WATER IN MARS ATMOSPHERE: COMPARISON OF RECENT DATA SETS.

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Introduction:

Water vapour, a minor constituent of the Martian atmosphere characterized by only trace content (few to one hundred precipitable microns in column), plays a major role in Martian climate. Water cycle is characterized by a strong sensitivity to variation of the orbital parameters. There are also strong indications that due to long-term accumulation the atmospheric water might form major geomorphologic features of the Martian surface, i.e. the asymmetric polar caps. Faint water ice clouds are believed to affect meridional water transport, as well as dust cycle and thermal regime of the atmosphere (Clancy et al., 1996). An assessment of such fine processes could be provided by sophisticated General circulation models of Mars (MGCMs), allowing to vary orbital and climatic parameters. Tuning of these models is only possible with detailed experimental data sets. Therefore, the understanding of the complex interaction of the atmospheric water with the Martian climate system and the surface relies upon experimental data.

Modern climatology of Mars atmospheric water and aerosols is based on MGS/TES, measurements performed in thermal spectral range during three full Martian years (Smith, 2004). A good knowledge of the temperature profile is required for the retrieval, and comparison to climate models suggests that TES sometimes overestimates water abundance. Viking epoch water climatology is based on MAWD data (Jakosky and Farmer, 1982) taken in the near infrared. These data are sensitive the aerosol contents, and are sometimes underestimated (Fedorova et al., 2004). There are physical reasons to have different values at different wavelengths: vertical distribution (H_2O vertically mixing ratio is non constant), and scattering by aerosol. Spectral resolution and other instrumental peculiarities affect error bars on the quoted values and could introduce some biases. Finally, retrieval techniques and even spectroscopic databases are perfectible.

Mars Express, a unique versatile atmospheric mission, carries three instruments capable to measure atmospheric water vapour from near-IR to thermal IR spectral ranges. The simultaneous use of these data should allow to validate both techniques, and, moreover, to obtain some additional information on the vertical distribution of water vapour. More information on water vapor is to be extracted from Mars Express limb and solar occultation measurements like it was done during Phobos-88 project (Rodin et al., 1997).

Some comparisons of data on the first Mars Express conference in ESTEC showed a substantial disagreement in the data sets even within PFS measurements, and also among SPICAM-PFS (near IR) and OMEGA-SPICAM-PFS. Few comparisons with TES were by far not sufficient to conclude on the subject. Only one paper on Mars Express water vapour measurements is published so far (Encrenaz et al., 2005). We went on with the effort and have mounted an International Team in the International Space Science Institute in Bern, named as the title, and encompassing the coauthors of the present abstract. The Team has gathered in Bern in November 2005, the next meeting scheduled for February 2006. The presentation will summarize the first results of this study.

Water vapour data sets:

We most extensively compare the measurements of Mars Express instruments:

- *PFS* measures in both IR spectral ranges with very good spectral resolution of 1.5 cm^{-1} (at 2.56 μm and 1.38 μm in the near-IR (SW channel), and at 30 μm in thermal-IR (LW channel), and its data should be self-consistent. Simultaneously PFS measures thermal structure (crucial for thermal-IR retrievals) and atmospheric dust content (needed for near-IR)
- *SPICAM IR* measures similarly to MAWD at 1.38 μm with good spectral resolution (3.5 cm^{-1}) and acceptable S/N. Algorithms to account for aerosol are to be implemented. We count to use simultaneous aerosol data from PFS spectra. SPICAM IR measures H_2O in nadir, at limb and in solar occultations.
- *OMEGA* contributes to the subject with spatially resolved measurements in near-IR, in particular at 2.56 μm with much lower spectral resolution but good S/N. OMEGA data validated with other measurements. Limb data are of spe-

cial interest because of their excellent spatial resolution.

There are also different research groups performing Mars Express data analysis is slightly different ways. PFS H_2O data are treated independently by two groups in IKI/IFSI and in LESIA, and OMEGA data are treated also independently in LESIA (Encrenaz et al., 2005) and in MPS Lindau.

TES on Mars Global Surveyor – thermal emission spectrometer with spectral resolution of 5-10 cm^{-1} measured water vapour at 30-50 µm in thermal-IR, and thermal structure started in 1997, and ended in Aug 2004 (Smith, 2004).

Preliminary comparison of Mars Express and MGS TES water vapour results analysis, as has been discussed at ESTEC Mars Express conference has shown large disagreement (Figure 1). PFS thermal IR data were generally in good agreement with SPICAM 1.38-µm measurements; TES data indicating 25-50% larger values, while PFS 2.56-µm measurements giving significantly larger results. Furthermore, PFS LW analysis by different groups revealed some significant discrepancies. OMEGA results from analysis of 2.56-µm absorption band by Lindau group (not shown in the Figure 1) are comparable in magnitude with PFS SW values.

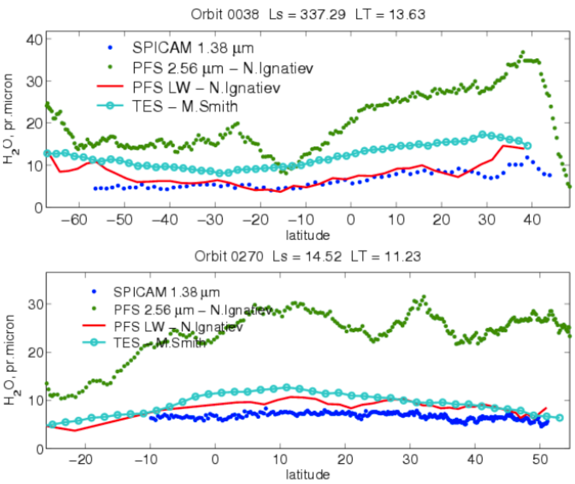

Figure 1. Intercomaprison of different vapour measurements from two Mars Express orbits, and the corresponding MGS TES measurements.

Ground-based observations:

We also try to summarize the available ground-based observation of martian water vapour, which coincide with TES and Mars Express measurements. Unfortunately, there is a very little coincidence:

- Centimeter (22 GHz) VLA Mars water vapor measurements during 2003 opposition Ls=265-290° (Butler et al., 2005) were preliminary compared to TES results, and revealed good match. VLA Mars water limb emission maps in the fall of 2004 (after the favorable opposition) taken with the intention of comparing to TES are to be processed. Future observations are planned for 2007 (MRO validation).
- A series of near-IR (870 nm) high-resolution spectroscopy measurements was performed in 1996-1999 in Arizona (Sprague et al., 2001), and compared to TES measurements (Sprague et al., submitted). These observations were discontinued after 1999.
- IRTF TEXES high-resolution imaging spectroscopy at 8 µm in June 2003 (Ls=206°) were found to be consistent with TES results (Encrenaz et al., 2005). Water vapor is retrieved from HDO lines. Next observation was planned for Dec 2005.

Summarizing ground-based results, so far there is no processed observations coinciding with Mars Express measurements. Ground-based IR results were found to be consistent with TES taking into account error bars. NIR results, though corrected for aerosol effect indicated significantly smaller water vapour values than TES in most of cases (Fig. 2).

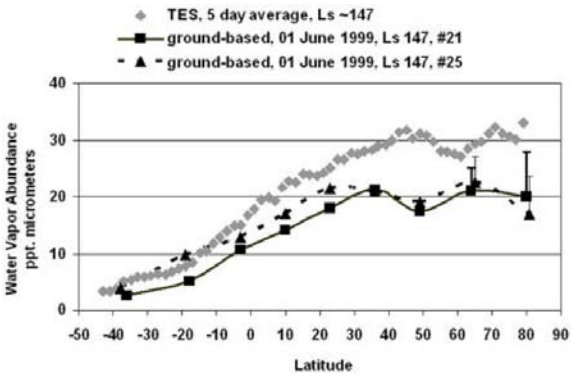

Figure 2. Comparison of high-resolution ground-based IR water vapour measurements to coinciding TES data (figure adopted from Sprague et al., submitted).

Differences in retrieval methods:

We have compared the different approaches by different groups to data analysis. The main differences are identified below.

Synthetic spectra computation: Spectroscopic data two main spectroscopic databases are used, HITRAN-2004 (Rothman et al., 2005), and GEISA-2003 (Jacquinet-Husson et al., 2005). To our understanding, GEISA-2003 data for the H_2O bands of interest correspond to earlier version of HITRAN database. A significant difference is found for some strong H_2O lines in the 1.38-µm band, measurements and HITRAN-2004 indicating 25-40% weaker lines than indicated in HITRAN-2001 and GEISA-2003 databases. The overall number of lines in the 1.38-μm band in new database is twice as larger w.r.t. the older one. This difference, however is not expected to have a significant impact on comparison, because the newer database is used for the 1.38-μm retrieval, and there are no reported difference between the databases in the thermal IR range. The 2.56-μm band is yet to be compared.

Line broadening in CO_2 is important. Although synthetic spectra calculated with different broadening are almost undistinguishable, slight difference in line widths appears to have a significant impact on retrieved H_2O amount. Previously used broadening factor in CO_2 of 1.3 w.r.t. the air (i.e. each database value for broadening is multiplied by 1.3) results in too narrow lines. Another possibility to cope with broadening is calculation used for Venus' spectra analysis (Pollack et al., 1993 and the references therein) and later calculations by Gamache et al., (1995) result is noticeably larger absorption lines (e.g, in the 1.38-μm band the average broadening factor is about 1.8). A frequently adopted factor for broadening is 1.5. Comparing broadening is not straightforward (Fig. 3). In spite of differences, on the average the factor of 1.5 or Gamache procedure lead to very similar results for the end-to-end water retrieval.

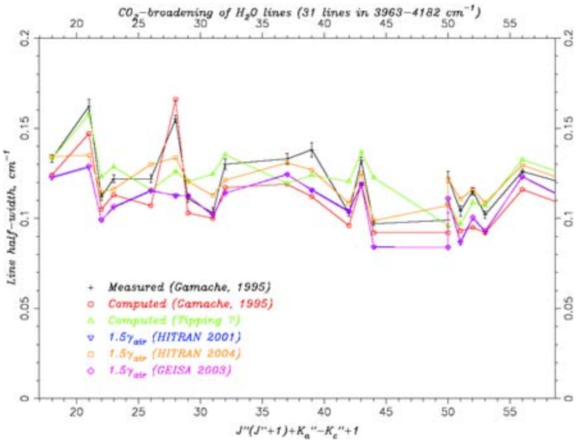

Figure 3. Comparison of H_2O line broadening in CO_2 from different sources for some lines in 2.56-μm band. Green triangles correspond to computation with early version of R. Gamache data provided by R. Tipping.

All groups compute spectra line-by-line, with subsequent construction of look-up tables, in slightly different manners; with the exception of OMEGA treatment by LESIA group, who computed band absorption, and used curves of growth (Encrenaz et al., 2005).

Atmospheric model:

The knowledge of the temperature profile is essential, in particular for thermal IR H_2O band. TES and PFS LW channel use consistent temperature retrievals from the CO_2 16-μm band. All teams working with NIR H_2O bands use LMD MGCM predictions (Forget et al., 1999) from EMCD, although the use of coinciding PFS profiles when available looks more appropriate. Water vapor saturation altitude is defined from the temperature profile (and depends on water contents). Below the saturation level water vapour in the atmosphere is assumed uniformly mixed; above we can assume it as constrained by saturation, or allow some degree of supersaturation, or imply zero value with no visible impact on the retrieved results. The MPS Lindau group ignores saturation both in PFS and OMEGA retrievals.

Pressure is defined from EMCD, sometimes with refinement of EMCD 3.5°x5° bins with MOLA data and subsequent integration according to an instrument FOV.

Solar spectrum:

The use of an appropriate solar spectrum is important for analysis of NIR spectra, in particular with high spectral resolution, because Fraunhofer lines mix up with H_2O absorption features. PFS team has made a significant effort to construct such a spectrum (Fiorenza and Formisano 2005). SPICAM team is using so far Kurucz (1995) spectrum having disadvantages of being theoretical within the H_2O bands, and undersampled for our purpose (1-cm^{-1} bins).

Correction for dust and aerosol:

Aerosol, suspended in the atmosphere diffuse a fraction of solar light, reflecting it backwards to an instrument, and therefore in the analyzed NIR spectrum the imprint of the water vapour band structure is superimposed by continuum aerosol spectrum. If albedo of the surface or the calibration of the instrument are not perfectly known, the spectrum interpretation indicates less water in the atmosphere. This effect is well known since long time, first analyzed by Davies and Wainio (1981) for MAWD/Viking polar data. The accurate account for aerosol is computation consuming, and the totality of MAWD data was reanalyzed only recently (Fedorova et al., 2004). The impact of aerosol is estimated in the above two papers. It is insignificant for the atmospheric dust load below τ=0.3 and airmass below 3, and reaches a factor of 3 to 4 for τ>1 and large arimasses. Thermal IR water vapor data are much less sensitive to atmospheric dust, unless its load is extremely high.

Mars Express NIR data are so far analyzed with no account for the aerosol, but such an analysis is planned to be implemented soon. For most of compared measurements dust load and airmass do not lead to correction larger then 20-30%, present discrepancies among different measurements being far beyond this value.

Preliminary results:

Preparing for the first meeting the teams have aligned the processing methods, in particular such critical parameter in computation of synthetic spectra as line broadening (1.5 broadening factor for CO_2, or Gamache et al., 1995 data), PFS low-level data processing etc. Cross-checking of synthetic spectra computation and even end-to-end water vapour retrievals between teams was performed. As a result, we have more consistent picture with much less (but still significant) discrepancy among PFS LW and SW channels (Cf. Figs 4 and 1). OMEGA values falling somewhere in between and frequently follow PFS LW. In rare cases OMEGA shows values above PFS SW.

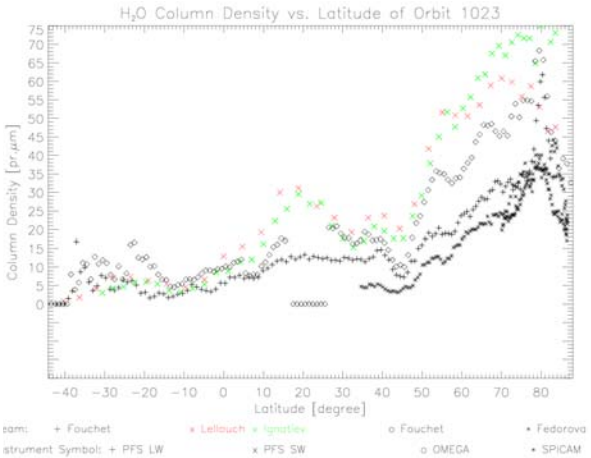

Figure 4. Comparison of water vapour measurements by three Mars Express instruments along orbit 1023. Crosses: PFS LW; x – (red and green) PFS SW by different teams; diamonds – OMEGA; asterisks – SPICAM.

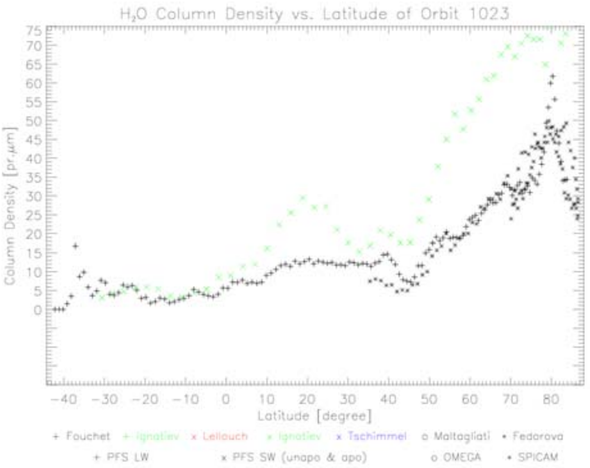

Figure 5. Same as in Fig.3 showing only PFS measurements compared to older version of SPICAM processing.

This alignment in processing method was, however fatal for SPICAM 1.38-μm measurements, which have previously shown a good much to PFS LW, now being far below all other measurements. It should be noted that internal calibration of SPICAM was refined, and a narrower function describes now the spectral resolution. One hypothesis might be that Gamache factors are overestimated for the 1.38-μm band, another is that there are instrumental biases specific to SPICAM.

The considerable differences among PFS SW and 2.56-μm band measurements by PFS and OMEGA are yet to be explained. For the future we plan to complete the comparison for several orbits, and to conduct multiparameter analysis seeking for correlation with altitude, surface albedo etc. OMEGA analysis by MPS team is to be compared with other data. The progress status of this work will be presented on the workshop.

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