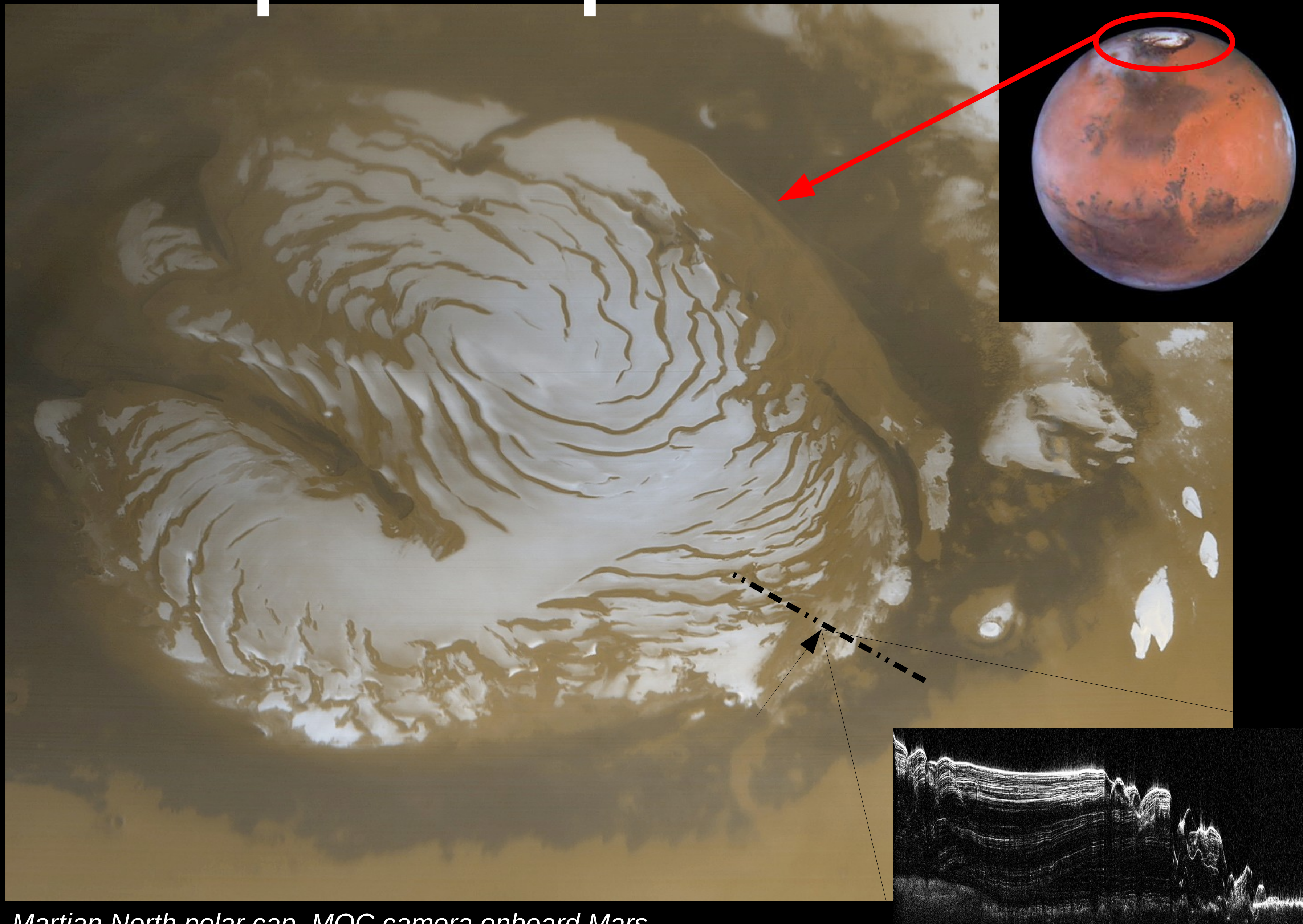
Improving the representation of the martian water cycle in the Global Climate Model of the LMD*

Margaux Vals, *Laboratoire de Météorologie Dynamique*, Paris,*
Aymeric Spiga, François Forget, Ehouarn Millour

CPS workshop, 28/03/2018

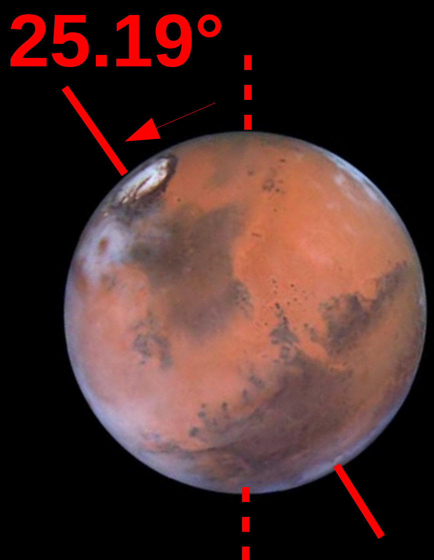
North polar cap !

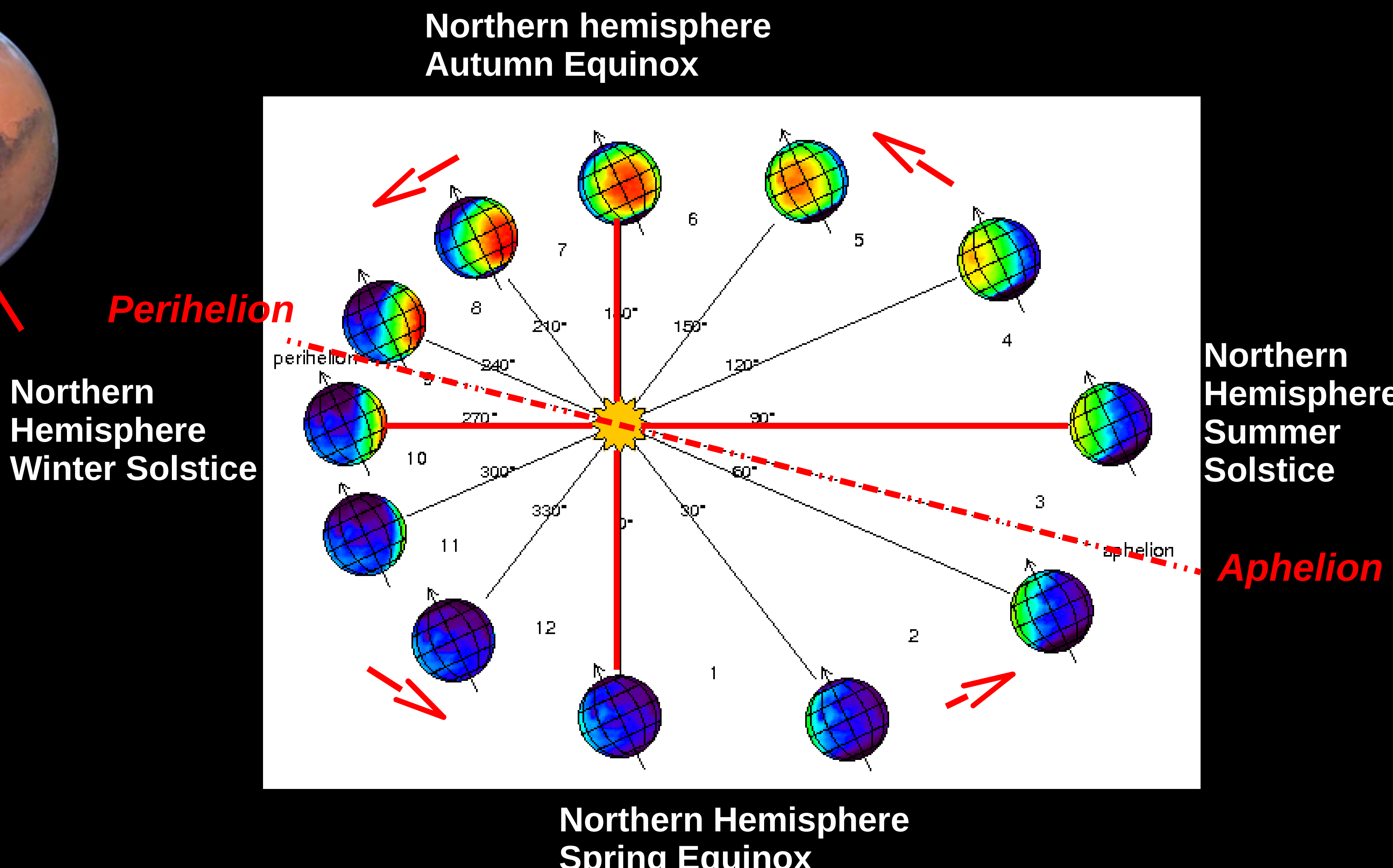


Martian North polar cap, MOC camera onboard Mars Global Surveyor, NASA/JPL

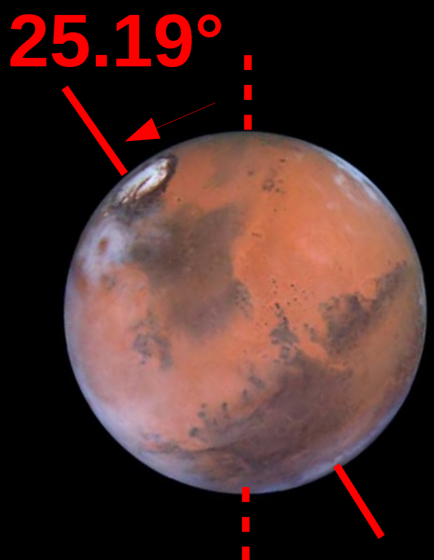
Vertical slice of the North polar cap, image from Sharad onboard Mars Reconnaissance Orbiter, NASA/JPL

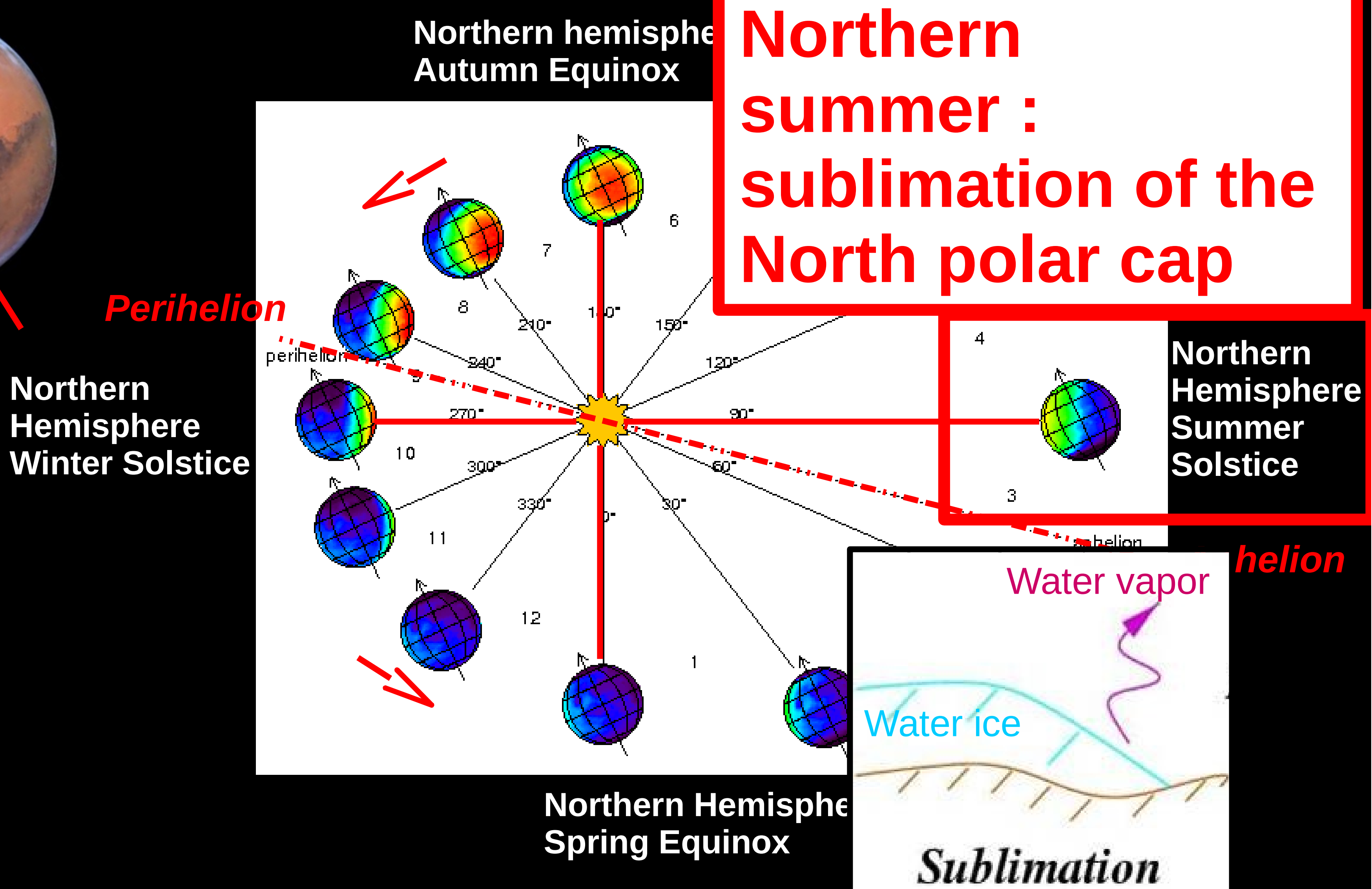
Martian water cycle controlled by the seasonal cycle



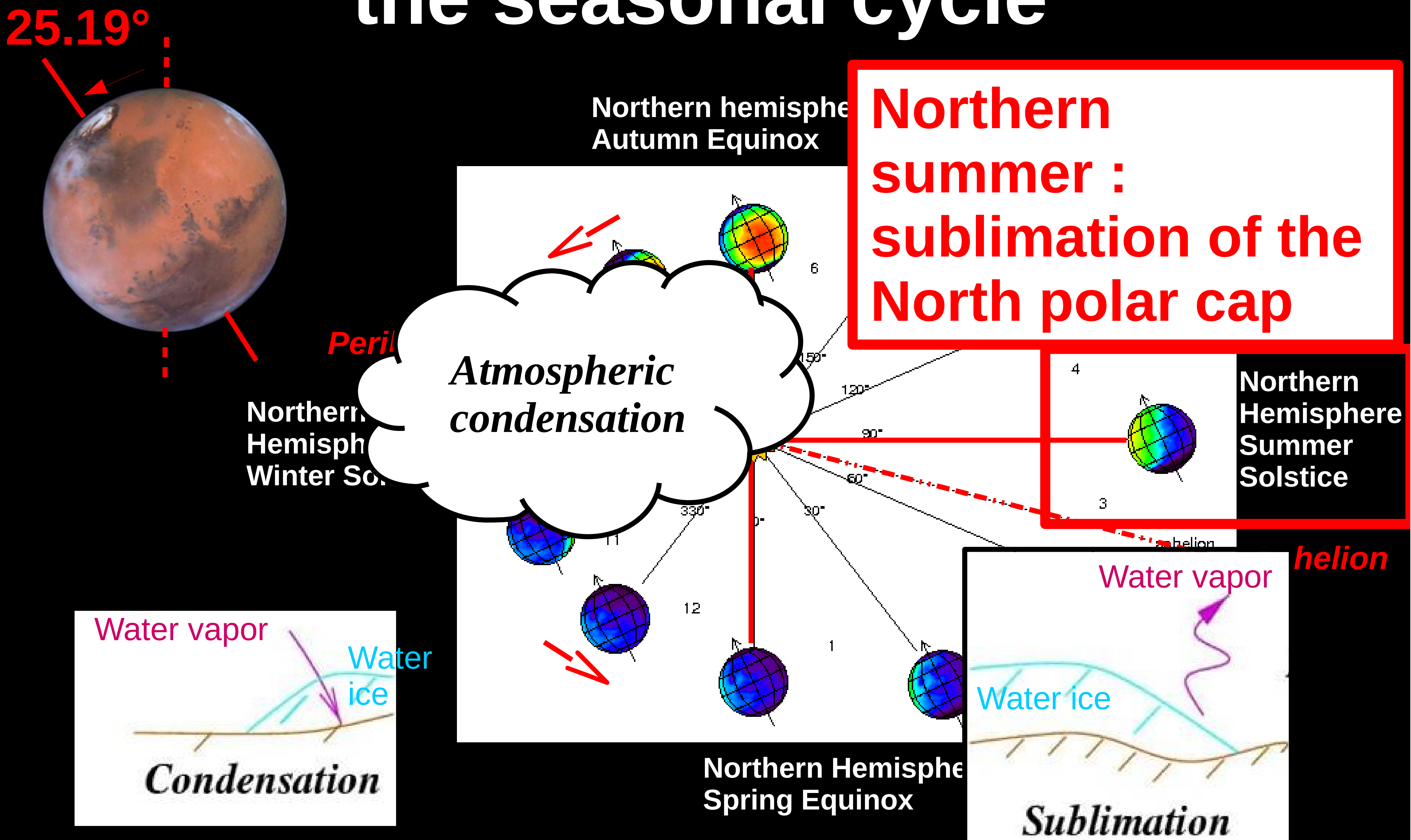


Martian water cycle controlled by the seasonal cycle

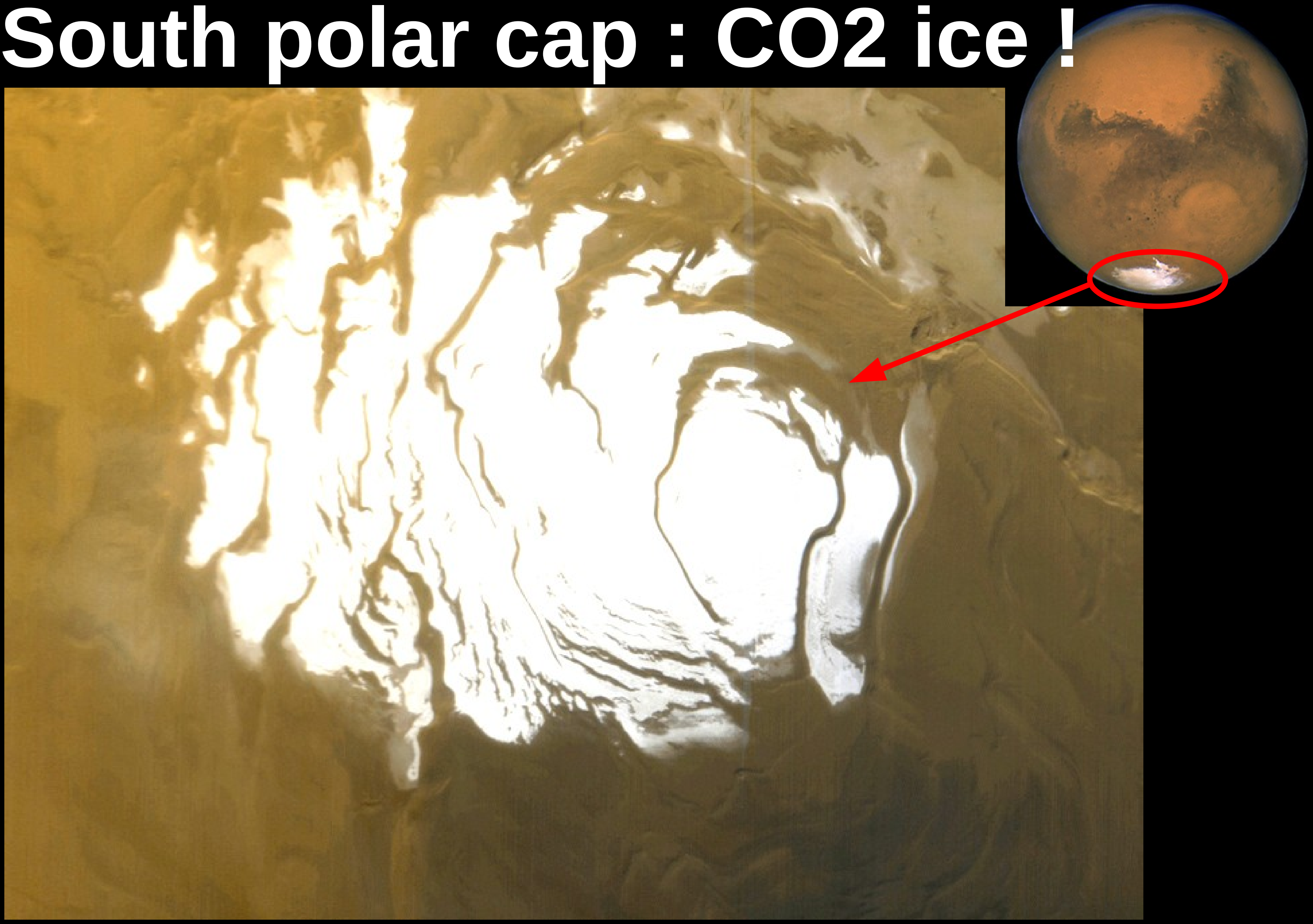




Martian water cycle controlled by the seasonal cycle

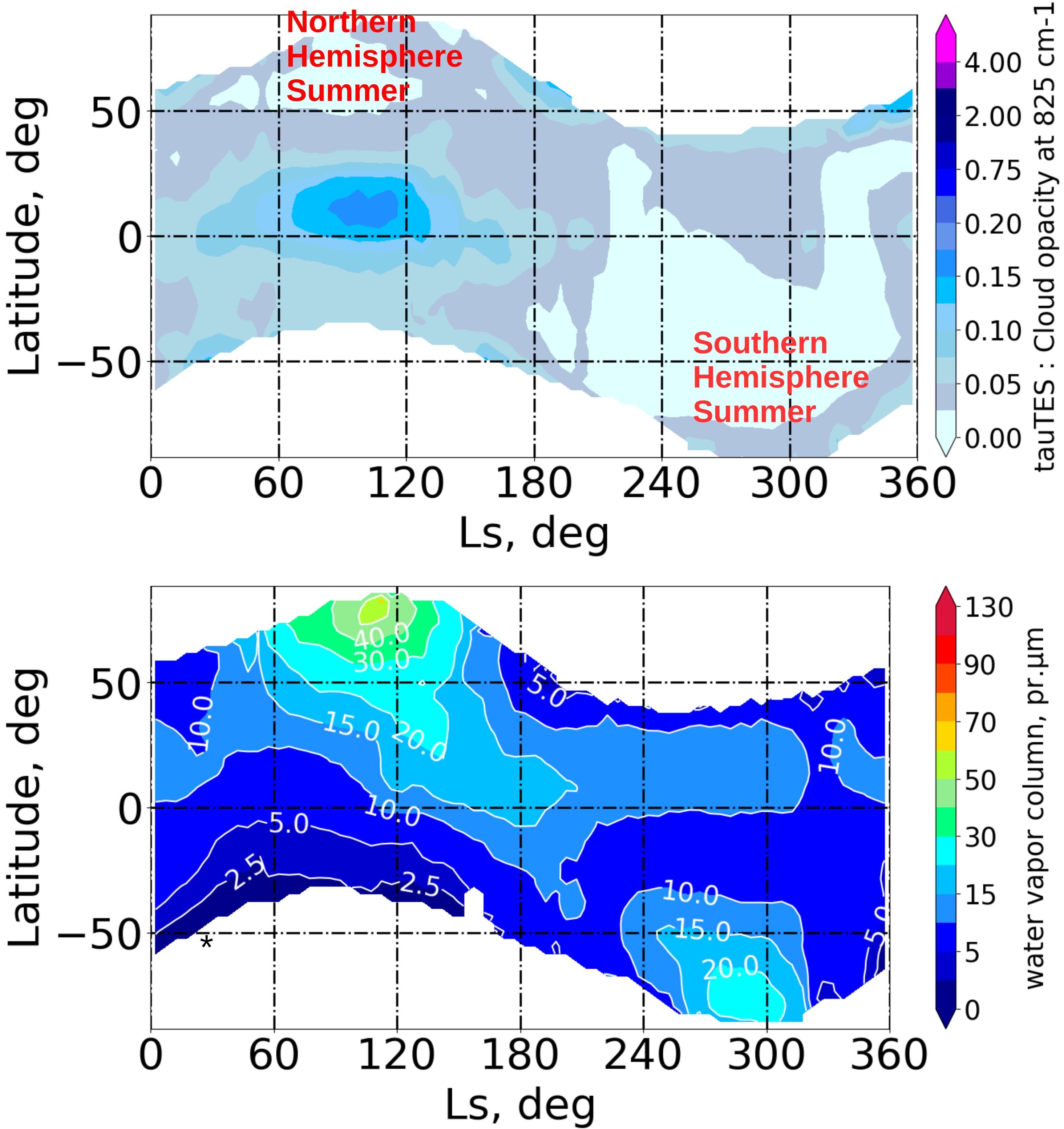


South polar cap : CO2 ice !



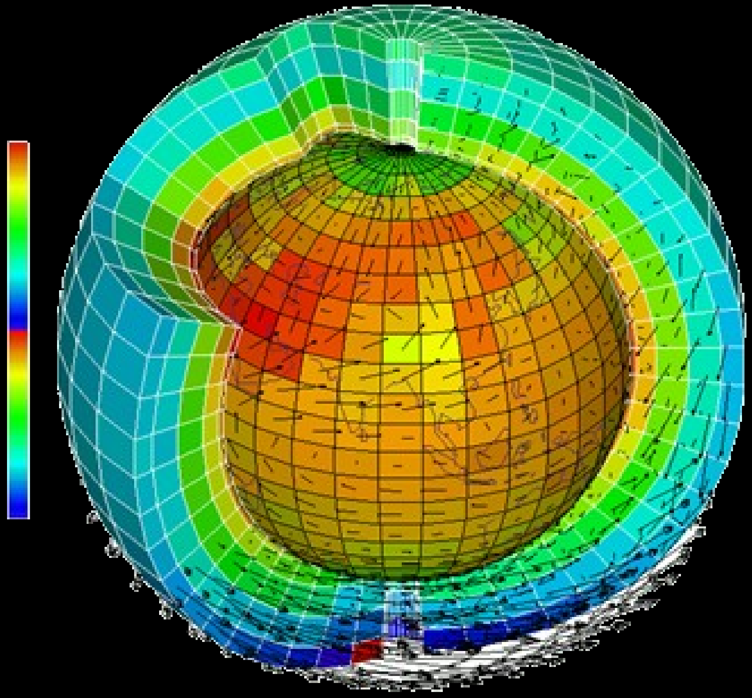
Martian South polar cap, MOC camera onboard Mars Global Surveyor, NASA/JPL

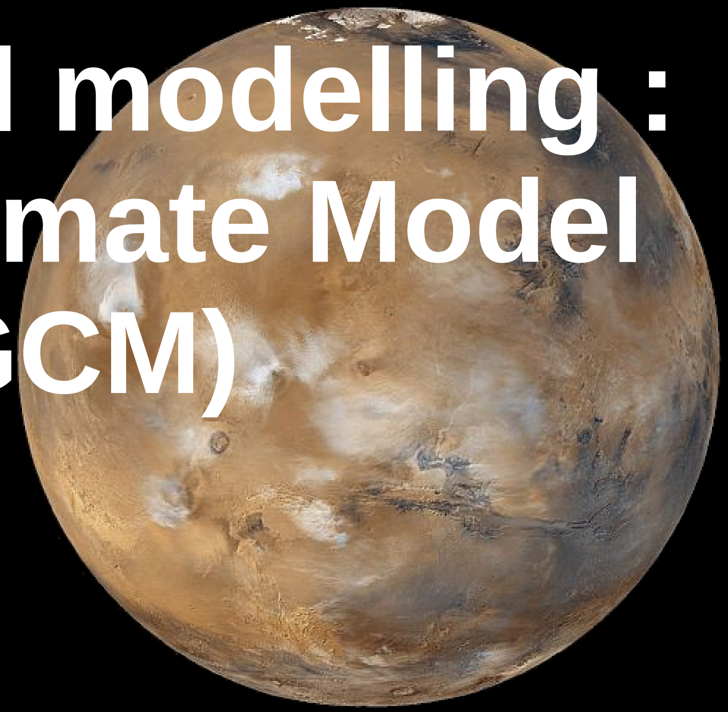
Martian water cycle controlled by the seasonal cycle

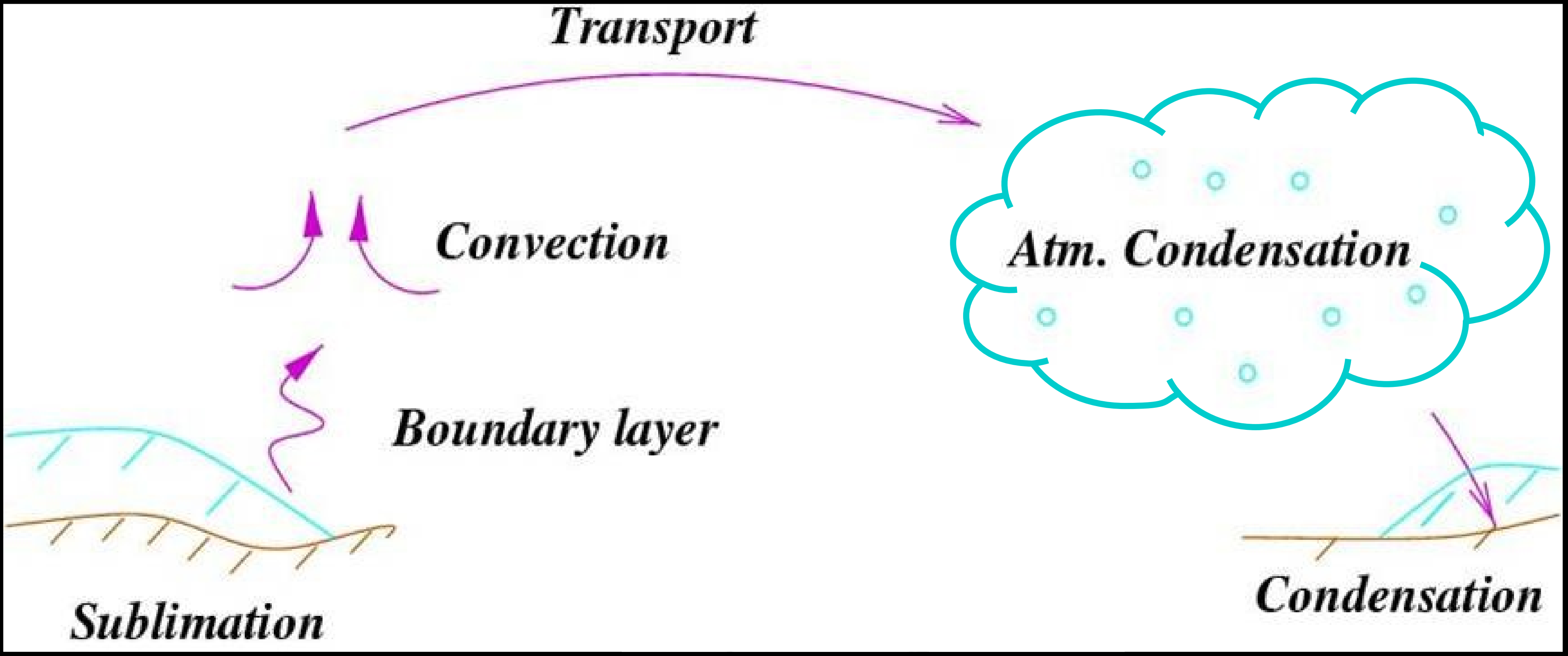


Water vapor column obtained by TES on board Mars Global Surveyor, NASA/JPL

Numerical modelling : Global Climate Model (GCM)





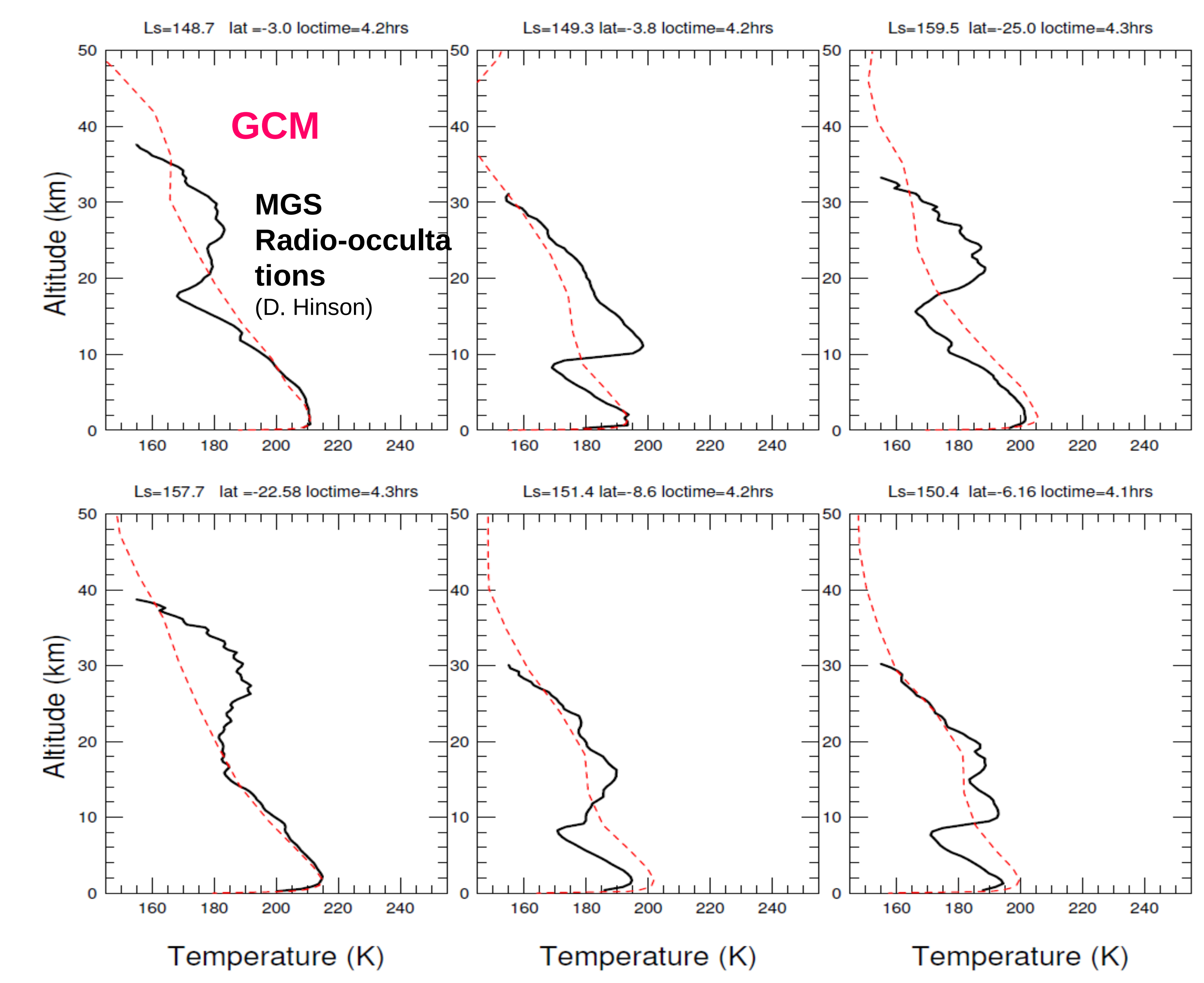


Main recent improvements

- **Radiatively active clouds** (*Madeleine et al. 2012, Navarro et al. 2014*)
- **Improved microphysics** *(Navarro et al. 2014*)
  - nucleation on dust particles
  - ice particle growth
  - scavenging of dust particles
  - supersaturation

Main remaining issues

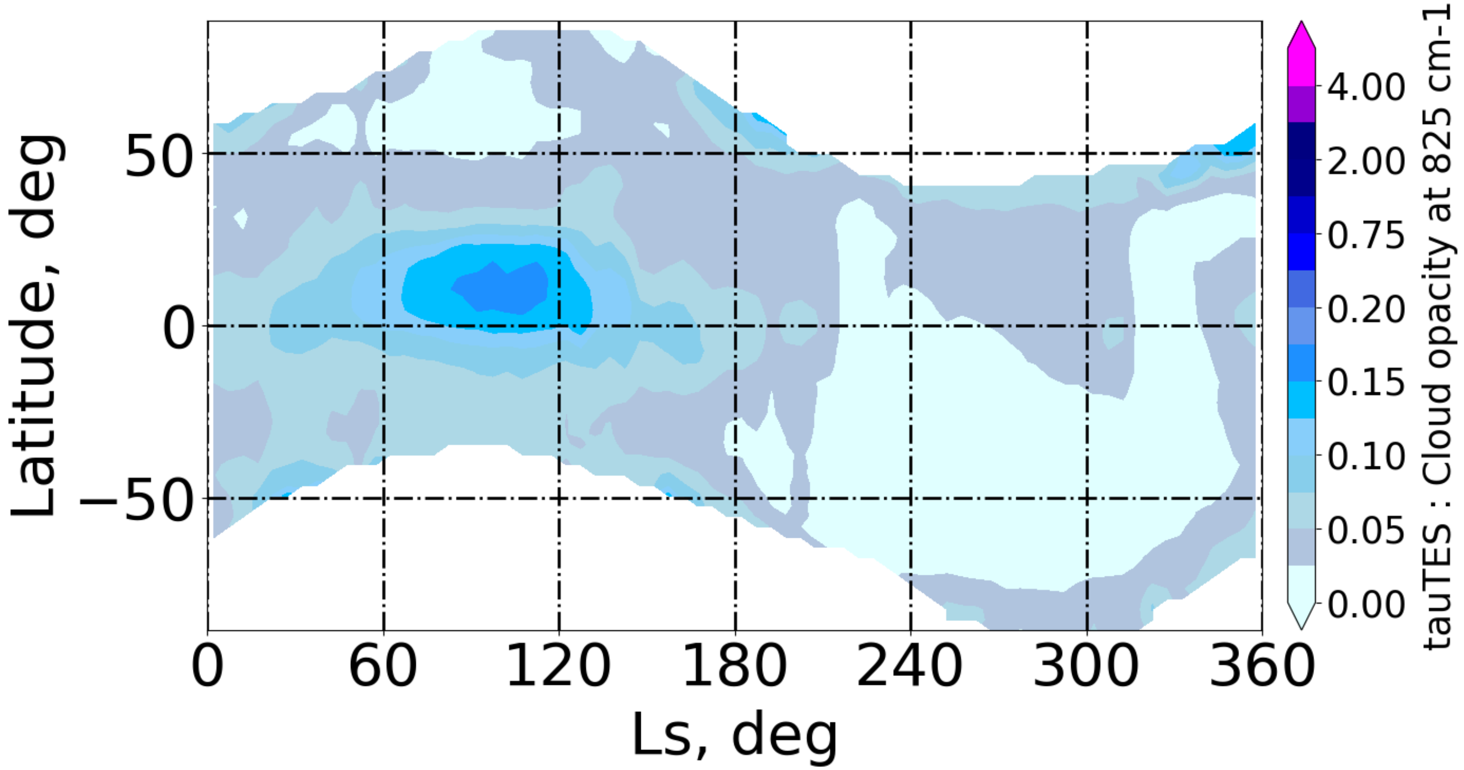
- **Systematic temperature inversion within nighttime clouds**

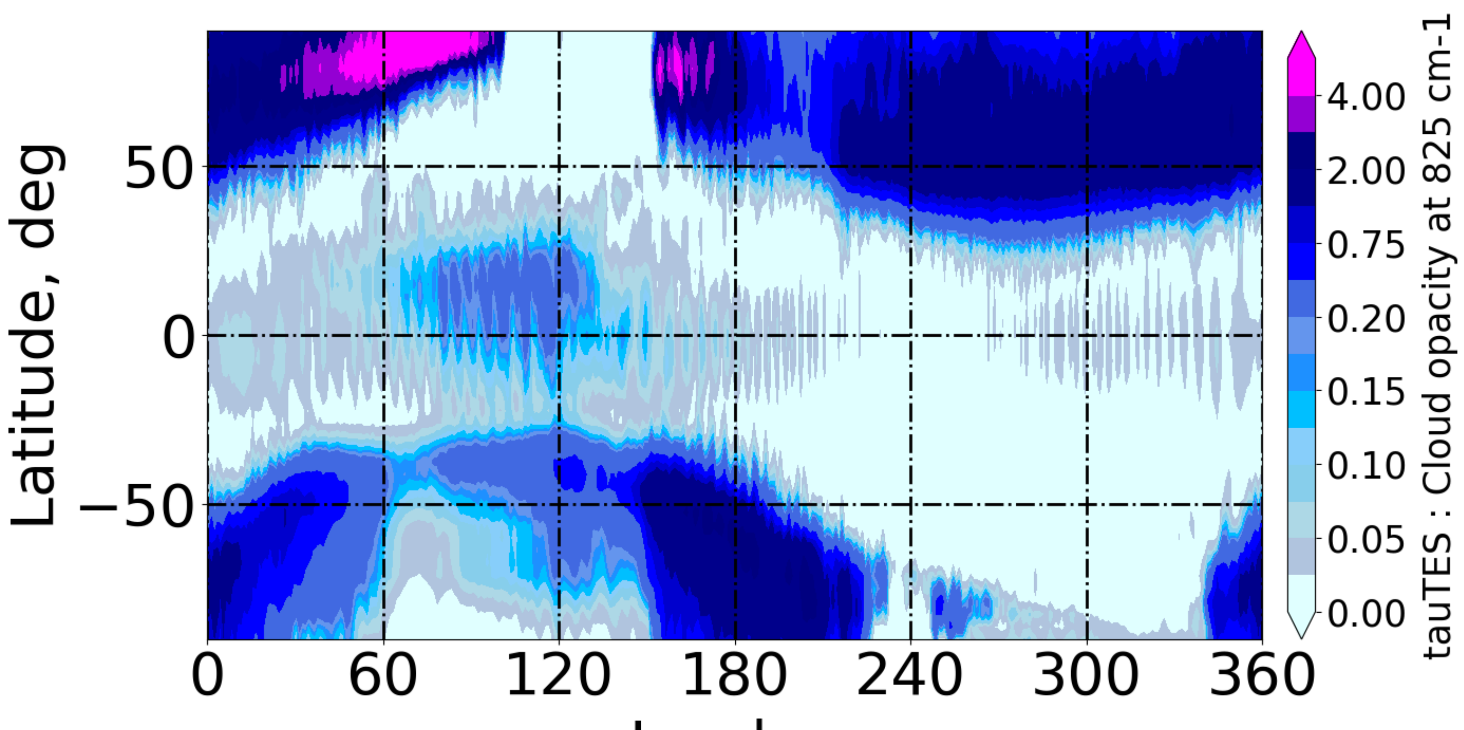


- **Polar hood too thick**

TES

GCM





ARTICLES
PUBLISHED ONLINE: 21 AUGUST 2017 | DOI: 10.1038/NGEO3008
nature geoscience

Snow precipitation on Mars driven by cloud-induced night-time convection

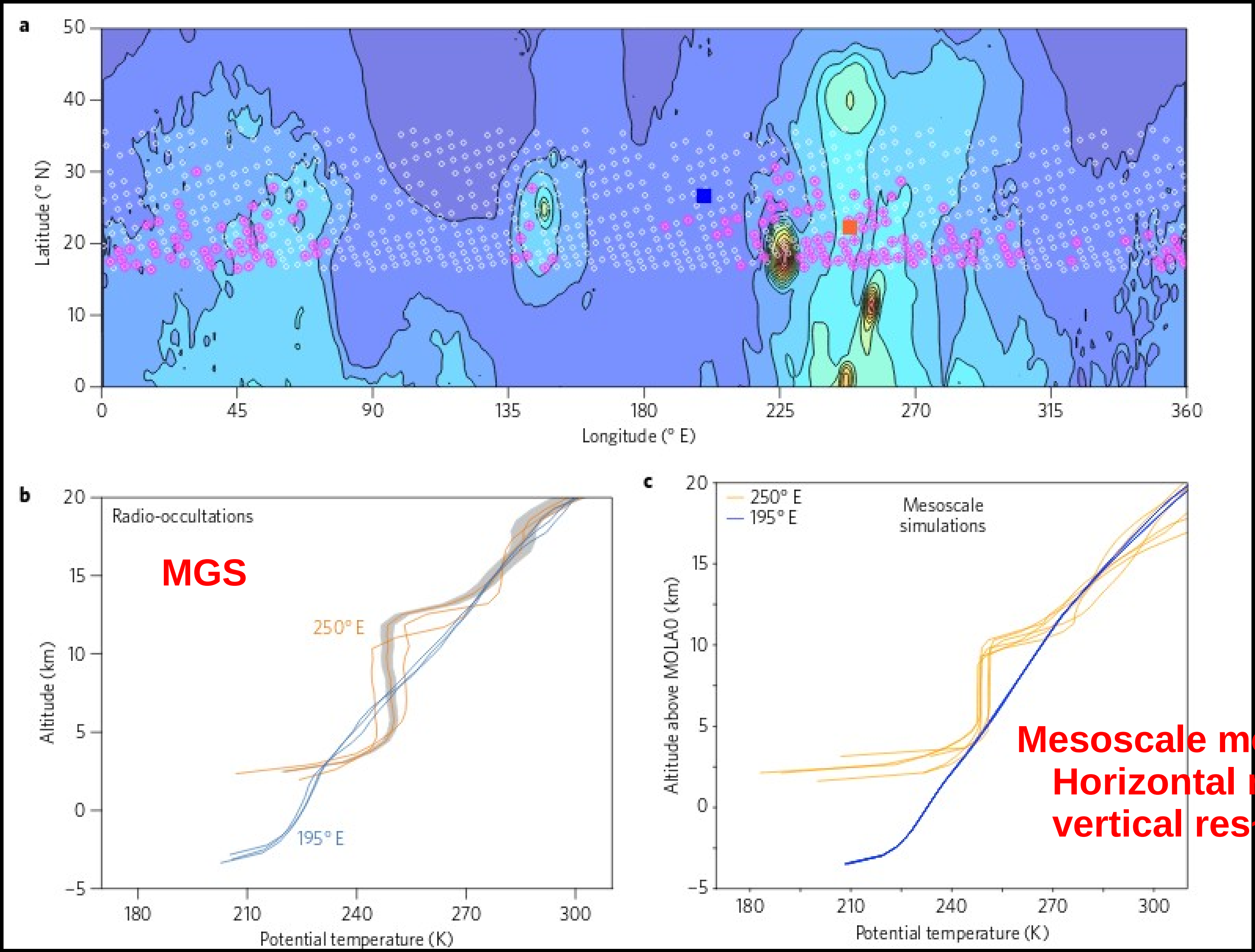
Aymeric Spiga[1]*, David P. Hinson[2,3], Jean-Baptiste Madeleine[1], Thomas Navarro[1], Ehouarn Millour[1], François Forget[1] and Franck Montmessin[4]

Although it contains less water vapour than Earth's atmosphere, the Martian atmosphere hosts clouds. These clouds, composed of water-ice particles, influence the global transport of water vapour and the seasonal variations of ice deposits. However, the influence of water-ice clouds on local weather is unclear: it is thought that Martian clouds are devoid of moist convective motions, and snow precipitation occurs only by the slow sedimentation of individual particles. Here we present numerical simulations of the meteorology in Martian cloudy regions that demonstrate that localized convective snowstorms can occur on Mars. We show that such snowstorms—or ice microbursts—can explain deep night-time mixing layers detected from orbit and precipitation signatures detected below water-ice clouds by the Phoenix lander. In our simulations, convective snowstorms occur only during the Martian night, and result from atmospheric instability due to radiative cooling of water-ice cloud particles. This triggers strong convective plumes within and below clouds, with fast snow precipitation resulting from the vigorous descending currents. Night-time convection in Martian water-ice clouds and the associated snow precipitation lead to transport of water both above and below the mixing layers, and thus would affect Mars' water cycle past and present, especially under the high-obliquity conditions associated with a more intense water cycle.

Martian water-ice clouds were one of the first atmospheric phenomena to be observed on Mars[1–3]. The absolute quantity of water vapour is much smaller on Mars than it is on the Earth (a few precipitable micrometers, 1 pr-μm = 1 g m^{-2}); yet the low pressure and temperature of the Martian atmosphere cause the relative humidity to often reach saturation conditions, leading to the formation of water-ice clouds[4]. Water-ice clouds on Mars exhibit seasonal[5,6] and diurnal[7] variability, with the formation of a tropical cloud belt during the aphelion seasons and 'polar hood' clouds at high latitudes in fall/spring[8,9]. Their infrared absorption and emission dominate scattering and absorption in the visible[10]

water-ice cloud formation is regularly observed[12,16,17]; the daytime convective boundary layer is particularly deep[18,19]; atmospheric tides impact the thermal structure[14,20]; and the gravity wave activity is significant[21]. Night-time mixing layers cannot be the remainder of the mixing layers from the daytime convective boundary layer, which disappear a few hours after sunset[15]; and they are both too deep and too low in the Martian troposphere to be caused by the breaking of atmospheric tides and/or gravity waves, according to existing modelling and observations[22]. Thus, the only plausible origin of the deep night-time mixing layers is aphelion water-ice

Night-time mixing layers under water ice clouds



MGS radio-occultation measurements

- Mixing layer
- 250°E
- 195°E

Potential temperature profiles

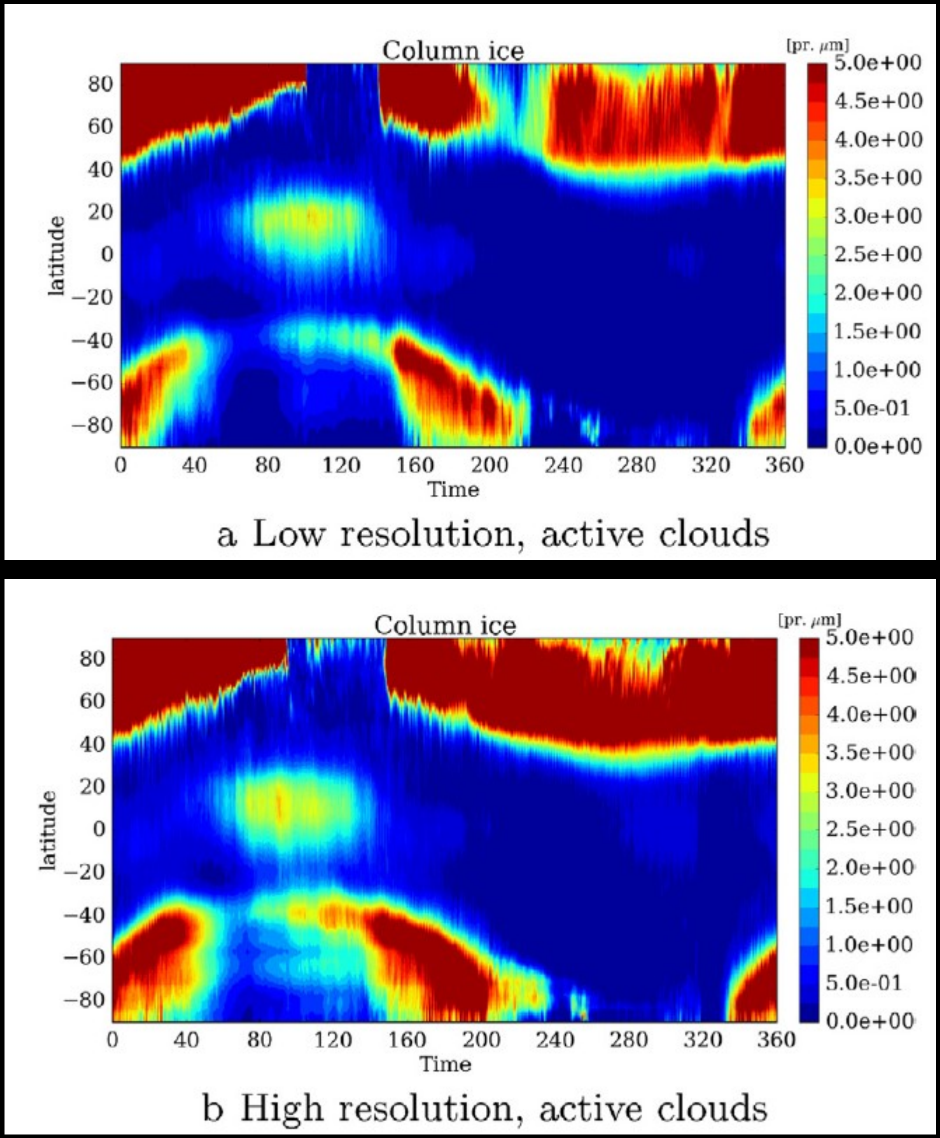
Mesoscale model :
Horizontal res~30km
vertical res~750m

Spiga et al. 2017

High horizontal resolution

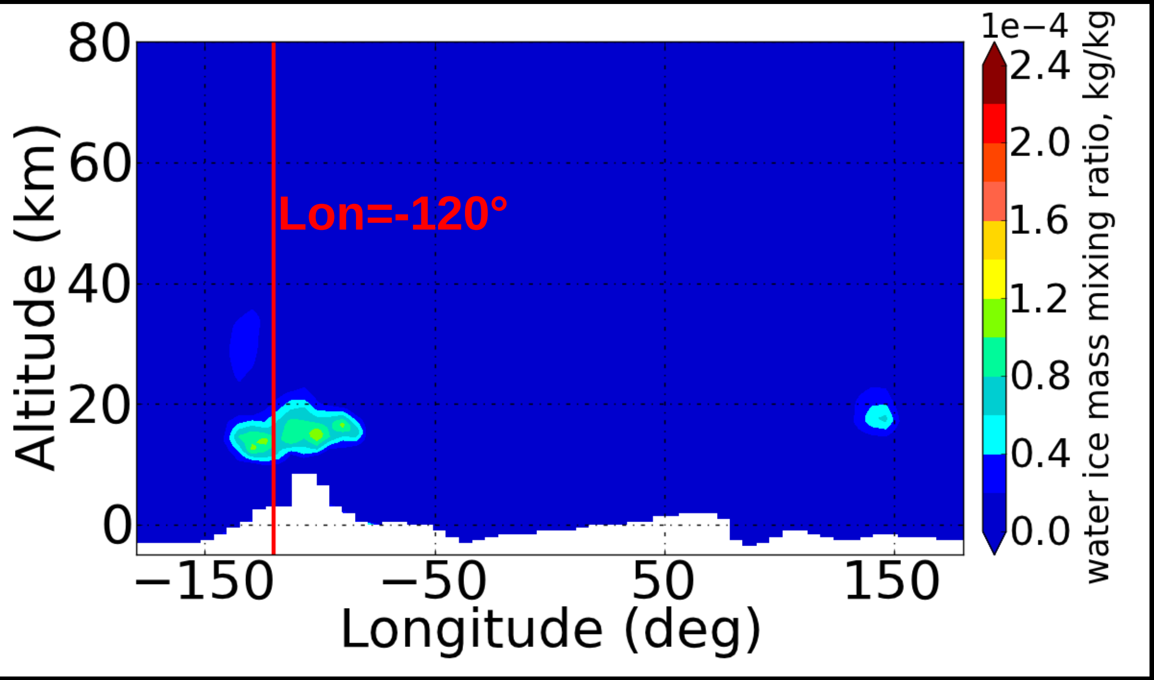
GCM
Usual
res~3,75x5,625°
(~220x330km)

GCM
High
res~1x1°
(~60x60km)

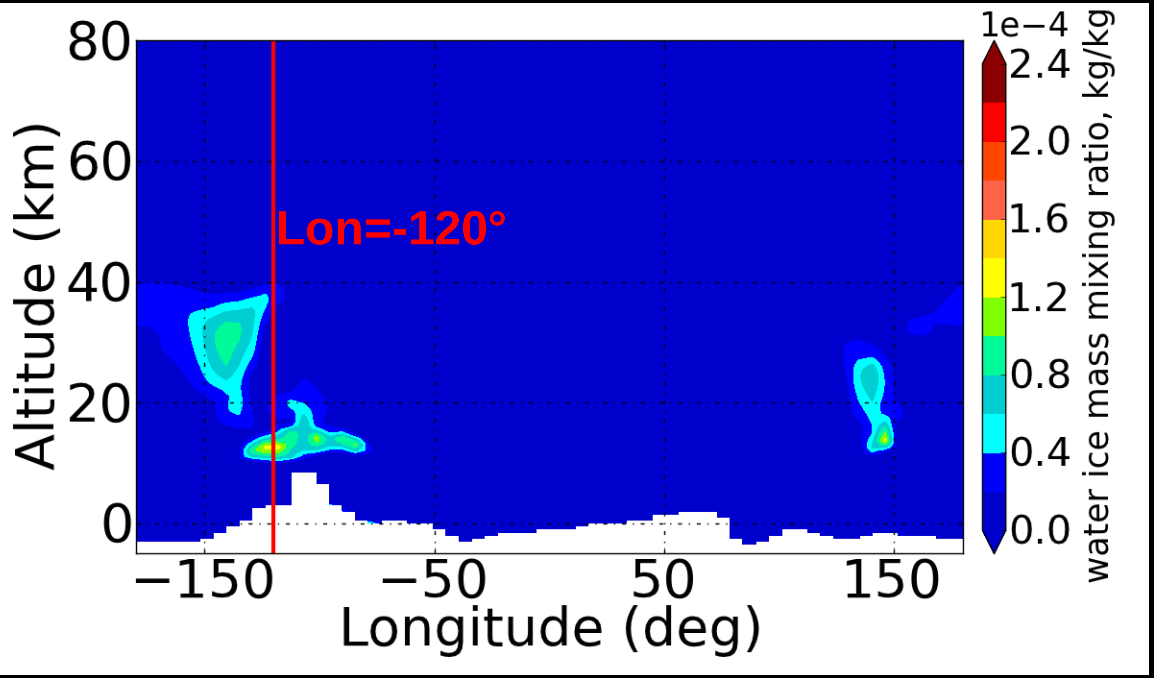


Pottier et al. 2017

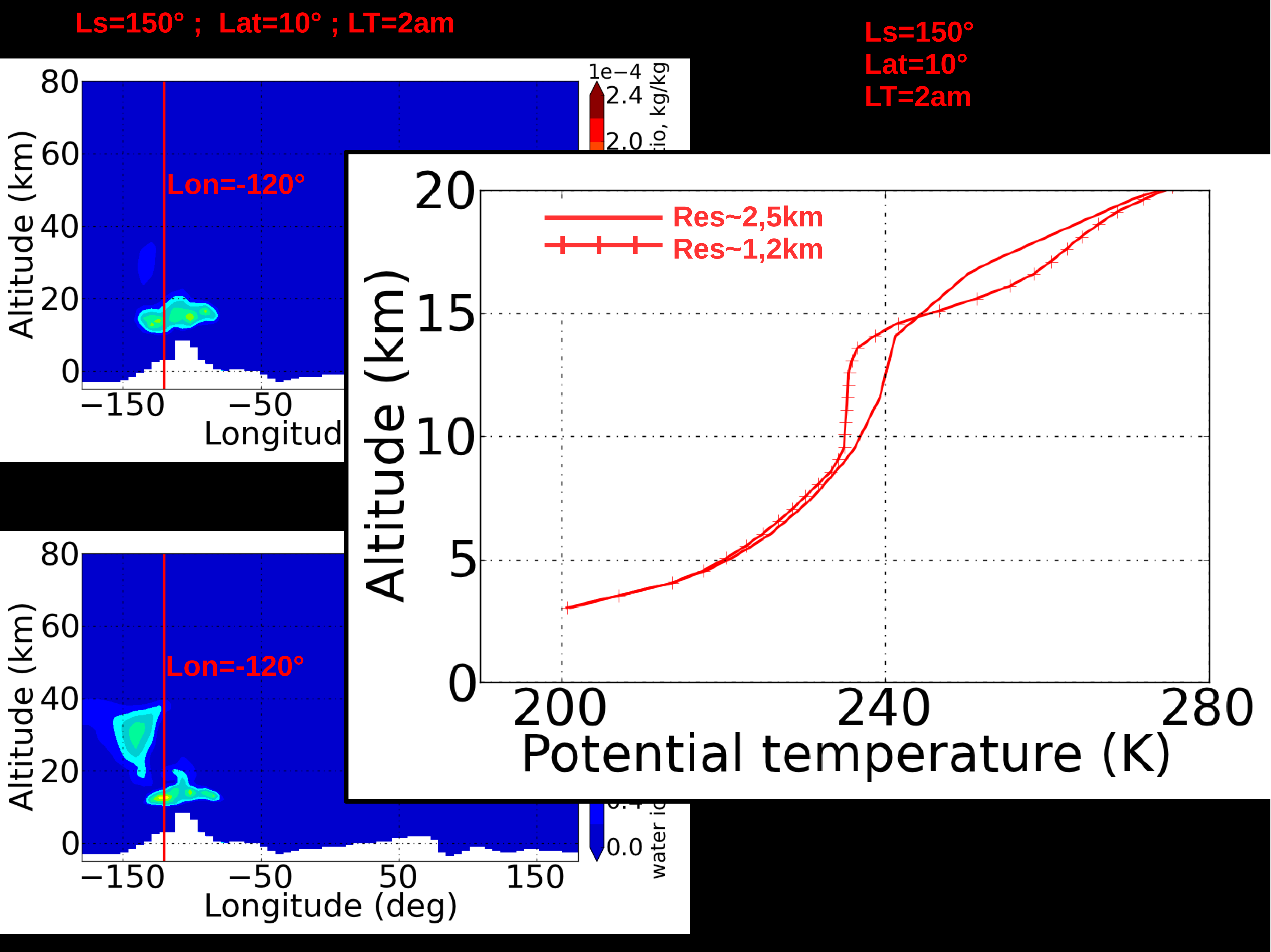
Ls=150° ; Lat=10° ; LT=2am



Usual vertical resolution~2,5km



High vertical resolution~1,2km

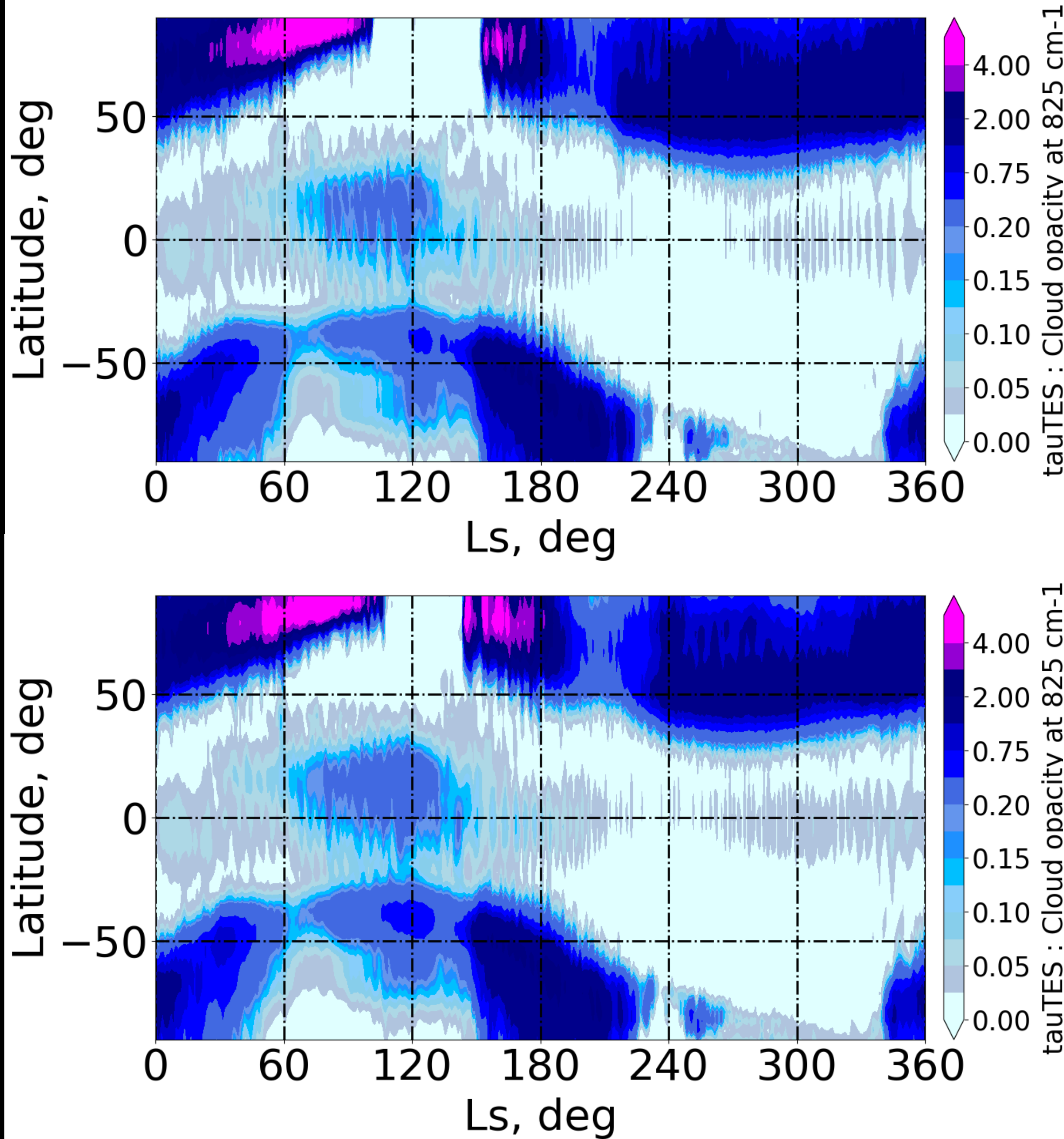


Ls=150° ; Lat=10° ; LT=2am
Ls=150°
Lat=10°
LT=2am
Lon=-120°
Lon=-120°
Altitude (km)
Longitude (deg)
1e−4
Res~2,5km
Res~1,2km
Altitude (km)
Potential temperature (K)

Water cloud cycle

GCM Vertical Res~2.5km

GCM Vertical Res~1.2km

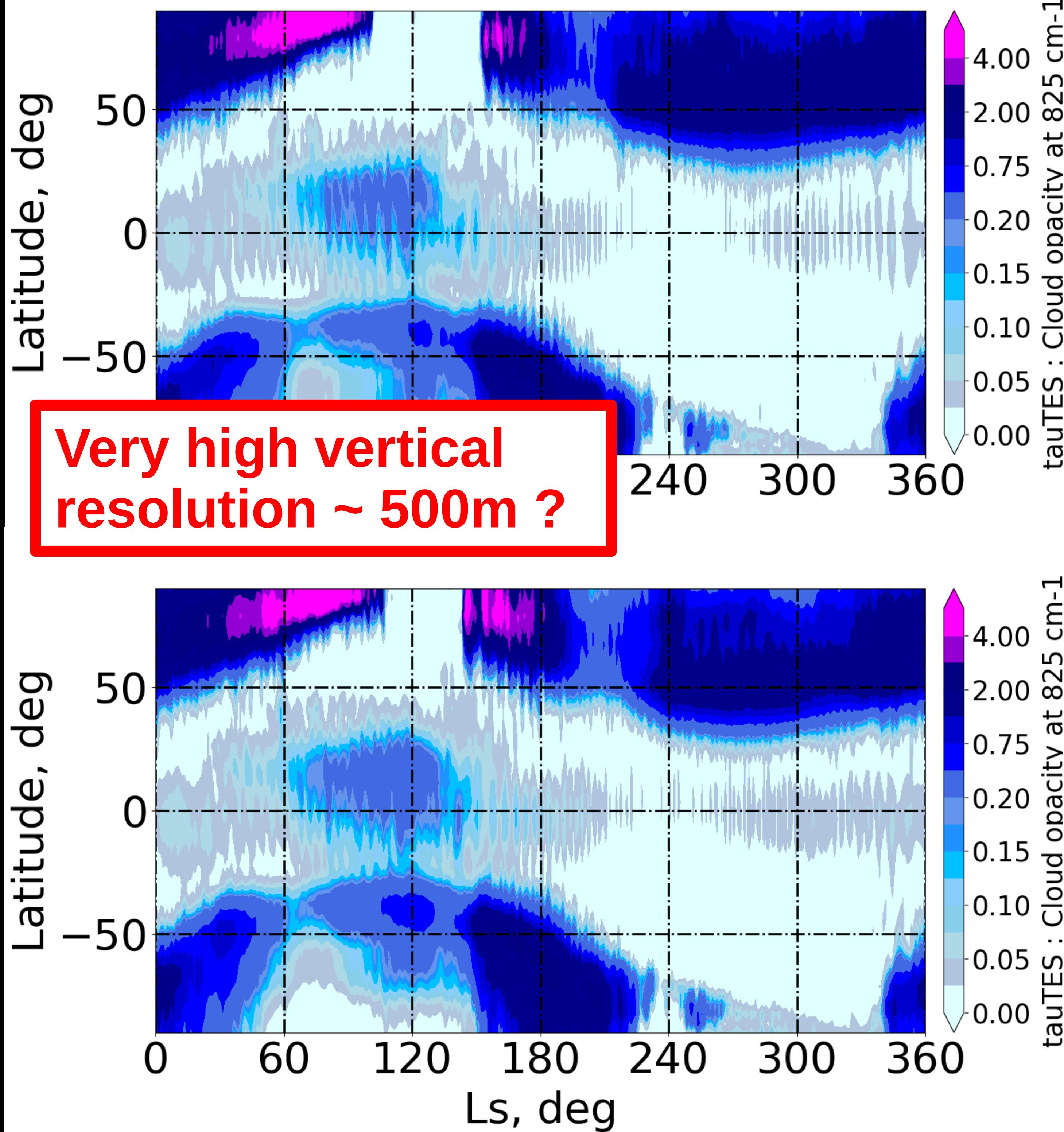


Water cloud cycle

GCM Vertical Res~2.5km

GCM Vertical Res~1.2km

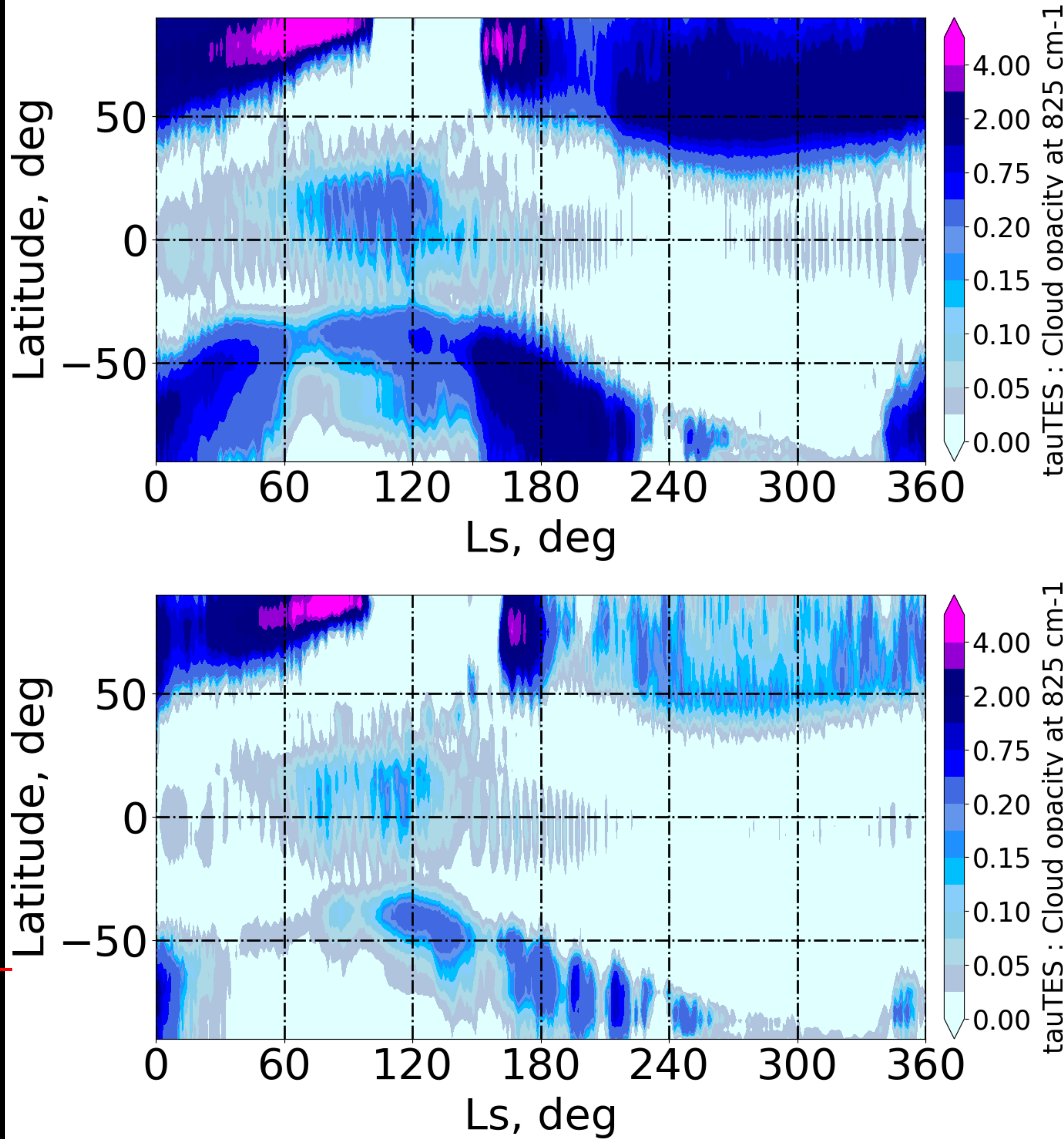
Very high vertical resolution ~ 500m ?



Water cloud cycle

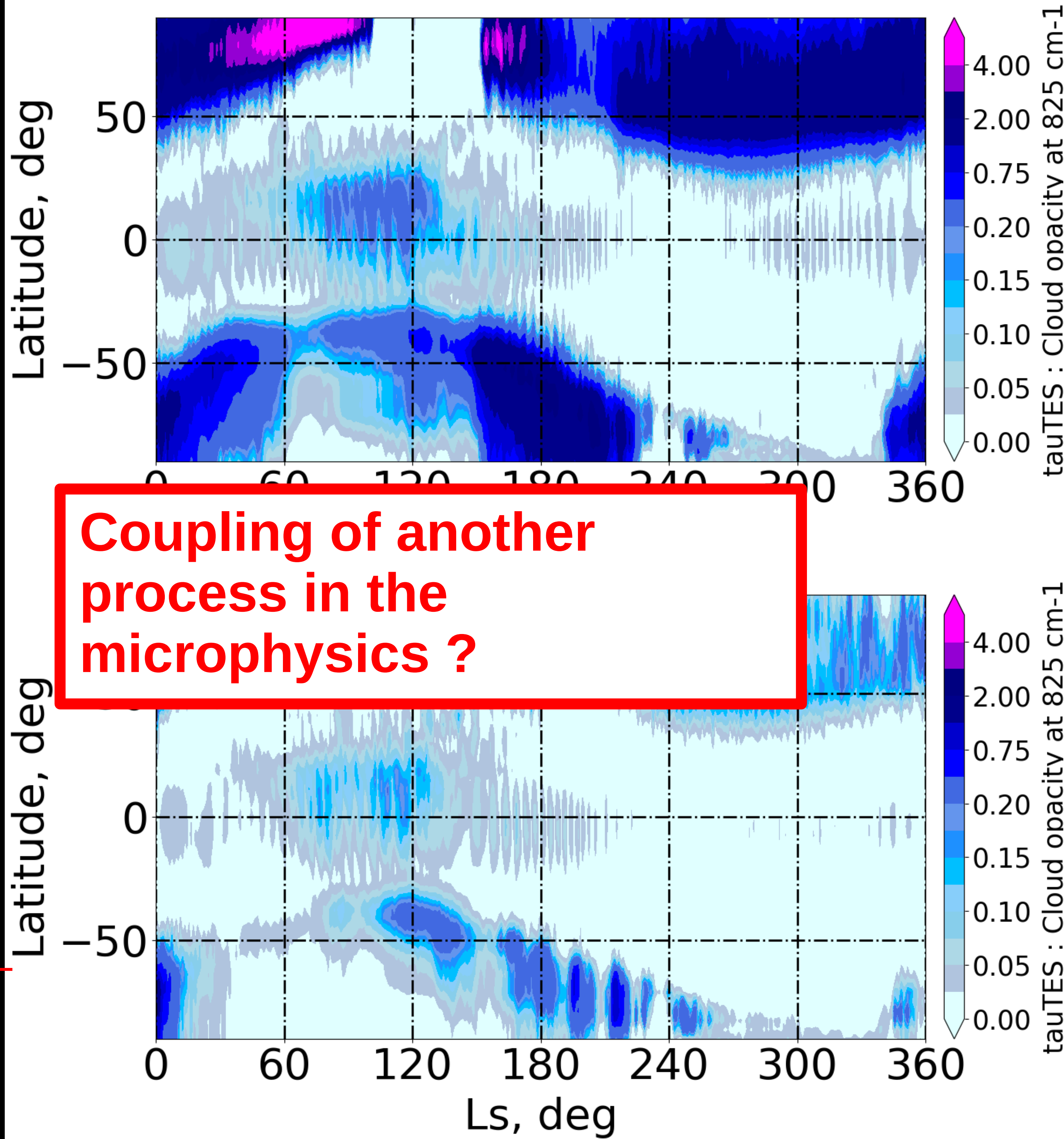
GCM Vertical Res~2.5km

GCM Vertical Res~2.5km **Physical Timestep twice lower than the usual one**



Water cloud cycle

GCM
Vertical
Res~2.5km

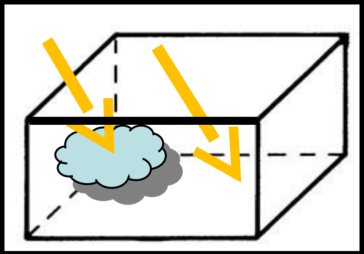


GCM
Vertical
Res~2.5km
Physical Timestep twice lower than the usual one

Conclusion & perspectives

- Microphysics resolution : coupling of ice particle growth and sedimentation, retuning parameters ?
- Investigate on significant improvements of the high vertical resolution
- Implement improvements :
  - Choice of a good vertical resolution
  - Sub-grid scale clouds implementation ?

    (A. Pottier)

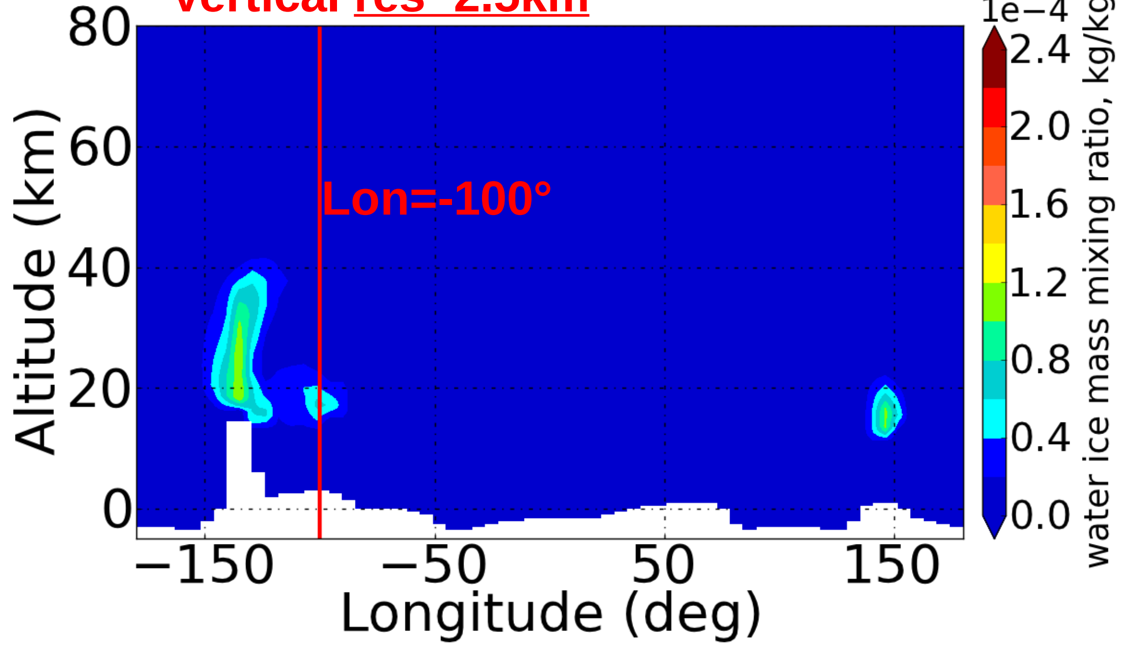


  - Dust cycle : parametrization of detached dust layers (PhD Chao Wang)
- Future comparisons with brandnew observations (TGO)

From here backup slides

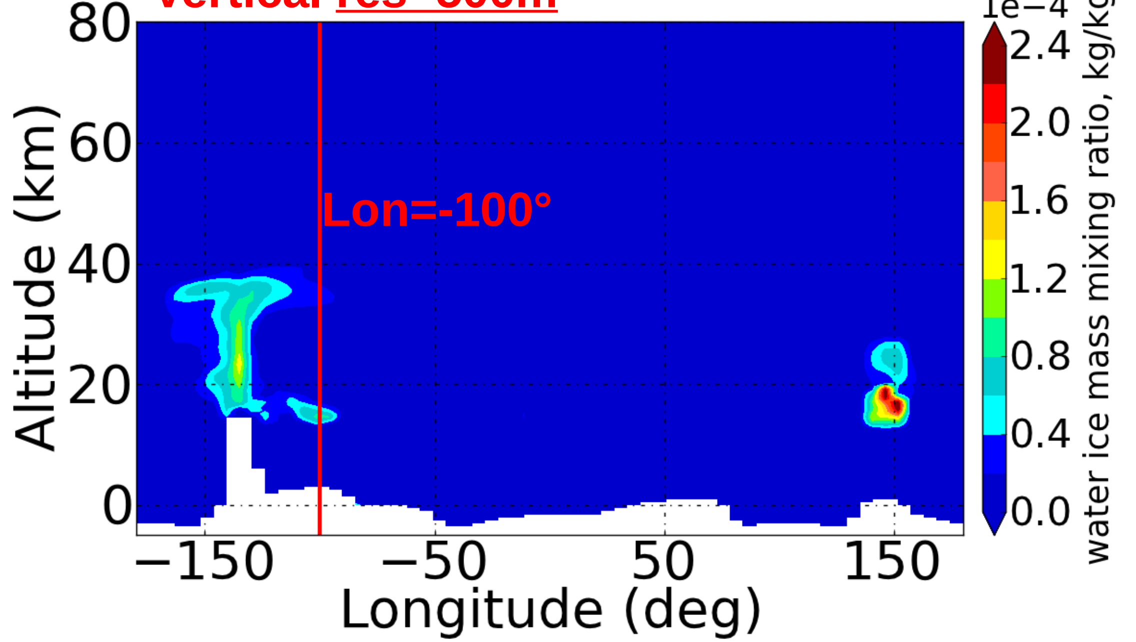
GCM :
Vertical res~2.5km

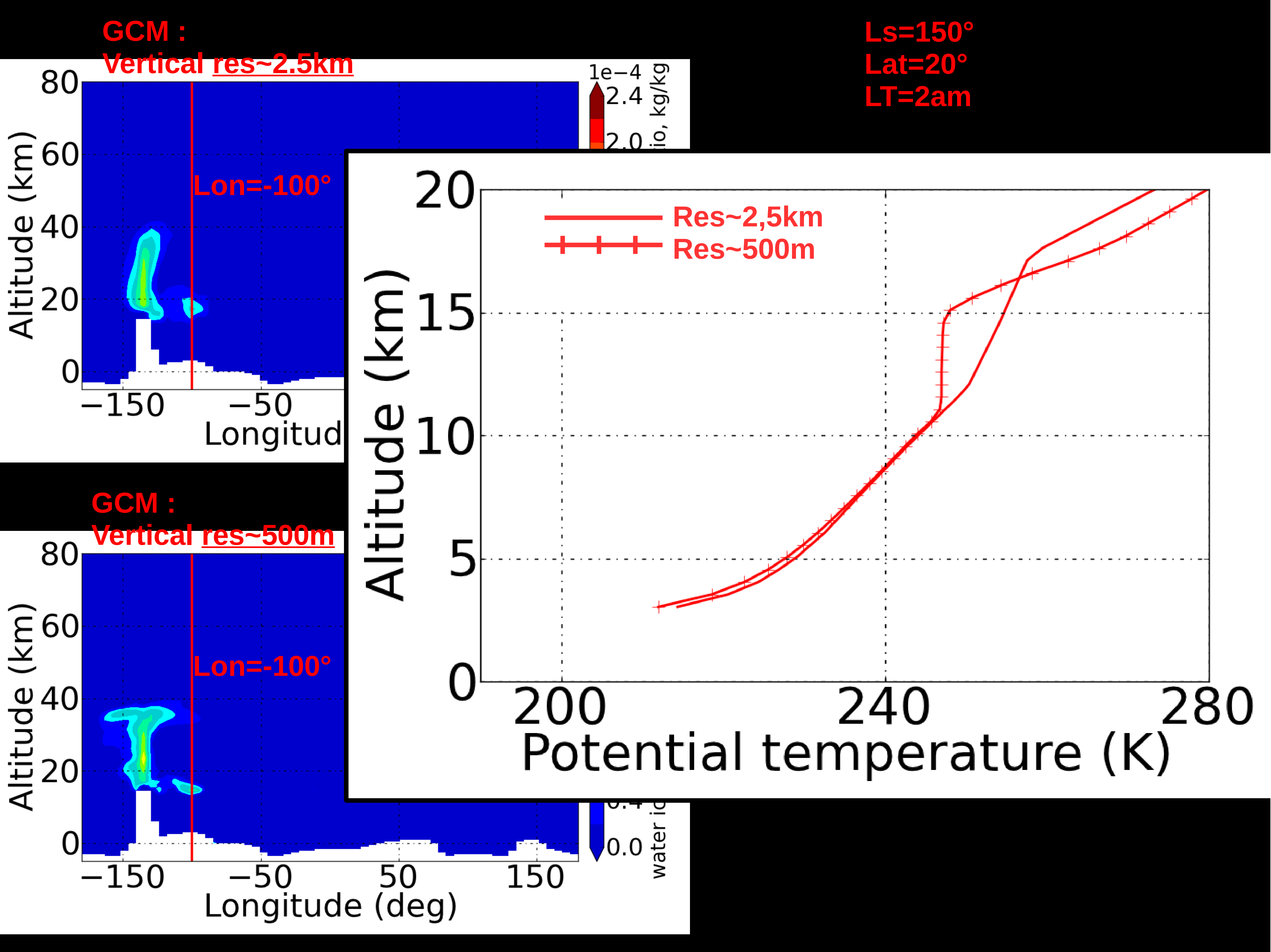
Ls=150°
Lat=20°
LT=2am



Very high resolution

GCM :
Vertical res~500m

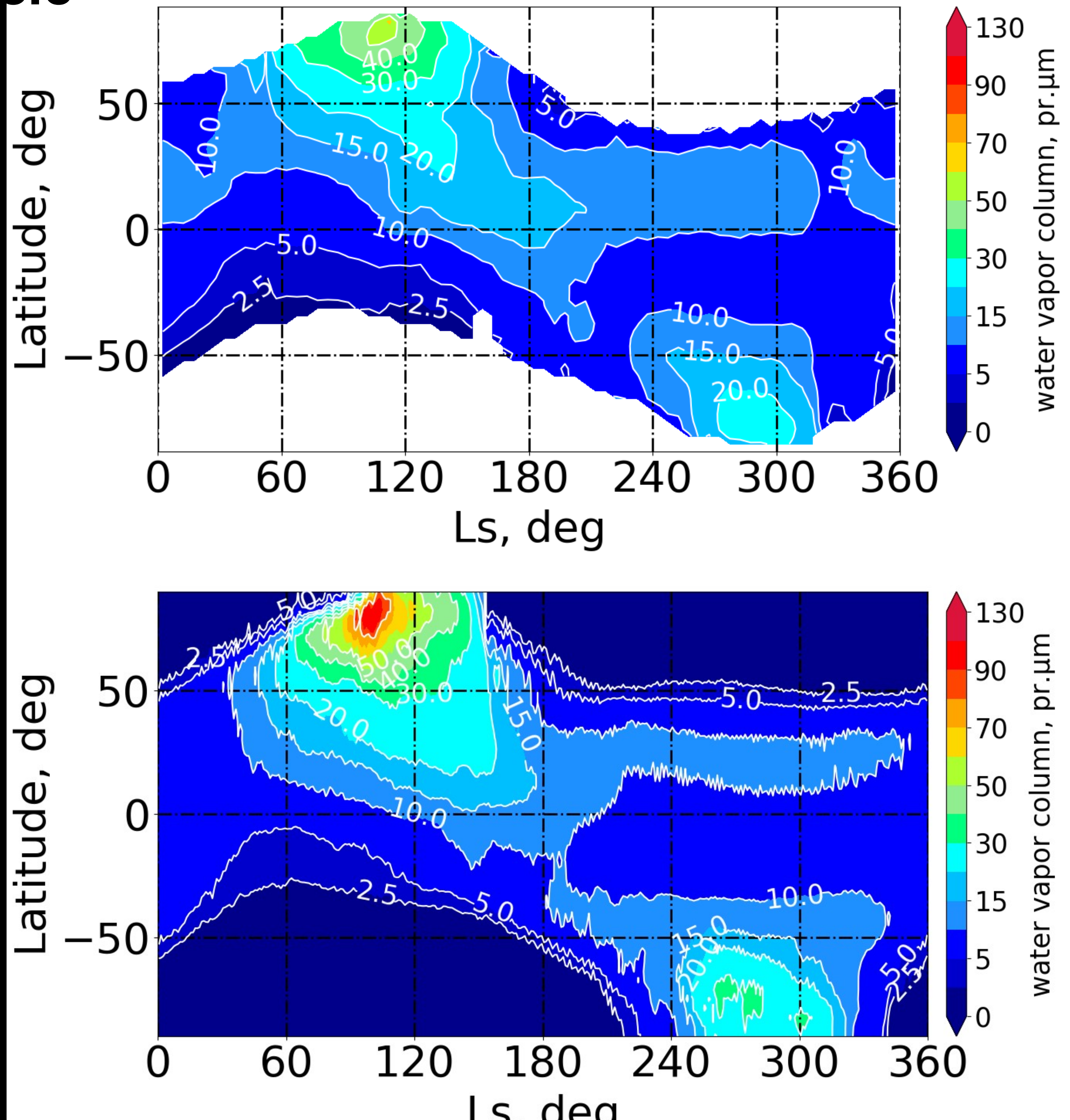



GCM :
Vertical res~2.5km
Ls=150°
Lat=20°
LT=2am
Lon=-100°
Altitude (km)
Longitude (deg)
1e−4
Res~2,5km
Res~500m
Altitude (km)
Potential temperature (K)
GCM :
Vertical res~500m
Lon=-100°
Altitude (km)
Longitude (deg)

cle

TES

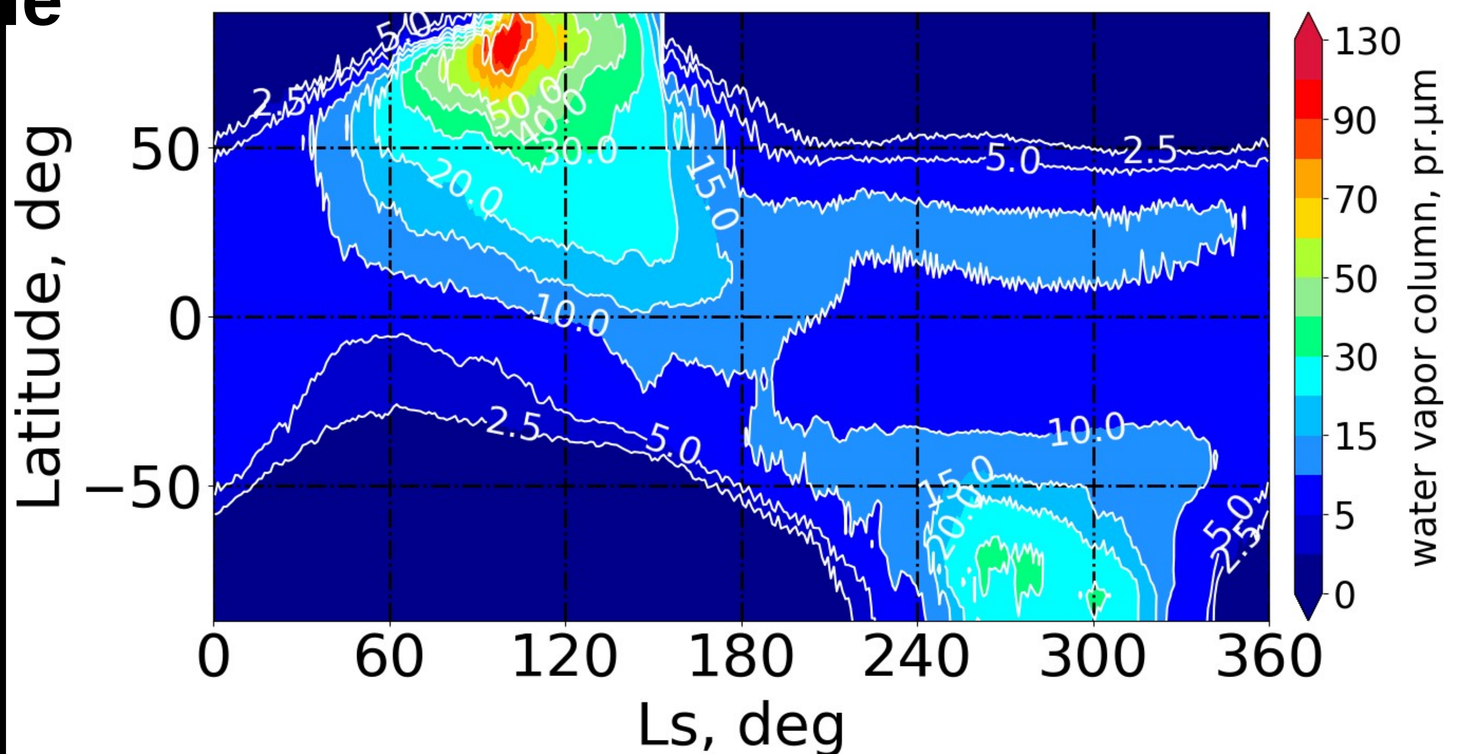
GCM



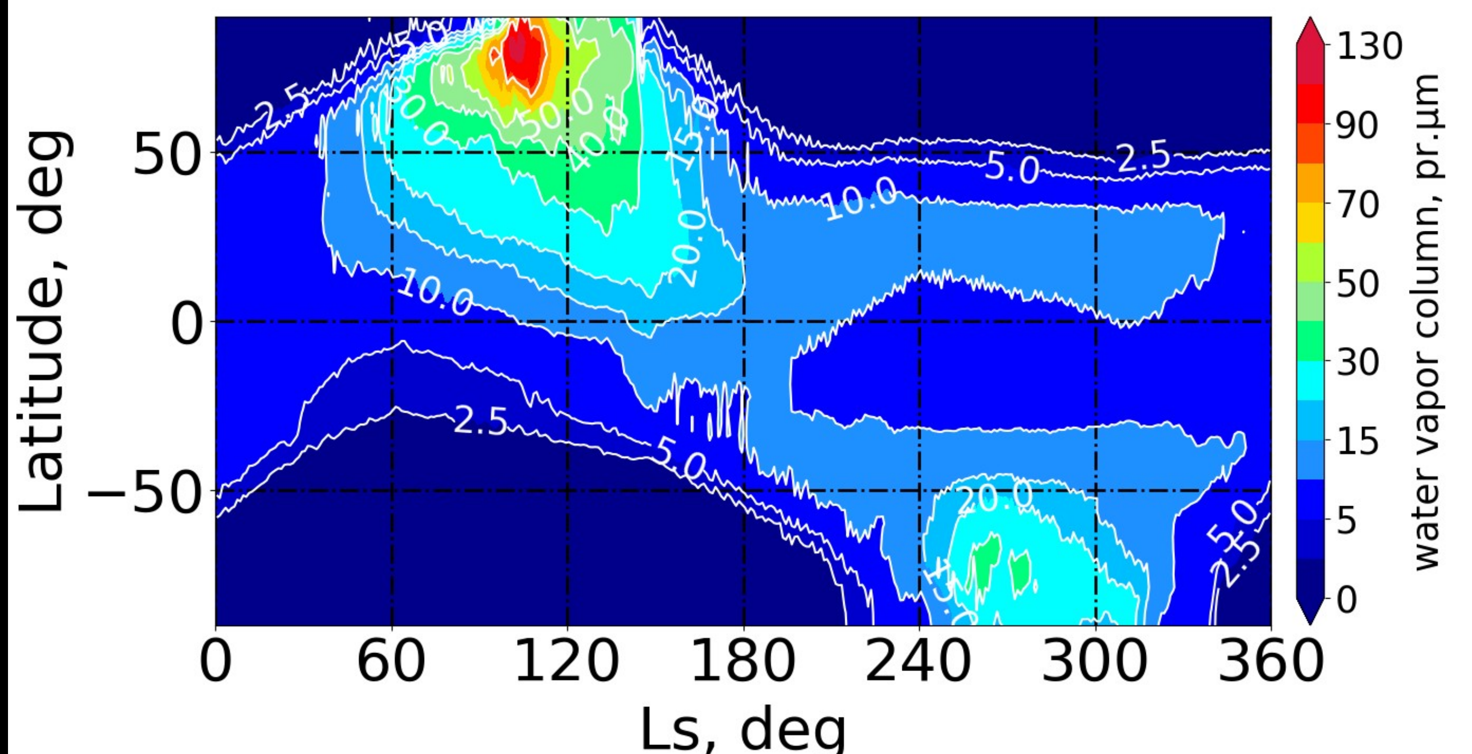
Latitude, deg
50
0
−50
0
60
120
180
240
300
360
Ls, deg
130
90
70
50
30
15
5
0
water vapor column, pr.μm
40.0
30.0
20.0
15.0
10.0
5.0
2.5
Latitude, deg
Ls, deg
water vapor column, pr.μm
50.0

[redacted]

GCM Vertical Res~2.5km

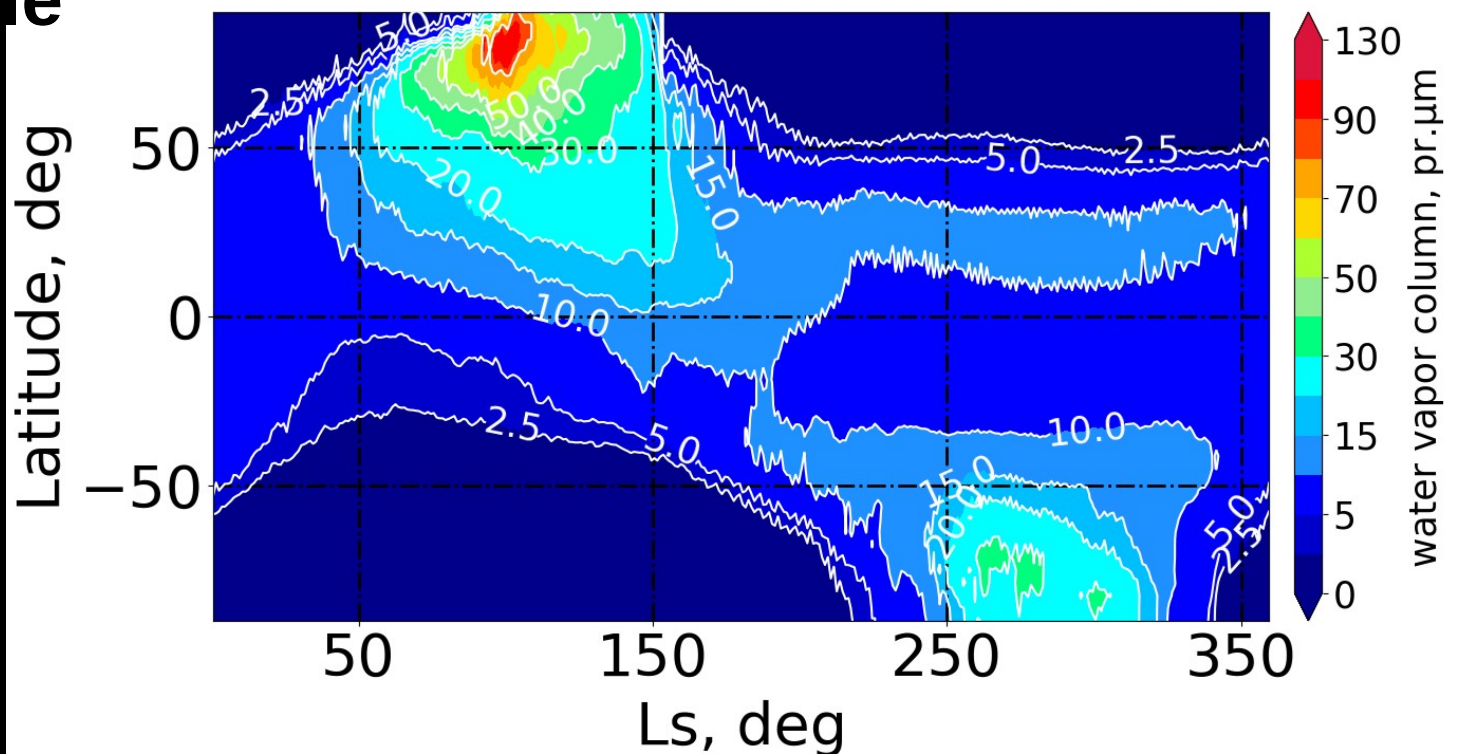


GCM Vertical Res~1.2km

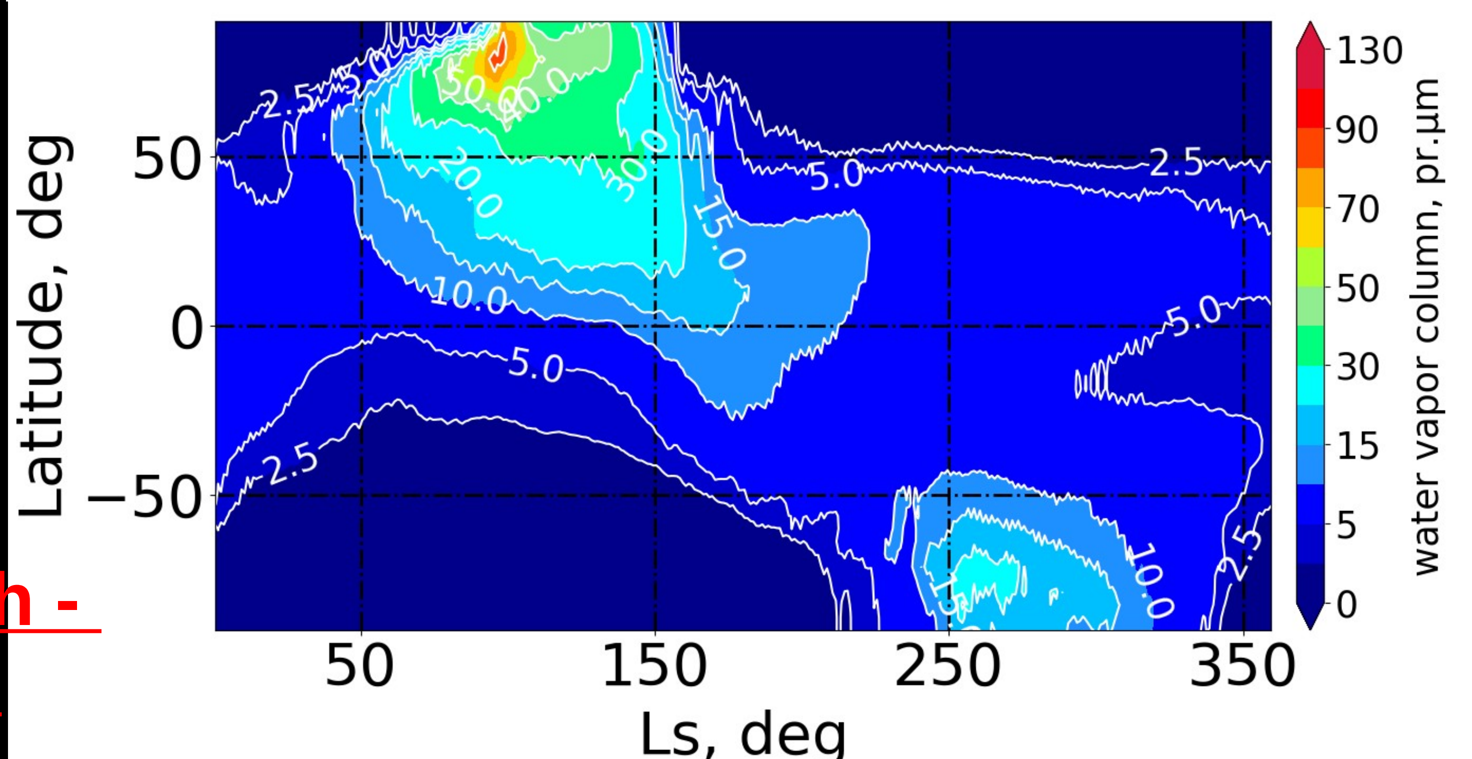


[redacted]le

GCM
Vertical
Res~2,5km

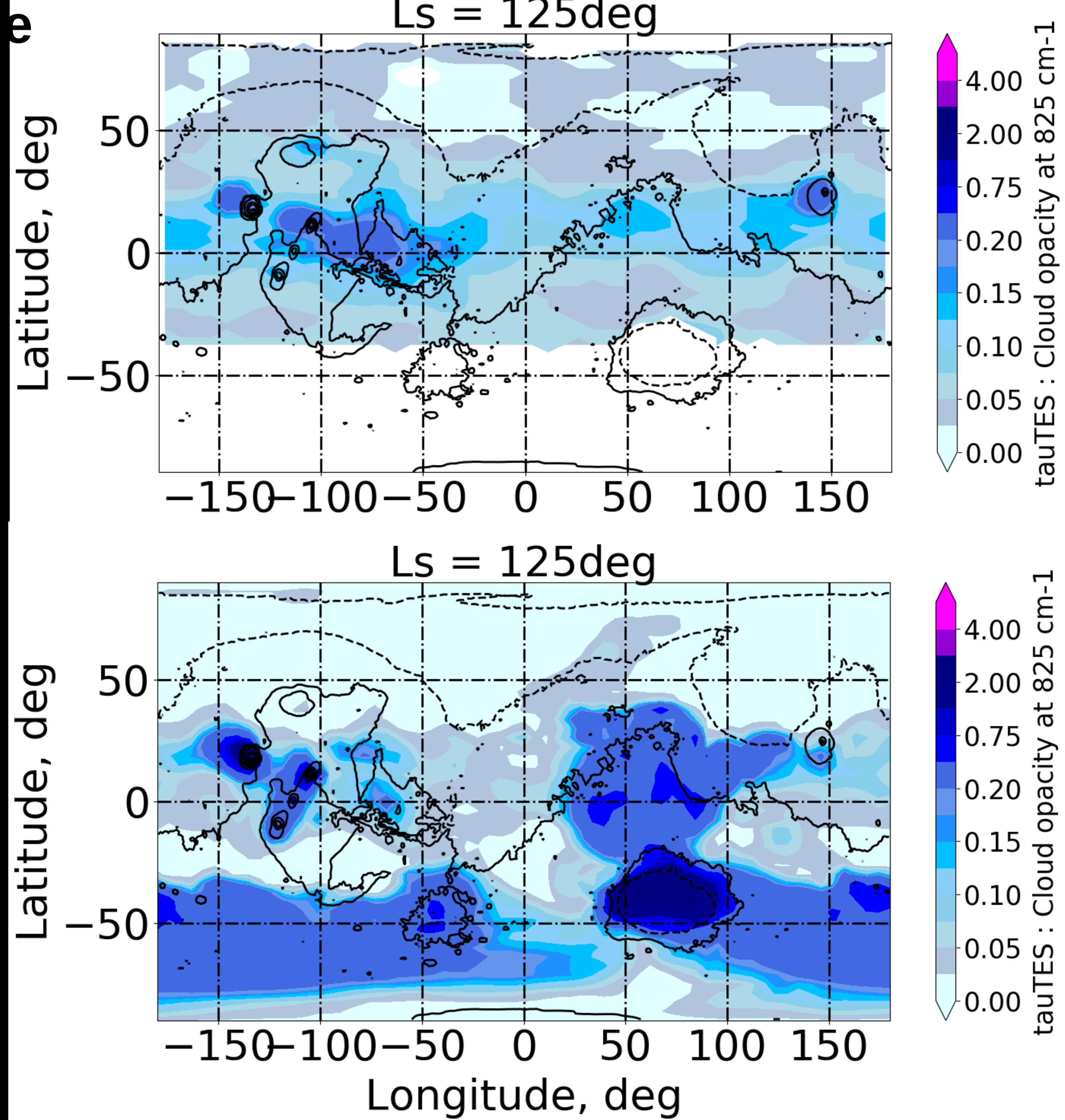


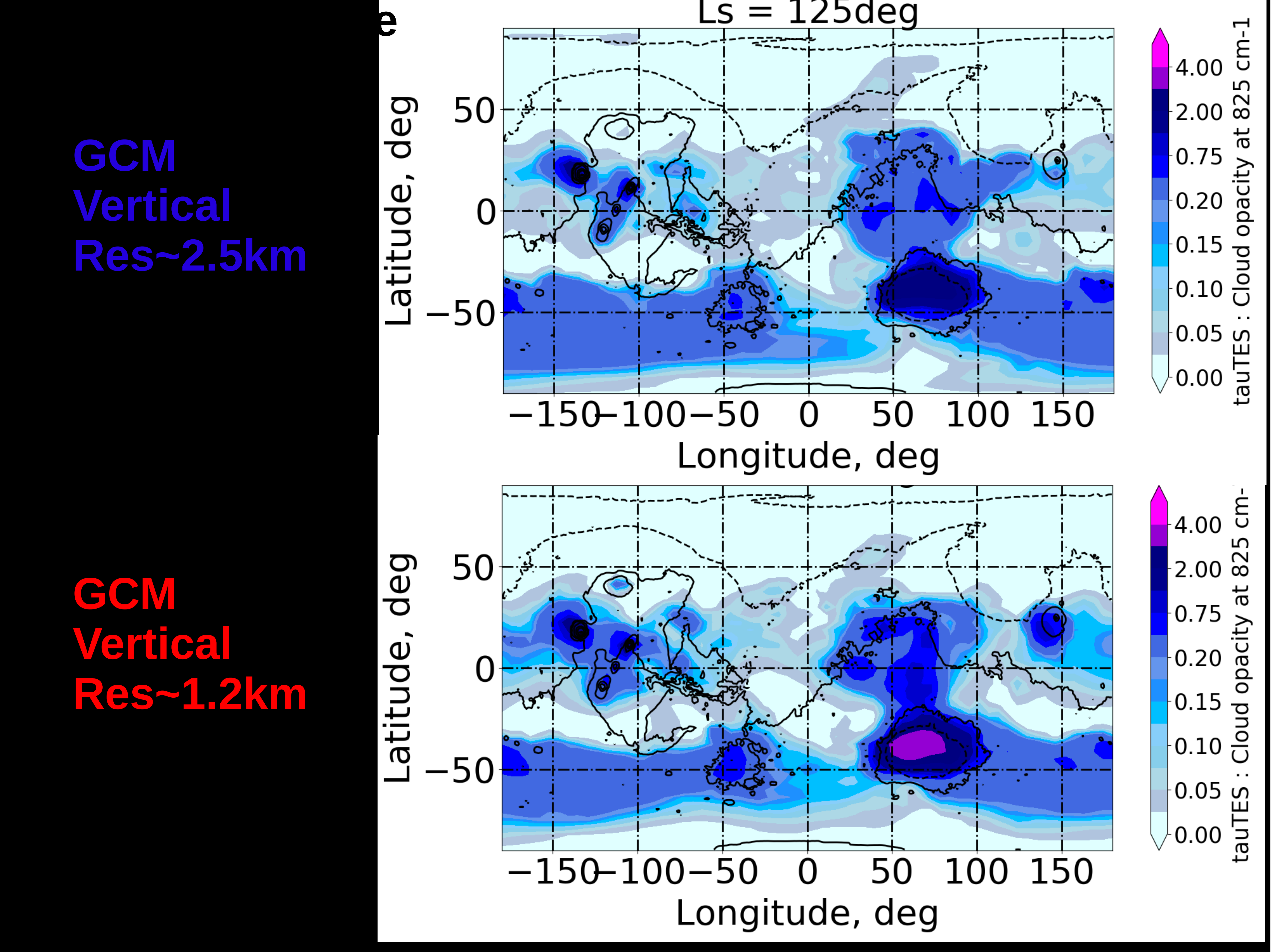
GCM
Vertical
Res~1,2km
<u>Improved Coupling Particle growth - sedimentation</u>



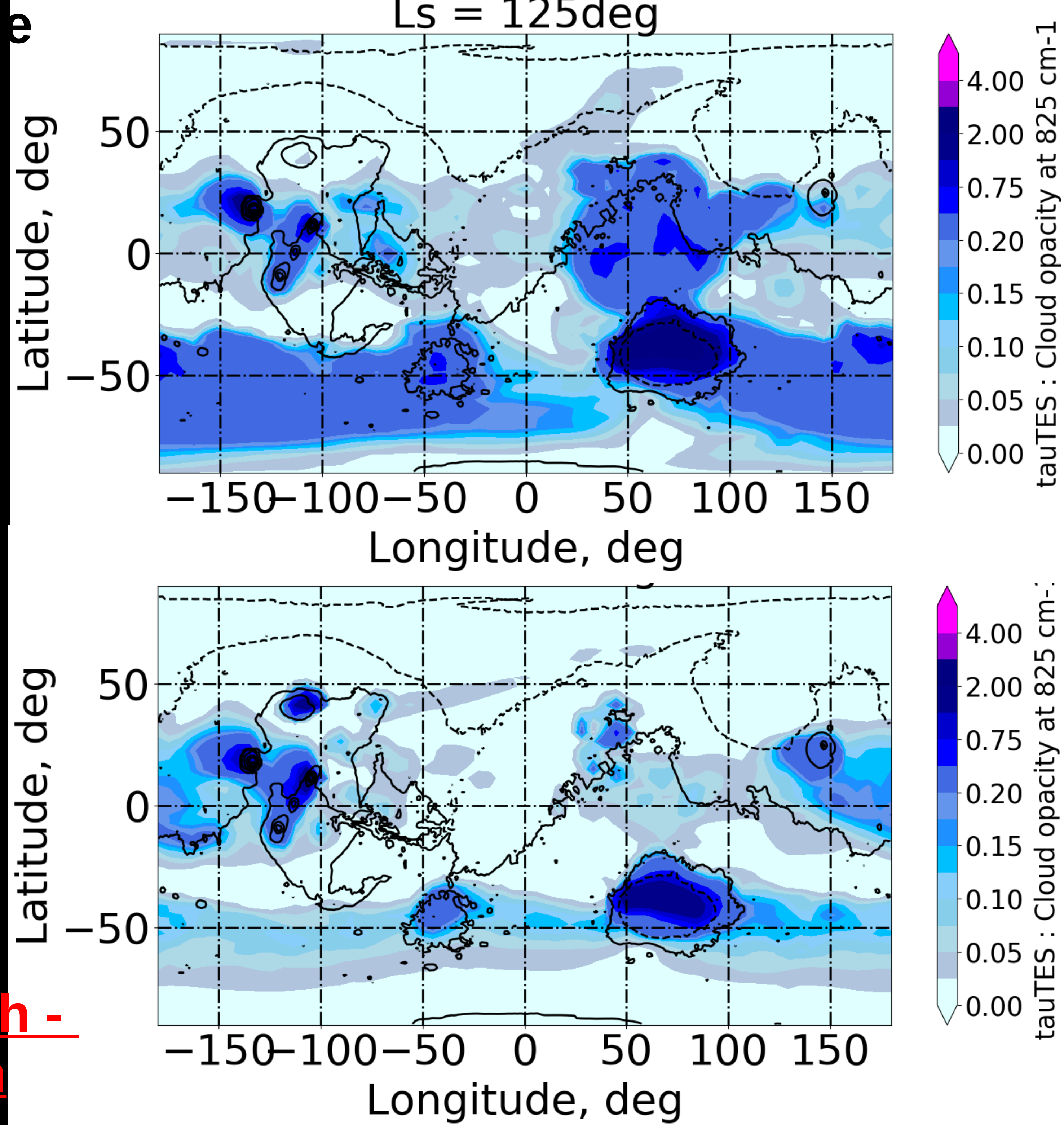
TES

GCM Vertical Res~1.2km




GCM
Vertical
Res~2.5km
GCM
Vertical
Res~1.2km
e
Ls = 125deg
Latitude, deg
Longitude, deg
tauTES : Cloud opacity at 825 cm-1
0.00
0.05
0.10
0.15
0.20
0.75
2.00
4.00
50
0
−50
−150
−100
−50
0
50
100
150

GCM
Vertical
Res~2,5km



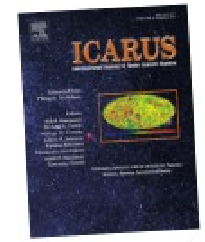
GCM
Vertical
Res~1,2km
Improved
Coupling
Particle growth -
sedimentation

Icarus 291 (2017) 82–106

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus



Unraveling the martian water cycle with high-resolution global climate simulations

Alizée Pottier[a,b,*], François Forget[b], Franck Montmessin[a], Thomas Navarro[b], Aymeric Spiga[b], Ehouarn Millour[b], André Szantai[b], Jean-Baptiste Madeleine[b]

[a] *LATMOS/IPSL, UPMC Univ. Paris 06 Sorbonne Universités, UVSQ, CNRS, Guyancourt, France*

[b] *Laboratoire de Météorologie Dynamique/IPSL/CNRS, UPMC Univ. Paris 06, Sorbonne Universités, Paris, France*

ARTICLE INFO

Article history:
Received 22 April 2016
Revised 12 December 2016
Accepted 23 February 2017
Available online 24 February 2017

Keywords:
Mars atmosphere
Atmospheres dynamics
Mars
Climate
Meteorology

ABSTRACT

Global climate modeling of the Mars water cycle is usually performed at relatively coarse resolution (200 – 300 km), which may not be sufficient to properly represent the impact of waves, fronts, topography effects on the detailed structure of clouds and surface ice deposits. Here, we present new numerical simulations of the annual water cycle performed at a resolution of 1° × 1° (~ 60 km in latitude). The model includes the radiative effects of clouds, whose influence on the thermal structure and atmospheric dynamics is significant, thus we also examine simulations with inactive clouds to distinguish the direct impact of resolution on circulation and winds from the indirect impact of resolution via water ice clouds. To first order, we find that the high resolution does not dramatically change the behavior of the system, and that simulations performed at ~ 200 km resolution capture well the behavior of the simulated water cycle and Mars climate. Nevertheless, a detailed comparison between high and low resolution simulations, with reference to observations, reveal several significant changes that impact our understanding of the water cycle active today on Mars. The key northern cap edge dynamics are affected by an increase in baroclinic wave strength, with a complication of northern summer dynamics. South polar frost deposition is modified, with a westward longitudinal shift, since southern dynamics are also influenced. Baroclinic wave mode transitions are observed. New transient phenomena appear, like spiral and streak clouds, already documented in the observations. Atmospheric circulation cells in the polar region exhibit a large variability and are fine structured, with slope winds. Most modeled phenomena affected by high resolution give a picture of a more turbulent planet, inducing further variability. This is challenging for long-period climate studies.

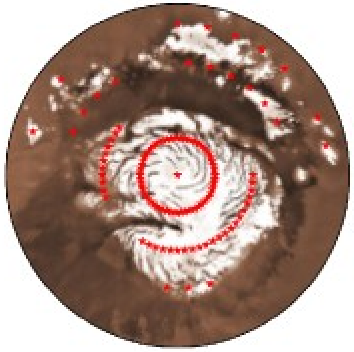
... models (GCMs) are useful tools to analyse the

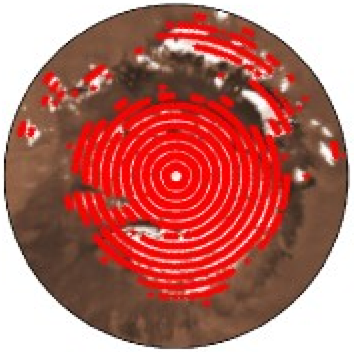
Alizée Pottier

Horizontal resolution

Géométrie de la haute résolution

Résolution	Standard	Haute
Points en longitude	64	360
Points points en latitude	48	180
Niveaux horizontaux	29	29
Largeur longitudinale (0°N)	333 km	59 km
Largeur longitudinale (45°N)	235 km	42 km
Largeur longitudinale (60°N)	166 km	30 km
Largeur longitudinale (80°N)	58 km	10 km
Largeur latitudinale d'une cellule	222 km	59 km





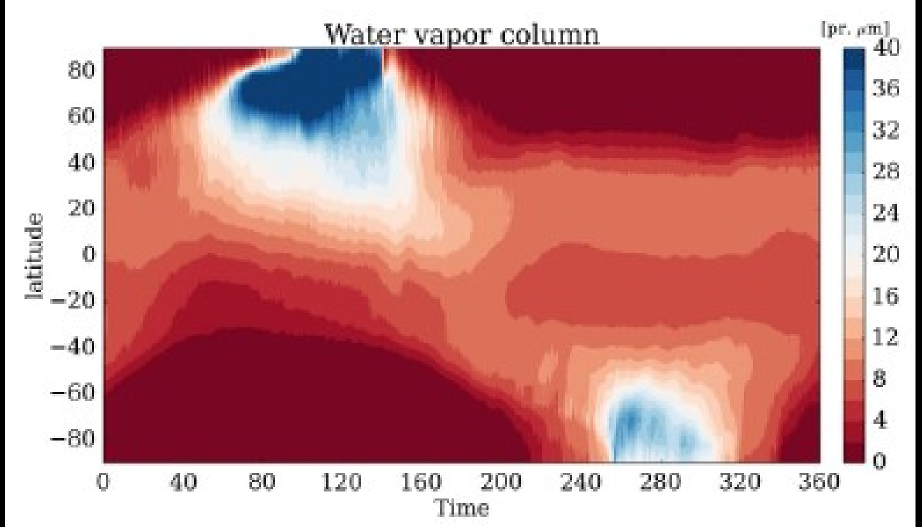
Effet sur la calotte nord, source principale d'eau

Plus de détails dans la représentation de la calotte nord (à droite, calotte permanente).

Alizée Pottier

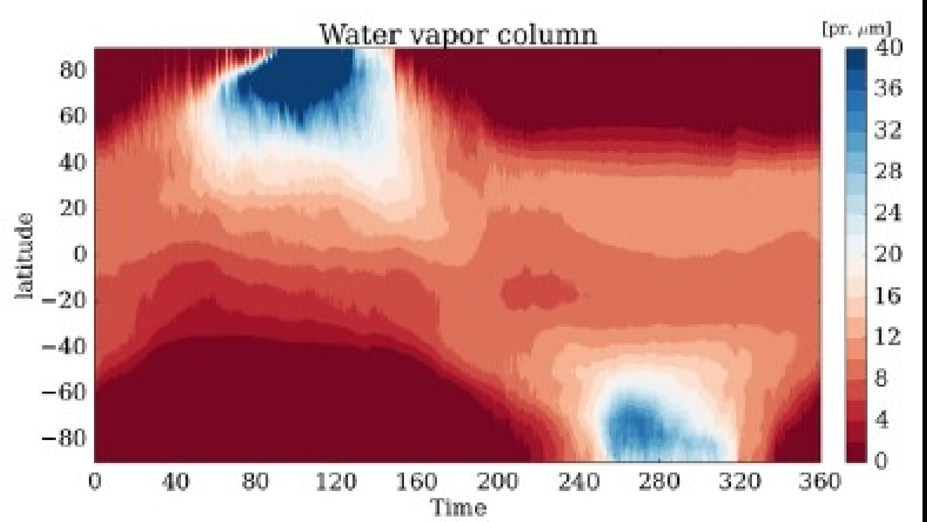
Horizontal resolution

GCM
3.75°x5.625°



a Low resolution, active clouds

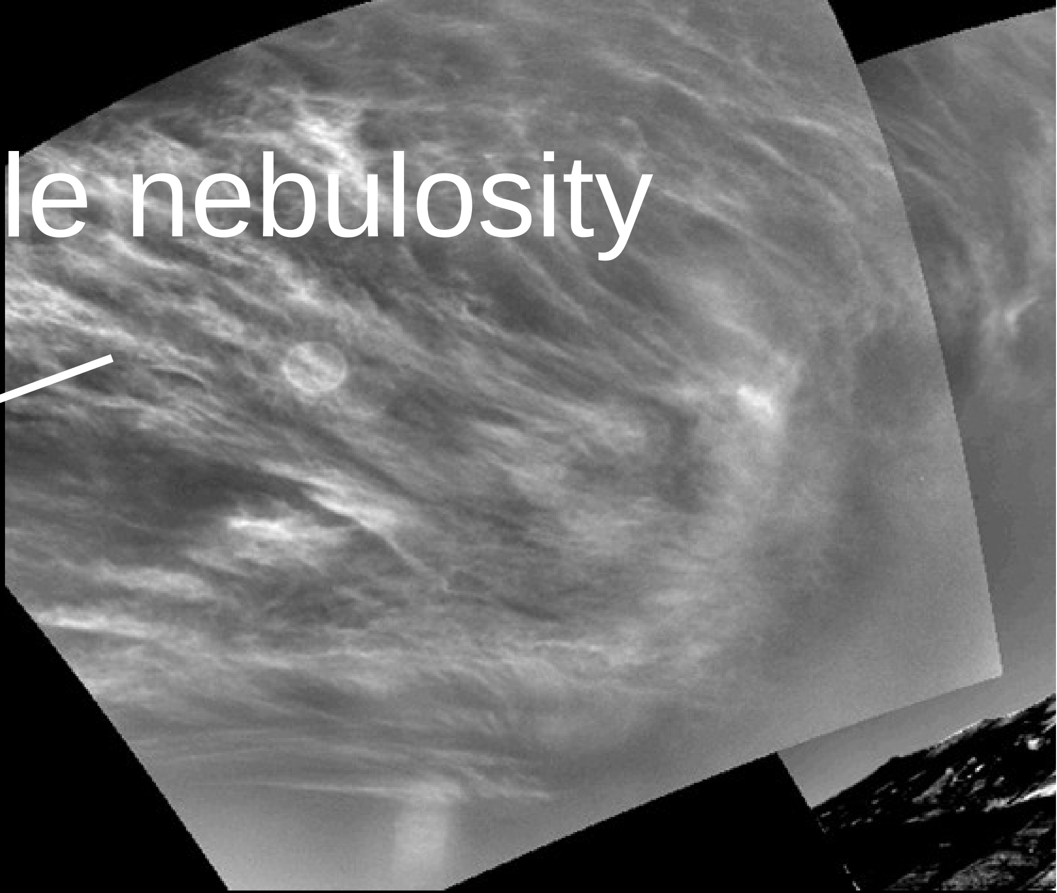
GCM
1°x1°



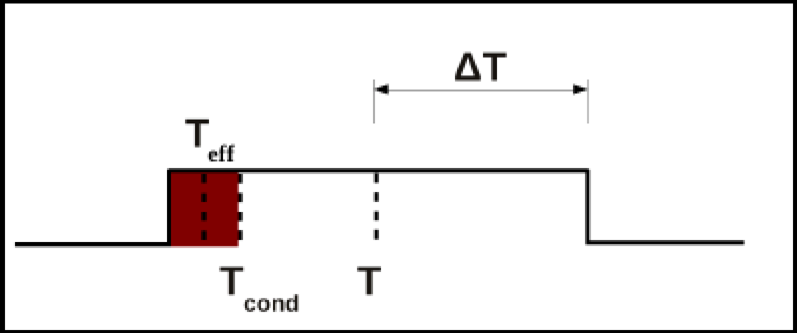
b High resolution, active clouds

Alizée Pottier

Sub-grid scale nebulosity



The sub-grid scale variability is represented by a temperature distribution



Sub-grid scale nucleation, ice condensation & growth

Sub-grid scale clouds
& radiative transfer