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Volcanic hazards in Búrfellslundur

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Lykilorð: Hekla, eldgos, náttúruvá, Búrfellslundur

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An overview of volcanic hazards that may impact the proposed wind farm Búrfellslundur, with emphasis on hazards due to Mt. Hekla. The volcanic hazards due to Hekla are listed and their potential impact on the planned wind farm.

Lykilorð: Volcanic hazards, Hekla, tephra dispersal,	**Undirskrift framkvæmdastjóra sviðs:** Jórunn Harðardóttir
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1 Introduction

In connection to an environmental assessment of the proposed wind farm Búrfellslundur, Mannvit asked the Icelandic Meteorological Office (IMO) to write a short report on volcanic hazards that can affect the proposed wind warm. In particular, volcanic hazard due to Mt. Hekla is of interest as the volcano is located about 15-20 km to the south of the proposed wind farm.

2 General description of the main volcanic hazards in the area

An extended review of literature on volcanic hazards in Iceland has been conducted within the Catalogue of Icelandic Volcanoes project, funded by the Icelandic government. Within the project an interactive catalogue has been created and it is now accessible online at futurevolc.vedur.is.

Mt. Hekla is one of the 32 volcanic systems listed in the catalogue and a complete description of its historical activity is available. Indeed, due to its frequent eruptions in the last hundred years the main potential hazards associated with a new eruption in the system can be identified.

Based on historical records Mt. Hekla can generate:

- **Tephra fallout –** Pyroclasts of different sizes, from few microns to centimetres, are carried aloft by the rising eruption plume and form a volcanic cloud. As the wind transports the plume, these solid particles fall out due to gravity and accumulate on the ground.
- **Volcanic lightning -** Plume lightning is common during explosive volcanism. Usually most lightning strikes are above the vent area, but some may strike down from the plume tens of kilometres from the volcano.
- **Lava flows** - Magma released from the vent can flow along the volcano slope at low velocities.
- **Pyroclastic flows** – A mixture of hot gases and pyroclasts can move at high velocities along the slope of the volcano. They can occur at the beginning, during and at the end of an eruption.
- **Meltwater floods –** Melting of the perennial snow on the top of the volcano can generate meltwater floods.
- **Laterally directed explosion –** The opening of a lateral vent can be accompanied by a lateral explosion. In this case the failure of the system could generate a pyroclastic surge (less dense than a pyroclastic flow) with a significant runout.
- **Gas and aerosol emission** - Major volcanic gases are released during a volcanic eruption. Fluorine is particularly abundant.

These will lead to hazards at different distances and in different areas, depending on the nature of the hazard itself, as well as on the size of the event and its location on Mt. Hekla. With the exception of pyroclastic flows and surges, for which the maximum runout expected is within a range of 5 km from the eruption site, all others phenomena can cover distances larger than 10-15 km from the vent. This means that during an eruption at Hekla, the area of the planned wind farm Búrfellslundur (located at about 15–20 km from the top of Hekla) can be affected by several types of volcanic hazards. The following sections include further details on these hazards.

3 Ash dispersal and tephra fallout

The main volcanological parameters controlling the severity of tephra fallout during an eruption are the amount of material erupted and the altitude of its injection in the atmosphere. The more intense an eruption is, the higher is the plume. In addition, the environmental conditions are important factors in determining the extension of the tephra dispersal. The dispersal of tephra and its deposition is indeed affected primarily by the wind field, which plays a major role in defining the direction and the width of the exposed area.

3.1 Wind statistics

The dispersion of tephra and volcanic gasses in an explosive eruption depends on the intensity of the eruption, i.e. at which altitude the volcanic material is injected into the atmosphere as the winds and stability of the atmosphere varies between levels. In particular it is of importance if the eruption plume is confined to the troposphere (the lowest ~10 km of the atmosphere at high latitudes) or extends into the stratosphere (~10-50 km in altitude).

The lowest part of the troposphere (~100s m – 2 km) is the atmospheric boundary layer, which is under direct influence of the Earth's surface. In this layer wind speed is in general lower than further up, depending on the surface characteristics, and wind direction may be significantly different. In addition heat, humidity and pollution are in general well mixed in the layer. Tephra dispersal into the boundary layer has short life time, i.e. it falls out and is deposited rather quickly. In the free troposphere above, the air flow is less restricted by Earth's surface and ash and other volcanic particles can be dispersed for 100 km – 1000 km, depending on the size of the particles and the wind speed, before being deposited due to gravitation and precipitation. However, if the injection is into the stratosphere (which is very stable and therefore there is little vertical mixing although winds can be strong) the particles can remain in the stratosphere for months and winds can transport them around the globe. Eventually all particles are deposited due to gravitation.

The dispersal direction is dependent on the wind direction, which varies with both altitude and season. Figure 1 emphasises how the frequency of wind directions depend on altitude for measurements from Keflavík international airport (data from 1973–2015). The figure shows wind roses where the frequency of the wind direction is shown with wind blowing toward the centre of the wind rose. The pressure levels 850 hPa, 500 hPa, 300 hPa and 100 hPa level are at approximately 1500 m, 5 km, 9 km and 16 km altitude, respectively.

At the lowest level, 850 hPa (~1500 m), the wind rose is rather diffuse. Winds from southerly wind direction, east-southeasterly to west-southwesterly, are the most common and there is also a considerable north-northeasterly component. However, northwesterly winds are the least common. At 500 hPa (~5 km), in the middle of the troposphere, the frequency is more distinct with southwesterly wind most common. At 300 hPa (~9 km), at the top of the troposphere, southwesterly and westerly winds are the most common with northeasterly and easterly winds having low frequency. Finally at 100 hPa (~16 km), in the lower stratosphere, westerly winds are by far the most common.

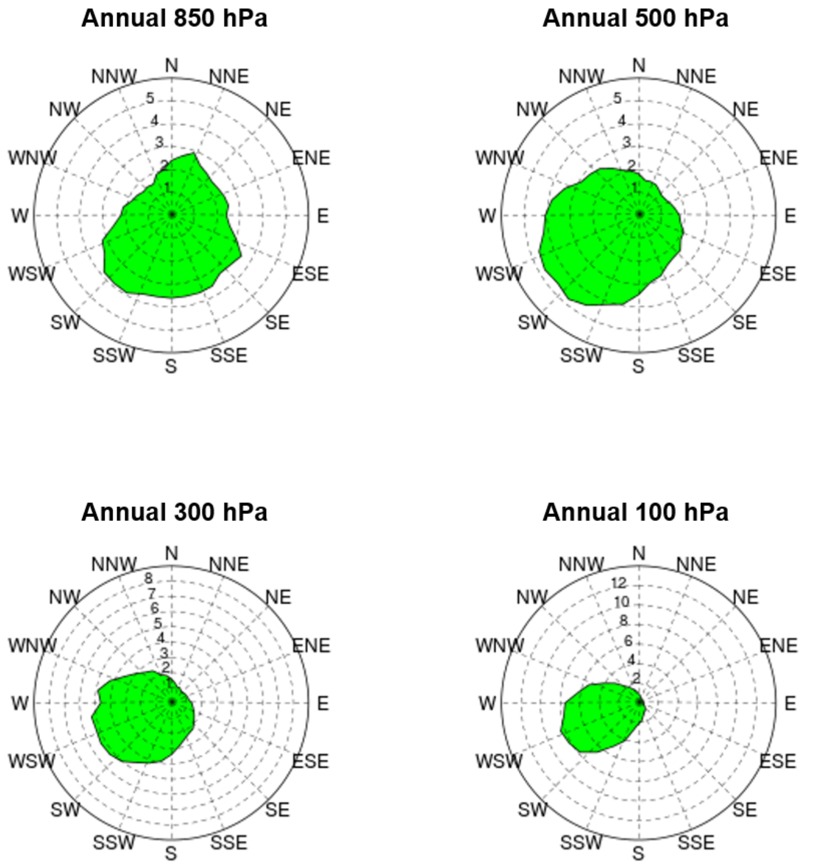

Figure 1. The annual wind rose over Keflavík international airport at 850 hPa, 500 hPa, 300 hPa and 100 hPa level, approximately 1500 m, 5 km, 9 km and 16 km altitude respectively. Measurements from 1973–2015. Note the frequency is shown up to 5% for the lower levels but up to 8% and 12% for the higher levels.

The wind pattern changes between seasons and thus the frequency of wind directions, see Figure 2. During summer the wind speed at lower levels is in general lower and wind direction more diffuse while in the winter time southwesterly winds are the more common. In the middle of the stratosphere, at 30 hPa (~24 km) the wind direction is extremely seasonal, westerly winds during summer and easterly winds during winter.

Búrfellslundur is located north of Mt. Hekla. Given that southeasterly to southerly winds are rather frequent in the lower part of the troposphere it is likely that in case of an explosive eruption in Hekla ash can be dispersed over the region. However, although there is a seasonal variability in the wind directional frequency, the general variability of wind direction and wind speed is great over Iceland and the ash dispersal direction therefore depends in each case on the intensity of the eruption as well as the weather situation.

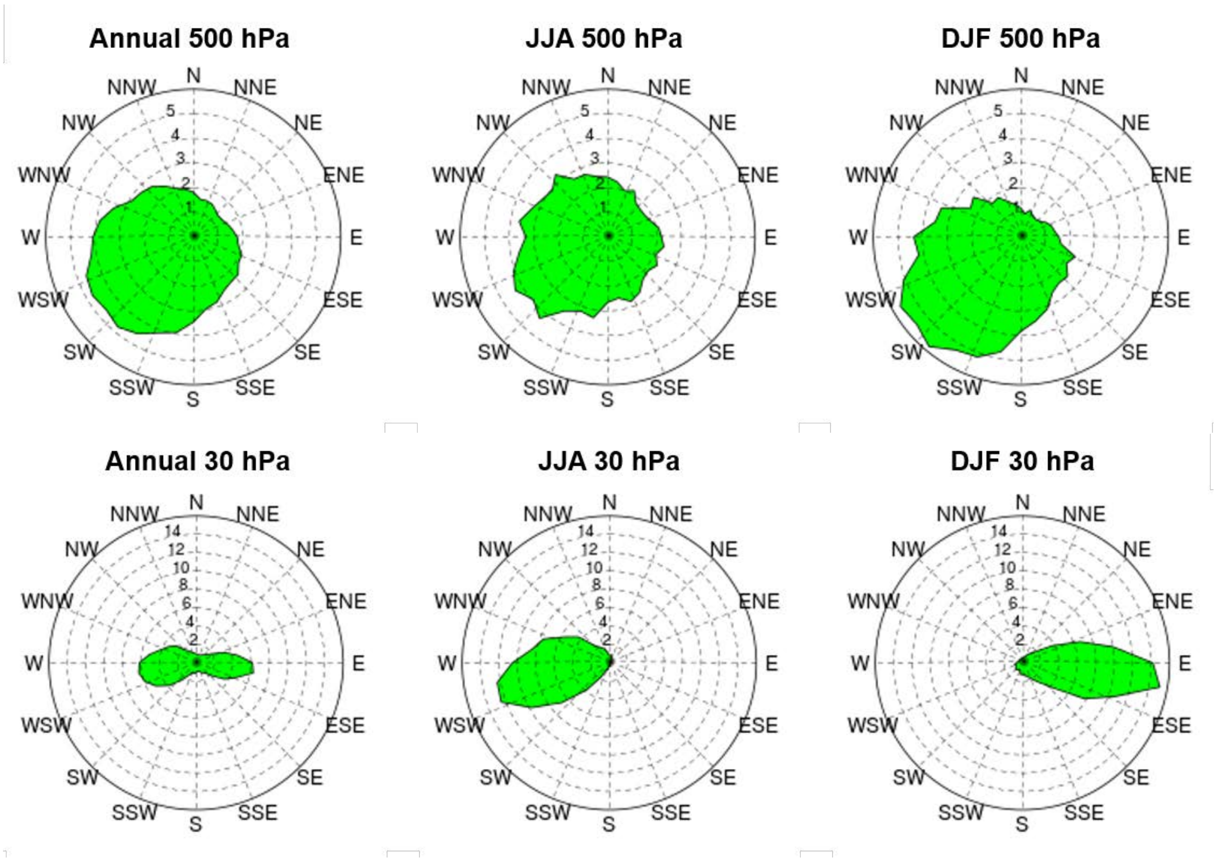

Figure 2. The annual, JJA (June, July & August) and DJF (Dec, Jan & Feb) wind roses over Keflavík international airport at 500 hPa and 30 hPa level, approximately 5 km and 16 km altitude. Measurement from 1973–2015.

3.2 Hazard assessment based on historical events and probabilistic approach

Tephra production during a Hekla eruption is common. From the beginning of the 20th century Hekla has erupted six times, with tephra fallout in all eruptions except for the one in 1913, which has been classified as purely effusive. The strongest explosive eruption occurred about 4300 years ago and has been assigned a VEI (Volcano Explosive Index) equal to 6. The ash cloud generated at that time extended as far as Central Europe. Based on historical data, the location of the planned wind farm is at a distance that can easily be affected by a tephra deposit of well above 10 cm but less than 100 cm (Figure 3, Thorarinsson, 1967). In addition, tephra records indicates that a tephra deposit towards the northern side of the volcano has a frequency of occurrence of 44% as shown in Figure 3 (Larsen & Gíslason, 2013).

In recent years a probabilistic hazard assessment has been conducted for some Icelandic volcanoes (Biass et al. 2014). For Mt. Hekla, the authors considered two hypothetical eruptive scenarios: 1) like-2000 case and 2) like-1947 case. By using a multiple runs approach and a meteorological statistics they computed the likelihood of exceeding specific thresholds of ground deposit across Iceland. Interpreting their data for the area of the proposed Búrfellslundur, in the case of scenario 1 the probability of the area being affected by a deposit of 10 kg/m^2 is between 20 and 30%. The probability of having a deposit of 1 kg/m^2 rises to almost 40% in case of scenario 2.

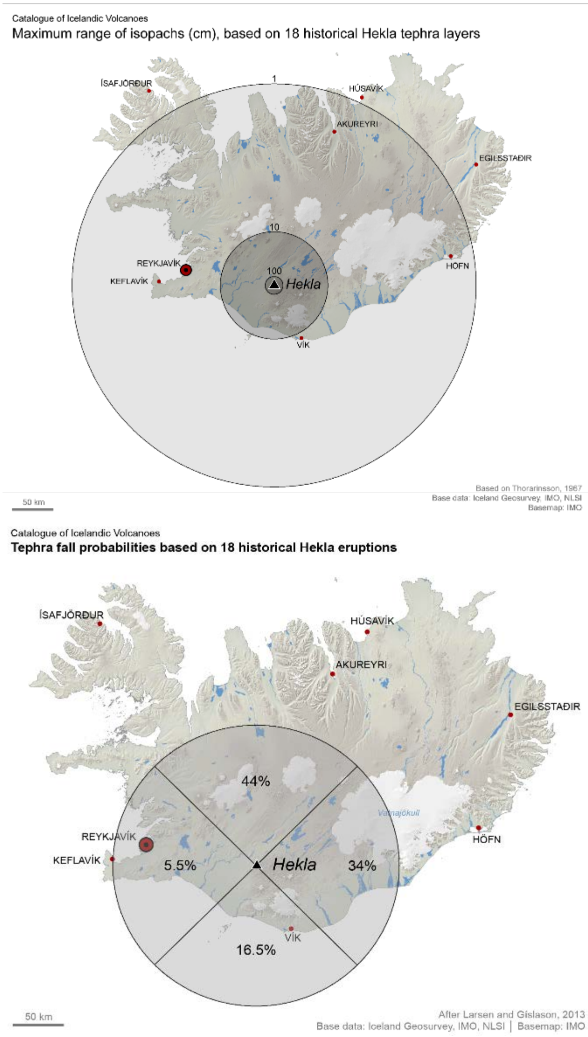

Figure 3. Left: Estimated maximum distances from the vent of tephra deposit thickness equal to 100, 10 and 1 cm. Right: Probabilities of tephra dispersal towards the four cardinal directions. The results are based on historical eruption records. From The catalogue of Icelandic volcanoes and based on Thorarinsson (1967) and Larsen and Gíslason (2013).

3.3 Volcanic ash dispersal forecasts

IMO is in charge of monitoring and forecasting impending natural hazards. Amongst others phenomena, IMO forecasts the dispersal in the atmosphere of volcanic ash and gases. Each day maps of ash concentration and deposition for hypothetical eruption at Mt. Hekla are produced for internal viewing. In case of a real event similar maps will be available on IMO‘s webpage as a public warning.

4 Volcanic lightning

Lightning is produced by active volcanic plumes. Lightning location systems have observed lightning during all explosive volcanic eruptions in Iceland since the installation of such systems 19 years ago. Usually, most of these lighting are confined to the volcanic column above the vent, but some activity is evident downwind in the plume. During the Katla 1755 eruption two persons were killed by a volcanic lightning 35 km from Katla. During the Hekla 2000 eruption, lighting were observed up to 80 km downwind of the volcano.

5 Lava flows

Lava flow emplacement is primarily driven by topographical features and its directionality is mainly determined by the steepest slope in the vicinity of the volcanic vent. The main volcanological parameters affecting the lava flow propagation is directly connected with its rheological properties which eventually control its viscosity and fluidity. The less viscous is the magma, the fastest it propagates. Hekla can erupt both silicic and intermediate and basaltic magma (Catalogue of Icelandic Volcanoes, 2015 and references herein).

5.1 Historical events

In the last 9000 years, about 50 eruptions produced basaltic lava flows, whereof 17 eruptions in the last 900 years were silicic. Historically lava flows were generated during both small and moderate eruptions, and they mainly occurred at the beginning of events lasting for days to weeks, occasionally for years (e.g. 1766–1768 CE). The volume erupted during a single eruption varied from ~0.01 up to >1 km^3 covering an area of 10 up to >60 km^2. Lava flows were directed isotropically around the volcanic edifice, with no special preferred directions, with the exception of the reliefs Næfurholtsfjöll and Sauðafell (located to north of the volcano) which deviated the lava flowing to the north-northwest (Figure 4). The maximum flow range observed is 25–30 km from source.

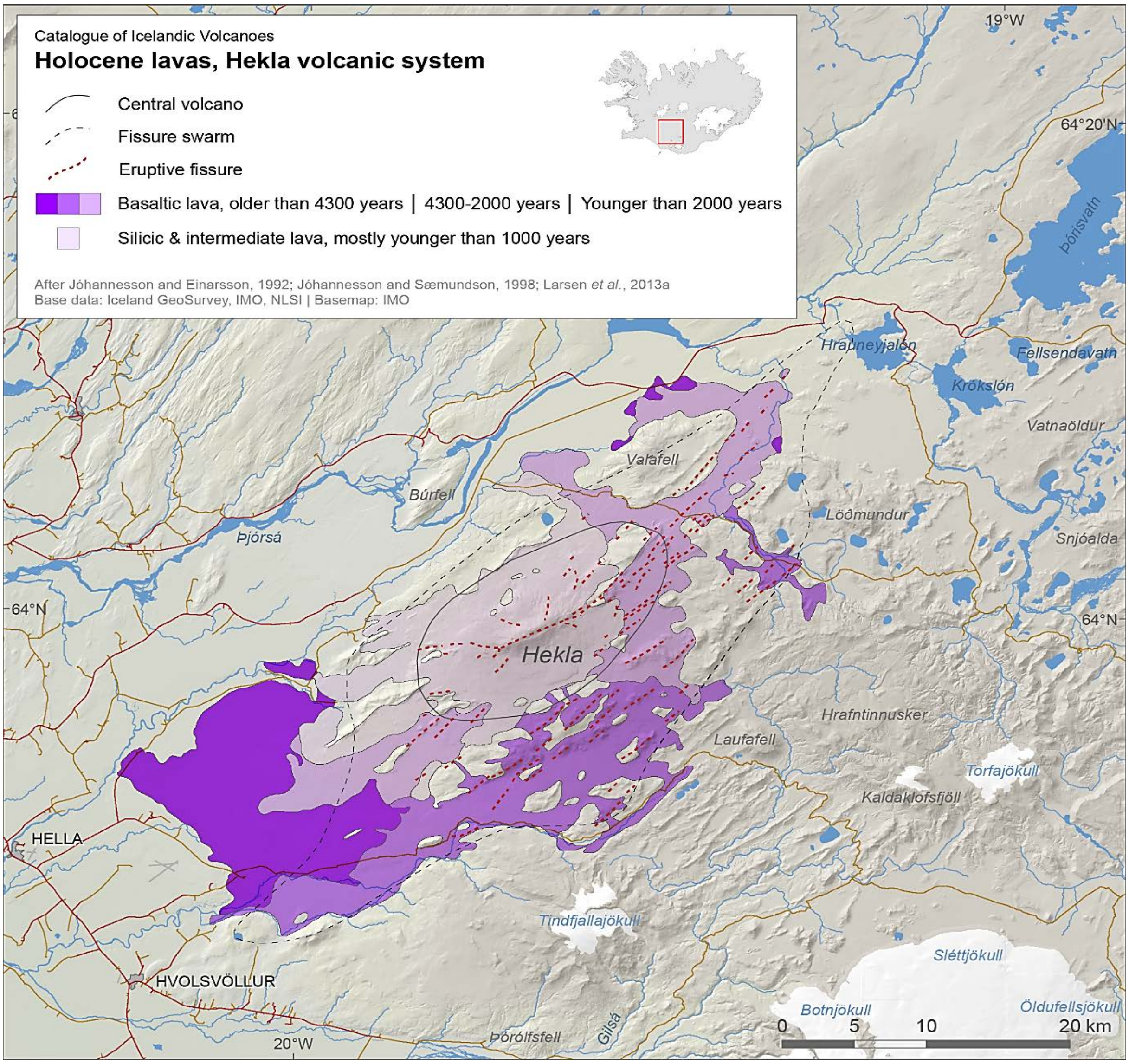

Figure 4. Lava flow patterns reconstructed from the field as produced by the effusive eruptions occurred during the Holocene. From The catalogue of Icelandic volcanoes.

6 Meltwater floods

During an eruption at Hekla the perennial snow cap can melt and generate a jökulhlaup. The size of the flood will depend on the volume of snow accumulated. It is estimated that the longest runout is up to 15 km from the originating source. In the 1947 CE Hekla eruption the volume of jökulhlaup water was estimated at about 3×10^6 m^3 and maximum discharge on the slopes of the mountain at about 900 m^3/sec. Tephra fall into rivers and river basins has caused damming and flooding in Ytri-Rangá river and tephra rafting in Þjórsá river (Catalogue of Icelandic Volcanoes, 2015 and references herein).

7 Summary and conclusions

Eruptions at Mt. Hekla can result in volcanic hazards that affect the proposed wind farm Búrfellslundur, in particular tephra fallout, lightning lava flows and jökulhlaup. The area affected by lava flows and jökulhlaup can to some extend be estimated based on the prior eruptions. However, tephra fallout and the number and location of lightning depends on the strength of the eruption and the atmospheric winds. Lightning has been observed up to 80 km from Hekla during a previous eruption. Historical data also suggests that tephra deposit thickness may be over 10 cm but less than 100 cm in the Búrfellslundur area. The tephra deposit direction depends on the wind direction, and the frequency of wind directions not only varies with altitude but also between seasons. Therefore, although from prior eruptions the probability of a dispersion to the north is 44% the ash dispersal in each case will depend on the intensity of the eruption, i.e. at which altitude the volcanic particles are injected into the atmosphere, as well as the current weather situation.

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