Mem. S.A.It. Suppl. Vol. 11, 53

Memorie della
Supplementi

Martian Aerosol characterization: Factor Analysis and Target Transformation applied to PFS-MEX data

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Abstract.
A retrieval technique is applied on data coming form the Planetary Fourier Spectrometer (PFS) instrument, onboard the Mars Express ESA mission. The data is composed by spectra collected in the TIR-NIR region. Ar result four representative spectral shape are extracted, describing the atmospheric dust and water ice clouds, a blackbody and a residual of the instrumental responsivity, showing as at this level the calibration process is not completed. Using these components to model the observation, the opacity latitudinal profile for dust and water ice clouds can be derived. Comparison with results based on radiative transfer approach show a good match.

Key words. Mars: aerosols , atmosphere , dust , water ice clouds

1. Introduction

PFS is an infrared spectrometer optimized for atmospheric studies and cover the wavelength range 1.2 to 45 μm (220 to 8190 cm^{-1}) splitted in two channels with a boundary at about 5 μm., called Long and Short Wavelength Channels (LWC and SWC) (Formisano et al. 2004). The instrument field of view is about 2 degrees FWHM (Full Width, Half Maximum) for the Short Wavelength (SW) channel and 4 degrees FWHM for the Long Wavelength (LW) channel. These fields of view correspond to a spatial resolution of 10 kilometers for the SW channel and 20 kilometers for the LW channel when Mars is observed from a height of 300 kilometers (the nominal height of the pericentre). The spectral resolution is of approximately 1 cm^{-1}. After about 2 martian years of activities more than 300.000 spectrum has been collected, from which a wide range of properties of atmosphere and surface of Mars can be studied, but there is still the need to study the surface in an effective way. The variety of atmospheric scenarios seen by the instrument, as varying concentration and composition of aerosols, doesn't allow for and easy extraction and interpretation of surface features. The aim of this work is to investigate on atmospheric components by means of Principal Component Analysis (PCA) and Target Transformation (TT) to determine their varying contributions in the observation (Bandfield et al. 2000). The final goal is in the direction to develop a feasible

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and accurate methodology to extract the surface features from the PFS data to take advantage of its high resolution.

2. Method

When a sample is observed (in remote or in laboratory) it is common that is composed of a mixture of several pure components. Determining the composition, or the relative abundance of components, of the sample from its spectral characteristics is a very common task in remote sensing data analysis. It is also common that superposition of several feature in the same zone can complicate the extraction of results, but usually a correct interpretation lead to results that cannot be extracted in other ways. These techniques are demonstrated to be able to extract the composition of laboratory sample (Smith et al. 1985), to extract the principal varying components from a big spectral data set in the thermal infrared (Bandfield et al. 2000) and then to identify them as atmospheric components of Martian atmosphere and separate their contribution from surface emission (Smith et al. 2000).

The identification of the principal varying components is accomplished by the PCA, that extract the eigenvectors and the eigenvalues from the covariance matrix, and from their relative values, establishes how many eigenvectors are needed to reconstruct the system in a linear fashion whitin the noise level of the data. Measurements can be written in matrix form as

$$D = R \cdot C$$

where D are the data, and R represent the matrix of reconstructing vectors and C are their concentration coefficients. The PCA decompose D in two matrix, where R will be composed by the orthogonal eigenvector extracted from D. This technique essentially reduces the dimensionality of the dataset, allowing to describe them as a combination of a limited number of eigenvectors. When the eigenvectors, eigenvalues and the minimum number needed to describe the data are evaluated, the TT technique allow to translate the R matrix by rotation in a set of physically significant vectors

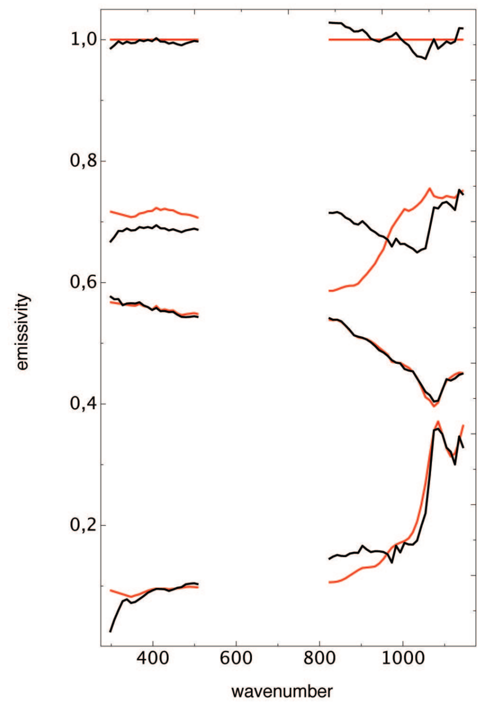

Fig. 1. Trial spectra from spectral library (dust and water ice clouds are derived from TES data) in red and their projection in black, shifted for clarity. From top : blackbody,dust clouds, water ice clouds, instrumental responsivity represent.

(i.e. vectors that can be easily recognized as a spectrum of a material, for example a mineral). Therefore the R matrix will translate a test vector t_n as

$$x_b = R \cdot t_n$$

where t_n came from a trial library, and x_b represent the projection of the test or trial spectrum in the space generated by R. If the distance $[x_b,t_n]$ is little, the original vector x_b belong to the space generated by R and can be used to form a new base of physically significant vectors that will reconstruct the original dataset D. Also if x_b and t_n are different, the x_b vectors will represent an accurate reconstruction of the pure component that vary in D (Bandfield et al. 2000). This process is iterated until the dimensionality of the new

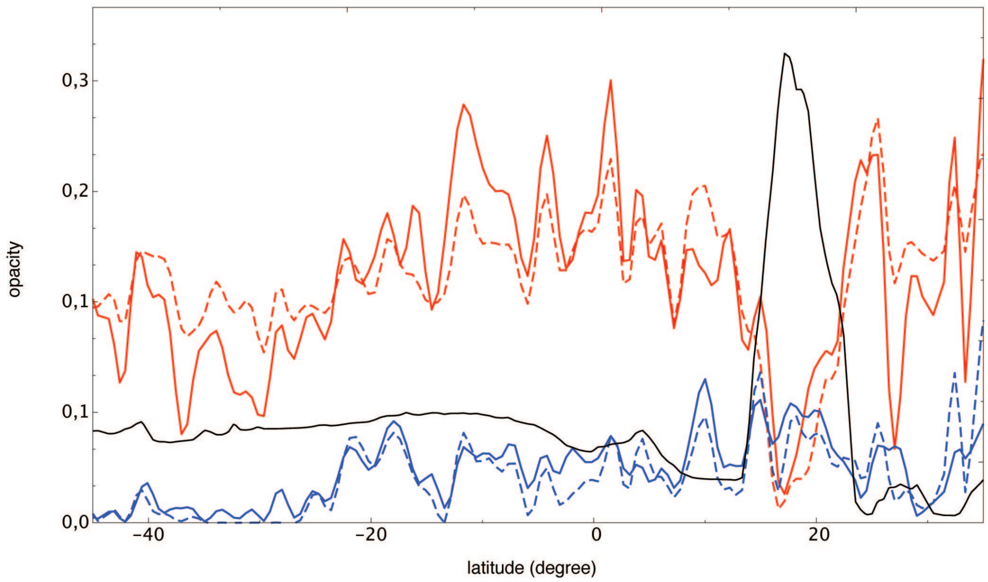

Fig. 2. Opacity of atmospheric components. Dust clouds are in red, water ice clouds in blue. Continuous line are data extracted in this work and dashed lire are data from Grassi et al. (2000).The black line is the MOLA altitude calculated on the footprints of PFS in arbitrary units, ranging -2,5 km from to 21 km.

base reach the number of needed eigenvetors estimated . This process also introduces user bias and its experience in the trial trial library construction and projected vectors selection. When the composition in term of atmospheric components is calculated, following Smith et al. (2000) it is possible to separate the contribution of the atmosphere from the surface, adding to the linear model that describe the observation the mineral constituent of the soil, as

$$D = \left(\sum_i c_i \cdot S_i\right) \cdot \left(\sum_j a_j \cdot R_j\right)$$

where S_i represent the soil components whit their concentration coefficients c_i, and the R_j are the atmospheric components with their concentration coefficients a_j.

3. Application

The data used in this study come from the orbit 37 of Mars Express. The first application is based on a reduced-resolution set (from 1 cm^{-1} to 10 cm^{-1}) to increase the Signal-to-Noise ratio and to a direct comparison with the Thermal Emission Spectrometer results. The trace on ground of PFS pass directly over the Olympus Mons caldera. The orbit is essentially South-North, whit Ls 337^o, local time is about 13, temperature at the surface great than 240 ^{o}K. The PCA analysis gives as result that four endmebers are needed to reconstruct the system, and after TT transformation, they are interpreted as spectral shape of atmospheric water ice clouds, atmospheric dust, a blackbody and a residual of instrumental responsivity, indicating that some spurious feature of residual calibration are still present in this dataset. It is also evident as for low-concentration components (water ice clouds) the shape is more noisy and can contain itself spurious instrumental responsivity residual (fig.1). For this reason the entire dataset available are explored and the most clean spectral shape are derived for each components. Apart for the residual instrumental responsivity, this work result in two distinct shape for the dust, relative to high and low concentration of CO2 in atmosphere, and also in two distinct shape for the water ice clouds. A direct comparison is possible with data calculated in a independent way, using a pure Radiative Transfer algorithm to fit the observation and determine the atmospheric properties (Grassi et al. 2000) where is evident that the match between the two retrieval methods is very good (fig.2). In the latitudinal profile is clearly visible the position of the volcano form the rapid raise in dust content in both the two methods.

4. Conclusions

The methodologies presented here are shown to be reliable to analyze the data from the PFS instruments. The dataset is still far to be complete, due to the calibration process that is still going on. Future steps will be to apply these techniques to the whole dataset (about four time greater than nowadays), increase the spectral resolution and compare with TES results. Preliminary results suggest that there is not a great variation in the scenario viewed from the two instruments, even if there is a large temporal gap between the two missions (Mars Global Surveyor and Mars Express was launched in 1999 and 2003 respectively).

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