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Estimating aeolian sand-drift potential for hazard mitigation

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SUMMARY:
Sand drift threatens human and environmental resources across a broad range of scales. We summarize the nature of threats at three scales, describe methods and data needed to estimate sand drift, and discuss aspects of the threats and general mitigation methods. The threats include those from saltation, channelized sand drift, and dune migration, ranging in scales from short- to long-term hazards.

Keywords: Saltation, streamers, dune migration

1. INTRODUCTION

Aeolian sand drift poses a substantial threat to many natural and human systems, especially in arid or coastal environments. These threats manifest across a suite of time and space scales, constraining optimal mitigation strategies. We review samples of threats that occur at a range of overlapping time and space scales and that are amenable to potential management. At the shortest time scales (seconds to days) and smallest spatial scales (millimeters to meters), threats from saltation are discussed with methods for measuring and estimating sand drift. At scales of meters to kilometers and minutes to weeks, threats and characteristics of a form of sand streamers are discussed. At the largest scale is dune migration. Methods for estimating migration rates are summarized.

2. SALTATION

Most wind-blown sand moves as saltation, a form of bedload transport, in which individual grains move across a surface in a series of discrete hops (Fig. 1). This is the elemental mode of sand drift and the other modes of sand drift hazard described herein rely first on saltation (c.f. recent reviews by Baas, 2019: and Sherman and Ellis, 2022). Saltation is concentrated near the bed, decreasing rapidly with elevation (Fig. 1). The saltation has been studied for most of a century and it has been generally accepted that the transport rate, q, is proportional to the third power of shear velocity, u_* (e.g., Bagnold, 1937; or Lettau and Lettau, 1978). Such models assume idealized transport conditions and their ability to predict sand drift in natural environments has been modest. The Lettau and Lettau (1978) model, Eq. (1), has been shown to perform at least modestly better than others (Sherman et al., 2013):

$$q = C\left(\frac{\rho}{g}\right)u_*^2(u_* - u_{*t}) \tag{1}$$

where C is an empirical constant, ρ is the air density, g is the gravity constant, and u_{*t} is threshold shear velocity.

Complicating factors that distinguish natural environments from idealized ones include sediment moisture content, uncertainty estimating u_{*t}, bed slope effects and other morphological variabilities, and vegetation effects. Multiple, individual corrective factors have been included with a u_*^3 equation. A comprehensive version is that of van Rijn and Strypsteen (2020):

$$q = \alpha_B \alpha_{ad} \alpha_{shell}\left(\frac{d_{50}}{d_{ref}}\right)^{0.5}\frac{\rho}{g}(u_*^3 - u_{*t}^3) \tag{2}$$

where the terms in α are corrective factors, B is an empirical constant (assumed to be 2), ad is the effective fetch length, $shell$ quantifies the effects of surface shell coverage (mainly for coastal environments), d_{50} is median grain size, and d_{ref} is a reference grain size, usually 0.25 mm. Moisture effects are subsumed in the u_{*t} estimate.

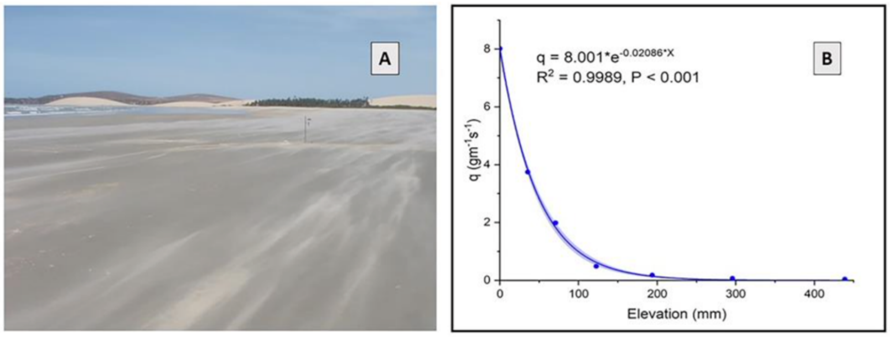

Figure 1. (A) Saltating grains are often organized into quasi-coherent aeolian streamers, especially on relatively flat surfaces. (B) Typical vertical profile of saltation flux, showing exponential decay away from the surface and the bulk of saltation occurring within about 100 mm of the surface, where abrasion and fouling hazards are most likely to occur. The blue banding encompasses the 95% confidence interval.

Theoretical treatments of saltation suggest further complications. Ralaiarisoa et al. (2020) argue, for example, that the power of the shear velocity relationship changes with transport intensity. For shear velocities near the threshold, transport is proportional to u_*^2. When $u_* \gg u_{*t}$, the relationship depends on u_*^4. Only at intermediate transport rates is the u_*^3 function applicable. This has not been verified through field observations. The challenges for the application of these approaches to estimating saltation include the necessity of having better models for, especially, the effects of moisture and the threshold of motion. The models also require robust estimates of grain size populations and shear velocity. These data typically stem from *in situ* measurements or a detailed understanding of local conditions and meteorological forcing. The immediate hazards associated with saltation include fouling equipment with sand (e.g., Bruno et al, 2018), abrasive scouring (Han et al., 2014), and the generation of dust (Alfaro et al., 2022). Mitigation methods include the stabilization of sand surfaces with vegetation or soil cement, avoidance of hazardous environments, and engineering solutions for fouling and abrasion of susceptible machinery, instruments, and surfaces.

3. CHANNELIZED SAND STREAMERS

In the context of mesoscale threats, we consider sand streamers that are channelized along preferential pathways (Fig. 2A). This is in contrast to the spatially random organization of saltation as depicted in Fig. 1A. Channelization of streamers is usually along 'streets' between vegetation such as dune grasses (Delgado-Fernandez, 2010) or shrubs (Gillette et al., 2006). Similar corridors may be formed in landform gaps or depressions (Nguyen et al., 2022). Sand drift through these corridors greatly exceeds transport rates through the inter-corridor spaces. The streets typically align with dominant transporting winds, which are accelerated through the gaps and slowed through the (for example) vegetated ridges. Sand drift is also increased in the streets relative to the ridges because of the faster wind speeds and because sand moving along the ridges will be preferentially directed into the troughs because of the effect of the downslope component of gravity on bedload paths. Where the transport corridors intersect resources, aeolian processes such as erosion, abrasion, scour, or deposition are amplified relative to expectations for an unobstructed surface.

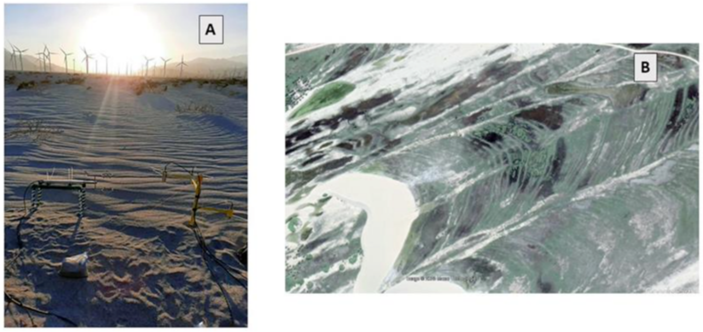

Figure 2. (A) A vegetation-constrained saltation corridor near Palm Springs, USA. (B) Annual barchan migration 'tracks' near Bitupita, Brazil.

Sand drift along corridors poses acute and chronic risks. Acute threats arise from individual saltation events, as described above, with the added complication of the large degree of spatial variability of the hazard. A data-driven approach to estimating chronic aspects of this hazard, morphological/vegetation maps displaying the location of potential drift streets would allow recognition of specific risk locations. Complementary climate data would allow estimations of potential sand drift in the area of concern. In this case, a drift potential calculation in vector units, Q, would be useful (Fryberger, 1978): $Q = V^2(V - V_t)t$, where V is wind speed, V_t is the threshold wind speed, and t is the percentage time that wind blows from a particular direction. Values of t can be estimated for a range of periods, for example, a yearly, seasonal, monthly, or shorter period. Specific sand drift control methods include planting vegetation or installing sand fences across corridors, or seasonal (or shorter) avoidance of hazardous zones.

4. DUNE MIGRATION

Dune migration into developed landscapes represents the greatest threat from sand drift. Dune migration is driven by saltation but operates across relatively large spatial and long-time scales. Predicting transport rates associated with dune migration most reliably depends on accurate estimates of dune volumes and migration. Dune volume can be approximated from the estimated measurement of dune morphology from field surveys (including drone mapping) or based on remote sensing (such as the U.S.G.S., 1 m digital elevation model for the U.S.A.). There are several methods for measuring migration rates. Direct field measurement is the least common, mainly because of the necessity of long-duration monitoring. More common is the use of aerial photography, or similar surface representations. This approach can yield long- term rates and migration variability, depending on the frequency of imagery. In a few environments dune migration leaves environmental signatures that can be used to measure annual rates of movement (Fig. 2B), as described in Levin et al. (2009), allowing migration variability to be assessed and related to climate variability. Dune stabilization requires substantial resource investment, assessed relative to the value of protection. Common approaches are surface stabilization by planting vegetation, especially trees, or through the use of structures to deflect the dune paths. Where the threatened resource is of relatively little value, abandonment is a common response.

5. CONCLUSIONS

Theories and methods to accurately predict sand drift remain inadequate for confident transport rate estimations and require substantial safety factors for the development of protective strategies to mitigate hazards. Most mitigation approaches require substantial investment, especially in cases where large-scale surface stabilization is necessary. This is a field where increased and careful empiricism remains fundamental to improved models.

REFERENCES

Alfaro, S.C., Bouet, C., Khalfallah, B., Shao, Y., Ishizuka, M., Labiadh, M., Marticorena, B., Laurent, B., Rajot, J.L., 2022. Unraveling the roles of saltation bombardment and atmospheric instability on magnitude and size distribution of dust emission fluxes: lessons from the JADE and WIND-O-V experiments. Journal of Geophysical Research: Atmosphere, 127, e2021JD035983.

Baas, A.C.W., 2019. Grains in motion. Aeolian Geomorphology: A New Introduction, 27-60.

Bagnold, R.A., 1937. The transport of sand by wind. The Geographical Journal, 89(5), 409-438.

Bruno, L., Horvat, M. and Raffaele, L., 2018. Windblown sand along railway infrastructures: A review of challenges and mitigation measures. Journal of Wind Engineering and Industrial Aerodynamics, 177, 340-365.

Delgado-Fernandez, I., 2010. A review of the application of the fetch effect to modelling sand supply to coastal foredunes. Aeolian Research, 2(2-3), 61-70.

Fryberger, S.G., 1978. Techniques for the evaluation of surface wind data in terms of eolian sand drift (No. 78-405). US Geological Survey.

Gillette, D.A., Herrick, J.E., Herbert, G.A., 2006. Wind characteristics of mesquite streets in the northern Chihuahuan Desert, New Mexico, USA. Environ Fluid Mech, 6(3), 241-275.

Han, Q.J., Qu, J.J., Dong, Z.B., Zu, R.P., Zhang, K.C., Wang, H.T., Xie, S.B., 2014. The effect of air density on sand transport structures and the adobe abrasion profile: a field wind-tunnel experiment over a wide range of altitude. Boundary-layer meteorology, 150, 299-317.

Lettau, K, Lettau HH. 1978. Experimental and micrometeorological field studies of dune migration. Exploring in the World's driest climate, 110-147.

Levin, N., Tsoar, H., Herrmann, H.J., Maia, L.P. and Claudino-Sales, V., 2009. Modelling the formation of residual dune ridges behind barchan dunes in Northeast Brazil. Sedimentology, 56(6), 1623-1641.

Nguyen, D., Hilton, M., Wakes, S., 2022. Aeolian sand transport thresholds in excavated foredune notches. Earth Surface Processes and Landforms, 47(2), 553-568.

Ralaiarisoa, J.L., Besnard, J.B., Furieri, B., Dupont, P., El Moctar, A.O., Naaim-Bouvet, F. and Valance, A., 2020. Transition from saltation to collisional regime in windblown sand. Physical Review Letters, 124(19), 198501.

Sherman, D.J., Li, B., Ellis, J.T., Farrell, E.J., Maia, L.P., and Granja, H. (2013). Recalibrating Aeolian Sand Transport Models. Earth Surface Processes and Landforms, 38: 169-178.

Sherman, D.J. and Ellis, J.T., 2022. 7.15 - Sand Transport Processes, Treatise on Geomorphology (Second Edition), 385-414.

van Rijn, L.C., Strypsteen, G., 2020. A fully predictive model for aeolian sand transport. Coastal Engineering, 156.