QUANTIFYING SNOW TRANSPORT USING SNOW FENCES AND SONIC SENSORS

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ABSTRACT
Using two snow fences we constructed in northern Alaska, and an existing municipal fence near Barrow, we measured the growth and size of the snow drifts. To define the timing and magnitude of the snow transport episodes, on the leeward side of each fence we installed a line of sonic depth sensors that were used to track the increase in snow depth with time. The time-dependent depth measurements have been combined with the drift profile surveys to produce a series of snow volumes before and after transport (or snow deposition) events. Thirty-six such events have been identified and examined as a function of wind-speed. We reviewed all previously published experimental values of snow transport at different wind speeds and added our new data. When taken together, these data show a scattered cloud, indicating that the windblown snow flux is not a single-valued function with respect to wind speed. Other factors (snow conditions, wind direction, and wind character) strongly affect the flux. We suggest describing this cloud with a “low” and “high” curves for estimating minimum and maximum likely snow transport. Further developments can be made to refine the curve position with respect to the particular climate/snow zone from ice sheet to alpine and Arctic environments.

1. INTRODUCTION
Accurately assessing snow transport during wind events is a prerequisite to reliable estimation of snow loads on infrastructure or avalanche forecast in the mountains. It is also a required component of the winter water balance in windy areas of tundra and alpine areas. Here we present four years of snow transport and snow drift measurements in northern Alaska designed to improve such assessments. The measurements were made at three sites in Arctic Alaska — Barrow, Franklin Bluffs and Innnavait (Figure 1).

Figure 1: North Slope of Alaska and location of three measurement sites.

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2. METHODS AND RESULTS
We constructed two snow fences (Imnavait and Franklin Bluffs) and used an existing municipal fence near Barrow. To measure the timing and magnitude of the snow transport episodes, on the leeward side of each fence we installed a line of sonic depth sensors. These were used to track the increase in snow depth along the drift profile (Figure 2), the principle being that rapid periods of snow depth increase would correspond with snow transport events.

Figure 2: (A) Photograph of snow fence in Barrow with sonic depth sensors SR50s. (B) Scheme showing snow depth measurements by sonic sensors during different stages of the drift growth.
The fence height, length, orientation and location of the sonic sensors for three snow fences are summarized in Table 1.

Table 1. Snow fence characteristics.

<table>
<thead>
<tr>
<th></th>
<th>Innnavait</th>
<th>Barrow</th>
<th>FranklinBluffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (m)</td>
<td>2.4</td>
<td>4.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Length (m)</td>
<td>71</td>
<td>915</td>
<td>100</td>
</tr>
<tr>
<td>Orientation</td>
<td>E to W</td>
<td>S to N</td>
<td>NW to SE</td>
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<tr>
<td>Prevailing wind</td>
<td>S, SE</td>
<td>E, W</td>
<td>NE, SW</td>
</tr>
<tr>
<td>Distance to the sonic sensors</td>
<td>3, 8, and 15 m</td>
<td>3, 10 and 20 m</td>
<td>10, 16, and 34 m</td>
</tr>
<tr>
<td>Profile surveys</td>
<td>6</td>
<td>13</td>
<td>2</td>
</tr>
</tbody>
</table>

2.1. Continuous snow depth records at the fence

Hourly averaged snow depth records from the Innnavait Fence are shown in Figure 3 for the three winters of complete snow records.

We also measured air temperature, relative humidity, wind speed and direction at the fence height and at 10 meters above the ground.

At several times during the winter there were sharp increases in depth at one or more sonic sensors indicating a snow deposition event (SDE). An SDE was formally defined as a period of blowing snow that lasted more than two hours, was separated from other periods by at least two hours of calm, and resulted in more than 0.3m of change in snow depth. However, if all sensors reported the same change in depth, the event was identified as a snowfall. In addition, sonic sensors can be “topped off” and fail to register an event because the snow drift had reached its equilibrium profile and the fence was full (for example, see April 2009 in Figure 3).

Noticeably different drift growing patterns were observed in different years, resulting in significant differences in the Innnavait drift size. For example, small (0.2–0.4 m/event) SDEs dominated the winter of 2010, while large SDEs (>1 m/event) occurred in the winters of 2009 and 2011 (Figure 3). Not surprisingly, that the drift reached its full volume in 2009 and 2011; however it filled only to 38% of the full volume in 2010. Comparing drift growth at all three sites, we can see that there was slow, steady drift growth with many SDEs at Barrow and rapid drift growth from a few SDEs at Franklin Bluffs. An alternation between these two types of drift growth was observed at Innnavait Creek.

2.2. Snow transport rate

The time-dependent snow depth measurements at the fence were combined with the drift profile surveys to produce a series of snow volumes before and after snow deposition events. The drift profiles were either measured in the field with the DGPS snow surface survey or calculated from the snow depths recorded by sonic sensors. Snow density was periodically measured with the snow cores and snow pits. We calculated the snow deposition rate \( Q_d \) per meter of fence length by combining information from the sonic sounders, the drift profile surveys and the snow cores:

\[
Q_d = \frac{\rho \Delta V}{\Delta t} \times \eta
\]  

where \( \rho \) is snow density (kg/m\(^3\)), \( \Delta V \) is the change in drift volume during an SDE (m\(^3\)/m), \( \Delta t \) is the duration of the snow transport (s), and \( \eta \) is snow fence trapping efficiency (dimensionless).
Because $\eta$ has not been well-established and most of the SDEs occurred during the earlier stages of drift development, when trapping efficiency tends to be high, $\eta$ is assumed to be 1 for purposes of calculation. Following this approach, we calculated snow transport during thirty-six SDEs and examined it as a function of wind-speed. Fitting a line to the data, we found the following regression between snow deposition flux and wind speed ($r^2 = 0.31$):

$$Q_d = -0.2 + 0.033 \times w_{10}$$

(2)

where $w_{10}$ is the wind speed at 10-m height averaged during each SDE (m/s).

3. DISCUSSION
We place only little reliability to preceding equation 2. To put our results and this equation in perspective, we reviewed all previously published experimental values of snow transport at different wind speeds including our new data. Our $Q_d$ estimates are generally higher than those reported in the literature, a little bit more scattered, and for a set of wind speeds that are generally higher than many of the previous studies. When taken together, all these data show a scattered cloud, indicating that the windblown snow flux is not a single-valued function with respect to wind speed. Other factors (snow conditions, wind direction, and wind character) strongly affect the flux. In another paper (Sturm and Stuefer, in press) we explore the best way to mathematically represent all these data.

REFERENCES
Sturm, Matthew; Stuefer, Svetlana; In Press. Windblown flux rates derived from drifts at arctic snow fences. Journal of Glaciology.