

# WHAT'S $z_0$ GOT TO DO WITH IT? COLLECTING WIND PROFILING DATA IN THE FIELD. J. R. Zimbelman, CEPS/NASM, Smithsonian Institution, Washington, D.C. 20013-7012, zimbelmanj@si.edu

**Introduction:** With apologies to Tina Turner, the title encapsulates the goal of efforts to collect wind profiling data in the field to determine  $z_0$ , the height at which a logarithmic wind speed profile is zero. During review of a 2016 paper, the crucial paper by Wieringa [1] was brought to my attention, which describes conditions to be considered when collecting and interpreting wind profile data to derive  $z_0$ .

**Background:** Bagnold [2, pg 47-49] said that wind data plotted as (linear) velocity versus (logarithmic) height project to a common height of zero velocity for multiple wind speeds. Bagnold also said that Prandtl related the height of the focus point (on a semi-log plot) to the roughness over which the wind is moving; the height of the zero-velocity point is 1/30 times the diameter of the roughness elements [2, pg 50]. The logarithmic relationship between height and velocity is called the Prandtl-von Karman equation, or 'the Law of the Wall' [3, pg 44]. Wind profiling data can be used to constrain aerodynamic roughness height ( $z_0$ ) by paying attention to factors that can limit the usefulness of the wind data [1]. Wieringa [1] describes several conditions that affect the usefulness of wind profile data (see Methodology section), and also makes this important statement: The popular saying " $z_0$  is the height at which the wind speed becomes zero" is true in a purely algebraic sense only, since it implies extrapolation of the equation (logarithmic fit) below its limit of validity [3, pg 325].

**Methodology:** Measurements are collected using a portable tower ~2.3 m in height with anemometers spaced logarithmically along its height. Early attempts to determine  $z_0$  used three anemometers that provided average and maximum wind speeds over a specified time interval ([4] and Table 1). Beginning in 2014, three recording anemometers allowed selection of the time interval during which meaningful average wind speeds were calculated. After 2016, five recording anemometers were used while also following the recommendations of Wieringa [1]: the lowest anemometer height was >20X the anticipated  $z_0$  for the area, the tower was sited at a distance downwind of the nearest obstacle that was >15X the obstacle height, the fetch upwind of the tower had consistent roughness elements for >80 m, and times near sunrise or sunset were avoided. Results using 5-anemometer towers during a 2018 trip to the Puna of Argentina are reported in two LPSC posters [5, 6]. A least-squares logarithmic fit was applied to the average wind speeds during each selected time interval. Fits were

considered useful if the correlation coefficient ( $r^2$ ) was  $\geq 0.90$ . The least-squares fit was then used to calculate the height at which the wind speed became zero ( $z_0$ ).

**Results:** Several aeolian environments were investigated using a three-anemometer tower array (Table 1). Influenced primarily by Bagnold's

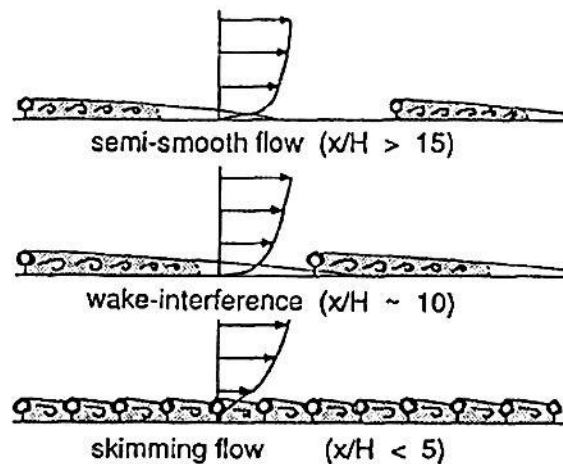
**Table 1.** Aerodynamic roughness height  $z_0$  and correlation coefficient  $r^2$  using 3 anemometers (duration in parentheses).

	$z_0$ (cm)	$r^2$
<b>Simpson Desert Dunes</b>	<b>8/27/02</b>	
Interdune-ave (20s)	4.2	0.99
Interdune-max (20s)	2.7	0.99
Interdune-ave (60s)	5.9	0.99
Interdune-max (60s)	5.8	0.99
Crest-ave (30s)	2.3	0.96
Crest-max (30s)	1.5	0.99
Crest-ave (3 min)	4.4	0.99
Crest-max (3 min)	2.3	0.97
<b>Killpecker Dunes</b>	<b>7/12/06</b>	
Sand flat-ave (1 min)	0.04	0.99
Sand flat-max (1 min)	0.01	0.99
Sand flat-ave (3 min)	0.06	0.93
Sand flat-max (3 min)	0.009	0.84
Grass-ave (3min)	4.5	0.94
Grass-max (3min)	3.6	0.99
<b>Kau Desert</b>	<b>8/16/09</b>	
Sand-a'a'-ave (2 min)	0.32	0.98
Sand-a'a'-max (2 min)	0.89	0.96
Sand-ave (7min)	0.09	0.88
Sand-max (7min)	0.005	0.99
<b>Great Sand Dunes</b>	<b>6/11/14</b>	
Megaripples (5min)	1.5	0.99
Megaripples (30min)	2.7	0.97
<b>Grand Falls</b>	<b>6/25/14</b>	
Vegetated desert (8min)	3.2	0.99
Sand-granules (9min)	0.9	0.89

statement that two wind measurements at different heights allows the average surface particle size to be determined from  $z_0$  obtained from a semi-log plot [2, pg 50], three anemometers initially were considered to provide sufficient redundancy and an assessment of the quality of the fit to the wind data. Experience in the field quickly revealed that obtaining good wind profile data was anything but straight-forward. Early results identified three broad categories of surface roughness: sand sheets ( $z_0 < 0.05$  cm), sand-granule megaripple fields ( $z_0$  1-3 cm), and grass/vegetated surfaces ( $z_0$  2-6 cm). Results from mixtures of these types tend toward

the most spatially abundant surface type. Expansion to five anemometers for gravel-covered megaripple fields in the Puna of Argentina improved confidence in the quality of the logarithmic fits but (surprisingly) did not alter the general result that large aeolian bedforms tend to have  $z_0$  of 1 to 4 cm [4-7].

**Discussion:** Weirunga [1] defines three flow types for wind blowing over surface roughness elements (Fig. 1). Sand and granule-gravel-covered surfaces are



**Figure 1.** Flow categories over terrain obstacles, from Fig 1 of Wieringa [1].  $H$  is the height of a roughness element and  $x$  is the distance between obstacles.

consistent with ‘skimming flow’, which occurs ‘when the surface is so closely covered with obstacles that flow in the spaces between obstacles has a regime quite separate from the bulk flow above’ [1]. In this situation, roughness height is less a result of the size of the individual particles than it is the cumulative effect from many closely spaced particles. As the scale of bedforms like large ripples or megaripples increases, wind flow over the bedforms may locally increase  $z_0$ , but results thus far indicate this does not appear to produce a dramatic increase in  $z_0$  if the tower is well outside of the ‘wake’ region downwind of obstacles (avoid locations with ‘wake-interference flow’, Fig. 1). The most useful wind profiling data comes from settings with a ‘semi-smooth flow’ regime (Fig. 1), where obstacle spacing is more than fifteen times the height of the obstacles. Since it is unclear how the atmosphere behaves among closely spaced surface particles, use caution in inferring the average particle size to be 30 times the value of  $z_0$ . The above should also be considered when planning to collect wind speed data using future spacecraft; caution is required in order to avoid spacecraft components from seriously compromising the potential use of wind measurements for possible wind profiling and  $z_0$  analysis.

It is instructive to consider how changes to the two coefficients of a least-squares logarithmic fit affect the extrapolated wind above the surface. Using a fit like the one obtained from a 2.5-hour measuring session in the Puna of Argentina [6], a 40% decrease in the first coefficient causes a 26% increase in  $z_0$  with <5% decrease in the wind speed at 5 m height. A 40% increase in the first coefficient causes a 31% decrease in  $z_0$  with <5% increase in wind speed at 5 m. A 20% increase to the second coefficient causes an 11% decrease in  $z_0$  with a 27% increase in wind speed at 5 m. A 20% decrease in the second coefficient produces a 21% increase in  $z_0$  with a 29% decrease in wind speed at 5 m. Thus, a small change in  $z_0$  translates to an even smaller change in the calculated wind speed at moderate (5 m) height; this should be kept in mind by modelers who use  $z_0$  to estimate wind speeds at large heights above the surface. The fit is always best between the lowest and highest anemometer heights, and the fit decreases in accuracy both toward  $z_0$  and above twice the highest anemometer height.

**Conclusions:** Three broad categories of surface roughness have the following ‘typical’  $z_0$  values: sand sheets ( $z_0 < 0.05$  cm), sand-granule-gravel megaripple fields ( $z_0$  1-3 cm), and grass/vegetated surfaces both on and between stabilized dunes ( $z_0$  2-6 cm). Mixtures of these three types tend toward the most spatially abundant surface type. Use logarithmic profile fits with appropriate caution.

**References:** [1] Wieringa J. (1993) *Bound. Layer Meteorol.*, 63, 323-363. [2] Bagnold, R. A. (1941). *The Physics of Blown Sand and Desert Dunes*. Chapman and Hall, London. [3] Lorenz, R. D. and J. R. Zimbelman (2014) *Dune Worlds: How Windblown Sand Shapes Planetary Surfaces*. Springer/Praxis, New York. [4] Zimbelman J. R. et al. (2016) *Icarus*, 266, 306-314, doi: 10.1016/j.icarus. 2015.11.08. [5] Zimbelman J. R. et al. (2019) *LPS L*, Abstract #1207. [6] Zimbelman J. R. et al. (2022) *LPS LIII*, Abstract #1502. [7] de Silva S. L. et al. (2013) *GSA Bull.*, 125, (#11/12), 1912-1929; doi: 10.1130/ B30916.1.