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Wind erosion of volcanic materials in the Hekla area, South Iceland

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ABSTRACT

Iceland has extensive areas with intense aeolian processes, in spite of humid climate. We measured wind erosion in a 110 km^2 heterogeneous sandy area near the Mt. Hekla volcano in South Iceland. The area is sparsely vegetated and covered by volcanic materials. Measurements were made during two summer seasons in 2008–2009 with dust traps at 25 locations employing a 'single dust trap method' after characterizing sediment height profiles. Sets of electronic equipment that measured wind erosion and several weather parameters were placed at two locations. The results show a large variation in sediment transport with maximum transport in storms ranging from 0 to 1788 kg m^{-1} at each site and maximum average transport during storm reaching 244 kg m^{-1} h^{-1}. The aeolian transport each summer ranged from 1 to 2981 kg m^{-1}. Amount of loose sandy sediments on the surface, sediment texture and proximity to water channels are important factors explaining site differences. Wind erosion was most intense in the north-eastern part of the area, with >80% loose sand on the surface but less intense closest to the volcano where coarse pumice characterizes the surface. The research shows a pathway of sediment transport on a landscape scale with north-easterly winds, into the Thjorsa river, enhanced by landscape characteristics and seasonally active water channel. Pumice grains >8 mm in diameter were transported by saltation. Grains >1 mm were commonly >20% of materials collected at 30 cm height, which is explained by low density of the volcanic materials and high wind velocities.

1. Introduction

Aeolian processes damage ecosystems and often prevent natural regeneration of vegetation (Maun, 1998; Armbrust and Retta, 2000; Warren, 2010). Furthermore, dust coming from desert areas can have far reaching effects on factors such as climate, soil formation, ecosystem fertility and human health (e.g. Buzea et al., 2007; Lawrence and Neff, 2009). Aeolian processes are usually associated with the arid and semi-arid regions, with quartz rich sediments being most common aeolian materials. However, aeolian processes are intense in Iceland in spite of relatively humid and cold climate, with desert surfaces constituting mostly volcanic glass (Arnalds et al., 2001a; Arnalds, 2010).

According to a national soil erosion survey, >40% of Iceland is classified with considerable to very severe erosion (Arnalds et al., 2001b). Much of this severe erosion occurs within areas with limited vegetation cover; deserts. Sandy desert surfaces cover about 21% extending from costal sand-fields to highland deserts (Arnalds et al., 2001b). The parent material of the sand is mainly basaltic–andesitic volcanic glass together with porous tephra and basaltic and/or andesitic crystalline materials, comprising the largest volcaniclastic desert areas on Earth (Arnalds et al., 2001a). Dust is known to be carried hundreds of kilometres out over the ocean and it is a significant source of aerosols in the North Atlantic (Arnalds, 2010).

Halting severe wind erosion is one of Iceland's environmental priorities. It is therefore important to understand surface processes on Icelandic desert surfaces. Attempts to measure wind erosion in Iceland include those made by Sigurjonsson et al. (1999), Gisladottir et al. (2005), Agustsdottir (2007), Arnalds and Gisladottir (2009) and Arnalds et al. (in press) on loose sandy surfaces, while Sigurjonsson (2002) made efforts to adjust wind erosion models to Icelandic conditions. This earlier research firmly confirms the severity of wind erosion in Iceland, but little is known of the dynamics of the aeolian processes on landscape scales. The purpose of the research presented in this paper is to obtain quantitative overview of wind erosion on a landscape scale in a large heterogeneous area covered by volcanic materials. An extensive, long term restoration effort has been initiated within the research area, making such overview important for enhancing the success of these efforts.

2. Geographical setting and experimental layout

Iceland is an island on the Mid-Atlantic Ridge with active volcanism. With its location in the North Atlantic Ocean, between 63°

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and 66° northern latitudes, Iceland has mostly maritime climate with mild and moist winters but cool summers (Einarsson, 1984). Rainfall varies between 400 and 2000 mm year. Icelandic ecosystems have undergone dramatic land degradation since human settlement during Viking times. Iceland is believed to have been largely covered with dwarf shrubs and birch woodlands when the first settlers came over 1100 years ago and it has been estimated that about 65% of the area of Iceland was vegetated at the time of settlement (Thorsteinsson et al., 1971). Livestock grazing and wood cutting in conjunction with highly erodible volcanic soils and a harsh climate have led to extensive vegetation degradation and soil erosion (Arnalds, 1987). There are many indicators that these problems became more severe in the late 17th century and during the 19th century when sand encroachment from the highlands into the lowlands in southern Iceland became a severe problem (Arnason, 1958).

The research area is located in the southern part of Iceland near Mt. Hekla (Fig. 1), covering about 110 km^2. The area stretches from lowland areas at 210 m elevation to highlands reaching 420 m a.s.l. The south-eastern boundary of the area is bordered by the steep slopes of the Valafell mountain, which acts as a barrier to wind and aeolian transport. The north-western boundary follows mostly the major river Thjorsa.

Volcanic eruptions from Hekla have played an important role in the development of the area. Since the end of the last glacial period, approximately 10,000 years ago, Hekla has produced more tephra than any other Icelandic volcano, or about 32 km^3, calculated as freshly fallen tephra (Hjartarson, 1995). Since the human settlement in the late 9th century, 18 eruptions are recorded in Hekla (Hjartarson, 1995; Hoskuldsson et al., 2007). The composition of the tephra ranges from acid and intermediate tephra (Gudmundsson et al., 1992) which is light in colour, to black basaltic ash (Thorarinsson and Sigvaldason, 1972).

Tephra dispersed from Hekla has had immense effect on the surrounding ecosystems, created large pumice and sand fields in the vicinity of the mountain and aeolian processes have caused extensive ecosystem damage downwind from the Hekla area (e.g. Arnalds, 1988).

2.1. Surface conditions

There are two dominant surface types in the area: (i) 'sandy lava' which constitutes rough lava surfaces partly filled with sand and pumice and (ii) 'sand-fields' which are relatively flat areas covered with sand and pumice.

Fluvial processes are important in sandy deserts in Iceland, transporting material during snow-melt floods to lower positions which often create new source areas for aeolian transport (Arnalds et al., 2001a). The number of dry waterways in the area show evidence of fluvial processes and their size indicates that the surface flow can be substantial. Fluvial processes are most common during thaw in early spring but they can also occur during freeze–thaw cycles in winter. Aeolian processes are dominant during summer but they can also occur during winter when the surface remains snow-free.

The surface in the research area has rapid infiltration rates during summer and the bedrock is permeable. Infiltration in winter is retarded by frozen water in the soil (Orradottir et al., 2008), intensifying periodic water erosion events in winter.

2.2. Climatic conditions

An automatic meteorological station has been operated since 1993 at Burfell, which is just outside of the research area (Fig. 1). The mean wind velocity at Burfell, measured at 10 m height, was 7.1 m s^{-1} and north-easterly winds were dominant for the period 1993–2009. North-easterly winds are most commonly dry winds while southerly winds tend to be wet and often with pronounced rainfall (Icelandic Meteorological Office, 2010).

The mean annual temperature ranged between 2.9 and 4.1 °C with mean July temperatures about 11 °C, and the annual precipitation ranged from 828 to 1459 mm. During the summer months

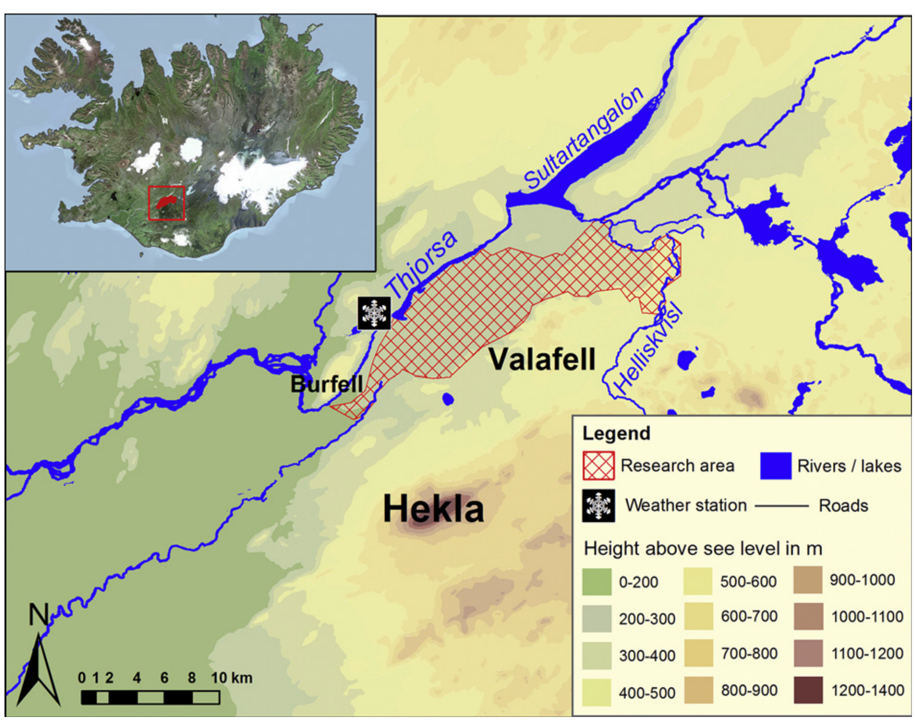

Fig. 1. The research area (cross hatched) and its surroundings. The smaller map to the left shows the location of the area in Iceland. A meteorological station at Burfell is marked with a star. Thjorsa is a major glacial river with numerous hydropower facilities with reservoir lakes including the Sultartangalon reservoir.