SCIENTIFIC REPORTS

OPEN

An extreme wind erosion event of the fresh Eyjafjallajökull 2010 volcanic ash

SUBJECT AREAS:
ENVIRONMENTAL SCIENCES
VOLCANOLOGY
GEOLOGY
CONSERVATION

Received
3 October 2012

Accepted
25 January 2013

Published
13 February 2013

Correspondence and requests for materials should be addressed to O.A. (oa@lbhi.is)

Olafur Arnalds[1], Elin Fjola Thorarinsdottir[2], Johann Thorsson[2], Pavla Dagsson Waldhauserova[1,2] & Anna Maria Agustsdottir[2]

[1]Agricultural University of Iceland, Hvanneyri, 311 Borgarnes, Iceland, [2]Soil Conservation Service of Iceland, Gunnarsholt, 851 Hella, Iceland.

Volcanic eruptions can generate widespread deposits of ash that are subsequently subjected to erosive forces which causes detrimental effects on ecosystems. We measured wind erosion of the freshly deposited Eyjafjallajökull ash at a field site the first summer after the 2010 eruption. Over 30 wind erosion events occurred (June-October) at wind speeds > 10 m s^{-1} in each storm with gusts up to 38.7 m s^{-1}. Surface transport over one m wide transect (surface to 150 cm height) reached $> 11{,}800$ kg m^{-1} during the most intense storm event with a rate of 1,440 kg m^{-1} hr^{-1} for about 6½ hrs. This storm is among the most extreme wind erosion events recorded on Earth. The Eyjafjallajökull wind erosion storms caused dust emissions extending several hundred km from the volcano affecting both air quality and ecosystems showing how wind erosion of freshly deposited ash prolongs impacts of volcanic eruptions.

Wind erosion has been extensively studied in arid environments, coastal areas and within agricultural fields[1,2]. It can have a direct negative impact on ecosystems by burial of vegetation[3], and by causing loss of fertile topsoil, with immense impact on agriculture[4]. Fine, airborne dust particles generated by wind erosion affect ecosystems, often far away (up to 1000s of km), but the nature of the impact depends on factors such as distance from the source, the amount transported, grain size and chemistry of the dust materials[5]. Most large active dust sources are associated with arid environments[6] with major sources traced to depressions with relatively fine materials (fine silt and clay)[7,8], but the contribution of agriculture to dust production is also important[4]. Aeolian deposition can have positive benefits for vegetation and soils if deposition is moderate (e.g., in mm) by adding nutrients to the ecoystem[9]. Dust can, however, have adverse effects on humans such as on respiratory systems[5,10]. In addition, dust in the atmosphere can have substantial influence on climate, including solar radiation and precipitation[11].

Volcanic eruptions can bury landscapes with tephra (a collective term for airborne volcanic materials) and create extensive areas with unstable surfaces[12]. Water erosion of fresh volcanic deposits can produce extreme sediment yields of $> 100\,000$ tons km^{-2} yr^{-1}, as was measured following the 1991 Mt. Pinatubo (Philippines) eruption[13]. Wind erosion of unstable newly deposited volcanic ash (tephra < 2 mm) has been reported to cause a range of problems such as burial of vegetation and agricultural land, and impact on livestock and humans[14]. Volcanoes are often found in mountainous regions where higher wind speeds and more turbulent winds can be expected than on relatively flat land surfaces, thus increasing the probability of wind erosion events near volcanoes. Low density of some of the tephra can lower the threshold velocity required to move the materials and increase sediment transport[14,15]. Dust emissions of volcanic materials from Iceland have recently received considerable attention[16,17], especially after the recent volcanic eruption in Eyjafjallajökull[18,19]. Catastrophic floods (jökulhlaups) that are caused by volcanic eruptions under glacier, with subsequent deposition of volcanic materials over large areas have also been identified as major sources of dust materials in Iceland[16,17]. However, knowledge of field conditions and wind erosion rates of fresh volcanic deposits under severe wind conditions is limited. Furthermore, wind erosion of fresh volcanic deposits are believed to have caused rapid and large scale ecosystem destruction during historic times in Iceland, with volcanic sand materials encroaching on fully vegetated agricultural areas, leaving sandy deserts behind[20]. Yet surface conditions during such events are poorly understood.

The Eyjafjallajökull volcano in Iceland erupted Mars - May 2010 with an ash plume reaching 3–10 km height[21–23]. The eruption produced about 0.27 km^3 of tephra with about ½ being deposited on Iceland[23]. The tephra was relatively fine, with a high proportion of 0.25–1 mm ash at 10 km from the crater[23]. The ash was commonly 1–15 cm thick at 5–20 km downwind from the volcano during the main ash deposition episodes[23]. This deposition caused severe damage to areas with sparse vegetation, while more resistant systems, such as woodlands, stabilised the ash without causing permanent damage. Dust storms were frequent in the years following the eruption. We monitored wind erosion the first seasons after the eruption employing collectors and automatic sensors in an area that received 2–5 cm tephra, about 12 km SE of the crater (Figure 1) (see Methods for site selection and characteristics). The purpose of the research was to quantify wind erosion of freshly deposited ash under field conditions. Such measurements are fundamental for understanding the remobilisation of volcanic ash by wind, dust production of such areas, the large scale ecosystem destruction, and for predicting negative impacts of volcanic ash deposition on ecosystems and society.

Results

There were > 30 wind erosion events recoded at the Eyjafjallajökull wind erosion research site during the period June – October 2010. In September 2010, an extreme storm event was recorded. It lasted from 13:46 on September 14th with the main episode ending at about 06:00 the following day. However, erosion recorded by the saltation sensor lasted until 23:08 on September 15th. The storm was divided into 7 episodes defined by saltation intensity determined by the automated saltation sensor (Figure 2). The temperature ranged between 5 and 9.3°C during the storm with relative humidity ranging between 67 and 74%. Wind was blowing from the NNE, hence carrying materials downwind from the volcano towards the instruments. The BSNE sediment samplers placed at 10, 30 and 60 cm filled up during the storm with 1,100 – 1,600 g collected in the samplers. As a result, only the sampling set with a sampler placed at 90 and 120 cm height gave us a reasonable estimate of the total transport during the storm that is discussed in this paper (see Methods).

The total transport during the storm was calculated as 11,802 kg m^{-1} based on materials collected in the BSNE samplers and average height distribution curves. Our results do not consider surface creep movement, which could add 10–30% to this value[24]. Saltation pulse counts at 10 cm height give a detailed description of the progress of the storm (Figure 2). Each pulse of the saltation sensor was assigned weight (see Methods), based on calculated total transport to obtain an estimate of the transport in kg m^{-1} for each of the storm episodes (Table 1). Average 1 minute wind speed for each episode ranged between 14.1 and 22.5 m s^{-1} with gusts reaching 38.7 m s^{-1} (one minute average) which were reached during episode V. During the 6½ hr long episode V, about 9,500 kg of material was transported over a one m wide transect, with an average flux rate of 1,440 kg m^{-1} hr^{-1}.

Discussion

The transport during the storm of 11 800 kg m^{-1} and the maximum rate of transport reaching about 38 kg m^{-1} min^{-1} (corresponds to about 2300 kg m^{-1} hr^{-1}). We have not been able to find such high measured transportation rates in the published literature.

The measured transport is considerably greater than previously measured in Iceland but storms of > 500 kg m^{-1} hr^{-1} have been predicted based on field measurements and up to > 5,000 kg m^{-1} in single storms based on modelling of the measurements[25]. In comparison, the maximum recorded transport of volcanic material in the Hekla area reached about 3,000 kg m^{-1} over one relatively calm summer season[15]. The largest previously measured amount in Iceland in one storm was about 4,200 kg m^{-1} at Landeyjasandur, South Iceland, in 2004[26]. During the period from the ash deposition

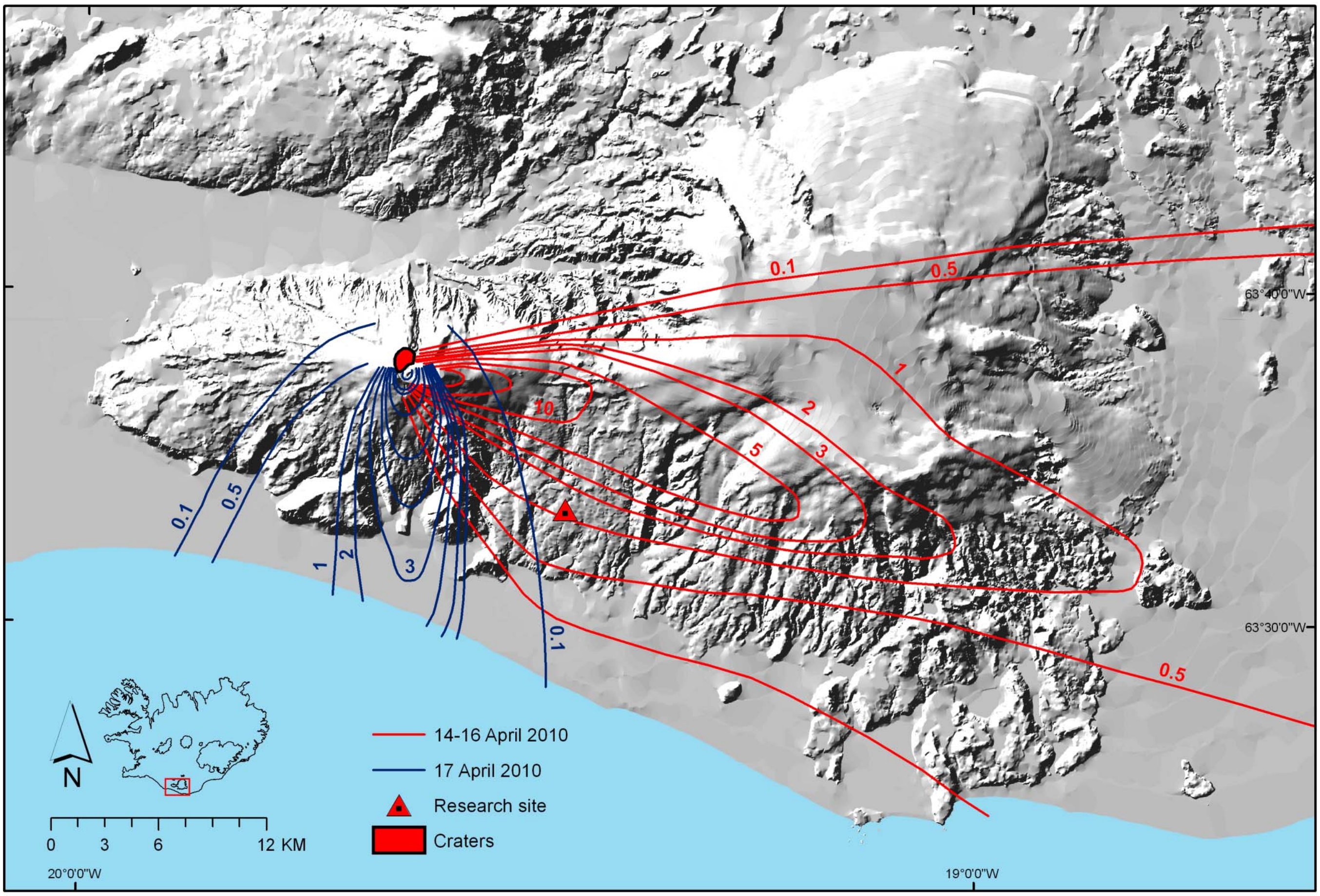

Figure 1 | Hill shade map of Eyjafjallajökull and the surrounding areas showing location of the research site and isopach data indicating the main distribution of the 2010 tephra. The distance from the crater to the research site is about 12 km. Isopach data from Gudmundsson *et al.*[23].

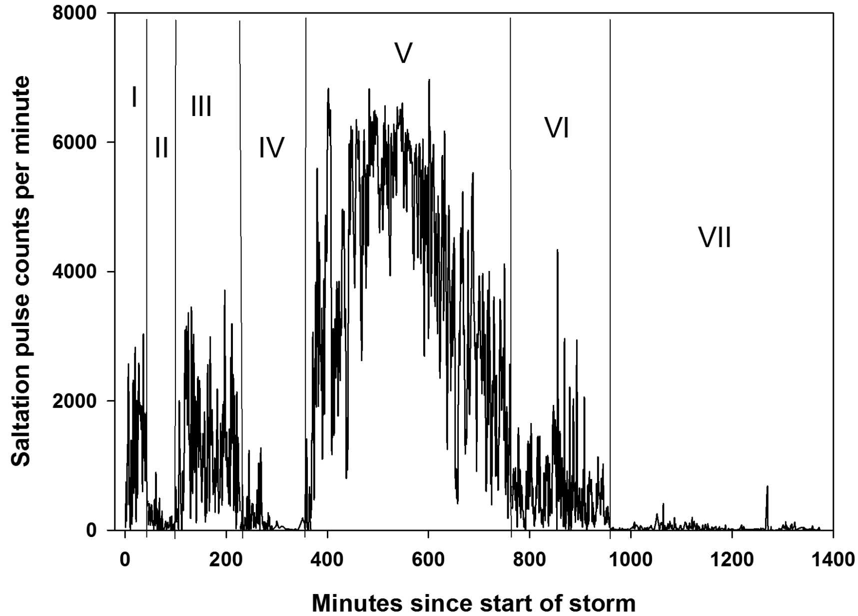

Figure 2 | Sediment transport measured with automated saltation sensor during the storm September 14 (13:46 hr) – September 15 (23:08); 2010. The storm is divided into 7 episodes labelled I-VII on the graph with the most intense sediment transport during episode V.

until the end of this storm, much of the 2–5 cm thick tephra had been removed from the barren exposed sites, with materials deposited in depressions such as gullies or blown away from the area, resulting in sediment yields of $> 10\ 000$ metric tons $km^{-2}\ yr^{-1}$. After such events, water erosion will eventually become more dominant in redistribution of the tephra materials, as was witnessed after the 1943–1990 Paricutin (Mexico) eruption[27]. We have noted evidence of water erosion starting to cause damage of previously stable surfaces in depressions at the experimental site. Wind-blown ash remained as a severe problem for more than 6 months after the 1991 Hudson (Chile) eruption[14]. However, more materials continued to be blown towards our research site from areas receiving thicker tephra deposition with continued wind erosion activity in 2012, indicating that dust events can be maintained for many years under Icelandic conditions.

We have found that the BSNE samplers give a good overview of total sediment movement, while the data generated by the automatic sensors are ideal to study the characteristics of each storm, which is consistent with conclusions made by Brachyn *et al.*[28]. The relationship between wind speed and saltation pulse counts over the entire storm period and during episode V of the storm is presented in Figure 3. The logarithmic relationship is evident with the average wind speed showing relatively narrow distribution considering the length of the storm, indicating relatively steady climatic and surface conditions during the storm. The most intensive part of the storm (episode V; Figure 3B) shows clear signs of transport saturation at the higher end of the curve at about 28 $m\ s^{-1}$ wind speed at sediment flux of about 2,300 $kg\ m^{-1}\ hr^{-1}$.

Mean grain size of the particles sampled in BSNE erosion samplers range from 0.1 to 0.7 mm, and grains > 2 mm were moved during the most intense storms during the first summer after the eruption. During the intense storm discussed here, about 78% of materials sampled in the 10 cm BSNE trap were 0.25 – 1 mm, and the proportion of this coarse ash remained similar all the way up to 120 cm (76% 0.25 – 1 mm) (Figure 4). This is coarser than reported for wind erosion within other active aeolian areas[29]. Our results show that the height of the saltation layer extends above 120 cm height, with relatively coarse materials saltating at such height during this storm, which is considerably higher than the 20–40 cm height often reported elsewhere[30,31]. Furthermore, grains > 2 mm are found in the 120 cm traps, which we have also experienced elsewhere in Iceland during major storms. The density of the material ranges from about 1.5 (porous tephra) to 2.8 $g\ cm^{-3}$ (dense glass)[20], which in part explains how high the materials are lifted, but the coarse grain size and high wind speeds also favour high saltation heights[32].

Icelandic land surfaces are unique in that they are subjected to long term continuous aeolian deposition of reworked volcanic materials originating from the desert areas. The deposition rates range from 15 to $> 800\ g\ m^{-2}\ yr^{-1}$ in all of Iceland[16]. Our results suggest that average sediment deposition rates for Iceland are influenced by such

Table 1 | Wind and sediment transport characteristics during each of seven storm episodes

Episode	Length	Wind speed $m\ s^{-1}$			Calculated transport	
	min	Average$	Max$	No of saltation pulses	$kg\ m^{-1}$	$kg\ m^{-1}\ hr^{-1}$
I	45	15.5	21.7	55,293	331	442
II	62	15.3	19.1	10,225	61	59
III	122	17.8	23.8	160,949	964	474
IV	148	14.4	21.5	19,023	114	46
V	397	22.5	38.7	1,589,559	9528	1440
VI	192	17.4	24.3	124,073	743	232
VII	405	14.1	20.1	9832	59	9

$: 1 minute averages, measured at 2.2 m height.

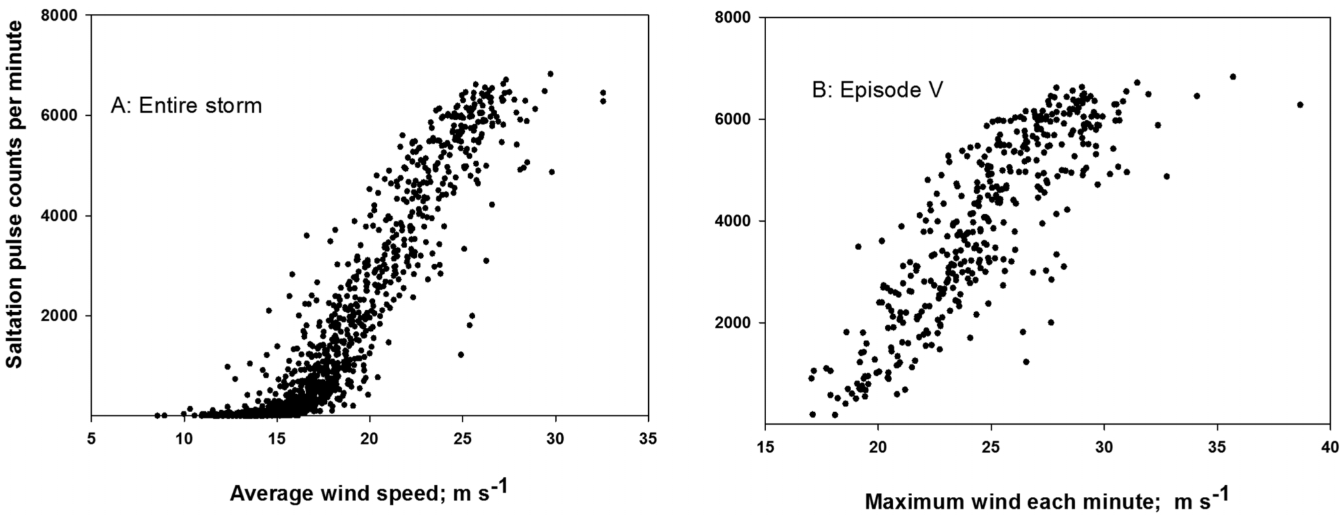

Figure 3 | Wind erosion of Eyjafjallajökull volcanic ash presented as saltation pulse counts at 10 cm height. Figure 3A shows data for the entire storm period while Figure 3B shows saltation as a function of maximum wind speed per minute for the most intense episode of the storm. Note different scale for the x-axis. Evidence of grain saturation is evident at maximum wind speeds above 28 $m\ s^{-1}$.

intense sediment production pulses. Icelandic dust storms are of regional scale, producing dust that reaches far over the North Atlantic[16,17], and they occur continuously, regardless of volcanic activity[16]. Eruptions of this kind seem to create temporary pulses which cause substantial inputs of fine ash into the atmosphere. The year following the eruption was characterized by many intense wind erosion events that greatly affected air quality over much of the South and Southwest Iceland and plumes of wind-born ash was seen far into the ocean on NOVA satellite images. As an example, the PM_{10} (particulate matter $< 10\ \mu m$) reached concentrations of $> 10{,}000\ \mu g\ m^{-3}$ in the vicinity of the volcano during the major storms and the PM_{10} value occasionally exceeded 2000 $\mu g\ m^{-3}$ in Reykjavik, 125 km from the volcano the first summer after the eruption[18]. Our measurements within the source areas during the storm give a good indication of the surface conditions during such immense dust events.

Volcanic eruptions are considered to be major contributors of nutrient renewal in ecosystems on a global scale[33]. Volcanic ash has furthermore been suggested to have a significant impact on ocean surface waters, releasing bio-available materials that benefit primary production[34,35]. Icelandic ocean areas have been reported to be nutrient limited, mainly by iron[36], which is among materials released by the ash[34]. Although there will be a higher nutrient availability with freshly deposited ash during eruptions compared to older ash the

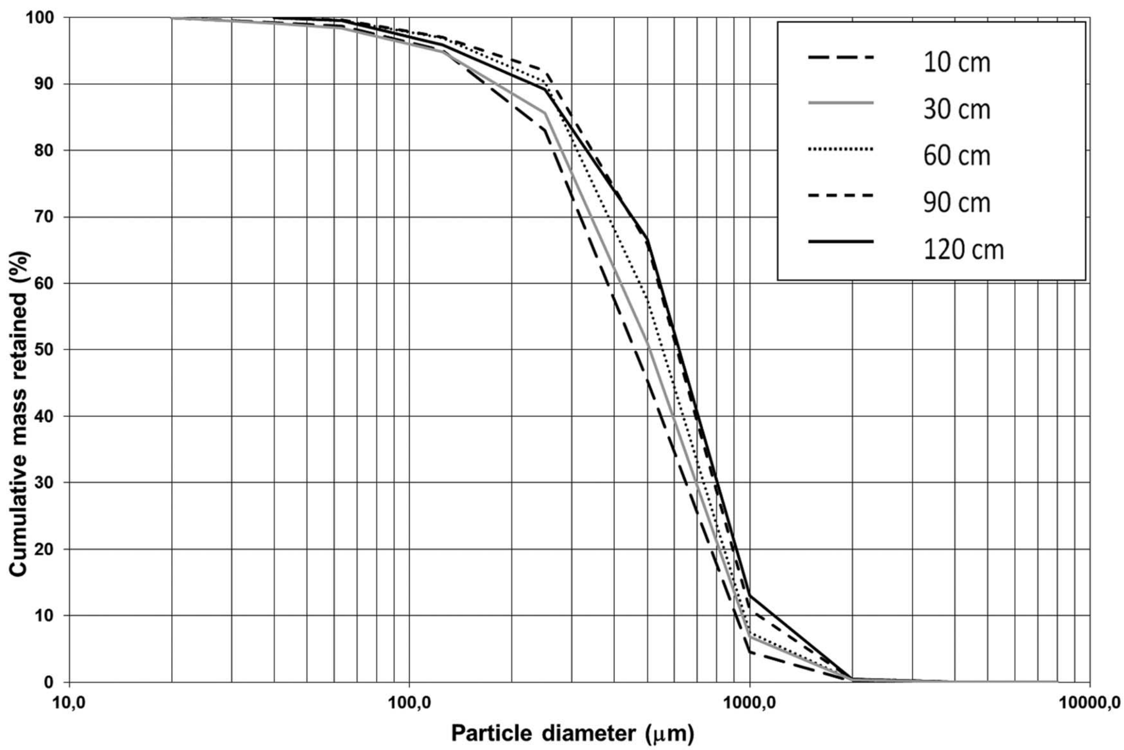

Figure 4 | Cumulative grain size for materials trapped by the BSNE samplers during the storm. The difference in grain size is notably small.

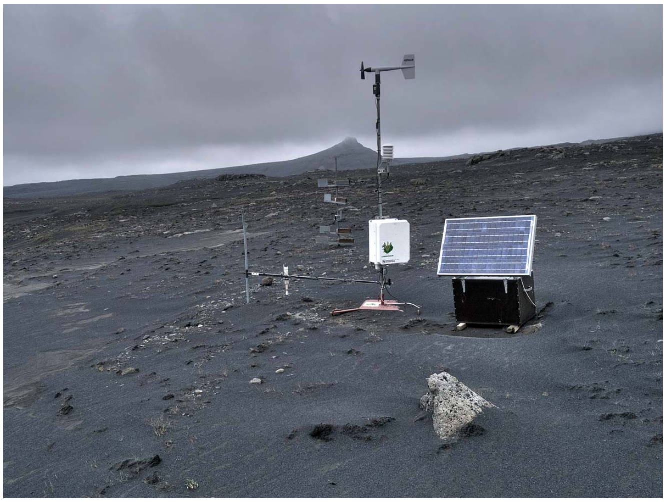

Figure 5 | Instrumentation at site. A Senist saltation sensor (white) together with equipment to measure wind speed and relative humidity. The instruments are solar powered and data is stored in a datalogger hosed in the white box, and can be accessed by a telephone link. BSNE samplers mounted on a pole in the background. The photo is taken after the occurrence of one major storm and ash has eroded from exposed sites while depressions have accumulated ash (photo: JT, June 23, 2010).

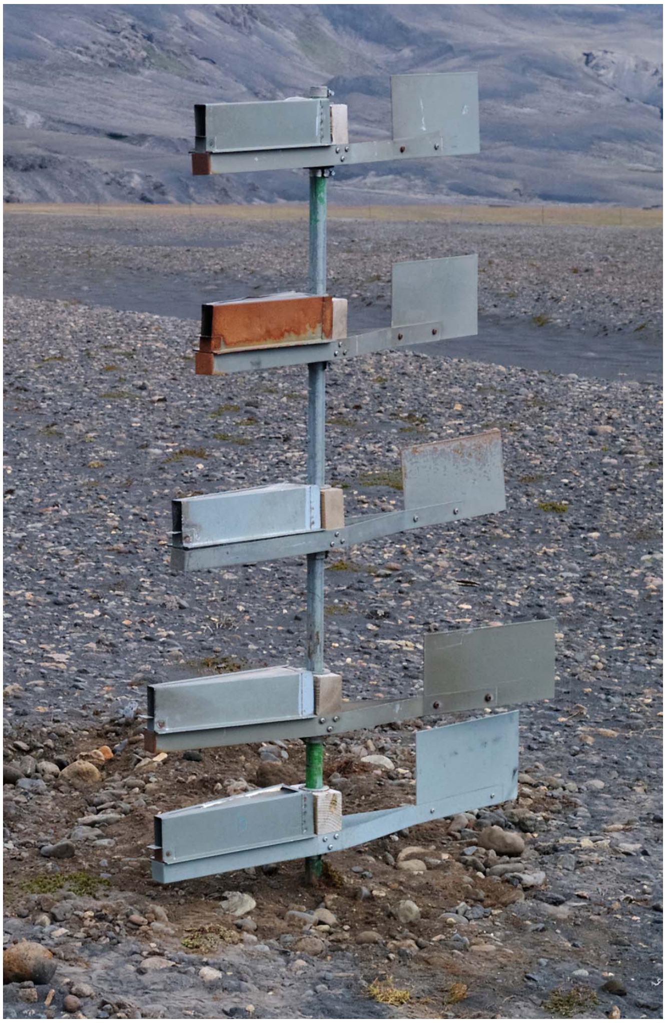

Figure 6 | A pole with five BSNE samplers placed at 10, 30, 60, 90, and 120 cm height. The opening is always directed upwind (photo: JT).

high intensity and the long duration of the dust storms related to volcanic activity may contribute to the fertility of surface waters around Iceland. This merits further research.

The erosion of the Eyjafjallajökull volcanic ash provides insight into possible scenarios for the severe soil erosion that took place in Iceland during the Middle Ages and up to the 19th century, causing large scale desertification and sand advancing over vegetated systems forming sandy areas. There are indications that when heavy land use had caused severe ecosystem degradation, some of the most severe soil erosion episodes occurred following volcanic eruptions and glacial river flooding[37]. Furthermore, the fate of the volcanic ash after deposition also highlights the importance of maintaining resistant vegetation cover such as woodlands closest to the most active

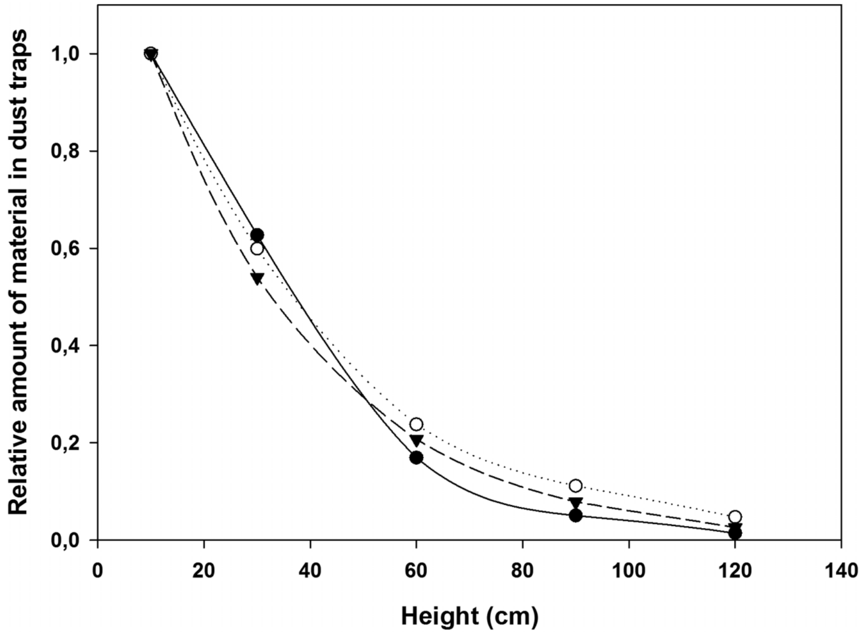

Figure 7 | Height distribution of materials collected at 10, 30, 60, 80, and 120 cm height during three storms prior to the main storm discussed in the paper. Materials collected in the 10 cm sampler is given the value of 1, others proportional to the amount in the 10 cm trap.

volcanoes in order to stabilise the tephra and prevent harmful intense dust storms.

Methods

Wind erosion was monitored on a 1,200 m long transect at 402 to 482 m elevation perpendicularly across the main ash deposition lobe about 10 km from the crater (Figure 1). The site was chosen because of relatively easy access by all-terrain vehicles along a rough track. The area received 2-5 cm of volcanic ash during the eruption. Vegetation cover was sparse prior to the ash deposition, consisting predominantly of mosses (*Racomitrium* spp. 1–2 cm high), but herbs and grasses were also common, including *Dryas octopetala, Silene acaulis*, *Armeria maritima* and *Festuca* spp.). Most of the surface, however, was barren, forming large patches of gravelly surface.

The amount of windblown material was estimated at 5 locations on the transect. We employed two methods to determine aeolian sediment transport rates: sediment accumulation in dust traps and an electronic saltation sensor (Figure 5). The dust traps were 'Big Spring number eight' (BSNE) samplers[38]. This sampler is a passive device, reliant on ambient wind conditions, to measure horizontal sand movement[39]. The sampler is placed on a pole and turns to place the opening into the wind (Figure 6). Dust-laden air passes through the sampler opening (about 9 cm^2) and the dust settles out in a collection pan. We placed a "cluster" pole at the middle of the sampling transect, with five BSNE collectors[38], mounted at heights of 10, 30, 60, 90 and 120 cm (Figure 6); and at 4 other locations a set of two samplers were employed (30 and 60 cm). Samples were dry sieved using the mesh sizes of 2, 1, 0.5, 0.25, 0.125, 0.063 and 0.040 mm, with grain size characteristics analysed and cumulative graphs made using Graditat software (v.8).

Response values used in wind erosion research varies considerably in the literature, but includes deflation (e.g., tons ha^{-1} yr^{-1}), sedimentation yield (e.g., tons km^{-2} yr^{-1}) and transport (e.g., kg m^{-1} hr^{-1} or kg m^{-2} hr^{-1}). Icelandic wind erosion research has commonly employed measurements of transport over a one m wide line or transect (kg m^{-1}) over a given time[15,25]. This unit relates well to practical situations working in the field in Iceland[25]. Previous research in Iceland suggests that height distribution curves tend to be relatively stable at the same site between storm events[25]. Average height distribution curve was constructed for available data from 2010 from the 5 sampler data sets, however excluding data when any of the traps filled up or when little was blown into the traps, a total of 3 storms (Figure 7). The average height distribution was used to calculate the transport over 1 m wide transect (kg m^{-1}) up to 150 cm height for each storm, with kg m^{-1} hr^{-1} as a flux unit, employing methods outlined in detail previously[15,25]. We assume that limited amounts of materials are saltated above 150 cm height. When the lower BSNE filled up during the most intensive storms, such as during the storm reported here, the average height distribution curve was employed, and total transport calculated based on the amount in the top samplers (90 and 120 cm). A piezoelectric transducer (Sensit) saltation sensor was used to detect the movement of wind-blown particles at 10 cm height, which has previously been found ideal height for measurements of wind erosion of volcanic materials in Iceland[15,25]. Simultaneous measurements were made of wind speed (2.2 m height), wind direction, air temperature and relative humidity. The total number of saltation counts were divided into the total amount of transported material measured by the BSNE traps to arrive at transport in g per each saltation pulse (1.97 million counts; 11,802 kg; about 6 g m^{-1} per saltation pulse).

1. Okin, G. S., Gillette, D. A. & Herrick, J. E. Multi-scale controls on and consequences of aeolian processes in landscape change in arid and semi-arid environments. *J. Arid Environ.* **65**, 253–275 (2006).
2. Skidmore, E. L. in *Soil Erosion Research Methods, 2nd ed.* : Wind erosion (ed Lal, R.) 265–293 (Soil and Water Conservation Society, Ankeny, Iowa,1994).
3. Maun, M. A. Adaptations of plants to burial in coastal sand dunes. *Can. J. Botany* **76**, 713–738 (1998).
4. Pimentel, D. & Harvey, C. in *Ecosystems of Disturbed Ground. Ecosystems of the World:Ecological effects of erosion* (ed Walker, L. R.) 123–135 (Elsevier Publ., Amsterdam, 1999).
5. Buzea, C., Pacheco, I. I. & Robbie, K. Nanomaterials and nanoparticles: Sources and toxicity. *Biointerphases* **2**, 17–71 (2009).
6. Lawrence, C. R. & Neff, J. C. The contemporary physical and chemical flux of aeolian dust: A synthesis of direct measurements of dust deposition. *Chem. Geol.* **267**, 46–63 (2009).
7. Prospero, J. M., Ginoux, P., Torres, O., Nicholson, S. E. & Gill, T. E. Environmental characterization of global sources of atmospheric soil dust identified with the NIMBUS 7 Total Ozone Mapping Spectrometer (TOMS) absorbing aerosol product. *Rev. Geophys.* **40**, 1002 (2002).
8. Washington, R. *et al.* Links between topography, wind deflation, lakes and dust: The case of Bodélé Depression, Chad. *Geophys. Res. Lett.* **33**, L09401 (2006).
9. Poortinga, A., Visser, S. M., Riksen, M. J. P. M. & Stroosnijder, L. Beneficial effects of wind erosion: Concepts, measurements and modelling. *Aeolian Res.* **3**, 81–86 (2011).
10. Gudmundsson, G. Respiratory health effects of volcanic ash with special reference to Iceland. A review. *Clin. Resp. J.* **5**, 2–9 (2011).
11. CCSP. *Atmospheric Aerosol Properties and Climate Impacts*, A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. (NASA, Washington, D.C., USA, 128 pp, 2009).
12. del Moral, R. & Grishin, S. Y. in *Ecosystems of Disturbed Ground. Ecosystems of the World: Volcanic disturbances and ecosystem recovery* (ed Walker, L. R.)137–160 (Elsevier Publ., Amsterdam, 1999).
13. Hayes, S. K., Montgomery, D. R. & Newhall, C. G. Fluvial sediment transport and deposition following the 1991 eruption of Mount Pinatubo. *Geomorphology* **45**, 211–224 (2002).
14. Wilson, T. M., Cole, J. W., Stewart, C., Cronin, S. J. & Johnston, D. M. Ash storms: impacts of wind-remobilised volcanic ash on rural communities and agriculture following the 1991 Hudson eruption, southern Patagonia, Chile. *B. Volcanol.* **73**, 223–239 (2011).
15. Thorarinsdottir, E. F. & Arnalds, O. Wind erosion of volcanic materials in the Hekla area, South Iceland. *Aeolian Research* **4**, 39–50 (2012).
16. Arnalds, O. Dust sources and deposition of aeolian materials in Iceland. *Icel. Agric. Sci.* **23**, 3–21 (2010).
17. Prospero, J. M., Bullard, J. E. & Hopkins, R. High-latitude dust over the North Atlantic: inputs from Icelandic proglacial dust storms. *Science* **335**, 1078–1082 (2012).
18. Thorsteinsson, T., Johannesson, T., Stohl, A. & Kristiansen, N. J. High levels of particulate matter in Iceland due to direct ash emissions by the Eyjafjallajökull eruption and resuspension of deposited ash. *J. Geophys. Res.* **117**, B00C05 (2012).
19. Leadbetter, S. J., Hort, M. C., von Löwis, S., Weber, K. & Witham, C. S. Modeling the resuspension of ash deposited during the eruption of Eyjafjallajökull in spring 2010. *J. Geophys. Res.* **117**, D00U10 (2012).
20. Arnalds, O., Gisladottir, F. O. & Sigurjonsson, H. Sandy deserts of Iceland: an overview. *J. Arid Environ.* **47**, 359–371 (2001).
21. Arason, P., Petersen, G. N. & Bjornsson, H. Observations of the altitude of the volcanic plume during the eruption of Eyjafjallajökull, April-May 2010. *Earth Sys. Sci. Data* **4**, 1–25 (2011).
22. Sigmundsson, F. *et al.* Intrusion triggering of the 2010 Eyjafjallajökull explosive eruption. *Nature* **468**, 462–430 (2010).
23. Guðmundsson, M. T. *et al.* Ash generation and distribution from the April-May 2010 eruption of Eyjafjallajökull, Iceland. *Sci. Rep.* **2**, 572 (2012).
24. Dong, Z. & Qian, G. Characterizing the height profile of the flux of wind-eroded sediment. *Environ. Geol.* **51**, 835–845 (2007).
25. Arnalds, O., Gisladottir, F. O. & Orradottir, B. Determination of aeolian transport rates of volcanic soils in Iceland. *Geomorphology* **167–168**, 4–12 (2012).
26. Agustsdottir, A. M. Research on the effects of wind barriers - Fences for wind erosion control at Halslon, the water storage reservoir for the Karahnjukar Hydropower Project, in Eastern Iceland [In Icelandic]: Landsvirkjun LV - 2007/111. Reykjavik, Iceland (2007).
27. Inbar, M., Hubp, J. L. & Ruiz, L. V. The geomorphological evolution of the Paricutin cone and lava flows, Mexico, 1943–1990. *Geomorphology* **9**, 57–76 (1994).
28. Barchyn, T. E., Hugenholtz, C. H. & Ellis, J. T. A call for standardization of aeolian process measurements: moving beyond relative case studies. *Earth Surf. Proc. Land.* **36**, 702–705 (2011).
29. Pye, K. & Tsoar, H. *Aeolian Sand and Sand Dunes.* Unwin Hyman Ltd, London (1990).
30. van Donk, S. J. & Skidmore, E. L. Field experiments for evaluating wind erosion models. *Ann. Arid Zone* **40**, 283–302 (2001).
31. Zobeck, T. M. *et al.* Measurement and data analysis methods for field-scale wind erosion studies and model validation. *Earth Surf. Proc. Land.* **28**, 1163–1188 (2003).
32. Dong, Z., Liu, X., Wang, H., Zaho, A. & Wang, X. The flux profile of a blowing sand cloud: a wind tunnel investigation. *Geomorphology* **49**, 219–230 (2003).
33. Vitousek, P., Chadwick, O., Matson, P., Allison, S., Derry, L., Kettley, L., Luers, A., Mecking, E., Monastra, V. & Porder, S. Erosion and rejuvenation of weathering-derived nutrient supply in an old tropical landscape. *Ecosystems* **6**, 762–772 (2003).
34. Frogner, P., Gislason, S. R. & Oskarsson, N. Fertilizing potential of volcanic ash in ocean surface water. *Geology* **29**, 487–490 (2001).
35. Duggen, S., Olgun, N., Croot, P., Hoffmann, L., Dietze, H., Delmelle, P. & Teschner, C. The role of airborne volcanic ash for the surface ocean biogeochemical iron-cycle: a review. *Biogeosciences* **7**, 827–844 (2010).
36. Nielsdottir, M. C., Moore, C. M., Sanders, R., Hinz, D. J. & Achterberg, E. P. Iron limitation of the postbloom phytoplankton communities in the Iceland Basin. *Glob. Biochem. Cycl.* **23**, GB3001 (2009).
37. Arnalds, O. *et al. Soil Erosion in Iceland.* Soil Conservation Service and Agricultural Research Institute, Reykjavik, Iceland (2001).
38. Fryrear, D. W. A field dust sampler. *J. Soil Water Conserv.* **41**, 117–121 (1986).
39. Goossens, D. & Offer, Z. Y. Wind tunnel and field calibration of six aeolian dust samplers. *Atmos. Environ.* **34**, 1043–1057.

Acknowledgements

This research was funded by the Soil Conservation Service of Iceland and the Agricultural University of Iceland. We greatly acknowledge the help of Odinn Burkni Helgason at the Soil Conservation Service of Iceland for technical support with electronic equipment at the site.

Author contribution

O.A. coordinated the writing of the paper. A.M.A., E.F.T., J.T. and O.A. made original plans for the project. All authors took part in data collection while analysis of sediment transport was made by E.F.T., P.D.W. and O.A. O.A., E.F.T., J.T., P.D.W. and A.M.A. commented and discussed the results during the writing.

Additional information

Competing financial interests: The authors declare no competing financial interests.

How to cite this article: Arnalds, O., Thorarinsdottir, E.F., Thorsson, J., Waldhauserova, P.D. & Agustsdottir, A.M. An extreme wind erosion event of the fresh Eyjafjallajökull 2010 volcanic ash. *Sci. Rep.* **3**, 1257; DOI:10.1038/srep01257 (2013).