LONG-TERM OBSERVATIONS OF WATER VAPOR IN THE MIDDLE ATMOSPHERE OF MARS BY SPICAM/MEX

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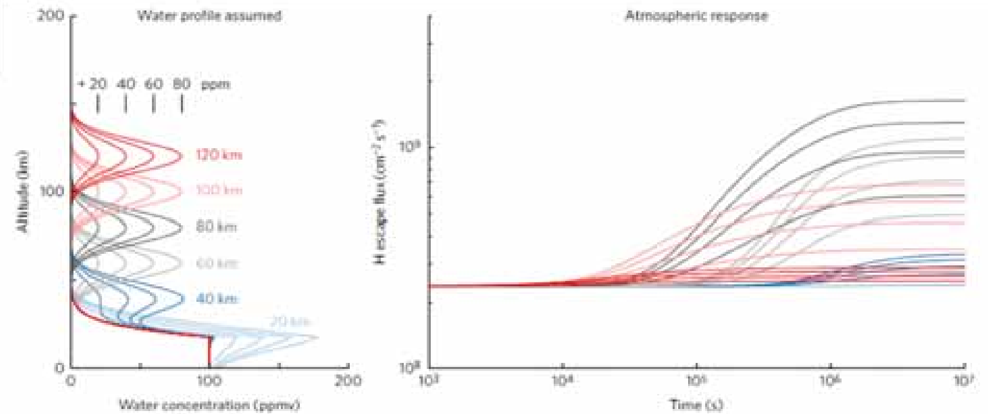
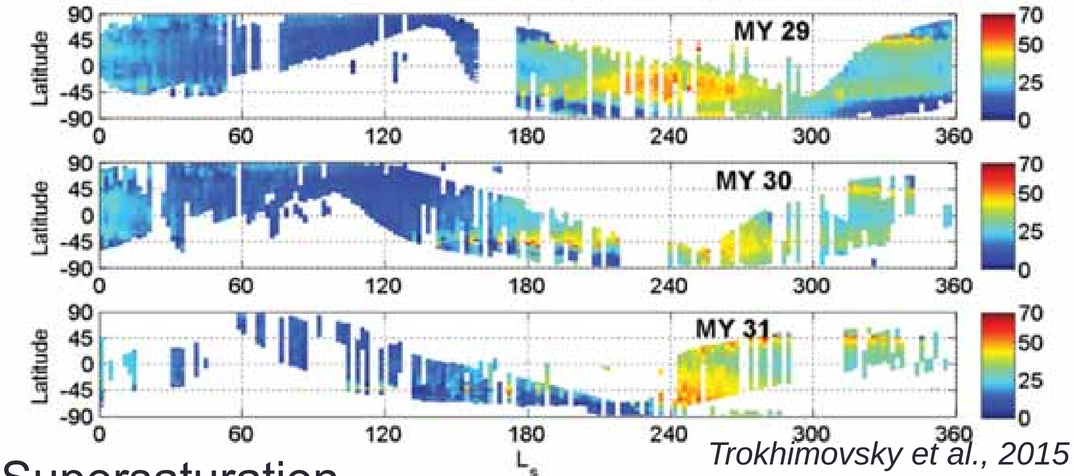
H_2O vertical distribution

- ❑ potentially driven by many processes
    - ➢ microphysics
    - ➢ chemistry involved
- ❑ diagnostics of the interaction with the CO_2 and dust climatic cycles
- ❑ Access of water to high altitude Important for the understanding of the escape process of water on Mars
- ❑ Direct measurements of hygropause variations
- ❑ supersaturation and an access of water above hygropause in the aphelion season



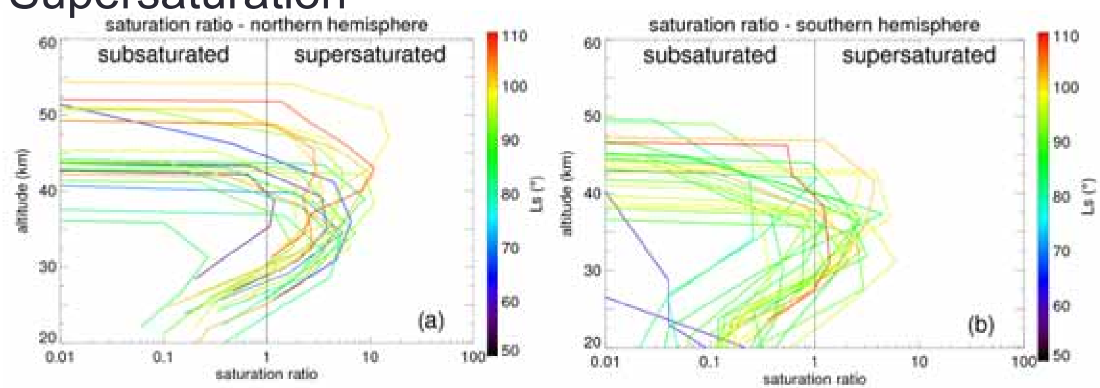
Chaffin et al., 2017

Saturation altitude



Trokhimovsky et al., 2015

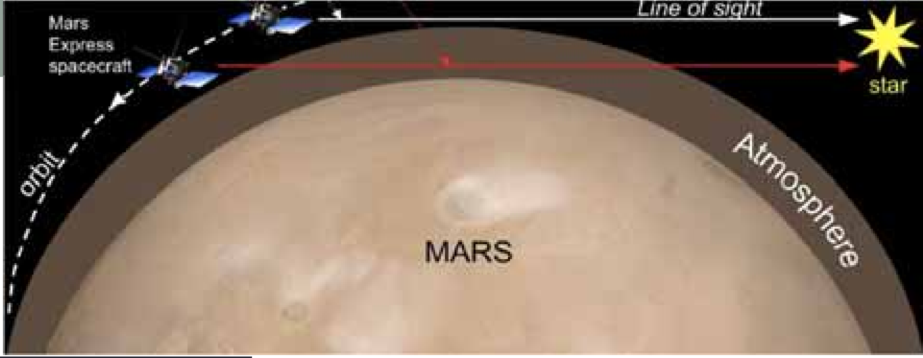
Supersaturation



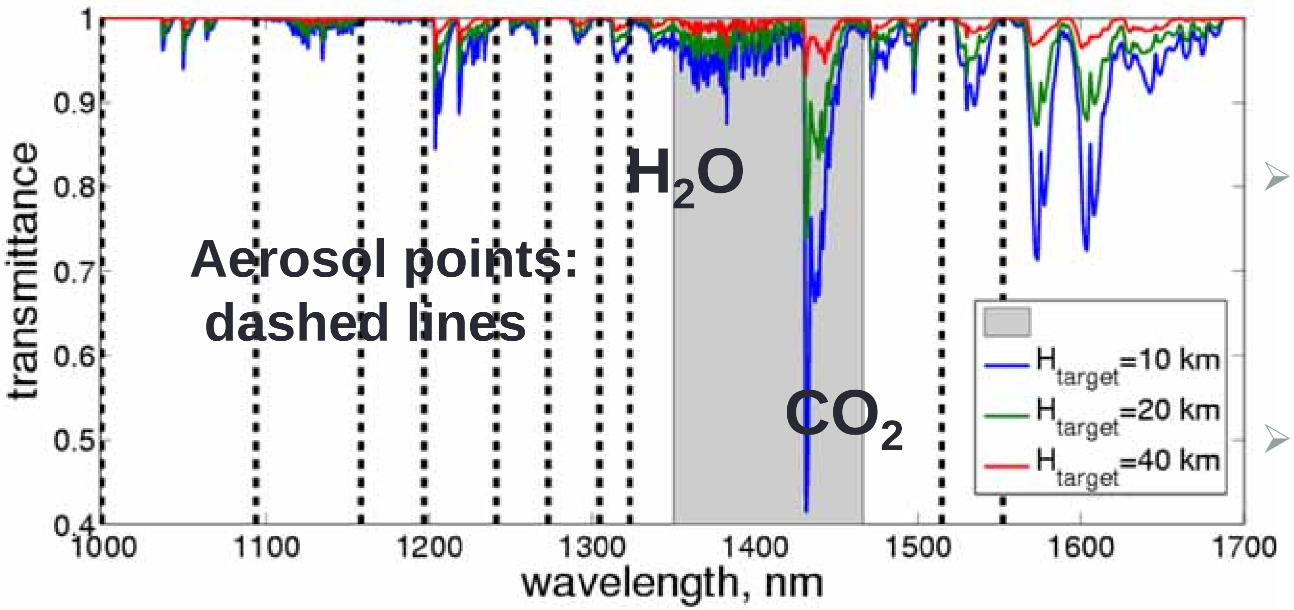
Maltagliati et al., 2011

Observations – instrument and method

SPICAM Mars-Express



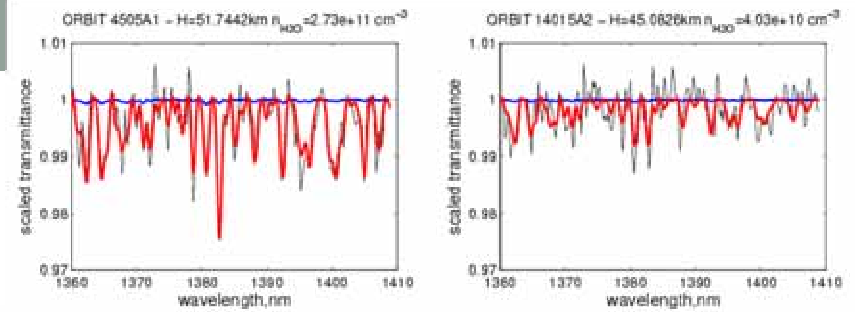
Channel	Modes	Spectral range	Spectral resolution	Species in SO
UV	Nadir Occultations	118-320 nm	>100	Aerosols, CO_2, O_3
Near-IR	nadir Occultations	1-1.7 µm	~2000	Aerosol, CO_2, H_2O



Occultation method:

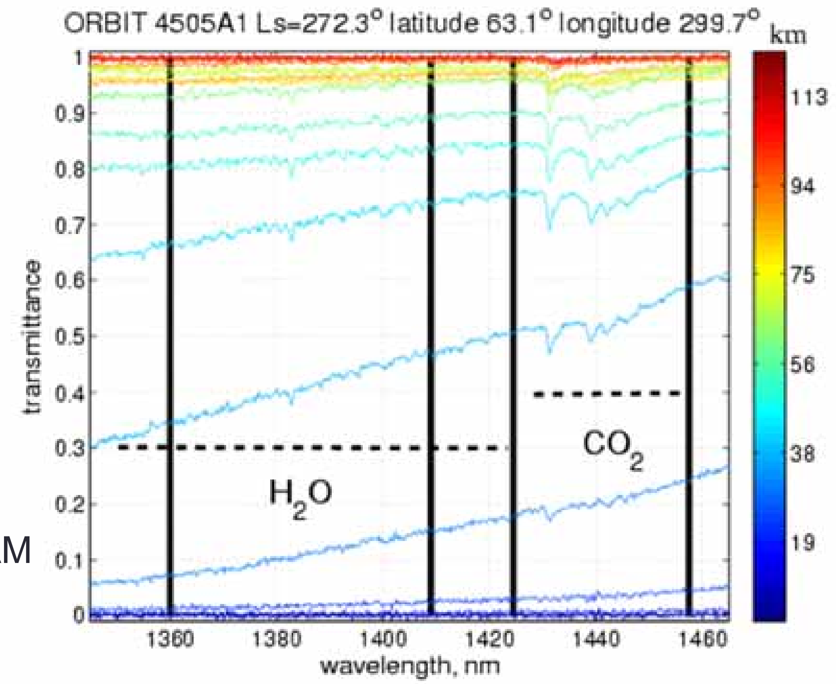
- Self-calibrated
- **H_2O density from 1.38 µm** band: retrieved **at 10-80 km** depending on season
- Atmospheric density from **1.43 µm CO_2 band**: retrieved at **10-120 km** depending on season
- Aerosol extinction profiles and particle size distribution with 10 spectral points outside gaseous absorption bands
- Vertical resolution is varied from 1.5 to 12 km

Retrieval of H_2O and CO_2 density



Since publications of 2009-2013:

- ➢Improvement of data processing
- ➢Levenberg–Marquardt iterative algorithm
- ➢HITRAN 2012 for H_2O and CO_2
- ➢MCD v.5.2 as a basis for temperature profiles
- ➢Detection limit for water density 5-8 10^9 cm-3



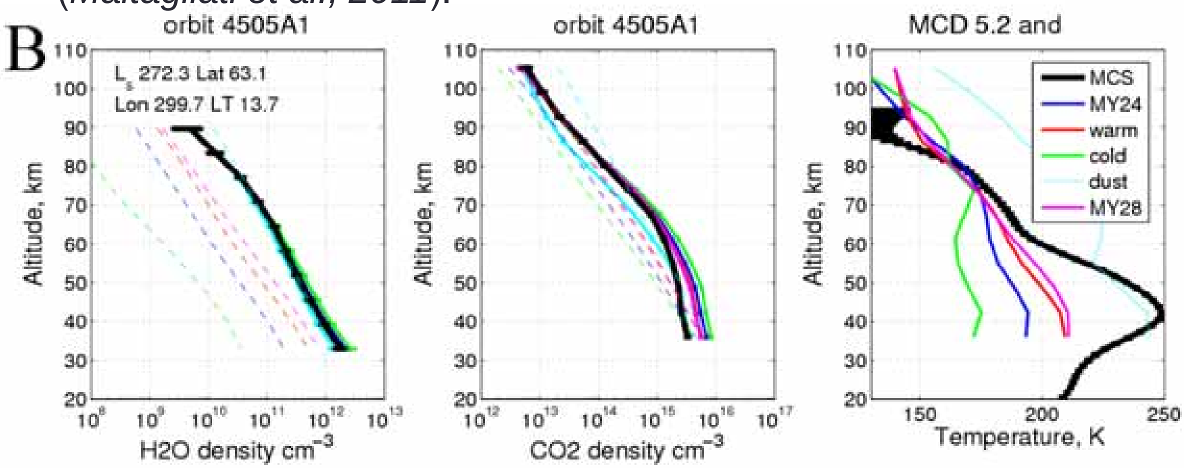
Main problem:

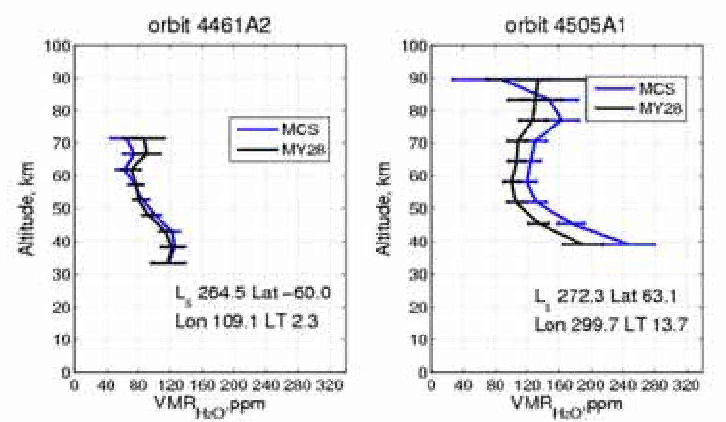
➢CO_2 density is sensitive to temperature.
In dust free aphelion season and quiet perihelion season the sensitivity is <20%; In dust storm condition (poorly determined MCD profiles) uncertainties can reach 50-60%

➢Temperature retrieval from the same data was fault

➢MCS profiles were used, close to location and time of SPICAM observations and approximated to local time based on MCD (*Maltagliati et al., 2011*).

B

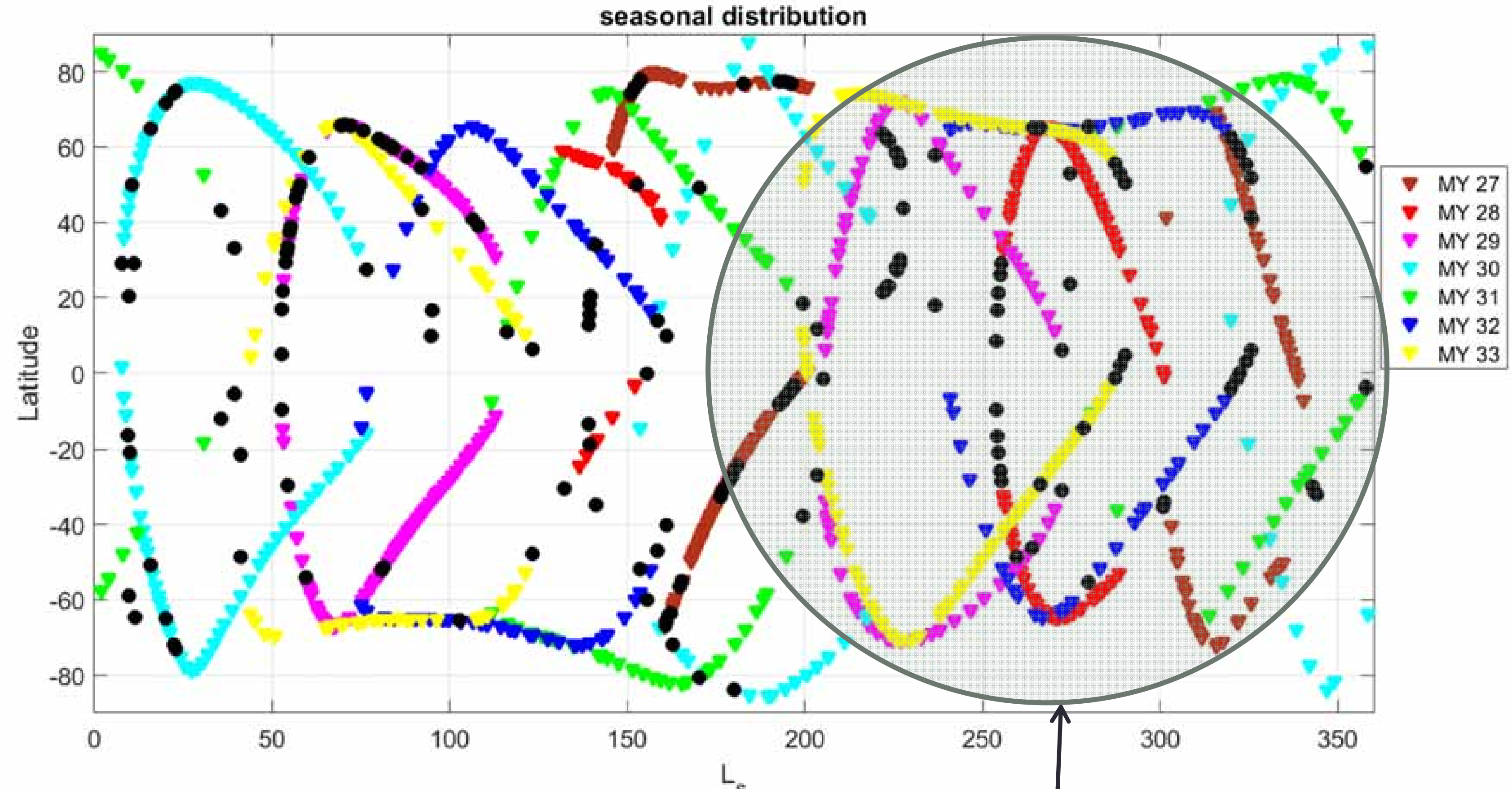




Seasonal distribution

7 Martian Years of observations (MY27-33)

~1200 occultations performed
~1000 successful occultations

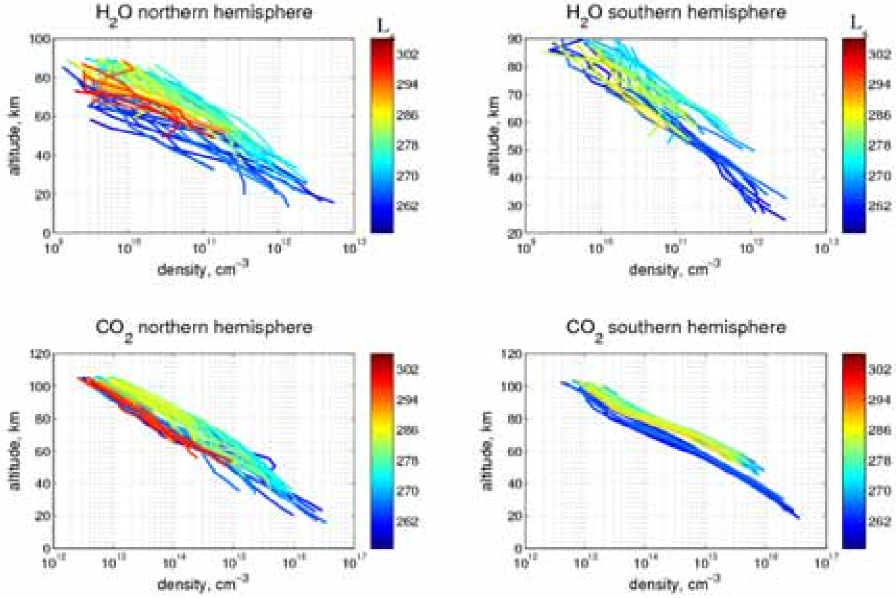


The black circles mark the observations inapplicable for retrieval for different reasons.

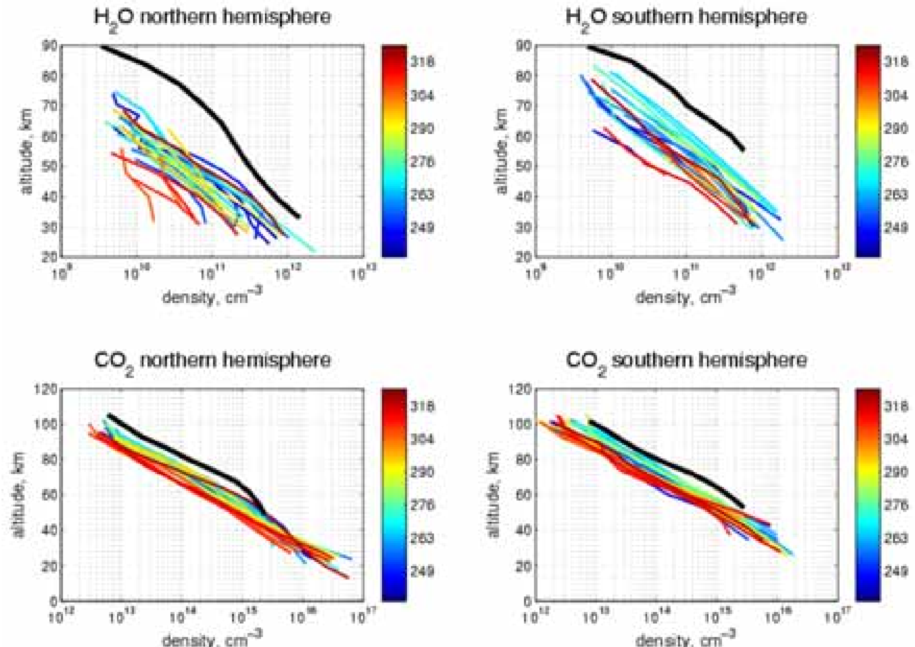
82 orbits in MY28 (Ls = 255-300°); 71 orbits in MY29 (Ls = 200-270°)
42 orbits in MY30 (Ls = 180-218; 320-360°);
48 orbits in MY31 (Ls = 180-203; 275-358°);
65 orbits in MY32 (Ls = 240-320°); 45 orbits in MY33 (Ls = 199-230°)

Retrieved H_2O and CO_2 density and H_2O mixing ratio

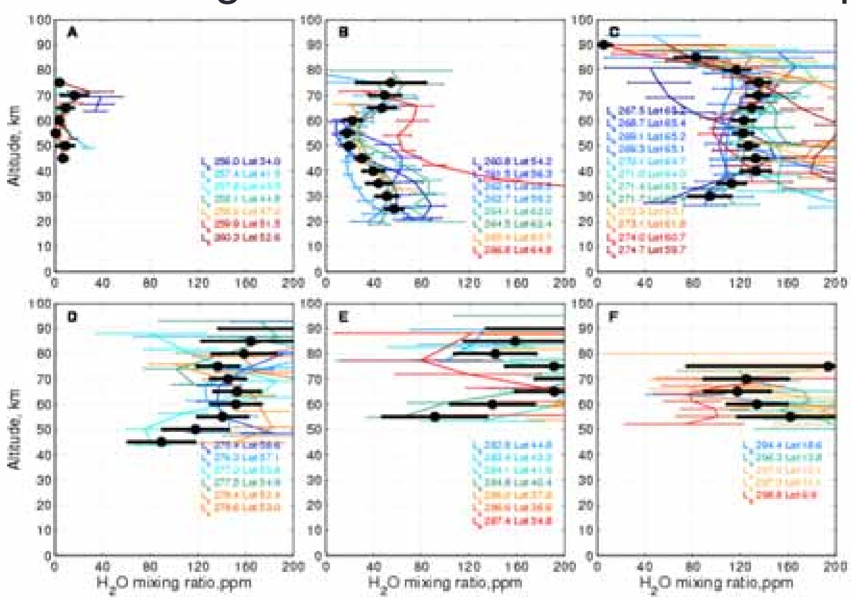
MY28

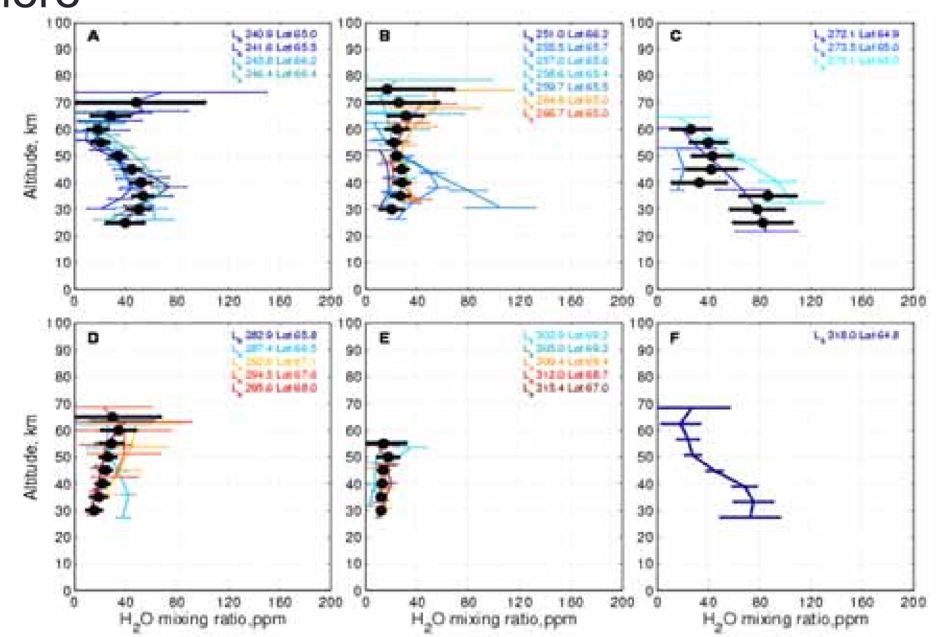


MY32



Mixing ratio for the Northern hemisphere

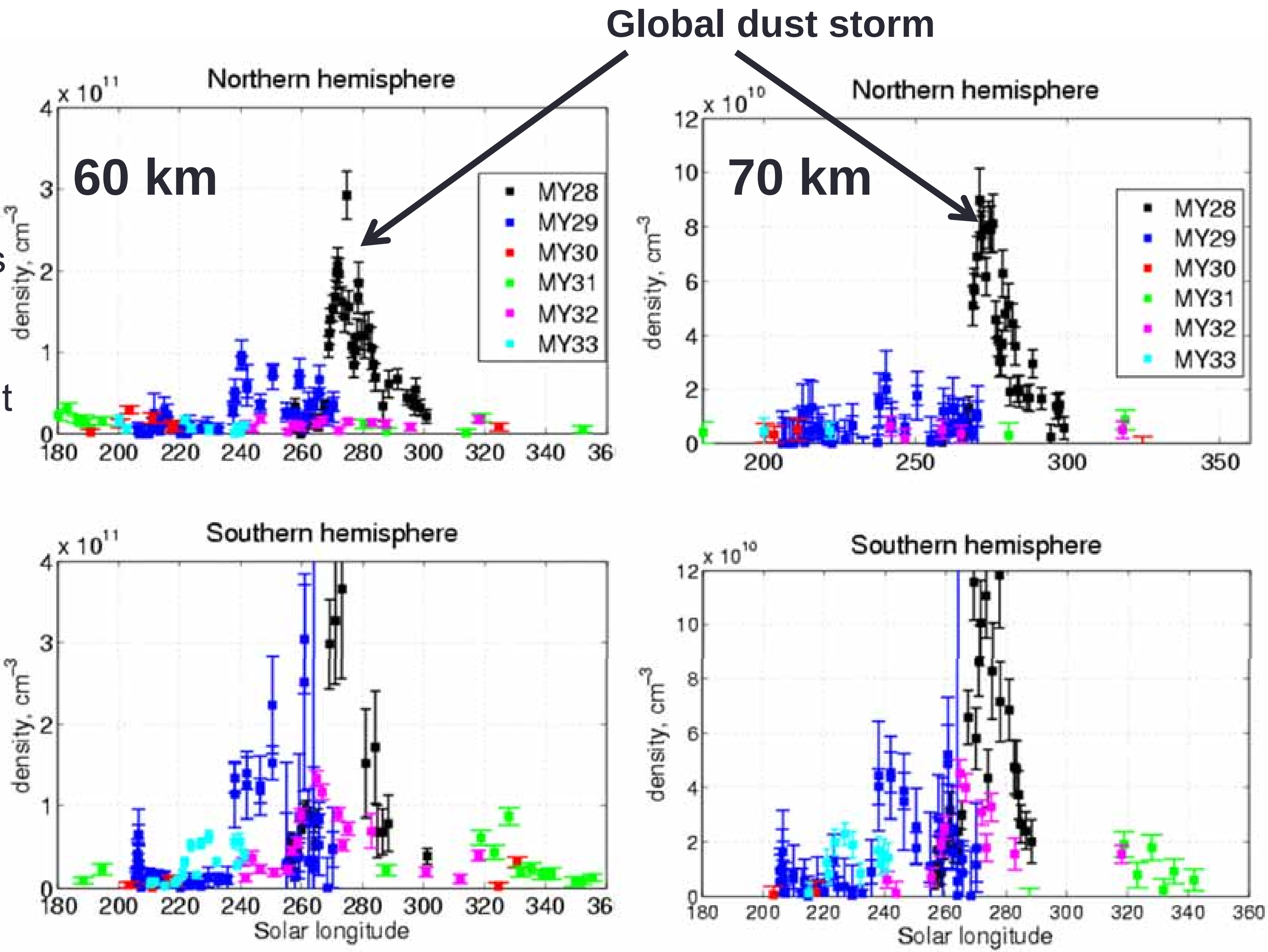




H_2O density for MY28-33 (6 years)

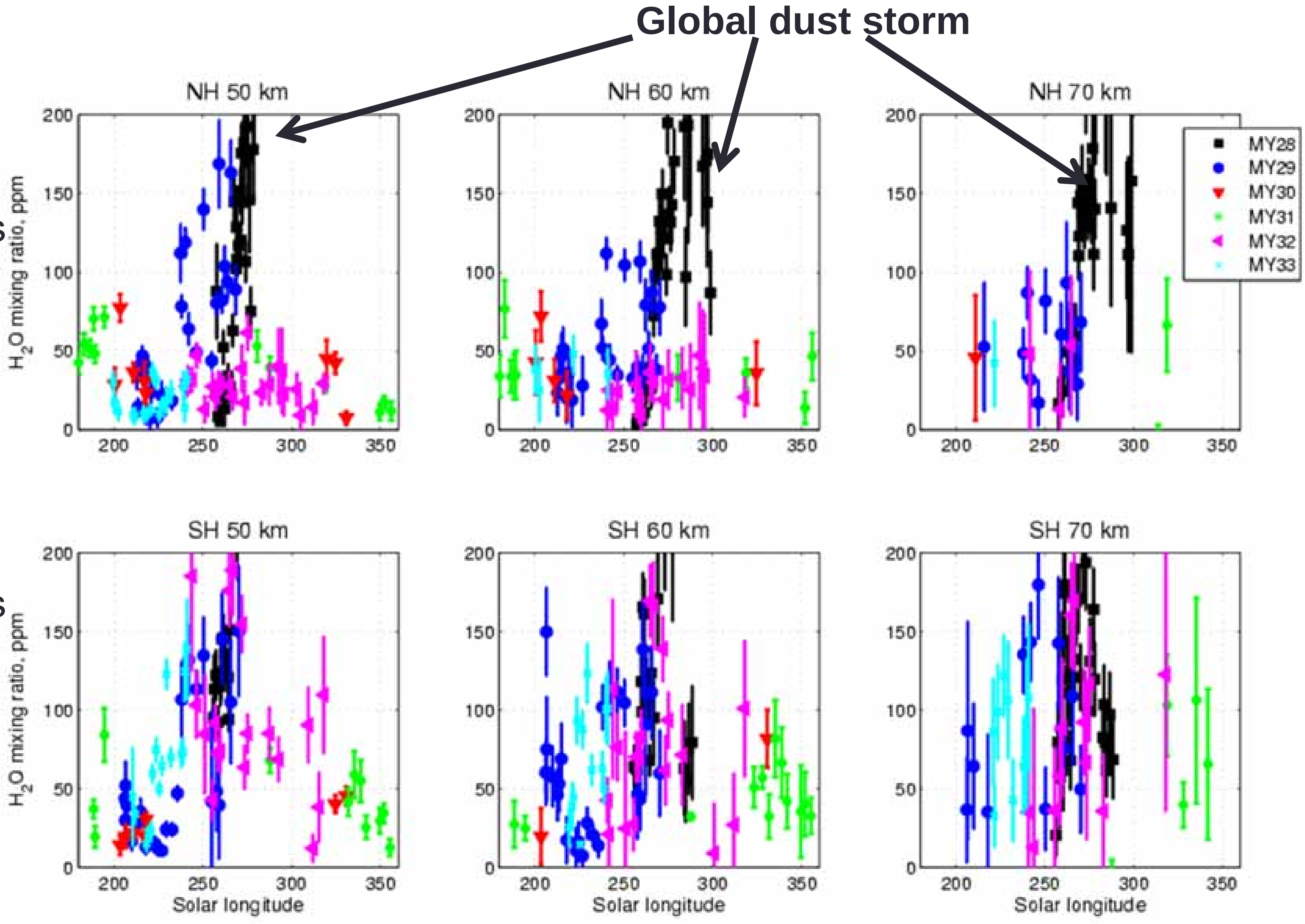
Northern hemisphere
H_2O density in MY28 exceeds in several times all other observations at 60 and 70 km

Southern hemisphere
H_2O density is also high in MY29 and 32 but in 2 times lower than in MY28



H_2O mixing ratio at 50, 60 and 70 km for MY28-MY32

The H_2O mixing ratio is mostly higher in the Southern hemisphere than in the Northern hemisphere at all altitudes except the global dust storm observations in MY28



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https://doi.org/10.1038/s41550-017-0353-4

Recently published (2018)

Hydrogen escape from Mars enhanced by deep convection in dust storms

Nicholas G. Heavens[1*], Armin Kleinböhl[2], Michael S. Chaffin[3], Jasper S. Halekas[4], David M. Kass[2], Paul O. Hayne[2], Daniel J. McCleese[5], Sylvain Piqueux[2], James H. Shirley[2] and John T. Schofield[2]

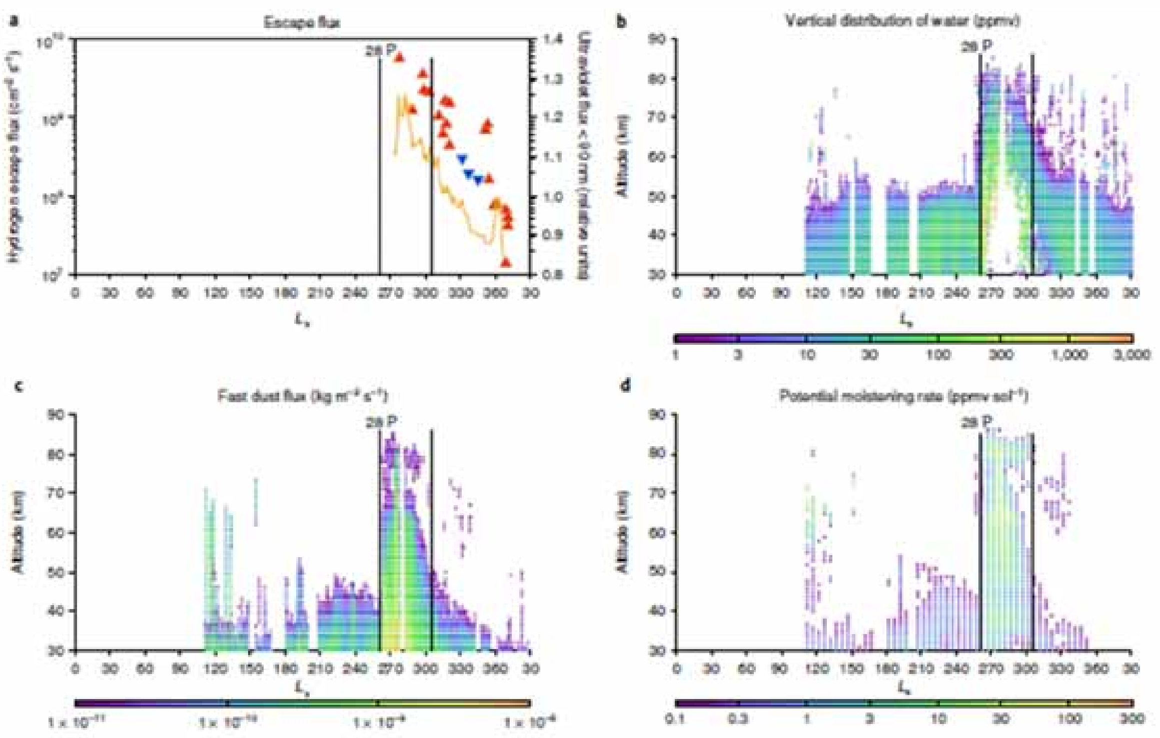
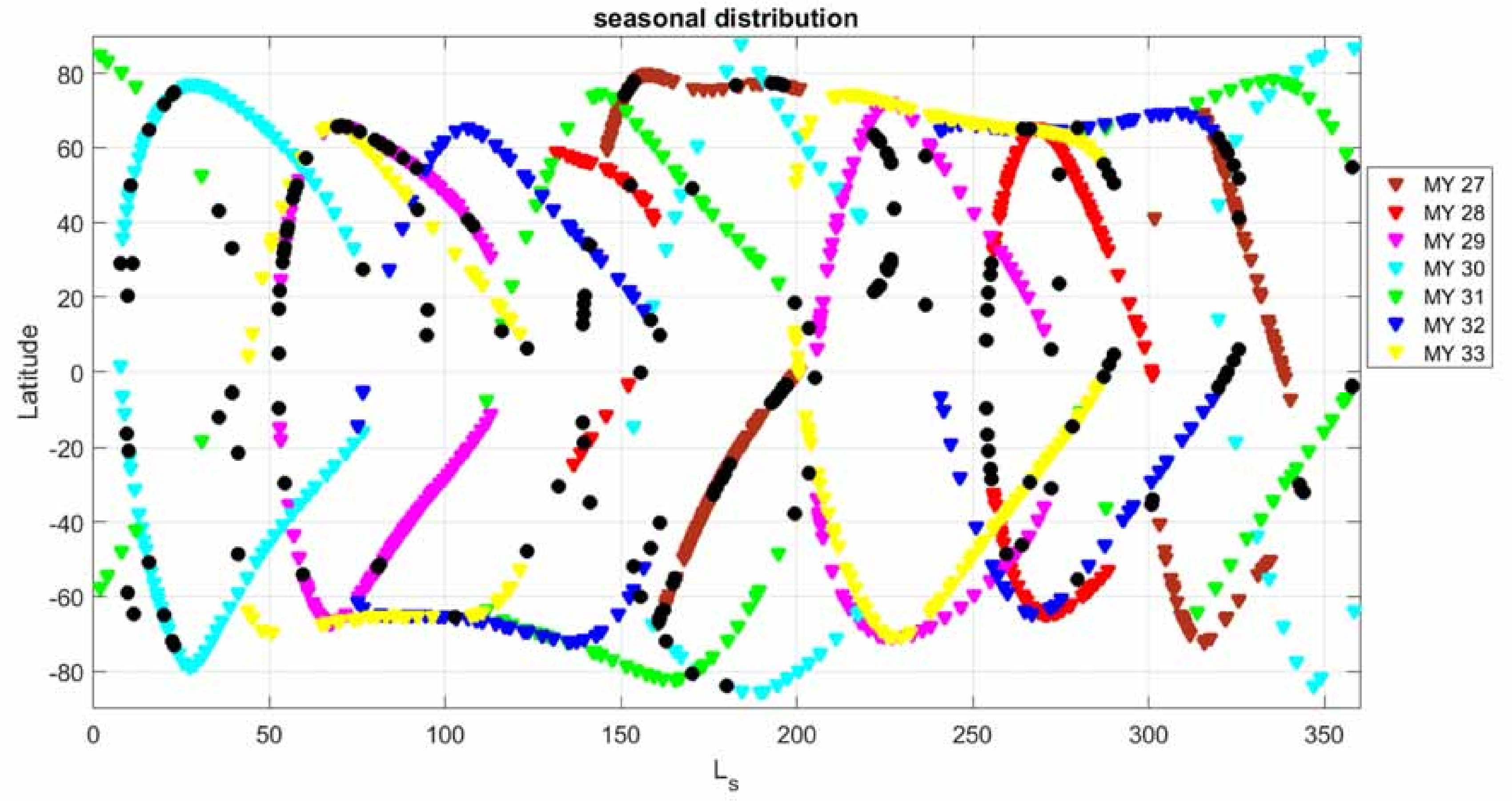


Fig. 1 | Hydrogen escape and explanatory factors during MY 28. a, Estimated hydrogen escape rates from Mars Express and the Hubble Space Telescope (red upward and blue downward triangles, respectively) and incoming flux of CO_2-ionizing photons (mustard line). **b**, Vertical distribution of total water content of the dayside middle atmosphere (ppmv) versus the mean areocentric longitude (L_s/season) of the orbital pair epoch (OPE). **c**, Dayside fast dust flux (kg m^{-2} s^{-1}) versus the mean L_s of the OPE. **d**, Dayside potential moistening rate (ppmv sol^{-1}) averaged over all available OPEs in 5° of areocentric longitude. In all panels, the beginning and end of dust storm 28 P is indicated by vertical black lines. All altitudes are relative to the areoid.

Seasonal distribution

7 Martian Years of observations (MY27-33) ~1000 successful occultations

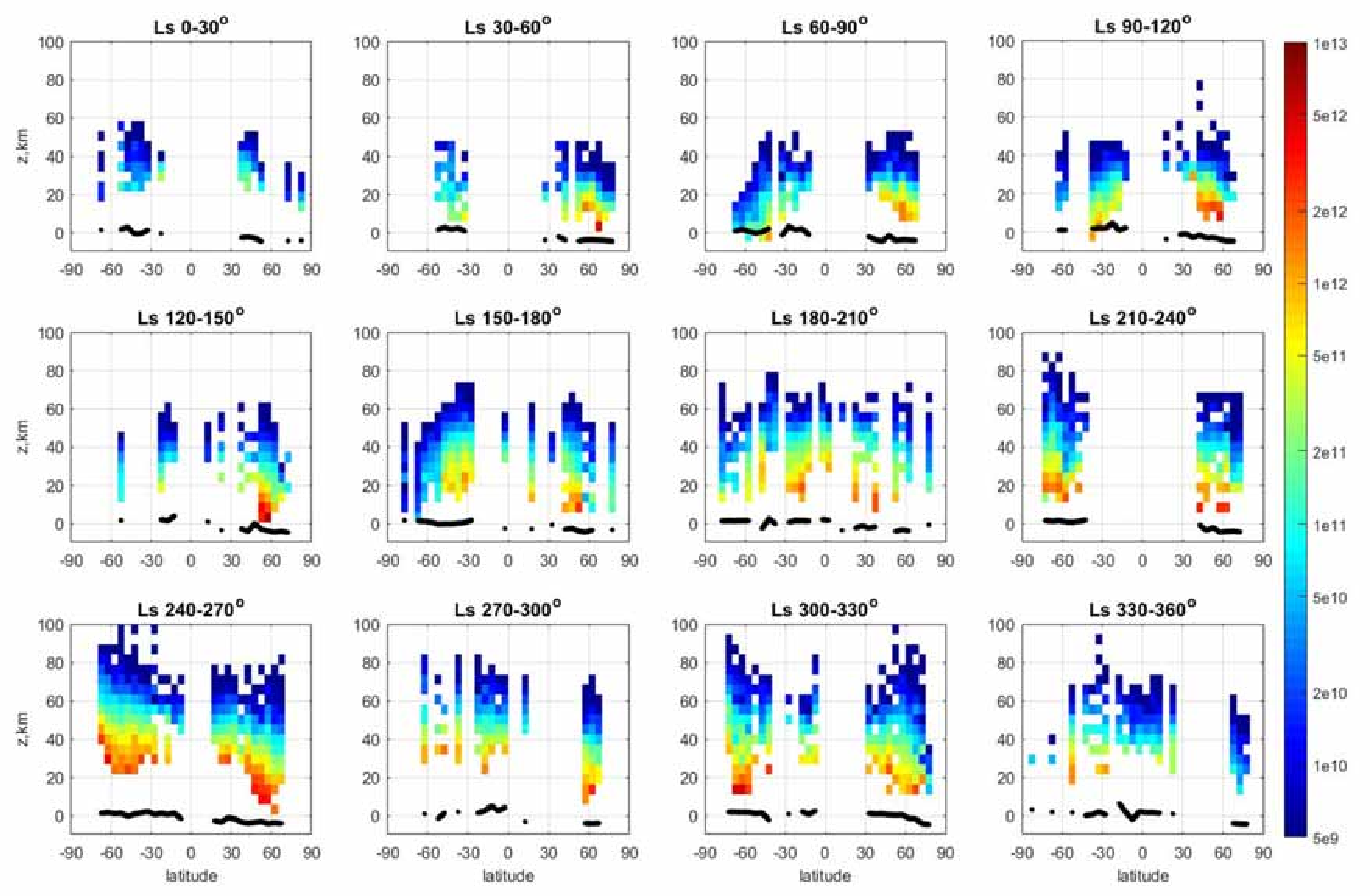


The black circles mark the observations inapplicable for retrieval for different reasons.

H_2O density distribution for 7 years (MY27-33)

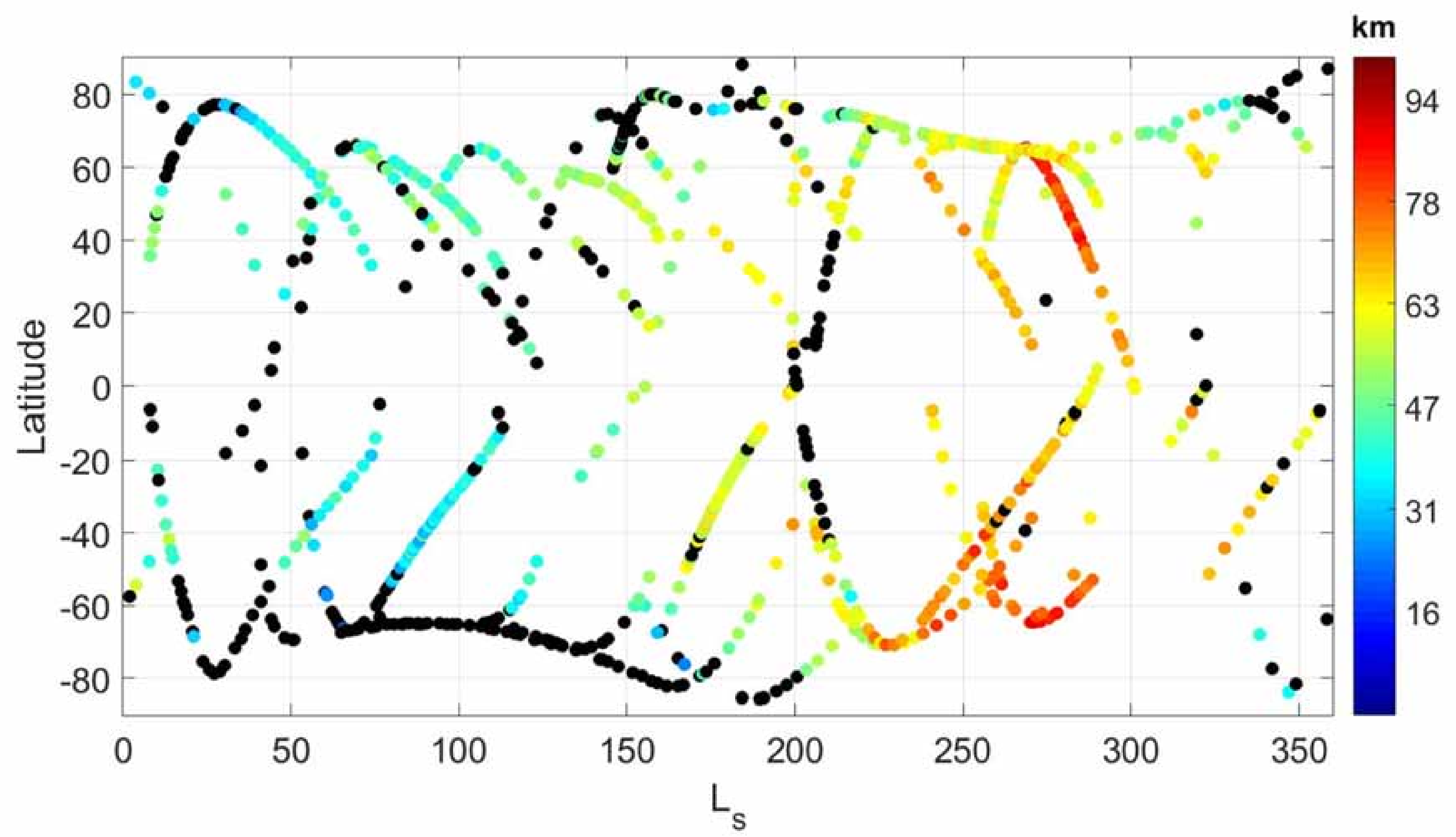
Global dust storm MY28 was excluded

Upper level of water density is 50-60 km in the aphelion season and 70-90 km in perihelion season



Criterion of water elevation in the atmosphere?

Altitude of water density of 10^{10} cm^{-3} (close to detection limit)

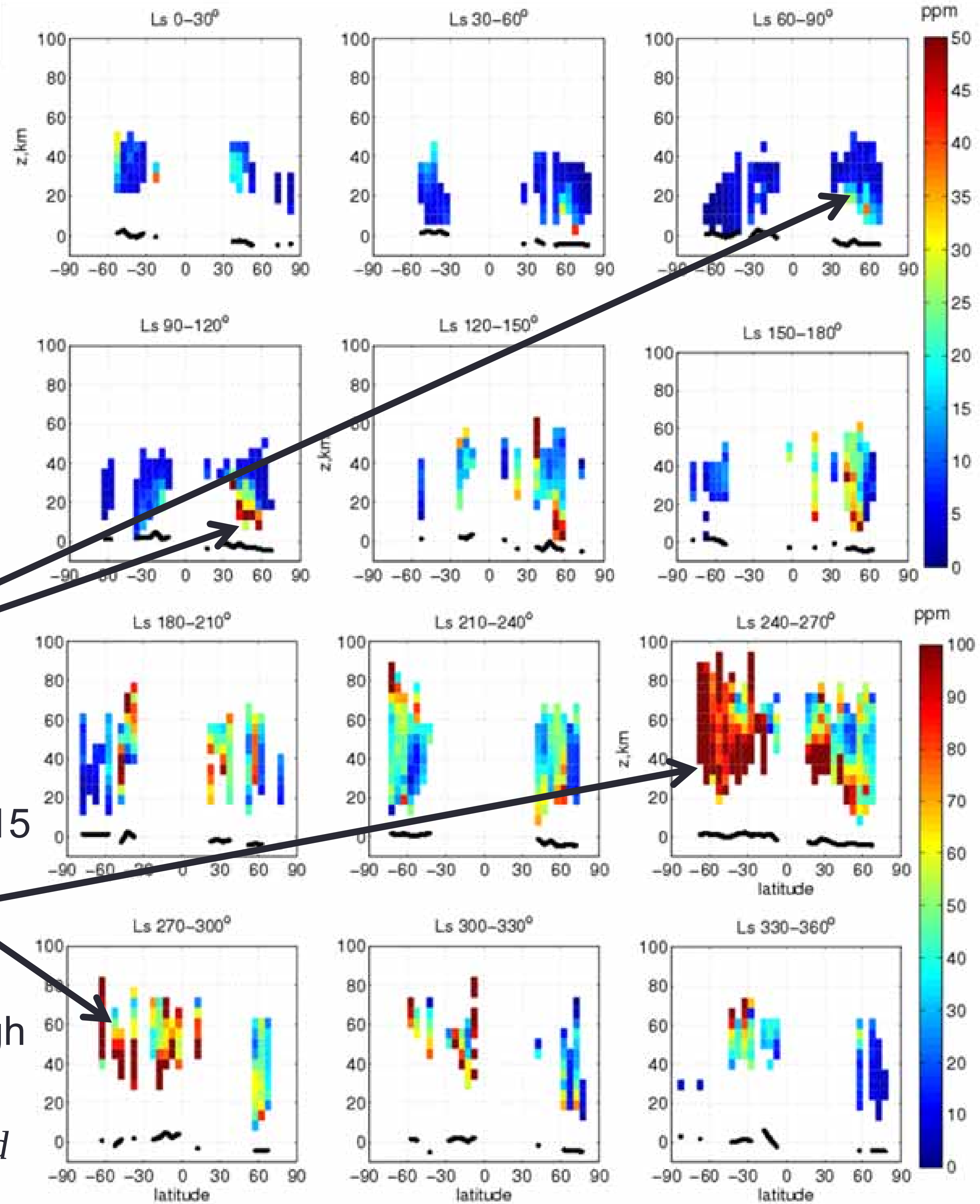


Black circles: there is no detection

H_2O mixing ratio distribution for 6 years (MY28-MY33)

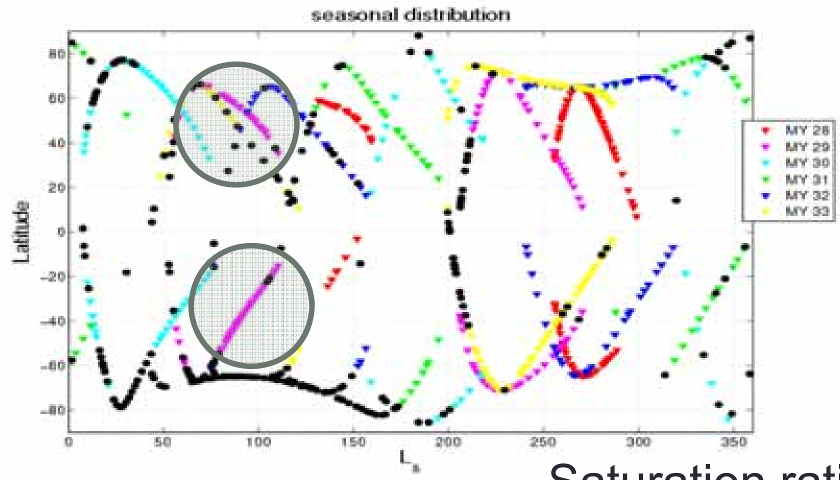
- The low H_2O mixing ratio <30 ppm in the aphelion season Ls=0-120° (altitude range is mostly higher than a hygropause).
- Sharp decrease of the mixing ratio indicates a hygropause in middle northern latitudes from 15 to 25 km
- The largest mixing ratio >100ppm was observed at Ls=240-300° at 40-90 km in high middle southern latitudes.

Global dust storm MY28 was excluded



Results

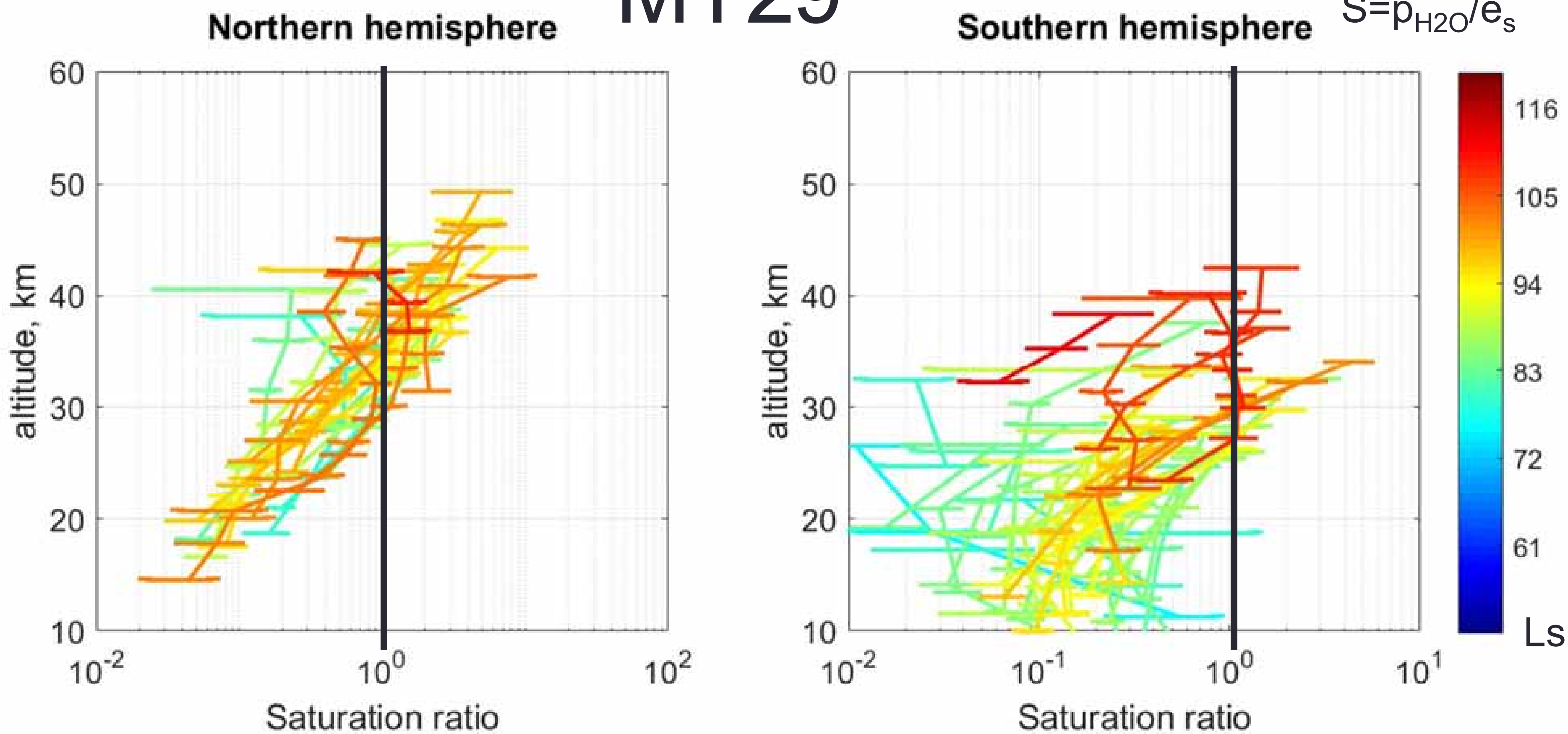
Study of supersaturation



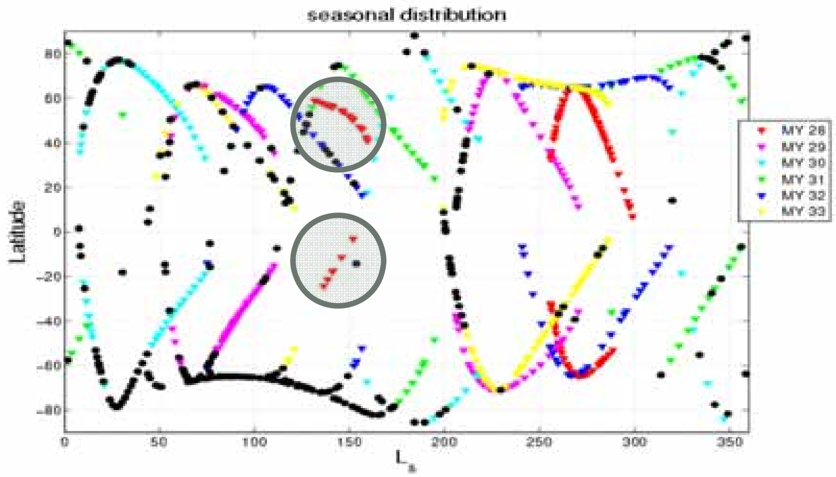
Detection of water vapor supersaturation in the middle atmosphere in MY29 (Maltagliati et al., 2011)
With new data we attempt to produce the supersaturation for the same year based on the MCS profiles

MY29

Saturation ratio
$S = p_{H_2O}/e_s$



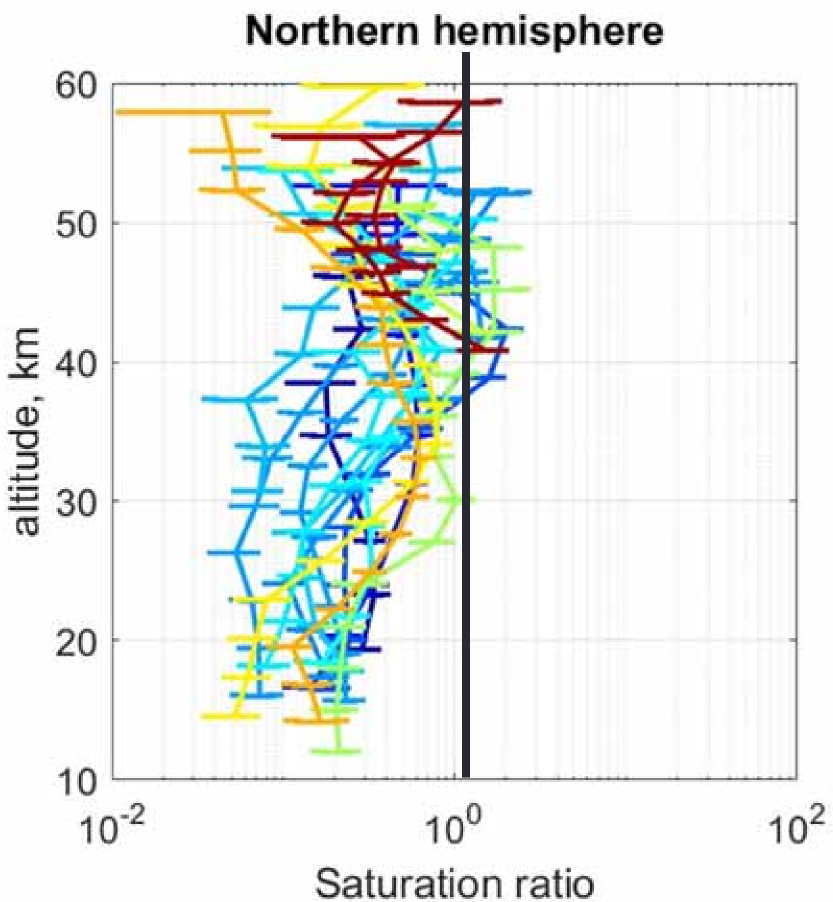
Study of supersaturation

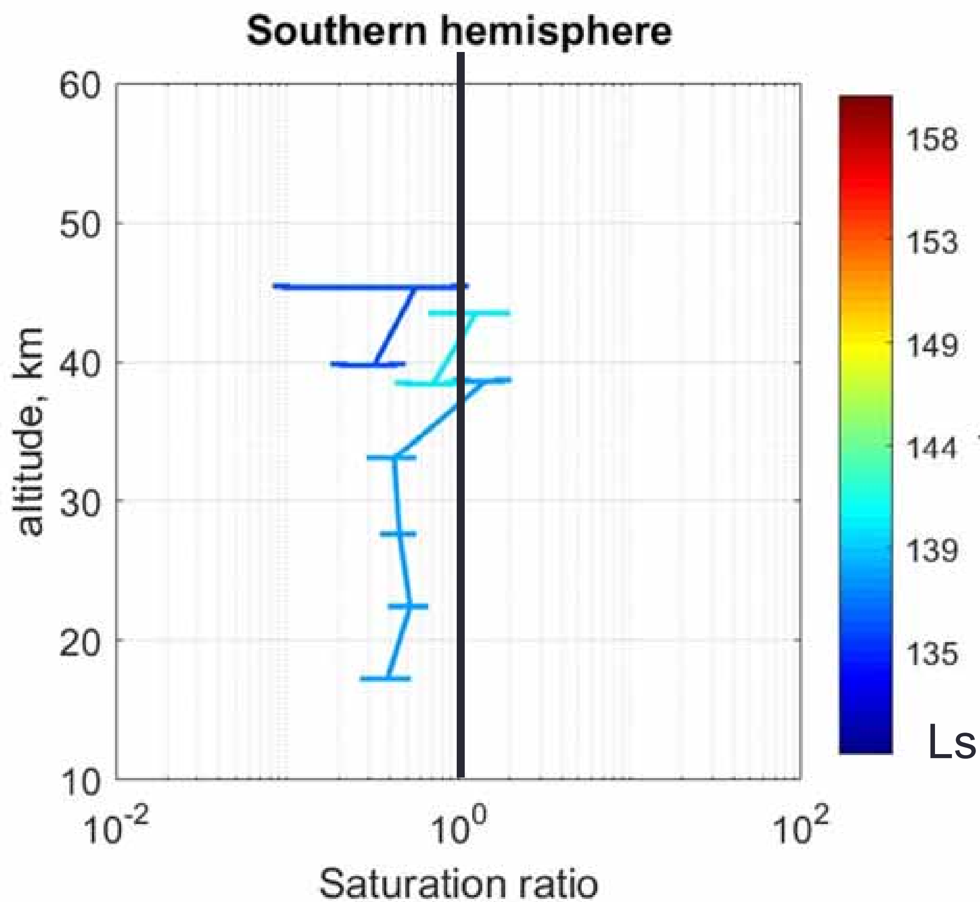


MY28

Saturation ratio

$S=p_{H2O}/e_s$





Study of supersaturation for 6 years Ls=0-180

Saturation ratio

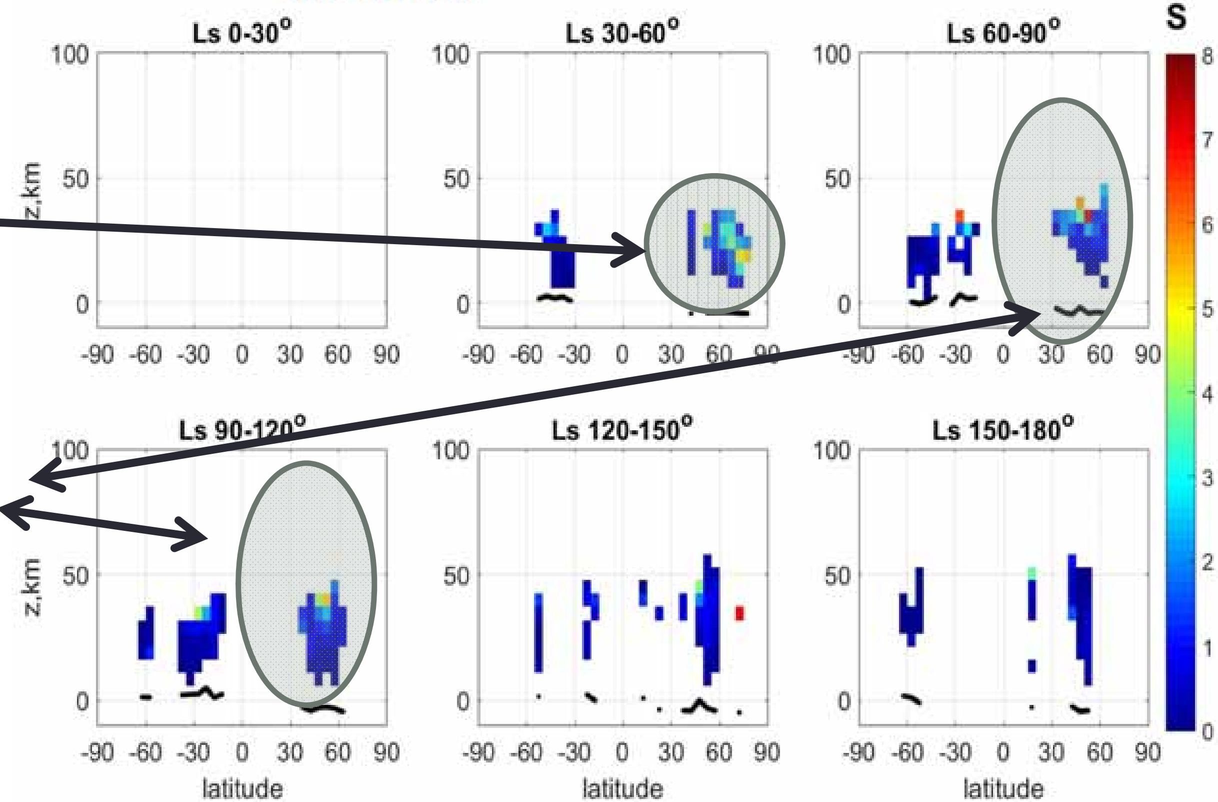
$S = p_{H2O}/e_s$

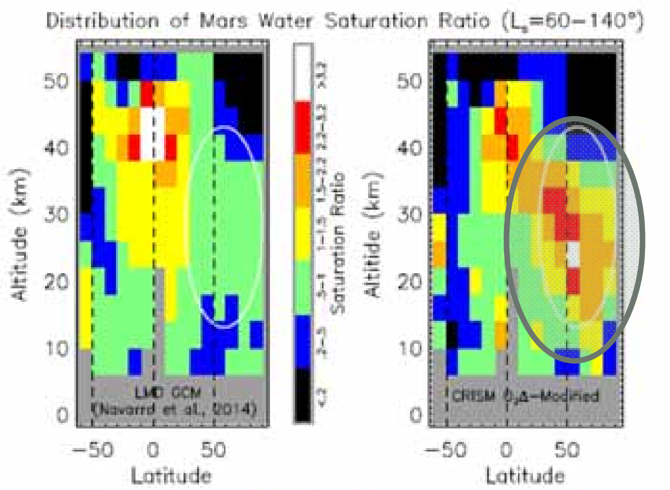
the Goff-Gratch equation

$$\log e_s = 2.07023 - 0.00320991T - 2484.896/T + 3.56654 \times \log T \quad (2)$$

where e_s is the saturation vapor pressure in mbar and T the temperature in Kelvin.

- At Ls=60-120 the supersaturation at 30-40 km is consistent with *Maltagliati et al., 2011* and *Clancy et al., 2017*
- At Ls=30-60 in latitudes of 60-80 there is also possible a presence of supersaturation at 20-30 km





a LMDGCM (left) and CRISM (right) Water Saturation Ratios

Clancy et al., 2017

Conclusions

- The water vapor density profiles have been retrieved for **7 Martian Years MY27-MY33** and the water vapor mixing ratio for **6 Martian Years MY28-MY33 .**

- **MY28 Global dust storm (unique event):**
  - SPICAM observed an increase of the H_2O concentration an order of magnitude and mixing ratio in 2-3 times at 60-80 km from Ls 268° to Ls 285° for both hemispheres. (*Fedorova, Bertaux, Betsis, Montmessin, Korablev, Maltagliati, Clarke, Water vapor in the middle atmosphere of Mars during the 2007 global dust storm, Icarus 300, 2018*)

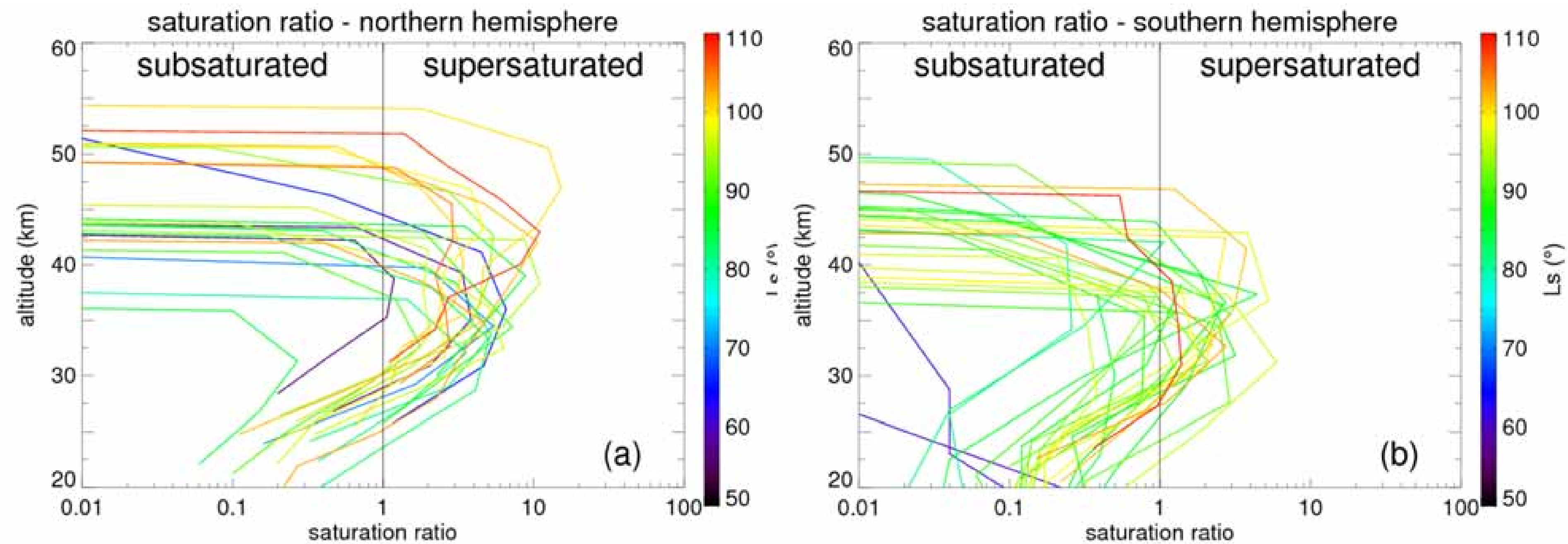
- **Other years in perihelion season:**
  - In the Northern hemisphere there is no prominent increase of the water content.
  - In the Southern hemisphere the increase of density and mixing ratio>100 ppm was observed for MY29 and 32 at altitude of 50-80 km (could give a seasonal response of the hydrogen escape rate) .

- **In whole:**
  - Upper level of water density is 50-60 km in the aphelion and 70-90 km in perihelion
  - The low H_2O mixing ratio <30 ppm in the aphelion season Ls=0-120° (higher than hygropause).
  - At Ls=60-120° a hygropause varies in middle northern latitudes from 15 to 25 km
  - The largest mixing ratio >100ppm was observed at Ls=240-300° at 40-90 km in high and middle southern latitudes.

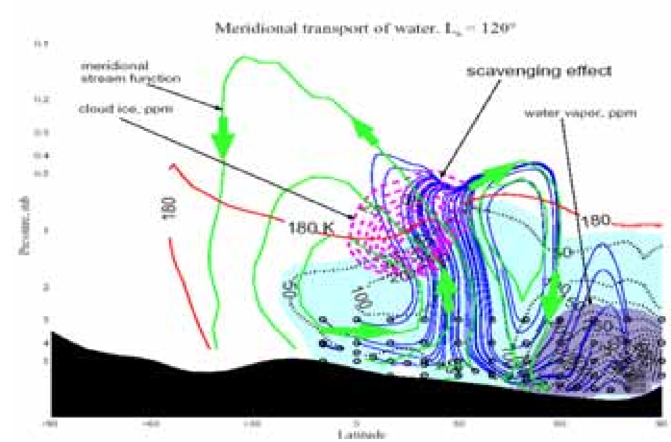
- **Supersaturation:**
  - The supersaturation in MY29 is still there with new data processing.
  - The possible supersaturation is also detected at Ls=30-60 in latitudes of 60-80 and 20-30 km of altitude

- *The current findings in water vapor vertical distribution will be considerably improved with solar occultation of ACS and NOMAD experiments on TGO*

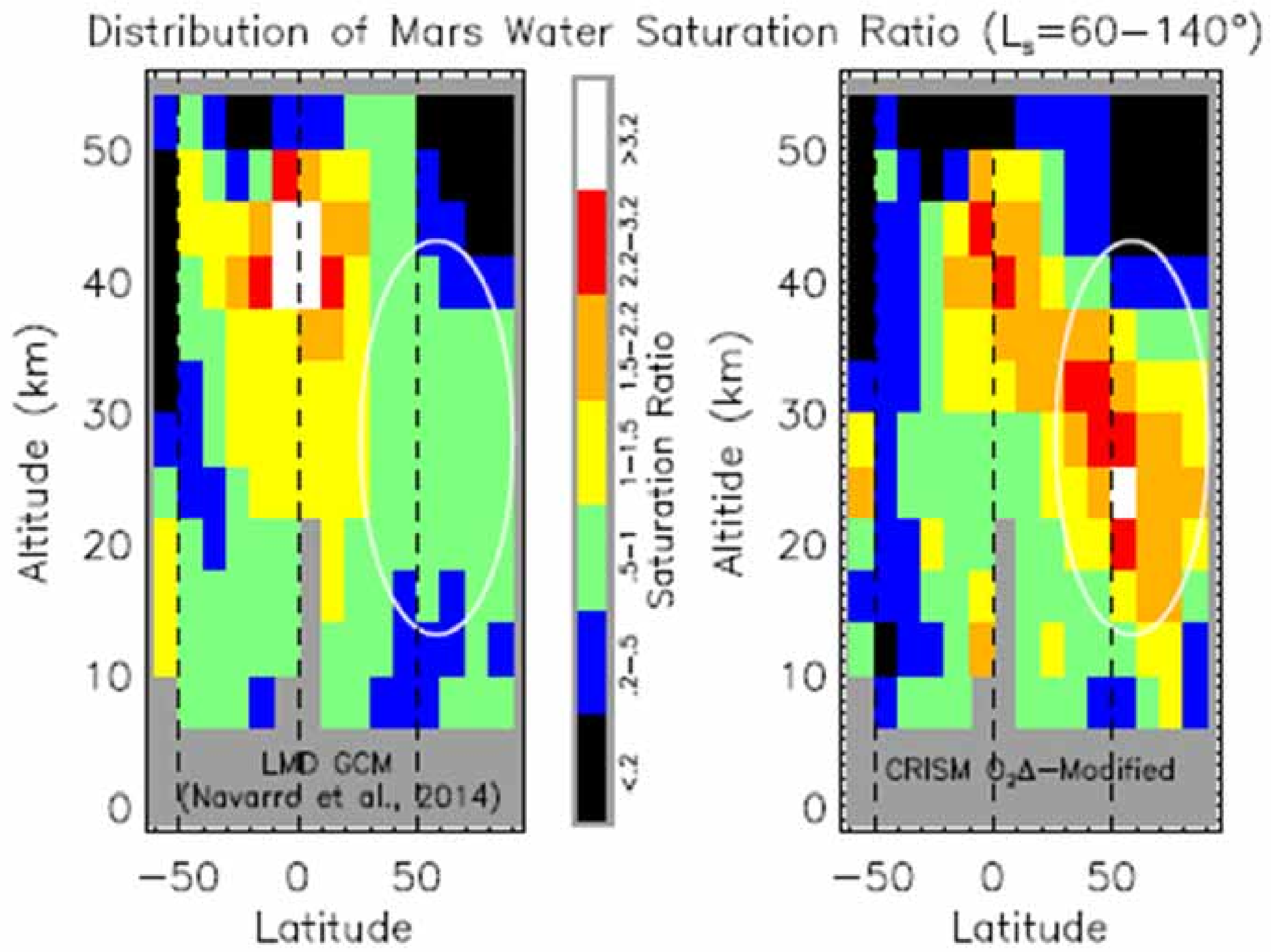
SPICAM/MEX: Detection of water vapor supersaturation in the middle atmosphere in MY29 (Maltagliati et al., 2011)



- ➢ 60% of orbits show a supersaturation at altitude 30 – 40 km
- ➢ supersaturation reaches ~ 10 (2-3 on the average)



CRISM/MRO
Indirect observations from the oxigen dayglow



a LMDGCM (left) and CRISM (right) Water Saturation Ratios

Unexpected variability of Martian hydrogen escape

Chaffin et al. (2014)

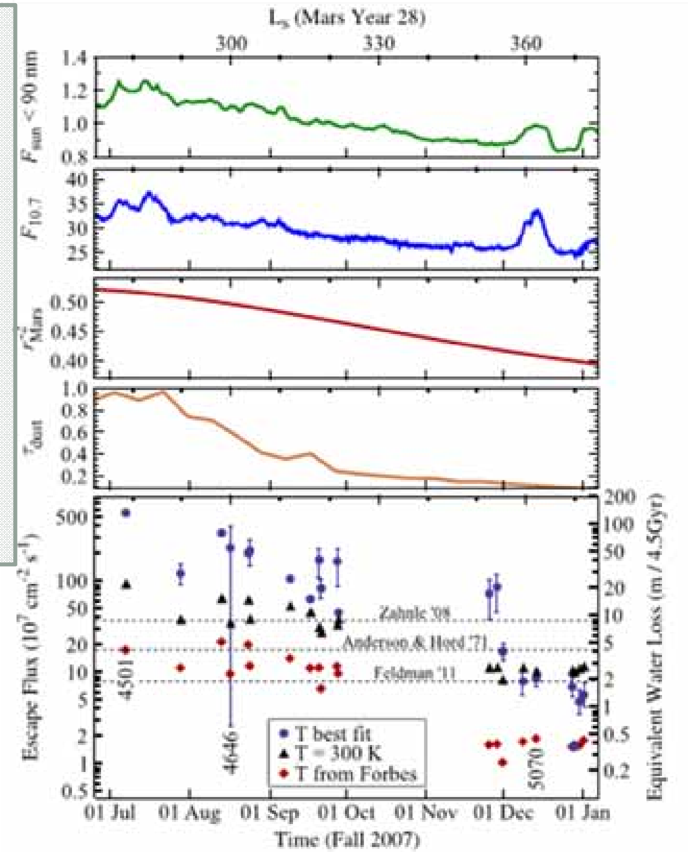
SPICAM UV/Mars-Express observations of the H Lα emission

summer –autumn 2007

A rapid decrease of the hydrogen corona of Mars

Clarke et al. (2014)

HST UV observations of H Ly α emission during the solar minimum in autumn of 2007

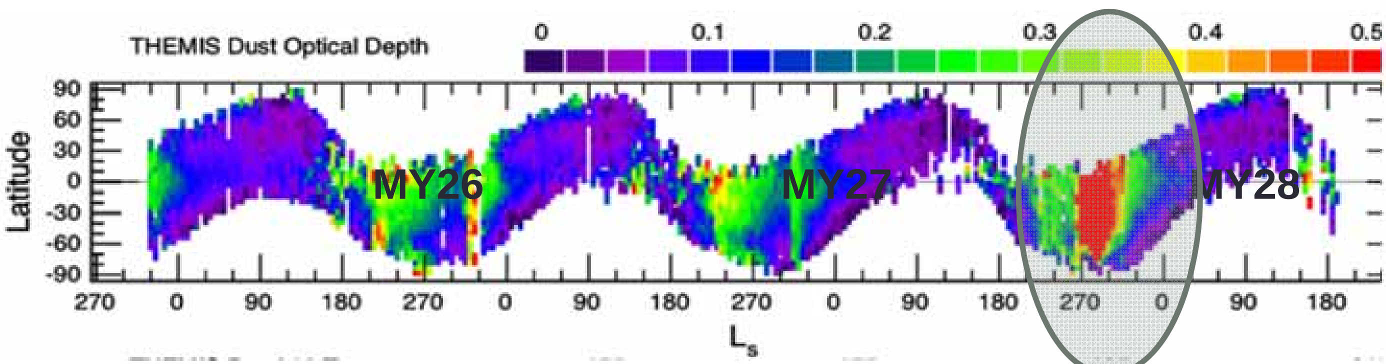


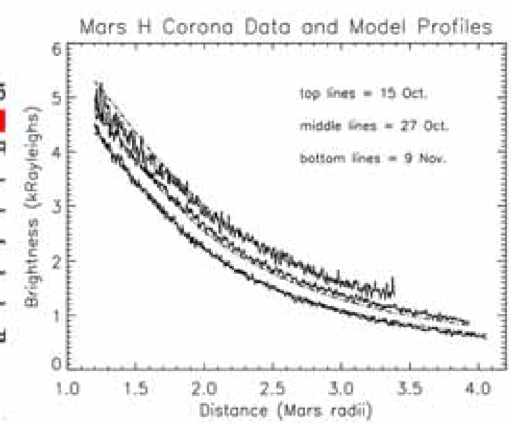
Summer 2007 (MY28)

Beginning: $L_s \sim 261.9°$.

Global dust storm observed by THEMIS in 2007

Smith et al. (2009)





Hydrogen source

The water vapor as a direct source of the hydrogen atom at high altitudes?

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Elevated atmospheric escape of atomic hydrogen from Mars induced by high-altitude water

M. S. Chaffin*, J. Deighan, N. M. Schneider and A. I. F. Stewart