PFS: Evaluation of atmospheric sounding capabilities

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Introduction:

Experimental data represent the fundamental benchmark for validation of atmospheric models. In order to allow meaningful comparisons with model predictions, realistic retrieval capabilities of instruments must be evaluated and properly taken into account. This is particularly important for remote-sensing instruments in orbit around other planets, where direct measurements of traditional meteorological parameters are very difficult.

Characteristics of the instrument:

We present here the performances of a retrieval software designed for the analysis of PFS spectra. PFS is an infrared Fourier spectrometer on board of Mars Express mission. It covers the far infrared [250-1750] cm^{-1}, with a resolution of 1.3 cm^{-1} (LWC), as well as the near infrared [2000-8200] cm^{-1} (SWC), with a resolution of 1.5 cm^{-1} (examples in fig.1). It has been designed primarily to investigate the atmospheric cycles of water, dust and carbon dioxide, and the interactions between surface and atmosphere.

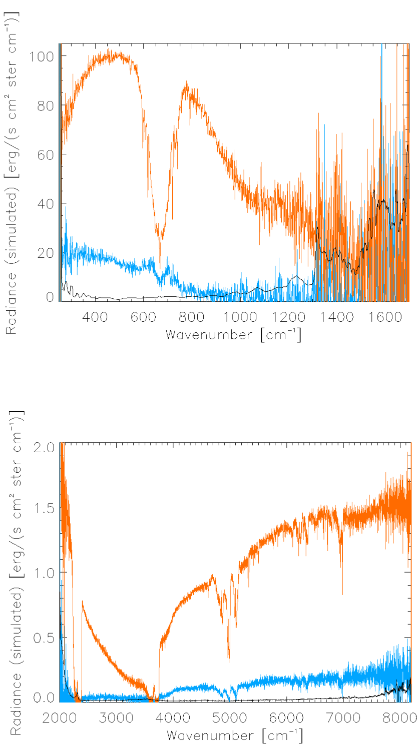

Fig.1: Simulated PFS spectra (top: LWC, bottom SWC) with instrumental NER (black lines)

Possible science:

These objectives can be achieved monitoring the fields of (i) temperature (as a function of height) in the lower atmosphere, from CO_2 bands @ 667 and 2300 cm^{-1} (ii) pressure, CO_2 bands @ 5000 cm^{-1} (iii) [H_2O] from bands @ 350 and 5200 cm^{-1}, and optical thickness at different wavenumbers related to (iv) water ice (band @ 830 cm^{-1}) and (v) dust integrated contents dust bands at 480, 1100 cm^{-1} and scattered radiation @ 3600 cm^{-1}. The above mentioned parameters can be retrieved from a single PFS measure, taking advantage of the instrument's wide spectral range and high resolution.

Structure of the analysis code:

The code for data analysis (BDM) adopts a multi-level iterative approach to build progressively a realistic model of Martian atmosphere from an initial guess. At each step, a single parameter in the model (e.g.: altitude at a given level or dust integrated content) is corrected comparing the consequent synthetic spectrum with PFS observations. Code takes full advantage of a new subroutine able to consider multiple scattering at each iterative step. A priori models for surface spectral characteristics and for dust optical properties are required and may be defined by the user.

Tests of retrieval code:

Code's capabilities are evaluated using as a reference a dataset of 288 simulated PFS observations. The synthetic spectra have been computed taking into account likely environmental conditions (extracted from the EMCD) and the actual instrument noise. The dataset can be considered as representative of average Martian conditions thanks to the uniform sampling in latitude, L_S, and local time adopted during extraction of atmospheric conditions from the model. Spectral dataset is particular severe for retrieval purposes, due to the high number of cases of low temperature surface (implying a very low signal level in LWC) or steep thermal gradients very close to the surface. Retrieval errors are evaluated comparing code's results with true conditions used for computations of synthetic spectra.

Vertical temperature profile T(z) is estimated from CO_2 band @ 667 cm^{-1}; attempts to include also CO_2 band at 2300 revealed as fruitless due to heavy NER-related errors. Two classes of algorithm have been implemented: relaxation (Twomay, Chahine, Chahine-Smith) and algebrical (Conrath – used by TES team- and Rodgers). Latter provide usually much satisfactory results, probably related to explicit treatment of NER in their formalism (fig. 2).

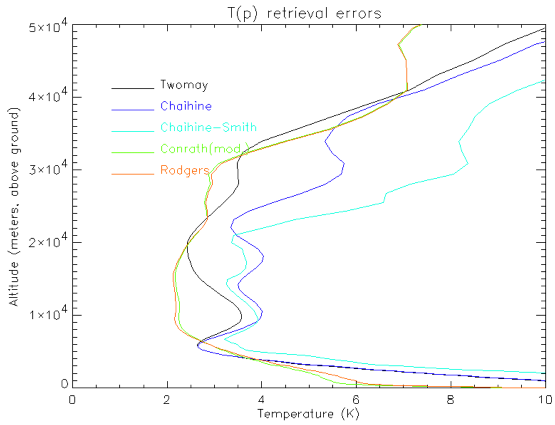

Fig. 2: T(z) retrieval errors from PFS LWC data

Most severe problems are related to conditions of very steep gradient close to the surface (poorly sampled by CO2 weighting functions) or almost isothermal profiles. Moreover, PCA analysis confirmed that low frequency features in T(z) profile are much better reproduced.

Integrated dust content Dust content is estimated from LWC bands only, because other methods involving scattered radiation in 3600 cm-1 CO2 saturated band (already employed in analysis of ISO data) demonstrated inadequate to account for instrumental NER. Evaluating dust load by value of τdust @ 1100 cm-1, BDM provides an error of ~0.2, strictly related to thermal gradient in the atmosphere (fig. 3)

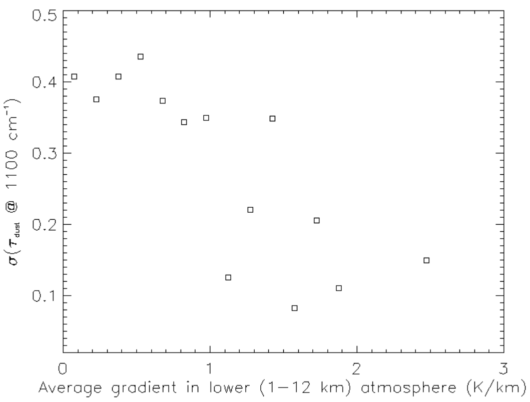

Fig. 3: Errors on dust load estimation as a function of thermal gradient in the atmosphere

Other important sources of errors are a wrong model for vertical dust distribution (i.e.: assuming an exponential function, a bad value for decay height) and the intimate relation, in determining upwelling radiation field, with surface temperature. Actually, tests demonstrated how neglecting the residual extinction of dust in evaluating radiation from surface may cause errors up to 10 K in evaluation of soil temperature. This observations lead us to embed T(z), τ_{dust}, and T_{surf} retrieval procedure in the same iterative cycle to ensure self-consistency of achieved model with the observed radiance in its whole spectral range.

Surface pressure Surface pressure can be retrieved by BDM with an error estimated around 0.7 mBar. The code try to reproduce the band shape of CO_2 complex @ 5000 cm^{-1}, and every source of error in the definition of continuum an the boundaries of the band heavily affects the results even in the case of apparently perfect fit. Among these sources, particularly important are the spectral shape of the region assumed by the user and the dust load (fig. 4).

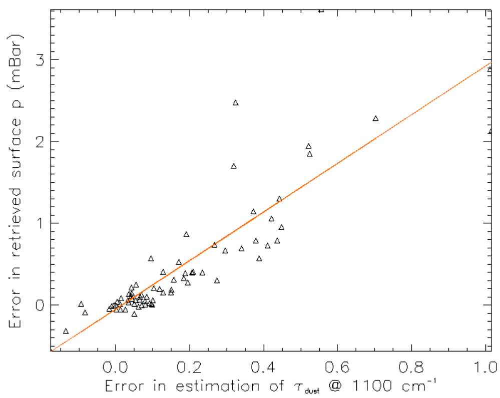

Fig 4: Errors surface pressure estimation as a function of errors on dust load estimation

Retrieved values of $p_{surface}$ are also affected by high Sun's zenith angles, probably due to plane – parallel atmosphere approximation used so far.

Future work:

We plan to complete BDM with subroutines able to (i) retrieve the water ice load (should be a simple modifications of dust procedures) and (ii) evaluate the water vapor content (severe issue may be represented by instrumental NER) an to study the relationship of errors on these retrievals with quantities presented in this work.

Conclusions:

PFS retrieval capabilities have been evaluated by a series of very conservative tests. These preliminary results demonstrate, in our opinion, the actual capability of the instrument to provide important constrains to atmospheric models in their description of lower atmosphere and to fulfill the PFS scientific tasks as stated in the instrumental proposal.

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