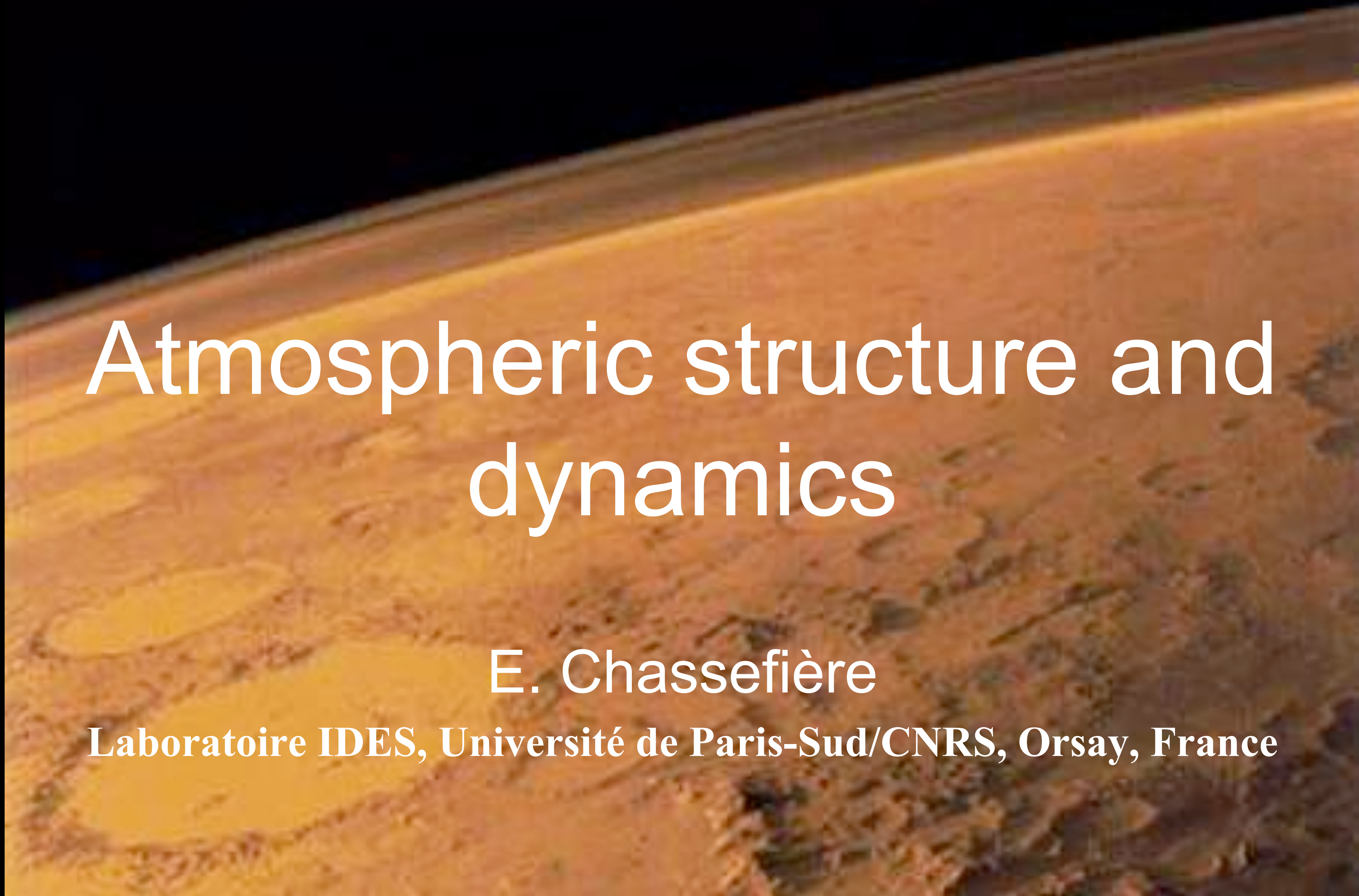


Atmospheric structure and dynamics

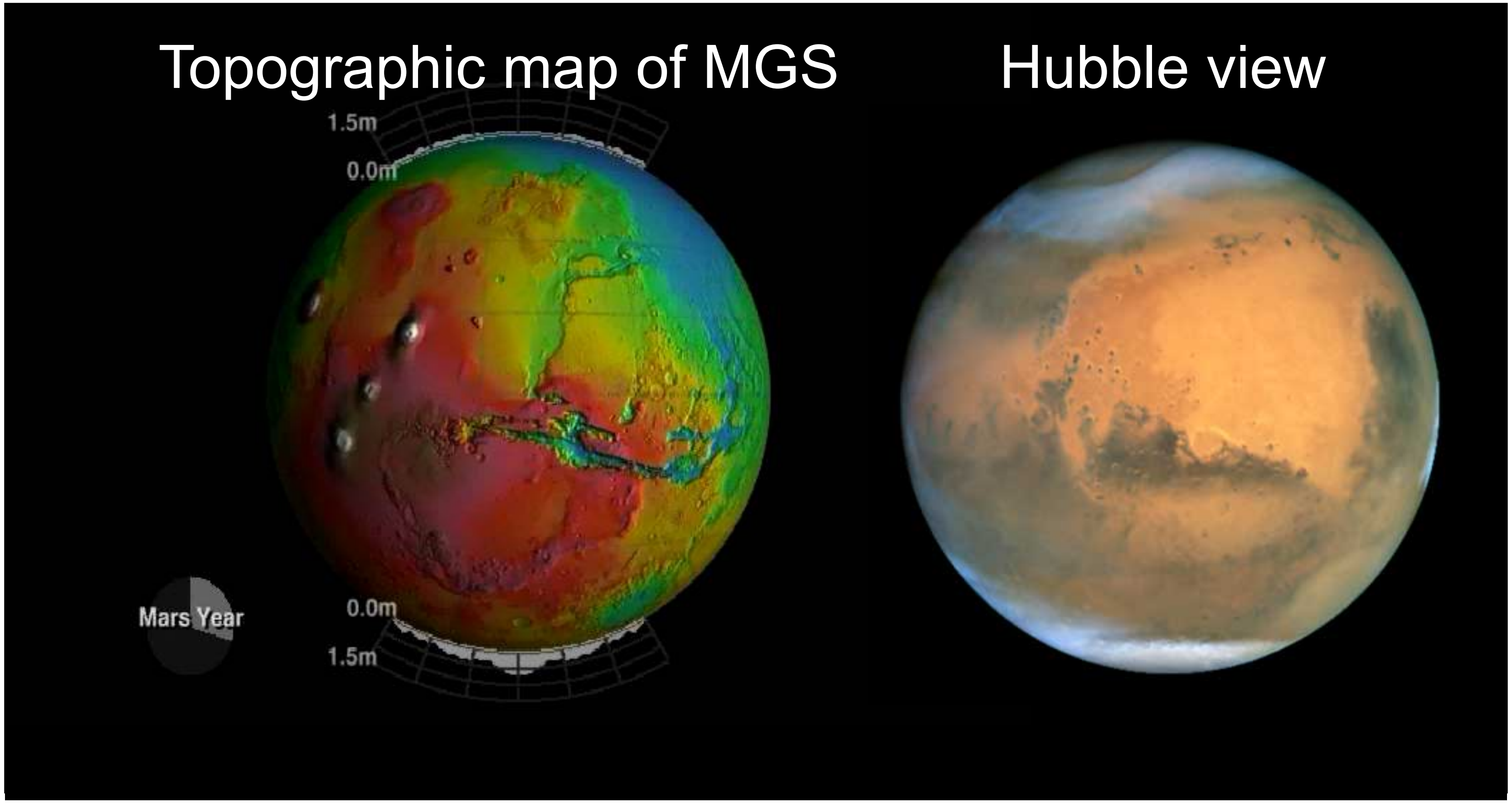
E. Chassefière

Laboratoire IDES, Université de Paris-Sud/CNRS, Orsay, France

Second ESA-CAS Mars Advanced School in China, 12-22 September 2011, Weihai, Shandong, China

Mars : the smallest terrestrial planet

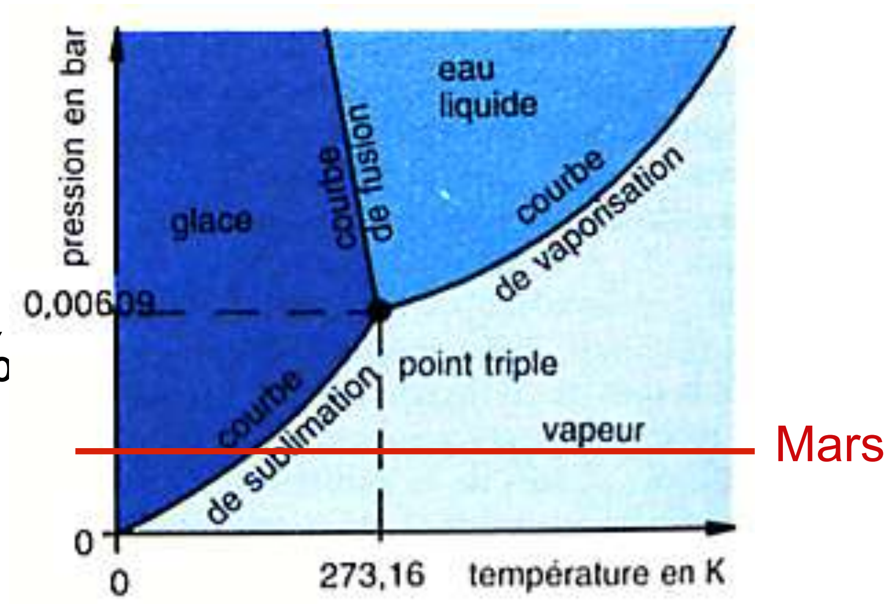
Condensation/ sublimation of water on Mars



- Seasonal polar caps
- Fogs, clouds

Main characteristics of Mars' atmosphere

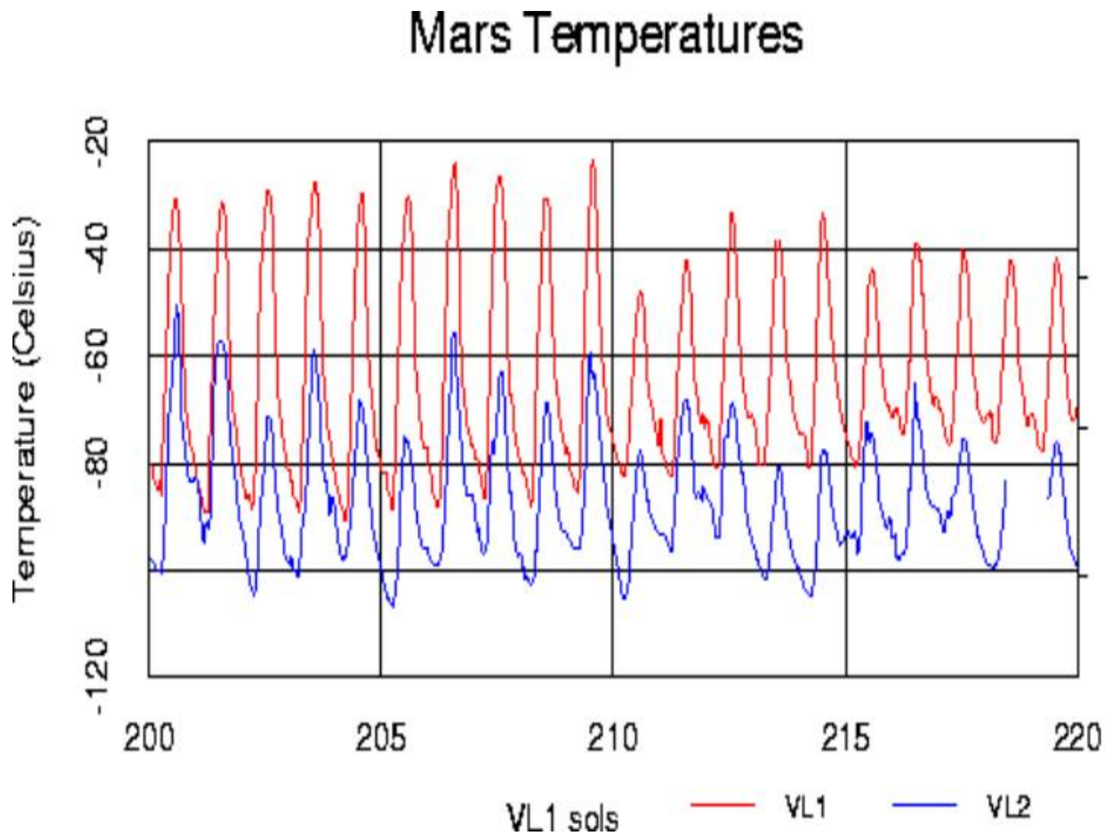
- Pressure : 7 mbars (mainly CO_2).
  - Most of CO_2 probably lost to space and/or to the subsurface (carbonates)
- Composition : 95% de CO_2, 2,7% de N_2, 1,6% de Ar, 0,13% de O_2, 0,07% de CO.
  - Very little O_2, contrary to Earth (oxygen from photosynthetic origin)
- Water vapor : between 1% and 0,001% (10 pr. µm in an average).
- Dust at the surface and suspended in the atmosphere (micron size) : storms.



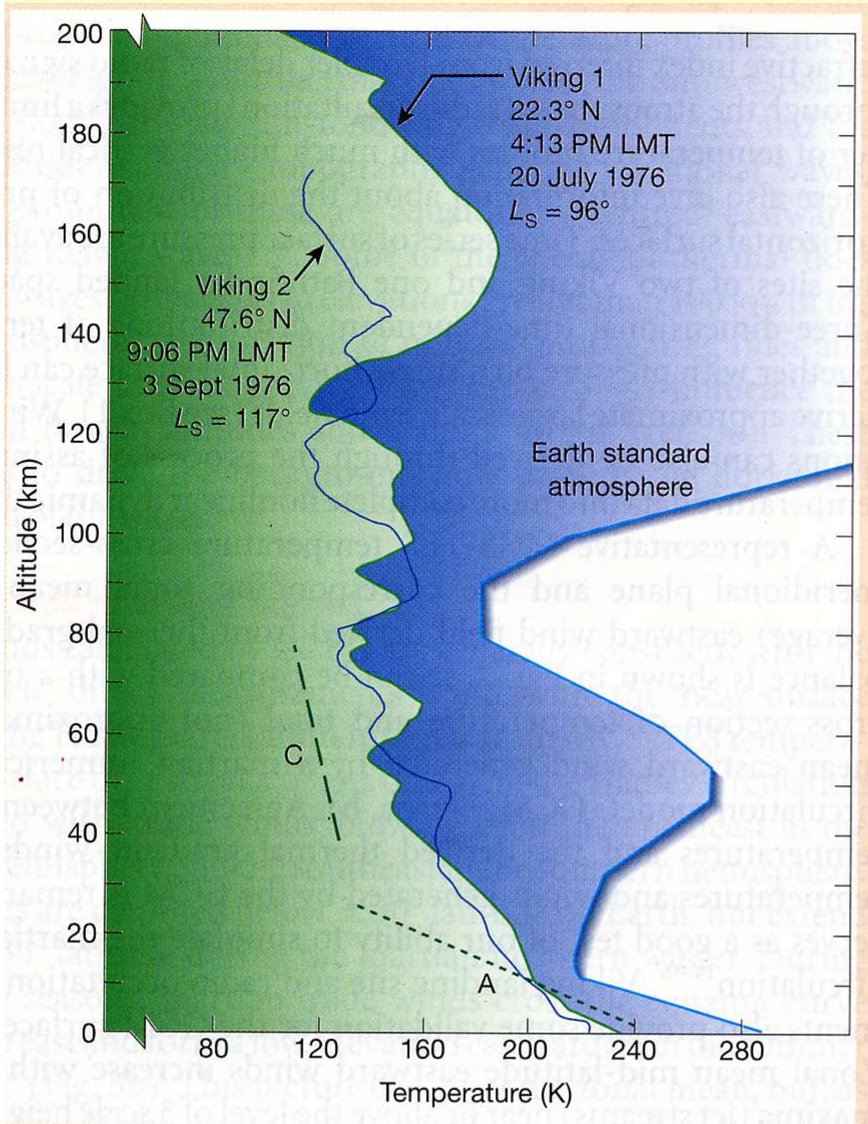
- Triple point of H_2O: 6 mbars, therefore no liquid water(only vapor or ice).

Diurnal cycle of temperature measured by Viking landers

- Large amplitude(like on the Moon) because of the tenuous atmosphere:
  - Small greenhouse effect (≈3 K, vs ≈33 K for Earth, and ≈500 K for Vénus).
  - Low thermal inertia.



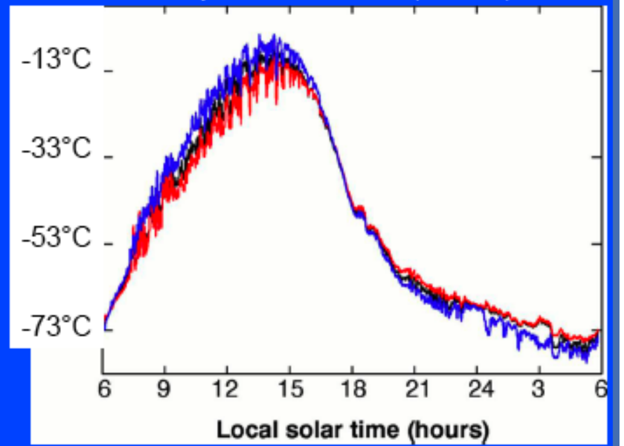
Strong temperature contrasts



Near Surface Temperature on Mars

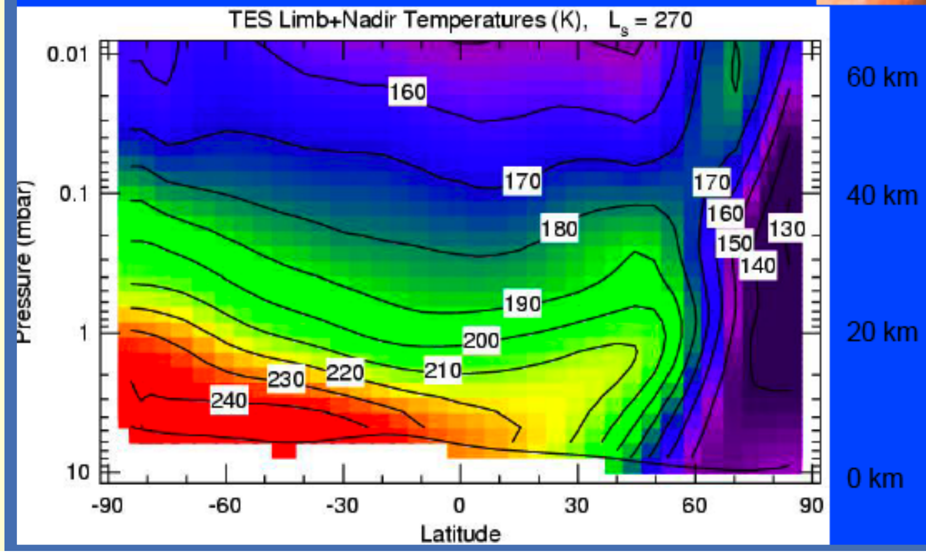
(Pathfinder, july 1997, martian summer 20°N)

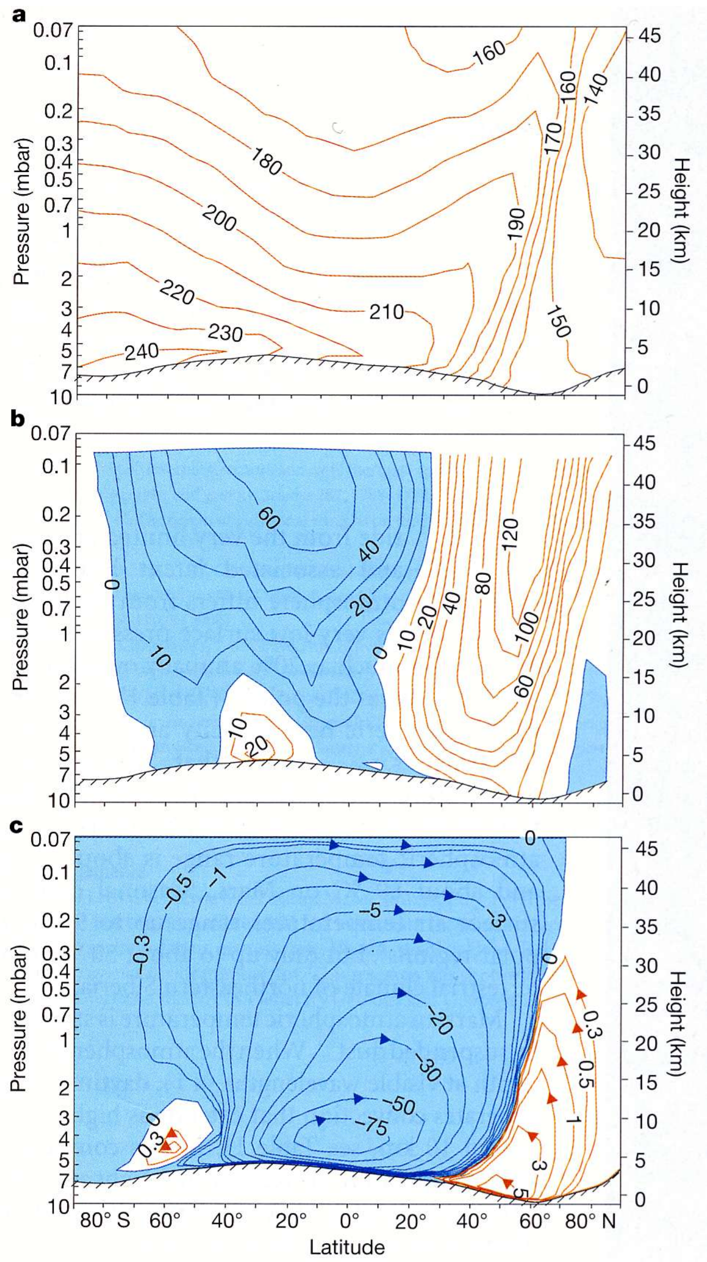
Température at 25 cm, 50 cm, 1m



Atmospheric Temperature (K)

(Northern winter solstice)





No ocean/ tenuous atmosphere

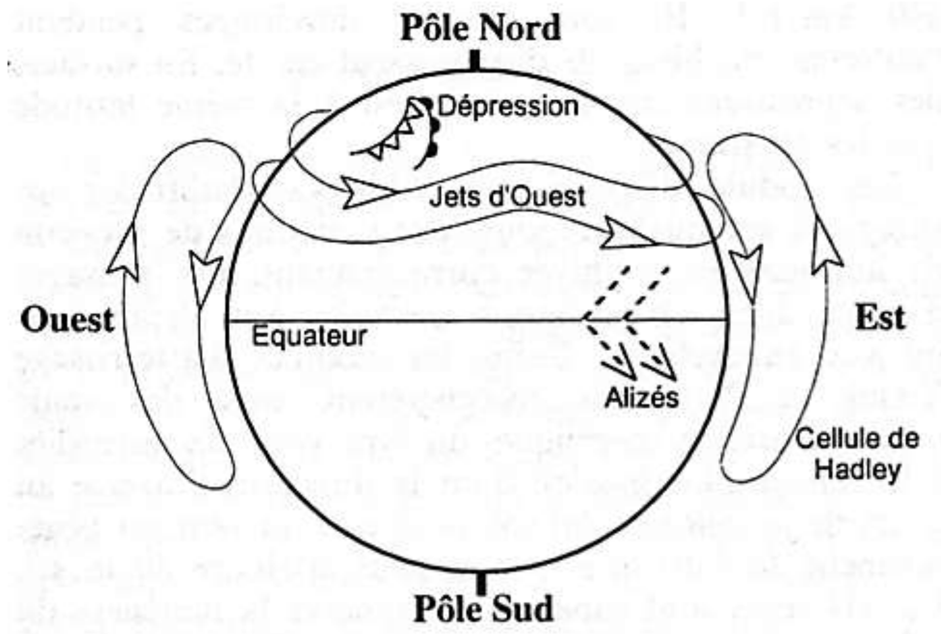
– Tenuous atmosphere, weak greenhouse effect (3 °C), atmosphere unable to store heat at night → large diurnal thermal variation.

– No ocean :

- no heat storage during winter → large seasonal thermal variation.
- global solar heating at hemispheric scale → one single Hadley cell (contrary to Earth).

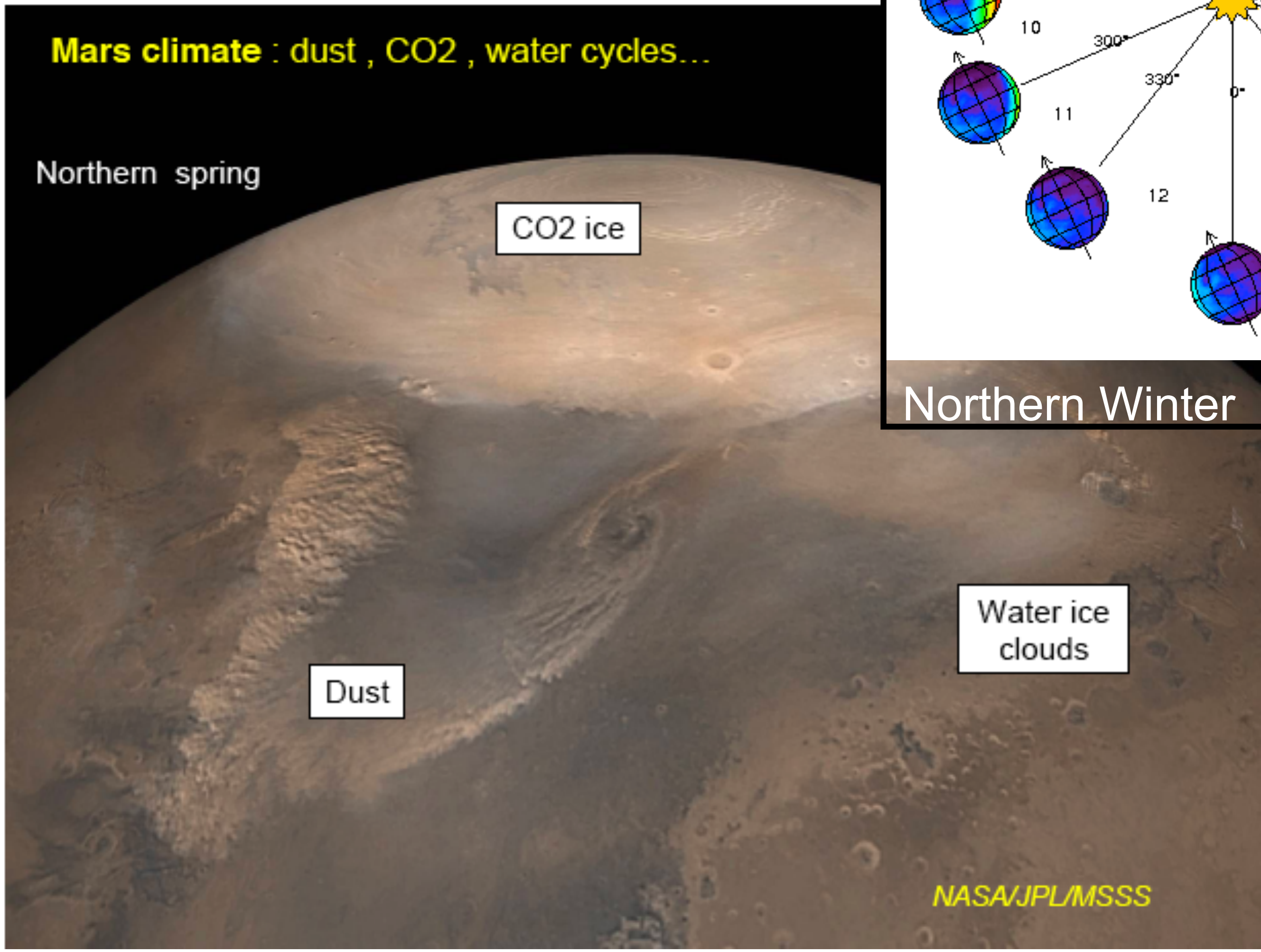
Global picture of meteorology and climate

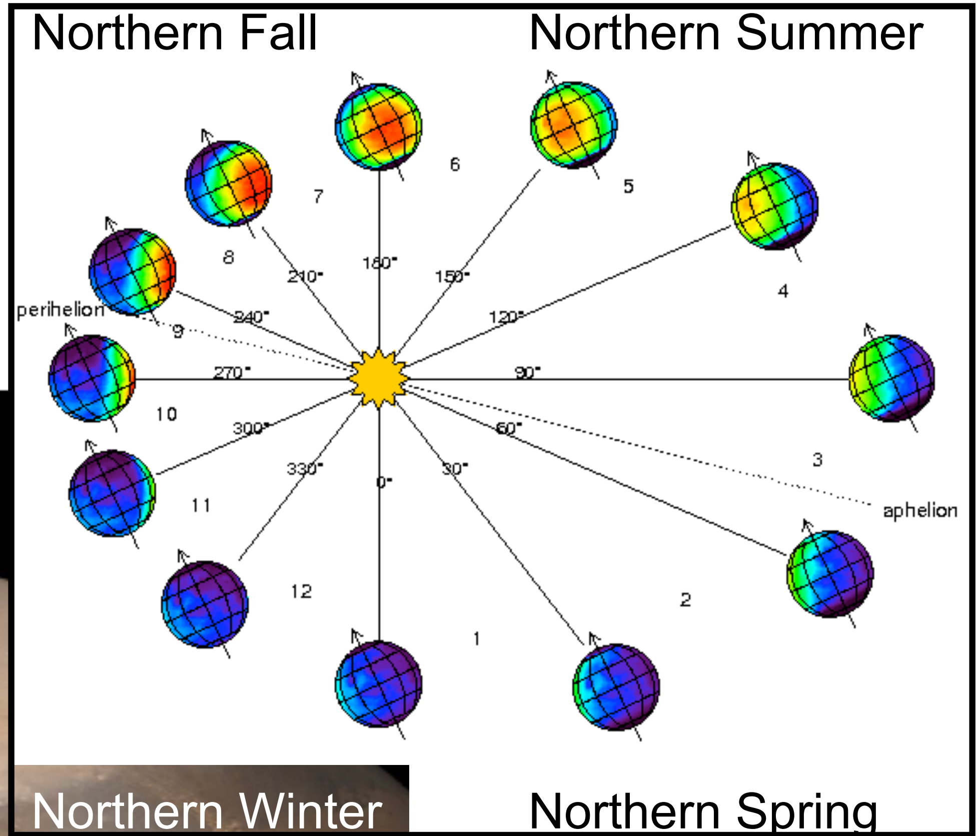
- Atmosphere heated from below by the surface (directly heated by the Sun).
- Rotation axis tilt angle (24,6°) and day duration (24h39mn) similar to Earth’s values. Twice longer year (687 jours).



- Similar meteorological systems:
  - Hadley cell in intertropical regions, eastern trade winds.
  - cyclones-anticyclones (baroclinic waves) at mid-latitudes.
  - Tidal waves, planetary waves.
  - Water ice clouds.

The 3 cycles of Mars climate





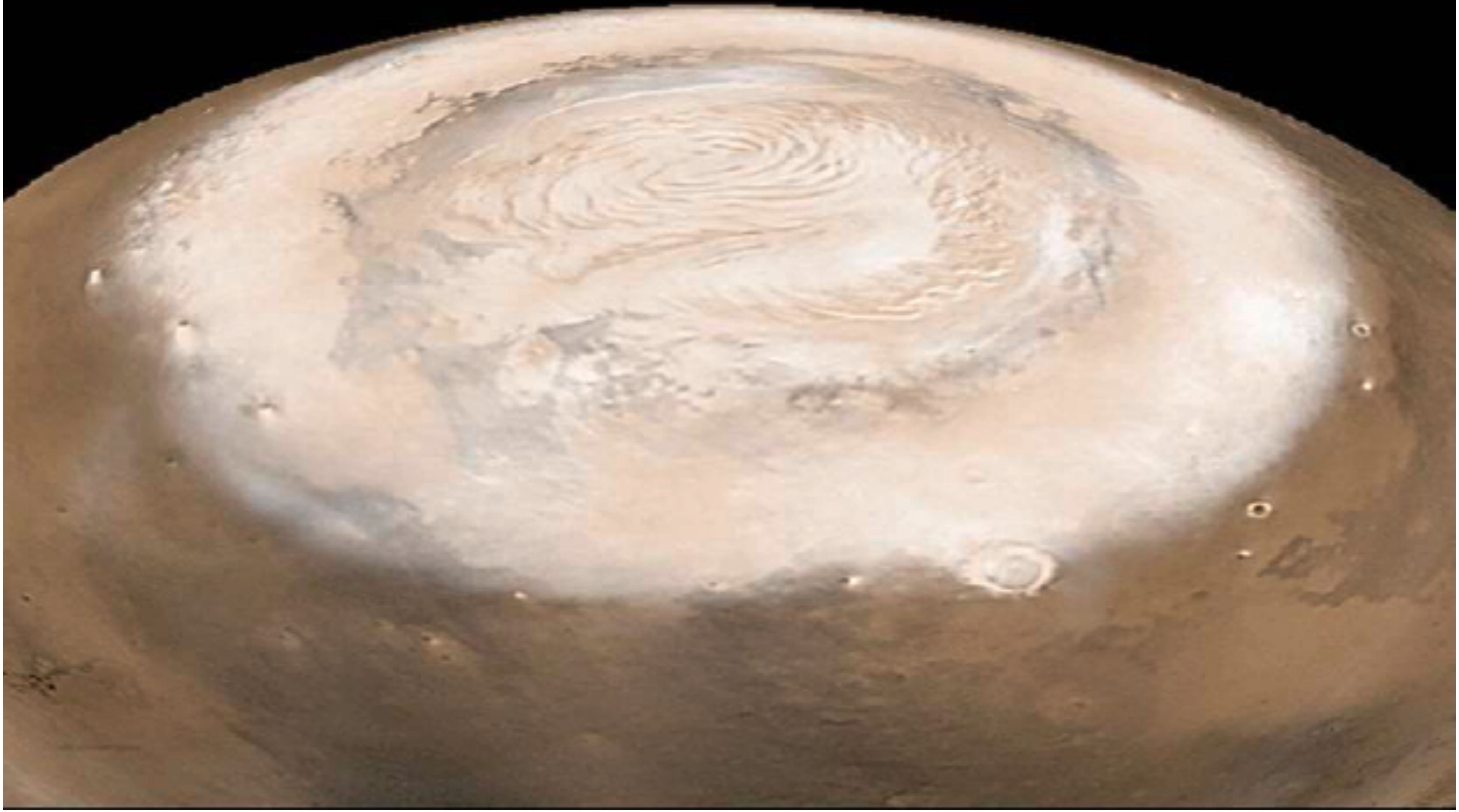
1) Carbon dioxide

2) Water/cloud

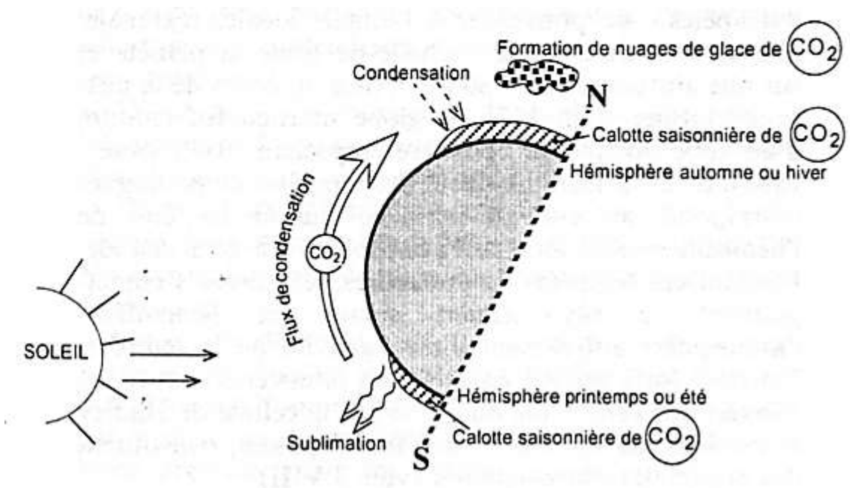
3) Dust

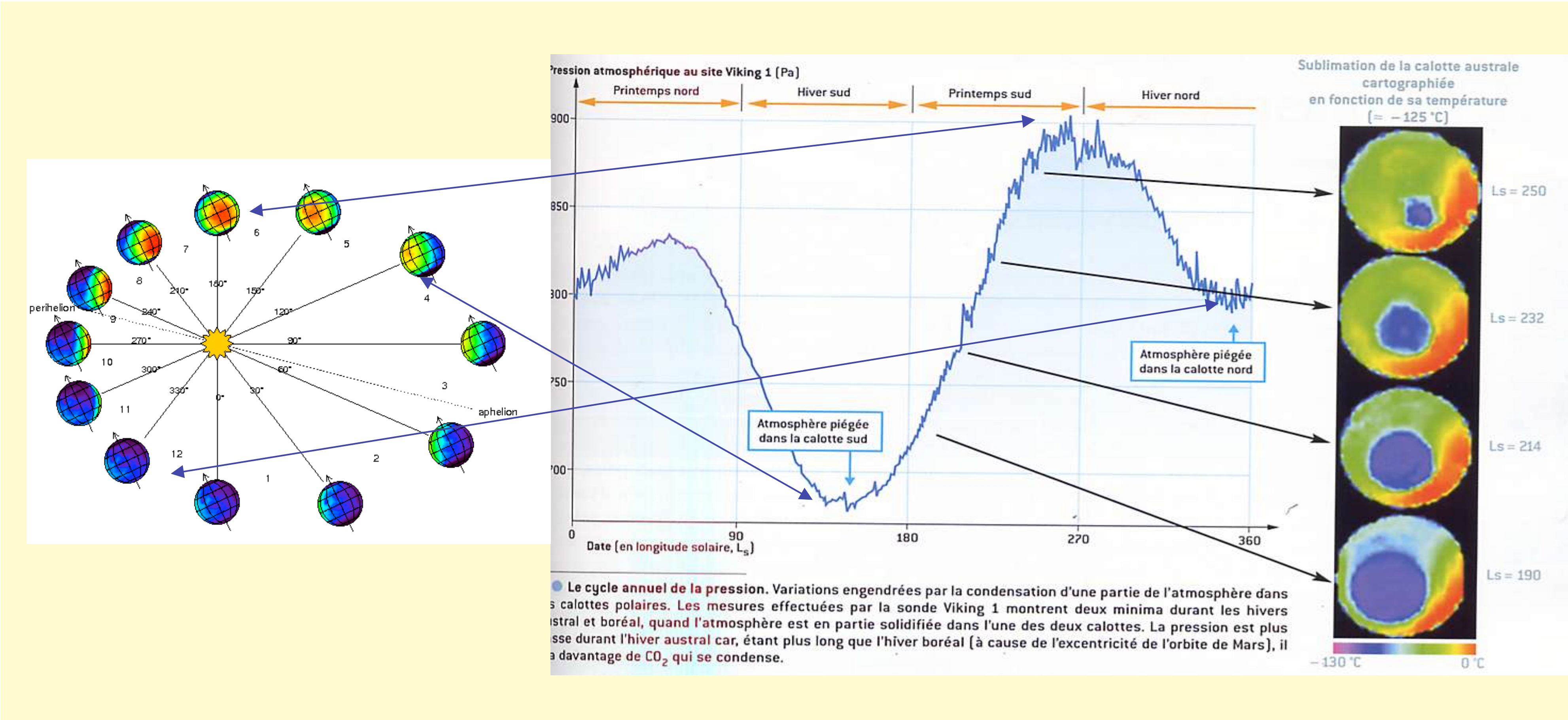
The CO_2 cycle

(mosaic of the northern polar cap in spring)



CO_2 cycle : alternate condensation on polar caps

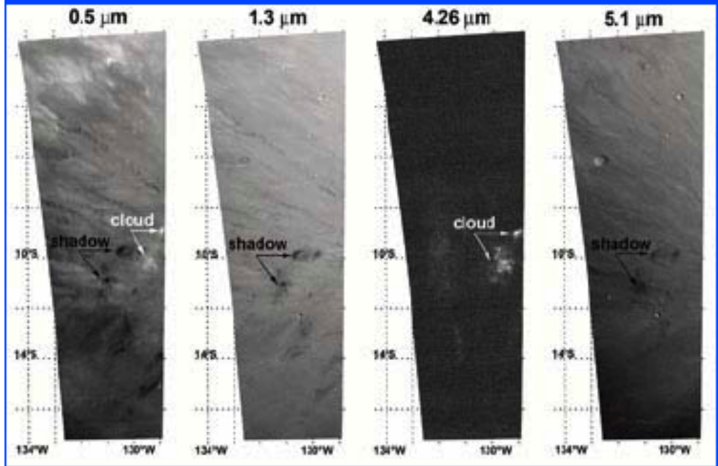




Le cycle annuel de la pression. Variations engendrées par la condensation d'une partie de l'atmosphère dans s calottes polaires. Les mesures effectuées par la sonde Viking 1 montrent deux minima durant les hivers istral et boréal, quand l'atmosphère est en partie solidifiée dans l'une des deux calottes. La pression est plus isse durant l'hiver austral car, étant plus long que l'hiver boréal (à cause de l'excentricité de l'orbite de Mars), il a davantage de CO_2 qui se condense.

CO_2 clouds

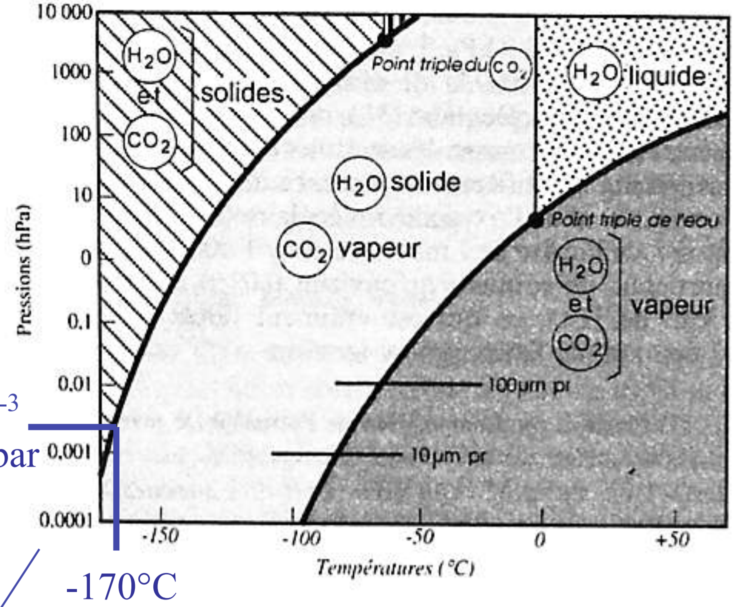
CO_2 ice clouds detected by OMEGA for the first time

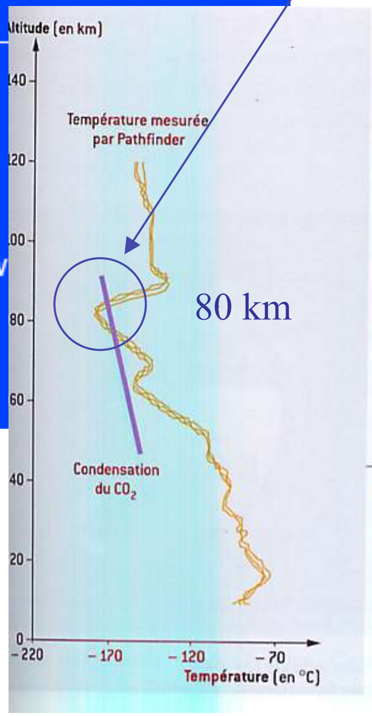


- Clear detection at 0.5 and 4.26 µ
- Shadow detected at all wavelengths
- Cloud altitude: 80 km
- Size: up to 100 km
- Cloud opacity > 0.5
- LARGE particles size: 1.5 microns

Clouds formed where and when the temperature plunge well below of carbon dioxide. Detected mostly at the equator.

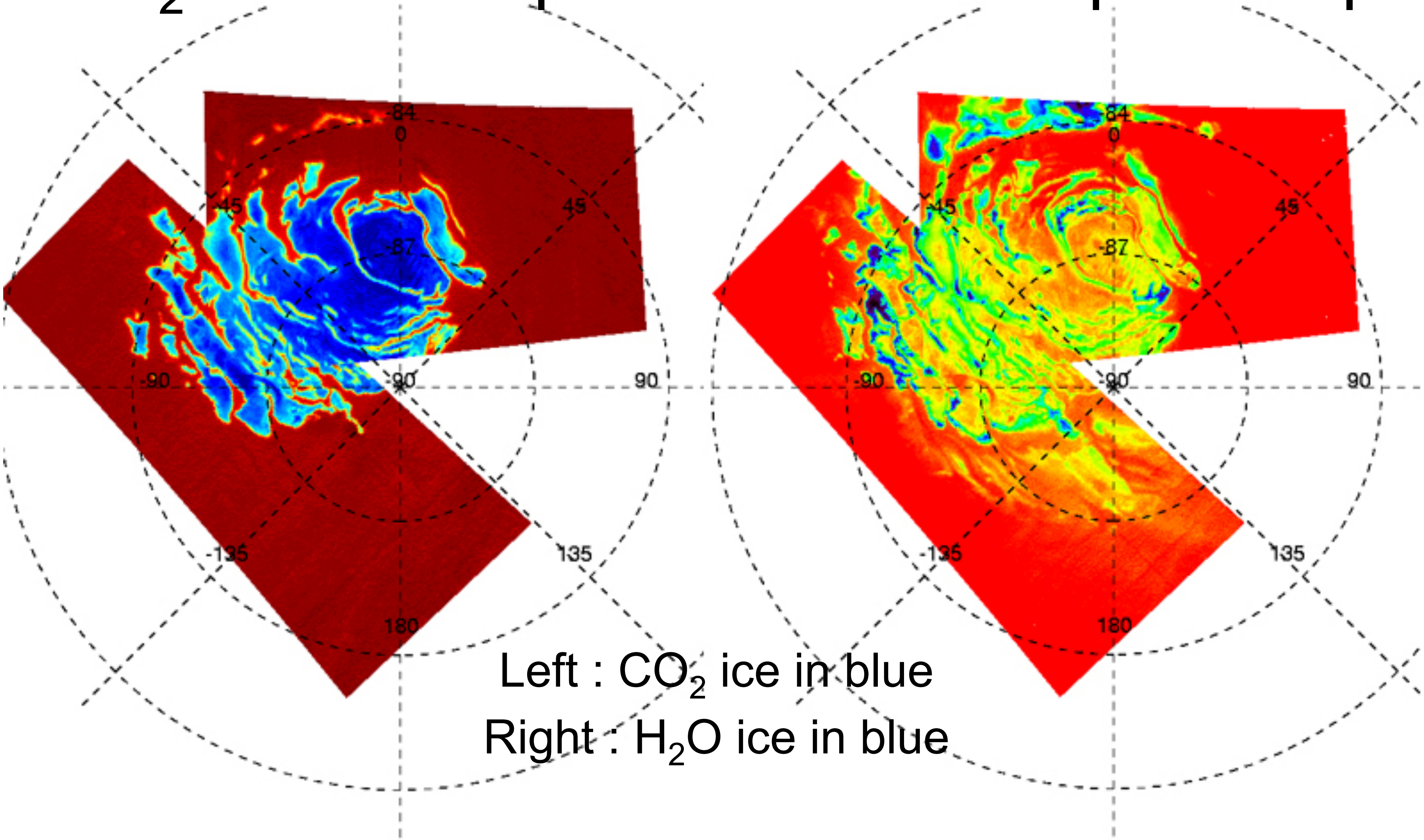
Montmession et al., J. Geophysical Research, 2007, Vol. 3112, Issue E11





Des nuages de CO_2 partout sur Mars ? Il est probable que des nuages de glace carbonique se forment aussi hors de la nuit polaire. Ainsi, ce liseré blanc (ci-dessus) repéré à 100 km d'altitude par Mars Global Surveyor pourrait être constitué de fines particules de CO_2 solide en suspension, mais on ne peut en être certain en l'absence de données spectroscopiques. Cependant, lors du survol de Mars par les sondes Mariner 6 et 7 en 1969, leurs spectromètres semblent avoir enregistré une réflexion lumineuse caractéristique de la glace de CO_2 dans un de ces nuages. Faute d'un instrument équivalent, ce phénomène n'a pas encore pu être confirmé (en attendant Mars Express en 2004). Il n'empêche que le profil de température enregistré par la sonde Pathfinder en 1997 montre que l'atmosphère en altitude peut atteindre le point de condensation du CO_2, même en été et sous les tropiques.

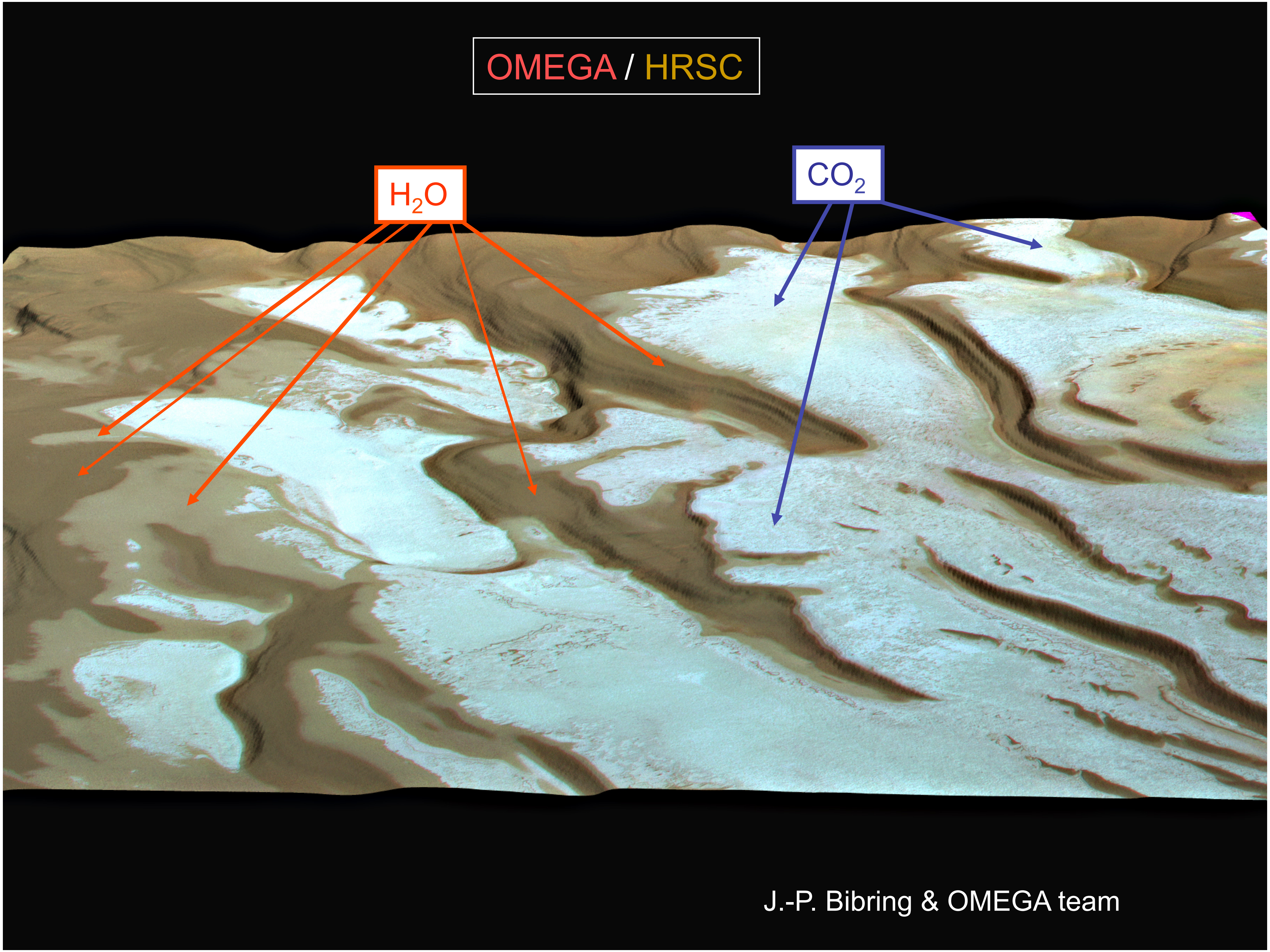
CO_2 ice on the permanent south polar cap



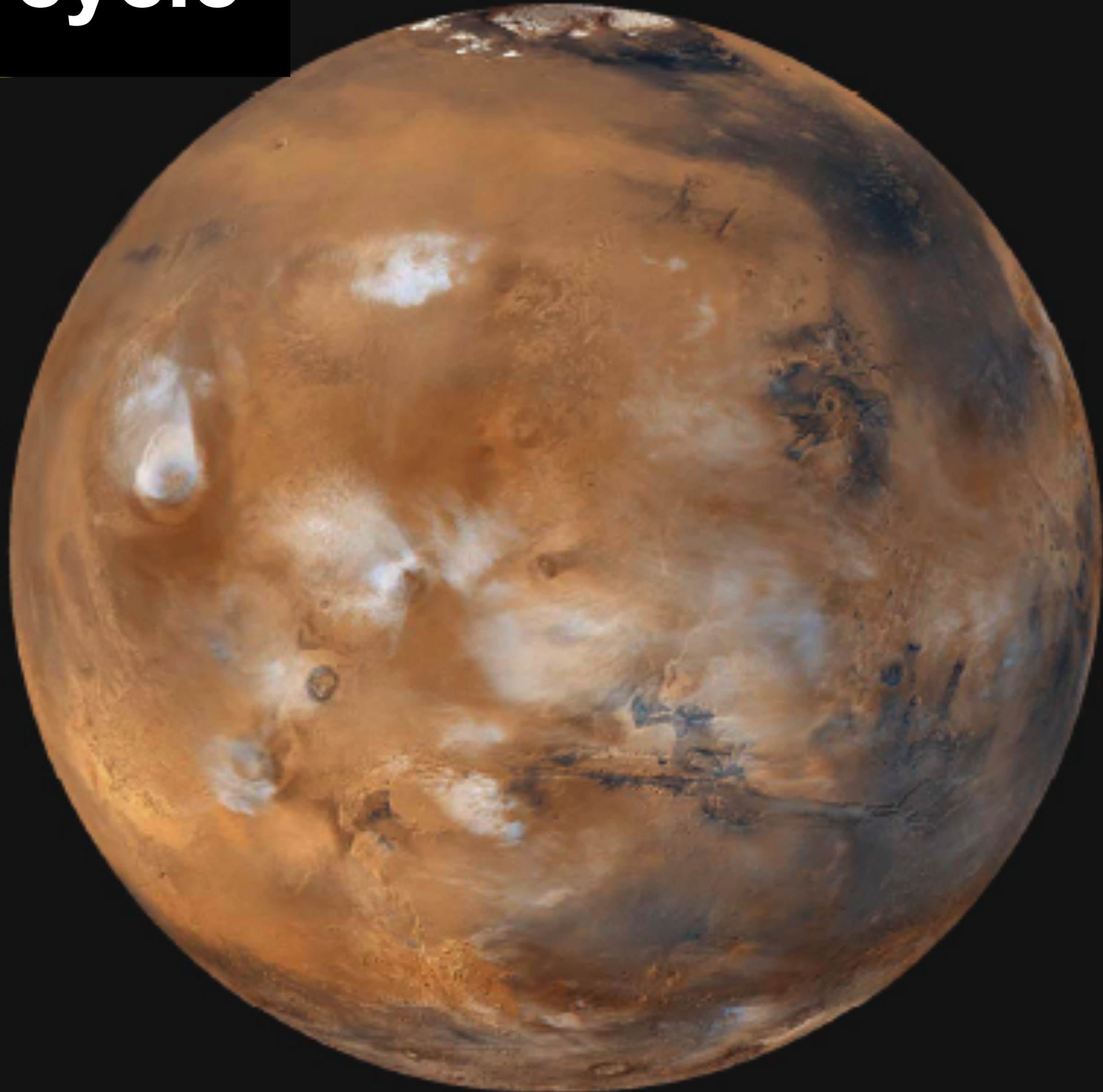
Left : CO_2 ice in blue

Right : H_2O ice in blue

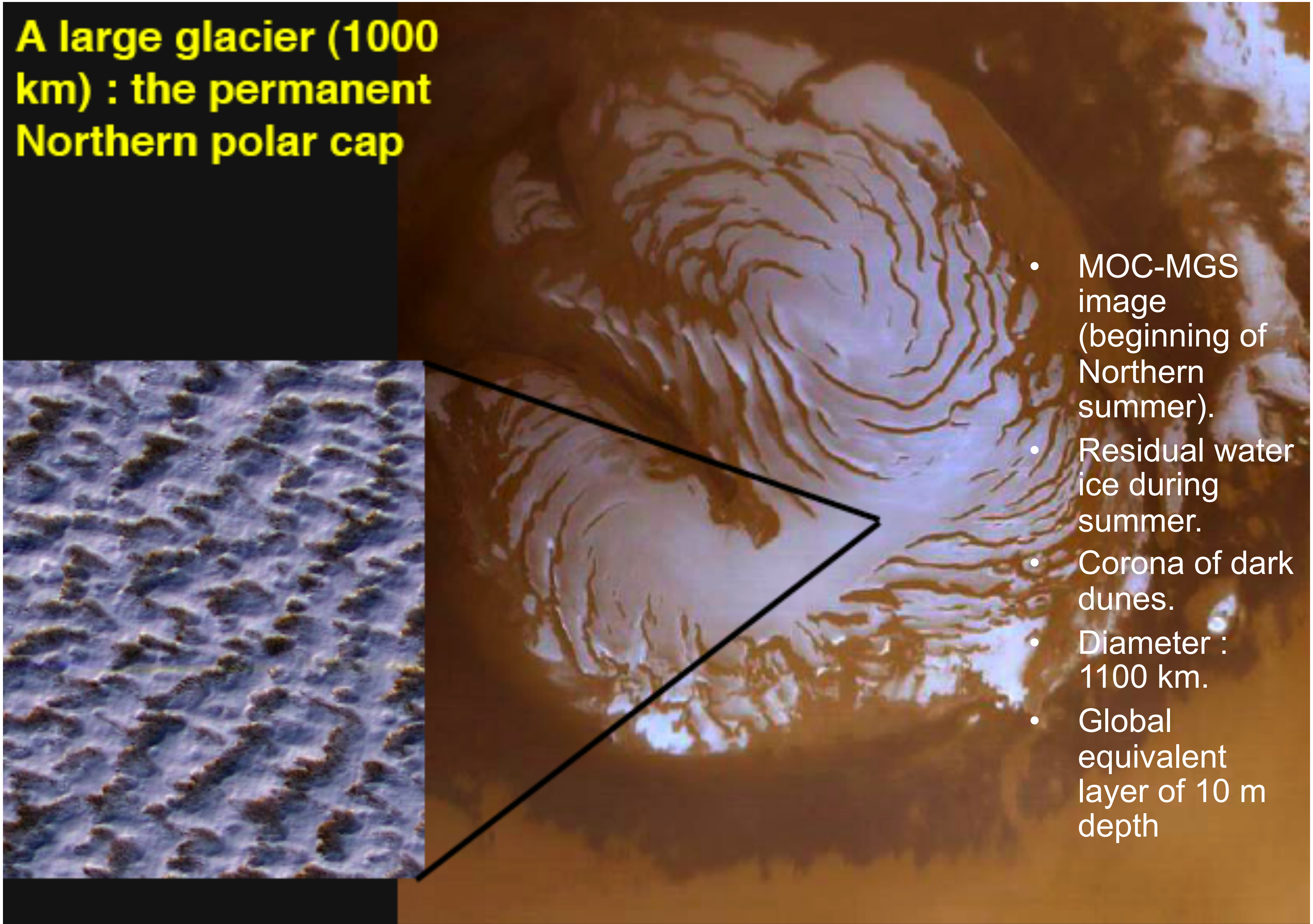
J.-P. Bibring & OMEGA team


OMEGA / HRSC
H2O
CO2
J.-P. Bibring & OMEGA team

The water cycle

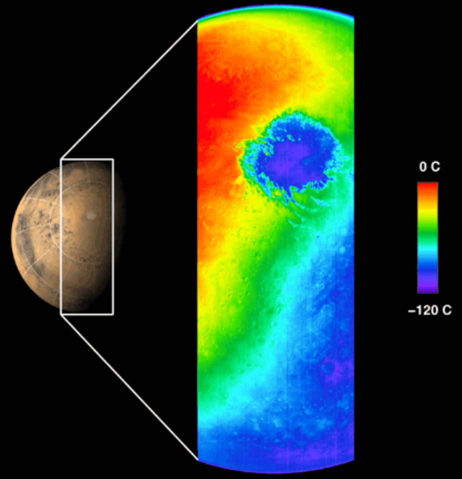


A large glacier (1000 km) : the permanent Northern polar cap

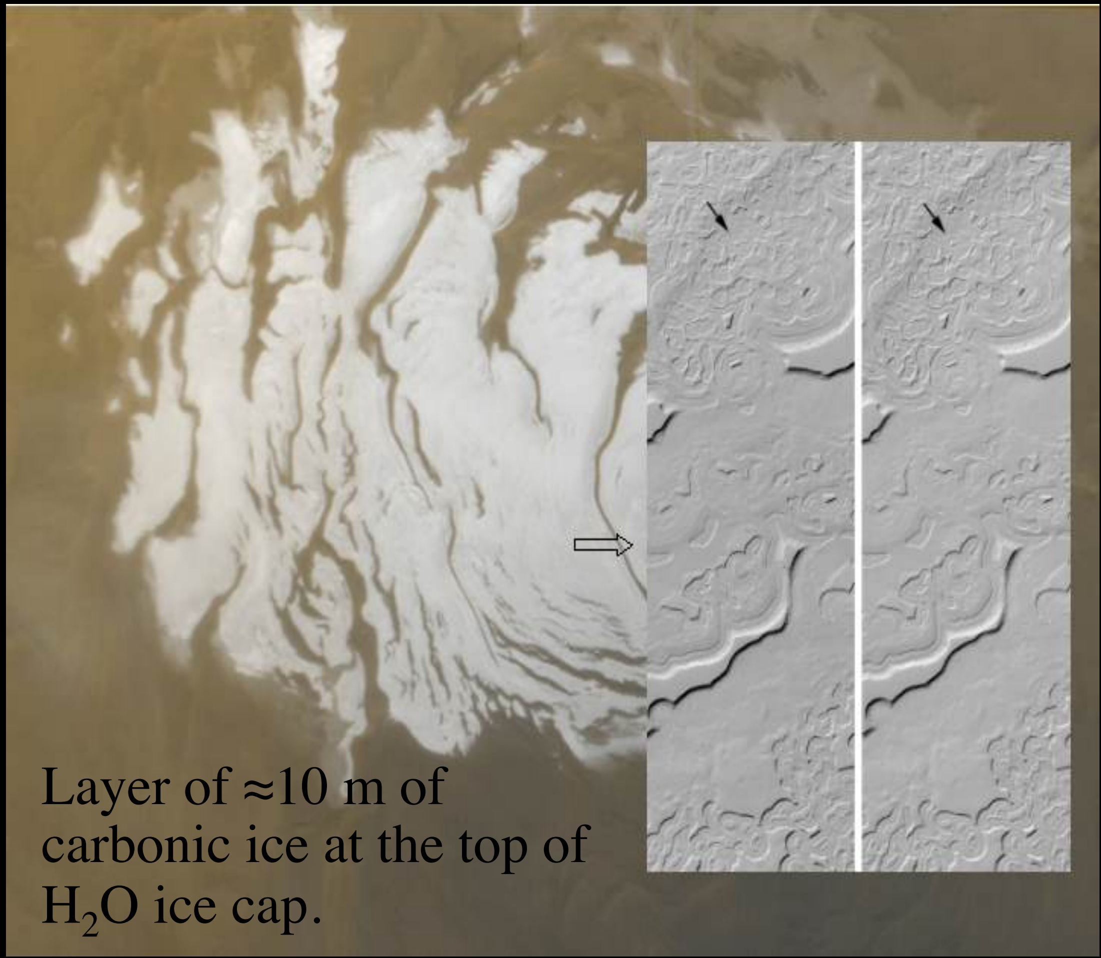


- MOC-MGS image (beginning of Northern summer).
- Residual water ice during summer.
- Corona of dark dunes.
- Diameter : 1100 km.
- Global equivalent layer of 10 m depth

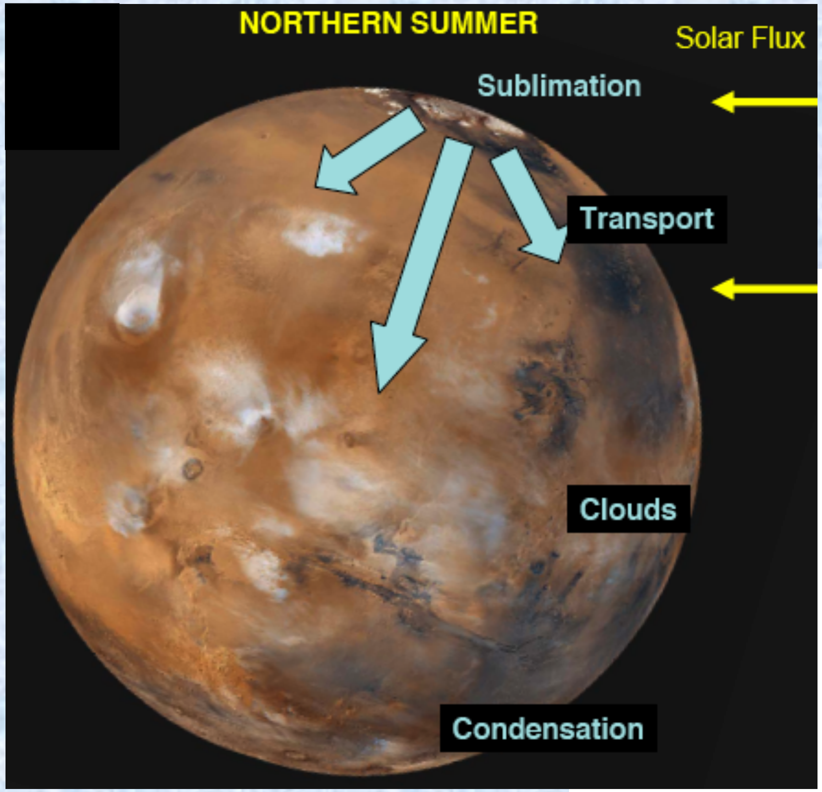
Residual Southern cap of H_2O ice with a supercicial layer of CO_2 ice

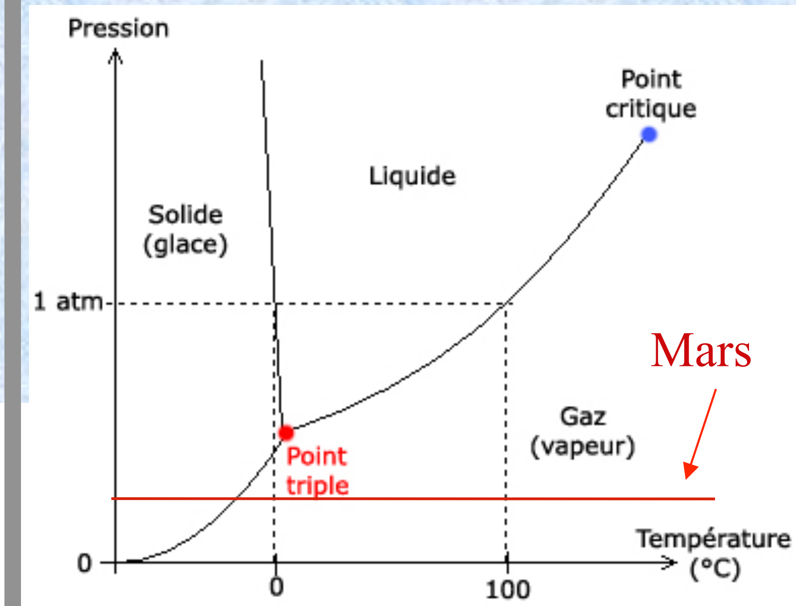


- Image MOC-MGS (Souther summer).
- Condensation temperature of CO_2 : - 125°C.
- Diameter : 420 km.
- CO_2 atmosphere at condensation equilibrium with CO_2 ice at the top of the southern polar cap.

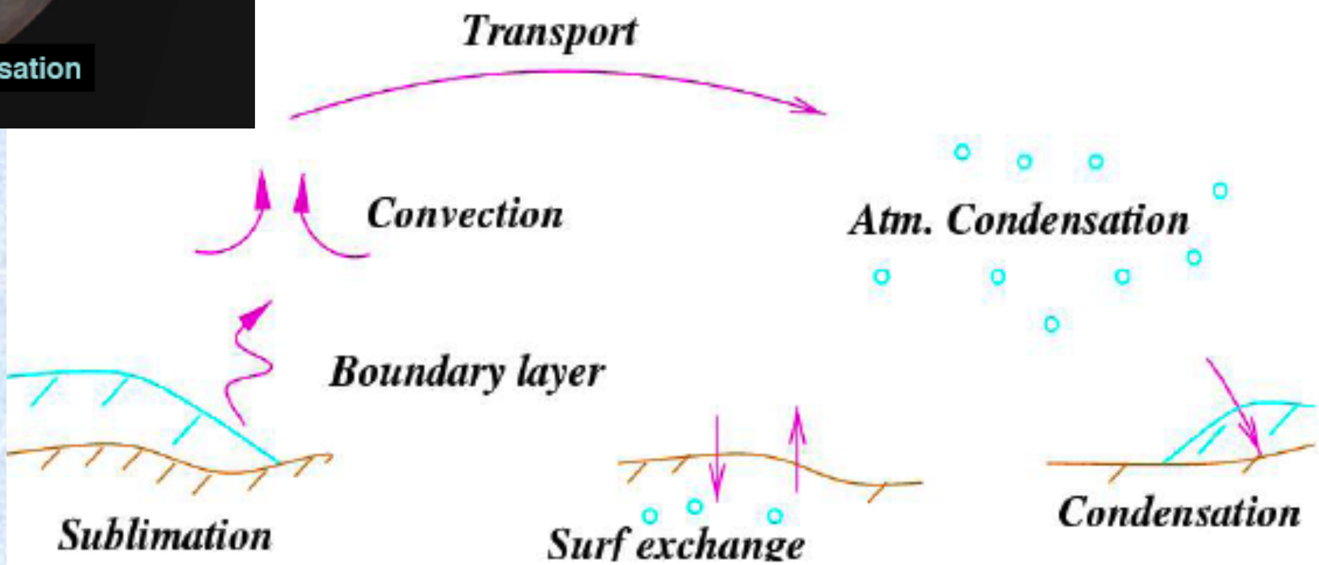


Water transport

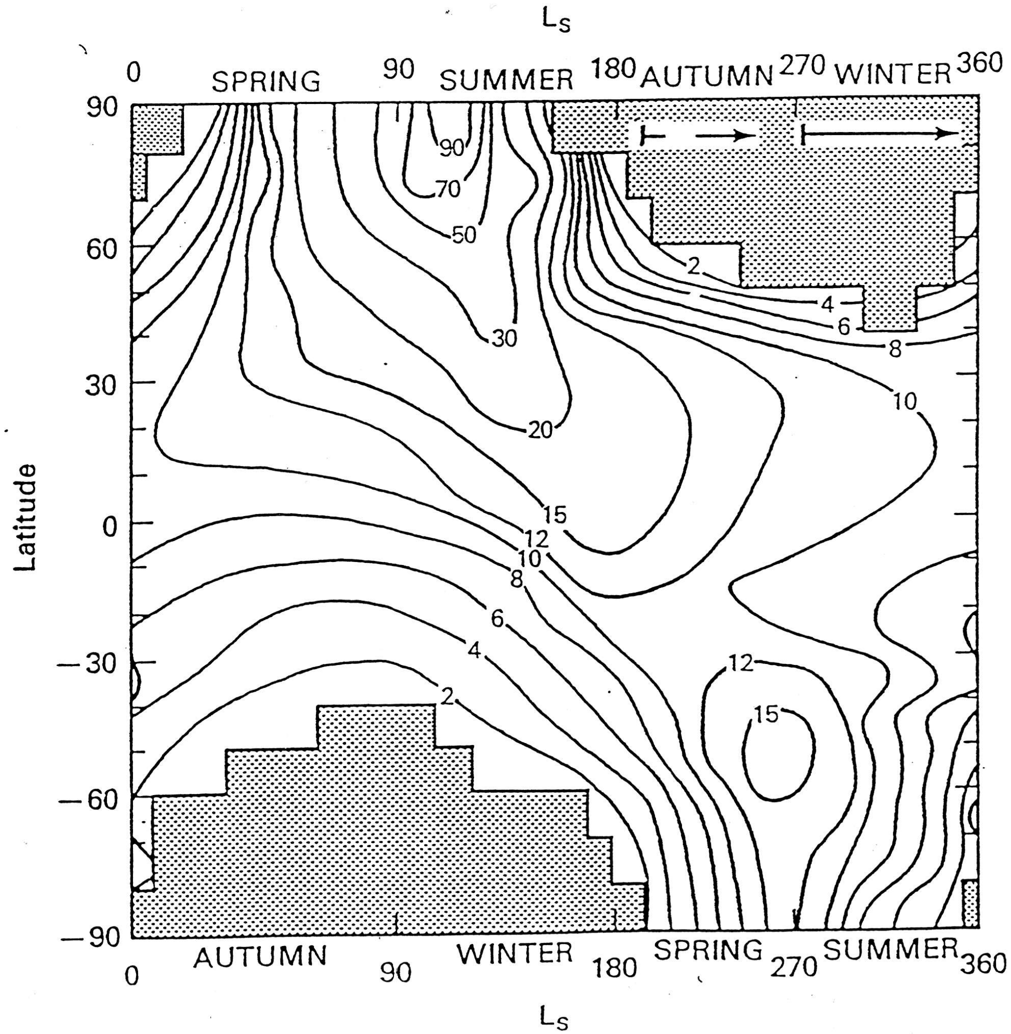




Water phase diagram

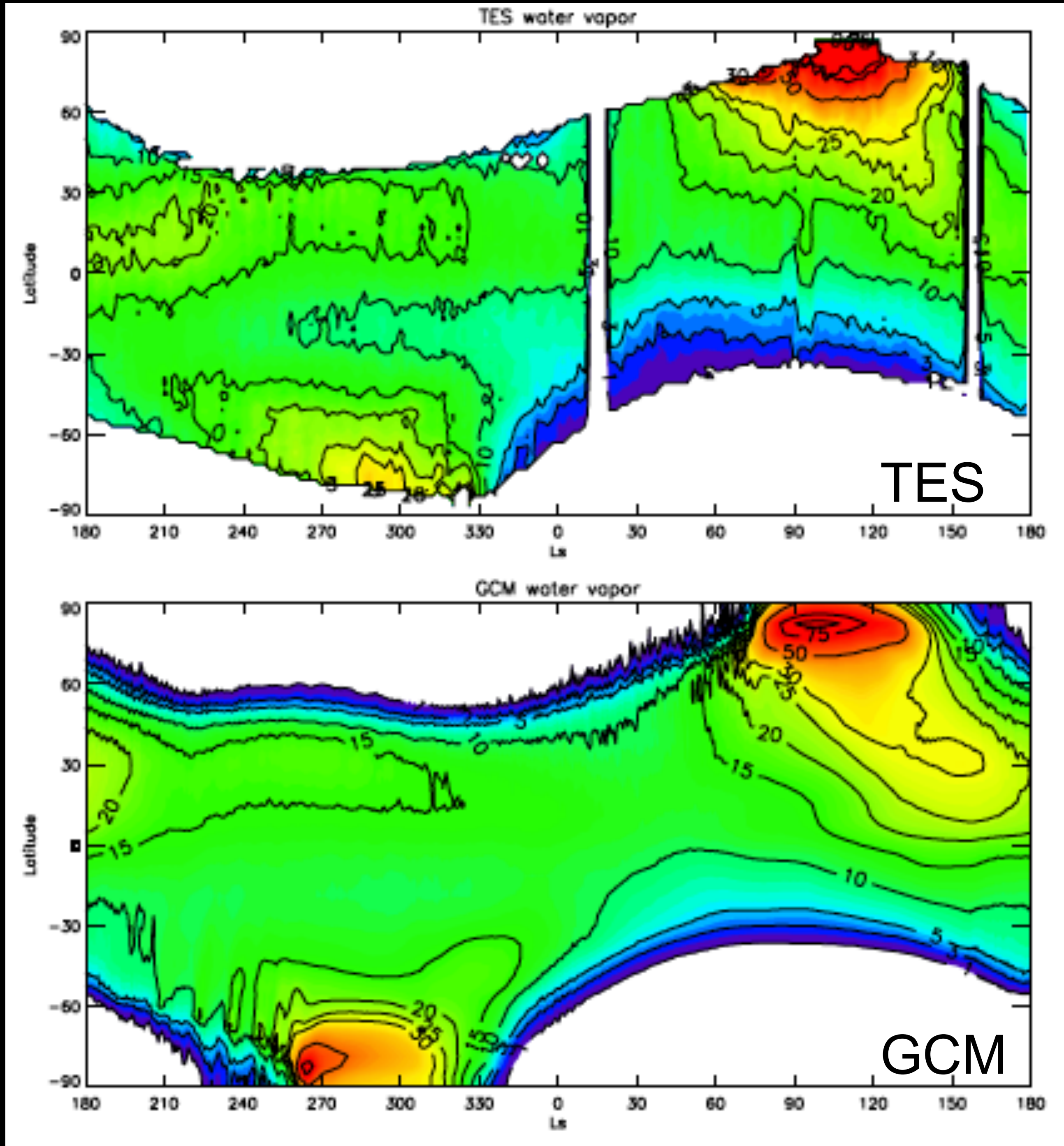


Seasonal cycle of H_2O recorded by Viking by near-IR reflectance spectroscopy



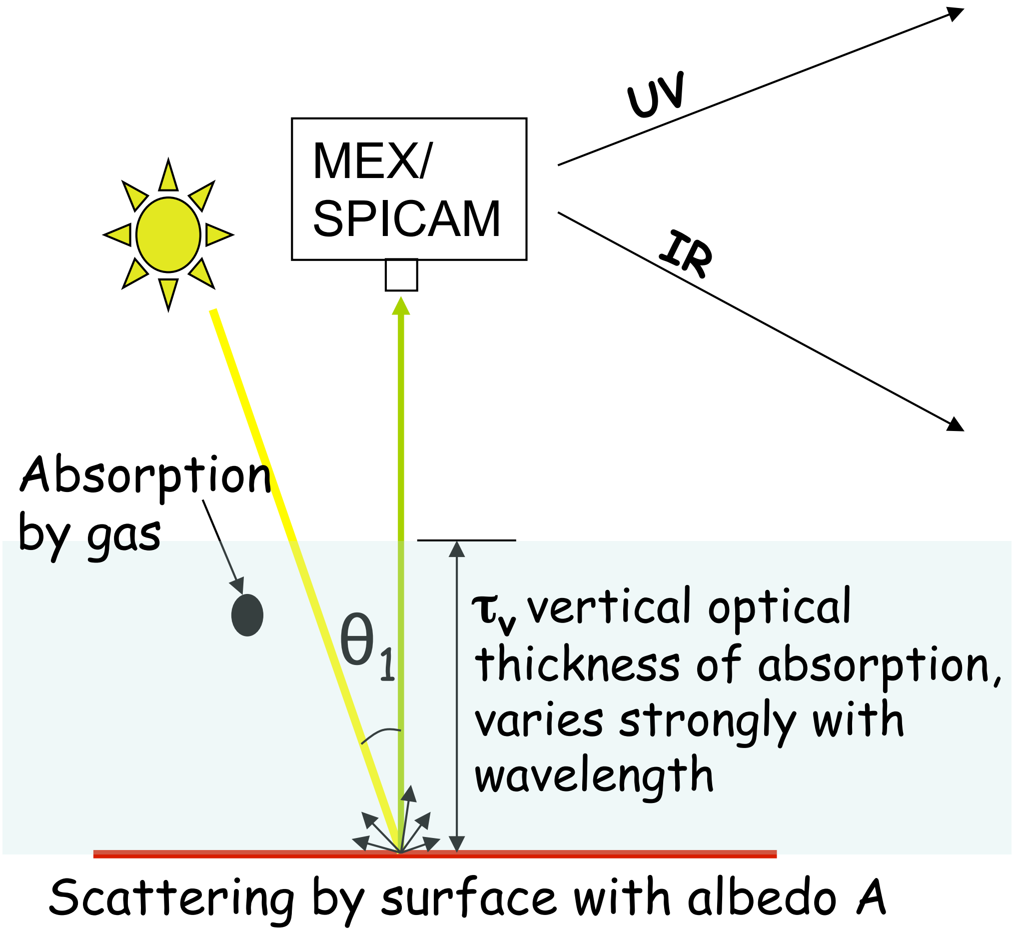
- Condensation of H_2O on the Northern polar cap and sublimation during spring.
- At the South, the very cold superficial layer of CO_2 ice acts as a trap of H_2O.
- Trapping of H_2O in the regolith at mid latitudes during winter

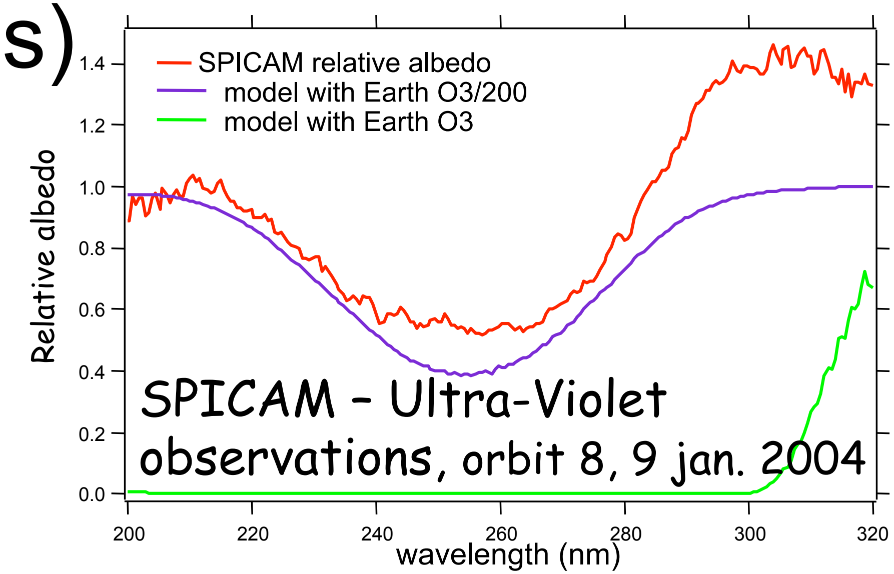
Observation and GCM modelling

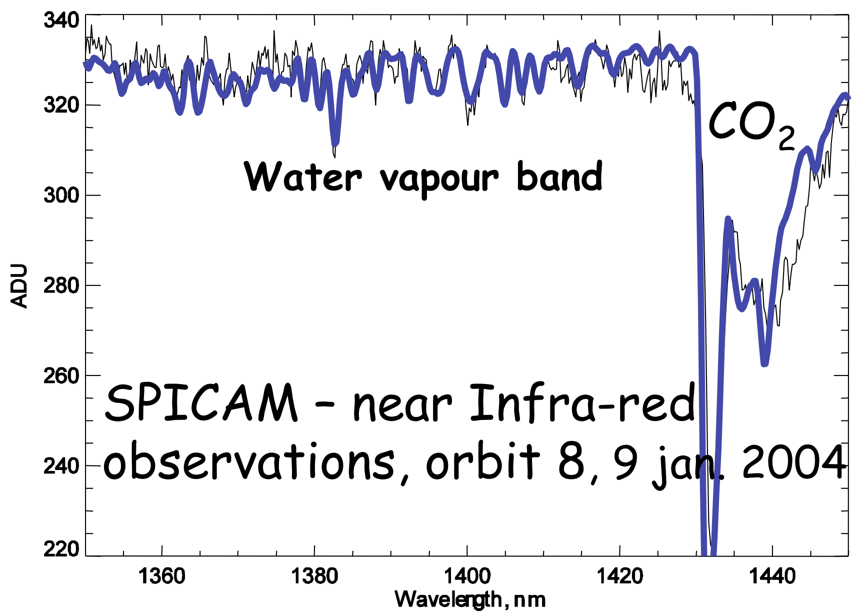


Montmessin et al (2004)

Reflectance spectroscopy in the UV and near-IR by Spicam (Mars-Express)

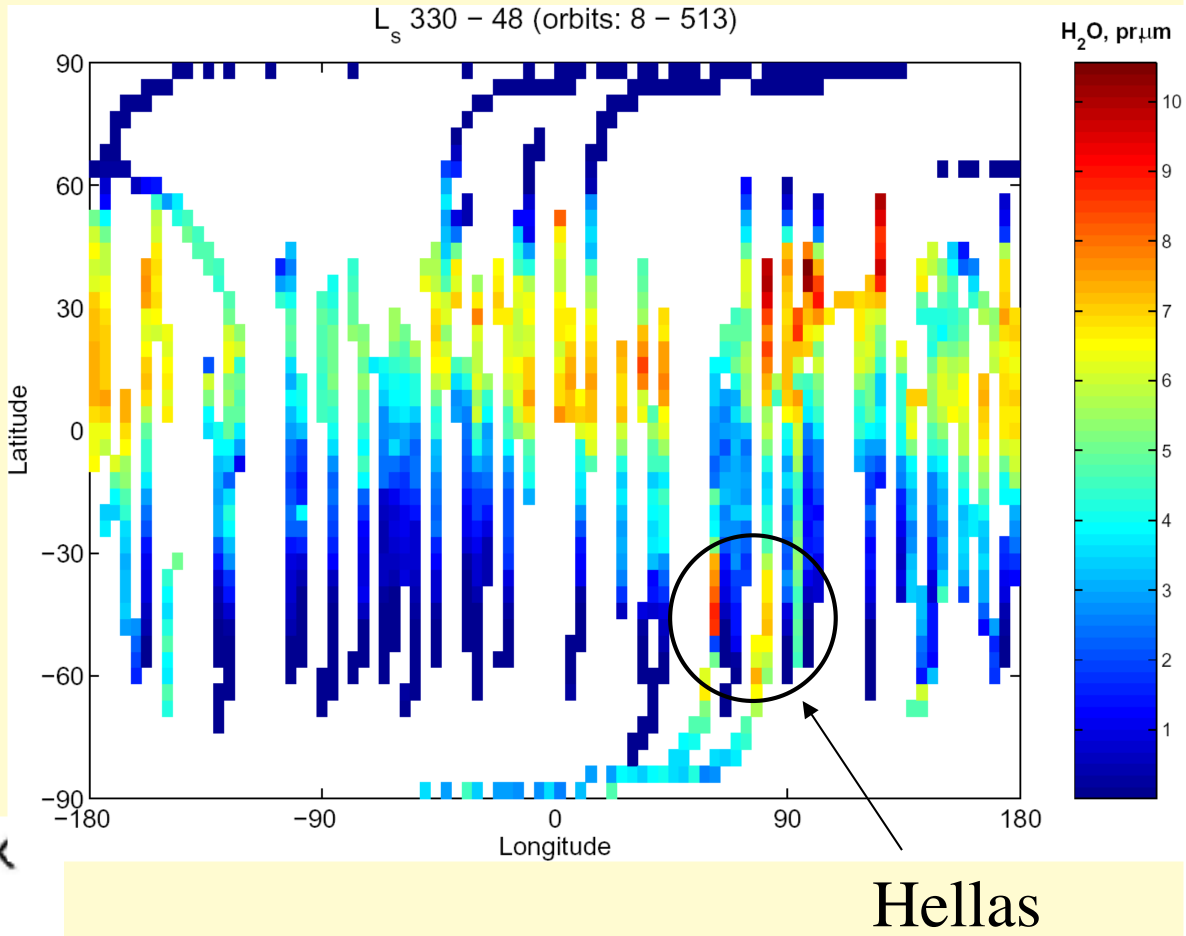


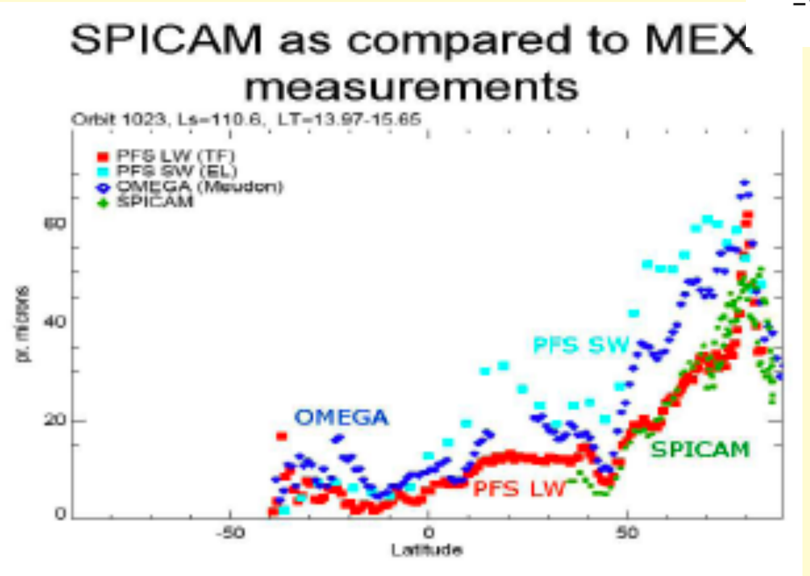




Mapping of H_2O from MeX orbit

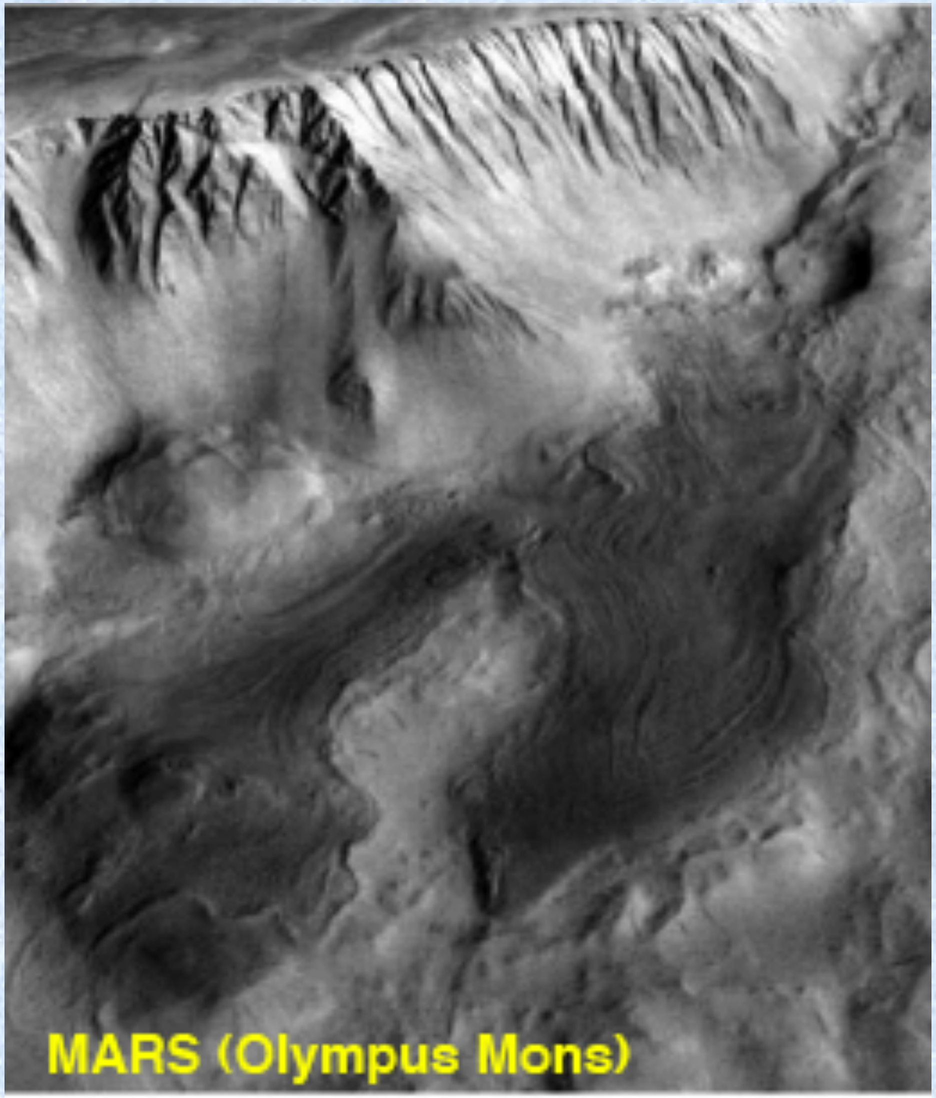
SPICAM H_2O map at 1.38 µm, near spring equinox)





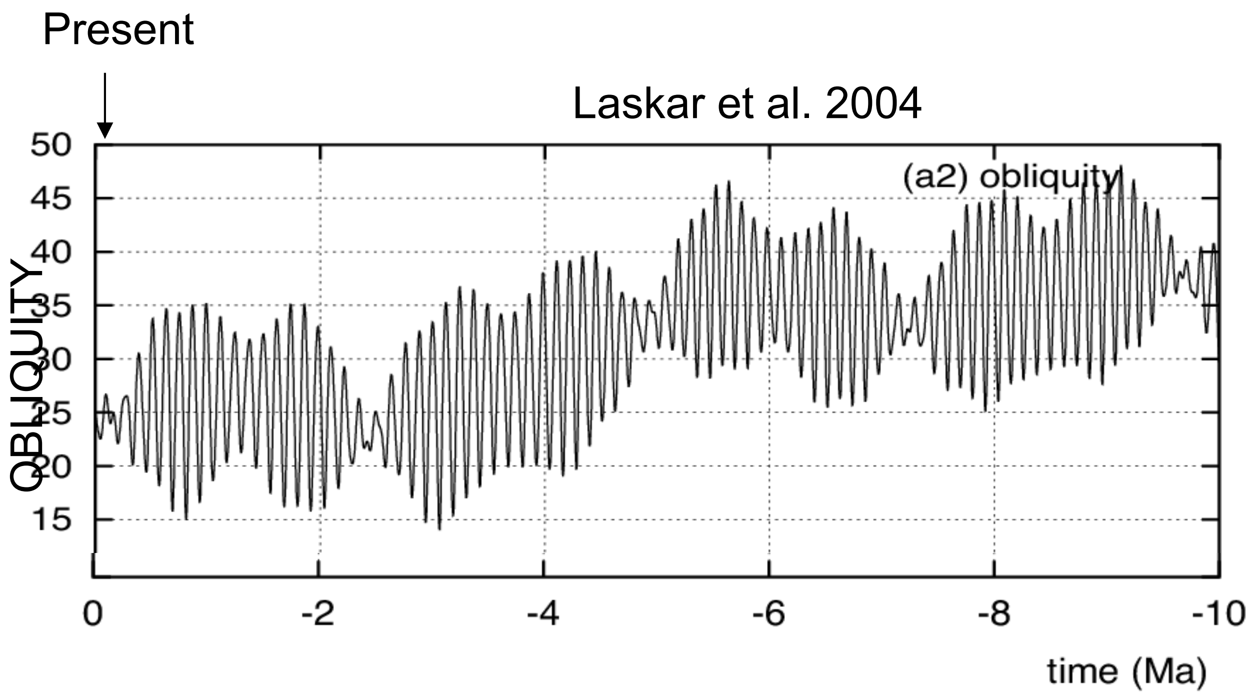
But need for further inter-calibration!

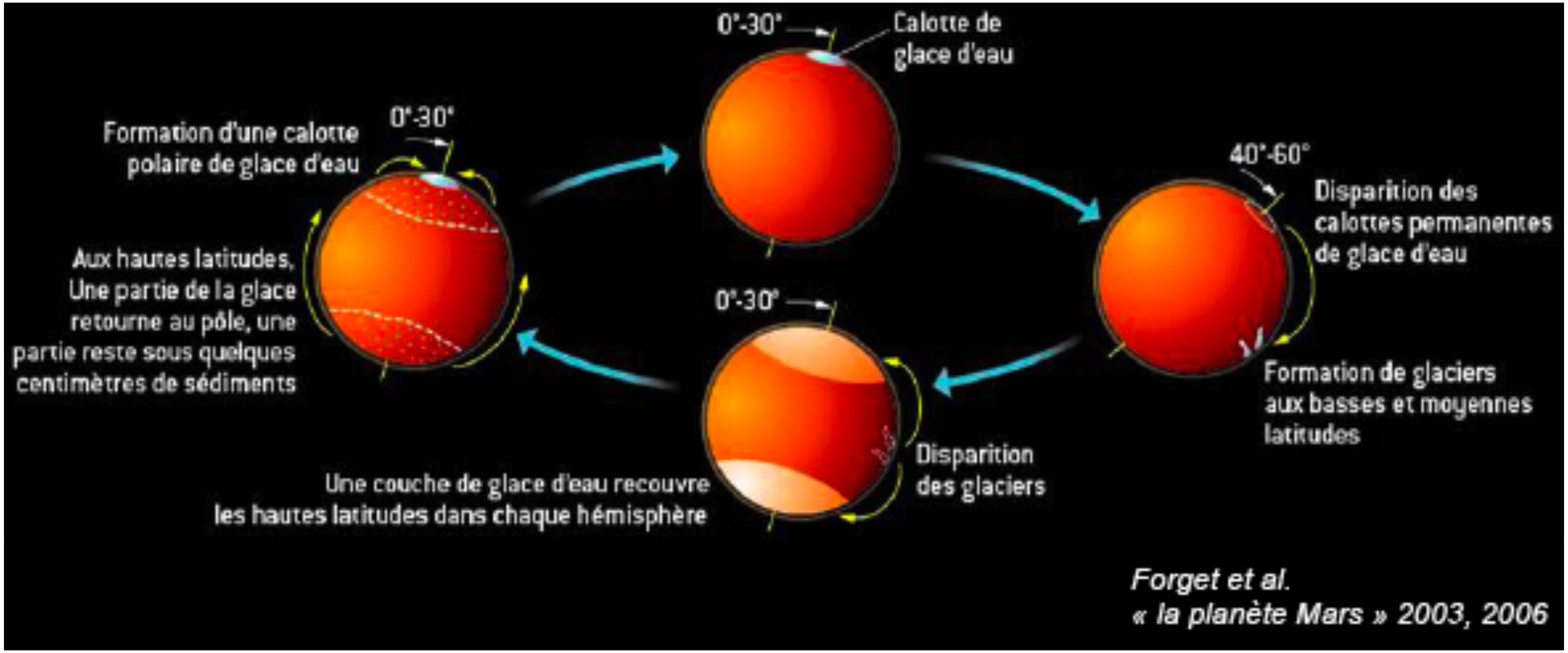
Past water cycle



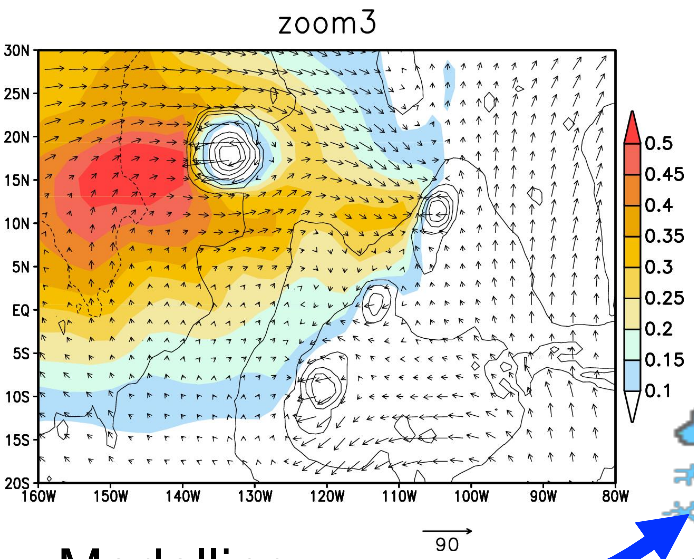
Head et al (2005)

Obliquity history

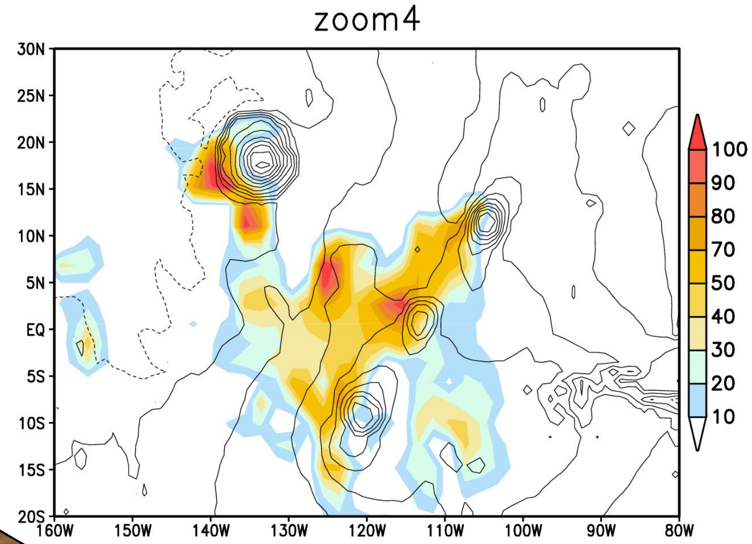




Modelling

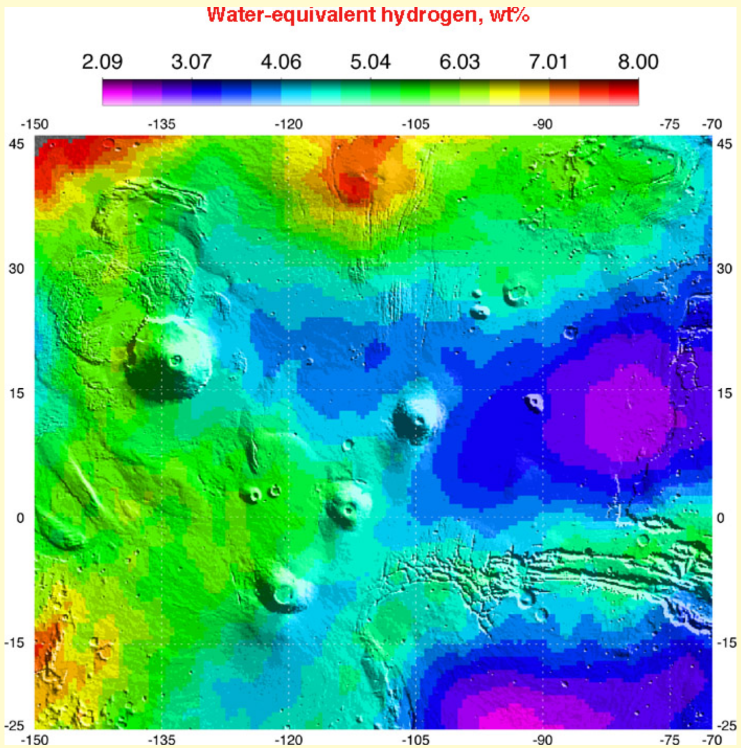


Cloud thickness (kg/m^2) and mean winds at 1 km above the surface during Northern summer

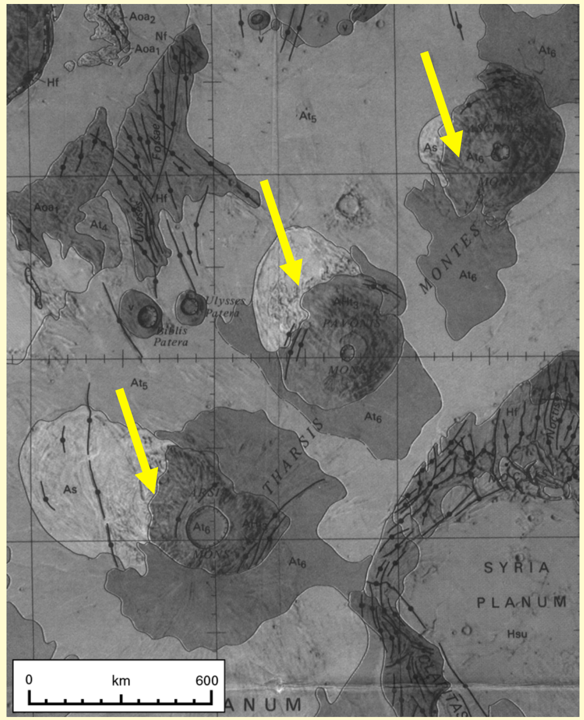


Forget and collaborators

Observations

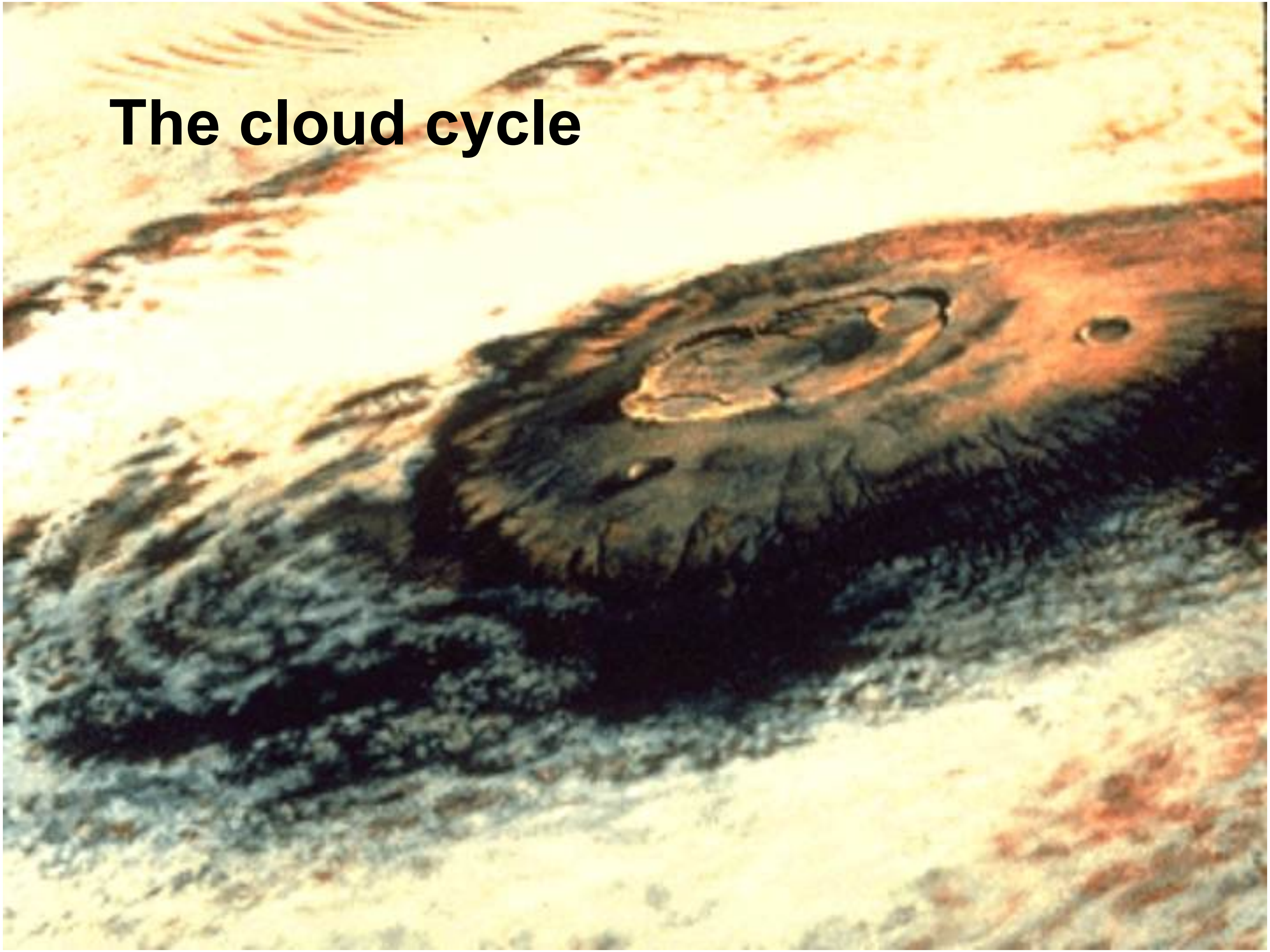


Subsurface « water » mapped by GRS aboard Mars Odyssey (Feldman et al. 2004)

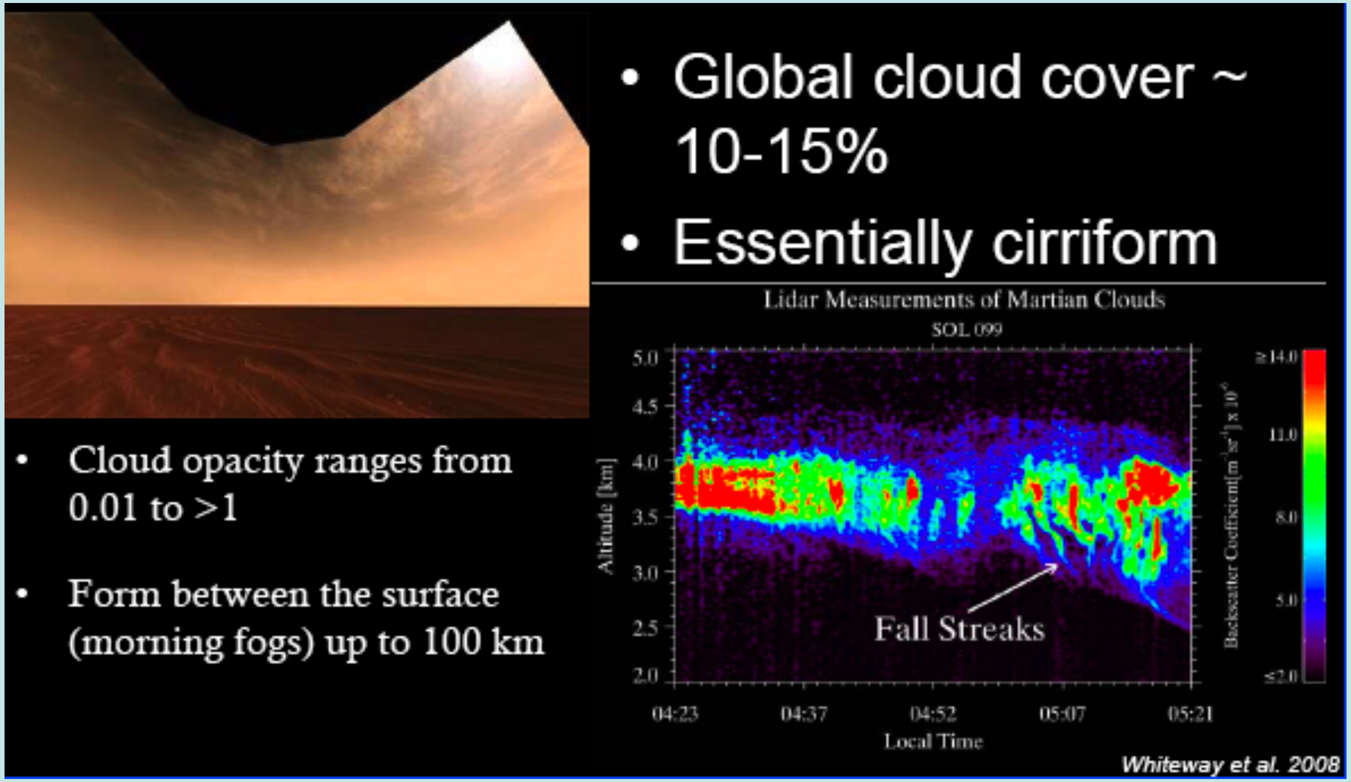


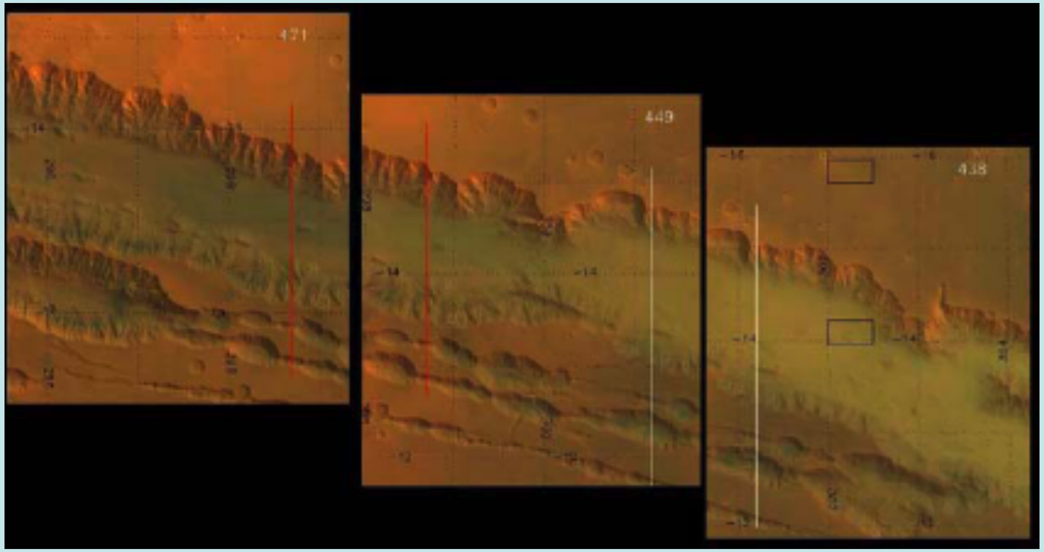
Mapping of remnant traces of cold-based glacier (*Head et al., 2003*)

The cloud cycle

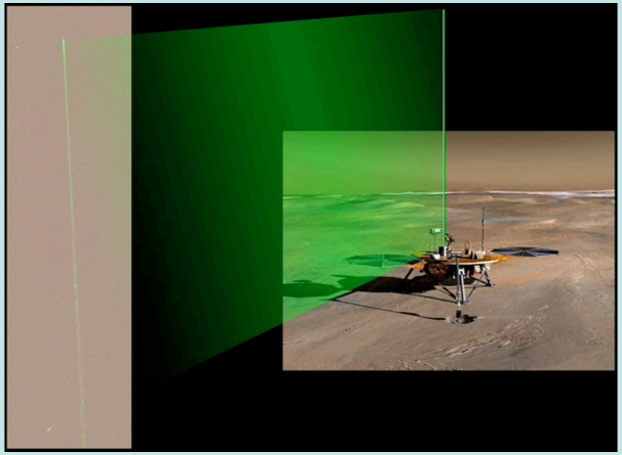



Morning frost at high northern latitudes
Persistant frost on a Viking
landing site Viking





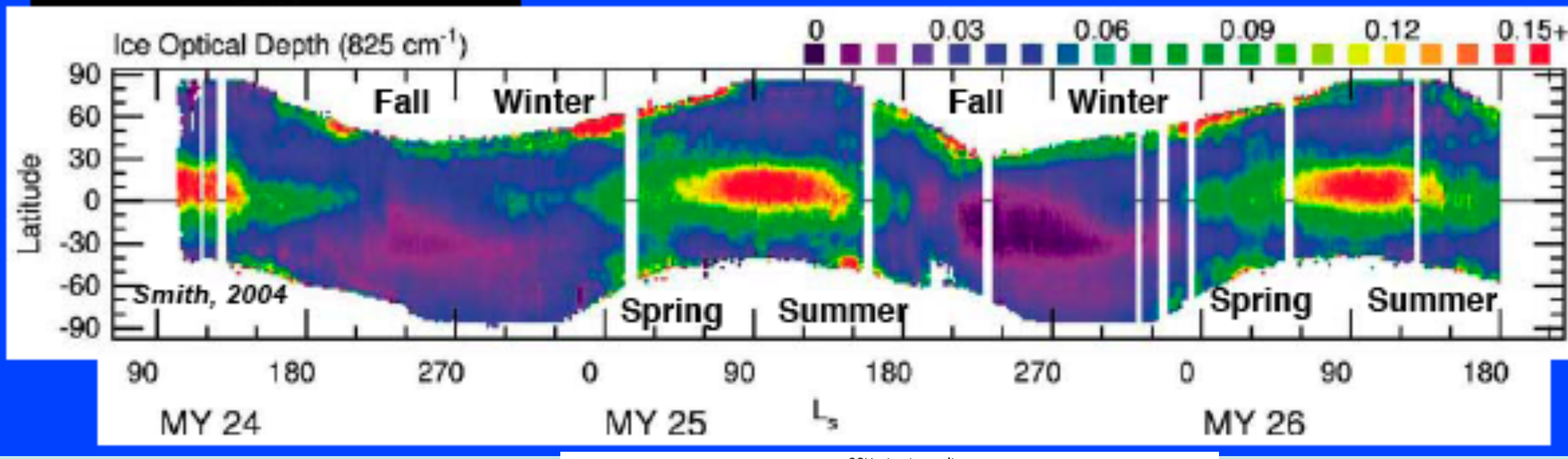
Hazes in Valles Marineris (HRSC/OMEGA, Mars Express, Inada et al, 2008)



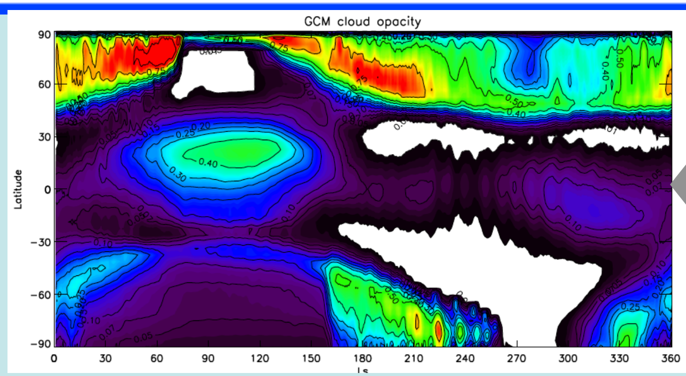
Lidar of Mars Polar Lander

Clouds concentrate in two principal regions and seasons:

- Intertropical latitudes during northern spring/summer = « cloud belt »
- Polar regions in fall/winter of both hemispheres = « polar hoods »



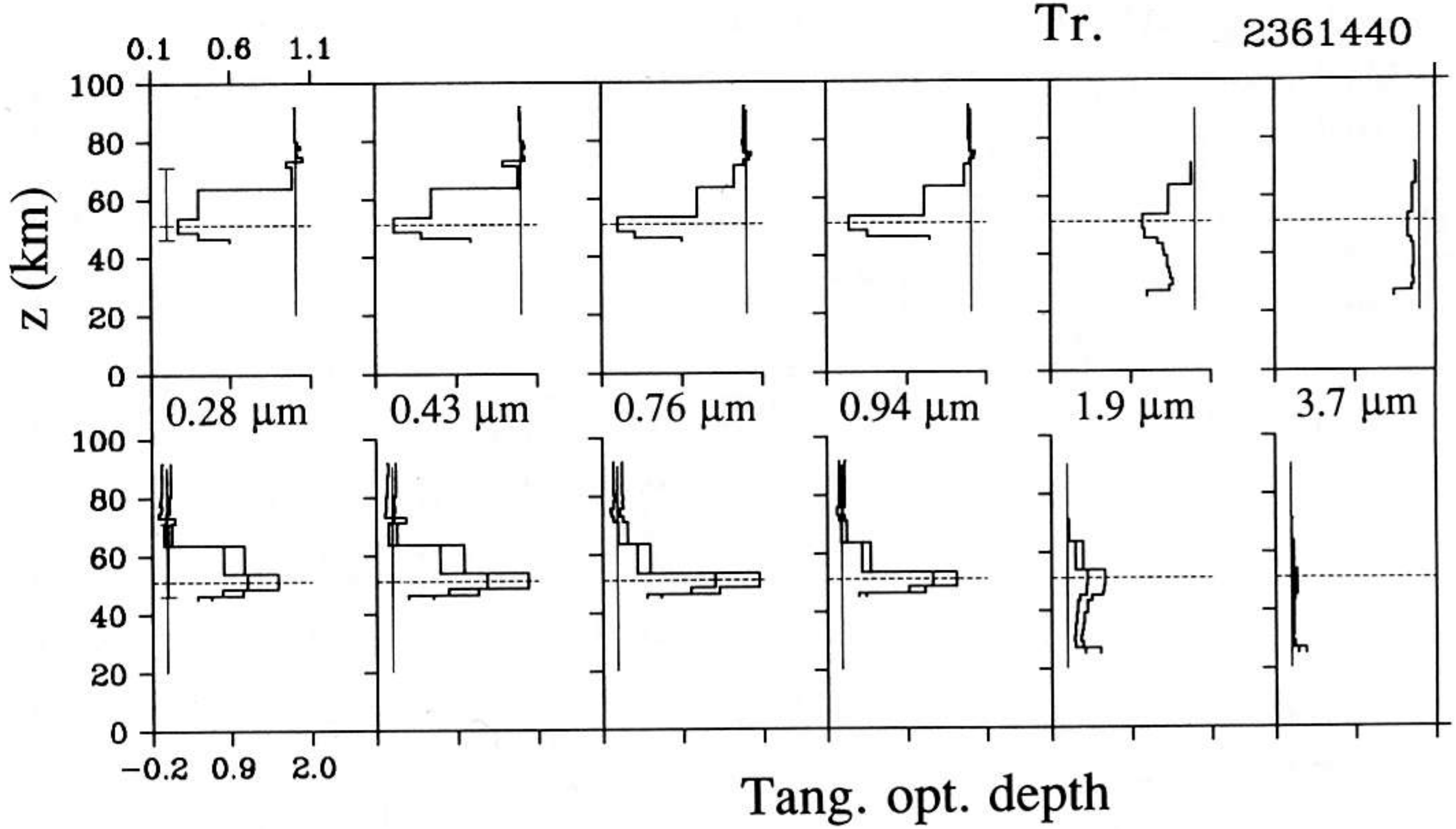
TES cloud opacity



GCM cloud opacity

Montmessin et al (2004)

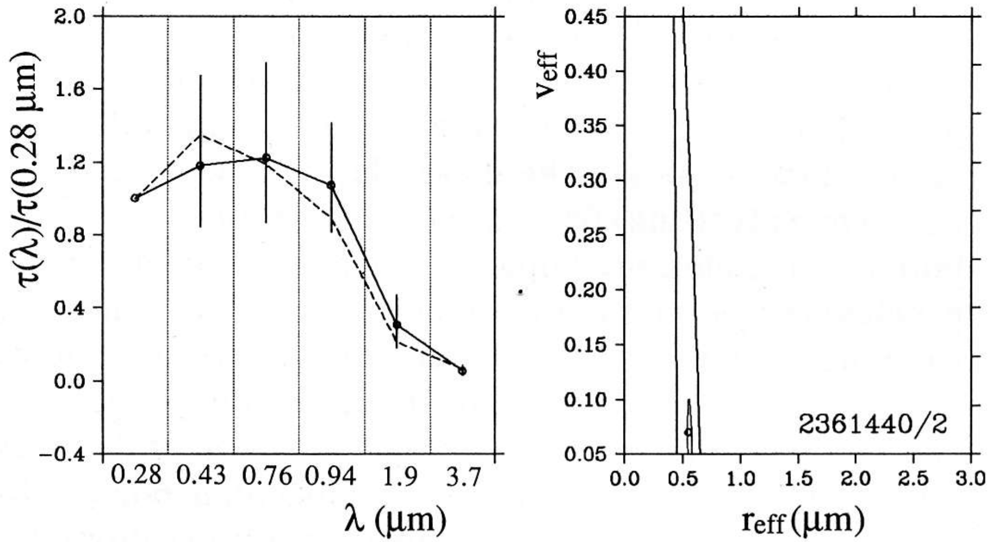
High clouds observed by solar occultation from Phobos 2 spacecraft



- Transmission and tangent optical depths of high cloud layers

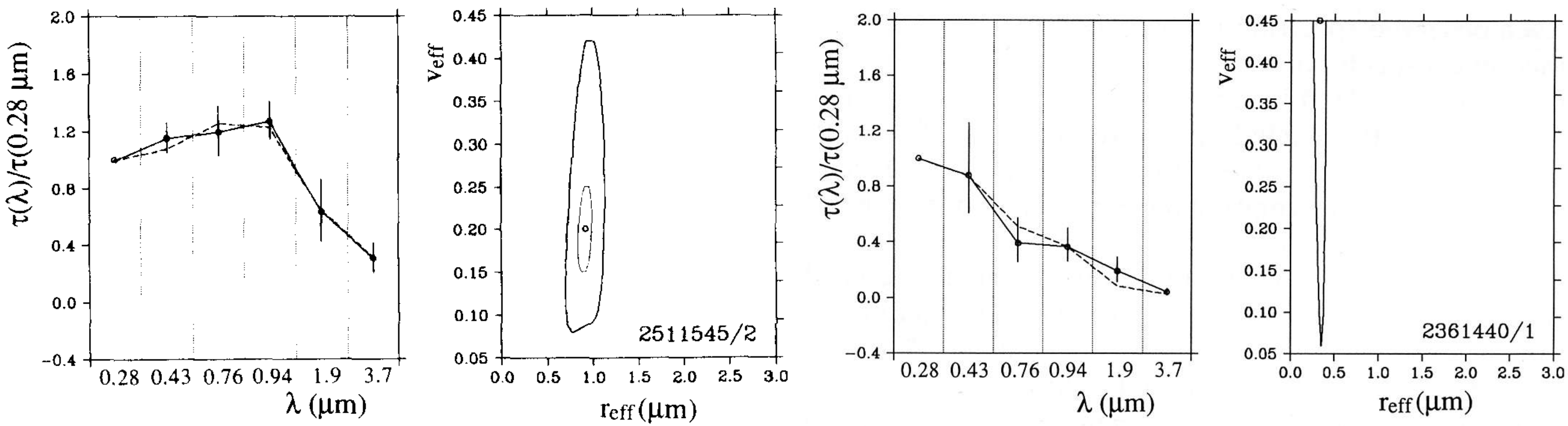
Chassefière et al, Icarus 97, 46, 1992

High clouds observed by solar occultation from Phobos 2 spacecraft



- Spectral slope → size of particles (submicron)

Chassefière et al, 1992

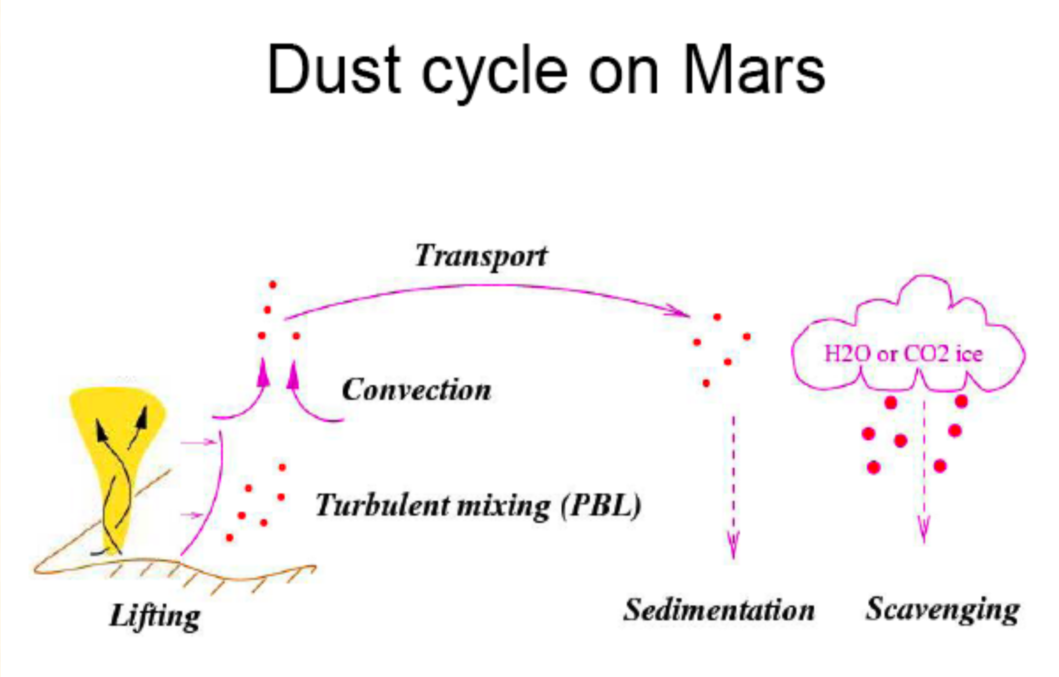


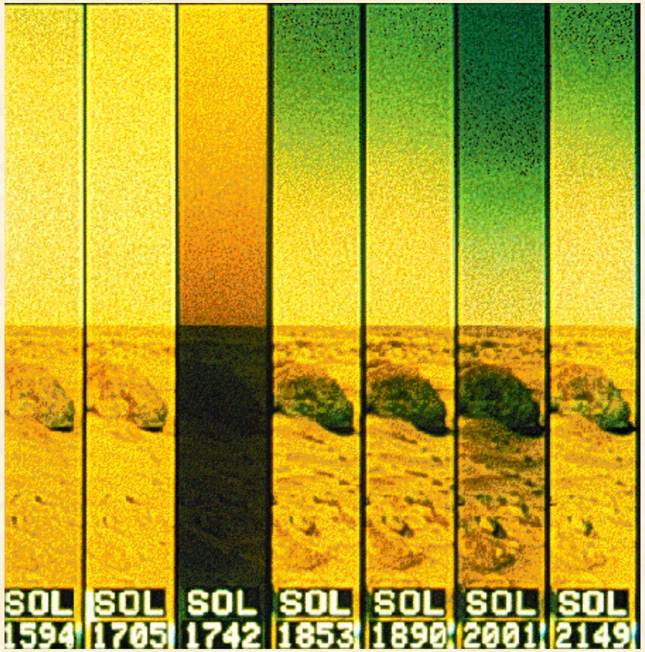
Characteristics of the 5 clouds observed by Phobos

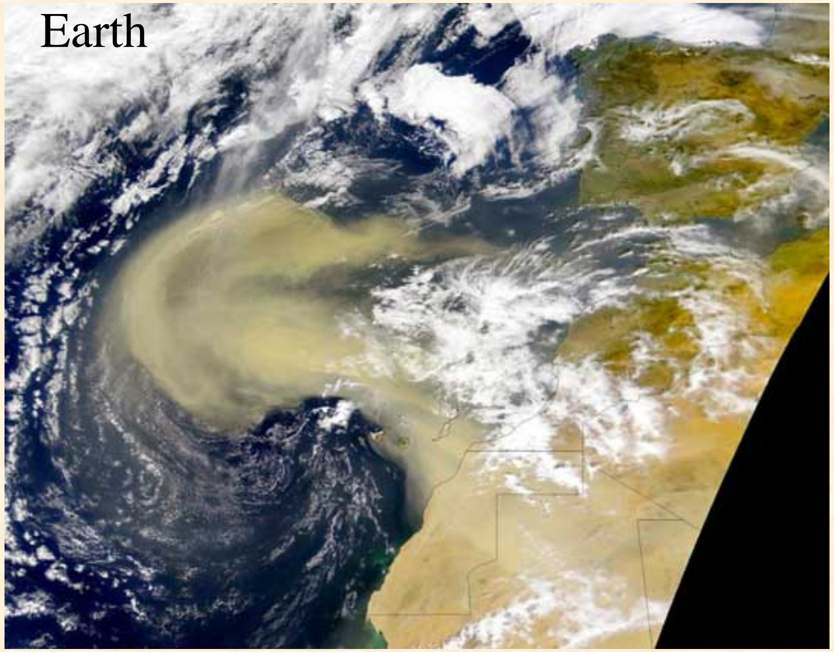
	Peak altitude (km)	W (km)	$\int\tau_{ext}$ (10^{-2})	τ_{ext} at peak (10^{-3} km^{-1})	layer	eff. radius (μm)	eff. var.	n_{part} at peak (cm^{-3})	$\int S$ (mm^2 cm^{-2})	$\int V$ (10^{-4} mm^3 cm^{-2})
C231	48 (+4, -3)	3	0.23 ±0.02	0.65 ±0.01	peak	0.65 ± 0.15	> 0.15	0.7 ±0.5	0.4 ±0.04	0.8 ±0.25
C236	56 (+?, -5)	6	2.7 ±0.2	3.4 ±0.2	top	0.3 ± 0.1	-	4.7 ±3.3	4.7 ±0.2	7.8 ±2.1
					peak	0.55 ± 0.1	-			
C237	50 (+4, -2)	≈3				-	-			
C245	53 (+2, -2)	4	0.36 ±0.02	0.79 ±0.01	peak	0.15 ± 0.1	-	0.5 ±0.3	5.3 ±0.4	9.7 ±2.5
C251	51 (+?, -7)	4.5	0.51 ±0.08	1.1 ±0.1	top	0.85 ± 0.2	-	0.8 ±0.5	6.1 ±0.5	12.4 ±3.2
					peak	0.9 ± 0.2	0.25 ± 0.15			

Chassefière et al, 1992

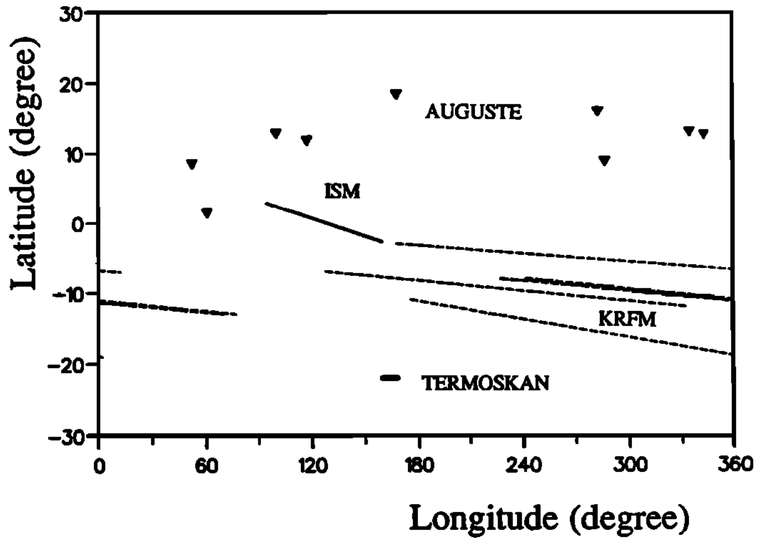
The dust cycle

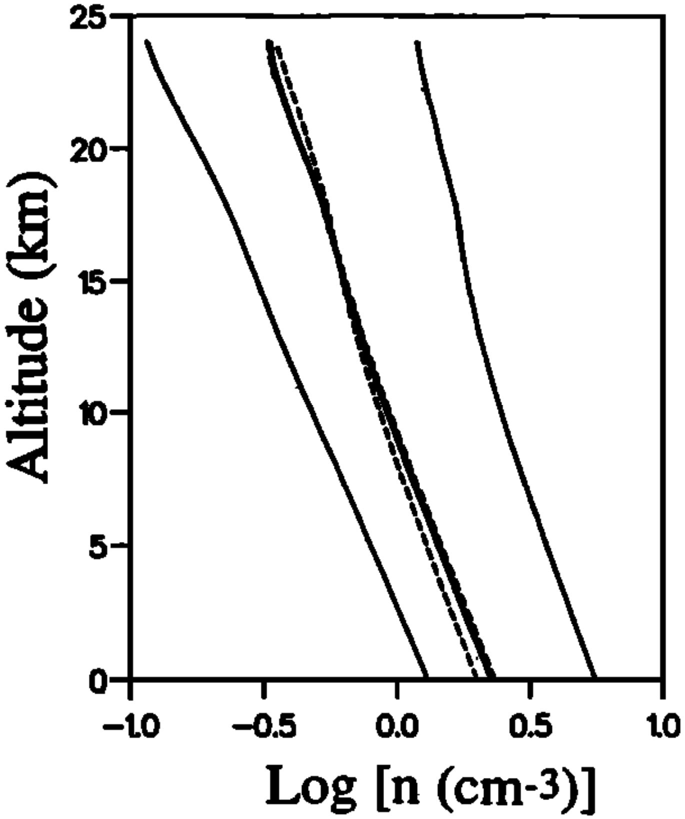


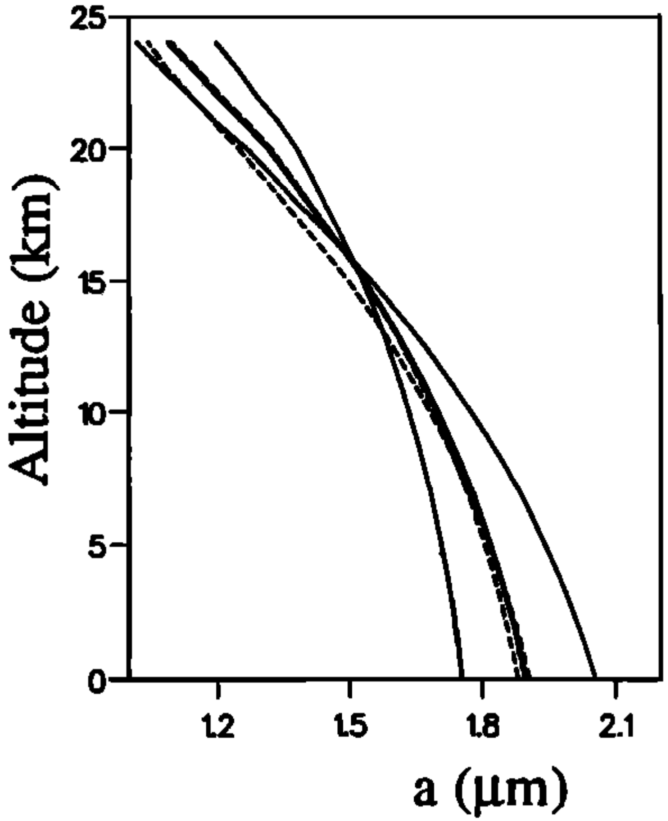




Vertical distribution and size of dust particles from Phobos observations

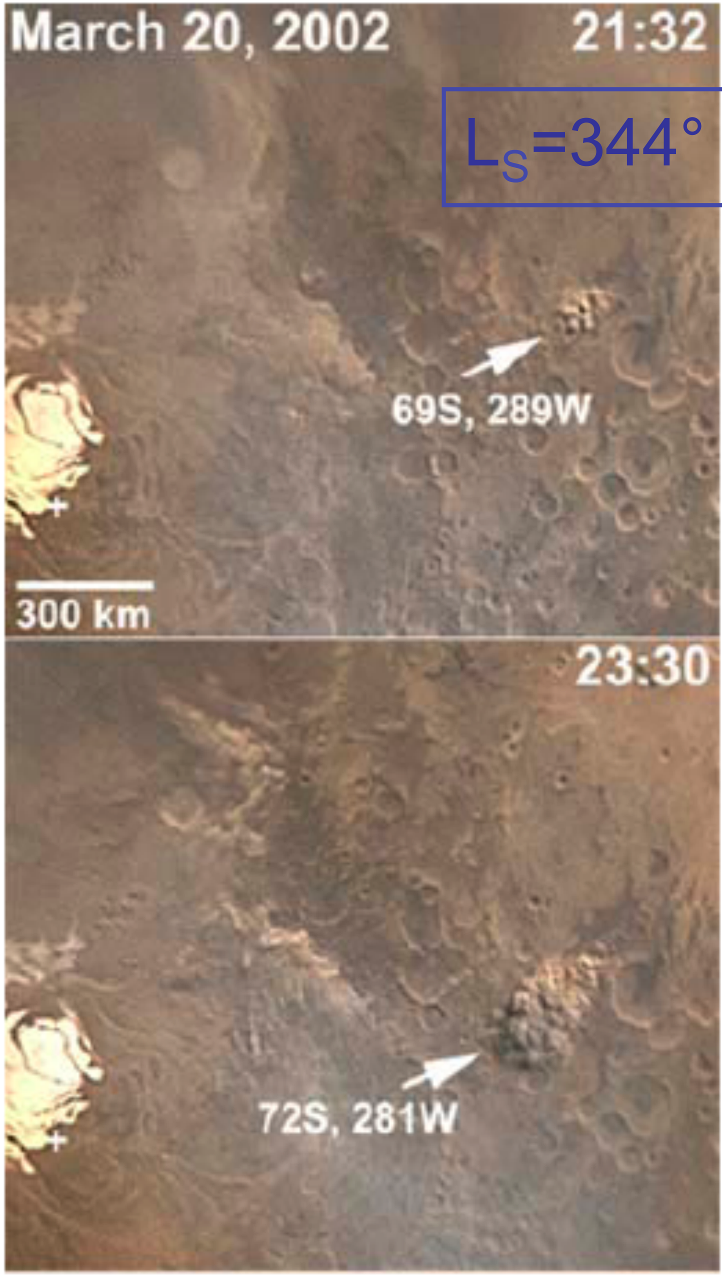




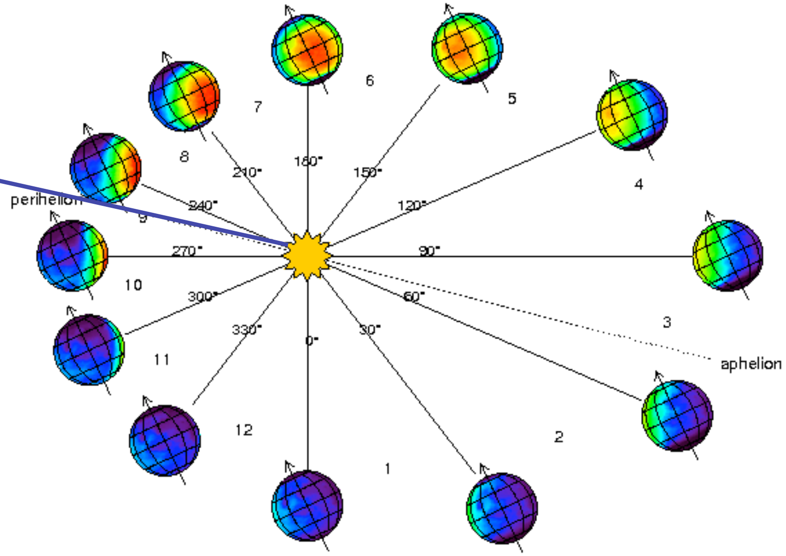


Chassefière et al, JGR, 1995

Occurrence of dust storms



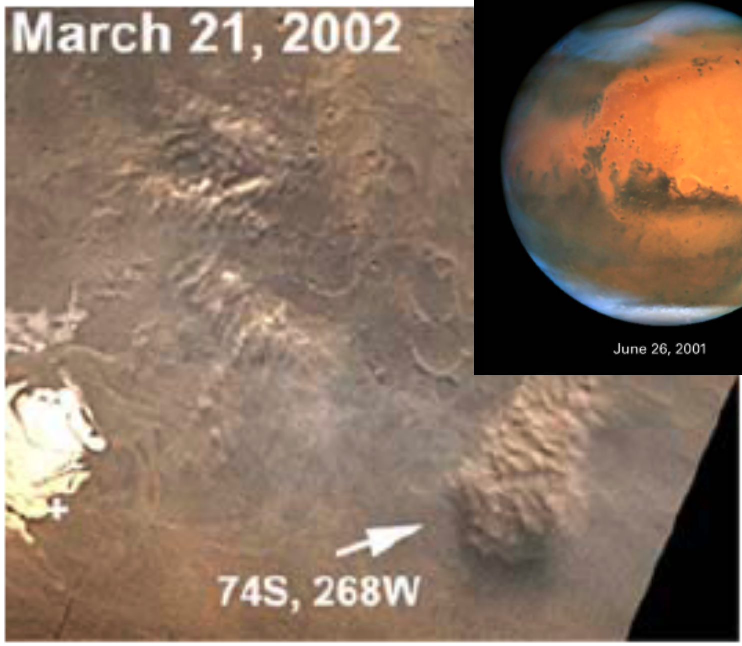
L_S=344°

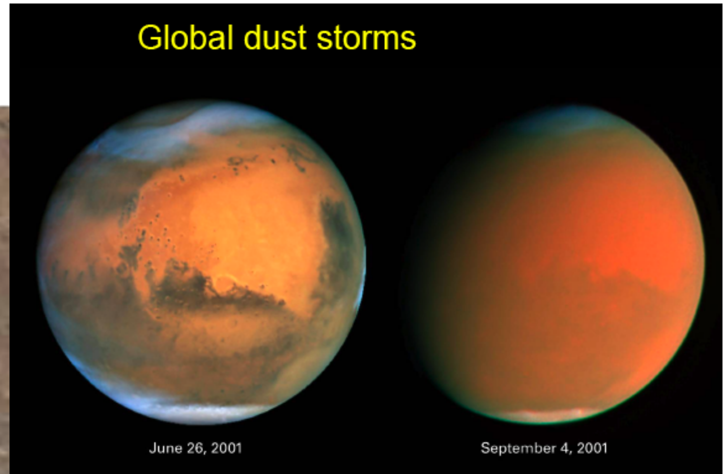


REGIONAL

or

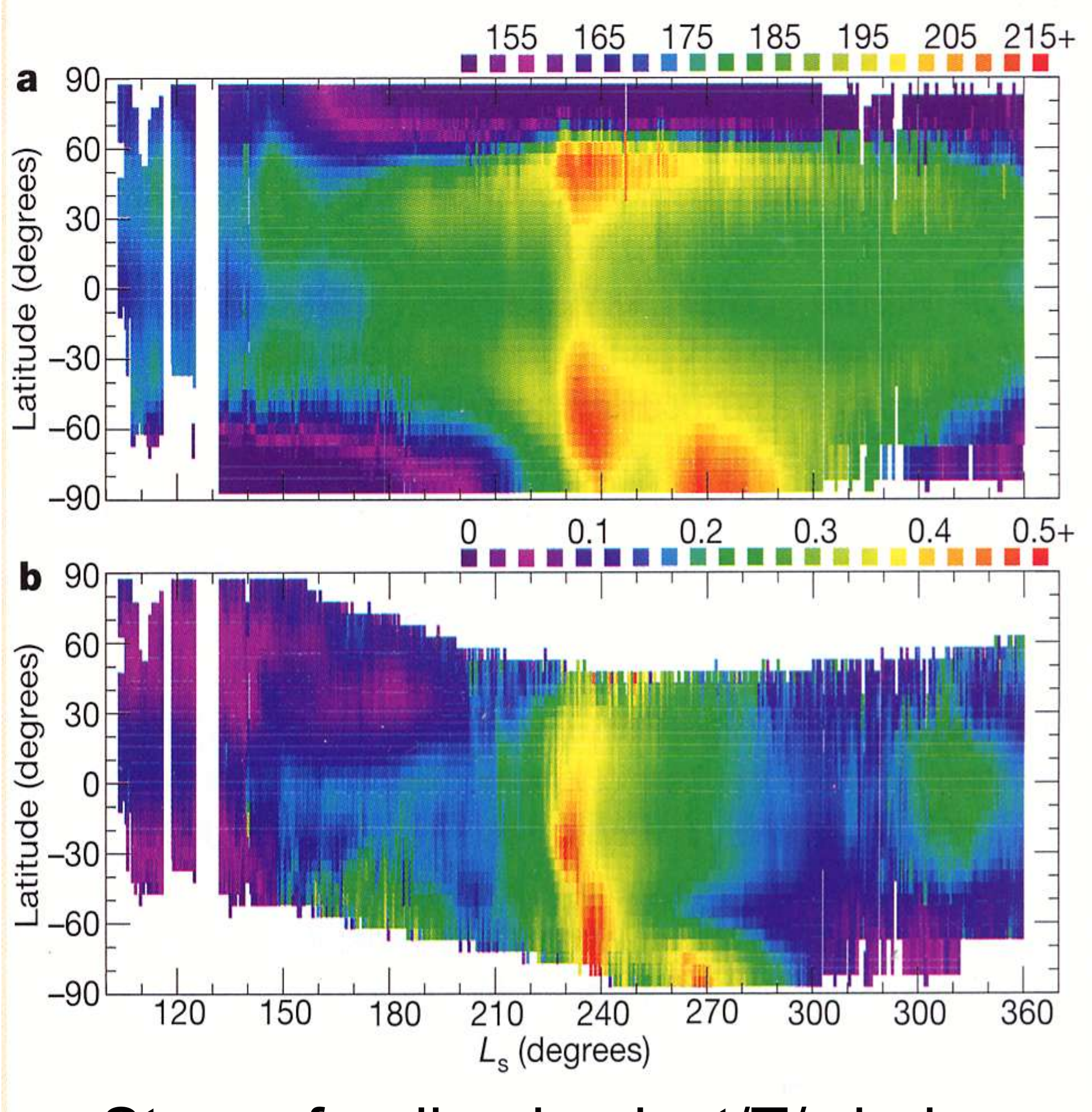
GLOBAL





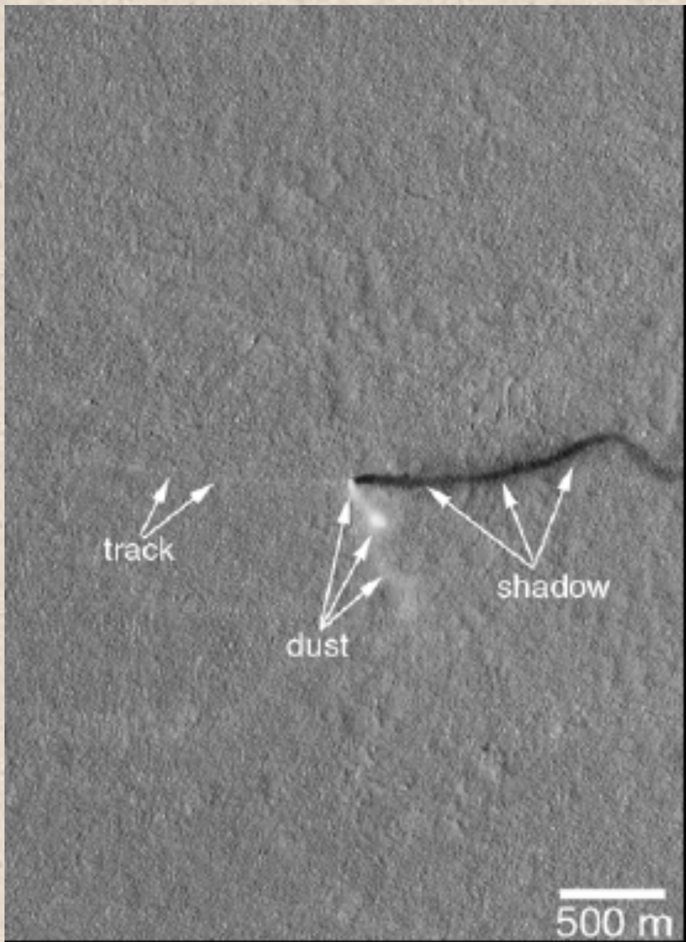
Global storms

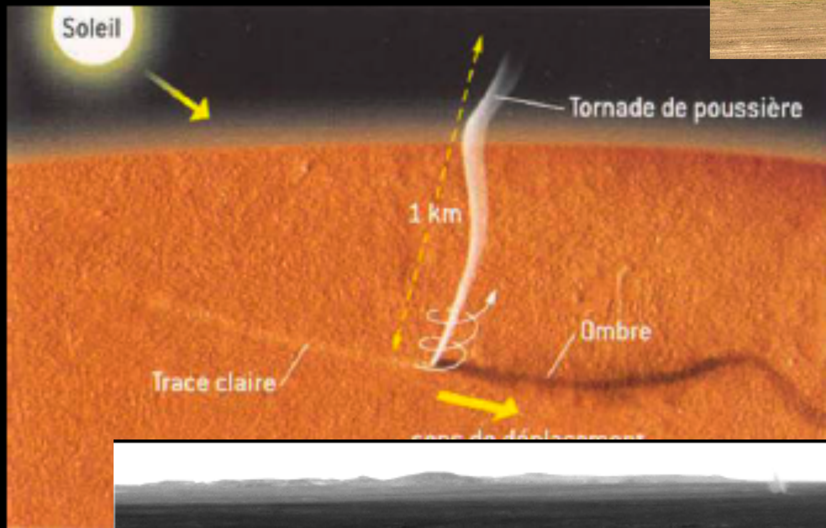
- No vertical stratification and unique Hadley cell : small global scale mixing time (a few days).
- Rapid transport of dust to the whole plate → global storms
- Formation at the boundary of the retreating south polar cap.



Strong feedbacks dust/T/wind

Dust devils





Rover NASA Spirit, aout 2005

Storm generation process