MARS MESOSPHERIC WINDS: STRATEGY FOR ACCURATE COMPARISONS BETWEEN GROUND BASED OBSERVATIONS AND GCM MODELS .

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Introduction

Ground based observations at high spectral resolution of the atmospheric non thermal (non-LTE) emission of CO2 around 10 um are becoming one of the best tools to sound the winds of Mars at mesospheric altitudes. With enough spectral resolution, the CO2 lines observed contain information on both the kinetic temperature of the atmosphere, via the rotational structure, and on the winds along the line of sight, from the Doppler shift of the lines [1]. Recent effort has been done for the estimation of the altitude of the emission layer in both Mars and Venus, and on how the emission varies with parameters like the pointing altitude (limb versus nadir observations) or like the SZA [2]. However, ground observations present other difficulties for their correct interpretation. One of the major ones is the large area observed with the IR telescopes used so far, which imposes a large spatial averaging. The impact on the interpretation of the measurements is difficult to estimate quantitatively without a dedicated and precise modelling.

On the other hand, atmospheric global circulation models for Mars extend nowadays to mesospheric and even higher altitudes [3]. But these theoretical frameworks requires data, in particular winds, to validate their predictions at those altitudes. A comparison of GCM predictions of winds' speed and direction with ground based observations is therefore of high value.

The main purpose of the present work is to design a sounded strategy for a more correct comparison of ground based measurements of Mars mesospheric winds with GCM simulations than what has been done so far. We present here the first results of an on-going work devoted to this problem. The method has been applied to recent measurements carried out with the Cologne Tuneable Heterodyne Infrared Spectrometer (THIS) at two observatories, the McMath-Pierce Solar Telescope on Kitt Peak, Arizona and the NASA InfraRed Telescope Facility on Mauna Kea, Hawaii. The measurements are compared to wind simulations taken from the Mars Climate Database [4,5] for the appropriate local times, latitudes and seasons. For details of the observations and the first results of the comparison we refer the reader to a companion contribution in this conference [6].

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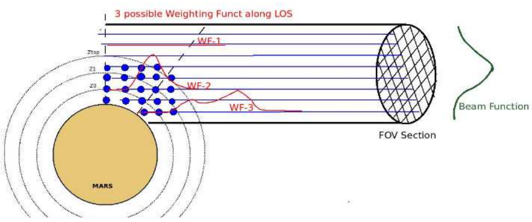

Figure 1: Schematic diagram of a telescopic beam pointing to a large area of the Martian disc, including limb and nadir ray pointings. A number of points along different lines of sight within the beam show, together with the "beam function", represent the 3-D FOV and the geometry of the problem. Three weighting functions for three line of sights pointing at different tangent altitudes are added in a cross section of the FOV to illustrate the possible variations of the radiative contributions with tangent altitude and with distance along the line of sight.

Goals and difficulties

The problem can be split in four tasks, or goals of this study.

1) First, to define clearly the geometry of the problem. Normally, wind measurements are performed pointing the ground-based telescope to the limb of Mars (or Venus). This permits the maximum signal in an optically thin medium like the upper Martian atmosphere, since an atmospheric tangent path is much larger than a nadir-pointing line of sight. This first objective is aimed at describing the proper field of view of the instrument and telescope, including its Airy function and integration time, and also planetary parameters like Earth-Mars distance and rotation of Mars at the particular pointing, and the fraction of the Mars disc and atmospheric limb which are relevant to the measurements. See figure 1 for a drawing that shows the 3-D nature of the problem.

2) Second, to use a radiative transfer model of the CO2 emissions to define clearly the 3-D emission region which actually contributes to the radiance measured from ground. This requires a computation of the radiative weights from all the altitudes sampled in the obser-

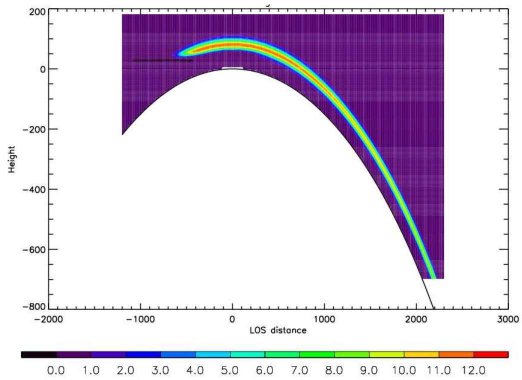

Figure 2: Simulation of the NLTE 10-um emission layer in a 2-D cross section of the Mars atmosphere. The emission varies with tangent altitude and distance along the line of sight. The line of sight, or point of view of the observer/ground based telescope, is to the right of the figure. Both limb and nadir pointings have a peak at mesospheric altitudes, as previously obtained by [2]. The integration of these functions along the line of sight is shown in Figure 3.

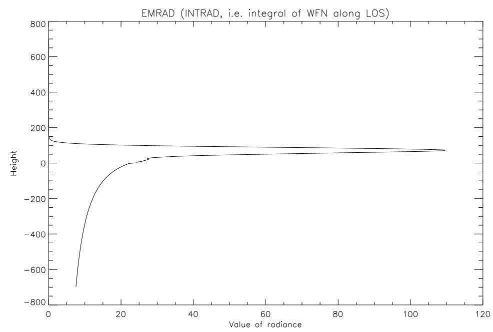

Figure 3: Simulation of the radiance emitted along the line of sight, obtained for a particular 1-D reference profile of the Martian atmosphere, extracted from the MCD. The vertical axis is tangent altitude over the planet; negative values for nadir pointing (see Figure 1). The maximum is obtained for a tangent altitude around 75 km.

vations along all the 2-D map of lines of sights which comprise the observations. To describe the 3-D field of weightings correctly, a fine grid is required, which makes this part an intensive computing exercise. This is because the grid is large and a full NLTE line-by-line radiative transfer model is needed to handle a mixture of optically thin and thick conditions and geometries.

3) Third, to sample the MCD to extract the winds along the line of sight at all the points of the 3-D field determined before. Since the grid used in the problem is determined by the telescopic observations, a number of 3-D interpolations is required in the dataset. The MCD is particularly well suited to such exercise, as it incorporates a routine to extract the fields at arbitrary points within the limits of the database. A geometrical projection is then required to convert the zonal, meridional and vertical wind components extracted from the MCD into components along the line of sight of the observations, from which we calculate the line-of-sight (LOS) wind.

4) Finally, a weighted average of the winds in the 3-D emitting region and considering the geometry of the observations is performed, which can now be compared to the winds determined from the observations. This is based on the assumption that the radiative and geometrical weightings apply to both the actual radiance observed and to the Doppler shift from where the winds are derived. The radiative weightings are always positive since they describe the contribution from a given path of region. The Doppler shifts induced by the winds can be positive or negative, depending on the wind direction. Both are multiplied, and normalized, to obtain the averaged Doppler shift in the whole region that is sounded in the observations.

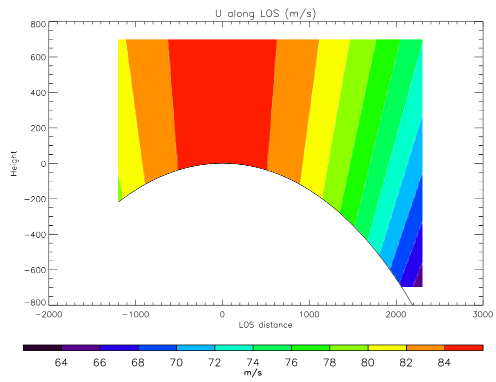

Figure 4: 2-D cross section of the winds projected along the line of sight in our problem, for an idealized constant zonal wind of 85 m/s. As in Figure 2, the viewing direction coincides with the lines of sight. The shape of Mars looks distorted due to the focus in the vertical scale. The wind value is maximum and equal to the zonal wind exactly at the limb (red area). See text.

Preliminary results

Although the work is ongoing at present, a number of results can be advanced.

Regarding the radiative contributions, there is a dominance of the atmospheric limb, in comparison to the nadir contributions (disc of the planet). This can be seen in Figures 2 and 3. This result is not surprising, for the geometrical reason mentioned above, but also due to the nature of the NLTE emissions at 10-um. These are specially strong in a well defined atmospheric region between 70 and 100 km, where the maximum absorption of solar radiation occurs in the CO2 ro-vibrational fundamental band at 4.3 um [2]. This absorption is the responsible for the daytime enhancement in the population of the CO2(001) state, the upper level of the 10-um emission band. The resulting weightings in Figure 2 indicate a strong contribution from a layer around 75 km, and an exponential decrease of the contributions above this altitude.

Regarding the wind field, in order to gain some insight into the major geometrical variations, a simple idealized wind structure was used, with only a zonal component of the wind aligned with the beam of the observations, and with a constant value of 85 m/s towards the observer. This simple case facilitates a comparison between the contributions of different regions to the outgoing emission. In the companion paper [6] a more realistic field, extracted from the MCD, is compared with the observations.

A first result is that the areas inside the disc of the planet (the nadir-pointing lines of sight) have a projected component of the wind along the line of sight which decreases as the pointing gets closer to the center of Mars (as the emission angle decreases). In other words, only a small fraction of the zonal wind is actually measured in this part of the field of view. On the other hand, the limb component is closer to the actual zonal wind. This can be seen clearly in Figure 3. When this is combined with the radiative weightings (not shown here), there is a strong contribution at the limb, with minor contributions in a much more extended area covering the nadir pointing. The precise weightings allow us to evaluate the error of assigning the wind measurements to a single altitude at the limb, as it has been done so far for simplicity.

As mentioned above, these results still need to be convolved with the beam function of the actual measurements. Figure 4 depicts a typical example of such functions, in this case taken from the observations mentioned above [6]. They have been shifted in the vertical in 250 km to study the impact of possible telescope pointing uncertainties, and are convolved with the winds along the line of sight of Figure 3 (not with the radiative weightings).

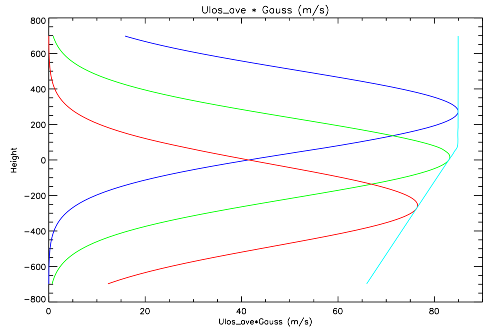

Figure 5: Airy functions of a particular ground observation campaign described by Sonnabend et al, 2011, pointing at the limb of the Mars disc (green line). The same beam but shifted upwards (to 250 km above the planet limb, in blue) and downwards (250 km towards the center of the planet, in red) are also shown. The Airy functions are weighted by the wind component along the line of sight obtained for an idealized wind field, as shown in Figure 3.

We will present and discuss the global convolution of all the geometrical functions and the implications for the averaged winds obtained in a more realistic mesospheric wind structure. The effects of atmospheric variability and of modeling uncertainties are still under investigation and will be presented only briefly. Although the methodology presented is applied here to a particular set of measurements and models, it is general and suitable for comparisons between other observations and models. Hence, recomendations for future observations and model comparisons, will also be given.

References

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[6] Sonnabend et al, 2011, companion work in this issue.