HiRISE OBSERVATIONS OF SAND DUNE MOTION ON MARS: EMERGING GLOBAL TRENDS. P. E. Geissler\textsuperscript{1}, M. E. Banks\textsuperscript{2}, N. T. Bridges\textsuperscript{3}, S. Silvestro\textsuperscript{4} and the HiRISE Science Team, \textsuperscript{1}US Geological Survey, Flagstaff AZ 86001 USA (pgeissler@usgs.gov), \textsuperscript{2}Center for Earth and Planetary Studies, Smithsonian Air and Space Museum, Washington, DC 20013, USA, \textsuperscript{3}Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, Maryland 20723, USA, \textsuperscript{4}Carl Sagan Center, SETI Institute, 189 N. Bernardo Avenue, Suite 100 Mountain View, CA, 94043, USA.

Introduction: Little was known about the extent and magnitude of sand dune motion on Mars prior to the arrival of Mars Reconnaissance Orbiter (MRO). Several searches for dune motion based on prior mission data had been carried out with negative results [1-3], and only one detection of dune disappearance was achieved [4], leaving the observational lower limit for planet-wide sand flux near zero. Repeated imaging observations at resolutions up to 25 cm/pixel by the HiRISE camera on MRO have now documented sand dune movement in several locations [5-8]. Other pairs of repeated HiRISE sand dune observations have failed to show any evidence of changes. Definitive detection or non-detection of sand dune motion requires repeated imaging under similar illumination conditions at intervals of 1 or more martian years, and has been achieved so far in only a limited number of locations. Although the total number of repeated observations of sand dunes is still small, we can begin to draw inferences about the global distribution of shifting sand dunes, at the peril of the vagaries of the statistics of small numbers.

Geographic Distribution: Figure 1 shows a map of the best documented detections and non-detections of sand dune movement on Mars to date. This map clearly indicates that the observations available are still very sparse. Only 40 definitive detections of sand dune movement have so far been made, out of a total of just 64 qualifying image pairs. Coverage remains uneven in both latitude and longitude. Note for example that there are no detections or non-detections in the latitude range from 30 to 65 degrees north. Many of these targets were deliberately chosen because of the ease of visibility of any changes, for example among dark sand dunes overlying bright dust or bedrock substrates. The data omit observations of transverse aeolian ridges (TARs), which are morphologically distinct from sand dunes and have not been observed to change.

Figure 1: Spatial distribution of dune movement detections (blue) and non-detections (red).

Latitudinal Distribution. Figure 2 shows the observations summed by latitude, represented as the fraction of observations demonstrating dune movement in each latitude bin. Also shown on this chart is the latitudinal distribution of the occurrence of sand dunes in each bin, expressed as a fraction of the total areal coverage of dunes, taken from the Mars Global Digital Dune Database statistics provided by the Mars-Dunes.org Consortium [9]. Although sand dunes in general are strongly concentrated in the southern highlands, the preliminary figures suggest that detections of dune motion tend to be most common at equatorial latitudes (and northern polar latitudes, of course).

Elevation Distribution. Figure 3 breaks the observations down by elevation, expressed as km above the 6 mbar datum. These preliminary numbers suggest that dune motion detections are more prevalent at lower elevations, while non-detections are more prevalent at higher elevations.

Figure 2. Latitudinal distribution of the fraction of dunes in motion (blue) vs. areal coverage of dunes (red).
Displacement Rates and Sand Fluxes: Various HiRISE observations have documented erosion and deposition of sand patches, movement of small ripples on the backs of sand dunes, and advances of the slip faces of individual barchans. Rates of ripple movement are best established, and range from 0.2 to 1.2 m per Earth year. Slip faces in Meridiani Planum have been observed to advance up to 0.25 m per Earth year [10]. The best documented dune field is in Nili Patera, where a series of HiRISE images has monitored sand motion at frequent intervals over a period of over 2 martian years. These images demonstrate frequent avalanches cascading down the slip faces of active dunes, and show the gradual advance of the slip faces as they are overtaken by the faster ripples. A digital elevation model constrains the volumetric changes in the Nili Patera dune fields [11]. Using this model together with terrestrial analogies, estimates can be made of the sand flux needed to produce the observed changes [12]. The results suggest sand fluxes on order of several cubic meters per meter per year, similar to sand fluxes in Victoria Valley, Antarctica [ibid.].

Discussion: That martian sands were mobile was long suspected for a variety of reasons, including the fresh appearance of the dunes and the lack of impact craters on their surfaces. However, HiRISE is the first experiment to quantify the extent and magnitude of sand dune motion on the planet, beyond giving an upper limit. The results suggest ubiquitous sand movement on Mars, from the equator to sub-polar latitudes, and sand fluxes comparable to terrestrial dune fields. These findings impact our understanding of landscape modification under current climatic conditions, and generate new questions concerning the modern day sources of martian sands.

Our analysis of the dune motion survey to date suggests that the more active dunes away from the north pole are found at low elevations near the equator of Mars. We speculate that the sands are more easily moved by the denser atmosphere at lower elevations, and by the strong seasonal winds crossing the equator. Continued monitoring of martian dune fields by HiRISE will decide whether these suggestions of global trends are sustained.