REVISITING THE RADIATIVE BALANCE OF THE MESOSPHERE OF MARS.

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Introduction

Customarily, the energy balance of the atmosphere, and the consequent thermal structure is used to define its major regions. The convective regime of the lower atmosphere is lost above a certain altitude (in the case of Mars, at approximately 40km) where radiative heating and cooling dominate the energy balance. This is where the mesosphere starts [1,2]. At these altitudes, the IR absorptions and emissions by the active molecules, CO_2 in Mars, determine the radiative field up to the mesopause (around 125 km for Mars). At this altitude and above, the solar heating in the UV and the efficient thermal conduction start to compete with the IR terms, and the atmosphere follows marked changes with the diurnal, seasonal and solar cycles [3,4].

The description of the radiative field in the case of the Mars mesosphere gets complicated due to the rupture of local thermodynamic equilibrium, or LTE [5]. The non-LTE nature of the emissions is complex in the case of a CO_2 atmosphere because many excited states participate in the emissions and absorptions in the IR, and the absorptions and emissions in their associated ro-vibrational transitions are key contributions to the productions and losses of the states [6]. Hence, a proper coupling of the statistical equilibrium equations and the radiative transfer solution is required, which has only been handled with theoretical models which are computationally very expensive. The coupling needed, and the non-linearity of the problem makes simple parametrizations not very appropriate. This is why current GCMs extending to the upper atmosphere are handling the non-LTE problem and the radiative field only partially, although important advances are currently being implemented.

The problem can be divided in two parts, the thermal cooling (TCR) of the atmosphere and the solar heating rate (SHR). These expressions refer to "net" balances, since both absorptions and emissions always contribute to the resulting balance.

1. Thermal Cooling Rates

1.1 The problem

With Thermal Cooling Rate we refer to the process by which CO_2 molecules extract energy from the thermal pool of the atmosphere and emit it to space. The typical route of this cooling is via vibrational-translational collisions (V-T energy transfer) with any molecule, mainly CO_2 and atomic oxygen, and loss of the vibrational excitation via spontaneous emission. Complications arise from the fact that the emissions are not always optically thin, and fast losses in vibrational-to-vibrational collisions (V-V energy transfer) occur to other states with different ro-vibrational bands and different optical properties [5].

When these processes dominate, the thermal structure follows a certain "radiative equilibrium" profile, which is close to a typical nighttime mesospheric thermal profiles [7]. But dynamical processes, from convergence by large scale movements or propagation of waves from the lower atmosphere, can produce departures from this situation, sometimes very large. If there are local maxima in the thermal structure the radiative cooling produced by the net emissions can be much larger. And if there are local minima, there may be a net heating of the atmosphere at that altitude by strong radiative transfer from the adjacent warmer layers [7].

1.2 Solutions so far

The parametrization employed in most GCM is that developed by López-Valverde and López-Puertas [8], first implemented in the LMD-GCM, and later in other GCMs, and which considered a reduction of the whole system of CO_2 levels to a simple system of two equivalent states, one for the strong Fundamental Band (FB) of the CO_2 main isotope in 15-um, and another for weaker 15-um bands, including the FB of three minor CO_2 isotopes and other hot transitions of the bending mode of vibration of CO_2.

1.3 More recent developments

An improved version of the parametrization [9], with an extended system of CO_2 levels and bands, more computationally expensive than the first solution,

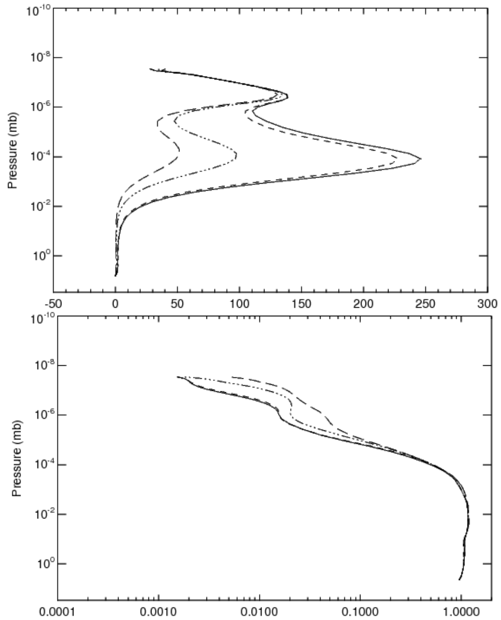

Figure 1: Impact of the solar illumination on the solar heating rate. Top panel: Solar Heating Rate profiles computed for SZA = 0 (solid), 30 (dashed), 60 (dash-dots) and 80 degree (long dashes), in units of K/day. Bottom panel: Ratio of the non-LTE to LTE SHR for the same four values of SZA; similar linestyles than in the top panel; note the log scale.

has been implemented in the LMD GCM, and research is on-going in order to obtain a substantial acceleration of the numerical code.

2. Solar Heating Rates

2.1 The problem

The non-LTE nature of the CO_2 state populations also affects the processes by which the solar energy is employed in heating the atmosphere. At high altitudes there is an initial absorption of the solar flux exciting a number of CO_2 vibrational states, but all this energy is not immediately converted to thermal velocities of the atmospheric molecules. The states involved in the solar absorption loose their vibrational excitation either via collisions or via spontaneous emission. In the second case there is no heating of the atmosphere, which is why an LTE approximation to the SHR at sufficiently high altitudes would produce an extremely large (and wrong) heating rate at those layers. In the case of collisional relaxations, a fraction of the excitation energy may be transferred to the thermal pool, but a larger fraction is normally transferred to other states via V-V collisions, or a mixture of V-T and V-V exchanges. The fraction finally thermalized is the result of a large series of paths between different CO_2 states, involving radiative re-absorptions in different CO_2 ro-vibrational bands [10].

2.2 Approximate solutions so far

A relatively simple approximation has been in place in most GCM of the Mars upper atmosphere, based on the results of López-Valverde et al, 1999. The approximation suggested by these authors is based on the fact that the net solar absorption and heating is mostly controlled by the density of the atmosphere, and to a lower degree by other parameters like solar zenith angle and the thermal structure. Since the density variation is included in any LTE computation, a ratio of non-LTE to LTE SHR would be an efficient method to incorporate the non-LTE effects in any GCM. The tables of those ratios proposed by López-Valverde et al., 1999, obtained for fixed values of SZA (maximum illumination) and atomic oxygen, can be converted to a simple formula for its implementation into GCMs [11,12].

2.3 Recent developments

We are currently working on the development of a better parametrization of the SHR. The idea is to incorporate other dependencies, at least three of them on three factors of importance: atomic oxygen abundance, thermal structure and SZA. A large set of 1-D calculations has been performed with the full non-LTE model developed in Granada for the Mars and Venus atmospheres [6,10,13], in its latest version [14], for varying atmospheric conditions. Some results follow.

Figure 1 shows the effect of changing the SZA on the SHR (left panel) and the impact on the ratio of non-LTE to LTE SHR (right panel). The calculations apply for one particular reference atmosphere (T/P profile), but similar results were obtained for other likely thermal structures. The largest impact on the SHR occurs around 0.1 microbar, and shows that the solar heating decreases with SZA, as expected. The error on the non-LTE/LTE ratio introduced by neglecting the SZA effect is illustrated in the second panel of Figure 1, and it increases with altitude.

And Figure 2 shows how a variation of atomic oxygen modifies the resultant SHR. As expected, a larger atomic oxygen abundance increases the thermalization, and therefore the SHR obtained. The maximum effect is obtained between 0.1 and 0.001 microbar for this particular atomic oxygen profile (that used in the parametrization mentioned above).

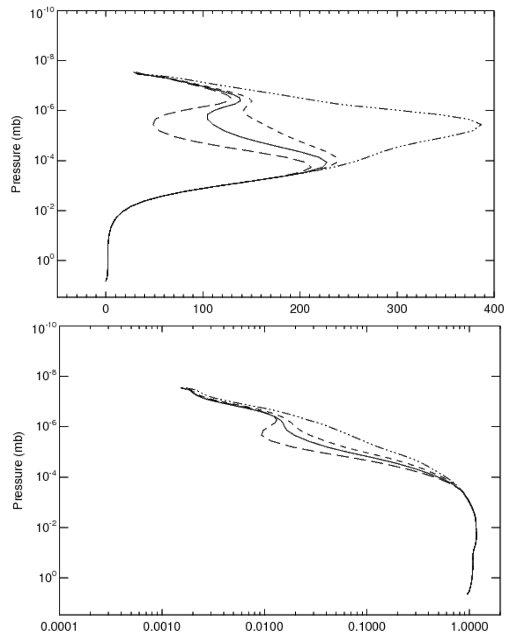

Figure 2: Impact of atomic oxygen abundances on the solar heating rate (top panel) and on the ratio of non-LTE to LTE SHR (bottom panel). The reference atomic oxygen profile was multiplied at all altitudes by factors 0.1 (long dashes), 1.0 (solid), 2.0 (dashed) and 10 (dash-dots). Units as in Figure 1.

Other aspects under investigation are those related to uncertainties in rate coefficients during V-T and V-V collisions, and on re-formulations of the problem in the full non-LTE model to prepare it for alternative parametrization. We will present and discuss an update of these results at the conference .

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