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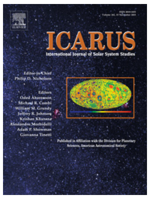

New column simulations for the Viking landers: Winds, fog, frost, adsorption?

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ABSTRACT

Boundary layer simulations are shown for the first sols of the two Viking landers (VL1, VL2) on Mars. The column model (with cloud/radiation interaction and Prandtl slope wind terms), used successfully for Phoenix and Curiosity, is equipped here with an adsorption-diffusion scheme for water vapor transport in porous regolith. The model's 1.6 m temperatures and winds are quite close to those observed by the two landers; in particular the weak summer slope winds of VL2 are excellently reproduced.

The model predicts for both sites diffusion and adsorption of water into regolith in the evening, very thin ground frost deposition from about midnight, and an early morning fog with an inflection in T1.6 m slightly weaker than observed. At the moister VL2 site fog increases optical depth as observed. Fogs and frosts sublimate away after sunrise, allowing desorption and diffusion of water off the sun-heated regolith. For porosity of 22% column water is approximately conserved from sol to sol at both sites with only little diurnal variation, as the depleted layer of air moisture is quite shallow.

In simulations without adsorption frost forms early and it grows thick. At VL2 fog now forms earlier and the jump in optical depth is larger than observed. At the drier VL1 fog still forms nearly as with adsorption, so observations could also be explained without adsorption. On the other hand VL1 certainly landed onto porous regolith and frost was not observed. Hence it is suggested that adsorption is likely at both VL sites in summer.

1. Introduction

The Viking 1 and Viking 2 landers (VL1, VL2) landed onto Mars in 1976 during local summer of Mars year (MY) 12 at about 22.5°N, 48.0°W, Ls 97° and 48.0°N, 225.7°W, Ls 117°, respectively. Their first-ever weather observations from the surface of Mars are reported in Pollack et al. (1977; optical depths) and Hess et al. (1977; surface pressures, temperatures and winds at 1.6 m, and surface temperatures from the Viking orbiters). The Mars Atmospheric Water Detector (MAWD) onboard the orbiters charted column moisture (Farmer et al., 1977). Many landers and rovers have since provided surface data from Mars, including observations of relative humidity (RH) and water vapor mixing ratio (q) for more than two Mars years from the Rover Environmental Monitoring Station humidity device (REMS-H) of the Mars Scientific Laboratory (MSL) onboard the Curiosity rover in Gale crater (Gómez-Elvira et al., 2012; Harri et al., 2014). All the in-situ meteorology observations from Mars up to 2016 are described and reviewed in Martinez et al. (2017).

The Viking and other lander data have provided validation for various atmospheric models, from local column models to GCMs. Here the University of Helsinki/Finnish Meteorological Institute 1-D column model is applied at the VL sites, as in Savijärvi (1991, 1995). The aim is to validate the 2017 model version with its radiatively active clouds and fogs, slope winds and adsorptive regolith, and in particular, to discuss the summertime diurnal cycle of near-surface moisture at the VL sites in the light of the simulations and available indirect indications of moisture. Jakosky et al. (1997, J97) suggested that some processes (possibly frost or adsorption to porous regolith) depleted water vapor every night at both sites, while Pollack et al. (1977) suggested that the early morning increases in optical depths could be due to fog. Frost persisted throughout the day at VL2 in wintertime (Martinez et al., 2017).

The REMS-H observations strongly suggest adsorption to take place at Gale. The UH/FMI 1-D model with a diffusion-adsorption scheme could closely simulate the daily cycles of RH and q at Curiosity (Savijärvi et al., 2016), whereas without adsorption it

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could not (Savijärvi et al., 2015). Steele et al. (2017) came to the same conclusion in mesoscale model experiments for Gale. Zent et al. (2016) suggested both adsorption and frost from recalibrated TECP data at polar Phoenix. Frosts and fogs were predicted but not detected at equatorial Curiosity (Martinez et al., 2016, 2017), but they could occur at subtropical VL1 and high-latitude VL2. Transient midnight formation of salty brines could also occasionally deplete some air moisture at Curiosity (Martin-Torres et al., 2015) but this effect is probably small and is not included in the present VL experiments.

Water vapor diffusion and adsorption into porous soil is sensitive to the surface flux of moisture (Savijärvi et al., 2016; Steele et al., 2017), whereas frost cuts the flux off and fog may reduce it. Frosts, fogs and fluxes are all notoriously sensitive to winds, temperatures and local stabilities, so a realistic simulation of the diurnal cycle of moisture needs to have the near-surface winds and temperatures accurately simulated. This is another reason for our return to the Vikings, as wind data from their first sols, when all instruments were working properly, are still probably the best available for model validation. Moreover, as will be seen, the two VL sites provide nearly ideal environments for column models, especially during the mild northern midsummer when the VL's arrived to Mars. The model is described in Section 2; its validation against the VL-observed temperatures and winds is given in Section 3. The moisture results and discussions for VL1 and VL2 are in Sections 4 and 5, respectively, with conclusions drawn in Section 6.

2. The column model

Only a brief account is given here; the references below provide details. The UH/FMI 1-D model is a hydrostatic boundary layer column model without advections. It is driven by a given large-scale geostrophic wind $\boldsymbol{V}_g$ and the varying surface temperature, which is predicted from the surface heat budget. The model's dynamics includes here a simple Prandtl theory –based slope wind mechanism. Turbulence is parameterized via a mixing length theory with a Monin–Obukhov surface layer, the vertical turbulent fluxes (including the moisture flux) depending on local stability and wind speed. The slope wind terms, stability functions and cloud physics are the same as described in Savijärvi and Määttänen (2010) for Phoenix, where the model simulated the “telltale” -observed winds and the LIDAR-observed night fogs and boundary layer clouds rather well.

The moisture predictands are the mass mixing ratios of water vapor (q) and fogice (q_i); ice condenses onto dust particles. Radiation (CO_2, water vapor, dust, fogs and iceclouds active) is based on a broadband LW emissivity scheme and an improved delta-two-stream broadband SW scheme, both validated against line-by-line dusty atmosphere results (Savijärvi et al., 2005). Ice may also condense at the surface (ground frost), as well as within the pores of the regolith. The eight-layer regolith scheme includes vertical diffusion of soil temperature and pore volume moisture together with the strongly temperature-dependent adsorption/desorption of moisture on regolith grains. The regolith scheme is as described in Savijärvi et al. (2016) for MSL, where the 1-D model gave a good simulation when using the palagonite-based adsorption isotherm of J97, which is also adopted here. If porosity is set to 0 (as for rocky ground), there is no adsorption and no moisture exchange through the surface.

The present Prandtl version is rather similar in its dynamics to the dry boundary layer model of Haberle et al. (1993). They also made comparisons with the VL data, to be commented later on (Section 3). In our model the atmospheric column contains 29 grid points, the lowest being at 0, 0.3, 0.7, 1.6, 3.7, 8.5 m … from the surface; the top is at 50 km. Time step is 10.27 s. Initially (0000 local solar time, LT) the winds are set to $\boldsymbol{V}_g$ and T to 220 K at the surface with a lapse of 1.5 K/km. $\boldsymbol{V}_g$ and $q(z)$ are based (because of lack of observations) on the VL site values of the GCM-derived Mars Climate Database (MCD). The results are shown from the third sol, when the 1-D model is repeating its diurnal cycle. The basic simulations are made with adsorption active; alternatively the surface interactions of moisture are shortcut by setting the porosity of the soil to 0.

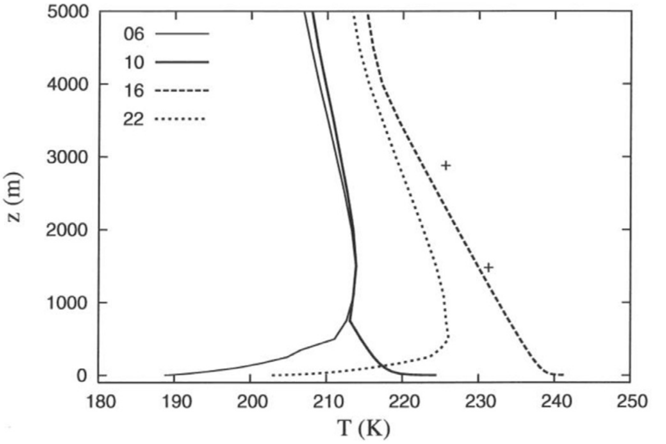

Fig. 1. Temperature profiles from 1.6 m to 5000 m at 0600, 1000, 1600 and 2200LT from the VL1 simulation. Also shown are two observed values at about 1615LT during the landing of VL1.

3. Validation of the model: temperatures and winds at the VL sites

For the first-sols simulations of VL1 at 22.5°N, L_s is set to 100° and the main atmospheric and site parameters (surface pressure 765 Pa, surface albedo 0.22, thermal inertia 283 SI units, roughness length 1 cm, dust optical depth 0.5) are based on observations and literature. A thin aphelion high cloud with optical depth of 0.07 is also present, as indicated by multiannual orbit observations (e.g. Smith, 2004). Upslope of 0.10° points to 247° (WSW), providing the best match with the observed winds (this was achieved in Haberle et al. (1993) with 0.17° upslope to SW).

Fig. 1 shows the resulting model temperature profiles from 1.6 m to 5 km at 0600, 1000, 1600 and 2200LT. At 1.6 m the temperatures are within ± 2 K to the observed values for the first VL1 sols from Hess et al. (1977); these were quite repetitive from sol to sol. Also shown in Fig. 1 are two measured temperatures during the parachute landing of VL1 at about 1615LT (Seiff and Kirk, 1977). The model's 1600LT T-profile is close to the observations, displaying a convective nearly adiabatic profile up to 4 km. After the development of a nocturnal strongly stable radiative surface inversion (to about 1 km height by 0600LT) the convective layer grows again in the morning, extending to about 700 m by 1000LT with a strongly superadiabatic layer near the surface in Fig. 1. The physics of the boundary layer temperature evolution is discussed in more detail in Petrosyan et al. (2011) and in Savijärvi (2012a, 2012b).

Fig. 2 displays the diurnal air and frost point temperatures at 1.6 m (T, T_f) and the ground surface temperature (T_g) from the VL1 simulations with and without adsorption. T and T_g are virtually the same in the two simulations, T ranging between 188–241 K and T_g between 185–263 K, as reported for the first VL1 sols (VL1 and orbiter data; Hess et al., 1977). T_g exceeds T from about 0730LT, triggering convection, and falls below T at around 1645LT, the surface layer then turning from convective to stable. The frost point temperatures will be discussed in the next section.

Observed VL1 winds at 1.6 m varied from sol to sol, although following a quite repetitive diurnal pattern. Hence Fig. 3 displays

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