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Weather in Vestfirðir before and during several avalanche cycles in the period 1949 to 1995

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Abstract

The most dangerous avalanche cycles in the northern part of the Vestfirðir peninsula in Iceland are associated with intense lows or troughs moving westward along the northern coast of Iceland directing strong N- or NE-ly winds to the Vestfirðir region. Storms similar to the ones that have caused the worst avalanche cycles in Vestfirðir have a return period on the order of one year. Storms that are particularly unfavorable for a particular starting zone (*e.g.* the Súðavík storm in 1995) are expected to have a significantly higher return period than one year, perhaps 5-10 years according to a subjective estimate. Violent storms that combine a high wind intensity with an unusual timing in the season (*e.g.* the Flateyri storm in 1995) may be expected to have an even longer return period, perhaps several decades. Weather conditions essentially similar to the Súðavík and Flateyri storms in 1995 are not unusual or unexpected when the climate of Vestfirðir is viewed on a time-scale of decades to a century.

Introduction

The most dangerous avalanche cycles in the northern part of the Vestfirðir peninsula in Iceland are associated with intense lows or troughs moving westward along the northern coast of Iceland directing strong N- or NE-ly winds to the Vestfirðir region. These lows approach the country from the south or east along one of several characteristic tracks. Thus they bring relatively warm and humid air of a S-ly origin to the Vestfirðir region with unusually large amounts of precipitation falling as snow. Wind speeds in excess of 90 knots (10 min. average) have been measured in the mountains under these conditions. Wind transport of snow from the extensive and relatively flat mountain plateau, adjacent to many of the starting zones of avalanches in the region, can then quickly lead to extreme accumulation of fresh unsettled snow in the starting zones. An avalanche cycle caused by a synoptic situation of this kind often consists of many avalanches that are released in several avalanche tracks in a part of the country on the same day or in a period of days. In the absence of a low pressure system as described above, prolonged periods of moderate or strong NE-ly winds with snowfall can also lead to dangerous accumulation of snow in the starting zones.

Snowfall is often not adequately measured by precipitation gauges at meteorological stations during the avalanche cycles due to the high wind speeds and the snow depth measured in the lowland may be much lower than the snow depth in the mountains. The snow depth is also notoriously difficult to measure due to drift formation. Wind speeds measured at lowland meteorological stations are also often not representative for prevailing wind conditions in the mountains or out on the open sea. For this reason, individual precipitation, snow depth and wind speed measurements at the lowland meteorological stations are often not sufficient to properly interpret the weather conditions that preceded avalanche cycles. The measured wind speeds associated with a weather system, that causes an avalanche cycle, may not be among the strongest winds measured at a lowland meteorological station even though the synoptic representation of the system on weather maps is clearly indicative of strong pressure gradients. The synoptic measurements, nevertheless, provide important information about the avalanche conditions. Supplementary information from weather maps is, however, vital for proper interpretation of the measurements in each case.

This report describes weather observations before and during several avalanche cycles in Vestfirðir and discusses the frequency of the synoptic conditions that cause the

avalanche cycles. It is meant to serve as background material for appraisals of avalanche defenses for Flateyri and Seljalandshlíð which are being prepared by VST, HNIT and NGI.

Time periods chosen for analysis

Below we compile synoptic measurements from several meteorological stations in the Vestfirðir region before and during seven avalanche cycles during the last thirty years. The meteorological stations are Hólar í Dýrafirði (Hól.Dr., 234), Þórustaðir (Þst., 240), Flateyri (Flt., 244), Galtarviti (Glt., 250), Bolungarvík (Bol., 252), Ísafjörður (Ísf., 254) and Æðey (Æð., 260). The periods that we consider are 23-26.10.1995, 14-18.01.1995, 12-14.01.1975, 09-12.02.1974, 07-10.11.1969, 03-05.02.1968 and 28-31.01.1966.

The catastrophic avalanches at Súðavík and Flateyri fell on 16.01.1995 and 26.10.1996, respectively, during violent storms. Several avalanches fell in other avalanche tracks in the Vestfirðir region during these time periods, *e.g.* two avalanches in Traðagil in Súðavík on 16.01.1995, in Seljalandshlíð on Ísafjörður on 16.01.1995, 17.01.1995 and on 18.01.1995, in Innra-Bæjargil on Flateyri and on the mountainside to the east of Flateyri on 18.01.1995 and in Seljalandshlíð on 23.10.1995. There was widespread avalanche activity over large areas in Vestfirðir and Northern Iceland during both these periods. Several avalanches hit farmhouses and barns and caused accidents and significant damages.

The longest documented avalanche from Innra-Bæjargil on Flateyri fell on 11.02.1974 and another avalanche fell in Seljalandshlíð on the following day. There were widespread avalanches in Western, Northern and Eastern Iceland on the days following a snowstorm on 10.02.1974.

One of the five longest documented avalanches from Skollahvilft on Flateyri fell on 10.11.1969 following a storm from the north. Several avalanches fell from Seljalandshlíð on Ísafjörður on the same day.

Strong N-ly storms occurred on 12-14.01.1975, 03-05.02.1968 and 28-31.01.1966. Although avalanches are not documented on Flateyri or Seljalandshlíð during these periods, there was considerable avalanche activity in Vestfirðir and Northern Iceland. These periods are taken for comparison with the other periods when documented avalanches fell on Flateyri or Seljalandshlíð.

Synoptic measurements during avalanche cycles

Synoptic measurements of wind speed, precipitation and snow depth during the periods listed above are given in tables in Appendix I. It is seen that daily precipitation on three or four days preceding and during the avalanche cycles is typically between 10 and 30 mm, the accumulated precipitation over the three or four days is between 20 and 60 mm, and typical measured snow depths are between 20 and 100 cm. Maximum wind speeds (10 min ave) measured at the lowland stations are between 40 and 80 knots and average daily wind speeds are between 30 and 60 knots, although both higher and lower values occur.

Snow depth measured at Breiðafell á Seljalandsdal

Snow depth at Breiðafell in Seljalandsdalur east of Seljalandshlíð has been monitored since 1989. The measurements are given in Appendix II. The maximum snow depth during the winters ranges from 202 to 490 cm. The measurement period is too short for a

meaningful return period analysis and it is not possible to estimate snow depth in the starting zone of avalanches in Seljalandshlíð from the measured snow depth at Breiðafell, except that local observations indicate that snow accumulation in Seljalandshlíð is less than in Seljalandsdalur.

Return periods

The 10 min wind speed with a return period of 10 years is in the approximate range 65 to 70 knots for many lowland stations in Iceland which are not especially exposed or on hills. The 10 min wind corresponding to a return period of 100 years is in the approximate range 75 to 85 knots for the same stations (Jónsson, 1995). Return period analysis has not been performed for the stations given in the tables in Appendix I, but the stations for which this analysis has been performed should give a rough picture of the windiness at the stations which we are considering, except that the station Æðey reports relatively high wind speeds for NE-ly winds compared to other lowlands stations due to channeling (Trausti Jónsson, personal communication).

We see from the tables in Appendix I, that the wind speeds measured at the Vestfirðir stations during the avalanche cycles are not exceptional in the sense that they correspond to return period significantly shorter than 10 years for many of the avalanche cycles. The precipitation intensity or the measured snow depth are not exceptional either, but here we must bear in mind that the catching efficiency of the precipitation gauges is very low under the conditions which we are considering.

The following table groups days with average temperatures (T) below zero according to measured accumulated 24 hour precipitation (P) for the meteorological station Galtarviti for the period 1954-1994.

P (mm)	T (°C) <=-10	<=-5 >-10	<=-1 >-5	<=0 >-1	>0
<5	40	551	1426	545	9028
5-9	17	188	402	144	1220
10-14	13	93	159	55	439
15-19	7	31	46	15	154
20-24	7	10	36	8	89
25-29	0	5	13	5	55
30-34	1	2	7	4	28
35-39	0	1	2	2	11
40-44	0	0	2	2	14
45-50	0	0	0	1	6

It is seen that precipitation over 15 mm in a day occurs on 170 days and precipitation over 10 mm occurs on 435 days in this 41 year period for days with average temperature below -1 °C. The precipitation values given in Appendix I are thus no more exceptional than the wind speed values in the Appendix. The combination of heavy precipitation and high wind speeds is of course not as frequent as the occurrence of either one, but it is nevertheless quite common that high wind speeds are caused by low pressure systems which bring with them moist air and generate heavy precipitation.

The number of stations in Iceland that report a maximum 10 min. wind speed of more than 9 on the Beaufort scale for the duration of a day is an indicator of the intensity and

extent of a storm on that day. This whole-country-indicator is not particularly well suited as a proxy for storm frequencies in the Vestfirðir region, because the area is quite often hit by NE-ly storms that do not affect other parts of the country. It is, however, not often that a NE-ly storm hits the country without affecting the Vestfirðir region and the most severe storms that lead to avalanche cycles in Vestfirðir score high on the whole-country-indicator described below.

The number of wind observing stations was around 50 in 1950. During the 1960's the number of stations steadily increased to 75-80, but during the last 5-10 years it has been about 70-75 (the rapidly growing number of automatic stations is not included). The number of such observing stations in Vestfirðir has been 6-10 during most of this 45 year period. The whole country storm-index method defined by Jónsson (1980) has been used to count storm-days from 1912 onwards. The index is calculated for all days as the ratio of the number of stations reporting at least Beaufort 9 to the total number of stations in operation at that time, expressed in %.

Two intensity definitions are applied to make lists of "stormy days". For inclusion in the first list a day has to fulfill at least one of the following;

1. At least 25% of the stations report Beaufort 9, OR
2. At least 10% report Beaufort 10.

The second list is more exclusive and includes only days when at least 45% of the stations report Beaufort 9. Every stormy day is also assigned a direction indicator. The first list we call category "O" days and the second category "A".

An average year includes 10-12 days of the first type ("O"), but only about 2 of the second. Note that the number of "storm-episodes" is smaller, as in some cases there are 2, 3 or even more days clustered together and are not "independent" events. More than half of the days are not relevant with respect to avalanche danger, i.e. the temperature is too high (see HNIT, NGI, IMO, 1995).

It is clear that a storm affecting only the limited number of stations in the Vestfirðir region but not other parts of the country, is rarely strong enough to make a hit on the list without "assistance" from other areas. Some stormy days in the area are thus missing from the list. The list of NE- and N-ly stormy days in category "A" consists only of 14 episodes in 40 years. A similar list of "O" storms during the same period includes 87 episodes, i.e. slightly more than 2 pr. year (a few cases in May-Sept are excluded).

Most, but not all, avalanche cycles are included in the "O"-list and it can thus, in spite of the shortcomings, be used as a useful indicator of recurrence of the synoptic conditions producing avalanche cycles. To compile a separate list for Vestfirðir is out of the scope of this report, but will be done in the near future.

In the absence of thorough storm analysis for Vestfirðir, we have made a simpler list of stormy days with special emphasis on avalanche danger in Vestfirðir. The list is based on days when the following limits were exceeded at the Bolungarvík/Galtarviti synoptic station (WMO 04005) in the period 1949 - 1995.

1. Average daily temperature below 0.0 °C
2. Total measured 24-hr precipitation exceeded 5.0 mm
3. Average daily wind speed in exceed of 30 knots.

Each day was then flagged with either:

1 the particular limit was exceeded
0 the limit was not exceeded

A list was then made of days when all flags were raised (flag sum = 3). A total of 79 events of one or more days in row with all flags raised occurred in the 47 year period, *i.e.* slightly less than 2 events each year on average. This crude method identifies most of the worst avalanche cycles (among others, all seven in the small sample listed above). However, it also "identifies" many days without any avalanche reports. In spite of this shortcoming, this "flag-index" can serve as a useful weather condition recurrance identifier.

It is not straightforward to derive quantitative estimates for return periods for the weather that causes the worst avalanches cycles in Vestfirðir. Individual synoptic measurements (precipitation, snow depth, wind speed) may not score particularly high in a return period analysis for the particular meteorological variable at a particular meteorological station. The overall synoptic picture as shown on a weather map, does however, indicate that the storms similar to the ones that have caused the worst avalanche cycles have a return period on the order of one year. Storms that are particularly unfavorable for a particular starting zone (*e.g.* the Súðavík 1995 weather) must be expected to have a significantly higher return period than one year, perhaps 5-10 years according to a subjective estimate of meteorologists that are experienced in observing these storms. Violent storms that combine a high wind intensity with an unusual timing in the season (*e.g.* the Flateyri 1995 weather) may be expected to have an even longer return period, perhaps several decades according to the same meteorologists.

Beyond these rather loose return period speculations we do not feel that the data presently available makes it possible to compute meaningful return periods of meteorological quantities, such as precipitation, snow depth or wind speed, for an analysis of weather conditions that precede snow avalanches in Vestfirðir. However, it does appears clear that weather conditions essentially similar to the Súðavík and Flateyri storms are not unusual or unexpected when the climate of Vestfirðir is viewed on a time-scale of decades to a century.

References

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Appendix I: Synoptic measurements during recent avalanche cycles

The following tables summarizes measurements of wind speed, precipitation and snow depth for several meteorological stations in Vestfirðir during the periods listed in Chapter II in the main text: 23-26.10.1995, 14-18.01.1995, 12-14.01.1975, 09-12.02.1974, 07-10.11.1969, 03-05.02.1968 and 28-31.01.1966.

The precipitation is given in mm and is measured at 09:00 GMT on each day. It gives the accumulated precipitation over the previous 24 hours. The snow depth is measured in cm at 09:00.

23-26.10.1995

Daily precipitation (mm)

Stn.	23.10	24.10	25.10	26.10	Sum
Hól.Dr.	10	1	11	14	36
Þst.	0	5	16	13	34
Flt.	13	11	25	8	57
Bol.	8	3	22	3	36
Ísf.	32	11	15	32	89
Æð.	13	1	12	2	28

Snow depth (cm)

Stn.	22.10	23.10	24.10	25.10	26.10
Hól.Dr.	0	5	6	12	30
Þst.		11	15	35	45
Bol.	2	4	4	12	8
Ísf.	4	20	25	27	35
Æð.	3	9	11	20	25

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	23.10	24.10	25.10	26.10
Bol.	30/44	32/45	38/46	25/45
Æð.	?/?	?/?	?/?	?/?
Strm	9/1	24/13	34/17	23/13

Note: Lowland temperature was -5 to -2 °C in the period. Wind speeds up to 90 knots were measured on Þverfell. Lows of this character have a return of roughly 2 years according to a subjective estimate of the meteorologists. However, they are rare this early in the fall. The return period of this kind of low at this early point in the winter season is much higher.

14-18.01.1995

Daily precipitation (mm)

Stn.	14.01	15.01	16.01	Sum3	17.01	18.01
Hól.Dr.	12	3	7	22	12	7
Þst.	11	0	14	25	10	45
Flt.	8	1	9	17	13	9
Bol.	12	3	12	26	9	1
Ísf.	10	1	7	18	0	0
Æð.	4	0	1	5	0	0

Snow depth (cm)

Stn.	13.01	14.01	15.01	16.01	17.01	18.01
Hól.Dr.	35	40	43	40	50	60
Þst.	50	50	52	?	95	124
Bol.	22	35	36	40	35	35
Ísf.	31	36	36	45	48	48
Æð.	22	25	25	?	30	0

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	14.01	15.01	16.01	17.01	18.01
Bol.	12/26	22/?	26/48	32/45	43/57
Æð.	19/30	37/56	61/88	58/70	75/90
Strm	2/1	19/5	30/22	7/3	33/22

Note: Lowland temperature was -9 to -5 °C in the period. Lows of this character have a return roughly 5-10 years according to a subjective estimate of the meteorologists.

12-14.01.1975

Daily precipitation (mm)

Stn.	12.01	13.01	14.01	Sum
Þst.	3	6	6	15
Glt.	12	19	16	47
Æð.	5	4	4	13

Snow depth (cm)

Stn.	11.01	12.01	13.01	14.01
Þst.	68	76	85	100
Æð.	12	16	16	17

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	12.01	13.01	14.01
Glt.	32/44	29/44	38/52
Æð.	49/60	60/68	63/68
Strm	51/31	49/31	62/43

09-12.02.1974

Daily precipitation (mm)

Stn.	09.02	10.02	11.02	Sum3	12.02
Þst.	3	4	5	12	13
Glt.	14	19	26	59	18
Æð.	4	5	5	14	20

Snow depth (cm)

Stn.	08.02	09.02	10.02	11.02	12.02
Þst.	52	55	58	62	89
Æð.	17	21	25	26	35

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	09.02	10.02	11.02	12.02
Glt.	31/44	40/52	34/44	41/68
Æð.	26/44	33/44	29/44	44/68
Strm	9/1	21/8	10/2	38/28

07-10.11.1969

Daily precipitation (mm)

Stn.	07.11	08.11	09.11	10.11	Sum
Þst.	3	3	5	5	16
Glt.	15	21	28	30	94
Æð.	6	3	3	26	41

Snow depth (cm)

Stn.	07.11	08.11	09.11	10.11
Þst.	27	25	45	64
Glt.	20	25	45	54
Æð.	23	27	27	31

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	07.11	08.11	09.11	10.11
Glt.	23/37	31/44	36/52	29/44
Æð.	40/60	16/37	48/60	36/60
Strm	11/4	2/1	29/17	36/16

03-05.02.1968

Daily precipitation (mm)

Stn.	03.02	04.02	05.02	Sum
Þst.	0	7	10	17
Glt.	0	15	37	52
Æð.	0	6	7	13

Snow depth (cm)

Stn.	02.02	03.02	04.02	05.02
Þst.	15	15	20	40
Glt.	50	50	100	104
Æð.	?	3	?	2

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	03.02	04.02	04.02
Glt.	5/16	48/68	31/52
Æð.	1/5	68/85	46/85
Strm	2/1	43/29	29/18

28-31.01.1966

Daily precipitation (mm)

Stn.	28.01	29.01	30.01	31.01	Sum
Þst.	2	4	7	6	19
Glt.	9	13	19	11	52
Æð.	9	5	23	18	55

Snow depth (cm)

Stn.	27.01	28.01	29.01	30.01	31.01
Þst.	3	8	20	40	52
Glt.	28	30	40	45	45
Æð.	?	?	?	5	5

10 min. wind speed (kn.) and # of storm stations (daily ave / daily max 10 min. wind; >=9 / >=10)

Stn.	28.01	29.01	30.01	31.01
Glt.	36/60	44/60	50/68	32/52
Æð.	50/52	64/68	62/76	34/52
Strm	29/16	51/38	50/36	26/12

Appendix II: Measured snow depth at Breiðafell

The measurements are taken at 600 m a.s.l. near an automatic weather station which is being installed.

Snow depth (cm)

Day	Snow depth (cm)
18.02.1989	138
08.03.1989	170
24.04.1989	202
30.01.1990	170
12.02.1990	255
11.04.1991	336
22.12.1991	210
05.01.1992	182
21.01.1992	160
19.03.1992	225
17.11.1992	235
17.12.1992	377
02.01.1993	270
13.01.1993	381
17.02.1993	277
24.04.1993	319
14.01.1994	130
30.01.1994	270
16.02.1994	340
03.03.1994	210
17.03.1994	240
24.03.1994	310
06.04.1994	245
20.12.1994	251
30.12.1994	256
12.01.1995	290
27.01.1995	460
15.03.1995	490
24.03.1995	300
24.04.1995	350
08.05.1995	440