STUDYING MARTIAN DUNE CHANGES WITH HIRISE DTMS AND ORTHOIMAGES. Sarah Mattson[1], N. T. Bridges[2], R. L. Kirk[3], E. Howington-Kraus[3], N. Mogk[1], L. Ojha[1], and the HiRISE Team. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA (smattson@pirl.lpl.arizona.edu), [2]Space Department, Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA, [3]Astrogeology Science Center, U. S. Geological Survey, Flagstaff, AZ, USA.

Introduction: Aeolian bedforms are common on Earth and Mars. On Mars, several types of dune forms have been identified [e.g. 1-3]. A current area of research is to understand the state of activity, if any, of the various types of Martian dunes. Dunes composed of relatively dark material have been observed to be active on Mars [4-7]. This fact has been shown with repeat high resolution imaging with the Mars Orbital Camera [8] that operated on Mars Global Surveyor from 1997-2006, and the High Resolution Imaging Science Experiment (HiRISE) operating onboard Mars Reconnaissance Orbiter (MRO) since 2006 [9]. Studies of dune activity with HiRISE images include gully formation, seasonal frost changes, ripple migration and sand flux [5,10-13].

The availability of HiRISE (nominal 25 cm pixel scale) time series images makes the study of Martian dune activity possible. HiRISE stereo image pairs are used to generate Digital Terrain Models (DTMs) of 1 m horizontal scale, with a vertical precision within tens of centimeters [14]. It is important to note that small ripples on dunes are not resolvable in the topography. Repeat images over an area where a DTM has been produced can be orthorectified to that DTM. Time series of these orthoimages are critical to measuring dune activity on Mars. There are many factors to consider in successfully targeting stereo over dunes, producing accurate DTMs, and orthorectifying images for change detection studies.

Targeting HiRISE stereo over dunes: HiRISE stereo images are acquired on different orbits by rolling, or slewing, MRO off-nadir for at least one of the observations. The ideal stereo viewing geometry has a convergence angle of 12º to 25º [12]. The timing of stereo acquisition over dunes should be as close as possible, as we now know that small changes can occur on relatively short time scales [7]. Additionally, changes in lighting between the first and second stereo image are more apparent in small-scale surface textural features such as dune ripples. Successful stereo targeting over dunes also requires sufficient signal-to-noise ratio (SNR), which can be challenging as the surfaces of the dunes tend to be dark and low contrast.

DTM Production: The HiRISE team primarily uses the commercial photogrammetry software SOCET Set (© BAE Systems, Inc.) for terrain extraction and orthorectification, using the processes fully described in [14]. The success of this method depends on inputting stereo images that have high SNR, good contrast, and minimal lighting differences. The surface of dark dunes pose challenges to this method in that they tend to be low contrast, smooth and dark, and also may contain brightly lit, relatively featureless slopes. Additionally, any small changes between the images, such as ripple movement and dust devil tracks, can cause the stereo matching algorithm to fail. SOCET Set provides editing tools to correct the DTM where such failures occur, providing the human operator can identify the ground surface successfully where the automated stereo matching algorithm failed. An additional preprocessing step of taking the difference of Gaussian filters of an image can bring out the ripple and dune feature edges, thereby allowing the SOCET Set stereo matcher more information to correlate to.

Editing DTMs. Improvements in the terrain extraction strategy and editing tools in SOCET Set (as of version 5.5.0) result in better success over bland areas, which cuts down on editing time. Manually editing a DTM is a time-consuming process (a HiRISE DTM contains millions of posts), so it is desirable to balance time spent editing with benefit to the end user. Therefore, editing is devoted primarily to the areas of highest scientific interest. The editing tools that are the most successful on dunes are the area editor with a snap-to-ground algorithm, the area editor using a first order interpolation algorithm, the Triangulated Irregular Network (TIN) editing tool and the geomorphic editing tool. Snap-to-ground works best where the lighting is sufficient and the surface has not changed in the stereo pair, but the stereo matcher failed, causing a large error. This tool re-runs the stereo matcher over a smaller area, isolating failed points, which may result in a much smaller error area (Fig. 1). If successful,

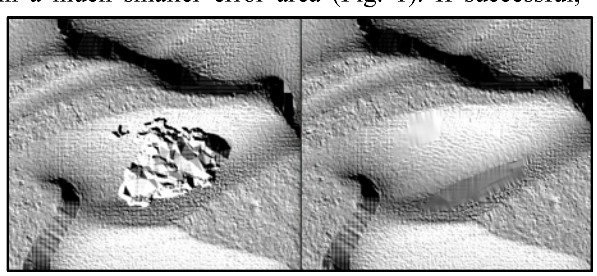

Figure 1. Example of error in the DTM and edits performed with the snap-to-ground and first order interpolation area editing tools in SOCET Set. Detail of HiRISE DTM shaded relief over Nili Patera Dunes, DTEEC_017762_1890_018039_1890_A01 [15].

elevation posts show as well-correlated, not interpolated, terrain. The first order interpolation area tool works well on planar areas, such as the steep flat sides of dunes, where shadows, or slight ripple changes have caused the stereo matcher to fail. The TIN editing tool temporarily converts a given area of the gridded terrain model to a triangulated network, allowing for a better estimation of the surface of the dune shape overall.

Figure of Merit Maps: The quality of the stereo correlation is recorded in an output product from SOCET Set called the Figure of Merit (FOM) map. This map, to be provided in the PDS released HiRISE DTM products [16] in the near future, codes each elevation post with a value indicating correlation quality, and if a post was manually edited or interpolated (Fig. 2). The FOM map is an important piece of information for understanding the quality of the model and any artifacts or errors.

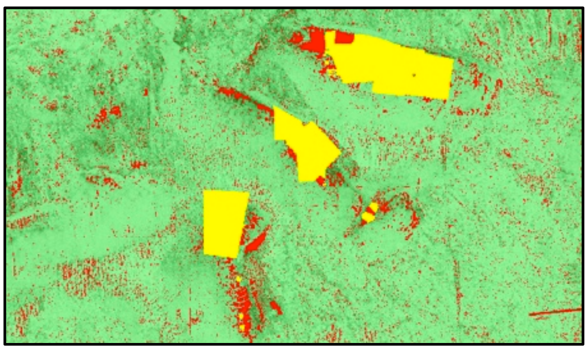

Figure 2. Detail of FOM map for a HiRISE DTM where increasing values of green indicate better correlation, red indicates poor correlation, yellow indicates manually edited or interpolated areas.

Orthoimages: Orthorectification is the reprojection of the image pixels onto the topographic model in order to produce an orthographic (overhead) view from which parallax distortions have been removed. Orthorectification removes the parallax effect caused by topographic features, given that those features are well resolved in the DTM, both horizontally and vertically. The purpose of orthorectification in this context is to facilitate comparison of small scale changes from image to image, without the confusing effects of different viewing geometry. Below the post-spacing of the DTM, parallax effects may not be removed and distortions can even be increased compared to the non-orthorectified image. To derive topography of features at these scales, photoclinometry using nadir or near-nadir images is recommended. The source stereo pair for a DTM is orthorectified at the time of production. Once the DTM is made, any other image acquired over the same area can be orthorectified. We use the same project in SOCET Set to import other images for orthorectification. There is no lighting or geometric observing constraints on such images. Significant lighting differences can make tie point measurements difficult, but the process of orthorectification is not dependent on photometric or geometric similarity of the images. Tie points are measured through all images, using the original stereo pair as a reference. The source stereo pair (which was controlled before DTM production) is held fixed, while the other images are adjusted for alignment. In the case of scenes containing dunes, tie points must be placed in areas that are non-dune material, such as the surrounding bedrock exposures, or any parts of the scene that are not moving or changing. HiRISE orthoimages are produced at two pixel scales: one matching the DTM (usu. 1 m/px), and the other at the nominal mapped full resolution of the source image (usu. 25 cm/px). All orthoimages are georeferenced with the same mapping definition as the DTM. One caveat to using orthoimages that have been rectified to a given DTM is that large changes (i.e. significant dune advancement or gully changes) in the surface will not be accurately shown. This implies that multiple stereo pairs should be acquired to produce DTMs that can effectively measure these topographic changes.

Conclusion: HiRISE DTMs and orthoimages are powerful tools for conducting change detection studies on Mars, particularly of aeolian bedforms. Improvements in DTM production are giving better results, which cuts down on the need for manual editing, although it is typically still required for portions of terrain that include dark dunes. Techniques have been developed by the HiRISE team for orthorectifying sequences of images, specifically using DTMs generated in SOCET Set. These products improve our ability to study Mars in high spatial and temporal resolution, leading to new discoveries about current active processes including dune and ripple movement.

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