Quantifying different climatic controls on d-excess and ^{17}O-excess with the isotope-enabled Community Atmosphere Model

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FNSNF Swiss National Science Foundation
NSF
NCAR UCAR CISL Computational & Information Systems Lab

Isotopic fractionation

Equilibrium effect

Heavy isotopes have higher binding energies

$\delta D, \delta^{18}O, \delta^{17}O$

$\delta = R - 1$

R = isotope ratio relative to VSMOW

$H_2{}^{16}O$ $HD^{16}O$ $H_2{}^{18}O$ $H_2{}^{17}O$

Non-equilibrium effect

Heavy isotopes have slower diffusion velocities

$$d = \delta D - 8 \cdot \delta^{18}O$$

(Dansgaard, 1964)

$$\Delta^{17}O = \ln R^{17O} - 0.528 \cdot \ln R^{18O}$$

(Barkan and Luz, 2007)

$$d_{\ln} = \ln R^{D} - 8.47 \cdot \ln R^{18O} + 28.5 \cdot (\ln R^{18O})^2$$

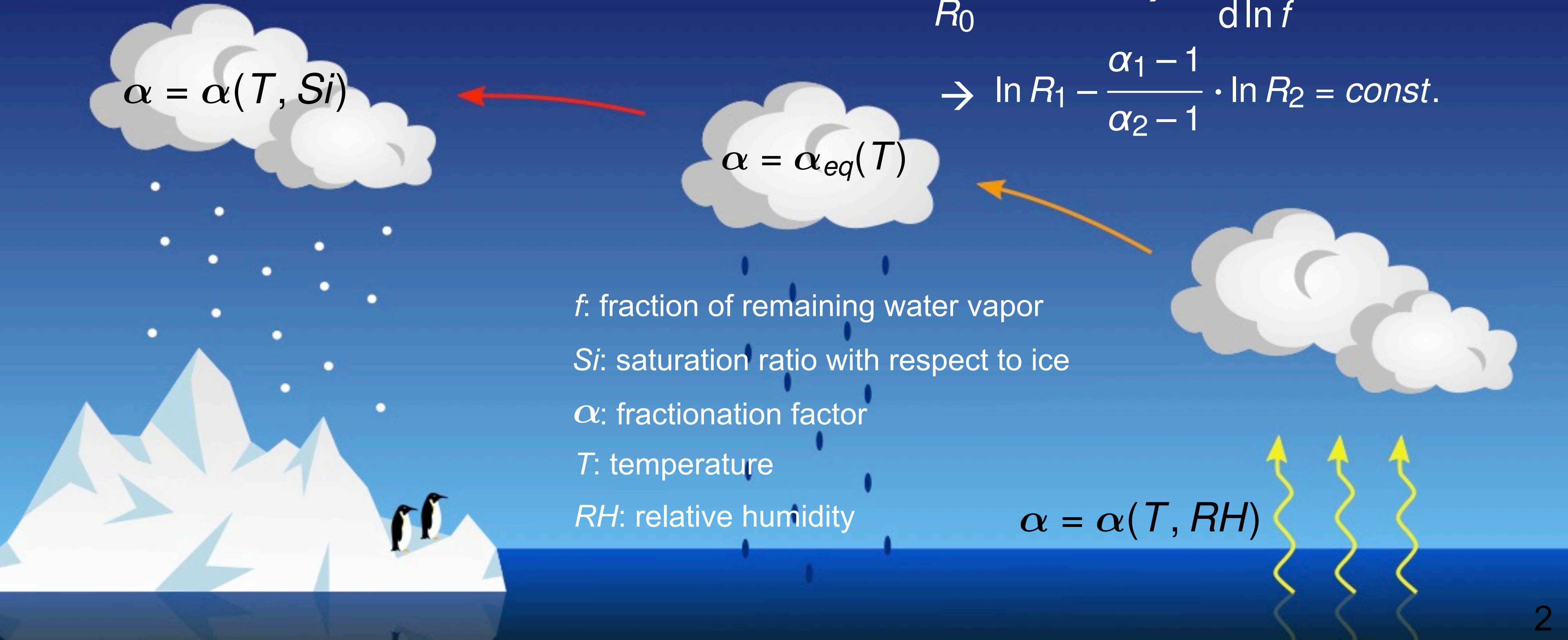
(Uemura et al., 2012)

Why a logarithmic definition?

Rayleigh condensation

$$\frac{R}{R_0} = f^{\alpha-1} \rightarrow \frac{d\ln R}{d\ln f} = \alpha - 1$$

$$\rightarrow \ln R_1 - \frac{\alpha_1 - 1}{\alpha_2 - 1} \cdot \ln R_2 = const.$$



f: fraction of remaining water vapor

Si: saturation ratio with respect to ice

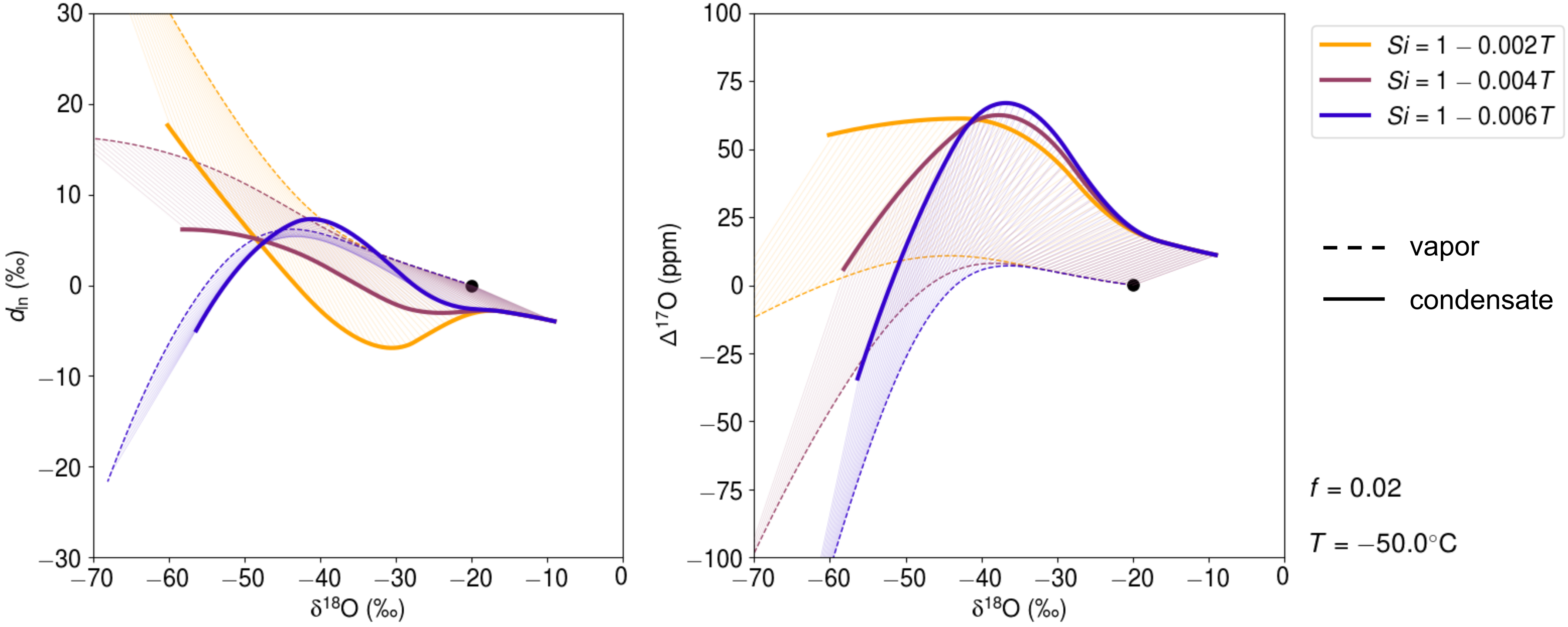
α: fractionation factor

T: temperature

RH: relative humidity

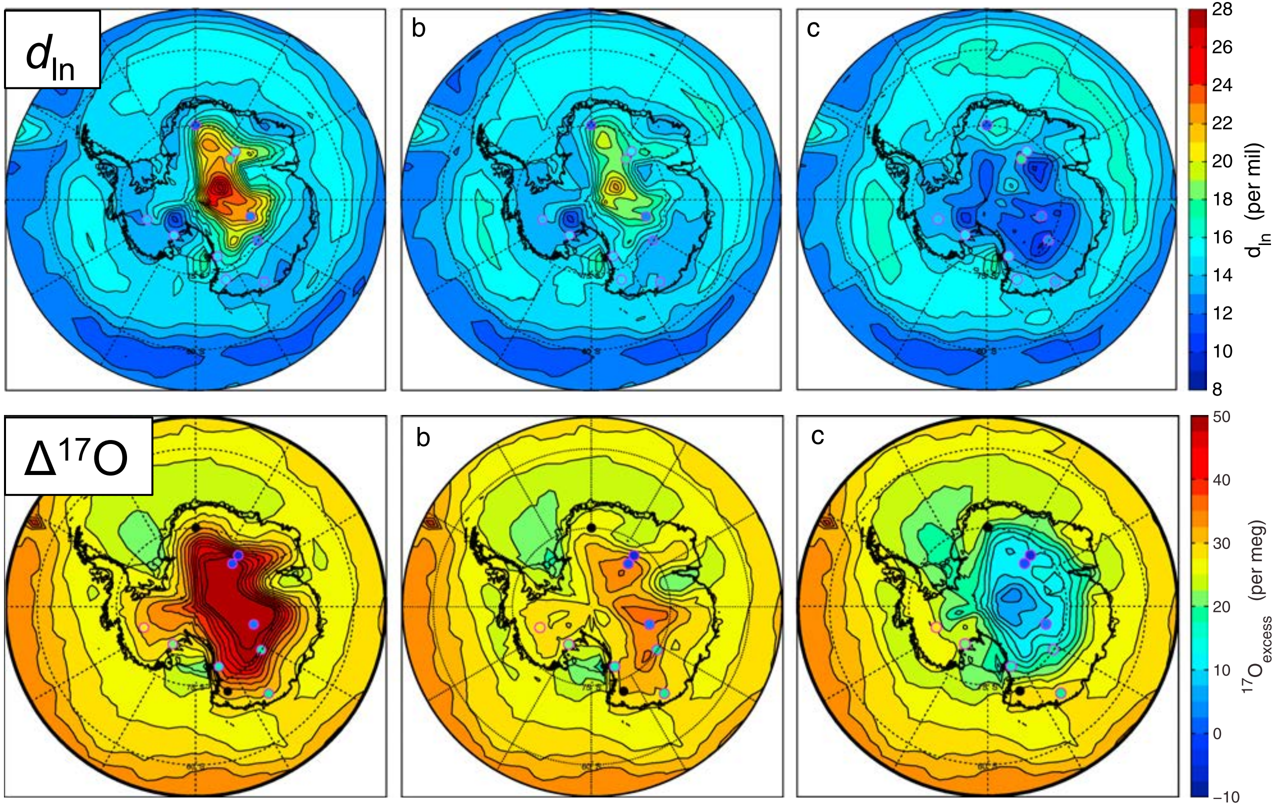
Rayleigh condensation

$$\frac{R}{R_0} = f^{\alpha-1}$$



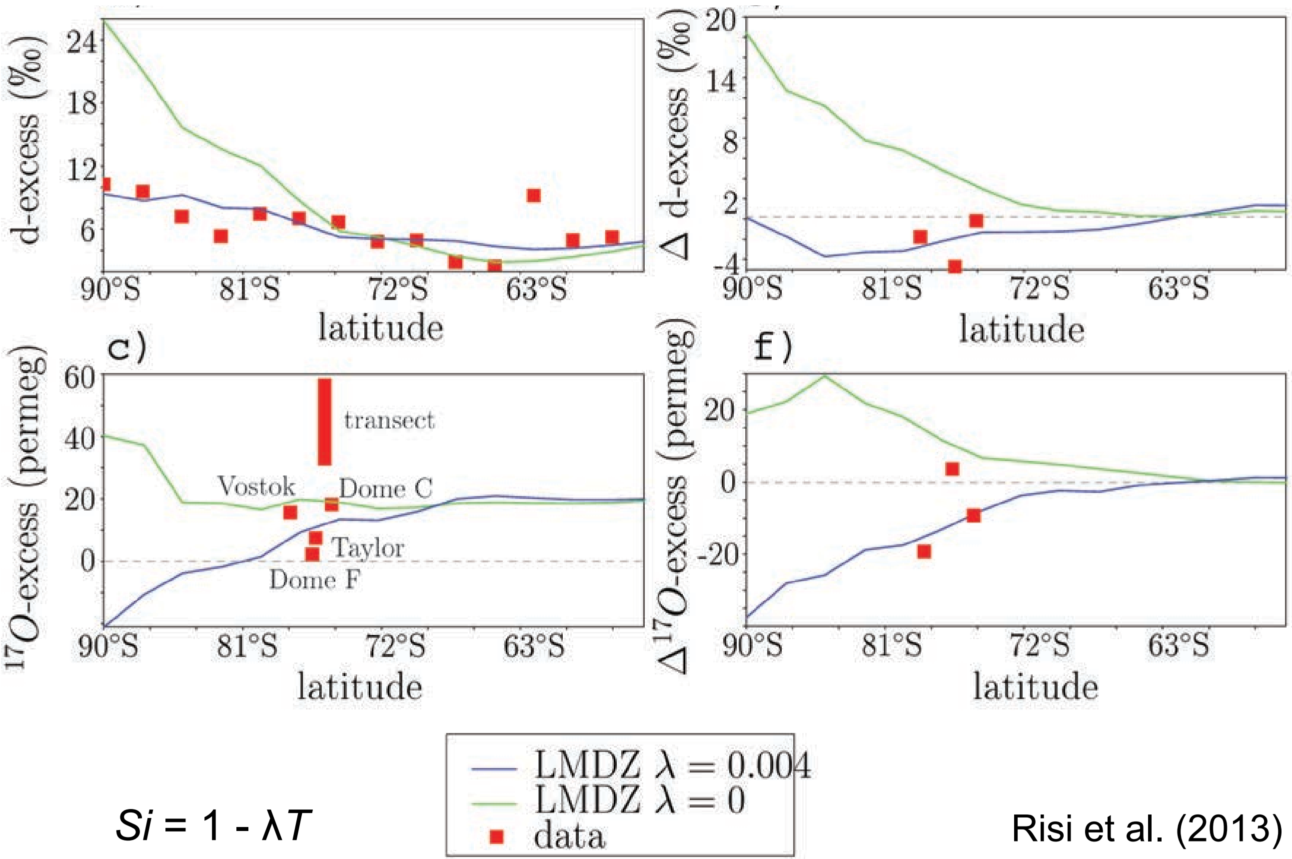
Modeling d_{ln} and (especially) $\Delta^{17}O$ is challenging

$Si = 1 - 0.002T$ $\quad$ $Si = 1 - 0.004T$ $\quad$ $Si = 1 - 0.007T$



Schoenemann et al. (2014)

Modeling d_{ln} and (especially) $\Delta^{17}O$ is challenging



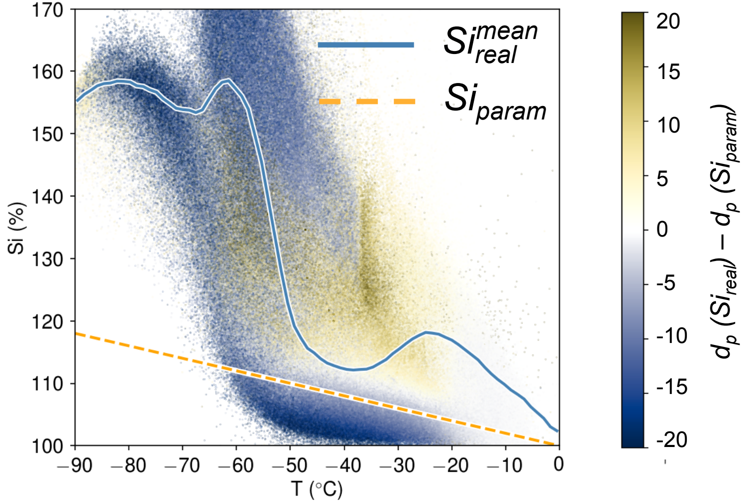
Si = 1 - λ*T*

Risi et al. (2013)

iCAM5

Microphysics scheme allows supersaturation with respect to ice
(Gettelman et al., 2010, Morrison & Gettelman, 2008)

→ using model-predicted *Si* for isotopes improves simulation of *d* in Antarctica
(Dütsch et al., under review)



Simulations

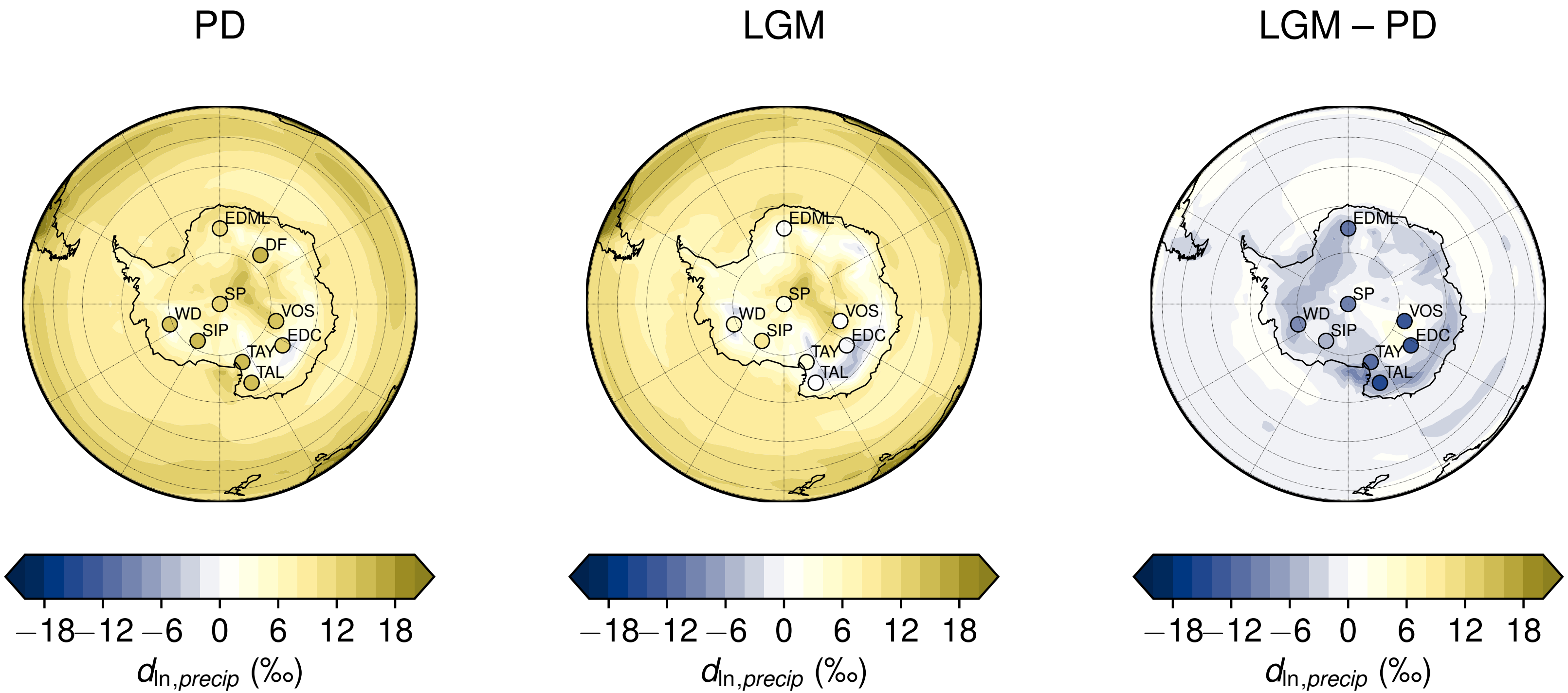
- Present day and last glacial maximum
- 10 years (+ 1 year spin-up)
- iCAM5 (Nusbaumer et al., 2017), iCLM4 (Wong et al., 2017), iCICE4 (Brady et al., 2019)
- Prescribed SST and sea ice concentrations (Hurrell et al., 2008, Zhu et al., 2017)
- 1.9° x 2.5° horizontal resolution

Objective

Quantify the contributions of

- evaporation from the surface
- transport
- cloud formation … on d_{ln} and $\Delta^{17}O$

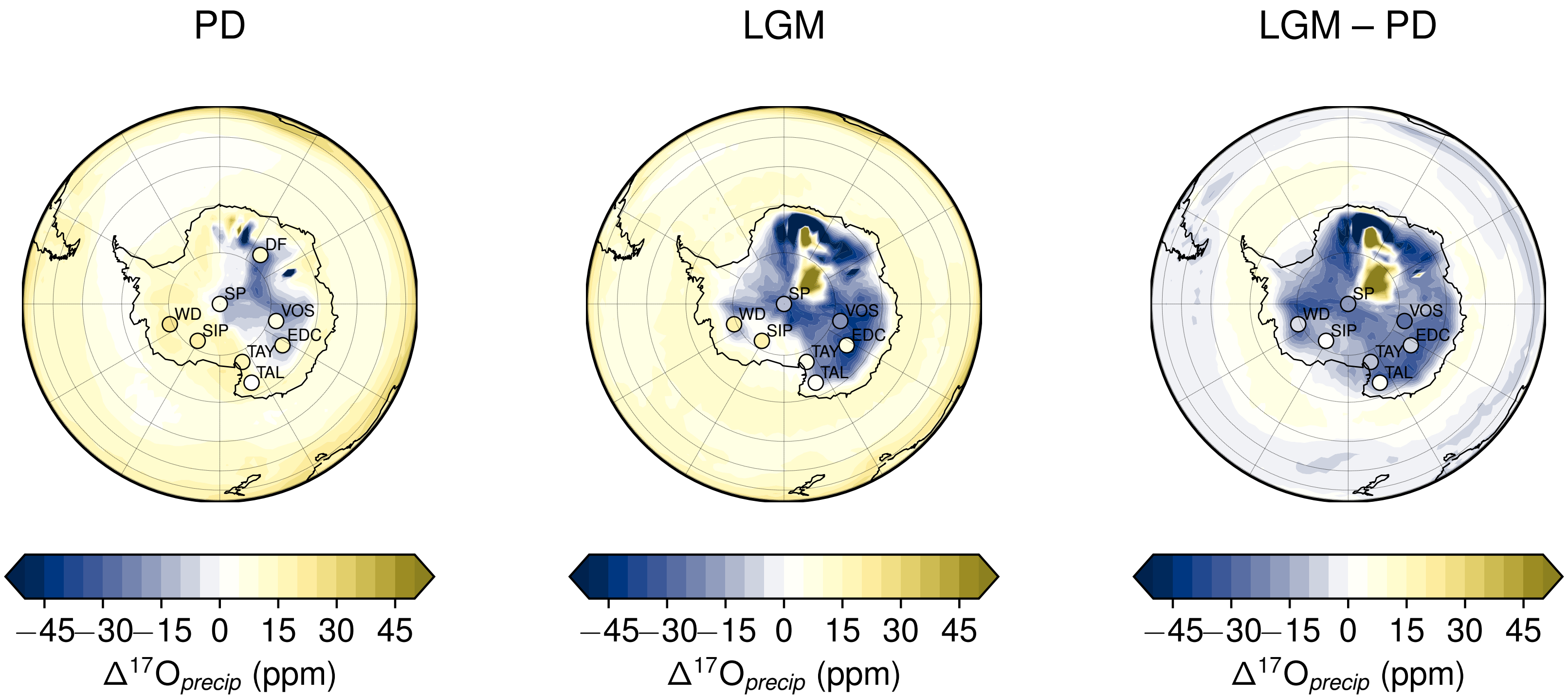
d_{ln} in iCAM5 and ice cores



DF: Dome F (Fujita and Abe, 2006; Touzeau et al., 2016)
EDC: EPICA Dome C (Jouzel et al., 2007; Stenni et al., 2010)
EDML: EPICA Dronning Maud Land (EPICA Community Members, 2006; Stenni et al., 2010)
SIP: Siple Dome (Brook et al., 2005; Schoenemann et al., 2014)

SP: South Pole (Steig, unpublished data)
TAY: Taylor Dome (Steig et al., 1998; Schoenemann et al., 2014)
TAL: Talos Dome (Buiron et al., 2012; Landais et al., 2015; Stenni et al., 2011)
VOS: Vostok (Vimeux et al., 2001; Landais et al., 2008, 2012; Risi et al., 2013)
WD: WAIS Divide (Markle et al., 2017; WAIS Divide Project Members, 2013, 2015)

$\Delta^{17}O$ in iCAM5 and ice cores



DF: Dome F (Fujita and Abe, 2006; Touzeau et al., 2016)
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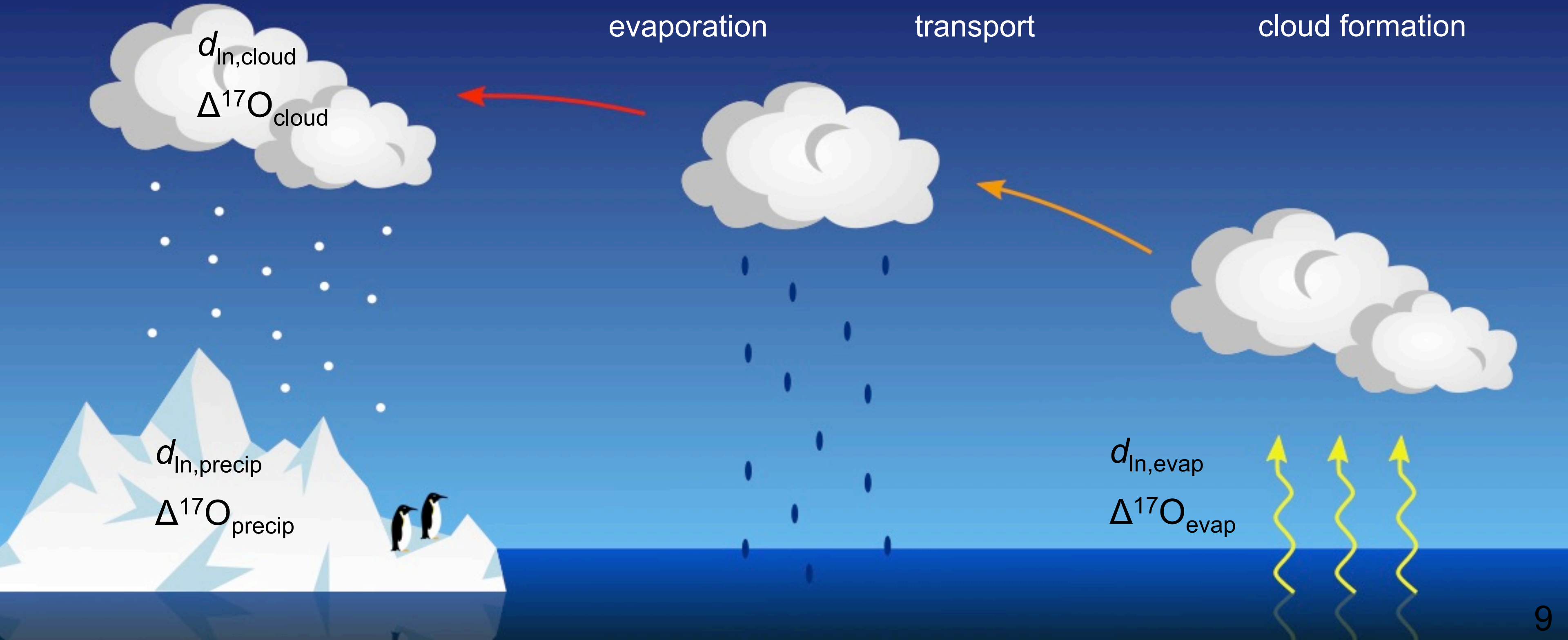
Contributions of different processes to $d_{\ln}$ and $\Delta^{17}O$

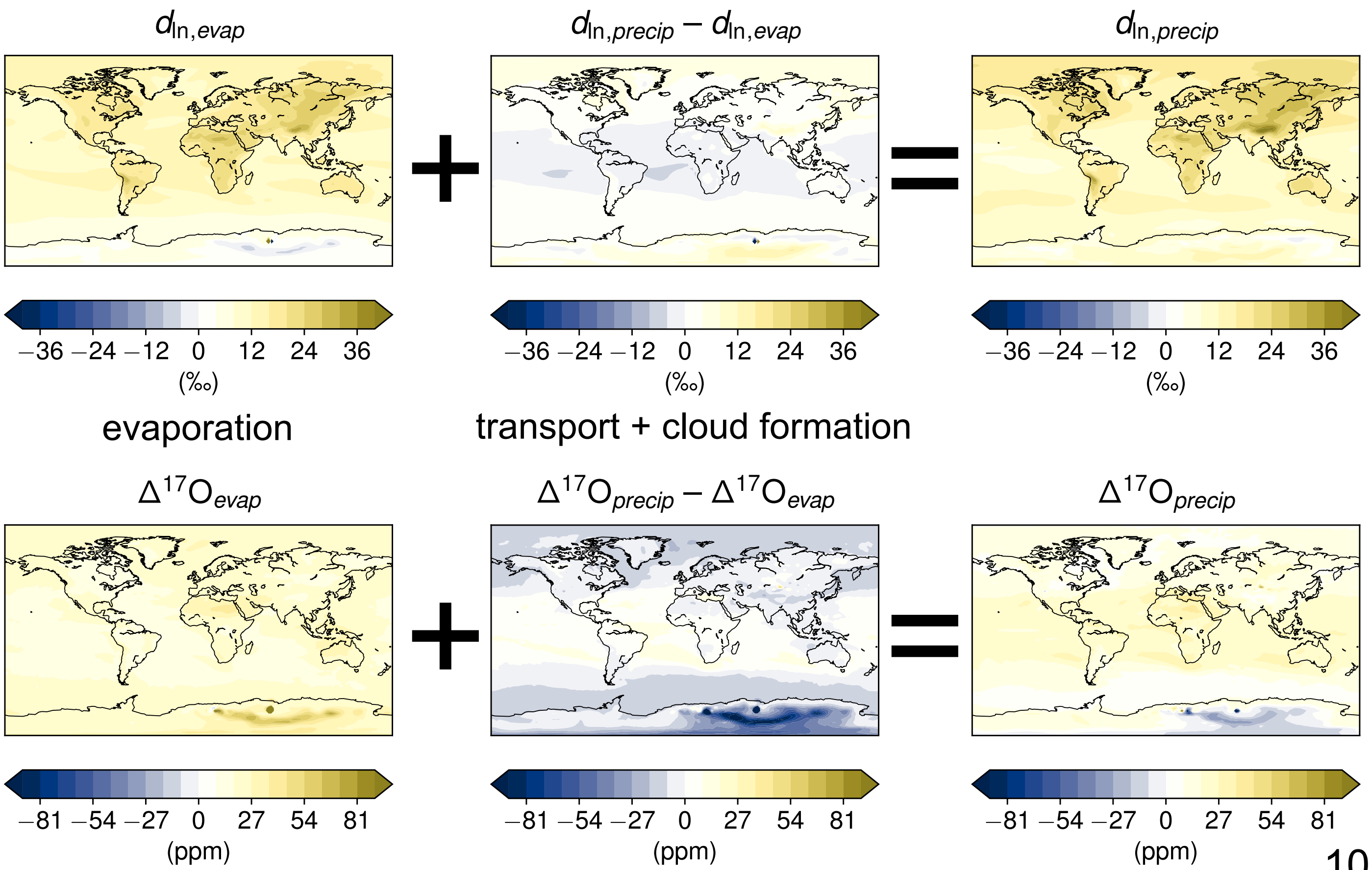
$$d_{\ln,\mathrm{precip}} = d_{\ln,\mathrm{evap}} + (d_{\ln,\mathrm{cloud}} - d_{\ln,\mathrm{evap}}) + (d_{\ln,\mathrm{precip}} - d_{\ln,\mathrm{cloud}})$$

$$\Delta^{17}O_{\mathrm{precip}} = \Delta^{17}O_{\mathrm{evap}} + (\Delta^{17}O_{\mathrm{cloud}} - \Delta^{17}O_{\mathrm{evap}}) + (\Delta^{17}O_{\mathrm{precip}} - \Delta^{17}O_{\mathrm{cloud}})$$

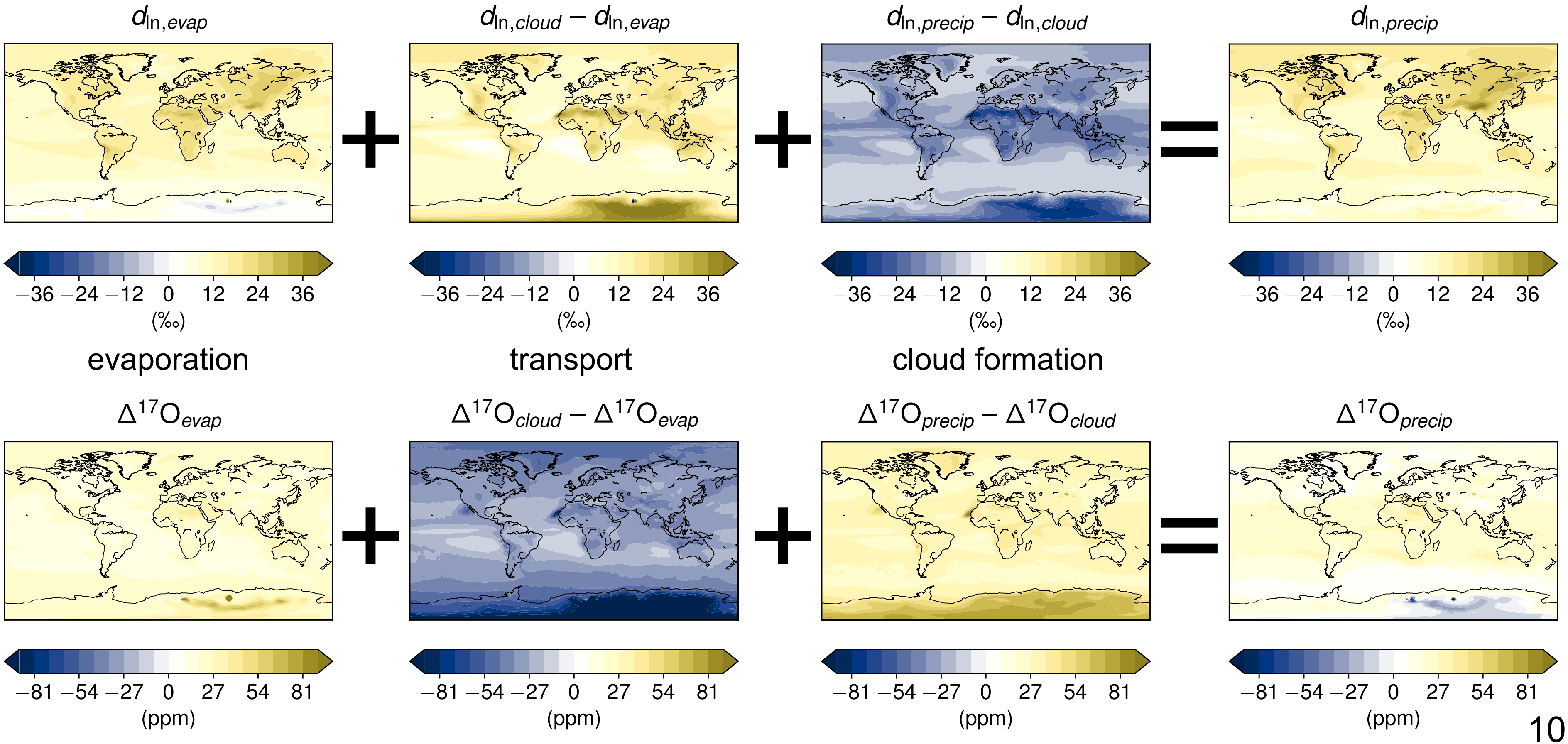
evaporation | transport | cloud formation



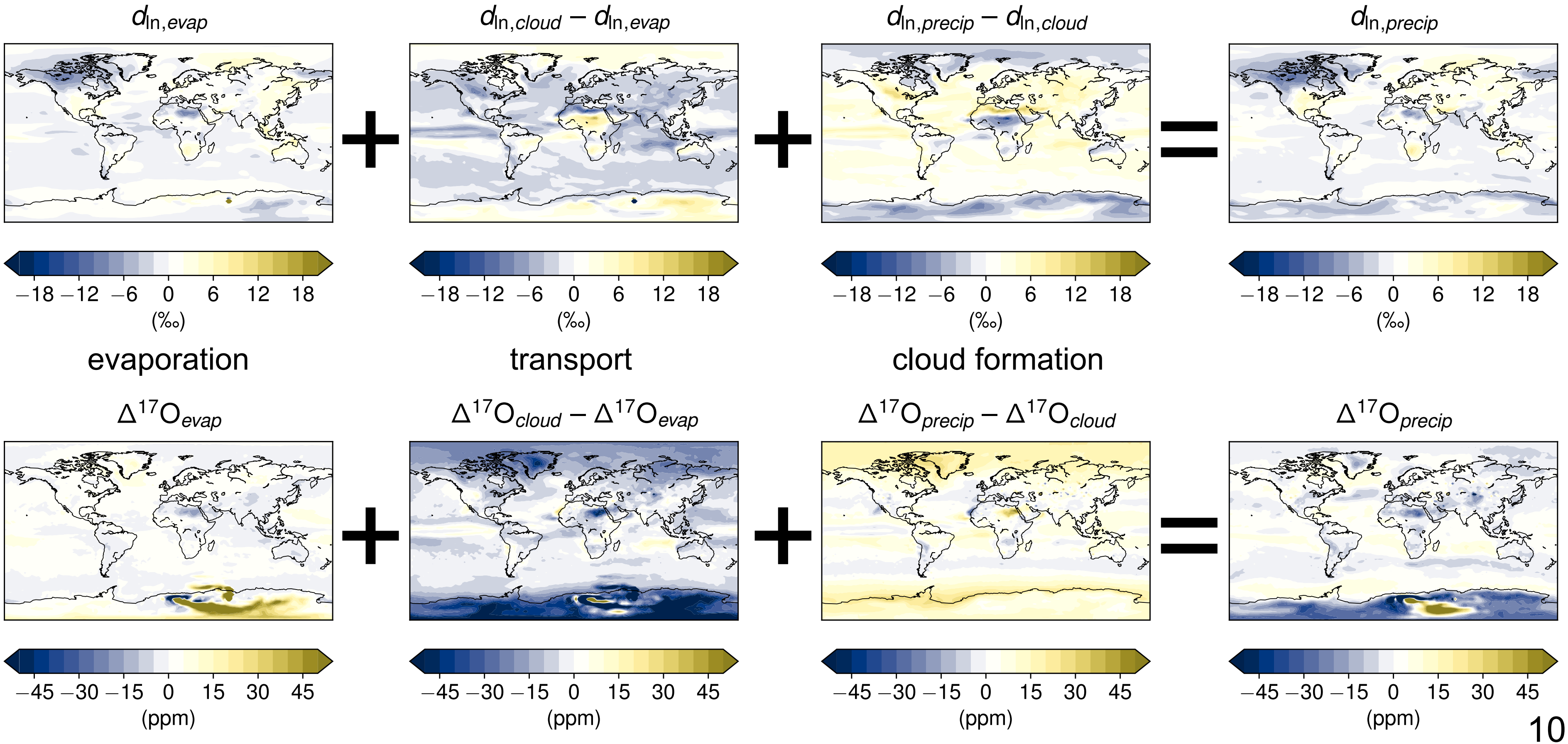
Contributions of different processes to d_{ln} and $\Delta^{17}O$ (PD)



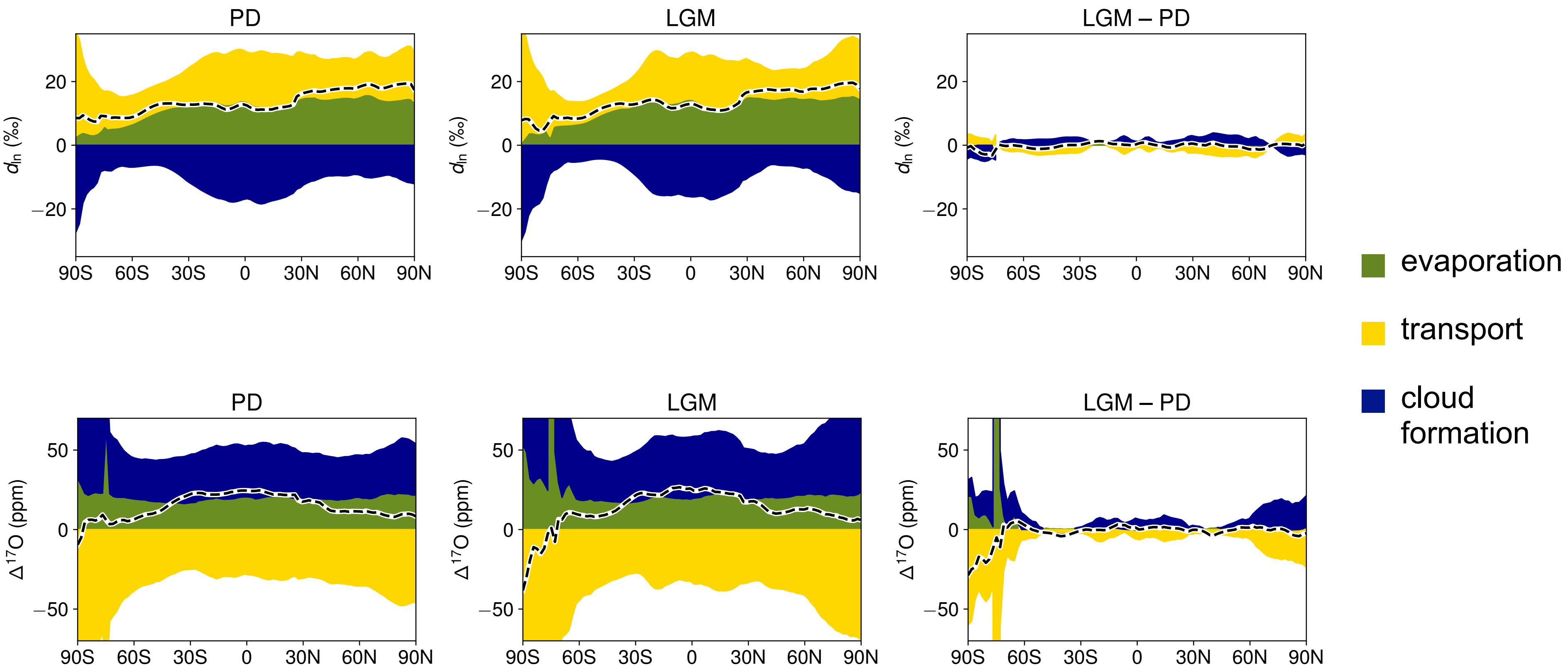
Contributions of different processes to d_{ln} and $\Delta^{17}O$ (PD)



Contributions of different processes to d_{ln} and $\Delta^{17}O$ (LGM –PD)



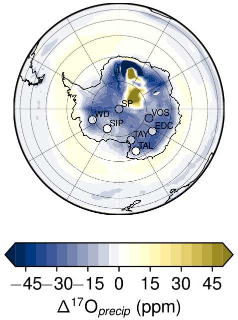
Zonal mean contribution of processes



Summary

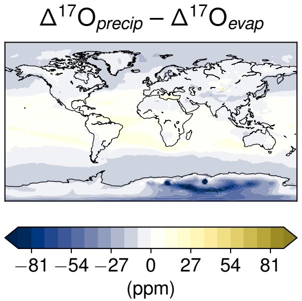
iCAM5 can simulate $\Delta^{17}O$ (and d_{ln}) in present day climate and during the last glacial maximum

- d_{ln} in iCAM5 is lower in present-day climate and slightly higher during the last glacial maximum than in ice cores
- $\Delta^{17}O$ in iCAM5 is mostly lower than in ice cores



$\Delta^{17}O$ and d_{ln} change significantly on the way from the moisture source to the precipitation site

- The effects of transport (including rainout and mixing) and cloud formation partially compensate each other, but not everywhere



Evaporation from the surface increases both $\Delta^{17}O$ and d_{ln}, transport and cloud formation have opposite effects on $\Delta^{17}O$ and d_{ln}

- Potential for combined metric to isolate the effect of moisture source conditions?