

# REMS INSTRUMENT DESIGN AND OPERATION STATUS: MONITORING THE ENVIRONMENT FROM A MOVING HOT EXPLORATION ROVER ON MARS

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**Introduction:** The Rover Environmental Monitoring Station (REMS) on the Mars Science Laboratory (MSL) Curiosity rover consists of a suite of meteorological instruments that measure pressure, temperature (air and ground), wind (speed and direction), relative humidity, and the Ultraviolet (UV) flux. A detailed description of the REMS sensors and their expected and after-landing performance can be found in [1,2]. Soon after landing, and following a short rover and instrument-commissioning phase, REMS started its regular acquisition mode. The REMS nominal operation program includes a regular release of data into the NASA Planetary Data System (PDS) website within 90-sol batches, with a 90-sol lag from observations. By August 2014 REMS will have provided to the scientific community the most extensive (two terrestrial years, that is one full Martian year, with up to 5 hours of daily cycling acquisitions at 1 Hz) and complete environmental data set of ground-atmosphere interaction on Mars ever. Furthermore, if the extended mission is approved, REMS will continue monitoring the Martian surface and delivering to the PDS an environmental record that will be used in future by the scientific community for validation of models and remote sensing observations and will provide more insight into the local and global scale observations that REMS has performed so far. In this abstract we summarize the design and operational performance of the REMS sensors and discuss our approach to solving some of the difficulties encountered, including the loss of one of the two wind sensors after landing, the dust induced degradation after long time exposure of the UV sensors, the thermal interaction of the rover with the local environmental and the influence of the rover

activities and rover tilt on the measurements. This summary is intended to serve for the correct understanding of the REMS data set.

## **Summary of contextual information required for the interpretation of REMS/MSL data:**

REMS data are being used to study the meteorology, climate, and habitability of the Curiosity landing site and to compare with results from the landing sites of the Viking landers, Mars Pathfinder and Phoenix missions. Curiosity's location (4.59°S, 137.44°E) on the floor of Gale Crater (-4.5 km elevation) is substantially different from that of the previous landed missions and provides an opportunity to explore the impact of the significant regional topography on the local atmosphere. Soon after-landing some interesting scientific phenomenon were observed [3,4]: predominantly dustless convective vortices, night-time katabatic winds and air and ground quick temperature variations, a relatively dry ambient, strong night-time ground-temperature drops, significant trends of upslope and downslope topographic winds, a enhanced amplitude of diurnal pressure oscillation, occasional night-time non-zero UV measurements, solar transits caused by the Martian moons and, overall, a strong correlation of the atmospheric and rover response to the atmospheric aerosol load. An example of the diurnal evolution of some of the environmental parameters is shown in Fig. 1.

However the accurate and unequivocal scientific analysis of the full REMS data is very challenging since it requires taking into account a full set of contextual data information that includes rover position, Radiosotope Thermal Generator (RTG) contamination on the temperature of the ground, rover surfaces and

local air, Sun heating of the rover, thermal conductivity within the rover and implications for the air temperature and humidity sensors, dust degradation of the UV sensors, thermal behaviour of the REMS electronics during the harsh night-time cold hours, etc. Other contextual information that is required for the correct interpretation of the measurements includes the Sun position and shadows on the ground and within the rover, Phobos and Deimos position (to pre-program acquisitions during solar transits), the Solar activity, as well as the sol-to-sol UV top of the atmosphere irradiance, the angle of tilt of the rover, along with the movements of the arm and rover, and the images of the UV dust degradation by the rover cameras, such as MAHLI.

One of the most challenging issues that the REMS team has encountered is how to disentangle, within the crude measurements, the rover induced effects, technical issues of the crude measurements and the real physical environmental Martian phenomena. Next we provide a summary of some relevant issues. The MSL platform alone imposes restrictions on the observations, in particular:

- 1) The MSL rover, as any other exploration platform, absorbs the Sun illumination and shows big thermal contrasts from illuminated to shadowed areas. 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 local offsets in temperature of up to 20 K, see Fig. 2.
- 2) The rover daily operations affect the instantaneous measurements of some sensors. An example of the effect of the shadow of the rover mast on the UV sensors, the deep temperature drop that it induces and the blockage of the direct sun beam is shown in Fig.3. In order to interpret these acquisitions it is required to know the position of the sun w.r.t. to the photodiodes and rover mast and arm during the full diurnal acquisition, this includes the use of information about the local rover tilt and orientation for every single acquisition.
- 3) The Curiosity rover is a huge mechanical device heated by a Radiosotope Thermal Generator (RTG) whose temperature oscillate along the

day but can typically be about 200 K above the ambient temperature. This induces unavoidable influences/artefacts on any local measurement of air/ground temperature, humidity and wind. A huge effort has been focused on providing bound estimates of this contamination. As an example the RTG contaminates the ground where the rover stands, when the rover moves to new observation areas the fresh ground shows non-contaminated lower temperatures, see Fig. 4.

- 4) Being located in the warmest location of Mars has also consequences on the local water cycle. Actually there is the risk during long stops of the rover of soil dehydration below the rover. It also has consequences on the humidity sensor (HS) and air temperature sensor (ATS) local air measurements, because of the thermal conductivity through the sensor mounting and board. The temperature sensor has applied a specific retrieval method to account for this contamination and provide the ambient and free fluid temperature.
- 5) The field of view (FOV) of the Ground Temperature Sensor (GTS) and changing thermal inertia during the rover transit has strong implications on the interpretation of ground temperature measurements. Information such as emissivity, size, and orientation of materials is required and a contextual image with the footprint of the GTS FOV is taken when the rover moves to a new observation spot.

Some technical issues are also important for the operation cadence and quality of the data:

- 1) A good technical knowledge of the booms electronic behaviour at low temperature is essential to understand the ground temperature, air temperature and wind sensors measurements. This becomes critical in the period of lower ambient temperatures (1-7 am local Martian time) due to the very low signal-to-noise ratio and to the malfunctioning of the ASIC2 when the ambient temperature falls well below -55°C. In particular the boom2 ATS temperatures may be not available during some of these cold sessions, and the boom2 WS

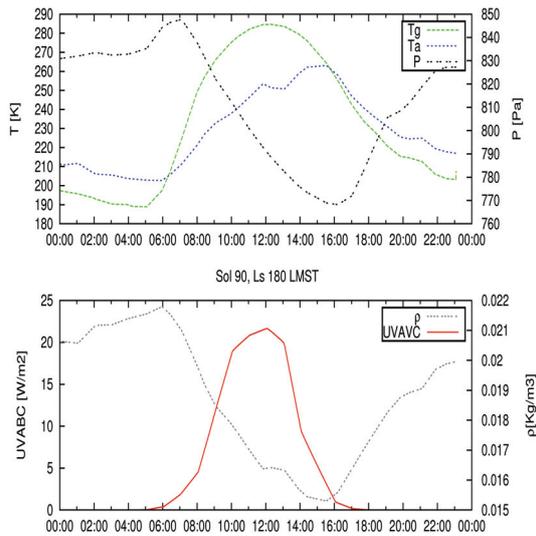
- (which is the only available after the landing-induced failure) does not provide quality data during these hours.
- 2) The GTS noise and the response time of some sensors like the ATS imposes a limit for averaging the data in order to have measurements that can be compared with physical phenomena. Different strategies such as sliding windows of 60s or 300 s have been successfully applied. The wind sensor has also specific requirements for assembly of information, and it is currently best interpreted per session and not on a 1 Hz base.
  - 3) The measurements from the ultraviolet sensor are a great challenge for data analysis as the impact of the field of view, stray-light, and diffuse sky-irradiance requires a good technical knowledge of the filters. Furthermore the natural degradation of the sensors exposed to atmospheric dust deposition limits its lifetime and imposes a need for regular imaging of the UV sensors by the rover cameras.
  - 4) The complexity of the Wind Sensor (WS) data processing has increased due to the loss of one sensor right after landing. The first consequence is the reduction of resolution for rear-winds. Another negative aspect is the difficulty in isolating the effect of the rover on the sensor reading. Such a huge platform with large thermal contrasts interacts, depending on the direction of wind incidence, as an obstacle with the wind and has its own thermal induced convection cells and plumes.
  - 5) The complexity of HS data processing has increased as well due to an artefact in the behaviour of the HS electronics.

While the underlying cause of this artefact is still not clear, a work-around scheme based on reasonable assumptions about the Martian atmosphere has been developed. The preliminary HS results are in good agreement with Thermal Emission Spectrometer (TES)/Mars Global Surveyor satellite observations and modelling results.

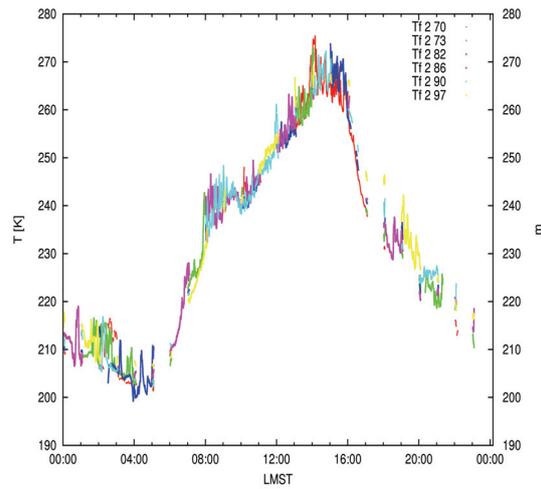
- 6) Furthermore the long-term exposure to the Martian daily thermal cycles and dust deposition requires regular calibration of the sensors to check for possible degradation.

### **Conclusions:**

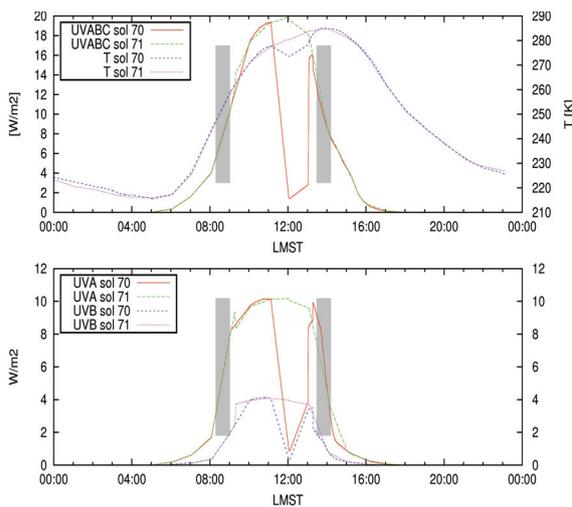
Being an environmental station, a critical constraint for REMS was the obvious requirement of operating on a hot moving platform. The RTG is at a temperature of about 200 K above the ambient temperature and the direct Sun heating of certain elements of the platform can easily increment the temperature by about 20 K w.r.t. shadowed areas. The REMS data interpretation task-force focuses on taking into account crucial ancillary information such as rover position, tilt, arm and mast position, arm and rover movements, RTG temperatures, Sun position with respect to the instruments and platform, angle of incidence as well as the variety of the materials (size, emissivity etc) within the GTS field of view, including other effects of the thermal environment on the electronics (such as night-time electronic noise or calibration offsets...). The final data products have been flagged according to the different quality and meaning and corrected, when possible, to account for some of these effects.



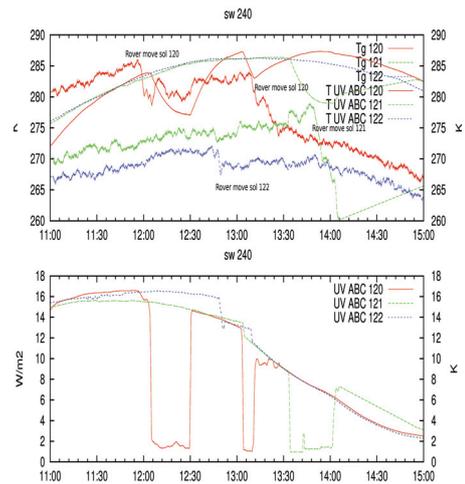
**Figure 1:** Diurnal Evolution of the pressure, air and ground temperatures, air density and UV irradiance.



**Figure 2:** Crude Diurnal profile of temperatures, including daytime solar-induced fluctuating thermal contamination around the rover mast and the night-time thermal variations induced by katabatic winds.



**Figure 3:** Mast shadows on the UV sensor and thermal contrast on the rover deck.



**Figure 4:** Ground brightness temperature from the GTS Channel A, spanning the 8-14 $\mu$ m region, the extended observations performed during rover movement show a quick temperature drop when the rover observes a non RTG-contaminated area.

**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] Gómez-Elvira, J. et al., REMS MEASUREMENTS DURING THE FIRST 100 SOLS ON GALE REMS submitted to *JGR*, (2013); [3] Martín-Torres, F. J. et al.,

(2013), this volume; [4] Patel M. et al (2013), this volume.

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