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Modelling of water stable isotope ratios in a 1.5D bin-resolved microphysics model

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Motivation:

During the past decades, the Arctic has warmed twice as fast as the global average, which state-of-the-art coupled ocean-atmosphere models fail to correctly simulate. The ANR-AC-AHC2 project aims to improve our understanding by quantifying the atmospheric moisture transport to the arctic and discriminating between local sources and long distance moisture transport. Water stable isotopes will be used as indicators and new measurements of precipitation and surface water vapour isotopic composition in north Greenland and Svalbard, will be compared with model output.

Adaptation of DESCAM for the exchange of ^{18}O isotopes during phase transitions with the liquid/solid cloud phase :

ρ'_v : water vapour content in kg m^{-3} containing ^{18}O with $\rho'_v = R_v\,\rho_v$

m' : drop/ice water mass containing ^{18}O with $m' = R_{l/i}m$ and $\alpha_{l/ie} = {R_{l/i}}/{R_{v,surf}}$

R_v, R_l, R_i isotopic ratios in the vapour, liquid and solid phase and α_{le}, α_{ie}: liquid/solid equilibrium fractionation factor = fct (T)

Liquid condensation/evaporation mass change (Pruppacher and Klett, 1997) is calculated using for the drops:

$$\frac{dm}{dt} = 4\pi a \frac{s_{v,w} - \frac{A}{a} + \frac{Br_N^3}{a^3 - r_N^3}}{\frac{R_v T}{D_v e_{sat,w}} + \frac{l_v}{kT}\left(\frac{l_v}{R_v T} - 1\right)}$$

accompagnied by uptake of « heavy water » :

$$\frac{dm'}{dt} = 4\pi a D_v{}' \rho_v \left[R_v - \frac{R_l}{\alpha_{le}}\right] + \left(\frac{R_l}{\alpha_{le}}\left(\frac{D'_v}{D_v}\frac{dm}{dt}\right)\right)$$

Total condensation yields :

$$\left(\frac{\partial LWC}{\partial t}\right)_{con/eva} = -\left(\frac{\partial \rho_v}{\partial t}\right)_{con/eva} = \frac{\partial}{\partial t}\int_0^\infty m\, f_d(m)dm$$

and « heavy water » liquid :

$$\int_0^\infty \frac{dm'}{dt} f_d(m)dm = -\frac{\partial \rho'_v}{\partial t}$$

In the figures the isotope ratio is displayed in °/oo:

$$\delta^{18}O = \left(\frac{\left(\frac{^{18}O}{^{16}O}\right)_{air/drop}}{\left(\frac{^{18}O}{^{16}O}\right)_{standard}} - 1\right)1000$$

where the standard is a known isotopic composition, such as the Vienna Standard Mean Ocean Water (VSMOW).

The uptake of ^{18}O into the ice phase is treated accordingly, changing the coefficient α_{ie} to α_{ie} and adapting the solid condensation equation. For the aerosol particles, at all times an equilibrium condition is assumed.

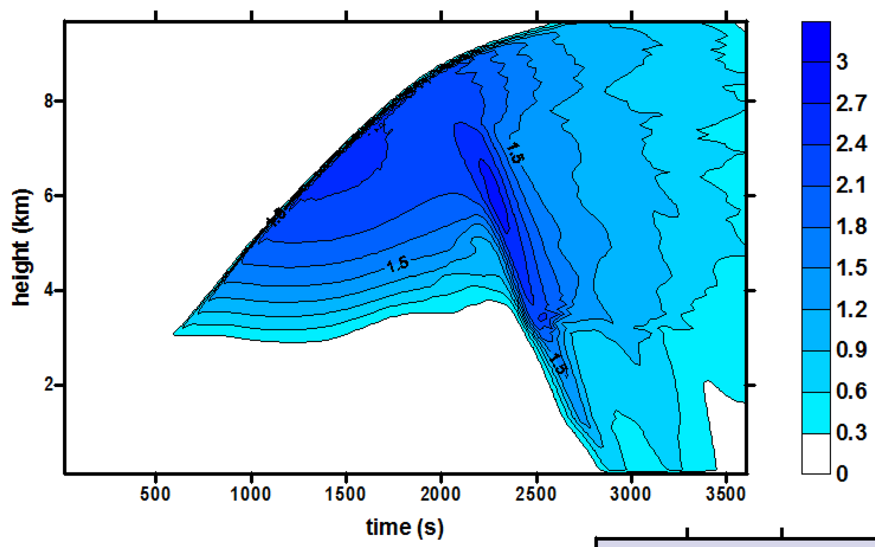


Fig. 1: Time/height evolution of the total condensate content (liquid and ice) in g/m³ for a 1D cloud

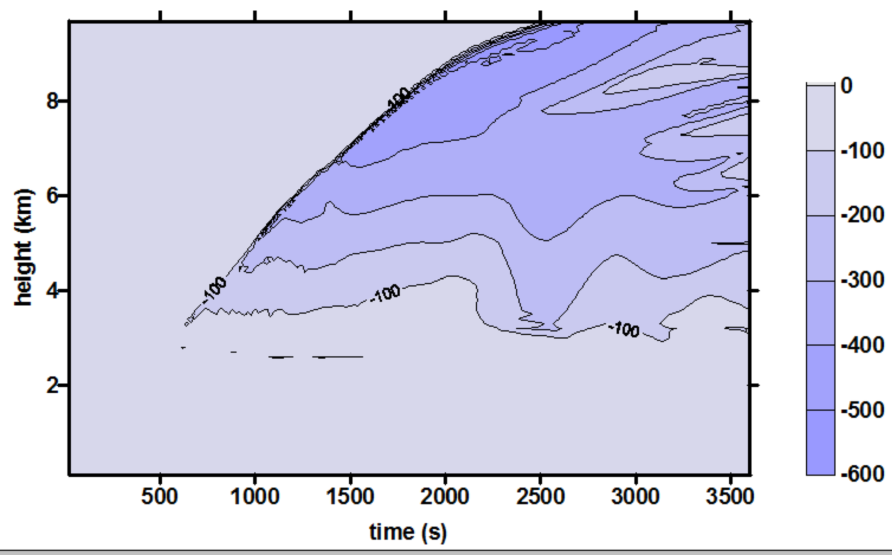


Fig. 2: Time/height evolution of evolution of $\delta^{18}O$ in the gaseous phase for a 1D cloud.

Note the increase of isotopic depletion with decreasing temperature (increasing height), compare e.g. Bolot et al (2013).

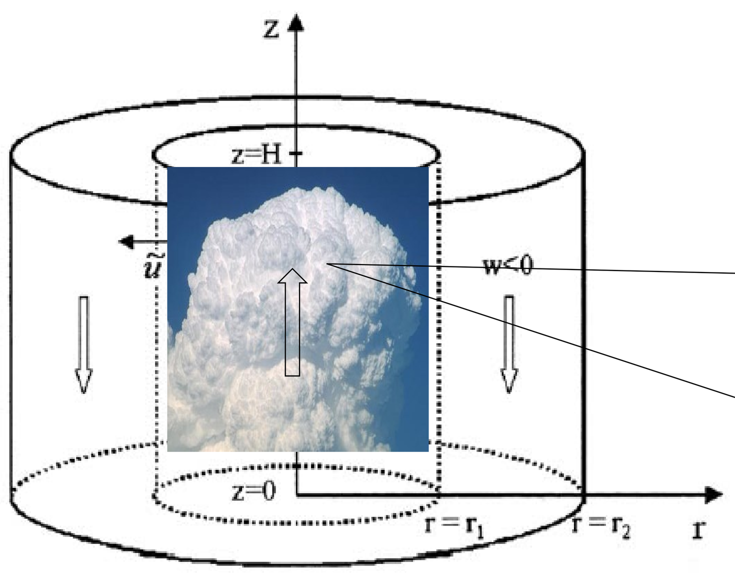
The model DESCAM (DEtailed SCAvenging Model)

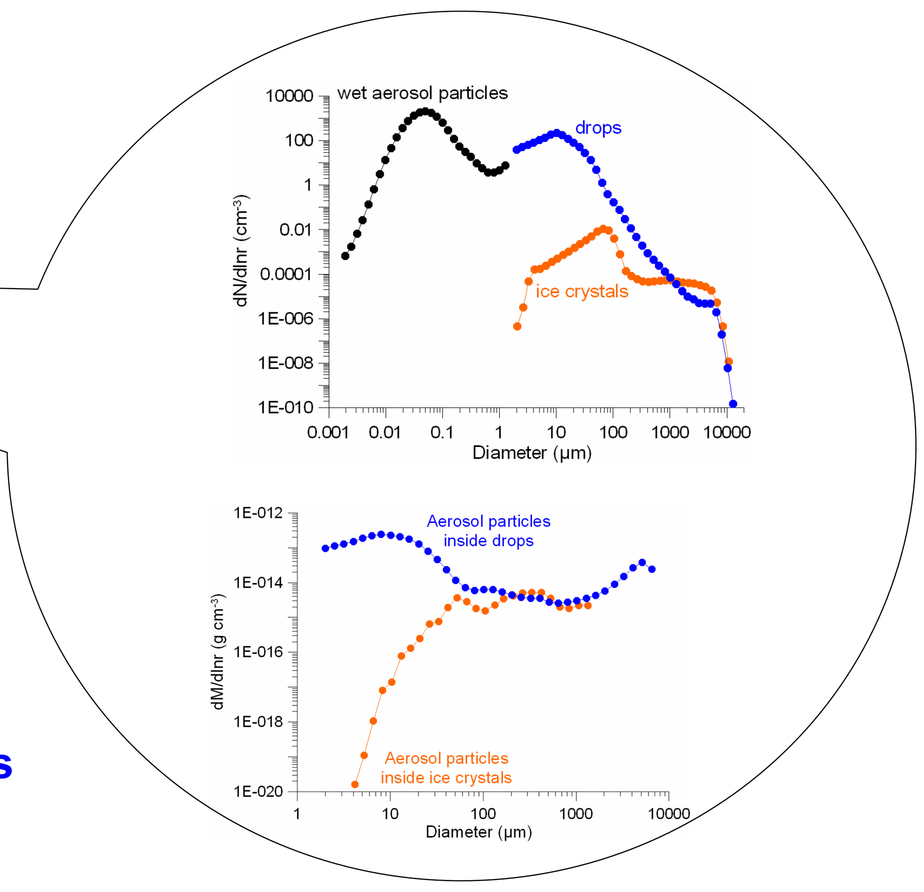
Flossmann and Wobrock (2010); Leroy et al (2009)

Old version: **3 + 2 *density distribution functions*:**

f_d : drop number
f_i : ice crystal number
f_{AP} : wet aerosol particle number
$g_{AP,d}$: aerosol mass inside drops
$g_{AP,i}$: aerosol mass inside ice crvstals

- *Warm microphysical processes* : aerosol particle growth and activation, droplet de-activation, growth of drops by condensation and collision-coalescence
- *Cold microphysical processes* : homogeneous and heterogeneous nucleation, growth by vapor deposition, riming and melting.





+ 2 new distribution functions:
$g_{iso,d}$:" heavy" water mass inside drops
$g_{iso,i}$: "heavy" water mass inside ice crystals

They are transported in the same way as a scavenged particle mass and are exchanged during phase transition processes with the gaseous phase.

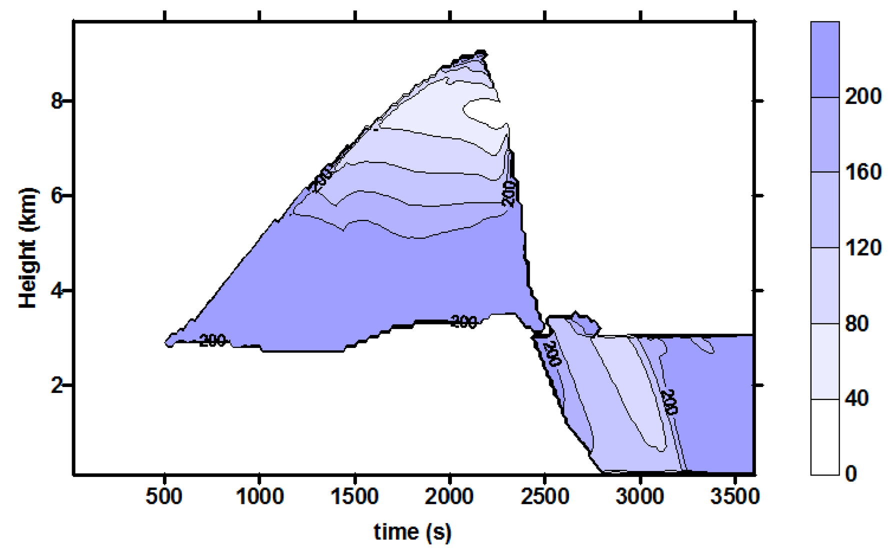
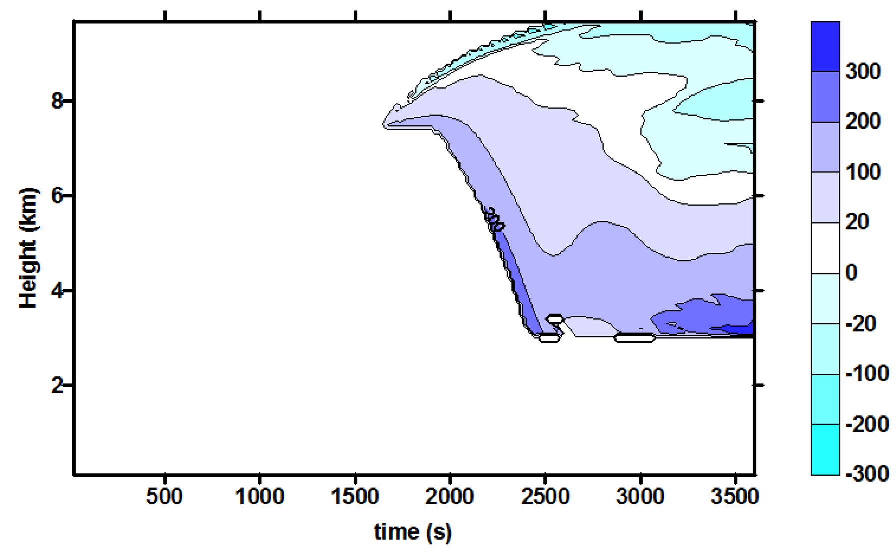


Fig. 3: Time/height evolution of $\delta^{18}O$ in the liquid phase.
Note the enrichment in the zones of highest condensation rates.

Fig. 4: Time/height evolution of $\delta^{18}O$ in the ice phase.
Highest enrichment in zones of strong solid condensation.



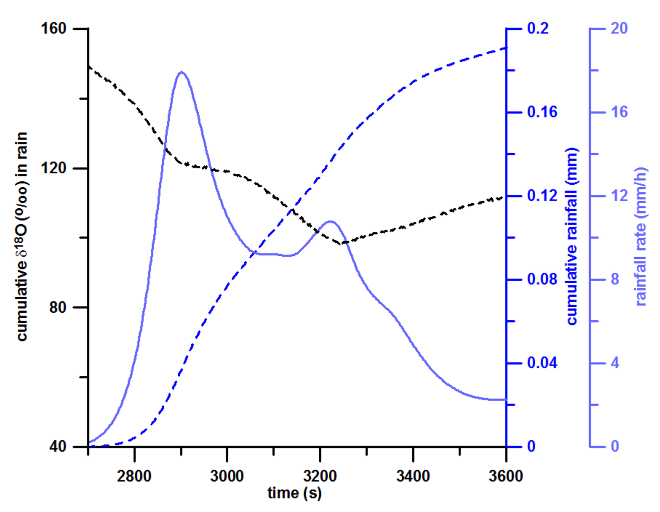


Fig. 5: Time evolution of the rainfall rate, the cumulative rainfall and the $\delta^{18}O$ in the rain on the ground.

Results:

The selective uptake of water stable isotopes were added to the liquid and solid phase.
The « heavy » isotopes condense more easily, which is reflected in the maxima of $\delta^{18}O$ in the zones of max. condensation (cf Fig. 3 and 4). Gaseous $\delta^{18}O$ is lower at lower temperatures.
The rain reaching the ground (Fig.1 and 5) has a mean $\delta^{18}O$ of 120, in the range of observed values.

Conclusions:

As a first step, the water stable isotopes were added to the 1.5D bin-resolved microphysics Detailed Scavenging Model (DESCAM) and their evolution in a single precipitating cloud was studied. The resulting depletion/enrichment rates depend strongly on initial conditions. Further sensitivity studies will be performed. Finally, the microphysical module can be coupled in a parcel version to meso- and global scale models (MAR and LMDz) and can be compared to observations.

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