An exploration of the intense fine-scale meteorology on Mars by modeling and observations

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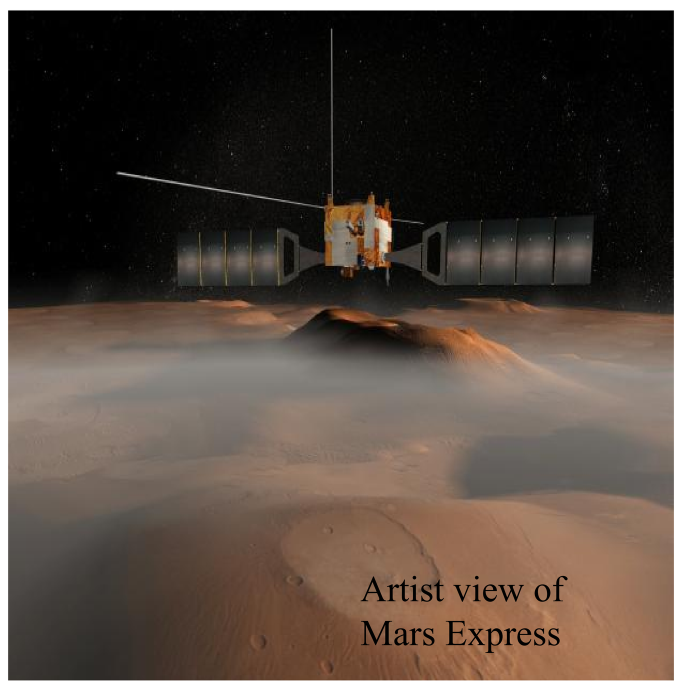
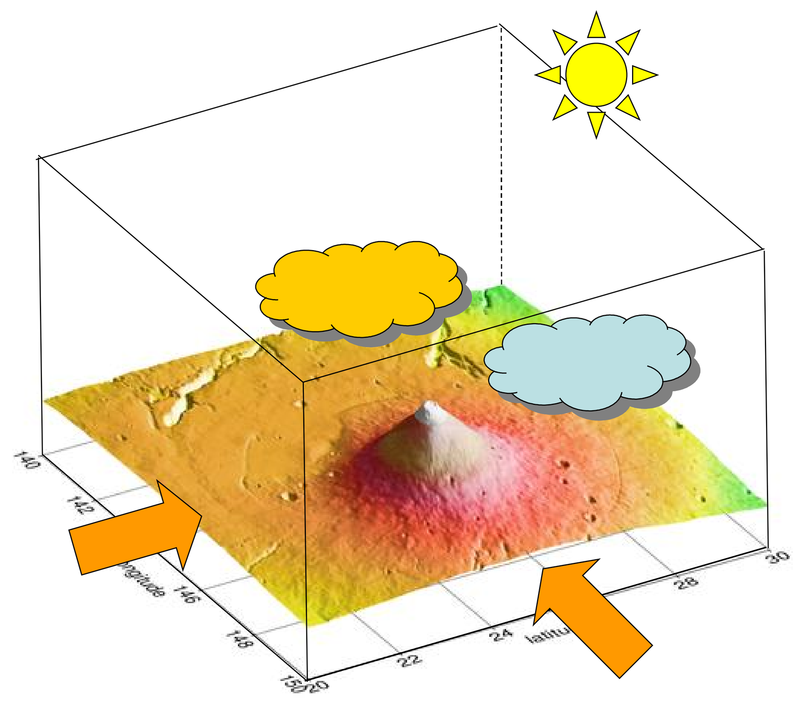


Background

Recent missions to Mars yielded unprecedented views of the Red Planet. High-resolution measurements carried out by the instruments onboard Mars Global Surveyor between 1996 and 2006 revealed the diversity of the Martian meteorological phenomena at various horizontal scales below 100 kilometers. More details were eventually provided by the (still ongoing) high-accuracy measurements of the Mars Exploration Rovers, Mars Express orbiter and Mars Reconnaissance Orbiter. Large-scale atmospheric circulation (horizontal scale ~ 100-1000 km) can be simulated by general circulation models with coarse grid and simplifying assumptions, such as hydrostaticity. From the early work of the 60s-70s to the recent efforts in the 90s-00s, these tools were crucial to achieve a satisfying understanding of the global climate on Mars, but were proved unable to adress key questions of local meteorology.

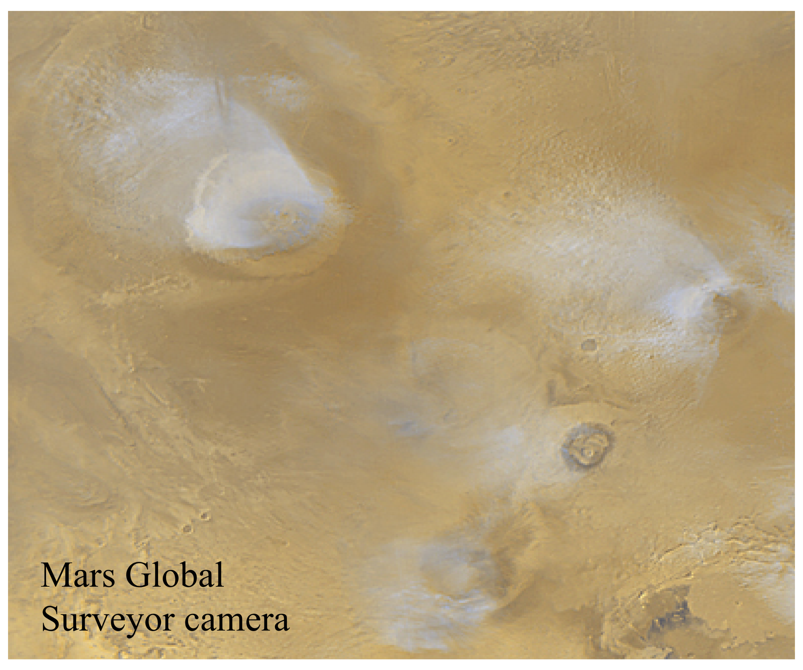
Recent modelling

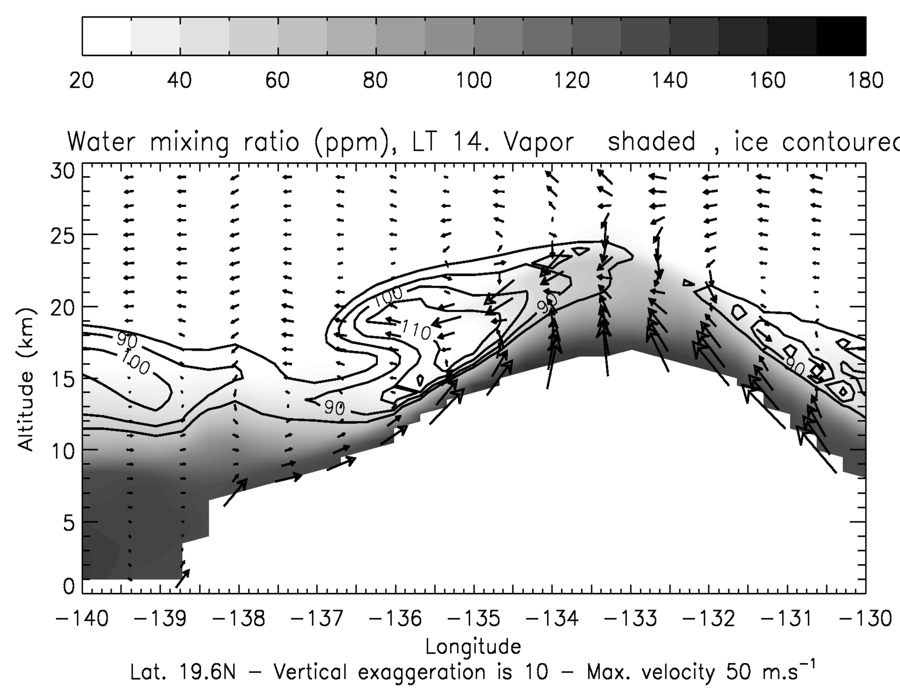
The need for realistic numerical models able to resolve atmospheric dynamics from the meso-scale (100-1 km) to the micro-scale (<1 km, where larger turbulent eddies are computed by the model) is thus critical. The LMD Mesoscale Model is a new versatile simulator of the Martian atmosphere and environment at horizontal scales ranging from 100s of km to 10s of m. The model combines the NCEP-NCAR fully compressible nonhydrostatic ARW-WRF dynamical core, adapted to Mars, with the LMD-GCM comprehensive set of physical parameterizations for the Martian dust, CO_2, water and photochemistry cycles. Since LMD-GCM large-scale simulations are also used to drive the mesoscale model at the boundaries of the chosen domain of interest, a high level of downscaling consistency is reached.



Topographic summer clouds

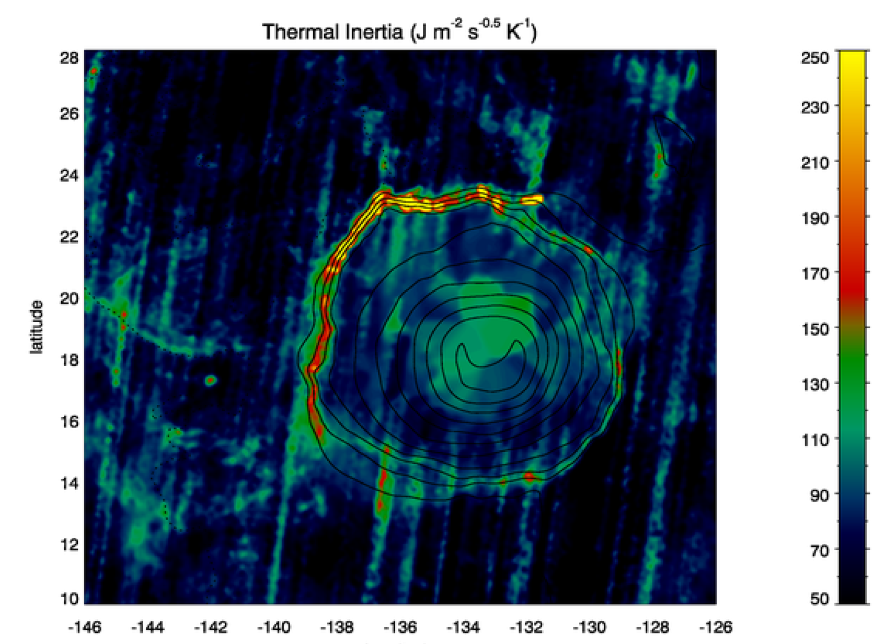
Water ice clouds have been observed between mid-spring and mid-summer in the vicinity of the Tharsis and Olympus Mons volcanoes. The water ice clouds controlled by the Tharsis and Olympus Mons topographical obstacles are reasonably reproduced by the model, which predicts consistent altitudes of the afternoon clouds with respect to remote-sensing retrievals. The main dynamical mechanism involved in the formation of the clouds is the strong water vapor advection by the afternoon upslope winds above the hygropause.



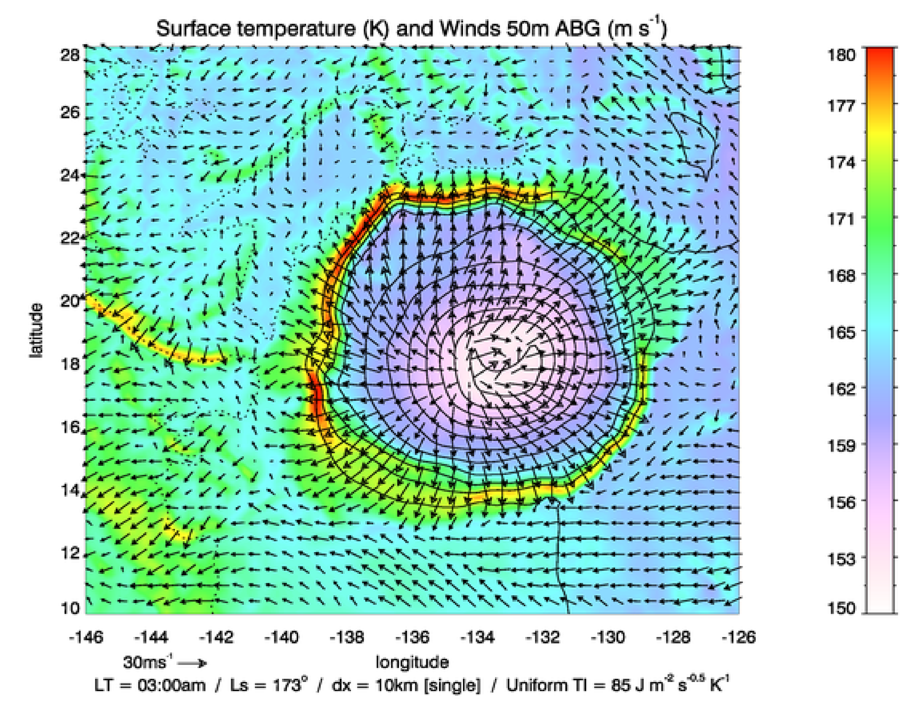


Nocturnal warm slopes

Warming of the surface occurs under the influence of katabatic (downslope) winds which develop during the night and cause air masses 10-100 meters above the surface to be adiabatically compressed as they descend along steep slopes. The surface temperature increases because the warmer overlying atmosphere enhances the downward thermal infrared flux to the surface. Apparent thermal inertia obtained through soil modeling (which does not take into account atmospheric circulation) might not correspond to actual thermal inertia as inferred from soil characteristics.

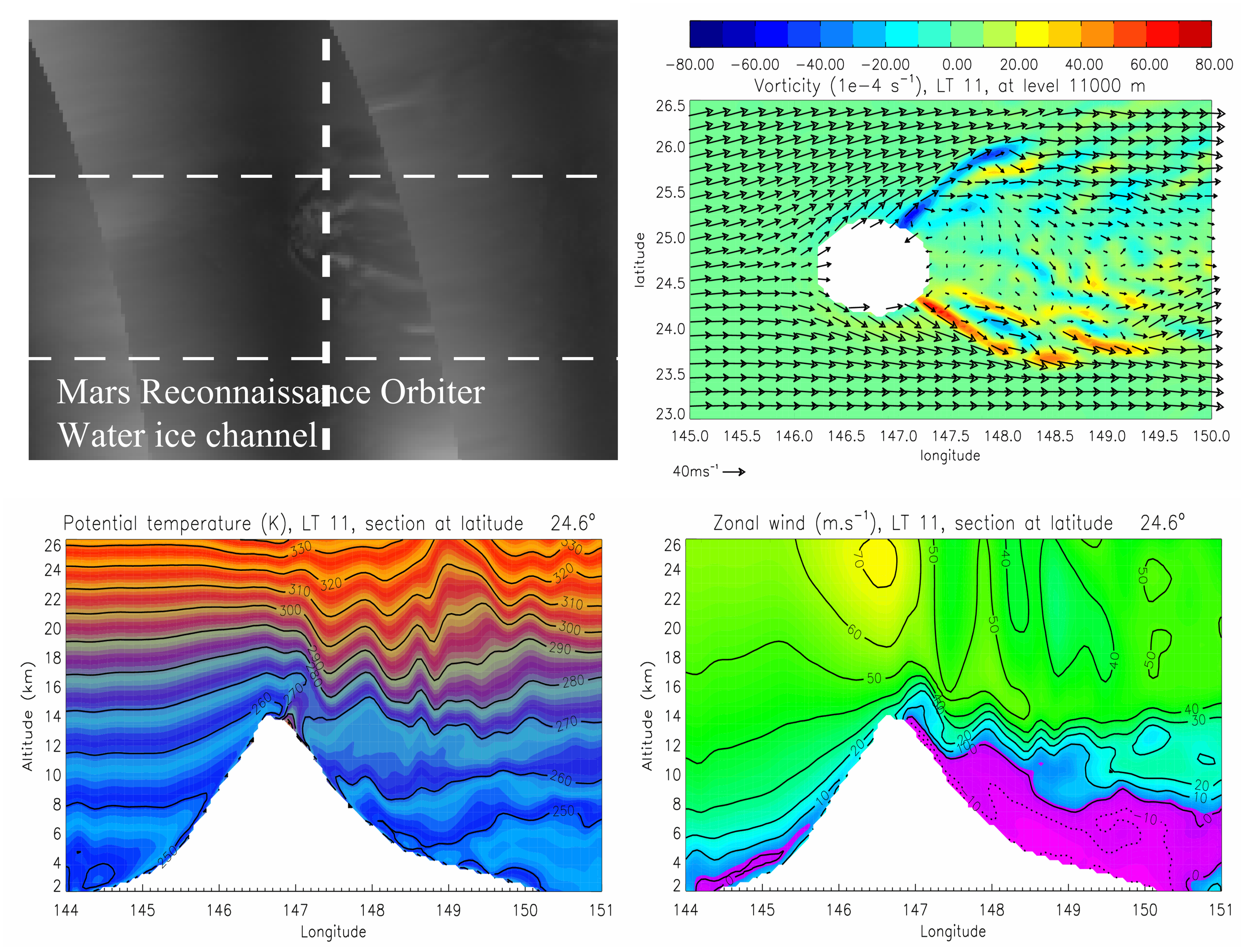


High Resolution retrievals by Putzig and Mellon [2007]



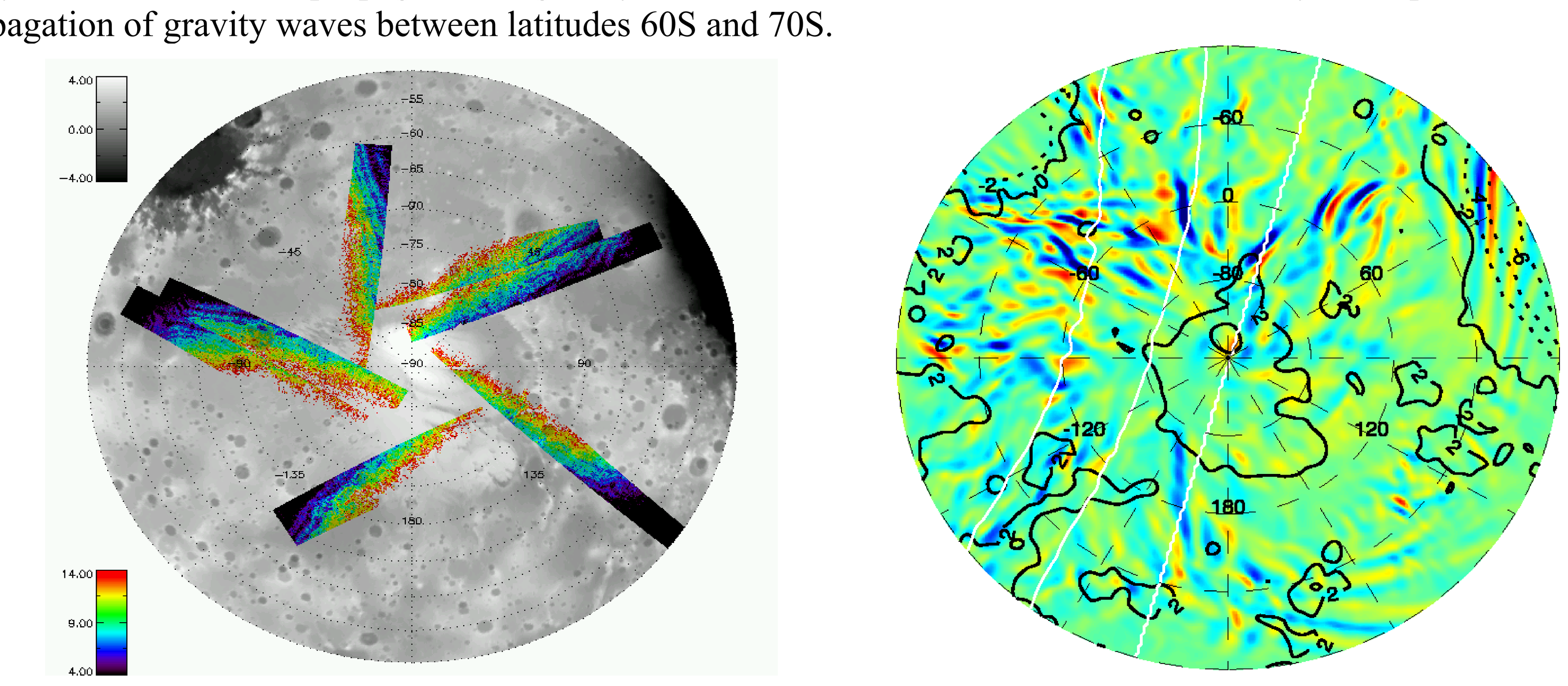
Wake vortices

Intense wake circulation takes place in Elysium Planitia when the northern fall jet-stream blows on the giant Elysium Mons volcano. Only at this specific season water-ice clouds with elongated shapes form in the wake of the volcano. The daytime flow is characterized by flow splitting and moderate trapped lee wave activity : vortices appear on the flanks of the volcan as the flow passes around the obstacle. Non-linear phenomena occurs in the lee of the volcano with distinct dynamical regimes between night and day. The nighttime flow is characterized by strong gravity wave activity, as a significant part of the incoming flow passes over the obstacle.



Gravity waves

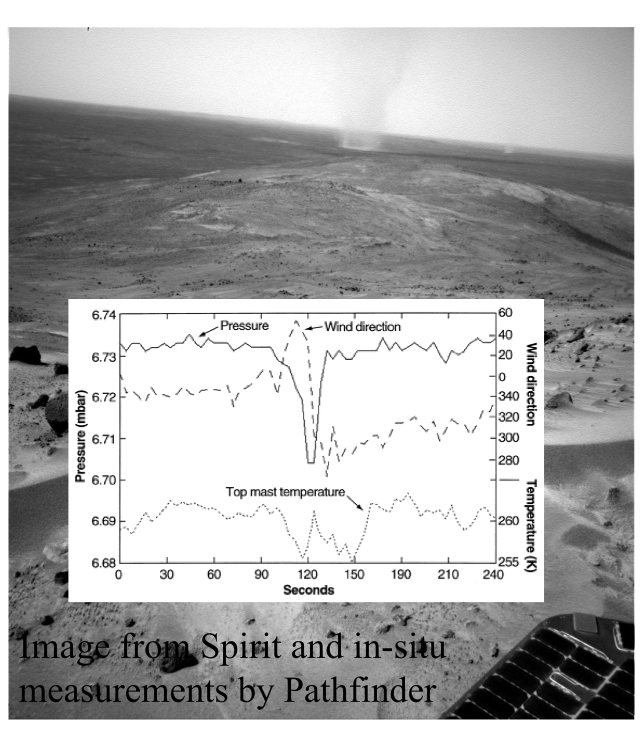
Wave patterns are detected on the southern polar region of Mars, traced by the O_2 dayglow emission at λ = 1.27 µm. Observations are carried out by the OMEGA spectrometer on board Mars Express. Mesoscale modelling of high-altitude vertical motion shows that the observed features can be related to gravity waves triggered by interactions between flow and topography. These results confirm that airglow imagery is a powerful method to detect and study the bi-dimensional propagation of gravity waves. Latitudinal variations of wave activity show preferential emission and propagation of gravity waves between latitudes 60S and 70S.

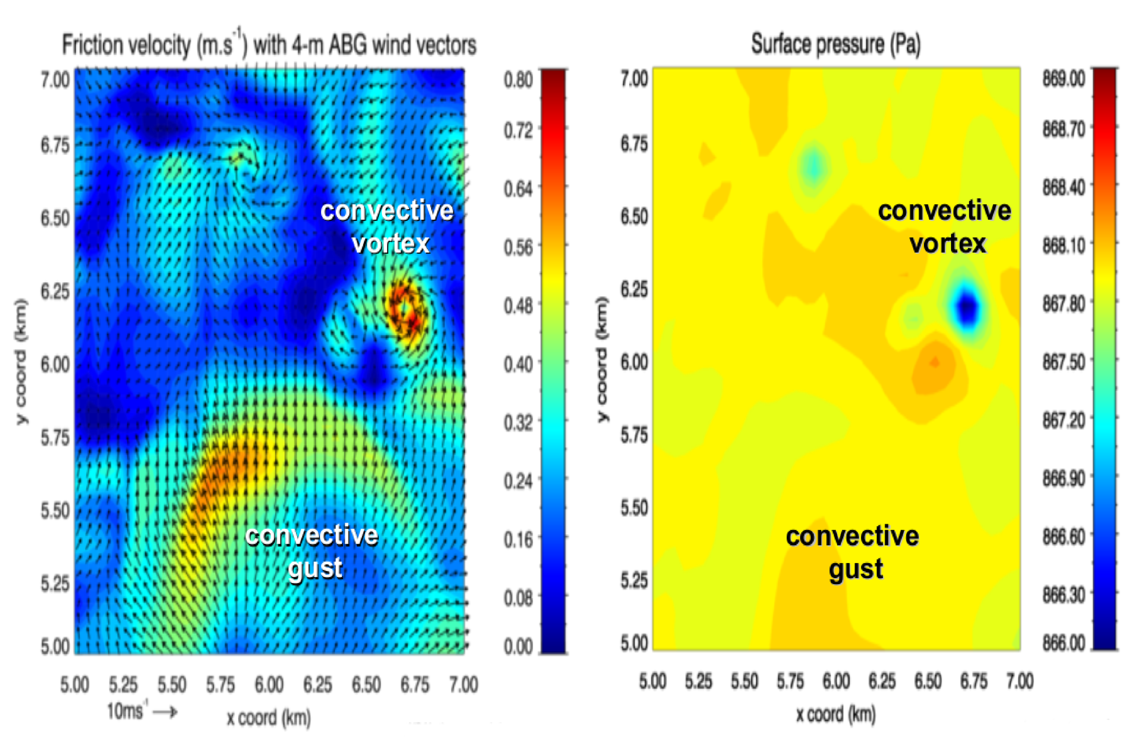


O2 dayglow from Mars/Express OMEGA in southern polar regions, end of summer. Modeled vertical velocity 40 km above MOLA reference areoid.

Dust Devils

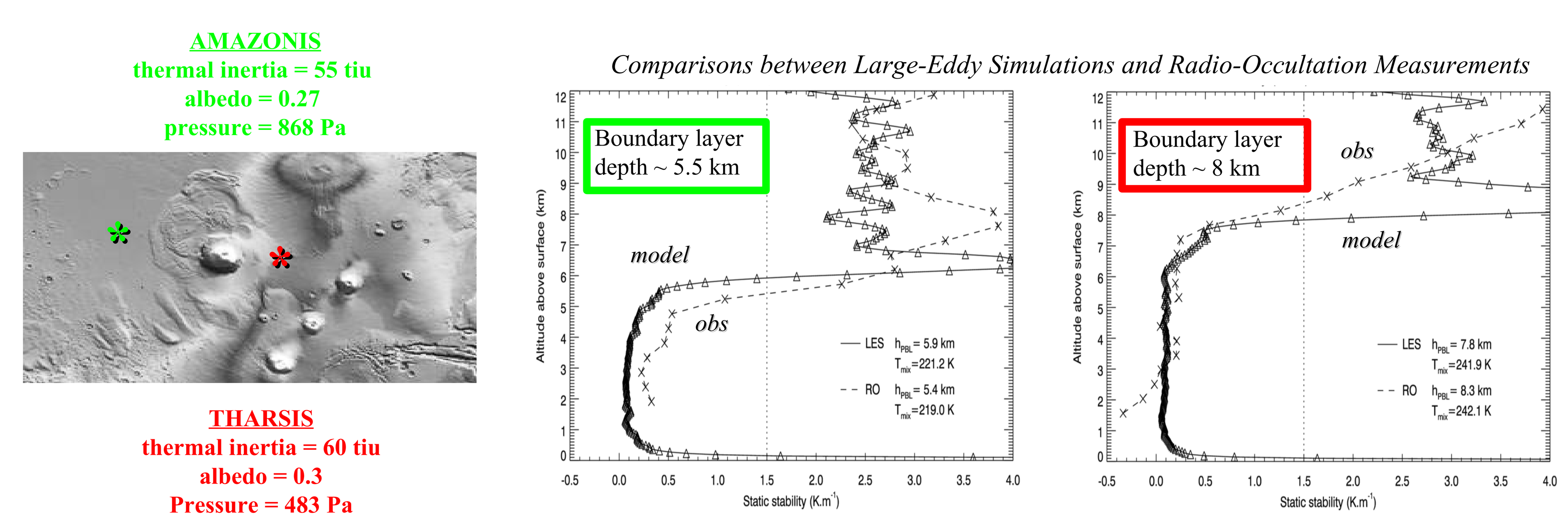
Dust devils are common on both the Earth and Mars. These small whirlwinds are caused by heating of the surface and made visible by entrained dust and sand. Such vortices are reproduced as part of the general structure of the daytime boundary layer convection by Large-Eddy Simulations performed in idealized conditions with the mesoscale model. Vortical structures in the model share all the characteristics of dust devils measured on Mars by Pathfinder.





Regional variability of convection

The dramatic regional variations of the boundary-layer depth revealed by Mars Express radio-occultations are quantitatively reproduced by the Martian Large-Eddy Simulations. Under specific conditions, both the model and the measurements show a distinctive positive correlation between surface topography and boundary-layer depth. In the tenuous CO_2 Martian near-surface environment, the daytime boundary-layer is to first order controlled by the infrared radiative heating, fairly independent of elevation, which implies a simple correlation between the BL potential temperature and the inverse pressure (« pressure effect »). No prominent « pressure effect » is in action on Earth where sensible heat flux dominates the BL energy budget.



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Please find further information in the following papers available in http://web.lmd.jussieu.fr/~aslmd/publications.html

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