Stable water isotope signals in tropical ice clouds in the West African monsoon simulated with regional convection-permitting model

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International partnership for cirrus studies (PIRE)
https://www.pire-cirrus.org

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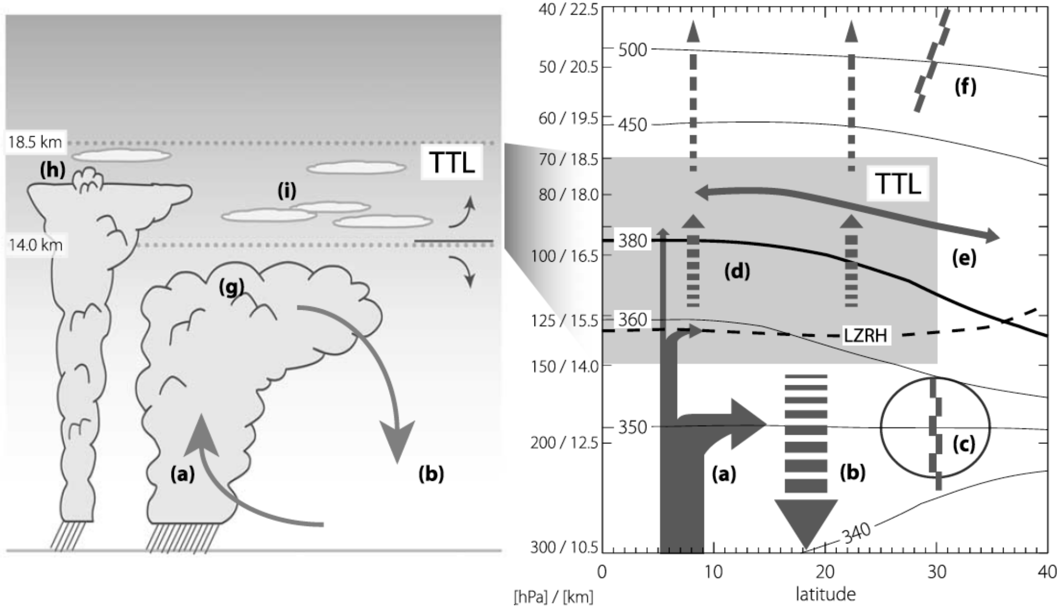
Tropical cirrus

Importance for the Earth's radiative balance

Tropical ice clouds
- Convection
- Large-scale uplift

Tropical tropopause layer (TTL)
- Transition troposphere to stratosphere
- Water budget



Fueglistaler et al., 2009

Use stable water isotopes to study these processes in the West African monsoon:
1. **Precipitation for model evaluation**
2. **Tropical ice cloud formation & decay**
3. **Influence of deep convection on the TTL water budget**

Regional model simulations

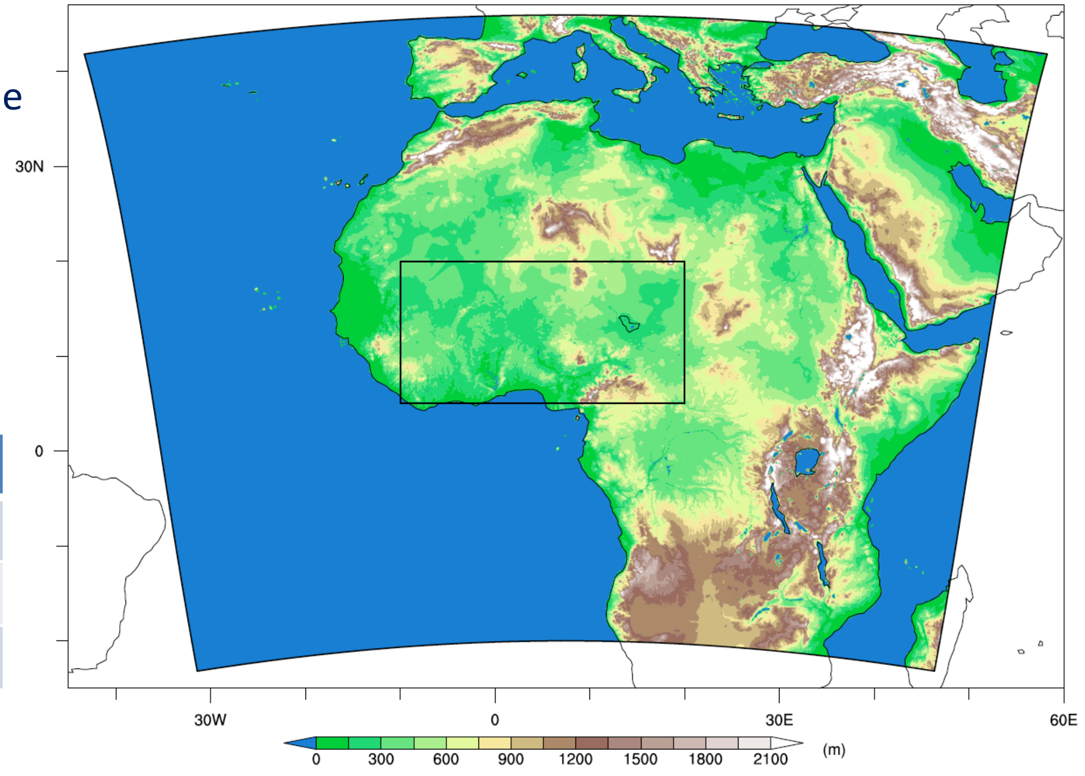
$COSMO_{iso}$ simulations (*Pfahl et al., 2012*)

- June-**July** 2016
- ECHAM5wiso (*Martin Werner*)
- One-moment bulk microphysics scheme

vapour
cloud ice
snow
=> **ice**
cloud water
rain

	resolution	Δt	convection
PAR14	14 km, 40 levs	60 s	param.
EXPL14	14 km, 40 levs	60 s	explicit
EXPL7	**7 km, 60 levs**	**40 s**	**explicit**

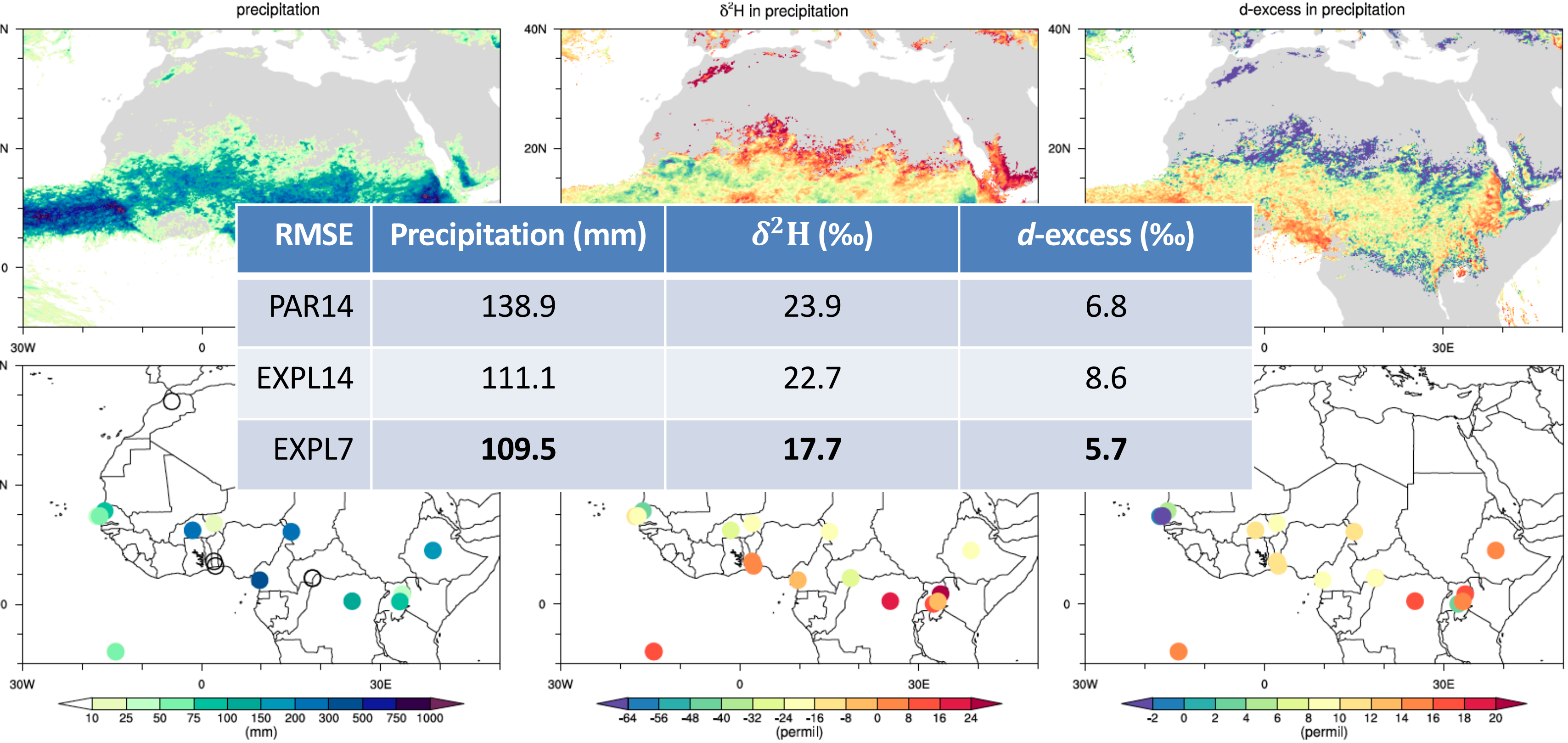
Model domain & topography



Precipitation (July 2016)

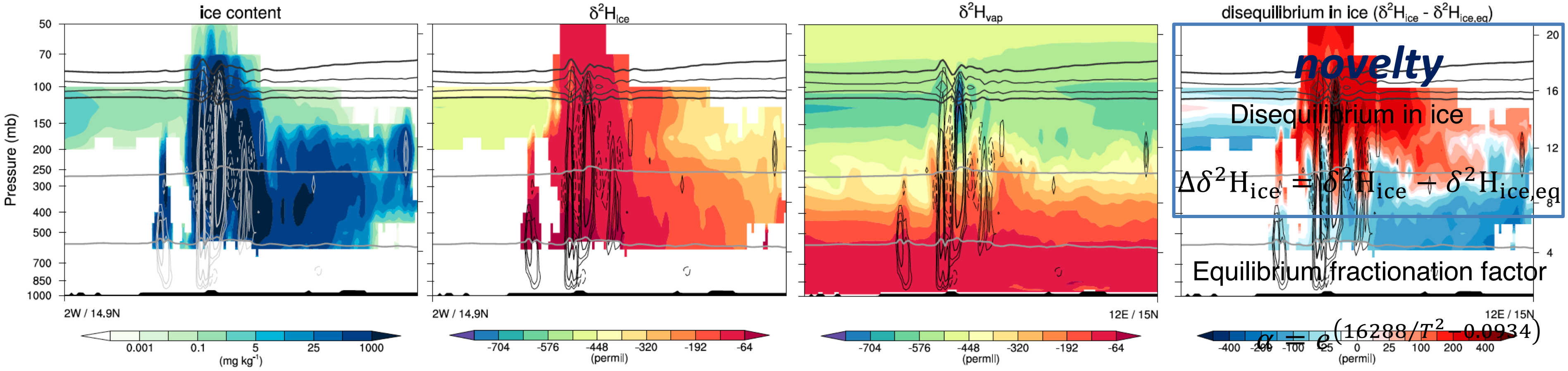
EXPL7

GNIP



RMSE	Precipitation (mm)	δ^2H (‰)	*d*-excess (‰)
PAR14	138.9	23.9	6.8
EXPL14	111.1	22.7	8.6
EXPL7	**109.5**	**17.7**	**5.7**

Case study of a Mesoscale Convective System



novelty

Disequilibrium in ice

$$\Delta\delta^2\mathrm{H}_{\mathrm{ice}} = \delta^2\mathrm{H}_{\mathrm{ice}} - \delta^2\mathrm{H}_{\mathrm{ice,eq}}$$

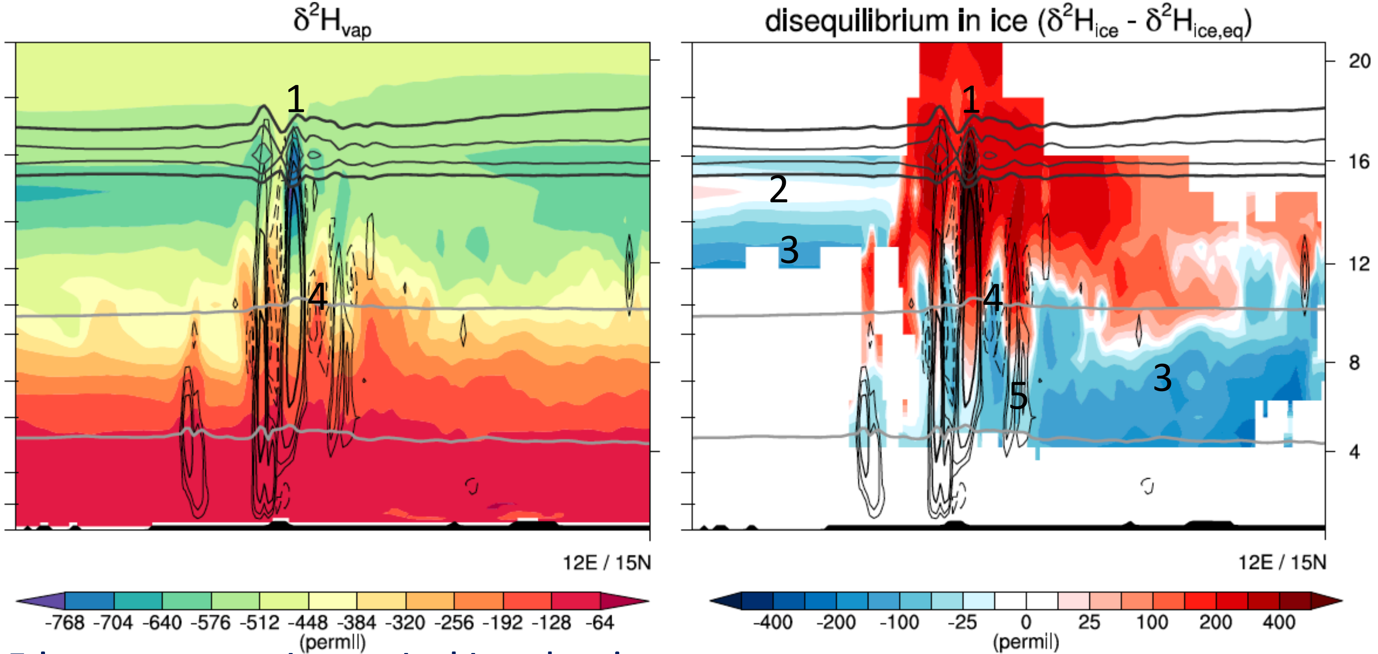
Equilibrium fractionation factor

$$\alpha = e^{(16288/T^2 - 0.0934)}$$

Merlivat and Nief (1967)
Rowley and Garzione (2007)

T=0°C and -38°C (light grey)
T=191, 193, 195K (dark grey)
W>0.5 m s^{-1} (solid black)
W<-0.5 m s^{-1} (dashed black)

Case study of a Mesoscale Convective System



5 key processes in tropical ice clouds

1) Convective ice lofting
2) In situ ice formation under equilibrium fractionation
3) Sedimentation and sublimation
4) Sublimation in downdrafts that enriches ambient vapour
5) Freezing of liquid water in updrafts

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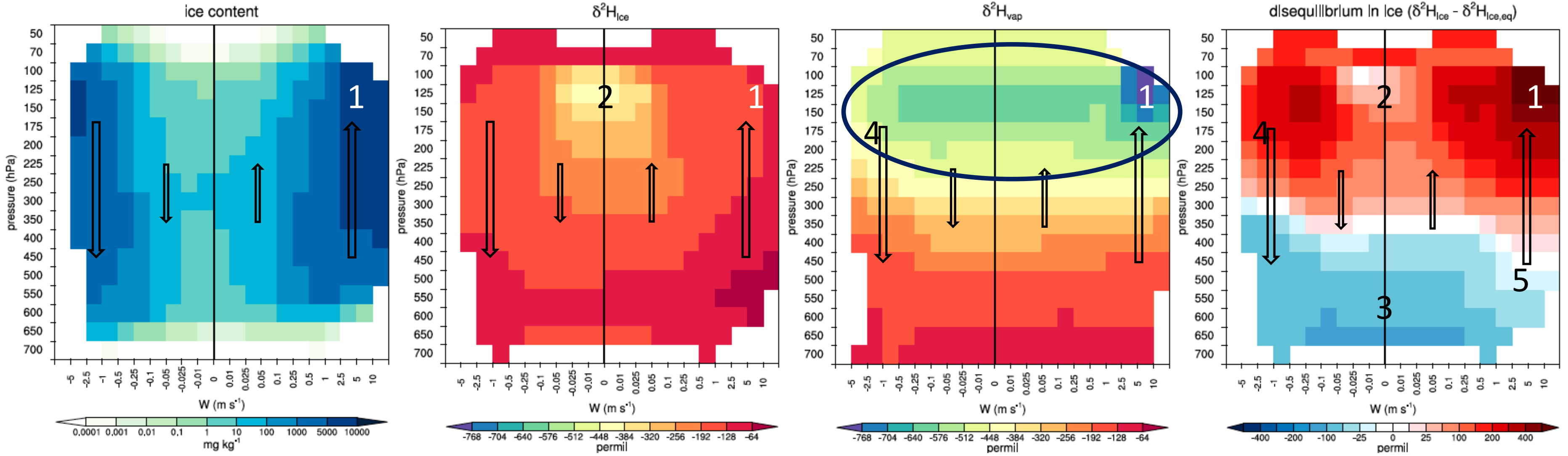
Convective updrafts and downdrafts (July 2016)



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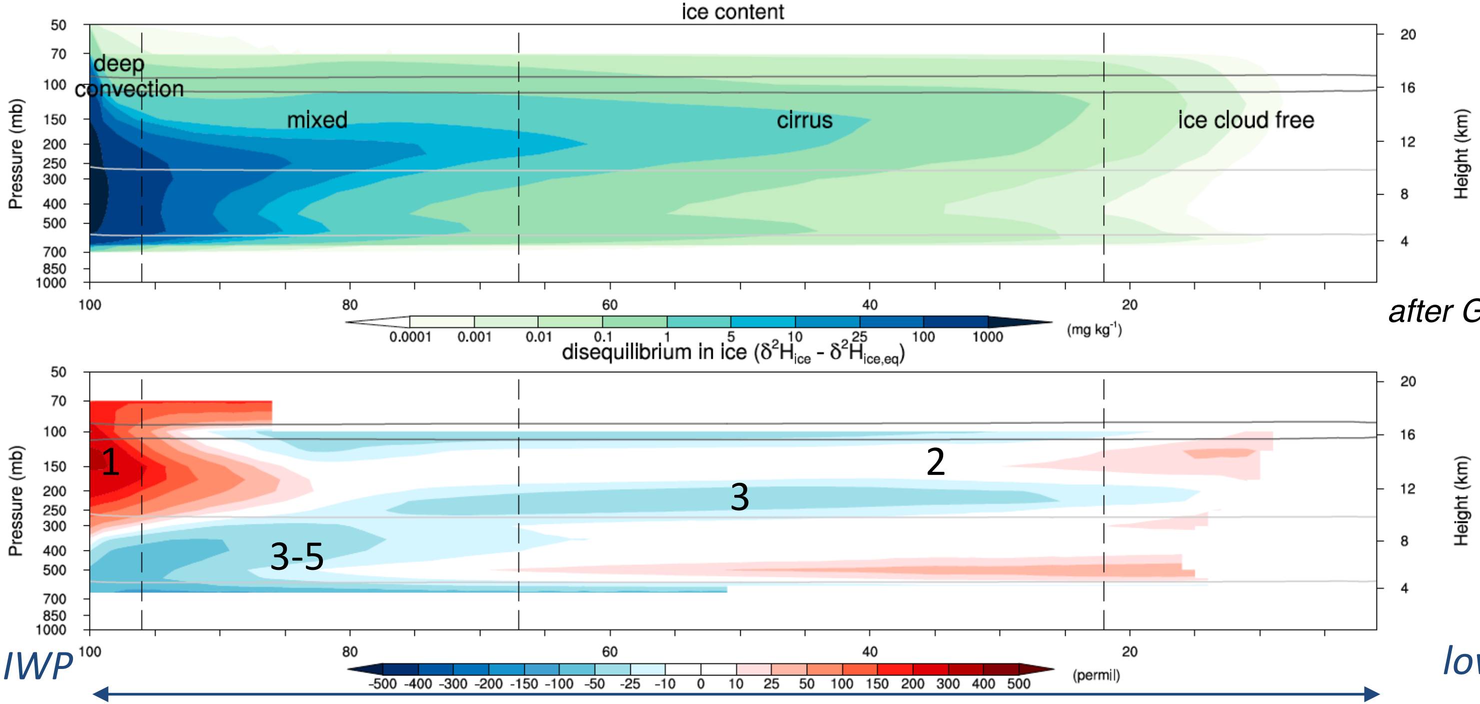
δ^2H in vapour – 800 ‰ to – 400 ‰

Consistent with observations (*Webster & Heymsfield, 2003; Hanisco et al., 2007; Sayres et al., 2010*)

Ice cloud classification

Ice cloud classifications (Sokol and Hartmann, 2020; Nugent et al., 2021; Turbeville et al., 2021):

- Deep convection IWP > 1 kg m^{-2}
- Mixed 0.01 < IWP < 1 kg m^{-2}
- Cirrus 0.01 < IWP < 1 kg m^{-2}
- Ice cloud free IWP < 0.0001 kg m^{-2}



after Gasparini et al. (2019)

high IWP *low IWP*

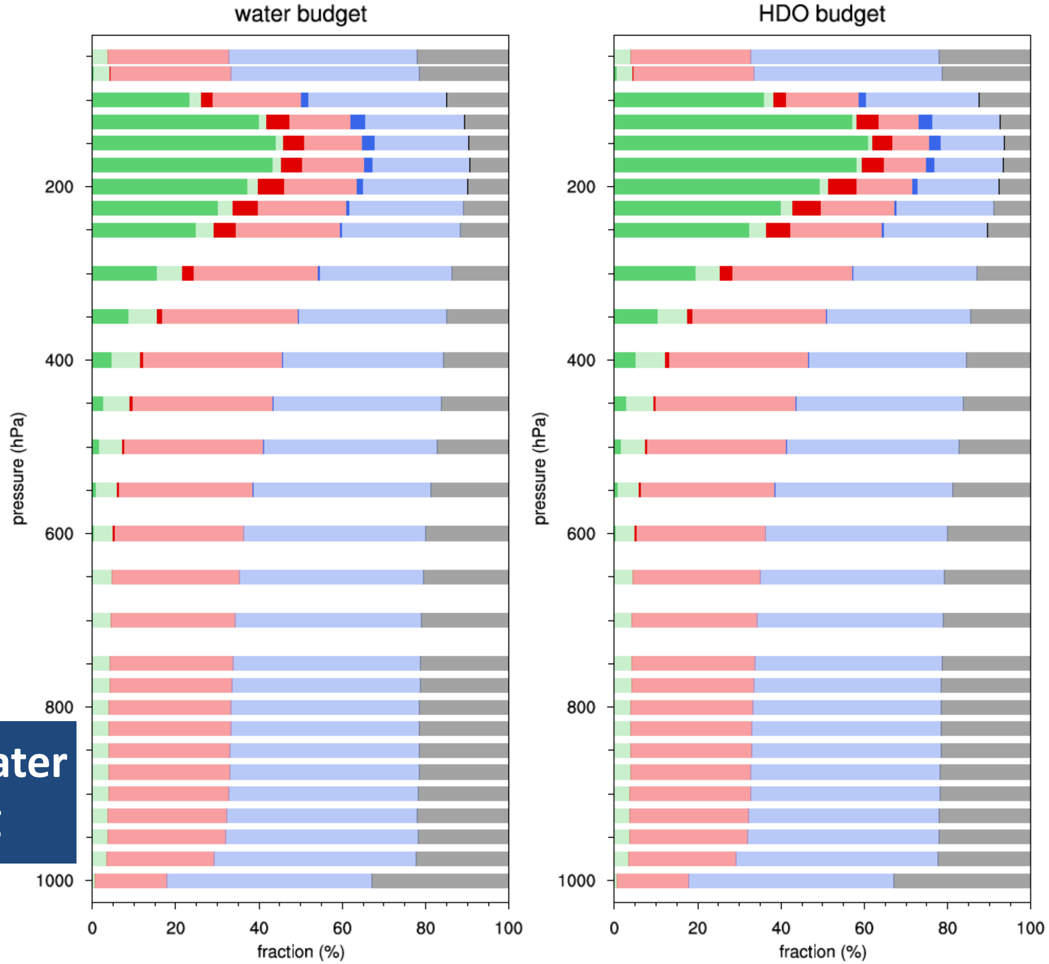
Water budget TTL

Ice cloud classifications
- Deep convection (3.8 %)
- Mixed (28.7 %)
- Cirrus (45.2 %)
- Ice cloud free (22.3 %)

water = vapour + cloud ice + snow
+ cloud water + rain

Deep convection in lower TTL
- > 40 % water
- ~ 60% HDO
- most water in ice phase

Key role of deep convection in TTL water budget through convective ice lofting



Conclusions

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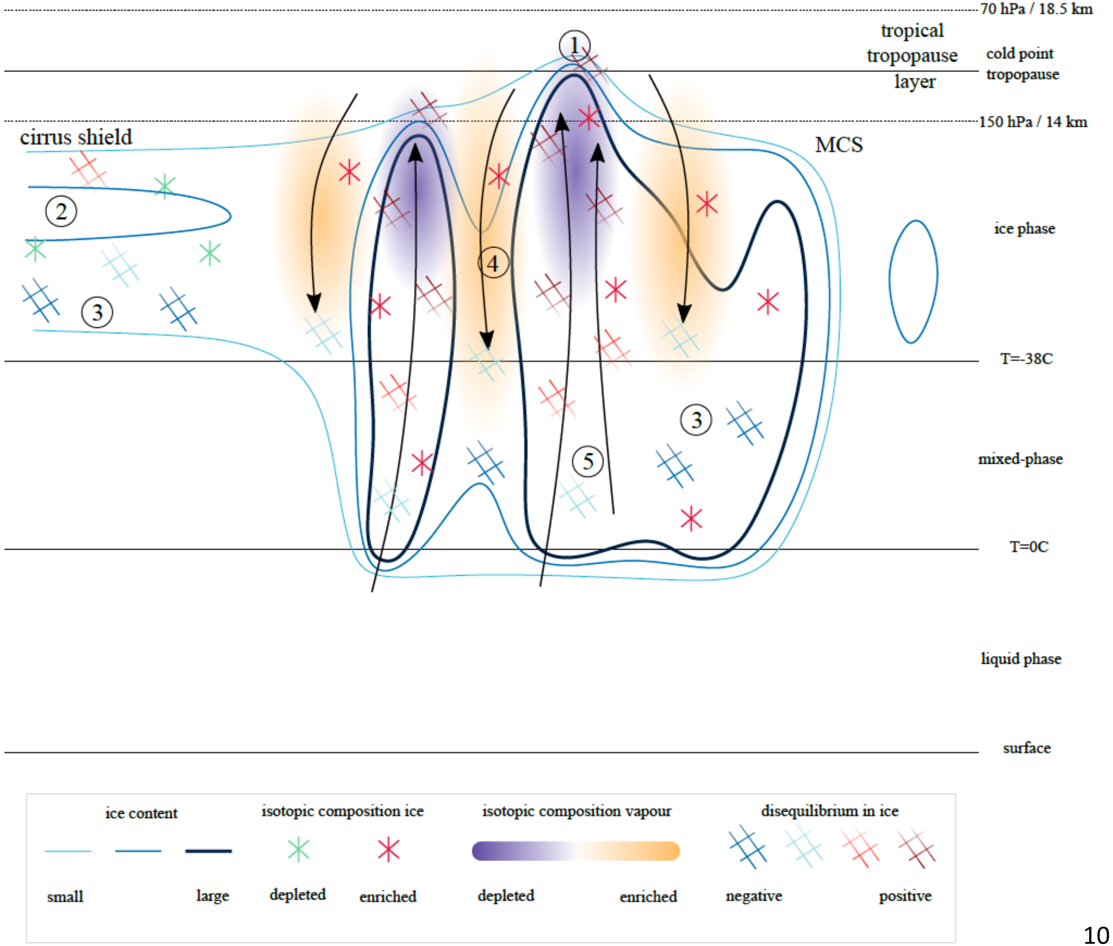
1. COSMO$_{iso}$ reasonably represents isotopes in monthly precipitation
2. 5 key processes in formation & decay tropical ice clouds
3. Convective ice lofting impacts TTL water budget



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