MODELLING THE MARTIAN BOUNDARY LAYER

W. Weng and P.A. Taylor, *Centre for Research in Earth and Space Science, York University, Toronto, Canada (wweng@yorku.ca, pat@yorku.ca)*, **H. Savijarvi**, *Department of Physics, University of Helsinki, Finland.*

Introduction:

Much progress has been made in our understanding of the Martian atmospheric boundary layer through observations and numerical modelling in the last twenty years or so. Recent numerical modelling study includes those by Haberle et al's (1999), Newman et al's (2002a, b) GCM simulations; Savijarvi's (1999) and Savijarvi et al's (2004) boundary layer simulations. Observations from the Viking Mars mission and Mars Pathfinder Lander were used in the model initialization and comparisons in these simulations. In our Martian boundary-layer modelling study, we use the University of Helsinki 1D atmospheric boundary-layer (ABL) model (Savijarvi, 2004). Instead of the simple mixing-length turbulence closure, we implement 1.5 order turbulence closures, with the usual prognostic turbulent kinetic energy equation and a diagnostic equation for turbulent length scale. The results from the model simulations are compared and discussed between the different turbulence closures and also with the observational data.

The Model:

The 1D ABL model of Savijarvi (2004) is moist: the full hydrologic cycle and ice cloud/fog are included, and the soil temperature is modeled with a five-layer soil thermal diffusion scheme. The moisture content of the regolith is fixed to a constant value, β. An emissivity scheme was used in the radiation calculations and a two-stream method was introduced for effects of Martian dust in the solar range (a delta-discrete-ordinate scheme with dust single-scattering albedo of 0.9 and asymmetry parameter 0.7). Dust is assumed to be well mixed all the time and its amount is defined by the visible optical depth, τ.

In the model, the turbulence scheme is based on a Monin-Obukhov treatment for the lowest layer and a first-order mixing-length approach above it. In their modelling study of the Earth's atmospheric boundary layer, Weng and Taylor (2003) have tested a few 1.5 order turbulence closure schemes and found that E-ℓ and $q^2\ell$ level 2.5 simulate the atmospheric boundary layer well. These two turbulence closures are implemented in the 1D model. In both closures, the turbulent flux terms are locally related to mean vertical gradient by an eddy diffusivity K, which is a property of the turbulent flow. For the 1.5 order turbulence closure, eddy diffusivities are often formulated by the turbulent kinetic energy and the turbulent length scale. Therefore, in the two turbulence closures, the usual prognostic turbulent kinetic energy and diagnostic turbulent length scale equations were used.

Unlike the original model with the mixing-length closure in which only 23 grid points were used in the vertical up to 30 km, a log-linear coordinate transform and a total of 121 points are employed for the model with two 1.5 order turbulence closures. We denote the model with the mixing-length turbulence closure as Model A, the E-ℓ turbulence closure as Model B and $q^2\ell$ level 2.5 closure as Model C.

The MPF Data, Results and Discussions

The Mars Pathfinder lander (MPF) made a successful landing on Mars (19.3^{O}N, 30^{O}W). The initial solar longitude L_s was 141^{O}.

In our MPF simulations, the visible optical depth of dust is 0.3, surface pressure is 6.75 hPa, surface roughness 0.01 m, albedo 0.21, surface emissivity 0.96, the regolith heat capacity 0.8 MJ m^{-3} K^{-1}, the heat conductivity 0.15 W $m^{-1}K^{-1}$, the sun declination 14.7^{O} and geostrophic wind speed is 10 m s^{-1}. The initial temperature profile, $T(z)$, is set to 225 K at the surface with a lapse rate of 2 K km^{-1}, the initial moisture profile is obtained by setting the relative humidity to 12.5% and the regolith wetness β=0.003% .

The MPF data used in our comparison are for sol 3 and were kindly provided by J. Murphy of New Mexico State University. The data consist of instantaneous measurements of temperature (thermocouples at about 0.52, 0.77 and 1.27 m above ground) and wind speed and direction (hot film sensors at about 1.3 m) at four-second intervals during the MPF weather observation periods.

Figure 1a

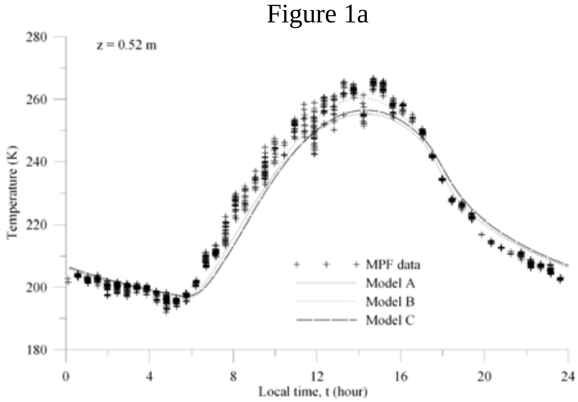


Figure 1 shows the MPF sol-3 observations together with the model results at z = 0.52 and 1.27 m. The temperatures display a strong diurnal cycle with lowest temperature around 06:00, a rapid increase after sunrise, strong variability during the morning and midday hours, reaching maximum temperature at about 1500 Martian hours local solar time (LT), and a quick drop in temperature in the late afternoon.

The three model results compare well with the observations: the results from Models A and C are very similar, while the results of Model B predicts slightly smaller values in the early morning but show better agreement in the late morning and early afternoon (1000—1700).

Figure 1b

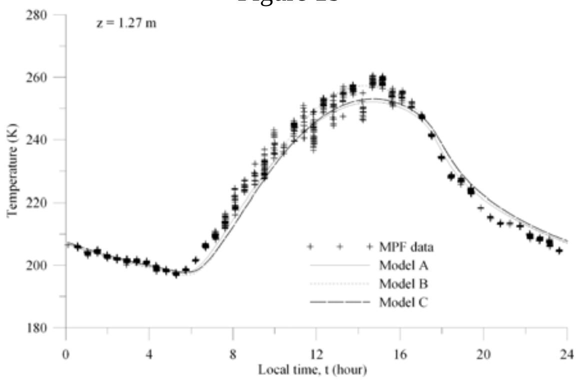
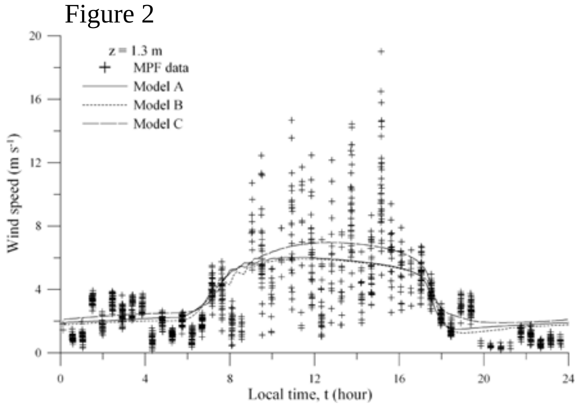


Figure 2



The comparison of wind speed is shown in Figure 2. There is a lot of variability during the unstable daytime hours in the observational data but steady and low wind speed during the night. The wind speeds from three models match the mean of the observations fairly well. The results from Models A and B are almost same while Model C's wind speed is slightly larger for the period of 1000—1700.

Figure 3

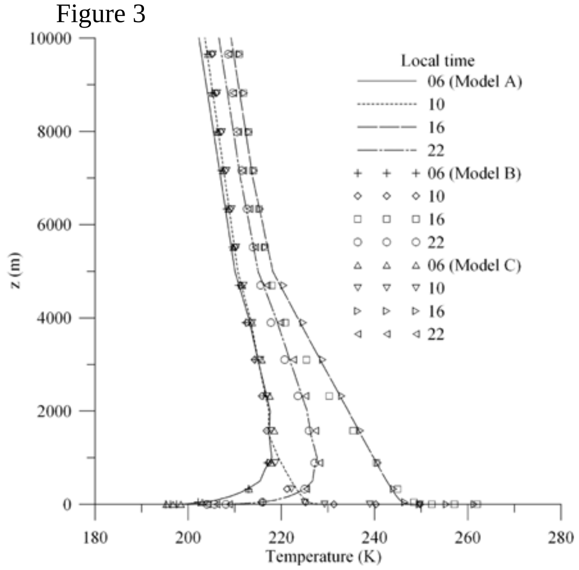
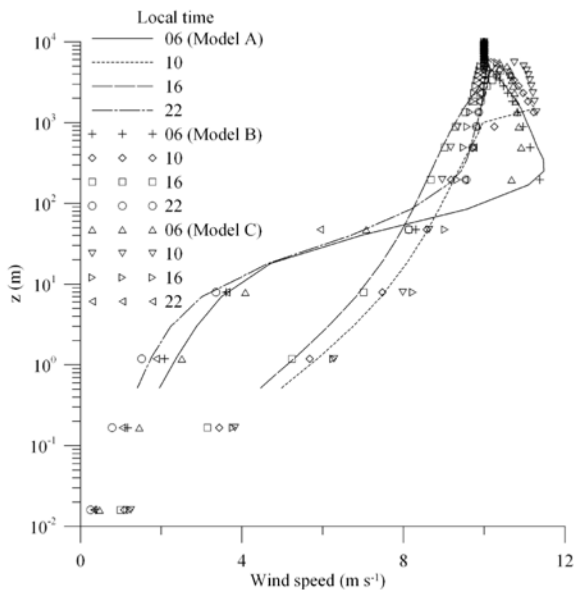


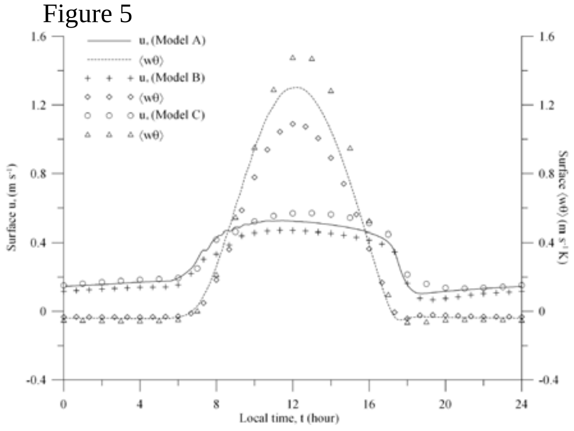
Figure 3 shows the temperature profiles from the present MPF simulation at 0600, 1000, 1600, 2200 LT. At 0600 LT (just after sunrise), there is a strong night-time surface inversion in the lowest 500 m. At 1000 LT the surface layer is quite unstable and the rapidly growing dry-adiabatic layer extends up to 1500 m. This well-mixed layer extends up to 5 km altitude by 1600 LT. At 2200 LT the surface inversion is again well established in the lowest 500 m.

Figure 4



The wind speed profiles from three models are shown in Figure 4. A clear diurnal cycle can be seen. Some broad features of wind speed profiles are similar for all the closures – the supergeostrophic wind or nocturnal jet is apparent at low level, wind speed and direction assume their geostrophic values at around 7 km. As expected, the wind shear is strong across the very stable surface inversion during the night hours (2200 and 0600 LT). However, the location of the low-level jet predicted by Model B is lower than that of Models A and C.

Figure 5



Finally, the surface friction velocity and heat flux from three models are shown in Figure 5. It can be seen that there are quite large differences around midday and Model C predicts the largest turbulent fluxes and Model B the smallest while Model A in between Models B and C. All these differences are due to slightly different formulations in turbulent length scale and eddy diffusivities among the three models.

Summary

Two 1.5 order turbulence closure schemes have been successfully implemented in Savijarvi's (2004) 1D ABL model. High-resolution simulations have been made for the Martian boundary layer. Model results are compared with the Mars Pathfinder Lander sol 3 high-frequency observations. The two 1.5 order turbulence closure models show very similar results with that of the mixing-length closure, especially that of *q2ℓ* level 2.5. The model with *E-ℓ* turbulence closure show some improvements compared with the observations during the later morning and early afternoon. Future work will include coupling this boundary layer model with a dust model to see the evolution of the dust and its effects on the radiation scheme.

References:

Haberle, R.M., Koshi, M.M., Murphy, J.R. Barnes, J.R., Schofield, J.T., Wilson, G., Lopes-Valverde, M., Hollingsworth, J.L., Bridger, A.F. C. and Schaeffer, J.: 1999, 'General circulation model simulations of the Mars Pathfinder atmospheric structure investigation/meteorology data', *J. Geophys. Res.*, **104**, 8957—8974.

Newman, C.E., Lewis, S.R., Read, P.L. and Forget, F.: 2002a, 'Modelling the dust cycle in a Mars general circulation model. 1: Representations of dust transport processes. *J. Geophys. Res.*, **107 E12**, 5123. doi: 10.1029/2002JE001910.

Newman, C.E., Lewis, S.R., Read, P.L. and Forget, F.: 2002a, 'Modelling the dust cycle in a Mars general circulation model. 2: Multi-annual radiatively active dust transport simulations. *J. Geophys. Res*., **107 E12**, 5124. doi: 10.1029/2002 JE001920.

Savijarvi, H: 1999, 'A model study of the atmospheric boundary layer in the Mars Pathfinder lander conditions', *Q. J. R Meteorol. Soc.,* **125**, 483—493.

Savijarvi, H., Maattanen, A., Kauhanen, J. and Harri, A.-M.: 2004, 'Mars Pathfinder: new data and new model simulations', *Q. J. R. Meteorol. Soc.,* **130**, 669—683.

Weng, W. and Taylor, P.A.: 2003, 'On modelling the one-dimensional atmospheric boundary layer', *Boundary-Layer Meteorol.*, **107**, 371—400.