Seasonal and Interannual Variability of Thunderstorms in Iceland and the Origin of Airmasses in the Storms

H. Ólafsson[1], Þ. Arason[2], T. Jónsson[2]

1: Háskóli Íslands (University of Iceland) and Veðurstofa Íslands (Icelandic Meteorological Office) and Rannsóknastofa í veðurfræði (Institute for Meteorological Research)
2: Veðurstofa Íslands (Icelandic Meteorological Office)

Abstract: Variability and the meteorological conditions of thunder in Iceland are explored. Most thunderstorms occur in winter, where arctic air moves rapidly from N-America over a relatively warm sea towards Iceland. A secondary maximum in the thunderstorm frequency is in summer. The summertime thunderstorms are formed within an airmass that has been advected from Britain and/or continental Europe. These thunderstorms tend to be associated with a frontal or a convergence zone. There is substantial interannual variability in the frequency of thunderstorms at the south coast of Iceland, but there is not a sign of a long-term trend.

Keywords: Iceland, seasonal cycle of thunder, origin of airmasses, variability of thunder.

1. Introduction

Although not as frequent as over the mid-latitude continents, lightnings are an important risk for power structures in Iceland. Yet, relatively little has been published on the climatology of thunder in Iceland [1] and no study has been made of the meteorological conditions leading to thunderstorms in Iceland. Here, the annual cycle of thunder reports from synoptic weather observations Iceland is explored. On the basis of the seasonal variation in the frequency of thunder, the year is divided into three seasons, summer, winter and an intermediate season. The synoptic scale meteorological conditions during the five most intensive thunderstorms of each season during a period of twenty years are studied. Trajectories are calculated at different levels in the troposphere in order to find the origin of the airmasses in the thunderstorms.

2. Seasonal variability

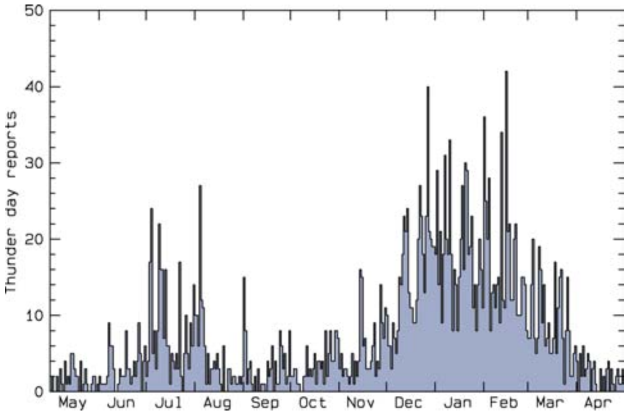

Figure 1: Seasonal cycle of the number of thunder reports from synoptic weather stations in Iceland 1951-2000.

Figure 1 shows the sum of thunder reports from synoptic weather stations in Iceland during the period 1951-2000. In general, thunder is not very frequent in Iceland and strong and widespread individual thunderstorms appear as peaks in the graph on the figure. In spite of the high relative impact of individual storms, the figure reveals significant seasonal variability in the frequency of thunderstorms. Unlike in most other countries, the maximum frequency of thunder is in mid-winter, from December to February. A secondary, but a much smaller maximum is during the warmest period of the year, in July and August. Thunder is rare during other seasons. To get a closer insight into the nature of the thunderstorms during the two peak seasons, observations from an automatic lightning detection system operated by the Icelandic Meteorological Office [2] are shown in Figures 2 and 3. In spite of the fact that thunder is rare in Iceland and that the period of automatic observations is short (1998-2003), many lightnings have been detected. The figures reveal quite different geographical distributions in the two seasons. In the winter (Fig. 2), the lightnings are almost exclusively in the southern part of Iceland, and over the ocean to the south. Usually, only a few lightnings come with each thunderstorm, so the lightnings are not clustered. In the summer (Fig. 3), the lightnings are to a greater extent grouped in clusters and more of the lightnings are over land. The two most prominent clusters are from two distinct thunderstorms. Furthermore, there are almost as many lightnings detected in the northern part of the island, than in the southern part.

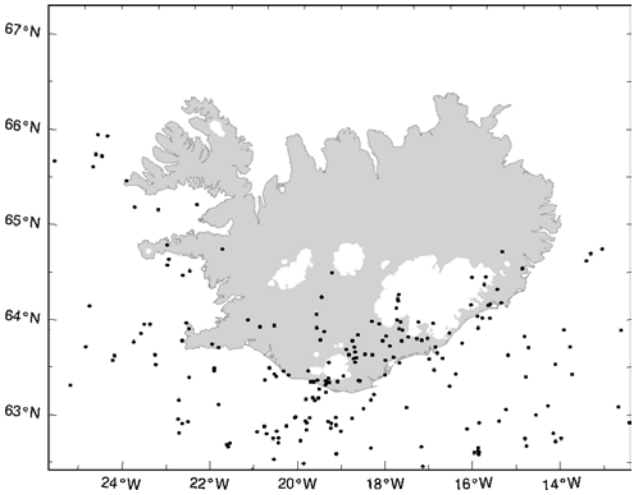

Figure 2: Lightnings detected by the automatic lightning detection system [2] Dec–Feb 1998-2003.

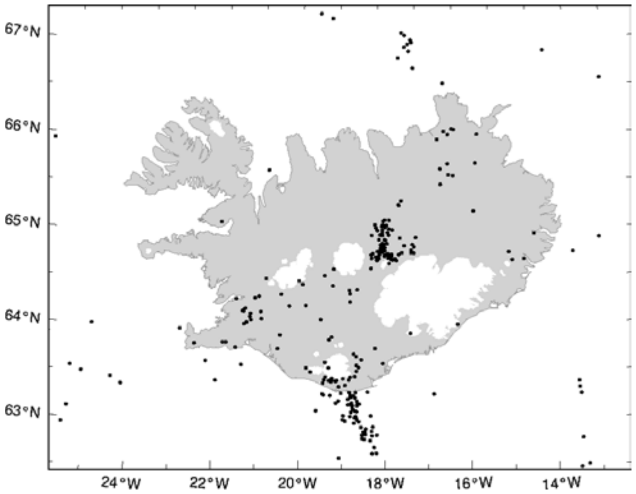

Figure 3: Lightnings detected by the automatic lightning detection system [2] Jun-Aug 1998-2003.

3. Interannual variability

For several decades, synoptic weather observations have been made regularly every 3 hours at Stórhöfði, in Vestmannaeyjar, located approximately 15 km off the south coast of Iceland. These observations can be expected to represent the main thunder activity in Iceland, i.e. the winter peak. The yearly number of days with thunder and the mean annual temperature at Stórhöfði 1949-2003 is shown in Figure 4. Apart from the peak values in 1963 and 1964, which are associated with volcanic activity [3], there is no clear trend in the frequency of thunder. The average yearly number of thunder days (excluding 1963 and 1964) is 2.5 with a maximum of 7 days and a minimum of 0 days. There is no clear connection between the mean annual temperature and the frequency of thunder.

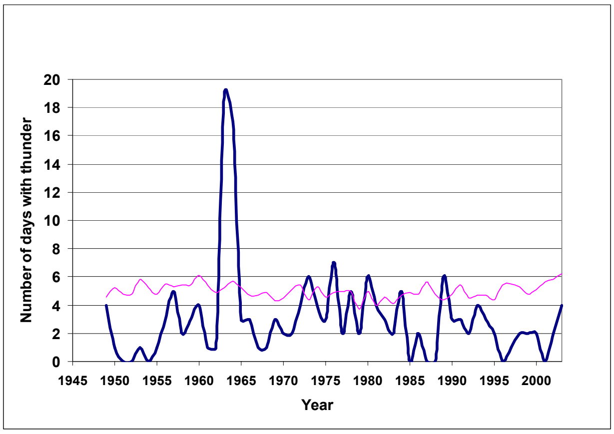

Figure 4: Annual number of days with thunder and mean annual temperature 1949-2003 at Stórhöfði, S-Iceland.

4. Comparison of thunderstorms in winter and in summer

4.1 Classification of thunderstorms

The seasonal variability of the frequency of thunderstorms calls for a further investigation of the nature of the storms in the different seasons. For this purpose, observations from all synoptic weather stations in Iceland during the period 1981-2000 have been studied. The thunderstorms have been grouped in winter events (DJFM), summer events (JJA) and intermediate season events (AM and SON). Five events leading to the greatest number of thunder reports in each group are given in Table 1. The airmasses at 500, 2000, and 6000 m.a.s.l. in each thunderstorm are traced 5 days back and the baroclinicity of the airmass is evaluated from the difference in the direction of the trajectories at 2000 m and 6000 m immediately before the thunderstorm. The table also gives information on how fast the advection of the airmass has been at 2000 m during the 24 hours preceding 12 UTC on the day of the thunderstorm.

Winter	Origin of low level airmass	Wind veering	Advection
94-01-21	N-America	0°	60 m/s
93-02-12	N-America	20° (warm advection)	40 m/s
91-01-30	N-America	10° (warm advection)	40 m/s
89-01-11	N-America	0°	10 m/s
83-12-27	N-America	0°	20 m/s
Summer			
91-08-02	Britain/Cont.Europe	0°	10 m/s
91-07-08	Britain/Cont.Europe	0°	10 m/s
88-07-10	Britain/Cont.Europe	0°	10 m/s
84-07-11	Britain/Cont.Europe	10° (warm advection)	10 m/s
82-07-03	S-Ocean	80° (cold advection)	10 m/s
Interm. Season			
99-09-05	N-America	50° (cold advection)	10 m/s
97-09-27	N-America	10° (warm advection)	30 m/s
89-10-31	N-America	0°	50 m/s
81-09-01	Britain/SE-Ocean	0°	30 m/s
81-05-14	Britain/Cont. Europe	0°	20 m/s

Table 1: Five most active thunderstorms of each of the three seasons during the period 1981-2000.

The most striking information revealed by Table 1 is the fact that the airmasses in the winter thunderstorms originate exclusively in North-America, while the airmasses in the summer thunderstorms originate close to Britain and/or over continental Europe. The thunderstorms in the intermediate season feature both sources of airmasses. There is always significant advection of the airmass prior to the thunderstorm, particularly in the winter storms. There is most often, but not always, only a very little change of wind direction with altitude, indicating limited baroclinicity.

4.2 A winter thunderstorm

A typical example of the meteorological conditions during a winter thunderstorm is given in Figs. 5-8. There is strong flow from the southwest at all levels. The airmass in which the convection develops originates in NE-Canada and has been advected over the warm Labrador Sea and the even warmer Greenland Sea between Iceland and S-Greenland. The satellite image (Fig. 8) shows well organized convection with towers reaching up through the troposphere over a large area over the ocean to the south of Iceland.

4.3 A summer thunderstorm

A typical example of the meteorological conditions during a summer thunderstorm is given in Figs. 9-12. There is moderate advection from the southeast at all levels and the airmass originates in continental Europe. As in the winter case, the flow is close to parallel at all levels immediately prior to the thunderstorm and the weather situation is relatively stationary with a low pressure area at all levels south of Iceland. The satellite image (Fig. 12) shows a cloud band reaching from Greenland, across the southern part of Iceland and extending towards Scotland, suggesting low level convergence on a synoptic scale.

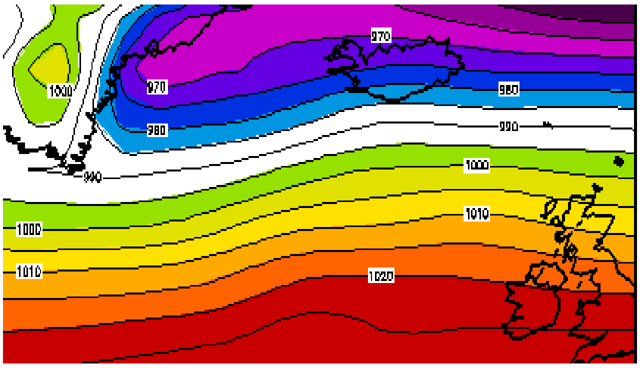

Figure 5: Mean sea level pressure on 21 January 1994 at 12 UTC. Contours with 5 hPa intervals.

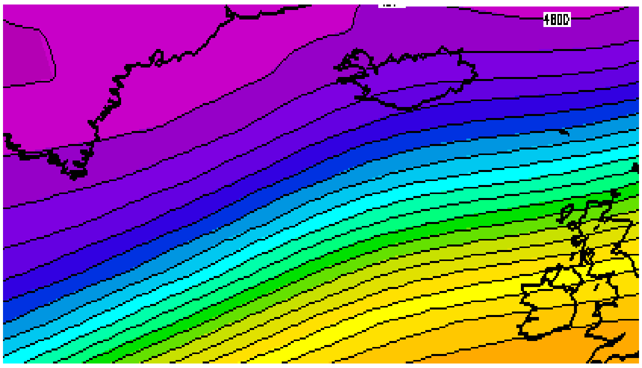

Figure 6: Height of the 500 hPa geopotential on 21 January 1994 at 12 UTC. Contours with 50 dam intervals.

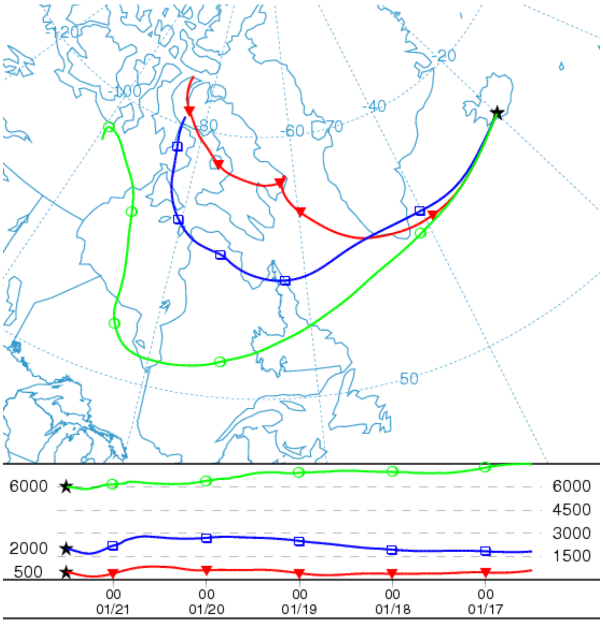

Figure 7: Trajectories at 500, 2000 and 6000 m.a.s.l. calculated backwards 5 days from 21 January 1994 at 12 UTC

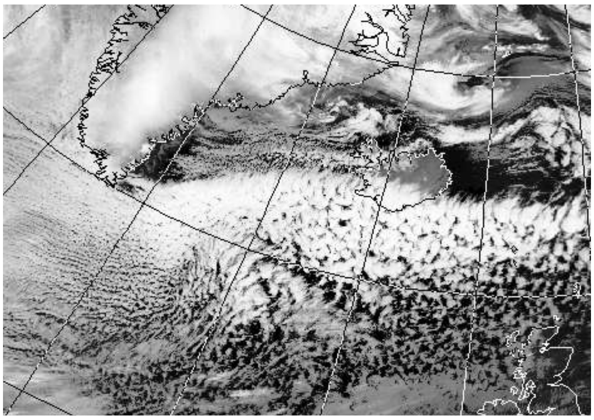

Figure 8: Infrared satellite image from 21 January 1994 at 17:07 UTC.

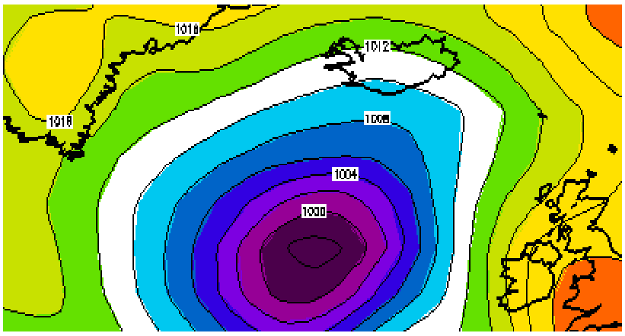

Figure 9: Mean sea level pressure on 2 August 1991 at 12 UTC. Contours with 5 hPa intervals.

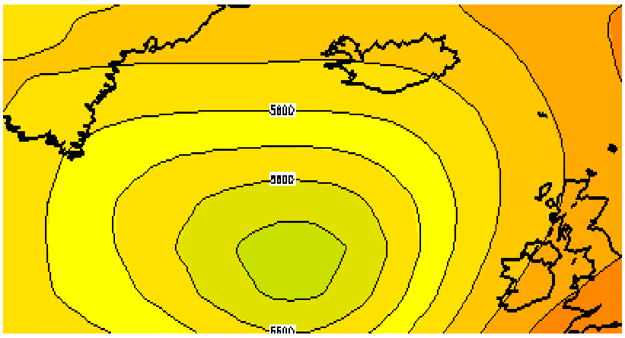

Figure 10: Height of the 500 hPa geopotential on 2 August 1991 at 12 UTC. Contours with 50 dam intervals.

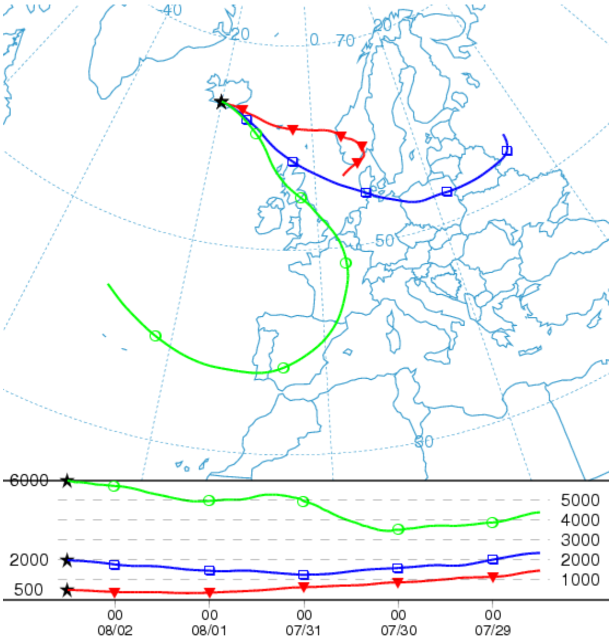

Figure 11: Trajectories at 500, 2000 and 6000 m.a.s.l. calculated backwards 5 days from 2 August 1991 at 12 UTC.

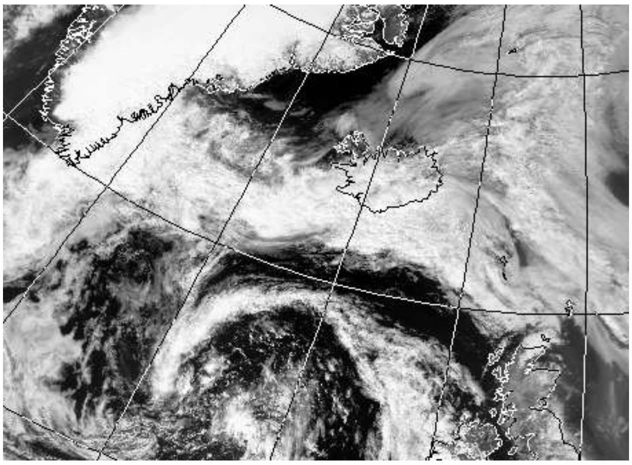

Figure 12: Visible-light satellite image from 2 August 1991 at 15:00 UTC.

5. Discussion

The differences between the winter and summer thunderstorms calls for a discussion on the dynamics of the storms. The well organized convection over the ocean in the winter storms and low static stability of the airmass (not shown) indicate that the flux of heat and moisture from the sea is of primary importance in creating the thunderstorms. The wind speed is very high in some of the cases and mixing through mechanical turbulence may therefore also play a role. Most of the summer thunderstorms are associated with synoptic scale convergence in southeasterly flow. In these storms, forcing from the surface may be of a smaller importance than in the winter storms. This would be in agreement with the fact that the relatively cold ocean has in general a stabilizing effect on the lowest part of the troposphere in this region in summer. Heat flux from the land surface may however play a role, and the fact that the summer thunderstorms are more frequent over land than over the sea supports this. With substantial winds in all cases, a positive effect on precipitation and thunder activity from topographic lifting should be expected [4]. In the winter storms this effect appears clearly in SE-Iceland, where the lightnings are no less frequent over the snow covered mountains with small surface fluxes than over the sea, where the surface fluxes feeding the storms are present and strong. In the summer, there are lightnings in the central highlands where the airmasses have been submitted to topographically forced lifting.

6. Conclusion

An investigation of observations of thunder and lightnings from manned weather stations and an automatic lightning detection system show that

- There is large seasonal variability in the frequency of thunder in Iceland. Most thunderstorms occur in mid-winter, but a secondary maximum is in July and August.
- There are indications that lightnings are more clustered in summer, than in winter and a higher proportion of lightnings are detected in the central and northern part of Iceland in summer than in winter.
- The winter thunderstorms are formed in an arctic airmass that has been advected rapidly from N-America over the warm N-Atlantic Ocean, while the summer thunderstorms tend to be associated with a front or a convergence zone extending from Iceland to the southeast or east. The low level airmasses in the summertime thunderstorms have been advected from the southeast, mainly from Britain and continental Europe.
- Most of the thunderstorms form in the absence of strong baroclinicity in the lower troposphere, including the storms in the summer season.
- There is significant interannual variability in the frequency of thunderstorms at the south coast of Iceland, but no sign of a long-term trend.

7. Acknowledgements

The trajectories are based on NCEP/NCAR reanalysis data using the HYSPLIT numerical model provided by NOAA/ARL. The satellite images are from NOAA, provided by the Dundee Satellite Station and the weather maps are provided by NOAA-CIRES/CDC.

8. References

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