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Dust generation on a proglacial floodplain, West Greenland

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ABSTRACT

The interplay of glacial dynamics, glaciofluvial and aeolian transport in proglacial landscapes plays an important role in local environmental systems and in the global context by affecting the amount of dust generated and transported at different phases of glacial-interglacial cycles. Glacial outwash plains are a significant source of dust, however the processes involved in dust generation on proglacial floodplains are poorly documented. We report a study of the quantity and characteristics of aeolian suspended sediment transport in Sandflugtdalen, a valley containing a proglacial floodplain and aeolian dunefield in West Greenland. Although the surface sediment of both the floodplain and dunefield contain a considerable amount of sand-sized material, wind speeds recorded were insufficiently strong to mobilise this material; this is probably due to the armouring effect of coarser particles in the surface deposits. Nevertheless, fine (dust-sized) aeolian sediments were transported down valley in suspension and the source of this material was a silt-dominated meltwater deposit up valley from the monitoring sites. Dust transport ranged from 0.0008 to 0.082 g m w s^{-1} over 7 days and 0.0035–0.011 g m w s^{-1} over a further 57 days during which no additional fluvial sediments were deposited. The reduction in sediment transport rate is attributed to both a depleted sediment supply and a decrease in above threshold winds. The supply of fine sediments to this proglacial region is dependent on meltwater suspended sediment loads which are predicted to increase during glacier retreat; reworking of the floodplain during ice retreat may also make more material available for aeolian transport.

1. Introduction

A strong coupling between dust and climate has been identified that is sustained through multiple glacial-interglacial cycles (e.g. Lambert et al., 2008). The interplay of glacial dynamics, glaciofluvial and aeolian transport in proglacial landscapes plays an important role therefore, not only in local environmental systems, but also in the global context by affecting the amount of dust generated and transported. Glacial outwash plains have been cited as a significant source of dust in the southern hemisphere (e.g. Sugden et al., 2009) and must also have been important dust sources in the northern hemisphere. Cold climate aeolian processes and landforms are widely acknowledged in proglacial and paraglacial geomorphology (e.g. Ballantyne, 2002; Seppälä, 2004), but have received considerably less attention than aeolian processes in warm arid or temperate coastal regions. Under contemporary conditions, many high latitude or high altitude regions have limited rainfall (e.g. mean annual precipitation in the Dry Valleys of Antarctica is <60 mm rainfall equivalent) including parts of the Andean altiplano, and some ice-free regions of the Arctic and Antarctic. Seppälä (2004) estimates that cold arid areas – defined as those where the mean temperature of the warmest month is less than 10 °C and mean annual precipitation is less than 250 mm – cover around 5 million km^2. In addition, some humid, cold areas such as in New Zealand and Iceland have limited vegetation cover and sufficiently strong winds for aeolian processes to be important (e.g. Arnalds et al., 2001; McGowan and Sturman, 1997; Marx and McGowan, 2005). Glacierised catchments in these areas typically receive an abundance of fluvially-supplied sediment <2000 μm in diameter. Diurnal and seasonal discharge cycles lead to the deposition of these sands and silts across outwash plains where, following desiccation and in the absence of dense vegetation, they may be entrained by strong katabatic or density-driven downglacier winds or, in the proximity of ice sheets, by winds driven by steep regional or continental pressure gradients associated with persistent atmospheric high pressure.

The principles of aeolian sediment transport established in temperate (usually coastal) or sub-tropical regions also apply to cold climate regions. For a given set of grain characteristics, aeolian sediment transport is positively related to wind velocity and turbulence intensity, but negatively related to surface roughness and sediment moisture content. There are, however, differences

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between threshold wind velocities required to entrain particles under warm or cool conditions depending on air temperature, pressure and humidity all of which affect the density of the air (McKenna Neuman, 2004; Selby et al., 1974); for example for a given particle size threshold wind velocities are lowered in cold conditions and increase as temperature increases. Additional considerations in cold climates include the impacts of snow, frost and sublimation (Kurosaki and Mikami, 2004; McKenna Neuman and Gilbert, 1986). Thick snow cover can protect sediments from deflation and frost can cement fine particles preventing their erosion – alternatively, frost activity may enhance surface erodibility by breaking up aggregates and limiting plant growth.

Hobbs (1942) argued that wind was the most important agent of sediment transport within extramarginal zones to continental glaciers, and the effects of deflation and aeolian modification on proglacial landforms has been widely reported (e.g. Derbyshire and Owen, 1996; Gisladottir et al., 2005; Glasser and Hambrey, 2002; Riezobos et al., 1986). There are, however, very few estimates of the quantity and characteristics of fine sediments deflated from proglacial areas. Exceptions include Nickling's (1978) study of aeolian sediment transport in the Kaskawulsh glacier valley (Yukon Territory) in which he measured rates of 4.5–52 g m w s^{-1} (grams per metre–width per second) for individual dust storm events, while in Iceland aeolian transport rates of 56 g m w s^{-1} for moderate storms on sand fields have been recorded (Arnalds et al., 2001). Church (1972) observed aeolian transport of 1600 g m w $month^{-1}$ on Baffin Island but 40% of this material was moved in 1 day. In addition to generating dust storms, aeolian sediments, when deposited, play an important role in proglacial geomorphology, notably as aeolian duneforms (Mountney and Russell, 2009), inputs to soil development and as loess accumulations (Muhs et al., 2004).

Glacioaeolian deposits often reflect a complex pattern of reworking in proglacial areas where sediments are repeatedly eroded, transported and deposited by both wind and meltwater (e.g. Derbyshire and Owen, 1996; Dijkmans and Törnqvist, 1991). Understanding the processes determining the supply and availability of sediments therefore requires some consideration of both aeolian and fluvial systems and the ways in which they interact at a variety of scales (e.g. Bullard and Livingstone, 2002; Field et al., 2009). In proglacial regions production and supply of suitable sediments is closely-linked to glacier and ice-sheet dynamics (such as ice velocity, sediment load and basal thermal conditions) and hydrology, relying on suspended sediments in meltwater being transported to proglacial areas before they can be entrained by the wind and further transported to distal regions. Climate-driven ice retreat is likely to result in increased mobilisation of material from long-term glacial sediment stores (Hodgkins et al., 2003; Jansson et al., 2005), delivering greater quantities of fine sediments to the floodplain than at present (assuming a proglacial lake does not form; Sugden et al., 2009). Moisture availability (meltwater, rain, snow, groundwater) has a significant impact on sediment availability as do the geomorphology, sedimentology and vegetation characteristics of the proglacial floodplain. For example, coarse lag deposits can prevent aeolian entrainment (e.g. Schwan, 1986) and vegetation cover can trap aeolian sediments, but is very limited on an active floodplain. Climate warming is likely to trigger more aeolian activity at glacial margins due to the degradation or burial of vegetation by aeolian sediments or more rapid desiccation of sediments by increased evaporation (Alho, 2003; Gisladottir et al., 2005). It is also known that locally-generated dust can play an important role in regulating ice albedo and the melting rate of glaciers and ice sheets (e.g. Adhikary et al., 2002; Oerlemans et al., 2009; Zdanowicz et al., 1998).

The aim of this paper is to examine the variability in surface characteristics and aeolian entrainment and transport across a proglacial floodplain. The experiment was conducted during the summer months with no snow or ice cover and started a few days after a meltwater flood event deposited fine sediments over large parts of the ice-proximal floodplain.

2. Study area

Fieldwork was conducted between May and August 2007 in Sandflugtdalen, West Greenland (Fig. 1). This proglacial valley extends from the head of Kangerlussuaq Fjord (67°00′N, 50°43′20″W) to the west margin of the Greenland Ice Sheet. It is representative of the Greenland coastal zone and geomorphic and stratigraphic mapping (Dijkmans and Törnqvist, 1991) have revealed extensive modern aeolian deposits, and indicate a close link between glacifluvial and aeolian activity.

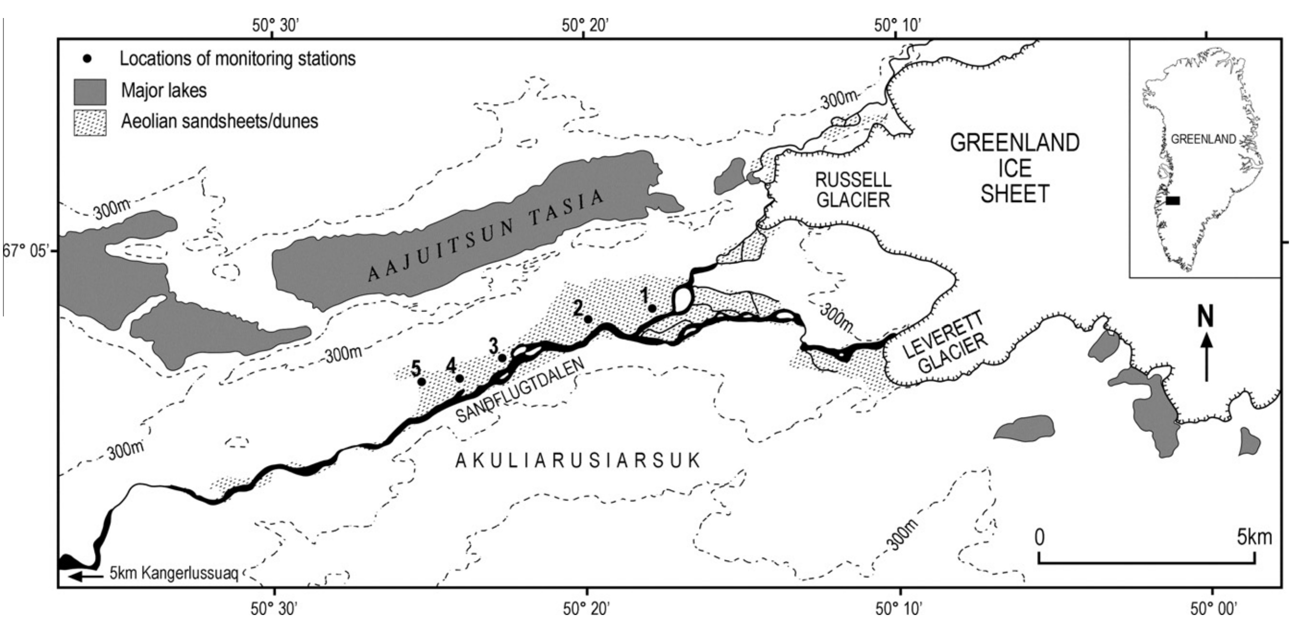

Fig. 1. Map of the study area indicating main area of aeolian deposits and location of five sampling sites.