# RESULTS FROM THE ROVER ENVIRONMENTAL MONITORING STATION (REMS) ON BOARD THE MARS SCIENCE LABORATORY

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**Introduction:** The Rover Environmental Monitoring Station (REMS), has been operational since almost immediately after the landing of the Mars Science Laboratory (MSL) on August 6, 2012 (UTC). The REMS instrument, designed, fabricated and operated by an international team led by the Centro de Astrobiología (CAB) in Madrid, Spain, consists of six separate sensor types, observing air and ground temperature, near-surface winds, relative humidity, surface pressure and UV radiation [1]. The instrument suite was designed to make regular observations throughout the day, semi-autonomously. Here, we present a high-level overview of the science return from the REMS suite through sol 269[1], as well as a brief discussion of the operational approach to taking measurements. This abstract serves as a complement to [2], which provides an overview of the REMS instrumentation and their operating status. More detailed discussions of early science findings can be found in additional presentations within this volume.

**REMS Operations and Cadence:** The standard cadence of REMS observations remained largely fixed through the first 269 sols of the mission, and consists of five-minute observations of 1 Hz frequency at the top of each hour. Additionally, typically between three and seven one-hour "extended" blocks are sampled each sol, also at 1 Hz frequency. The positioning of these hourly extended blocks was designed to maximize frequency of coverage across the diurnal cycle while taking into account needs for temporal coverage requested by other instruments (e.g. CheMin, SAM) and to strategically respond to interesting scientific observations made on prior sols.

In principle, the base cadence consists of four hourly blocks spaced six hours apart, and retreating one hour each sol. Under this approach, REMS can obtain full diurnal coverage in six sols. In practice, due to both rover and instrument constraints, such coverage is not perfect, and there are occasional gaps in coverage. While the instrument operates independently of the rover computing element (RCE), periodic transfer of the REMS flash memory to rover memory is necessary, which requires communication with the RCE. Tactical sequencing restrictions may preclude transferring this data at the ideal time, resulting in modifications to the base cadence. Apart from periods of time corresponding to RCE-A failure and recovery, solar conjunction and flight software updates, on only five sols were no REMS observations made, indicating a very robust instrument and dedicated operations team.

**REMS Observations:** Through sol 269, almost 5.5 million individual measurements of the martian atmosphere have been made, spanning ~40% of the Mars year. A brief overview of the most compelling findings of the REMS instruments follows.

*Pressure cycle.* Figure 1 illustrates the annual pressure cycle through the first 269 sols (see, also, [3],[4]). Curiosity landed close to the annual minimum in surface pressure (in late northern summer) and passed through the annual peak in surface pressure (around sol 160). Timing of the seasonal cycle is in line with prior observations at the surface, e.g. [5]. On shorter temporal scales, the diurnal cycle in pressure revealed a surprising finding in the peak-to-trough pressure variation (Figure 2). Variations of about 90 Pa have been observed, which correspond to a variation of ~12% of the diurnal mean. This variation is substantially greater than the peak-to-trough variations observed by Viking at a similar season (about 3%) and appears to be a consequence largely of the local topography. 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. This flow acts to amplify the daily

[1] As of the time of this writing, the most recent PDS release contains data through sol 269. At the time of the workshop (January, 2014), an additional 90 sols (through sol 359) will have been released.

tides, resulting in substantially larger variability than on more benign topography [6].

On even shorter timescales, small pressure drops of order 1 Pa are regularly observed during peak heating periods, lasting for 10-20 s. These signals (Figure 3) coincide with a brief rise in air temperature and shift in wind direction, but with no change in opacity measured by the UV sensor. A lack of observed dust devils in Gale Crater during this period suggests that these pressure events may be 'dustless' vortices, with strength insufficient to lift dust from the surface.

*Air/ground temperature.* Observations by both the GTS and ATS have confirmed that temperatures above 273 K are measured at the Gale Crater landing site during daytime (e.g., Figure 4). Measurements of ground temperature exhibit diurnal signatures that do not match models of thermophysically homogeneous surfaces and may also include observational effects. [7]. Between sols 96 and 100 of the mission, a small, regional dust event passed over Gale Crater, increasing the 880-nm optical depth to ~1.2 [8]. Coincident with this increase in dust loading of the atmosphere was a decrease in the diurnal range of both air and ground temperatures—daytime solar insolation at the ground was reduced, and nighttime downwelling IR reduced surface cooling. A more significant change in the GTS reading was observed around sol 120-125, coincident with the descent of Curiosity into Yellowknife Bay, and a different geologic unit. There is a clear shrinking in the diurnal range of ground temperature across this geologic transition (Figure 4), likely indicative of a change in surface properties.

*UV measurements.* Along with the aforementioned changes in ground and air temperature during the sol 96-100 dust event, the UV sensor noted a marked decrease in UV irradiance (Figure 5), due to the obscuration of UV flux by atmospheric dust.

A typical diurnal trace of UV flux is at the mercy of rover orientation, and generally has many periods where the UV signal prematurely 'drops out'; these periods correspond to occultations by the RSM. While stationary, this behavior can be easily modeled, however during rover mobility periods, changes in rover heading with time can result in complex UV trace.

Periodic observation of the UV sensor by rover imaging assets has seen a secular increase in dust obscuration of the photodiodes, despite the presence of the ring magnets, resulting in a degraded signal.

*Relative humidity/water cycle*. It was anticipated that water frost might possibly be observed at Gale Crater early in the mission, during the coldest, predawn periods. Preliminary calibrated measurements by the RH sensor during this period have found the near surface relative humidity never reaches saturation, and is mostly below ~60%, which occurs just before dawn (Figure 6). Immediately after sunrise, as the surface and atmosphere begin to warm, the relative humidity drops quickly to what is essentially zero, as expected [9]. This is by no means a wet location on Mars. Inferred values of the mixing ratio find values typically in the range of ~50-150 ppmv.

*Wind.* An accurate measure of the wind has proven largely elusive due to the loss of the Boom 1 wind sensor, which precludes measurements, at any given time, from half of all possible azimuths. Further, wind measurements are at the mercy of the rover orientation, which changes day-to-day, and which is not necessarily optimal for 'good' wind measurements (especially at night, when the rover is 'parked'—if winds happen to blow from behind the rover during this time, they cannot be reliably measured). Despite these limitations, wind direction can be inferred during specific periods of the sol, and shows a shift in direction with time. Pre-landing model simulations of wind direction anticipated a strong influence due to slope flows along the crater rim and Mt. Sharp.

Wind speed appears to be generally mild, in the 0-10 m/s range, with winds only infrequenly exceeding 15 m/s. The distribution of wind speed is unimodal, with a peak at around 3-5 m/s, and a long, extended tail out to faster wind speeds.

**Conclusions:** The REMS instrument has been immensely successful on Mars and has yielded many new and intriguing findings during its first 269 sols on the surface. Noisy electronics at cold temperatures have presented difficulties with certain nighttime measurements, and the loss of the Boom 1 wind sensor has made accurate wind measurements difficult. Despite these setbacks, the instrument suite as a whole has performed quite well. The PS has shown a markedly more variable pressure cycle than at previous locations, and has highlighted a previously unheralded phenomenon in hydrostatic slope flow on Mars. The GTS is returning information that feeds directly into models of the surface composition and thermal inertia and, along with the ATS, have shown the response of the near-surface environment to dust loading in the atmosphere. The RH sensor has found little evidence for surface frost thus far in Gale Crater, and reveals a largely dry environment throughout the day.

With a goal of capturing at least one full Mars year of weather data, the REMS instrument will greatly augment the existing record, largely populated by Viking Lander measurements for over 30 years. Data is being regularly released into the PDS in 90-sol batches, with a 90-sol lag from observations.

**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., REMS instrument design and operation status: Monitoring the environment from a moving hot exploration rover on Mars, *5th MAMOW,* (2013); [3] Haberle, R.M. et al., Preliminary interpretation of the REMS pressure data from the first 100 sols of the MSL mission, *submitted to JGR,* (2013); [4] Harri, A.-M. et al., Pressure observations by the Curiosity rover—initial results, *submitted to JGR*, (2013); [5] Tillman, J.E., Mars global atmospheric oscillations—annually synchronized, transient normal-mode oscillations and the triggering of global dust storms, *JGR*, 93, 9433-9451 (1988); [6] Richardson et al., Why the diurnal pressure range at Gale Crater is so large, *submitted to JGR,* (2013); [7] Hamilton, V.E. et al., Observations and preliminary science results from the first 100 sols of MSL REMS Ground Temperature Sensor measurements at Gale Crater, *submitted to JGR*, (2013); [8] M. Lemmon, *personal communication*; [9] Genzer, M. et al., Mars Science Laboratory (MSL)—first results of relative humidity observations, *EGU General Assembly,* 3870, (2013).

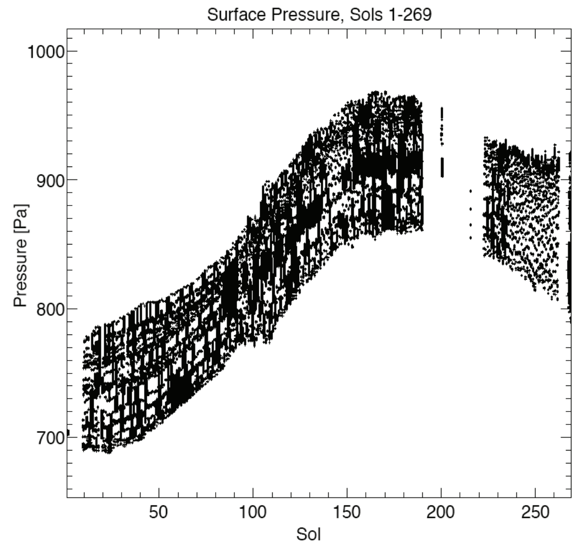


**Figure 1:** Seasonal pressure cycle on Mars through the first 269 sols of the MSL mission. Curiosity landed near a seasonal pressure minimum in late northern summer (around $L_s$=151°). Pressures peaked between sols 160-170 of the mission (~$L_s$=250°) at around 960 Pa. Large gap between sols 190-225 corresponds to the rover RCE anomaly when no data was collected.

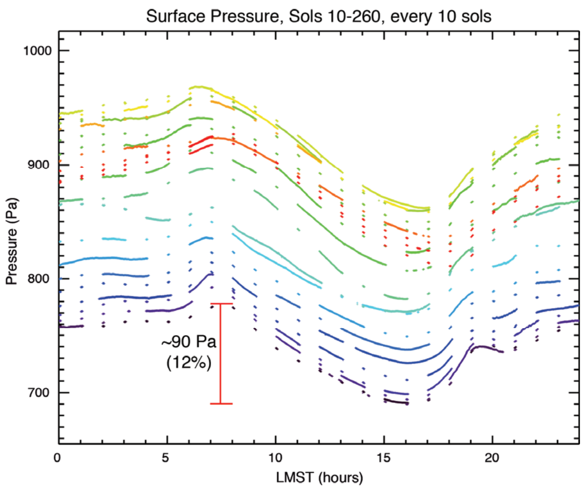


**Figure 2:** Surface pressure as a function of time of day, every ten sols from sol 10 (dark purple) through sol 260 (red). Peak-to-trough diurnal range exceeds 10% as indicated.

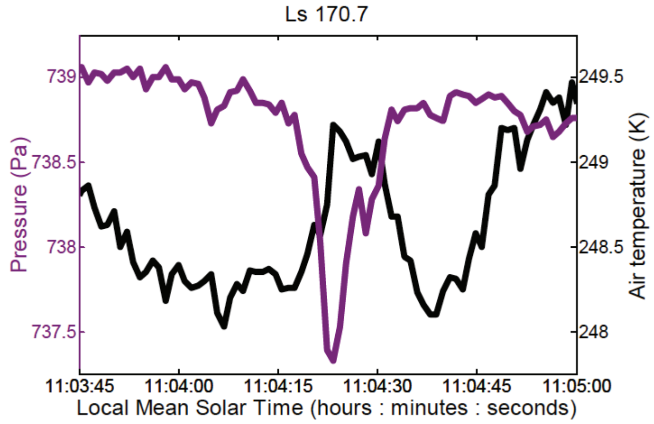


**Figure 3:** Surface pressure and air temperature as a function of time, over a 75-second period on sol 37. The marked pressure drop, coincident with a rise in air temperature, is consistent with a vortex passage.

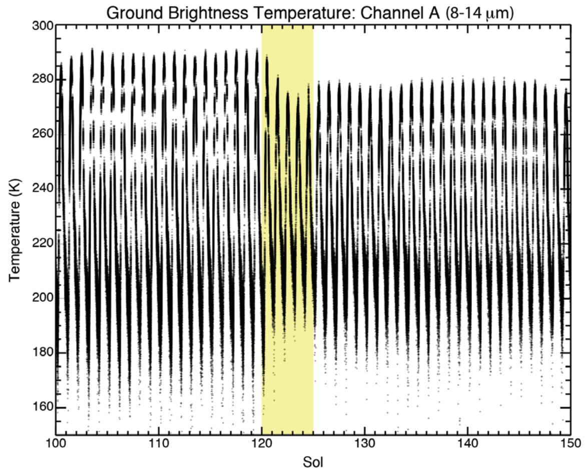


**Figure 4:** Ground brightness temperature from the GTS Channel A, spanning the 8-14 μm region, from sol 100-150. During this period, the rover was driving eastward into a region known as Yellowknife Bay. Between sols 120-125 (highlighted), the rover descended into a new geologic unit showing a smaller diurnal cycle in ground temperature, consistent with a higher thermal inertia.

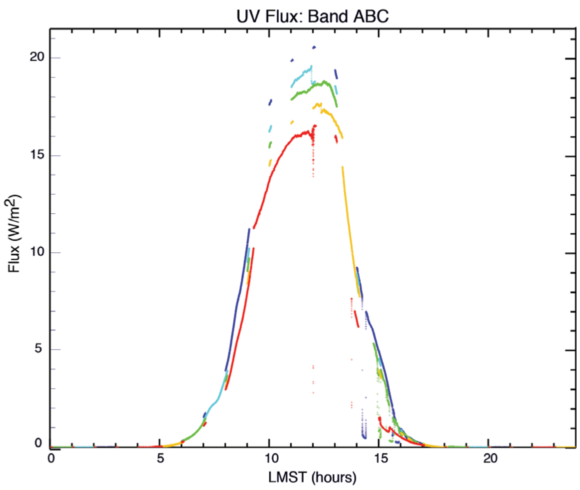


**Figure 2:** UV flux in the ABC band (200-380 nm) from sols 96 (dark purple) to 100 (red), during a regional dust event that increased atmospheric opacity by about 50%. Individual dropouts in the UV signal are a consequence of obscuration of the UV sensor by the RSM.

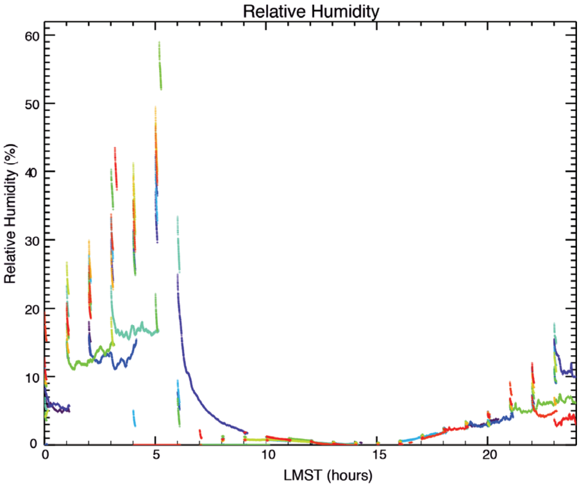


**Figure 6:** Relative humidity as a function of time of day from sol 20 (dark purple) to sol 30 (red). The highest RH values observed were ~76% on sol 15 (not shown), decreasing later in the season. Humidity drops off markedly after sunrise before slowly increasing late in the day. Individual observations show a rapid drop in RH, which is due to warming of the sensor during operation. Only the initial values are deemed reliable.