WATER VAPOR IN THE ATMOSPHERE OF MARS: FROM PATHFINDER TO MARS POLAR LANDER. D. V. Titov, W. J. Markiewicz, N. Thomas, and H. U. Keller, Max-Planck-Institut fuer Aeronomie, Max-Planck-Strasse 2, D-37191, Katlenburg-Lindau, Germany; e-mail: titov@linmpi.mpg.de.

IMP observations of atmospheric water vapor. The Imager for Mars Pathfinder (IMP) was the first instrument to study atmospheric water from the surface of Mars [1]. The camera took images of the Sun at sunrise and sunset in six filters in and around the 0.94 µm H_2O band. The average value of 6±4 pr.µm of atmospheric water column density was derived from the measurements [2]. The main result of IMP observations was the indication of that the atmospheric water is probably not uniformly distributed with altitude, but is rather confined to a 1-3 km layer at the surface.

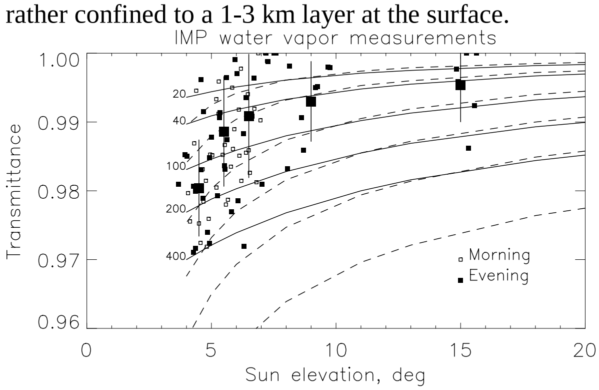

Figure 1. Water vapor transmittance measured by IMP. Small open and filled rectangles show the individual determinations of transmittance in the morning and evening correspondingly. Large rectangles and error bars are the mean values of transmittance and its standard deviation within the bins of 1° in elevation.

Figure 1 compares the results of water vapor determination by IMP to the predictions of uniform (solid lines) and non-uniform (dashes) models of H_2O vertical distribution. Numbers at the curves denote H_2O mixing ratio in the uniform model. The non-uniform model in which water vapor was confined to the lowest 1-3 km of the atmosphere reproduces the fast decrease of the measured transmittance with decreasing Sun elevation angle much better than the uniform model.

"Low" atmospheric water: other observations and models. The indication that atmospheric water is located close to the surface is a controversial result. Till now the atmospheric water on Mars was usually considered to be uniformly mixed in the lower atmosphere at least below the level of saturation (10-30 km). So the IMP result requires broader discussion and comparison to the available measurements and models.

High-resolution spectroscopy can give an estimate of the pressure at the level of absorption lines formation. Analysis of the data from the Mars Atmospheric Water Detector (MAWD) onboard Viking orbiters shows that this level gradually descends from half of the surface pressure at L_s~0° to full surface pressure at L_s~140° [3]. This means that the atmospheric water evolves from the uniformly mixed state in early spring to strongly non-uniform distribution in late summer. This was approximately the time of Pathfinder measurements (L_s~150°).

Indirect evidence that the atmospheric water is located close to the surface can be derived from the ISM/Phobos imaging spectrometry [4]. The maps of water vapor spatial distribution retrieved from the data show up to a factor of 3 spatial and local time variations of atmospheric water amount [5]. Such variations are caused by water release from the regolith and, hence, they should occur in vicinity of the surface.

Various models predict that the regolith-atmosphere water exchange significantly affects the water column density both on seasonal and diurnal time scales [6-8]. At daytime the water vapor molecules desorbed from the regolith are quickly transported within the boundary layer due to intensive convection driven by the surface heating. Thus, the lowest few kilometers of the atmosphere - the planetary boundary layer (PBL) - are enriched in water vapor during the day.

Such a non-uniform vertical distribution of water is unstable and several processes will tend to smooth it out. They are the overnight adsorption of water molecules on the cold regolith, advective transport, and mixing with free atmosphere above the boundary layer. The first process affects only few hundreds of meters above the surface because mixing of the PBL is strongly suppressed at night due to stable temperature structure of the lower atmosphere. The second one is not effective at this season since the Hadley circulation gradually weakens by the end of the summer resulting in reduction of its ability to transport water [9]. The most important process that can destroy the near surface water "anomaly" is the mixing of PBL and free atmosphere.

Table. Mixing time scales in the lower atmosphere.

z, km			K, cm^2/s	τ_{mix}, day
6	Free atmosphere		10^5	100
4				
2	Boundary layer	Day	10^7	1
0		Night	10^4	1000

The Table presents typical values of eddy diffusion coefficient K and corresponding mixing times based on the results of observations and models [10-12]. It shows that the daytime mixing within the PBL is much faster than that in the free atmosphere. Thus the water vapor transport from the PBL to the free atmosphere is very slow as compared to the diurnal cycle of regolith-atmosphere water exchange. This means that the boundary layer is virtually decoupled from the free atmosphere at least on the monthly time scale.

Water vapor observations planned onboard the Mars Polar Lander. The Mars Polar Lander (MPL) is on the way to Mars with the Surface Stereo Imager (SSI) onboard. This camera, the twin of the Imager for Mars Pathfinder, will carry out similar observations of atmospheric water. However, the H_2O measurements by SSI are expected to be more difficult. The reason is that MPL will operate during the polar day when the Sun will not approach the horizon closer than 5-6°. Figure 1 shows that the range of elevations from ~6° down to horizon is crucial for distinguishing between the uniform and non-uniform model of H_2O vertical distribution. Thus it is desirable to continue the measurements down to the very horizon.

This difficulty can be avoided if different observational strategy is implemented. In the case of IMP the Sun was directly observed through the atmosphere. However, the water vapor absorption feature is present in the spectrum of the Martian sky as well. Thus taking the images of the sky in the same filters we can measure H_2O absorption down to the very horizon thus achieving maximum air mass. In order to substantiate this approach we calculated the depth of 0.935 μm H_2O absorption feature in the spectrum of Martian sky using the combination of line-by-line technique [13] and multiple scattering routine [14]. The results for the Sun zenith angle of 60° and dust optical depth of 0.5 are shown in Figure 2.

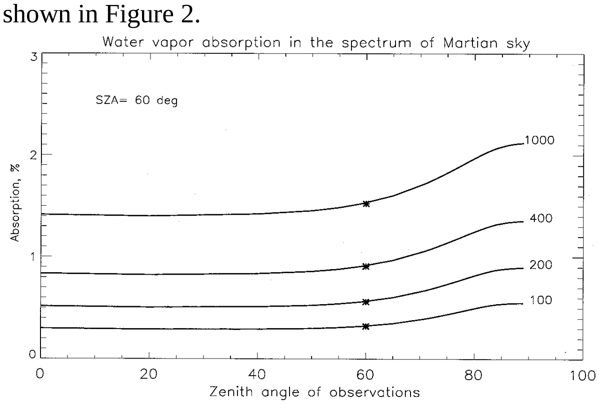

Figure 2. Water vapor absorption in the spectrum of Martian sky for several H_2O mixing ratios (numbers at the curves in ppm). Asterisks show the value of absorption in the case of direct observations of the solar disc.

Figure 2 demonstrates the advantage of the observations of Martian sky: the depth of absorption feature in the sky spectrum close to the horizon is about twice as great as in the case of direct Sun observations. Thus by taking the images of Martian sky one can detect water vapor even when the Sun is relatively high above the horizon. This will give a chance to observe diurnal variations of the atmospheric water content.

The Tunable Diode Laser (TDL) onboard Mars Polar Lander will carry out *in situ* measurements of the water vapor concentration close to the surface. The joint analysis of the SSI observations of H_2O column density and TDL measurements will provide independent estimate of the water vapor vertical distribution.

References. [1] Smith P. H. et al. (1997) *JGR, 102*, 4003-4025. [2] Titov D. V. et al. (1999) *JGR, 104*, 9019-9026. [3] Hart H.M. (1989) *Ph.D. thesis,* Univ. of Colorado. [4] Bibring J.-P. et al (1989) *Nature, 341*, 591-593. [5] Titov D. V. et al. (1997) *Ann. Geophys. 15*, Suppl. Ser. [6] Jakosky B. M. (1985) *Space Sci. Rev., 41*, 131-200. [7] Zent A. P. et al (1993) *JGR, 98*, 3319-3337. [8] Titov D.V. et al. (1995) *Adv.Space Res., 16*, 623-633. [9] Haberle R. M. and Jakosky B. M. (1990) *JGR, 95*, 1423-1437. [10] Kulikov Y. N. and Rykhletskii M. V. (1984) *Solar Sys. Res., 17,* 112-118. [11] Kahn R. (1990) *JGR, 95*, 14,677-14,693. [12] Michelangeli D. V. et al. (1993) *Icarus, 100,* 261-285. [13] Titov D. V. and Haus R. (1997) *Planet. Space Sci., 45*, 369-377. [14] Evans K. F. (1998) *J. Atmos. Sci., 55,* 429-446.