AEOLOGICAL TRANSPORT OF COARSE SEDIMENT IN THE MODERN MARTIAN ENVIRONMENT. M. Baker1, K. W. Lewis1, N. Bridges2, C. Newman3, J. Van Beek4, M. Lapotre5. 1The Johns Hopkins University Morton K. Blaustein Department of Earth and Planetary Sciences (mmbaker@jhu.edu), 2Applied Physics Laboratory, Johns Hopkins University, 3Ashima Research Corporation, 4Malin Space Science Systems, 5Division of Geological and Planetary Sciences, California Institute of Technology.

Introduction: Evidence of aeolian sandstone outcrops, migrating sand dunes, and changes in surface albedo changes caused by redistribution of surface dust on Mars demonstrate that aeolian processes have been and continue to be a dominant agent of surface modification [3] [7] [9]. It is known that strong wind events on Mars can be responsible for lifting large amounts of sediment into the atmosphere. Entrained dust can significantly decrease optical visibility and saltation of sand can cause large amounts of particle splash due to Mars’ low gravity. For these reasons, and many more, the effects of surface wind need to be carefully considered for any mission to Mars. Ensuring that instruments remain operational in these conditions requires a full understanding of the modern-day aeolian processes. Yet, transport within Mars’ low atmospheric pressure environment is still not fully understood and requires a combination of modeling, experiments, and ground truth observations [1] [4] [6]. Here we present results from a series of systematic change detection campaigns conducted by Curiosity over three Martian years (site locations shown on basemap in Figure 1).

These results include the first-ever observations of coarse-grained (1-3mm) sediment transport in the modern Martian environment. These unforeseen results are particularly noteworthy -and potentially enigmatic- given the frequency with which grain motion occurs and the overall wind strength implied by standard saltation models. For this reason, the motion of coarse sediment likely requires an alternate explanation, such as strong but infrequent wind gusts or impact-driven creep by smaller, saltating particles.

Identifying how wind transports coarse sand grains in the modern Martian environment is important for understanding the danger that sediment-lifting events pose for robotic instruments as well as for future human exploration. Our results confirm that winds are most active during Southern Summer on Mars, and ongoing work is focused on classifying diurnal variations in wind activity. Direct imaging of surface sediments changes is useful for collecting information on the strength, frequency and duration of individual wind events, all of which can be used to keep future explorers safe. These results can also be used to test and improve general circulation models.

Methods: Change detection. The primary component of this research study was visual inspection of Mastcam images (M100 camera) taken along the Curiosity traverse (between Sol 176 and Sol 1498). At each site in question, the rover was stopped for an extended period of time to conduct various in situ rock analyses or for solar conjunction events. At each site, we acquired a set of images right after ingress and right before egress; the “before” and “after” images are separated by anywhere from 8 to 100 sols, depending on the site.

An example of our Mastcam images is shown in Figure 2. Coarse grains that we see moving between the first and second images are highlight with black arrows. The M100 camera’s high spatial resolution (0.22mm/pixel at a typical distance of 3 meters) allowed us to accurately resolve coarse sand grains and observe precise grain movement up to several meters away from the rover. Our study is most sensitive to the creep population, which is both large enough, and moves slowly enough, to detect by eye. We are not able to resolve the movement of saltating sand, but this does not eliminate the possibility that fine sands are undergoing salination during these campaigns.

Figure 1: Basemap of Curiosity traverse through Gale Crater. Site marker size is scaled to the length of each campaign. Red marker = motion observed, black marker = no motion observed).

Figure 2: Example of a Mastcam image taken on Sol 872 at Pahrump. Black arrows indicate coarse sand grains that move between the two imaged sols.
Grain motion. A large number of these small-scale grain paths were then combined to reconstruct the average local wind directions and speeds. Grain motion was identified manually in Matlab and geometrically projected to determine the 2D geographic motion vectors. Individual motion vectors were combined and mapped as a tracer of surface wind direction. Obtaining images from many sites over a long period of time helped us discern the effects of regional topographic feedback and seasonal variations in wind. The winds inferred by observations at each site are also compared to the wind speeds and directions predicted by a mesoscale model nested within a MarsWRF GCM (as shown in Figure 5).

Results: Overall, we observed that each site demonstrated either significant grain movement or virtually no grain movement; this distinction allowed for binary classification of wind dominated sites. All positive detections occurred near $L_s \sim 270^\circ$ (close to perihelion and southern summer solstice). Figure 2 shows a full timeline of this study over three Martian years.

Contrary to expectations, we find that coarse grains are frequently transported on the Martian surface today. At all of the active sites, a significant fraction of the mobile population consisted of very coarse sand grains >1mm in diameter (using the Wentworth 1922 classification scheme). These results are surprising due to the fact that wind speeds needed to detach particles of this size from the surface are much higher than ever recorded or predicted to occur on Mars [2] [5]. It is possible that coarse grain motion is being caused by impact-driven creep, where the impacting populations are too small and transient for us to observe by eye. Such impacts could cause slow accumulation of surface changes over time [11]. Our observations show surface changes occurring on ~daily timescales, requiring that a sufficient amount of sediment is saltating with high enough kinetic energies during those days. The likelihood of this remains to be resolved. The size ranges for mobile grain populations can be seen in Figure 4.

The individual 2D grain motions at each site were combined to assess local wind directions. Three of the four sites revealed consistent net transport directions, which we infer to be induced by consistent wind patterns. The fourth (Marias Pass) seemed to demonstrate more randomized motion. These discrepancies could be caused by local topographic interactions or by diurnal/seasonal changes in wind direction, both of which will be examined in greater detail. These wind tracers were compared directly to nested MarsWRF predictions (Figure 5).
The largest disagreement between observations and predictions occurs at the Narrows site, which could be caused by its relative proximity to the rim of Gale crater. Winds at this site could be subjected to the strong night-time winds flowing down the crater rim. Furthermore, since Narrows is further from large topographic features (e.g. Mount Sharp), the surface winds at Narrows could be influenced more by small-scale topography that is not resolved in models. Pahrump and Paria are much closer to Mount Sharp than Narrows and thus the wind at these locations is likely dominated by the strong down-slope morning winds coming off the mound.

Discussion: Here we present the first ongoing analysis of surface images obtained during Curiosity's change detection campaigns. We find that wind activity follows a clear annual trend, validating previous theories of seasonally variable wind. Yet, wind speeds predicted for even the peak windy season are far lower than the speeds needed to move coarse sand following the classic saltation model. It is possible that strong, intermittent gusts are responsible or that impacts from smaller saltators cause the motion we observe.

Now that seasonal variations have been well-chronicled in sediment flux measurements, global wind models, and in the in-situ observations presented here, future work will aim to constrain diurnal variations in the strength and direction of wind. These results can be shed light on the accuracy of wind models and improve our understanding of surface-atmosphere interactions as a whole. Ultimately, we found that models are inconsistent in their ability to predict net transport direction on the surface, possibly due to unresolved topographic feedback. But the potential effects of diurnal variations have not been well-constrained and are thus not used to analyze the data presented here.

Observing modern aeolian transport in images taken by Curiosity could aid in deciphering the deposition and preservation of cemented aeolian sandstones in Gale Crater, especially those containing dispersed coarse grains [5] [9]. The apparent ability of the modern atmosphere to transport coarse sand, even in creep, can help constrain the environmental conditions present during deposition. Furthermore, characterizing modern-day wind behavior (strength of wind, frequency of dust-lifting events etc.) is of critical importance for assessing hazards for future rovers and human explorers.


