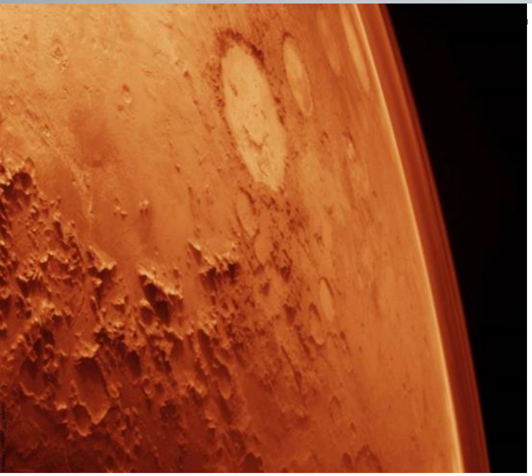
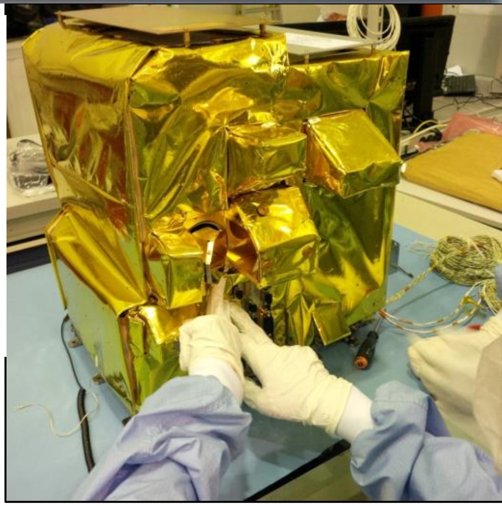
esa Trace Gas Orbiter EXOMARS



ACS Atmospheric Chemistry Suite



The distribution and saturation of water vapor with ACS/TGO for first Martian year of observations

Anna Fedorova, Franck Montmessin, Oleg Korablev, Mikhail Luginin, Alexander Trokhimovskiy, Denis Belyaev, Nikolay I. Ignatiev, Franck Lefèvre , Juan Alday, Kevin Olsen, Jean-Loup Bertaux, Ehouarn Millour, Anni Määttänen, Alexey Shakun, Alexey V. Grigoriev, Andrey Patrakeev, Svyatoslav Korsa, Colin F. Wilson and the ACS team

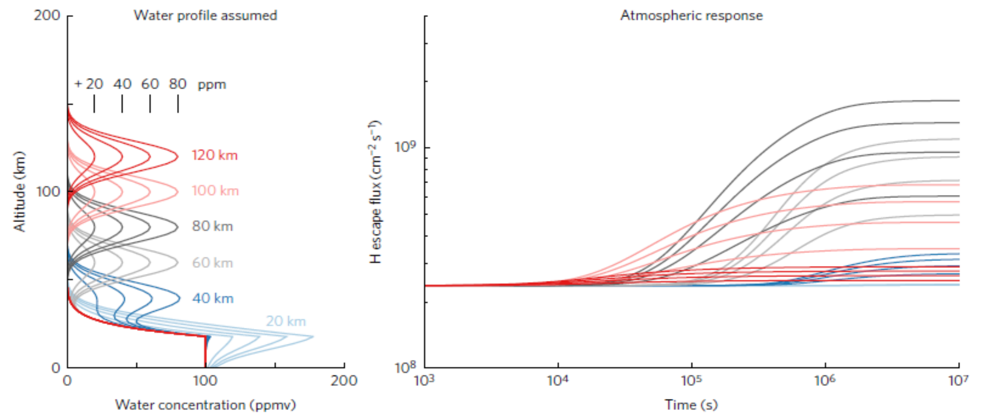
EGU General Assembly 2020

Online | 4–8 May 2020

Introduction

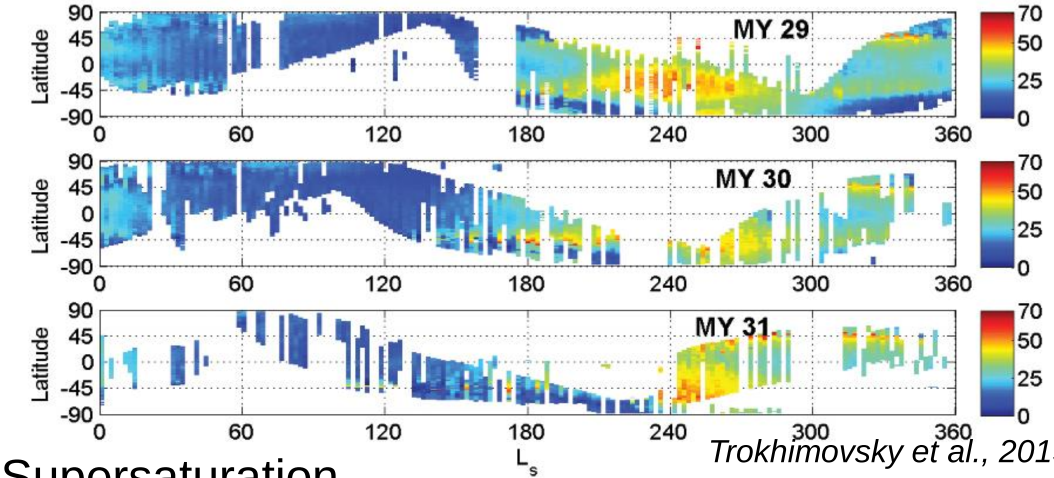
Vertical distribution of H_2O on Mars

- ❑ 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 the hygropause in the aphelion season



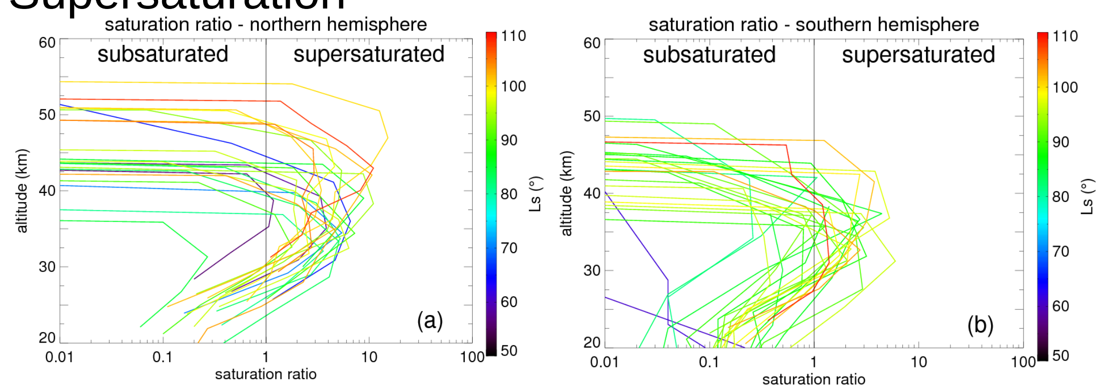
Chaffin et al., 2017

Saturation altitude



Trokhimovsky et al., 2015

Supersaturation



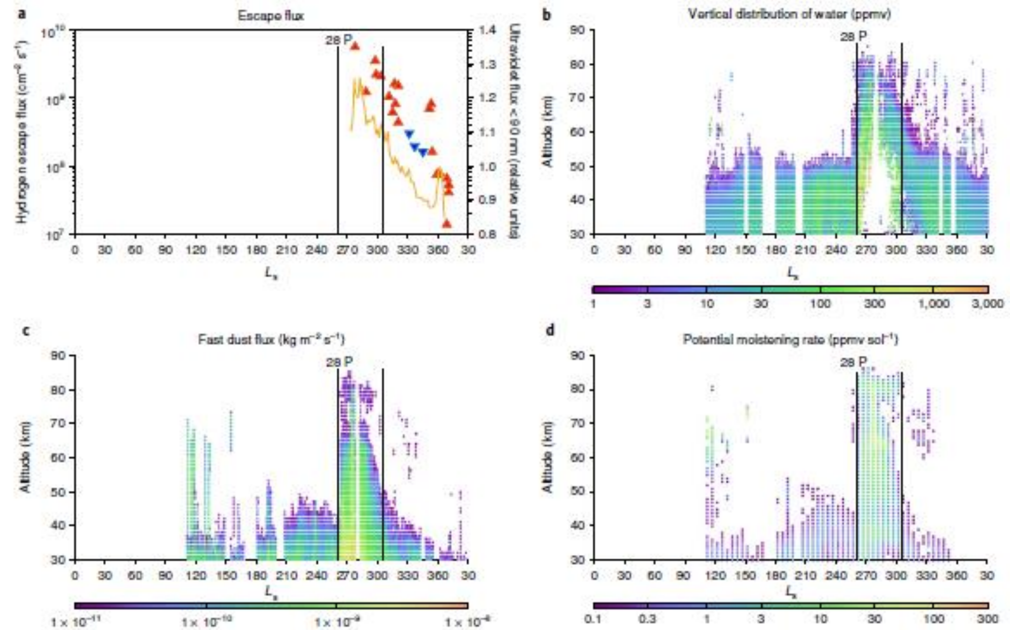
Maltagliati et al., 2011

Atmospheric Chemistry Suite

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

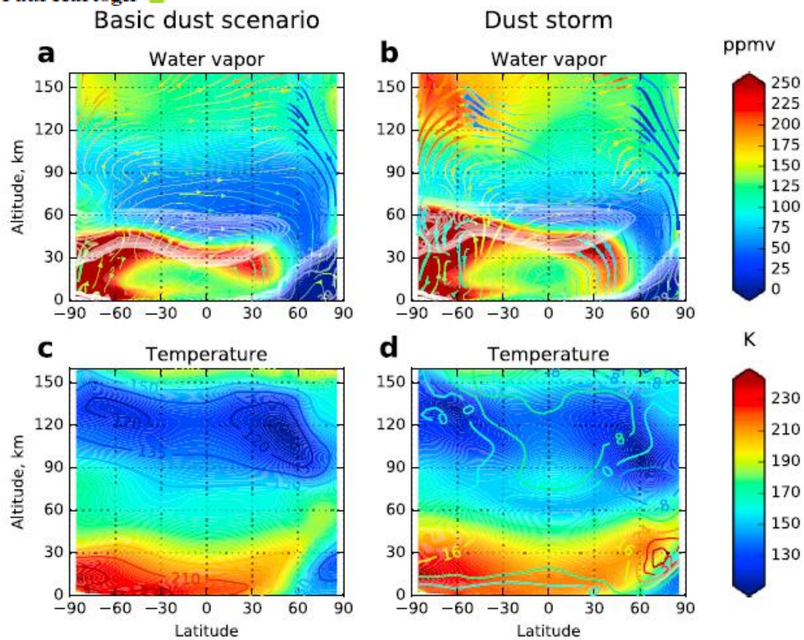
Hydrogen escape from Mars enhanced by deep convection in dust storms

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]



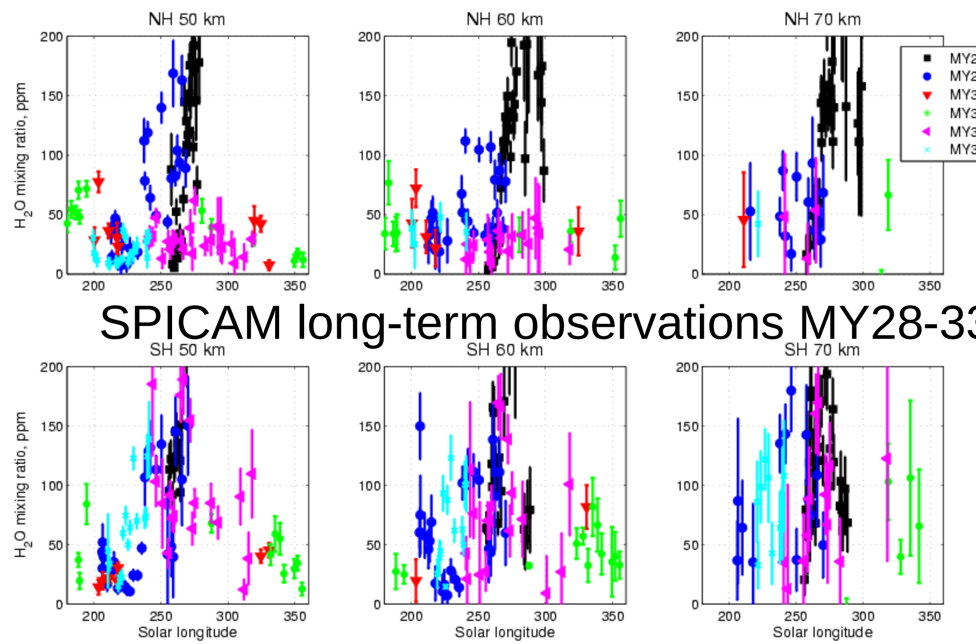
Seasonal Water "Pump" in the Atmosphere of Mars: Vertical Transport to the Thermosphere

Dmitry S. Shaposhnikov[1,2], Alexander S. Medvedev[3], Alexander V. Rodin[1,2], and Paul Hartogh[3]



Water vapor in the middle atmosphere of Mars during the 2007 global dust storm

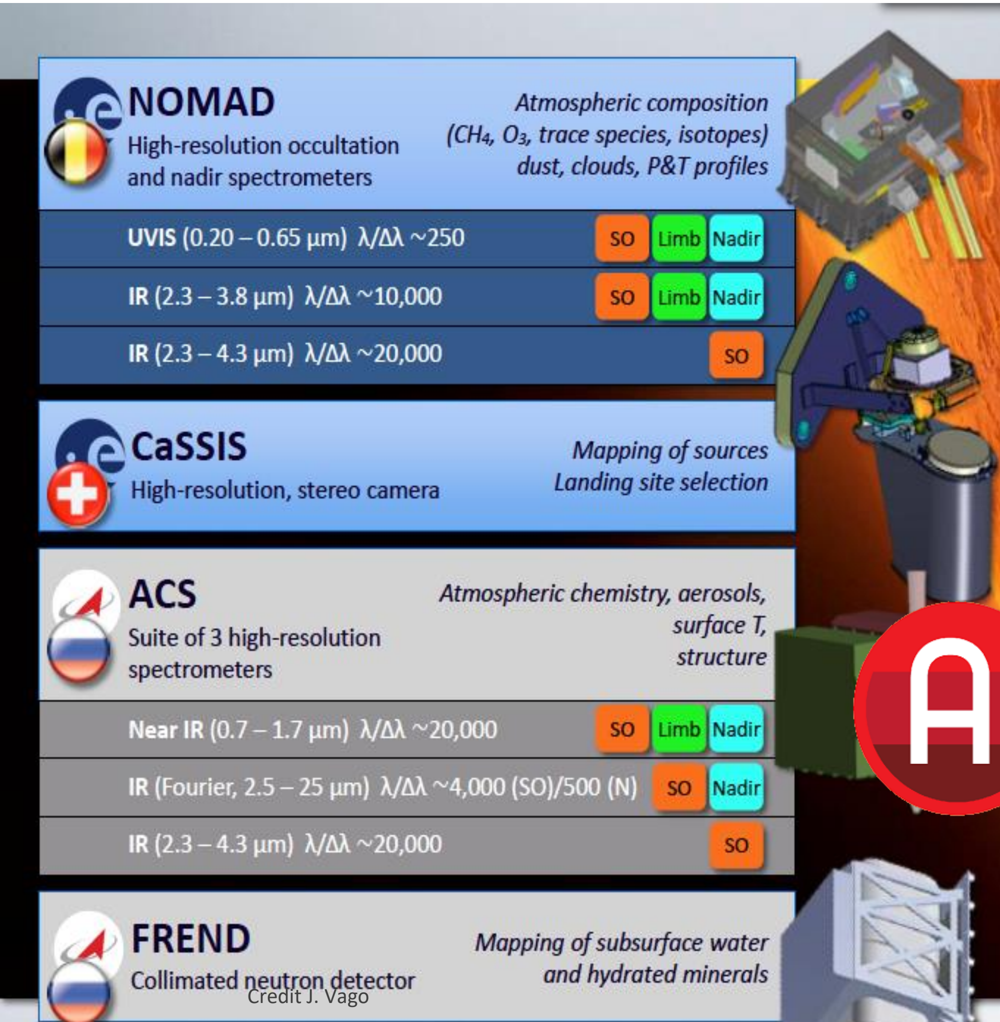
Anna Fedorova[a,*], Jean-Loup Bertaux[b,a], Daria Betsis[a], Franck Montmessin[b], Oleg Korablev[a], Luca Maltagliati[c], John Clarke[d]

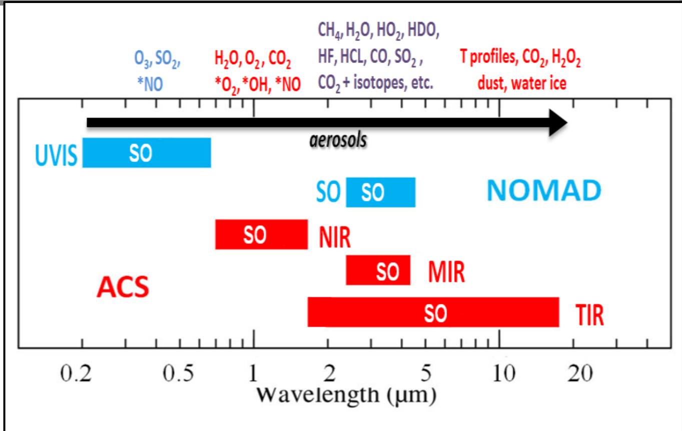


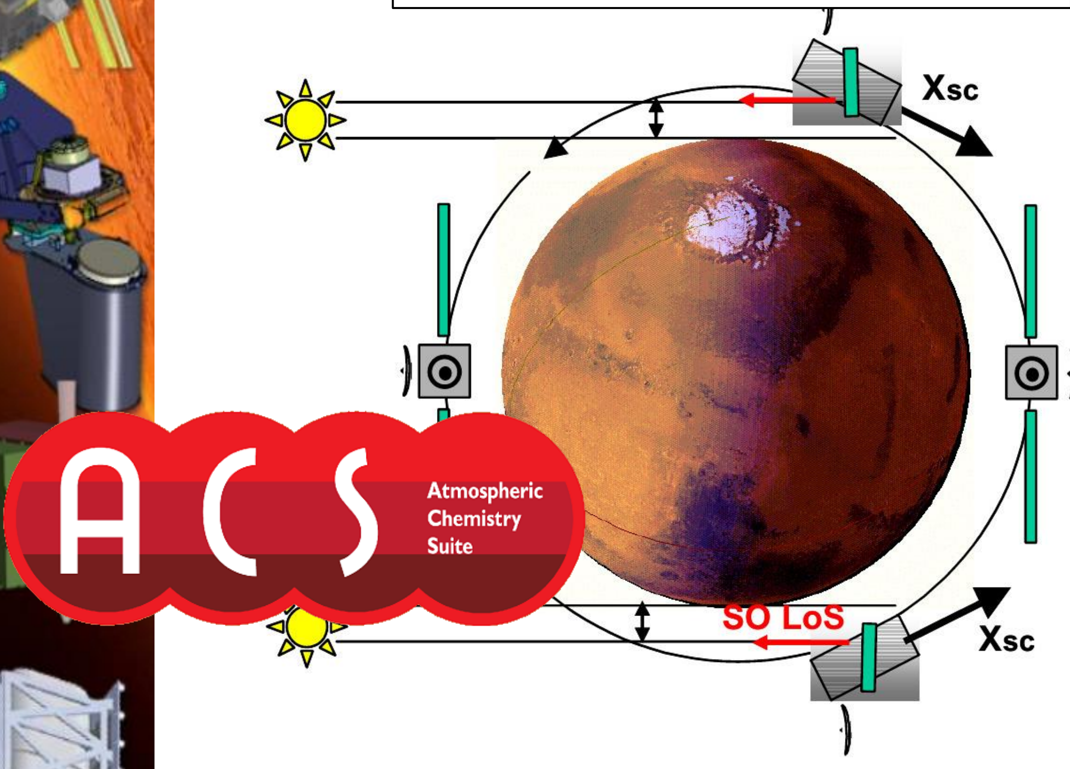
Trace Gas Orbiter

EXOMARS

The 2016 mission consists of a Trace Gas Orbiter (TGO) with four science instruments. It also included an EDL Demonstrator Module (EDM=Schiaparelli). Launched 14.03.2016, in orbit since 19.10.2016, aerobraking completed ~10.03.2018





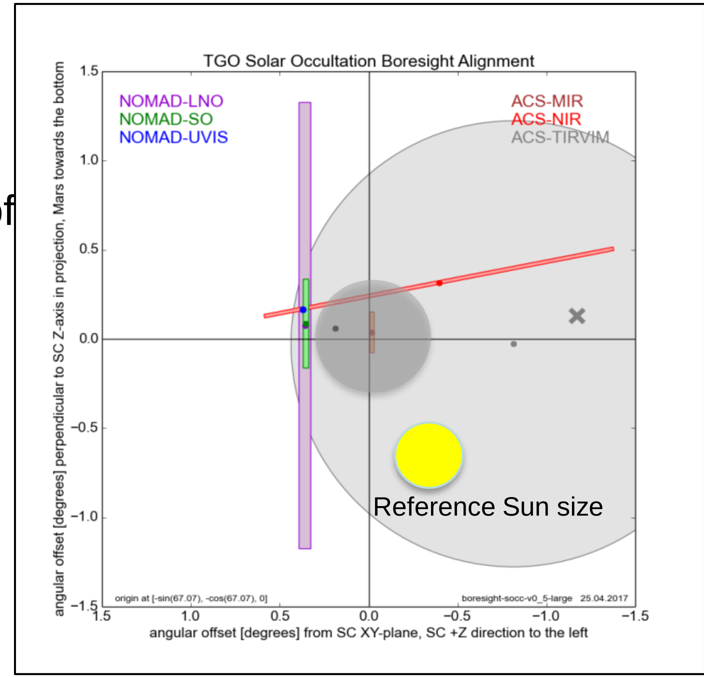


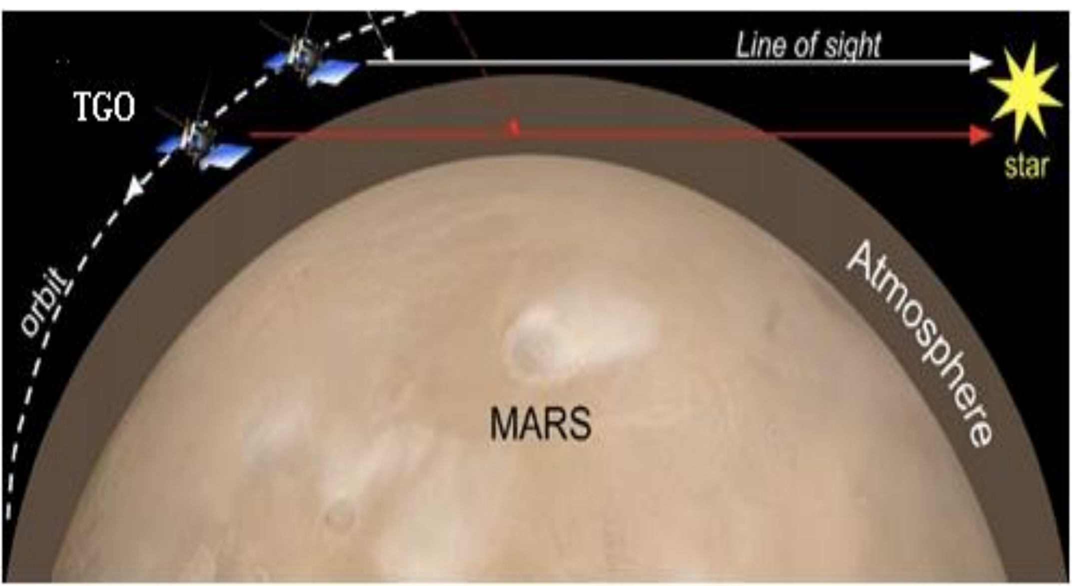
Solar Occultation is the main point of the TGO atmospheric science

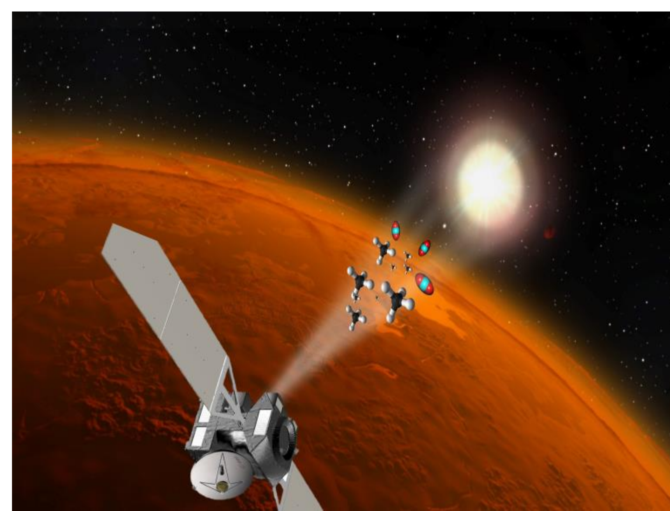
High sensitivity
When we observe the direct sun light through the atmosphere of Mars the intensity is 10^6 times more then observing the Mars surface. The air mass factor at the limb is ~30

For 12 TGO orbits per day 24 occultations per day is possible

- ➢10 occultations per day for with ACS driven pointing (trace gas study+climatology)
- ➢14 occultations per day with NOMAD driven pointing







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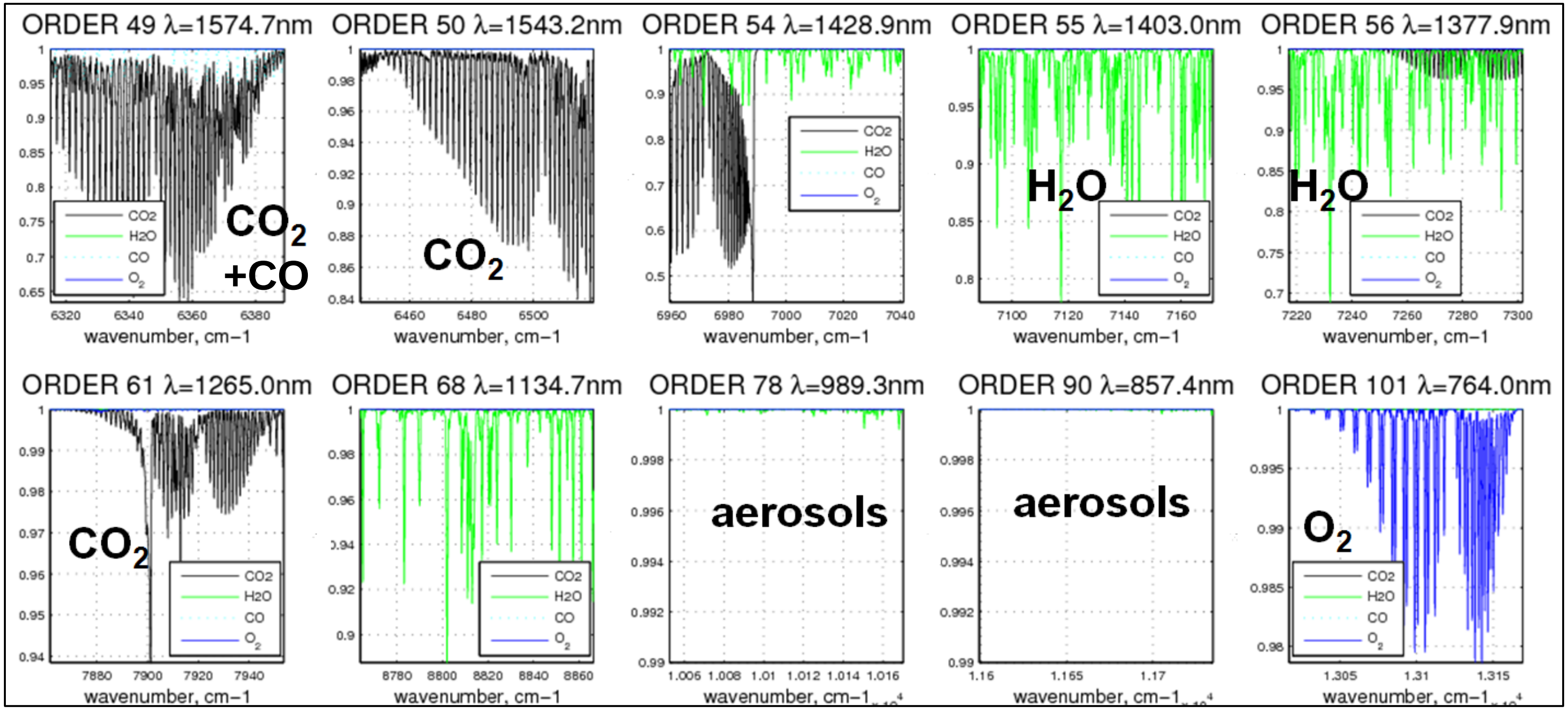
ACS NIR occultations observations

- Spectral range: 0.73 – 1.6 µm (not covered by other TGO instruments)
- Spectral resolving power λ/Δλ:~25 000

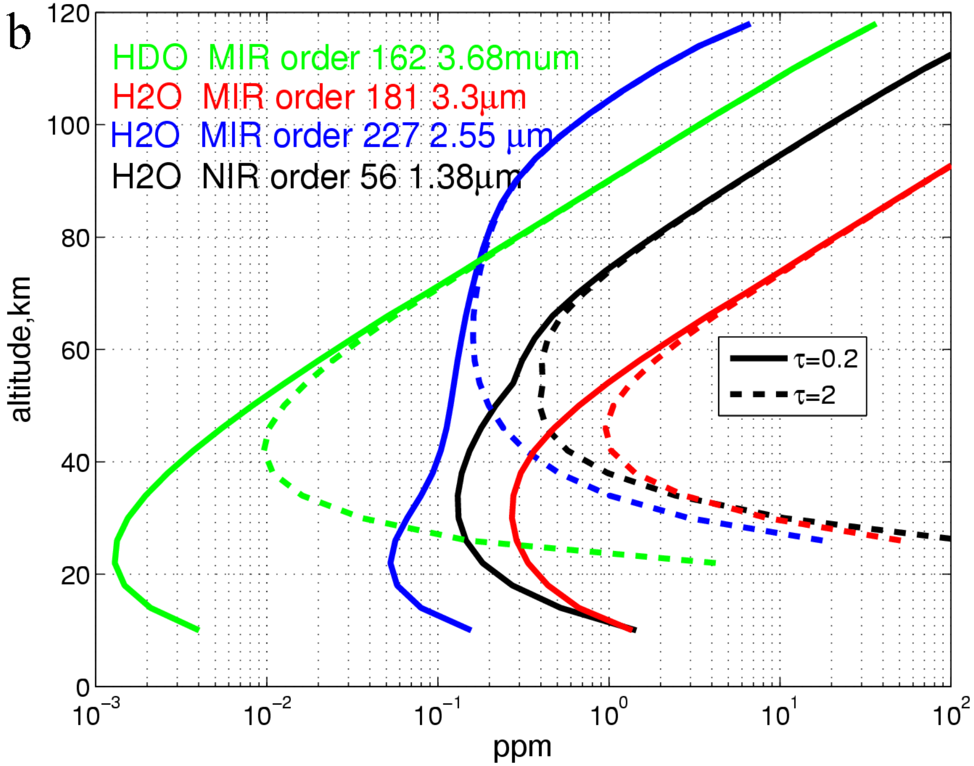
➢Standard planned measurement sequence of NIR in solar occultation includes 10 diffraction orders in the range of 0.76 -1.58 µm (H2O, CO2, aerosols + Novel O2).



➢ACS NIR has a very flexible setup of observation parameters. Data volume with the highest data rate (vertical resolution 0.7 km)

➢To decrease the altitude step it is possible to decrease number of orders to 6 (excluding two CO2 and two H2O orders)

Sensitivity to measure H_2O for NIR for different dust conditions



For ACS-NIR: λ/Δλ=25000 and SNR=4000 for an integration time of 1 ms and with 32 accumulations.

CO_2 and H_2O retrieval

Direct model:

- Spectroscopy: HITRAN2016 (Gordon et al., 2017):
  - H2O with air broadening multiplied by 1.7
  - CO2 with self broadening
- MCD 5.3 “climatology” temperature-pressure profiles as an initial assumption *(for CO_2)*
- Temperature and pressure from NIR CO_2 for the water retrieval:
  - First step: independent T and P retrieval
  - second step: hydrostatic assumption
- The order overlapping due to far wings of the AOTF function is included
- Spectral resolution is varied with a pixel and the spectral range of an order

Inverse model:

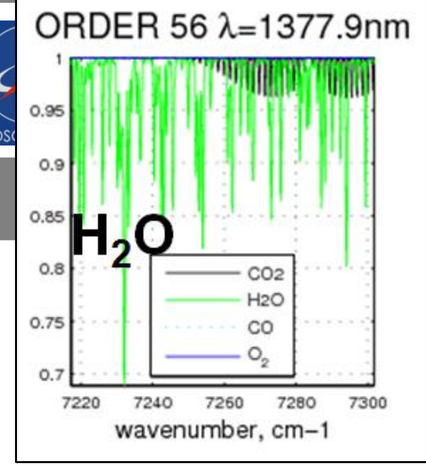
- Based on SPICAM IR algorithms (Fedorova et al., 2009; 2018; Maltagliati et al., 2013)
- The whole profile is retrieved at the same time using Levenberg–Marquardt iterative algorithm (Levenberg, 1944; Marquardt, 1963).
- The Tickhonov regularization is applied a posteriori, customary for vertical inversions in order to smooth the profile and minimize the errors (Ceccherini et al., 2005, 2007).
- The uncertainties in the retrieved parameters are given by the covariance matrix of the solution errors.

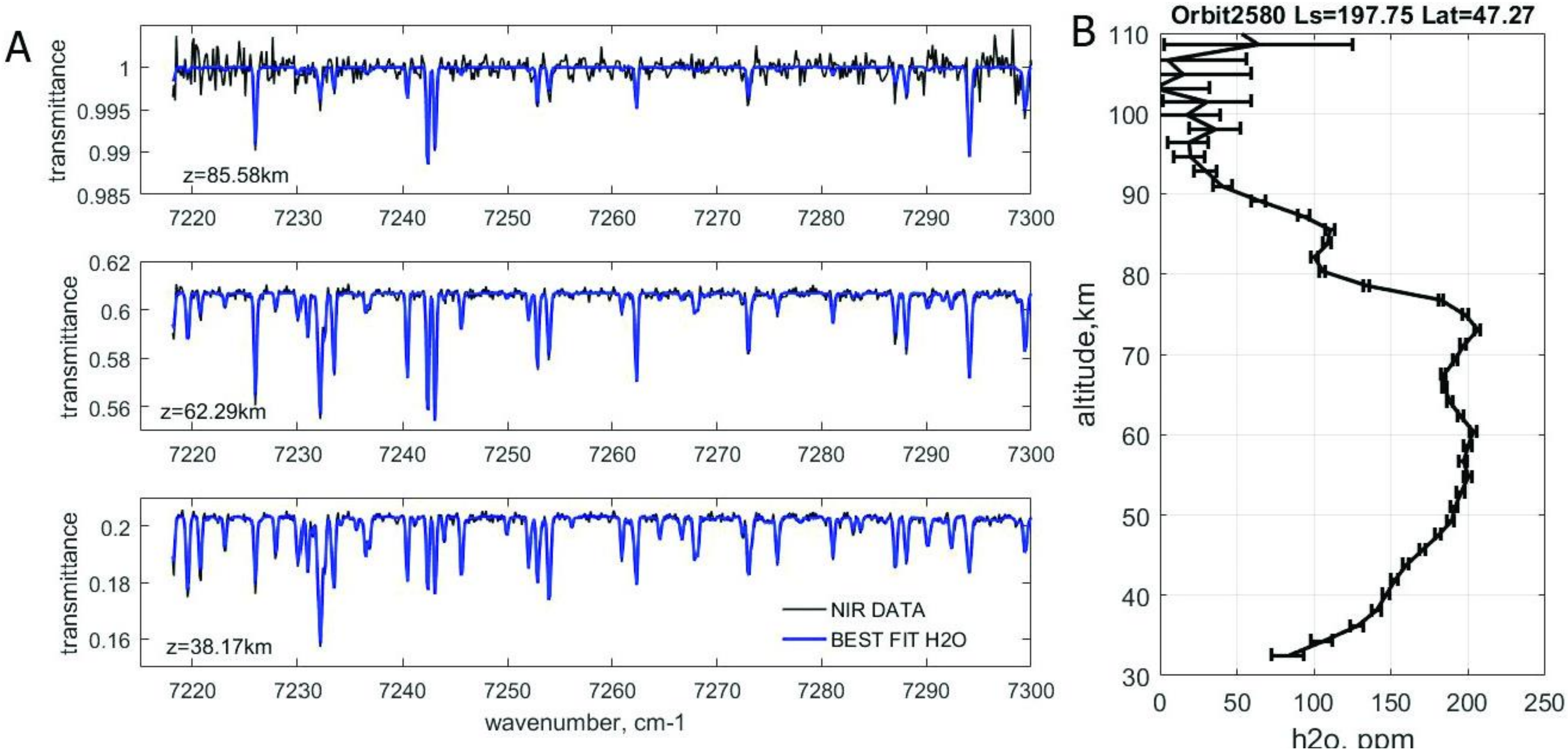
ACS Atmospheric Chemistry Suite

ACS NIR occultations retrieval

Examples of H_2O spectra

1.38 µm

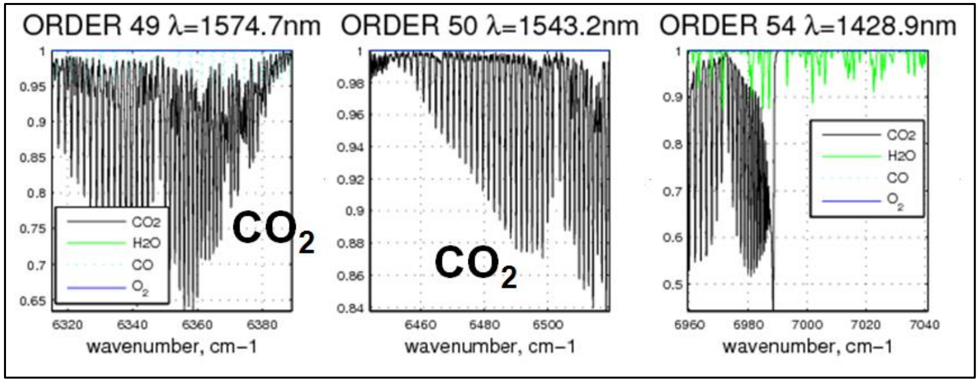


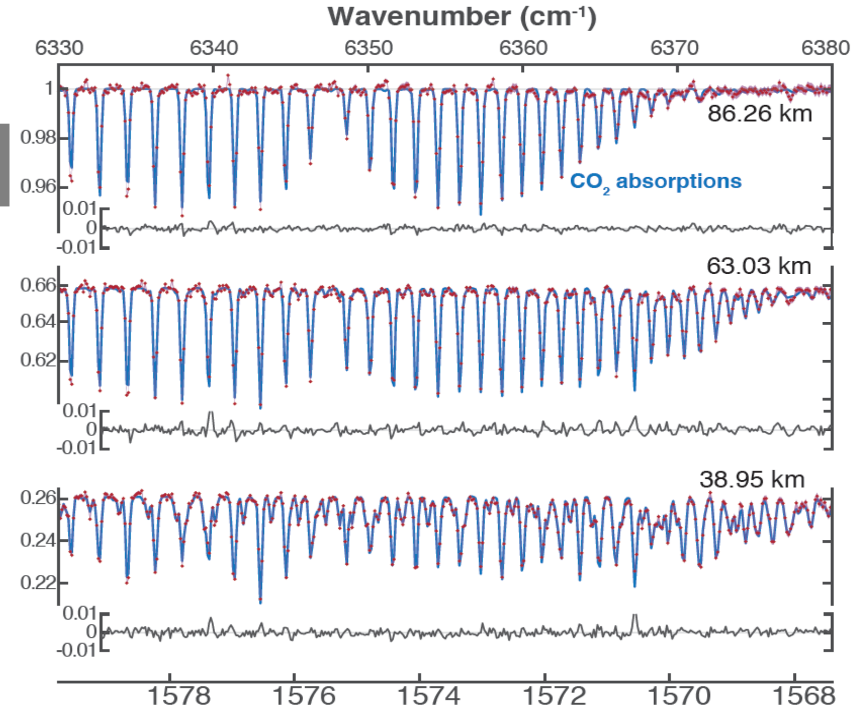


H2O can be retrieved using order 56. But we need temperature and pressure profiles

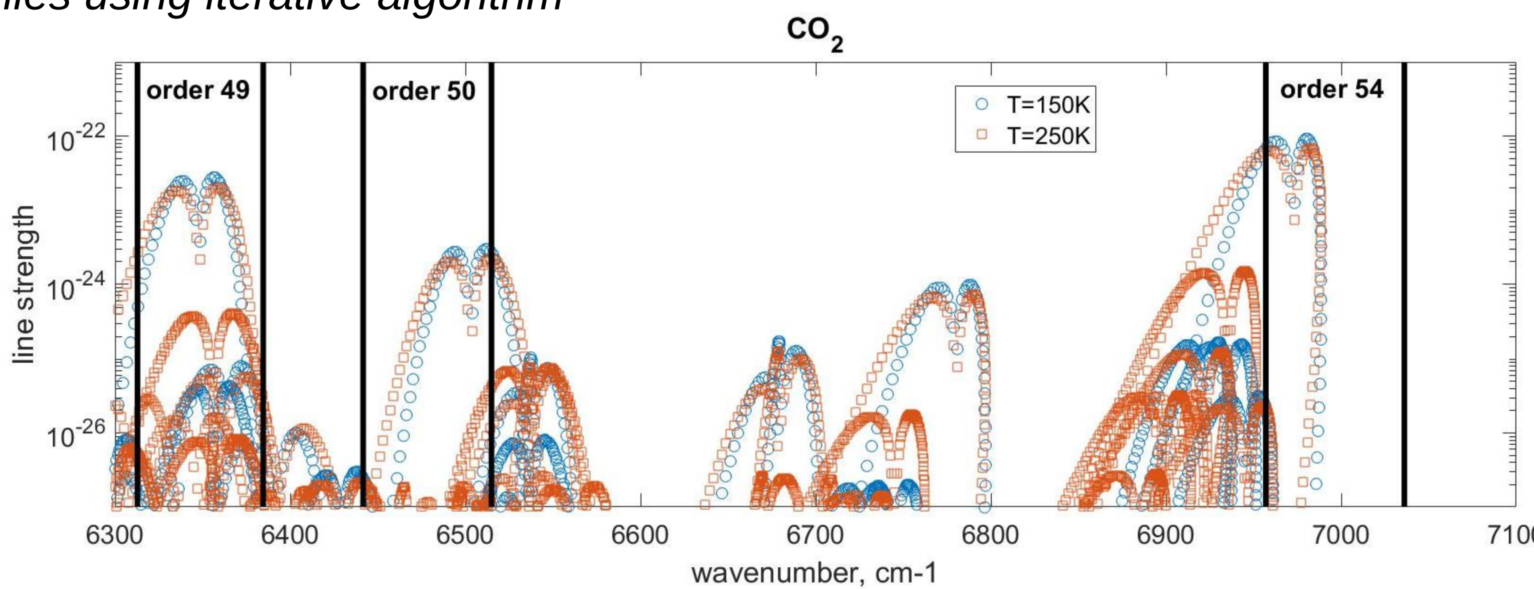
ACS NIR occultations results

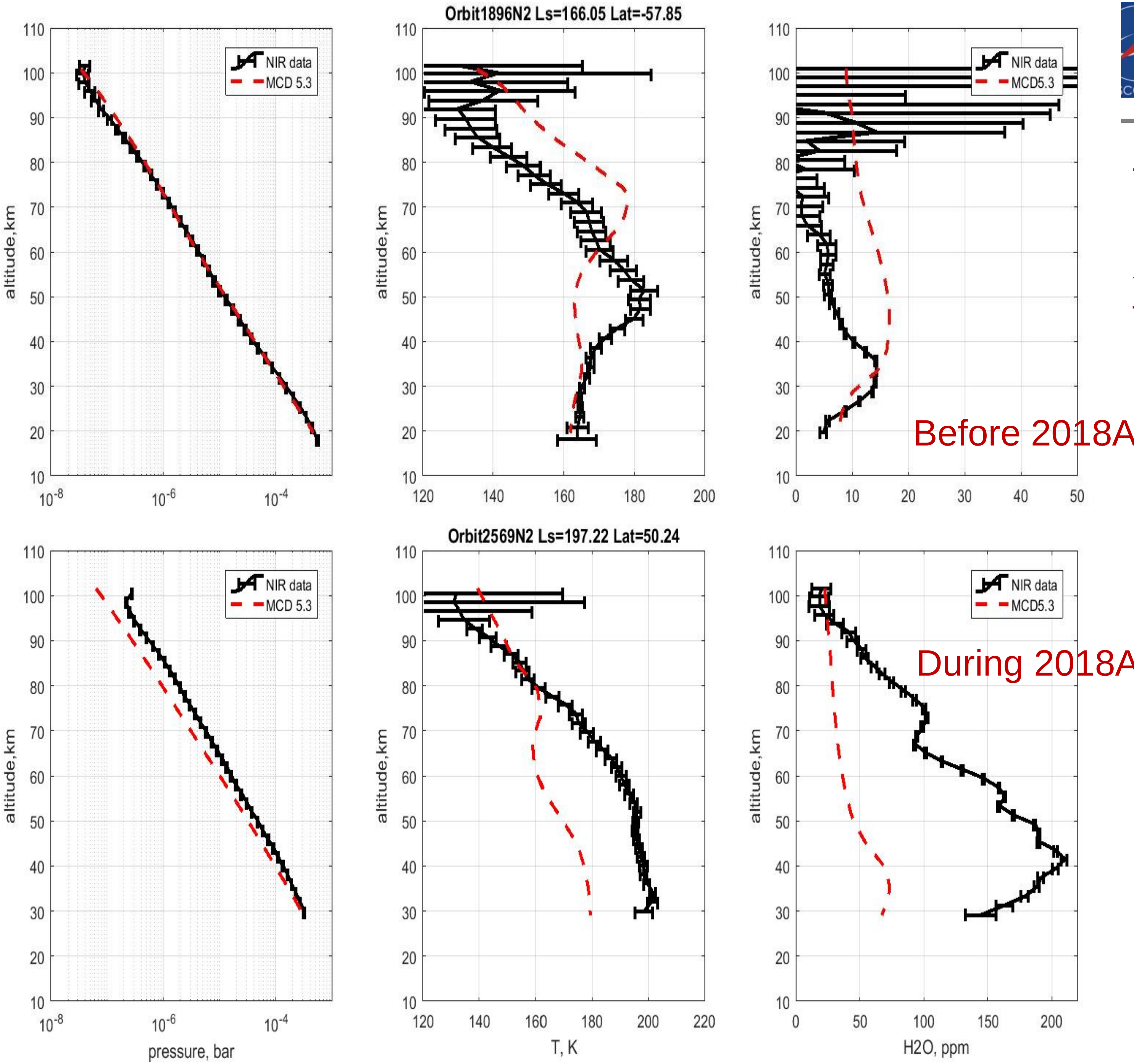
CO_2 retrieval





***Order 49 –** good sensitivity to temperature, possibility to retrieve temperature-pressure profiles using iterative algorithm*





Temperature retrieved simultaneously from NIR CO_2 bands (1.57 μm)

- Temperature (and density) underestimated by models
- Too much water v.m.r. with a model atmospheric profile

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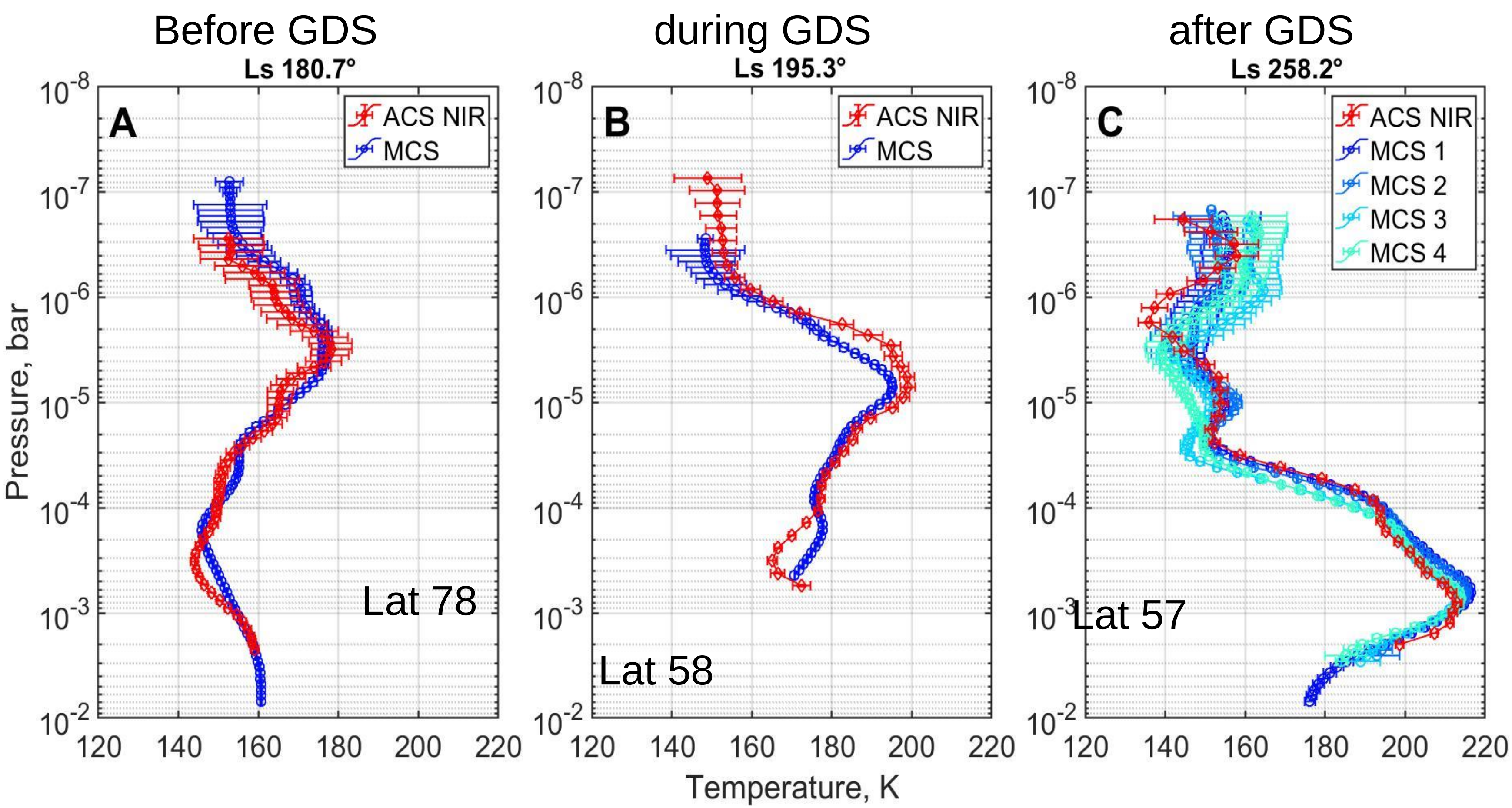
ИКИ ROSCOSMOS esa

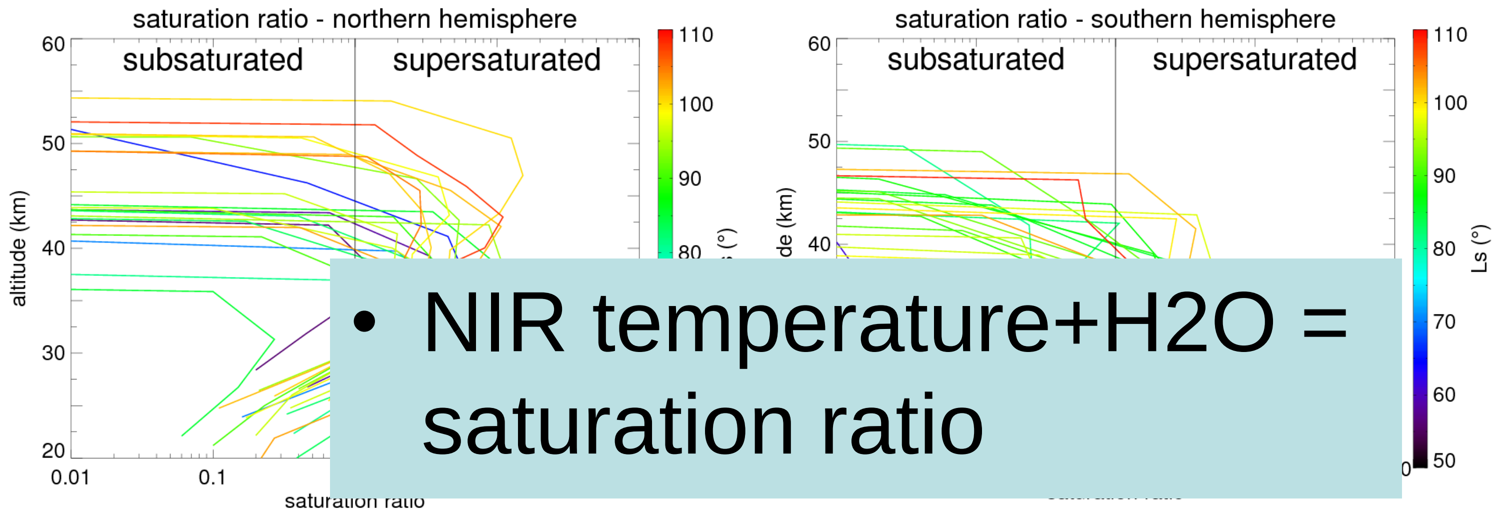
ACS NIR occultations retrieval

Comparison of temperature with MCS/MRO

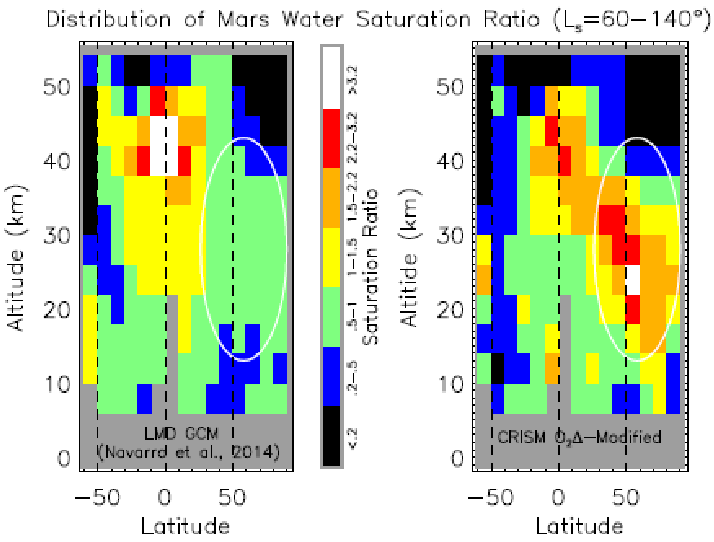


applying criteria on collocation (within ±1° latitude and longitude)
local time (2 hours) and season (within 0.5° of Ls)

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



- NIR temperature+H_2O = saturation ratio



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

CRISM/MRO
Indirect observations
from the oxigen dayglow
(Clancy et al., 2017)

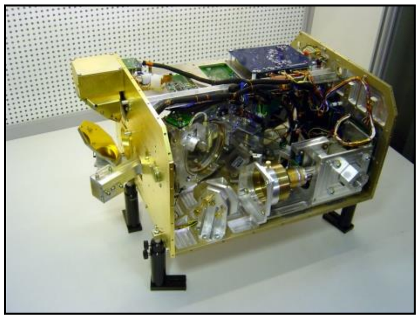
Saturation ratio
$S = p_{H2O}/e_s$

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

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

To distinguish water ice and dust: TIRVIM and MIR observations in 3 μm band

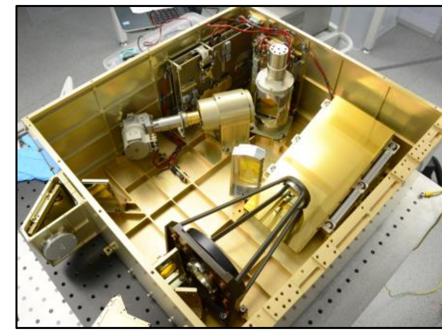
TIRVIM, Fourier

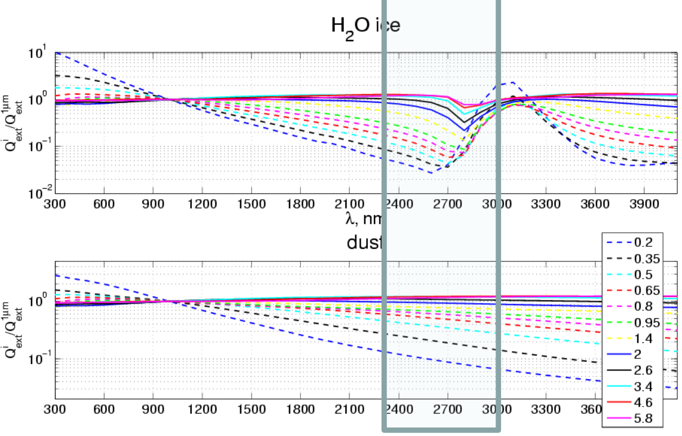


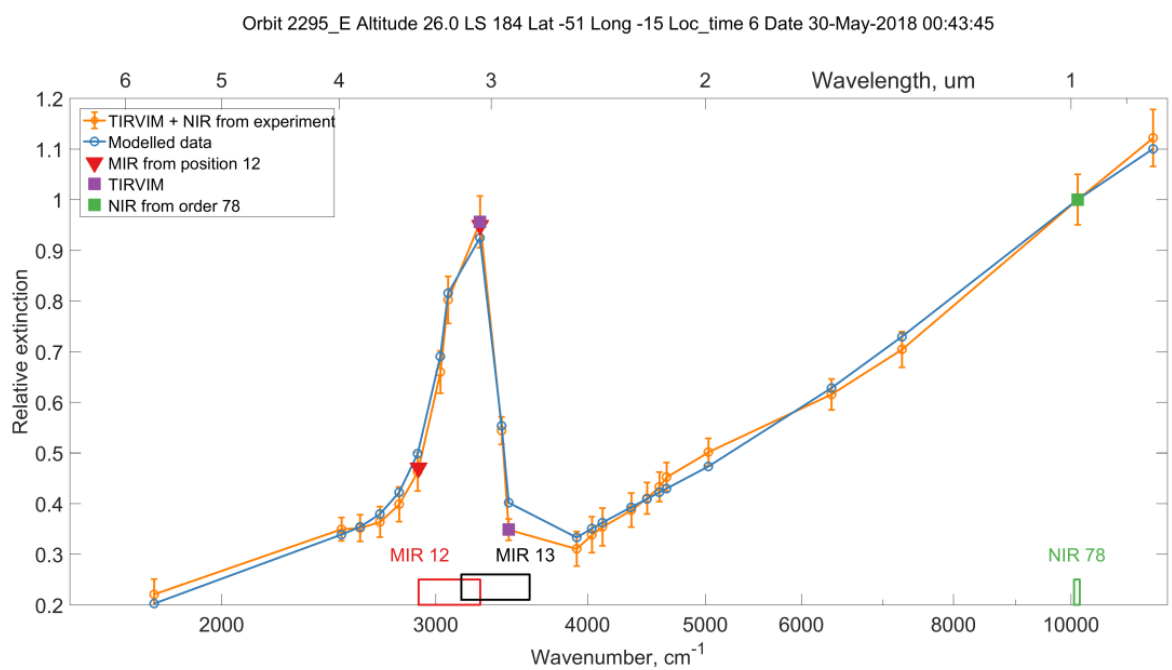
- Spectral range 1.7 – 17 μ (580–5800 cm-1)
- Δυ~ 0.13 cm-1 (Sun), 0.8 cm-1 (Mars)
- Operation modes: Nadir and Solar Occultation
- FOV: Ø2.5°

MIR, echelle+cross-dispersion

- Spectral range 2.3 – 4.2 μ
- λ/Δλ~ 50 000
- Operation modes: Solar Occultation
- FOV: 0.23°×0.02°



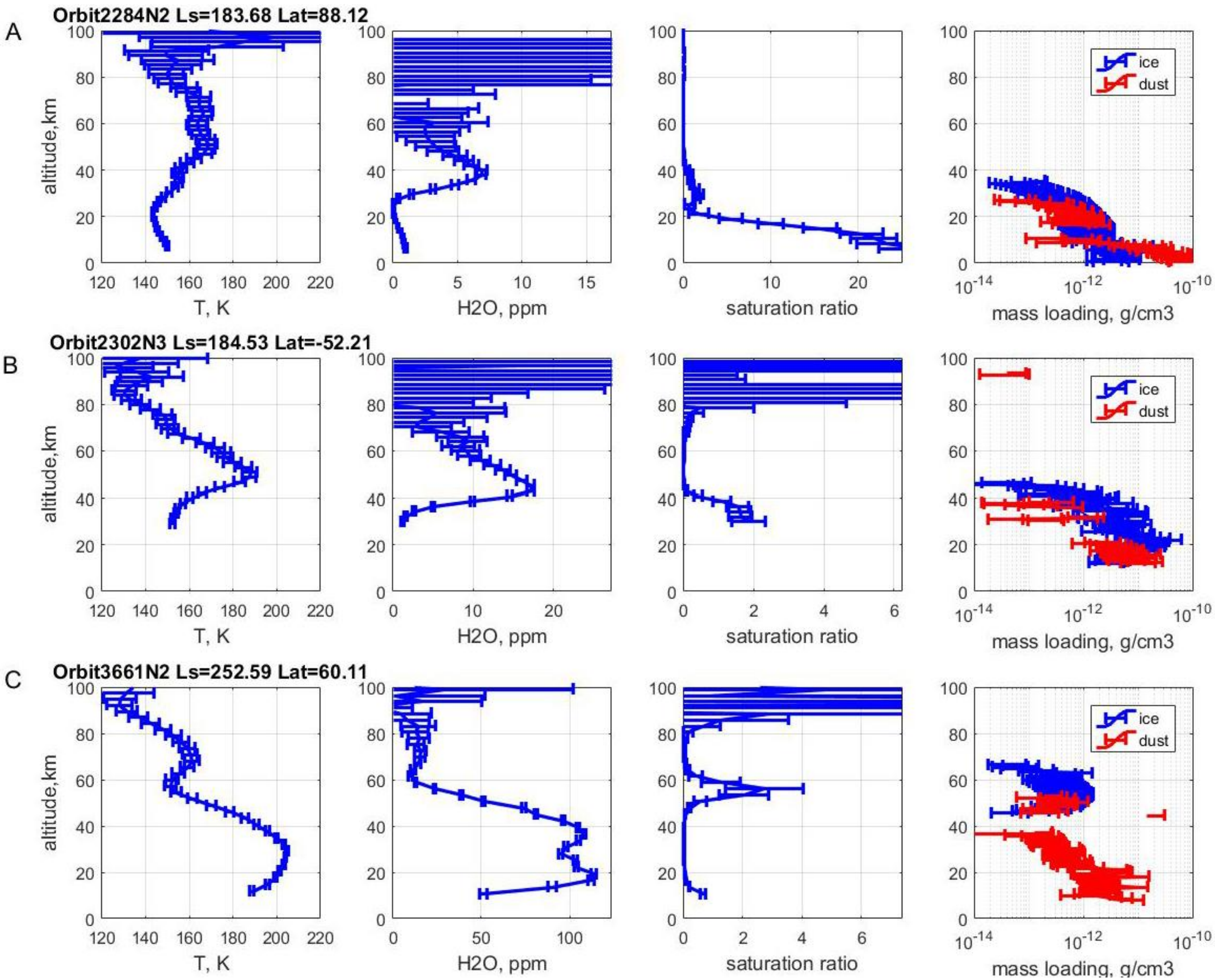




Luginin et al.

MIR extinctions by Denis Belyaev

ACS occultations results



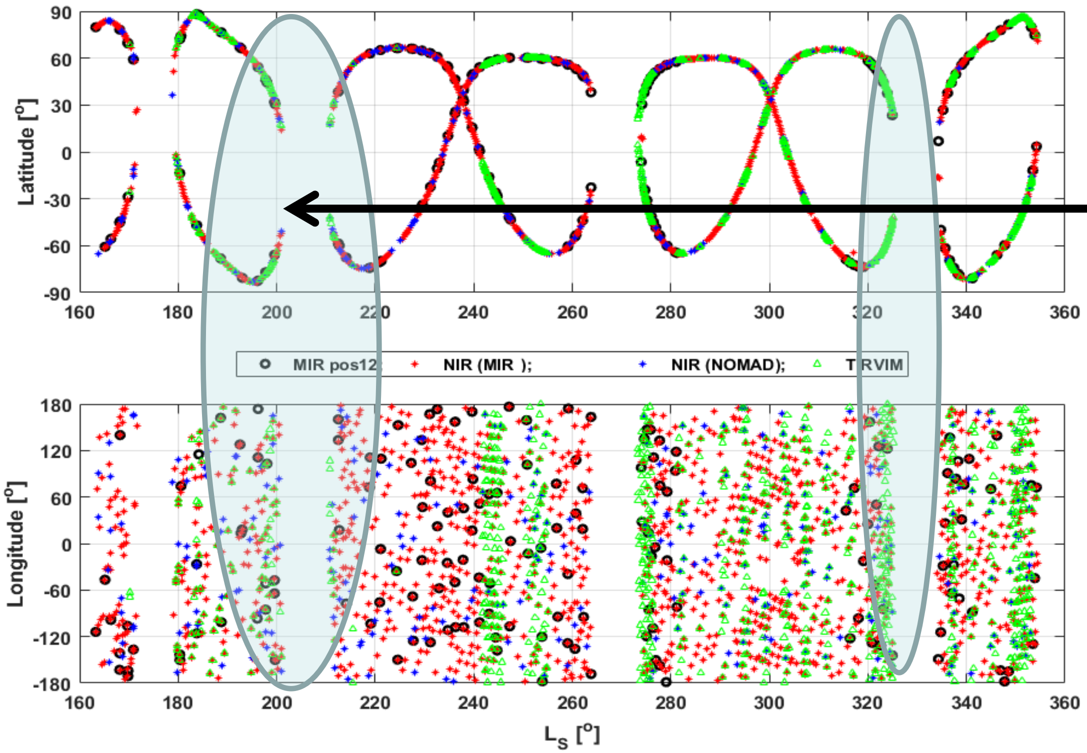
Three ACS NIR occultations showing occurrences of supersaturation: temperatures, water vapor vmr profile, saturation ratio and aerosol mass loading (dust and water ice)

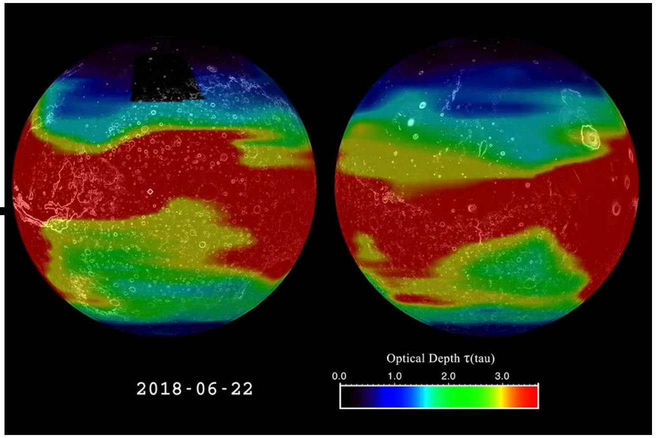
ACS Atmospheric Chemistry Suite

ACS occultations results

Coverage with three channels Ls=163-360

Global dust storm **Regional dust storm**

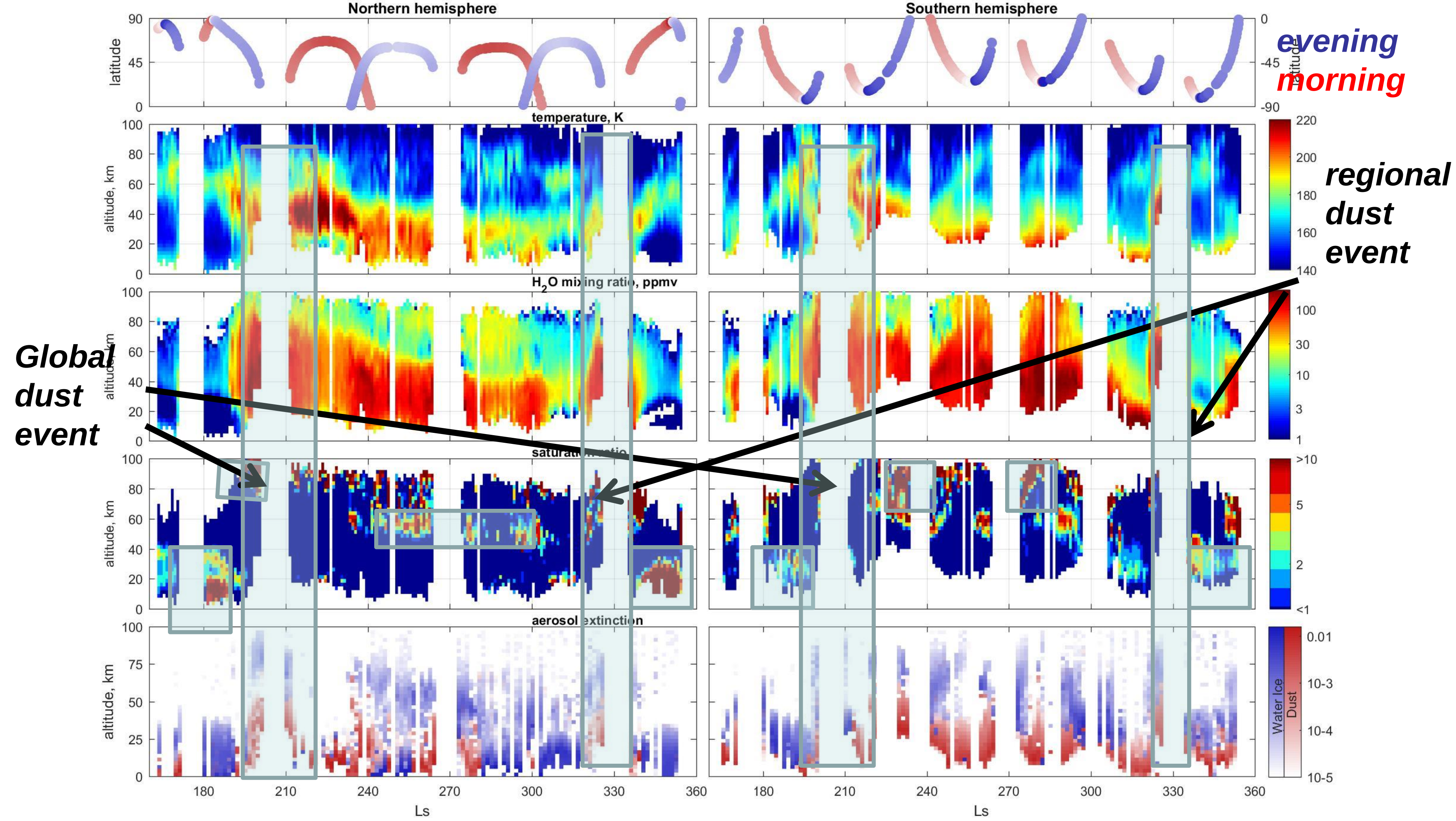




NIR		MIR (position 12)	TIRVIM (climatology)
MIR pointing	NOMAD pointing		
1192	57	161	889

ACS occultations results

H_2O, saturation, aerosols and temperature

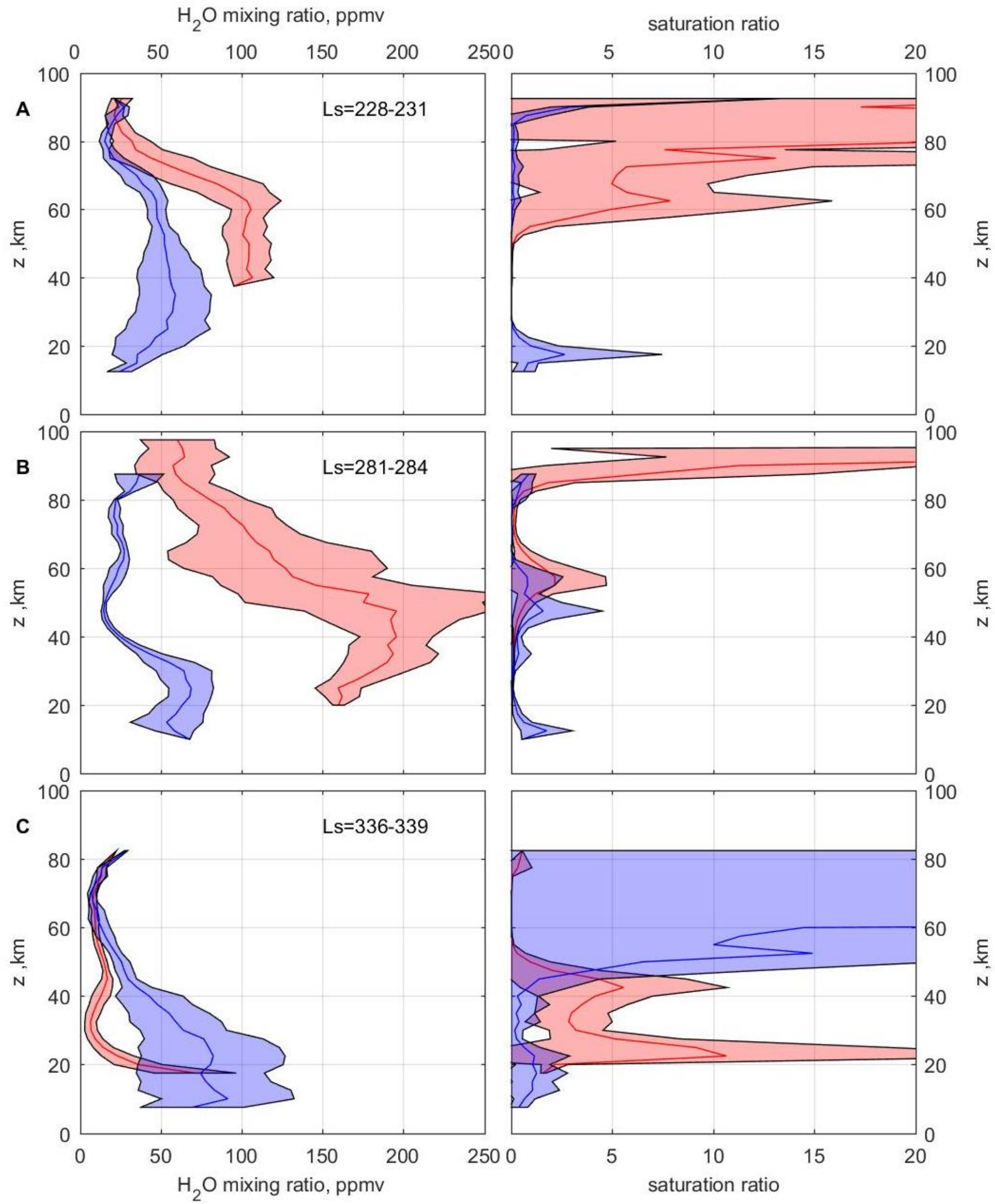


The water vapor and saturation ratio vertical distribution

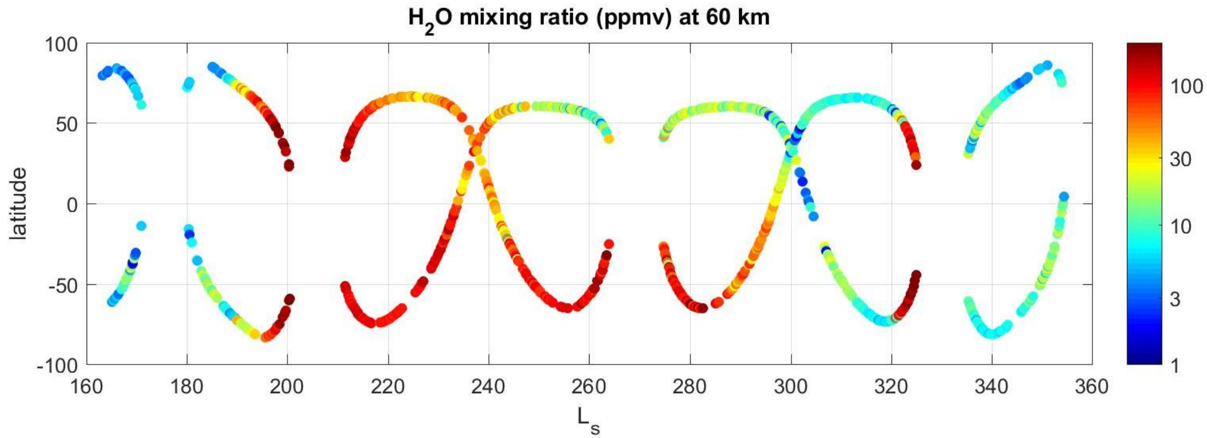
in the **northern (blue color)** and the **southern (red color)** hemispheres

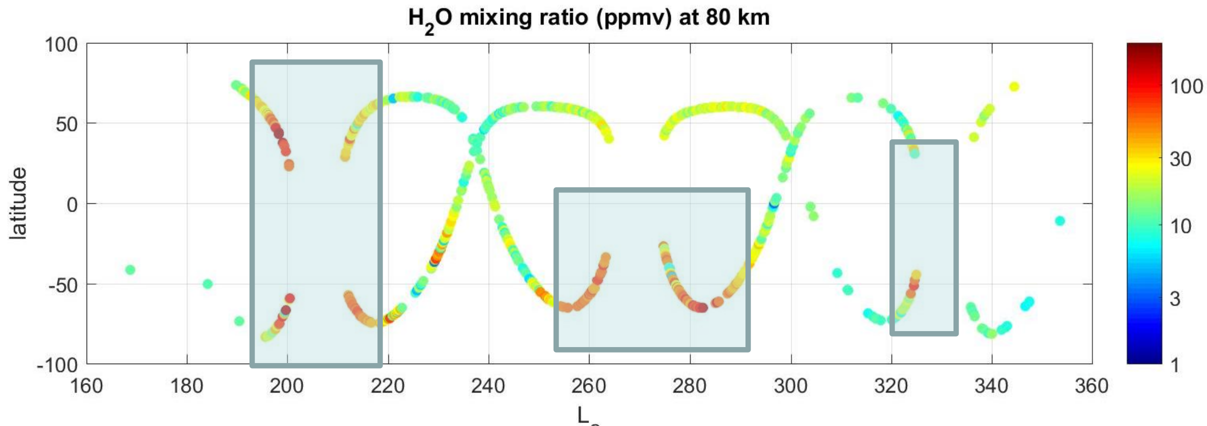
binned into three characteristic periods:
(A) the decay of 2018A GDS;
(B) the perihelion period of the southern summer;
(C) end of the regional dust storm “C”;

The shaded areas indicate the statistical dispersion (1σ) of measurements.

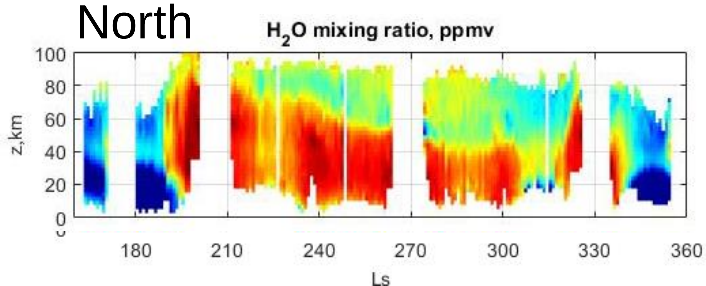


High altitude water

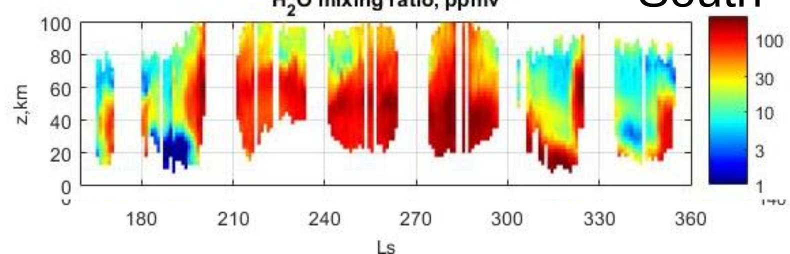




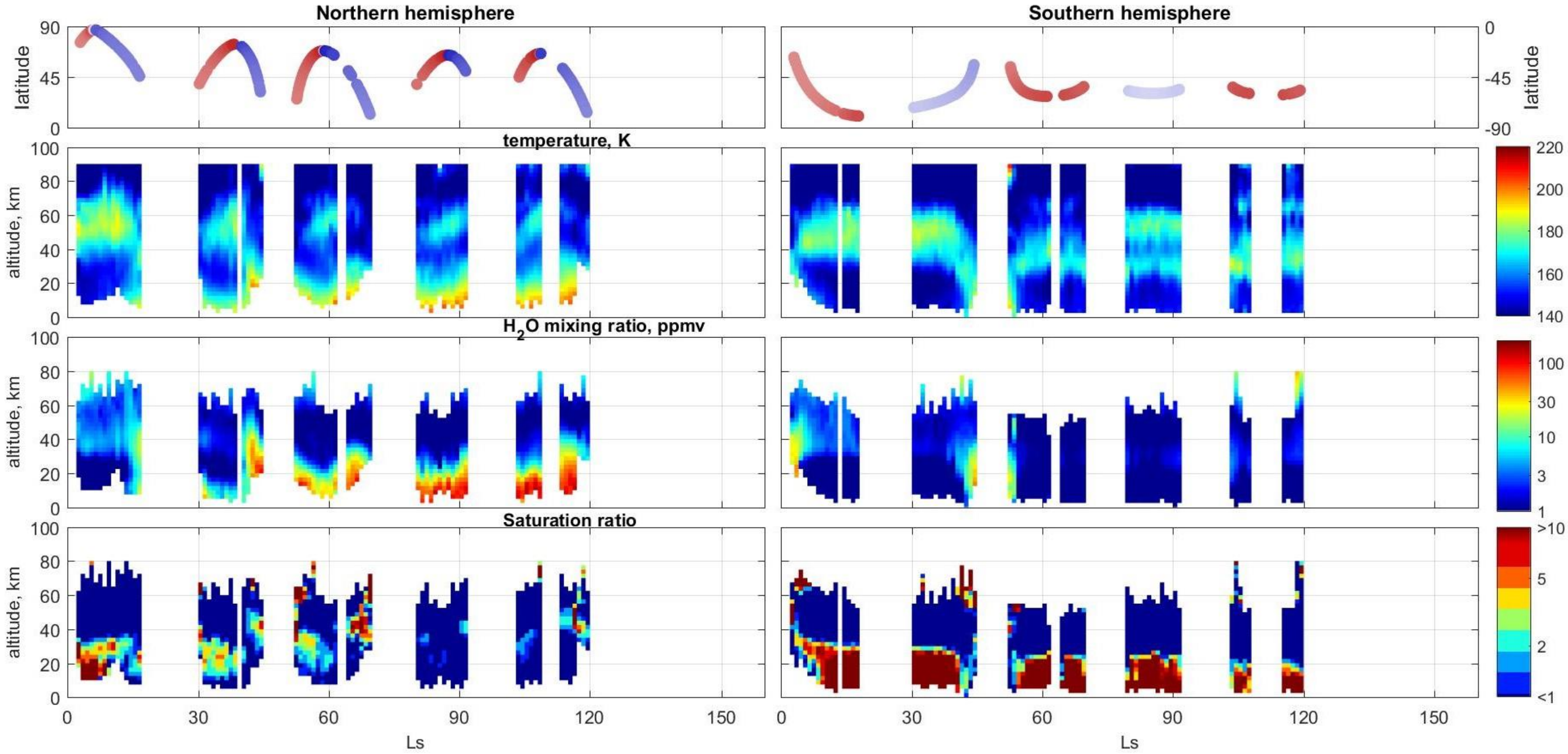
North



South



H_2O, saturation and temperature aphelion season, preliminary results



REPORT

Recently published

MARTIAN ATMOSPHERE

Stormy water on Mars: The distribution and saturation of atmospheric water during the dusty season

Anna A. Fedorova[1]*†, Franck Montmessin[2]†, Oleg Korablev[1]†, Mikhail Luginin[1], Alexander Trokhimovskiy[1], Denis A. Belyaev[1], Nikolay I. Ignatiev[1], Franck Lefèvre[2], Juan Alday[3], Patrick G. J. Irwin[3], Kevin S. Olsen[2,3], Jean-Loup Bertaux[1,2], Ehouarn Millour[4], Anni Määttänen[2], Alexey Shakun[1], Alexey V. Grigoriev[1,5], Andrey Patrakeev[1], Svyatoslav Korsa[1], Nikita Kokonkov[1], Lucio Baggio[2], Francois Forget[4], Colin F. Wilson[3]

Fedorova *et al.*, *Science* **367**, 297–300 (2020)

Summary

- Joint analysis of ACS NIR, MIR and TIRVIM data from April 2018 to March 2019 (Ls=163-355°) at the morning and evening terminator and ACS NIR up to Nov 2019
- NIR provides simultaneous measurements of:
  - **CO_2 band at 1.56 μm (order 49)** - temperature-pressure profiles (0-110 km)
  - **H_2O band at 1.38 μm (order 56)** - vertical profiles in the low atmosphere (0-100 km)
- TIRVIM and MIR provide H2O ice near 3 μm and dust extinctions
- Main results for H2O:
  - Atmospheric heating during the dust events (expected)
  - High altitude water during the dust events Ls=193-240 (global) and Ls=220-235 (regional)
  - High-altitude water during the summer in the southern hemisphere Ls=250-290
  - **Supersaturation region has been observed**:
    - ✓ In low atmosphere 20-40km Ls<190 and Ls>335 and Ls=0-120
    - ✓ In the upper atmosphere> 70km Ls=200-300 in both hemispheres
    - ✓ In the middle atmosphere at 50 km during the southern summer
  - **Supersaturation of water occurs even in the presence of clouds**