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Modelling the transport of trace gases in the Martian atmosphere

P. Wajer (1), P. Witek (1), M. Banaszkiewicz (1), W. Kofman (1,2), A. Pommerol (3) and P. Wolkenberg (4,1)

(1) Space Research Centre PAS, Warsaw, Poland (wajer@cbk.waw.pl), (2) Institut de Planetologie et d'Astrophysique de Grenoble CNRS/UJF, Grenoble, France, (3) Physics Institute, Space Research and Planetary Sciences - University of Bern, Bern, Switzerland, (4) Istituto di Astrofisica e Planetologia Spaziali (IAPS) – Istituto Nazionale di Astrofisica (INAF), Rome, Italy.

Abstract

The European-Russian ExoMars Trace Gas Orbiter (TGO) is set to reach its scientific orbit at the end of 2017 after the aerobraking campaign. The data returned by the probe will help to understand the origin and evolution of trace gases, especially methane (CH_4), in the Martian atmosphere. To analyze the data sent back by the probe we have developed a model of the photochemistry in the atmosphere of Mars. The model follows a few dozen molecules that are present or expected to exist in the atmosphere due to a few hundred considered chemical and photochemical reactions. The radiative transfer equation is solved by using two-stream approximation to calculate solar photon flux that determine the photochemistry at different altitudes above the surface. The model takes into account the role of dust, ice clouds as well as the densities and fluxes of considered gases at the surface as a result of their transport from subsurface/surface sources.

1. Introduction

In 2003 and 2004, a few groups of scientists by using Earth ground based observations and Mars Express Orbiter observations announced the discovery of methane (CH_4) in the atmosphere of Mars [2][3] then other observation were made by the Curiosity rover [6]. Since then, the debate has been carried out on several unexplained issues: (i) fast (seasonal) variability of CH_4 that is in contradiction with the long photochemical lifetime (a few hundred years) of this molecule in the atmosphere, (ii) sources of CH_4 that could quickly increase the concentration, (iii) sinks of methane that could reduce its concentration to the background level in several months.

Analysis of the sources and sinks of CH_4 on Mars will be an important step to understand the history, the evolution and a possible existence of life (current or past) on this planet. The biological origin of CH_4 could be explained by activity of bacteria called methanogeneses. The bacteria can exist deep under surface of Mars, or they lived in the past and CH_4 is stored in the permafrost as clathrates. There exist alternative explanation of its origin based on chemical processes called serpentinisation. It implies that if the methane is produced in this reaction, its presence is related to subsurface hydrothermal activity [1].

We plan to study propagation of CH_4 and other trace gases (e.g. hydrocarbons as C_2H_6, C_2H_4 and species containing sulphur as H_2S and SO_2 that should be observed in the atmosphere at very low concentration levels) in the Martian atmosphere by using chemical and photochemical modelling. This kind of modeling is an important step to understand observational data taken by the space instruments (for example NOMAD from TGO mission [5]) as well as to distinguish between different hypothesis that concern potential surface and subsurface sources of CH_4 and other trace gases (CaSSIS [4]).

2. Research methodology

To model photodissociation and chemical processes in the atmosphere of Mars we develop 1D model to compute the steady-state chemical composition of the atmosphere. In our study we solve one-dimensional time-dependent transport equations:

$$\frac{\partial n_i}{\partial t} = -\frac{\partial \Phi_i}{\partial z} + P_i - n_i L_i \qquad (1)$$

Where n_i means i-molecule concentration, Φ_i describes a vertical transport of molecules ($cm^{-2}s^{-1}$), P_i – production rate (cm^{-3} s^{-1}), L_i means the loss rate (s^{-1}), z - altitude over planet’s surface.

The separated code was constructed to simulate the interaction of species with radiation. Since the photochemical destruction of the atmospheric molecules depends on the solar flux, thus including absorption, Rayleigh scattering, scattering on small particles as dust or ice crystal is an important part of our simulation (see fig. 1 where we plotted the exemplary results where we modelled downstream solar photon flux in case when only absorption is present in the atmosphere. We restricted the plot to 300nm in order to show differences between the two fluxes in the part of the spectrum below about 200nm that is important for CO_2 absorption).

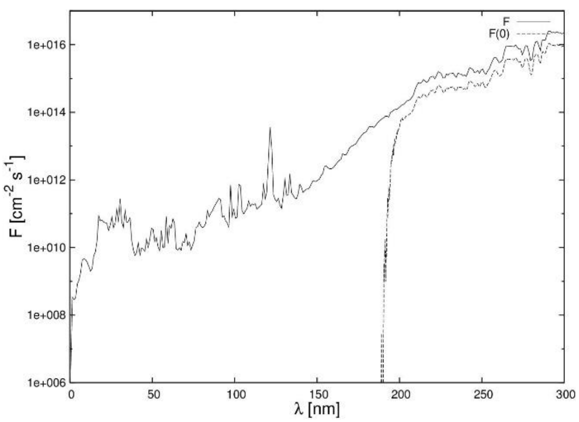

Figure 1: The solar photon flux in UV part of the spectrum at the top, F, and bottom, F(0), of the Martian atmosphere.

Both upper and lower boundaries that must be fixed in the photochemical model depend on the given molecule. The upper boundary conditions describe the atmospheric escape of molecules, for example H or H_2 [7]. Conditions at the lower boundary are determined by the chemically active surface (surface emission and deposition) and potential transport of species from subsurface sources.

To verify our numerical modelling we plan to use images obtained from stereoscopic camera CaSSIS [4], that should give us the mineralogical description of the surface from where the methane originates, and another instruments, especially instruments on TGO.

3. Summary and Conclusions

The origin of sources and sinks of methane in the atmosphere of Mars is not fully understood, although many hypotheses have been proposed [1]. In this work in progress we aim to develop a photochemical model of the Martian atmosphere. This model helps us to better understand the origin and evolution of trace gases, especially CH_4. We also plan to use the data of computer simulations of gases transport from subsurface to the surface and the data obtained from the spacecraft instruments to describe the lower boundary conditions (at the surface) for the atmospheric photochemical model, which results will later be confronted with measurements.

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