RIPPLE ORIENTATIONS AS AN INDICATION OF RECENT WINDS ON MARTIAN DUNES. M. B. Johnson[1] and J. R. Zimbelman[1], [1]Center for Earth and Planetary Studies, MRC 315, National Air and Space Museum, Smithsonian Institution, Independence Avenue and 6th Street SW, Washington, DC 20013, JohnsonMB@si.edu.

Introduction: Sand dunes on both Earth and Mars have been shown to preserve the most recent wind patterns in their ripple formations [1, 2]. This investigation, supported by NASA MDAP grant NNX12AJ38G, continues the documentation of ripples on martian dunes in order to assess recent surface wind flow [3]. This information will provide insight into the modes of dune formation and ripple morphology, and offer current constraints for global circulation models.

Background: Movement of martian sand ripples was first observed by the Spirit rover [4] and is now studied with images from the High Resolution Imaging Science Experiment (HiRISE) camera [5]. This instrument provides unprecedented views of Mars, including sand dunes in diverse areas with resolution as high as 25 cm/pixel [6]. Some dunes have complex structures and crest positions which may have been created by multiple wind directions or seasonal wind variations. Being unable to determine between multiple possible wind regimes leaves dune morphologies open to interpretation. However, dune crests and ripples mapped by Neilson and Kocurek show that the ripple-scale patterns are a better indicator of recent wind flow which modify the principle crests [1]. This same mapping technique can be used to document recent flows on Mars. Because wind speeds have yet to be measured directly in many areas, we must rely on high resolution images and ripple scale features for recent wind information.

Methodology: Martian study sites in this investigation must have clear HiRISE frames and be able to represent diverse locations across the surface, decided primarily by their latitude and longitude. Frames with stereo pairs are preferred because of their ability to create digital terrain models (DTMs) with 3D modeling software such as SOCET SET. The resulting 30 frames studied to date are indicated in Table 1. The ripple documentation method for the first 7 images was the Java Mission-planning and Analysis for Remote Sensing (JMARS) geospatial information system (GIS) while the remaining images were studied using ESRI's Arc GIS. In both systems, lines were drawn perpendicular to ripple crests across three adjacent ripples in order to document ripple wavelength from line length and inferred wind direction from azimuth (Figure 1). It is not possible to infer a unique wind direction from ripple orientation alone and therefore these inferred directions have a 180 degree ambiguity [7]. For example, a crest with North-South alignment may have been constructed by an Easterly, Westerly, or bi-directional wind. Due to this ambiguity, results presented in this study will assume azimuths to be between 0 and 180 degrees. Actual orientations may be defined after further study by using additional information about dune morphology, such as known dune types, and the rule of maximum gross bedform-normal transport [8]. Ripples in each study site are then categorized by the cardinal wind direction they suggest and percentages of each inferred direction are calculated. Percentages of wavelength values are also displayed in order to look for possible patterns. In some areas with DTMs, inferred wind direction is compared to the slope magnitude on which the ripple formed. This gives an idea of how great the effect of slope may be on ripple orientation by the process described by Howard [9].

Site	Region	HiRISE frame ID	Lon E	Lat
1	Hellespontus	PSP_007663_1350	38.779	-44.859
2	Gale Crater	PSP_009571_1755	137.497	-4.463
3	Nili Patera	ESP_017762_1890	67.321	8.779
4	North Polar	PSP_010019_2635	118.543	83.505
5	Aonia Terra	ESP_013785_1300	293.1	-49.804
6	Lus Chasma	ESP_027341_1720	276.387	-7.718
7	Arabia Terra	ESP_016459_1830	4.553	3.12
8	Terra Cimmeria	ESP_025645_1455	138.437	-34.23
9	Lyot Crater	PSP_009746_2290	29.287	48.864
10	Icaria Planum Crater	ESP_029478_1350	259.932	-44.482
11	South of Promethei Terra	ESP_022731_1080	143.002	-71.68
12	Terra Sirenum	ESP_023928_1205	218.035	-59.098
13	Vastitas Borealis	ESP_018925_2520	344.658	71.906
14	Milankovic Crater	ESP_018930_2350	213.42	54.576
15	Becquerel Crater	PSP_001955_2015	351.899	21.445
16	Terra Tyrrhena	ESP_026675_1655	97.769	-14.552
17	Gamboa Crater	PSP_002721_2210	315.704	40.78
18	Aeolis Mensae	PSP_010178_1825	122.357	2.247
19	Wirtz Crater	ESP_021603_1315	334.681	-48.256
20	Near Cerberus Fossae	PSP_008449_1885	169.194	8.566
21	Coprates Chasma	ESP_026905_1660	296.894	-14.092
22	Kaiser Crater	PSP_007110_1325	18.794	-46.98
23	North Polar	ESP_027474_2610	223.471	80.832
24	Syrtis Major Planum	ESP_019845_2000	79.425	19.823
25	West of Daedalia Planum	ESP_024838_1630	207.988	-16.72
26	Herschel Crater	PSP_006974_1635	128.39	-16.391
27	Capen Crater	ESP_026757_1865	13.958	6.349
28	South of Valles Marineris	ESP_025625_1580	320.382	-21.603
29	Promethei Terra	ESP_023285_1230	133.179	-56.923
30	Terra Sirenum	ESP_023731_1405	195.967	-38.96

Table 1: Information for the 30 study sites where ripple measurements have been recorded to date. Sites are listed in order of completion.

Terra Sirenum Observations: One site explored in this study is in Terra Sirenum (HiRISE frame ESP_023928_1205), where 333 ripples were recorded and analyzed for dominant wind direction, emerging patterns of ripple wavelength, and effect of slope on ripple deflection. The percent of measurements in each each direction are as follows: 1% ESE-WNW wind, 36% SE-NW, 38% SSE-NNW, 24% S-N, and the remaining 1% SSW-NNE. This shows that the wind is likely from the SSE with additional ripples centered around this direction. The wavelengths varied from 2 to 4 meters and the distributions show that 3 to 4 meter wavelengths make up the majority of measurements in the ESE and SE while 2 to 3 meter wavelengths make up the majority of SSE, S, and SSW measurements. It is not yet clear whether there is a relationship between the two. The slope distribution shows that very few (about 5%) measurements were on slopes of larger than 15 degrees, which is not an adequate number for affirming significance. However, these measurements fell into two of the larger categories (SSE and S), which does not indicate a tendency toward anything other than the same distribution. Further investigation into one small dune in this frame (Figure 2) shows that while the angle between the direction of inferred wind and direction of maximum slope ranges between 13 and 87 degrees, the dune shape suggests NW-SE wind on the majority of the dune with some variation on the base of the eastern side, where form flow would occur. This indicates again that slope does not seem to have a large affect on ripple orientation and deflection.

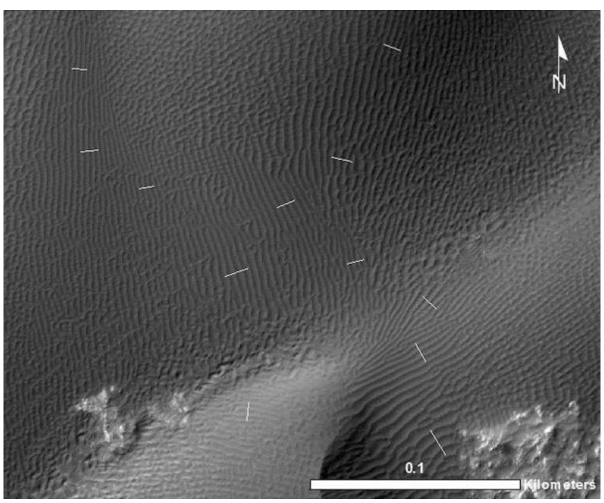

Figure 1: Ripple mapping of HiRISE frame ESP_025645_1455. Note that areas with clear ripple definition for tens of meters contain measurements while areas with overlapping patterns have been avoided.

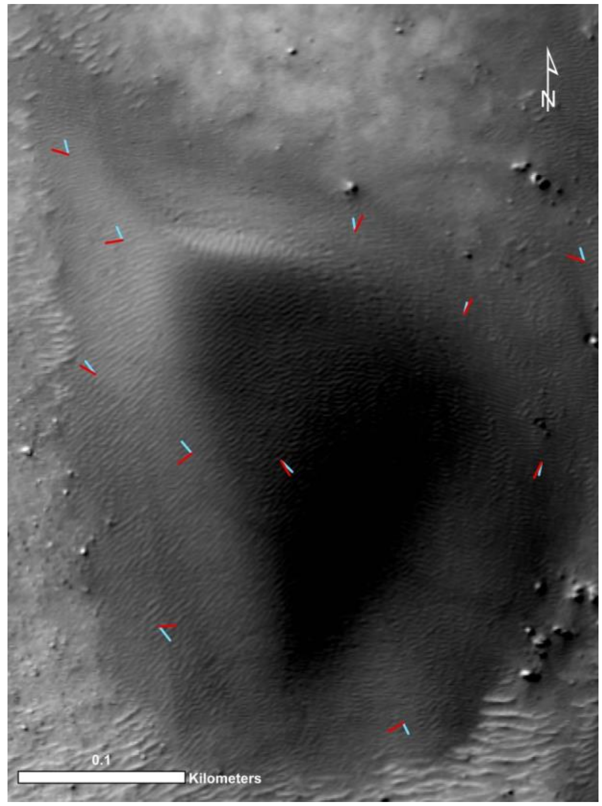

Figure 2: Subscene of HiRISE frame ESP_023928_1205 with blue lines indicating ripple measurements and red lines indicating the direction of maximum slope.

Results: This study has yielded several preliminary results. Firstly, the martian surface supports many dune types, including barchan and linear, in areas with adequate sand supply. The complexity of ripple patterns varies from uniform directionality for hundreds of kilometers to complex, overlapping patterns which create areas that cannot be documented by this process. These suggest the existence of multiple dominant, perhaps seasonally varying winds. The study of individual frames has indicated that there may be a relationship between wavelength and azimuth, though more study is needed. It has also suggested that slope angle does not have a significant effect on ripple formation with regards to orientation. The study of additional frames will expand our understanding of these relationships.

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