LOOKING FOR PRESSURE WAVES IN THE MARTIAN ATMOSPHERE — A COMPARISON OF ISM AND MOLA DATA SETS.

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Introduction: Topographic maps of Mars were derived from NIR spectral observations by ISM/Phobos-2 in 1991. These maps were computed by comparison of the profile of the 2-µm CO_2 band with modeled atmospheric spectra [1]. The overall accuracy was estimated to be on the order of 100 m. However, topography as estimated from absorption measurements depends not only on the atmospheric path length, which varies with surface elevation, but also on several other factors as detailed below. In particular, pressure variations along the line of sight affect these estimates: wherever the atmosphere is denser, the path length appears longer and the surface elevation is underestimated. Conversely, the comparison with direct measurements of the topography (i.e., MOLA observations) can evidence these variations of atmospheric pressure at the time of ISM observations. A first order comparison is presented here, with the particular aim to look for pressure waves, as described by [2].

Method: We used the calibrated data in the form available in the ISM PDS data base (accessible at http://www.ias.fr/cdp/Base_ISM). Projections of the data on the Martian surface were originally computed from orbital parameters and instrument characteristics. These coordinates proved to be in error by a few tens of arcminutes, so that the session maps were translated in both latitude and longitude in order to best fit the Mars topographic map available at the time, as detailed in the data base documentation [3].

In the present work, the ISM sessions have been registered on the MOLA topographic map, which is much more accurate [4]. The MOLA data were first degraded to ISM spatial resolution, ~25 km/px. Registration consists in a simple translation of the ISM sessions so as to get the best correlation between the two sets of measurements. No attempt is made to correct possible internal deformations. This correction amounts to ~1°, i.e. 2 ISM pixels. The results found with this method are listed in Table 1. The first column represents the name of the session, as described in [3]. The second and the third column contain the offset added to ISM longitude and latitude, respectively. Residual mismatches due to internal deformations of the ISM sessions are limited to about 1 ISM pixel.

On the first order, the match is better with MOLA than it was with the previous topographic map, essentially derived from stereophotogrammetry measurements from Viking. This latter method is intrinsically less accurate in smooth areas with minor variations in elevation.

Session name	Offset in longitude	Offset in latitude
Arabia	-0.3125 °	0.3125 °
Daedalia	-0.6875 °	0.8125 °
Syrtis-Isidis	-1 °	1.125 °
Valles Marineris	-0.0625 °	1.25 °
Aurorae	-0.6875 °	1.25 °
Olympus	0.4375 °	0.4375 °
Gordii	0 °	0.5625 °
Ascraeus	-0.3125 °	0.6875 °
Hebes	0.1875 °	0.9375 °

Table 1

In a second step, we computed an optimized correlation between ISM and MOLA measurements. For each ISM session, we determined the most linearly correlated parts of the images, and computed the linear regression coefficients in these regions only. The coefficients were then used to scale the part of the MOLA topographic map overlapping the ISM session. MOLA altimetry was converted into pressure, using the same relationship between altitude and pressure used for ISM by [1]. Finally, we subtracted these two images. The residual images, as explained before, are expected to contain information about variations of pressure in the atmosphere.

Results: However, the differences between MOLA and ISM altimetry data may result from many other causes, including: differences in mineralogical composition between two neighboring areas; residual difference in spatial resolution; misregistration of the two images, including internal deformations in the ISM images; limitation in the model used to retrieve pressure from ISM band depth. Our purpose was to isolate, among the features cited above, those which result from differences in atmospheric pressure. We first checked that the features in the residual maps are not systematically correlated with MOLA measurements, suggesting that they are not related to limitations in the atmospheric model used here. We also compared the residual images with maps of reflectance and various spectral parameters from ISM, and checked that they are not related to spectral features due to specific surface compositions.

In the figures presented below, negative residues are figured in blue, indicating that ISM provided lower pressures than MOLA. If we interpret these features in terms of pressure, they thus correspond to 'depressions' at the location and time of ISM observations. Conversely, red zones correspond to 'overpressures'. Figure 1 shows a feature similar to a pressure wave, with three high pressure areas separated by lower pressure areas. Such features are expected in the Martian atmosphere [2], and have indeed been measured by the Viking landers as temporal variations over a given location. The pressure variations, which are on the order of 0.1 mbar, appear consistent with the variability measured at the Viking landing sites, which can reach 1 mbar [5].

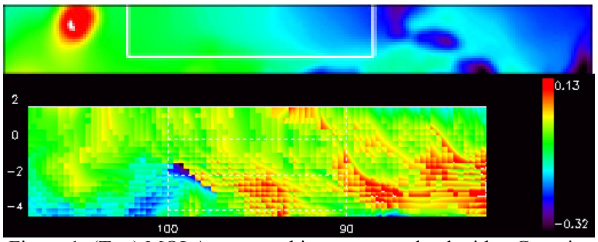

Figure 1: (Top) MOLA topographic map convolved with a Gaussian function to ISM resolution, over the footprint of the Hebes session. (Bottom) Residual image corresponding to the rectangle in the top image. This is the most explicit example of a possible pressure wave.

Figure 2 and 3 show a region observed twice by ISM, which allows comparing the state of the atmosphere on two different days, and at two different local times.

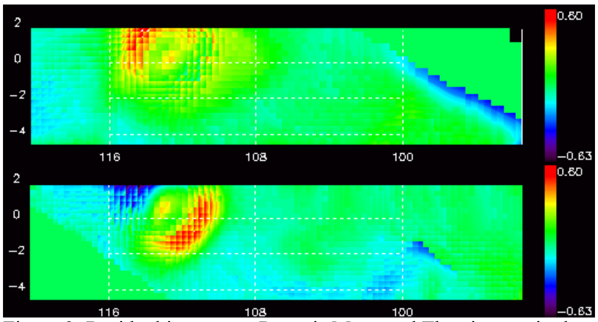

Figure 2: Residual images on Pavonis Mons and Tharsis, acquired on two different occasions (see text). Many differences in pressure (detailed in figure 3) can be seen eastward of Pavonis Mons. The scale is the estimated pressure difference relative to MOLA, in mbars.

The main structure with circular outline, present on both images, is Pavonis Mons. The image on top corresponds to the session acquired on March 14th, 1989 (Gordii) at local times ranging from 3 to 4 PM. The bottom image is derived from the session acquired on March 26th (Hebes) at local times 10:30 to 11:30 AM. The Martian season is Ls ~ 15° (early northern hemisphere spring). The most striking difference is related to the location of the overpressure (the red area), on the western flank of the volcano in the top image, and on its eastern flank on the bottom image. This can be attributed to the different illumination conditions, with higher pressures observed over the illuminated slope. In both cases, an apparent overpressure is also observed inside the caldera of the volcano; this, however, can be related to important scattering by aerosols inside the caldera, as evidenced by [6]. Other differences can be noticed on Tharsis, eastward of Pavonis Mons, which are enlightened in Fig. 3.

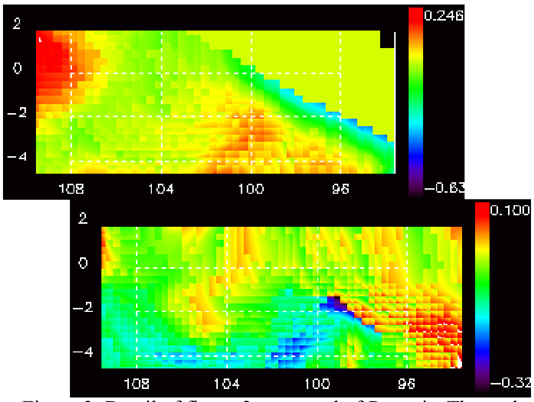

Figure 3: Detail of figure 2, eastward of Pavonis. The scale is the estimated pressure difference relative to MOLA, in mbars.

The bottom frame in Fig. 3 is actually an enlargement of Fig. 1. This region includes many areas where pressure is higher than expected. Possible dust concentrations have been previously mentioned by [6] in this area, for this single session. The present features are indeed not observed on the Gordii session acquired 12 days before (top frame of Fig. 3), demonstrating that the possible atmospheric structures detected in Fig. 1 are not permanent features. The distance between consecutive maxima observed in Fig. 1 (typically 500 km) could represent the wavelength of pressure waves. However, no atmospheric wave has been observed on Mars at this scale. Alternatively, these features are apparently consistent with Lee vortices on the Tharsis volcanoes [2], the amplitude of which is expected to reach at least some 0.01 mbar.

Conclusion: This first order comparison between ISM and MOLA data evidences subtle variations in pressure measured by ISM from the Phobos-2 spacecraft. Some of these features have a spatial structure consistent with Lee vortices several 0.1 mbar in amplitude, or with waves with characteristic wavelength ~500 km. Further atmospheric modeling is required to identify other possible atmospheric structures in the ISM data set.

References: [1] Rosenqvist, J. (1991) PhD thesis, University Paris-7. [2] Kahn, R (1983) *JGR* 88, 10189-10209. [3] Erard, S. (1997) IAS Tech. Rep. 97-01. [4] Smith, D. E. et al. (1999) *Science*, 284, 1495-1503. [5] Zurek, R. W. *et al.* (1992) in "Mars" (Kieffer et al. eds), pp. 835-933. [6] Drossart, P. *et al.* (1991) *Ann. Geophysicae* 9, 754-760.