# LMD – SWRI MARTIAN MESOSCALE AND MICROSCALE MODELS INTERCOMPARISON FOR EXOMARS LANDING CHARACTERIZATION

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*Martian mesoscale models realistically simulate Martian meteorology at finer scales (~10km) than Global Climate Models (GCM). However, they don't simulate Martian boundary layer processes, which can be modelled using Large Eddy Simulation (LES), microscale models having a horizontal resolution of few tens of meters and evaluating vertical wind component and horizontal wind gustiness associated with the boundary layer turbulence. These modelling are becoming a central source of insights and diagnostics for future exploration of Mars and are useful to provide best-guesses of atmospheric variations of temperature and wind at mesoscale level and in the boundary layer. In such context, Model intercomparisons are a fruitful way to evaluate and assess the obtained predictions and a strong driver for improvement of these models.*

**Context: a European Mission to Mars**

ExoMars is an astrobiology mission to Mars currently under development by ESA, in collaboration with Roscosmos. The program includes two launches with an orbiter (Trace Gas Orbiter, TGO) and a stationary lander (Entry, Descent and Landing Demonstrator Module, EDM) planned for 2016 as well as a rover with its lander planned for 2018. In the context of this mission, the Laboratoire de Météorologie Dynamique (LMD) and South-West Research Institute (SwRI) Martian Mesoscale (respectively LMD_MMM [1] and MRAMS [2]) and Microscale (LES) Models have been compared. The goals were to determine a range of uncertainties and dispersions of their numerical models' predictions, for the entry, descent and landing characterization of the EDM spacecraft in 2016 and in particular for the critical phase of this descent in the turbulent Martian boundary layer. This intercomparison has therefore been performed at ExoMars landing site, namely in the Terra Meridiani region, for the landing scheduled in northern autumn at Ls = 244°.

This study is the first intercomparison performed in a systematic way between two different Martian mesoscale and microscale models, since Kass [3] and Tyler [4] studies in 2002-2003.

**Models**

<u>SwRI model:</u> "MRAMS" model, based on the RAMS dynamical core (Pielke et al., 1992) and NASA AMES GCM physical parameterizations for Mars (Haberle et al., 1993).
<u>LMD model:</u> based on the WRF dynamical core (Skamarock and Klemp, 2008) and LMD GCM physical parameterizations for Mars (Forget et al., 1999).

**Intercomparison strategy**

This project is driven by a basic rule: both LMD and SwRI have agreed on model configurations, physics package options, and initial conditions, namely dust loading in order to ensure a consistent intercomparison between both models.

<u>Mesoscale strategy:</u> LMD carefully determined in a key preliminary step optimal values of tuneable parameters of the radiative transfer scheme so that the two independent models radiative responses match as much as possible in similar settings. Furthermore, the intercomparison has been tested for three typical different atmospheric dust opacity $\tau$, bracketing Mars atmosphere reality:

- $\tau = 0.2$, representative of a clear atmosphere
- $\tau = 1$, representative of a dusty atmosphere
- $\tau = 5$, representative of a very dusty atmosphere

<u>LES strategy:</u> Two simulations tested with constant dust opacity of 0.2:

- without background wind
- with 15 $m.s^{-1}$ background wind

**Model configurations**

<u>Mesoscale configuration</u>: three nested numerical grids have been adopted. In both models, horizontal resolutions for the three nests are the same: 135 km for nest 1 (mother domain), 45 km for nest 2 and 15 km for nest 3. This nest is the highest resolution domain and is a "zoom" on the ExoMars landing site while the upper-level nests provide the regional to

large-scale meteorological conditions. Figure 1 shows the configuration of these nests:

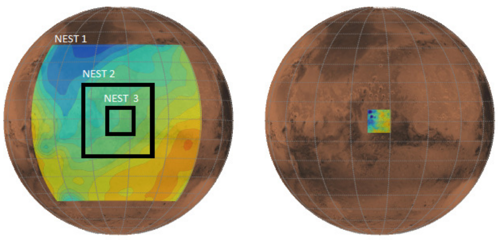


Figure 1: *Topography of simulation domains around ExoMars landing site (-1.82°N, -6.15°W). Left is the nest 1 (mother domain) along with nest 1 and 2 boundaries. Right is only nest 3.*

<u>*LES configuration:*</u> The domain has to be large enough to contain a large amount of convective cells thus allowing consistent statistics to be obtained from results, and the horizontal resolution small enough in order to enable a fine representation of the "large eddy" part of the turbulence spectra. As well, the vertical resolution has to be fine enough to resolve a significant part of the turbulent large eddies.
The dynamical time step for LES simulation is 0.5s.

| | Mesoscale configuration | LES configuration |
|---|---|---|
| **Nest** | Three two-way nests in non-hydrostatic mode | One nest with periodic boundary conditions (flat terrain) |
| **Grid** | 61x61x81 for all nests | LMD 145x145x201<br>SwRI 145x145x150 |
| **Horizontal resolution** | 135km x 45km x 15km | 50m |
| **Model top** | 45km above surface | 12km above surface |
| **Remarks** | Topography, thermal inertia, albedo and dust scenario based on TES measurement | SwRI used specific Deardorff sub-grid scale diffusion scheme LMD used WRF terrestrial LES diffusion scheme |

Table 1: *Mesoscale & Microscale Models Configurations*

## Results and Analysis

<u>*Mesoscale Results*</u>

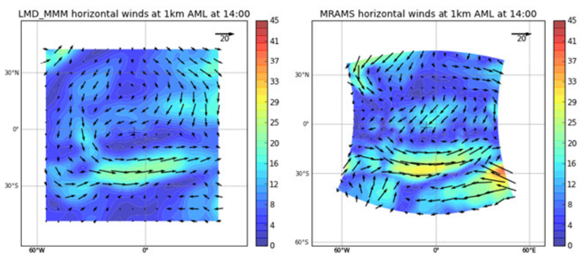


Figure 2: *Horizontal winds obtained from LMD model (left) and MRAMS (right) for a clear atmosphere (τ = 0.2) at 14:00 at 1km altitude in Terra Meridiani Region.*

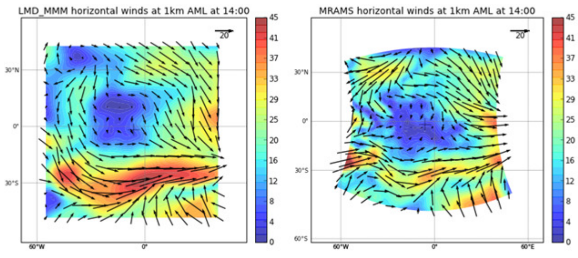


Figure 3: *Horizontal winds obtained from LMD model (left) and MRAMS (right) for a very dusty atmosphere (τ = 5) at 14:00 at 1km altitude above Terra Meridiani Region.*

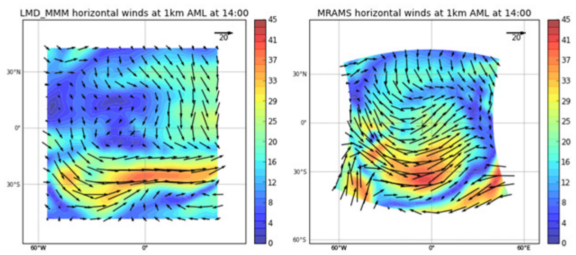


Figure 4: *Horizontal winds obtained from LMD model (left) and MRAMS (right) for a dusty atmosphere (τ = 1) at 14:00 at 1km altitude in Terra Meridiani Region. Strong discrepancies in wind directions and speed are observed.*

Both LMD and SWRI models give qualitatively similar wind and temperature structures. Western boundary currents, slope winds and other wind circulations are observed in both models. Figure 2 and 3 gives an example of obtained results. However, noticeable discrepancies are also observed for the estimated wind and temperature trends, in all three test cases. Indeed, in clear and very dusty atmosphere cases, wind speeds are slightly different.
The dusty atmosphere case (τ = 1) is more critical and shows interesting discrepancies both in terms of wind directions and amplitudes (up to 70% differences) as illustrated by figure 4.
Different tests have been performed to support the analysis of this intercomparison. First, differences in GCMs results and their sources have been analysed. Then, it has been noticed that using a Planetary Boundary Layer (PBL) with a thermal plume model [5] in LMD_MMM yields more comparable results with MRAMS than without it and without convective adjustment. In fact, the thermal plume PBL gives estimates of wind directions closer to MRAMS results with maximum differences of wind speed of less than 30%. Other findings concern the sensitivities to the chosen date (i.e. regarding day to day variability), to the use of hydrostatic modelling and of a finer topography; these sensitivities are found to be low. Further investigations are in progress to understand the origin of the discrepancies.

## *LES Results*

Both LMD and SwRI LES models show similar diurnal evolution of the Martian boundary layer convection and similar organization and structures in the horizontal and vertical winds, as shown by figure 5. As well, similar standard deviations for vertical velocities have been noticed in both models.

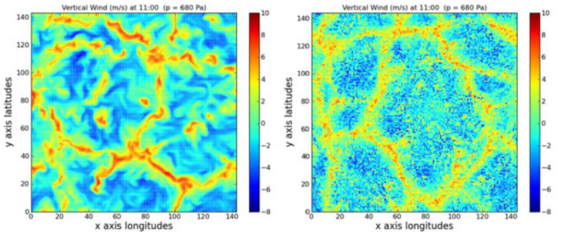


Figure 5: *LMD (left) and SwRI (right) horizontal sections of vertical velocity at 250m altitude at 11:00*

However, large discrepancies are found when comparing maximal values of vertical winds. SwRI results show much higher variability at grid-point scale than LMD results, as shown by figure 6. It results a more vigorous convection in SwRI LES than in LMD LES, with typical maximal updrafts around 16 $m.s^{-1}$ in LES results and 23 $m.s^{-1}$ in SwRI results.

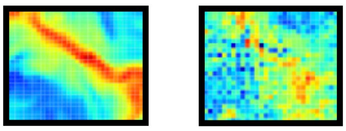

Figure 6: Zoom on figure 5: *LMD (left) and SwRI (right) horizontal sections of vertical velocity at 250m altitude at 11:00*

Large differences from 50% to 100% between both models for turbulent heat flux (see Figure 7), turbulent kinetic energy, downdraft and updraft speeds are found. The observations are independent to the presence or not of background winds.

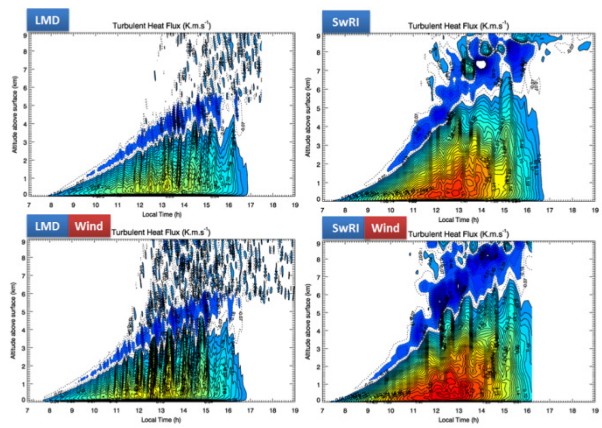


*Figure 7: Variation of turbulent heat flux between 7:00 and 19:00 and 0 and 9km altitudes. Left are LMD results, right are SwRI results for both simulation cases (top: without background wind, bottom: 15m.s$^{-1}$ background wind).*

However, it is important to note that all values obtained from both models remain realistic (with the caveat in mind that no measurements of vertical wind in the Martian convective boundary layer are available from previous missions).

These discrepancies do not seem to come from boundary conditions since similar a forcing has been applied in both model (same physical options, same incident solar flux). They are thought to be due to the different small scale diffusion schemes, making the diffusion weaker in SwRI than in LMD model. Simulations with different diffusion properties are currently in progress to complete this intercomparison and investigate deeper these discrepancies.

**Bibliography**

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