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Simulated Atmospheric Vortex Threshold

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A number of people have studied experimentally the threshold of small particles in a boundary layer wind tunnel (see, e.g., Bagnold 1941, Chepil 1945, Zingg 1953,). The writer has also studied boundary layer threshold including the effects of small particle cohesion (Iversen et al 1976, Iversen & White 1982), fluid density (Iversen et al 1987), and surface slope (Iversen & Rasmussen 1994, 1999). Much less work has been done to date on the threshold of particles being lifted from the surface by an atmospheric vortex such as a “dust devil”. Recent data returned from probes to the planet Mars have stirred new interest in the dust devil phenomenon. The writer first performed vortex threshold experiments in 1975 in a “tornado simulator” designed by C.T. Hsu (Hsu & Fattahi 1976, threshold experiments reported in Greeley et al 1981).

The mechanism of entrainment of sand and dust particles into a dust devil seems to be somewhat different from the normal boundary layer entrainment. The surface shear stress most likely reaches a maximum directly under the vortex radius at which the tangential wind speed is a maximum. In addition to the shear stress acting to lift particles from the surface, however, there is also a decrease in pressure from the ambient at large radius towards the vortex center. This pressure difference may also be effective in lifting small particles from the surface. The minimum pressure point, however, is not directly under the maximum tangential wind speed but at the center of the vortex.

Since the dust devil moves across the surface over which it has formed, the flow at a given point on the surface is unsteady. Thus as the vortex moves over a given point, the pressure on the surface at that point decreases with time. If the decrease is sufficiently fast, it is conceivable that the pressure difference, as well as the surface shear stress, can act to lift particles from the surface. Stresses acting to oppose particle motion include the particle layer weight per unit area and a cohesive stress due to interparticle forces. Thus an equation of equilibrium at threshold can be written by equating effective stresses due to pressure difference and shear stress to the sum of particle layer weight and cohesive stress.

A recent improved version of C.T. Hsu’s vortex generator has been constructed at Arizona State University. New threshold experiments have been conducted with this device at ASU and in an altitude chamber at the NASA Ames Research Laboratory in California (Balme et al 2002). The results of these experiments and the earlier experiments at ISU show that the vortex strength required for threshold is a function of particle layer weight, as expected, but there are indications that the effects of vortex Reynolds number and cohesive stress are also important, and the resultant threshold figures look quite different from those for boundary layer threshold.

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