# CHARACTERIZING THE MARTIAN ATMOSPHERE FOR THE EXOMARS 2016 LANDER

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**Introduction:**
The 2016 ExoMars mission led by ESA and launched by NASA will include the Trace Gas Orbiter and the ExoMars Entry, Descent and Landing Demonstrator Module (EDM) which main goal is to allow Europe to acquire a Mars landing capability with some science investigations.

The EDM will be designed to land during one of the dustier season on Mars, around Ls=245°. To prepare this landing and help design the probe, we have performed numerous studies to characterize the environment during the descent and during the short surface mission. These studies have been performed within the frame of several contracts with ESA and CNES, and working in collaboration with Thales Alenia Space Italia. They combine modeling studies performed using a hierarchy of models ( Global Climate Model, Meso-scale atmospheric model, Large Eddy simulation -LES- models), and a detailed investigation on the dust and temperature conditions using most of the available data. Below we present a few example of studies, and report some of the conclusions from Phase B, which concentrated on the environment for a mission landing on a "reference landing site" in the Sinus Meridiani region near 6°W, 2°S.

**Analysis of the available observations at the season and location of the EDM reference landing case.**

*Global dust storms*. Because of the intensity of such global events, the large spam of areocentric longitudes they affect, and their sudden (and therefore mostly unpredictable) occurrence, planetary-encircling dust storms are the source of large uncertainties for Exomars's EDL operations.
To date, solstitial storms seem more frequent than equinoctial storms (5 to 2), posing higher risk for Exomars' nominal landing at Ls =250◦. Equinoctial storms can raise the overall dust loading for long times therefore they can greatly affect Exomars's EDL as well. One (out of 7) planet-encircling storms occurred very close to Exomars' nominal landing time: Ls = 249◦. One occurred within 10 degrees of areocentric longitude.

*Regional storms.* From the statistics of regional storms in the Meridiani area and from the results of TES data assimilation, it appears that the likelihood of cross-equatorial dust storm onset decreases around solstice ("solstitial pause"). No regional storm has been recorded in Meridiani from MY 24 to MY 29 within 15◦ areocentric longitude from Exomars' landing time. Moreover, Meridiani Planum does not appear to be a likely location for the direct onset of a regional storm in the range of areocentric longitudes and Martian years considered here. Regional dust storms can neverthess pose hazards even at large distances from the location where they have their original onset, due to possible advection by large-scale winds and to their effects on the overall background dust opacity.

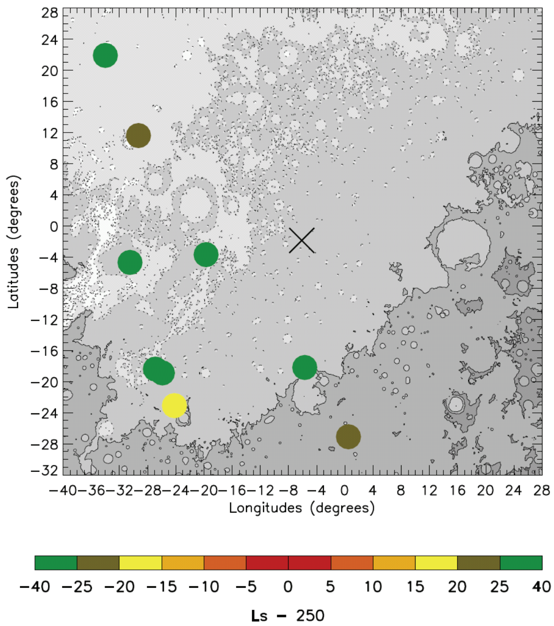


**Figure 1**. Locations of the centres of the regional dust storms occurring between Ls = 210◦ and Ls =290◦ fromMY 24 to MY 29 in the Meridiani area. Data are provided by B. Cantor (Malin Space Science Systems, San Diego, California). Each circle in the figure locates the centre of a storm that reached regional storm status, namely a storm older than 72 hours extending over an area larger than 1.6 · 106 km2. The colours indicate the time proximity to the nominal Exomars' landing time. For instance, red colour is for hazardeous storms occurring within ±5◦ areocentric longitude from Ls = 250◦. Green colour is for "safe" storms occurring more than ±25◦ areocentric longitude from Ls = 250◦. Figure by Luca Montabone.

*Local dust storms* are frequent on Mars. They can occur at almost any time of the year and almost any location on the planet (except for ice-covered regions) . A complete statistics of local dust storms in Meridiani show that it is likely to have the development of a minor storm close to Exomars' landing location and time (at least within ±10◦ areocentric longitude from Ls = 250◦). Such a storm is unlikely to last for more than one sol, if the observations to date constitute a good statistical sample.

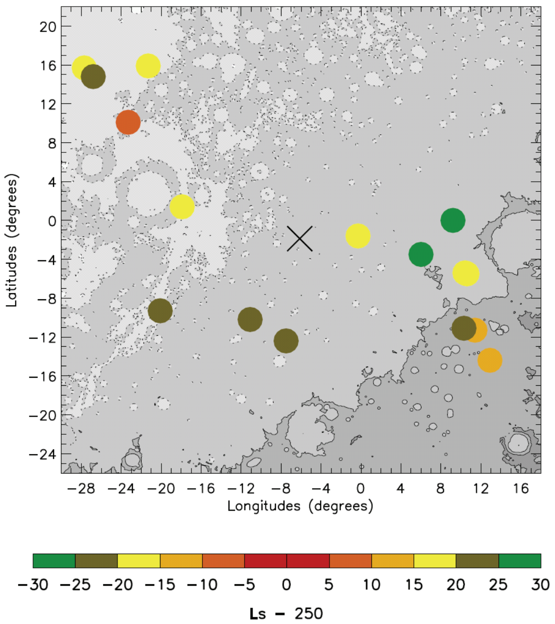


**Figure 2.** Same as figure 1, but for local dust storms. Each circle in the figure locates the centre of a storm that only lasted less than 3 sols and extended over an area smaller than 1.6 $10^6$ $km^2$. Figure by Luca Montabone.

*Range of dust opacities at the reference landing site.*. On the basis of observations of dust opacities from MY 24 to MY 29, Meridiani showed values around 1.0 or lower (down to 0.6) in the range Ls = [240◦, 260◦], except in MY 25 when the slow decay of the equinoctial planet-encircling dust storm maintained high values of opacity (decreasing from 1.7 to 1.1 in the considered Ls range). Of course, any planetary-encircling dust storm occurring before the landing (equinoctial storm or early solstitial storm) may increase the normal value of dust opacity by a factor of more than 3.0 (on average) especially if it happens at a time very close to the landing.

*Dust and temperature profile*. Our analysis of available temperature profiles over Meridiani at the season planned for Exomars' landing showed that it is unlikely to have a temperature structure significantly different from a "typically expected" one, except in years characterized by the occurrence of planet-encircling dust storms, e.g. MY 25. By "typically expected" atmospheric structure we mean the average temperature structure observed in MY 24, 26, 28 and 29 (no TES or MCS observations are available in MY 27), which did not change significantly in those years. Although the average temperature structure might not change in years without global dust storms, intrinsic atmospheric variability (i.e. weather systems - large scale variability - and gravity waves - small scale variability -) can always modify the instantaneous temperature profiles by a few degrees at any altitude.

*Comparison of the available observations with the Mars Climate Datase V4.3 predictions.* When the observed average temperature profiles for all available Martian years are compared to the predictions by the Mars Climate Database, the results are encouraging. MCD v4.3 with its four dust scenarios (cold, MY24, warm and dust storm) is perfectly able to bracket, at all altitudes, the inter-annual and intra-seasonal variabilities of temperature showed by the available observations. There are differences, of course, but they might be due to the use of data which are intrinsically non-homogeneous.

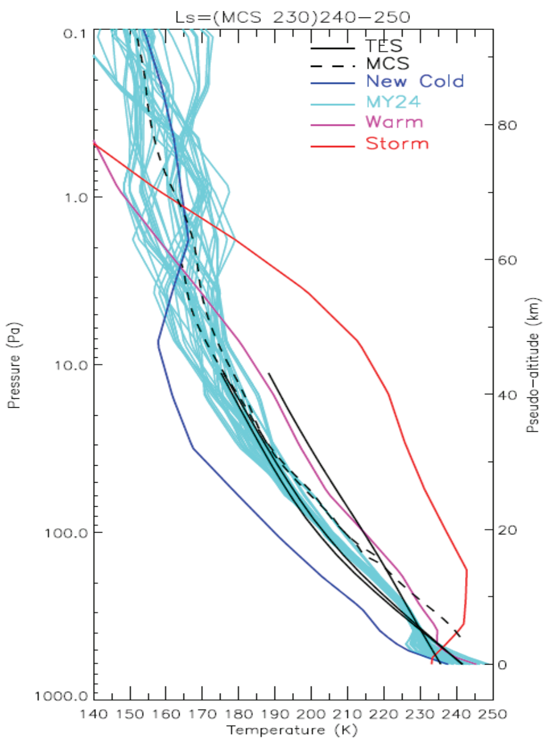


**Figure 3.** Comparison among average TES temperature profiles in MY24, 25 and 26, average MCS temperature profiles in MY 28 and 29, and Mars Climate Database v4 predictions [see *Millour et al.* this issue] with different dust scenarios (including the new "coldest" EDM scenario), at Exomars' reference landing site. Figure by Luca Montabone

Using the MCD for predicting the temperature and density structures at the time of Exomars' EDL in Meridiani, therefore, appears reasonable if the atmospheric state is bracketed using its MY24, warm and dust storm scenarios. Initially, the cold scenario was found to be too extreme (too cold) to represent even the coldest possible atmosphere at Ls = 250◦ in Meridiani, (which is characterized by total dust opacities higher than 0.6 on average). A new “low dust scenario” with $\tau$=0.3, and not as cold as the “cold” scenario in the MCD, was designed for the EDM landing simulation to be used as a lower limit.

**Analysis of the landing environment using Global and mesoscale modelling**

The LMD GCM (Forget et al. JGR 1999) and the LMD Mesoscale model (Spiga and Forget, JGR 2009) were used to perform a detailed analysis of the wind variability, using a range of dust scenarios (various global dust loadings, regional dust storms, local dust storms). The main conclusion was that the reference landing site is usually located in a low wind area (avoiding the jet stream, “monsoon jets” and “western boundary currents”) Also, no particular, strong additional winds in relation to the topography were predicted from mesoscale processes.

Overall, winds tend to be higher for larger opacities, but this is not true for all altitudes and locations. The main conclusion was that no horizontal winds larger than the engineering constraints are predicted above 100m, for all global dust opacities and local times. Opacities of 1 and 2 offer the lowest winds at the reference landing above 2km above the local surface, and it would appear safer to land at local time14:00 when winds are even lower. Opacities of 0.5 and 5 show the lowest winds in the near surface environment, and the most hazardous situation would be to land at local time 16:00 for opacities of 1 and 2, as Meridiani landing site would then be prone to winds above constraint value.

Simulation performed with realistic regional “flushing” dust storms reached similar conclusions.

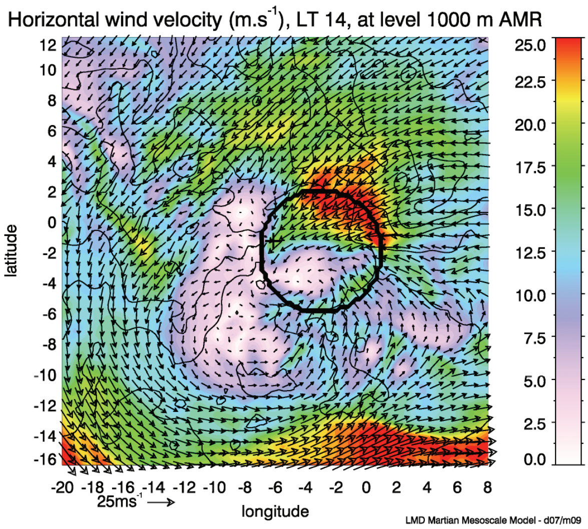


**Figure 4.** An example of the horizontal wind speed and vectors simulated by the LMD meso-scale model at 1km above MOLA zero datum at local time = 14, in the case of a local, vertically confined, dust storm (black circle). with $\tau$=10 Figure by Aymeric Spiga.

The case of a local, vertically confined “dust bomb” local dust storm was also considered. These simulations showed that thermal circulations take place within the dusty column and its surroundings, inducing, strong horizontal (sometimes reaching 25 m s−1) and vertical (sometimes reaching 2.5 m s−1) winds in the lower troposphere within the dusty column or close to its walls. Higher up above the local dust storm, extreme horizontal winds exceeding 35 m s−1 were predicted. Those correspond to diverging motions from the local dust storm, which, especially at the end of the afternoon, are predicted to be still strong several hundreds kilometers apart from the local dusty center in the most intense storm cases.

**Analysis of the convective winds with Large Eddy Simulations (LES).**

We used idealized high-resolution Large-Eddy Simulations (LES) [Spiga and Forget, JGR 2009; see *Spiga et al*. this issue] to simulate the boundary layer environment at the landing site. We studied in particular the influence of dust loading and of the background wind on the atmospheric circulation in the Martian Boundary Layer. Emphasis was put on the atmospheric environment limits that would allow safe entry, descent and landing of the ExoMars module (the key danger during the parachute phase beeing the strong downward winds). A horizontal organization into polygonal cells is predicted by the model, with narrow updrafts on the ridges of the cells and large subsidences in the middle of the cells. In a typical case, updraft speeds can reach 15 m $s^{-1}$ around local times 12:00 – 14:00 between altitudes 2 to 4 km. Downdraft amplitudes peak between local times 12:00 and 14:30 at values about 8 to 9 m $s^{-1}$ from 300 m to 2.5 km above the surface. The dustiness of the Martian atmosphere strongly determines the strength of Boundary layer convection. The sensitivity of turbulence to dust is controlled by a complex combination of 1) dust influencing surface temperature, 2) dust influencing atmospheric stability, 3) dust influencing maximal turbulent heat flux and 4) turbulent motions adjusting to those various modified forcings.

Maximum updraft and downdraft values throughout the whole day vary dramatically with dust loading: For a dust opacity of 5, updrafts of 6 m $s^{-1}$ and downdrafts of −2 m $s^{-1}$ are predicted by the LES .

Mixing layer is of significantly lower vertical extent for higher dust opacities [*Spiga et al*., this issue]. At local time 14:00, BL depths are respectively 5, 4.3, 3.6, 1.6 km for dust loadings $\tau$ = 0.5, 1, 2, 5.

Adding a background wind influences the results. Convective cells are stretched towards the preferential direction of wind propagation, although an horizontal wind of 20 m s−1 is still not sufficient to form linearly organized convective rolls on Mars as observed on Earth. Quantitative estimates about maximum vertical winds have to be raised to about 15 % in windy conditions compared to no-wind estimates.

To conclude, one can show that the primary influence on the intensity of the convection winds are the surface thermal properties (albedo, thermal inertia) which controls the surface temperature. Figure 5 show an example of the maximum updraft wind which can be obtained in such an extreme case.

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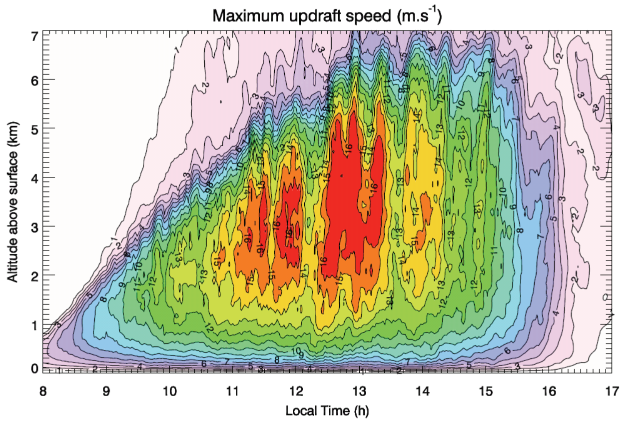


**Figure 5**. Maximum  speed for convective updrafts r simulated in the Large Eddy Simulation domain between local times 08:00 and 17:00 and altitudes above ground 0 and 7 km, at the Exomars reference landing site. The simulation is performed with a visible dust opacity of 1, no background wind, and extreme soil conditions for the site yielding to maximum surface temperature and thus convective activity(thermal inertia of 50 J $m^{-2}$ $K^{-1}$ $s^{-0.5}$ and albedo of 0.10). Figure by Aymeric Spiga.