Characterization of atmospheric gravity waves on Mars at altitudes 10 - 180 km as measured by the ACS/TGO solar occultations

Photography not allowed

E.D. Starichenko[1,2], D.A. Belyaev[1,2], A.S. Medvedev[3], A.A. Fedorova[1,2], O.I. Korablev[1,2], F.Montmessin[4], A.Trokhimovskiy[1]

[1]Space Research Institute (IKI), Moscow, Russia
[2]Moscow Institute of Physics and Technology, Dolgoprudniy, Russia
[3]Max Planck Institute for Solar System Research, Göttingen, Germany
[4]LATMOS/CNRS, Guyancourt, France

Abstract:

We present the preliminary results on gravity wave (GWs) characterization in the Martian atmosphere. The analysis is based on retrievals of vertical distributions of temperature from the solar occultation experiment by the Atmospheric Chemistry Suite (ACS) onboard ExoMars Trace Gas Orbiter (TGO). These are the first profiles covering the entire atmosphere measured by a single instrument.

Gravity waves:

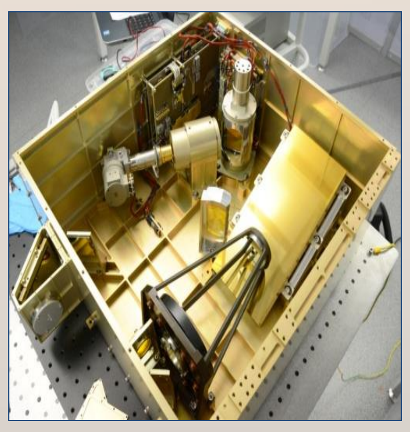
Gravity waves (GW) in the planetary atmospheres appear as periodic oscillations of density, temperature, winds and pressure. Measuring vertical distribution of density and temperature, one can characterize vertical propagation of atmospheric GWs. Here, the main parameters of GWs – amplitude and vertical wavenumber spectrum - can be estimated.

Instrument description:

To characterize the parameters of GWs, we use the solar occultation experiment being performed by the ACS instrument onboard ExoMars/TGO [1]. The ACS is a set of infrared spectrometers operating at the orbit of Mars since April 2018. The MIR channel of ACS is a cross-dispersion echelle spectrometer working in the 2.3–4.2 μm spectral range with resolving power reaching λ/Δλ~30 000. In the solar occultation mode, the spectrometer can observe thin layers of the Martian thermosphere and dense layers of the lower atmosphere in strong (e.g. 2.7 and 4.3 μm) and weak (about 1.57 μm) CO_2 absorption bands. The NIR [2] channel is a combination of an echelle spectrometer and an acousto-optic tunable filter (AOTF) working in the 0.73–1.6 μm spectral range with the resolving power λ/Δλ~25000[2]. With high resolution infrared CO_2 spectroscopy, these instruments provide an opportunity to thoroughly study density, temperature and pressure from the Martian low atmosphere through to the thermosphere. The experiment covers latitudes 88°N - 90°S and heights from 0 to 180 km.

NIR, echelle+AOTF

MIR, echelle+cross-dispersion



NIR:
- Spectral range 0.73 – 1.6 μm
- λ/Δλ ~25 000
- Operation modes: Nadir and Solar Occultation
- FOV: 2°×0.02° nadir, 0.3°×0.02° occultation
- [Fedorova et al., 2020, Science][2]

MIR:
- Spectral range 2.3 – 4.2 μm
- λ/Δλ ~30 000
- Operation modes: Solar Occultation
- FOV: 0.23°×0.02°

Retrieval of temperature profiles:

$$J(z) = \exp\left[-\int \left(\sigma_{CO_2}(T,p)\, n_{CO_2}(z)\right) dz - \tau_{aer}\right]$$ - transmittion

1) Spectroscopic database HITRAN 2016 for σ(T,p)[3];

2) Priori (T, p) and CO_2 vol. mixing ratio profiles from the MCD 5.3 (climatology)[4];

3) Use of multi-iterative scheme of retrieving T(z) и n_{CO2} for evaluation of hydrostatic pressure; $p(z) = p_0 \exp\left(-\int \frac{m(z)g(z)}{kT(z)} dz\right)$

4) Use Levenberg-Marquardt algorithm with an jacobian based on cross-section derivatives dσ/dT and dσ/dp;

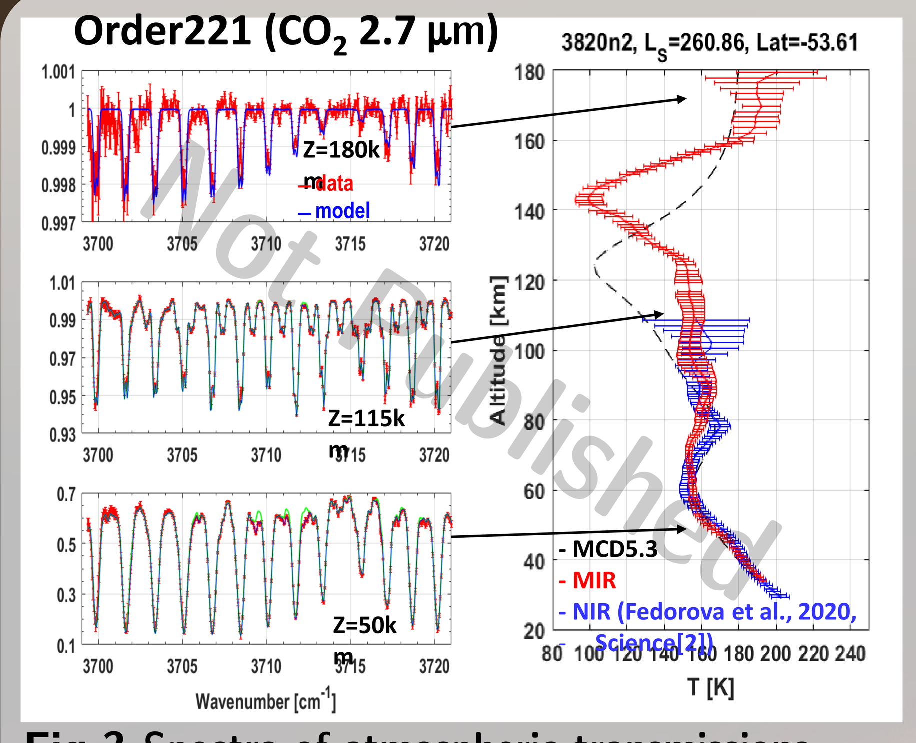


Fig.3 Spectra of atmospheric transmissions measured by the ACS-MIR nearby 2.7 μm and retrieved temperature profile (in red) and comparison with NIR channel (blue) [2]. Black dashed line is the MCD5.3 climatology profile.

Fig.1 Latitude and solar longitude (Ls) data coverage for ACS-NIR MY34.

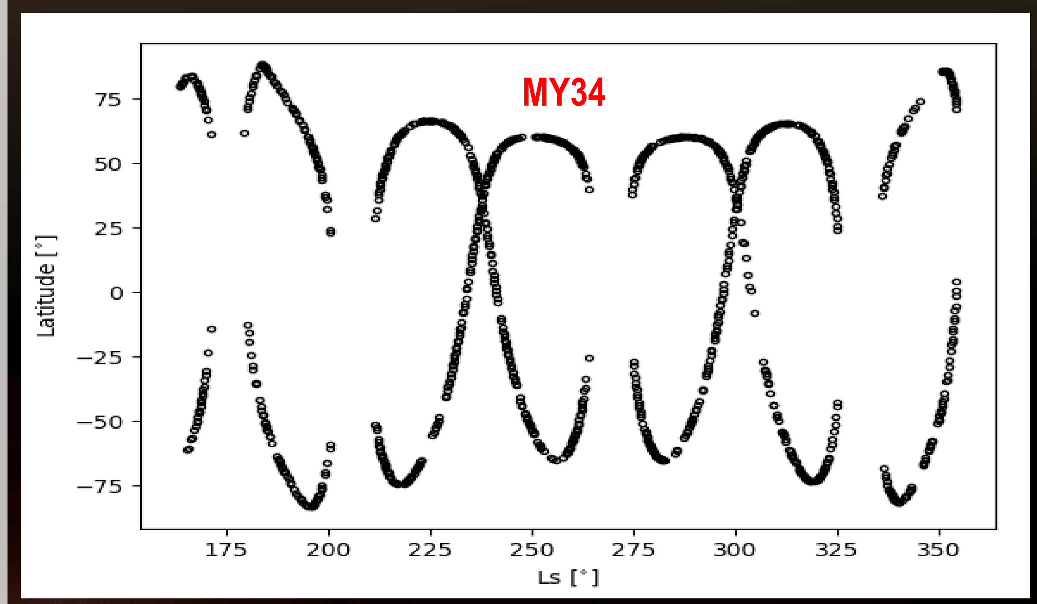
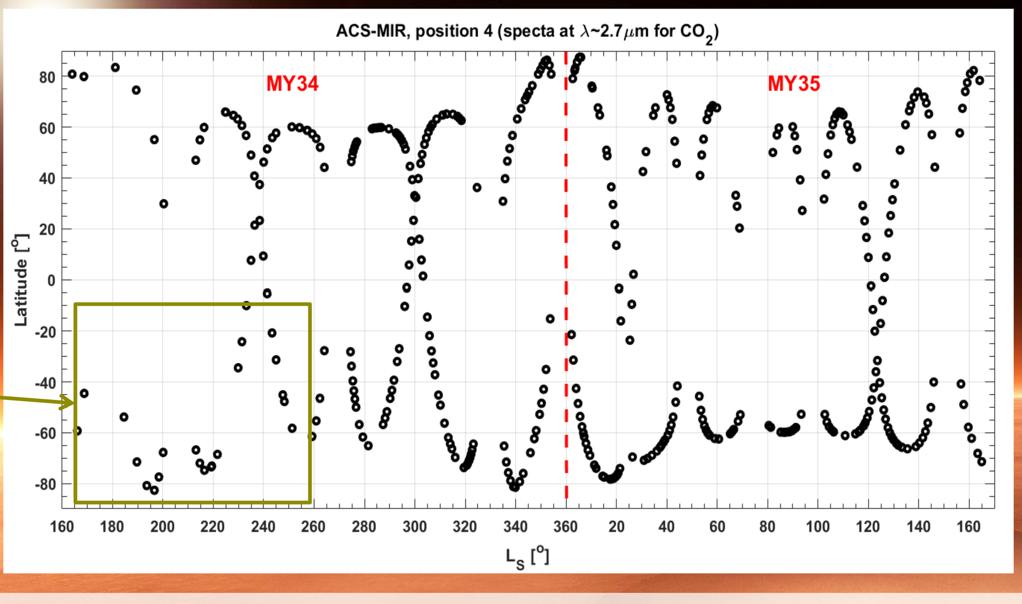


Fig.2 Latitude and Solar Longitude (Ls) data coverage for ACS-MIR.



Processed profiles

GW analysis technique [5]:

Atmospheric GWs as vertical profiles of relative temperature perturbations, T'(z)/T0(z), where T'(z) = T(z) - T0(z), T0(z) is the mean of T(z) with small vertical-scale fluctuations removed. It was retrieved by sliding a cubic fit over a range of 24 km. The fit was shifted up by 7 km at each step and averaged with previous overlapping points. The final results were then smoothed.

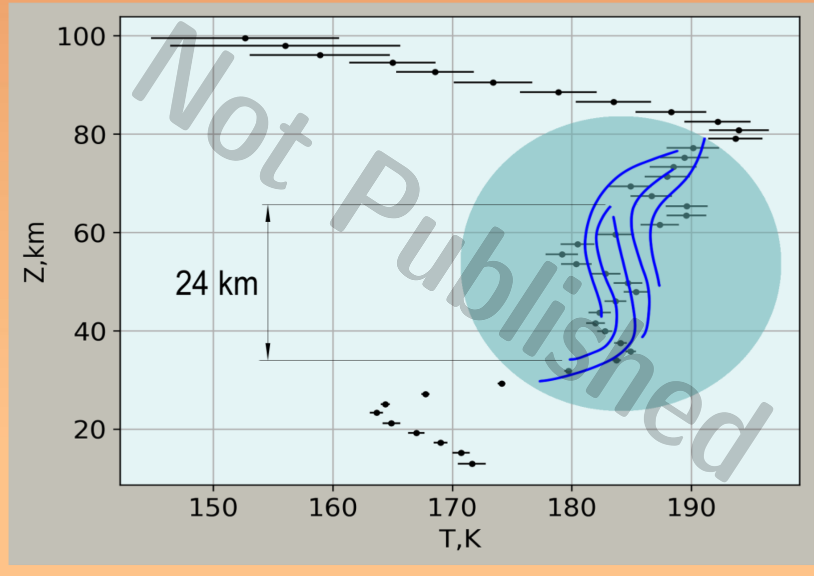


Fig.4 The process of sliding cubic fit interval for one temperature profile

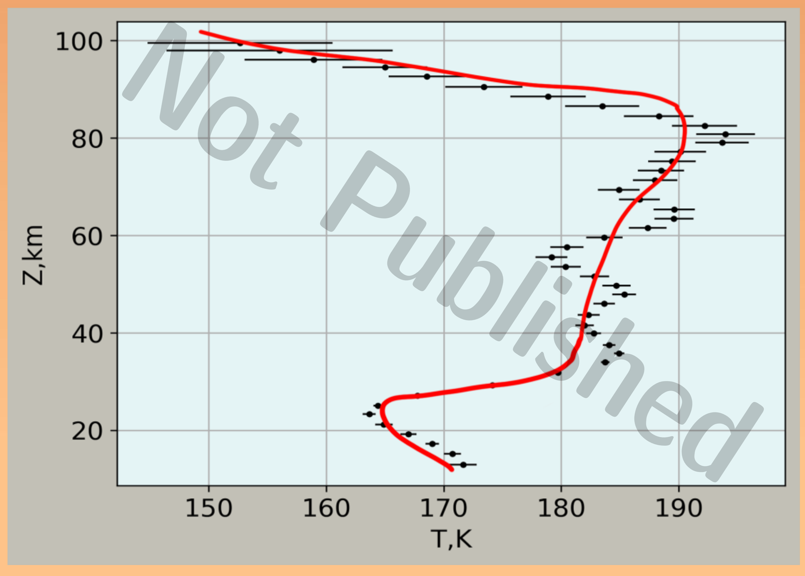


Fig.5 The mean temperature profile

Calculation of Brunt-Väisälä frequency and other parameters:

The Brunt-Väisälä frequency is estimated by the equation:

$$N^2 = \frac{g}{T}\left(\frac{\partial T}{\partial z} + \frac{g}{c_p}\right).$$

Where g is the acceleration of gravity and cp is the air specific heat capacity at constant pressure.

We also find Fourier spectrum of relative perturbations of temperature by fast Fourier transformation and gather the statistics of amplitude on different heights depending on the Ls.

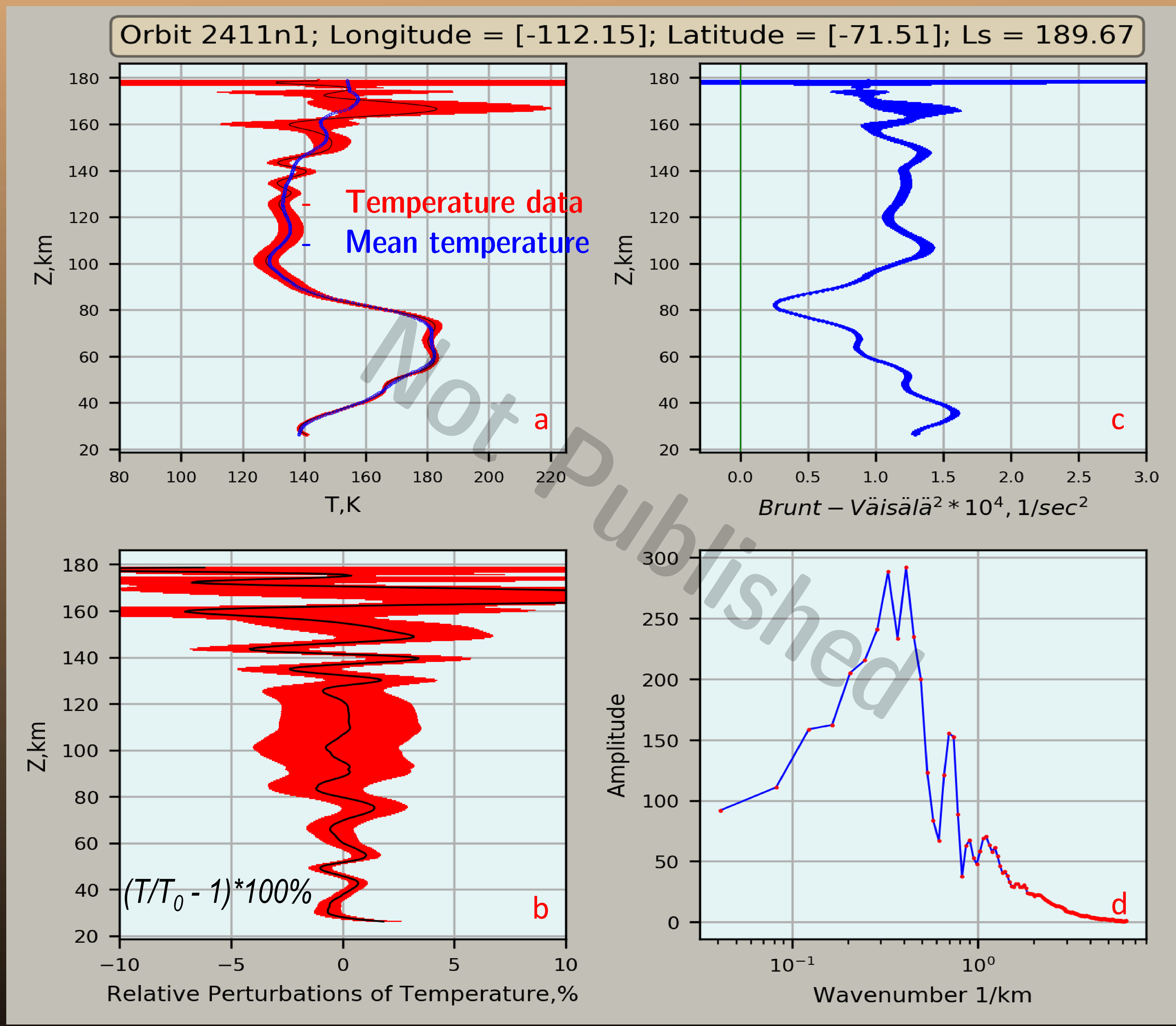
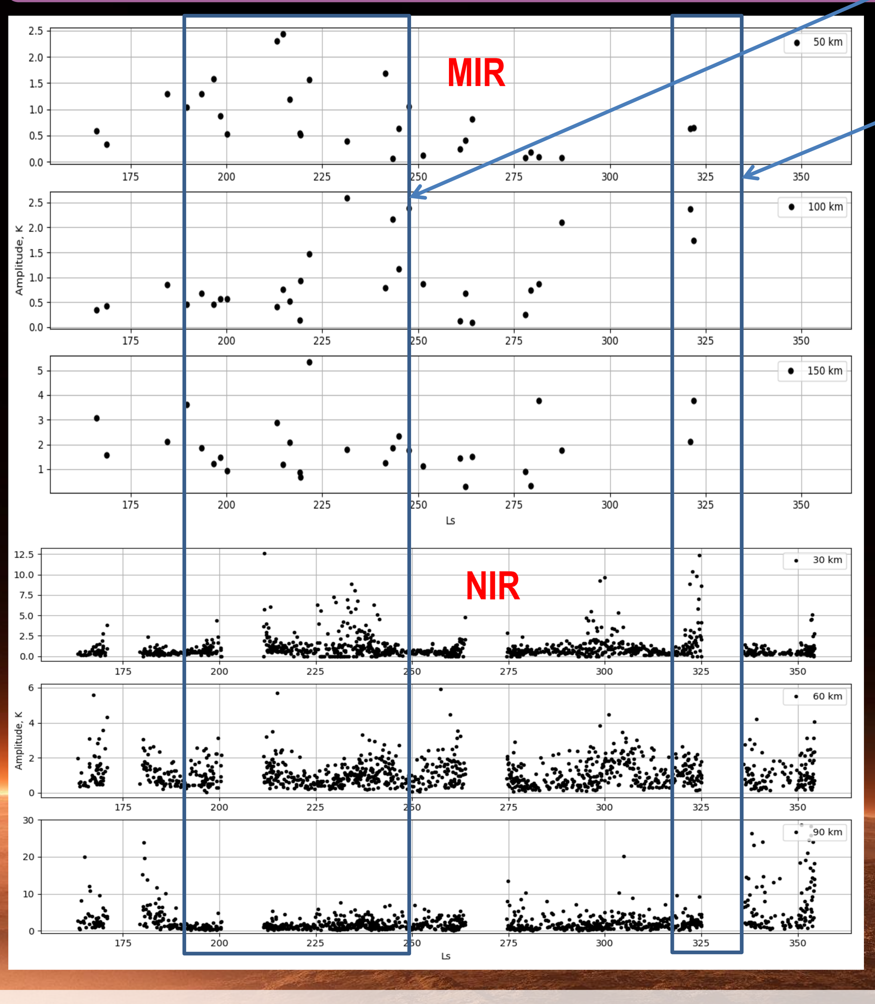


Fig.6 a) Temperature and mean temperature vertical distributions; b) Relative perturbations of temperature with height; c) Vertical profile of Brunt-Väisälä frequency; d) Fourier spectrum of temperature perturbations;

Fig.7 Distribution of the temperature relative perturbations amplitude with Ls on different heights.

Global dust storm

Local dust storm



Conclusions:

- We have retrieved and analysed atmospheric GW properties from ACS-NIR and ACS-MIR temperature profiles at altitudes 10-180 km;
- The algorithm of defining the parameters of GW has been developed and tested;
- The dataset covers the altitude ranges 0-100 km, LS 165-360 of MY34 for the NIR channel and 20-180 km, LS 165-270 for the MIR;
- The study of climatology of wave activity by potential energy, amplitude of perturbations and fluxes is in progress.

ACKNOWLEDGEMENTS:

ExoMars is the space mission of ESA and Roscosmos. The ACS experiment is led by Space Research Institute (IKI) in Moscow. The altitude profiles interpretation in IKI is funded by the Russian Science Foundation (RSF) grant #20-42-09035.

REFERENCES:

[1] Korablev O., Montmessin F., and ACS Team."The AtmosphericChemistry Suite (ACS) of threes pectrometers for the ExoMars 2016 Trace Gas Orbiter", SpaceSci. Rev., 214:7, 2018.

[2] Fedorova et al., 2020. Stormy water on Mars: The distribution and saturation of atmospheric water during the dusty season, Science, doi: 10.1126/science.aay9522 (2020).

[3] Gordon I.E. et al., 2016. The HITRAN2016 molecular spectroscopic database. Journal of Quantitative Spectroscopy and Radiative Transfer, vol. 203, 3-69. https://doi.org/10.1016/j.jqsrt.2017.06.038

[4] http://www-mars.lmd.jussieu.fr/mars/access.html

[5] Whiteway, J. A., Carswell, A. I. (1995). Lidar observations of gravity wave activity in the upper stratosphere over Toronto. Journal of Geophysical Research, 100(D7), 14,113–14,124. 10.1029/95JD00511