Aeolian Megaripples as a Self-Organization Phenomenon: Mathematical Modeling, Field Studies and Implicatuins to Martian Megaripples . H. Yizhaq [1], Ori Isenberg[2], Rimon Wenkrat[2] and Haim Tsoar[2], [1] Solar Energy and Environmental Physics, BIDR, Ben-Gurion University, Midreshet Ben-Gurion, Israel (yiyeh@bgu.ac.il), [2] The Department of Geography and Environmental Development, Ben-Gurion University, Beer Sheva, Israel (orisenberg@gmail.com, rimon@bgu.ac.il, tsoar@bgu.ac.il).

Introduction: Aeolian sand ripples are a common feature on sandy deserts and beaches. Standard aeolian ripples have wavelengths of a 10-15 centimeters and amplitudes of few millimeters. Megaripples, which are much larger ripples, are composed of a mixture of coarse and fine grains. They are characterized by a bi-modal distribution of particle sizes, which is necessary for their formation. Megaripples are bigger in size than regular ripples.

Interestingly enough, aeolian processes are extremely important for understanding the geology of Mars [1]. Images from the Mars Global Surveyor clearly portray dust storms, dust devil traces, dunes and megaripples. Large ripple-like bedforms have been observed in numerous locations on the planet [2]. Various applications of sand ripple studies on Earth and Mars were recently reviewed by Rubin [1]. We present here results from a fieldwork of one and a half year conducted at Nahal Kasuy's mega-ripples field located in the southern Negev Desert, Israel. The Aeolian mega-ripples in Nahal Kasuy have mean wavelength of about 70 cm (Fig. 1). Regular sand ripples superposed on mega-ripples, are formed by weaker winds of a different directions. We also present a simple mathematical model which is based on Anderson's model [3]. The model with the field experiments show that the basic mechanism responsible for megaripples formation is the same as for normal ripples i.e spatial change in reptation flux. The large wavelength is due to the coarsening process. The large wavelength of megaripples reflects longer time which the patterns have been developing through interactions between smaller ripples. The megaripple system exhibits a self-organization behavior, where ordered spatio-temporal structures spontaneously emerge [4].

Field results: We present here preliminary results from our fieldwork on mega-ripples formation from a flat surface. Mean diameters of coarse and fine grains are 0.7 mm and 0.18 mm, respecteively. The time evolution of the megaripples, starting from a flat surface, was monitored. Megaripples grow due to coarsening mechanism. They start their development as regular ripples that subsequently coarsen via coalescence with other ripples. The smaller, faster-moving ripples overtake larger, slower-moving ripples, resulting in increased size and spacing (Fig. 1). The final state is analyzed by a new technique we developed, using a digital elevation model (DEM) constructed from stereo digital photographs. We also present data on the wind power (DP=drift potential) during the fieldwork and grain-size analysis of samples taken from the mega-ripple crest and trough. The grain-size characteristics are used to prove that due to the low wind power at Nahal Kasuy, only the fine particles saltate. The megaripples evolution at Nahal kasui is slow (more than one year) due to the low value of DP (50 in 2007).

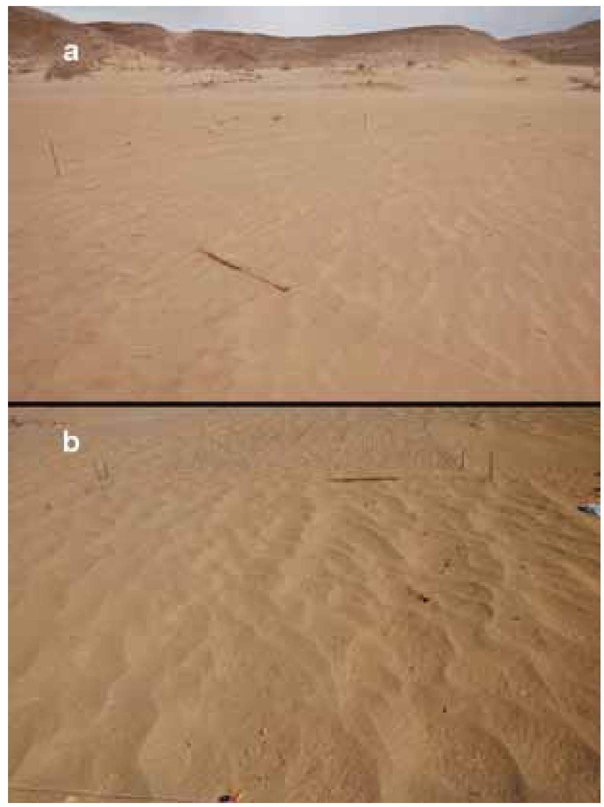

Figure 1. The plot which we had flattened on January 2007, on March 15 (a) and Februray 1st 2008 (b) . The ripples wavelength is about 15 cm in (a) (the ruler's length is 1 m) and increases to 40 cm in (b) .

Mathematical model: Here we adopt the view of ripple formation that was formalized by Anderson [3]. According to this interpretation, the only role of saltatin grains is to bring energy to the system, extracting it from the wind that blows above the sand surface which is consist of fine and coarse particles. In this view, ripple formation is entirely due to spatial chages in the reptation flux of coarse and fine particles. We build a one dimensional heuristic model of sand transport based on the Exner equation [5]:

$$(1-\lambda_p)\rho_p \frac{\partial h}{\partial t} = -\frac{\partial Q}{\partial x}, \qquad (1)$$

where $h(x,t)$ is the local height of the sand surface at point x and time t, ρ_p is the porosity of the bed, and $Q(x,t)$ is the sand flux which include both saltation and reptation flux. Here, we assume that saltation flux can be taken as constant and we do not consider it in the Exner equation. Thus, in Eq. 1 we take into account only reptation flux of fine and coarse particles, Q_{rf} and Q_{rc} repectively. The repatation flux at a certain point and time, is obtained by the sum on all the grains that are passing by that point at that time. The grains have a probability distribution of repatation lengths. Following Anderson [3] we derive the explict expressin for reptation flux on a flat surface:

$$Q_{rf}^0 = m_f n_{rf} \int_{-\infty}^{\infty} d\alpha\, p_f(\alpha) \int_{x-\alpha}^{x} N_{im}(x')dx' \qquad (2)$$

$$Q_{rc}^0 = m_c n_{rc} \int_{-\infty}^{\infty} d\alpha\, p_c(\alpha) \int_{x-\alpha}^{x} N_{im}(x')dx,$$

where the subscript f denots fine grains and c stands for coarse particles. m_f, m_c are the mass of each particle, n_{rf} and n_{cr} are the average numbers of reptating grains ejected by the impact of one saltating grain, and p_f, p_c are the probability distributions of reptating grains, taken as exponential. Because saltation flux is uniform, and the fixed angle ϕ at which the grains descend back to the ground is assumed to be constant, the number density of impacting grains change only because of varations in bed slope. Baesd on geometrical considerations, we obtain,

$$N_{im}(x) = N_{im}^0 \frac{1+h_x \cot\phi}{\sqrt{1+h_x^2}}, \qquad (3)$$

where h_x is the local slope and N_{im}^0 is the number density of impacting grains on a flat surface. We further modify Eq. (2) to take into account correction of the reptation length on inclined plane [5]. This correction leads to a mean repatation length that is shorter on the windward slope and longer on the leeward slope of the bedform. The full model can be written as:

$$h_t = -Q_0 \partial_x \left[(1-\mu_f) Q_{rf}^0 + \delta(1-\mu_c) Q_{rc}^0 \right] \qquad (4)$$

where the parameters μ_f and μ_c heuristically includes the correction to reptation flux discussed above, $Q_0 = m_f N_{im}^0 \cot\phi / \rho_b (1-\lambda_p)$ and $\delta = m_c / m_f = (D_c / D_f)^3$. According to Bagnold [6] a saltation grain can sustain a forward movement of a coarse grain with a diameter 3-7 times larger than its own diameter thus, $27 \le \delta \le 343$.

Fig.2 shows numerical solutions of the model equations (Eqs. 2-4). The smaller, faster-moving ripples overtake larger, slower-moving ripples, resulting in increased size and spacing. Merging can be viewed as a selection process leading to the production of bedforms with similar-sized ripples

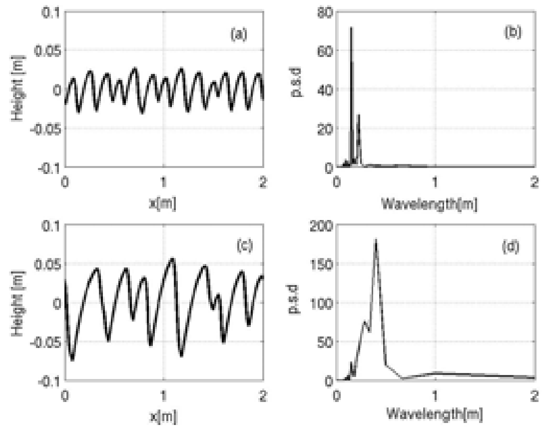

Figure 2. Numerical soutions of the model equation at intial times (a) 0.5 minute, (c) 3 minutes and the corresponding power spectrum density (subplots b and d). After two minutes the average wavelength increased from 15.38 to 40 cm. The mean reptation lengths of the coarse and fine grains were 5 cm and 1.5 cm respectively.

Disscusion: Field experiments conducted at Nahal Kasuy dunes field located at the southeren Negev in Israel, show that megaripples start as normal ripples and grow due to rapid coarsening process. Their evolution is a function of DP (drift potential) and the wind direction variability. Storms can inject new defects to the system by breaking existing megaripples crest and change their dirction. The mathematical model we developed can be used to describe Martian megaripples once the diameter ratio between coarse and fine particles and the number density of impact grains and the average repataion lengths are known.

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