MAPPING WINDS OVER MARTIAN SAND DUNES FROM RIPPLES AND DIGITAL TERRAIN MODELS.
M. B. Johnson[1] and J. R. Zimbelman[1], [1]Center for Earth and Planetary Studies, Smithsonian Institution, Independence Ave and Sixth St SW, Washington, D.C. (JohnsonMB@SI.edu; ZimbelmanJ@SI.edu)

Introduction: Sand dunes have been shown to preserve wind flow patterns in their ripple formations on both Earth [1] and Mars [2]. By documenting ripple orientations shown in High Resolution Imaging Science Experiment (HiRISE) images of sand dunes at widely distributed sites across Mars, we can begin to identify the most recent wind directions at these locations [3]. However, we must also consider the effects of form flow and slope deflection on these wind patterns [4]. These considerations reinforce the value of DTMs for comparing ripple measurements to elevation and slope information. DTMs can also be used with wind modeling software to create raster maps of simulated wind speed and direction. Together, documented ripples, DTMs, and wind models can offer a more complete picture of recent wind flow patterns on Mars.

Ripple Mapping: Using GIS, 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. Because it is not possible in most areas to infer a unique wind direction from the ripples alone, line orientations have a 180 degree ambiguity. Actual orientations can be defines after further study. Measurements are made about 40 meters apart, though this number may decrease in areas where ripples quickly change wavelength or orientation, and increase where ripple patterns are obscured or complex. Figure 1 is an example of these lines.

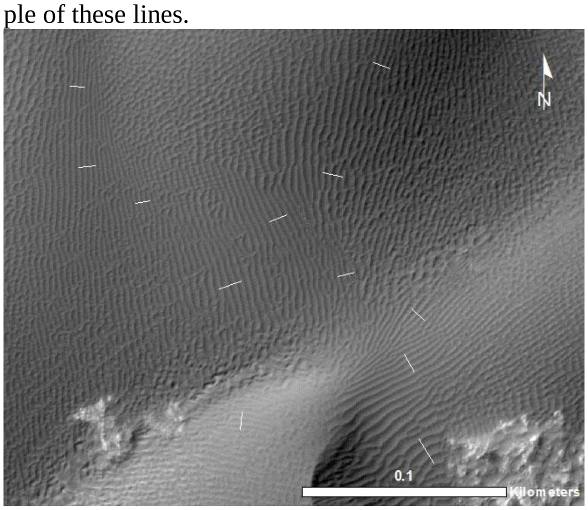

Figure 1: Ripple mapping in a subscene of HiRISE frame ESP_025645_1455. Note that areas with clear ripple definition for tens of meters contain measurements while areas with over-lapping patterns have been intentionally avoided.

DTMs: DTM creation software uses two stereo images along with absolute height reference points to create an elevation map for the overlapping area. The Soft Copy Exploitation Toolkit (SOCET SET) used by the USGS in Flagstaff can create a DTM with 1 meter post spacing from 25 cm/pixel resolution HiRISE images and MOLA track data [5]. To ensure the best quality product without artifacts, the images should be taken close together in time and have minimal untextured areas. Further manual editing, such as editing by interpolation in selected areas, may alter the product quality.

Wind Modeling: Though it has been shown that surface slopes on a sand dune can deflect ripple orientation with respect to the incident wind [4], we have found this effect to be not large in our study sites when slip faces are avoided, and when the dunes lack great vertical relief [6, 7]. DTMs can therefore be used to predict reasonable form flow deviations. To do this, we have begun to explore open source software that simulates spatially varying winds dependent on DTM data, starting with OpenFOAM and WindNinja. OpenFOAM has been compared to WindNinja for dune sites which include large obstacles on both Earth and Titan. OpenFOAM was found to be superior, but was also more complicated and more difficult to use [8, 9]. WindNinja can be used in three modes: with model data from the US National Weather Service, with one or more surface wind measurements, or a user-specified average surface wind speed and direction. Because of its ease of use and multiple run options, we chose to first explore WindNinja for Mars DTMs.

Using WindNinja:

Methods: We used a subset of the DTM DTEED_016907_1330_016973_1330_U01 (seen partially in Figure 2), which covers a large dune within Kaiser Crater. The DTM data were loaded into WindNinja along with an average incident wind direction of 80° (cw from N), based on the shape of this barchan dune. Separate runs with an average wind speed of 20, 30, 40, and 50 mph (1 m/s = 2.2 mph) were used to evaluate the effect of differing speeds. Because of the nature of the program, we then chose constraints closest to our situation (e.g., ‘grassy’ for the terrain type). A domain average wind model was used because we lack wind data for this location. The WindNinja output for this DTM is shown in Figure 3.

Results: For each of the simulated regimes (20, 30, 40, and 50 mph average wind speed, each with 80 degrees average wind direction and 1 meter above the ground), the wind direction output was the same at corresponding points. For each run, the directional summary information was an 80° average wind direction with a standard deviation of 3.5°. Changing the average wind speed for each run showed that both the standard deviation and range of wind speed measurements (highest value-lowest value) increased. Specifically, standard deviation increased by 1.3° and range increased by 20 with each change in speed (10 mph).

When the assumed height of the wind measurements increased to 3m above the ground, the wind direction output was identical to those at a 1m height, but the average wind speed output decreased.

Summary: DTMs, though sometimes difficult to create, are necessary in order to evaluate wind flow over a dune or dune field, in order to aid in the interpretation of documented ripple measurements. DTMs can be used with circulation models in order to simulate possible winds for comparison to documented ripples. WindNinja is a fast and easy way to create a raster map of simulated wind directions, but can be relatively low resolution (less than 70 m is usually not recommended) and is sometimes trivial. Further work will include using WindNinja with additional DTMs of dunes with ripples, and including data from global or regional circulation models as tie points for the WindNinja simulations.

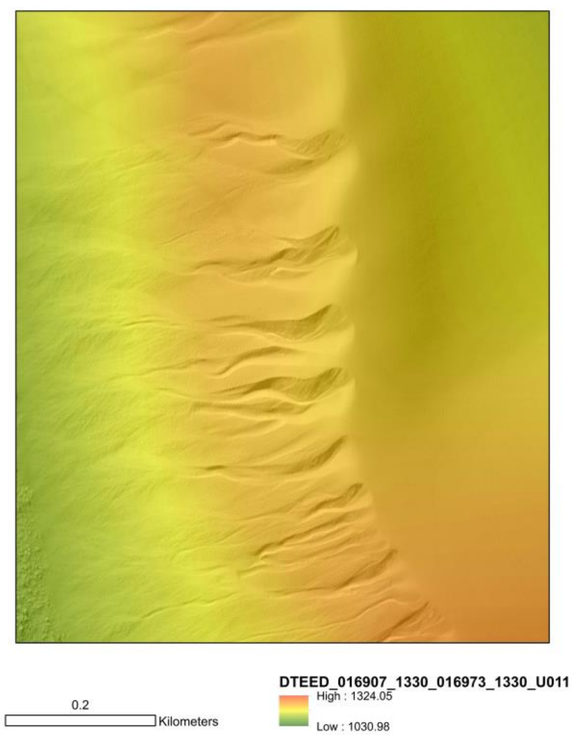

Figure 2: Small subscene of HiRISE DTM DTEED_01607_1330_16973_1330_U011 showing the dune crestline and gullies, which may affect wind flow.

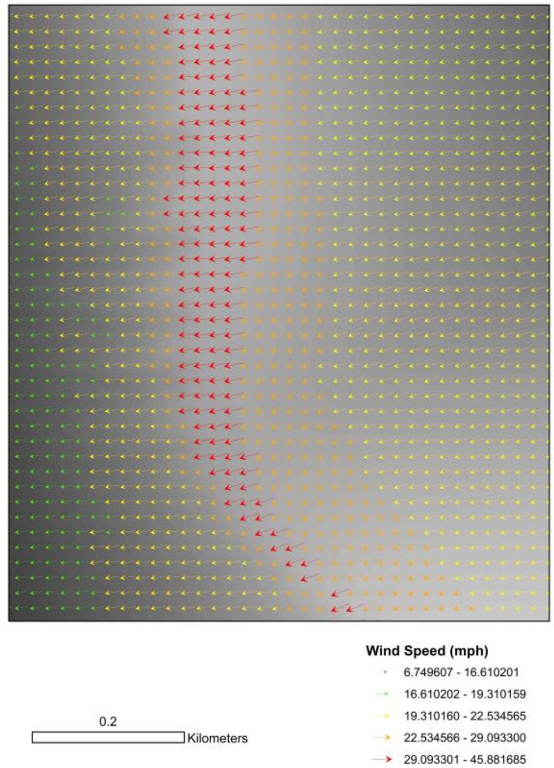

Figure 3: WindNinja output for the same subscene shown in Figure 2, using an average wind direction from 80 degrees, average wind speed of 20 mph, and wind height of 1 m above the ground. The fastest speeds are observed at the crest of the dune, consistent with likely form flow effects. The largest change in wind direction occurs where the crest changes direction.

References: [1] Neilson J. and Kocurek G. (1987) *Geol. Soc. Am. Bull., 99,* 177-186. [2] Ewing R. C. et al. (2010) *J. Geophys. Res., 115,* E8. [3] Johnson M. B. and Zimbelman J. R. (2013-2015) LPSC abstracts 2111, 1518, 1539. [4] Howard A. D. (1977) *Geol. Soc. Am. Bull., 88,* 853-856. [5] USGS (2013) *Photogrammetric Processing of Planetary Stereo Images Using ISIS3 and SOCET SET,* http://astrogeology.usgs.gov/search /details/Docs/Photogrammetry/Primer/docx. [6] Johnson M. B. and Zimbelman J. R. (2014) *Geol. Soc. of America* meeting abstract 329-11. [7] Zimbelman J. R. and Johnson M. B. (2014) *Am. Geophys. Union*, Fall meeting abstract EP43B-3564. [8] Cisneros *Am. Geophys. Union*, Fall meeting abstract EP43B-3570. [9] Cisneros J. (2015) LPSC abstract 2683.