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Determination of aeolian transport rates of volcanic soils in Iceland

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ABSTRACT

Sandy deserts cover > 20 000 km^2 in Iceland, consisting primarily of volcanic materials with basaltic volcanic glass being the main constituent. Wind erosion is severe in the country, causing dust pollution with widespread aeolian redistribution affecting most Icelandic ecosystems and sand movement over vegetated areas in the form of advancing sand fronts. We quantified wind erosion, using BSNE field samplers and automated sensors over several years at two sites with contrasting environments. The study sites are Holsfjöll with andic soil materials in the arid northeast highlands (<400 mm annual precipitation) and Geitasandur on sandy surfaces in the humid south lowlands (> 1200 mm). Both areas show similar annual aeolian transport of 120–> 670 kg m^{-1} yr^{-1}. Aeolian flux in storms at the NE site was 3–43 kg m^{-1} h^{-1} on average with up to > 200 kg m^{-1} h^{-1} during gusts. Multiple regression shows potential flux of > 200 kg m^{-1} h^{-1} during intense storms of > 20 m s^{-1} (at 2 m height). The research shows major aeolian activity in the humid South Iceland. Height distribution curves indicate considerable transport high above the surface at both sites (> 60 cm). Stable height distribution curves for each location allow for measurements using single dust trap over long periods. The research explains the intense activity of advancing sand fronts in Iceland and the significance of continuously recharged sand sources for maintaining severe wind erosion in humid areas of Iceland.

1. Introduction

Iceland is a volcanic island in the North-Atlantic Ocean with cold humid oceanic boreal to arctic climate (Einarsson, 1984). About 45% of Iceland is covered by vegetation, ranging from rich ecosystems such as wetlands and birch shrublands to highland areas characterized by moss and lichens (Traustason et al., 2007). Areas with limited vegetation stretch over about 45% of Iceland, but glaciers cover about 10%. Icelandic environments are subjected to large scale dust deposition of 25–> 250 g m^2 yr^{-1} in extensive areas as a result of intense aeolian activity (Arnalds, 2010), in addition to tephra deposition from frequent volcanic activity (e.g., Thordarson and Höskuldsson, 2008). Most soils of Iceland are Andosols (Arnalds, 2008), which are soils that develop in volcanic materials. Aeolian deposition is a major factor contributing to the characteristics of Icelandic soils (Arnalds and Oskarsson, 2009). Icelandic Andosols are often sandy, especially close to the active volcanic zone and near unstable glacially-fed floodplains.

Icelandic ecosystems have been subjected to large scale ecosystem degradation and destruction over the past millennia since the island was settled (Thorarinsson, 1961; Arnalds, 1987; Arnalds, 2000; Arnalds et al., 2001a; Aradottir and Arnalds, 2002). Desert-like conditions, with limited plant cover, have been created in extensive areas, where the Andosol mantle has been truncated from the surface by wind and water erosion processes. However, many of the sandy deserts in Iceland are formed by glacio-fluvial process along floodplains of glacial rivers and on outwash plains in front of glaciers, and also by deposition of volcanic materials during eruptions. The sandy deserts of Iceland occupy nearly 22 000 km^2 or about 22% of the land area (Fig. 1), and these areas are subjected to aeolian processes contributing to major redistribution of aeolian materials (Arnalds et al., 2001b). Arnalds (2010) identified two major types of dust sources in Iceland: i) plume areas of intense dust production in relatively small areas (5–30 km^2) covered with fine sediments, frequently recharged by glacio-fluvial processes (melt-water floods and fluctuating water tables); and ii) sandy deserts in general, covering extensive areas with more coarse textured materials that have been subjected to sorting in repeated wind erosion events.

The main threat associated with sandy deserts is the formation of so-called '*advancing sand fronts*', ('afoksgeirar' in Icelandic) where sand buries vegetation and kills it (Arnalds et al., 2001a,b). Subsequently, with continuous sand supply, the soil materials under the vegetation (often 1–2 m thick soils) are combined with the sandy materials, and the front continues to advance, often > 10 m and even > 100 m yr^{-1} (Arnalds et al., 2001a). Historical accounts (e.g., Arnason, 1958) show advancement of advancing sand fronts capable of destroying numerous farms in one major storm lasting several days, leaving sandy desert behind. These sand fronts are soil

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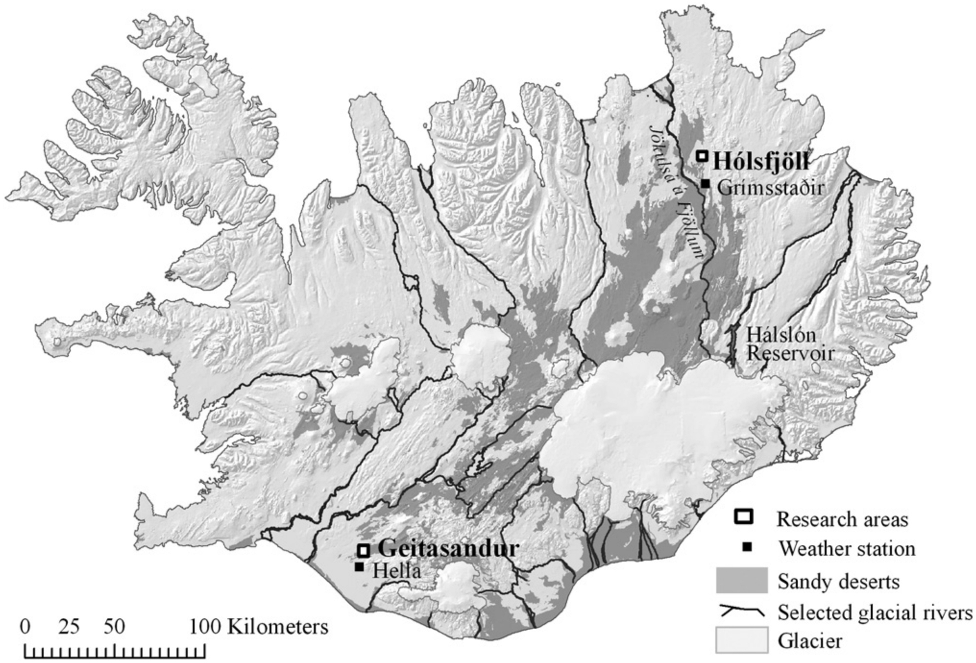

Fig. 1. Map of Iceland showing the location of the research areas at Holsfjöll and Geitasandur. The map shows the spread of sandy deserts (shaded) in Iceland, glaciers, and major rivers that have contributed to sand sources. The Halslon Reservoir is also shown, and the Grimsstadir and Hella weather stations.

stabilization priority areas, and are reclaimed with vegetation where possible. Many present day desert areas were formed because of advancing sand fronts (Arnalds, 2000; Arnalds et al., 2001a,b).

Quantification of rates of erosion/sand flux are important for understanding the aeolian behavior of the sandy systems and for developing soil conservation measures, especially where sand is moving over vegetated areas (advancing sand fronts) and/or where erosion is causing major dust production. In addition, the creation of a major hydroelectric reservoir, the Halslon Reservoir (see Fig. 1), calls for understanding of aeolian behavior of such materials to prevent environmental damage to the surrounding ecosystems. This reservoir has >50 km long shorelines which are >1 km wide in places. These shorelines are covered by loose sediments during much of summer, when water levels are low. The main purpose of the research reported herein was to develop and adopt simple methods to characterize surface transport during wind erosion under field conditions in Iceland, and to determine wind erosion transport rates on soils and sandy surfaces in Iceland. An additional impetus for the research was to obtain background information to aid in devising measures to prevent wind erosion from the shores of the Halslon Reservoir in East Iceland.

2. Materials and methods

2.1. Study sites

Two research sites were used: Holsfjöll and Geitasandur, representing two geographical areas in Iceland with contrasting climatic conditions and surface characteristics.

The Holsfjöll research location is located in Northeast Iceland (Fig. 1). The selection of the Holsfjöll site was based on: i) the existence of active advancing fronts in the area; the research location is situated within one of these fronts; ii) similarity to many major dust plume areas with substantial silt component (estimated 30–50%); and iii) similarities with the Halslon Reservoir area in environmental conditions, which includes dry climate, sandy soils and relatively high elevation (400 m a.s.l.). There has been massive soil erosion in the Holsfjöll area in general over the past centuries, partly because of sediments deposited by a nearby glacial river ('Jökulsa a Fjöllum', see Fig. 1) during catastrophic flooding, with sand moving northeast by dry SW winds, desertifying extensive areas in the path (Arnalds et al., 2001a,b). The experimental location has limited vegetation cover (Fig. 2). The materials are loose, poorly sorted silty and sandy materials with a mean grain size of 0.87 mm (dry-sieved). The area is relatively flat compared to many areas in Iceland, with no major hills or mountains closer than 10 km away.

The site is in an area with active wind erosion of Andosols as a result of an advancing front that had moved through the area, exposing about 3000 ha of soils in 1994. Most of the soils have since been blown off the area, but the experimental site was on location where soils and some vegetation cover still remained. The area is presently protected from grazing and several places in the vicinity of the site are subjected to large scale restoration efforts. The soils are a mixture of fine silt–loam and more coarse sandy–loam; being andic in nature. The soils do not contain phyllosilicate clays (layer silicates), and are therefore non-cohesive. The allophane clay present (estimated about 10% on average at the site) tends to form stable silt-sized

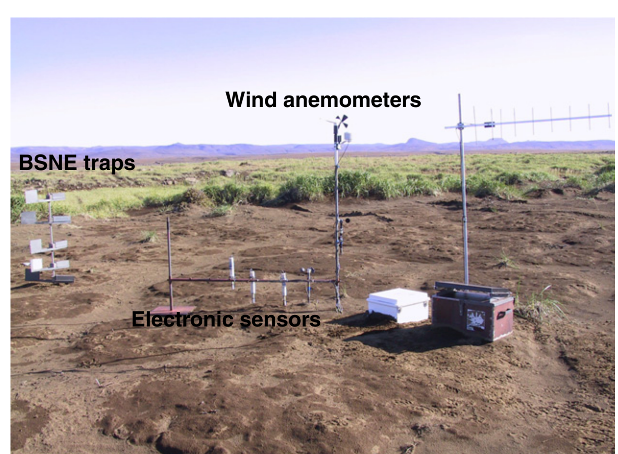

Fig. 2. The surface at the experimental site at Holsfjöll, with bare Andosol cover. Data storage module and battery inside boxes to the right, and an antenna for downloading data with a telephone.