Martian Planetary Boundary Layer Characterization under Convective Conditions

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1 Introduction

An extensive study of the magnitudes characterizing the convective Martian Planetary Boundary Layer (MPBL) at the Viking Lander 1, Viking Lander 2, and Pathfinder sites has been carried out. From the first meters up to a few kilometers (typical height of the convective MPBL), the fundamental similarity scales and the main turbulent statistics have been calculated. Concerning the Surface Layer (SL), typical values of Monin-Obukhov length L, friction velocity u_*, scale temperature T_*, and, for the first meter, turbulent viscous dissipation rate ϵ, eddy transfer coefficients for momentum k_m and heat k_h, and vertical wind speed standard deviation σ_w have been obtained. Regarding the Mixed Layer (ML), values of the MPBL height z_i, convective velocity scale w_*, convective scale temperature θ_*, mean temperature $< \sigma_\theta >$ and both horizontal $< \sigma_u >$ and vertical $< \sigma_w >$ wind speed standard deviations have been derived.

The SL has been researched through similarity theories ([1], [2], [3], and [4]). On the other hand, 1D ([5]), 2D ([6], and [7]), and 3D ([8], and [9]) models, together with Large eddy simulations ([10], [11], and [12]), have been used to characterize the ML. However, in these studies, just few of the above mentioned magnitudes have been presented, and ordinarily for generic runs. In addition, LES's and 3D models take an expensive computational time. For these reasons, we felt that a complete and low time cost research of the MPBL was needed in order to have an estimation of the order of magnitude of all the relevant turbulent parameters at VK's and PF sites from the SL up to the ML.

2 Data

In situ temperature and horizontal wind speed (at around 1.3 m for the PF and 1.6 m for the VK's), together with simulated ground temperature (a version of [5]) form the inputs of this work. Expected values for the surface roughness, a parameterization of the molecular sublayer, and SL and ML similarity relationships have been applied in the most convective hours to yield the results.

We have chosen three Sols for the VK1 (27, 28, and 35) and two (20 and 25) for the VK2 as an inputs. These Sols meet the next conditions: measurements have the least lander interferences, have the highest sampling rate, and correspond to summertime. Just Sol 25 have been chosen for the PF since this was the only Sol in which in situ wind speed and temperature measurements were available the whole Sol.

As ground temperature is a key parameter in this work, a carefully sensitivity study of this magnitude has been performed. We have investigated those external parameters which influence simulated ground temperature the most and whose values have not been accurately obtained: thermal inertia, albedo, surface emissivity, and dust optical depth. Then we have found in the literature the expected range of these values at the VK's and PF sites and run our version of [5]. By doing so, and taking also into account the other two in situ temperature heights at the PF site, we have created the warmest, the coldest, and the most probably scenario (see Figs. (1) and (2)) for all Sols under study. Finally we have cheked the variation of the results under such scenarios.

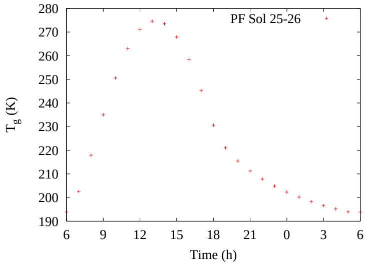

Figure 1: Most probably ground temperature scenario for Sol 25-26 PF Sol.

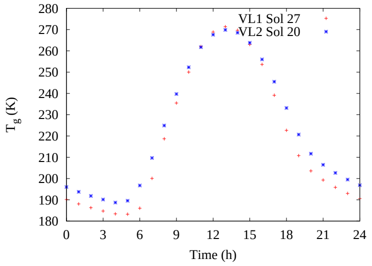

Figure 2: Most probably ground temperature scenario for the VL1 Sol 27 and for VL2 Sol 20.

3 Results

We have divided the results into SL and ML magnitudes and explained how they have been calculated. Finally, we show a table comparing the order of magnitude of all the calculated parameters on Mars and on Earth.

3.1 Surface Layer

The way in which Monin-Obukhov length L, friction velocity u_*, scale temperature T_*, eddy transfer coefficients for heat and momentum $k_{h,m}$, and turbulent viscous dissipation rate ϵ have been obtained can be seen in [4]. Temperature and horizontal wind speed standard deviations have been measured in situ (at 1.6 m and 1.3 m for VK's and PF respectively), while for the vertical wind speed standard deviation the next relation [13] under unstable conditions has been used

$$\frac{\sigma_w}{u_*} = 1.3\,(1 + 3(-z/L))^{1/3} \qquad (1)$$

The results are shown in Table 1.

Table 1: Typical values of some relevant surface layer parameters under convective conditions for the VK's and PF sites. They have been calculated at about 1.3 m height for the PF, and 1.6 m for the VK's.

	VL-1	VL-2	PF
$\|L\|$ (m)	27	7	40
u_* (m s^{-1})	0.50	0.25	0.40
$\|T_*\|$ (K)	1.5	2.5	1
k_m (m^2 s^{-1})	0.4	0.2	0.25
k_h (m^2 s^{-1})	0.45	0.35	0.30
ϵ (m^2 s^{-3})	0.20	0.02	0.17
σ_u (m s^{-1})	2.5	1.3	2.5
σ_w (m s^{-1})	0.7	0.35	0.50
σ_θ (K)	3.0	2.7	3.5

3.2 Mixed Layer

The following similarity relationships have been used to derive the main ML parameters. From [13], and using SL inputs, the mixed layer height can be deduced from

$$\frac{\sigma_u}{u_*} = (12 + 0.5(z_i/|L|))^{1/3} \qquad (2)$$

Convective velocity w_* and temperature scale θ_* have been calculated from their definitions.

Concerning the mean standard deviations of vertical wind speed $< \sigma_w >$ and temperature $< \sigma_\theta >$, we have calculated them by two ways. The first involves SL inputs

$$\frac{< \sigma_w >}{u_*} = 0.8(z_i/|L|)^{1/3} \qquad (3)$$

$$\frac{< \sigma_\theta >}{T_*} = -1.2(z_i/|L|)^{-1/3} \qquad (4)$$

while the second ML inputs

$$\frac{\sigma_w}{w_*} = (1.8)^{0.5}\,(1 - 0.8z/z_i)^{1/3} \qquad (5)$$

$$\frac{\sigma_\theta}{\theta_*} = (1.8)^{0.5}\,(z/z_i)^{-1/3} \qquad (6)$$

with Eqs. (3) and (4) from [14], Eq. (5) from [15], and Eq. (6) from [16].

The mean horizontal wind speed standard deviation

$$\frac{\sigma_u}{w_*} \simeq \frac{< \sigma_u >}{w_*} = 0.6 \qquad (7)$$

has been derived from [17].

Finally, the mean turbulent viscous dissipation rate

$$< \epsilon >= \frac{0.5 w_*^3}{z_i} \quad (8)$$

has been calculated from [16].

The summary of these results can be seen in Table 2.

Table 2: Typical values of some relevant mixed layer parameters under convective conditions for the VK's and PF sites.

	VL-1	VL-2	PF
z_i (km)	7	2	9
w_* (m s^{-1})	4	2	4
θ_* (K)	0.20	0.25	0.12
$< \epsilon >$ (m^2 s^{-3})	0.007	0.004	0.005
$< \sigma_u >$ (m s^{-1})	2.5	1.4	2.5
$< \sigma_w >$ (m s^{-1})	2.6	1.4	2.5
$< \sigma_T >$ (K)	0.35	0.5	0.20

3.3 Comparison to Earth

It is quite interesting to compare the values of all these parameters on both planets. After having researched the terrestrial literature, Table 3 has been completed, with the terrestrial values obtained for mid-latitudes flat terrains under no baroclinic disturbances.

The main differences can be observed in those magnitudes that are highly sensible to the lower Martian thermal inertia and air density. As the net radiation that reaches the Martian soil is almost the same than on Earth, and sensible and latent fluxes are much lower on Mars (low atmospheric density and virtual absence of water vapour), the heat conduction in the soil becomes very important. In addition, the thermal inertia is low. This all results in large ground temperature fluctuations (around 80 K through one Sol). Since the air atmospheric density is very low, Martian first few meters air can not be heated so efficiently and does not follow the ground temperature diurnal evolution. Consequently, large temperature gradients are created and therefore higher values of T_*, σ_θ^{SL}, z_i, θ_*, and $< \sigma_\theta >$ are observed.

Table 3: Comparison of the Martian and Earth Planetary Boundary Layers under the most convective hours. The terrestrial height in which these parameters have been calculated is around 4 m.

	Mars	**Earth**
Surface Layer		
$\|L\|$ (m)	$\simeq$30	Same values
u_* (m s^{-1})	$\simeq$0.4	Same Values
$T*$ (K)	$\simeq$2	(0.15,0.88)
ϵ (m^2 s^{-3})	0.15	(0.001,0.01)
σ_u (m s^{-1})	$\simeq$ 2	$\simeq$1.5
σ_w (m s^{-1})	$\simeq$ 0.5	(0.4,0.6)
σ_θ (K)	$\simeq$3	(0.18,1.7)
Mixed Layer		
z_i (km)	$\simeq$6	(0.2,2)
w_* (m s^{-1})	$\simeq$4	(1,2.41)
θ_* (K)	$\simeq$ 0.1	(0.03,0.1)
$< \epsilon >$ (m^2 s^{-3})	$\simeq$0.005	(0.001,0.005)
$< \sigma_u >$ (m s^{-1})	$\simeq$ 2.4	(0.47,1.13)
$< \sigma_w >$ (m s^{-1})	$\simeq$ 2.4	(0.6,1.4)
$< \sigma_T >$ (K)	$\simeq$0.3	(0.06,0.2)

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