Explicit modelling of water isotopes within ECHAM5/MPI-OM

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contributions by:
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V. Masson-Delmotte, J, Sjolte, C. Sturm, S. Jasechko, J. Jouzel, and many others
Water isotope-enhanced climate models

A general circulation model of water isotope cycles in the atmosphere

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<table>
<thead>
<tr>
<th>Model</th>
<th>Institute</th>
<th>References</th>
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<tr>
<td>atmosphere model CAM3</td>
<td>U. Colorado</td>
<td>Noone et al., w.i.p.</td>
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<td>CAM2</td>
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<td>Lee et al. (2007)</td>
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<td>Risi et al., submitted</td>
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<td>MIROC3.2</td>
<td>JAMSTEC-Yokosuka</td>
<td>Kurita et al. (2005)</td>
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(table from: Sturm and Noone, 2010)
Explicit modelling of water isotopes in the hydrological cycle

No isotope records (ice cores etc.) are used within the model!
Water isotopes within ECHAM5/MPI-OM

- atmosphere model: ECHAM5
- atmosphere + terrestrial biosphere: ECHAM5/JSBACH
- ocean model: MPIOM
Water isotopes within ECHAM5/MPI-OM

- isotope fluxes of different components have been successfully coupled
- model has been evaluated for present-day climate
- paleoclimate simulations have been performed for various time slices
Isotopes in the atmosphere - ECHAM5-wiso

atmosphere model

ECHAM5-wiso
Werner et al., 2011

or

ECHAM5/JSBACH-wiso
Haese et al., 2013

+

MPIOM-wiso
Xu et al., 2012

atmosphere+
terrestrial biosphere

ocean model
results in a more realistic representation of the isotopic composition of precipitation on a continental or even smaller spatial scale. As an example, the different ECHAM5-wiso simulations result in a global pattern of precipitation that is more realistic than simulations with coarser resolutions.

The RMSE between the observed GNIP mean annual 18Op values and the simulated 18Op values slightly increases with a higher spatial resolution. For the T31L19 resolution, the simulated 18Op values benefit more from the finer grid, as compared to the simulations with the coarse T106L31 resolution. However, in very dry desert regions, such as the Sahara, the Taklamakan, and central Australia, the wiso results appear robust and do not depend on the chosen model resolution. When comparing the simulated 18Op pattern with the observed data, at least 5 years of measurements are required to calculate a meaningful correlation coefficient. The correlation coefficients are significant (p < 0.05) for all 9 low-latitude GNIP stations with an annual mean temperature equal or above 20°C and the four ECHAM5-wiso experiments (Table 2).

The correlation coefficient for these GNIP stations is 0.46 ± 0.07, which is similar in all four ECHAM5-wiso experiments. Figure 3, bottom shows that the RMSE for the global 18Op pattern is rather small (Figure 1, bottom). While there is a significant relationship at the global scale (Figure 1, bottom), the relationship at the local scale is not as strong. The correlation coefficient for the 9 GNIP stations is 0.67, which is similar in all four ECHAM5-wiso experiments.
ECHAM5-wiso: How important is model resolution?

### Table: Model resolution and vertical levels

<table>
<thead>
<tr>
<th>Model</th>
<th>Horizontal Grid Size</th>
<th>Vertical Levels</th>
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</thead>
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<td>T31L19</td>
<td>3.8° x 3.8°</td>
<td>19</td>
</tr>
<tr>
<td>T63L19</td>
<td>1.9° x 1.9°</td>
<td>19</td>
</tr>
<tr>
<td>T63L31</td>
<td>1.9° x 1.9°</td>
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</tr>
<tr>
<td>T106L31</td>
<td>1.1° x 1.1°</td>
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</tr>
<tr>
<td>T159L31</td>
<td>0.8° x 0.8°</td>
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*Werner et al., JGR, 2011; Langebroek et al., EPSL, 2011*
ECHAM5-wiso: How important is model resolution?

**Diagram Description**

The diagram shows a comparison of simulated isotopic processes during the formation of ice crystals at very low temperatures in different resolution models for Antarctica.

- **Map:** A color-coded map of Antarctica with contour lines indicating the spatial distribution of water isotope values. The color bar ranges from -400 to 100 in parts per thousand (‰) for δD_p.

- **Graphs:**
  - **a) T31L19**
  - **b) T63L19**
  - **c) T63L31**
  - **d) T159L31**

  Each graph plots δD_p (‰) against Tsurf (°C), showing the relationship between surface temperature and precipitation δD_p in various model simulations.

- **Table:**

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**References:**

Isotopes in the land biosphere - ECHAM5/JSBACH-wiso

- Atmosphere model
  - ECHAM5-wiso
    - Werner et al., 2011
  - or
  - ECHAM5/JSBACH-wiso
    - Haese et al., 2013
  - +

- Atmosphere + terrestrial biosphere
  - MPIOM-wiso
    - Xu et al., 2017

- Ocean model
How important are land surface processes?

(i) Impact of fractionation during evaporation on $\delta^{18}O$ changes

(ii) Impact of fractionation during evaporation + transpiration on $\delta^{18}O$ changes

*Fig. 1. The path of oxygen atoms of water into the plant and typical $\delta^{18}O$ values (versus SMOW). The indicated values of $\delta^{18}O$ in precipitation and shallow soil water are representative for summer in Switzerland, the values for ground water, water vapour, leaf water and glucose are estimated according to the theory in Section 2, and the value for cellulose is the mean of our data for beech trees.*
How important are land surface processes?

ECHAM5/JSBACH

LPX-Bern

(a)

(b)

Leaf water δ¹⁸O (‰)

Water vapor δ¹⁸O (‰)

Soil water δ¹⁸O (‰)

Leaf water-soil water δ¹⁸O (‰)

Stem cellulose δ¹⁸O (‰)

Keel et al., Biogeosciences, 2016
Isotopes in the ocean - MPIOM-wiso

atmosphere model

ECHAM5-wiso
Werner et al., 2011

or

ECHAM5/JSBACH-wiso
Haese et al., 2013

+ ocean model

MPIOM-wiso
Xu et al., 2012

corresponding terrestrial biosphere
errors (NRMSE) are 8.3% and 9.4%, respectively. We find enriched values in North Atlantic and relatively depleted areas. The spatial structures of $\delta^{18}O$ and $\delta D$ in ocean surface waters as simulated by MPI-OM are similar to the available observations (Figs. 2b and 3b). Both model results and observational data show strongly depleted values in the Southern Ocean. The 1:1 line is colored in red.

Comparison of observed water isotopic values (averaged onto the MPIOM model grid) versus modelled surface isotopic values. The correlation coefficients ($R$) are 0.75 and 0.96 for $\delta^{18}O$ and $\delta D$ respectively, where evaporation is the dominating influence on the isotopic composition of seawater. The distributions are distinctly different from the surface and more homogeneous.

The meridional sections of $\delta^{18}O$ and $\delta D$ simulated by MPI-OM are similar to the available observations (Figs. 2b and 3b). Analyses of the correspondence between simulated and observed fields indicate a good agreement between these two fields. The correlation coefficients ($R$) are 0.75 and 0.96 for $\delta^{18}O$ and $\delta D$ respectively. We find enriched values in North Atlantic and relatively depleted areas ($\delta^{18}O < 5 \text{‰}$, $\delta D < 20 \text{‰}$) in coastal regions with continental river discharge. For a more quantitative model-data comparison, we average all observations within a specific grid cell and compare the mean value with the corresponding MPI-OM result (Fig. 4). Analyses of the correspondence between simulated and observed fields indicate a good agreement between these two fields. The correlation coefficients ($R$) are 0.75 and 0.96 for $\delta^{18}O$ and $\delta D$ respectively.
Water isotopes within ECHAM5/MPI-OM

atmosphere model

- ECHAM5-wiso
  - Werner et al., 2011

or

atmosphere + terrestrial biosphere

- ECHAM5/JSBACH-wiso
  - Haese et al., 2013

+ 

ocean model

- MPIOM-wiso
  - Xu et al., 2012
Water isotopes within ECHAM5/MPI-OM

atmosphere model
ECHAM5-wiso

ocean model
MPIOM-wiso

15M
Late Miocene

130-120K
Last Interglacial

„H#“

21K
LGM

6K
Holocene

4K

2K
PI/present-day

„Heinrich event“

fully-coupled atmosphere-ocean model
ECHAM5/MPIOM-wiso
The last millennium - changes of water isotopes in precipitation

- Model setup
  - Isotope enabled Earth System Model (ESM) – Werner et al. (2016 GMD)
  - The model includes isotope fractionation in the atmosphere and at the surface-atmosphere boundary
    - Three different kinds of water: H$_2$O, H$_2$O$^{18}$, HD
- Model setup
  - Natural and anthropogenic forcings
  - Time period AD 800-2000
- Similar to CMIP5 'past1000' model ensemble (CMIP5, Taylor et al., 2012)
- Results: global mean T2m
  - General climate similar to simulations of Jungclaus et al. – COSMOS E1 Jungclaus et al. (2010) – COSMOS-wiso Sjolte et al. (unpub.)

Last Millennium simulation (by Jesper Sjolte, Lund University):
- fully-coupled setup (COSMOS=ECHAM5/MPI-OM-wiso)
- natural and anthropogenic forcing
  (identical to COSMOS simulations by Jungclaus et al., CP, 2010)
- solar forcing: updated $^{14}$C-based reconstruction by Raimund Musheler
- time period: AD 800-200
The last millennium - changes of water isotopes in precipitation

- $\delta^{18}O$ in precipitation follows temperature changes on millennial time scale (linear relation constant?)
- Temporal variations of NH land $\delta^{18}O$: $\sim 0.15\%$o
- Temporal T-$\delta^{18}O$-gradient (0.2-0.3\%/K) is much smaller than present-day spatial gradient
- Regional $\delta^{18}O$ variations (5-year means) of up to $\pm 3\%$o are simulated

(all values: 31-yrs running mean)
The last millennium - correlation of $\delta^{18}O$, $T_{2m}$ and precip

- millennium run reveals areas of strong correlation between $\delta^{18}O$ in precipitation with surface temperature and precipitation amount

- model results indicate that in most regions $\delta^{18}O$ will be controlled by both $T_{2m}$ and precip


