Arctic Mountain Meteorology at the Sornfelli Mountain in Year 2000 in the Faroe Islands

Arktiska Fjallaveðrið í 2000 á Sornfelli

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Úrtak

Umgirdar av Norðuratlantsstreyminum eru Føroyar eitt fyrimyndarligt landaøki til kanningar av veðurlagsbroytingum elvdar av broytingum í Norðuratlantsstreyminum. Afturat hesum gevur føroyska fjallalendið møguleika til at kanna, hvussu veðrið broytist við hæddini. Tætt við sjóvarmálan hava Føroyar miðalheitt veðurlag, sum við hæddini uml 200 m omanfyri sjóvarmálan gerst arktiskt. Fyri at byrja innsavningina av dátu umboðandi fjallaveðri 300m yvir sjóvarmálan varð tann fyrsta fjallaveðurstøðin uppsett á Sornfelli í 1999 722 m omanfyri sjóvarmálan. Sornfelli veðurstøðin byggir á nýskapandi tøkni har mátitólini í stutt tíðarskeið verða lyft út úr einum hitaðum sylindara, sum annars verjir tey móti vindi og frosti. Støðin er sjálvvirkin og kann røkkast og stýrast við mótaldi. Veðurstøðin á Sornfelli hevur eydnast væl og hevur rokkið 95% dátuskiftisavkasti í ár 2000. Árligi miðalhitin í 2000 á Sornfelli var 1.71°C. Árliga miðalvindferðin var 6.5 m/s. Ráðandi vindættirnar vóru útsynningur, landsynningur og norðan. Hitafallið við hæddini frá sjóvarmálanum til Sornfelli var –0.0077°C/m.

Abstract

Surrounded by the North Atlantic Drift the terrestrial environment of Faroe Islands is an ideal place to study climatic changes caused by oscillations in the North Atlantic Drift. The high relief of the Faroes enables the study of the altitudinal climate gradient. Close to sea level the climate is cool temperate or subarctic, grading into a low arctic climate around 200 m asl. To initiate collection of data representing the mountain meteorology the first meteorological station above 300 m asl was established at the Sornfelli mountain measuring at 722 m asl in 1999. The Sornfelli meteorological station is based on innovative technology with the instruments only periodically exposed from a heated cylinder, protecting them from strong winds and icing conditions. The station is operated automatically with modem access. The Sornfelli meteorological station has proved successfull achieving 95% data coverage in 2000. Mean annual air temperature (MAAT) in 2000 at Sornfelli was 1.71°C. Mean annual wind speed was 6.5 m/s. Dominating wind directions were from southwest, southeast and north. The annual mean lapse rate between Sornfelli and the coast was –0.0077°C/m.

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Introduction

The location of the Faroe Islands in the Northeast Atlantic Ocean offers a unique setting for registering the timing and severity of late Quaternary climatic changes, caused by fluctuations of the North Atlantic Drift (Humlum *et al.*, 1996; Humlum and Christiansen, 1998a). The islands are the only land area completely surrounded by the warm North Atlantic Drift. This causes an oceanic temperate climate at sea level, significantly warmer than the latitude of 62°N indicates (Cappelen and Laursen, 1998). The area of the islands is too small to generate any continental feedback effects.

In comparatively warm periods, when generally strong, or northward-displaced, circulation occurs in the atmosphere and ocean, the Faroe Islands lie continuously in the northward flow of the North Atlantic Drift. In colder periods, when the North Atlantic Drift weakens, or its northerly branch takes a more southerly position, a tongue of polar water from the East Iceland branch of the East Greenland Current approaches the Faroe Islands from the northwest, and sea ice approaches the Faroes. As a consequence, the Faroe Islands are well placed to register meteorological effects of shifts of the ocean current boundaries in the North Atlantic Ocean.

Instrumentally recorded surface air temperature observations indicate the North Atlantic region including Greenland, Iceland and the Faroe Islands to have cooled

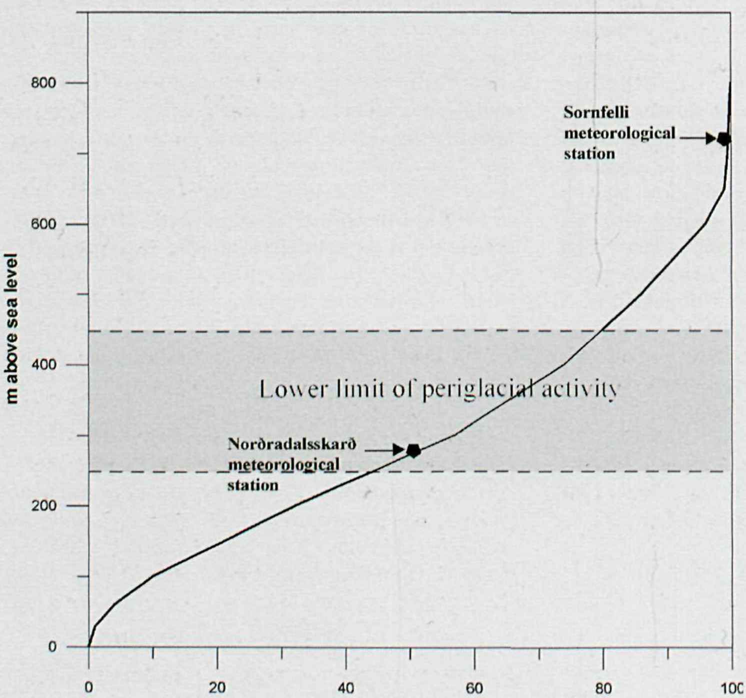

Figure 1. Hypsography of the Faroe Islands. The mean height above sea level is 282 m. The highest located meteorological station at Norðradalsskarð at 282 m asl. is shown. Also the lower limit of the periglacial zone (Humlum and Christiansen, 1998b) is included.

significantly in the latter half of the 20th century (Jones and Briffa, 1992; Mann, 2000; Hansen and Østerhus, 2000; Hansen *et al.*, 2001), which makes this an important area for global change research, past and present. In the high relief topography of the Faroe Islands a cool temperate oceanic climate at the coast grades into an arctic climate in the mountains, where periglacial landforms are found. Therefore, it becomes possible to study the dynamics of the temperate/subarctic-low arctic boundary in the Faroese mountains. However, the official net of meteorological stations run by the Danish Meteorological Institute, DMI, (DMI, 2002) and the Faroese Office of Public Works, LV, (LV, 2002) only operates in the coastal region below 282 m asl. The area above 282 m asl. represents more than 50% of the total area of the Faroe Islands (Fig.1). To improve the knowledge of the lower atmosphere interactions with the Faroese highlands, a robust meteorological station was established on the Sornfelli mountain summit in November 1999.

This paper presents the design of the Sornfelli meteorological station, located 722 m asl. at 62fl04'02"N, 06fl58'06"W, and data from the first full year of operation in 2000, as the first high altitude dataset from the Faroe Islands, with air temperature, wind direction and wind speed. The air temperature data are used for an annual analysis of the lapse rate between Sornfelli and the coast. The Sornfelli station also has a shallow borehole for monitoring ground temperature, and was later supplied with two web cameras for snow cover registration and a sensor to measure the air pressure. None of these installations and their data are discussed in this paper, as they all only started operating during the year 2000.

Meteorological and climatological conditions of the Faroe Islands

The area of the Faroe Islands is 1397 km^2, and they are located between 61°20'N and 62°24'N and 6°15'W and 7°41'W. The highlands rise gradually to rolling plateaus 400-600 m asl. in the southern part of the islands, while the steep alpine mountains of the northern and northeastern areas reach above 800 meters, with 882 m asl. at the highest mountain peak, Slættaratindur. The average altitude is 282 m asl. The western and northern seaward facing coasts have steep headwalls, up to 720 m high, while eastern and southern facing coasts are more gently sloping into the sea.

The climate of the Faroe Islands has an oceanic character and is characterised as humid, unsettled and windy, with a small annual temperature amplitude, due to the influence of the North Atlantic Drift and frequent passages of cyclones from the south and west along the polar frontal zone (Cappelen and Laursen, 1998). The meteorological seasonality at the Faroes is primarily controlled by the location of the polar frontal zone. In summers the Azores High often is displaced northwards towards the islands, causing relatively warm and stable weather for weeks, whereas in winter cold air from northerly areas reach the islands with snowfall and frost occurring, when the polar frontal zone moves south of the islands. Snow covers the ground for 44 days in Torshavn, close to sea level (Cap-

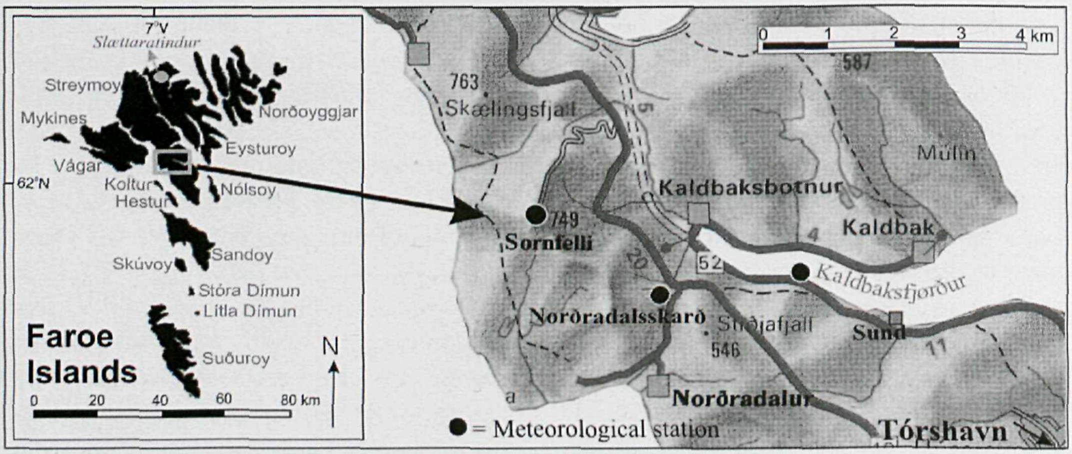

Figure 2. The location of the Sornfelli Mountain on the island Streymoy in the central part of the Faroe Islands. Based on maps by the Danish Survey and Cadastre.

pelen and Laursen, 1998), but not as a stable winter snow cover, such as can be observed at sheltered sites in the mountains.

The climatological normals for the last WMO standard period 1961-1990 in the Faroe Islands are presented in Table 1, based on 3 synoptical weather stations all located below 101 m asl. (Cappelen and Laursen, 1998). These observations and the general mapping of the Köppen climate types (Ahrens, 2000; Köppen, 1918) characterise the Faroese climate as a Cfc climate, a moist mild mid-latitude climate with cool summers. However, no systematic long-term meteorological recordings exist above 282 m asl. Humlum and Christiansen (1998a) presented two years of near surface air temperature measurements from different altitudes in the northern part of the Faroe Islands, and reported a mean annual air temperature (MAAT) of 0.8°C at 856 m asl. for 1996-1997. Data from the same area, but for the recent 1996-2001, five-year period, show a MAAT based on mean monthly air temperatures (MMAT) of 1.2°C at 856 m asl. (Christiansen and Humlum, submitted).

This implies that during cold intervals of the Little Ice Age, nominally the period AD 1400 to 1900 (Kreutz *et al.*, 1997), the lower limit for periglacial activity may temporarily have approached sea level, simultaneously with incipient establishment of sporadic permafrost in the highlands, when presumably a number of sites in the highest mountains approached reglaciation (Humlum and Christiansen, 1998b). Therefore the collection of present day meteorological information from the Faroese highlands is essential to modelling former conditions in this arctic zone.

The location of the Sornfelli meteorological station

Several Faroese mountain tops reach 700 m asl., which is well into the arctic zone. However, only the 749 m high Sornfelli mountain offers infrastructure useful for the establishment and operation of a meteorological station. The Sornfelli mountain holds a Danish military facility, Flyvestation Thorshavn, on the summit, with road access and power supply, including support from the military personnel. This in combination with its central location on the island Streymoy, and the existence of two operating meteorological stations located at different altitudes in the landscape below Sornfelli (Fig. 2), led to the location of the mountain meteorological station at this particular mountain.

The summit of Sornfelli is a 200 m wide plateau, delimited by steep up to 200 m high headwalls. The plateau dips 8° south southeast (Fig. 3), and is covered by a diamict, with scattered boulders and an up to 2 m deep, coarse-grained soil cover above the basalt bedrock. The surface is dominated by active periglacial patterned ground, and has moss vegetation in a few parts. The mountaintop was severely weathered during the last glaciation, when it was a nunatak (O. Humlum, pers. comm.), thus explaining the relatively deep soil cover. The meteorological station is located at 722 m asl., centrally in the southern part of the plateau (Fig. 3), minimizing the lee effect from the military installations in the northern end of the plateau, and preventing most of the edge wind effects along the headwalls.

Challenges to the Sornfelli meteorological station

Previous attempts to run a meteorological station on Sornfelli using a conventional mast with fixed instruments, recording wind with cup anemometers have failed primarily due to icing and destructive wind forces (Military personnel Sornfelli, pers.comm.). Sornfelli as a mountain is relatively frequently struck by lightning, so

1961-1990 period	Akraberg lighthouse	Vágar airport	Tórshavn
Altitude of station (m asl)	101	84	54
Mean annual air temperature (2 m)	6.4	6.0	6.5
Warmest month (Aug)	10.0	10.4	10.5
Coldest month (Jan)	3.8	2.7	3.4
Annual precipitation (mm)	884	1555	1284
Wind speed (10 min average) m/s	8.1		5.9
Most frequent wind direction	W		W

Table 1. *Climatological parameters observed in the latest World Meteorological Organisation (WMO) standard normal period 1961-1990 at the Faroe Islands based on synoptical stations (Cappelen and Laursen, 1998). Precipitation was at Vágar airport only measured from 1988-1997. All other observations at Vágar airport were during the period 1968-1997. The wind speed observations at Akraberg were from 1962-1990. Cappelen and Laursen (1998) do not report wind measurements at Vágar airport.*

this needed consideration when constructing the station. Icing problems are not as important as at one of the most extreme icing settings, at the Mt. Washington Observatory (44flN, 71flW) at 1917 m asl., New Hampshire, USA (Whiteman, 2000). However, ice covers several cm thick were observed on installations at Sornfelli (Military personnel Sornfelli).

The extreme nature of hazardous wind forces is obvious from a hurricane on 21 Dec 1988, when the steel mast of the meteorological station at Norðradalsskarð, at 282 m asl. (Fig. 2), was bent (Fig. 4). The recorded wind speed, when the mast was bent, was 77.2 m/s (Poulsen and Brimnes, 1996). In comparison one of the highest wind speed ever recorded at 104.6 m/s was registered in 1934 at Mt. Washington (Pagliuca *et al.*, 1934). Therefore a durable meteorological station at Sornfelli should resist harsh mountain weather conditions, and would need to be equipped with robust instruments with respect to icing, extreme wind conditions and lightning.

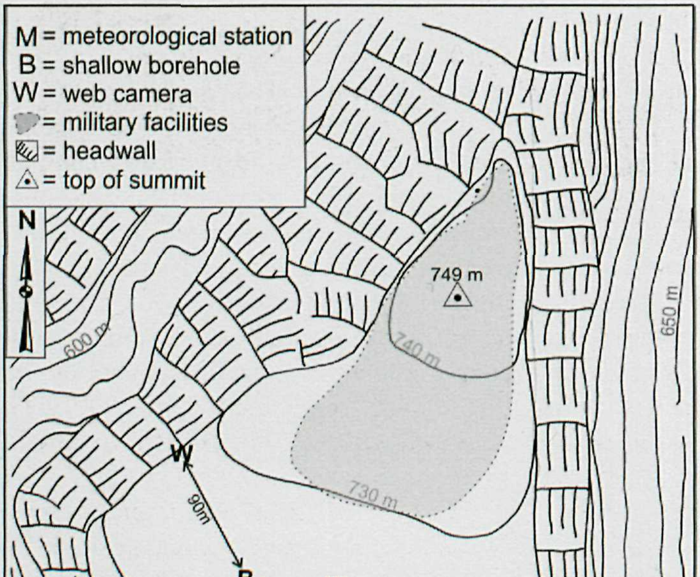

Figure 3. *The Sornfelli mountain plateau showing the installations. The map is based on surveying by DGPS in the summer of 1999, by Anne Marie Norby, LV, in combination with 1:20000 mapping by the Danish Survey and Cadastre.*

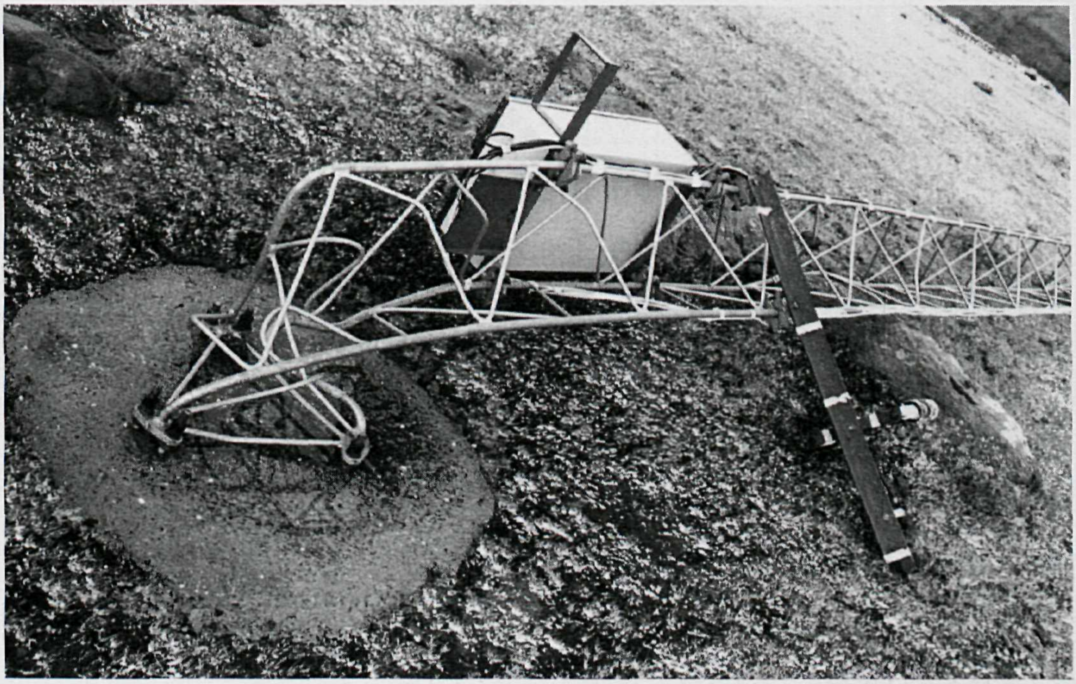

Figure 4. The lower part of the completely bent meteorological mast at Norðradalsskarð, 282 m asl., after the 21 December 1988 hurricane. Photo by LV, Dec 1988.

The technical design of the Sornfelli meteorological station

Only 700 km southeast of Sornfelli, in the Scottish Highlands, the Cairn Gorm Automatic Weather Station, located at 1245 m asl., at 57°N and 3°W, operates in a mountain climate much like the one at Sornfelli. This station was designed and built by the Physics Department, University of Edinburgh, and has been in operation since 1977, recording wind speed, wind direction and air temperature, in one of the most severe climates of the UK (Crowder and Barton, 2000). To combat the effects of heavy icing the instruments are housed in a heated cylinder, fixed to the underside of a lid, which is lifted up and the instruments exposed for recording for 3 minutes every half hour (Crowder and Barton, 2000). This station was used as the basic design idea for the Sornfelli meteorological station.

The meteorological consultancy company Metsupport, ApS. from Roskilde in Denmark, was contracted to design the station at Sornfelli including maintenance. The Sornfelli meteorological station is constructed to combat icing, by keeping the instruments inside a heated cylinder and exposing them for measuring periodically (Fig. 5). The engineering preparations of the Sornfelli site were carried out by LV.

The fully automatic Sornfelli meteoro-

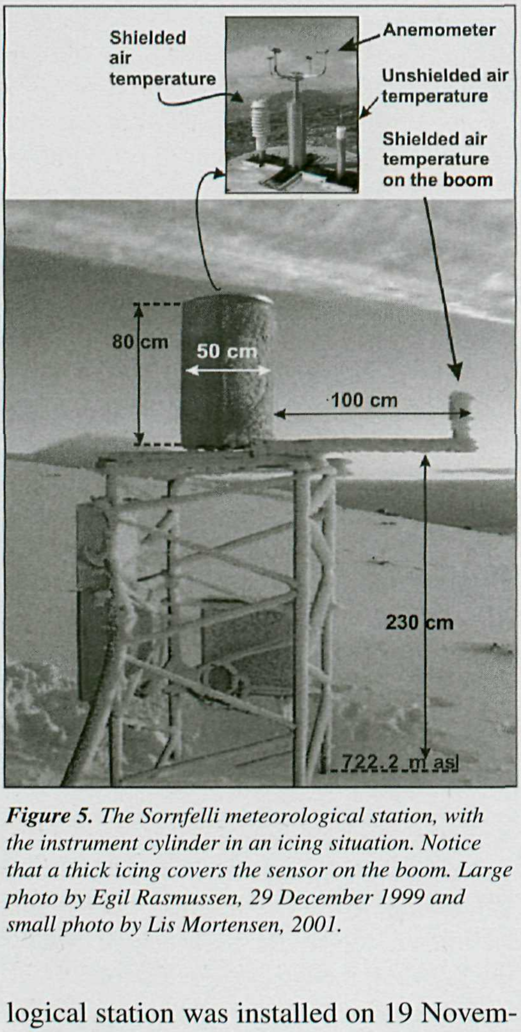

Figure 5. The Sornfelli meteorological station, with the instrument cylinder in an icing situation. Notice that a thick icing covers the sensor on the boom. Large photo by Egil Rasmussen, 29 December 1999 and small photo by Lis Mortensen, 2001.

logical station was installed on 19 November 1999. It is remotely controlled, with facilities for remote downloading of data. Inside the 80 cm high cylinder, which is standing on a 2.3 m mast, the instruments are fixed upright onto a platform, which is lifted out through the cylinder top lid for 10 minutes every half hour (Fig. 5). The lid hole is covered with plastic brushes to keep out snow. Heaters, fans and thermostats inside the cylinder keep the inside temperature above a minimum of 3 °C. At the platform air temperature is measured at 725.6 m asl., and the wind recordings at 725.7 m asl. (Fig. 5). Air temperature is also recorded every half hour by a sensor fixed to a 50 mm round boom extending 1 m from the cylinder (Fig. 5).

For wind speed and wind direction recording, a 2 axis ultrasonic anemometer, Solent Wind Observer model 1172T, is used. At each axis a transducer sends a sound pulse across to its paired transducer and the flight time is measured. A sound pulse is then sent in the opposite direction, the wind speed along the axis being given by the difference in the two flight times. Unlike conventional cup anemometers, this type of anemometer has no moving items, which eliminates the possibility of damage by strong winds. Sonic anemometers are, however, susceptible to ice formation on the transducers, but this is prevented by storage of the instruments in the heated cylinder.

The military station supplies 230V electricity to the station. To prevent severe lightning damage, the electronic systems are protected with fuses and relays, and the site is firmly connected to a lightning conductor system.

Two cabinets attached to the mast (Fig. 5) house the station computers and devices for control and communication. Recorded data are stored on computers. The computers are set up in a WindowsNT network with a server and connected PC's. Every hour the station connects to the internet and raw data are transmitted to a receiving server at Metsupport in Denmark. Here the

data are quality controlled and stored in a database. Plots of the most important parameters are shown on the website
http://www.metsupport.dk/data/sornfelli.
These plots are updated hourly. Data are also published on the website of the Faroese Office of Public Works,
http://www.lv.fo/egl_en/real_sornf/sornfnow.html,
which also has photographs from the preparation of the site during 1999.

The instrument cylinder is continuously monitored by 4 internal temperature sensors and 15 other control parameters, enabling remote inspection of the overall operation. Since the start not many data have been lost. This is mainly due to the remote inspection, which enables dealing remotely with issues like turning on more heat in the lid if snow accumulated there, checking the lifting mechanism, checking that the drain in the bottom of the cylinder is open, and being able to call for local assistance, supplied by LV, and the military personnel at Sornfelli, when needed.

Air temperature

Four different air temperature values are recorded at the Sornfelli meteorological station. A shielded and an unshielded mean air temperature from the platform sensors (Fig. 5), which are granted 9 minutes for acclimatization, then one minute of recording before the platform is lowered into the cylinder. A shielded 30 min mean air temperature from the temperature sensor fixed on the external boom (Fig. 5), and a shielded 1 min mean air temperature from the same sensor, recorded during the same minute as the platform sensors record.

In the year 2000, one minute mean temperature values from all three sensors recorded simultaneously, showed the unshielded sensor to be warmest, with a MAAT of 2.18°C, while the shielded sensor fixed on the boom was coldest with a MAAT of 1.76°C. The shielded sensor on the platform had a MAAT of 1.83°C.

These three measurements are combined into one corrected annual air temperature (Fig. 6) using the following two rules: 1) Use the coldest sensor. 2) Use data from the coldest platform sensor, if the shielded fixed sensor is in the interval +0.2°C to –0.8°C. The first rule both prevents the use of data from the shielded platform sensor, when it is not sufficiently cooled in calm weather, and generally prevents the use of data from the unshielded sensor. The second rule prevents using the fixed sensor, when icing keeps the temperature stable during freezing or thawing.

Using these simple rules the shielded platform sensor contributed 61% to the data of the corrected air temperature in 2000, while 37% came from the fixed outside sensor, and only 2% from the unshielded platform sensor. The corrected air temperature (Fig. 6) for year 2000 has a MAAT of only 1.71°C. The annual amplitude was only 8.7°C (Table 2), based on monthly values. The warmest month was August with 6.5°C, while April was coldest with –2.2°C (Table 2). Analysing the distribution of data used from the different sensors for the constructed air temperature curve, shows that the unshielded sensor was used only during calm nights, when both of the shielded sen-

Air temperature	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean	-0.9	-2.0	-1.9	-2.2	2.6	3.0	6.1	6.5	5.4	3.2	0.6	-0.7	1.7
Min.	-8.4	-7.7	-10.6	-9.1	-2.9	-3.2	0.7	2.3	0.8	-1.5	-5.4	-10.6	-10.6
Max.	8.6	4.8	4.2	6.1	12.3	9.1	14.6	10.9	12.5	7.3	5.6	5.7	14.6

Table 2. *Mean monthly and annual air temperature (°C) at the Sornfelli meteorological station during the year 2000, calculated from the half hourly corrected temperature values.*

sors were insufficiently ventilated. The main use of the shielded sensor on the platform is because of radiational effects from the ground heating the shielded fixed sensor. This occurs when the ground is snow covered or heated by the sun in summer.

Wind speed and direction

The wind speed data are scanned continuously four times per second throughout the 10 minute platform exposure period. Three parameters are calculated from these data: A 10 min mean wind speed, a 32 sec gust and a 2 sec gust. Wind direction is calculated as the average wind direction in 10 minutes. Some single spike values of extreme wind speeds occurred on rather calm days. These error readings most likely are caused by rain or snow in the sound path. From 4 September 2000 wind and gust values above 40 m/s have been filtered out of the processed dataset.

The 10 min wind speed in the year 2000 (Fig. 7) had a mean value of 6.5 m/s. The most windy periods occurred during the late winter and mid autumn, with monthly wind speeds up to 8.8 m/s, while the summer from May through August had mean wind speeds generally less than 5 m/s (Fig.

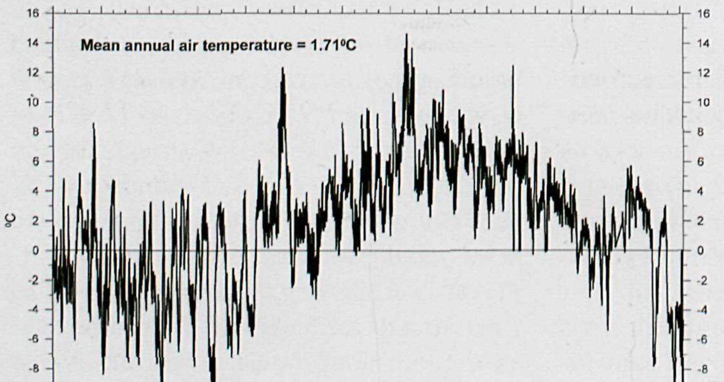

Figure 6. *The corrected air temperature for the year 2000 from the Sornfelli station based on data from the three different temperature sensors. For further details on the construction of the curve see the text. Mean annual air temperature (MAAT) is shown.*

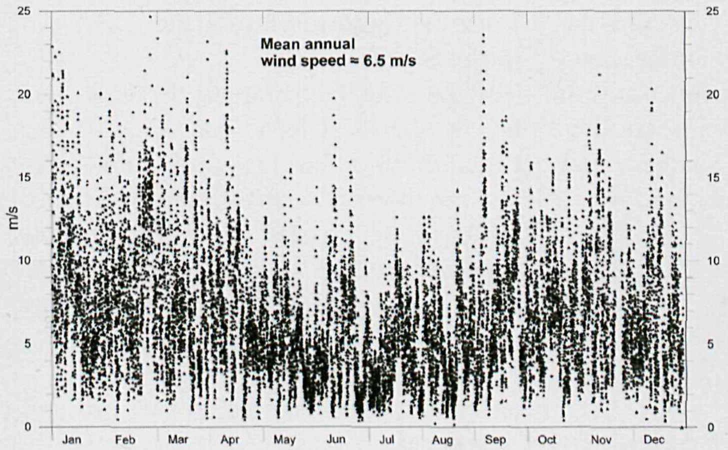

Figure 7. *The 10 minutes mean wind speed for year 2000 from the Sornfelli station. The mean annual wind speed is shown. Only a 41.34 m/s value from the 31 March was removed from the figure, and from 4 September values above 40 m/s was filtered out.*

7 and 8).

The distribution of the wind direction data for year 2000 (Fig. 8) shows three dominating wind directions from the north, southeast and southwest. The mountain setting of the Sornfelli station causes topographic effects on the measurements. The cylinder will produce some airflow distortion. The effect of this has not been investigated. The data, however, demonstrates that the measuring site is not dominated by strong turbulence. This would have produced significant variation in the wind speed values and a more uniform distribution of the direction frequencies. This indicates that the Sornfelli station is successfully located for recording the general wind pattern. Presumably it is suffering from some lee effects, from the slightly higher located, northern part of the plateau.

The gust winds with a 10 min mean wind speed above 15 m/s (Fig. 8) show that most of the storms during 2000 came from southwest. Storms from the southeast occurred only in January and February, while northerly storms occurred in March, April, November and December. The southwesterly storms dominated in the spring. Although the summer was generally calm, 32-sec gusts of up to 28 m/s did occur 13 June. The highest gusts recorded during 2000 were 30 m/s for the 32 sec gust 1 January, and 40.7 m/s for the 2 sec gust 3 January.

Windchill

The mean annual windchill value (U.S. National Weather Service, 2001) calculated based on the corrected air temperature data at Sornfelli is –7.07°C. This is 8.77°C lower than the MAAT value, and shows the significant cooling of the mountain due to wind activity. The relationship between windchill values and wind direction (Fig. 9) shows that the coldest winds primarily come from the north and some from the southwest, whereas winds in the sector from east to southwest predominantly bring winds with windchill values from +5°C to

–10°C. This distribution indicates that the largest cooling of the ground surface, and thus freezing of the ground, occurs on north and southwest facing slopes, while lee sites for snowpatches occurs on southern and north-eastern sides of the mountain.

Local temperature lapse rate in the Sornfelli area

The rate of temperature decrease with height, the local lapse rate (Fig. 10), between the Sornfelli meteorological station and the lowermost, nearby meteorological station at the coast at 3.5 m asl. at Sund, Kaldbaksfjørður (Fig. 2) is calculated through the year 2000. The MAAT for 2000

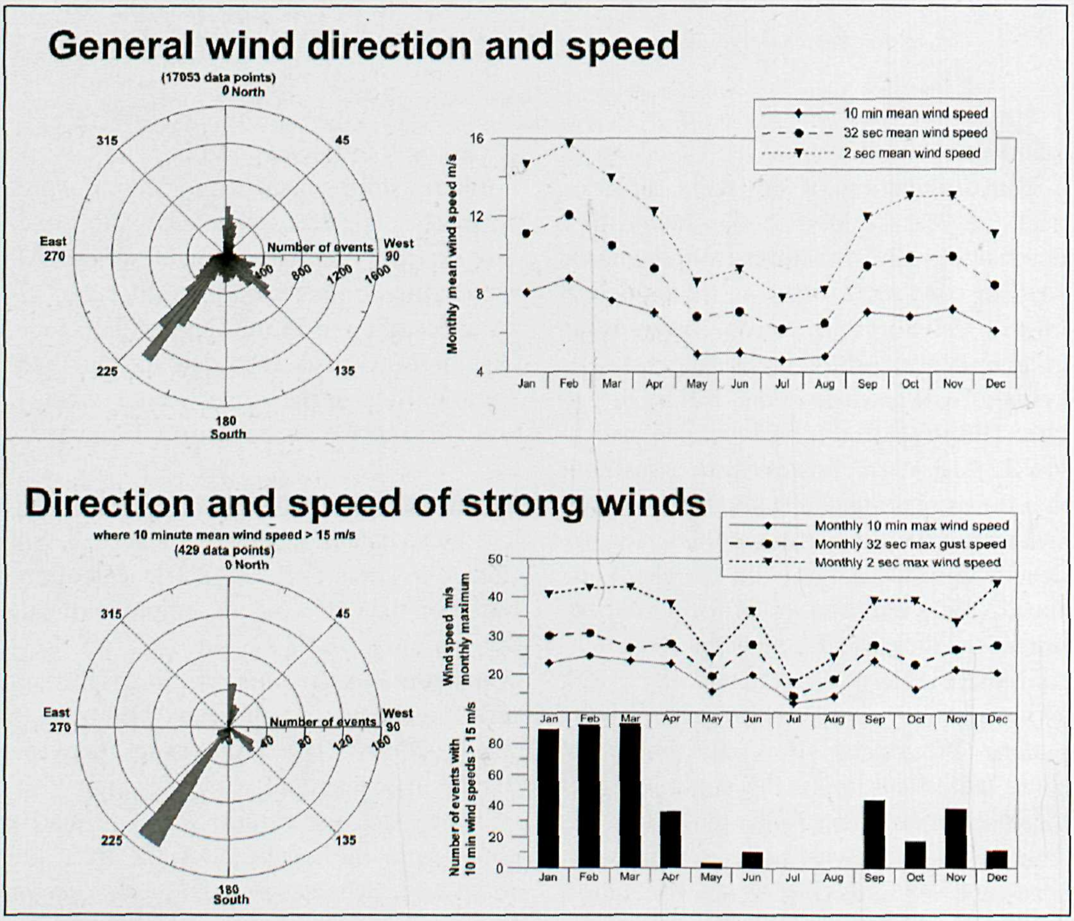

Figure 8. Wind speed and direction data from the Sornfelli meteorological station in the year 2000.

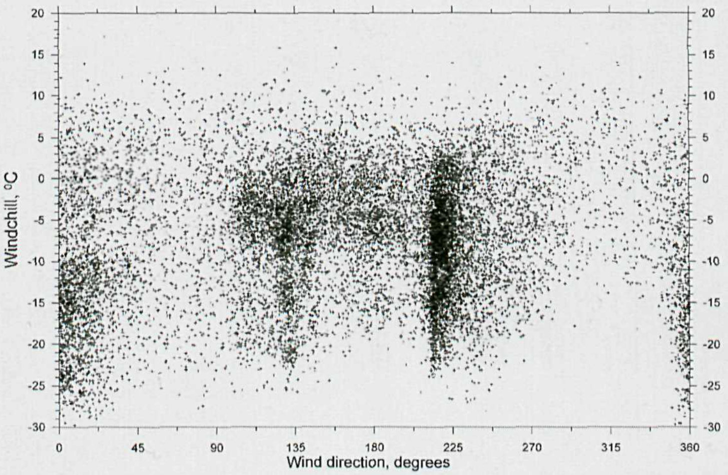

Figure 9. Windchill as a function of wind direction at the Sornfelli meteorological station. The windchill values are calculated based on the corrected air temperature data for 2000.

for the Sund station was 7.3°C, a value somewhat warmer than the Torshavn 1961-1990 annual mean of 6.5°C (Table 1).

The mean annual lapse rate was -0.0077°C/m (Fig. 10). This value is well above the standard value of -0.0065°C/m (Ahrens, 2000) for oceanic regions, and shows that the atmosphere in general is unstable. Winter lapse rates generally between -0.007°C/m and -0.009°C/m, and summer values of -0.004°C/m and -0.005°C/m are recorded for temperatures close to the ground surface in the Slættaratindur mountain area, in the northern part of the Faroe Islands, in the period 1995-2001 (Christiansen and Humlum, submitted). The seasonal variation in the lapse rate (Fig. 10) shows the atmosphere to be generally unstable all the year, but with several summer periods with stable conditions, when values above -0.0065°C/m occur. During summer temperature inversions occurred primarily during calm conditions, when the Sornfelli mountain received more direct insulation than the more shaded, lower located Kaldbaksfjørður valley, where also moist air and fog occurred at the coast.

Freezing, thawing and growing indices at Sornfelli

The corrected air temperature (Fig. 6) was used to calculate freezing, thawing and growing degree days (FDD, TDD and GDD) (Andersland and Ladanyi, 1994; Molau and Mølgård, 1996) at Sornfelli (Fig. 11), based on daily mean air temperatures. The annual TDD sum of 973 is much larger than the 361 FDD sum, indicating a positive ground thermal regime without permafrost.

The annual sum of GDD is 160, which is significantly less than found at the same altitude at the Slættaratindur area by Humlum and Christiansen (1998b, Fig. 5: 178), based on ground surface temperatures.

Discussion

The new concept of the Sornfelli meteorological station, with a heated cylinder housing the instruments in an advanced auto-

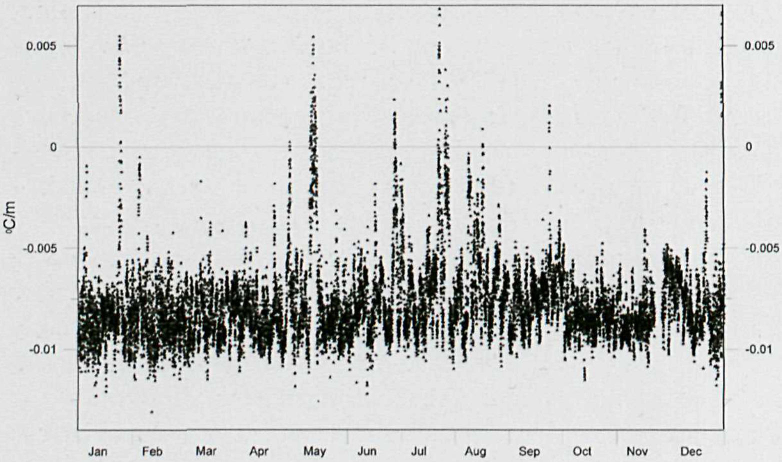

Figure 10. *Lapse rate between Sornfelli meteorological station (726 m asl.) and the meteorological station at Sund, Kaldbaksfjørður (3.5 m asl.), operated by the Office of Public Works for the year 2000. Normally the air temperature is lower at Sornfelli than at Sund with a negative lapse rate.*

matic environment with remote access, has proven successful. The station withstood severe lightning and was operative through a whole winter with several storms and 6 major icing events. The longest icing lasted around 12 hours. The station had a 95 % data coverage during the first year of operation, which is primarily due to the constant remote monitoring of the station performance and quick local assistance.

The combination of the three air temperatures for constructing a corrected air temperature, excludes icing effects and radiational reflection from the ground, and allows better measurements during calm overcast or night conditions, when the unshielded sensor is used. Only 37 % of the time the recordings from the fixed sensor outside the cylinder was used for the corrected air temperature, showing that the heated platform concept is useful, when measuring at Sornfelli. The wind recordings did suffer from rare unreal spikes with the low frequency of 0.3‰.

Therefore the Sornfelli meteorological station has turned out to be a reliable and robust mountain meteorological station, able to record the oceanic, maritime mountain climate of the Faroe Islands. The presented air temperature and wind data from Sornfelli thus contribute significantly to start documenting the Faroese mountain climate, and its vertical gradients.

Arctic climate on the Faroe Islands

In 2000 the MAAT was 1.71°C at Sornfelli at 726 m asl. and 7.3°C at sea level at Sund in Kaldbaksfjørður, with a mean annual lapse rate of -0.0077°C/m. These meteorological data clearly locate the Sornfelli mountain well within the polar ET-climate of the Köppen climate classification system (Köppen, 1918), with a mean air temperature of the warmest month higher than 0°C, but lower than 10°C. At sea level a moist climate with a short and cool summer and a mild winter of the Cfc climate type exist according to the Köppen classification.

The lower limit of the ET climate type is located where the mean air temperature of the warmest month is 10°C, corresponding to the tree limit. Using the Sornfelli mean August air temperature of 6.5°C and the local August lapse rate of -0.0068°C/m, the limit between the polar and temperate climate is located at 216 m asl. in the Sornfelli region in the year 2000. Thus the data from the Sornfelli meteorological station emphasize that about 68% (Fig. 1) of the land area of the islands had a polar climate in 2000. The lower limit of the periglacial zone, based on the distribution of periglacial landforms in the Faroe Islands, have previously been located at 250-450 m asl. (Humlum and Christiansen, 1998a;b) (see Fig. 1), which corresponds very well with the suggested 200 m asl. lower limit of the low arctic. Biogeographically, Tuhkanen (1987) located the Faroe Islands in the hemiboreal zone at sea level, but with a hemioroarctic zone in areas above 700 m. He stressed that even lower oroarctic zones may well be found at levels below 700 m asl. His vertical zonation is based on meteorological data from the 1931-1960 period, which was slightly warmer than the 1961-1990 period, and on a too low standard Fennoscandinavian lapse rate of only -0.0053°C/m, as he did not have access to any local lapse rates. Therefore his arctic zone probably would also be significantly lowered using the Sornfelli meteorological data. The potential tree line has been located at 150 m asl. (Ødum, 1991) and later at 300 m asl. (Leivsson, 1993) for sheltered locations. These values also largely agree with the lower boundary of the low arctic zone located around 200 m asl.

Traditionally the polar climate of the northern Hemisphere is also known as the arctic climate. In the southern parts a low arctic climate exist, in which the mean air temperature of the warmest month is below 10°C, but above 5°C. At the highest moun-

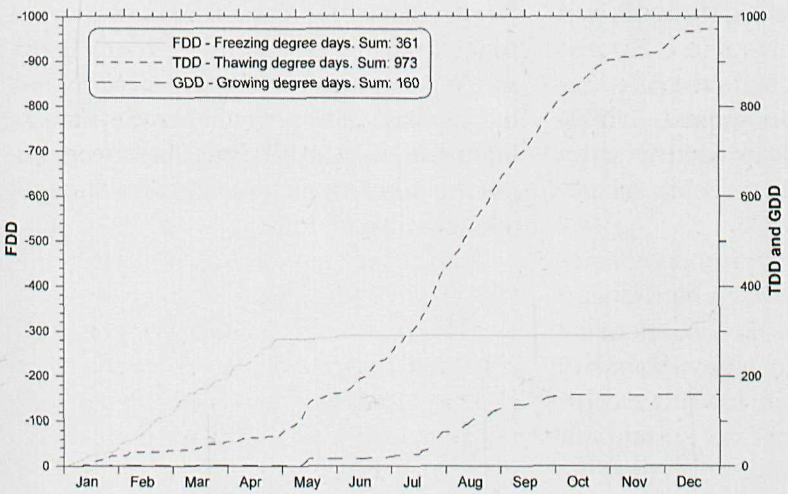

__Figure 11.__ Cumulative indices of freezing (FDD), thawing (TDD) and growing (GDD) degree days for the year 2000 at Sornfelli, calculated from the corrected air temperature data.

tain peak in the Faroe Islands, Slættaratindur at 882 m asl., the air temperature of the warmest month should be in average 5.5°C, calculated from the Sornfelli air temperature data for the year 2000. Therefore low arctic conditions today dominate from the highest mountain peaks and down to around 216 m asl. in the islands. However, a slight mean temperature decline of only 0.5°C in summer would bring high arctic conditions to the very peaks of the Faroese mountains.

Between the temperate zone, where trees can grow economically profitably and the arctic climatic zone, the narrow subarctic boundary zone exists, in which the air temperature of the warmest month is just above 10°C, and low and dispersed woods can occur. The lower part of the Faroese landscape today has almost no woods, and in Torshavn, at 54 m asl., the mean 30 year air temperature of the warmest month is 10.4°C (Table 1), while at Sund, at 3.5 m asl., in an inner fjord location (Fig. 2), the air temperature of the warmest month in 2000 was 11.5°C. Therefore the main part of the lowermost 216 m of the Faroese landscape seems to belong to the subarctic zone. Heide-Jørgensen and Johnsen (1997) also use the subarctic type, when characterising the Faroese climate as being subarctic-temperate.

The complete climatological dominance of low arctic and subarctic climatic conditions at the Faroe Islands does not fit many traditional maps of the southern boundary of the northern hemisphere low arctic zone. This border is often placed not far north of the Faroe Islands, locating the Faroes in the temperate climate zone. Such mapping, however, often refers to conditions at sea level. In the Faroes the zone up to 100 m asl. comprises less than 10 % , due to the topography (Fig. 1). Cold climatic conditions similar to the Arctic in mountains outside the polar climatic zone are referred to as alpine climates. Therefore the Faroese low arctic zone could be termed alpine according to this definition, if conditions at sea level were temperate. However, the subarctic conditions at sea level and the nearness to the arctic zone at sea level, as e.g. just northwest of the Faroes in Iceland, imply that the cold climate above 200 m asl. in the Faroe Islands, should be included in the low arctic climate zone of the Northern Hemisphere.

The presented vertical distribution of climate zones at the Faroe Islands offers a unique setting for monitoring meteorological conditions in the southernmost part of the northern hemisphere low arctic zone. This is particularly important in the Northeast Atlantic area where variations in the North Atlantic Drift could move the terrestrial altitude of the low arctic zone. Therefore it is important to obtain long-term meteorological data series from the Faroese highlands, as it will be possible by operating the Sornfelli meteorological station for a longer time period.

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