THE ISSI INTERNATIONAL STUDY TEAM ON THE MARTIAN PBL – STATUS REPORT AND PLAN.

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Summary: 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 important components of 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 Martian boundary layer, a combination of theoretical, modeling and observational studies are necessary. Interactions between theorists, modelers, and observational scientists are needed to make progress and to provide a basis for analysis of data expected from Phoenix, Mars Science Laboratory, ExoMars and other future landed missions (such as a surface network mission), or missions such as balloons or other aircraft operating in the neutral atmosphere. The prime goal of this project under the auspices of the International Space Science Institute (ISSI) is to review and assess the current knowledge and understanding of Martian planetary boundary layer and its interactions with the surface and free atmosphere. We aim to promote international communication and collaboration to enhance the rate of acquisition of knowledge and understanding. This will be achieved through an International Study Team and publication of overview papers and individual reports on recent advances in this area.

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 the convective boundary layer can reach a depth of over 5 km 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 atmosphere and the rough surface still generate a turbulent stirring of the atmosphere that maintains a finite-depth boundary layer.

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 and convection within dust storms have been observed by both orbiter and landers) and large-scale wind stresses. Both lifting mechanisms depend strongly on the dynamics of the boundary layer. Dust devils and convective dust storms depend directly on the nature of thermal convection, and the nature of large-scale events involving strong surface winds depend on the mechanisms of stress communication to the surface.

Water is of major interest on Mars: determining its distribution and stability on and beneath the Martian surface is a major goal of both ESA and NASA. The atmosphere provides a fast conduit of water transport across the planet – water vapor transport has been inferred from global data sets provided by V1ng, Mars Global Surveyor, and more recently by Mars Express. The supply of water to the global free atmosphere is provided by water vapor fluxes through the boundary layer. In this sense, the nature of the boundary layer water vapor exchange is 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 an understanding of 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 Odyssey, Mars Express, and 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 significantly incomplete or of doubtful validity, especially under strongly stable conditions.

A final reason for the necessity of a better understanding of 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 (EDL) 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 about the atmosphere comes from orbiters), least well measured. The observations that we currently 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 (~1 m) and at moderate temporal resolution (> 1 s 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 substantially different from that of the Earth for a number of key reasons. As a result, terrestrial models should only be applied to Mars with caution, despite the fact that this is almost universally the current practice. Instead, there is a significant need to directly investigate the Martian boundary layer, and to develop a theoretical understanding and parameterizations that can be used elsewhere. The major difference between the Martian and terrestrial boundary layers lie 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 lower efficiency of heat transfer away from the surface by the atmosphere. This difference yields a very much deeper boundary layer development on Mars (over 5 km versus 1 km 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 questionable validity of some aspects 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 turbulence in the stable and unstable boundary layer?
6. How well do terrestrial parameterizations of boundary layer turbulence do when forced under Martian conditions?

Team composition: The team includes theorists, modelers, and those with experience in the analysis of Martian and terrestrial boundary layer data. In addition to the current more senior members of the current team, a limited number of graduate students close to finishing the Ph.D. and recent Ph.Ds can be invited to join the team.

Timeliness: 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 and the Phoenix lander, are beginning to expose limitations in our understanding of this part of the atmosphere. Those two missions, as well as other missions in the development stages (such as NASA's Mars Science Laboratory and ESA's ExoMars), yield the opportunity to undertake more detailed observations of this part of the atmosphere. We hope that the results of this ISSI project have relevance and influence upon analyses of the observations of past and ongoing missions as well as on the design of future instruments and on the planning of their observations.

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 results will be reported in conferences and workshops, but the expected main output will be articles submitted to leading journals (co-authored by team members), including a review article that will include recommendations for future observations. We also hope to include guidance on how the boundary layer might be better parameterized in numerical models. A reference model of the boundary layer (useful both for science as well as for preparation, design and implementation of future Mars missions) will be generated and documented in the review article and in a technical report, together with the compilation of some key observational datasets for use in comparative studies and model validation.

Schedule: The team will meet three times to coordinate the work carried out on the issues outlined above. The first five-day meeting was held at ISSI in May 2008. The second similar meeting will be scheduled for early 2009 and the third for second half of 2009.