NITROGEN AND IONOSPHERIC CHEMISTRY IN THE THERMOSPHERIC LMD-MGCM

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Introduction

NO nightglow emissions, already detected on Venus by Pioneer Venus [1], have been observed for the first time on Mars by SPICAM on board Mars Express [2]. These emissions are produced by the recombination of Nitrogen and Oxygen atoms. These atoms are created by photodissociation of CO_2 and O_2 in the dayside thermosphere. The interhemispheric transport followed by a downwelling takes them to the nightside lower thermosphere/upper mesosphere, where they recombine. Each recombination produces a photon in the γ and δ bands of NO. So, a coupling of radiative, transport and radiative processes is at the core of this emission. It is for this reason that the observations of the NO nightglow by SPICAM can be very valuable to constrain the rather unknown dynamics of the Martian upper atmosphere.

MGS Radio Science (RS) experiment and Mars Express MaRS instrument have allowed to measure the electron density profiles of the Martian atmosphere [3,4]. Given that the electron density at the peak is controlled by local photochemistry and it is thus very sensitive to the neutral density, these measurements of the electron density profiles can provide important information about the coupling between the lower and the upper atmosphere [3].

Both datasets are very valuable to constrain the recently extended to the thermosphere LMD-MGCM. However, specific tools to simulate these processes have to be included in the model, that does not include, in its reference version [5], nor the chemistry of the Nitrogen species neither ionospheric chemistry. This is the main aim of this work.

Nitrogen chemistry on the LMD-MGCM

The thermospheric chemistry included in the reference version of the LMD-MGCM is described in [6]. In short, it considers 27 reactions between 12 species of the C, O and H family (in particular, CO_2, CO, O_3, O_2, O, $O(^1D)$, H, OH, HO_2, H_2, H_2O, H_2O_2). The approximation of photochemical equilibrium is used for the fastest species. The most important catalytic cycles, essential for the long-term stability of the Martian atmosphere, are included. The reaction rates are taken from the latest JPL compilation.

To simulate the NO nightglow, 5 new species of the N family have been included: N, $N(^2D)$, NO, NO_2 and N_2. The UV heating module has been extended to accomodate for the absorption of UV solar radiation by N, NO, NO_2 and N_2. This absorption can drive towards dissociation or ionization of the chemical species. 18 new chemical reactions are considered, including the photodissociations of N_2 and NO_2. As before, the reaction rates are taken from the JPL compilation.

This new chemical scheme was first implemented and tested in a 1-D model of the Martian atmosphere developed at the Instituto de Astrofísica de Andalucía (Granada, Spain) [7]. The lower CPU time requirements of such a 1-D model when compared to a GCM allowed to perform a number of tests to guarantee the stability and numerical behavior of the chemical model.

In order to be implemented in the LMD-MGCM, and given that some of these species have a very short chemical lifetime, the approximation of photochemical equilibrium has been used for the fastest constituents. The accuracy of this approximation was first carefully tested in the 1-D model.

These 5 new species are included as tracers in the LMD-MGCM, so the changes in their concentration due to dynamics, molecular diffusion and other processes can be calculated, allowing for the coupling between chemistry and dynamics.

Ionospheric chemistry on the LMD-MGCM

The main aim of this ionospheric model is to study the coupling between the plasma and the neutral atmosphere, including the effects over the energy balance and the dynamics of the GCM. The inclusion of the ionospheric module on the LMD-MGCM will also allow the comparisons with the measurements of the electron density profiles.

The model is specially designed to reproduce the main features and the variability of the mean ionospheric peak, located at about 140 km of altitude. The latest observations confirm that this region is largely controlled by photochemistry [3], therefore we do not include processes like ambipolar diffusion and interaction with the solar wind. This limits the validity of our model to altitudes below about 180 km, but does not affect the results in the region of the mean ionospheric peak.

As for the Nitrogen chemistry, the extension of the chemical scheme to include ionospheric reactions was

first done in a 1-D model. New chemical species and new chemical reactions had to be included. We have selected 37 reactions between the most abundant ions of the Martian atmosphere (O_2^+, O^+, CO_2^+, CO^+, N^+, NO^+, N_2^+, H^+, NO^+, N_2^+, H^+ and C^+). We have also modified the scheme that calculates the absorption of UV solar radiation to obtain the photoionization rates of CO_2, O_2, O, CO, NO, N_2, H and N in their different channels. The plasma is considered to be globally neutral.

In order to accelerate the calculations to make this scheme suitable for the GCM, the photochemical equilibrium approximation was tested and implemented for all the ionic species. This approximation is possible because most of the ions have short lifetimes when compared with the neutrals. A number of numerical stability and internal consistency tests have been made, showing a good numerical behavior.

Nitrogen chemistry: first results

The Nitrogen chemistry model has been exercised for a full Martian year with the aim of studying the seasonal and latitudinal variations of the NO nightglow emissions and comparing with SPICAM observations. These variations will be presented and analyzed.

We will pay special attention to the comparison of the predicted peak intensity and altitude with SPICAM observations. Two representative examples are shown in fig. 1, where the black solid lines represent the emission profiles predicted by the LMD-MGCM at the location of two specific observations of SPICAM. The observed profiles are shown as red dashed lines. It can be seen that, in the first case, the model reproduces correctly the intensity of the peak, but its altitude is overestimated. In the second case, both the intensity and the altitude of the peak are overestimated by the model. Although the model is not able to successfully reproduce each of the observed profiles, the average observed intensity is adequately predicted. However, the altitude of the predicted peak is on average higher than observed. The model also predicts an important variability of the peak intensity with local time and geographic longitude. This could explain in part the high variability observed by SPICAM.

The sensitivity of the predicted peak intensity and altitude to different parameters that are known to be important in the upper Martian atmosphere will be studied.

Ionopheric chemistry: first results

A series of preliminary results can be obtained from the ionospheric modules. They still need to be confirmed

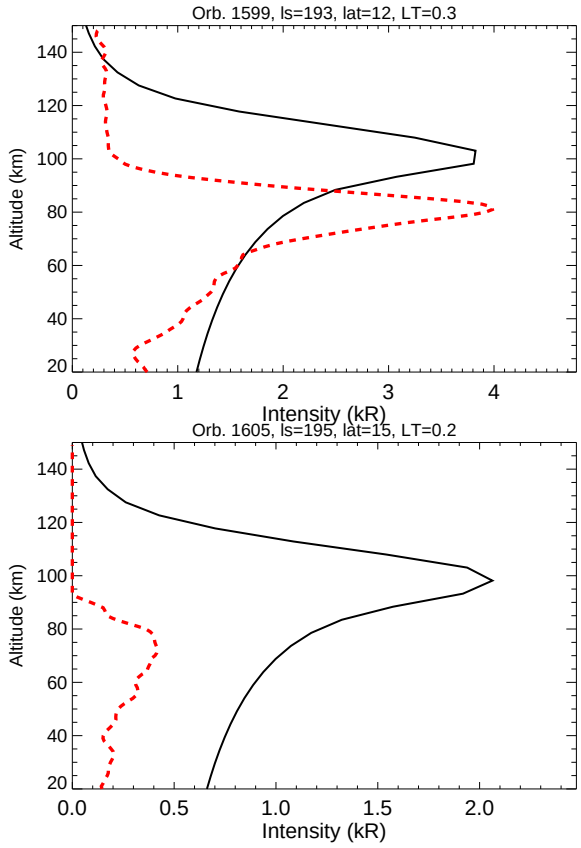

Figure 1: Red dashed lines: emission profiles observed by SPICAM at two particular orbits. Solid black lines: emission profiles predicted by the LMD-MGCM at the same location and Local Time

by further tests, so the results mentioned below should be seen more as an indication of the capabilities of the model than as evidences of a real behavior of the Martian ionosphere. However, they reproduce qualitatively some of the latest observations of the Martian ionosphere.

The ionospheric chemical scheme predicts a ionospheric peak between 120 and 140 km, approximately. The most abundant ion is O_2^+, as it is well known from previous models and measurements [8]. A lower secondary peak is occasionally obtained.

Our model can track the daily concentration changes in the ionosphere, that as expected are higher in the lower ionosphere (between about 90 and 120 km), where collisions are more frequent. Due to their short lifetime, most of the ions quickly disappear at night. NO^+ is an exception due to its longer lifetime, so it maintains a nighttime ionosphere, although much weaker than during the

day. Large abundances of NO^+ are obtained in the lower ionosphere, in good agreement with previous models [9].

The variation of the ionospheric peak with the Solar Zenith Angle (SZA) will also be presented. It will be seen that the results of our model fit well with the Chapman approximation at low SZA, with some deviation at higher SZA values. This is a typical behavior of most ionospheric models [8]. Also the altitude of the peak changes with SZA.

The sensitivity of the ionosphere to the solar activity has also been studied. The larger effects are obtained at the altitude of the ionospheric peak.

Summary

The thermospheric chemistry module included in the LMD-MGCM has been extended and includes now the chemistry of the Nitrogen family and a basic ionospheric chemistry. This opens the doors to comparisons with some of the lattest observational results, such as the NO nightglow and the electron density profiles. This will allow for a better interpretation of these observations and will be a very valuable validation exercise for the recently extended to the thermosphere LMD-MGCM.

References

[1] A. I. Stewart and C. A. Barth. Ultraviolet night airglow of Venus. *Science*, 205:59–62, 1979.

[2] J.-L. Bertaux, F. Leblanc, S. Perrier, E. Quemerais, O. Korablev, E. Dimarellis, A. Reberac, F. Forget, P. C. Simon, S. A. Stern, and B. Sandel. Nightglow in the Upper Atmosphere of Mars and Implications for Atmospheric Transport. *Science*, 307:566–569, 2005. doi: 10.1126/science.1106957.

[3] S. W. Bougher, S. Engel, D. P. Hinson, and J. R. Murphy. MGS Radio Science electron density profiles: Interannual variability and implications for the Martian neutral atmosphere. *J. Geophys. Res.*, 109:3010–+, 2004. doi: 10.1029/2003JE002154.

[4] M. Pätzold, S. Tellmann, B. Häusler, D. Hinson, R. Schaa, and G. L. Tyler. A Sporadic Third Layer in the Ionosphere of Mars. *Science*, 310:837–839, 2005. doi: 10.1126/science.1117755.

[5] M. Angelats i Coll, F. Forget, M. A. López-Valverde, and F. González-Galindo. The first Mars thermospheric general circulation model: The Martian atmosphere from the ground to 240 km. *Geophys. Res. Lett.*, 32:4201, 2005. doi: 10.1029/2004GL021368.

[6] F. González-Galindo, M. A. López-Valverde, M. Angelats i Coll, and F. Forget. Extension of a Martian general circulation model to thermospheric altitudes: UV heating and photochemical models. *Journal of Geophysical Research (Planets)*, 110(E9):9008, 2005. doi: 10.1029/2004JE002312.

[7] M. A. López-Valverde, F. González-Galindo, and F. Forget. 1-D and 3-D modelling of the upper atmosphere of Mars. In F. Forget, M. A. Lopez-Valverde, M. C. Desjean, J. P. Huot, F. Lefevre, S. Lebonnois, S. R. Lewis, E. Millour, P. L. Read, and R. J. Wilson, editors, *Mars Atmosphere Modelling and Observations*, pages 623–+, 2006.

[8] J. L. Fox and K. E. Yeager. Morphology of the near-terminator Martian ionosphere: A comparison of models and data. *J. Geophys. Res.*, 111:10309–+, 2006. doi: 10.1029/2006JA011697.

[9] V. A. Krasnopolsky. Mars' upper atmosphere and ionosphere at low, medium, and high solar activities: Implications for evolution of water. *Journal of Geophysical Research (Planets)*, 107:5128–+, 2002. doi: 10.1029/2001JE001809.