VEÐURSTOFA ÍSLANDS

Report
03029

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Hazard zoning for Patreksfjörður, Vesturbyggð

VÍ-ÚR20
Reykjavík
August 2003

Contents

1 Introduction

This report is an assessment of avalanche hazard for the village Patreksfjörður which is within the community of Vesturbyggð. It was carried out by the Icelandic Meteorological Office (IMO). The assessment is done according to a regulation on hazard zoning due to avalanches and landslides, classifications and utilization of hazard zones, and preparation of provisional hazard zoning issued by the Ministry for the Environment in July 2000.

Similar reports have been published for Neskaupstaður, Siglufjörður, Seyðisfjörður, Eskifjörður, Ísafjörður and Bolungarvík (Thorsteinn Arnalds *et al.* 2001a,b,c, 2002a,b,c; Kristján Ágústsson *et al.* 2002).

1.1 Work process

The main participants in this work were Kristján Ágústsson, Tómas Jóhannesson, Hörður Þór Sigurðsson, Þorsteinn Arnalds, Esther H. Jensen (IMO), Siegfried Sauermoser (Austrian Forest-technical Service), Thomas Glade and Rainer Bell (University of Bonn).

Other employees of IMO have also contributed to the work. Þóranna Pálsdóttir has analysed the weather preceding avalanche cycles. Leah Tracy has drawn maps in the report and the local snow observer, Jónas Sigurðsson, assisted in the field work and helped in many other ways.

Halldór G. Pétursson (Icelandic Institute of Natural History) has compiled debris flow chronicles (Halldór G. Pétursson 2000).

Sólrún Geirsdóttir (Natural Research Center of the NW Peninsula of Iceland) has collected information on the development of the settlement as well as the history of individual houses (Sólrún Geirsdóttir 2000).

The work on this project started in the summer of 2000. A field investigation was carried out in the autumn of 2000 when Siegfried Sauermoser and Kristján Ágústsson mapped the potential avalanche paths. Esther H. Jensen, Thomas Glade and Rainer Bell investigated debris flow and rockfall conditions.

The following items were the subject of the field investigations regarding avalanche conditions:

a) *Topographic conditions, i.e.* the topography of the starting zone, track and runout area.

b) *Climatic conditions* would be dealt with mostly on a regional basis, but locally the effect of the regional climate on snow accumulation in starting areas would be discussed.

c) *Assessment*. The group would give its general opinion of the avalanche hazard in a particular path. This would be done by quantifying the size of the starting areas and their relative frequency with respect to other paths.

These descriptions form the basis of the final report presented here.

In the debris flow and rockfall investigation (Glade and Esther H. Jensen 2003), similarly, potential starting areas and runout zones were mapped and the recurrence time estimated.

A hazard zoning committee for Vesturbyggð was formally established 23.04.2003. The first meeting of the committee with the IMO staff was held on 14.04.2003.

To strengthen the basis of the hazard zoning, two-dimensional model calculations were carried out by Advanced Simulation Technologies (AVL) of Graz, Austria (Leah Tracy and Tómas Jóhannesson, 2003).

Based on the background data described above the hazard zones were delineated. The delineation was done by Kristján, Tómas and Hörður Þór.

1.2 Organisation of the report

The first part of the report is an overview of the general topographic and climatic conditions in the area and a review of the settlement history and former work on hazard related investigations. The investigated area is shown on Map 1.

The next five sections contain more detailed description of avalanche areas in Patreksfjörður in which the following items are addressed:

Topographic conditions: Physical characteristics of the starting zone, track and runout area.

Local climatic conditions: Characteristics of the starting areas with respect to snow accumulation.

Chronicle: A short review of the avalanche history.

Assessment: Discussion of the avalanche conditions and qualitative hazard analysis.

Model estimates: Model results are the basis of the hazard zoning.

Conclusion: Hazard evaluation and proposed hazard zoning.

Then there is a section on slush flows, debris flows and rockfall. Finally, there is a summary of the results of the project.

There are four appendices in the report. In appendix A technical concepts and notations are explained. Those are parameters like runout indices (r) and runout angle (α). Further, definitions of α- and β-points and a description of the α/β-model. A short description of recorded avalanches is given in appendix B and maps are in appendix C. Appendix D contains the longitudinal sections of the profiles and the results of runout modeling.

Table 1. *Icelandic hazard zone definitions*

Zone	**Lower level of local risk**	**Upper level of local risk**	**Construction allowed**
C	$3 \cdot 10^{-4}$/yr	–	No new buildings, except for summer houses*, and buildings where people are seldom present.
B	$1 \cdot 10^{-4}$/yr	$3 \cdot 10^{-4}$/yr	Industrial buildings may be built without reinforcements. Domestic houses have to be specially reinforced. Existing hospitals, schools *etc*. can be enlarged and then have to be specially reinforced.
A	$0.3 \cdot 10^{-4}$/yr	$1 \cdot 10^{-4}$/yr	Houses where large gatherings are expected, such as schools, hospitals *etc*., have to be specially reinforced.

*If the risk is less than $5 \cdot 10^{-4}$ per year.

1.3 Methodologies and regulations

The hazard zoning presented in this report is based on Icelandic hazard zoning regulations that were issued in July 2000 after having been under development for several years. A summary of these regulations is included below.

Hazard zoning in Iceland has since 1995 been based on individual risk which is the yearly probability that a person living at a given place will be killed by an avalanche. The definition of hazard zones is based on the *local risk* defined as the annual probability of being killed given that a person is staying all the time in a house which is not specially reinforced. The *actual risk* can be found by taking into account the probability of the person being present in a house when an avalanche hits and the increased safety obtained by reinforcing houses. Increased safety by evacuations and other non-permanent safety measures is not taken into account in the hazard zoning. The authorities in Iceland have adopted the value $0.2 \cdot 10^{-4}$ per year as an accepted actual risk for avalanche hazard zoning (The Ministry for the Environment, 1997). This value corresponds to different values of the local risk for different types of constructions depending on the fraction of time people may be expected to spend in the buildings (typical values are assumed to be 75% in domestic houses, and 40% in commercial buildings). The regulations on hazard zoning (The Ministry for the Environment, 2000) defines three types of hazard zones, see Table 1.

These guidelines for zoning are tailored to attain the acceptable risk level of $0.2 \cdot 10^{-4}$ per year in residences when presence probability and increased safety provided by special reinforcements have been taken into account. The risk in industrial buildings is probably somewhat higher.

The methodology used here to estimate avalanche risk was developed at the University of Iceland and the Icelandic Meteorological Office in the period 1995–1998. The methods are described by Kristján Jónasson *et al*. (1999).

The methodology for hazard zoning with regard to debris flows and rockfall is described by Tómas Jóhannesson and Kristján Ágústsson (2002) and summarised in the following section.

This discussion is concluded by quoting §10 of the Icelandic regulations on how to proceed where formal risk calculation is impossible: “In areas, where it is not possible to estimate the risk formally due to insufficient information, a hazard map shall nevertheless be prepared according to §12 [§12 describes the risk zones of a hazard map]. In the preparation of the map an attempt shall be made to estimate risk.”

1.4 General guidelines regarding debris flows, rockfall, slushflows and torrents

Hazard zones in Iceland shall according to the hazard zoning regulation of July 2000 (Ministry for the Environment, 2000) take into account hazard due to debris flows and other landslides, rockfall and torrents in addition to snow avalanches and slushflows. Guidelines for hazard zoning with regard to such processes have been formulated by IMO (Tómas Jóhannesson and Kristján Ágústsson, 2002). The guidelines attempt to formulate a zoning procedure where the delineation of hazard zones reflects the risk that people are exposed to due to the respective events.

The principle problem encountered in this type of hazard zoning is how to treat the risk in areas where neither the landslide chronicle nor geological investigations directly indicate an impeding danger to the settlement. Another problem is the widely different probability of death for people that encounter the different types of events. It is, for example, clear that typical torrents in Iceland pose a much smaller risk to the lives of people than snow avalanches. Thus, the probability or return period corresponding to a set value of acceptable risk is widely different for the different events.

According to the guidelines, the landslide chronicle and geological investigations are first used to identify potential areas of high risk where the danger of catastrophic landslide events may be directly inferred from such investigations. The delineation of hazard zones with regard to the results of these investigations cannot be formulated beforehand and must be subjectively determined by the experts performing the zoning.

It is assumed that hazard zones with regard to *rockfall* will typically be of type A (the lowest risk zones), except in special circumstances where the danger of rockfall is judged very high. It is recommended that the hazard line with regard to rockfall is drawn where the return period of rockfall is on the order of 50–100 years. This return period should reflect an area of the size of a building or a typical lot on which a building stands. This location may be estimated by a statistical or a dynamical rockfall model. The model should be calibrated to reproduce the runout distance corresponding to observed loose rocks below source areas of rockfall that have fallen during the last decades or century.

The guidelines propose following classification for slush flow and debris flow paths.

1. **A well confined path of a river or a brook** such that a landslide may be expected to be largely limited to the course of the river. A less powerful part of it may overflow the banks

and spread into nearby areas. The area of the watershed of paths in this class is on the order of 10–30 hectares up to and over 100 hectares and extreme floods may range from a few m^3/s up to tens of m^3/s.

2. **A partly confined path of a river or a brook** where landslides do not follow a predetermined direction and may take different directions when they enter the endangered area. The area of the watershed and the size of extreme floods is similar as in class 1.

3. **A gully or the path of a small brook** which may be dry for a part or most of the year. The watersheds of these paths are smaller than in the first two classes, *i.e.* on the order of a hectare or a few hectares, and extreme floods are on the order of a m^3/s or less.

The guidelines propose that type C hazard zones will in general be delineated for the central parts of paths of class 1, type B hazard zones will be defined for the wide paths of type 2 and type A hazard zones in areas affected by paths of type 3. A delineation of watersheds and an estimation of extreme floods in the main rivers and brooks of the mountainside is recommended as a part of the preparation of a hazard zoning for paths of this kind.

In some areas there is a danger of *debris flows* outside of the courses of rivers or brooks that are classified above. Unless there are special indications of high danger, such debris flows are considered to be much less dangerous than snow avalanches. The guidelines propose that the hazard line with regard to debris flows in such areas corresponds to a return period of several hundred years, *i.e.* a much shorter return period than for snow avalanches but longer than for rockfall.

According to the guidelines, river floods should only be considered in steep paths where there is a danger of debris flows or slushflows. General river flooding problems are not to be considered as a part of the snow- and landslide hazard zoning according to the Icelandic hazard zoning regulation of July 2000.

In Patreksfjörður debris flows have caused some damage and they are considered to pose some threat to human lives. Rockfall is frequent and large boulders have recently fallen down the slope and stopped just above the settlement.

1.5 Uncertainty

The estimation of avalanche risk is difficult in many areas. This is especially the case when dealing with a slope that from the topographical point of view has the characteristics of an avalanche path, but where no avalanches have been recorded. Accurate records of avalanches have only been kept for a few years or decades in many areas and the settlement may be quite recent. In such a situation, it is almost impossible to rule out the possibility that an avalanche hitting the settlement might be released from the slope. An attempt must then be made to strike a compromise that balances the lack of recorded avalanches and the possibility of avalanche release.

Another problem that must be addressed is the estimation of avalanche hazard in non-typical or low avalanche tracks. The available data about Icelandic avalanches was mostly collected from hills between 500 and 800 m high with large starting areas. The runout potential of avalanches from smaller slopes, both with a lower fall height and smaller starting areas, is not as well investigated.

While delimiting the hazard zones, an attempt has been made to classify the uncertainty in each area by dividing the uncertainty into three classes according to the level of uncertainty in the area. An uncertainty of $\frac{1}{2}$ means that the estimation could be wrong by half a hazard zone, *i.e.* the hazard lines may misalign by approximately $\frac{1}{2}$ of a hazard zone. Since the risk varies by a factor of 3 between the risk lines of the hazard map, the risk may be over- or underestimated by factor of $\sqrt{3}$. Similarly, classes 1 and 2 certainty mean that the zoning could be wrong by 1 and 2 zones in either direction, respectively, meaning that the risk could be over- or underestimated by factor of 3 or 3^2 respectively. Considering the ìnominalî nature of avalanche risk estimates, it is not possible to attach a given significance level in a statistical sense to these uncertainty indicators. They are intended to mean that the work group considers it ìunlikelyî that the risk is over- or underestimated by the indicated uncertainty, but the meaning of ìunlikelyî is not further quantified.

The three chosen classes of uncertainty and their characteristics are:

$\frac{1}{2}$ Records of avalanches are available and the avalanche path is large and typical.

1 Some records of avalanches are available and the avalanche path is small or atypical.

2 No records of avalanches are available, but the topography indicates avalanche hazard.

The uncertainty of hazard zoning in areas where protective measures have been built will probably be in class 1 or 2.

Figure 1. *Overview of the area around Patreksfjörður. Meteorological stations are marked with red circles. © The National Land Survey of Iceland.*

2 General

The tertiary geological formation of Iceland consists, in general, of a relatively flat, layered basaltic lava pile. Individual lava layers are separated by sedimentary layers which are made of fossil soils, lake deposits, eroded material and scoria. The thickness of both types of layers varies from a few meters to some tens of meters. Generally the lava beds are thicker than the sedimentary layers.

The characteristic erosional form in these areas is a stepped profile of the upper part of the mountainside. The cliffs and cliffbands are made of individual thick lavas or a sequence of thinner lava layers separated only by scoria. The shelfs between the cliffs, usually gently sloping and covered with debris and in some cases vegetation, are the sedimentary layers. Below a talus is formed by rockfall from the cliffs. In the talus the size of stones and blocks increases downwards. Some lava layers are more competent than others and form cliffbands along the mountainside within the talus zone. The longitudinal section of an undisturbed slope below the cliffs is typically parabolic in shape.

Generally the slopes are cut by several gullies. They can be separated into two main types. First, small elongated depressions in the cliffs below the edges of the mountains with small and unclearly defined debris cones below. Second, large bowls in the cliffs which open in narrow gullies or canyons in the lowest part of the cliffs. Large debris cones have accumulated at the foothill below gullies of this type. The location and direction of the large gullies is mainly tectonically dependent and, to some extent, also their size.

Above the edges of the mountains there are in many cases large plateaus which are remnants of an old peneplain. These plateaus serve as catchment areas of snow which accumulates in the gullies below during snowdrift and snowstorms.

The NW part of Iceland as well as the E part are of tertiary age.

2.1 Topographic description

Patreksfjˆrður is a fjord on the southern part of the NW-peninsula of Iceland and this large peninsula is called Vestfirðir. The village of Patreksfjˆrður is located on the northern shore of the fjord (see Map 1 and Figures 1 and 2) which opens to NW. This shore is mainly continuous mountainside leaving little or no lowland along the coast. The largest valleys that cut the mountainside in the vicinity of the settlement are Litli- and Miklidalur. Litlidalur has an EñW trend and Miklidalur NW-SE trend parallel to the fjord and opens into Litlidalur. The northernmost part of the mountain between Miklidalur and the fjord is Geirseyrarm˙li. The area at the coast where the valleys open to the fjord is called Geirseyri. About 1 km outwards (NW) of Geirseyri there is a small peninsula, Vatneyri. Just outwards of Vatneyri there is a little valley, FjÛsadalur. The mountain between FjÛsadalur and Litlidalur is named Brellur.

The main part of the settlement is located below the mountain Brellur, from the outer part of Vatneyri to the river Litladals·. Further, a quarter of domestic houses named Bjˆrg is located SW of Mikladals· and NW of the mountain Geirseyrarm˙li.

Figure 2. *Patreksfjörður and the name of the main landmarks. (Photo: © Mats Wibe Lund).*

The aspect hillside of the mountain Brellur is SW above Vatneyri. It changes gradually to S above the innermost part of the settlement. This generally convex hillside is cut by one large gully, Geirseyrargil below which there is a large debris cone. Inwards (SE) of the rim between the valley FjÛsadalur and the fjord there is about 300 m wide bowl in the hillside. Below this bowl avalanche transported boulders and rockfall boulders are found in an area that is called Urðir.

The top of the mountain is a large plateau at an altitude of 400ñ500 m and the edge is 350ñ400 m a.s.l. There are cliffs at the edge above the bowl in the Urðir area. In Geirseyrargil and inwards there are also cliffs at the edge. Some bowls are observed in the cliffs inside of Geirseyrargil. In between, the transition from the plateau to the hillside is gentle. This part of the hillside, *i.e.* between the Urðir area and the gully Geirseyrargil, has a generally even or upward convex longitudinal section from the edge down to about 50ñ70 m a.s.l. It is mostly covered with debris but three cliffbands can be traced and there is a change in the inclination across those cliffs. The uppermost cliffband is at an altitude of about 325 m and can be traced NW-wards from Geirseyrargil. The middle one is at an altitude of about 240 m and is a continuation of the cliffs in the bowl above Urðir and goes halfway to Geirseyrargil. Finally, the third cliffband is at about 120 m a.s.l. It lies also from the bowl above Urðir but has a bit shorter inward extension than the middle cliffband.

The peninsula Vatneyri is at an elevation of 3–4 m a.s.l. Above the peninsula and the shore inwards of it to the debris cone below Geirseyrargil there is a bank. The part of the bank between Vatneyri and Geirseyri is called Klif. Its edge is about 10 m a.s.l. and the inclination from the bank to the foothill of Brellur is 10–15°.

2.2 History of the settlement

Shortly after the middle of the nineteenth century, fishing on deckboats started in Patreksfjörður. The largest companies operated on Vatneyri and Geirseyri and initially two separate villages grew in the neighbourhood of these main fishing industries. Gradually the coastline between Vatneyri and Geirseyri was settled. Later, Vatneyri became the main industrial area and the settlement on it and above it increased. The most recently developed areas are the innermost and outmost parts of the village and most of the houses in these areas were built 1965–1985 (Sólrún Geirsdóttir, 2000).

The population of Patreksfjörður grew continuously until 1970 when the inhabitants were about 1000. Since then there has been a decrease in the population and the number of inhabitants is now about 720.

2.3 Chronicle

On Map 2 recorded avalanches, slushflows, debris flows and rockfall are shown and Appendix B contains a list of the events including a brief description of each. A more detailed description is given in the landslide and avalanche chronicle of Patreksfjörður (IMO, 2003).

Systematic recording of avalanches started in Patreksfjörður in 1995 when local snow observers were hired by the IMO. Below, a short overview of the events is listed.

There have not been casualties in dry snow avalanches in the community of Patreksfjörður but they have caused considerable material damage. The slushflows have caused fatal accidents and severe material damage. Altogether five persons have lost their lifes in three slushflows, four in the last century and one in the nineteenth century as far as known. Debris flows have also caused some damage.

Snow avalanches and slushflows

In the middle of the nineteenth century (1852 or 1854) a flow in Litladalsá killed one man and damaged some sheepsheds. It is not certain whether this was a flashflood or a slushflow.

In 1906 or 1907 a large avalanche fell from the bowl above Urðir. It broke a cowshed and stopped on the peninsula of Vatneyri and would have reached the present day harbour.

In 1921 a large avalanche fell just to the inside of the avalanche of 1906/1907. It reached at least the middle of the present day harbour.

In 1943 an avalanche fell in the Urðir area and it stopped just below the streets Urðargata/Mýrar. The avalanche broke a henhouse and killed the hens in it.

In March 1958 a large avalanche fell in the Urðir area. Its width above the settlement was about 400 m. A 150 m wide tongue almost reached the harbour. The avalanche broke three garages and destroyed cars in them. Further, powerlines, fences and gardens were damaged and one domestic house was hit.

Just before Christmas 1948 a slushflow came from Geirseyrargil and it reached the sea. In 1966 or 1967 another flow reached the shoreline. There are historical sources of two other slushflows from the gully in the nineteenth century.

In 1981 an avalanche fell at Urðir. It stopped about 10 m below the street Urðargata.

On the 22 of January 1983 a slushflow fell from the gully Geirseyrargil and another one along the river Litladalsá. Four persons were killed and six were injured in the flows. Sixteen houses were damaged or destroyed. Sheepsheds, fences and gardens were also damaged. The width of each flow was over 100 m at the coastline.

In March 1989 two small avalanches fell above the street Mýrar.

16–30 of January 1995 three small avalanches fell above the settlement in Patreksfjörður. Two of them fell above the street Sigtún and one in the Klif area, just outside of the school.

In March 1995 an avalanche fell in the Urðir area. It was about 150 m wide and stopped at about 40 m a.s.l.

In January 2000 a small avalanche fell above the street Sigtún.

Debris flows and rockfall

In 1933 or 1934 a debris flow occurred in the Klif area. It went over the street Aðalstræti and hit the house no. 47. The width was 100–150 m and the thickness 2–3 m. In 1958–1959 another debris flow fell in a similar location.

In November 1961 a debris flow fell in the Urðir area and stopped just above a residential house.

Around 1950 a large boulder fell from the hillside above Klif. It stopped a few meters above where the outer end of the school is now.

In 1984 a boulders fell from the mountainside above the Klif. One of them stopped on the debris cone of Geirseyrargil, about 50 m above the houses.

2.4 Previous investigations and hazard assessments

In 1983 Hafliði Helgi Jónsson and Helgi Björnsson (1983) investigated the situation after the slushflows in January that year.

In 1984 Erik Hestnes (1985) went to Patreksfjörður. Preliminary hazard zoning of Vatneyri made by H. H. Jónsson is presented in his report. Furthermore, he recognized potential starting areas for avalanches.

A hazard assessment was confirmed in May 1992 (Almannavarnir ríkisins/VS, 1991). The work was carried out according to a former regulation on avalanche hazard assessment where two zones were delineated *i.e.* a hazardous zone and a safe zone. In short, the zoning for Geirseyrargil and Litladalsá is similar to the zoning presented here. The hazardous zone at Urðir has somewhat smaller extent than the C hazard zone that is delineated here.

In 1997 the Icelandic Meteorological Office made plans for emergency evacuations of several communities in Iceland. The plans included a division of the communities into evacuation zones and a description of the conditions when the individual zones should be evacuated. Such a plan was made for Patreksfjörður (IMO, 1997). According to the plan a considerable part of the settled area is a part of evacuation zones that need to be evacuated under extreme conditions. When a final hazard map has been issued officially the evacuation plan will be revised to reflect the hazard zoning.

VST consulting engineers made preliminary investigation on avalanche defence structures in 1993 (VST, 1994) and slushflow defence structures in 1997 (VST, 1998). Tómas Jóhannesson *et al.* (1996) investigated the need for avalanche defence structures in Iceland and in their report suggestions and cost estimate for such structures in Patreksfjörður are included. Kristín Marta Hákonardóttir (1997) has studied slushflows in Iceland in general and suggests defence structures for slushflows in Patreksfjörður.

2.5 Climatic conditions

The climate of Vesturbyggð is influenced by the rough topography of the region, with high mountains and narrow fjords and a location adjacent to the Denmark Strait. Sea ice is more often brought to the neighbourhood of Vestfirðir than to any other area in Iceland. There are a number of weather stations in the southern part of Vestfirðir. Summaries of station data can be found in Appendix D. The mountain stations Hálfdán and Kleifaheiði are automatic weather stations (AWS) owned and operated by the Icelandic Public Roads Administration. The stations Bíldudalur and Patreksfjörður are automatic stations, Kvígindisdalur is a synoptic station and Mjólkárvirkjun is a precipitation station operated by Veðurstofa Íslands (see Fig. 1). Kvígindisdalur is the only station that measures snow depth and snow cover is observed there and at Mjólkárvirkjun too.

The mean temperature in the region for the period 1997–2002 is 3,8–4,9°C in the lowland which is significantly higher than for the standard period 1961–1990. At the station Kleifaheiði, 400 m above sea level, the mean temperature is 1,0°C and at Hálfdán, 525 m a.s.l., the mean temperature is 0,4°C. This indicates a temperature decrease with altitude of about 0,6–0,8°C for every 100 m. At all stations, temperatures below zero may be measured in all months of the year and the lowest measured temperature is down to -20°C.

Precipitation is highly variable from location-to-location and from year-to-year. High winds and sub-zero temperatures are associated with the largest systematic errors in precipitations measurements. In general, the precipitation tends to be underestimated in such conditions. It seems that automatic precipitation gauges measure smaller precipitation amounts than the gauges used at manned stations. The average total precipitation at Kvígindisdalur is 1380 mm per year and the yearly sum varies much from year-to-year. The highest measured daily, *i.e.* 24 hour (09–09), accumulated precipitation is 131,6 mm in March 2000, and a 24 hour precipitation larger than 100 mm has been measured on three other occasions, in September 1942 and 1949 and in October 1987. In the wintertime (November-April), rain amounts to about 30% of the precipitation and sleet and snow about 70% in Kvígindisdalur. At Mjólkárvirkjun, rain is about 50% and sleet and snow about 50% during winter.

Wind direction and wind speed is estimated subjectively by the observers at Kvígindisdalur and only 16 wind directions are used. The wind directions at each station are strongly influenced by the topography of the adjacent area and wind directions in the fjords are predominantly “inwards or outwards”. In wintertimewhen temperature is below 1°C, precipitation in Kvígindisdalur occurs mainly when the wind is blowing from southwest to west but the most common wind directions there are from north and northeast. In Patreksfjörður, the wind directions from east to northeast is the most common and the wind speed is strongest from that direction.

Snow cover is lighter in Vesturbyggð than in the northern part of Vestfirðir and the snow depth is smaller. The climate is milder and thaw periods during winter are more frequent. The monthly average snow depth in Kvígindisdalur is calculated for days when the ground is totally covered with snow and is 12 cm in January for the period 1961–1990 and 10–12 cm in February–April. The maximum measured snow depth is 88 cm in February and March 1957. In the region around Patreksfjörður, the maximum snow depth with a 50 year return period is 100–160 cm and 150–200 cm for a return period of 200 years.

The danger of snow avalanches in Vestfirðir arises most frequently during strong winds from the north associated with intensive low pressure systems coming from south or east. These low pressure systems bring relative warm air masses from the south with intensive precipitation to the area and lead to heavy snow accumulation in the starting areas of many avalanche paths. In the same paths, heavy snow accumulation can also occur in prevailing northeasterly winds with snow fall. The weather preceding many avalanches in the northern part of Vestfirðir is according to this description. The danger of snow avalanches in the southern part of Vestfirðir arises most likely during similar conditions, although the strength of northerly winds and the intensity of snow fall is not as large there as in the northern part of the peninsula. The snow avalanches in Patreksfjörður on 16th March 1943 and on 14th Mars 1958 are an example of this. On the day when the avalanche near Urðir fell in 1943 there was very strong east or northeasterly wind with snow fall and when the avalanche in 1958 occurred there was northeasterly force eleven Beaufort wind in Kvígindisdalur with heavy snow drift. It is reported that enormous snow drift could be observed from the top of the mountain above Patreksfjörður on that occasion. The avalanches in January 1995 fell during a widespread avalanche cycle of this type that affected the whole Vestfirðir peninsula and most of northern and northeastern Iceland. Because the dates of the avalanches at Urðir in 1906/1907 and 1921 are not known, it is not possible to analyse the weather conditions preceding these avalanches.

During the early winter before the slush flows at Patreksfjˆrður and BÌldudalur on 22nd January 1983, there had been heavy snow in Vestfirðir. The snow depth at KvÌgindisdalur was in the range 40ñ60 cm from the beginning of January until shortly before the avalanches fell. An occluded frontal zone came from the south on the 21st and moved to north over Vestfirðir in the early morning of the 22nd followed by heavy rain. The temperature reached 8°C in the lowland. In KvÌgindisdalur, the measured precipitation from 18hr on the 21st to 18hr on the 22nd was 124 mm and it is estimated that 110 mm of this precipitation fell during 21 hours before the slush flow fell from Geirseyrargil in Patreksfjˆrður at 15:40hr. According to this description and an investigation of the weather preceding slush flows at BÌldudalur, the largest slush flows in both these villages have been preceded by heavy precipitation. The slush flow in BÌldudalur 1997 and 1998, on the other hand, show that smaller slush flows can occur without intensive precipitation.

2.6 Debris flows and rockfall hazard

As described before, the current Icelandic regulation on hazard zoning requires the same criteria to be used for debris flows/rockfall hazard zoning as for avalanche hazard zoning, *i.e.* individual risk. Furthermore, the combined risk should be presented on one map. Therefore, debris flow hazard zoning should be done in synchronisation with avalanche hazard zoning.

A debris flow chronicle for Patreksfjˆrður has been compiled by HalldÛr G. PÈtursson (2000). A geomorphological map of the area has been prepared and the potential runout of debris flows and rockfall in the area has been estimated by modeling (Glade and Esther H. Jensen, 2003). The debris flow chronicle is included in the avalanche chronicle (IMO, 2003).

Debris flows have caused some damage to the present settlement of Patreksfjˆrður. Rockfall has not caused damage but is a potential danger. Low catching dams have been constructed to prevent that. Although these processes impose some threat to the inhabitants, the debris flow and rockfall hazard is not considered to be serious compared to the snow avalanche hazard. It is therefore concluded that taking debris flows specifically into account will not alter the hazard zoning. In spite of this it may be feasible or even advisable to take actions to prevent property damage due to debris flows at some locations in the village.

3 Vatneyrarsv¾ði

The area above Vatneyri can be divided into two subareas. The outer one is below the rim of FjÛsadalur and the inner one is the area of Urðir and the bowl above it.

Figure 3. *Vatneyri (Photo: © Mats Wibe Lund).*

3.1 Outer part

3.1.1 Topographic description

Starting area

The starting area is from 230 to 70 m a.s.l. It is triangular in shape and is located below the rim between FjÛsadalur and the mountainside of the fjord. The area is approximately 2.5 ha and the width is approximately 200 m in the lower part. The inclination is 30ñ45°. In the middle there are cliffbelts. The lower part consist of a scree of 30° inclination. On the average the longitudinal section is smoothly convex upwards and the aspect is SW. The surface is made of weathered rock and is interrupted by the cliffbelt mentioned above. There is no vegetation.

Track

The track is from 70 to 40 m a.s.l. and is unconfined. The inclination of the slope is from 22° to 12°. The track consists of scree material with some vegetation in the lower part.

Runout area

The inclination of the runout area fluctuates between 4–10° for about 150–200 m distance and it is covered with vegetation. Then there is a bank sloping 15–20° down to the road above the harbour and along the shore. Domestic houses are located along and just above the bank.

3.1.2 Local climatic conditions

Snow can accumulate in the area by drift from Fjósadalur in N to NE wind directions. According to the local snow observer, snow drifts from this area and settles down in the neighbouring area above Urðir in W to NW wind directions.

3.1.3 Chronicle

Two small avalanches are recorded in the area. They stopped just below 60 m a.s.l., about 120 m distance from the uppermost houses. They were close to each other and are marked as one on Map 2.

3.1.4 Assessment

Avalanche frequency is not expected to be high in this area due to the rather unfavourable conditions for snow accumulation. Secondly, the starting area is interrupted and rough and it is not considered probable that an avalanche is released simultaneously from the whole area. Finally, the runout zone is partly quite flat. Large avalanches with long runout distances are not expected in the area.

3.1.5 Model estimates

The location of profiles and the results of the model calculations are shown on Map 3 and longitudinal sections of profiles `patr01` and `patr02` are shown on Drawings 1 and 2.

The houses at the street Hólar, which are more affected by avalanches from the bowl above Urðir, are located close to runout index $r = 11$ for avalanches starting in area 1 (Map 3). The houses at the street Mýrar farther to NW than Hólar are located at runout indices $r = 12$–13.

The location of the β-points is 60–100 m above the street Mýrar, close to runout index $r = 11$.

The SAMOS simulations indicate that large avalanches (Run 2) can reach the street Mýrar. Smaller avalanches (Run 1) stop about 50 m above the street at runout index $r = 12$–12.5.

3.1.6 Conclusion

As mentioned above it is considered improbable that an avalanche is released from the whole area simultaneously. The two recorded avalanches were small and stopped at 55 m a.s.l. which is 200 m above the street Mýrar ($r = 6.3$).

A reasonable estimate for the category C zone for avalanche hazard is close to runout index $r = 11.5$ for the outmost part. This delineation is also consistent with the hazard due to rockfall (see section 8). The hazard in the inner part is mainly because of avalanches originating in the starting area above Urðir and is dealt with in the next section.

Hazard line B is delineated close to runout index $r = 12.5$, and hazard line A is located just above the bank above the shore at runout index $r = 13.5$. The uncertainty of the delineation is estimated to be between 1 and 2.

3.2 Inner part – Urðir

3.2.1 Topographic description

The mountainside above Urðir is a typical avalanche area with frequent avalanches which have long runout distances. Some attention has been paid to this fact in the town planning. There is a gap in the settlement where the avalanches are most frequent and two low deflecting dams have been built close to the inner (SE) border of the track.

Starting area

The starting area is a large bowl facing SW below the edge of the mountain. The edge is at 350 m a.s.l. and the potential starting area extends down to about 150 m a.s.l. but this lower limit is not clearly defined. The width is about 250 m and the area is about 6 ha. The average inclination is 41° and there is hardly any vegetation in the starting area.

The upper part consists of cliffs with more than 50° inclination. The surface is rough with the typically stepped profile of the tertiary formation of Iceland. Below the cliffs there is coarse scree and the inclination decreases gradually to 30° at 150–170 m a.s.l.

Track

The area between approximately 150 m a.s.l. and 25 m a.s.l. can be considered as an avalanche track. The surface consists of a scree with some vegetation in the lower part. The inclination in the upper part is 26° and decreases gradually to 10°. The area is fairly even and the track is unconfined. As hazard indicators, some avalanche transported boulders are found in the lower part. Two small avalanche deflecting dams with a height of 5–7 m have been built in the inner part at about 40 m a.s.l.

Runout area

The runout area starts at about 25 m a.s.l. and reaches the harbour. Avalanche transported boulders are also found in this area. The runout area is covered with grass and the inclination varies between 5 and 10°. The inclination of the bank above the road by the harbour is around 15°.

There are many domestic houses located in the runout area. Further, fishing industries, workshops, shops and general harbour activity is in the area.

3.2.2 Local climatic conditions

Precipitation is mainly during westerly wind directions. In N to SE directions snowdrift from the plateau above and along the slope frequently causes large snow accumulation in the starting area. The cliffs at the edge are often completely covered with snow. According to the local snow observer, snow can drift from Fjósadalur over the rim and accumulate in the lower part of the starting area. Prior to the largest recorded avalanches with known dates, the wind direction was NE to ENE at the nearest meteorological station in Kvígindisdalur.

3.2.3 Chronicle

In the last century 3 snow avalanches reached into the area where the harbour is now. The avalanches have caused some material damage.

3.2.4 Assessment

Due to geomorphological conditions, which lead to a frequent and rapid snow accumulation in the starting zone, this is a typical avalanche path with high frequency of avalanches, as can be seen in the chronicle. The profile is typical for avalanches with long runout distances. Avalanches of 100 to 200 thousand m^3 are to be expected. As mentioned above this hazard is well known and has been taken into consideration to some degree in the planning of the village.

3.2.5 Model estimates

The results of the model calculations are shown on Map 3 and longitudinal sections of profiles `patr03` and `patr04` are shown on Drawings 3 and 4.

Due to the variable inclination the location of the β-point is not well defined. That is reflected in the location of the α-points which are at runout indices from $r = 13.2$ to $r = 14.7$. The avalanche with the longest runout extends beyond the α-point and runout index $r = 15$ at least but the exact location of the tongue is not well known (IMO, 2003)

The result of the SAMOS simulations show large and wide tongues. The inward and outward borders of the tongues of the simulated avalanches are close to those of the observed avalanches. The extent of the outer edge may, however, be slightly overestimated due to effects of superposition since avalanches are released from all starting areas simultaneously in the SAMOS simulations. Generally, the results of the SAMOS simulations and the extent of the recorded avalanches are consistent with each other.

3.2.6 Conclusion

Three avalanches with runout greater than runout index $r = 13$ were recorded during the last century. It is therefore expected that annual frequency at runout index $r = 13$ is about 0.03 ($F_{13} = 0.03$). According to the RiskEst calculations (Jónasson *et al.*, 1999) hazard line A is then located a bit further out than runout index $r = 17$. Hazard lines B and C are located at runout indices $r = 16.3$ and $r = 15.8$, respectively. This is consistent with the SAMOS simulations.

Delineation of the inner and outer borders is based on the available observations of the areal extent of the historical avalanches and the results of the SAMOS simulations.

The width of the tongues of the observed avalanches with the longest runout is about half of the width of the runout zone indicating that the avalanches were not released from the whole potential starting area simultaneously, at least not with the same force. This may partly be due to lack of recording for the older avalanches since one of the large avalanches (no. 7004, 14.3.1958) is indeed very wide. In other words, there is no reson to delineate the hazard zones otherwise than assuming that an avalanche can be released from the whole starting area simultaneously. The uncertainty of the delineation in the area is estimated to be 1/2.

4 Klif

The area between Urðir and Geirseyrargil is called Klif in this report. It is divided into two main parts. In the outer part one large starting area is delineated (Area no. 3 on Map 3) while two smaller areas are in the inner part (Areas no. 4 and 5 on Map 3).

The overall shape of the mountainside is convex but the potential starting areas are below the edge of the mountain Brellur where there are slight depressions in the mountainside.

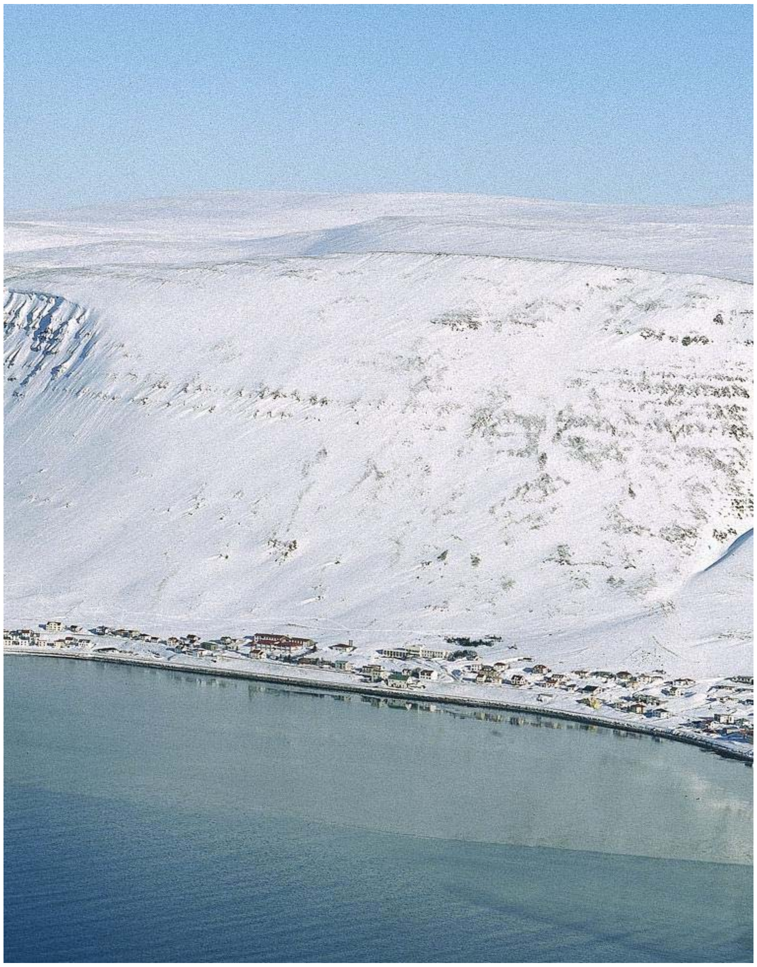

Figure 4. *Klif (Photo: © Mats Wibe Lund).*

4.1 Klif – outer part

4.1.1 Topographic description

Starting area

The starting area extends from 400 m a.s.l. down to about 165 m a.s.l. The areal extent is about 20 ha. This area includes the cliffband which extends inwards from the bowl above Urðir at an altitude of about 250 m a.s.l. Above the cliffbelt the inclination is about 31°. Below it the inclination is 35°. The area is convex and the aspect is WSW.

Apart from the cliffband the surface is made of coarse talus material and there is no vegetation.

Track

The separation of the starting area and the track is based on the pronounced convexity of the slope but not the inclination. It starts about 165 m a.s.l. where the inclination is about 35°. At about 100 m a.s.l. there is a cliffbelt with inclination over 40°. Above these cliffs the longitudinal section of the mountainside from the edge is more or less convex outwards or even.

The inclination of the bank above Vatneyri and further inwards varies and it is close to or above 10°. Consequently, the β-point is on the bank or at its foot.

The surface consists of scree in the upper part with occasional cliffs. The lower part has vegetational cover. There are residential houses in lowest part of the track.

Runout area

Most of the runout area is the Ðat peninsula of Vatneyri which is 3ñ4 m a.s.l. It is used for domestic houses, trading and industrial activity. The innermost part of the runout area is a narrow strip by the shore.

4.1.2 Local climatic conditions

According to the local snow observer winds from WNW and SE clear this area of snow. Snowdrift from NE as well as heavy snowfall in calm weather can cause snow accumulation in the starting zone.

4.1.3 Chronicle

Only one small avalanche is recorded in the area. It stopped below the inner border of the starting area, close to the inner corner of the school. In addition, the avalanche at Urðir 14.3.1958 (no. 7004) was wide and part of it started in this area.

4.1.4 Assessment

Due to the shape of the starting area and prevailing weather conditions snow accumulation is not frequent in the area. Further, it is not probable that a single large avalanche is triggered in the whole area simultaneously. On the other hand, the settlement is close to the mountain and even small avalanches could reach the settlement.

4.1.5 Model estimates

The results of the model calculations are shown on Map 3 and longitudinal sections of profiles `patr05`, `patr06`, `patr07` and `patr08` on Drawings 5–8.

The β-point is within the settlement. The α-point is between the runout indices $r = 13$ and $r = 14$. It is about 1/3 of the distance from the bank to the tip of the peninsula of Vatneyri for the outer part and in the fjord for the inner part.

4.1.6 Conclusion

Taking the avalanche in 1958 into account, two avalanches are recorded in the area. The innermost arm of the large avalanche in 1958 reaches the uppermost houses of the street Urðargata at runout index of $r = 10.3$. A small avalanche stopped close to the outer end of the school in 1995 at runout index $r = 8.5$ approximately. It is not clear where it started. The houses are of variable age but many were built before 1950 and some around 1900. It is reasonable to assume that most avalanches with $r > 10$ in the last century would have been recorded. That indicates that the combined annual frequency of avalanches may be on the order of 1/100 or lower at runout index of $r = 9.5$. The RiskEst methods are not applicable to paths where the data available is restricted to such low runout indices. Due to this the delineation is based on the model calculations in a subjective way, the climatic conditions and the shape and form of the starting zones with respect to snow accumulation.

Above the street Urðargarta there is slightly higher probability of snow accumulation than elsewhere in the area. There is a shallow depression below the cliffband which continues inward from the bowl above the Urðir area. The avalanche of 1958 reached runout indices $r = 10.3$ to $r = 9.4$, decreasing inwards. Hazard line C is drawn at runout indices $r = 11.5$ to $r = 10.5$, similarly decreasing inwards, and this is just below the β-point. Hazard lines B and A are drawn at runout indices $r = 11.5$ and $r = 12.5$, respectively, for the inner part of the Vatneyri peninsula. For the outmost part of the area the delineation of the hazard lines B and A is affected by the hazard due to the large bowl above Urðir.

Above the street Aðalstræti (Aðalstræti 27 to 51) the starting area is atypical. Also, as mentioned before, the prevailing weather conditions do not favour snow accumulation in the area. With reasonable confidence the hazard lines can be drawn closer to the foothill in this area. Here the hazard line C is at runout index $r = 8.5$ approximately. Hazard lines B is close to the β-point at runout index about $r = 10$ and line A is at runout index $r = 11$–11.5.

The delineation is comparable to some areas in Ísafjörður and Siglufjörður for the outer part (Arnalds *et al.*, 2001c, 2002c). The uncertainty of the delineation is considered 1 for the outer part and increasing to 2 for the inner part.

4.2 Klif – inner part

4.2.1 Topographic description

Starting area

Two separate shallow depressions can be found in this part of the slope which are considered potential starting areas. One is on the slope from the plateau above at 390 m a.s.l. down to 300 m a.s.l. It is located in the gap of the cliffbelt going outwards from Geirseyrargil at an altitude of about 330 m. The other one is in the cliffs just outside of Geirseyrargil from 385 m a.s.l. down to 300 m a.s.l. There is a depression in the mountainside above and below the cliffs there. The outer one has a width of 200 m and area of 3.6 ha. The inner one has a width of 120 m and area of 1.6 ha. The areas are separated by cliffs and their inclination is 35–40°. The surface consist of screes in the lower part but in the upper part screes are partly interrupted by a cliffband.

The whole area below the 300 m altitude down to 150 m a.s.l. can also be considered as a possible starting area. It is slightly convex with an average inclination of 34° and the total area is 16 ha.

Track

The track starts at 300 m a.s.l. assuming only the uppermost starting areas. At about 150 m a.s.l. the inclination is 30°. For the outer part it is fairly even and unconfined. The inclination gradually decreases to 10° at the foothill. The track of the inner part is close to the gully Geirseyrargil where the hillside has a pronounced convexity. At about 50 m a.s.l. it hits the debris cone of Geirseyrargil where the inclination changes to about 15°. The upper parts are screes and the lower part is the debris cone. The debris cone is covered with coarse gravel, stones and boulders in the upper part and vegetation in the lower part. Residential houses and official buildings are located in the lower parts of the track. These include the school and the hospital of the village.

Runout area

In the outer part the runout area starts at about 20 m a.s.l. and reaches the shoreline. The runout area is the terrace from the β-point and then the steep bank towards the shore. In the inner part, the β-point is at the shoreline on the debris cone of Geirseyrargil. The whole area is settled.

4.2.2 Local climatic conditions

Snow can accumulate in the shallow depressions when there is a snowdrift from NW to E. Since they are shallow, winds blowing along the slope do probably not cause large snow accumulation. Winds from NE as well as snowfall in calm weather could on the other hand cause large snow accumulation in the starting zones.

4.2.3 Chronicle

The avalanche from 1995 (no. 7012) stopped close to the border of the areas Inner-Klif and Outer-Klif. It is not certain where it started.

4.2.4 Assessment

The outer part of the area has all geomorphological conditions for medium to large avalanches with runout distances well into the settlement or into the sea. The settlement dates from the beginning of the last century but there are no records of avalanches reaching the settlement. The large buildings at the foothill offer some protection for the houses below them.

Avalanches from the inner area will probably spread out and possibly fall into the gully Geirseyrargil and follow that track. There is some tradeoff between the spreading and the favourable longitudinal section of the debris cone for long runout.

4.2.5 Model estimates

The results of the model calculations are shown on Map 3 and longitudinal sections of profiles `patr09` and `patr10` on Drawings 9 and 10.

For the longitudinal section `patr09` the β-point is located on the terrace at runout index $r = 10$ and for the longitudinal section `patr10aa` it is located by the shore at runout index $r = 12.8$.

The SAMOS simulations show that the modeled avalanches reach the sea in the outer part. In the inner part the SAMOS simulations indeed show that it is probable that the avalanches from staring area 5 (Map 3) fall into the gully Geirseyrargil.

To conclude, the model calculations indicate that even small avalanches are likely to reach the settlement and average sized avalanches can reach the shore.

4.2.6 Conclusion

The arguments on which the delineation of the hazard lines is based is similar to the ones regarding the area just outside of this *i.e.* Klif–outer part. The starting area no. 4 (Map 3) is considered to have a somewhat higher potential for snow accumulation than the area just outside of it. Consequently, the hazard zones are a bit further away from the mountainside below it. The hazard line C is drawn at runout index $r = 9.5$. Hazard lines B and A are at runout indices 11 and 12.2, respectively. The uncertainty of the zoning is considered to be 2.

Below the inner part is the debris cone of Geirseyrargil. The delineation for this part is dominantly based on the slushflow hazard from the gully which is described in a separate section.

5 Geirseyrargil

Historically, the main hazard in this area has been due to slushflows which have caused fatal accidents and great material damage. There is also potential hazard due to avalanches which is described in this section.

Figure 5. *Geirseyrargil og Sigtúnssvæði (Photo: © Mats Wibe Lund).*

5.1 Topographic description

Starting area

Below the cliffs at the edge of the plateau, between 360 and 300 m a.s.l., there is a funnel shaped area that is a potential starting area for snow avalanches. It has a size of 0.8 ha and its inclination is between 35° and 45°. The surface is made of stepped cliffbelts interrupted by smaller gullies. The surface is very rough due to these steps. In addition, the topography and the SAMOS simulations indicate that avalanches starting in the small startings areas inside and outside of the gully (Areas no. 5 and 7 on Map 3) may fall into it.

Track

The track is the narrow gully which is of 10 to 20 m width between the cliffs in the upper part and with an inclination of 34°. Further downwards it widens and where it opens the inclination is about

20°. The gully curves slightly outwards and the track is confined.

The gully opens at approximately 120 m .a.s.l. Below the opening, there is a large debris cone which reaches the sea. The cone inclines 20° at the top and about 10° at the coastline. It is covered with vegetation in the lower part and gravel and boulders in the upper part. The width of the debris cone by the shore is about 250 m. Presently, the brook of the gully runs in a shallow creek along the inner edge of the debris cone. There are many domestic houses in the area.

Runout area

The outer part of the debris cone has an inclination just above 10° all the way to the shore. The inner part is not as steep and the β-point is reached at about 20 m a.s.l. The area is settled.

5.2 Local climatic conditions

Snow can accumulate in this bowl by snow drift from the large plateau in wind directions from NW to E.

5.3 Chronicle

From Geirseyrargil there are only recorded slushflows.

5.4 Assessment

The bowlshaped starting area can be completely filled with snow so the cliffs between the small gullies and the steps within it disappear. Avalanches coming down the gully loose energy due to the curving and narrowness. Spreading on the debris cone also decreases the runout distance.

5.5 Model estimates

The location of profile `patr11` and the results of the model calculations are shown on Map 3 and the longitudinal section on Drawing 11.

For the outer part of the cone the coastline is at runout index $r = 13.7$ and the β-point is also there. Further inwards the coastline is at runout index $r = 14.6$ and the β-point is at runout index $r = 13$.

The SAMOS simulation indicate that even small avalanches can reach the ocean. This result may be somewhat exaggerated since during the simulation, avalanches from the starting areas on each side of the gully (Areas no. 5 and 7 on Map 3) combine with the avalanche from the gully itself. But it is very unlikely that avalanches from these three areas start simultaneously.

5.6 Conclusion

Due to the fact that the inclination of the debris cone fluctuates close to 10° and the superposition of snow from adjacent starting areas, the results of the SAMOS simulations is probably an overestimate of the runout.

The hazard lines due to the dry avalanches are completely within the hazard lines defined by the slushflow risk.

6 Sigtúnssvæði

Sigtúnssvæði is the area from Geirseyrargil and inwards to the river Litladalsá.

6.1 Topographic description

Starting area

Inwards of Geirseyrargil there are several shallow tracks in the mountainside. Above them there are small bowls below the edge of the mountain. Avalanches originating in the three bowls closest to Geirseyraragil impose a hazard for the settlement below. These bowls have aspects slightly W of S. Their sizes are 0.3, 1.2 and 0.5 ha, respectively, counting inwards. The bowls reach 360 m a.s.l. The middle one goes down to 285 m a.s.l. but the other ones to 320 m a.s.l. The surface consists of stepped cliffs which protrude between the bowls which have scree material at the center. The inclination is about 38–40°. It is not considered probable that an avalanche is released from the whole area simultaneously.

Below these areas the mountainside is convex and smooth and has inclination over 30° down to 180 m a.s.l.

Track

Below the bowls the inclination is about 34° and gradually decreasing to 10° at a level of 40 m a.s.l. The tracks are unconfined. In the upper part there are screes and the lower part has a vegetational cover.

Runout area

The runout area starts at about 40 m a.s.l. The inclination decreases gradually to 5° over a distance of 300 m. The innermost part of the runout zone reaches the course of the river Litladalsá. The area is covered with vegetation. The settlement in the area consists mainly of residential houses.

6.2 Local climatic conditions

Snow accumulation is probable in these starting areas by snowdrift in NW, N to ESE wind directions.

6.3 Chronicle

Two avalanches above the settlement and one a little bit inwards of it have been recorded.

6.4 Assessment

The longitudinal sections are favourable for avalanches with long runout distances. On the other hand individual starting areas are small and it is not probable that the whole area can act as one large starting area.

6.5 Model estimates

The location of profiles and the results of the model calculations are shown on Map 3 and longitudinal sections of profiles `patr12`, `patr13` and `patr14` are shown on Drawings 12, 13 and 14.

The β-point is close to runout index $r = 11.5$ which is just above the uppermost houses. The hillside below the outmost starting area inclines to the gully Geirseyrargil. According to the SAMOS simulations avalanches from that area fall into the gully. For the other starting areas, the larger run the SAMOS simulations reaches runout index $r = 12.5$.

6.6 Conclusion

The starting areas are small, particularly the inner- and outermost ones. On the other hand, the slope below has inclination which is typical for starting areas so the possibility of substantial entrainment of snow exists. Generally the slope is convex and avalanches can spread out. In addition, an avalanche released from the outermost area will, at least partly, fall into the gully Geirseyrargil.

The houses in the area were mainly built between 1970 and 1980 and most likely the record of avalanches is incomplete before that time. Based on the limited history, the frequency of avalanches at runout index $r = 11$ is perhaps 1/1000 to 1/100 per year. Because of the small size of the starting area and the convex slope it is expected that the runout is shorter than in a more typical avalanche path. The hazard line C is delineated at runout index $r = 12$ for the inner part and approaches the mountain to runout index $r = 11.5$ in the outer part. Hazard lines B and A are located at runout indices 13 and 13.8, respectively, for the inner part and 12.2 and 12.8 for the outer part. The uncertainty is estimated between 1 and 2.

7 Other areas

The area between the rivers Litladalsá and Mikladalsá, *i.e.* the lowermost part of the valley Miklidalur, was investigated. Within this area there is a soccer field and constructions for electrical and water distribution.

Further, the area from the river Mikladalsá to the mountain Geireyrarmúli and the settlement below it, *i.e.* Björg, was considered.

It is concluded that the avalanche risk in these areas is within acceptable limits.

8 Slushflows, debris flows and rockfall

Slushflows, debris flows and rockfall impose a significant risk for the community of Patreksfjörður.

The slushflows are particularly hazardous and have caused fatalities and significant material damage. There are mainly two slushflow tracks where accidents have occurred recently and where there are records and vague stories of several other flows. Those are the gully Geirseyrargil and the course of the river Litladalsá.

Debris flows and rockfall has been mapped (Glade and Esther H. Jensen 2003) and it is estimated that there is some risk at several locations in the village due to these processes.

8.1 Slushflows

8.1.1 Geirseyrargil

A large amount of snow can accumulate in the gully, from the area at the edge of the mountain down to the top of the debris cone at about 100 m a.s.l. In addition to thaw and heavy rain, water may flow from the relatively large watershed on the plateau above and take part in the saturation of the snowpack.

The snowmass that was mobilised in the slushflow 1983 was in the lowermost part of the gully, just before it opens out on the debris cone. The flow followed the creek where the brook from the gully presently flows which is at the cone's inner border. Older tracks of the brook are found in different places and some are clearly recognisable on the cone's outer wing. A couple of recent slushflows have taken that path.

It is clear from the historical evidence that the slushflows can find their way anywhere on the debris cone and flow there with full force all the way down to the sea. The whole cone is classified as hazard C zone accordingly.

8.1.2 Litladalsá

Several slushflows or flashfloods have occurred in the river Litladalsá. They have caused fatal accidents at least two times as well as considerable material damage.

It is considered likely that the slushflows originate in a gully named Eyvarardalsgil which is located in a small tributary valley to the north of the valley Litlidalur. The average inclination of the river Litladalsá through the settlement is about 4°. The river runs in a shallow but wide depression. The banks of the depression are typically about 2 m high and its width is 50–80 m. The cross-section of this course through the settlement is therefore on the order of 100–170 m^2 down to the community house (Félagsheimili). There it widens considerably and the banks become lower.

Flows in Litladalsá will more or less be restricted to the course described above. They will widen considerably where the channel opens just above the street Strandgata and can reach up to

200 m width by the shore.

Only hazard line C is drawn in this area. It follows the banks of the channel where it is sharp. Near the shore, the delineation is based on the observations from the slushflow of 1983.

8.2 Debris flows and rockfall

Debris flow and rockfall pose some threat to the settlement. Hazard due to those processes has been investigated by Glade and Esther H. Jensen, (2003).

The extent of the runout zones due to rockfall is larger than the zones due to debris flows in Patreksfjörður. In the outer part of Vatneyri the hazard line due to rockfall is located in a similar place as the avalanche hazard line C. In the Klif area the rockfall line is within the hazard zone C. In Sigtúnssvæði the situation is similar.

Generally, the runout zones due to rockfall and debris flows are within or similar to the hazard zones C due to snow avalanches. Since hazard caused by these processes is considered smaller compared to the avalanche hazard they do not affect the hazard zoning due to avalanches significantly.

9 Conclusion

A large proportion of the settlement of Patreksfjörður is within hazard areas and about 60 domestic houses are within the category C hazard zone. The majority of these houses are in the Urðir area and on the debris cone of Geirseyrargil.

The main problem in the hazard zoning is the limited data available, particularly in the Klif area. There, it is highly probable that any movement of snow, rock or debris will not stop until the settlement is reached since the houses are so close to the mountain. In this context the importance of detailed recording of avalanches, debris flows and rockfall is stressed. The observations are the base for evacuations, construction of defence structures and eventual reevaluation of the hazard zoning. We conclude that the delination of the hazard zones below Geirseyrargil, along Litladalsá and in the Urðir area is done with some certainty and it is unlikely that future observations will alter this conclusion considerably.

Rockfall and debris flows pose threat to the settlement, though not of the same degree as the snow avalanches. These processes may also cause significant damage and have to be taken into consideration in town planning. Avalance defence structures will presumably also protect the settlement from debris flows and rockfall.

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A Technical concepts and notation

α-angle: The slope of the line of sight from the stopping position of an avalanche to the top of the starting zone (see Figure 6).

β-angle: The slope of the line of sight, from the location in the avalanche path where the inclination of the slope is 10°, to the top of the starting zone (see Figure 6).

α/β-model: A topographical model used to predict avalanche runout or to transfer avalanches between paths. The model uses the β-angle to predict the α-angle of the longest recorded avalanche in a given path. The model was first derived by Lied and Bakkehøi (1980). The version of the model used in this project was derived by Tómas Jóhannesson (1998a, 1998b) using data on 45 Icelandic avalanches. The formula of the model is

$$\alpha = 0.85 \cdot \beta, \qquad \sigma = 2.2^\circ$$

where σ is standard deviation of the residuals from the model. It is customary to denote an avalanche with an α-angle $n\sigma$ lower than the predicted α-value as an avalanche with runout of $\alpha - n\sigma$ and conversely $\alpha + n\sigma$ if the α-angle is higher than given by the above equation. Note that as the α-angle is lower the runout is longer, and therefore $\alpha - \sigma$ corresponds to an avalanche with a longer runout distance than α.

PCM-model: A one-dimensional physical model used to simulate the flow of avalanches. The model has two parameters, μ, a Coulomb friction coefficient, and, M/D, an inverse drag coefficient. It was developed by Perla *et al.* (1980).

Runout index: The runout measured in hectometers of an avalanche that has been *transferred* (Sven Sigurðsson *et al.*, 1997) to the *standard path* making use of some transfer method. The runout index in this report is obtained by using the PCM-model with parameters lying on a predefined parameter axis. An avalanche that has a runout index of r_0 is referred to as an avalanche with $r = r_0$. The method was developed by Kristján Jónasson *et al.* (1999).

$F_{r_0}(F_{13})$: The expected frequency of avalanches with a runout index greater or equal than r_0. The value F_{13} is most often used, *i.e.* the frequency at the runout index $r_0 = 13$.

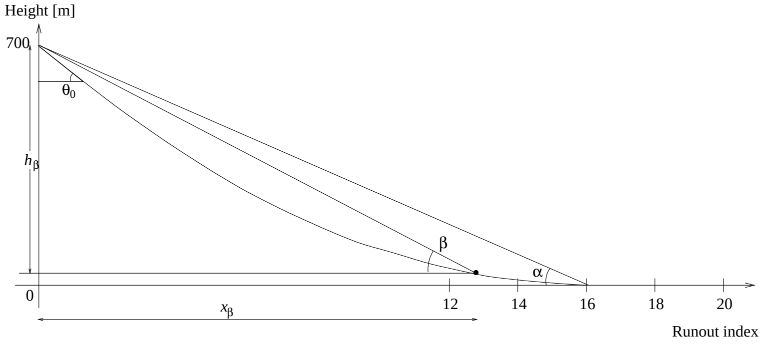


Figure 6. *The standard path. The* α*-angle is the expected runout angle of an avalanche according to the* α/β*-model.*

B Chronicle

This appendix lists recorded avalanches, debris flows and rockfall in the mountain Brellur above the village of Patreksfjörður. Further, slushflows and flashfloods from the gully Geirseyrargil and in the river Litladalsá are also listed. The database number, date and a short description is given for each event. Runout indices are given for snow avalanches where the runout distance is known. A more detailed description is given in the avalanche and landslide chronicle for Patreksfjörður (IMO, 2003).

Number Date *Runout index*	**Description**
7013 before 1900	A slushflow was released from Geirseyrargil.
7007 1852 or 1854	A flashflood was released from the Litladalsá creek. One man was killed and a sheep shed was damaged.
7014 around 1880	A slushflow was released from Geirseyrargil.
7001 1906/1907 *14.5*	An avalanche fell over a field called Nýjatún and destroyed a cow shed.
7002 early 1921 *> 15.2*	A powerful avalanche fell at Urðir and reached far from the hillside. It was not very wide but carried a lot of snow.
7008 after 1920	An avalanche fell in Vatnskrókur.
7015 1933/1934	A debris flow fell on the house at Aðalstræti 47.
7003 16.3.1943 *12.0*	An avalanche destroyed a henhouse above the streets Urðargata/Mýrar.
7017 Fall 1948	A flashflood or slushflow fell from Geirseyrargil.
7025 about 1950	A rock fell from the hill above the settlement before 1950.
7016 1955–1958	A debris flow fell on the house at Aðalstræti 47.
7004 14.3.1958 *13.2*	An avalanche fell at Urðir. It damaged buildings and destroyed three cars.
7023 13.11.1961	A debris flow fell at Urðir.

Number Date *Runout index*	**Description**
7018 1966/1967	A slushflow fell from Geirseyrargil.
7005 12.2.1981 *12.1*	A dry avalanche fell 10 meters below the street Urðargata.
7006 22.1.1983 *> 15.0*	A slushflow fell from Geirseyrargil. It killed three people and damaged 13 buildings.
7009 22.1.1983	A flashflood in the Litladalsá river killed one person and damaged several houses.
7024 August 1984	Rocks fell from the hill above the settlement. A large boulder stopped about 50 m above the setlement on the debris cone of Geirseyrargil.
7020 31.3.1989 *6.3*	Two snow avalanches were release above the street Mýrargata.
7010 16–21.1.1995	A thin avalanche was released above the street Sigtún.
7011 30.1.1995 *10.6*	A thin avalanche was released above the street Sigtún.
7012 30.1.1995	A small avalanche was released from Klif.
7019 22.3.1995 *8.8*	An avalanche fell above Vatneyri.
7022 28.2.2000 *8.9*	A small avalanche fell from the hill in the inner part of Sigtúnssvæði.

C Maps

Map 1. An overview of the village of Patreksfjörður and surroundings and the boundary of the investigated area (A4, 1:15 000).

Map 2. Recorded avalanches, slushflows, debris flows and rockfall in the mountain above Patreksfjörður. (A3, 1:10 000).

Map 3. Results of model estimates in the mountain Brellur above the village of Patreksfjörður. (A3, 1:10 000).

Map 4. Proposed hazard zoning for the investigated area (A3, 1:10 000).

D Climatic data

Summary statistics: Temperature and wind

Climatic data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Bíldudalur (AWS no. 2428)						**1999-2002**							
t, °C	1.3	-1.3	-1.0	2.5	6.5	9.9	11.3	10.9	8.6	5.1	2.5	1.7	4.9
t_max, °C	10.4	10.3	10.2	12.7	16.0	22.8	22.1	18.4	18.7	17.0	14.6	11.5	22.8
t_min, °C	-9.6	-12.4	-13.3	-7.8	-4.1	0.5	3.3	1.1	-1.7	-5.8	-10.0	-11.7	-13.3
f, m/s	5.5	5.2	4.5	3.5	3.7	2.8	2.7	2.6	3.0	3.4	4.6	4.3	3.8
fx, m/s	22.6	35.7	21.4	20.2	18.2	14.5	15.3	13.7	15.5	14.7	26.8	26.2	35.7
gust, m/s	43.5	50.0	30.7	26.7	29.4	31.7	19.1	22.0	30.8	30.1	35.7	42.2	50.0
r, mm	134.3	103.1	86.0	51.1	79.1	25.4	58.7	57.6	62.8	79.9	112.4	103.4	953.8
r_max, mm	42.1	53.3	76.4	13.9	22.7	15.2	23.8	38.8	26.9	38.3	39.6	39.0	76.4
Patreksfjörður (AWS no. 2319)						**1997-2002**							
t, °C	0.4	-2.1	-1.9	1.9	5.3	8.2	9.9	10.0	8.0	4.4	2.3	1.5	4.0
t_max, °C	9.8	8.2	7.9	11.4	16.9	23.2	19.8	18.9	19.0	16.3	11.9	11.2	23.2
t_min, °C	-11.8	-15.1	-15.2	-8.7	-6.8	-1.3	3.5	2.3	-1.8	-5.9	-9.2	-11.2	-15.2
f, m/s	6.1	6.1	5.6	4.3	3.6	3.4	2.9	3.2	3.9	4.7	5.8	5.8	4.6
fx, m/s	21.7	25.3	21.4	19.6	16.3	16.1	14.9	15.6	18.3	20.8	23.6	21.6	25.3
gust, m/s	39.3	38.1	36.2	28.3	26.1	24.8	26.9	23.1	27.1	31.5	40.8	33.5	40.8
r*	113.7	135.8	117.5	49.8	119.7	43.9	57.5	59.7	99.0	104.1	116.6	89.2	1185.8
r_max*	42.0	43.6	69.3	23.6	43.0	27.7	20.3	20.9	51.4	38.9	39.6	65.0	69.3
* periode 1997-2001													
Hálfdán (AWS no. 32322)						**1997-2002**							
t, °C	-3.7	-6.0	-5.9	-2.0	1.5	5.4	7.3	6.9	4.2	0.4	-1.7	-2.4	0.4
t_max, °C	5.8	4.1	4.3	8.4	11.3	18.4	17.1	19.5	14.1	11.7	9.3	6.7	19.5
t_min, °C	-14.6	-19.3	-19.4	-12.6	-8.7	-4.7	-0.5	-1.2	-3.7	-9.2	-11.8	-15.1	-19.4
f, m/s	10.8	9.5	9.2	6.9	6.7	5.4	5.0	5.0	6.6	7.1	8.7	8.3	7.4
fx, m/s	39.3	35.2	41.1	28.1	26.2	27.5	23.8	24.9	26.0	27.8	43.1	32.0	43.1
gust, m/s	50.1	43.1	49.9	34.4	32.1	33.4	30.4	31.2	31.9	35.8	55.5	41.9	55.5
Kleifaheiði (AWS no. 32224)						**1997-2002**							
t, °C	-2.9	-5.4	-5.2	-1.5	2.1	5.7	7.5	7.4	4.9	1.2	-0.9	-1.8	1.0
t_max, °C	6.4	4.3	5.4	7.3	12.3	18.2	16.9	18.3	15.1	12.7	9.1	7.2	18.3
t_min, °C	-14.1	-18.9	-19.2	-13.4	-8.4	-4.4	0.6	0.6	-3.1	-9.1	-11.2	-14.1	-19.2
f, m/s	8.4	8.2	7.5	6.3	6.0	5.0	4.9	5.2	5.8	6.3	7.4	7.7	6.5
fx, m/s	29.1	32.3	29.1	24.0	24.5	20.8	19.4	21.9	25.4	23.1	23.6	34.7	34.7
gust, m/s	47.9	41.8	37.8	31.6	35.3	27.6	26.9	29.2	33.8	31.5	36.9	36.5	47.9
Kvígindisdalur (Synoptic st. no. 224)						**1997-2002**							
t, °C	0.2	-2.2	-2.1	1.7	5.2	8.2	9.9	9.8	7.7	4.2	2.1	1.4	3.8
t_max, °C	10.0	7.6	7.5	10.4	13.4	21.0	18.6	17.6	18.0	16.2	11.7	11.5	21.0
t_min, °C	-11.5	-13.8	-15.0	-12.0	-5.0	-0.4	2.6	2.1	-1.5	-5.5	-9.2	-11.0	-15.0
f, m/s	5.8	5.4	5.1	3.5	3.5	3.0	2.4	2.7	3.4	4.0	4.8	4.5	4.0
fx, m/s	26.8	30.9	26.8	22.7	22.7	15.4	15.4	19.0	19.0	22.7	26.8	26.8	30.9
r, mm	137.9	122.9	148.5	88.1	130.2	45.6	81.5	74.7	126.3	109.5	140.0	125.0	1304.6
r_max, mm	49.9	32.0	131.6	31.3	74.0	44.8	41.9	29.7	81.0	62.1	62.1	74.5	131.6
Kvígindisdalur						**1961-1990**							
t, °C	-1.2	-0.7	-1.2	1.3	4.7	7.8	9.4	9.2	6.4	3.7	0.7	-0.9	3.3
t_max, °C	10.4	10.5	10.5	12.0	16.5	18.6	19.5	21.0	17.5	14.0	11.2	10.6	21.0
t_min, °C	-17.4	-17.0	-18.5	-18.0	-9.4	-2.7	1.5	0.2	-4.0	-9.2	-12.0	-16.0	-18.5
f, m/s	4.7	4.7	4.2	3.6	2.7	2.7	2.4	2.6	3.2	4.0	4.3	4.6	3.6
fx, m/s	35.0	35.0	30.8	29.8	26.7	26.7	22.6	26.7	32.9	30.8	26.7	30.8	35.0
r, mm	126.5	128.6	124.8	111.8	62.5	79.6	82.2	97.4	116.9	161.9	148.4	137.2	1379.5
r_max, mm	93.1	96.6	85.8	59.6	64.9	71.7	57.4	60.7	71.4	102.4	101.6	73.9	102.4
Mjólkárvirkjun (Precipitation st. no. 231)						**1997-2002**							
r, mm	135.1	86.3	96.7	35.7	80.8	14.0	40.5	49.8	87.2	116.1	101.0	117.3	960.5
r_max, mm	50.2	43.1	68.3	16.6	36.1	18.4	14.9	16.7	61.6	33.7	48.6	35.2	68.3
Mjólkárvirkjun						**1961-1990**							
r, mm	93.2	90.0	81.2	63.4	38.3	37.2	32.8	51.7	72.6	115.5	103.2	84.9	850.4
r_max, mm	69.0	66.7	121.7	53.5	49.5	24.0	28.4	46.7	33.0	82.1	66.4	53.9	121.7

t=average monthly temperature, t_max=highest measured temp., t_min= lowest measured temp.
f=average windspeed, fx=maximum 10min windpeed, gust=maximum 3 sec. gust
r=monthly average accumulated precipitation , r_max=maximum 24hr accumulated precipitation
AWS=automatic weather station

Precipitation, weather stations

	Kvígindisdalur				Mjólkárvirkjun		
1961-1990	precip.,mm	rain %	sleet %	snow %	precip.,mm	rain %	sleet %
Jan	126.5	32	43	25	93.2	42	36
Feb	128.6	28	52	19	90.0	47	37
Mar	124.8	33	44	22	81.2	44	37
Apr	111.8	47	38	14	63.4	61	28
May	62.5	84	15	1	38.3	74	21
Jun	79.6	98	2	0	37.2	96	4
Jul	82.2	100	0	0	32.8	100	0
Aug	97.4	99	1	0	51.7	99	1
Sep	116.9	98	4	1	72.6	87	13
Oct	161.9	78	19	3	115.5	81	15
Nov	148.4	60	34	8	103.2	55	33
Dec	137.2	33	46	21	84.9	52	29
Year	1379.5	60	28	11	850.4	64	26
1997-2002							
Jan	137.9	53	35	12	135.1	66	27
Feb	122.9	14	45	41	86.3	21	49
Mar	148.5	39	41	20	96.7	42	39
Apr	88.1	37	60	3	35.7	61	19
May	130.2	92	8	0	80.8	97	3
Jun	47.6	93	7	0	14.0	99	0
Jul	81.5	100	0	0	40.5	100	0
Aug	74.7	100	0	0	49.8	100	0
Sep	126.3	99	1	0	87.2	95	5
Oct	109.5	77	21	2	116.1	82	15
Nov	140.0	70	24	6	101.0	62	26
Dec	125.0	51	38	11	117.3	59	31
Year	1304.3	68	21	12	960.5	69	22

Station no.	Name	lattitude	longitude	altitude, m	since year
32322	Hálfdán	65°36'	23°42'	525	1995
2319	Patreksfjörður	65°35'	23°58'	43	1996
224	Kvígindisdalur	65°33'	24°00'	49	1927
231	Mjólkárvirkjun	65°46'	23°10'	8	1959
2428	Bíldudalur	65°40'	23°36'	16	1998
32224	Kleifaheiði	65°30'	23°42'	400	1996

Snow depth

Kvígindisdalur

Monthly average snow depth, cm

	Jan	Feb	Mar	Apr	May	Sept	Oct	Nov	Des
1951	5	6	7				3	6	20
1952	78	7	4				3	3	2
1953	8	2	6	5			3	10	4
1954	8	14	27						9
1955	10	10	9	1			5	5	9
1956	12	6	5	1			2	4	6
1957	30	88	62	8			9	7	14
1958	33	9	23				5	3	2
1959	2	3	19	9				9	11
1960	13		3	0					7
1961	6		13	14			1	5	5
1962	5	8		3			3	4	5
1963		15			3				
1964		15	8	5			6		9
1965	4						2		0
1966			4	24					19
1967	16	5	5				5	10	8
1968		16	6	8					3
1969	3		8				5	14	5
1970	6	21	3	3			2	5	10
1971	13			5			1	11	20
1972	35	8	6				2	4	12
1973	7	7	18	46				8	16
1974	15	8	11					4	19
1975	13	9	3					7	6
1976	11	17	10	15				1	3
1977	3	4	2	12				4	9
1978	6	4	6	2			6	8	1
1979	11	11	13	1	5		1	1	5
1980	3	5	9	1					
1981	11	23	17	4	2	2	1	9	3
1982	5	8	13	2	7		3	4	14
1983	42	8	15	27			3	20	8
1984	36	24	7	4	1		1	3	14
1985	2	3	2	2			0	5	1
1986	4	3	12	8			10	4	6
1987	8	5	8	10	3		8	0	6
1988	10	11	13	18	1		1	3	8
1989	23	0	35	12			2		5
1990	10	13	15	12				3	12
1991	12	6	4	5			2	4	8
1992	10	12	7	2	2			6	5
1993	31	11	6	2	3			4	2
1994	5	6	9	6				3	10
1995	20	39		5		0	6	0	1
1996	5	4		4			1	4	2
1997	3	15						2	5
1998	2	10	6				3		
1999	6	7	9	1				4	7
2000				4				4	5
2001	2	4	6	5				5	13
2002	2	3	3				2		3
Monthly average snowdepth 1961-1990, cm									
	12	**10**	**10**	**10**	**3**	**2**	**3**	**6**	**8**

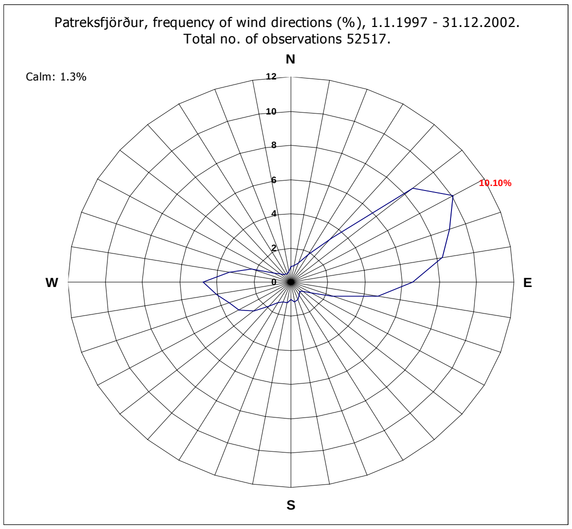
Maximum observed snow depth, cm

	Jan	Feb	Mar	Apr	May	Sept	Oct	Nov	Des
1951	13	2	1				3	7	5
1952	1	4	4				3	5	4
1953	15	5	2	12			5	2	1
1954	17	27	36						22
1955	22	19	23	1				5	2
1956	16	13	6	1			3	5	1
1957	8	88	88	1			25	1	25
1958	47	1	29				4	4	
1959	14	14	32	15				13	2
1960	32		4						1
1961	7		27	2			1	22	11
1962	1	19					4	7	9
1963		3			7				
1964		16	2	8			13		18
1965	15						2		
1966			1	57					26
1967	26	15	1				5	25	15
1968		5	12	11					3
1969	4		35				13	19	1
1970	7	39	8	7			5	7	19
1971	2			9			1	27	42
1972	56	1	19				2	6	28
1973	3	13	36	59				15	32
1974	32	12	4					4	43
1975	23	18	1					15	15
1976	2	38	25	28				1	9
1977	11	7	3	18				7	16
1978	15	1	12	2			7	22	1
1979	24	2	2	1	5		1	3	8
1980	12	14	2	3					
1981	25	5	25	5	2	2	1	14	8
1982	1	2	26	5	1		5	12	32
1983	63	16	38	38			4	34	28
1984	5	5	2	8	2		1	6	24
1985	3	6	4	3				7	3
1986	1	4	25	16			15	11	12
1987	15	12	18	26	3		11	1	9
1988	24	22	25	25	3		3	4	26
1989	45		48	2			2		16
1990	21	21	28	24				5	35
1991	35	19	12	16			3	2	24
1992	27	25	18	3	2			15	12
1993	42	27	14	4	3			9	4
1994	8	14	17	9			2	8	27
1995	43	48	61	9			9		2
1996	1	8	2	6			1	8	4
1997	8	33	35					2	8
1998	5	19	16				5	1	4
1999	11	12	11	2				7	14
2000	25	29		12				5	15
2001	3	15	14	6				12	27
2002	4	8	7	2			2		3
Maximum observed snow depth, cm									
	63	**88**	**88**	**59**	**7**	**2**	**25**	**34**	**43**

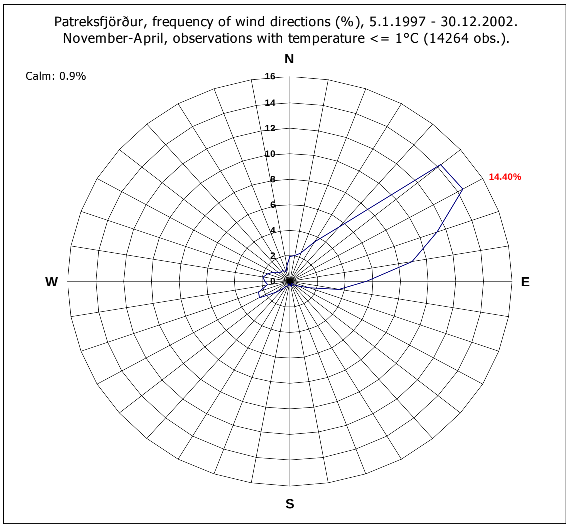
Snow cover

														Kvígindisdalur												
	Average snow cover in lowland, %														Average snow cover in mountains, %											
	J	F	M	A	M	J	J	A	S	O	N	D			J	F	M	A	M	J	J	A	S	O	N	D
1951	85	94	96	72	1	0	0	0	0	26	12	80		**1951**	85		98	74	1	0		0		29	13	
1952	100	94	46	48	2	0	0	0	0	9	26	49		**1952**	99	93	75	53	3	0	0	0	2	29	65	73
1953	65	71	69	71	3	0	0	0	0	33	63	63		**1953**	86	93	82	88	40	21	0	0	0	61	85	89
1954	54	94	79	38	0	0	0	0	0	17	55	84		**1954**	88	99	87	61	31	11	0	0		46	70	90
1955	77	93	92	12	2	0	0	0	0	0	14	99		**1955**	87	100	97	45	16	0	0	0	0	0	56	100
1956	98	49	30	18	0	0	0	0	0	34	30	60		**1956**	100	65	71	68	35	19	0	0	0	70	48	81
1957	76	100	95	31	0	0	0	0	0	31	47	82		**1957**	88	100	98	64	45	25	0	0	0	55	78	94
1958	98	98	86	42	0	0	0	0	0	3	28	52		**1958**	100	98	89	62	37	21	0	0	0	8	79	87
1959	86	73	34	62	2	0	0	0	0	0	63	24		**1959**	97	88	60	72	30	4	0	0	2	21	78	77
1960	50	56	20	7	0	0	0	0	0	0	0	76		**1960**	65	74	51	52	19	0	0	0	0	0	0	83
1961	44	60	88	71	4	0	0	0	0	10	48	77		**1961**	66	70	89	76	28	3	0	0	0	17	64	81
1962	81	91	43	39	0	0	0	0	0	24	58	69		**1962**	83	96	67	56	14	0	0	0	0	26	58	73
1963	53	74	9	27	18	0	0	0	18	2	42	35		**1963**	70	82	35	42	39	0	0	0	31	56	91	59
1964	29	26	20	13	0	0	0	0	0	13	28	91		**1964**	54	47	25	46	6	0	0	0	0	23	42	94
1965	68	19	33	23	0	0	0	0	0	3	3	78		**1965**	71	21	51	40	0	0	0	2	0	14	16	65
1966	56	57	99	80	1	0	0	0	0	10	64	98		**1966**	56	49	95	70	23	20	0	0	3	20	83	100
1967	73	42	90	58	2	0	0	0	0	10	79	88		**1967**	83	59	93	68	42	3	0	0	1	56	85	91
1968	94	93	81	65	14	0	0	0	0	4	13	40		**1968**	98	96	84	70	48	8	0	4	7	38	17	52
1969	61	86	92	61	3	0	0	0	0	22	76	74		**1969**	77	89	94	79	32	4	0	0	33	69	94	75
1970	58	80	85	75	2	0	0	0	0	34	55	62		**1970**	61	84	94	82	44	18	2	0	7	48	71	81
1971	56	74	35	39	3	0	0	0	0	19	58	81		**1971**	85	88	52	66	22	3	0	0	7	43	77	87
1972	46	39	31	34	0	0	0	0	0	21	74	56		**1972**	53	73	64	52	25	0	0	0	0	27	87	82
1973	55	98	76	39	3	0	0	0	0	18	76	89		**1973**	80	100	83	71	33	25	2	3	0	36	87	94
1974	97	86	19	10	0	0	0	0	0	2	14	100		**1974**	97	97	60	53	25	3	0	2	9	33	78	100
1975	99	63	62	25	5	0	0	0	0	0	48	73		**1975**	100	74	76	66	31	8	0	0		24	61	91
1976	98	89	90	61	9	0	0	0	0	0	17	45		**1976**	99	90	90	71	56	16	0	0	0	15	26	65
1977	70	74	31	44	0	0	0	0	0	3	83	46		**1977**	94	79	65	75	24	0	0	0	3	18	93	73
1978	98	98	69	8	0	0	0	0	0	12	78	38		**1978**	100	98	92	48	33	1	0	0	3	41	94	73
1979	67	54	85	34	12	0	0	0	3	10	33	71		**1979**	82	92	93	79	50	17	0	0		36	98	100
1980	87	68	73	39	0	0	0	0	0	3	28	82		**1980**	100	100	100	88	31	8	0	0	0	0	58	91
1981	93	100	100	33	3	0	0	0	3	16	63	49		**1981**	97	100	100	81	55	18	0	0		88	90	88
1982	69	79	89	42	16	0	0	0	2	10	53	94		**1982**	92	86	92	70	63	15	0	0		39	87	100
1983	98	77	95	92	44	0	0	0	0	23	48	89		**1983**	100	91	98	100	56	42	0	0	0	50	75	97
1984	100	98	76	58	11	0	0	0	0	8	50	82		**1984**	100	100	92	95	66	50	10	0	0	58		100
1985	52	70	60	20	2	0	0	0	0	0	37	45		**1985**	87	96	92	72	35	0	0	0	2	18	70	97
1986	74	27	85	32	0	0	0	0	0	53	65	87		**1986**	98	55	97	82	53	35	0	0	3	68	97	97
1987	40	68	68	57	6	0	0	0	0	44	4	31		**1987**	81	91	97	90	45	0	0	0	2	71	60	74
1988	89	83	90	83	10	0	0	0	0	13	20	81		**1988**	100	91	90	92	40	0	0	0	3	56	77	97
1989	90	100	100	98	48	0	0	0	0	5	0	47		**1989**	100	100	100	100	97	38	0	0	5	15	78	68
1990	87	100	100	90	15	0	0	0	0	0	22	79		**1990**	92	100	100	100	53		0	0		27	42	94
1991	84	75	69	55	0	0	0	0	0	13	58	73		**1991**	92	100	98	100	63	2	0	0	0	50	92	92
1992	61	88	82	51	8	0	0	0	0	0	69	95		**1992**	84	98	100	98	69	10	0	0	3	24	93	100
1993	100	82	81	43	5	0	0	0	0	0	48	55		**1993**	100	100	100	93	66	35	0	2	0	16	77	100
1994	50	80	89	67	2	0	0	0	0	40	35	92		**1994**	100	89	98	75	45	0	0	0	10	61	75	100
1995	98	100	95	62	6	0	0	0	5	24	37	44		**1995**	100	100	100	100	53	32	0	0	22	66		84
1996	44	88	40	17	0	0	0	0	0	11	58	48		**1996**	87	100	66	62	2	0	0	0	0	48	95	
1997	52	96	97	38	0	0	0	0	2	45	8	29		**1997**	95	100	100	65	42	2	0	0	3	0	87	68
1998	16	79	90	32	2	0	0	0	0	48	28	53		**1998**	79	100	94	55	50	0	0	0	2	58		
1999	85	89	68	38	2	0	0	0	0	2	55	89		**1999**	90	93	95	72	16	0	0			29	87	92
2000	66	97	84	23	6	0	0	0	0	0	23	52		**2000**	82	100	92	58	50	15		0		23	95	92
2001	34	57	68		2	0	0	0	0	2	50	46		**2001**	92	93			31	0	0	0		18	63	
2002	31	73	71											**2002**	92	100	98									
Average 1971-2000																										
Kvígi.	**74**	**81**	**74**	**45**	**7**	**0**	**0**	**0**	**1**	**15**	**43**	**67**			**92**	**93**	**89**	**78**	**45**	**13**	**0**	**0**	**3**	**38**	**79**	**89**
Mjólk.	**71**	**72**	**64**	**47**	**13**	**1**	**0**	**0**	**2**	**13**	**39**	**59**			**85**	**88**	**84**	**83**	**60**	**35**	**23**	**18**	**24**	**40**	**66.2**	**81**

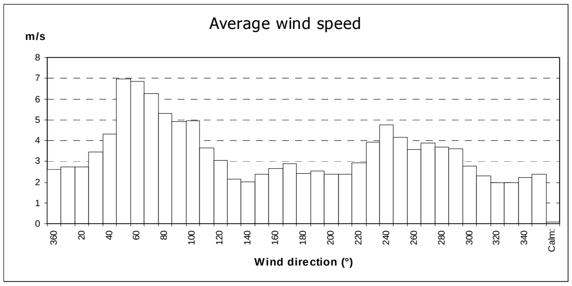
Wind roses



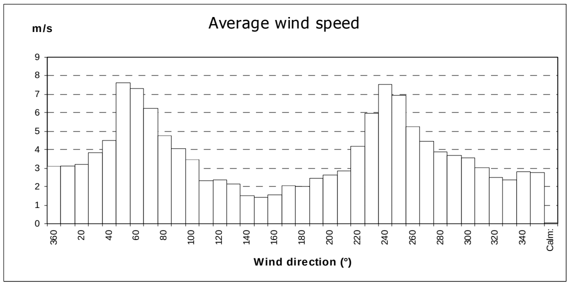
Patreksfjörður, frequency of wind directions (%), 1.1.1997 - 31.12.2002.
Total no. of observations 52517.



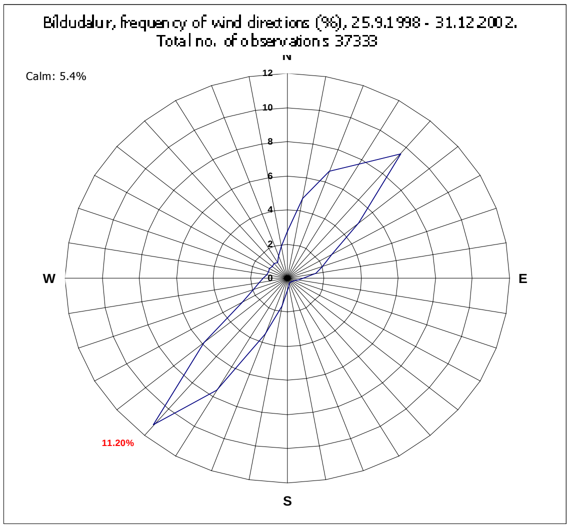
Patreksfjörður, frequency of wind directions (%), 5.1.1997 - 30.12.2002.
November-April, observations with temperature <= 1°C (14264 obs.).



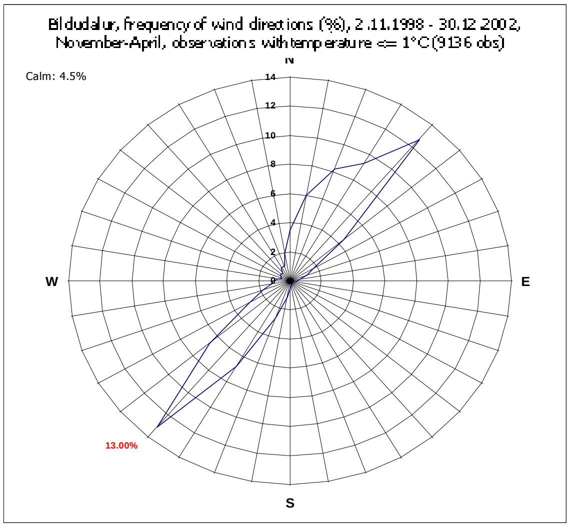
Average wind speed



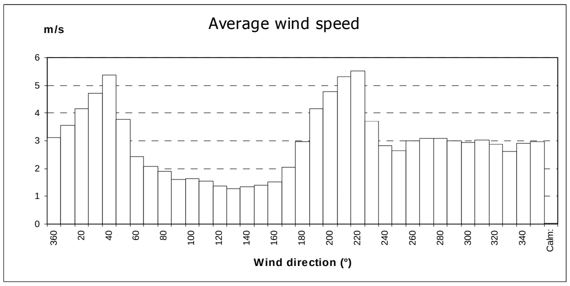
Average wind speed



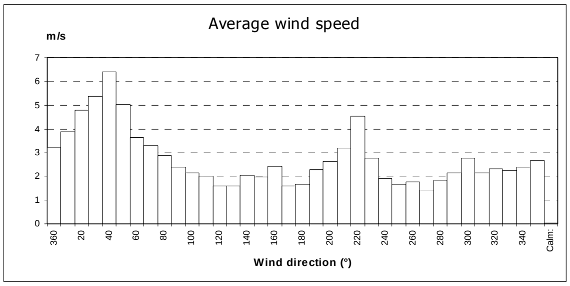
Bíldudalur, frequency of wind directions (%), 25.9.1998 - 31.12.2002.
Total no. of observations 37333



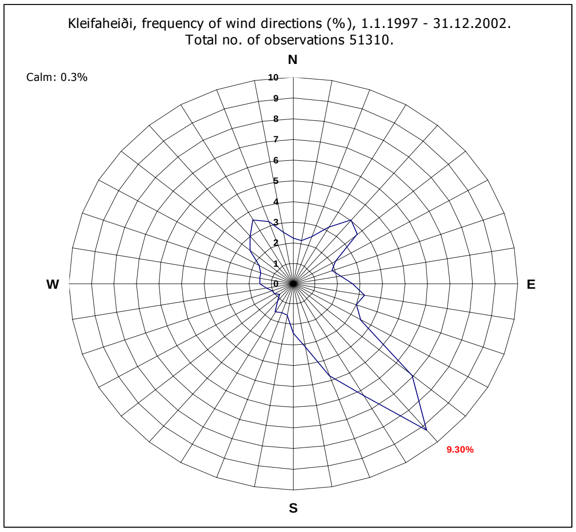
Bíldudalur, frequency of wind directions (%), 2.11.1998 - 30.12.2002,
November-April, observations with temperature <= 1°C (9136 obs)

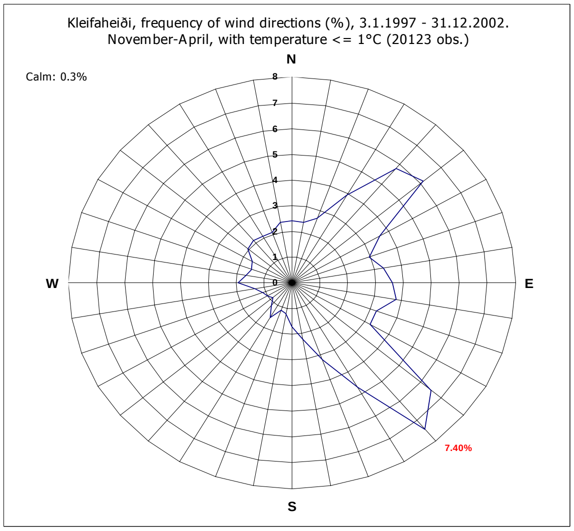


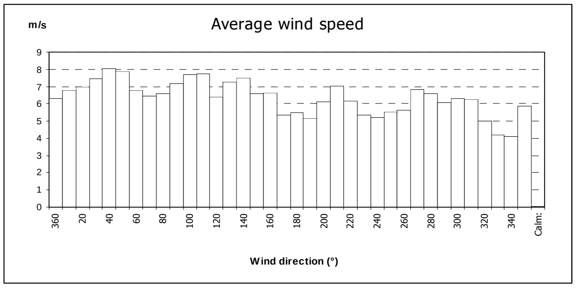
Average wind speed

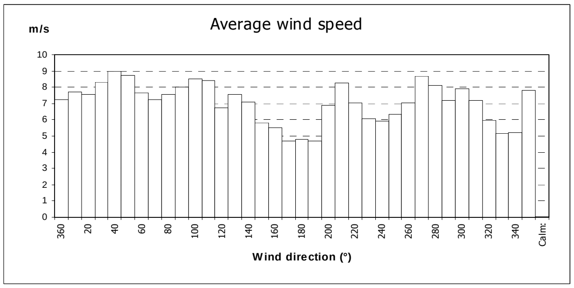


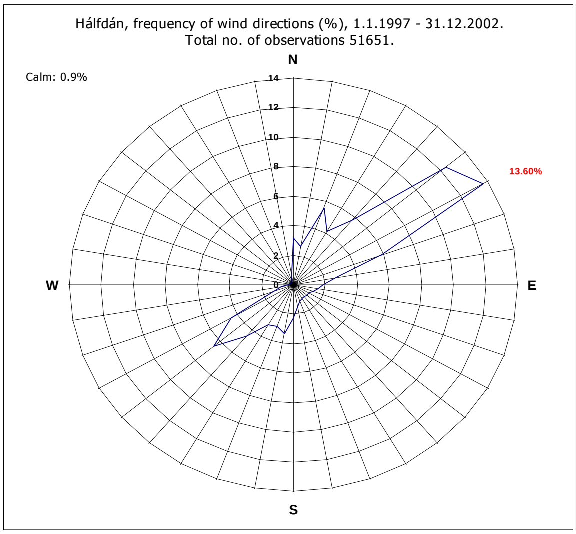
Average wind speed

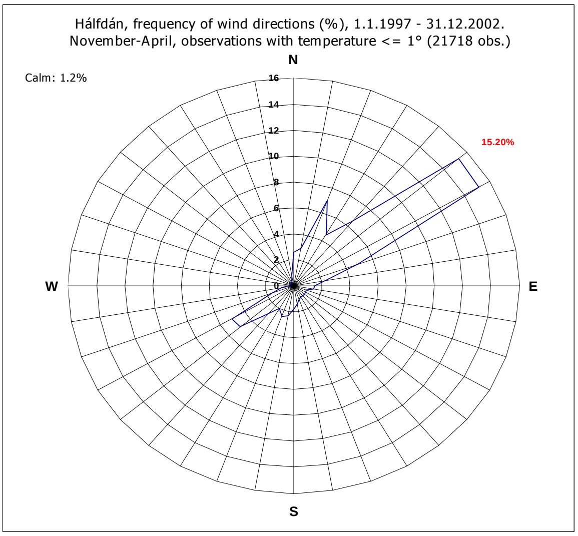

Kleifaheiði, frequency of wind directions (%), 1.1.1997 - 31.12.2002.
Total no. of observations 51310.
Calm: 0.3%
N
E
S
W
0
1
2
3
4
5
6
7
8
9
10
9.30%

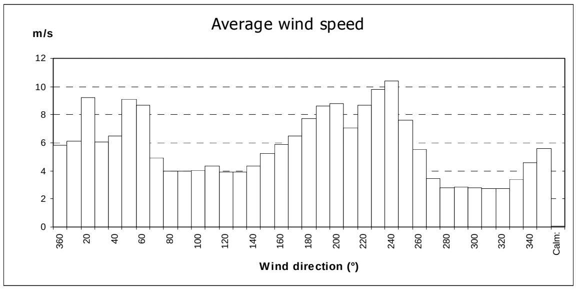

Kleifaheiði, frequency of wind directions (%), 3.1.1997 - 31.12.2002.
November-April, with temperature <= 1°C (20123 obs.)
Calm: 0.3%
N
E
S
W
0
1
2
3
4
5
6
7
8
7.40%

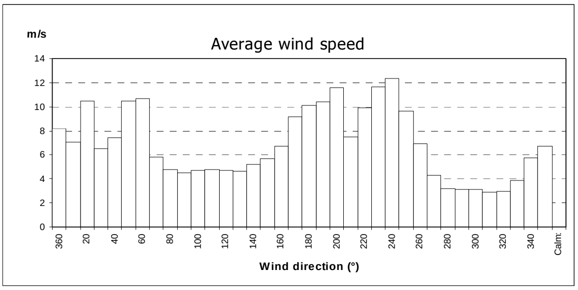

Average wind speed
m/s
0
1
2
3
4
5
6
7
8
9
360
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Calm:
Wind direction (°)

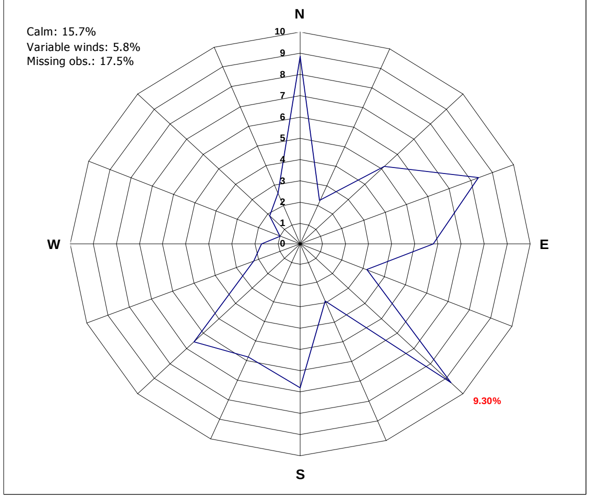

Average wind speed
m/s
0
1
2
3
4
5
6
7
8
9
10
360
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Calm:
Wind direction (°)


Hálfdán, frequency of wind directions (%), 1.1.1997 - 31.12.2002.
Total no. of observations 51651.
Calm: 0.9%
N
E
S
W
0
2
4
6
8
10
12
14
13.60%

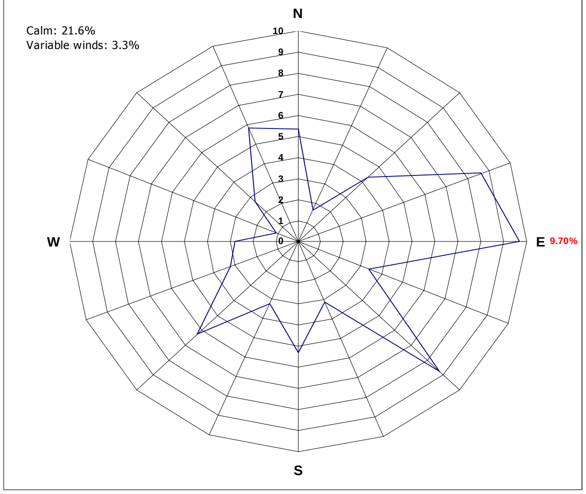

Hálfdán, frequency of wind directions (%), 1.1.1997 - 31.12.2002.
November-April, observations with temperature <= 1° (21718 obs.)
Calm: 1.2%
N
E
S
W
0
2
4
6
8
10
12
14
16
15.20%


Average wind speed
m/s
0
2
4
6
8
10
12
360
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Calm:
Wind direction (°)

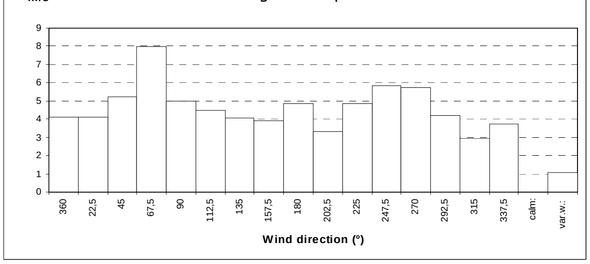

Average wind speed
m/s
0
2
4
6
8
10
12
14
360
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
Calm:
Wind direction (°)



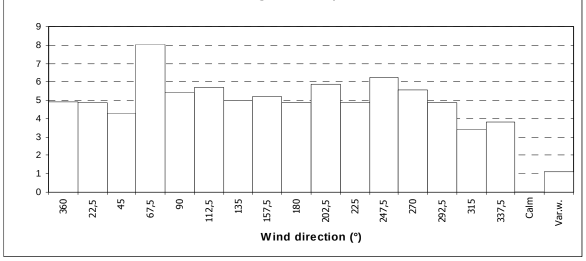
Kvígindisdalur, frequency of wind directions (%), 1.1.1961 - 31.12.1990.
Total no. of observations 43003



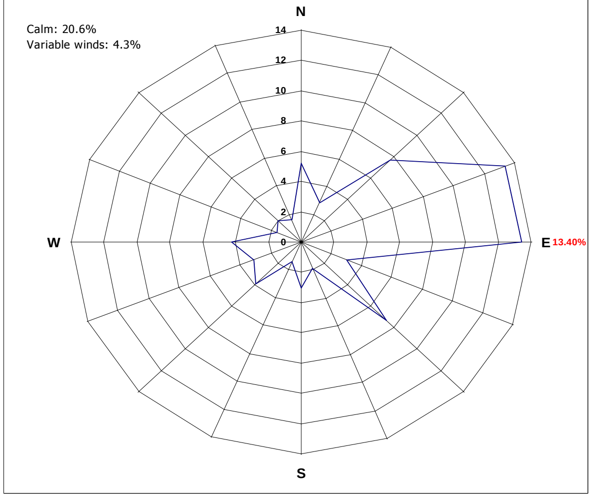
Kvígindisdalur, frequency of wind directions (%), 1.1.1997 - 31.12.2002.
Total no. of observations 10435.



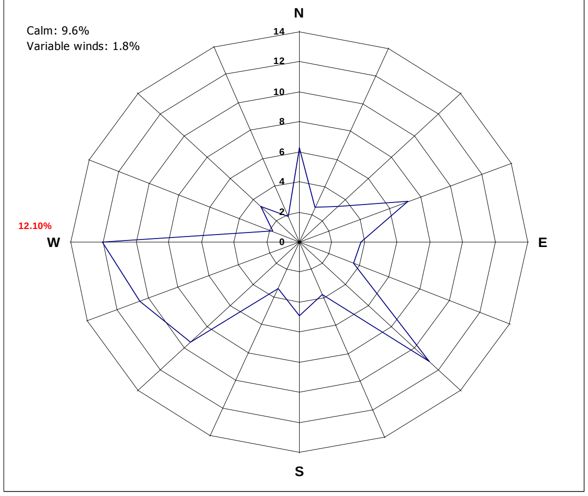
Average wind speed



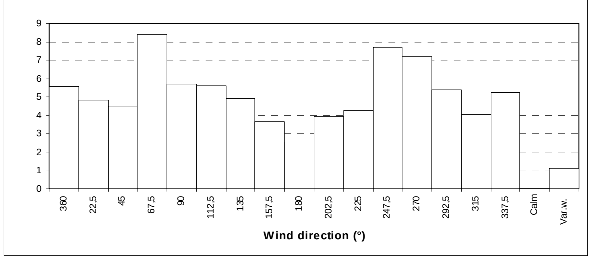
Average wind speed



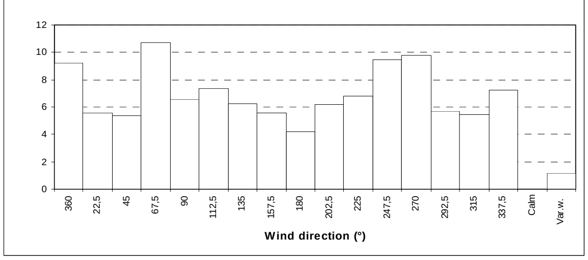
Kvígindisdalur, frequency of wind directions (%), 5.1.1997 - 31.12.2002.
November-April, observations with temperature <= 1°C (3029).



Kvígindisdalur, frequency of wind directions (%), 14.1.1997 - 23.12.2002.
November-April, observations við precipitation and temperature <=1° (448 obs.).



Average wind speed



Average wind speed