Martian Planetary Boundary Layer: Dynamics and Interactions with the Surface and Free Atmosphere

Abstract

Dynamical processes in the Martian boundary layer provide the means of communication between surface ice deposits and the free atmosphere, and the means of lifting dust from the surface. The boundary layer is therefore one of the most critical systems within the Martian climate system. The Martian boundary layer differs from that of the Earth in that it is more strongly forced, it is deeper, and the relative importance of radiative and convective heat fluxes in the lower boundary layer can be quite different. In order to understand the boundary layer, a combination of theoretical and modeling study is needed, in combination with the limited available data from the Martian surface. Interactions between theorists, modelers, and observational scientists is needed to make progress and to provide a basis for analysis of data expected from the NASA Phoenix and Mars Science Laboratory missions.

Science Rationale

The planetary boundary layer is a critical region of the Martian atmosphere, with a major role in the Martian climate system through its control of volatile fluxes, the lifting of mineral aerosol "dust", and the exchange of heat and momentum between the surface and atmosphere. The "boundary layer" is that portion of the atmosphere where frictional exchange with the surface is important. During the daytime, the rapid solar heating of the surface yields an unstable thermal profile and convection is initiated. It is estimated that that convective boundary layer can deepen to over 5km on Mars. At night, the surface cools more rapidly than the atmosphere, and the boundary layer collapses, but does not completely disappear. Mechanical interaction between the winds and the rough surface still generate a turbulent stirring of the atmosphere even at night.

The Martian climate system is strongly moderated by the presence of mineral dust in the atmosphere that interacts with both solar and thermal radiation. This dust is observed to be injected into the atmosphere through a combination of convective processes (dust devils have been observed in both orbiter and lander images) and large-scale wind stresses. Both lifting mechanisms depend strongly on the dynamics of the boundary layer: the former directly on the nature of thermal convection, and the latter on the mechanisms of stress communication to the surface. Water is of major interest on Mars: determining is distribution and stability on and beneath the Martian surface is a major goal of both ESA and NASA. The atmosphere provides a fast route of water transport across the planet – vapour transport has been observed in global data sets provided by Viking, Mars Global Surveyor, and now by Mars Express. The supply of water to the global free atmosphere is provided by vapour fluxes through the boundary layer. In this sense, the nature of boundary layer vapour exchange are critical to understanding the stability of surface and subsurface water – parameterizations of this exchange capacity are a vital component of models used to understand and retrieve information on water stability from data sets such as the gamma ray / neutron detector hydrogen abundance observations collected by the Mars Odyssey orbiter. Finally, the boundary layer fluxes of heat and momentum are critical to understanding the regional and global dynamics of the Martian atmosphere. These fluxes are parameterized in global and mesoscale models of the atmosphere used to analyze atmospheric data sets collected by Mars Global Surveyor, Mars Express, and the upcoming Mars Reconnaissance Orbiter spacecraft. Currently, these parameterizations are simply adapted versions of terrestrial boundary layer schemes, but there are important reasons for thinking that the Martian boundary layer is sufficiently different from that of the Earth, that these schemes may not be valid.

A final reason for the importance of understanding the Martian boundary layer is that it is within this portion of the atmosphere that most non-orbiting spacecraft must operate. Landers must descend through this portion of the atmosphere during the critical "entry, descent, and landing" portion of the mission, and they must operate on the surface. Other systems, such as balloons or winged aerial platforms would actually have to operate at some altitude in these regions of the atmosphere. As a result, there is a direct, pragmatic need to understand the boundary layer from the perspective of designing spacecraft and missions to Mars.

Despite its central importance, this portion of the Martian atmosphere is one of the least well understood, and because of constraints on spacecraft observational systems (most of what we know of the atmosphere comes from orbiters), least well measured. The observations that we do have come from five landers: only three of which were designed to measure meteorological variables. The Viking and Mars Pathfinder landers carried meteorological stations which were able to measure pressure, temperature, and some wind information near the surface (~1m) and at moderate temporal resolution (>1s per sample) and over the diurnal cycle. The Mars Exploration Rovers do not carry meteorological instruments, but measurements of the near surface temperature profile are possible with the mini-Thermal Emission Spectrometer instrument.

The Martian boundary layer is likely substantially different from that of the Earth for a number of key reasons. As a result, terrestrial models cannot be brought directly across to Mars, despite the fact that this is current practice. Instead, there is a significant need to directly investigate the Martian boundary layer, and to develop theoretical understanding and parameterizations that can be used elsewhere. The major difference between the Martian and terrestrial boundary layers lies in the fact that the Martian atmosphere is much thinner than that of the Earth. Typical surface pressure on Mars is about 600 Pa, versus 10^5 Pa for Earth. This yields a very different net heat capacity of the atmosphere, which allows very much larger surface-atmosphere temperature contrasts to develop as a result of the much lesser ability of heat to be carried away from the surface by the atmosphere. This difference yields a very much deeper boundary layer development on Mars (over 5km versus 1km for Earth), since the amplitude of the diurnal surface temperature variations can be much larger (over 100 K for tropical locations).

Because of the importance of the boundary layer, the wide variation of models applied to diverse problems on Mars that use terrestrial parameterizations, and the likely invalidity of these schemes to Mars requires that effort be put into directly studying the Martian boundary layer.

The specific aspects of boundary layer dynamics that need to be studied include:

1. how important are radiative and convective fluxes for the vertical movement of heat as a function of height?
2. what is the relationship between surface thermal forcing and the depth of the boundary layer?
3. what is the relationship between the surface forcing and the scales and intensity of motion?
4. how effectively are heat, momentum, and tracers mixed within the stable nighttime boundary layer?
5. what is the nature of the turblence in the stable and unstable boundary layer?
6. how well do terrestrial parameterizations of boundary layer turbulence do when forced under Martian conditions?

Timeliness

A team of theorists, modelers, and those with experience in the analysis of Martian and terrestrial boundary layer data would provide a unique catalyst for this work. This is particularly timely as the development of mesoscale and "large eddy" models for Mars, and studies undertaken for NASA prior to the landing of the MER rovers are beginning to highlight our ignorance of this part of the atmosphere, and missions now in the early development stages (including NASA's Phoenix and Mars Science Laboratory) yield the opportunity to undertake more detailed observations of this part of the atmosphere. Results from our team study have a significant possibility of influencing the nature of these experiments.

Expected Outputs

The outcome of this study is hoped to be increased understanding of the boundary layer and an indication of what observations and modeling tools might be necessary to make further progress. We are confident that this project will be of great interest worldwide. Therefore we attach considerable importance to dissemination and to consequent feedback. The main expected output will be articles submitted to leading journals, co-authored by team members. We intend to generate a review paper that will include recommendations for future observations. We also hope to include guidance on how the boundary layer might by better parameterized in numerical models. A reference model of the boundary layer will be generated and documented in a review article. Lectures will be presented at relevant conferences and workshops. ISSI making our interaction possible will be acknowledged in all relevant publications. A special technical document on reference model will be prepeared and will be sent to NASA and ESA to use in future Mars mission preparations.

Relevance to ISSI

ISSI is a preferred implementation site for this team as it provides a unique venue for collaboration between European and American scientists.

Team Members

Mark Richardson	CALTECH
Arakel Petrosyan	IKI, MOSCOW
Nick Thomas	U.BERN
Hannu Saviljarvi	U.HELSINKI
Francois Forget	U.PARIS6
Claire Newman	CALTECH
Anthony Toigo	CORNELL
Soeren Larssen	RISO
Nilton Renno	U.MICHIGAN
Peter Read	U.OXFORD
Tero Siili	FMI, HELSINKI
Patrick Russell	U.BERN
Kurt Gunderson	U.BERN
Karsten Seiferlin	U.BERN
Stephen Lewis	U.Oxford
Peter Rogberg	U.Oxford

Schedule

A critical number of scientists covering all the required expertise have been invited. The team will meet three times to work on the issues outlined above. We suggest having our first meeting in fall 2005. The second meeting will be scheduled 6 months later, and final meeting 12 month later. The meetings would last 5 days including probably either a Saturday or a Sunday to minimize return fees.

Required facilities

We will need the larger meeting room on the first or third floor with overhead projection and PowerPoint presentation facilities and expect to use the computers on both 1st and 3rd floors for electronic mail connections. No special computational facilities are required.