Stable Isotopes in rivers - spatial and temporal variations

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Workshop of the DFG Research Group FOR 1670

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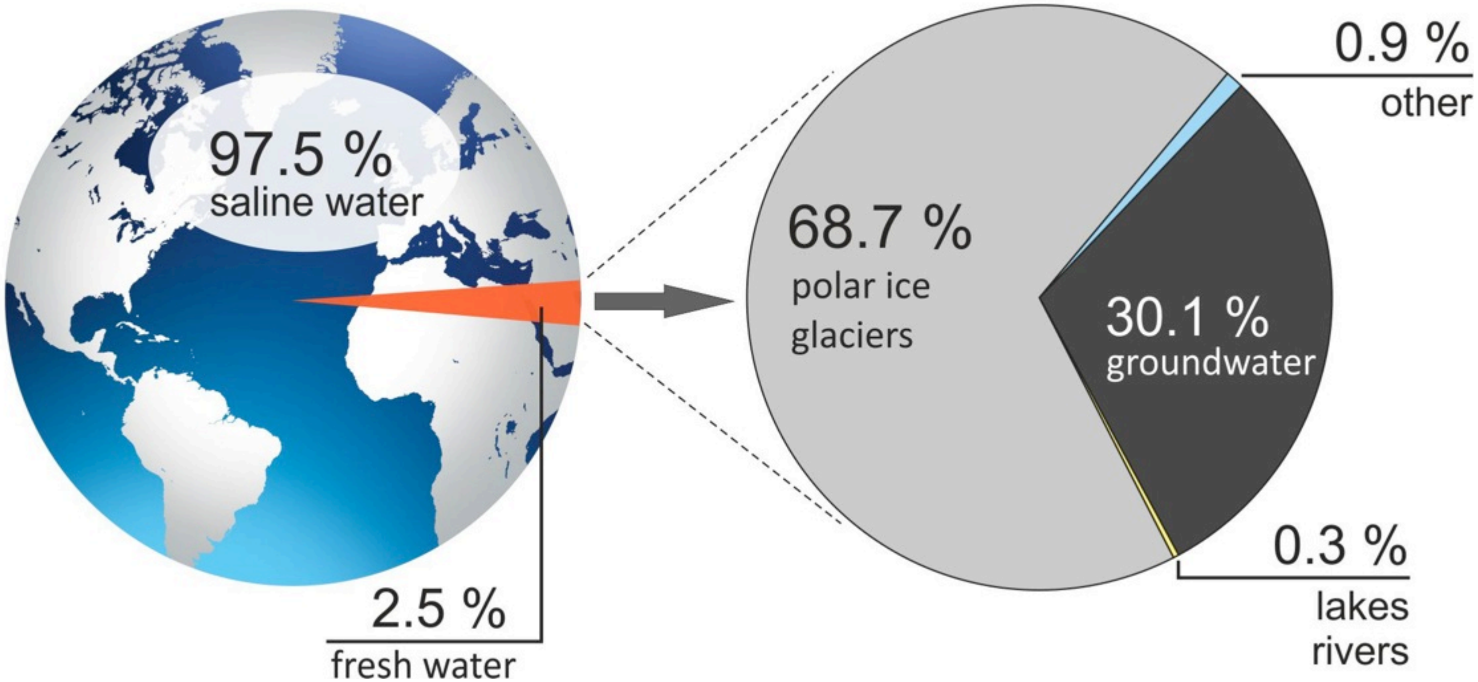
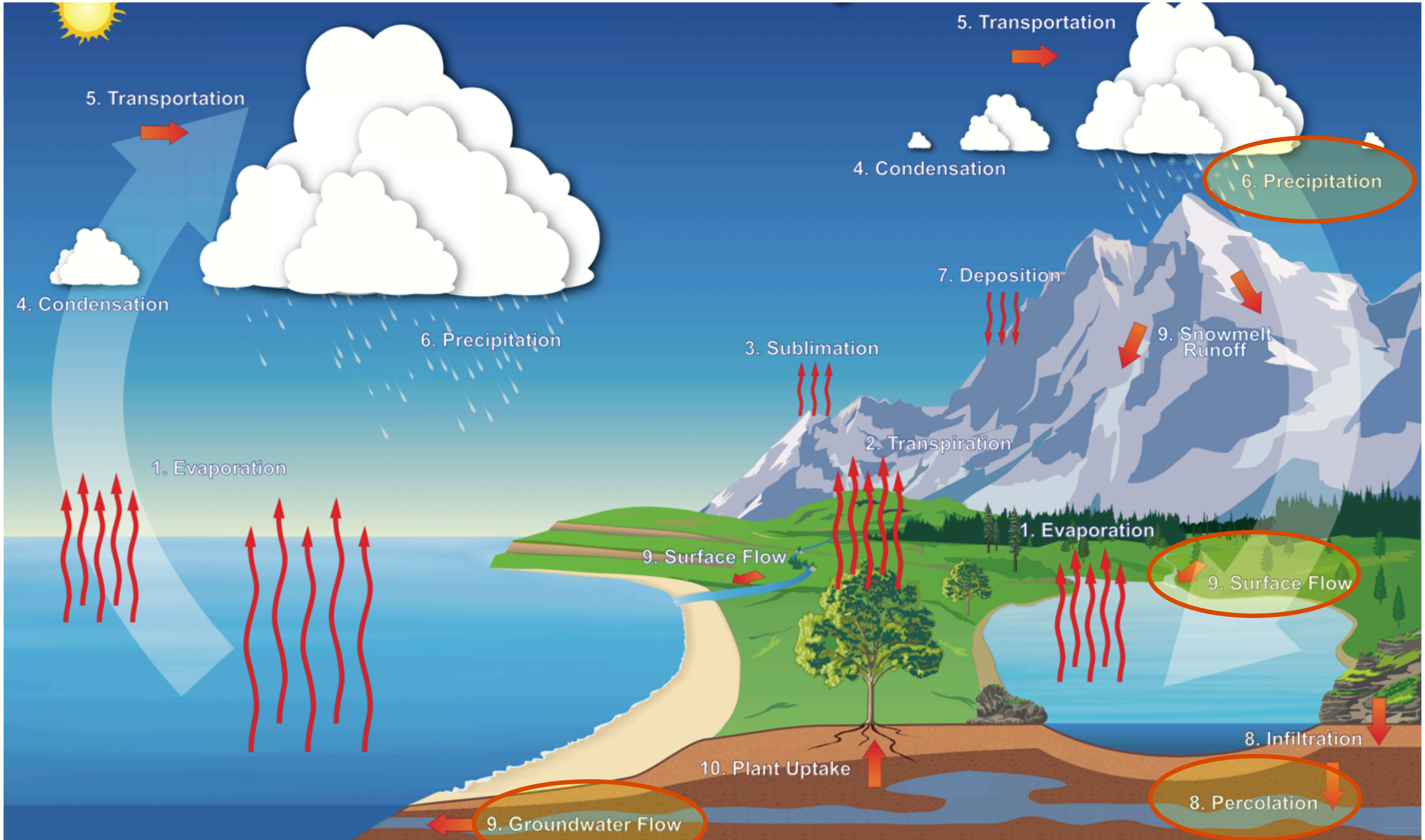
Water on the Earth



numbers after Gleick (1996),
NASA Earth Observatory

- Only a small fraction of Earth's water is directly accessible for daily use
- Todays need: 20 – 50 Liter clean water

The hydrologic cycle



NOAA National Weather Service

Outline

- Stable isotopes in the hydrologic cycle
- Global isotope distribution maps
  - RCWIP – next generation water isoscapes
- Linking precipitation, rivers, and groundwater
  - Wiesent River (Germany)
  - Island of Corsica (France)
  - Nuremberg aquifers (Germany)
  - New Jersey Shelf (USA)
- River isotope monitoring programs
  - GNIR^3 – rivers worldwide
  - Global Rivers Observatory

Tasmania, Australia

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Zaragoza, Spain

Stable isotopes in the

HYDROLOGIC CYCLE

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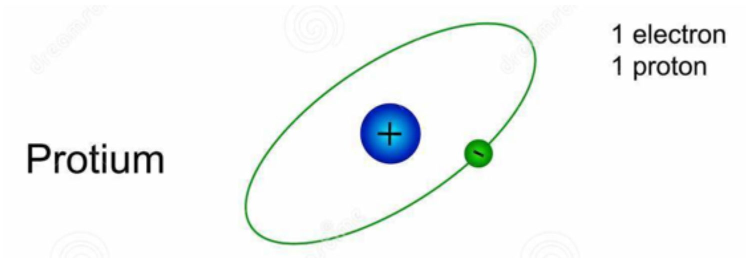
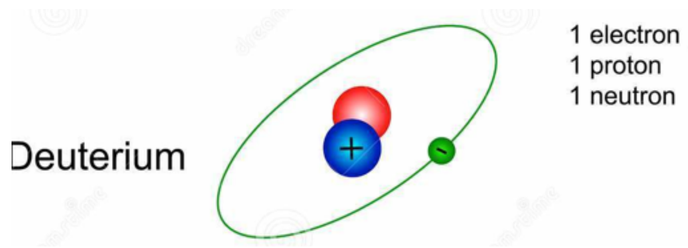
Stable isotopes and fractionation





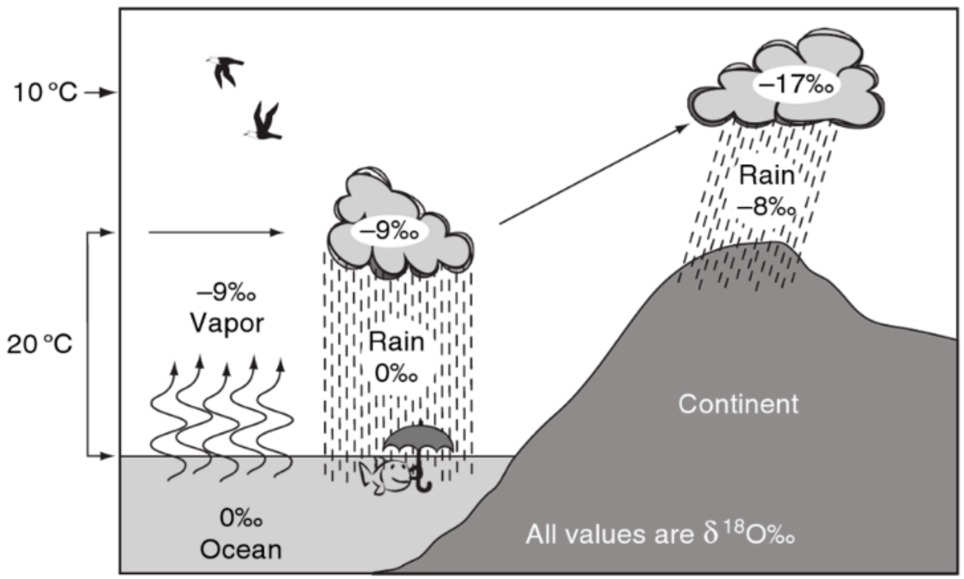
- **Fractionation**
  Change of an isotope ratio (δ-value) due to chemical or physical processes
  - equilibrium fractionation
  - kinetic fractionation
  - *mass-independent fractionation*

- **Fractionation factor α**
  - Example: H_2O liquid(l) – water vapor (g) (T = 20 °C)

$$H_2{}^{16}O(l) + H_2{}^{18}O(g) \leftrightarrow H_2{}^{18}O(l) + H_2{}^{16}O(g) \qquad \alpha = R(l) / R(g) = 1.0098$$

Isotopes in the hydrologic cylce

Rayleigh destillation



Emerson and Hedges (2008)

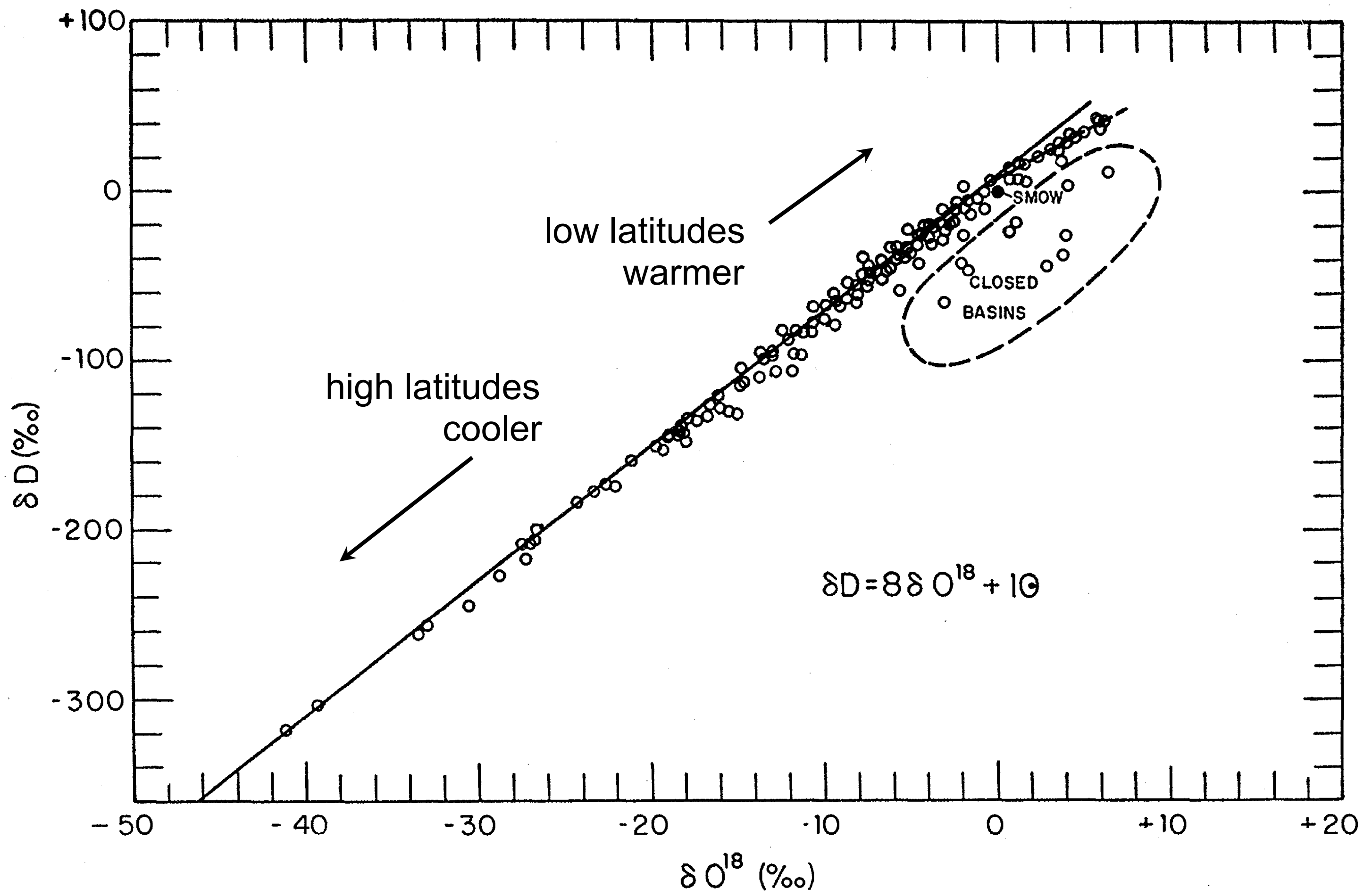
- Water vapor is depleted in $^{18}O/^{2}H$ (➞ low $\delta^{18}O/\delta^{2}H$ values)
- Rain is relatively enriched in $^{18}O/^{2}H$ (➞ higher $\delta^{18}O/\delta^{2}H$)
- Clouds and rain get continuously depleted along their journey (➞ lower $\delta^{18}O$ and $\delta^{2}H$ values)

Standard „delta“ notation in per mil (‰) *vs* Standard Mean Ocean Water (VSMOW):

$$\delta = \left(\frac{R_{sample}}{R_{reference}} - 1 \right)$$

H_2O ➞ isotope fingerprint

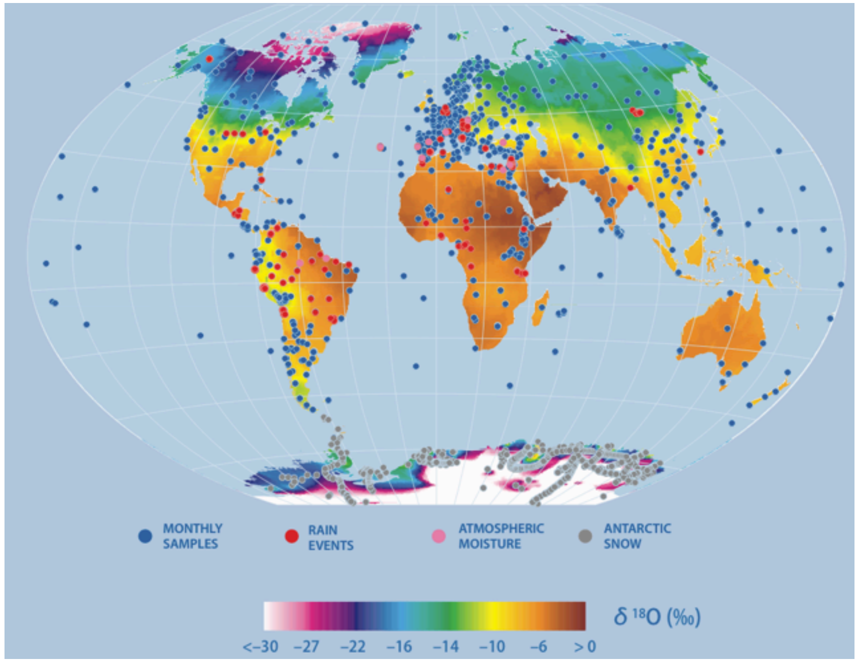
Global Meteoric Water Line (GWML)



Craig (1961)

GNIP network

GNIP – Global Network of Isotopes in Precipitation
1961 – today



IAEA (Water Resources Programm)

- Global precipitation data of δ^2H and $\delta^{18}O$, ^3H (Tritium)
- about 900 stations in more than 100 countries
- 120.000 monthly data sets
- Applied in various research fields
  - Climate change
  - Water resources
  - Hydrogeology
  - Food authenticity
  - Paleoenvironmental studies (e.g. tooth enemal, tree rings, speleothemes)
  - Forensic sciences
  - …
- One of the most important and successful monitoring programs in hydrology

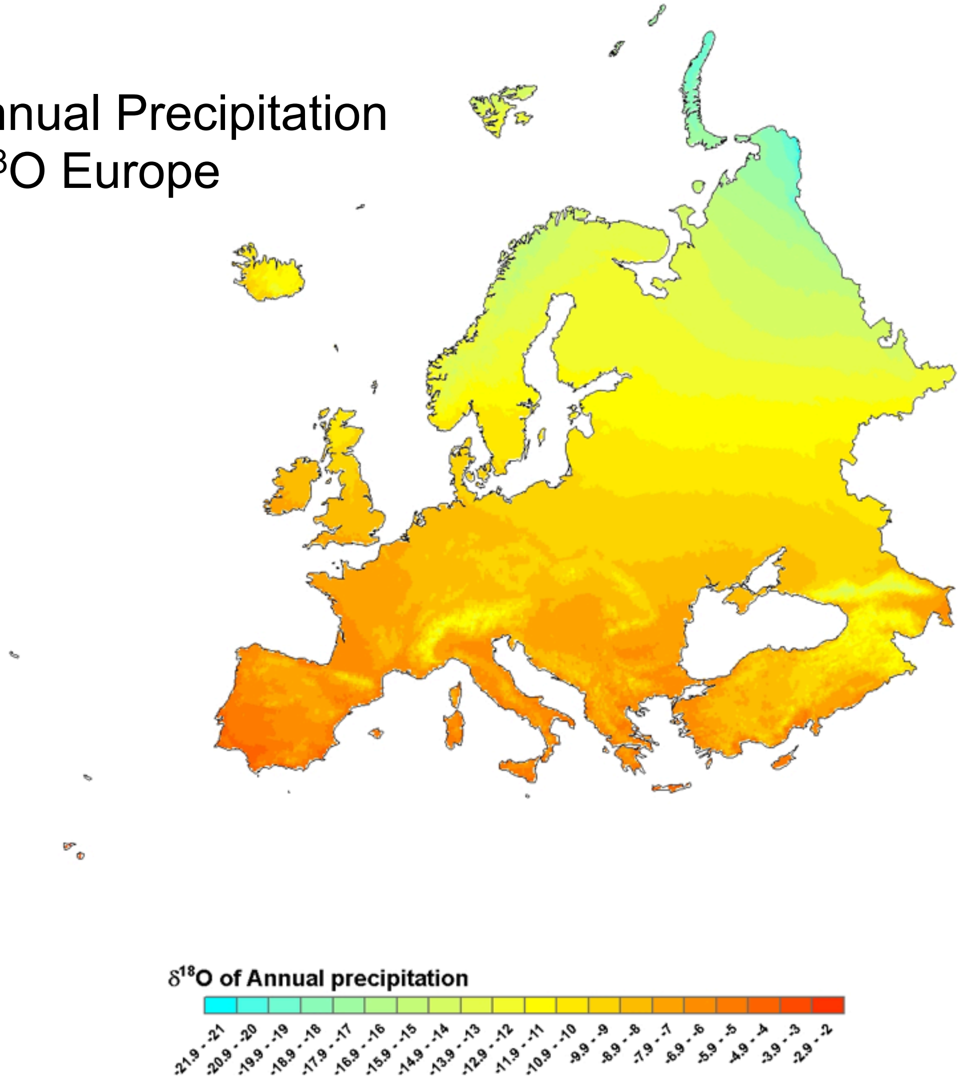
WMO | Hydrology and Water Resources Programme (HWRP)

IAEA International Atomic Energy Agency | Water Resources Programme

Global spatial distribution maps – ‘Isoscapes’

- Key publications: Bowen and Revenaugh (2003), WRR

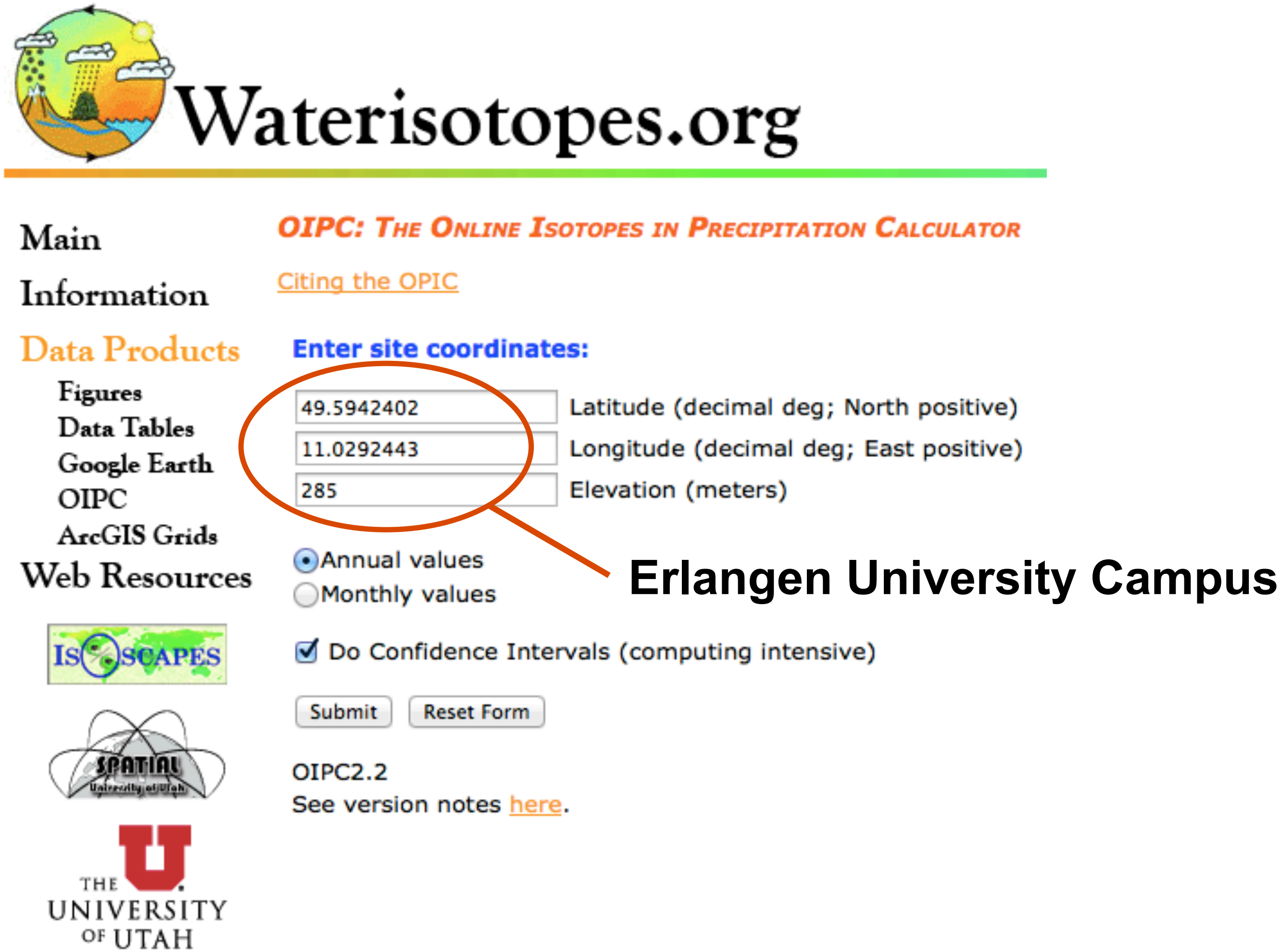
Annual Precipitation
$\delta^{18}O$ Europe



Spatial means 3D:
- Latitude
- Longitude
- Elevation

www.waterisotopes.org

Interpolated isotope data



Isoscape results versus local analytical data

Isoscape results

www.waterisotopes.org

Data Products

- Figures
- Data Tables
- Google Earth
- OIPC
- ArcGIS Grids

Web Resources

ISOSCAPES

Estimates for latitude 49.5

δ^2H (‰, V-SMOW)	-59
δ^2H 95% CI (‰)	3
$\delta^{18}O$ (‰, V-SMOW)	-8.7
$\delta^{18}O$ 95% CI (‰)	0.3

Measured data (weighted annual means)

δ^2H = -66 ‰

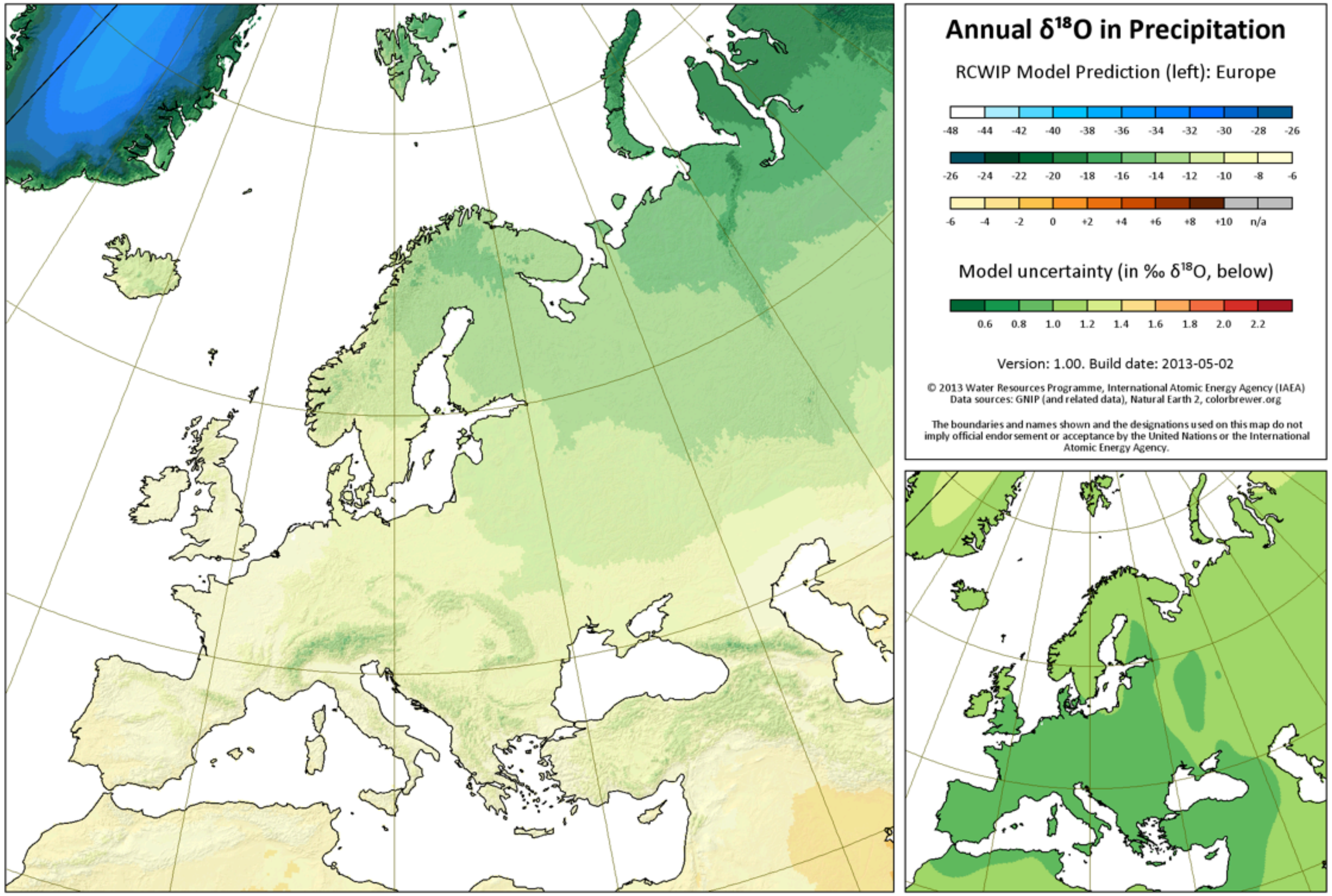
$\delta^{18}O$ = -9.4 ‰

GeoZentrum GNIP sampler

→ Water isotope composition depend on local effects that cannot be reproduced precisely in global interpolation models

RCWIP-next generation precipitation isoscapes

(regionalized cluster-based water isotope prediction)



www.iaea.org/water

Terzer et al. (2013), HESS, vol. 17

Tasmania, Australia

Linking

PRECIPITATION, RIVERS AND GROUNDWATER

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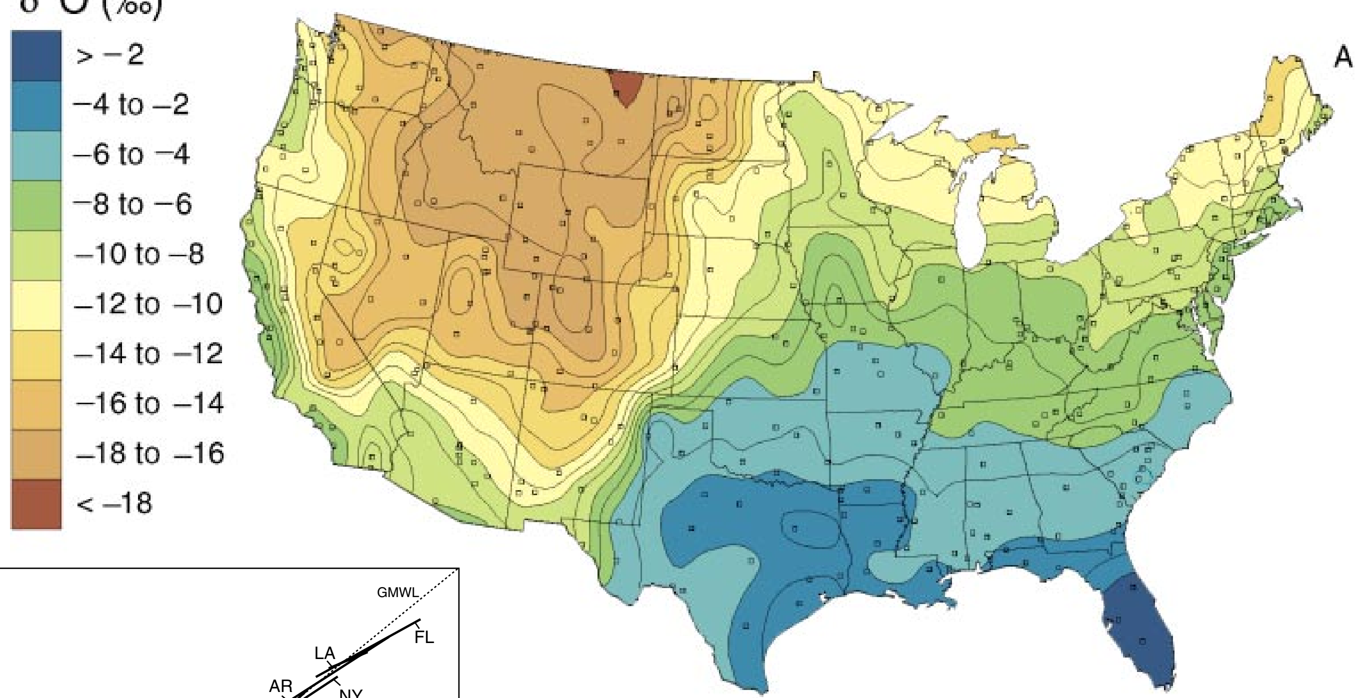
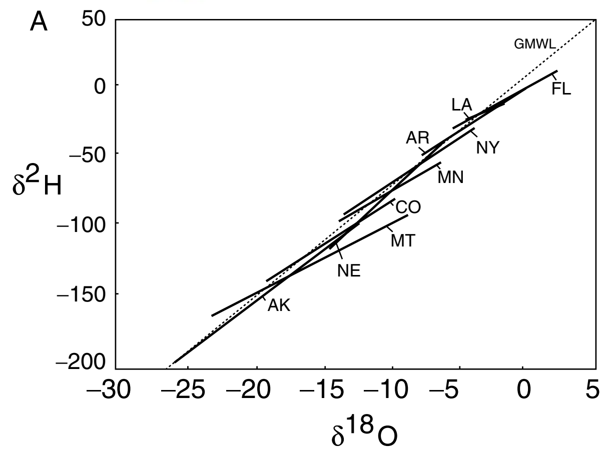
Linking rivers and precipitation

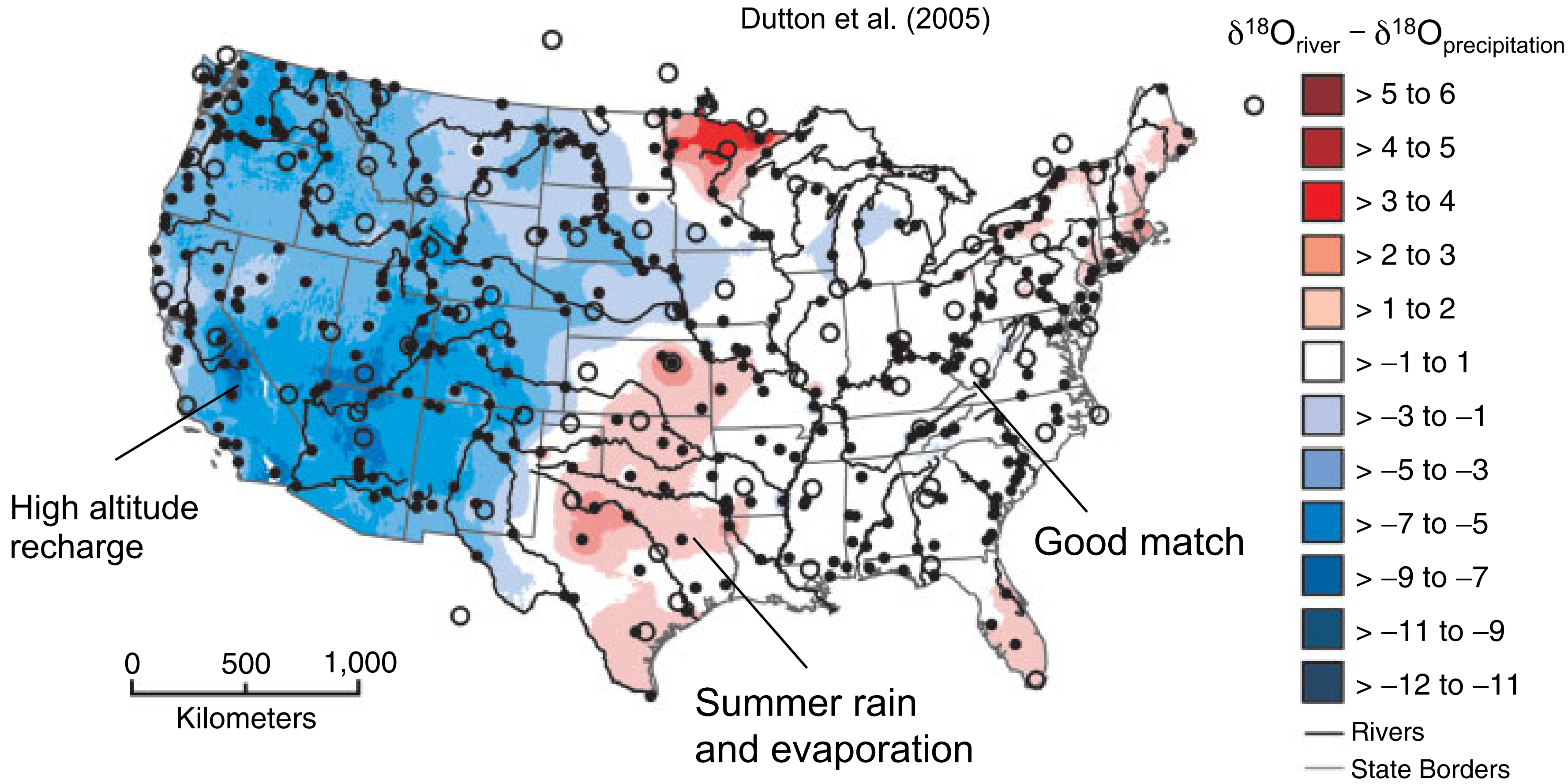
Kendall and Coplen (2001)





→ Local Meteoric Walter Lines (LMWL) derived from river water data

Catchment effect

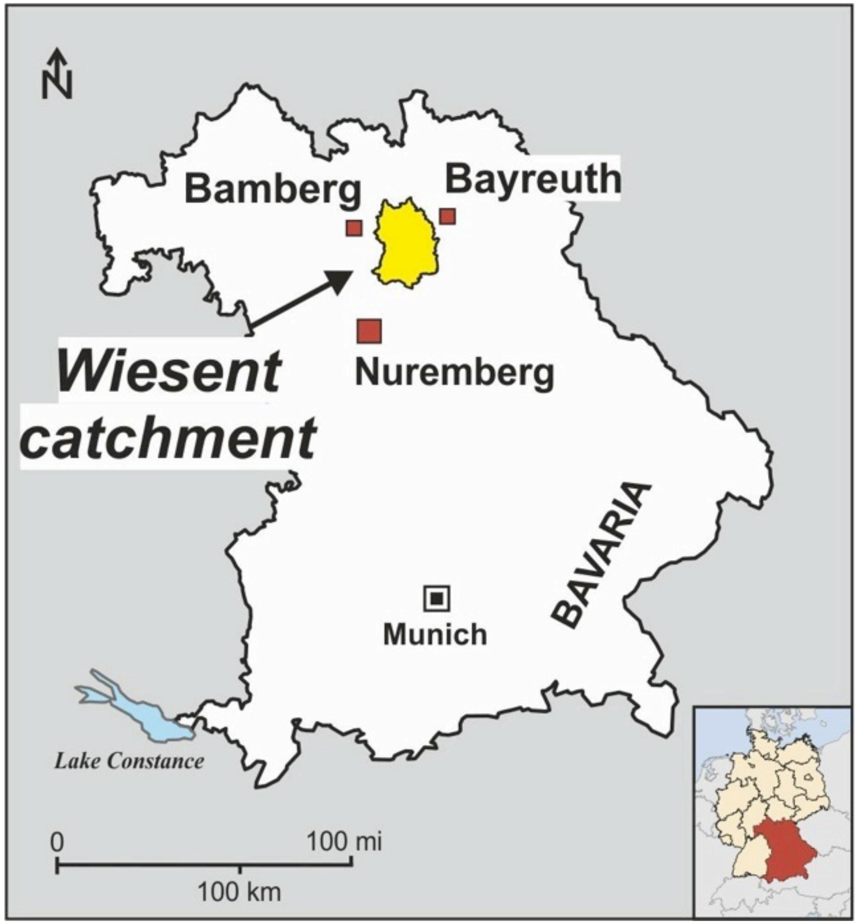


→ Differences between $\delta^{18}O_{precipitation}$ and $\delta^{18}O_{river}$

Wiesent River

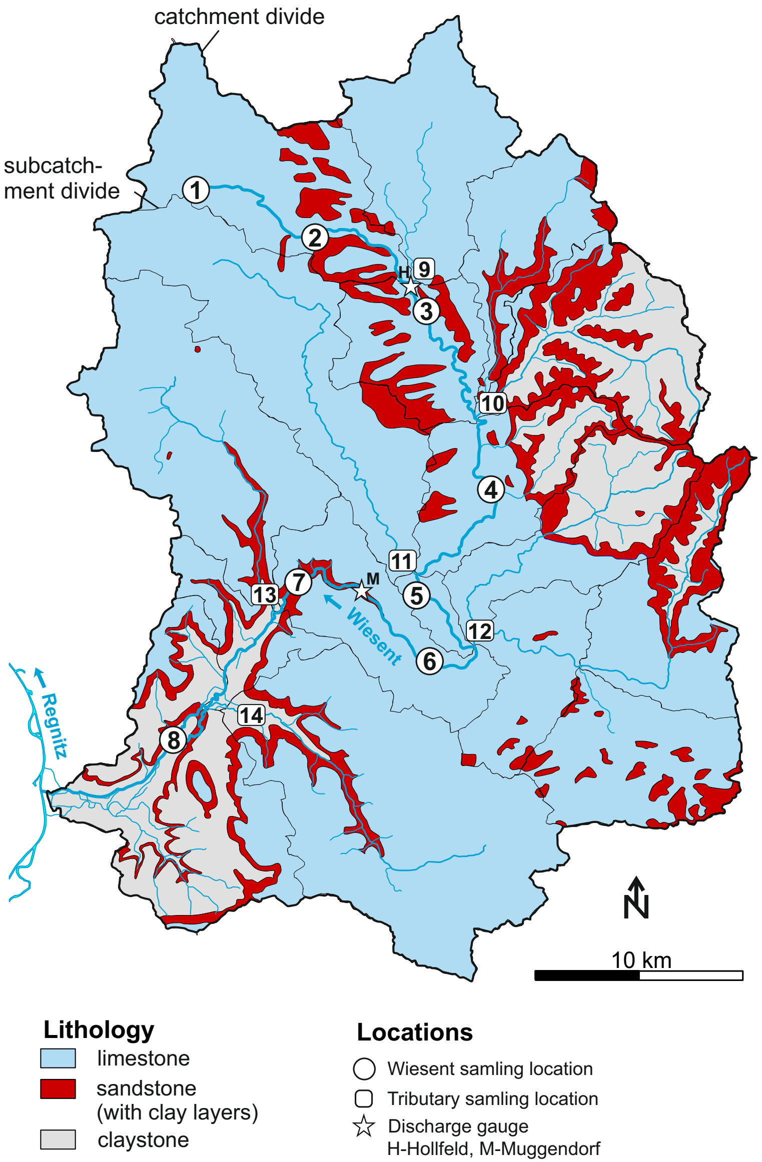
WIESENT RIVER

Wiesent River (southern Germany)



Wiesent spring at Steinfeld

Wiesent catchment



van Geldern et al. (subm.)

- Area: ~1040 km^2
- River length: ~73km
- 8 sampling locations
- (6 tributaries)
- Sampled over one year to cover all seasons

Lithology:

- Jurassic carbonates (67%), >100m thickness (deep karst)
- Sandstones (14%)
- Shale (15%)

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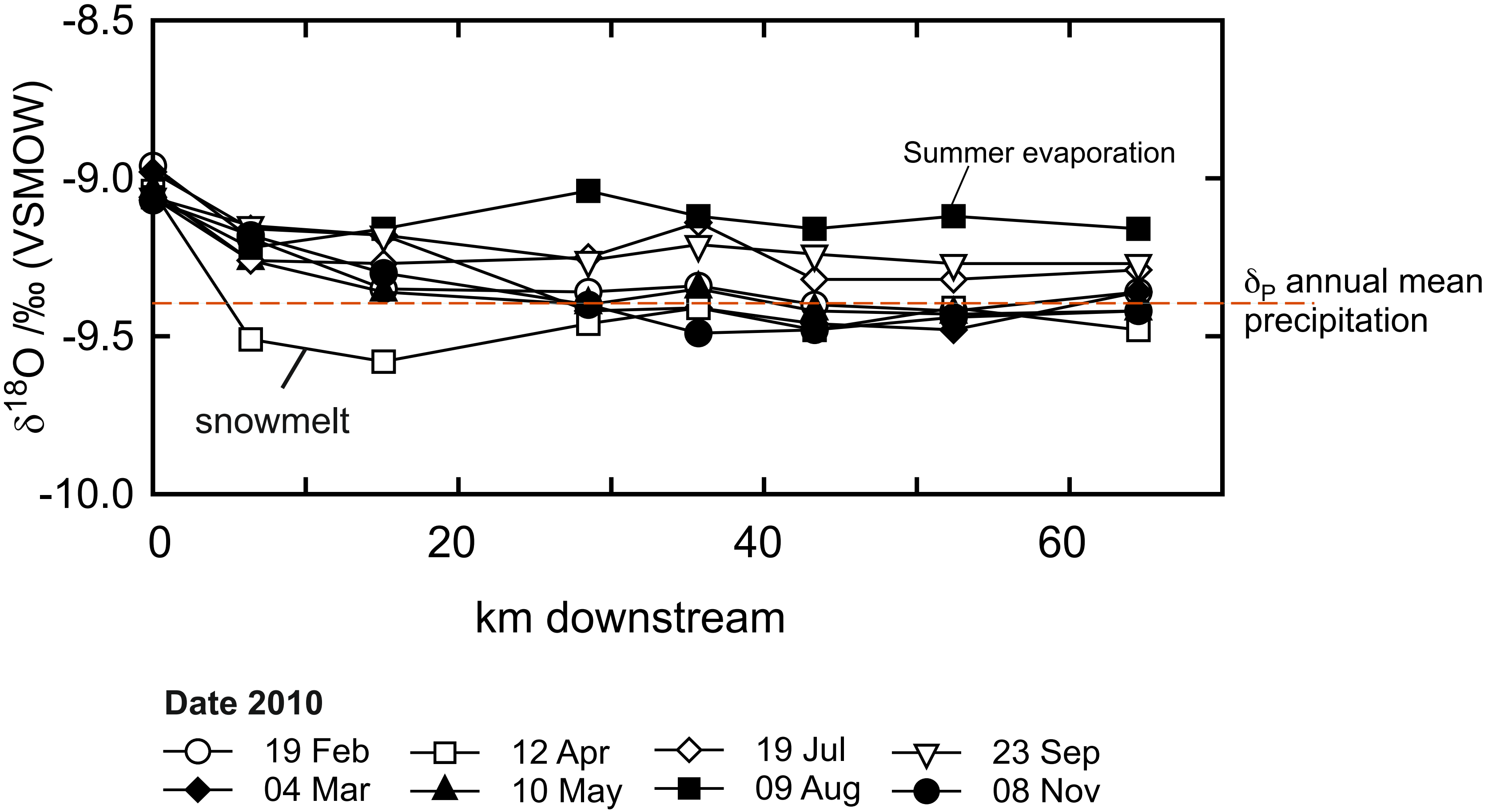
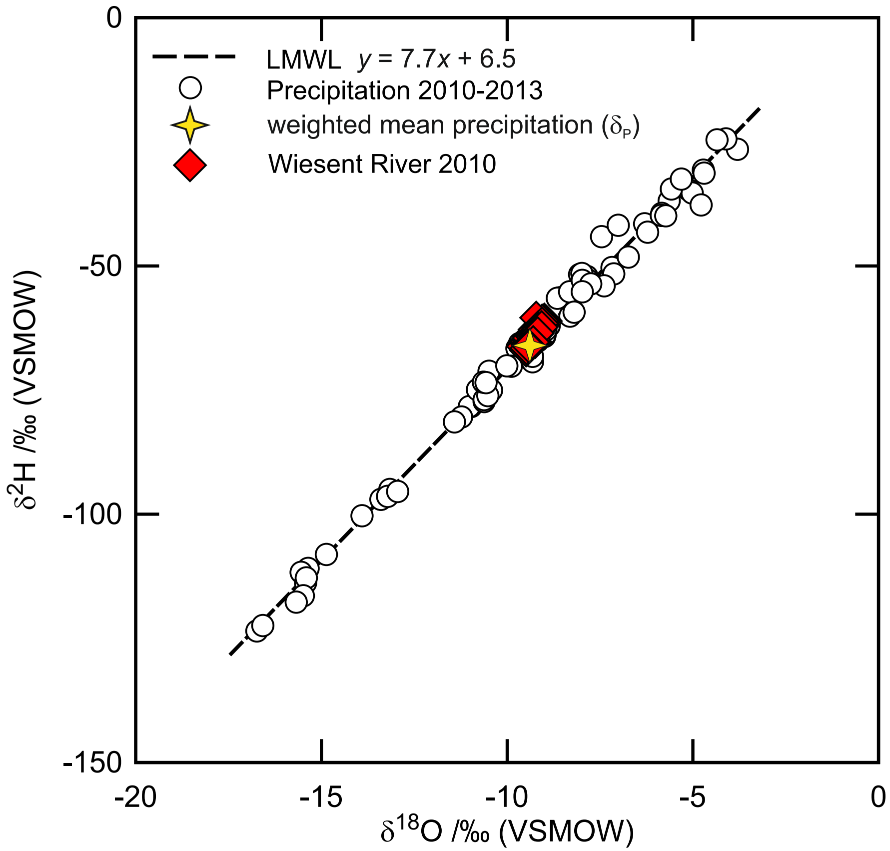
Water stable isotopes



River water and LMWL



Stable isotopes

- Wiesent data plot on LMWL
- Stable source value
- No seasonal cycle in river

Stream flow generation

- groundwater dominated river over entire course
- system buffered by deep karst groundwater body
- minor importance of surface run off

Solenzara River, Corsica

Isotope hydrology of the

ISLAND OF CORSICA

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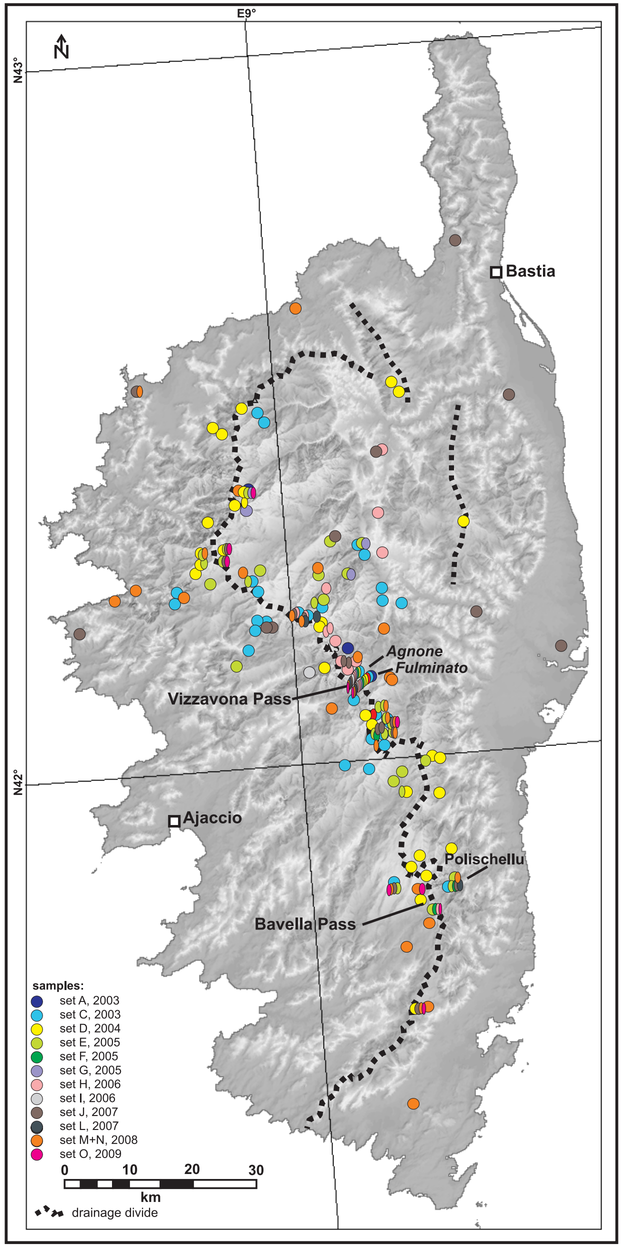
Sampling locations



- Paleoclimate study on tree rings of our institute
- Accompanying water sampling from 2003 to 2009
- 210 surface water samples
- Isotope analysis performed at Tübingen, Erlangen and Hanover
- 3 different compartments:
  - (1) Lakes (*n* = 19)
  - (2) Springs (26)
  - (3) streams (166)

van Geldern et al. (2014)

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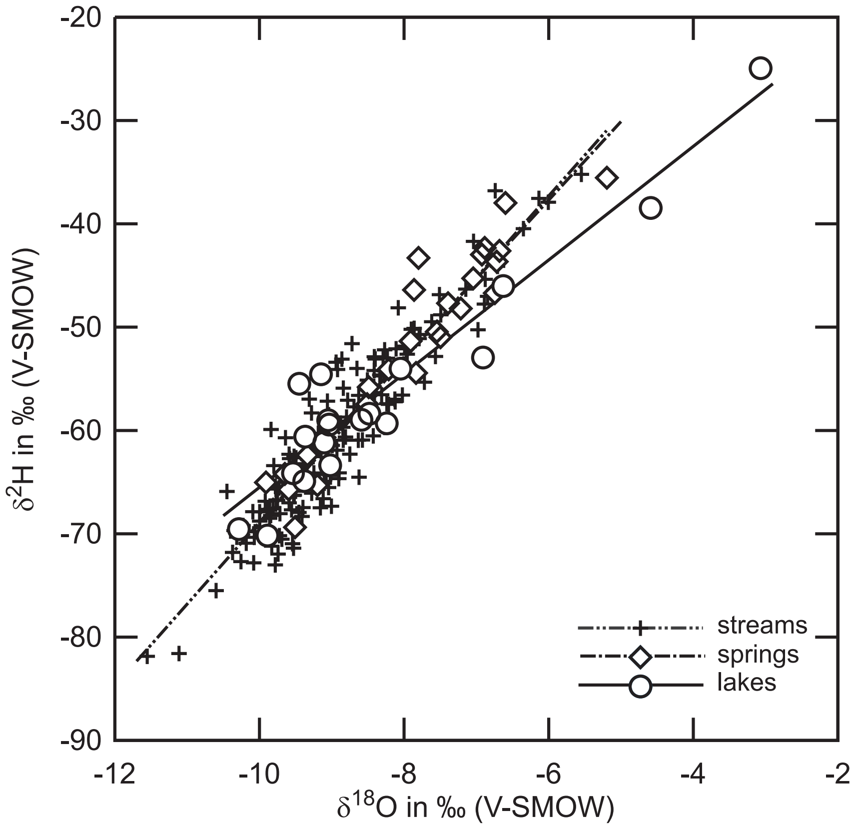
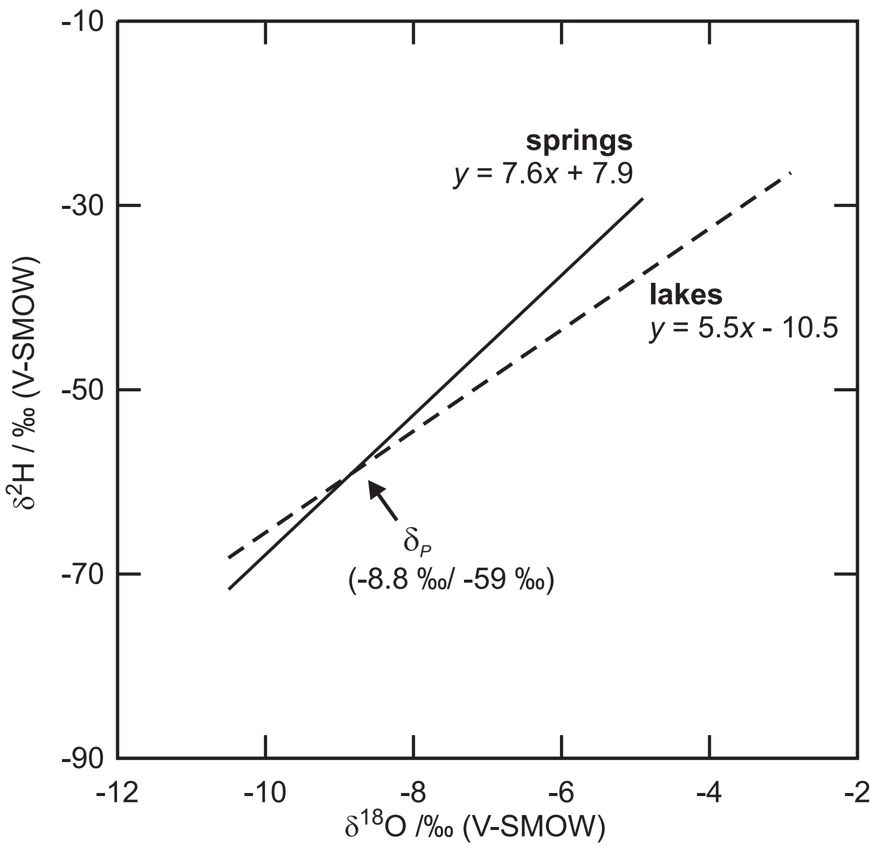
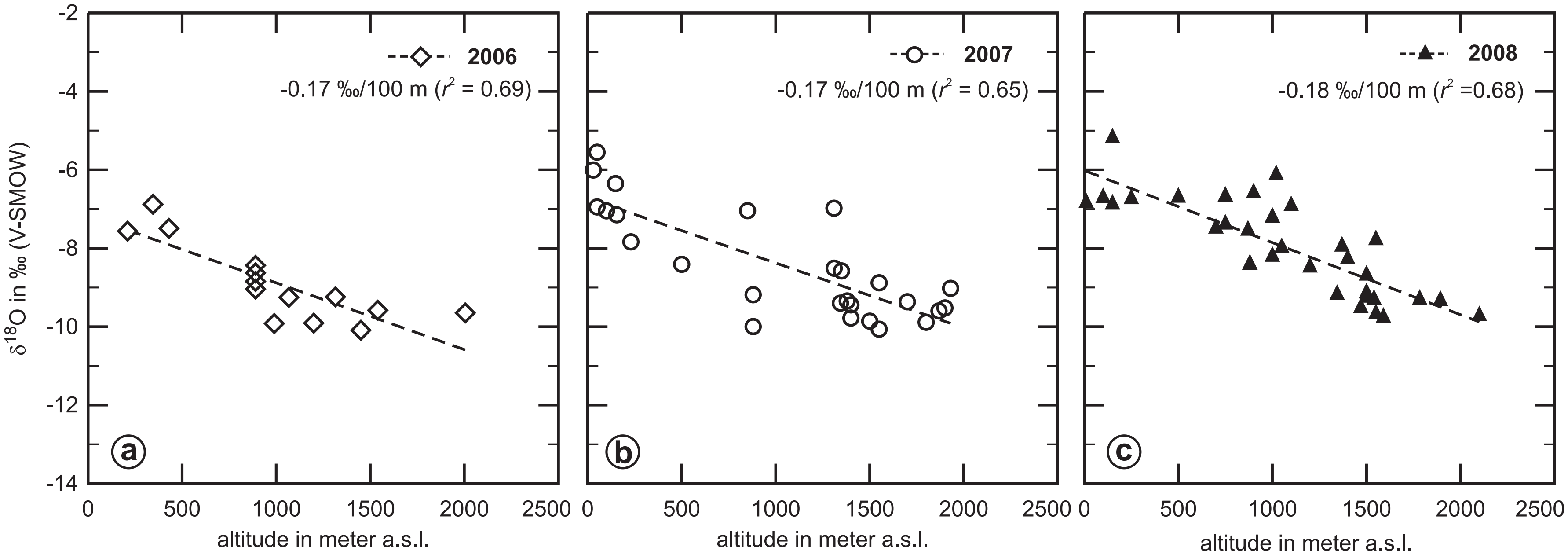
From streams to the LMWL



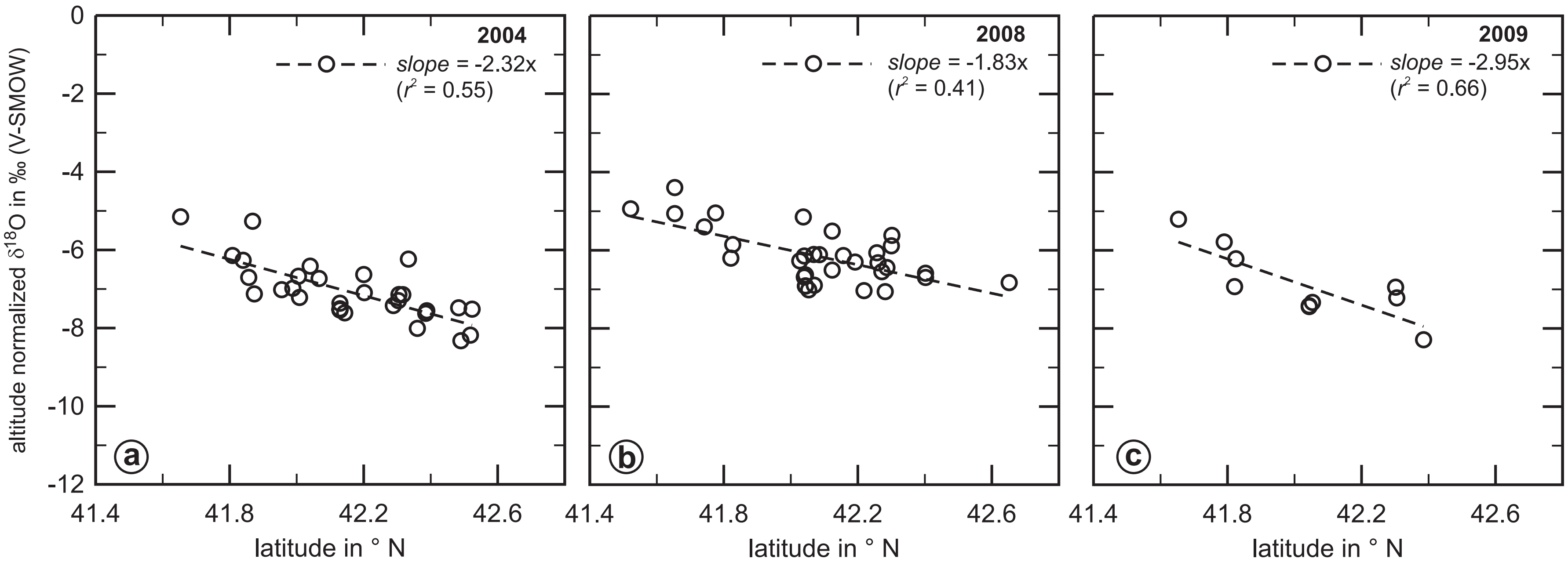


van Geldern et al. (2014)

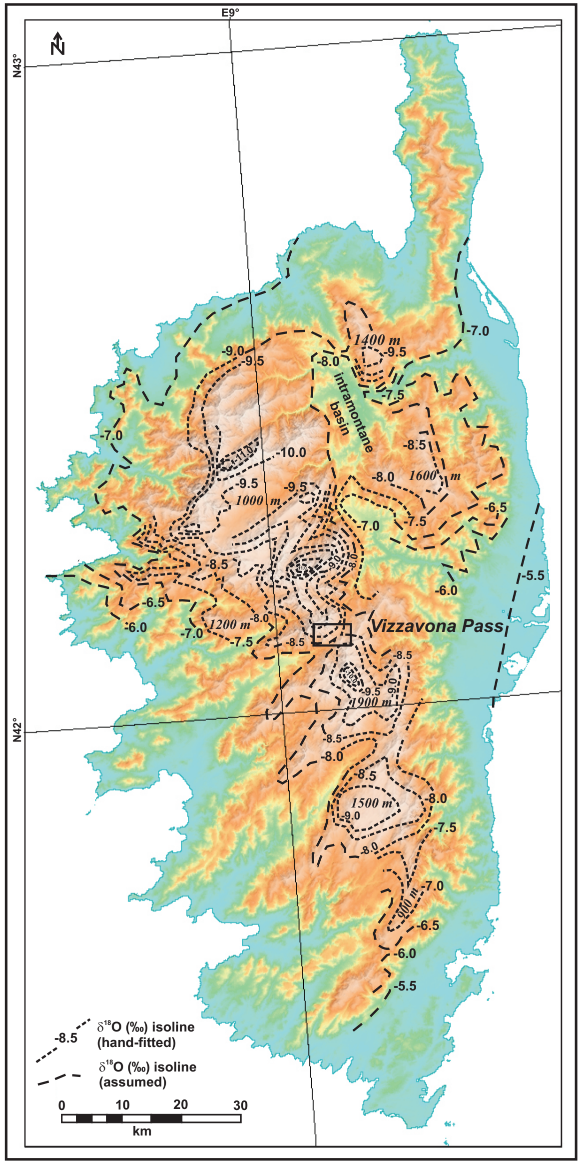
Altitude effect



Latitude and climatic effects



Corsica isotope map from river water data



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Klingengraben spring, Nuremberg

Stable isotopes and

PALEOWATERS

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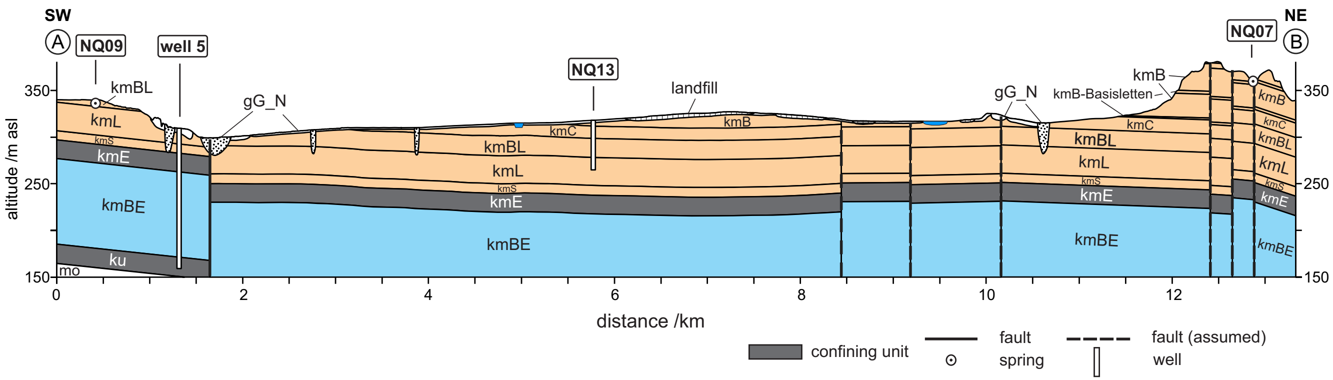
Nuremberg

Tiefer Brunnen, Nuremberg Castle

Hydrogeology

SYSTEM	EUROPEAN LITHOSTRA-TIGRAPHY		GEOLOGIC UNIT	SYMBOL	THICK-NESS [m]	HYDROGEOLOGIC UNIT
Quaternay	Pleistocene		sand and gravel	gG_N	0-30	Aquifer Ia
Triassic	Keuper Group	Sandstein-keuper	Burgssandstein	kmB	~90	Aquifer Ib
			Coburger Sandstein	kmC	~15	
			Blasensandstein	kmBL	~25	
		Gips-keuper	Lehrbergschichten	kmL	~30	
			Schilfsandstein	kmS	4-30	
			Estherienschichten	kmE	20-30	confining unit
			Benkersandstein	kmBE	~90	Aquifer II
			Lettenkohlenkeuper	ku	~20	confining unit

van Geldern et al. (2014)



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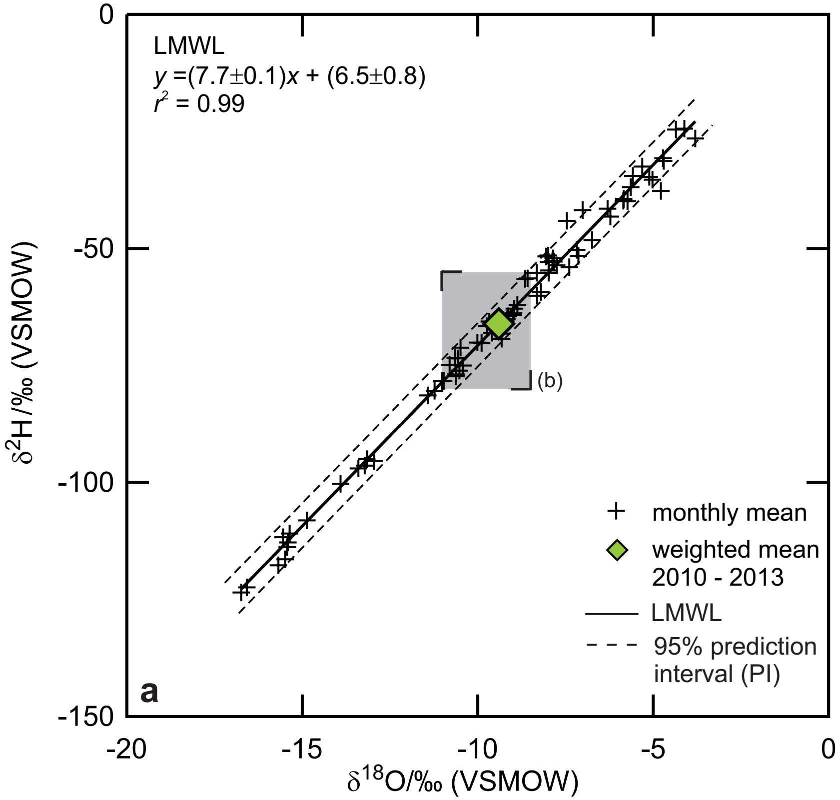
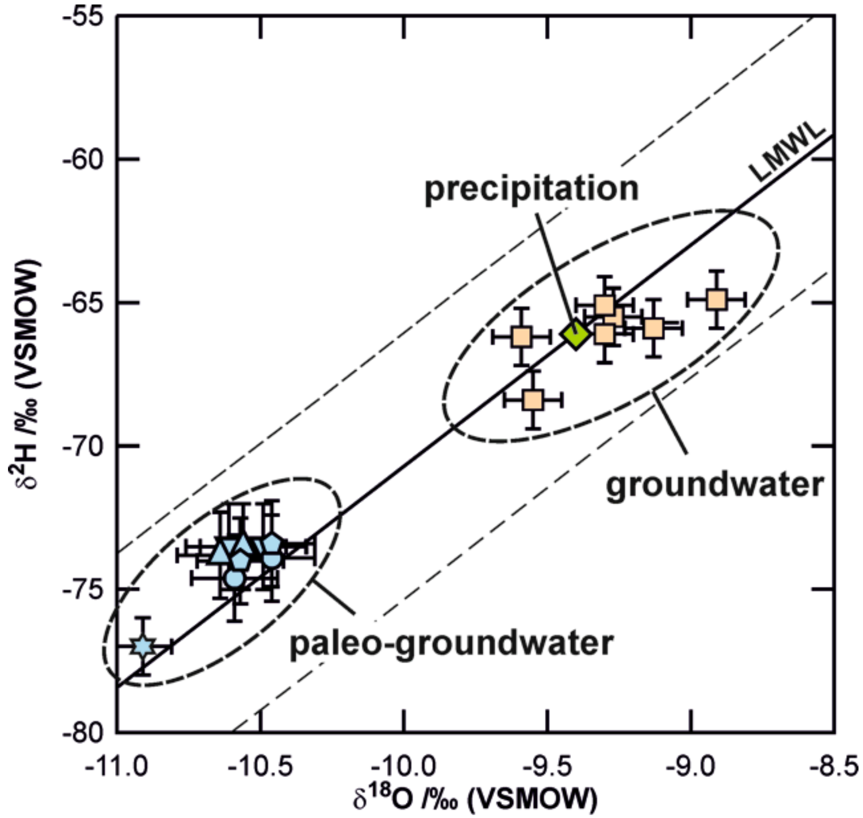
Paleowaters





van Geldern et al. (2014)

Radiocarbon dating of deep aquifer

Table 3
Radiocarbon ages for different correction models. Ages are in years BP rounded to 100 years.

	Well 4 (sampling A)	Well 4 (sampling B)
Uncorrected ^{14}C-years	26,000	27,500
Vogel (1970)	24,700	26,100
Pearson and Hanshaw (1970)[a]	21,200	23,400

[a] pH = 6.5, pCO_2(soil air) = 10^{-2} atm, δ^{13}C(soil air) = −23‰, δ^{13}C(carbonate) = 0‰.

- Stable isotopes of the deep aquifer are depleted in ^{18}O/^{2}H
- Radiocarbon age suggests that water is > ~21,000 years
- No tritium found
- → Paleowaters recharged before the end of the LGM under **cooler climatic conditions.**
- GeoZentrum, LfU, and Helmholtz Munich will start to measure groundwater samples systematically in 2015

45 km offshore Atlantic City, NJ

New Jersey Shallow Shelf

COASTAL AQUIFERS

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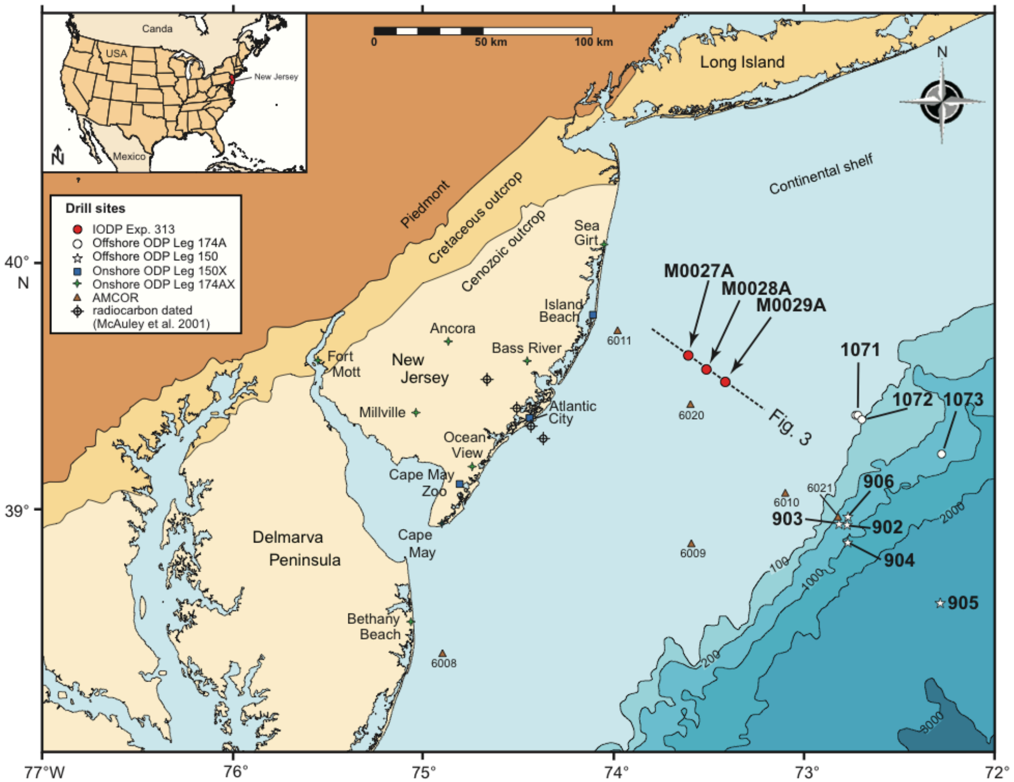
IODP 313 Drilling Site



van Geldern et al. (2013)

Photo: ECORD

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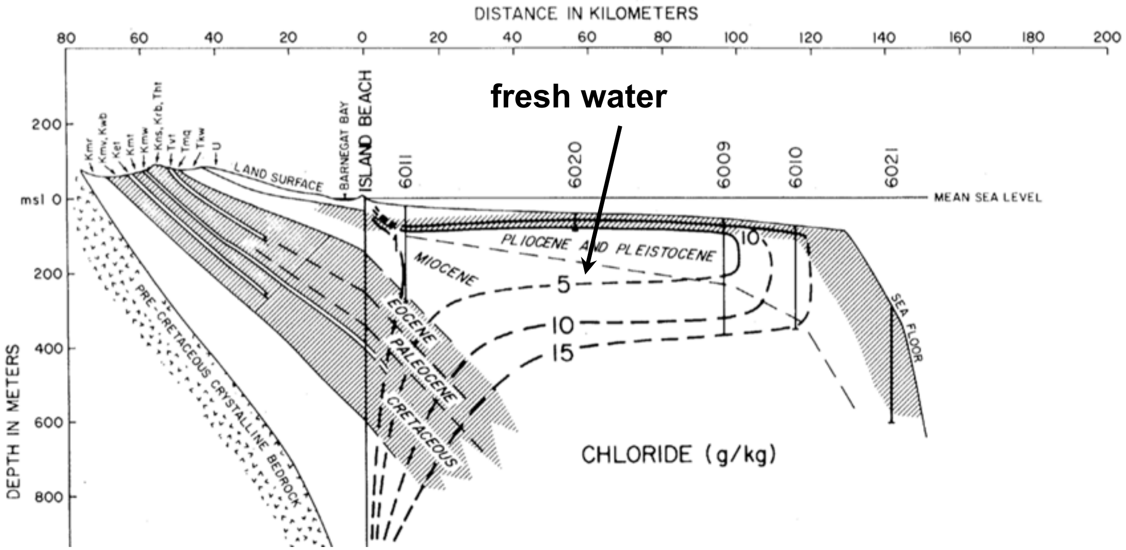
Submarine fresh water

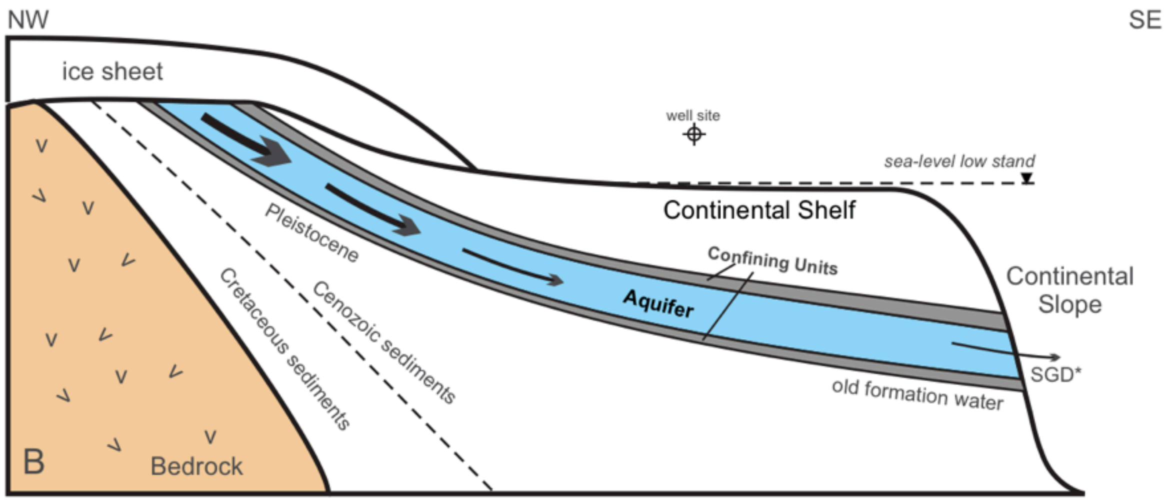


Hathaway et al. (1979)

- Fresh water lens known since 1970s
- Simple geometry assumed
- All hydrogeological models base on these assumptions

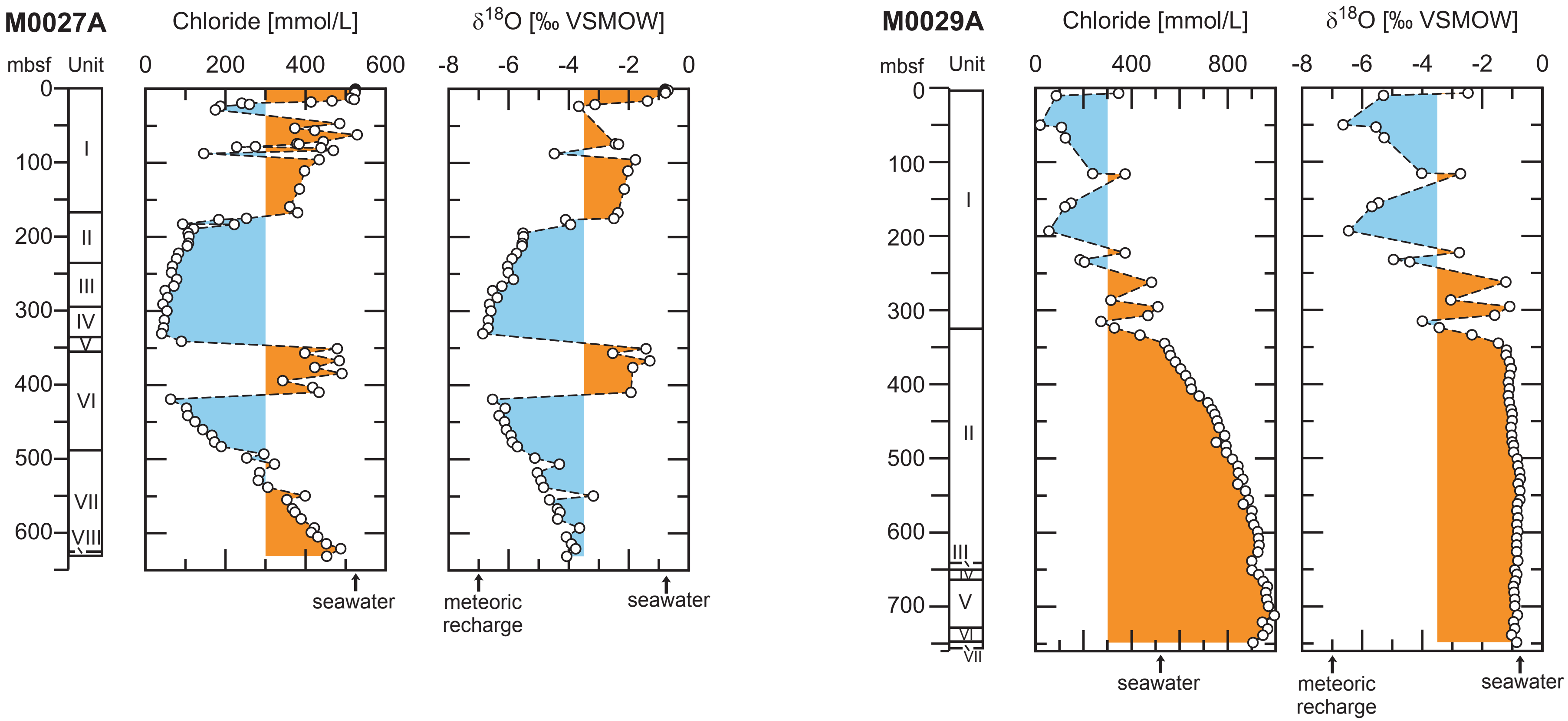
before IODP 313

- Paelowater recharged during the Pleistocene
- from melt waters below ice sheets (LGM)



van Geldern et al. (2013)

Stable isotopes



van Geldern et al. (2013)

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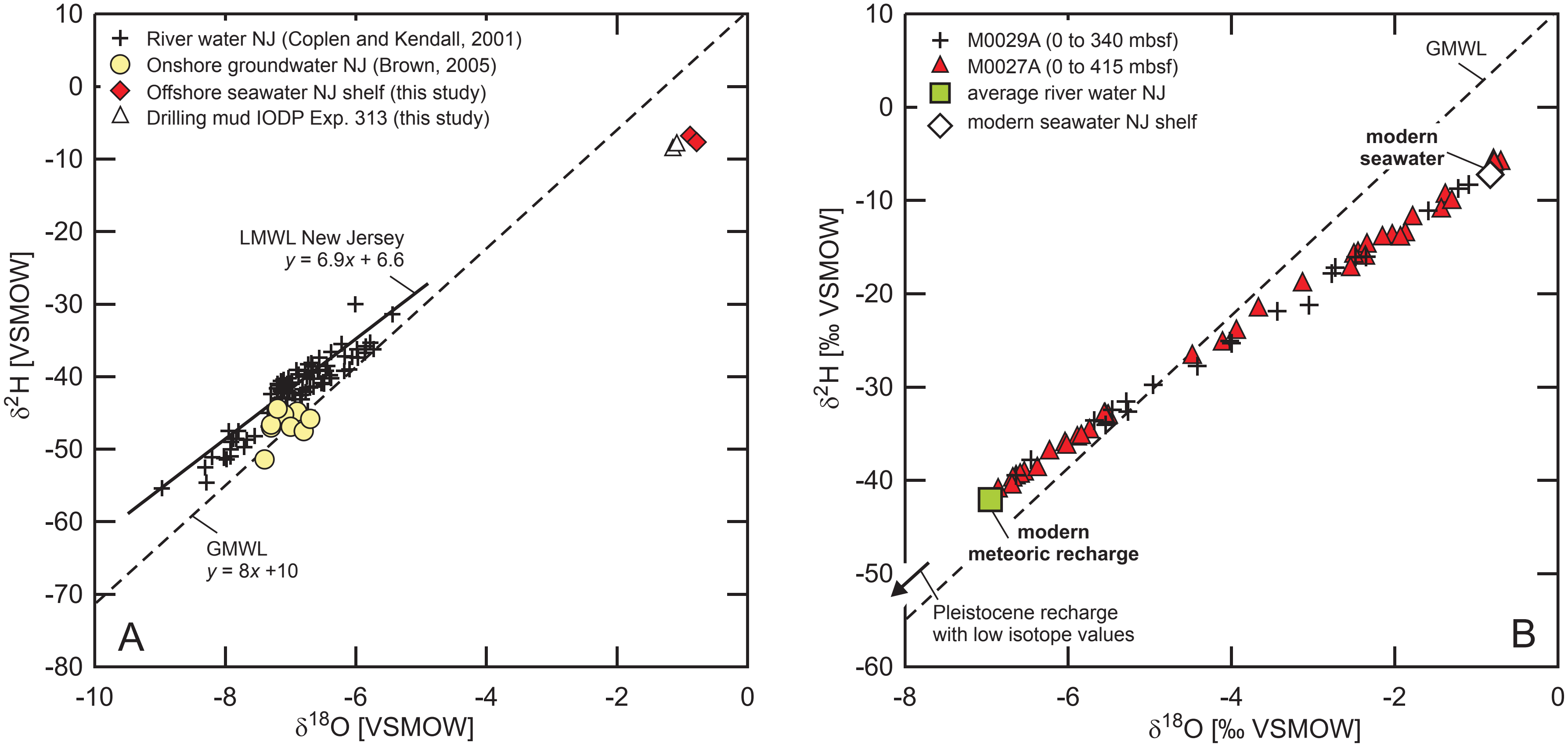
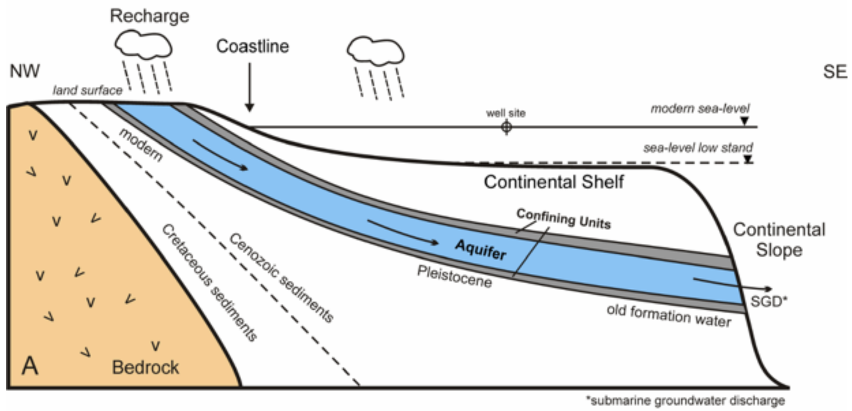
Water origin



van Geldern et al. (2013)

Paleoclimatic implications

- Todays onshore recharge is characterized by stable isotope analyses from river water
- Stable isotopes of fresh water below the shelf is identical to todays onshore recharge
- No indications for cooler recharge conditions or recharge during the last glacial maximum
  - Isotope hydrology was identical to modern conditions during the LGM?
  - Water is older (millions of years?) and was recharged during similar conditions that today
  - Water is younger (<20.000 years) and is actively recharged



van Geldern et al. (2013)

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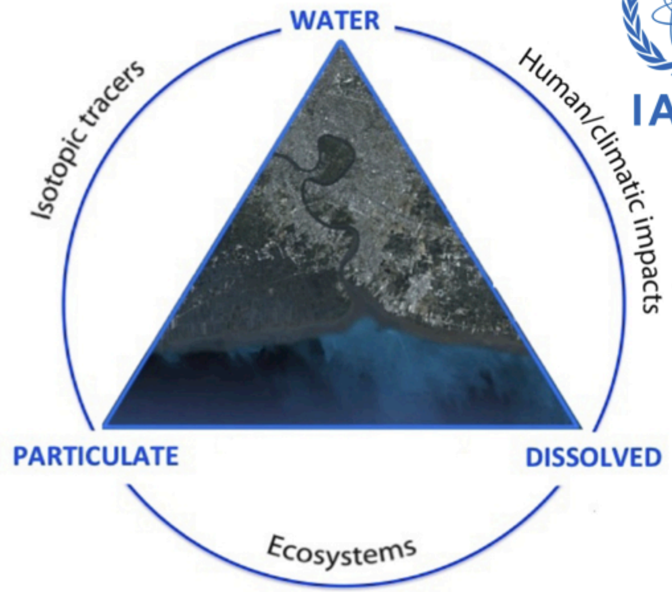
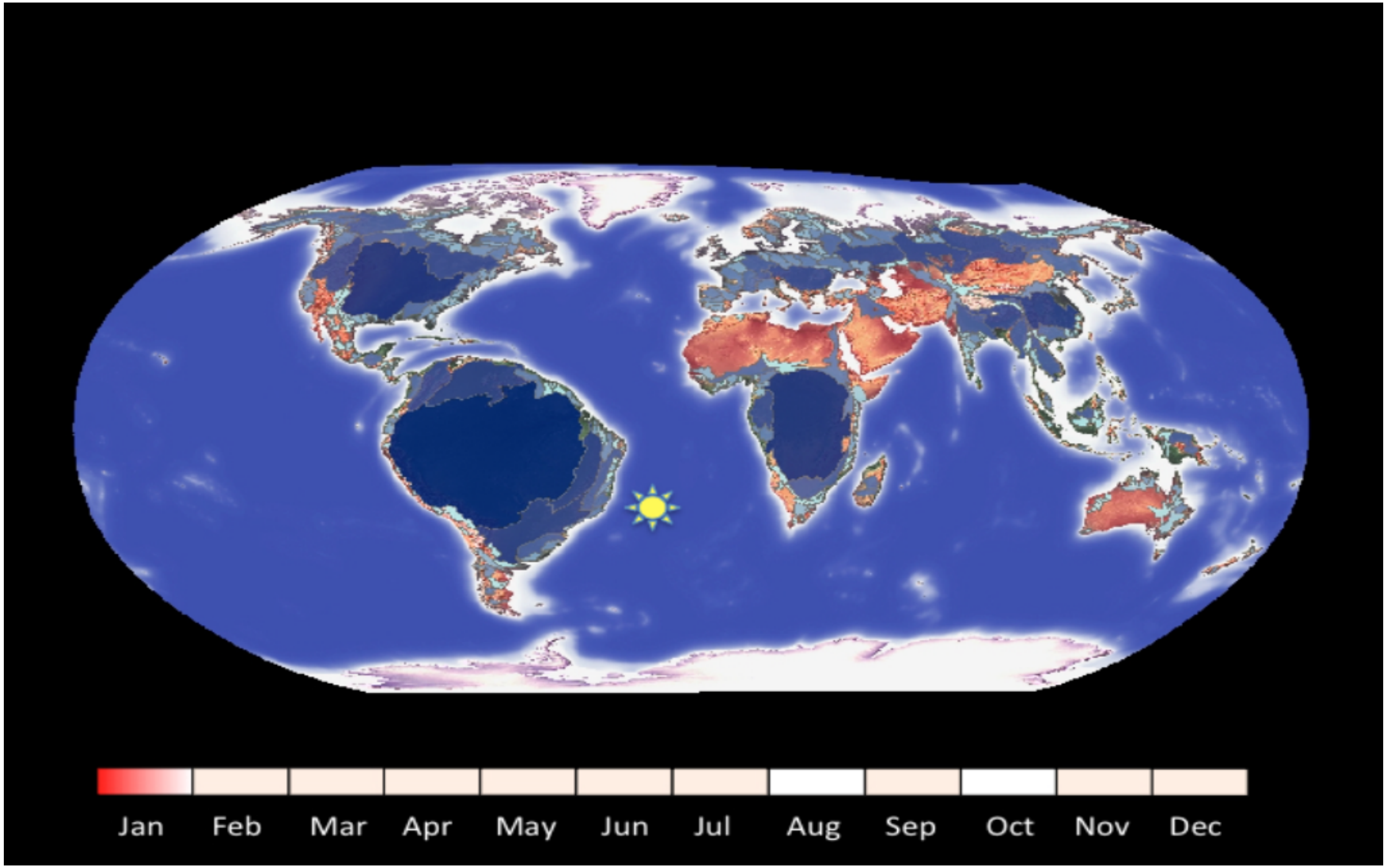


Global Network of Isotopes in Rivers

GNIR³ AND GLOBAL RIVERS OBSERVATORY

Global discharge data

www.globalrivers.org



Data from GRDC (BfG Koblenz)
Animation: B. Peucker-Ehrenbrink (WHOI)

GNIR^3 – Rivers worldwide

- **GNIP** is one the most successful isotope monitoring programs
  - numerous applications that were not initially thought
  - radically improved our understanding of recharge mechanisms
  - rivers are less understood and not systematically investigated
- **Rivers** transport valuable information about
  - climate change and mankind adaption to it
  - changes in land use
- **GNIR** should change this
  - Pilot GNIR 2002 – 2006 as IAEA Coordinated Research Project (CRP)
  - New IAEA-CRP launched in 2014 (2014 – 2018)
  - Focus on worlds largest rivers

Summary

Stable isotopes in hydrology

- are the geochemical fingerprint of the water molecule
- allows to trace water along its journey from precipitation to the sea
  - rivers integrate signals from an entire region and transport them
- carry information about the impact
  - of climate change
  - of anthropogenic induced changes of ecosystems
- help to monitor these changes and investigate the reasons
- identify paleo-climatic conditions through preserved paleowaters

Isoscapes derived from precipitation or river water data

- are helpful tool in identifying potential regions of origin
- **must not be used** as a ‘black box’
- do not account for every isotope effect
- try to understand the regional hydro(geo)logical system for reliable results

Acknowledgments

- Irene Wein, Lars Wunder, Silke Meyer, Christian Hanke (GZN laboratory)
- Sonja Konrad (GZN/LGL)
- Alfons Baier (GZN)
- Laura Balk, Markus Lehner, Hannah Subert (BSc Students)

Isotope ratio mass spectrometer (IRMS)

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Laser spectroscopy (IRIS)

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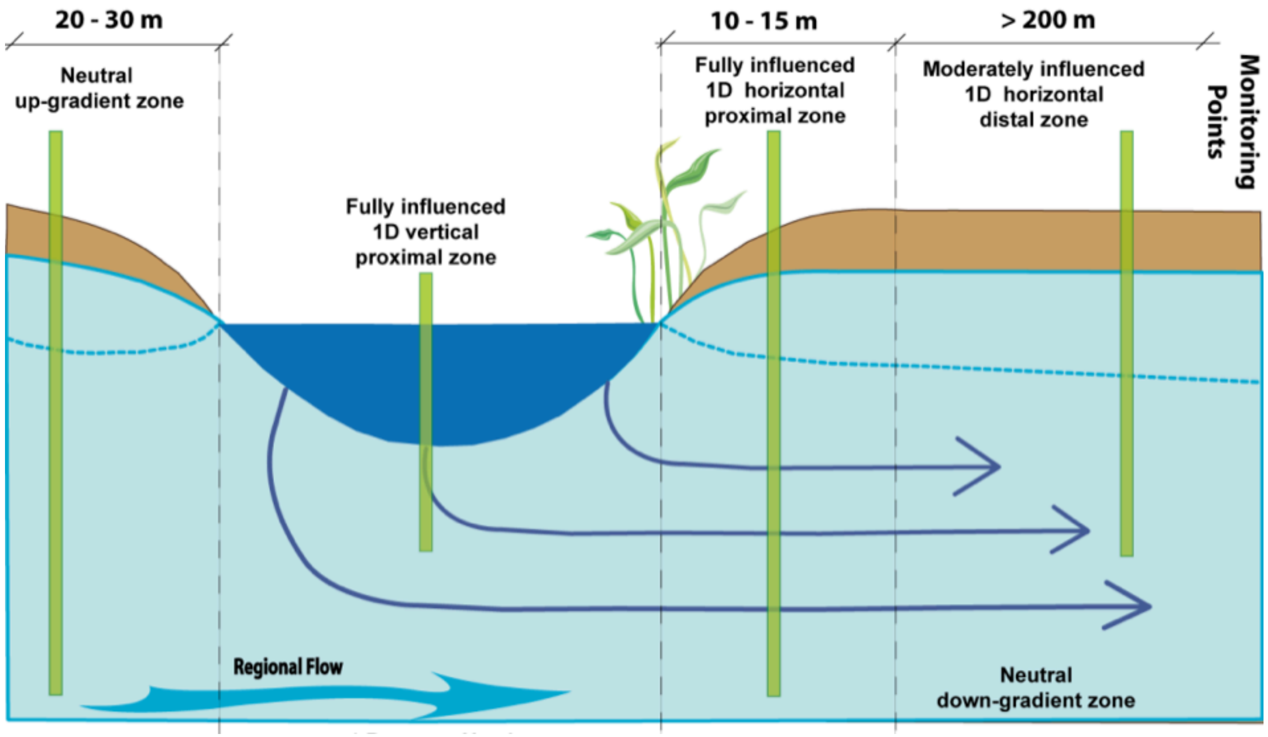
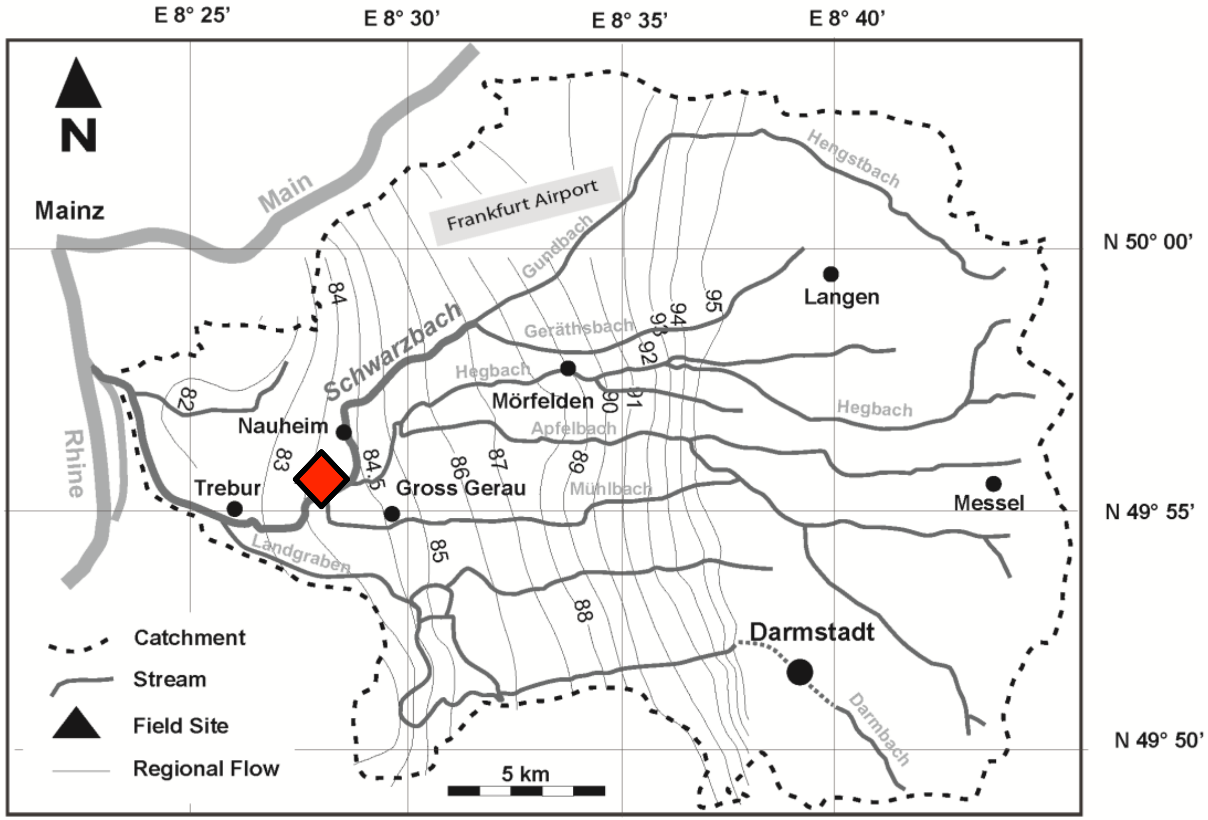
Surface water – groundwater interaction



- Principle hydraulic conditions
  - Infiltration of stream water into groundwater ➔ loosing stream
  - Exfiltration of groundwater into stream ➔ gaining stream
- Potential thread
  - Infiltration of sewage into drinking water wells *via* surface water – groundwater interaction

Study Site



Schwarzbach

- 7 km upstream of the river Rhine
- Intensive agricultural and industrial land use
- Mean discharge with about 50% waste water from sewage water treatment plants (SWTP; municipal and Frankfurt airport)

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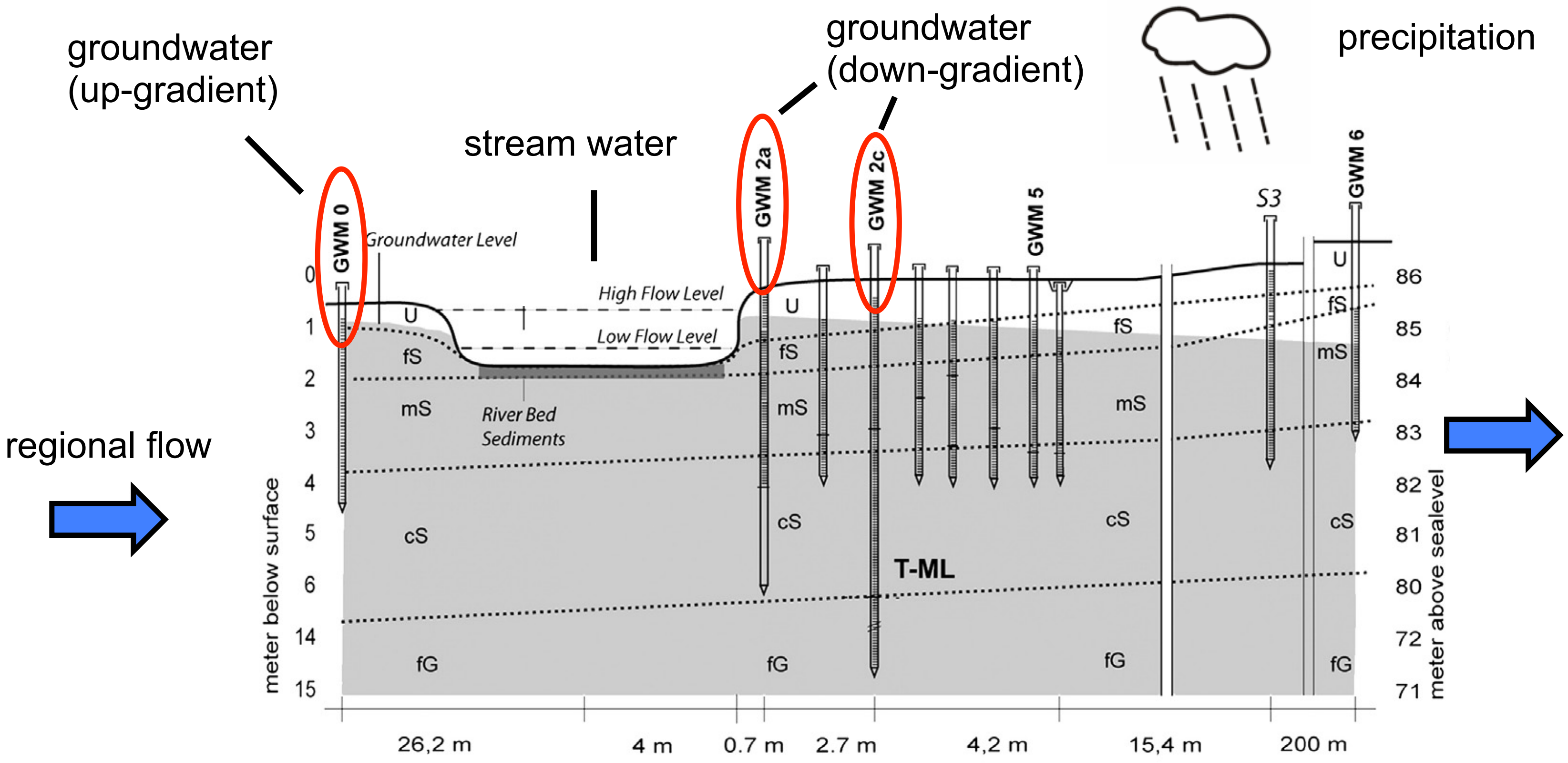
2D transect parallel to flow lines



- Comparative geochemical tracer analyses over 5 months
  - **Stable isotopes** (δ^2H and $\delta^{18}O$)
  - **Artificial sweetener Acesulfam K** ($C_8H_8KN_2O_8S_2$)
  - (X-ray contrast media (Iomeprol) and metabolites)
- Numerical flow (MODFLOW) and transport (MT3DMS) simulation

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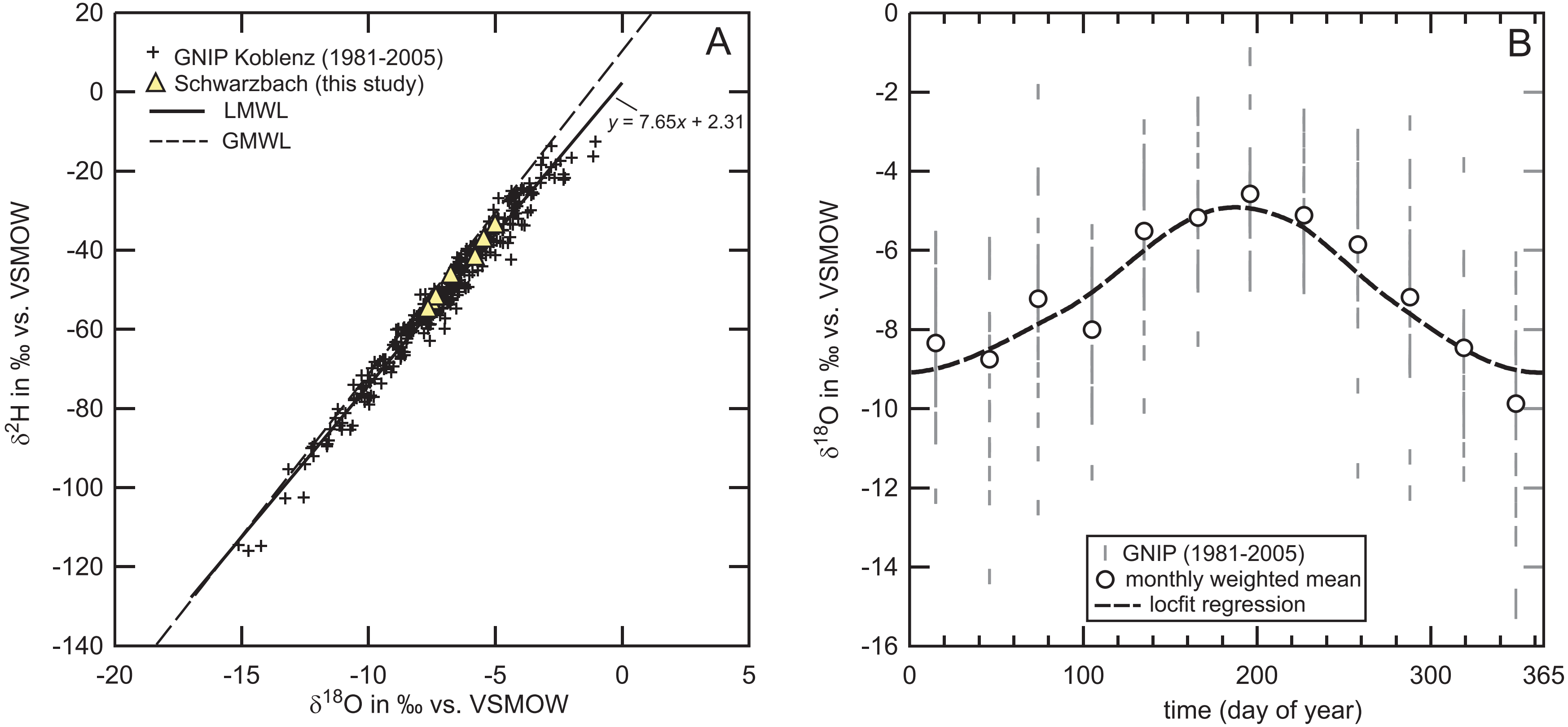
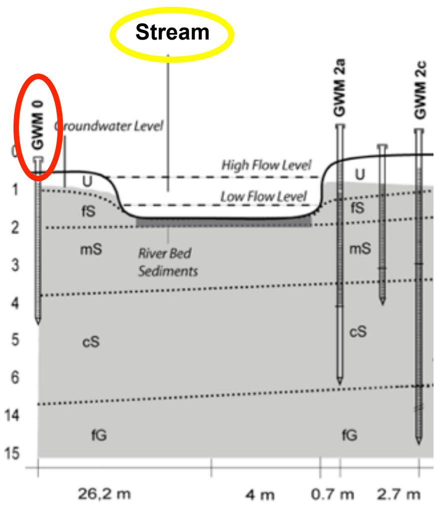
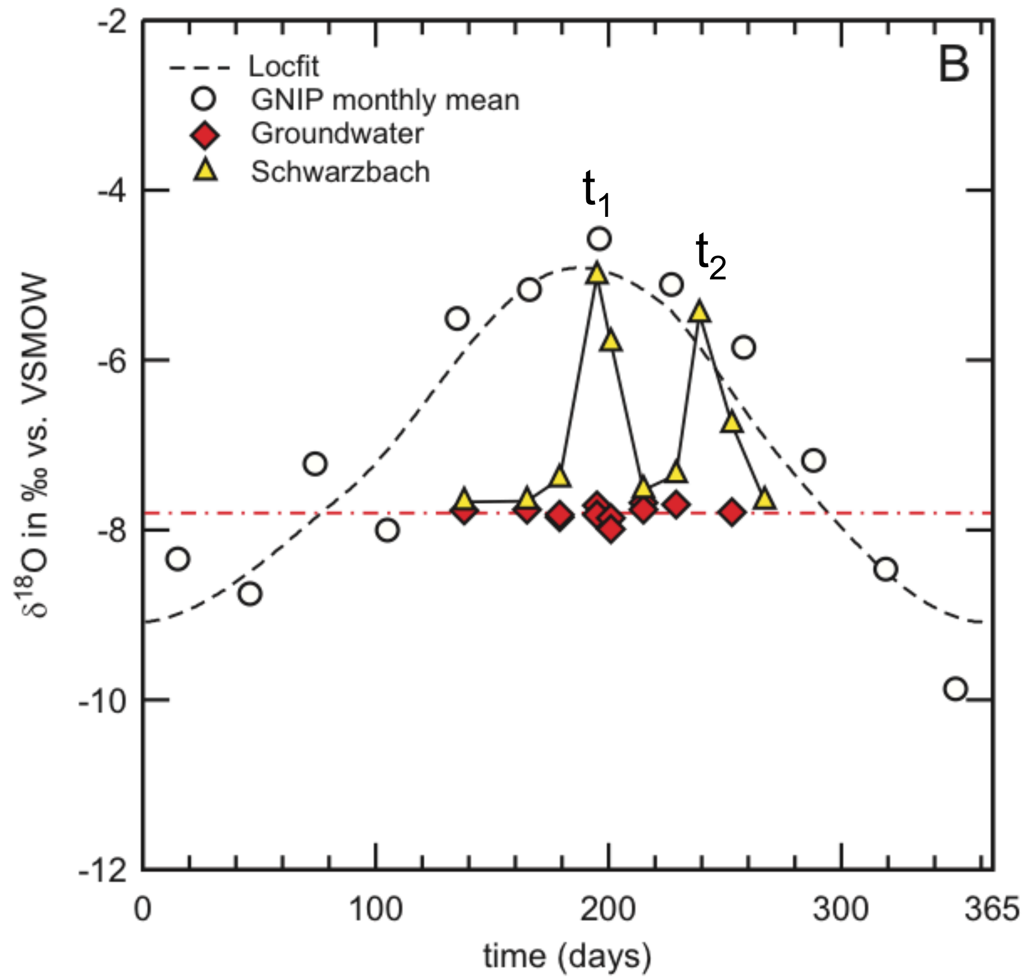
Stable isotopes in precipitation



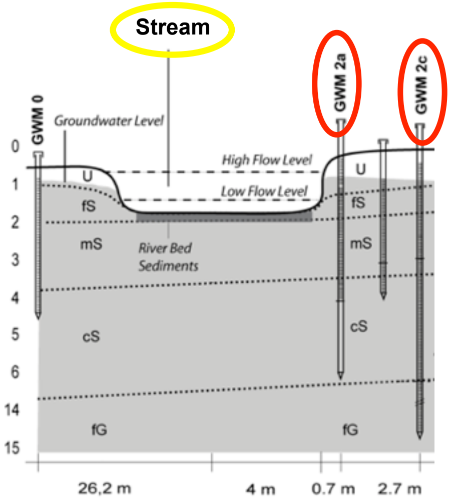
Stable isotopes events

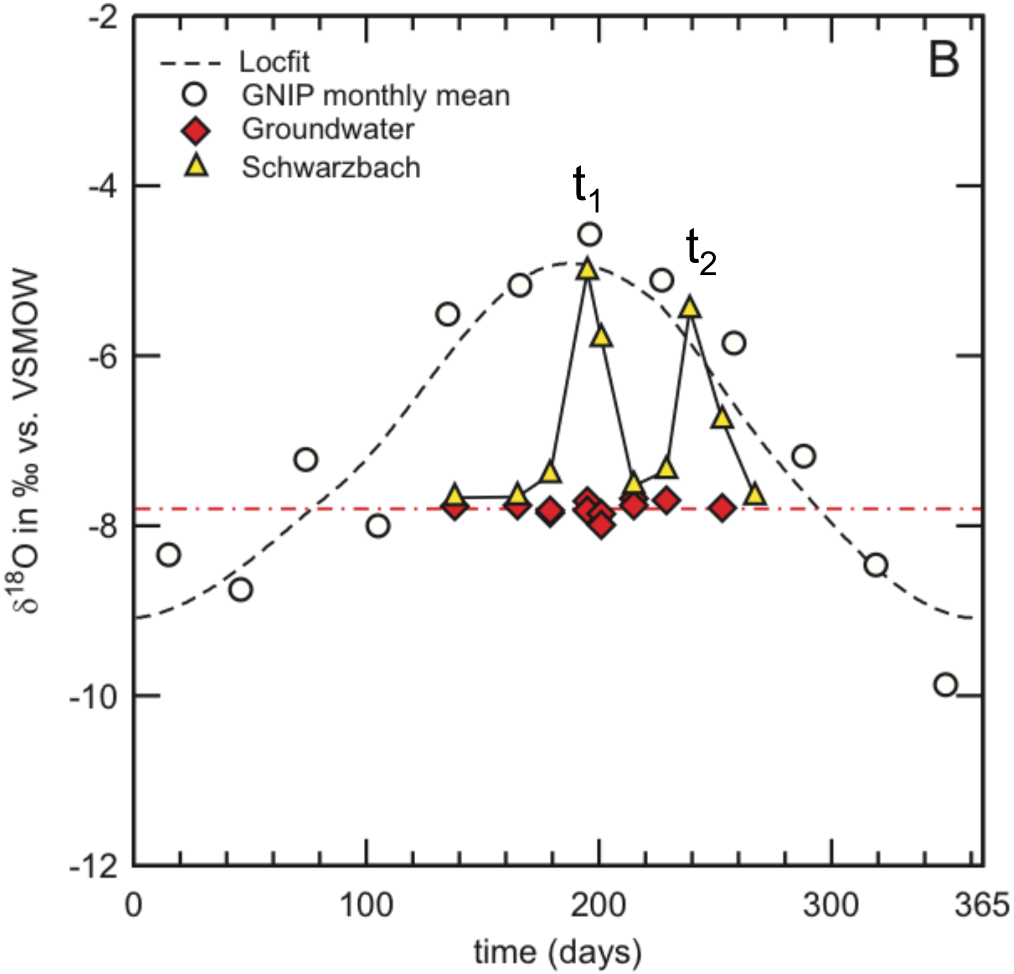


- Stable $\delta^{18}O$ value in groundwater
- Precipitation events traced in stream water



Stable isotopes





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