Threshold for sand mobility on Mars calibrated from seasonal variations of sand flux

Francois Ayoub(1), Jean-Philippe Avouac(1), Claire Newman(2), Mark Richardson(2), Antoine Lucas(1), Sebastien Leprince(1), Nathan T. Bridges(3)

(1) California Institute of Technology, Pasadena, CA 91125

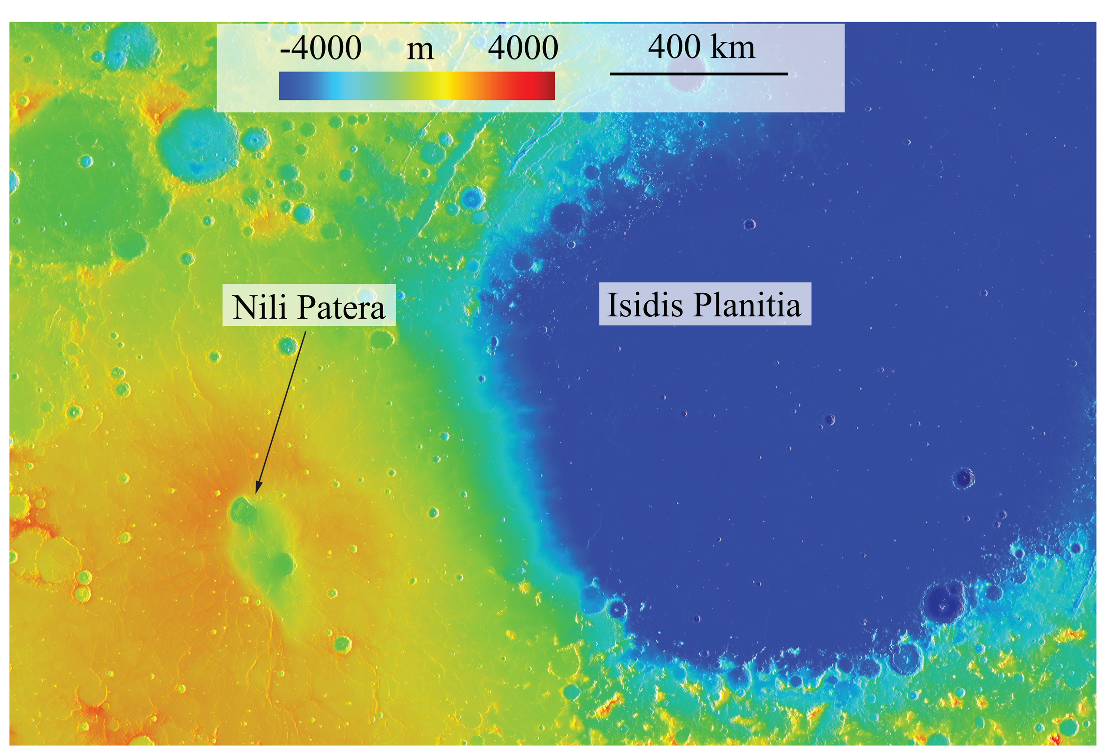
(2) Ashima Research, Pasadena, CA 91106

(3) John Hoopkins University Applied Physics Laboratory, Laurel, MD 20723

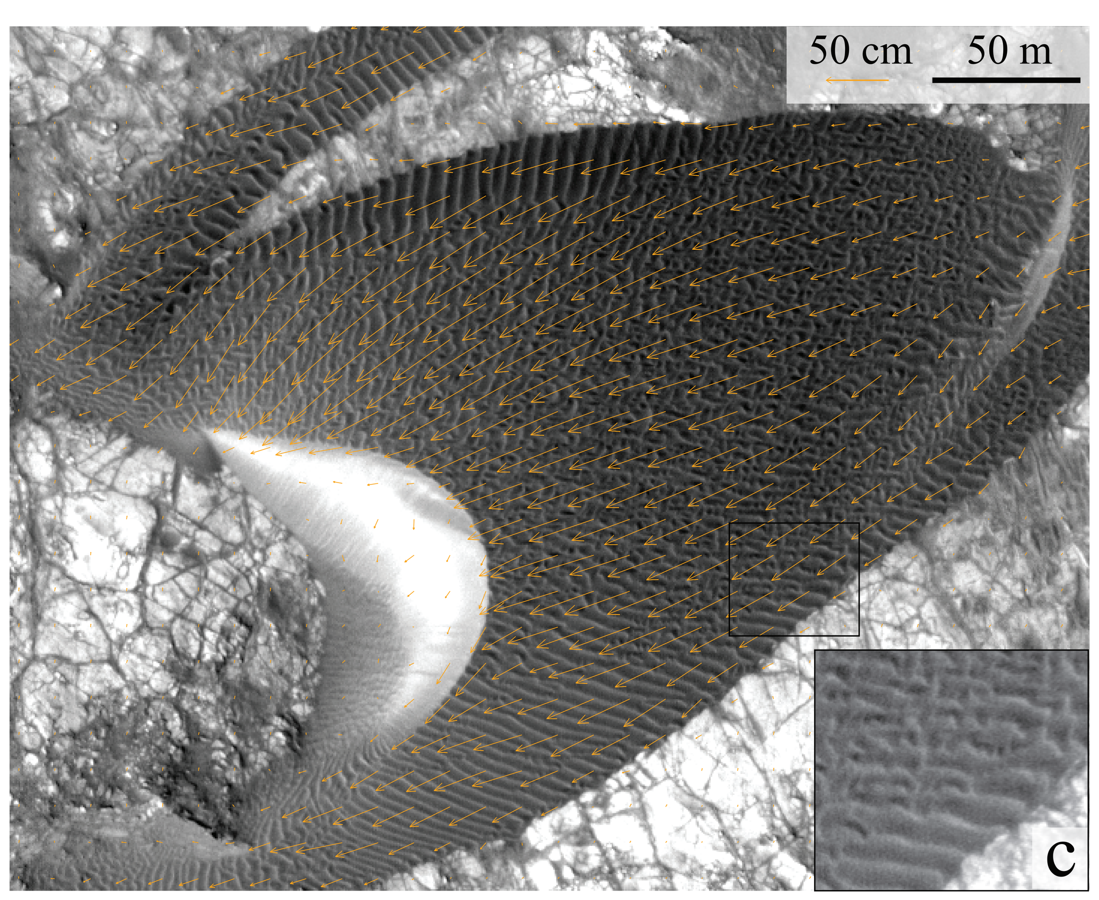
Abstract

Coupling between surface winds and saltation is a fundamental factor governing geological activity and climate on Mars. Saltation of sand is likely crucial for both erosion of the surface and for the emission of finer (dust) particles into the atmosphere. Theory and experiments suggest that winds should only rarely move sand on Mars. While wind-induced dust emission has been observed to dominate large dust storm onset, evidence for currently active dune migration has only recently accumulated. Crucially, the frequency of sand-moving events and the implied threshold wind stresses for saltation have remained unknown. Here, we present detailed measurements over Nili Patera dune field based on HiRISE images demonstrating that sand motion occurs daily throughout much of the year and that the resulting sand flux is strongly seasonal. Analysis of the distinctive seasonal variation of sand flux suggests an effective threshold for sand motion for application to large scale model wind fields of $\tau_s \sim 0.01 \pm 0.002$ N/m^2.

Data & Situation



Nili Patera dune field is located next to Idisis Planitia crater which creates diurnal winds in Nili Patera area from solar input.

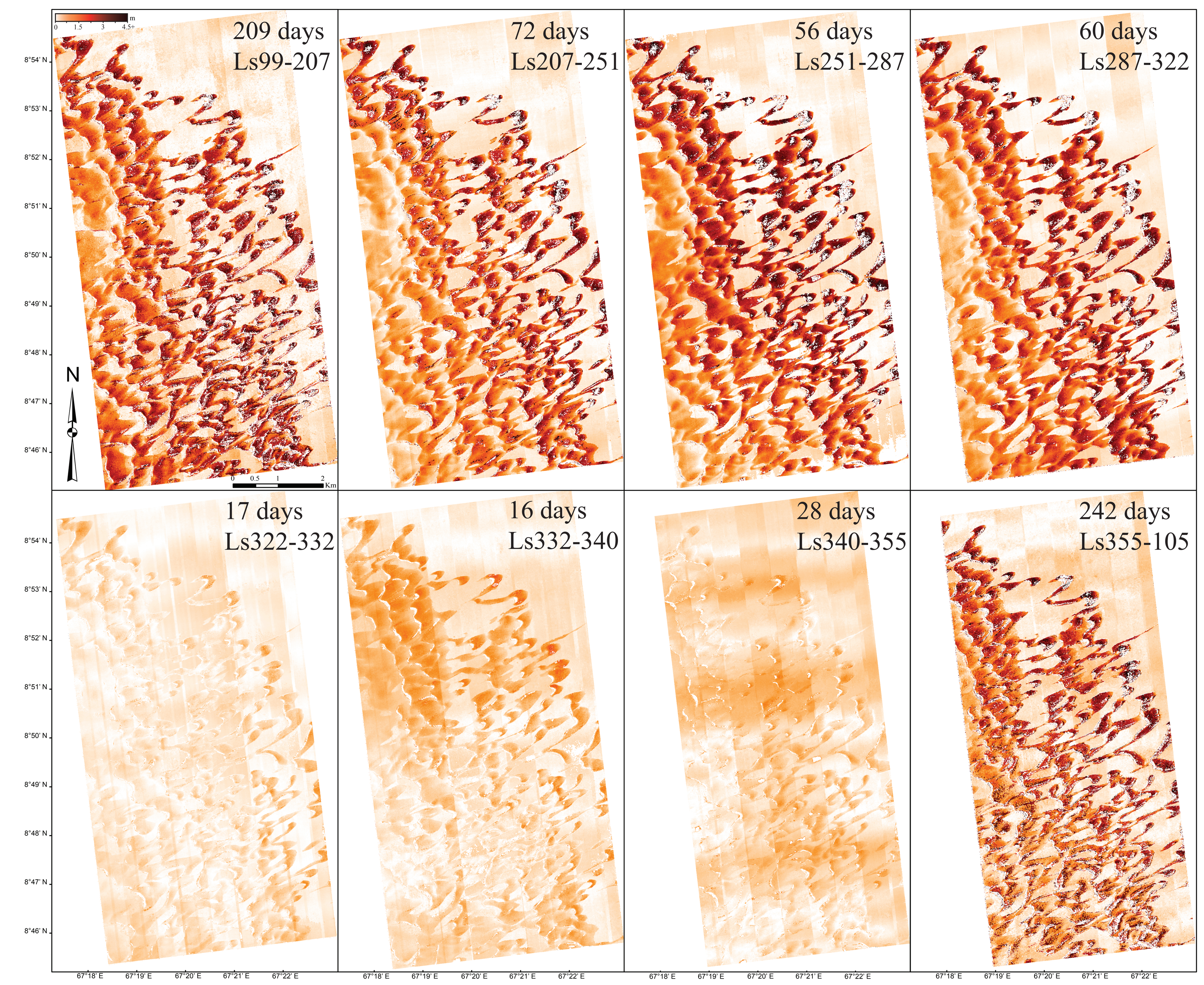


HiRISE image of a dune in Nili Patera. The inset shows the sand ripples whose displacement are measured. The vector field indicates the ripple migration direction (from displacement measurement).

ImgID	Ls	Date	Δdays	ImgID	Ls	Date	Δdays
18039	98.8	06/02/10	-	23353	331.6	07/21/11	17
20729	206.9	12/28/10	209	23564	340.4	08/06/11	16
21652	251.8	03/10/11	72	23920	354.8	09/03/11	28
22364	286.6	05/05/11	56	27032	105.0	05/02/12	242
23142	322.4	07/04/11	60				

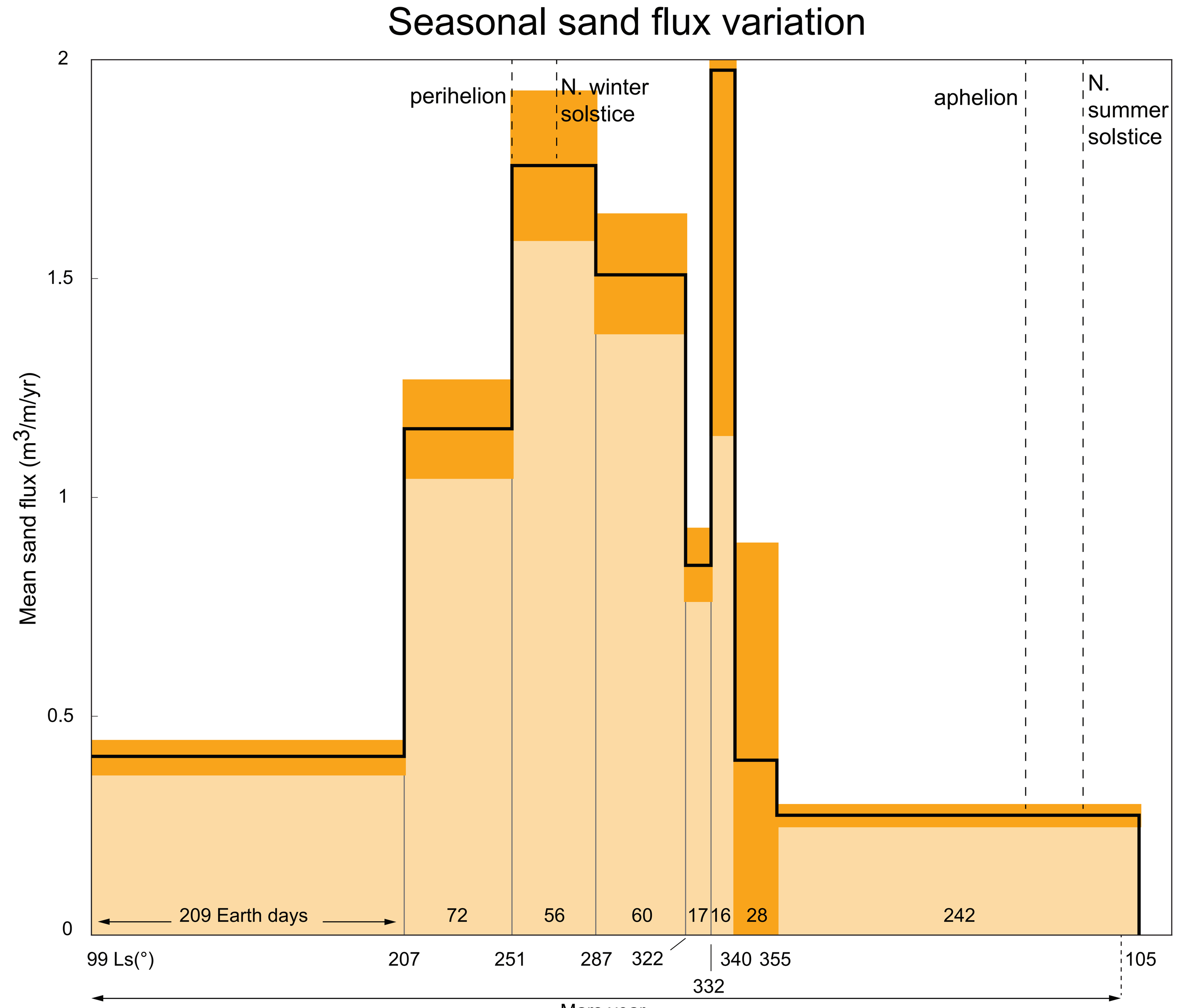
HiRISE image ID: ESP_XXXXX_1890

Data processing



Amplitude of the sand ripple displacements in the Nili Patera dune field derived from correlating eight HiRISE pairs of images acquired over a Mars year. All images were pre-processed using ISIS (USGS) to stich back the CCD stripes to provide reconstructed, distortion-free, full images. The images were then processed into COSI-Corr, i.e., 1) sub-pixel coregistration of orthorectified images on a 25 cm ground grid, 2) precise correlation of the ortho-images to extract the sand ripple migration that occured between the acquisition time. Residual of HiRISE CCD misalignment and MRO jitter can be observed.

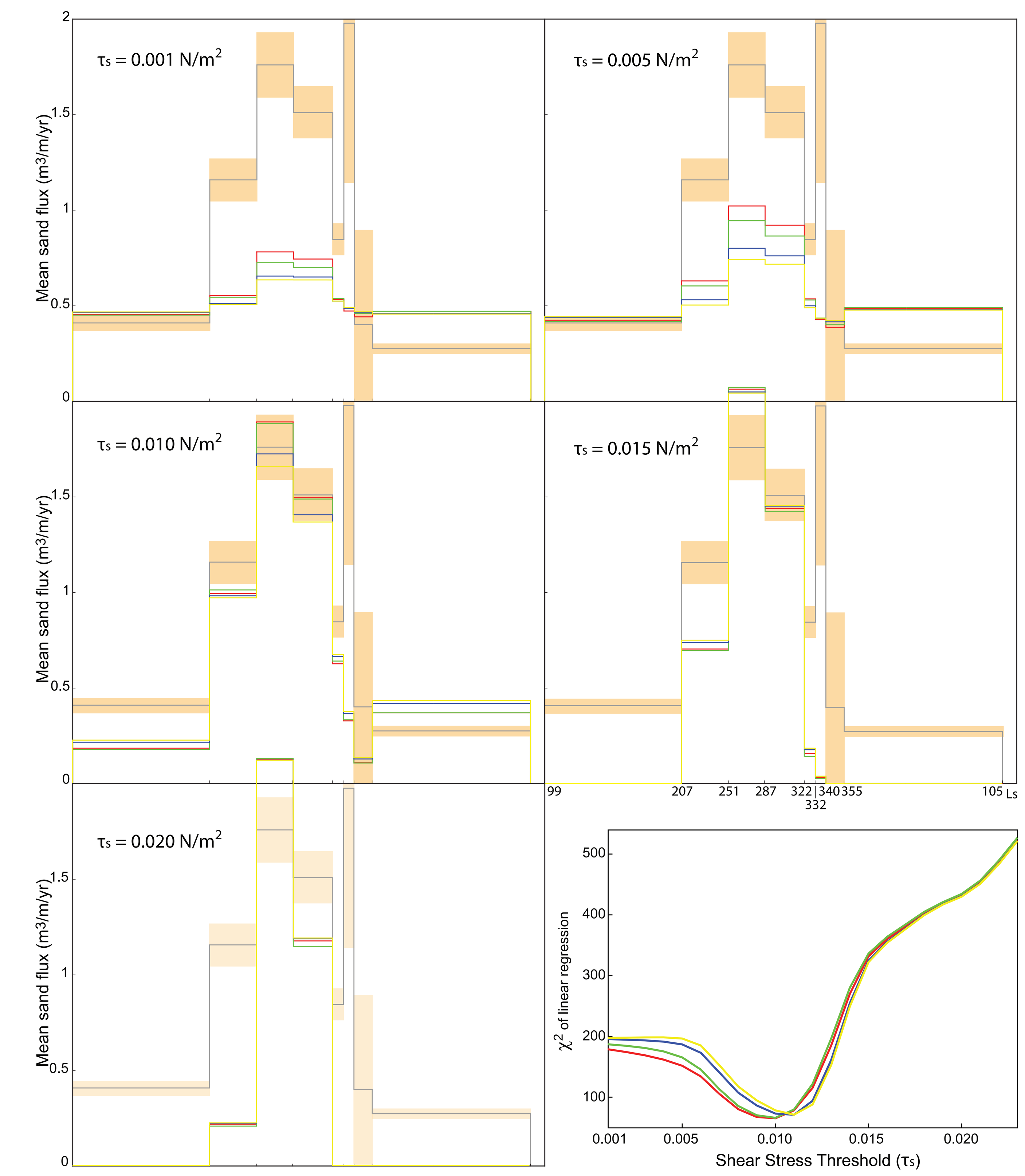
Seasonal sand flux variation



The sand flux is derived from measuring ripples migration from the correlation of HiRISE images using COSI-Corr. We estimate a mean sand flux for each period separating the dates of acquisition of two successive images (acquisition date is given in Ls along the x-axis). The sustained sand flux throughout the year, and the significant values obtained over periods of only 10 days, suggest that sand-moving winds probably occur daily. The flux is about three times larger in northern winter than in northern summer.

Coupling with atmospheric measurements

The seasonal variation of sand flux provides us with the opportunity to use the sand flux measurements to constrain an effective sediment shear stress threshold, by adjusting the stress threshold used with the GCM to predict the seasonal variation of sand flux until it matches the observed seasonal variation.



$q \propto \rho u^{*2} (u^{*2} - u_t^*)$

$q \propto \rho (u^* - u_t^*)^{1.2}$

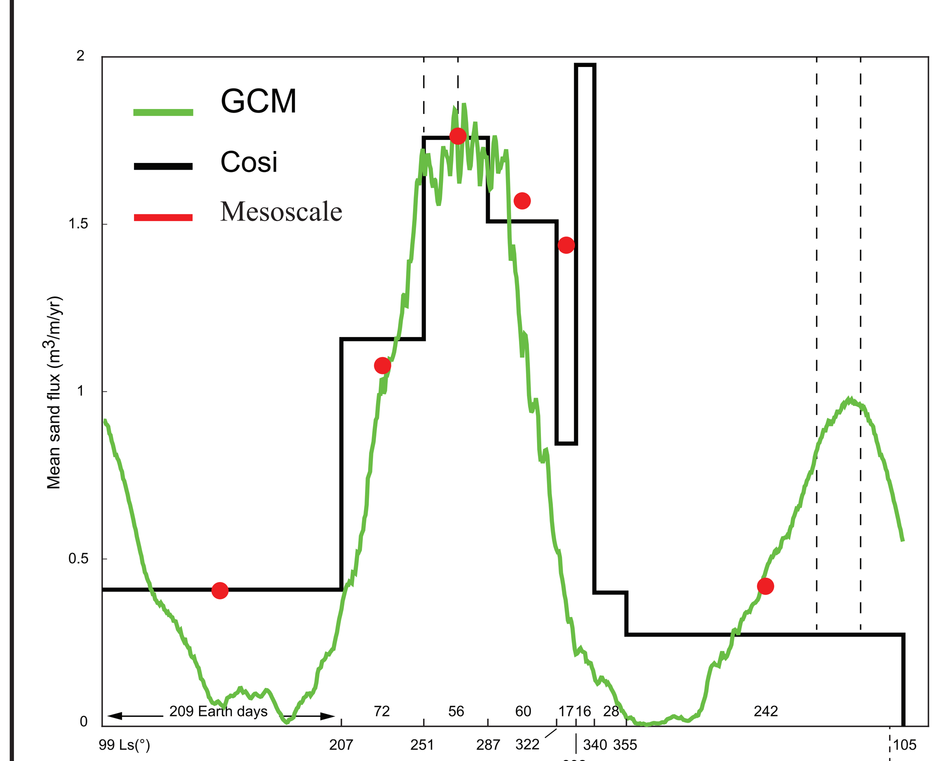
$q \propto \rho u_t^*(u^{*2} - u_t^*)$

$q \propto \rho (u^{*3} - u_t^{*2}/u^*) (\alpha + \gamma u_t^*/u^* + \beta u_t^{*2} / u^{*2})$

with ρ: air density, u^*: shear velocity, u_t^*: shear threshold velocity, stress threshold $\tau_S = \rho (u_t^*)^2$

Lettau and Lettau, 1978 (red); Werner, 1990 (green); Duran et al., 2011 (blue); Sorensen, 2004 (yellow)

Comparison of measured (gray histograms) and predicted (red/green/blue/yellow) sand flux computed for different shear stress threshold (τ_S). Shear stress thresholds from 0.0 N/m^2 to 0.024 N/m^2 with a step of 0.001 N/m^2 were tested. Only five of these tests are represented here. The predicted sand flux is computed based on the winds simulated from atmospheric circulation model (GCM - MarsWRF) and using the four transport laws (see above).The bottom right profile displays the Chi square of the linear regression between the predicted and measured sand fluxes (with the intercept forced to zero). The best linear correlation Minimum is obtained for a shear stress of 0.010-0.011 N/m^2.



Comparison of the predicted flux from the MarsWRF GCM (100 km cell grid) (green) and a mesoscale simulation (1.5 km cell grid) (red). The mesoscale was run for short periods of 8-10 days every 30 degrees (Ls). The average flux computed from the mesoscale simulation over the time span of the image pairs is displayed in red dots. Although we cannot correlate the image measurements with the mesoscale simulation as we did with the GCM (temporal sampling limitation of the mesoscale), we observe that GCM and mesoscale do agree on first order. This suggests that GCM capture most of the flow causing sediment transport, and that the shear threshold should not vary much at scale between 1-100km