Glacier Surface Ablation and Roughness Measurements
Using Terrestrial Laser Scanning for Energy Budget Model Applications

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1. Background

Calculations of glacier surface melt rates are useful for a variety of applications: the use and management of water resources; studies of glacier hydrology and dynamics; and studies of glacier mass balance and the contribution of the melting of mountain glaciers and ice caps to sea level change. In recent years spatially-distributed surface energy balance models have been used to calculate surface melt rates. These models typically partition the energy available to drive melt into radiative and turbulent heat flux components. Although the theoretical basis for modelling these fluxes is well understood, a particular difficulty lies in estimating surface roughness, which has a strong influence on turbulent fluxes (Hock, 2005).

Terrestrial laser scanning (TLS) is an innovative non-invasive surveying technique that provides very accurate high resolution point clouds of topographic data. Herein we explore the potential of TLS to improve both the parameterisation of surface roughness within the energy balance model (Section 3) and the determination of spatially distributed measurements of ablation over glacier surfaces (Section 4).

2. Field Site and Methods

Detailed morphological, spectral and atmospheric measurements were undertaken during the 6–8th Sept. 2008 on the Bas Glacier d’Arolla, an Alpine valley glacier located in Valais, Switzerland. Wind speed was greater on the first two days; direction was predominantly down-glacier. Rainfall (total 22.2 mm) was observed during the 6-7th, but the site was cloud free on the 8-9th. Aerial photos were taken from a low level blimp (Fig. 2.1).

The glacier surface was surveyed from two locations using a Leica Scanstation (Fig. 2.2). The scans were co-registered with typical tie-points to the glacier surface, aligned perpendicular to the wind direction. The topographic data along the transects were detrended and \( z_0 \) values calculated using (Lettau, 1969; Munro, 1989; Brock et al., 2006):

\[ z_0 = 0.5 \frac{1}{s} \]

where \( h \) is the average obstacle height (twice standard deviation of detrended elevation), \( s \) is the silhouette area and \( S \) is the unit ground area.

Similar to Brock et al. (2006) our sensitivity analyses show that \( z_0 \) is independent of transect lengths in the range 1 to 30m (Fig. 3.1a). However, we found that \( z_0 \) is sensitive to sampling interval sizes below 5cm (Fig. 3.1b). Average \( z_0 \) values obtained from our data agree with commonly measured values of between 0.1 and 5.8 mm for smooth glacier ice (Brock et al., 2006), and were greater on the lower section of the snout (up to 1.5mm). \( z_0 \) values derived from TLS transects are therefore consistent with traditional methods but offer the advantage of enabling data collection at a high resolution over a large area and without disturbance to the glacier surface.

3. Roughness Measurements

Herein we employ two methods to estimate surface roughness height from the TLS data. First, we extract high resolution transects to evaluate \( z_0 \) using traditional methods. Specifying we take advantage of the large number of TLS data in each transect to assess how transect length and sampling interval employed in these traditional methods influence \( z_0 \). Next we use the spatially distributed character of the data to construct roughness maps by passing a ‘moving window’ over ice surface DEMs and investigate the potential to equate \( z_0 \) to the standard deviation of elevations (\( \sigma_n \)) of grid cells within the moving window as per alluvial fan methods of Frankel and Dolan (2007).

**Transect Method**

Fifteen transects were selected at random locations on the glacier surface, aligned perpendicular to the wind direction. The topographic data along the transects were detrended and \( z_0 \) values calculated using (Lettau, 1969; Munro, 1989; Brock et al., 2006):

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Moving Window Method

As an alternative to the transect method, \( z_0 \) was calculated for varying symmetrical moving window widths (0.3 to 4m) on a 10cm DEM (Fig. 3.2). Micro scale or skin roughness defined by a small window size was greatest on the lower section of the glacier (\( h=30 \)) (Fig. 3.3). This pattern of small scale roughness variation is in agreement with the more traditional transect calculations. Larger features, associated with fractures, crevasses and shallow meltwater channels were dominant on the middle and upper areas of the ice surface. These quasi linear features are identified by using asymmetric moving windows (Fig. 3.4). We found that \( z_0 \) calculated from transects does not relate directly to small-scale moving window derived roughness, but is a function of both the small and large scale contributions associated with surface structures aligned in both the transverse and flow parallel directions (Fig. 3.5).

4. Ablation Measurements

Very high resolution (2500 points/m²) ablation measurements were obtained by repeat topographic surveys (via TLS). Point cloud data from each scan was co-registered with 10cm resolution DEMs were created. These DEMs were compared to calculate differences in ice surface elevation. Average daily ablation ranged from approximately 33mm during 6-8th (Fig. 4.1) to 38mm during 8-9th (Fig. 4.2). These differences comfortably exceed the minimum level of detection defined by scan registration errors (6mm).

**Moving Window Method**

When combined with the combination of rain, wind and overcast conditions increased ablation over the lower, snoutal section of the glacier (\( h=30 \)) (Fig. 3.3). This pattern of small scale roughness variation is in agreement with the more traditional transect calculations. Larger features, associated with fractures, crevasses and shallow meltwater channels were dominant on the middle and upper areas of the ice surface. These quasi linear features are identified by using asymmetric moving windows (Fig. 3.4). We found that \( z_0 \) calculated from transects does not relate directly to small-scale moving window derived roughness, but is a function of both the small and large scale contributions associated with surface structures aligned in both the transverse and flow parallel directions (Fig. 3.5).

**References**


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