Modeling of HDO in the Martian atmosphere

L. Rossi[1], Margaux Vals[1], Franck Montmessin[1], François Forget[2], Ehouarn Millour[2], Kevin S. Olsen[1], Anna Fedorova[3], Alexander Trokhimovskiy[3], Oleg Korablev[3] and the ACS team.

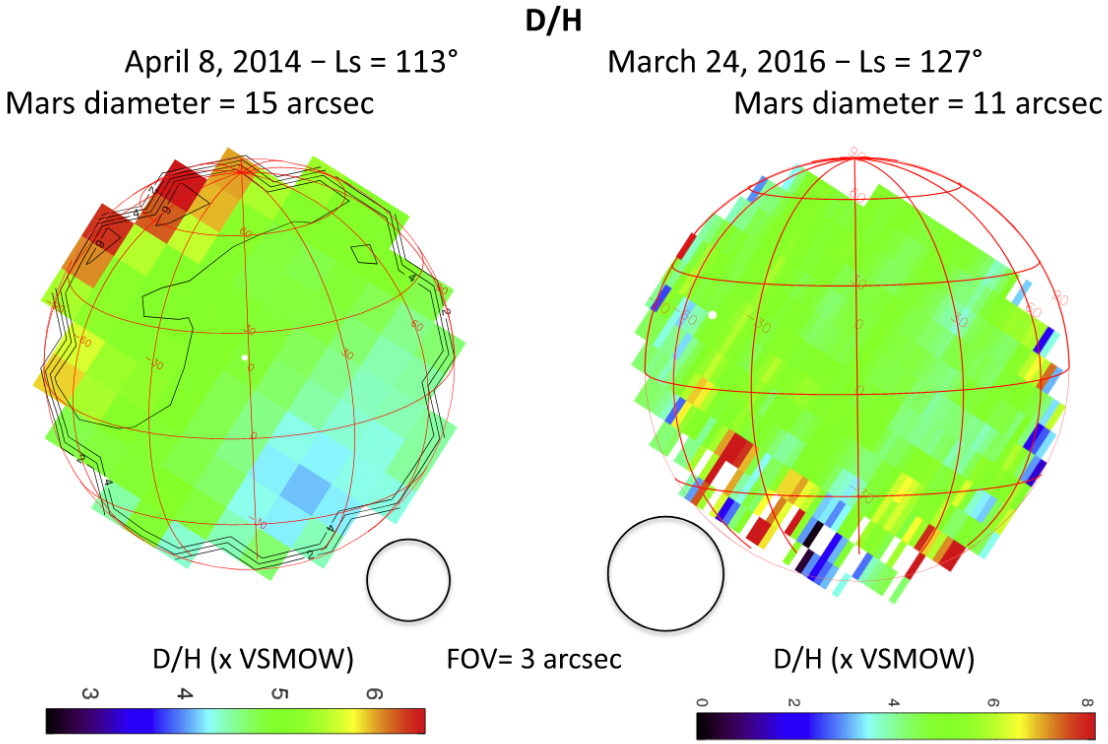
[1] : LATMOS/IPSL, UVSQ, Université Paris-Saclay, Sorbonne Université, CNRS, Guyancourt, France (loic.rossi@latmos.ipsl.fr)
[2] : LMD, Paris, France
[3] : Space Research Institute (IKI), Moscow, Russia

Twitter : @AstroLR

EGU 2020

Why HDO?

- The D/H ratio is used to study the inventory of water on Mars
  - Preferential escape of H atoms over D atoms
  - D/H ratio can thus be used to estimate the past water inventory
- The current value is about 5 times the Earth's value (SMOW).
- The martian climate can also intervene and change the D/H ratio, so we need to understand it!



D/H maps from Encrenaz et al. (2018) (CC-BY)

HDO Fractionation

- HDO has saturation pressure different from that of H_2O
  - Preferential condensation of HDO
- Fractionation Factor:

$$\alpha_c = \frac{\left(HDO/H_2O\right)_{ice}}{\left(HDO/H_2O\right)_{vap}} = \exp\left(\frac{16288}{T^2} - 9.34\ 10^{-2}\right)$$

- The ice will therefore be enriched in deuterium with respect to the vapour phase.
- One can expect strong fractionation in the cold areas (in particular, the polar areas)

Processes considered

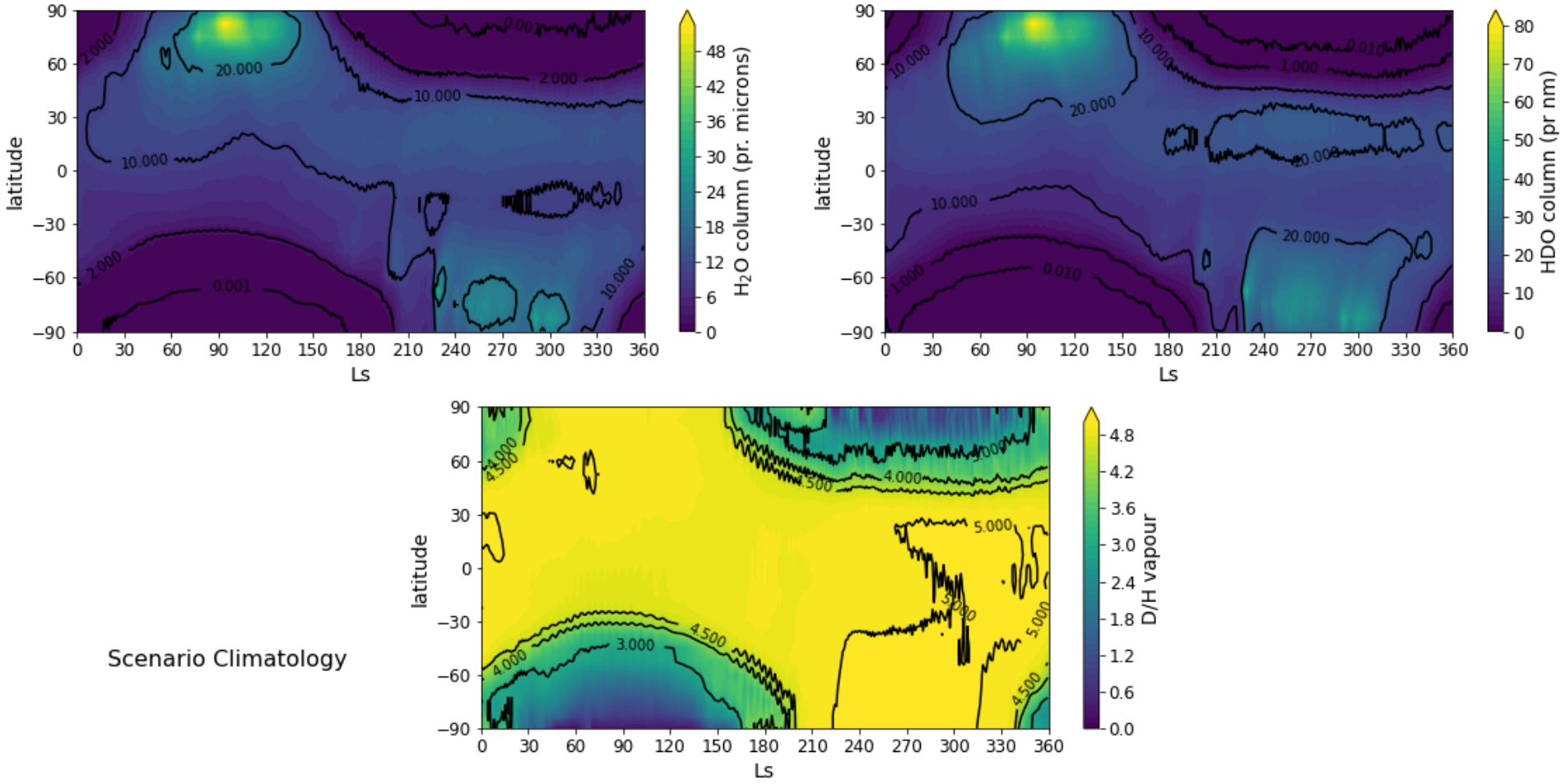
- Condensation/sublimation in the clouds
  - Everything is condensed or sublimated at once with respect to the saturation pressure
  - So no realistic microphysics
- Condensation/sublimation at the surface
- Sedimentation of ice crystals

For the most part, HDO is treated like H_2O, except for the fractionation.

Model parameters

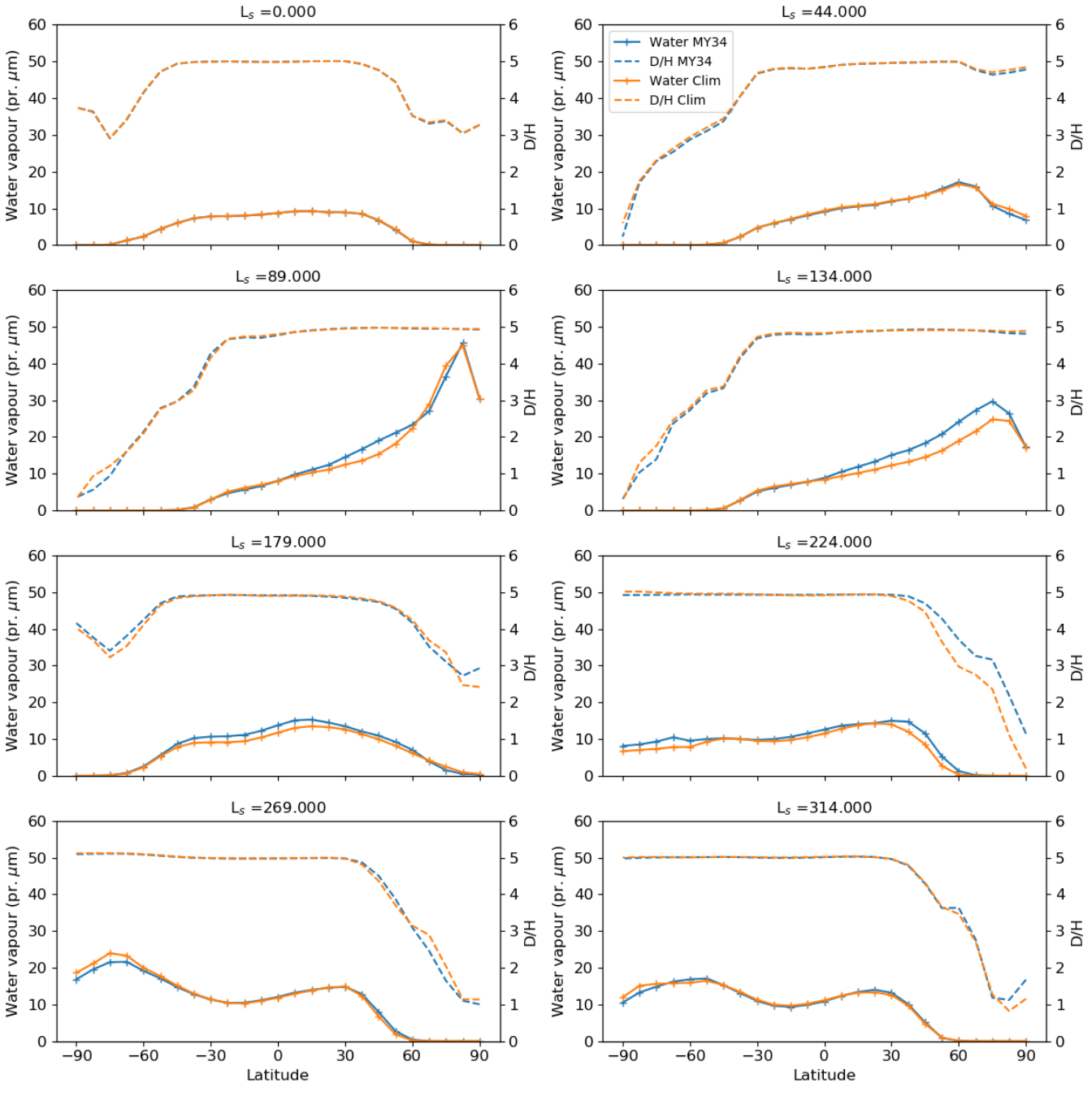
- We use the IPSL Mars GCM (Forget et al. 1999)
- HDO is represented with 2 tracers (vapour, ice)
- D/H initialized with 5 (SMOW) everywhere on the planet
- The ice in the north polar cap is assumed to have D/H=5
- Clouds are not radiatively active
- We use a 64x48x32 (lon x lat x alt) grid
- Unlike in Montmessin et al. (2005), the dust is not prescribed but transported with a semi-interactive scheme (Madeleine et al. 2011)

HDO Seasonal Cycle



HDO follows well H_2O, except for the polar areas, where the fractionation traps HDO in the ice and reduces the D/H ratio of the column.

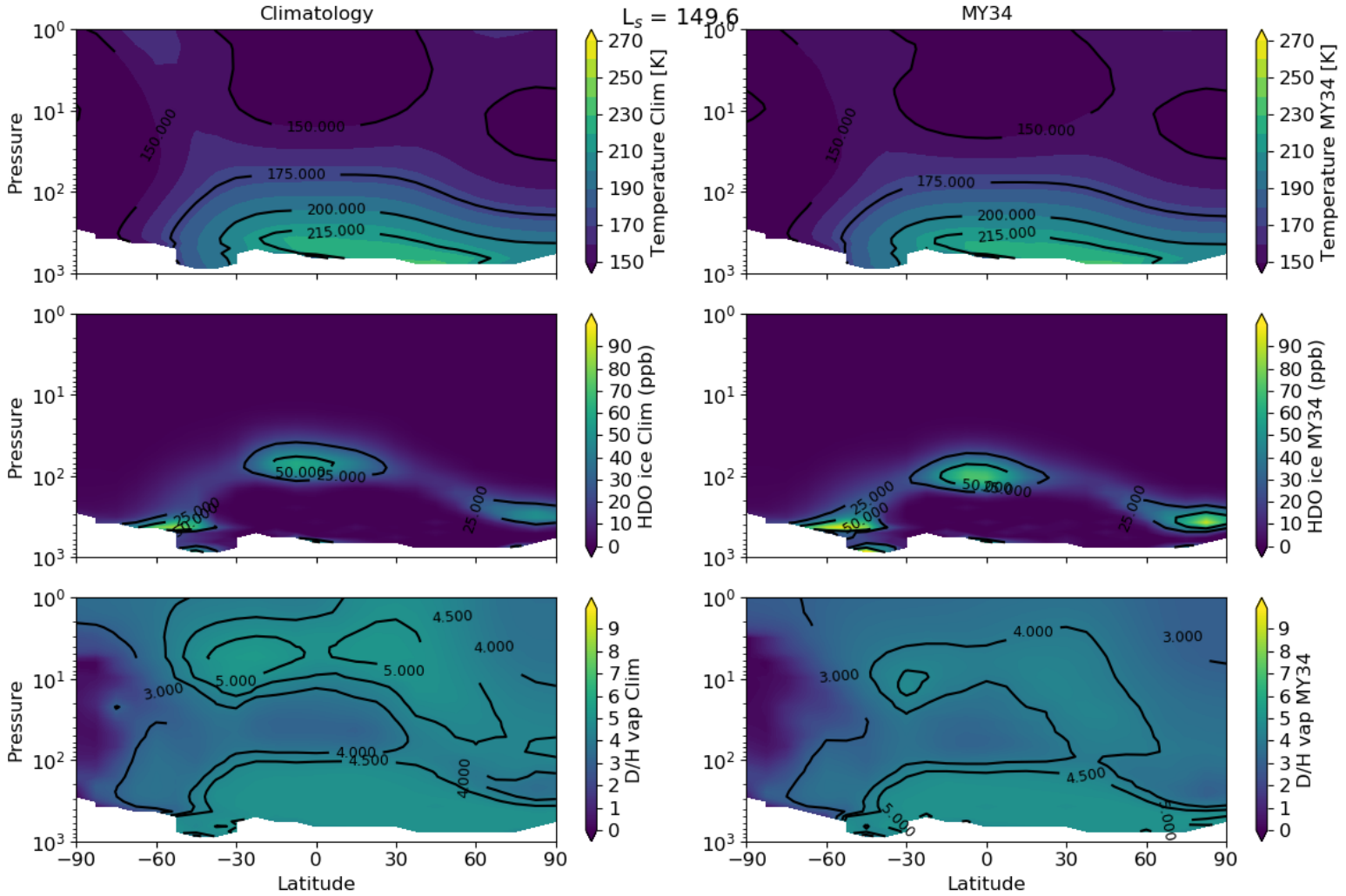
Latitudinal variations



Zonally averaged profiles of water vapour (filled line) and D/H ratio (dashed line)

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.

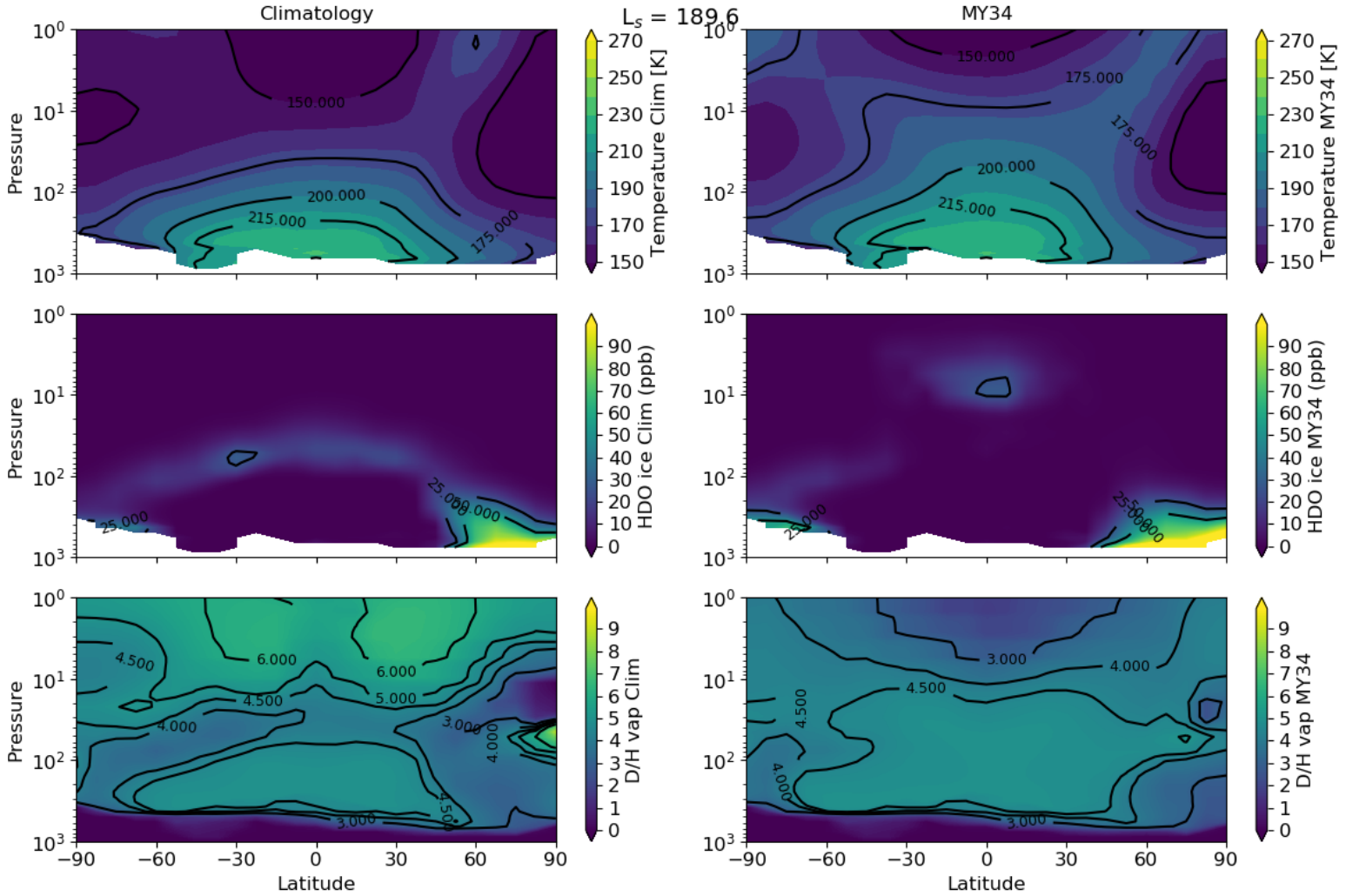


Cloud formation constrains the vertical distribution of HDO

Before the storm

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



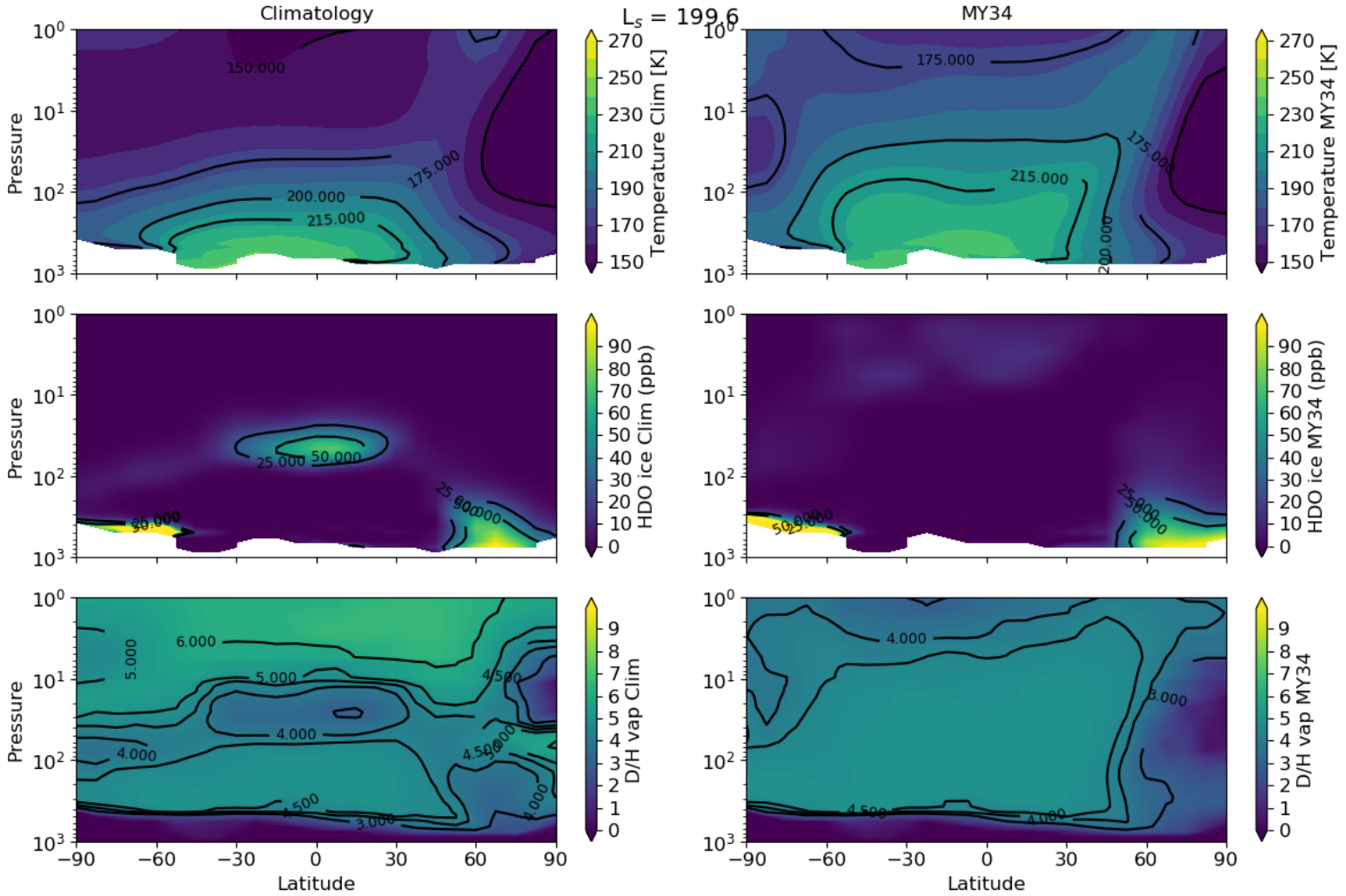
Higher temperatures affect cloud formation

Less cloud formation means HDO can reach higher altitudes

During the storm

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



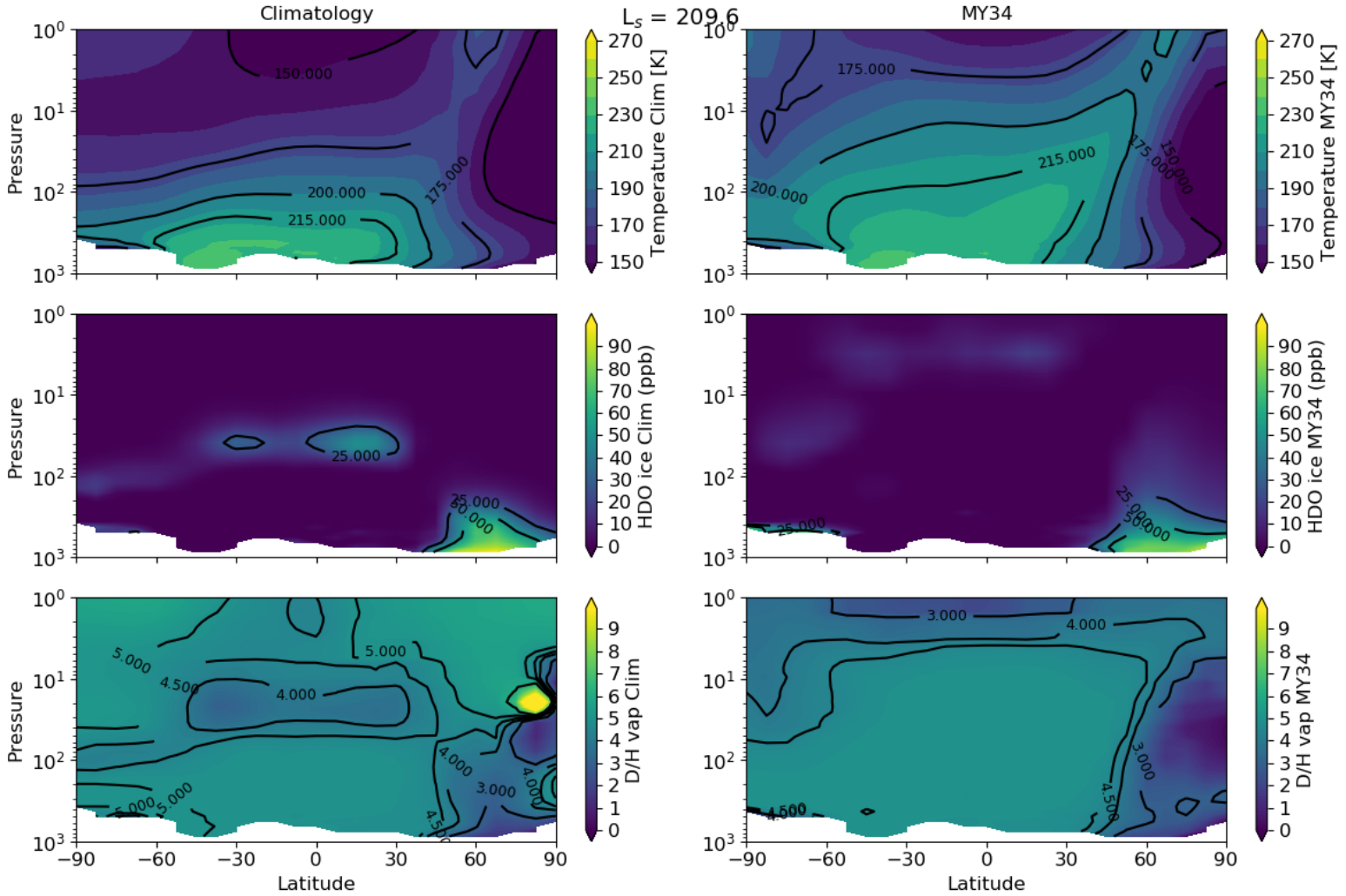
Higher temperatures affect cloud formation

Less cloud formation means HDO can reach higher altitudes

During the storm

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



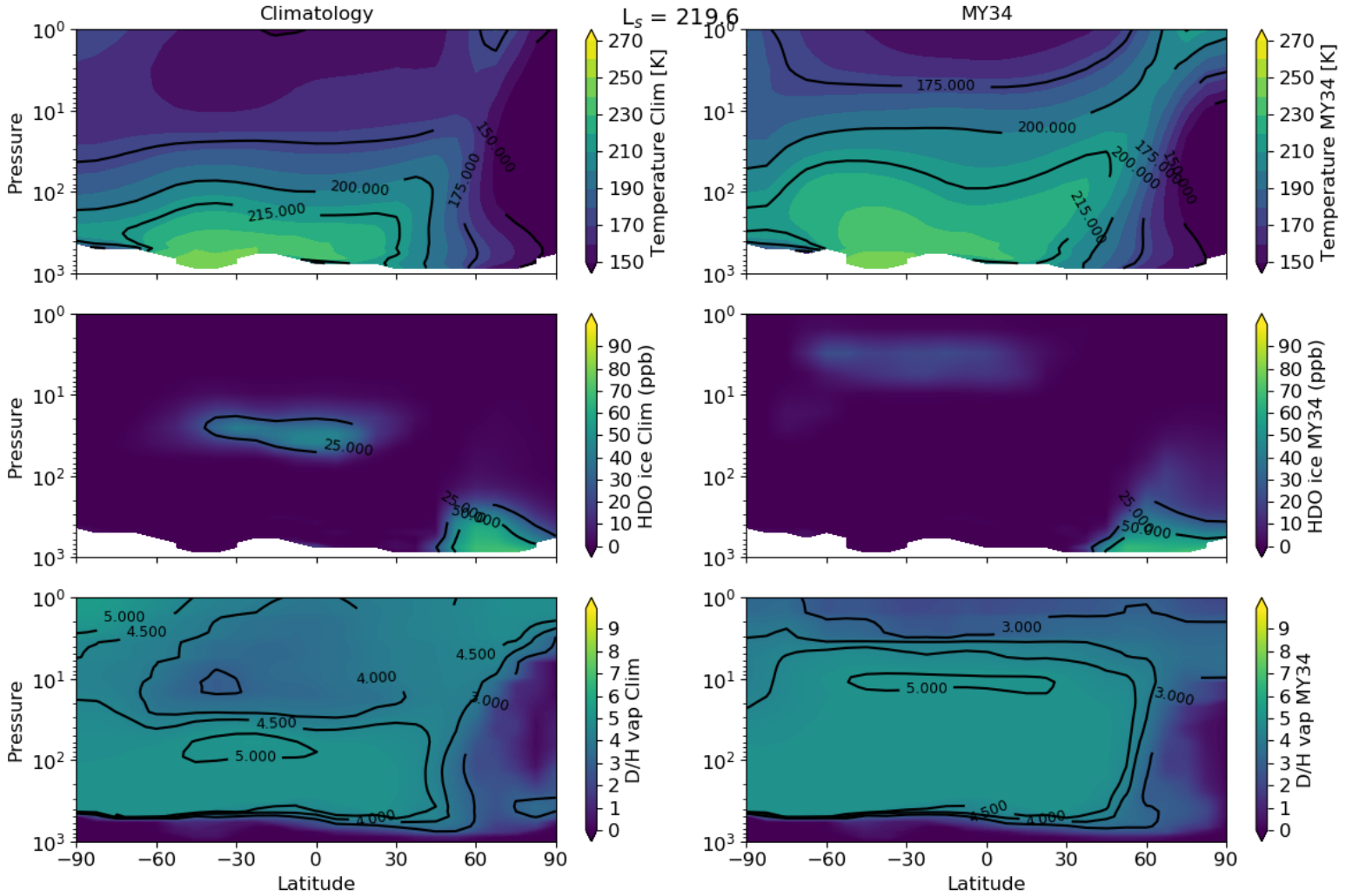
Higher temperatures affect cloud formation

Less cloud formation means HDO can reach higher altitudes

During the storm

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



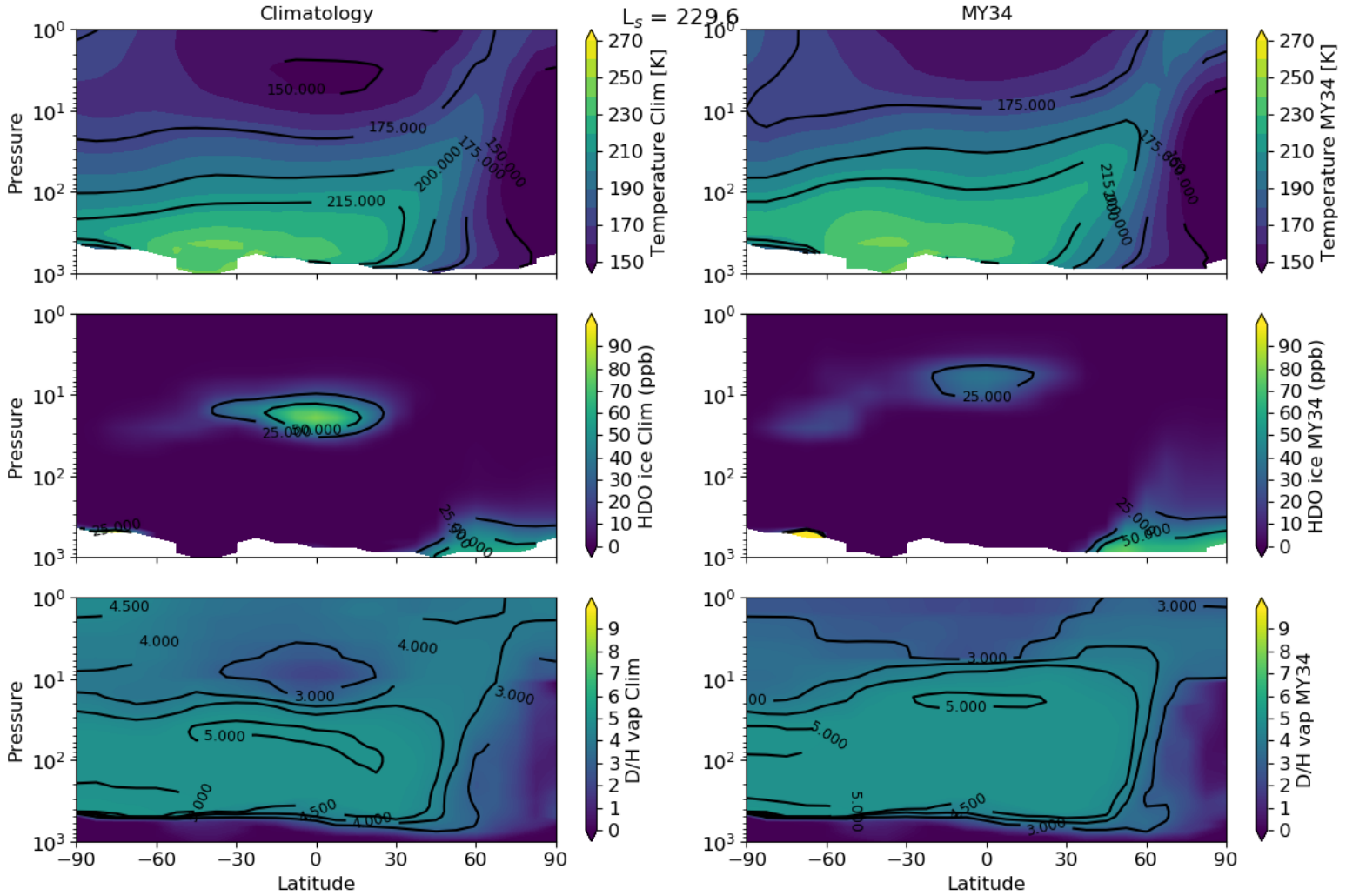
Higher temperatures affect cloud formation

Less cloud formation means HDO can reach higher altitudes

During the storm

The dust storm of MY 34

- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



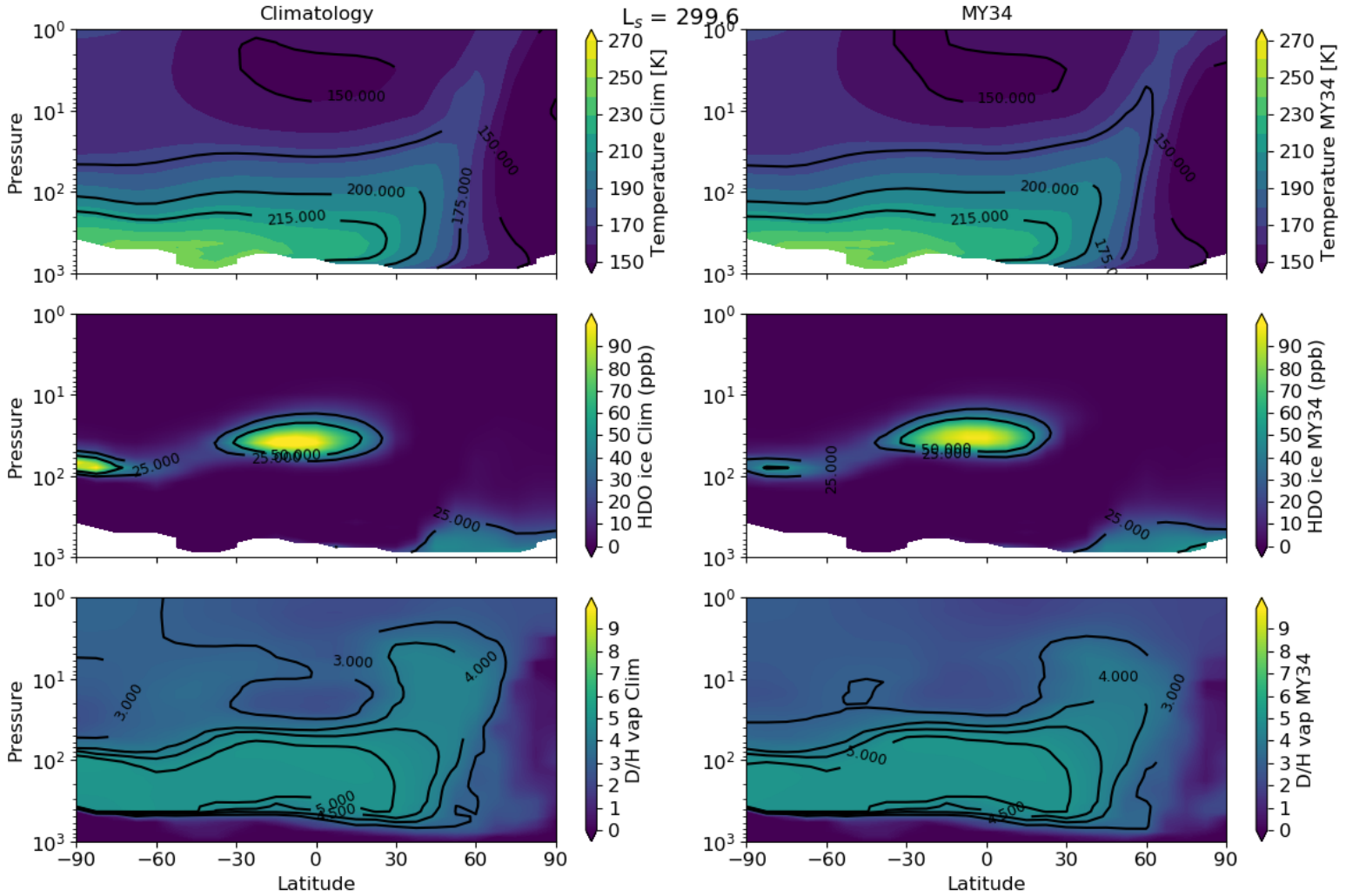
Higher temperatures affect cloud formation

Less cloud formation means HDO can reach higher altitudes

During the storm

The dust storm of MY 34

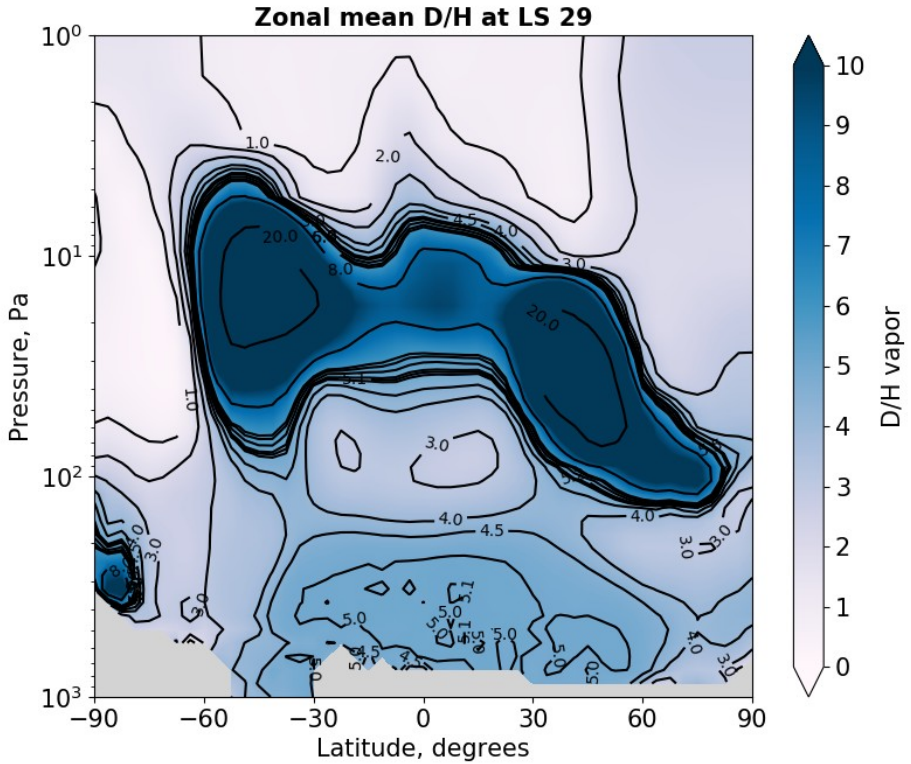
- We apply the dust scenario from MY34 to the HDO cycle to explore the effect of the dust storm.



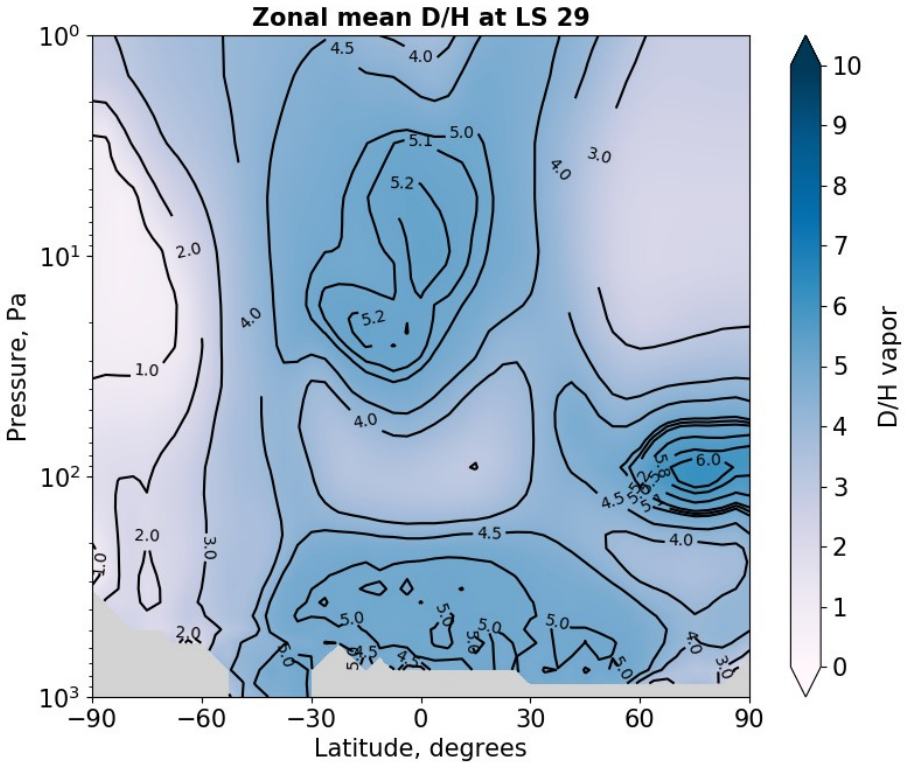
After the storm

Genealogy of tracers

Need to conserve the isotopic ratio during the dynamic transport:
it is necessary to transport the isotopic ratio and not HDO alone (Risi et al. 2009).
Numerically, HDO is transported “within the mass of water”:
“HDO is a son of H_2O”



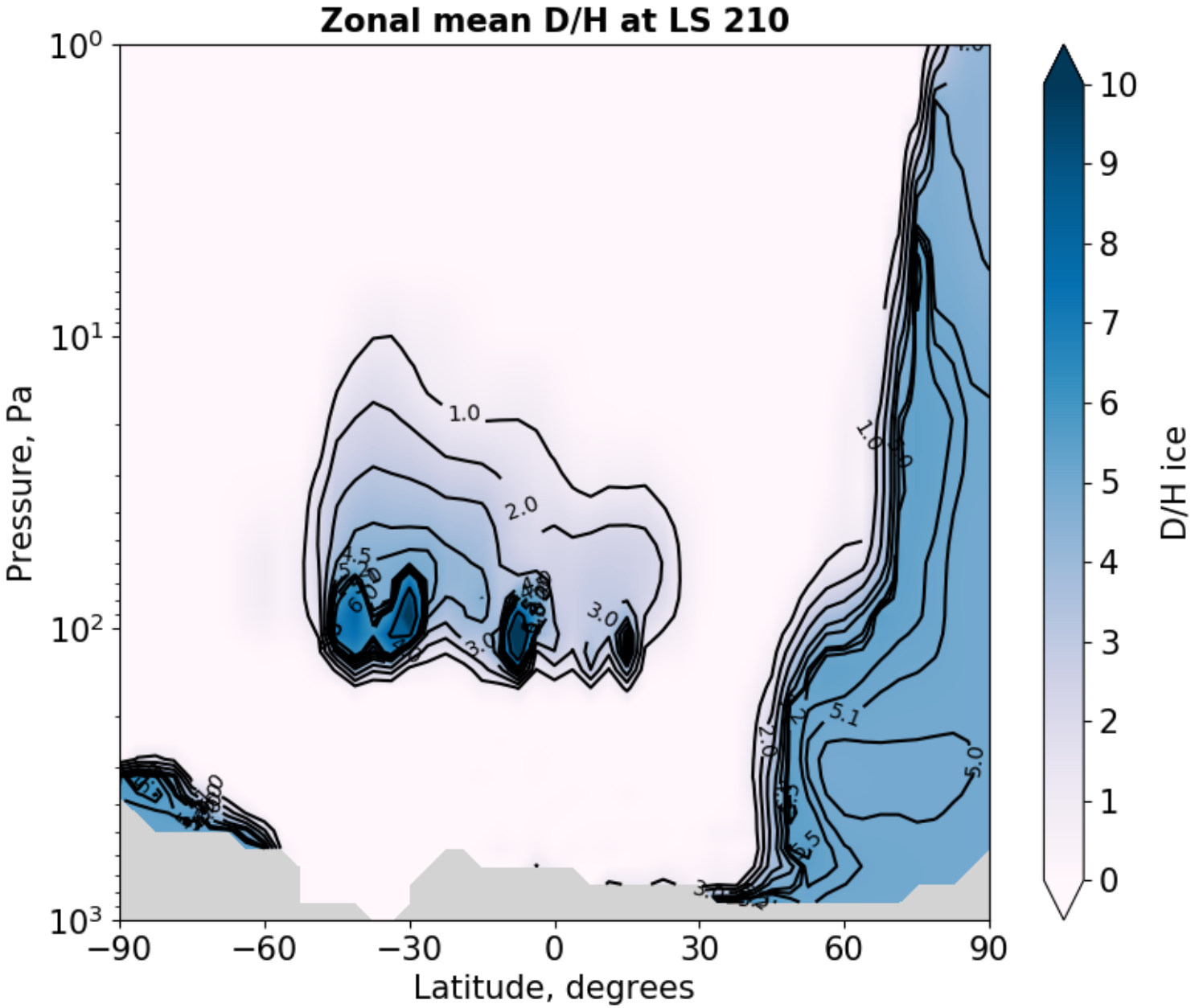
Without genealogy



With genealogy

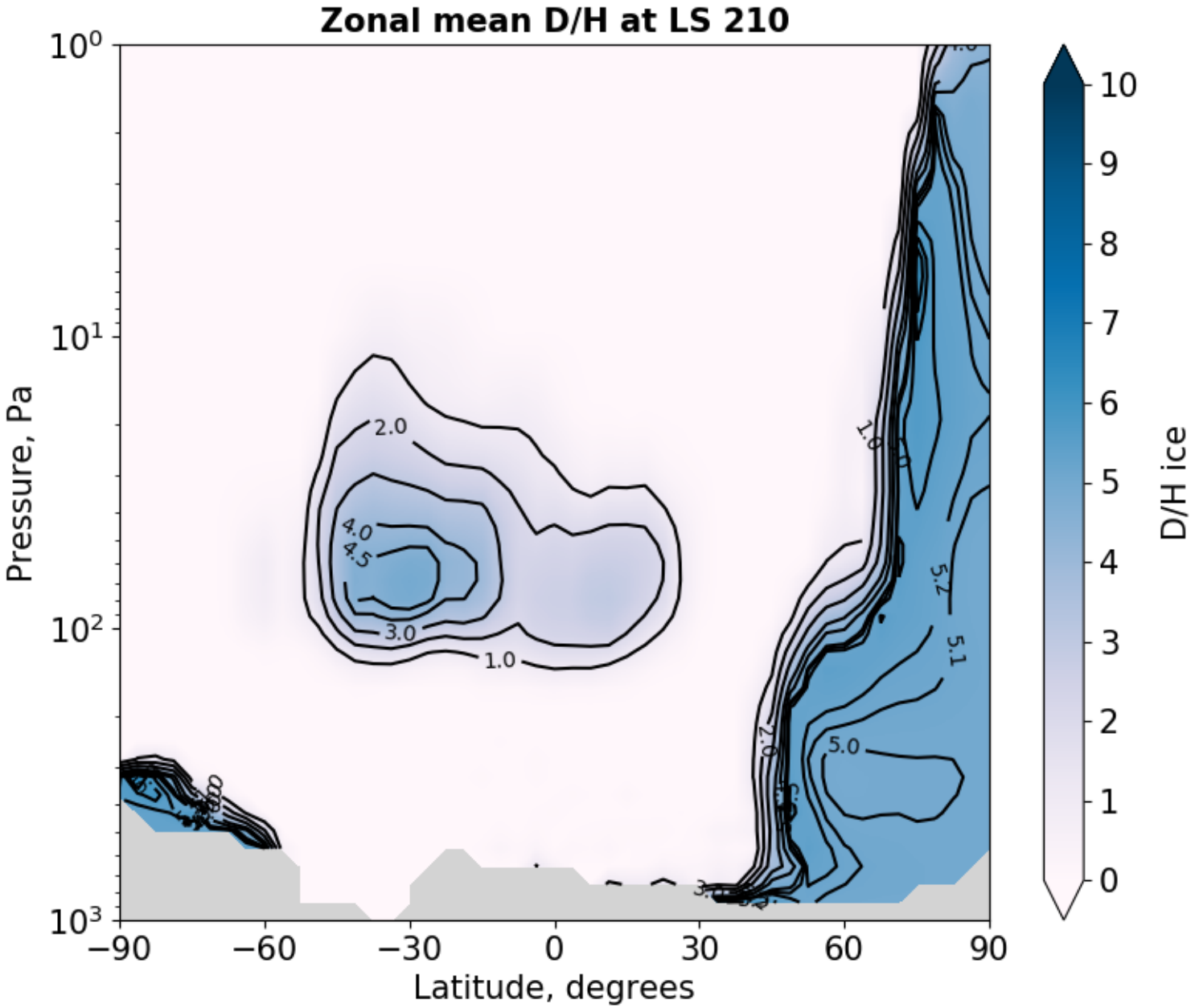
This provides a huge improvement in places where there is little water vapour, and solves many of the spurious values of D/H we had.

D/H ice ratio with sedimentation of HDO



D/H ice ratio with sedimentation of Ratio=HDO/H_2O

Transporting the ratio seems to also improve the sedimentation



Conclusions / summary

- General agreement with
  - previous models from Montmessin et al. (2005)
  - observations of latitudinal variations (e.g. Khayat et al. 2019)
- The dust storm has a visible effect on the D/H ratio:
  - the temperatures are changed
  - cloud formation and circulation is affected
  - fractionation of HDO happens at higher altitudes, if at all.

Perspectives/ameliorations

- Implementing the microphysics of the cloud formation
- Comparison with ACS and NOMAD observations of HDO and D/H profiles
- Experimenting with new fractionation formulas based on lab experiments conducted at temperatures closer to the Martian situation (Lamb et al. 2017)
- Possibility of simulating paleoclimate scenarii, in collaboration with Eran Vos (Weizmann Inst., Israël) and Joseph Naar (LMD).