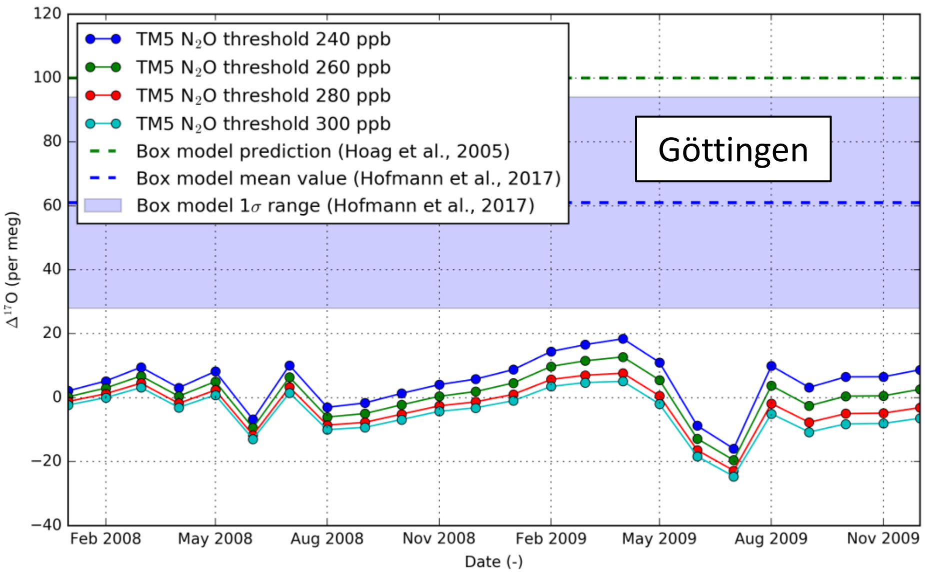
Sensitivity analysis for N_2O-$\Delta^{17}O$ fit

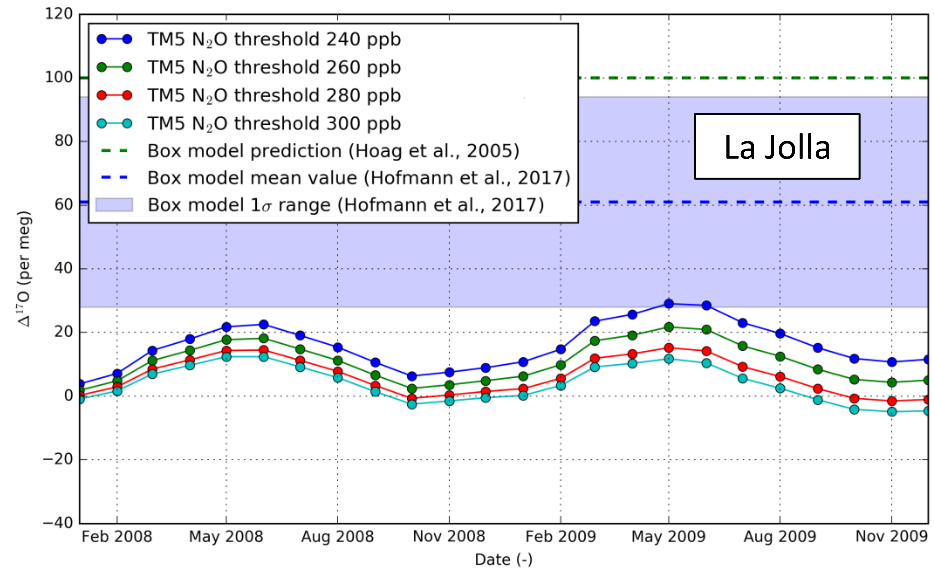




- Monthly average $\Delta^{17}O$ at surface for Göttingen (Germany) and La Jolla (California)
- Fit is applied for model level 20 (~60 hPa) and above
- Sensitivity of calculated $\Delta^{17}O$ on N_2O-$\Delta^{17}O$ fit is not negligible (~10 per meg)

N_2O threshold for N_2O-$\Delta^{17}O$ fit



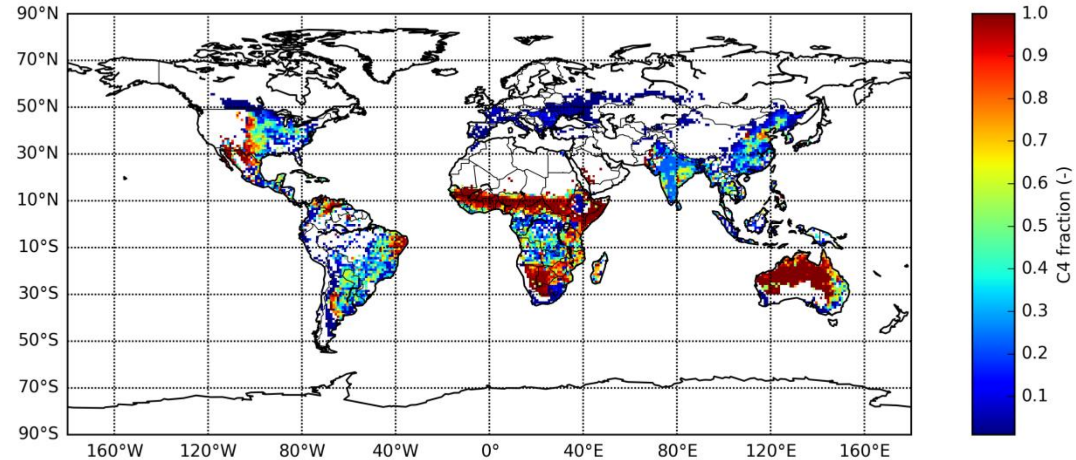


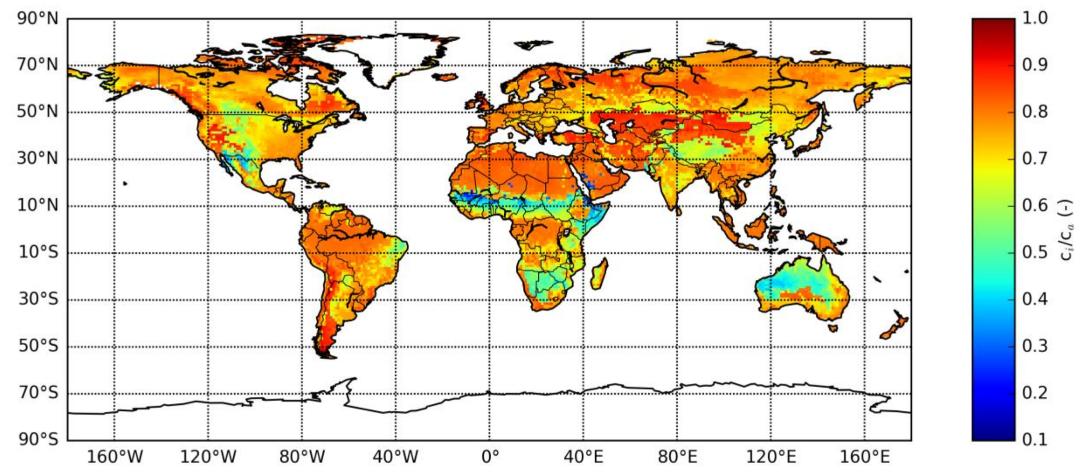
- Monthly average $\Delta^{17}O$ at surface for Göttingen (Germany) and La Jolla (California)
- Fit is only applied for cells where simulated N_2O is below N_2O threshold

Vegetation model for $\Delta^{17}O$ in CO_2

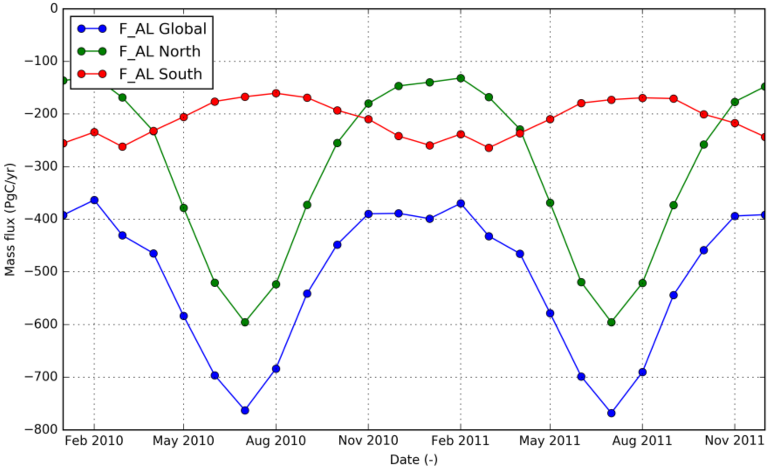
- Vegetation model SiBCASA with ERA-Interim meteorology
- C_3 and C_4 vegetation photosynthesis scheme
- Internal and external CO_2 concentrations for leaf stomata
- Gross atmosphere-leaf flux from c_i / c_a

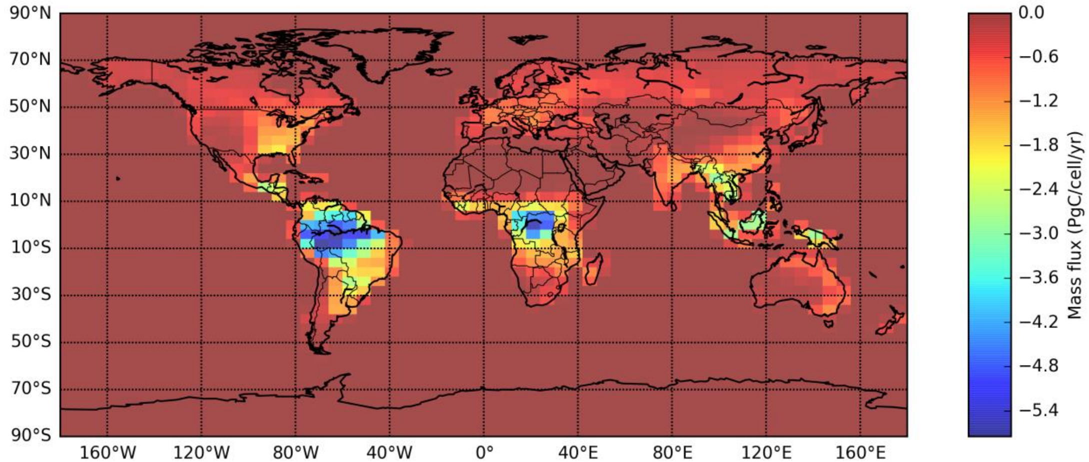
$$F_{AL} = F_A \frac{c_a}{c_a - c_i}$$





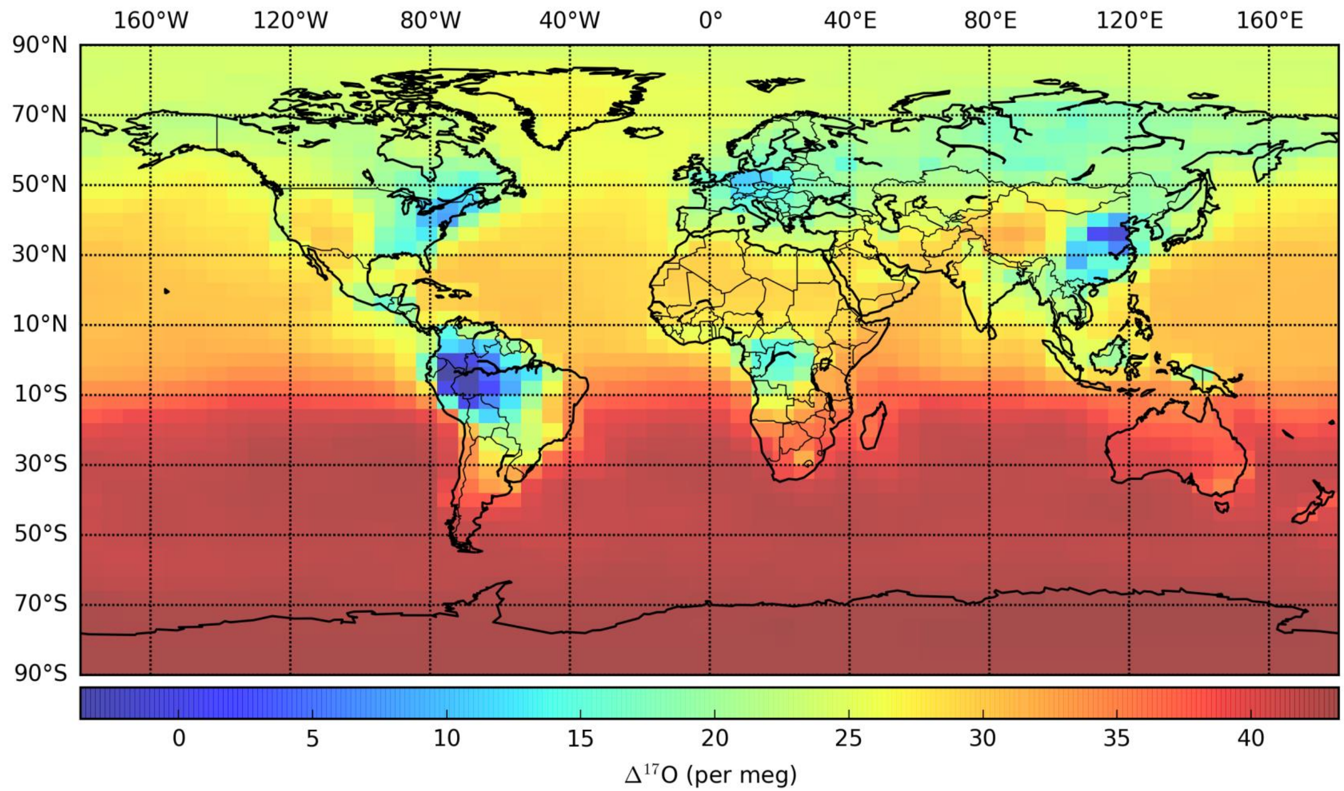
Gross atmosphere-leaf flux of CO_2





- Gross atmosphere-leaf flux shows large seasonality (amplitude ∼400 PgC/yr)
- Average gross atmosphere-leaf flux > 350 PgC/yr from Hofmann et al. (2017)
- Spatial distribution of atmosphere-leaf flux for years 2010 and 2011

Spatial variation of $\Delta^{17}O$ in CO_2



- Average $\Delta^{17}O$ in CO_2 at surface for 2011
- Confirms potential of $\Delta^{17}O$ in CO_2 as tracer of GPP

Project overview

- Summary

  - Stratospheric source of $\Delta^{17}O$ based on N_2O- $\Delta^{17}O$ correlation

  - Vegetation model allows for explicit calculation of atmosphere-leaf flux

  - Spatial pattern of $\Delta^{17}O$ at surface confirms its potential as tracer of GPP

- Future work

  - Compare gross STE fluxes (Appenzeller et al. ,1996; van Noije et al., 2004)

  - Improve soil invasion model (e.g. scaling hydrogen deposition maps)

  - Incorporate production of $\Delta^{17}O$ in CO_2 from tropospheric chemistry

  - Perform sensitivity tests and runs at higher resolution

References

Appenzeller et al., Seasonal variation of mass transport across the tropopause, *Journal of Geophysical Research: Atmospheres*, 1996.

Bergamaschi et al., Top-down estimates of European CH_4 and N_2O emissions based on four different inverse models, *Atmospheric Chemistry and Physics*, 2015.

Boering et al., Observations of the anomalous oxygen isotopic composition of carbon dioxide in the lower stratosphere and the flux of the anomaly to the troposphere, *Geophysical Research Letters*, 2004.

Hofmann et al., Atmospheric measurements of $\Delta^{17}O$ in CO_2 in Göttingen, Germany reveal a seasonal cycle driven by biospheric uptake, *Geochimica et Cosmochimica Acta*, 2017.

Kawagucci et al., Long-term observation of mass-independent oxygen isotope anomaly in stratospheric CO_2, *Atmospheric Chemistry and Physics*, 2008.

Thiemens et al., Carbon Dioxide and Oxygen Isotope Anomalies in the Mesosphere and Stratosphere, *Science*, 1995.

van Noije et al., Implications of the enhanced Brewer-Dobson circulation in European Centre for Medium-Range Weather Forecasts reanalysis ERA-40 for the stratosphere-troposphere exchange of ozone in global chemistry transport models, *Journal of Geophysical Research*, 2004.

Wiegel et al., Unexpected variations in the triple oxygen isotope composition of stratospheric carbon dioxide, *Proceedings of the National Academy of Sciences*, 2013.