Reviewed research article

Present morphoclimates and morphodynamics of Latnjavagge, the northern Swedish Lapland and Austdalur, east Iceland

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Abstract – *Until recently, the present-day climate has often only been characterized by monthly and annual means or sum values of wind speed, temperature, and precipitation. As most geomorphologic processes consist of discrete events which are only partly correlated to these meteorological means or sum values, there is a need for an additional approach of statistical analysis of meteorological data. In this investigation the "morphoclimates" of Austdalur, in Seyðisfjörður, East Iceland and Latnjavagge, in the northernmost Swedish Lapland are analysed with particular emphasis on (1) the frequencies or recurrence intervals of meteorological events of given magnitudes, and (2) the frequencies of geomorphologically important thresholds. Aspects of the wind, temperature, and precipitation regimes which control the type, frequency, duration, intensity and the sediment budgets in the two periglacial environments are presented. In Austdalur aquatic slope denudation is more important than chemical denudation. The Latnjavagge drainage basin is characterized by a dominance of chemical denudation over mechanical fluvial denudation. In both environments the intensities of the geomorphologic processes operating in the present periglacial morphoclimates are low.*

INTRODUCTION

It is expected that predicted climate change will cause major changes in polar and subpolar environments. From a geomorphological point of view, it is of increasing importance to obtain a better understanding of the relationships between present-day geomorphological processes and present-day climatic conditions to get a more reliable assessment of the possible geomorphological effects of climate change.

According to Chorley (1962), and Chorley and Kennedy (1971), drainage basins are open geomorphologic systems, which are parts of higher and larger systems and are connected to these by transfers of energy and material. Fluvialmorphologic process-response systems - consisting of static components (material components, form components), process components and the relationships between static components and process components - are driven by endogenic and exogenic energy supplies like crustal movements and meteorological events (Chorley and Kennedy 1971; Ahnert 1998). In process geomorphological investigations the exogenic energy supplies are often only characterized by annual and/or monthly sums or mean values of precipitation, temperature, and wind speed (see e.g., Peltier 1950; Fournier 1960; Chorley *et al.* 1984). As, however, most geomorphologic processes consist of discontinuous process events, not or only partly correlated to these meteorological sum or mean values, there is a need for an additional approach of statistical analysis of meteorological data.

Ahnert (1982; 1986; 1987; 1988; 1998) developed a "morphoclimatology" specially related to geomorphologic needs. "Morphoclimate" in this sense is defined as the totality of those climatic characteristics of an area that influence the type, frequency, duration and intensity of the exogenic geomorphologic processes in this area. The statistical method primarily used in this context is the *magnitude-frequency analysis*; it provides evidence of frequencies and recur-

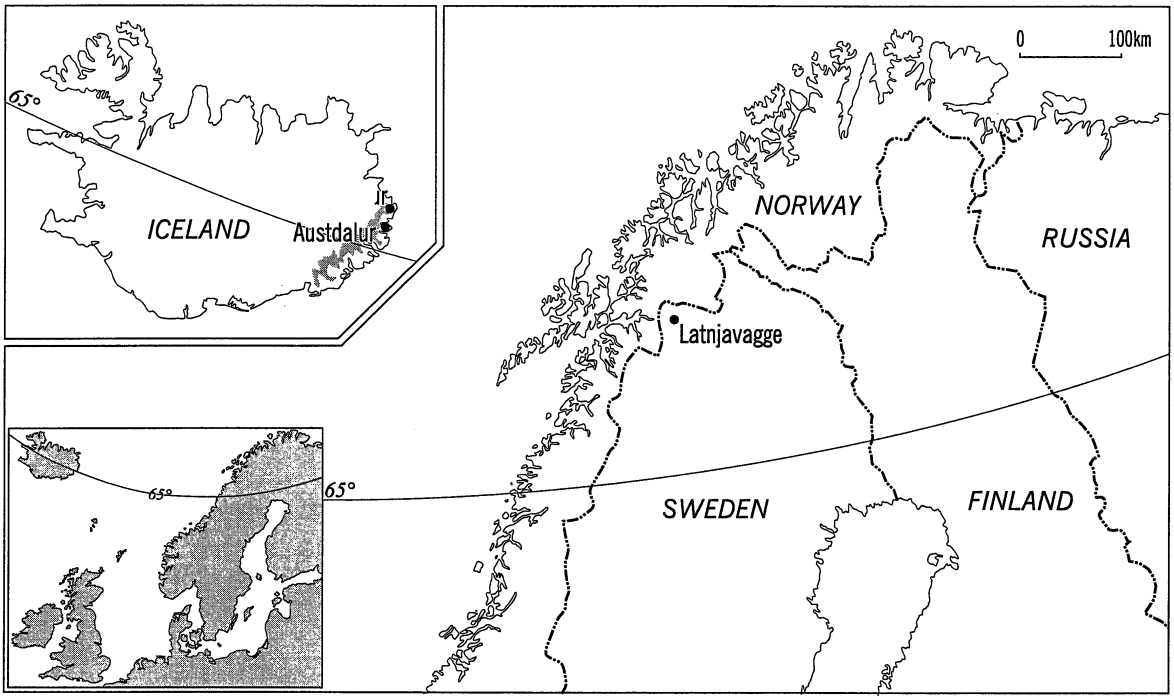

Figure 1. Location of the study areas in Austdalur, Seyðisfjörður, East Iceland and Latnjavagge, in the northern Swedish Lapland. – *Rannsóknarsvæðin í Austdal við sunnanverðan Seyðisfjörð og í Latnjavagge, Lapplandi, Norður Svíþjóð.*

rence intervals of meteorological events of given magnitudes and of frequencies of geomorphologically important thresholds of precipitation, temperature and wind speed. The calculation of the recurrence intervals (RI) is according to the following equation (Chow 1964; Ahnert 1982; 1986; 1987).

$$RI = (N + 1)r^{-1} \quad (1)$$

where N = total number of time units and r = rank of the meteorological event.

The development of a "morphoclimatology" oriented to geomorphology is still in its beginning (De Ploey *et al.* 1991; Ahnert 1998; Beylich 1999a; 1999c; 2000c; 2001b; 2003). This investigation on the morphoclimates and on recent geomorphodynamics of two different periglacial environments is based on a quantitative statistical analysis of meteorological data from the Dalatangi meteorological station, situated about 10 km east of Austdalur (65°16'N, 13°35'W, and 9.0 m a.s.l.), and the Latnjajaure Field Station (LFS) situated in the Latnjavagge drainage basin, Swedish Lapland (68°20'N, 18°30'E at 981 m a.s.l., see Molau 2001; 2003) (Figure 1). Additionally, it is based on quantitative geomorphodynamic field work, including daily observations and process measurements in two small drainage basins which are representative for the study areas. The Austdalur field work was conducted during the summer field seasons of 1996, 1997, 1998 and autumn field season of 1997, (Beylich 1999a; 2000b; 2003) and the Latnjavagge fieldwork during the summer field seasons of 2000, 2001 and 2002, (Beylich 2001a; 2001b; 2003; Beylich *et al.* 2003).

THE STUDY AREAS

The morphoclimate of an area is largely dependent on the regional climate and existing landforms (Ahnert 1982). The mountains of northernmost Swedish Lapland are situated close to the North Atlantic in a prevailing westerly wind regime which gives rise to a pronounced orographic effect and strong west-east gradient in cloudiness and precipitation. Precipitation is mainly connected with cyclonic activity. The northerly position of the area is partly counteracted by the influence of the Gulf Stream. The mountains belong to the northern part of the Scandinavian mountain chain (the Scandinavian Caledonides) with individual peaks reaching 1440 m a.s.l. Typical are flat plateaux at 1300 m a.s.l., intersected by glacially sculptured valleys with floors at 1000 m a.s.l. (Kling 1996; 2003).

Iceland is located in the polar front area. The proximity of passing low-pressure areas implies a high cyclonic activity. Moreover, the climate in the coastal areas of East Iceland is modified by the cold East Iceland Stream, which may from time to time carry drift-ice (Schunke 1979; Liebricht 1983; Einarsson 1991). The mountains of the Icelandic Eastern Fjords (Austfirðir) rise steeply out of the North Atlantic, reaching maximum elevations of more than 1000 m a.s.l.

The Austdalur drainage basin is located at 65°16'N, 13°48'W in the subarctic-oceanic mountain area of Seyðisfjörður whereas the Latnjavagge drainage basin is situated at 68°20'N, 18°30'E in the arctic-oceanic mountains of northernmost Swedish Lapland. Both exhibit principal geomorphologic and geological characteristics and were thus chosen as representative test areas for the field work (Figure 1). Direct anthropogenic impact on the natural systems is presently small.

Latnjavagge

The Latnjavagge drainage basin drains to the south into the larger Kårsavagge basin. It has an area of approx. 9 km^2, a length of 4600 m, and elevation ranging from 950 m a.s.l. to 1440 m a.s.l. The bedrock of Latnjavagge is mainly composed of Cambro-Silurian mica-garnet shists and inclusions of marble (Kulling 1964; Kling 2003). Latnjavagge is dominated by flat plateaux at approx. 1300 m a.s.l., steep slopes which bound the glacially sculptured valley, and the flat valley floor situated between 950 and 1200 m a.s.l. Regional deglaciation occurred about 8000–10000 yr ago (André 1995). The plateaux largely consist of bare bedrock and boulder fields. The transition to steep slopes is generally abrupt and, on the east-facing side, covered by perennial snow and ice patches. The lower part of the valley floor is dominated by a lake, Latnjajaure (0.73 km^2), and a series of moraine ridges. The regolith thicknesses are generally small (Beylich *et al.* 2003). The area belongs to the mid-alpine zone with a continuous vegetation cover comprising dwarf shrub heaths and alpine meadows and bogs (Molau 2001; 2003). The distribution of permafrost is still not thoroughly investigated but drilling outside the drainage basin at 1200 m a.s.l. suggested permafrost down to 80 m below the surface (Kling 1996; 2003; Beylich *et al.* 2003). Active denudative slope processes are frost weathering, rockfalls, boulder falls, ploughing boulders, avalanches, slush flows, debris flows and slides, solifluction (lobes and sheets), creep processes, chemical weathering and denudation, aquatic slope denudation, and deflation. In the main channels dissolved solids, suspended sediments and debris are transported. The largest part of the fluvially transported sediments is trapped in the lake. The hydrological regime is nival (Beylich 2001a; 2003; Beylich *et al.* 2003).

Austdalur

The 23 km^2 Austdalur basin drains to the north into the Seyðisfjörður fjord. It has a length of 6850 m, and elevation ranging from sea level up to 1028 m a.s.l. The Austfirðir Mountains are mainly composed of Upper-Miocene plateau basalt layers with intercalated sedimentary rock layers slightly dipping to the west (Schunke 1975; Einarsson 1994). Pleistocene glaciations produced steep, alpine relief with trough valleys, corries, ridges, and rock walls (Schunke 1979; Sigbjarnarson 1983). Regional deglaciation occurred about 10000–12000 yr ago (Ingólfsson 1991). The drainage basins of the Austfirðir Mountains are mainly characterized by their steepness and high drainage density. In addition to the talus cones de-

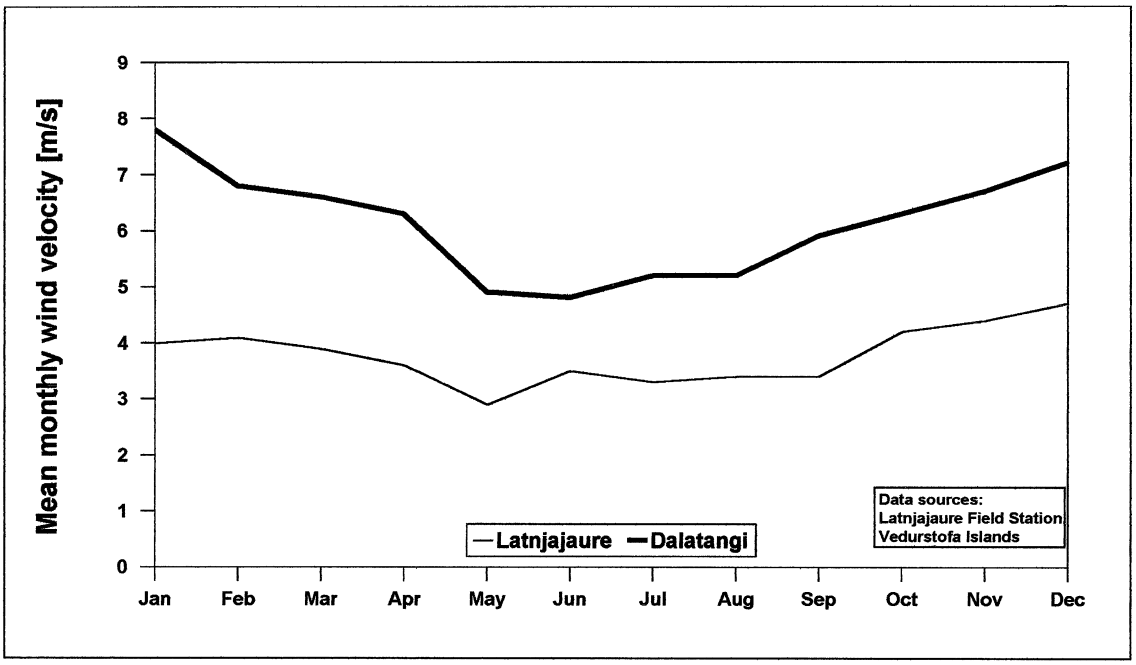

Figure 2. Mean monthly wind velocities at the Dalatangi meteorological station (∼10 km east of Austdalur) and the Latnjajaure Field Station (Latnjavagge, northern Swedish Lapland). – *Mánaðarmeðaltöl vindhraða á Dalatanga og í Latnajaure, Lapplandi.*

veloped below rock walls and rock ledges there are Pleistocene moraines in the catchments. The regolith thicknesses are generally small (Beylich 1999a). The North European flora, apart from dwarf shrubs, is formed by meadows and cryptogams (mosses and lichen) (Glawion 1985). With increasing altitude, the gaps in the vegetation cover increase, so that above 500 to 600 m a.s.l. there is hardly any closed vegetation. Larger areas, particularly convex slope surfaces exposed to the wind, are free of vegetation or affected by turf exfoliation ("Rasenabschälung") (Troll 1973; Glawion 1985). There is probably no permafrost in the area. Active denudative slope processes are frost shattering, rockfalls, boulder falls, ground avalanches, debris slides and flows, creep processes, chemical denudation, nivation, aquatic slope denudation (slope and rill wash), and deflation. The steep main channels are predominantly resistance-limited bedrock channels with numerous knickpoints, displaying high flow velocities and highly turbulent discharges. Dissolved salts, suspended sediments and debris are transported in the main channels. Typical are high temporal variations of discharge, with high runoffs during intense thaws and heavy rainfalls (Beylich 1999a).

MORPHOCLIMATIC INVESTIGATIONS

Geomorphologically Relevant Aspects of the Wind Regimes

Seasonal wind variations at Dalatangi and Latnjajaure are shown in Figures 2 and 3. The highest wind speeds occur at both stations during the autumn and winter months. The Dalatangi values are significantly higher than at Latnjajaure.

High wind speeds particularly occurring with autumn and winter snow storms generate a very irregular snow distribution in both areas. In both environments convex slope surfaces exposed to the wind are largely

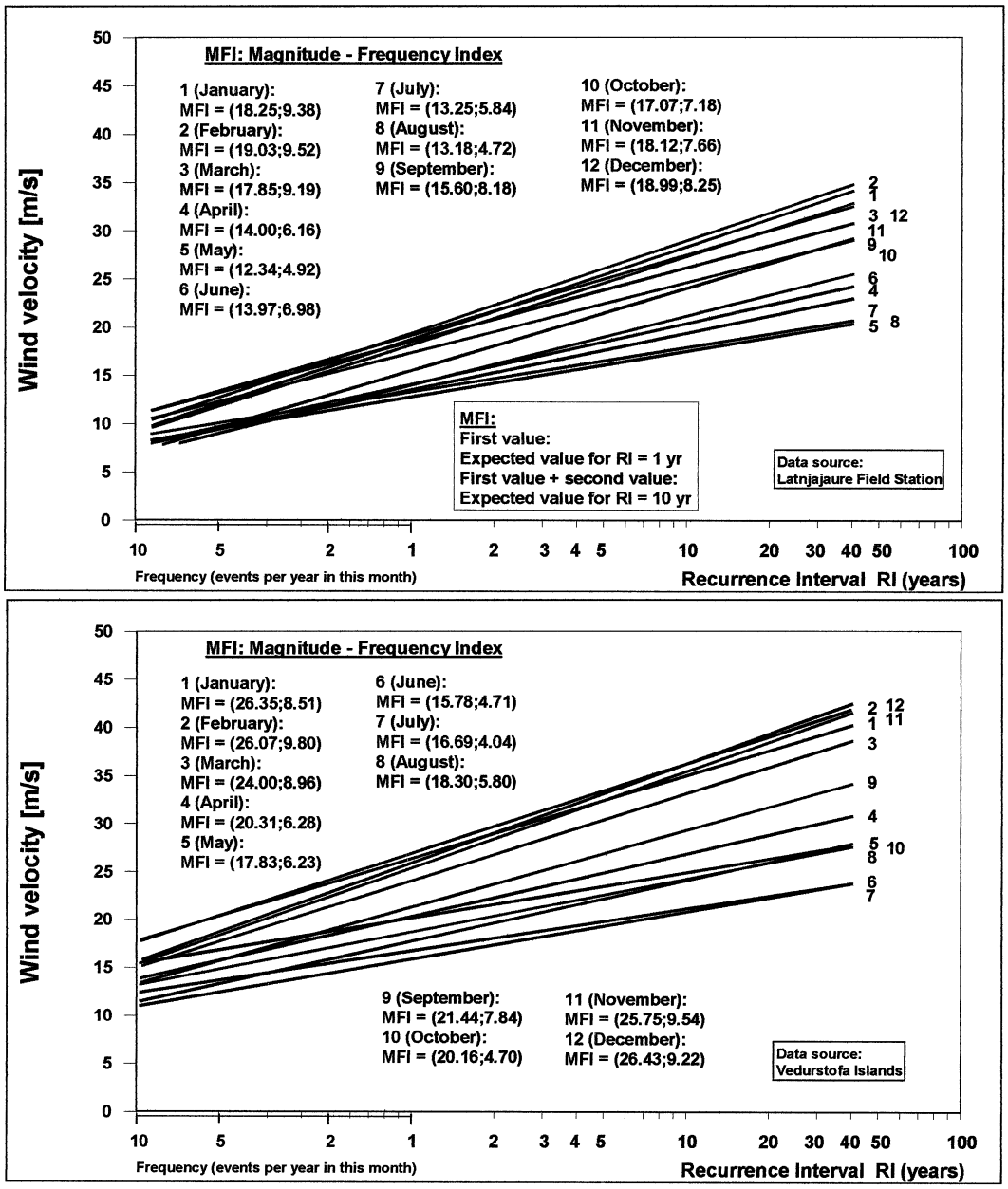

Figure 3. Magnitude-frequency analyses of daily wind velocities (maxima) >7.5 m/s at Latnjajaure (top) and Dalatangi (bottom). The two Magnitude-Frequency Index (MFI): numbers show the calculated recurrence interval (RI) of 1 and 10 years, respectively, based on equation 1, where N denotes the number of days and r the daily wind maxima above 7.5 m/s during this period. – *Tíðni-þröskuldsgreining á fjölda daga í mánuði þar sem vindhraði í Latnjajaure (efri mynd) og á Dalatanga (neðri mynd) fer yfir 7.5 m/s. X-ásinn er tvískiptur, tíðni viðkomandi atburða er sýnd til vinstri og reiknað endurtekningabil (RI) til hægri. Tíðni-þröskuldstalan (MFI) hefur tvö gildi, þ.e. reiknað endurtekningabil (RI) yfir eitt ár og tíu ár samkvæmt jöfnu 1.*

blown free of snow, whereas leeward areas, gullies, channels, and concave slope surfaces are characterized by snow accumulations and snow beds. In Latnjavagge the predominant wind direction in winter is generally N-NW, causing snow beds to form in almost exactly the same places year after year (Molau, *pers. comm.* 2000; 2003). These variations in snow cover are of considerable geomorphologic significance, because they lead to a spatial differentiation of the types and intensities of processes operating in autumn, winter and during snow melt. Whereas the snow covered areas are to a large extent protected against variations of the air temperature and display almost no geomorphological activity until snow melt, frost and wind can act on exposed, convex slope surfaces free of snow, and on rock walls and rock ledges.

In the Austfirðir Mountains the high autumn and winter wind speeds coincide with a large number of daily freeze-thaw events causing needle ice (see below). Apart from the progressive destruction of the vegetation cover by turf exfoliation (Troll 1973; Gerrard 1991), the deflation of fine material here results in the development of stone pavements, due to the relative accumulation of coarse components. In both environments fine material blowing away from convex slope surfaces is accumulated in the snow in neighbouring leeward areas, in gullies, channels and concave slope areas, remaining there until snow melt. On the east- facing slope in Latnjavagge and in gullies of the Austdalur slope systems, characterized by accumulations of wind-blown snow, geomorphologically effective ground avalanches occur during snow melt in early summer. Furthermore, in slope areas covered by wind-blown snow during autumn and winter, slope wash processes induced by snow melting have a higher intensity and last distinctly longer than in slope areas where snow is blown away in autumn and winter. During summer, after several successive days without precipitation, vegetation-free regolith dries up and deflation results. In both environments strong gusts can trigger secondary rockfalls from rock walls and rock ledges.

In Austdalur, N- and E-winds lead to an increasing supply of moistness, and cause considerable atmospheric salt supplies (approx. 19 tons $km^{-2}yr^{-1}$) in the coastal area (Beylich 1999a). In Latnjavagge, the annual atmospheric salts supply is about 3.4 tons $km^{-2}yr^{-1}$ (Beylich *et al.* 2003; compare with Darmody *et al.* 2000) .

GEOMORPHOLOGICALLY RELEVANT ASPECTS OF THE TEMPERATURE REGIMES

Latnjavagge

The Latnjajaure Field Station (981 m a.s.l.) is characterized by an annual mean temperature of -2.3°C (1993–2001). The range between the highest recorded annual mean temperature of -1.95°C in 1997 and the lowest of -2.90°C in 1995 is 0.95°C. July is the warmest month of the year (8.0°C). The coldest month is February (-10.1°C). The study area has an ET climate according to Köppen (1936). The monthly mean temperatures are above freezing point between June and September. Early summer snow melt normally starts at the end of May/beginning of June. Rapid snow melt in May/June can trigger geomorphologically effective slush flows (see also Nyberg 1985; Gude and Scherer 1999). Stable freezing temperatures with little daily fluctuation at 10 cm above ground and autumn snow accumulation usually occur from September-October onwards. A stable snow cover >10 cm in areas without strong snow redistribution by wind is normally recorded from October onwards. At Latnjajaure Field Station frost events may occur all through the year. The average annual number of frost days is 267 (Figure 4). The months of July and August are the only months normally free of frost. From the end of September to the beginning of October until the end of May to the beginning of June there is a phase of nearly permanent winter frost. The 267 frost days consist of 188 ice days and 79 freeze-thaw days (Figure 4). The months of November to April predominantly have ice days. Only in July and August are there no ice days. Most of the freeze-thaw days occur in May-June and September-October. These are the interseasonal periods between the several months lasting winter frost phase and the summer months of July and August being largely free of frost. The minimum air temperatures reached on freeze-thaw days are mostly between 0°C and -10°C (Figure 5). Due to the frost sensitive-

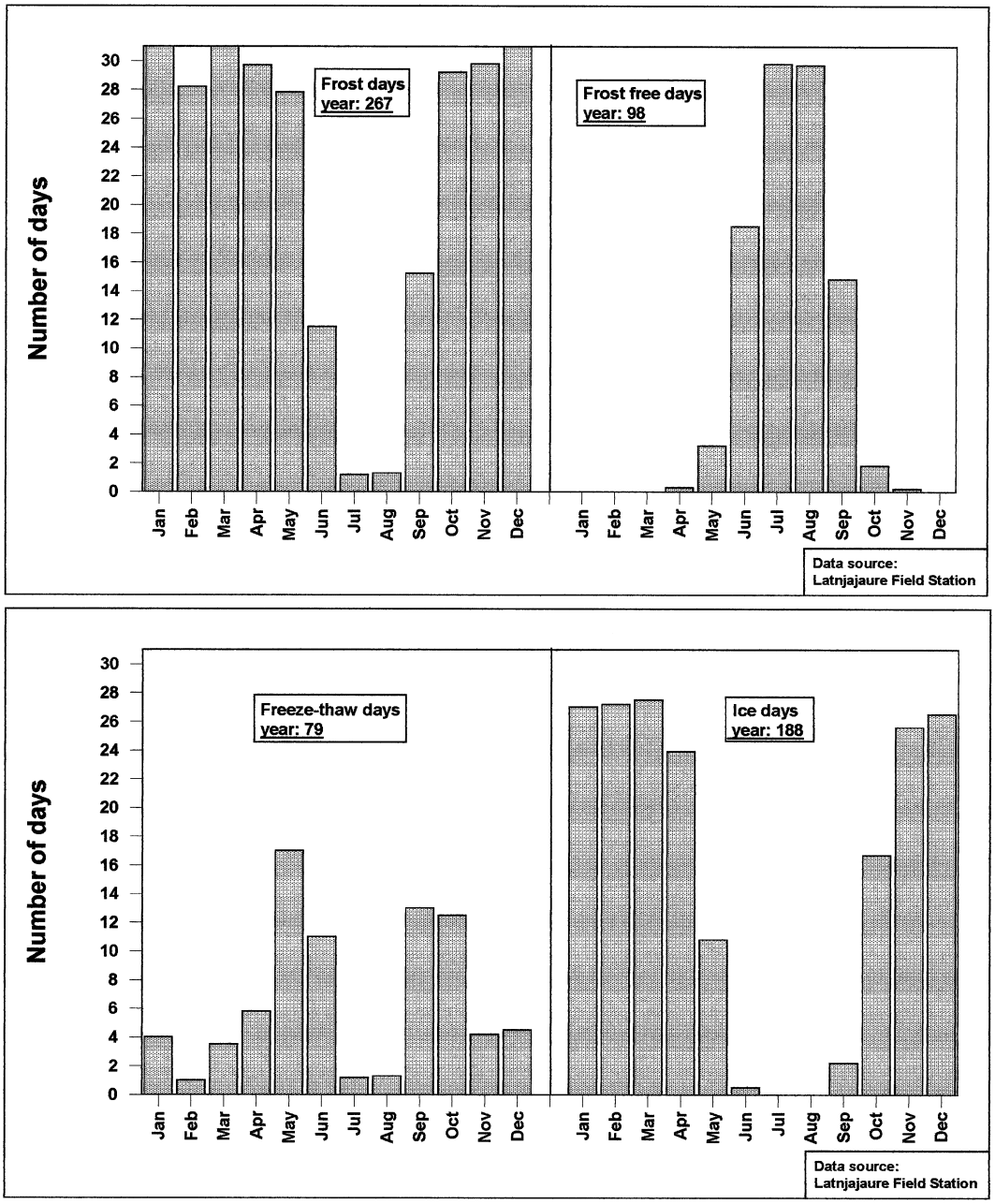

Figure 4. Number of frost days (freeze-thaw days + ice days), frost free days, freeze-thaw days (daily maximum > 0°C, daily minimum < 0°C) and ice days (daily maximum < 0°C) at Latnjajaure. – *Fjöldi frostdaga (frost-þíðu daga og ísdaga), frostlausra daga, frost-þíðu daga (með hitastig yfir 0°C og lágmark undir 0°C) og ísdaga (hitastig <0°C) í Latnjajaure.*

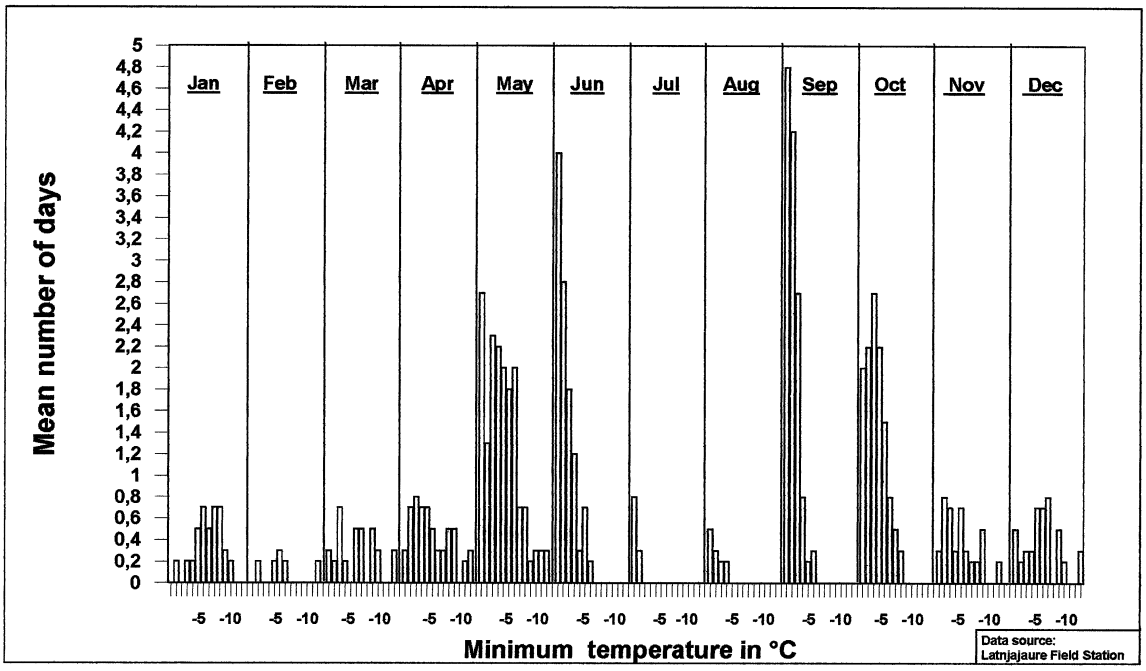

Figure 5. Mean number of freeze-thaw days per month and their minimum temperatures, in Latnjajaure. – *Meðalfjöldi frost-þíðu daga og lágmarkshitastig þeirra, í hverjum mánuði, í Latnjajaure.*

ness of the silt-rich regoliths daily freeze-thaw events cause creep movements with single stone movements on vegetation-free talus cones. In June and September minimum air temperatures will usually not be below -5°C, with the daily freeze-thaw cycles and creep processes being limited to near-surface substrates. In May daily freeze-thaw events with higher frost intensities also occur. Field observations showed that daily freeze-thaw cyles with minimum air temperatures around -10°C can trigger rockfalls from snow free but wet rockwalls and rock ledges. Rockfall activity is caused by both the annual freeze-thaw cycle and daily cycles and reaches its highest intensity in May and June. Avalanches occurring mainly in May and June on the east-facing slope are very important for triggering rockfalls and also boulder falls at this slope. On slopes without avalanche activity boulder falls were only observed in July and August and were mainly caused by melting of segregation ice developed deeper within rockwalls and rock ledges. These boulder falls are mainly caused by the annual freeze-thaw cycle.

Information on frequencies and intensities of frost events to be expected at Latnjajaure in different months is presented by magnitude-frequency analyses (Ahnert 1986; 1987; 1998) of daily air temperature minimum below -15°C, as shown in Figure 6. Most severe frost intensities occur during the winter frost phase between December and March, and particularly in February. The long-lasting winter frost phase with its high frost intensities and the considerable aeolian redistribution of snow are the reasons that, in some areas, frost penetrates deeply into the regolith and rocks, and that permafrost exists at least sporadically in the area, despite relatively high winter precipitation (Kling 1996; 2003; Beylich *et al.* 2003). Larger areas, especially on the gentle, W-facing slope of the valley, are characterized by solifluction lobes and sheets.

Due to the characteristics of the temperature

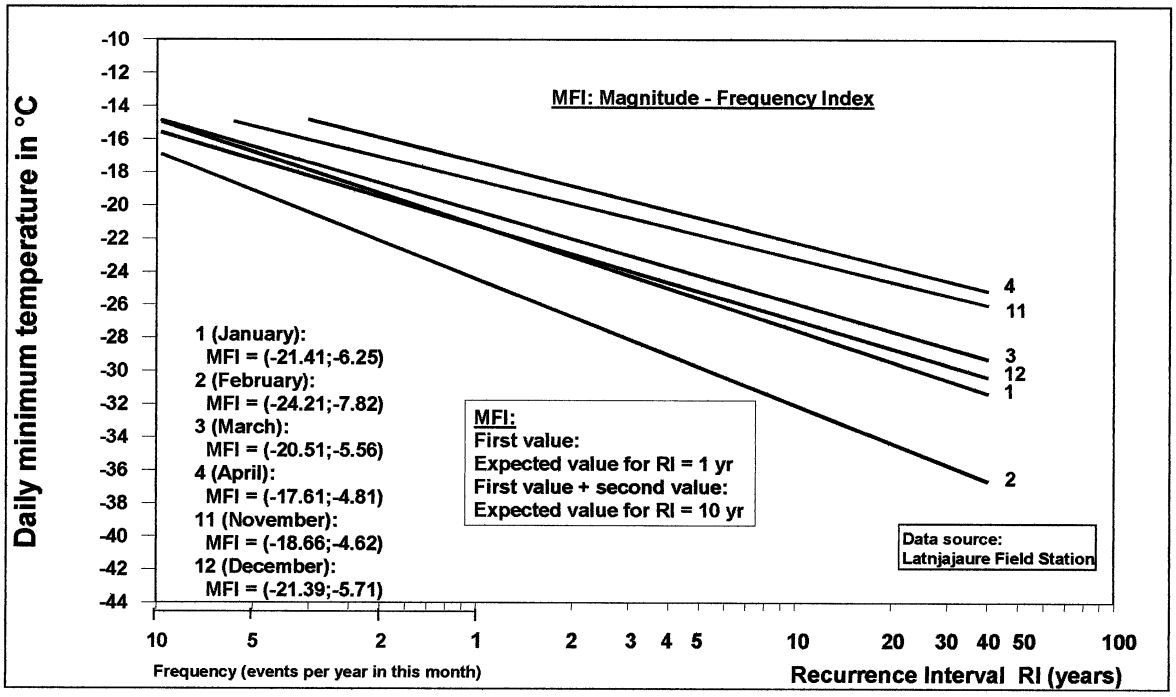

Figure 6. Magnitude-frequency analyses of daily minimum temperatures below -15°C at Latnjajaure. – *Tíðni-þröskuldsgreining á fjölda daga þar sem lágmarkshiti fer niður fyrir -15°C í Latnjajaure.*

regime, the discharge regime in Latnjavagge is nival, with runoff being limited to the period from middle/end of May until October-November. During the winter frost phase from October-November until April-May, Latnjavagge does not reveal a significant activity of geomorphological processes.

Austdalur

In order to gain knowledge about changes of the temperature regime with changing altitude a.s.l., air temperature data from the Dalatangi meteorological station (9.0 m a.s.l.) were converted to the altitudes of 300 m a.s.l., 600 m a.s.l., and 900 m a.s.l. (Beylich 1999a). The mean vertical temperature gradient which was used for that was defined as 0.6 K/100 m for the months November-April and 0.5 K/100 m for the months May-October (see Schunke and Stingl 1973; Liebricht 1983).

The annual mean temperature at Dalatangi is 3.6°C (1960–1996). The highest annual mean during this period was 4.9°C in 1960 and the lowest 1.9°C in 1979. A very low annual mean temperature of 2.3°C was also recorded in 1968. The low annual means and the resulting variations of the annual mean temperatures are mainly due to drift-ice transported by the East Greenland and the East Iceland current to the East coast of Iceland. According to Schunke (1979) and Liebricht (1983), drift-ice lying in front of the coasts causes a considerable strengthening of the frost regime.

The mean temperatures of the warmest and coldest months are 8.6°C and -1.2°C, respectively, with an annual variation of 9.8°C. The warmest month is normally August. February is the coldest month of the year. Altogether, the environment displays *an ET climate* according to Köppen (1936). According to the classification introduced by Troll and Paffen (1964), the climate is subpolar-high oceanic.

Whereas the Dalatangi meteorological station records mean monthly temperatures exclusively above freezing point, the number of months revealing mean temperatures below freezing point distinctly rises with increasing altitude. For instance, at an altitude of 300 m a.s.l. mean monthly temperatures above 0°C are found only from May until November, at 600 m a.s.l. from May to October and at 900 m a.s.l. only from June to September. The general increase of the air temperature from April-May onwards manifests itself in the lower parts of the study area in the beginning of the main snow melt period. In the upper areas, temperatures, while increasing, remain below freezing. Accordingly, snow cover has a longer duration. In shaded areas snow patches and fields exist all year long.

At the Dalatangi meteorological station, frost events are generally recorded for the first time at the end of September or in October. The last frost events normally occur between end of April and beginning of June. At 300 m a.s.l., the frost period lasts from September-October until June, at 600 m a.s.l. from September-October to June-July. At 900 m a.s.l., there is no month which is free of frost (Beylich 1999a; 2000c).

Frost days are mostly and normally recorded from November to April. From a morphoclimatic point of view, it has to be emphasised that the lower parts of the study area have shorter frost phases interrupted by phases which are free of frost (Figure 7), whereas the upper areas are characterized by frost phases lasting several months from November until April-May at (600 m a.s.l., and from October to May-June at 900 m a.s.l., (Figure 8) (Beylich 1999a; 2000c). Furthermore, the altitude-related increase of frost days mainly implies an increase in the number of ice days, whereas the frequency of freeze-thaw days only increases up to an altitude of 300 m a.s.l. While February, March and April are the months with the highest number of freeze-thaw days at Dalatangi, these are the months of January, February, and April at 300 m a.s.l., April, May and November at 600 m a.s.l., and May, June and October at 900 m a.s.l. The minimum air temperatures on freeze-thaw days are seldom below -5°C, with the daily freeze-thaw events normally being confined to the near-surface substrates. During the field research period, minimum air temperatures of -5.8°C on freeze-thaw days did not lead to frost penetration into the ground to depths of 5 cm (Beylich 1999a).

Information on frequencies and intensities of frost events to be expected in different months at different elevations a.s.l. can be gained by the magnitude-frequency analyses shown in Figure 9. Even at higher altitudes frost intensities in Austdalur are far from reaching the levels recorded at Latnjavagge (see Figure 6).

It can be assumed that frost weathering is enhanced during longer and more severe frost spells (Schunke 1975; Church *et al.* 1979; Washburn 1979; Walder and Hallet 1985; 1986; Hallet *et al.* 1991; Matsuoka and Sakai 1999). This assumption is supported by the fact that frost weathering and rockfall activity from rockwalls in the study area becomes more intense with increasing altitude a.s.l. (Beylich 1999a). Another indication is the seasonal variability of rockfall activity at basalt rockwalls situated at an altitude of 450 m to 750 m a.s.l. Here the highest rockfall activity occurs after the winter frost period that lasts several months (Beylich 1999a).

The duration of frost periods is also important for the intensity of chemical weathering and for fluvial channel discharges. Numerous and long lasting frost spells decrease the intensity of chemical weathering, which is in any case small due to the subarctic morphoclimate (Beylich 1999). Also geomorphologically relevant is the lowering of channel discharges during frost spells.

Daily freeze-thaw events imply the forming of needle ice at convex, vegetation- and snow- free, soil covered slope surfaces exposed to the wind in autumn and winter. Field work in Austdalur showed that even slight night frosts may cause the formation of needle ice (Outcalt 1971). The formation of ice crystals causes the substrate to break up and dry and solids are lifted. Thus a large number of freeze-thaw days favours the deflation of fine material and the destruction of vegetation cover by turf exfoliation. Due to heaving of particles at vegetation free and inclined slope areas, needle ice has a direct denudative ef-

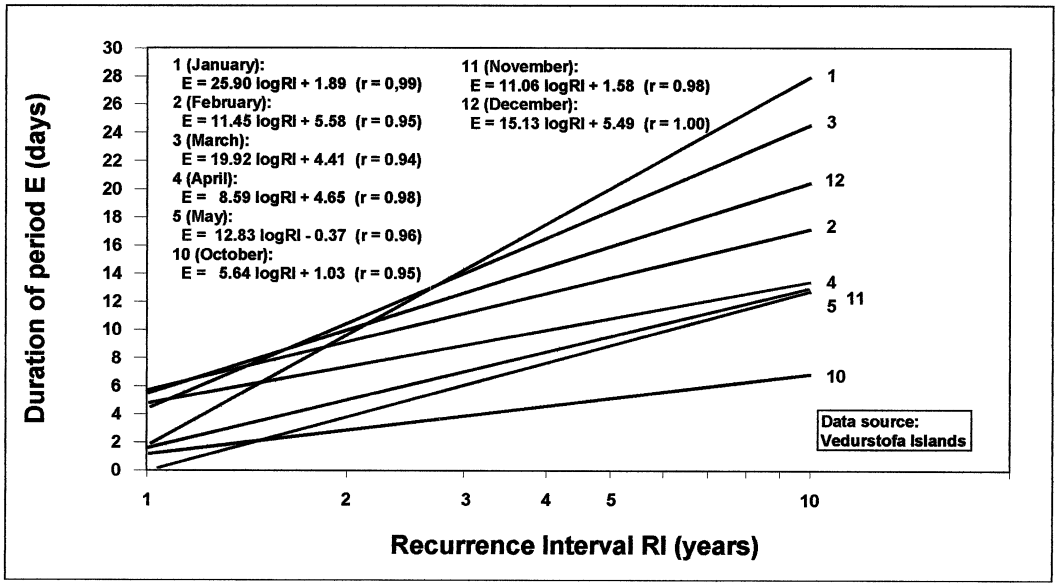

Figure 7. Annual number of days between frost days during November-May at Dalatangi. – *Fjöldi daga á milli frostdaga á Dalatanga, frá nóvember og fram í maí.*

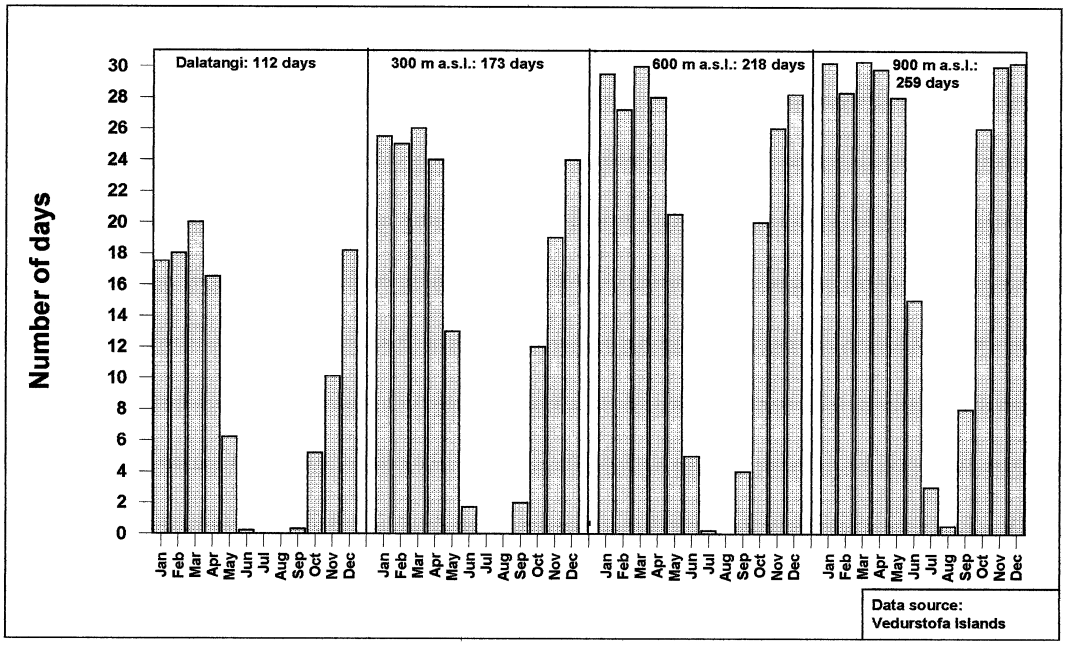

Figure 8a. Number of frost days at different altitudes a.s.l., derived from data from the Dalatangi meteorological station. – *Fjöldi frostdaga á Dalatanga, ásamt reiknuðum fjölda frostdaga í 300, 600 og 900 m hæð yfir sjó, sjá skilgreiningar við 4. mynd.*

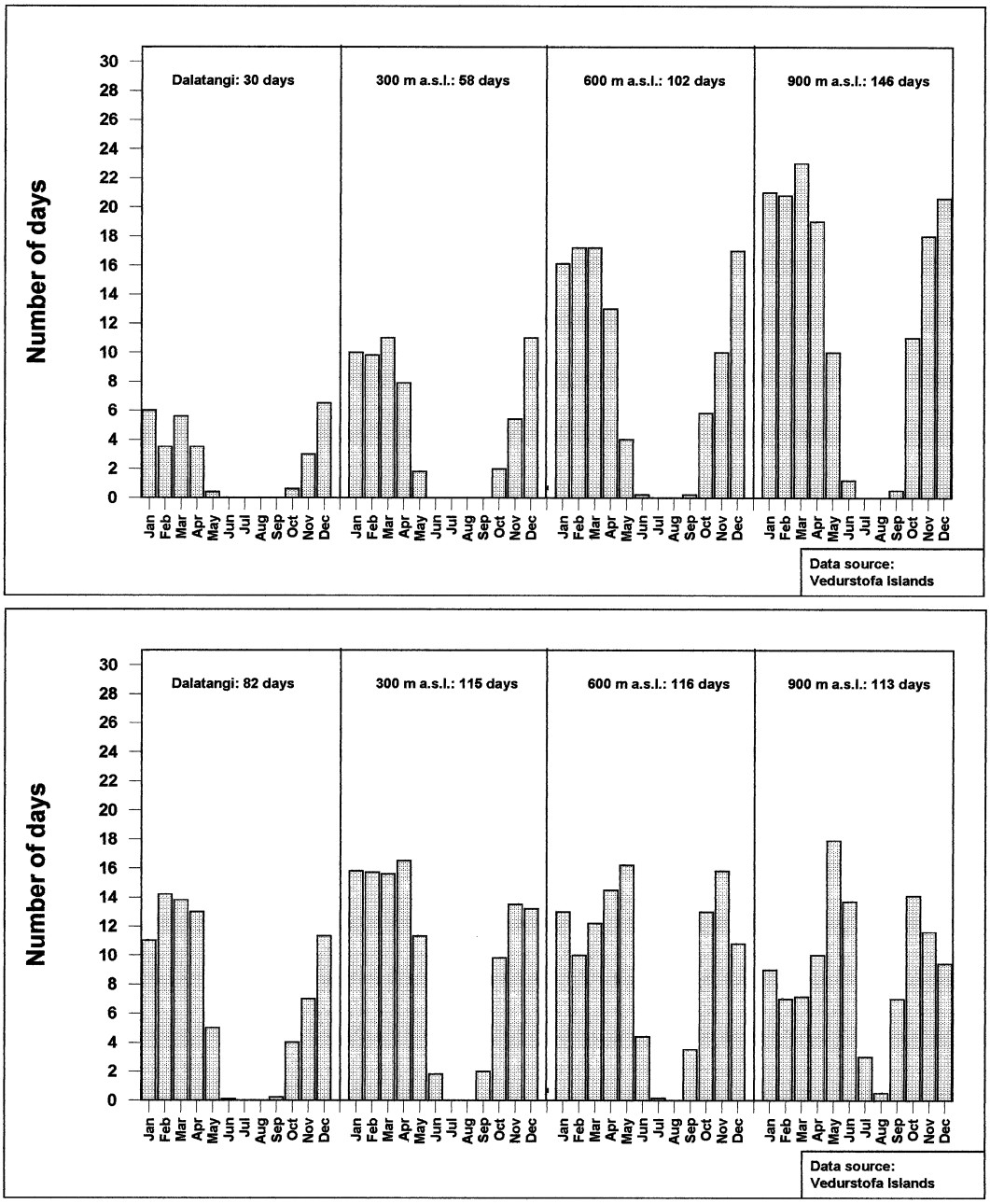

Figure 8b. Number of ice days and freeze-thaw days at different altitudes a.s.l., derived from data from the Dalatangi meteorological station. – *Fjöldi mældra ís- og frost-þíðudaga á Dalatanga, ásamt reiknuðum fjölda slíkra daga í 300, 600 og 900 m hæð yfir sjó.*

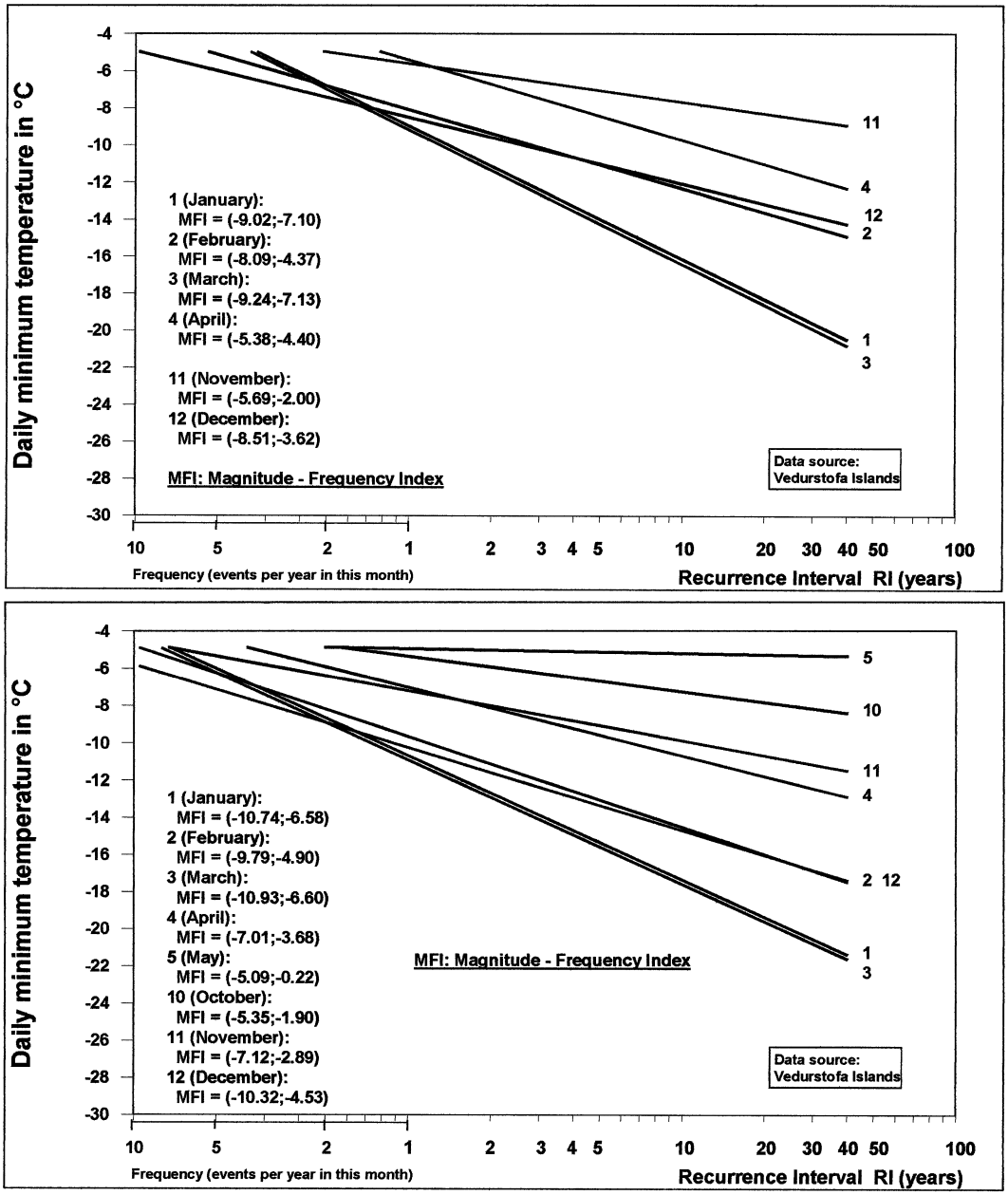

Figure 9a. Magnitude-frequency analyses of daily minimum monthly temperatures below -5°C at Dalatangi (top) and at 300 m a.s.l. in Austdalur (bottom). – *Tíðni-þröskuldsgreining á fjölda daga í mánuði með lágmarkshita undir -5°C á Dalatanga (efri mynd) og framreiknuðum dagafjölda í 300 m hæð yfir sjó í Austdal (neðri mynd).*

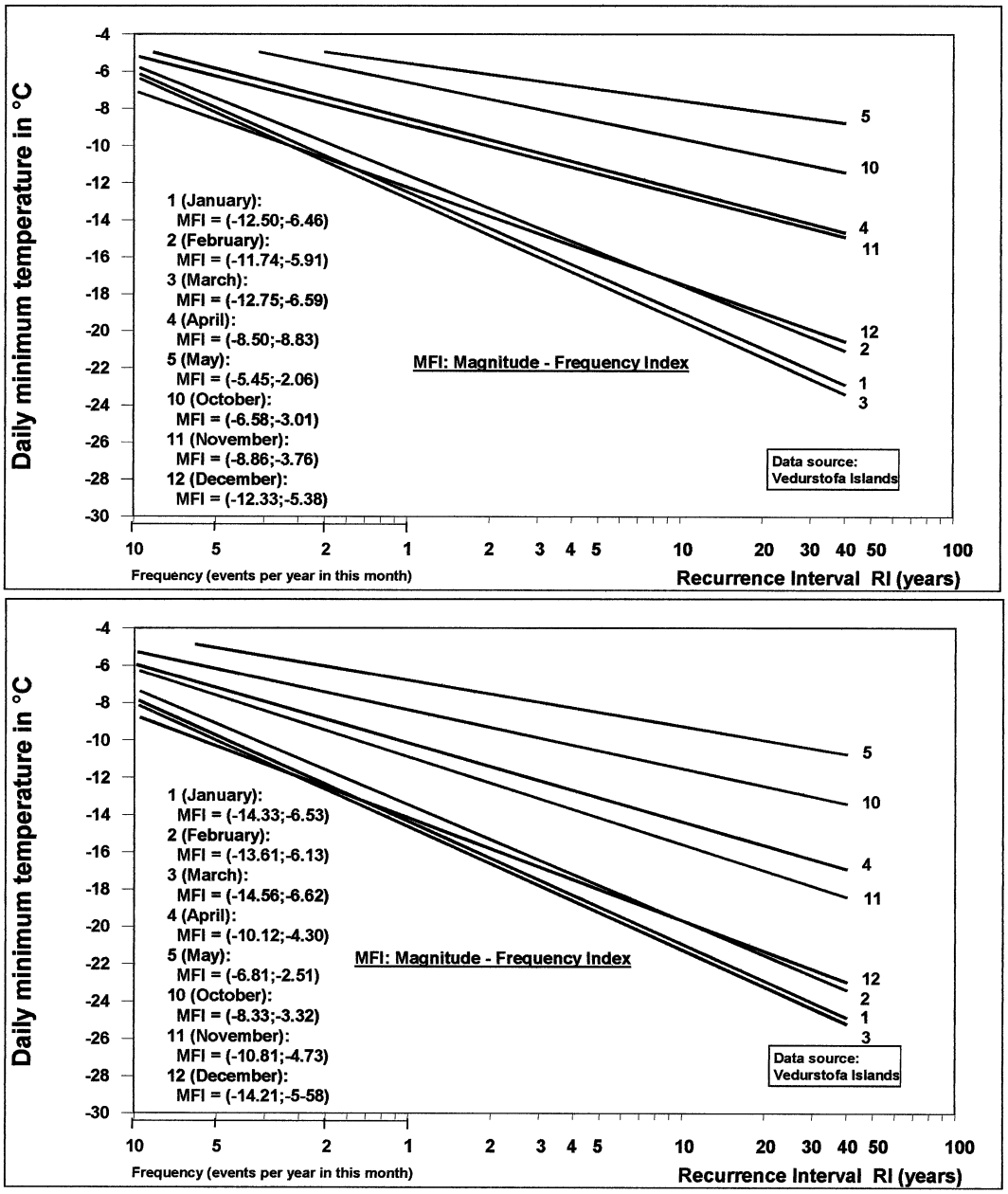

Figure 9b. Magnitude-frequency analyses of daily minimum monthly temperatures below -5°C at 600 m (top) and 900 m a.s.l. (bottom) in Austdalur. – *Tíðni-þröskuldsgreining á reiknuðum fjölda daga í hverjum mánuði með lágmarkshita undir -5°C í 600 m (efri mynd) og 900 m (neðri mynd) hæð yfir sjó í Austdal.*

fect, which, however, is considered to be rather small. Frost creep recorded on talus cones at higher altitudes of the Austfirðir Mountains requires seasonal freeze-thaw cycles with frozen ground of several months and frost penetration depths of more than 50 cm (Beylich 1999a). High rates of geomorphic activity in the Austfirðir Mountains occur when air temperatures rise significantly above freezing point during winter (Figure 10). High maximum temperatures in autumn and winter cause high channel discharges due to intensive thaws. In the lowest parts of the study area, there is no complete snow cover over several months during autumn and winter.

GEOMORPHOLOGICALLY RELEVANT ASPECTS OF THE PRECIPITATION REGIMES

Latnjavagge

Precipitation totals in this environment are mainly connected with cyclonic activity. At the Latnjajaure Field Station, the mean annual precipitation is 818 mm (1990–2001). The highest recorded annual sum value is 990 mm (1993), the lowest 605 mm (1996). The range between the highest and the lowest annual sum thus is 385 mm. The ratio between the highest and the lowest annual sum is approx. 1.6:1.

Precipitation is quite irregularly distributed over the year, with October, recording 111 mm on average, being the month with the highest precipitation (Figure 11). The lowest precipitation is in May with an average of 34 mm. The ratio between the mean for October and that for May is 3.3:1. Most of the precipitation which occurs between October and May, and together accounting for 66% of the mean annual precipitation, is temporarily stored as snow. The thickness of the snow layer in Latnjavagge normally reaches its maximum in April. During the summer months June–August, August records the highest mean precipitation (82 mm). Altogether, precipitation from June to August accounts for 24% of the mean annual precipitation. The average number of precipitation days per month ranges from 23 in October to 16 in July.

The magnitude-frequency analyses carried out with daily precipitation values above 5 mm for the months of May to October (Figure 12) provide information on frequencies and recurrence intervals of precipitation events of certain magnitudes. Field research in Latnjavagge showed that even daily amounts of 31.2 mm (rainfall event on August 8th, 2000) and 31.5 mm (rainfall event on July 12th, 2002) do not trigger debris flows or slides on the slope systems. Due to the stability of the slope systems and the almost complete and very stable vegetation cover, there is also no significant increase of suspended sediment concentrations (suspended sediment concentrations are normally 0–4 mg L^{-1}) in the creeks and channels of the catchment area. Daily precipitation of 31 mm, causing saturation overland flow on the slopes and high channel discharges are most frequent in August and have a 4-year recurrence interval in this month. In July such rainfall events can be expected every 16 years. It should be noted that the rainfall events of August 8th, 2000 and July 12th 2002 had durations of several hours. The rainfall intensities during these events were not extremely high. It is known that short summer rainstorms with very high rainfall intensities can cause debris flows and slides on the slope systems and increased suspended sediment concentrations and bedload transportation in the channels in a number of other valleys in the Abisko mountain area (Jonasson and Nyberg 1999). In the more stable Latnjavagge drainage basin, higher concentrations of suspended sediments (up to 50 mg L^{-1}) were only observed during intense snow melt and were mainly caused by the ice patches in the valley, mobile channel debris beds exposing fines and material mobilized by slush flows. The channel beds are characterized by stable step-pool systems developed in debris. These fluvial step-pool systems have been stable over the entire investigation period and only movements of single stones over smaller distances (<15 m) occurred.

Longer periods without precipitation are highly probable in June and above all in July. Longer dry spells during the snow melt period have the effect that the runoffs are to a large extent thermally determined. Summer dry spells after snow melt lead to low runoffs, with smaller creeks drying up completely. The drying up of vegetation-free regolith can lead to increased deflation.

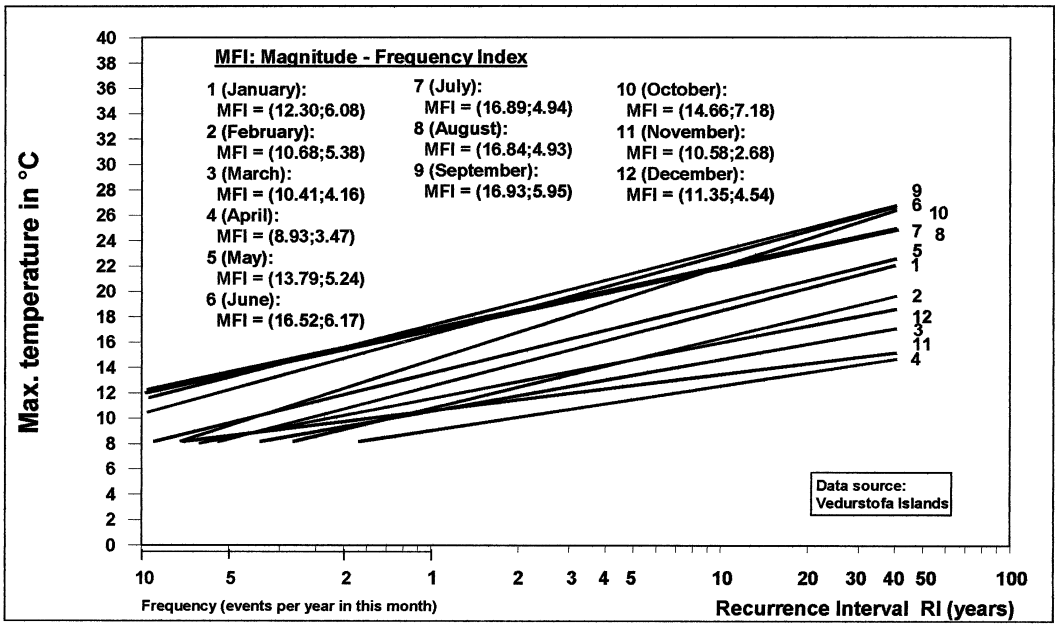

Figure 10. Magnitude-frequency analyses of daily maximum temperatures above 8°C each month at Dalatangi. – *Tíðni-þröskuldsgreining á dagafjölda með hámarkshita yfir 8°C. Gögn frá Dalatanga, 1960–1996.*

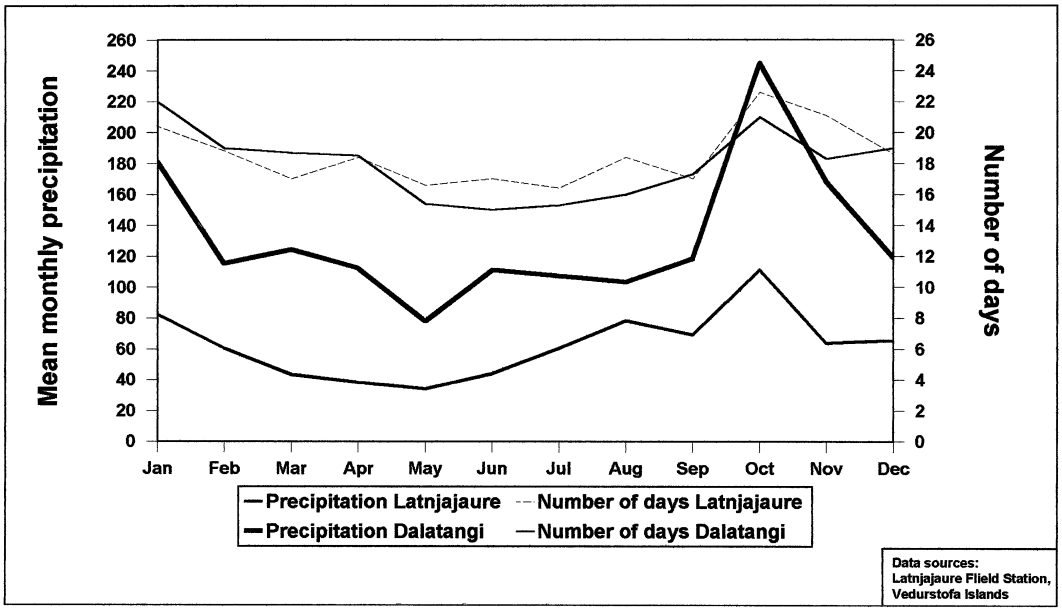

Figure 11. Mean monthly precipitation and number of days with precipitation, at Dalatangi and Latnjajaure. – *Meðaltal mánaðarúrkomu og fjölda úrkomudaga á Dalatanga og í Latnjajaure.*

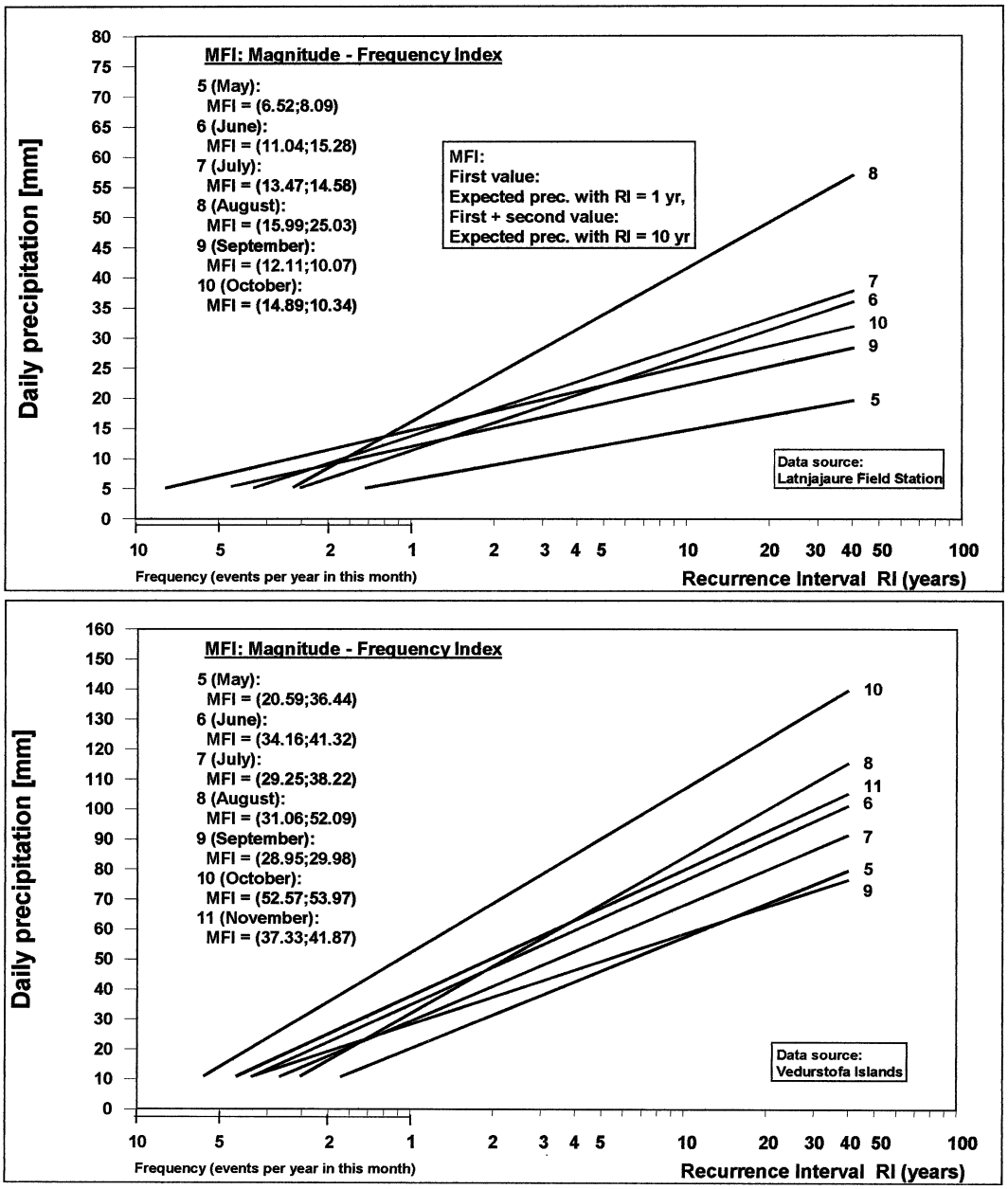

Figure 12. Magnitude-frequency analyses of daily precipitation >5 mm during May-October at Latnjajaure (top) and >10 mm during May-November at Dalatangi (bottom). – *Tíðni-þröskuldsgreining á dagafjölda með yfir 5 mm úrkomu í maí-október í Latnjajaure (efri mynd) og dagafjölda með yfir 10 mm úrkomu á Dalatanga á tímabilinu maí-nóvember (neðri mynd).*

Austdalur

The Austfirðir Mountains are characterized by high annual precipitation, with normally low precipitation intensities. The mean annual precipitation at the Dalatangi meteorological station is 1431 mm (1960–1996), which clearly exceeds the annual sum in Latnjavagge. During the 37 years from 1960 to 1996, the range between the highest sum value (1985 mm in 1974) and the lowest sum value (1008 mm in the following year 1975) was 977 mm. The ratio between the highest and the lowest value is approx. 2:1. Between 1960 and 1996 there was a gradual increase of annual precipitation (Beylich 1999a; 2000c). A similar increase of the annual sums was also recorded in other regions of Iceland in the last decades (Jónsson 1991; Lawler and Wright 1996).

In Austdalur, precipitation also occurs quite irregularly over the year (Figure 11). The month with the highest precipitation is October, with an average of 245 mm. The lowest precipitation is May with 78 mm. The ratio between the mean monthly amount of October and that of May is 3.1:1. The precipitation from December to April, which is also relatively high, is to a large part temporarily stored as snow, and with increasing altitude above sea level the share of snow in total precipitation rises. Of the months accounting for the major share of the early summer's snow melt (May-July), June - with 111 mm - records the highest average precipitation. The average monthly number of days with precipitation ranges from 22 in January and 15 in June (Figure 11). The magnitude-frequency analyses of daily precipitation of more than 10 mm (Figure 12) carried out for the months May to November reveal once again high amounts of precipitation in October and a low level in May and furthermore give evidence of frequencies and recurrence intervals of precipitation events of certain magnitudes. Field research in Austdalur proved that daily sums exceeding 20 mm during times of intense snow melt lead to saturation overland flow and to reinforced wash processes in gullies as well as on lower slope areas which are already free of snow and vegetation-free due to turf exfoliation. These slope wash processes result in a significantly increased aquatic slope denudation (Beylich 1999a). Daily precipitation exceeding 20 mm can be expected once per year in May, 2.2 times per year in June, 1.8 times per year in July, 4 times per year in October and 2.6 times per year in November. Without additional snow melt, rainfall sums of more than 40 mm d^{-1} result in saturation overland flow and wash processes, with such daily sums occurring every 3.4 years in May, in June every 1.4 years, in July every 1.9 years, in August every 1.5 years, in September every 2.3 years, in October 1.7 times each year and in November every 1.2 years. Compared with Latnjavagge, the debris beds of the tributaries in Austdalur are less stable and more debris is transported during higher discharges. Mobility of the channel debris beds causes also a high supply of fine materials and an increase of the suspended sediment concentrations in the channels. The higher mobility of the channel debris beds in Austdalur compared with Latnjavagge is mainly due to the greater steepness of the Austdalur drainage basin. A transfer of debris on talus cones and in gullies caused by wash processes was identified only once during the 2-yr study period after an extreme rainfall event with 92 mm/d in October 1997. Furthermore, this extreme event entailed secondary rockfalls from rock walls, very high runoff, increased bed- load transport and bank erosion in the main channels. Daily precipitation of 92 mm can be expected to occur every 91.1 years in May, every 25.1 years in June, every 43.8 years in July, every 14.8 years in August, every 126.8 years in September, every 5.4 years in October, and every 20.2 years in November, with a comparatively high probability being found in October. The geomorphic effect is expected to be especially high when such rainfalls coincide with intense snow melt, which happens mainly during the autumn and–with significantly less probability–in winter and during snow melt in early summer (V. Þorgrímsson, *pers. comm.*, 1997). The extreme rainfall event of October 1997 did not trigger new debris slides and debris flows on the steep slopes of Austdalur. These process events require higher amounts of rain than 92 mm d^{-1} with correspondingly longer recurrence intervals or comparable rainfalls combined with intense snow melt and/or other favouring factors.

Longer dry spells in May and June have the effect that runoff during the main snow melt period is rela-

tively low. In July, August and September they give rise to low channel discharges, with smaller creeks drying up completely (Beylich 1999a; 2000c).

MORPHOCLIMATE AND PRESENT-DAY MORPHODYNAMICS IN LATNJAVAGGE AND AUSTDALUR

A quantitative recording and labelling of present-day morphodynamics of Austdalur is possible after calculating the sediment budget of the drainage basin (Beylich 1999a; 1999b; 2000a; 2000b; 2003). The dominance of aquatic slope denudation over chemical denudation is due to the low intensity of chemical weathering, to the relatively high share of vegetation-bare slope surfaces, and to the mobility of channel debris beds in the very steep drainage basin. The very high wind speeds cause a further expansion of the vegetation-bare surfaces. The process which is third most important regarding annual mass transfer [t m yr^{-1}] are ground avalanches, followed by rockfalls/boulder falls, creep processes, debris slides and flows and deflation. High amounts of runoff may occur all year long. Annual mass transfers in the main channels clearly dominate over slope processes, with the fluvial transport of solids being more important than the transport of dissolved salts. The intensity of the processes active in the present periglacial morphoclimate is altogether low (Beylich 1999a; 1999b; 2000a; 2000b). The hydrological regime in Latnjavagge is very different from Austdalur, with fluvial discharge and general forming activity being limited to the period from middle/end of May to October/November. Permafrost exists at least sporadically in the area (Kling 1996; 2003; Beylich *et al.* 2003). Slush flows, triggered by rapid snow melt in early summer, are an important process. Because of the almost complete and very stable vegetation cover and the stability of fluvial step-pool systems in the less steep drainage basin slope wash processes are much less important than in Austdalur. Although the intensity of chemical weathering is low, chemical denudation is more important than mechanical fluvial denudation (Beylich 2001a; Beylich *et al.* 2003). The intensities of the geomorphological processes active in this periglacial environment are also low. In both periglacial environments Holocene modification of the glacial relief is negligible (Beylich 2001a; 2003; Beylich *et al.* 2003).

CONCLUSIONS

The characteristics of the present-day morphoclimates control the type and intensity of geomorphologic processes in Latnjavagge and Austdalur. The comparison of the different periglacial environments provides information on controlling factors of the processes and sediment budgets in the areas. Similar studies to the present one carried out in other periglacial environments having different morphoclimates seem to be worthwhile in order to obtain a better understanding of the importance of the prevailing wind, temperature and precipitation regimes for the current geomorphologic processes, sediment budgets and trends of relief development. They would also provide a more reliable evaluation of possible geomorphologic effects of predicted (morpho-)climate changes (Barsch 1993; Schlyter *et al.* 1993; Rapp 1995; Beylich 2001b; Beylich 2003).

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ÁGRIP

Samanburður á áhrifum mismunandi veðurþátta á landmótunarferli í Austdal, Seyðisfirði og Latnjavagge, Lapplandi

Við rannsóknir á landmótun er veðurfar yfirleitt skilgreint út frá mánaðar- og ársmeðaltölum eða summu gilda á vindhraða, hita og úrkomu. Þar sem flest þau ferli sem stuðla að landmótun samanstanda af ákveðnum „atburðum“ sem eru aðeins að litlu leyti tengd þessum veðurfarslegu meðalgildum, er þörf á nýrri tölfræðilegri nálgun á veðurfarsþáttum sem áhrif hafa á landmótunina. Í þessari rannsókn er „landmótunarveðurfar“ hálendis Austurlands og Lapplands í norður Svíþjóð borin saman, þar sem sérstök áhersla er lögð á (1) tíðni eða endurkomu veðurfarslegra atburða af ákveðnum styrkleika, og (2) tíðni mikilvægra landmótunarþröskulda. Fjallað er um einkennandi veðurfarsþætti (vindáttir, hita og úrkomu) sem stjórna tegund, tíðni, viðkomu og styrkleika landmótunarferla, auk algilds og afstæðs mikilvægis þeirra og setmyndunar. Í Austdal við sunnanverðan Seyðisfjörð er aflrænt fallvatnarof mikilvægara en efnarof. Hins vegar einkennist vatnasvið Latnjavagge af efnarofi. Í báðum umhverfum er styrkleiki landmótunarferla sem vinna í núverandi veðurfari (morphoclimate) lágur.

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