EVENING SURFACE TEMPERATURE ANOMALIES OBSERVED BY CURIOSITY IN GALE CRATER.

V. E. Hamilton[1], S. C. R. Rafkin[1], J. Pla-García[2], E. Sebastian[2], P. R. Christensen[3], A. R. Vasavada[4], M. de la Torre Juarez[4], F. J. Martin-Torres[5], M.-P. Zorzano[2], [1]Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80302, hamilton@boulder.swri.edu, [2]CAB-INTA, Madrid, Spain, [3]Arizona State University, Tempe, AZ 85287. [4]Jet Propulsion Laboratory, Pasadena, CA 91109. [5]CSIC-UGR, Granada, Spain.

Introduction: A subset of diurnal ground temperature measurements from Curiosity's first 100 sols on Mars exhibit variability in cooling rate in the evening hours [1] that is not predicted by a standard thermal model [2] or a mesoscale atmospheric model [3]. These events also are observed in data collected through sol 595. Here we examine these anomalous events in terms of their frequency of manifestation and the differences they exhibit from predicted trends.

Background: [1] compared the average (Martian) hourly temperatures measured by the GTS [4, 5] to the temperatures predicted by a thermal model for a homogeneous surface [2] in an effort to determine the thermal inertias of the surfaces traversed by Curiosity. Their results demonstrated that surfaces observed by Curiosity through sol 100 tended to remain warmer than predicted until ~20:00 LMST. [1] also reported, but did not explore in detail, the presence of short-duration reductions in the evening cooling rate relative to that predicted by thermal models (e.g., **Figure 1**).

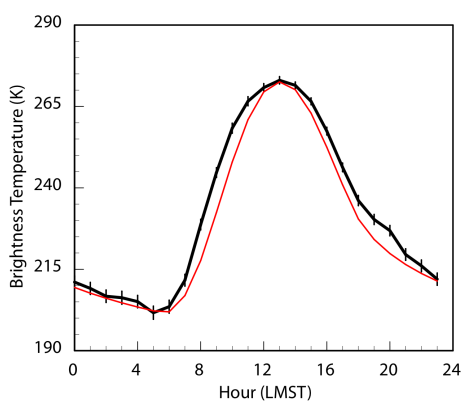

Figure 1. Ground temperatures at Gale crater on sol 157 (thick black line) showing slow-down in cooling rate at ~19:00 – 20:00 LMST relative to the rate predicted by a thermal model (thin red line).

Methods: Our preliminary examination of the GTS data uses the average hourly temperature from the nominal 5-minute background sessions of the REMS suite [1]. Our first method for determining the frequency of occurrence of these anomalies involves fitting the GTS temperatures between 16:00 – 23:00 LMST with a cubic polynomial obtained via a chi-squared minimization. These hours were selected to encompass the range of times during which qualitative analysis suggests the cooling rate changes are present, and includes times at either end during which such changes generally are not observed. From the derived fit, we calculate a temperature at each hour and subtract the fit values from the measured temperatures. Using these difference values, we calculate a root mean square error (RMS) for each sol. This polynomial fitting approach is not intended to be thermophysically rigorous, rather, it is intended to be computationally efficient for processing nearly 600 sols of data. Future analyses will incorporate a thermophysical model.

Preliminary Observations: The RMS error values for our fits range from 0.17 to 2.51 (**Figure 2**). There is an increase in the mean RMS errors after sol 300 (L_s = ~334°) – this trend peaks around sol 530 (L_s = ~84°) and then the values appear to begin decreasing, although more data are needed to convincingly demonstrate this trend. Cubic fits to sols after 300 are therefore less representative overall of the observed ground temperature cooling rates and may indicate a seasonal influence on the observed temperature anomalies. This seasonal variation corresponds with seasonal variations observed in air density measured by MSL.

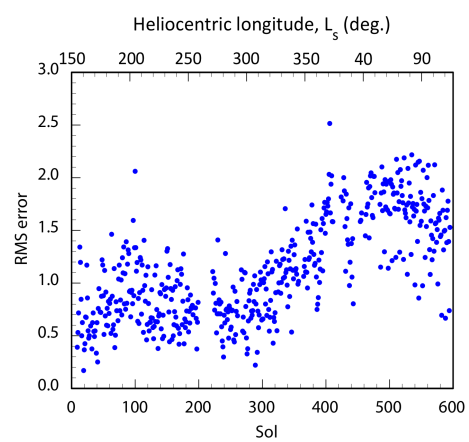

Figure 2. RMS errors for cubic fits to ground temperatures between 16:00 – 23:00 LMST through sol 595.

Figure 3 shows that the greatest absolute differences between the measured and fit-derived temperatures occur at 17:00 LMST, with an average of 1.68 K and a range of ~0 – 4.8 K; the smallest absolute differences, at 23:00 LMST, have an average of 0.44 K and a range of ~0 – 1.5 K. Air temperature data from MSL

also show enhanced variability around 17:00 LMST, also with an increase in this behavior after sol 300. Wind sensor data exhibit the greatest speeds in the early evening as well.

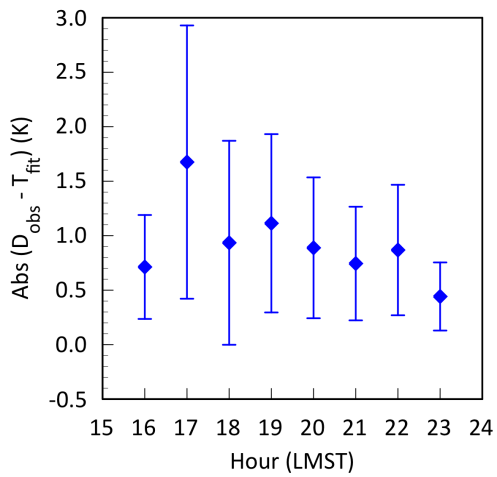

Figure 3. Average hourly absolute difference between measured and cubic fit-derived temperatures. Vertical bars represent values for ~68% of the data.

Hypotheses for Temperature Variations: Any candidate explanation(s) for the observed deviations from the expected cooling trend must correspond in time and duration with the deviations in the ground temperatures. We consider two possibilities below.

Rover-related variables: Rover activities are being examined to determine if these might be leading to instrumental anomalies or surface temperature changes. Instrumental anomalies have not been eliminated, but are not high-likelihood candidates. Heat from the rover's radioisotope thermoelectric generator (RTG) is a known contributor to surface heating [1], but the greatest effects of the RTG are expected and usually observed shortly after arrival at a new location, with stabilization times on the order of minutes to tens of minutes. Rover drives typically occur near midday, so RTG effects are not expected in the evening hours. There is no clear correlation between the temperature anomalies and drive sols.

Natural Environmental Variables: The most likely natural cause of changes in the evening surface temperature cooling rate is atmospheric phenomena. One such event is downslope winds driven by mountain wave activity, similar to the Chinook winds along the eastern slopes of the U. S. Rocky Mountains. These winds are forced by large amplitude gravity wave dynamics and are distinctly different than downslope katabatic winds [e.g., 5]. Another possibility is that the change in cooling rate results from enhanced turbulence driven by increasingly strong shear at the nocturnal inversion interface. As the nocturnal inversion develops, the winds above become decoupled from the surface and the decrease in friction produces a net acceleration. Once the critical Richardson Number is reached (Ri ~< 0.25), shear instabilities can mix warmer air aloft down to the surface. This turbulent mixing process has been observed in the Owens Valley (USA) under similar katabatic wind conditions emanating from the Sierra Mountains [e.g., 6]. Importantly, the warming (or slow-down in cooling) is not due directly to the katabatic winds, which are by definition cold. MRAMS simulations show evidence for both gravity wave activity and nocturnal mixing, although the latter is generally not sufficient to produce the trend that is observed [1]. However, the turbulent parameterizations in mesoscale models are notoriously poor at representing turbulence under very stable conditions [e.g., 7], so this result is not unexpected.

In a scenario where winds are responsible for the observed change in cooling rate, a plausible inference is that the uppermost 10s – 100s of microns of the surface layer (to which the GTS is most sensitive) are: 1) warmed, 2) stabilized against cooling, or 3) the cooling rate is slowed by the passage of warm air over top. This condition may be enabled or enhanced by the presence of fine dust, which is known to be present and optically thick on the floor of Gale crater [e.g., 8, 9], and has been observed directly by Curiosity. Presumably, the regular cooling rate resumes as soon as the wind dies down. This interpretation suggests that there are warm winds reaching the floor of Gale crater on a regular basis, and that these winds are either constrained to a relatively narrow period of day, or the surface and GTS measurements are only sensitive to them during these hours.

Ongoing work: Future analyses will include data from REMS extended sessions at the hours of interest. We also are looking at simultaneous ground temperatures measured by the 2001 Mars Odyssey Thermal Emission Imaging System (THEMIS) to see if there are seasonal trends in that correlation that would indicate sub-pixel temperature variation in THEMIS data.

References: [1] Hamilton, V. E. et al. (2014) *JGR*, doi:10.1002/2013JE004520. [2] Kieffer, H. H. (2013) *JGR, 118,* 451-470. [3] Rafkin, S. C. R. et al. (2001) *Icarus, 151*, 228-256. [4] Gomez-Elvira, J. et al. (submitted) *JGR*. [5] Klemp, J. B. and Lilly, D. R. (1975) *J. Atmos. Sci., 32*, 320-339. [6] Whiteman, D. C. and Hoch, S. W. (2009) *J. Appl. Meteor. Climatol., 48*, 776-788. [7] Lee S.-M. et al. (2006) *Boundary-Layer Met., 119*, 109-134. [8] Ruff, S. W. and Christensen, P. R. (2002) *JGR, 107,* doi:10.1029/2001JE001580. [9] Rogers, A. D. and Bandfield, J. L. (2009) *Icarus, 203*, 437-453.