ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

Explicit modelling of water isotopes within ECHAM5/MPI-OM

M. Werner, AWI Bremerhaven

contributions by:
G. Lohmann, P. Gierz, B. Haese, P. Langebroek, X. Xu, X. Zhang, G. Knorr,
V. Masson-Delmotte, J, Sjolte, C. Sturm, S. Jasechko, J. Jouzel, and many others

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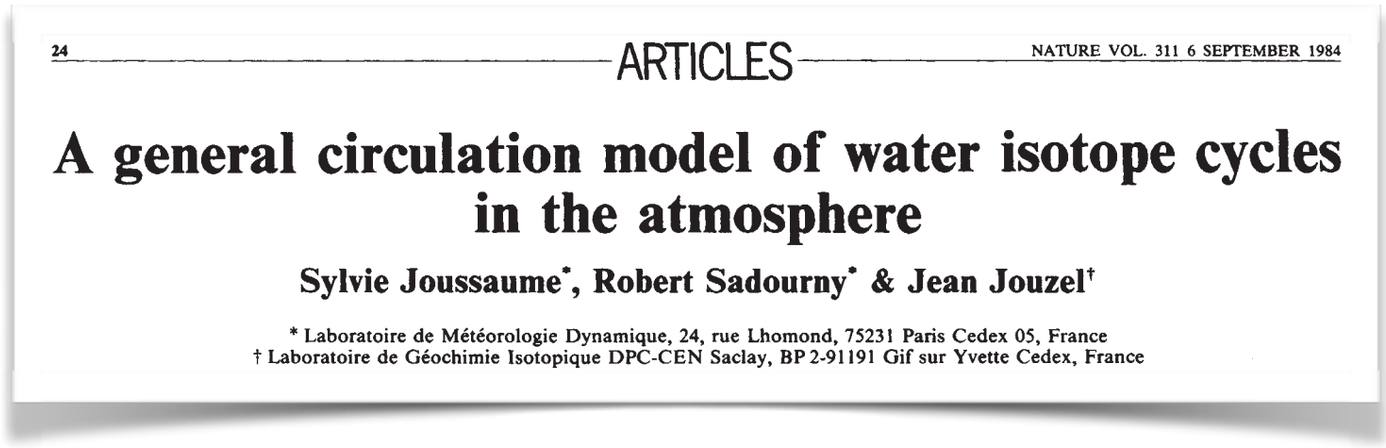
Water isotope-enhanced climate models



24 ARTICLES NATURE VOL. 311 6 SEPTEMBER 1984

A general circulation model of water isotope cycles in the atmosphere

Sylvie Joussaume*, Robert Sadourny* & Jean Jouzel†

* Laboratoire de Météorologie Dynamique, 24, rue Lhomond, 75231 Paris Cedex 05, France
† Laboratoire de Géochimie Isotopique DPC-CEN Saclay, BP 2-91191 Gif sur Yvette Cedex, France

	Model	Institute	References
atmosphere model	CAM3	U. Colorado	Noone et al., w.i.p.
	CAM2	UC Berkeley	Lee et al. (2007)
atmosphere model	ECHAM5	AWI-Bremerhaven	Werner et al., w.i.p.
	ECHAM4	MPI-Hamburg	Hoffmann et al. (1998)
atmosphere model	LMDZ4	LMD-Paris	Risi et al., submitted
atmosphere model	MIROC3.2	JAMSTEC-Yokosuka	Kurita et al. (2005)
atmosphere model	GSM	Scripps-San Diego	Yoshimura et al. (2008)
fully coupled	GISS-E	GISS-New York	Schmidt et al. (2007)
	GENESIS	Penn U.	Mathieu et al. (2002)
	ACCESS	ANSTO-Sydney	Fischer et al., w.i.p.
fully coupled	HadCM3	U. Bristol	Tindall et al. (2009)
atmosphere model	HadAM3	BAS-Cambridge	Sime et al. (2008)
fully coupled	**MPI-ESM**	**AWI**	
fully coupled	**CESM**	**NCAR, U. Colorada**	
regional model	**REMO**	**MPI-Hamburg**	
regional model	**COSMO**	**ETH Zurich**	
intermediate complexity	**LoveClim**	**LSCE**	
intermediate complexity	**uVic**	**U. Victoria, U New South Wales**	

(table from: Sturm and Noone, 2010)

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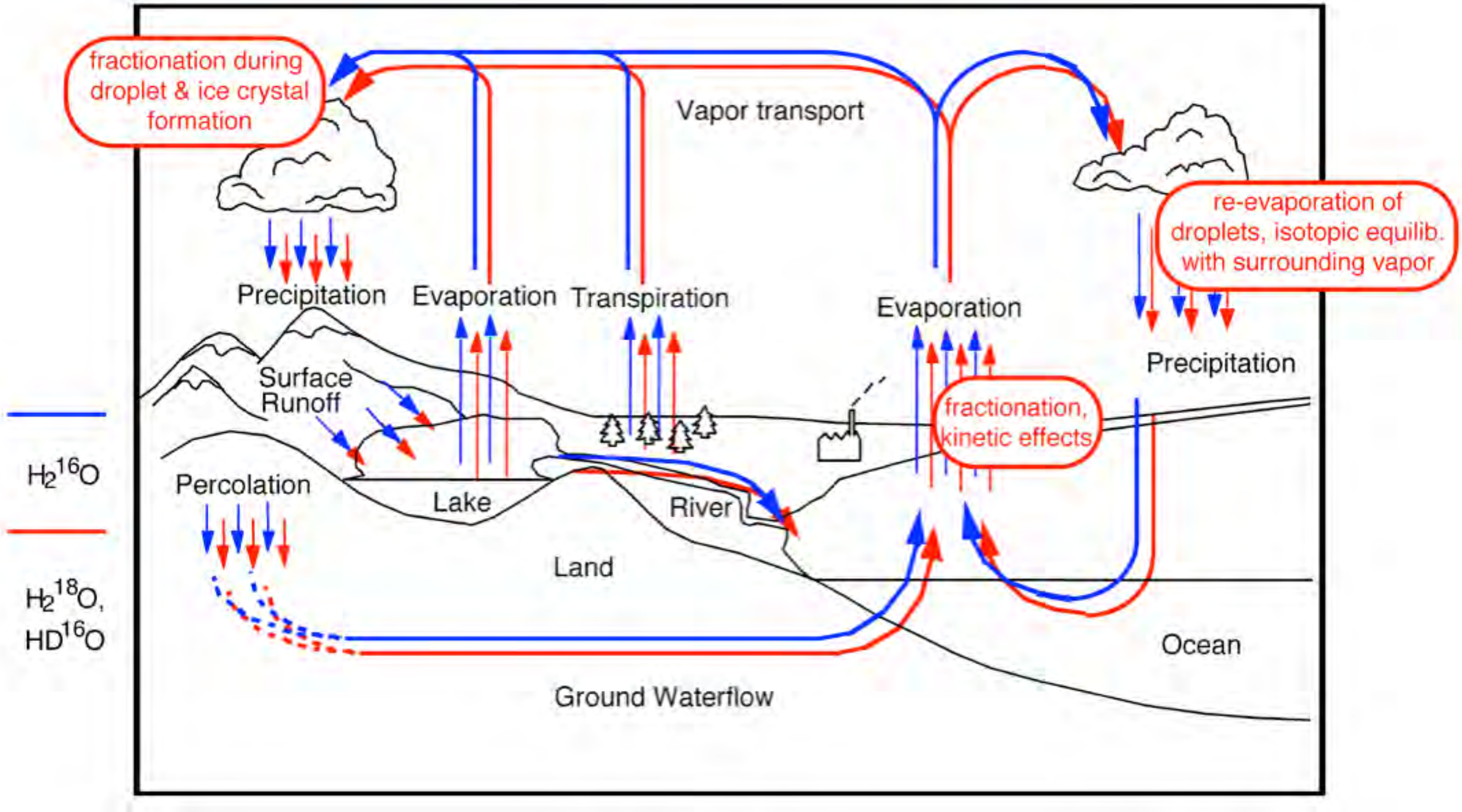
Explicit modelling of water isotopes in the hydrological cycle



No isotope records (ice cores etc.) are used within the model!

Water isotopes within ECHAM5/MPI-OM

atmosphere model

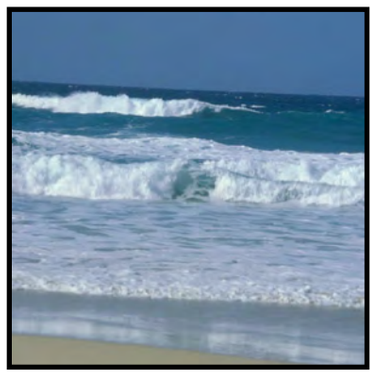
ECHAM5

atmosphere+
terrestrial biosphere

ECHAM5/JSBACH

ocean model

MPIOM



Water isotopes within ECHAM5/MPI-OM

atmosphere model

ECHAM5-wiso

Werner et al., 2011

or

atmosphere+ terrestrial biosphere

ECHAM5/JSBACH-wiso

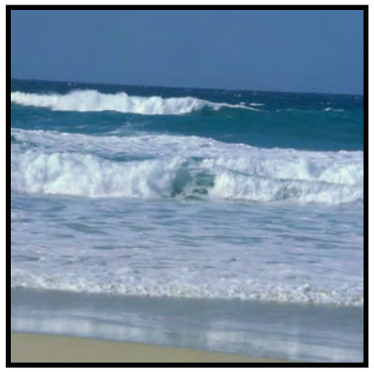
Haese et al., 2013

+

ocean model

MPIOM-wiso

Xu et al., 2012



- **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

atmosphere+
terrestrial biosphere

ECHAM5/JSBACH-wiso

Haese et al., 2013

+

ocean model

MPIOM-wiso

Xu et al., 2012

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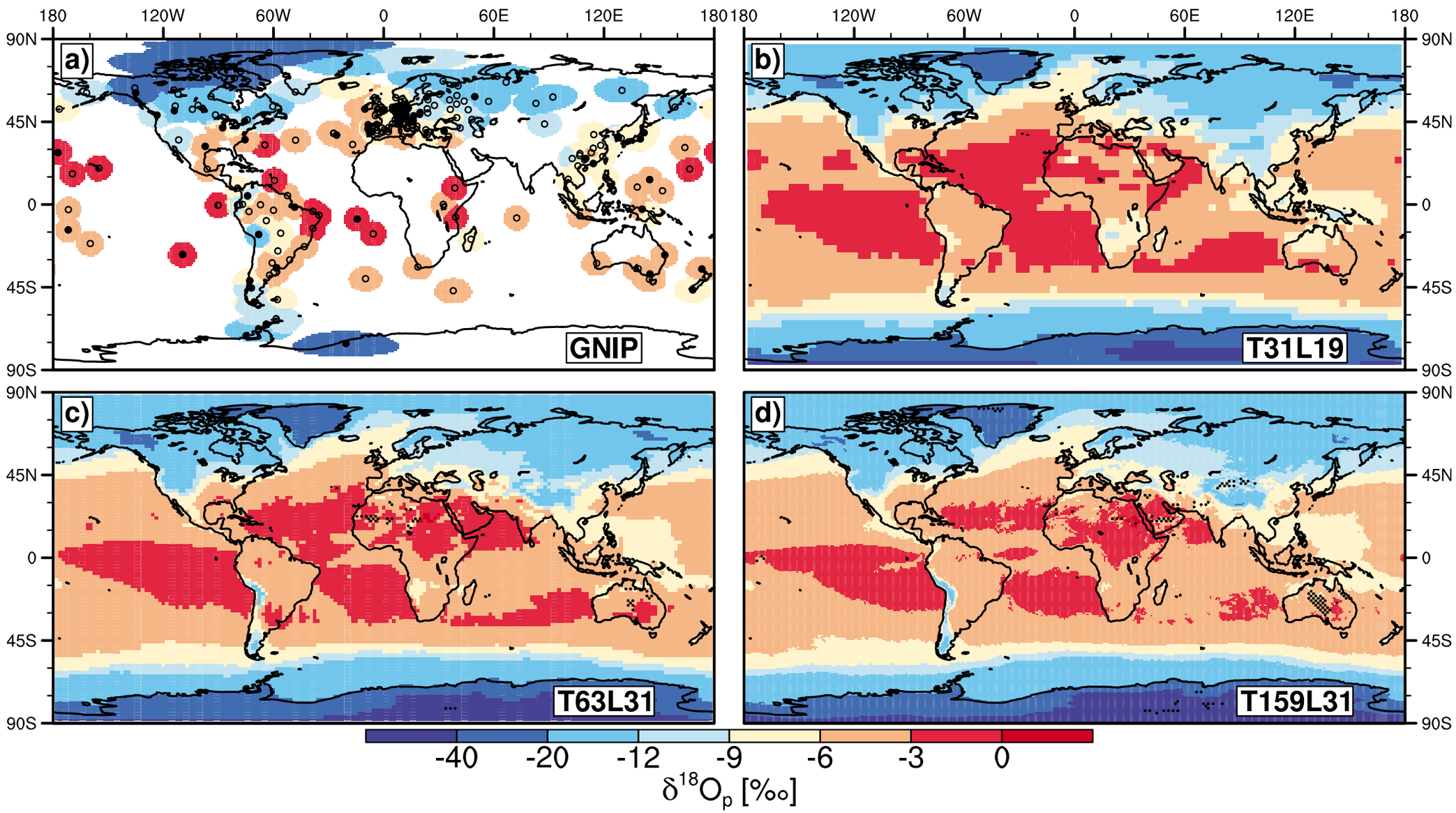
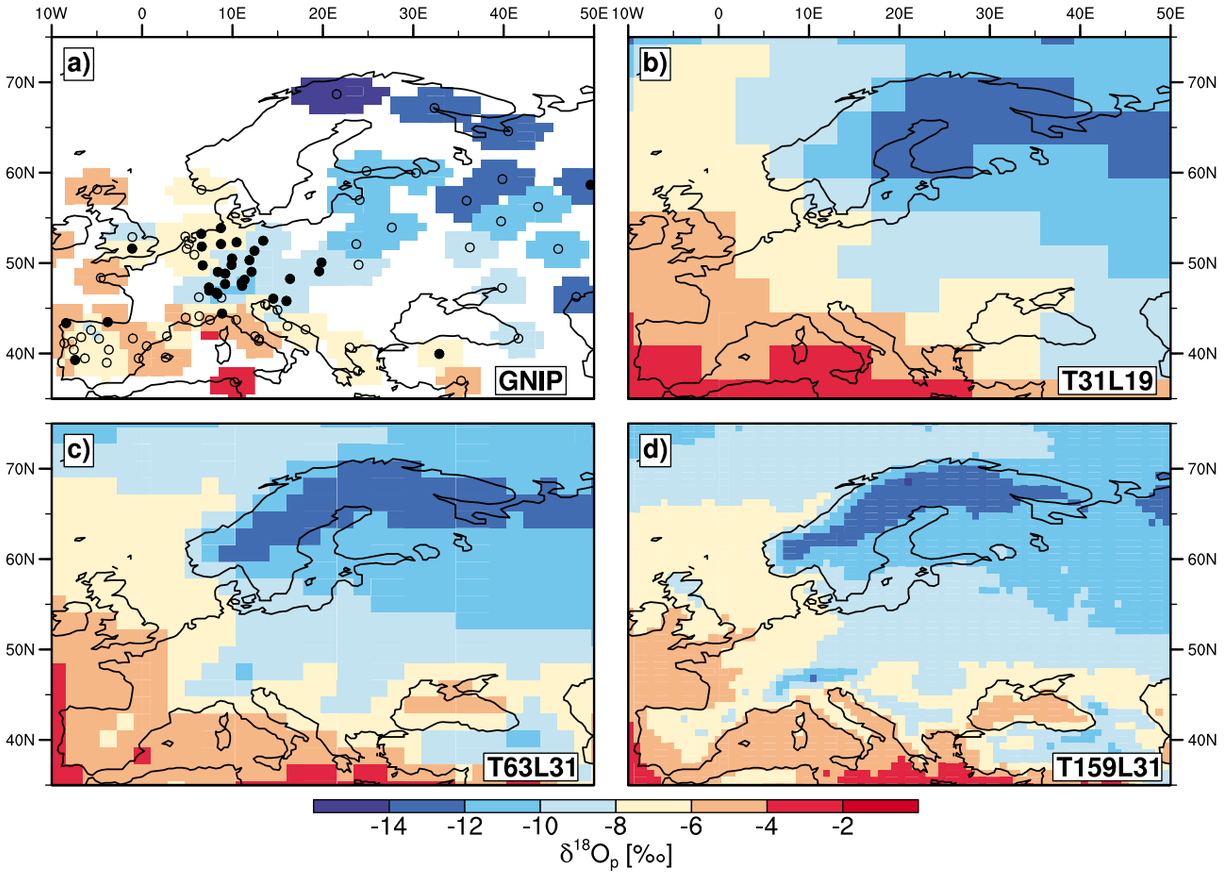
ECHAM5-wiso - present-day climate

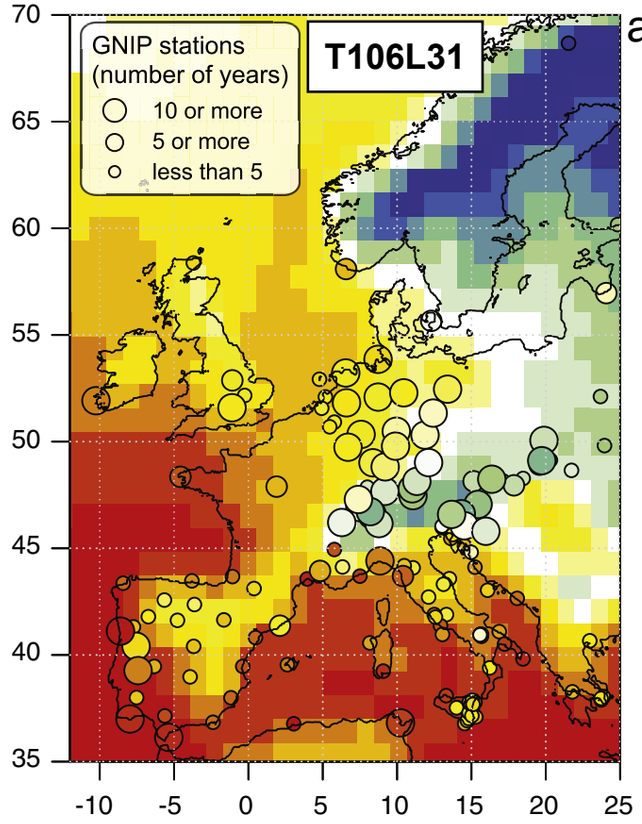


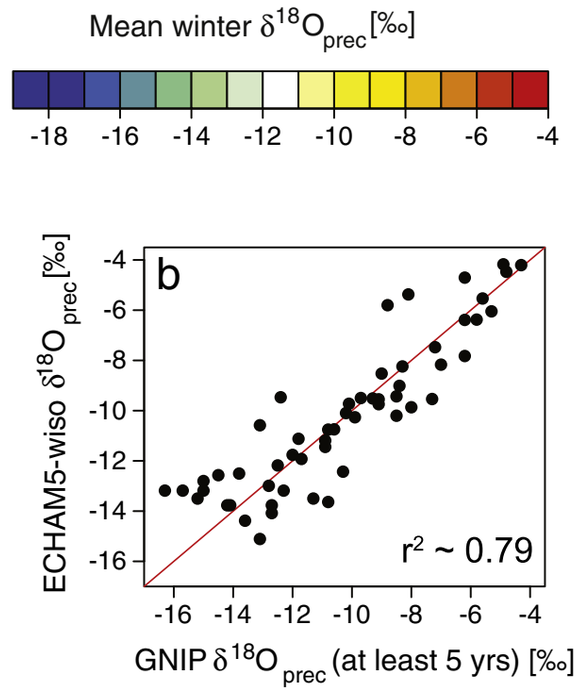
	horizontal grid size	# vertical levels
T31L19	3.75° x 3.75°	19
T63L19	1.88° x 1.88°	19
T63L31	1.88° x 1.88°	31
T106L31	1.13° x 1.13°	31
T159L31	0.75° x 0.75°	31

Werner et al., JGR, 2011

ECHAM5-wiso: How important is model resolution?



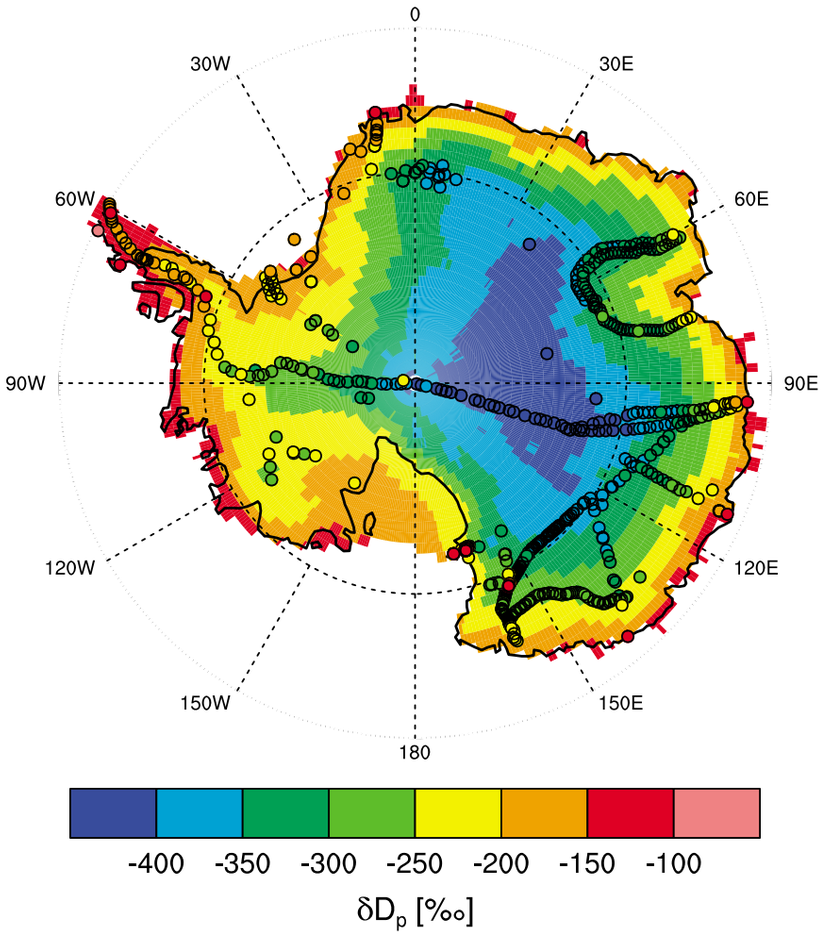


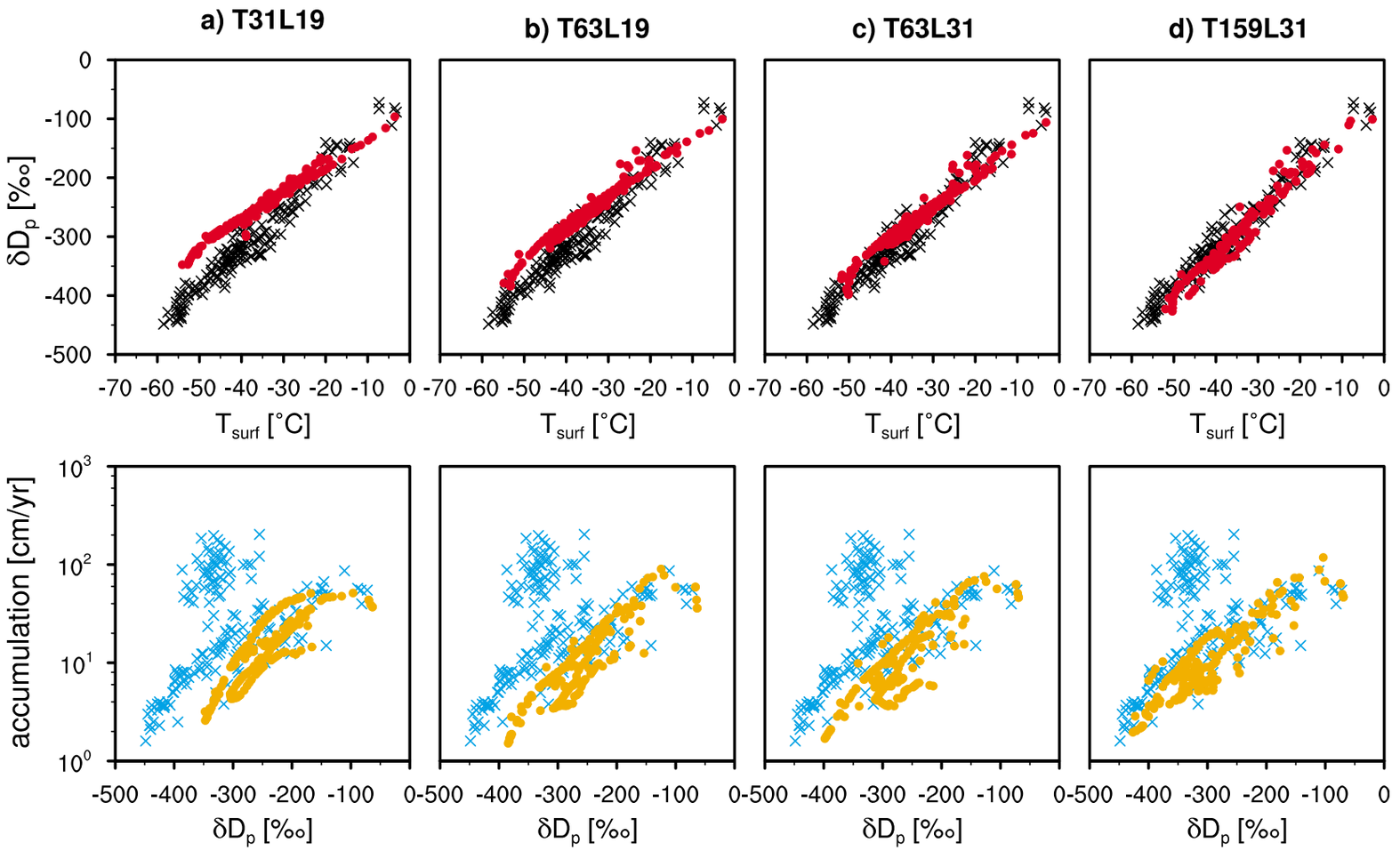


Werner et al., JGR, 2011; Langebroek et al., EPSL, 2011

	horizontal grid size	# vertical levels
T31L19	3.8° x 3.8°	19
T63L19	1.9° x 1.9°	19
T63L31	1.9° x 1.9°	31
T106L31	1.1° x 1.1°	31
T159L31	0.8° x 0.8°	31

ECHAM5-wiso: How important is model resolution?





Werner et al., JGR, 2011

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T63L31	1.9° x 1.9°	31
T106L31	1.1° x 1.1°	31
T159L31	0.8° x 0.8°	31

Isotopes in the land biosphere - ECHAM5/JSBACH-wiso

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

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How important are land surface processes?

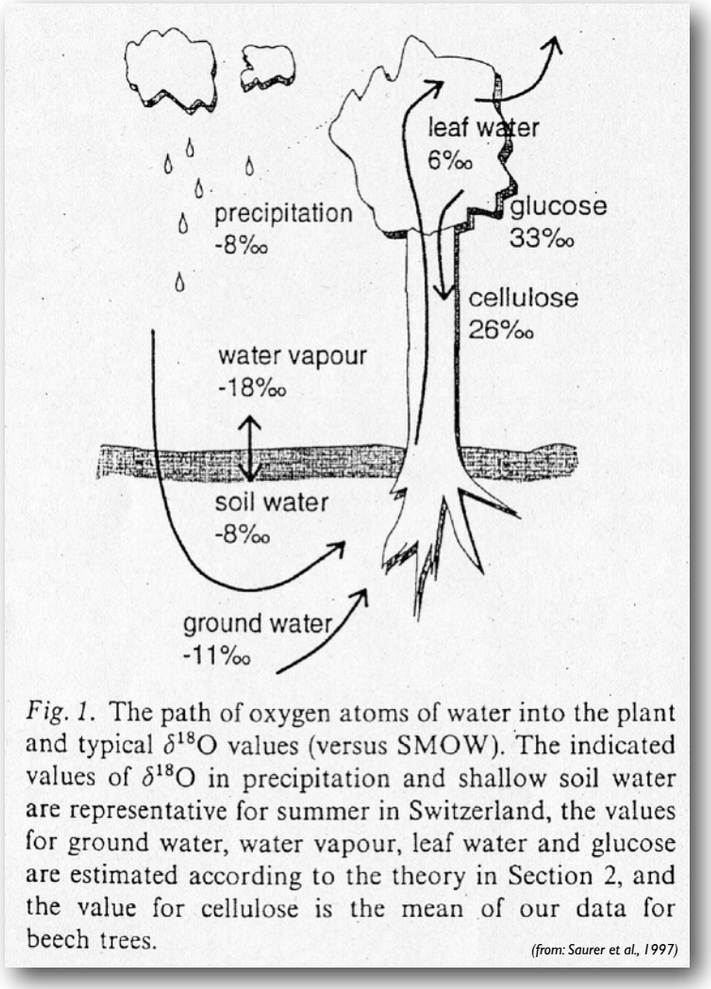
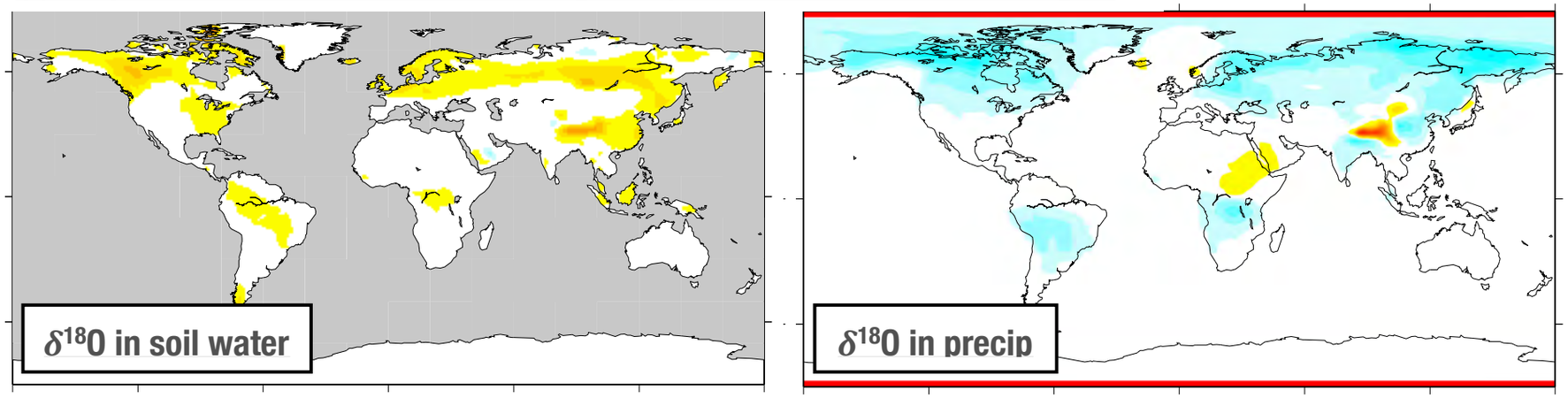


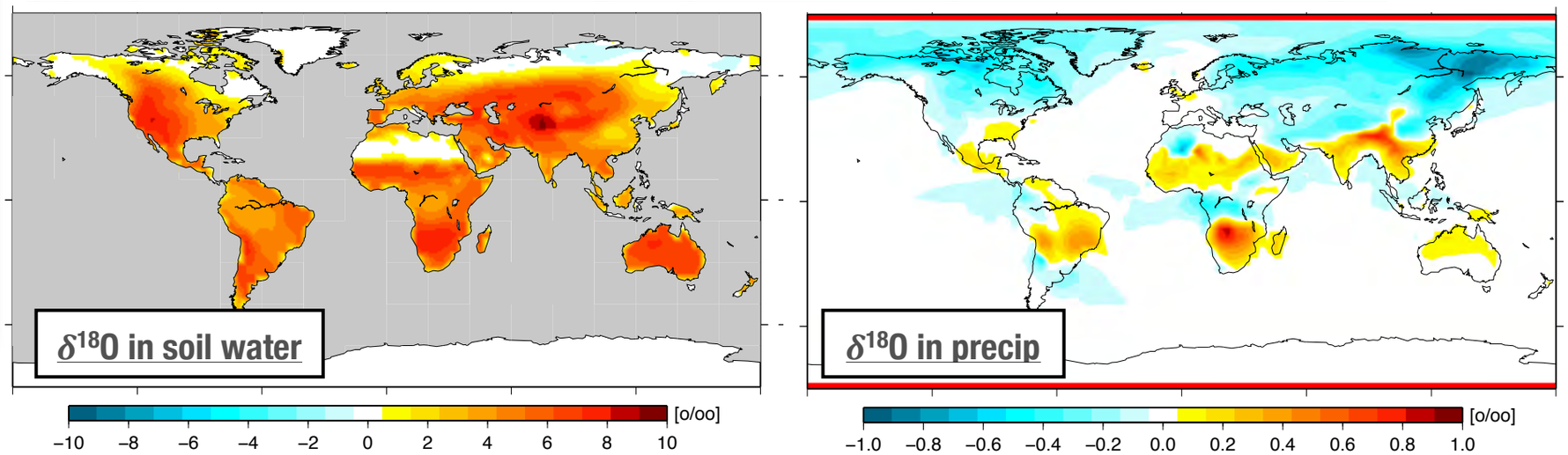
Fig. 1. The path of oxygen atoms of water into the plant and typical $\delta^{18}O$ values (versus SMOW). The indicated values of $\delta^{18}O$ in precipitation and shallow soil water are representative for summer in Switzerland, the values for ground water, water vapour, leaf water and glucose are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

(from: Saurer et al., 1997)

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



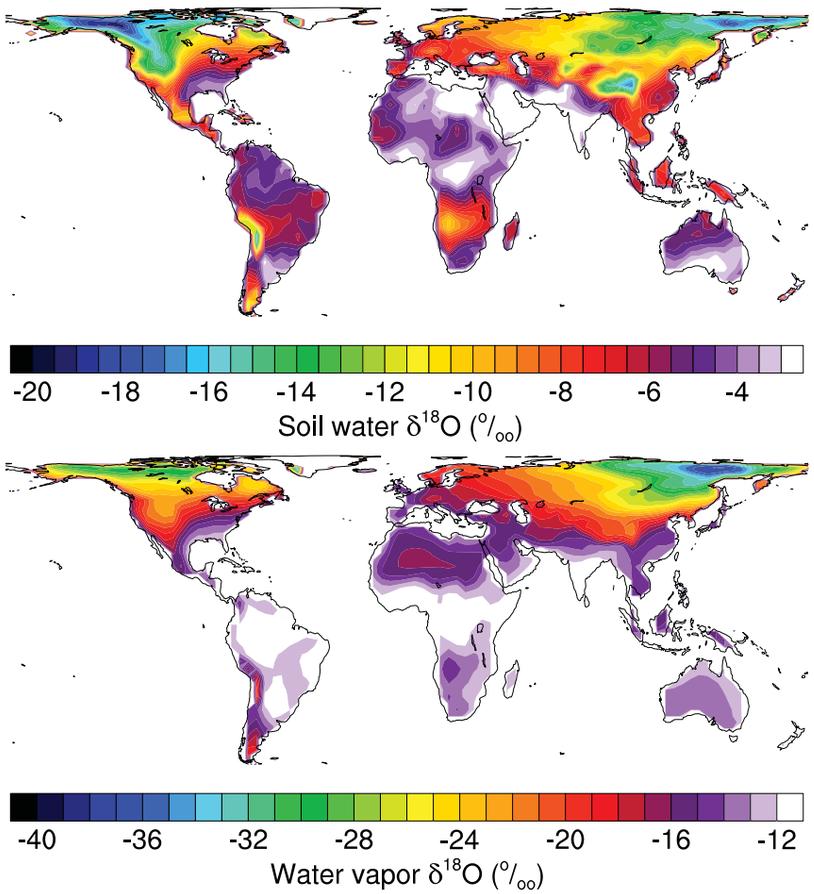
(ii) impact of fractionation during evaporation+transpiration on $\delta^{18}O$ changes



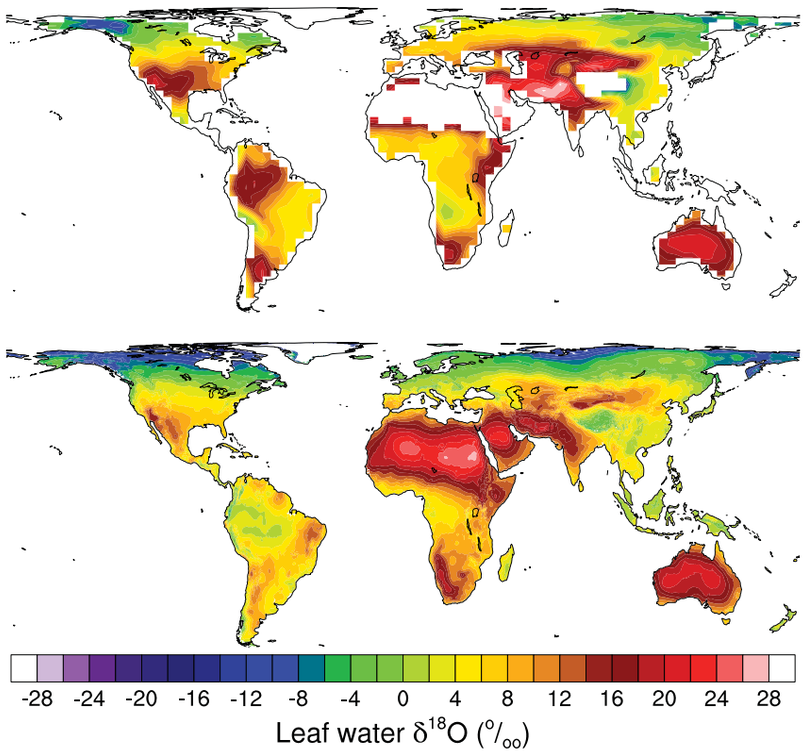
Haese et al., GMD, 2013

How important are land surface processes?

ECHAM5/JSBACH



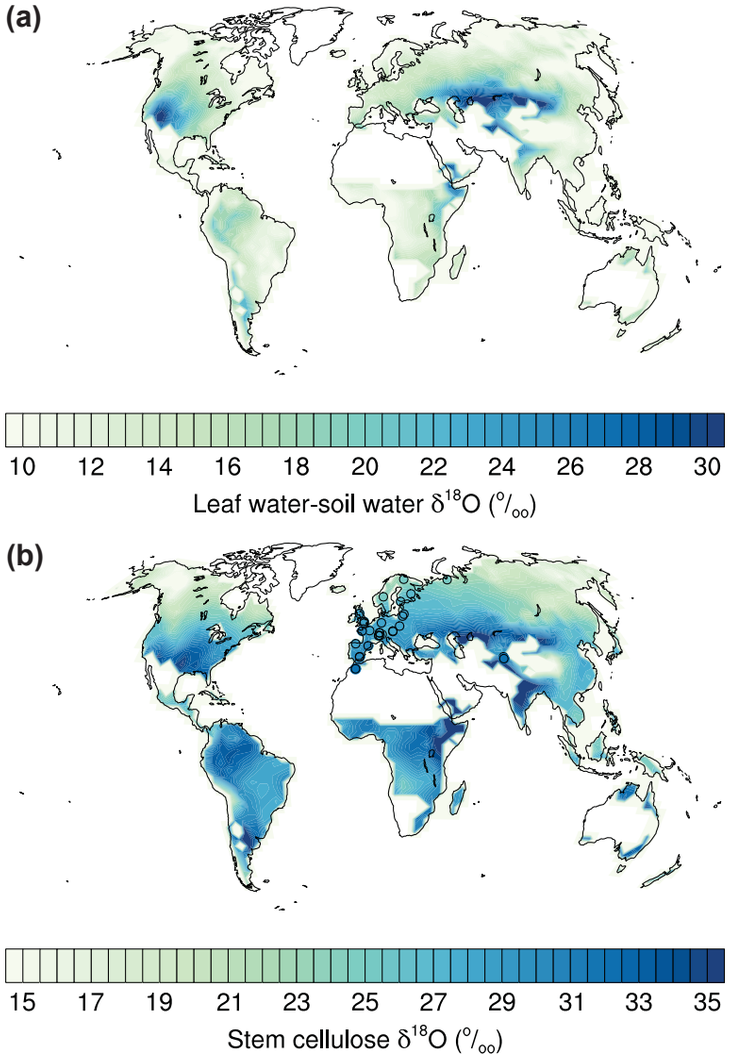
LPX-Bern



LPX-Bern

(a)

(b)



Keel et al., Biogeosciences, 2016

Isotopes in the ocean - MPIOM-wiso

atmosphere model

ECHAM5-wiso

Werner et al., 2011

or

atmosphere+
terrestrial biosphere

ECHAM5/JSBACH-wiso

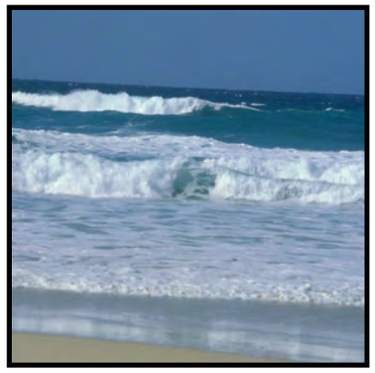
Haese et al., 2013

+

ocean model

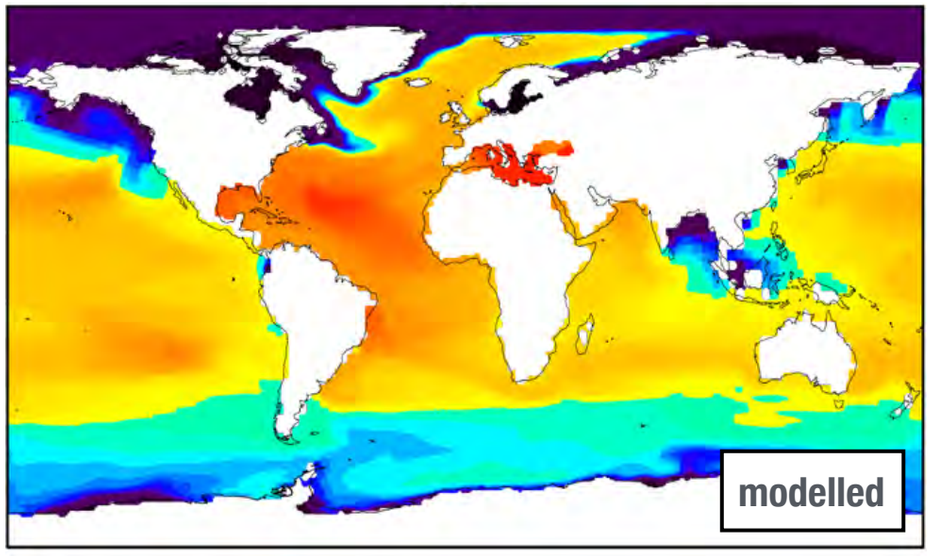
MPIOM-wiso

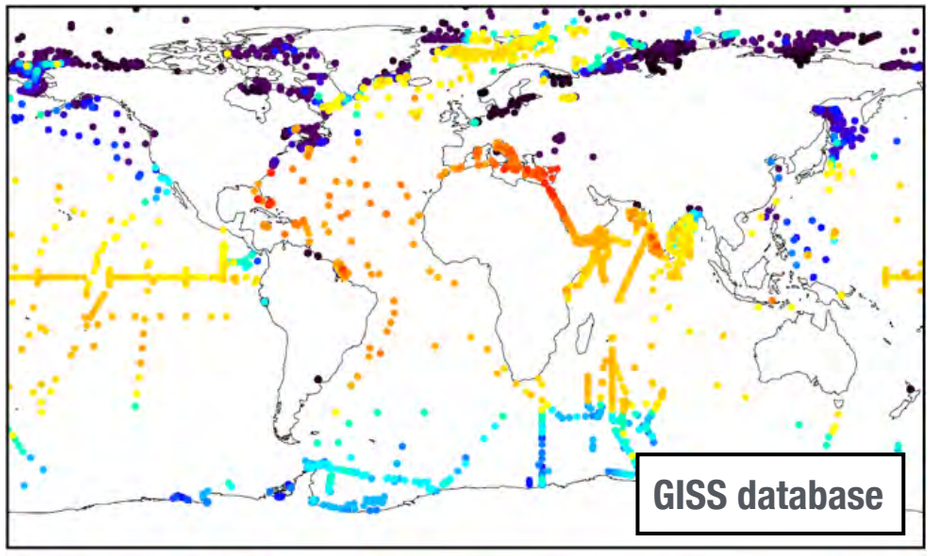
Xu et al., 2012

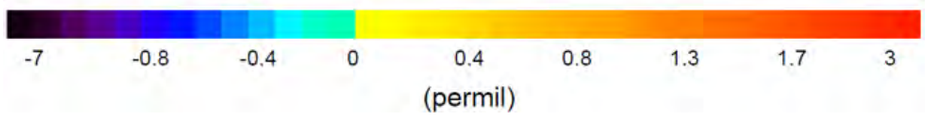


MPIOM-wiso - present-day climate

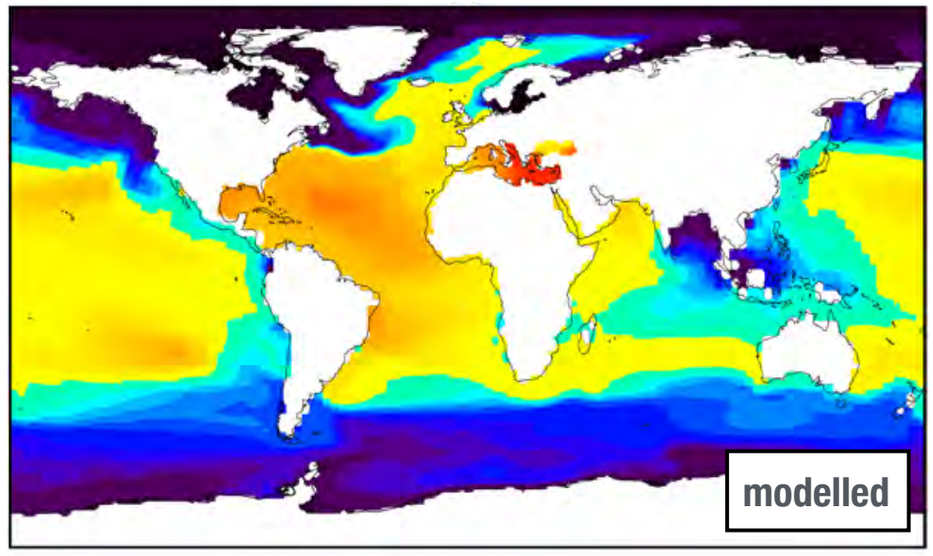
$\delta^{18}O$

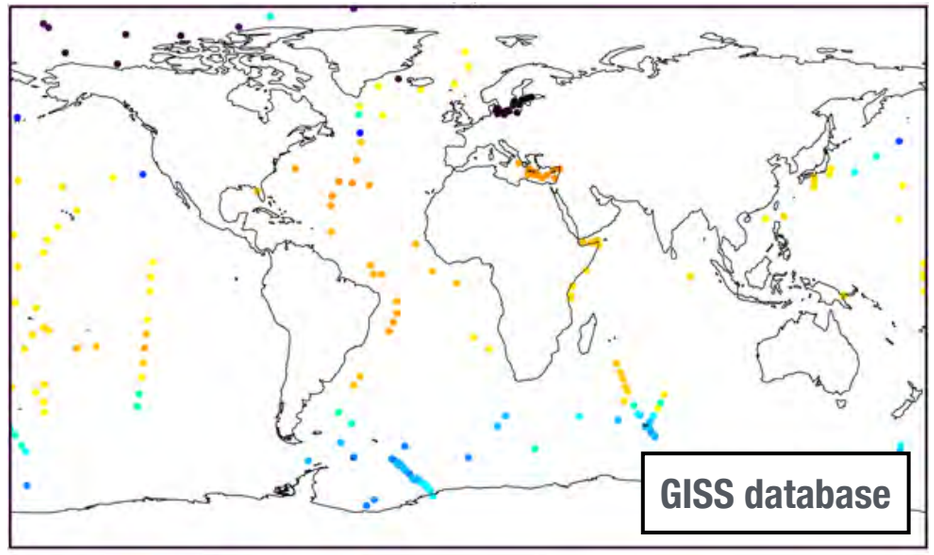


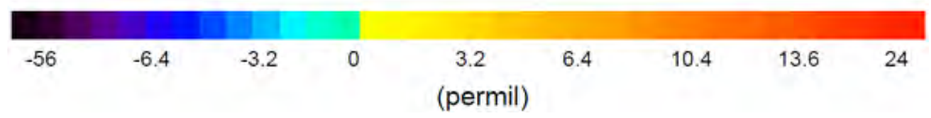




δD







Xu et al., GMD, 2012

Water isotopes within ECHAM5/MPI-OM

atmosphere model

atmosphere+
terrestrial biosphere

ocean model

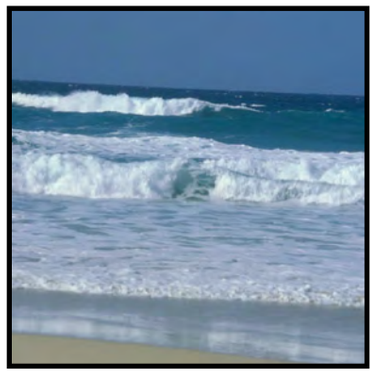
ECHAM5-wiso
Werner et al., 2011

or

ECHAM5/JSBACH-wiso
Haese et al., 2013

+

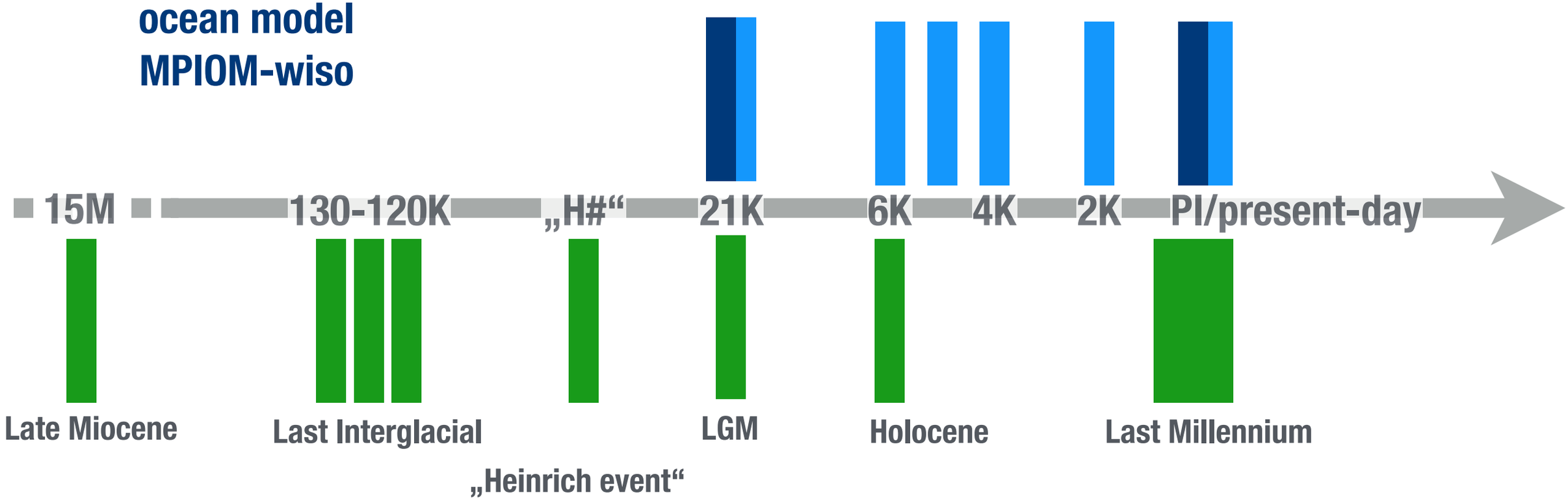
MPIOM-wiso
Xu et al., 2012



Water isotopes within ECHAM5/MPI-OM

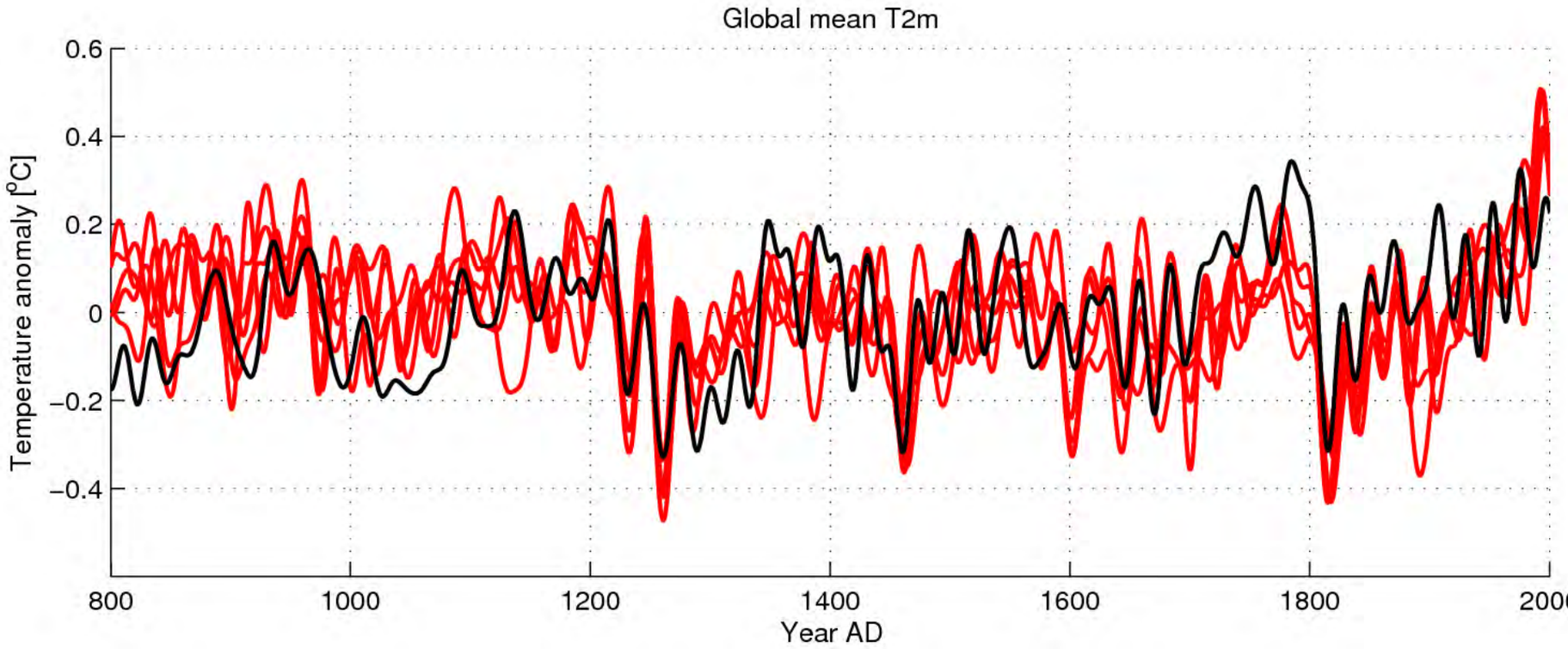
atmosphere model
ECHAM5-wiso

ocean model
MPIOM-wiso



fully-coupled atmosphere-ocean model
ECHAM5/MPIOM-wiso

The last millennium - changes of water isotopes in precipitation



– 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**

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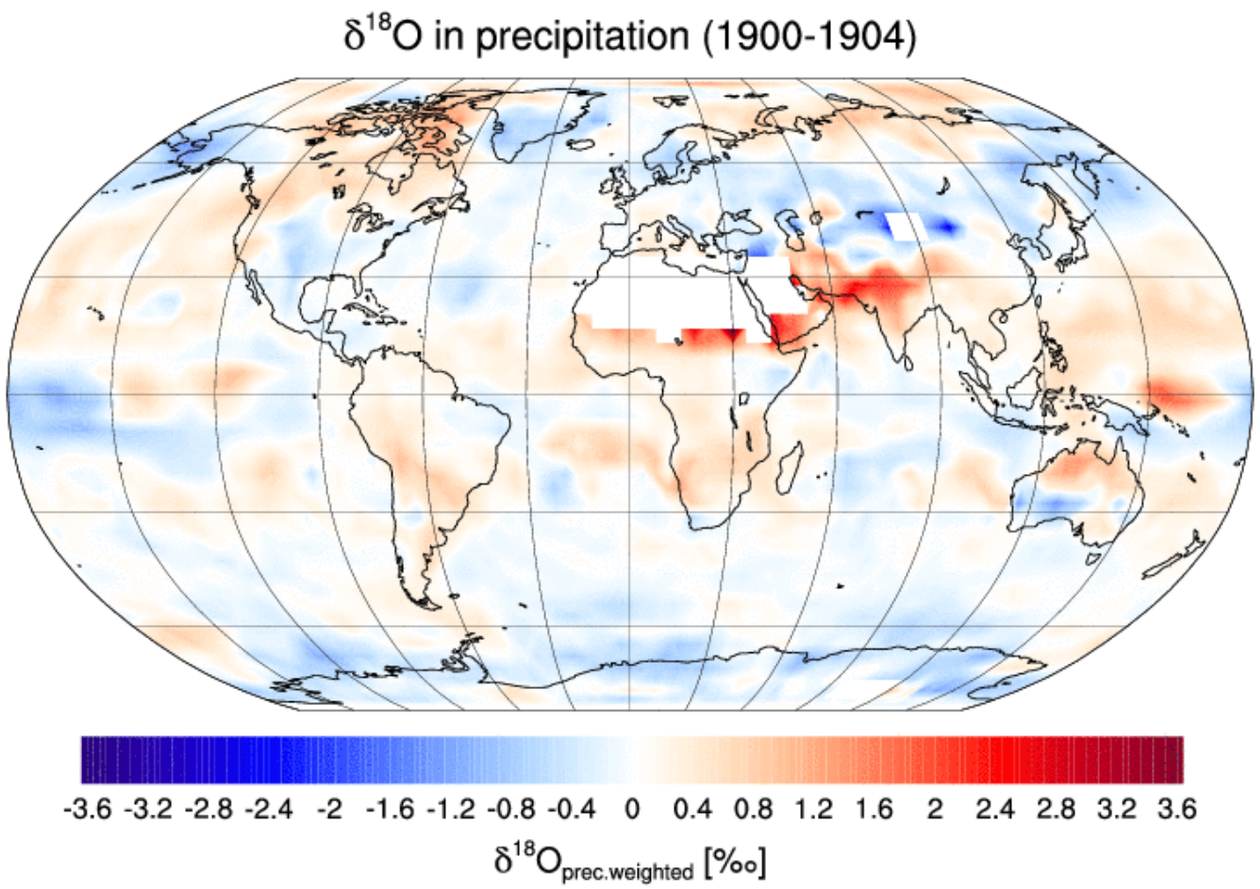
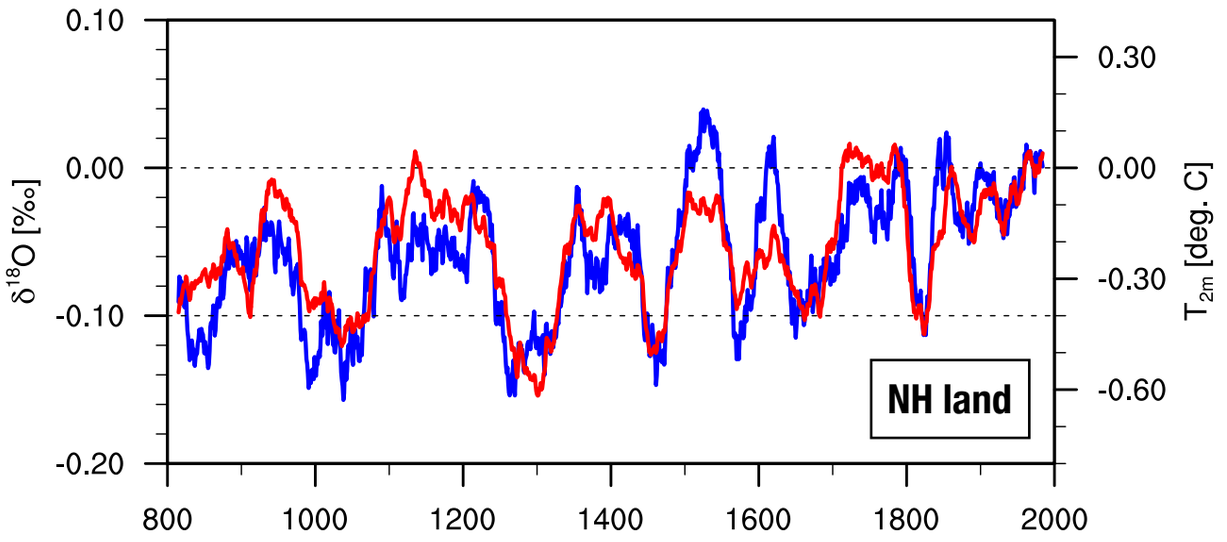
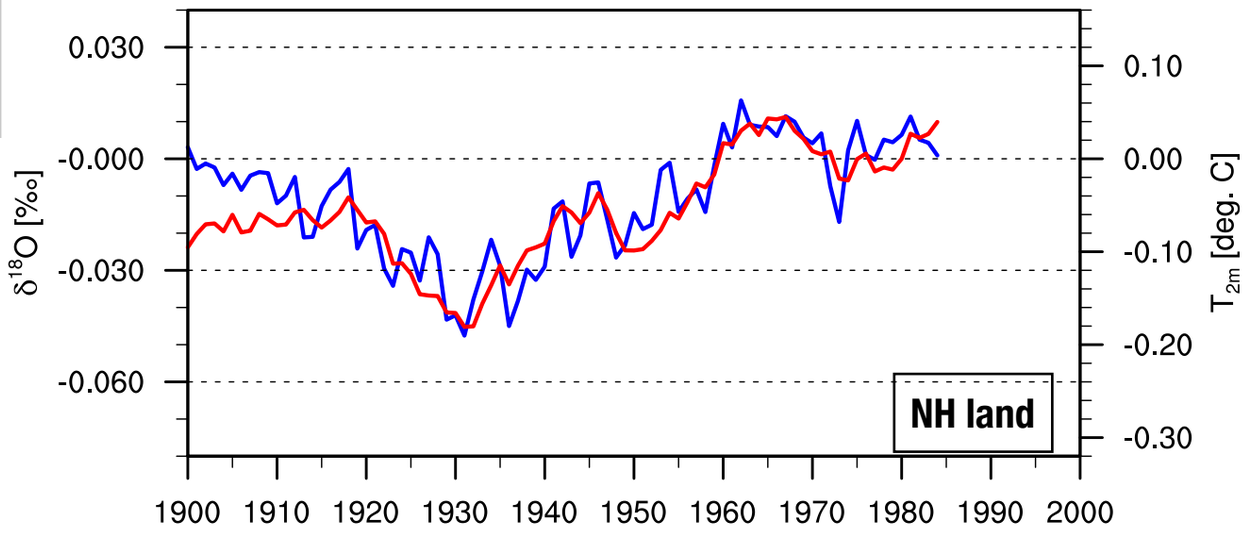
The last millennium - changes of water isotopes in precipitation





- $\delta^{18}O$ in precipitation follows temperature changes on millennial time scale (linear relation constant?)
- temporal variations of NH land $\delta^{18}O$: ~0.15‰
- 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 ±3‰ are simulated

$\delta^{18}O$ in precipitation 2m temperature



(all values: 31-yrs running mean)

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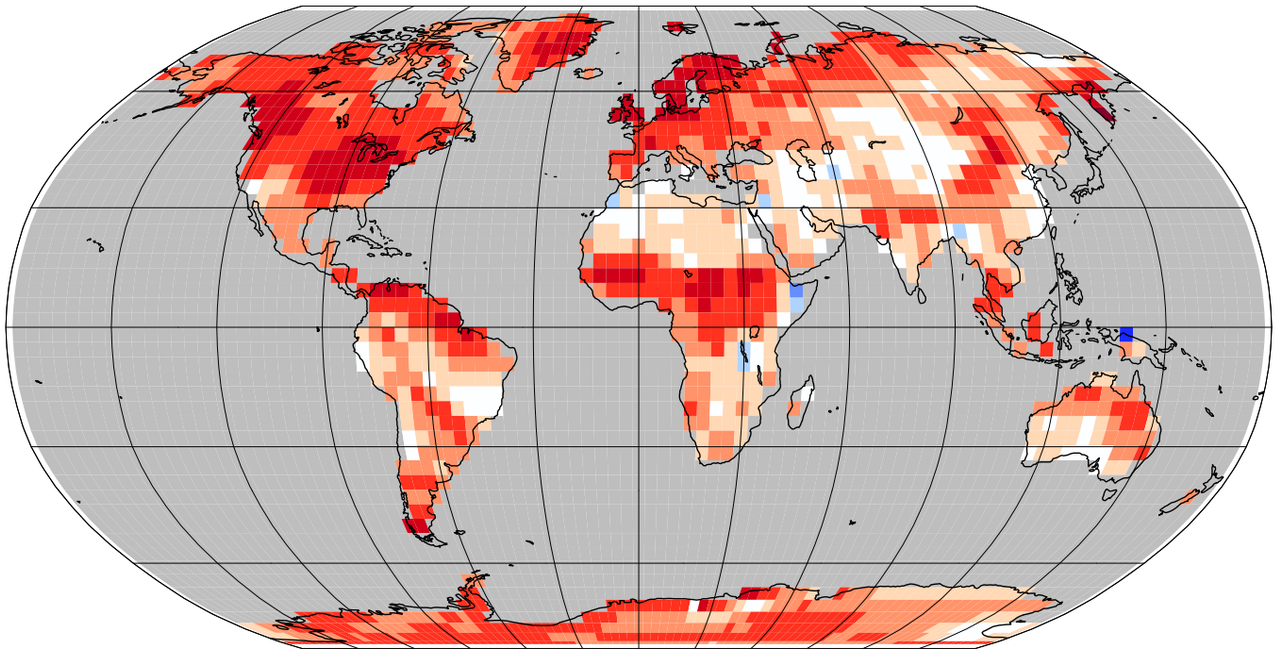
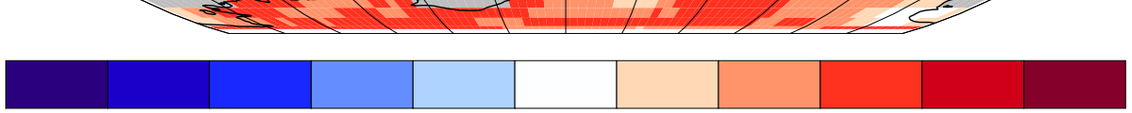
The last millennium - correlation of $\delta^{18}O$, T_{2m} and precip

Correlation: $\delta^{18}O$ and T_{2m} (AD 800-1999)

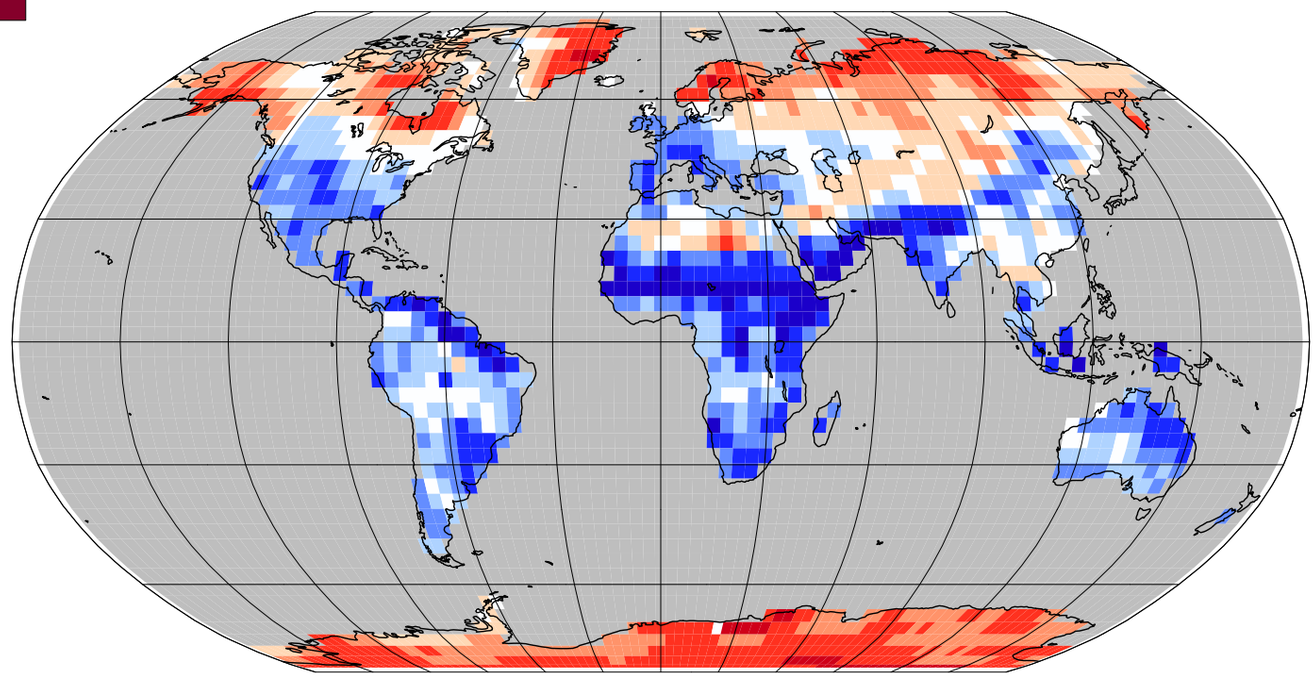


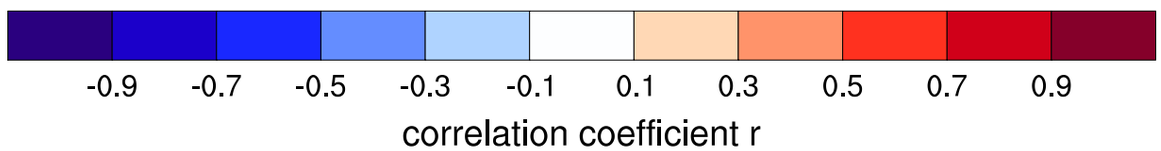


- **millennium run reveals areas of strong correlation between $\delta^{18}O$ in precipitation with surface temperature and precipitation amount**

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

Correlation: $\delta^{18}O$ and precipitation (AD 800-1999)





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