ROUGHNESS HEIGHT MEASUREMENTS FOR MEGARIPPLES IN THE PUNA OF ARGENTINA, FORM FLOW OVER THE LARGEST MEGARIPPLES, AND IMPLICATIONS FOR MARS.

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Introduction: Gravel-coated megaripples in the Puna of northwestern Argentina [1, 2] have been investigated as part of a Mars Fundamental Research Program grant [2]. One component of the project was to determine the aerodynamic roughness height (z_0) of these large aeolian bedforms. Here we present results derived from wind profile measurements at four locations within the Puna study area [2], obtained during field studies conducted in December 2010 and November 2013. The results provide a good estimate of z_0 for large megaripples, as well as demonstrating that the features are large enough so that form flow [3,4] affects the logarithmic wind profile that is presumed in most aeolian studies [3], a situation that could also be applicable to some Mars aeolian studies.

Methodology: Wind profile data were collected using three logarithmically spaced recording anemometers mounted on a portable pole (Fig. 1). A logarithmic least-squares fit to the wind profiles (r^2) gives z_0, the height above the surface at which the wind velocity is zero (Table 1). Wth z_0 and the wind speed at a known height, the wind speed at any other height should be calculated using the traditional 'Law of the Wall' logarithmic relationship [3, but see Discussion]. The rightmost column in Table 1 lists the measured wind speed for the highest anemometer in each profile, along with the height of that anemometer; anemometer height remains the same for following entries in the table until a new height is given. Most wind profile data were collected during two-minute intervals, except as noted. The anemometers recorded the maximum, average, and minimum wind speeds during each interval, but the minimum values gave the most unreliable results and are not reported here. Table 1 also indicates where the anemometer tower was located along a cross-section of the megaripples, and how the wind was blowing relative to the orientation of the crest lines of the bedforms.

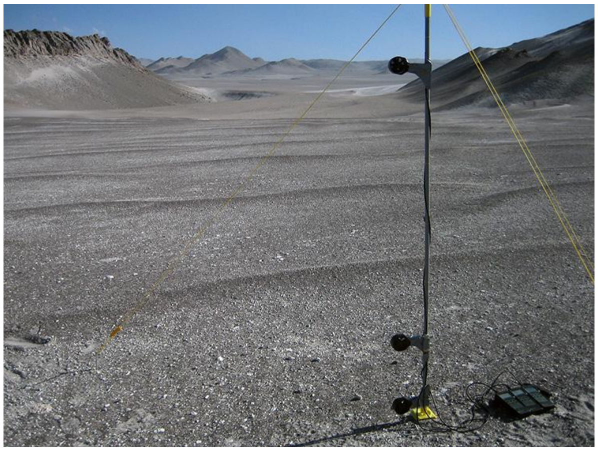


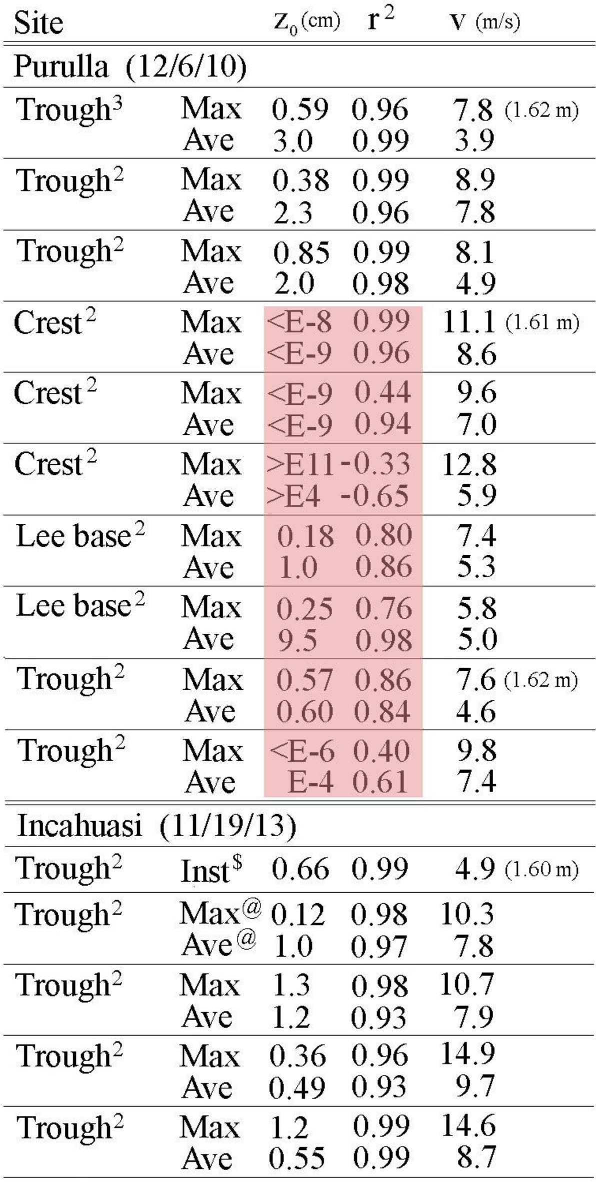
Figure 1. Wind profiling set-up used for all data reported here. This view is looking upwind at the White Barchan study site [2] (JRZ, 12/5/10).

Table 1. Roughness height (z_0) derived from wind profile measurements at the Campo Piedra Pomez (CPP) and White Barchan sites [see Fig. 1 of 2]. Wind was nearly along the megaripple crest lines at CPP.

Site		z_0 (cm)	r^2	V (m/s)
CPP (12/5/10)				
Trough[1]	Max	1.8	0.95	18.4 (1.59 m)
	Ave	1.9	0.93	15.9
Trough[1]	Max	2.1	0.95	18.4
	Ave	1.7	0.93	14.5
Stoss base[1]	Max	2.9	0.97	18.2
	Ave	3.3	0.97	16.6
Stoss base[1]	Max	3.8	0.98	16.2
	Ave	3.7	0.98	12.6
Crest[1]	Max	0.82	0.93	24.6
	Ave	0.13	0.91	23.4
Crest[1]	Max	0.49	0.93	24.7
	Ave	0.60	0.94	16.5
Trough[1]	Max	1.4	0.97	17.8
	Ave	0.94	0.99	12.8
Trough[1]	Max	1.2	0.99	15.6
	Ave	1.4	0.98	13.7
White Barchan (12/5/10)				
Trough[2]	Max	1.6	0.97	13.7 (1.60 m)
	Ave	2.1	0.96	11.8
Trough[2]	Max	3.1	0.95	12.7
	Ave	3.0	0.94	9.8
Trough[2]	Max*	0.34	0.98	13.1
	Ave*	1.1	0.98	6.8

[1] Wind from 15° along crest line.
[2] Wind perpendicular to crest line.
*22 min average.

Table 1, cont. Roughness height (z_0) derived from wind profile measurements at the Campo Purulla and Salar de Incahuasi sites [see Fig. 1 of 2]. Red figures are strongly affected by form flow.



Site		z_0 (cm)	r^2	v (m/s)	
Purulla (12/6/10)					
Trough^3	Max	0.59	0.96	7.8	(1.62 m)
	Ave	3.0	0.99	3.9	
Trough^2	Max	0.38	0.99	8.9	
	Ave	2.3	0.96	7.8	
Trough^2	Max	0.85	0.99	8.1	
	Ave	2.0	0.98	4.9	
Crest^2	Max	<E-8	0.99	11.1	(1.61 m)
	Ave	<E-9	0.96	8.6	
Crest^2	Max	<E-9	0.44	9.6	
	Ave	<E-9	0.94	7.0	
Crest^2	Max	>E11	-0.33	12.8	
	Ave	>E4	-0.65	5.9	
Lee base^2	Max	0.18	0.80	7.4	
	Ave	1.0	0.86	5.3	
Lee base^2	Max	0.25	0.76	5.8	
	Ave	9.5	0.98	5.0	
Trough^2	Max	0.57	0.86	7.6	(1.62 m)
	Ave	0.60	0.84	4.6	
Trough^2	Max	<E-6	0.40	9.8	
	Ave	E-4	0.61	7.4	
Incahuasi (11/19/13)					
Trough^2	Inst$^\$$	0.66	0.99	4.9	(1.60 m)
Trough^2	Max$^@$	0.12	0.98	10.3	
	Ave$^@$	1.0	0.97	7.8	
Trough^2	Max	1.3	0.98	10.7	
	Ave	1.2	0.93	7.9	
Trough^2	Max	0.36	0.96	14.9	
	Ave	0.49	0.93	9.7	
Trough^2	Max	1.2	0.99	14.6	
	Ave	0.55	0.99	8.7	

^{2}Wind perpendicular to crest line.
^{3}Wind from 20° along crest line.
$^\$$Instantaneous measurement.
$^@$1 min average.

Discussion: Results indicate that the precise orientation of the wind, relative to the bedform, is not as critical as may have been presumed. z_0 results for CPP (1-3 cm), where the wind was nearly parallel to the crests of 70-cm-high megaripples, are generally consistent with z_0 results from other sites, where the wind was perpendicular to the crests. Even more instructive, z_0 values were quite consistent when the wind changed direction by ~70° within several minutes (first two entries for Purulla). The 10-cm-high granule ripples at the White Barchan site (Fig. 1) have roughly the same z_0 values as at other sites. The 1-m-high megaripples at the Purulla site (Fig. 2) are large enough so that form flow [3, 4] occurred, which caused calculated z_0 values to vary wildly (red figures in Table 1) because the bedform shape made the wind velocity profiles to no longer be logarithmic. Once the potential influence of form flow for large megaripples was recognized (following the 2010 trip), reasonable z_0 values were subsequently obtained for 1-m-high megaripples at Salar de Incahuasi when the wind tower was located in a ripple trough, well removed from the zone of flow separation [3] induced by these large aeolian bedforms.

Figure 2. Wind profiling station on crest of megaripple at Campo Purulla [2]; this site showed the strongest form flow effects. (JRZ, 12/6/10).

Implications for Mars: The Puna megaripples apparently are large enough to induce form flow, so that the possibility of form flow also should be considered for m-high aeolian bedforms on Mars, such as some Transverse Aeolian Ridges (TARs) [5, 6].

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