MEASURING SAND FLUX AND ITS SEASONALITY FROM A TIME SERIES OF HIRISE IMAGES

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Introduction: The volumetric transport rate of sand, or flux, is a fundamental parameter that affects the rate of landscape modification through surface covering and removal, and abrasion of rocks and landforms. This is particularly the case on Mars, where aeolian processes are the dominant geomorphic agents. Measuring sand flux on Mars was previously not possible because of the lack of high spatial and temporal resolution images, and of quantitative techniques, for making displacement and accurate topographic measurements. These limitations have now been overcome because, 1) It is found that many dunes and ripples on Mars are mobile in High Resolution Imaging Science Experiment (HiRISE) images [1-4], and 2) the application of precise image registration and correlation methods permits the quantification of movement to sub-pixel precision that, when combined with topographic data, permits the derivation of reptation and saltation sand flux [5].

Here, we first measure the migration rate of sand ripples and dune lee fronts at Nili Patera, Mars over a 105 days, and derive the reptation and total fluxes. Second, the seasonal variation of the sand flux is assessed from the processing of a time-series of images spanning almost a Mars year. Third, from the extraction of two DEMs acquired 390 days apart, we measure dune migration rate. The dunes have unexpectedly high sand fluxes similar to those in Victoria Valley, Antarctica, implying that rates of landscape modification on Mars and Earth are similar.

Methods: Recent advances in image registration and correlation techniques permit the quantitative measurement of changes down to the sub-pixel level. This has been implemented in the COSI-Corr tool suite, which provides quantitative surface dynamics measurements via automatic and precise ortho-rectification, co-registration, and sub-pixel correlation of images [6]. Under a Mars Data Analysis Program effort, we have used COSI-Corr on HiRISE images, with the goal of quantifying bedform changes on Nili Patera dune field, where unambiguous ripple motion has been identified.

Four images were used in the first part of our analysis (Table 1 – 4 first rows). ESP_017762_1890 (subsequently designated *S*1) and ESP_018039_1890 (*S2*) were processed to make a stereo-derived digital elevation model (DEM). PSP_004339_1890 (*T*1) and PSP_005684_1890 (*T*2) were draped onto the DEM to make an orthorectified model. In processing orthorectified images *T*1 and *T*2 through COSI-Corr, the displacement of ripples across the entire dune field in the overlap region was computed (Figure 1). In addition, using the registered image *S*1 and comparing to *T*2, the displacement of dune lee fronts was measured.

Image ID	L_s(°)	Date Acquired	ΔDays
PSP_004339_1890	268	6/30/07	0
PSP_005684_1890	330	10/13/07	105
ESP_017762_1890	89	5/11/10	941
ESP_018039_1890	99	6/2/10	22
ESP_020729_1890	207	12/28/10	209
ESP_021652_1890	252	03/10/11	72
ESP_022364_1890	287	05/05/11	56
ESP_023076_1890	319	06/29/11	55
ESP_023353_1890	331	07/21/11	22
ESP_023564_1890	340	08/06/11	33
ESP_023920_1890	354	09/03/11	28

Table 1: HiRISE images used in the analysis

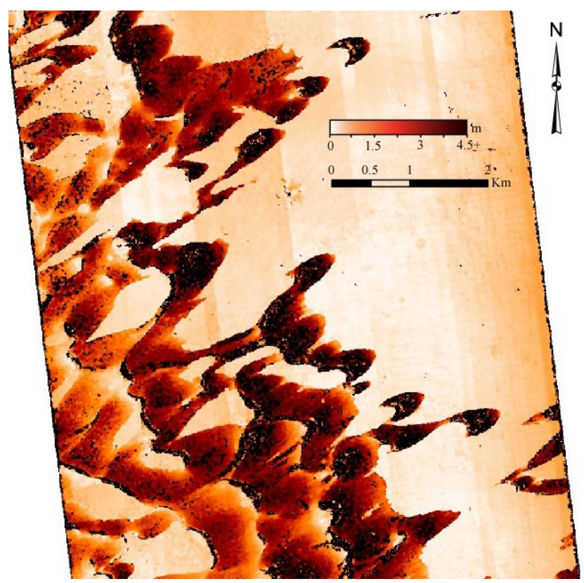

Figure 1: Map of the ripple migration amplitude over 105 days at Nili Patera. Displacement as large as 4m could be measured. The entire dune field is subject to ripple migration.

Interpretation: The ripple and dune migration rates are related, as they both reflect sand transport, and can be used to estimate sand flux [7,8]. The dune migration rates derived from lee front advancement are approximately 5 times larger than the ripple-derived rates. The higher values characterize the contribution of the saltation sand flux that is not considered in the correlation of ripples-to-dunes-derived fluxes.

Sand fluxes at the dune crests is comparable to sand fluxes for dunes in Victoria Valley, Antarctica, based on their crest heights and migration rates [9]. Terrestrial studies show that bulk and interdune sand fluxes are about 1/3 that of the crest flux [10], such that typical fluxes in Nili should be ~2.3 $m^3/m/yr$.

Seasonal variability: Once the methodology was established on the previous pair of image acquired in 2007, the same technique was applied to a time-series of eight images acquired in 2010-2011 (Table 1) which covers a period of more than 2/3 of a Mars year. The objective was to assess the variation of the ripple migration, and the associated sand flux, over time. Pairs of sequential images, *i.e.*, ESP_018039 and ESP_020729, ESP_020729 and ESP_021652, and so forth, were processed in COSI-Corr for a total of seven displacement maps obtained. Using a Principal Component Analysis (PCA) on the time-series of ripple displacement maps, the seasonal variation of the ripple migration rate was estimated. Around 65% of the variance is explained by the first component of the PCA. This rate is directly related to the sand flux as seen in the first part of this study.

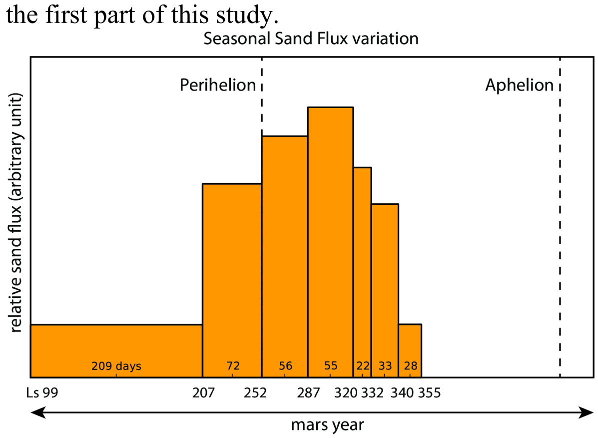

Figure 2: Relative average sand flux observed between the acquisition dates, function of the time of a mars year starting 06/02/10. A strong sand flux activity is observed around perihelion. Around 1/3 of the year cannot be measured due to absence of data.

Figure 2 represents the variability of the ripple migration rate for the seven pairs. Although we do not have a temporal coverage of a full Mars year, we clearly observe a variation of the migration rate, or sand flux, with a peak in activity that corresponds to the perihelion season. These measurements suggest that the migration rate, or sand activity, is permanent over the year, with a high activity around the perihelion season that spans ~1/3 of a year. The orientation of the ripple displacement is stable in time at ~115 degrees from the North direction (counter-clockwise), suggesting also that the wind direction is quite constant in the area, consistent with earlier studies [1,4].

Dune migration from DEM comparison: In addition to the time-series a second stereo pair of images was acquired in 2011, 390 days after the first stereo pair. The DEM extraction was operated using SOCET-SET with the same post-spacing resolution than the first DEM. The objective is to detect and measure dune migration, as opposed to ripple migration, by comparing the two DEMs. Prior to comparison, the DEMs registration, which was not precise enough out of SOCET-SET, was improved by wrapping the second DEM onto the first one using the bedrock only as a support for registration. The registration residual was estimated at around 40cm RMSE and is mostly due to residual in CCD registration and uncorrected attitudes. Once the DEMs were registered, a few topographic profiles on the dunes were extracted (Figure 3). The good registration of the bedrock and misalignment of the dunes reveal a dune migration of up to 1 meter per Earth year for the fastest dunes. An ongoing work is to automatically retrieve the full dune migration map from the DEMs.

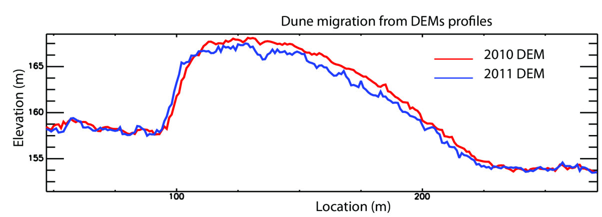

Figure 3: Comparison of dune profiles extracted from registered 1-m post-spacing DEMs that were acquired 390 days apart. A migration of about 1m can be observed in that time span.

References: [1] Silvestro, S. et al. (2010), *GRL, 37*. doi:10.1029/2010GL044743. [2] Chojnacki, et al. (2011), *JGR, 116*, doi:10.1029/2010JE003675. [3] Hansen, C.J. et al. (2011), *Science, 331,* 575-578. [4] Bridges, N.T. et al. (2012), *Geology, 40*, 31-34. [5] Bridges, N.T. et al. (2012), Nature, in press. [6] Leprince, S. et al. (2007), *IEEE Tran Geosci. Rem. Sens., 45*, 1529-1558. [7] Claudin, P. and B. Andreotti, B. (2006), *EPSL, 252*, 30-44. [8] Andreotti, B. et al. (2006), *Phy. Rev. Lett., 96*, 028001. [9] Bourke, M.C. et al. (2009), *Geomorph., 109,* 148-160. [10] Ould Ahmedou, D. et al. (2007), *JGR, 112*, doi:10.1029/2006JF000500.