1-D AND 3-D MODELLING OF THE UPPER ATMOSPHERE OF MARS.

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Introduction

Theoretical models of a planetary atmosphere and numerical simulations of its physics, chemistry, radiation and dynamics, are becoming an essential tool in nowadays atmospheric research. Traditionally, the first numerical tools developed were one-dimensional, intended to describe the maximum variation of the atmospheric parameters, which occurs in the vertical. Later, the need to fully describe the fluid dynamics and to understand the role played by horizontal transport on 1-D profiles of key parameters (ozone abundance, thermal structure, airglow emissions), required to solve the equations in three-dimensions. In addition to the advantages of representing latitudinal and longitudinal variability in a more realistic manner, they are also well known the limitations of 3-D models when describing the atmosphere. These include their high demands on computer power, the need to parameterise most processes, the difficulty to validate their results and/or to initialise the fields when not much data are available.

This lack of data has been, and still is, the case of the Martian upper atmosphere. For these reasons, 1-D models can still be nowadays very useful tools to understand the behaviour of the Mars' atmosphere, in particular at thermospheric altitudes. These 1-D simulations can handle parameterisations and also more elaborate physical models, and are specially useful to simulate global values of long term species or averaged fields of temperature and radiative forcing, for example.

These are the main scientific aims of the 1-D non-stationary radiative-convective-chemical model being developed at the IAA-CSIC, in Granada, in recent years. In addition, there is an extra motivation in the framework of the project "Mars Climate Database", financed by ESA and CNES, and nowadays within the ESA Aurora Program. This additional objective is to support the development of parameterisations for the 3-D models used in the project, in particular, to design and implement fast calculations of key atmospheric processes at high altitudes, like the UV heating (González-Galindo et al., 2005), the IR cooling and the near-IR solar heating of the atmosphere, both subject to non-LTE conditions (Lopez-Valverde and Lopez-Puertas, 2001a, 2001b), or the photochemical behaviour of some species of relevance for the energy budget (González-Galindo et al., 2005).

Here we describe some results of the Martian atmosphere temperature field obtained with this 1-D model, selected in order to compare them with similar and more realistic results from the 3-D models. The idea is to illustrate how a hierarchy of models of different dimensionality can be used to improve our insight into the behaviour of the upper atmosphere of Mars. Similar hierarchy of models has been proved very useful in the past for studies of the Earth's upper atmosphere Andrews et al (1987).

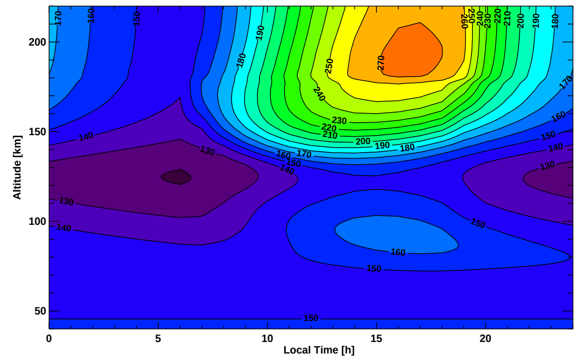

Figure 1: Altitude - Local Time cross section of the Mars' atmospheric temperature at equator, solar medium activity and equinox conditions, Ls=0, obtained with the 1-D time-marching model. See text for more details.

Equatorial temperature fields in 1-D and 3-D

Figure 1 shows the altitude versus local time cross section of the thermal structure in the upper atmosphere of Mars obtained with the 1-D model for mean solar activity, equinox conditions and at the equator. And Figure 2 shows the same result obtained with the 3-D code, the LMD Mars GCM (Forget et al, 1999) extended to the thermosphere (Angelats i Coll et al, 2005; González-Galindo et al., 2005). The physical modules included in the 1-D model run are similar to those in the 3-D model, in particular, the UV heating fast code (González-Galindo et al., 2005), the non-LTE thermal cooling and solar heating parameterisations (Lopez-Valverde and Lopez-Puertas, 2001a, 2001b), and also the thermal conduction, and the turbulent and molecular diffusions (Angelats i Coll et al., 2005). A UV heating efficiency of 16% was used in both models. The 1-D model was run from an initial reference atmosphere for

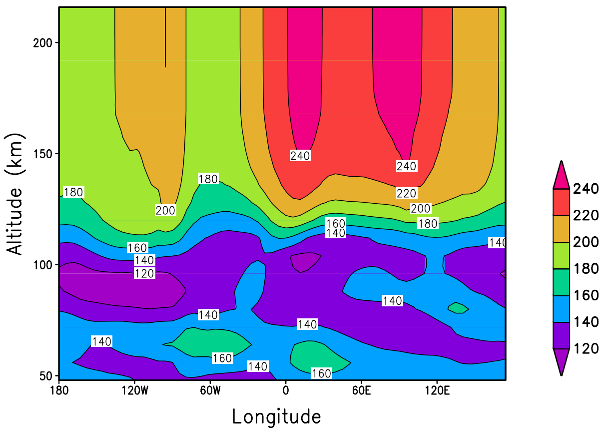

Figure 2: Same as Figure 1 but obtained with the 3-D GCM. See text for more details.

seven Martian days, with time steps of 15 minutes, and the results in Figure 1 are the solution obtained in the last day of the simulation, when the situation has reached a stationary daily cycle. The GCM was run until stationary conditions were obtained and the Ls=0 results were extracted from averages for the period Ls=0-30. The presentation in Figure 2 is in term of longitude, which is easily convertible to the local time units of Figure 1 (LT=0, 9, 12, 18 correspond to Longitude=180W, 90W, 0, 90E, respectively).

Two major modelling differences between these 1-D and 3-D runs, in addition to the horizontal transport, obviously not included in the 1-D model, are:
(1) the tropospheric description; the pressure and thermal structure in all the layers below 50 km is fixed in the 1-D model run, in order to eliminate dynamical effects from those low altitudes.
(2) the chemistry; which is only used above 100 km in the 1-D model, while it was extended downward to the ground in the GCM.

The second effect surely has a very small impact on the major features we want to highlight here, while the tropospheric influence and the three-dimensional description of the wind field and of the wave propagation are surely the largest effects. Actually this is what we find in the results shown in Figures 1 and 2, as explained next.

The daily cycle observed in the 1-D model shows a maximum temperature in the upper thermosphere around 270 K, and located at the end of the afternoon, while the minimum is obtained at the end of the night (LT=6h), right at the terminator, and reaches 150 K, i.e., a daily cycle or 120 K between day and night. The 3-D model results, although showing larger variability and structure, also show the same trend, with maximum and minimum temperatures at the end of the afternoon and in the early morning. The extreme temperatures, however, are milder than in the 1-D model, from 180 to 240 K, with a daily cycle of only 60 K. We can not disregard the possibility of some differences between both models, like in the absolute abundances of several radiatively active species (O_2, CO_2) at a given altitude. In fact, the altitude grid is surely shifted regarding atmospheric density, as deduced from the different location of the mesopause in the two models (at 125 km versus 100 km in the 1-D and 3-D cases, respectively). However, we believe that the main reason for the difference in the thermospheric daily cycle is of dynamical nature, due to the transport from the sunlit hemisphere to the night hemisphere. These effects have been known for more than a decade in the case of Mars (Bougher et al., 1990), and were used to explain the lack of a cryosphere of the type observed in Venus, due to the heating by the downwelling winds in the Mars nightside and the cooling by upwelling in the dayside.

The second major result of interest for us is the thermal structure at the altitude of the mesopause. The 1-D model shows a clear wave-1 or diurnal tide in the temperature, with maxima and minima at the same local times than in the upper thermosphere. We believe this is mainly due, in the 1-D model, to the local forcing from the near-IR solar heating by CO_2. The GCM, however, presents much more variability in the mesosphere, and the gross feature around the mesopause is closer to a wave-2 semidiurnal structure. Previous studies have shown how important is the daily cycle in the lowest atmospheric layers on setting a semidiurnal component at higher altitudes, in particular when the dust content is large (Bougher et al, 1993). Therefore, this discrepancy between the 1-D and the 3-D model shows clearly the impact of such wave propagation from below.

Conclusions and Future work

A 1-D model of the Martian atmosphere is used here to generate maps with longitudinal or latitudinal variability, in a 3-D usual fashion. A small sample of results obtained with the 1-D is used to compare with more sophisticated 3-D models of the upper Martian atmosphere in order to highlight a couple of important mechanisms acting at these altitudes: the redistribution of the available energy between the day and the night hemispheres, and the propagation of a semidiurnal component from the lower atmosphere which affects the thermal structure at mesospheric altitudes. This is an example of the potential of the 1-D simpler approach if used in conjunction with a 3-D model which shares the same physical package.

The development of the 1-D model will continue with the extension of the Mars Climate Database project, with the scientific motivations mentioned above: to describe the Martian atmospheric fields in a 1-D fashion, to incorporate detailed models of the physics at these altitudes, to test the quality/efficiency of different parameterisations, and to compare with the more realistic 3-D models in order to highlight and to continue learning about fundamental mechanisms of the Martian atmosphere.

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