HIGHLIGTHS FROM THE ROVER ENVIRONMENTAL MONITORING STATION (REMS) ON BOARD THE MARS SCIENCE LABORATORY: NEW WINDOWS FOR ATMOSPHERIC RESEARCH ON MARS

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Introduction: The Rover Environmental Monitoring Station (REMS) on the Mars Science Laboratory (MSL) mission has sensors recording air and ground temperature, pressure, relative humidity, wind speed, as well as ultraviolet radiation in different bands (between 280 and 400 nm). Since sol 9 after landing REMS has collected data from all sensors simultaneously on an almost daily basis [1].

REMS measurements are being analysed carefully since the beginning of operations on Mars, and they are revealing a number of discoveries from both technical and scientific sides that will mark a before and after in Martian meteorology studies and our understanding of Martian atmosphere, as well as the use of meteorological stations in rover platforms on Mars.

Some of the great advantages of REMS with respect to previous meteorological stations are:

- It provides unprecedented simultaneous observations of environmental variables routinely for at least a full Martian year (nominal MSL mission), including nighttime.
- It is mounted on a moving rover platform, so it allows monitoring the diurnal evolution of the ground temperature and other environmental variables every day at the different sites visited by the rover during its operation on Gale crater.
- It is providing the first measurement of surface UV irradiation ever measured from the surface of another planet.

Some of these advantages, like being mounted on a moving platform or measuring at night-time, imply a challenge for a correct interpretation of the data, as explained in [2], and it is teaching us about technical details to be taken into account in future designs in order to avoid or minimize these challenges in the data interpretation from future meteorological stations in Mars.

The capability to measure consistent and simultaneous data sets of multiple environmental variables is essential for meaningful interpretation of near-surface processes including the characterization of soil thermal properties, and boundary-layer diurnal and annual behaviours.

We remark here the importance of including the UV sensor in the REMS suite of instruments: The Martian atmosphere is generally transparent to solar radiation, but atmospheric dust absorbs solar radiation and heats the atmosphere, while UV radiation ionizes atmospheric gases and is harmful to any potential Martian organisms (past or present). For this reason, knowledge of the UV radiation flux at the surface of Mars is important for understanding habitability conditions, one of the main goals of the MSL mission. Moreover UV radiation is a significant driver in the photochemistry of the atmosphere and surface.

In this paper we present the REMS science findings that in our opinion will open a new window for future studies of Mars atmosphere and environment. In particular, we present several phenomena that have been either extensively observed by REMS for the first time or that are adding critical new information that helps in understanding the Martian atmosphere:

Diurnal pressure beat and topographic effects: A common feature of all sites sampled by surface meteorology stations prior to the Mars Science Laboratory (MSL) has been the relatively flat terrain. With MSL situated within a crater exhibiting significant topographic variability, there is a substantial hydrostatic adjustment flow in response to the daily variations in air temperature. The augmented range of daily pressure variation observed by REMS is due to a process of hydrostatic adjustment in the presence of slopes in response to the daily cycle of air temperature [3]. The pressure diurnal beat is not only amplified by this lateral mass transport associated to the hydrostatic adjustment [3], but additionally, the timings when the maximum and minimum of the pressure are achieved are no longer synchronous with the sunrise and sunset times (see Figure 1). There is a systematic time shift difference, of about 1 and a half hour that is consistent along seasons. This time difference appears to be the second footprint of the existence of a lateral mass transport from and to the crater rim at speeds of 3-5 m/s. Both features are associated with the strong topographic variations of Gale crater.

Boundary-Layer, air density and thermal tides: Thermal tides are planetary-scale gravity waves with periods that are harmonics of the solar day and are caused by the interaction of the atmosphere on the illuminated side of the planet with the solar radiation. REMS (as both Viking landers did) senses, on a daily base, the passage of the planetary sun-synchronous thermal tide whose $\Delta\rho/\rho$ (ρ=surface air density) amplitude depends on the latitude (because of the angle of incidence of the solar illumination) and season (Ls) (because of the Sun-Mars distance). It increases towards the equator and decreases in perihelion. The maximum observed relative variations of surface density are of the order of 40% and the minimum of the order of 10% - expected to decrease towards zero at the polar regions- (see Fig. 2)

Atmospheric opacity and solar irradiance: The atmospheric opacity has been monitored by the dedicated Mastcam observations of the sky and by the passive, daily observations of the REMS UV sensor, their measurements showing a very good agreement. The characteristic Martian known Ls-pattern of the dust loading and settling processes has been observed also at Gale landing site. The MSL rover, as any other exploration platform, absorbs the solar illumination and shows huge thermal contrasts from illuminated to shadowed areas. This has been investigated in detail using the two REMS air temperature sensors (ATS). The thermal contrast from the illuminated/shadowed areas correlates with the atmospheric opacity; in fact this thermal contrast can be used to retrieve the opacity. This unavoidable Sun-related thermal contamination is inherent to any platform on Mars and affects the temperature of the air in the vicinity of the spacecraft, inducing daily variations in temperature of up to 20 K. This effect that has been unveiled by REMS has implications on the air temperature measurements of any environmental monitoring instrument (including those past missions) for Mars. See Fig. 3 for the atmospheric opacity evolution of the first 200 sols, obtained by the Mastcam and UV measurements and the comparison with the ATS-thermal contrast opacity retrieval.

Nighttime katabatic winds: REMS has observed the existence of nighttime thermal fluctuations that correlate with pressure drops and winds that affect the ground skin-temperature (see Fig. 4) These winds must be present at other sites with strong topographic features and must have an impact on the retrieval of ground temperature from orbiter measurements.

Ultraviolet measurements (habitability, O_3/H_2O, Solar events, radiative properties): The downwelling UV irradiance has been measured within 6 different integrating bandpass. The ABC integrating channel has been used to monitor the opacity. The other channels are used for habitability assessment, and atmospheric ozone remote sensing. The ozone cycle is a proxy for the atmospheric water cycle. Furthermore the UV sensor has detected nighttime solar activity-related events, and the daytime eclipses of Phobos and Deimos. The UV sensors can distinguish the direct and diffuse component of downwelling irradiance, and their measurements provide priceless information of the atmospheric environment complementary to that obtained by the usually used sensors for meteorological studies (pressure, temperature, relative humidity).

Future Exploration campaigns to the Martian surface

Besides the interest of the analysis of REMS data per se, the lessons learned from the analysis of REMS data will be of utility for future projects of meteorological stations in Mars. Future exploration campaigns to the Martian surface will follow similar designs (ExoMars, Insigth, NASA rover 2020, MetNet) and thus all the expertise acquired within the MSL mission will also be essential for their design, calibration and data exploitation. In particular, some of the deliverables of REMS data analysis that will be useful to future Mars exploration are: 1) Characterization of environmental conditions and global circulation patterns; 2) Information for Entry-Descent-Landing; 3) Validation of satellite measurements; 4) Validation of mesoscale and global GCMs; and 5) Useful Information to redefine our current Planetary Protection Policies. All these protocols are essential for mission instrumentation sterilization and definition of landing sites targets.

Conclusions:

The REMS dataset is revealing a number of discoveries from both technical and scientific sides that will mark a before and after in Martian meteorology studies and our understanding of Martian atmosphere, as well as the use of meteorological stations in rover platforms on Mars.

In this paper we present succinctly a number of phenomena that have been either extensively observed by REMS for the first time or that are adding critical new information that helps in understanding modeling of the Martian atmosphere.

The unprecedented simultaneous observations of environmental variables routinely during at least one Martian year are one of the great advantages of REMS.

Of special interest is the UVS: our advice is that every rover mission to Mars should include a set of UV photodiodes that are small, lightweight, consume no-power (SiC photodiodes are fed by solar radiaton) and do not add electronic complications but that provide an amazing, and unexpected, scientific return.

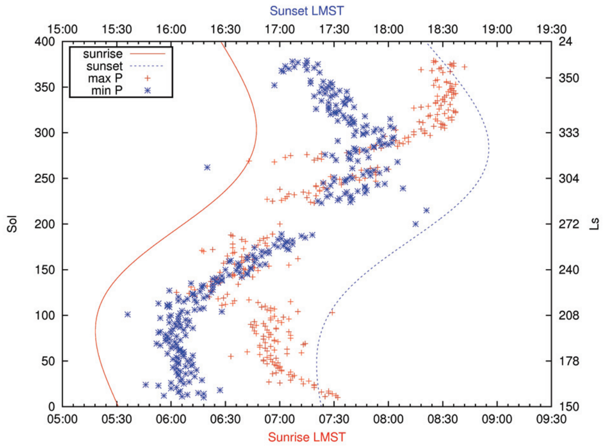

Figure 1: Sunset and sunrise times at the MSL landing site and comparison with the timing of maximum and minimum in the pressure diurnal wave. There is a systematic time shift that correlates with the sunset and sunrise times. Ground thermal inertia, which has varied significantly across the rover traverse, does not appear to be the cause for the time shift.

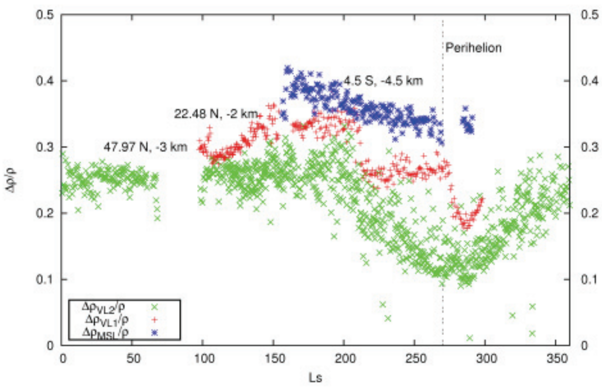

Figure 2: REMS (as both Viking landers did) senses, on a daily base, the passage of the planetary sun-synchronous thermal tide whose Δρ/ρ amplitude depends on the latitude (because of the angle of incidence of the solar illumination) and season (Ls)

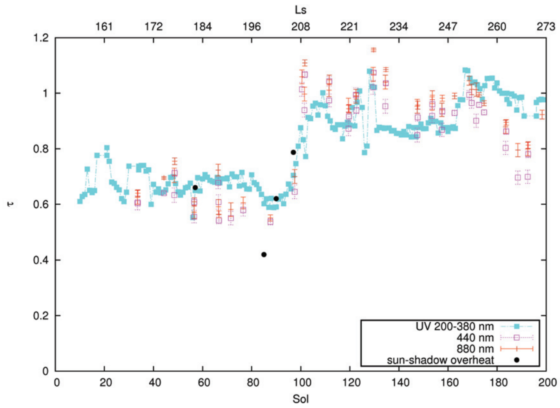

Figure 3: Evolution of the atmospheric opacity during the first 200 sols, from UVS (200-380 nm), and Mastcam (440- and 880-nm) measurements. Two opacity regimes are clearly distinguished, before and after sol 100. Before sol 100 the sky was relatively clear and more radiation reached Mars surface. Another regime started in sol 100 after load of dust.

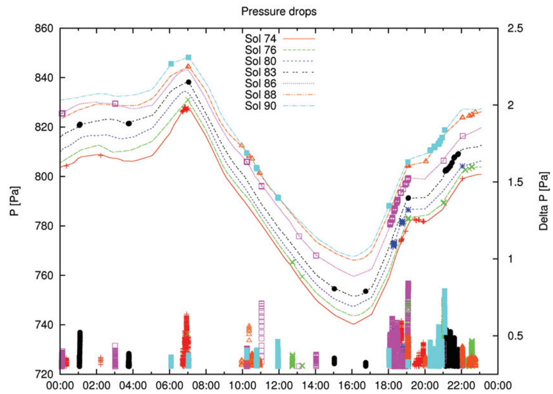

Figure 4: Detection of nightime pressure wiggles induced by slope-winds. These pressure variations are synchronous with air and ground temperature oscillations.

References: [1] Gómez-Elvira, J. et al., REMS: The environmental sensor suite for the Mars Science Laboratory rover, *Space Sci. Rev.*, 170, 583-640, (2012); [2] Zorzano, M.P. et al., (2014), this volume; [3] Richardson et al., Why the diurnal pressure range at Gale Crater is so large, *submitted to JGR,* (2013).

Acknowledgements

The REMS Spanish Team is supported by Economy and Competitivity Ministry (AYA2011-25720). S. R. is supported by the MSL Project at JPL, contract 1293480.