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The depth of the convective boundary layer and implications for a Walker-like circulation on Mars

S. R. Lewis (1), D. P. Hinson (2) and A. Spiga (3)

(1) Department of Physics & Astronomy, The Open University, UK (s.r.lewis@open.ac.uk), (2) SETI Institute, Mountain View, CA, USA (3) Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, Paris, France.

Abstract

Radio science observations indicate that the depth of the martian convective boundary layer varies strongly with surface height, although the surface temperature does not. We show that this effect is reproduced in martian limited area models and in global climate models. The implications for the global circulation when convective boundary layer depth varies with location are considered.

1. Introduction

Mars has a particularly active convective boundary layer during the day, which can extend to over 10 km altitude above the surface. Radio occultation observations [2] have shown that the maximum depth of the martian convective boundary layer, usually reached during the late afternoon around 17:00LT, is strongly correlated with the surface elevation relative to a standard areoid, or, equivalently, strongly anti-correlated with surface pressure. This result has important implications for the global circulation and it is vital that atmospheric models are able to reproduce this behaviour. We show that a large-eddy simulation [10, 11] does indeed exhibit a similar correlation and that a global model, with a turbulence closure planetary boundary layer parameterization and dry convection scheme [1], also shows evidence that the depth of convection is correlated with surface height. Results are shown from high- and medium-resolution simulations, including global models into which Thermal Emission Spectrometer thermal data from NASA Mars Global Surveyor have been assimilated [3].

2. Global Model Results

We examine the planetary boundary layer in a global atmospheric model, the UK spectral version of the LMD Mars GCM [1, 4]. The global model has a 2.5

level Mellor-Yamada turbulence closure parameterization and enforces static stability with a dry convection scheme that ensures that the vertical gradient of potential temperature can never become negative; in contrast, super-adiabatic profiles are often observed on Mars close to the surface during the day [6, 7, 8].

Figure 1 shows a potential temperature cross-section through the lower part of the model atmosphere from an experiment with high vertical resolution (100 levels). The division between a convective lower atmosphere with essentially constant potential temperature in the vertical and the statically stable body of the atmosphere is clear, as are variations in the depth of the convective layer correlated with surface elevation.

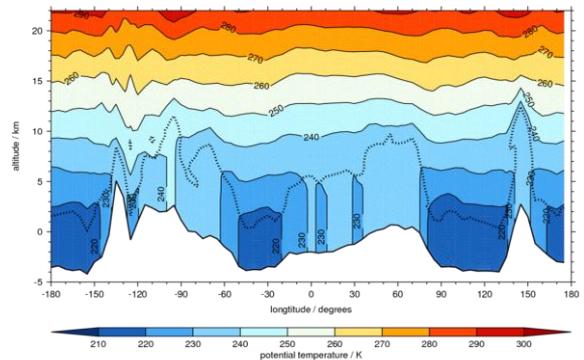


Figure 1: Potential temperature at 1600LT at all longitudes from the lowest part of the atmosphere of a high vertical resolution Mars general circulation model along the 22.5°N line of latitude at $L_S = 60^\circ$. The dotted line shows where the vertical gradient of potential temperature first exceeds 1.5 K/km, a proxy for the top of the convective boundary layer.

3. Summary and Conclusions

We have established that the convective boundary layer depth is correlated with surface elevation on Mars. This has important implications for the global circulation on Mars.

It is important that any boundary layer parameterization used in a martian global model is able to reproduce this effect in order to model the circulation realistically and planetary boundary layer schemes should be validated against observations and detailed large-eddy simulations.

Since the variation of boundary layer depth is fixed with respect to the surface it will act to enhance the, already large, martian topographic contrasts, affect stationary wave generation and modulate the non sun-synchronous thermal tides produced in the martian atmosphere as a result of the interaction of the direct thermal tide with surface topographic and thermal variations.

It is possible that variations in the boundary layer depth will induce differences in the large-scale martian circulation and Walker cell-like structures along latitude circles in equatorial regions.

Wind speeds within the planetary boundary layer are strongly dependent on boundary layer depth [11]. Regions where the convective boundary layer is deep will show enhanced wind speed, and so enhanced dust lifting, compared to regions where the boundary layer is less active.

The convective boundary layer plays a vital role in surface-atmosphere interactions. Dust lifted from the surface is effectively mixed into the body of the atmosphere, where it may be transported by large-scale winds. Without convective mixing in the lower atmosphere, dust lifted by near-surface wind stress would remain at low altitudes and would rapidly fall out of the atmosphere [e.g. 5]. Similarly, water vapour sublimated from surface sources and other trace gas, such as methane, will be mixed into the atmosphere. These processes will be much more efficient above regions of high surface elevation as a result of the variation in boundary layer depth.

Accurate prediction of the turbulent winds in the convective boundary layer may be important to the safe entry, descent and landing of future spacecraft missions, such as NASA Mars Science Laboratory and ESA/NASA ExoMars. It is harder to land in regions of lower surface pressure since there is less atmospheric mass available on the descent trajectory to decelerate a spacecraft. A more active convective boundary layer above regions of high elevation could make landing in such regions even more hazardous.

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