AERODYNAMIC ROUGHNESS AS A FUNCTION OF WIND DIRECTION OVER ASYMMETRIC SURFACE ELEMENTS

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Abstract. Wind speed and temperature profiles to a height of 8 m were recorded for 30-, 60-, and 90-min averaging times over a striated snow surface at the geographic South Pole during the austral winter of 1975. A gradient Richardson number was calculated for each averaging time to determine conditions of neutral stability under which the logarithmic wind law would hold. A log-linear regression technique was used to determine values of aerodynamic roughness height ($Z_0$) for those profile averages recorded in conditions of neutral stability. A plot of $Z_0$ as a function of average wind direction revealed a variation in $Z_0$ of almost three orders of magnitude, from 0.01 to 7 cm, over 120 deg of wind direction. A simple model is presented to justify the fact that aerodynamic roughness is a function of wind direction and erosion history.

1. Introduction

Prediction of the surface shear stress ($\tau_0$) using gradients within a constant flux layer depends on the proper parameterization of the roughness height ($Z_0$) of that surface. Under neutral conditions,

$$\bar{U} = \frac{U_*}{k} (\ln Z - \ln Z_0),$$

where

$$U_* = \left(\frac{\tau_0}{\rho}\right)^{1/2}.$$

Characteristic values of $Z_0$ are frequently reported for various natural surfaces, vegetation, and structures (e.g., Sellers, 1965). It has been shown that values of $Z_0$ can be estimated for a given surface based on the dimensions of the roughness elements. Plate (1971) discusses a relation of the form:

$$Z_0 = Ch,$$

where $Z_0$ is the aerodynamic roughness length, $h$ is the height of the roughness element or field crop, and $C$ is a constant, usually about 0.14.

A consideration that is often overlooked in the measurement of $Z_0$, or the calculation of $U_*$ is the possible variation of the roughness length with wind direction. Lettau (1969) and Marshall (1971) show that the aerodynamic roughness length $Z_0$ is a function of the silhouette area of the surface roughness elements, which may or may not be dependent on wind direction. Wooding et al. (1973) summarized these and other studies. Many surfaces which are subject to aeolian...
erosion develop surface features which have preferred asymmetric orientations with respect to the direction of the wind which formed them. There are also many situations in which anthropogenic activity can produce distributions of roughness elements with preferred linear orientations. Hicks (1973) was able to show a change in surface drag coefficient with wind direction over a vineyard planted in rows. In this note, the variation of aerodynamic roughness with wind direction is examined over a dry snow surface which is unaffected by melting snow or surface recrystallization.

2. The Data

The measurements used in this study were taken at Amundsen-Scott Station at the geographic South Pole in 1975. The complete program is described by Carroll et al. (1977). The station lies on a flat, gently sloping surface (<1°). A uniform fetch exists for more than 100 km in all directions.

The surface texture is produced by wind erosion which creates snow dunes or sastrugi (see Figure 1). Unlike dunes formed of sand or soil particles, sastrugi are aligned with their major axes parallel to the generating wind direction. They are uniformly distributed and rarely exceed 0.5 m in height. The major features of the these elements are that they have a high, nearly streamlined upwind edge which extends downwind a short distance with nearly vertical sides aligned with the preferred wind direction. At a short distance back from the leading edge, the sides

Fig. 1. Photograph of snow surface at the South Pole.