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A Martian Thermals Model for the Convective Boundary Layer

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Background

Transport, mixing and radiative tendencies within the planetary boundary layer are subgrid-scale processes in General Circulation Models (GCM) and have to be parametrized. Most common parameterizations rely on classical diffusive approaches combined with convective adjustment. However, the major part of turbulent flux within the boundary layer is carried out by mesoscale structures, commonly called thermals. In the last decade, a large effort has been put to develop mass-flux schemes of those boundary-layer thermals for use in earth models.

On Mars, Large-Eddy Simulations (LES) and observations have revealed fine and powerful mesoscale structures [9] [4] which are currently not parameterized in any martian GCM, the latter relying on overaggressive convective adjustment [5]. These structures, shown in figure 1, are very dynamic and can extend up to 8km [9]. This work focuses on the general principles and choices behind Earth boundary layer parameterization of thermals in order to assess their applicability to Mars. A new thermal plume model is then proposed and implemented based on a modified version of the Earth LMDZ GCM thermals [3], yielding significant improvements.

The thermals formulation

LES of the Martian boundary layer have been performed for a large variety of sites where observations are available [9], characterized by different thermal inertia, albedo and altitudes. Extremes cases with low thermal inertia/albedo at low opacities have also been studied. Updraft selection techniques [1] are used to separate updrafts from environment data. Analysis of the turbulent heat flux reveals that updrafts do not represent the large majority of vertical heat transport, as shown in figure 2. Further analysis of the data based on a decomposition on updrafts, downdrafts and environment [7], reveals the important role of downdrafts, which can represent as much as half of the total turbulent heat flux.

Updrafts and broad downdrafts

If slow compensatory subsidences are assumed in Earth models, LES results and observations [4] have convincingly shown that broad downdraft structures must be taken into account in Martian mass-flux representations of thermals. We adapted the LMDZ-GCM thermals to Martian updrafts, tuning entrainment and detrainment rates with LES data [6]. The vertical velocity equation is reassessed, compared with several approaches [8] [2] [6], and adapted to suit Martian physics. Broad downdrafts are then implemented based on similarities observed with updrafts in LES, resulting in a very satisfying representation of the turbulent heat flux and of the super-adiabatic gradient near the surface. 1D results comparing potential temperatures and turbulent heat flux profiles are shown in figure 3.

Perspectives

Early 3D simulations show that using the thermals' model improves the representation of the polar warming. The thermals model can also be adapted to the LMD mesoscale model to study other phenomena, like the coupling of thermals with dust lifting and transport.

Acknowledgements and References

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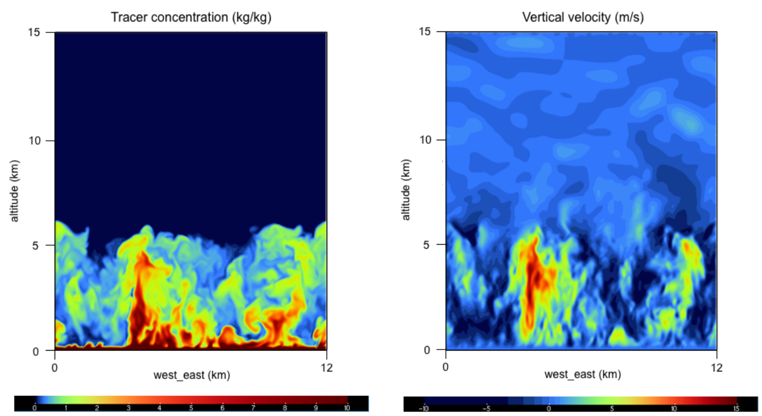

Figure 1: Data from the LES case A [9], at local time 12:30. (Left) Concentration of a decaying tracer emitted at the surface with a half time of 10 minutes. (Right) Vertical velocity field corresponding to the left figure. LES resolution is 257x257x301 with dx=dy=dz=50m.

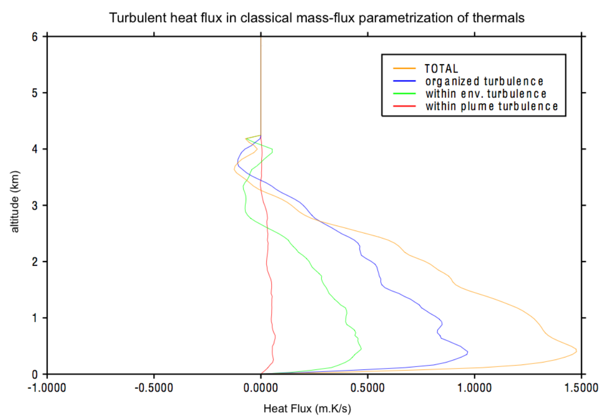

Figure 2: Decomposition of the turbulent heat flux over two domains : an updraft and an environment. The organized term represents turbulence associated with large-scale structure, i.e. updrafts and compensatory subsidence.

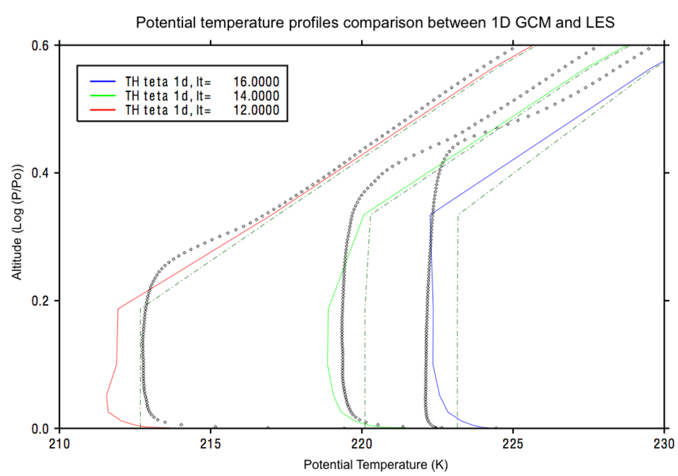

Figure 3: Potential temperature profiles from the 1D GCM model, featuring thermals (colored lines). The line-dashed curves correspond to 1D simulations without thermals, using the convective adjustment. Diamonds corresponds to LES data. Local times are indicated on the legend and corresponds to both 1D GCM and LES data. 1D simulations are conducted with similar resolution and timestep as in the baseline GCM configuration : 32 vertical levels to 150 km, 48 timesteps per day.