Abstract 1163

# Evolution of the Vertical Extent of Water Vapor in the Martian Summer Polar Atmosphere

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## 1. ABSTRACT

**We present a new method to retrieve column abundances and vertical extent of the water vapor from the Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) spectra. The new method enables retrievals from the nighttime TES spectra. The retrieval algorithm employs a new model of the vertical distribution of water vapor in the Martian atmosphere. In this model water vapor is confined to a layer of finite height in the lower atmosphere. The atmosphere is dry above this 'wet' layer. Within the 'wet' layer the water vapor has a constant mixing ratio below the water ice cloud condensation height and is saturated above that height. The new retrieval method simultaneously fits the daytime and nighttime TES spectra for a given location using a single mixing ratio profile modified between day and night to account for cloud formation and interaction with soil.**

**We apply this new method to the TES spectra collected over the site of the Phoenix spacecraft landing during late northern spring and summer. Retrieved daytime column abundances are ~1–5 pr-μm higher than in the previous TES retrieval. Nighttime column abundances are lower than the daytime abundances by ~5–10 pr-μm due to exchange with soil and water ice clouds. The height of the 'wet' layer varies with season, reaching ~18 km around Ls=80–100° and decreasing to 7–10 km by Ls=140°. Changes in the vertical extent of vapor reflect seasonal changes in the intensity of the turbulent mixing in the lower atmosphere and in the water ice cloud condensation height. Water vapor extends above the top of the boundary layer at ~4 km, suggesting that vertical transport of vapor is not limited to the boundary layer.**

## 2. MODEL OF VAPOR VERTICAL PROFILE

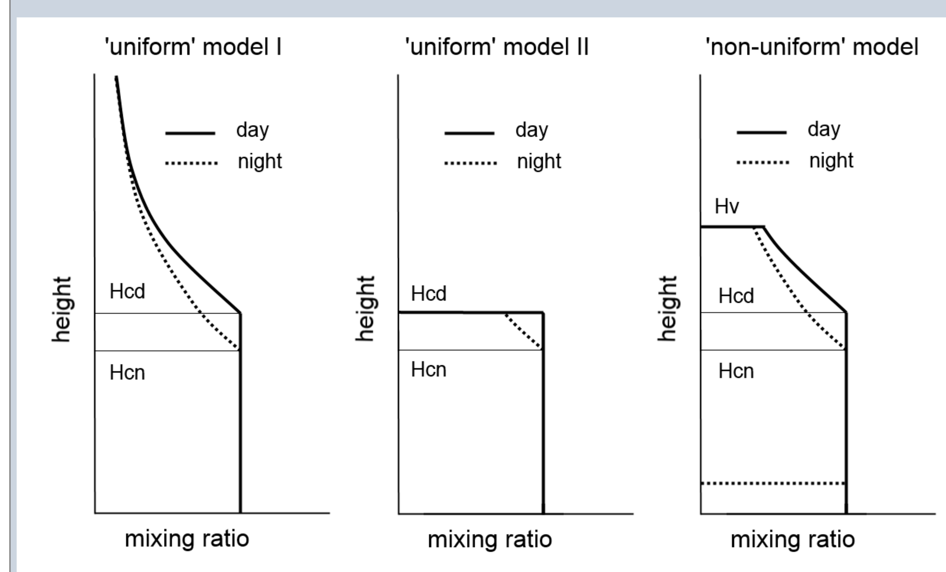


***Figure 1. Schematic representation of the water vapor mixing ratio vertical profiles in the 'uniform' and 'non-uniform' models. Solid and dotted lines represent mixing ratios during day and night, respectively. $H_v$ denotes the height of the 'wet' later in the 'non-uniform' model. $H_{cd}$ and $H_{cn}$ mark water ice cloud condensation heights during day and night, respectively. Atmosphere is dry below the dotted horizontal line in the 'non-uniform' model at night to mimic desiccation observed by the Phoenix lander.***

Current models of the water vapor vertical distribution on Mars assume that it is distributed uniformly (has a constant mixing ratio) below the ice cloud condensation height, and is saturated or absent above that height. Schematic representation of the mixing ratio profile in this 'uniform' model is shown in Figure 1. The 'uniform' model was successfully applied to daytime MGS TES data to establish a global view of the interannual, seasonal and geographic variability of the Martian water cycle (Smith 2004). However, the 'uniform' model fails when it is applied to the nighttime data (see Figure 2).

We introduce a 'non-uniform' model of the atmosphere where atmospheric water is limited to a 'wet' layer extending from the surface to some height that does not necessarily coincide with the condensation height (see Figure 1). The height of the 'wet' layer and the water vapor mixing ratio in the 'wet' layer are model parameters. We have developed a new retrieval algorithm that uses MGS TES nadir spectra collected during different local times to determine the 'non-uniform' model parameter. As a proof of concept, we apply the new algorithm to the TES data collected over the Phoenix spacecraft landing site during northern summer because of the wealth of *in situ*, remote sensing and modeling data available for comparison.

***Smith, M.D., 2004. Interannual variability in TES atmospheric observations of Mars during 1999–2003. Icarus 167, p.148.***

## 3. NEW RETRIEVAL ALGORITHM

The retrieval is an iterative process in which the new height of the 'wet' layer and the mixing ratio are calculated during each step:

1) for a given pair of TES daytime and nighttime spectra, calculate the band depth indices representing the strength of the water vapor bands between 230–300 cm$^{-1}$ (~30–40 μm);
2) set or adjust the height of the 'wet' layer;
3) calculate model water vapor indices for a range of mixing ratios for daytime and nighttime conditions;
4) find daytime mixing ratio by comparing modeled and observed indices; the daytime mixing ratio profile is calculated taking into account vapor saturation and the height of the 'wet' layer;
5) calculate nighttime mixing ratio profile using the daytime profile and nighttime atmospheric temperatures;
6) calculate nighttime band depth index;
7) compare to observed night index – go to 2) if no match.

Figure 2 shows modeled and observed band depth indices calculated using TES data for $L_s$=70-140° during MY25 and MY26 at the Phoenix landing site. Figure 2 A and B show band depth indices calculated with 'uniform' models I and II (Figure 1). The 'uniform' model I cannot match nighttime indices, while 'uniform' model II fails to match both daytime and nighttime indices at different $L_s$'s. Uncertainty in the atmospheric temperatures cannot explain the failure of the 'uniform' model. The 'non-uniform' model enables finding the mixing ratio profile that is consistent with both daytime and nighttime TES spectra (Figure 2 C).

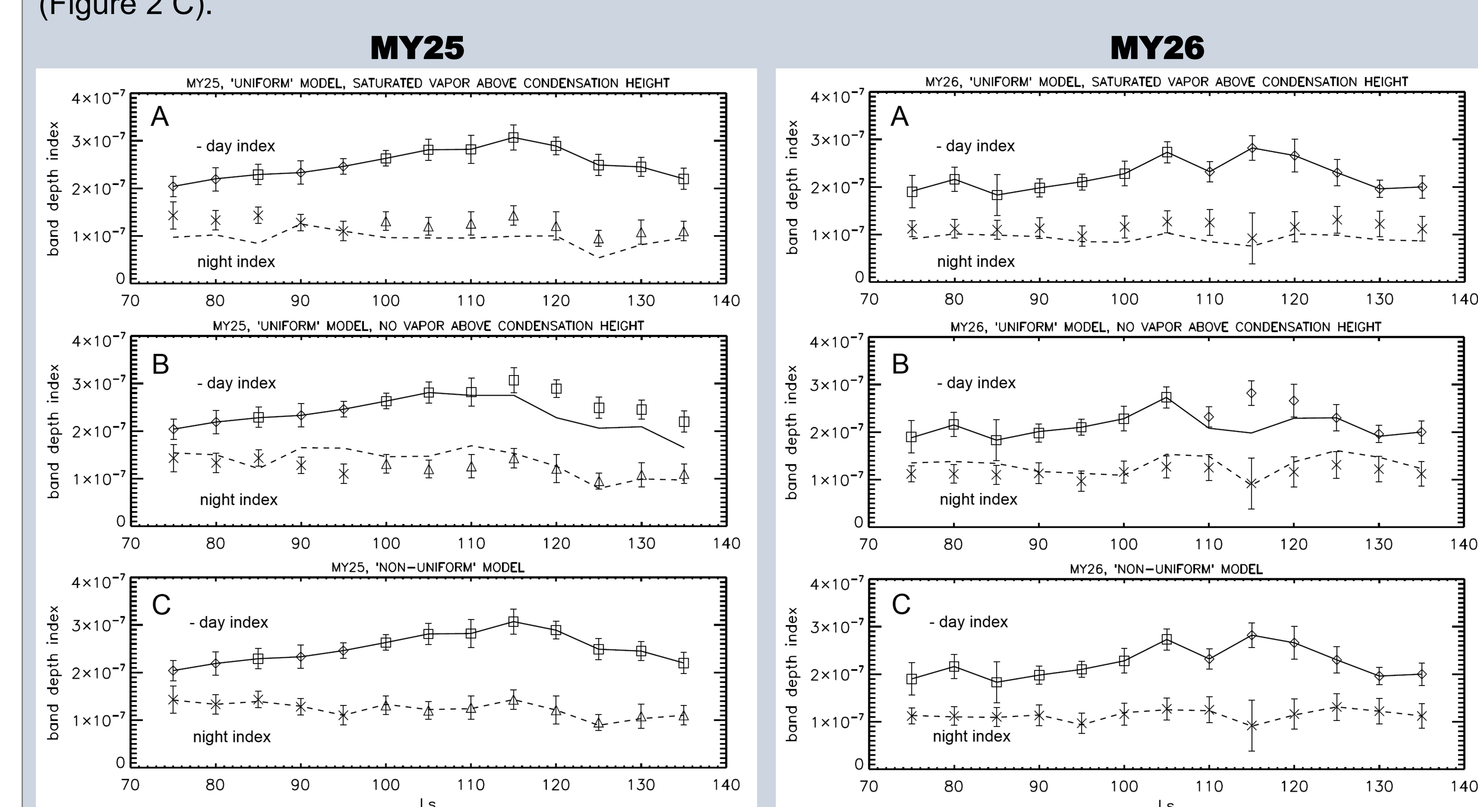


***Figure 2. Observed and simulated daytime and nighttime band depth indices at the Phoenix lander location in MY25 (left) and MY26 (right) for different water vapor models: (A) 'uniform' model I; (B) 'uniform' model II and (C) 'non-uniform' model. Observed daytime indices are shown by diamonds and squares, and nighttime indices – by x's and triangles. Modeled indices are shown by solid (daytime) and dashed (nighttime) lines. Error bars show variations of individual observed band depth indices in a given spatial-temporal bin.***

## 4. 'WET' LAYER HEIGHT, MIXING RATIOS AND COLUMN ABUNDANCES

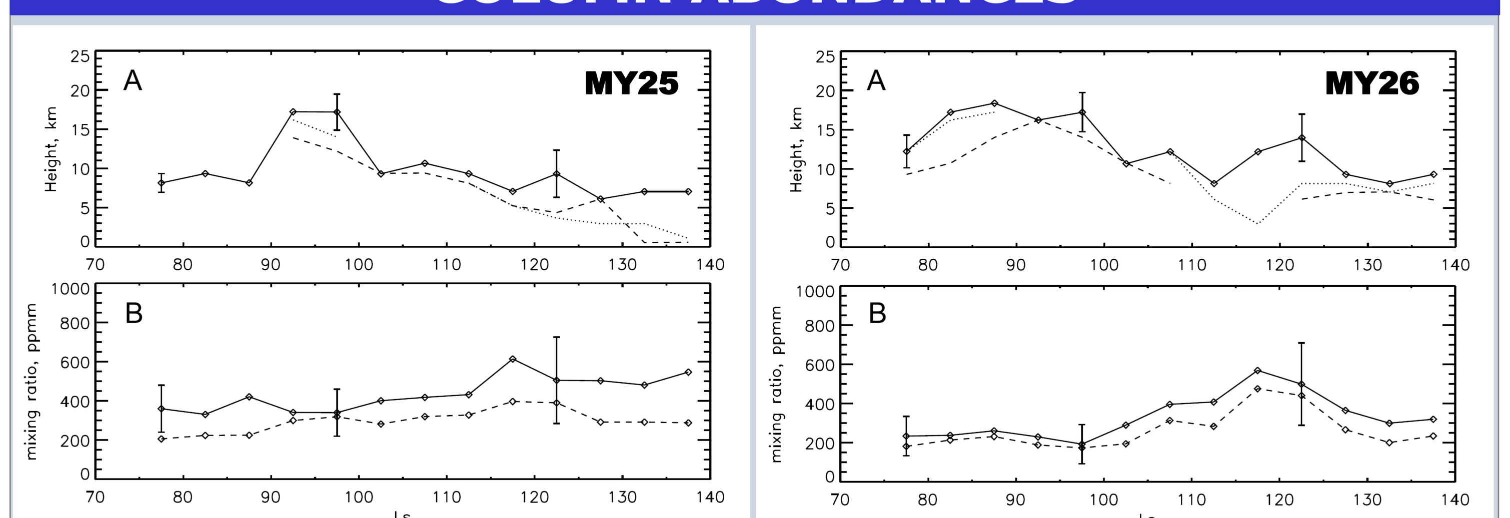


***Figure 3. "Wet" layer height and mixing ratios at Phoenix site in MY25 (left) and MY26 (right). (A) 'Wet' layer height $H_v$ (solid) and daytime and nighttime water ice cloud condensation heights $H_{cd}$ (dotted) and $H_{cn}$ (dashed), respectively. (B) Mixing ratios in the 'wet' layer in the 'non-uniform' model (solid) and in the 'uniform' model I below condensation height (dashed). Error bars show estimated uncertainties.***

In MY25:
- Vapor mostly confined below 8-10 km, except during $L_s$=90-95° when it extends up to ~17 km.
- Daytime clouds appear at 15-16 km at $L_s$=90-95°, and after $L_s$=110° – at 1-8 km.
- Nighttime clouds appear after $L_s$=90°, height decreases from 15 to 0 km.
- Condensation heights uncertain by 3-4 km, below top of the 'wet' layer.
- Condensation heights after $L_s$=120° consistent within uncertainties with Phoenix LIDAR (~4 km).
- Mixing ratios are higher than in the previous retrievals with 'uniform' model I.
- Mixing ratios show increasing trend with time.
- Daytime column abundances (Figure 4) are ~0-10 pr-μm higher than in 'uniform' model I retrievals.
- Nighttime abundances ~5-10 pr-μm lower due to simulated exchange with soil (~5 pr-μm) and cloud formation (0-5 pr-μm)

In MY26:
- Vapor extends higher than in MY25, correlates with higher atmospheric temperatures in MY26.
- 'Wet' layer height increases to 15-18 km during $L_s$=80-95°, decreases to 8-14 km afterwards.
- Condensation heights several km below top of the 'wet' layer.
- Night clouds predicted above 9 km during $L_s$=75-105°.
- Clouds after $L_s$=120° consistent with Phoenix LIDAR within uncertainties (6-8 km vs ~4 km).
- Mixing ratios only slightly higher than in the retrieval with 'uniform' model I, due to higher vertical extent of vapor.
- Daytime column abundances (Figure 4) are ~1-5 pr-μm higher than in 'uniform' model I retrievals.
- Nighttime abundances ~5-10 pr-μm lower than daytime.

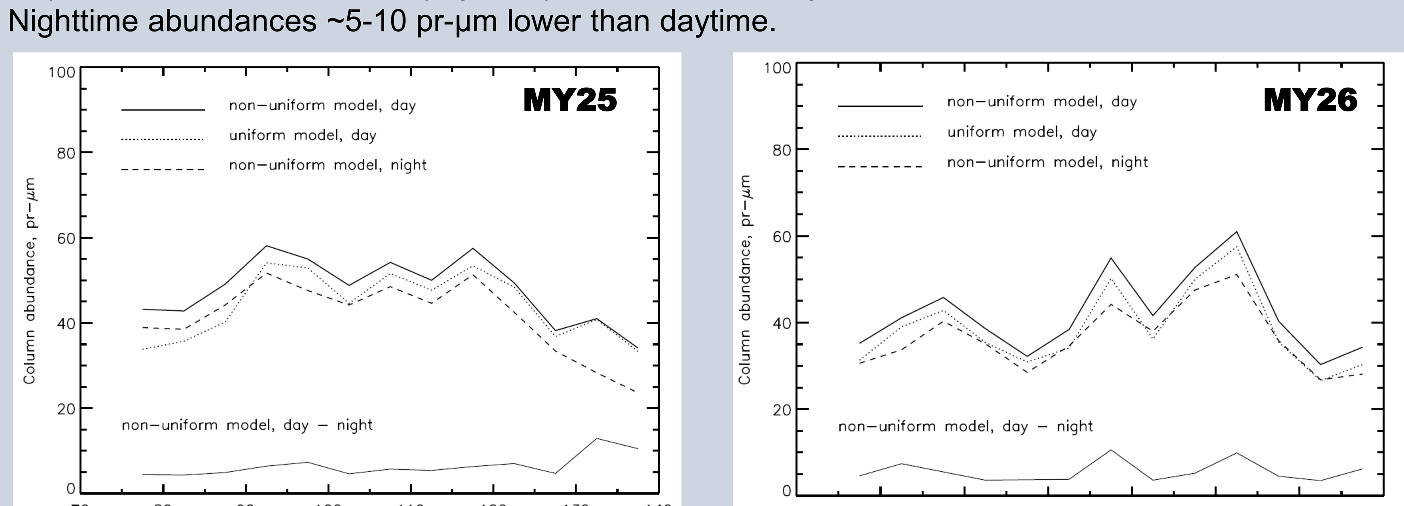


***Figure 4. Water vapor column abundances in MY25 (left) and MY26 (right) retrieved with the 'uniform' model I (dotted lines) and 'non-uniform' model (solid and dashed lines). The thin black line at the bottom is the difference between day and night abundances in the 'non-uniform' model.***

## 5. WATER VAPOR DENSITY CHANGES

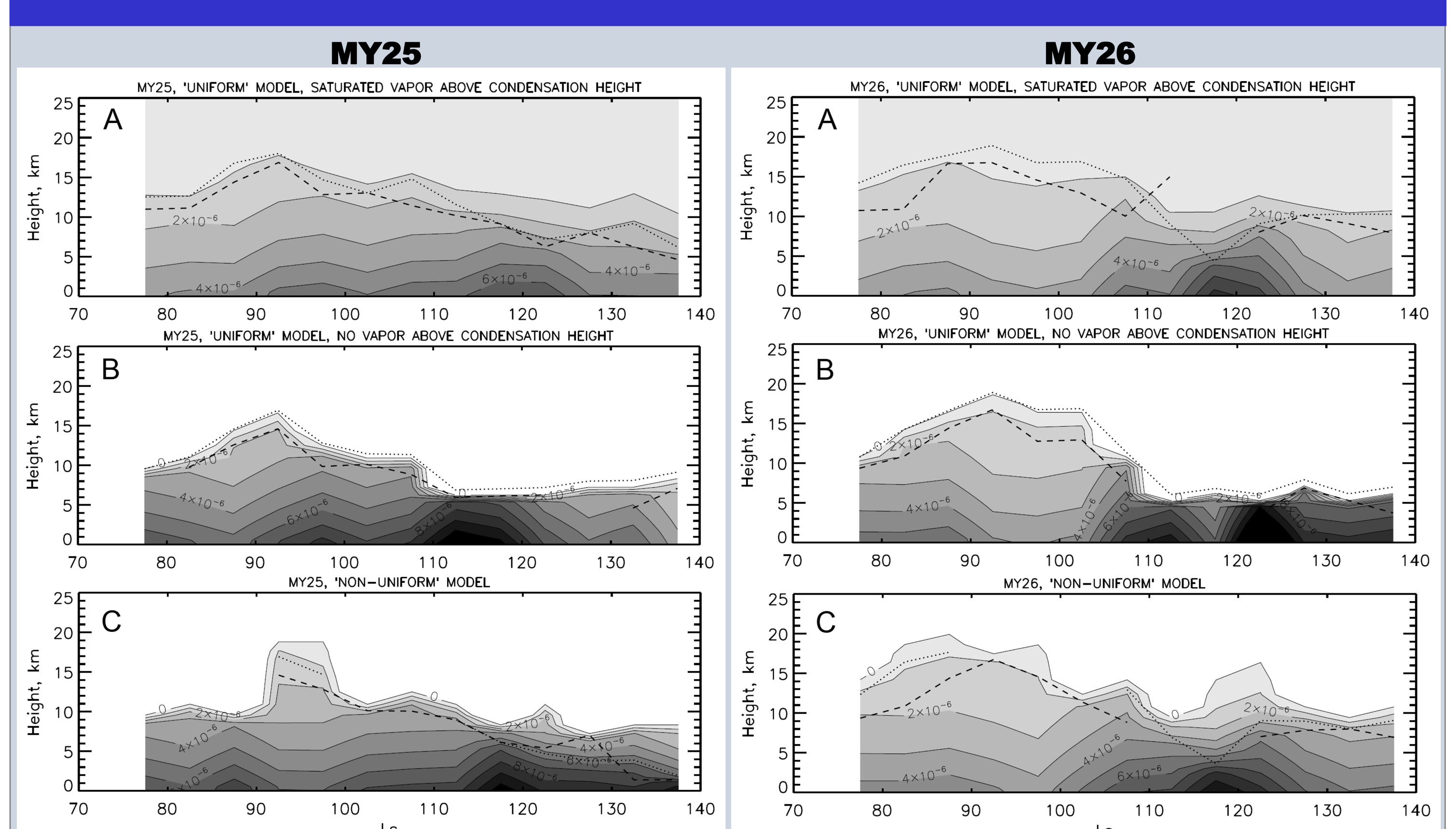


***Figure 5. Contours of vertical daytime density profiles as a function of $L_s$ in MY25 (left) and MY26 (right) for retrievals with different models: (A) 'uniform' model I; (B) 'uniform' model II and (C) 'non-uniform' models. The constant density contours are plotted at $10^{-6}$ kg/m$^3$ interval. Thick dotted and dashed lines show daytime and nighttime cloud condensation heights. Nighttime densities differ only between daytime and nighttime cloud condensation heights and in the lowest ~0.5 km.***

- The water vapor density distribution retrieved with the 'non-uniform' model represents an intermediate case between the density distributions of 'uniform' models I and II: vapor is present above the condensation height, but it does not extend to the top of the atmosphere.
- In MY25 the 'non-uniform' model produces higher densities than the 'uniform' model I.
- In MY26 the 'wet' layer extends higher and the density structure produced with the 'non-uniform' model is similar to the of the 'uniform' model I.
- The height of the planetary boundary layer at Phoenix site was estimated at ~4 km based on dust vertical extent and water ice clouds. In our retrievals water vapor extends higher than the top of the boundary layer during late spring and most of the summer.
- Changes in the height of the 'wet' layer correlate with the changes in atmospheric temperatures in the lower atmosphere (~5 km). Higher 'wet' layer in MY26 also correlates with generally higher atmospheric temperatures. This suggests that turbulent mixing is responsible for the vertical transport of water vapor.

## 6. CONSCLUSIONS

1. **'Non-uniform' model of water vapor vertical distribution with the 'wet' layer height decoupled from the cloud condensation height enables matching both the daytime and nighttime TES spectra at Phoenix landing site.**
2. **New retrievals produce higher column abundances and mixing ratios.**
3. **Appearance of water ice clouds at the Phoenix site reflects seasonal changes in the vertical extent of vapor and in the atmospheric temperatures.**
4. **Seasonal changes in the 'wet' layer height reflect changes in the turbulent mixing in and above the planetary boundary layer.**
5. **Cloud condensation height does not cap water vapor vertical distribution (at least at Phoenix site during spring and summer).**
6. **Water vapor is not confined to the planetary boundary layer.**
7. **The new retrieval algorithm can be applied at other locations and seasons on Mars, yielding estimates of vapor vertical extent. These estimates can provide information on the seasonal and geographic variability of the turbulent mixing and large scale transport in the atmosphere of Mars**

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