MAPPING MARTIAN GROUND PRESSURE USING OMEGA MEASUREMENTS IN THE 2 μM CO_2 BAND.

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Introduction

Among Mars Express unprecedented measurements, this abstract focus on the high resolution mapping of surface pressure variations by the OMEGA instrument. Beyond Mars meteorology, since such a measurement is not possible on the Earth, it is of high interest for atmospheric science in general.

We start with some elements about the quantitative measurement method for Mars ground pressure using the spectral data supplied by the instrument OMEGA. Then we give first results and ground pressure maps obtained by this method.

1. Ground pressure retrieving technique

a. General description

OMEGA [1] is a visible and near-IR mapping spectrometer, analysing diffused solar light and surface thermal emission. On each resolved pixel, OMEGA acquires a spectrum in 352 contigous spectral channels ("spectels") from 0.35 to 5.1 μm, with a spectral sampling ranging from 7 nm (visible channel) to 13 nm (near IR, from 1 to 2.7 μm) and 20 nm (short wavelength IR, from 2.7 to 5.1 μm). OMEGA has achieved global coverage of Mars at medium spatial resolution (2 to 5 km). Some high-resolution (< 350 m) spectral images are also available, when surface was observed near-periapsis.

Ground pressure value is an indicator of the quantity of gas residing at a given location. As CO_2 is the main gas composing martian atmosphere, a strong correlation exists between the relative band depth of the CO_2 2 μm absorption band and the ground pressure (an increase of 1 mbar causes an increase in the relative band depth of approximately 6%) ; this correlation is the starting point of our ground pressure mapping purpose.

b. First corrections

A difficult task in the OMEGA data analysis is the separation of the contributions from the atmosphere and from the ground. Even if the CO_2 2 μm absorption band is primarly sensitive to the atmospheric composition, the ground absorption influence on the signal received by the orbiter must not be neglected and require some correction.

Sensitivity tests have shown that the simple use of the band depth will not be accurate enough to mesure pressure variations with a high accuracy (i.e. less than 40 Pa). Consequently, we chose to focus on the 25 OMEGA spectels between 1.8 μm and 2.2 μm, i.e. the whole CO_2 absorption band at 2 μm.

c. Method description

Initially, we simulate for a given ground pressure the values of the 25 spectels of the 2 μm band, and for that purpose, we use a line-by-line radiative transfer model, using inputs (temperature profile, dust opacity) from the Mars Climate Database [2]. Then this simulated spectra is compared with the OMEGA data, and the closest fit would give us the accurate value of the ground pressure.

The minimization method chosen to estimate the ground pressure implies the calculation of many CO_2 absorption bands, one per pixel of a given OMEGA session. In order to create maps in reasonable time, simulating the absorption band must be a fast process. As the complete radiative transfer calculation is too long, and the 2 μm band depth variations are sufficiently regular, we choose to create a look-up table of spectra computed along a chosen parameter grid and calculate the wanted spectrum by multi-dimensional interpolation. Compared to a complete radiative transfer calculation, the error done with this faster method is only less than 2%.

d. Radiative transfer inputs

1. Atmospheric composition : Any other gas than CO_2 has a negligible impact on the absorption band from 1.8 μm to 2.2 μm.

2. Temperature profile : Temperature profile needed in the radiative transfer model is extracted from the Mars Climate Database as a sigma-coordinate profile. In order to lower the amount of information needed for each profile, we choose to approximate each profile by a simpler two-points profile, defined by two temperatures corresponding to the lower layer and the seventh layer. Then the isothermal hypothesis over the seventh layer and a linear representation of the lower layers (where most of the gas mass reside) are chosen. The error made with this approximation is reasonable (less than 1.5%).

3. Dust influence : Influence of dust on the solar light flux received by OMEGA (before and after having been reflected on Mars surface) must be taken in account. Atmospheric dust presence can lower the relative band depth of more than 2%, equivalent to a shift in ground pressure of 50 Pa. These effects are simulated using the Sobolev single-scattering equations [3]. Multiple diffusion is neglected (acceptable for weak optical depth i.e. $\tau < 0.6$), but in order to decrease the error caused by this approximation, we introduce a corrective factor in the equations. Dust properties for scattering are derived from Ockert-Bell [4].

4. Ground albedo : Ground is described as a lambertian surface. Surface albedo must not be too high (typically < 0.5, generally true for Mars in the NIR range) to ensure a correct diagnostic of the radiative transfer model, especially if dust optical thickness value is high. In addition, a specific spectral signature in our domain of interest must be taken in account if CO_2 ice or specific minerals (Pyroxenes HCP & LCP, see) are present on the Mars surface. Thus we compute a ground albedo varying with the wavelengths, taking in account possible icy ground or LCP/HCP presence.

2. Ground pressure maps

a. General results

Once the minimization process has come to an end, the simulated spectrum is considered fitted to the OMEGA data, and we are able to retrieve the ground pressure field P_Ω. We compare this value to a MCD "best-guess" value of ground pressure, P_{ref}, which relies on VL1 measurement, MOLA topography and global circulation pressure variations. This comparison give us a first indication of the accuracy of our pressure absolute measurement.

Relative agreement between P_Ω and P_{ref} fields is found for all the OMEGA sessions analyzed - the two fields being, as expected, under the main influence of the local topography. As P_{ref} calculation features MOLA topography, and P_Ω calculation did not feature any topographic reference, the systematic good relative agreement between the two fields validates our ground pressure mapping method.

Absolute agreement between P_Ω and P_{ref} is for most OMEGA sessions analyzed very good. However, in some cases, a systematic error between the two pressure fields emerges. This shift between P_{ref} and P_Ω observed in some OMEGA sessions must be related to the numerous hypothesis made in section 1.d : the sessions could be too dusty, or water-vapor rich, or temperature profiles are not truly simulated etc ... In addition, our method is found to be less precise in areas featuring strong topographic gradients, or insufficient insolation. Further enhancing of the method needs to be done, although results presented here can be regarded as very satisfying.

b. Retrieving meteorological signal

Our interest being meteorological analysis, we need to remove the main topographic component from the ground pressure field P_Ω. This is done by artificially moving the ground gas layer to an altitude of reference z_0 with an adiabatic transformation. We name this pressure field P_{adiab} ; topography influence have been totally removed by a process used on Earth under the well-known terminology "sea-level pressure reduction". This new field is numerically obtained for each pixel by the following formula $P_{adiab} = P_\Omega e^{-\frac{z_0 - z}{H}}$, where z is the altitude of the pixel, H is the scale height given by the MCD and z_0 is the mean altitude of the zone covered by the OMEGA session.

If we compare P_{ref} and P_Ω, a registration shift (i.e. misalignment) between OMEGA and MOLA data can be highlighted, depending on the session chosen. For any other application than ground pressure retrieving, this shift (in most cases no more than 1 to 3 pixels in longitude and/or latitude) leads to an acceptable error. However, in our case, such a shift leads P_{adiab} maps to be strongly correlated to altimetry, which is clearly not wished. We thus need to correct this registration shift. We make the (rough) hypothesis of a linear shift on all an OMEGA session and we minimize a "special" euclidian distance between P_{ref} and P_Ω fields (after substracting 2D linear regression of these fields). The "special" euclidian distance is designed with exponentials to ensure a shift correction based on the main topography features. The correction obtained is good, and the features seen in the P_{adiab} field no longer depend on topography variations. Moreover, artificially higher/lower pressure values at the borders of any topographic accident (mountain or crater) are removed by the shift correction. Note that supposing the shift to be linear over a whole session could be quite a false assumption ; that is the reason why, when zooming on a particular zone in a given session, we choose to re-calculate the shift only for the two fields P_{ref} and P_Ω reduced to this special zone. This latter correction allow us to check the linear hypothesis leads to acceptable errors in the shift correction process.

c. Examples of ground pressure maps

1. ORB0278_3 : This medium-resolution session is located near cratered terrains in Arabia Terra at Ls = 16 (beginning of Northern Spring). Note the very good quantitative and qualitative agreement between P_{ref} and P_Ω fields (see figure 1 top and bottom). Plotting the P_{adiab} field allows us to find local depressions within the craters, and

higher pressure zones near craters'borders (see figure 2 top). Between 9N and 12N, these zones of higher/lower ground pressure seems to be oriented north/south, and could be correlated with the synoptic-scale southern ground wind indicated by the MCD for this region at this season. However, a specific study of flow/obstacle interactions, involving meso-scale dynamics, is needed for further analysis of such ground pressure signatures.

2. ORB0363_3 : This medium-resolution session was first chosen because it corresponds to Viking Lander 1 location. It is located in a plain in Chryse Planitia, at Ls = 28 (Northern Spring, low probability of major dust storms). Agreement between P_{ref} and P_{Ω} fields is qualitatively and quantitatively good (not shown). The P_{adiab} field shows areas of higher pressure values in the vicinity of some craters (see figure 2 bottom). These areas seems to be located for instance southern of the 12-14N 310-312E craters, and eastern of the 17-20N 313-314E small craters. This orientation of higher pressure zones could be correlated quite well with synoptic-scale southern ground wind indicated by the MCD for this region at this season, but as mentionned before, mesoscale simulations are needed for further analysis.

3. ORB0964_5 : This high-resolution session is located western of Kasei Vallis and eastern of Alba Patera/Tharsis volcanoes, at Ls = 102 (beginning of Northern Summer). Part of the session is not very well insolated, and is obsolete. Zooming in the correct part of the session reveals however a quantitative and qualitative good agreement between P_{ref} and P_{Ω} fields (see figure 3 top and bottom). In addition, on the P_{adiab} field, a spectacular feature, showing alternating higher/lower pressure values patterns, appears above a local terrain elevation near 33.5N (see figure 4 top). This could be interpreted as a gravity wave signature, but, again, we must perform some meso-scale simulations to investigate the meaning of this surface pressure signature.

d. Sensitivity tests

Some additionnal sensitivity tests and VL1 comparison have also been conducted using results of ORB0363_3. Pressure mapping does not seem to be very sensitive to optical depth variations. Same conclusion can be drawn for realistic temperature variations (see figure 4 bottom). Moreover, P_{Ω} at VL1 location is close enough to VL1 measured pressure at the same time to consider our ground pressure calculation as satisfying. Let us mention as an end that a Monte-Carlo statistical analysis was performed, taking in account instrumental and numerical sources of uncertainties. RMS error on pressure retrieval was found to be around 7 Pa, which is very satisfying.

Conclusion

Observing and analyzing the variations of the atmospheric pressure on the surface of a planet is essential to understand the dynamics of its atmosphere. To this end, we designed on Mars a remote sensing technique to retrieve ground pressure maps, using the main phenomenon that 2 μm CO_2 absorption band depth is an indicator of the martian ground pressure. We used data from Mars express OMEGA spectrometer, a fast and accurate line-by-line radiative transfer model, an additive single scattering model and a ground contribution modelisation. We were then able to get ground pressure maps correctly correlated, quantitatively and qualitatively, with the MOLA topography (given a small registration shift correction). Using an adiabatic reduction of ground pressure to a level of reference, it was then possible to remove the main topographic component of the pressure signal, and detect local meteorology phenomena such as barometric depressions, or gravity wave signature. Further understanding of ground pressure signatures observed should be obtained by completing the Mars Climate Database analysis with some meso-scale simulations.

References

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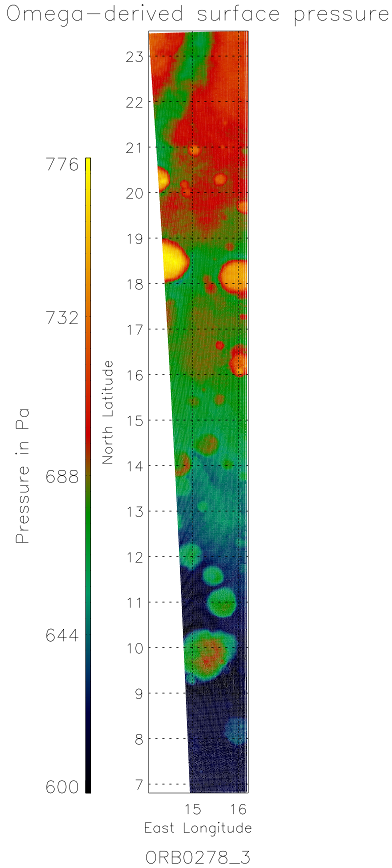
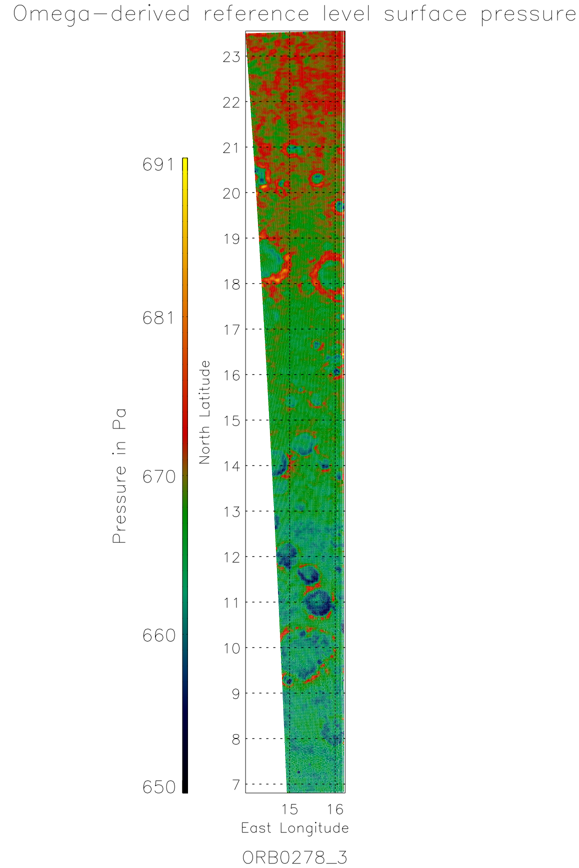




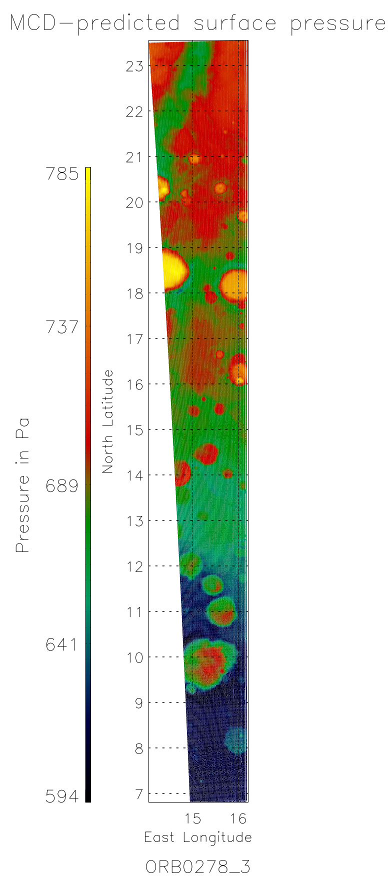
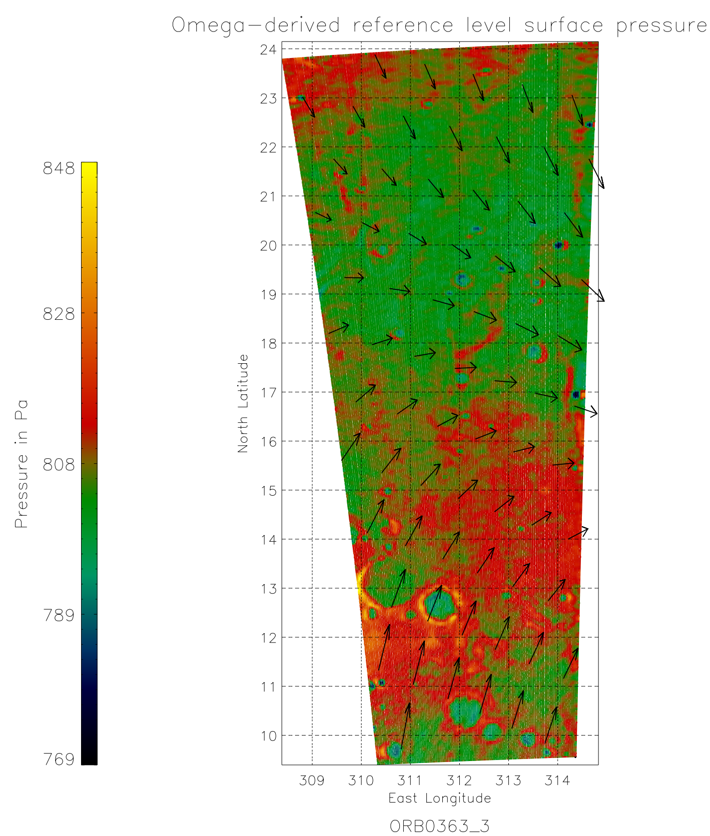


Figure 1:



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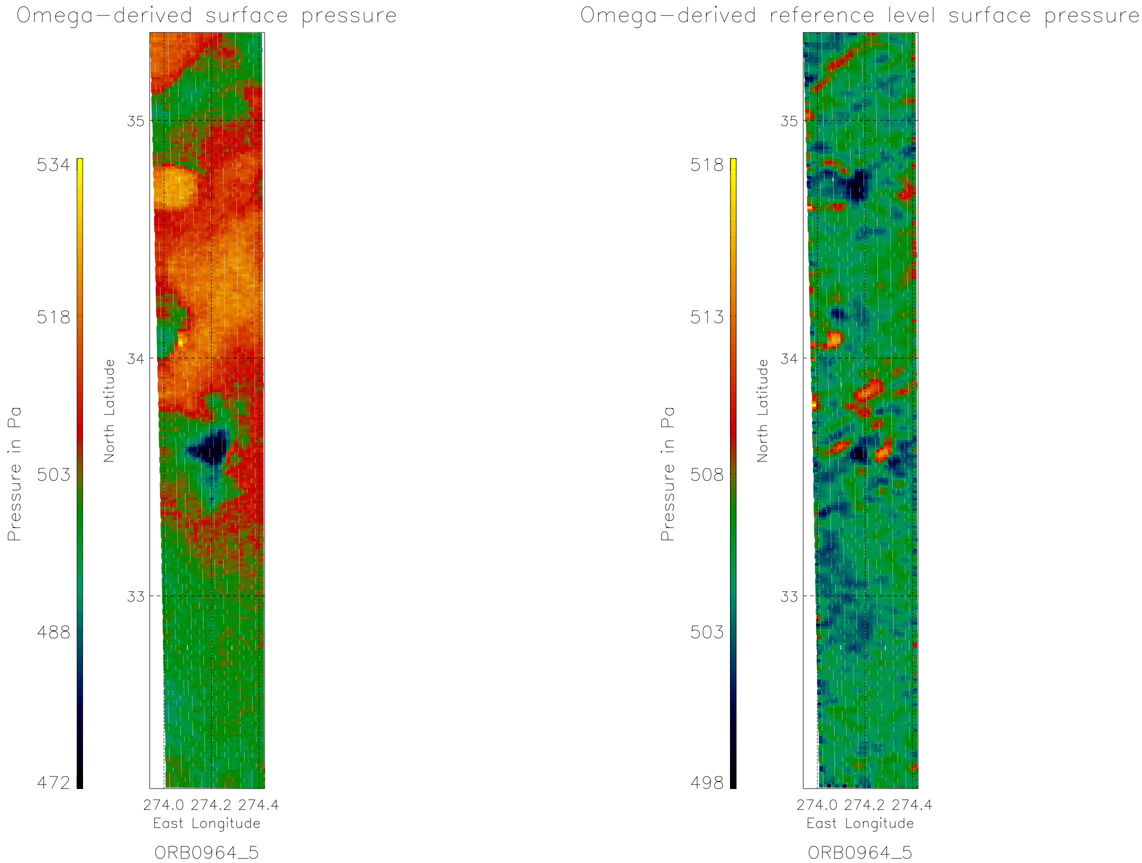

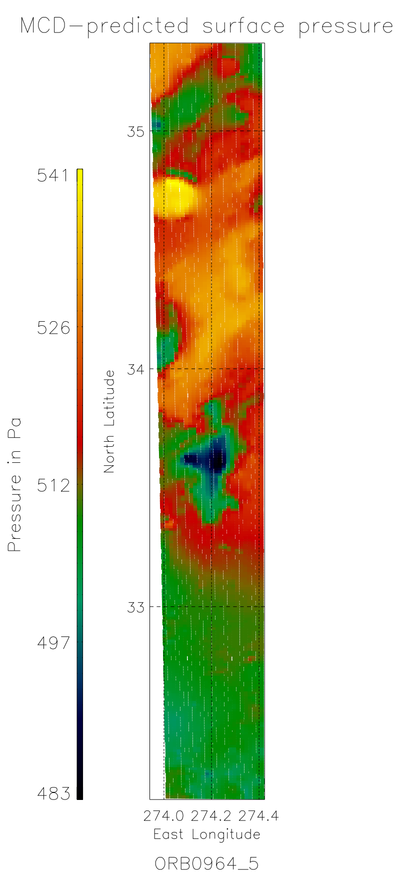

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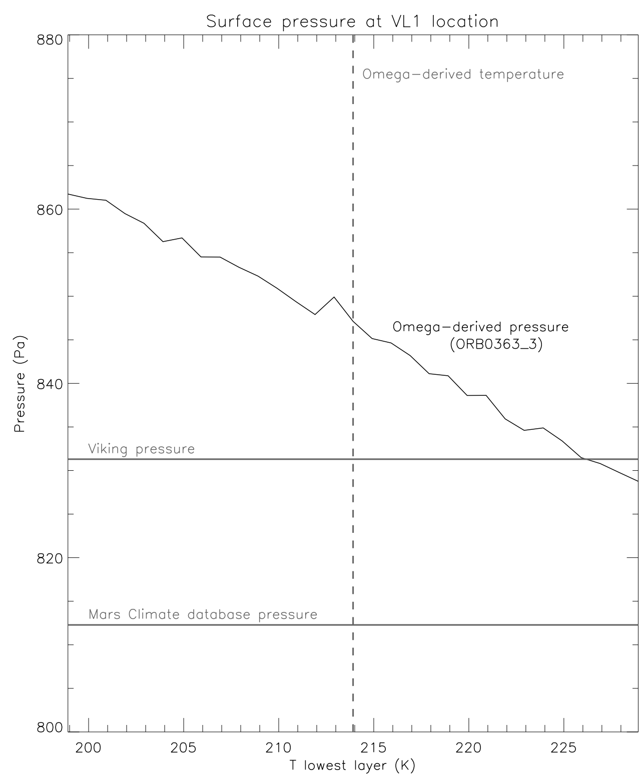

Figure 4: