DECADAL SURVEY 2009: THE MARTIAN PLANETARY BOUNDARY LAYER

The Martian planetary boundary layer (PBL) comprises those layers of the atmosphere closest to the surface, within which interactions between the atmosphere and the surface itself are dominant. In practice, this represents the lowest 1-10 km of the atmosphere, including a shallow surface layer (depth ~1cm - 1m), a deep convective layer within which surface-driven intense convection may take place with convective plumes and vortices rising to altitudes of 5-10km during the daytime, and the entrainment layer at the top of the PBL. During the night, convection collapses to result in a much shallower layer, which becomes highly stratified and statically stable as the surface cools through radiation to space. It is therefore a highly dynamic and variable region of the atmosphere at virtually all locations on Mars, with additional variability and dynamical phenomena induced by interactions with local surface topography and changes on seasonal and interannual timescales.

This portion of the atmosphere is extremely important, both scientifically and operationally. It is the critical interface between the free atmosphere and the surface and regolith, mediating both short and long term exchanges of heat, momentum, dust, water and a variety of chemical tracers (such as argon and methane) between surface/sub-surface and atmospheric reservoirs. It is also the region of the atmosphere within which surface lander (and possibly airborne) spacecraft must operate. Finally, it is the region of the Martian atmospheric environment that is perhaps most likely to be inhabited by living organisms, should any have evolved. A clear and quantitative understanding of this part of the atmosphere, the range of conditions it supports and the way in which it interacts with the surface and free atmosphere, should therefore be a vital part of any program to explore and understand the Martian environment, present, past or future. Such an understanding will also enable reliable predictions to be made of environmental conditions encountered during spacecraft entry, descent and landing, and during surface operations, which are essential for mission safety and efficient design.

At the present time, our understanding of the Martian PBL and ability to model it are strongly guided and influenced by studies of its terrestrial counterpart. While this may be a valid initial approach, the Martian environment differs from that of the Earth in a number of important respects. The much lower atmospheric pressure at the Martian surface may be significant, especially within the thin surface layer, affecting the details of heat, momentum and mass fluxes. The range of conditions encountered in the Martian PBL may also be substantially more extreme than found typically on Earth, with diurnal contrasts from extreme convective conditions, with sustained super-adiabatic thermal gradients, to very strongly stably stratified conditions during the night. Such widespread and extreme variability across the entire planet places extraordinary demands on predictive models to capture accurately and to compute levels of turbulence and implied vertical transports of heat, momentum and tracers.

- **A key goal for future Mars exploration should therefore be to test and validate models for boundary layer structure and vertical transport over the full range of conditions encountered at the Martian surface.**

This aspect of Martian atmospheric science has been comparatively neglected in recent exploration activities, despite the fact that the success and safety of every surface landing on Mars depends on accurate and realistic predictions of the conditions encountered. One of the main sources of information on the Martian PBL continues to be the multi-annual series of measurements from the Viking Landers in the 1970s. The quality and consistency of these datasets have scarcely been superseded by any subsequent lander mission in recent years. The recent Mars Exploration Rovers (*Spirit* and *Opportunity*) were not even equipped with the most basic of meteorological instrumentation to measure atmospheric parameters *in situ* (although the mini-TES remote sensing instrument did provide valuable information on low-level thermal structures in the PBL). Some more recent missions (Phoenix, MSL) have indicated a greater recognition on the part of NASA of the need to obtain better information on the PBL and a commitment to providing improved instrumentation. But we note with considerable regret the current lack of any such instrumentation approved for ESA's forthcoming ExoMars mission. In the following list, we outline the key parameters that should be measured in future missions in order to provide an adequate test and validation of PBL models, together with a prioritised list of measurement objectives.

Key parameters

- Near-surface atmospheric fluxes of momentum and heat at least at two well separated altitudes
- Surface temperatures
- Near-surface winds (both mean and fluctuations, all three components)
- Daytime mixing layer potential temperature
- Temperature profile in the boundary layer
- Height of the afternoon convective boundary layer
- Dust devil wind, pressure, temperature perturbations + dust devil activity

Key new measurements

- Measurements of the above key parameters over full diurnal and seasonal cycles, at locations representative of the ***full range*** of Martian terrains (flat plains, smoothly sloping terrain, rough boulder terrain, mountainous terrain…..)
- Measurements of near-surface temperature and 3D wind fluctuations with ~10Hz sampling, preferably over a profile from the surface to >2000m altitude.

Principal Recommendations

1. **The PBL structure on Mars is highly variable in both space and time across the planet. ALL future surface and low altitude airborne missions to Mars should therefore be equipped with at least a minimum complement of *in situ* meteorological instrumentation to measure temperature, wind speed and direction, surface pressure and radiative balance. This would ideally lead eventually to a coordinated network of meteorological stations across the planet.**

2. **There is also a clear need for a concerted campaign of specialist PBL measurements at a few representative locations with a deep vertical profiling capability (e.g. using sonic anemometry) and high temporal resolution (~10Hz for wind components), in order to be able to measure diurnally- and seasonally-varying turbulent fluxes of heat and momentum within the surface and convective layers of the PBL.**

3. **To ensure unambiguous interpretation of such *in situ* measurements, they should be further complemented by contemporaneous remote sensing measurements of the large-scale meteorological context of each surface station.**

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