THE HEAT SOURCE OF THE FOEHN

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Abstract: Twelve years of upper air data and surface observations across Iceland are used to investigate the connection between the difference of surface air temperature upstream and downstream of the Icelandic highlands and several parameters of the airflow, such as precipitation, static stability and wind speed. The data does not support the well-known concept of the heat of the foehn being a result of latent heating. In the winter, warm air, descending from above the upstream boundary layer appears to be responsible for the downslope heating. There is little correlation between the upstream wind speed and the upstream-downstream temperature difference. This is explained by weak winds contributing to low level upstream blocking and descent from upper levels in the lee, while strong winds contribute directly to vertical mixing through mechanical turbulence. The annual cycle of temperature difference between the upstream and the downstream slopes indicates that in the summer, solar heating over the downstream slopes is responsible for a substantial part of the heating of the foehn.

***Keywords** – foehn, latent heat, upstream precipitation, downstream heating, Nh/U, inverse Froude number, Iceland*

1. INTRODUCTION

Most specialists in dynamic meteorology probably associate the heat of the air immediately downstream of mountains primarily with the process of potentially warm airmasses being brought down from levels above the atmospheric boundary layer. Yet, authors of meteorological textbooks, papers and texts for the general public underline very often the role of release latent heat in heating the foehn. (Einarsson, 1971; Quaile, 2001; Ahrens, 2003). This includes a large number of web-based texts of which some are edited by respected national weather services. The concept of the release of latent heat being responsible for the heating of the foehn is generally based on illustrations of symmetric mountain flow, i.e. the surface flow following the terrain up the upslopes and down the downslopes. The associated calculations figure a pseudo-adiabatic lapse rate (-0.6 K/100m) up the upslopes and a dry adiabatic lapse rate (+1 K/100m) down on the other side. The condensed water is implicitly assumed to fall out as precipitation. Several problems are associated with the application of this model. Firstly, the precipitation rate may not be sufficient to explain any substantial heating. This is indeed often the case in Iceland: pronounced cases of foehn in NE-Iceland often occur when there is only light drizzle in the central highlands and on their southern side. A closely related problem associated with the calculations explained above is that it is not realistic to assume that the condensed water is completely released from the surface flow at the mountain crest and that no evaporation takes place over the downwind slopes. A third problem is that in many foehn cases the kinetic energy of the low level flow upstream of the mountain is not sufficient to overcome the barrier of the mountain. In such cases the nondimensional mountain height (Nh/U where N is the Brunt-Väisälä frequency, h is mountain height and U is upstream wind speed) is greater than ~1 and the upstream low-level flow is blocked. An overview of some early textbook explanations of the heat source of the foehn is given by Seibert (2004).

2. DATA

In this study, surface data from 1993-2004 is collected from four weather stations in Iceland (Fig.1). The temperature difference between the stations AK and HJ at 1800 UTC is compared to different flow factors which are determined by the upper air observations at Keflavíkurflugvöllur at 12 UTC. The precipitation observations are based on a 9 hrs period (9-18 UTC). For days to be included into the database, the wind direction at 925 hPa must be between 200 and 230 degrees and the wind speed must be at least 12 m/s. This gives a total of 166 cases.

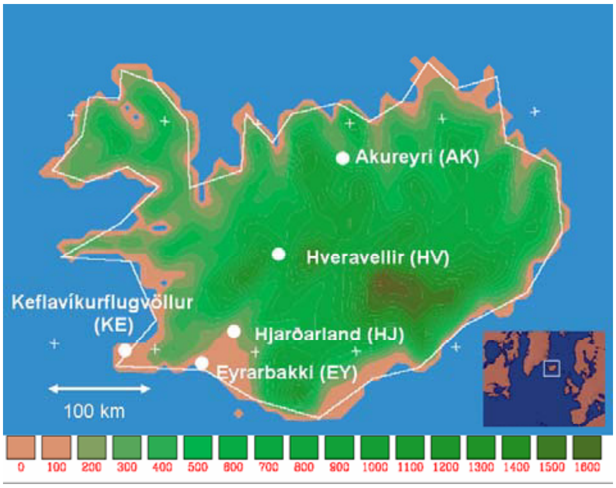

Figure 1. Location of the weather stations used in the study. The height of the terrain (m) is smoothed to a 9 km grid and shown by shading. KE, EY, HJ and AK are close to sea level, while HV is located at 640 m.a.s.l.

3. RESULTS

If the release of latent heat is important for the heat of the foehn in N-Iceland, one would expect a positive correlation between the temperature difference between AK and HJ on the one hand and the average precipitation rate on the upstream side on the other hand. Figure 2 shows no such correlation and most the cases with greatest difference between the temperature downstream and upstream do in fact have very little precipitation upstream and in the mountains. Correcting for variations in the amount of airmass receiving the latent heating (rate of advection) does only give a slight inverse correlation between precipitation and downstream heating (not shown). One way to shed some light on the impact of shortwave radiation on the aforementioned temperature difference is to investigate its seasonal cycle. Figure 3 shows that during the period May-August, the mean temperature difference is 5-6°C, while in the other seasons the mean difference is only about 2°C. Here, it should be mentioned that the mean static stability during this period is not very different from what it is in the cases during the rest of the year (not shown). The impact of solar heating is quite obvious in the foehn cases during the sunniest months (May-August) and in the remaining figures we only investigate the data during the autumn and winter (October-March). As mentioned before, the nondimensional mountain height (Nh/U) is a key indicator of a blocking of the low-level upstream flow. At high values of Nh/U, the flow can be expected to be blocked and the airmasses at the surface in the lee must therefore originate from upper levels. Figure 4 shows a weak, but slightly positive correlation between the upstream-downstream temperature difference and the Nh/U. Figures 5 and 6 show that this positive correlation can be attributed to the stability (N) alone. In fact, there is a slight positive correlation between the downstream-upstream temperature difference and the upstream wind speed (U) and the best indicator of the upstream-downstream temperature difference found here is N*U, giving a R^2 of 0,064 (not shown).

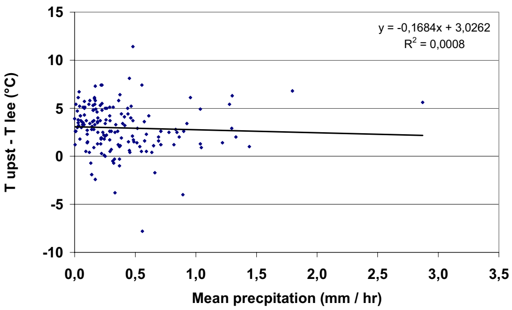

Figure 2. Temperature difference between the lee and upslope (T_{AK}- T_{HJ}) as a function of mean precipitation intensity at EY, HJ and HV

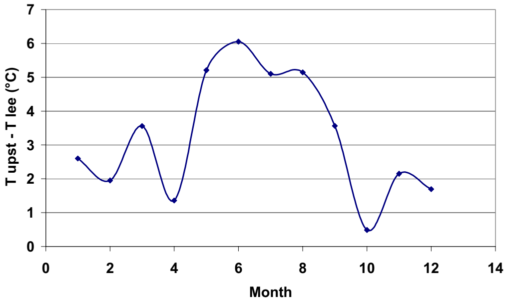

Figure 3. Mean monthly temperature difference between AK and HJ in the dataset

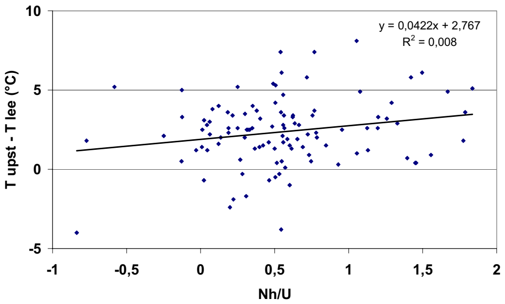

Figure 4. Temperature difference between the lee and upslope (T_{AK}- T_{HJ}) as a function of Nh/U in October-March. N is the Brunt-Väisälä frequency between the surface and 925 hPa, U is the wind speed at 925 hPa and h is mountain height which is set to 800 m

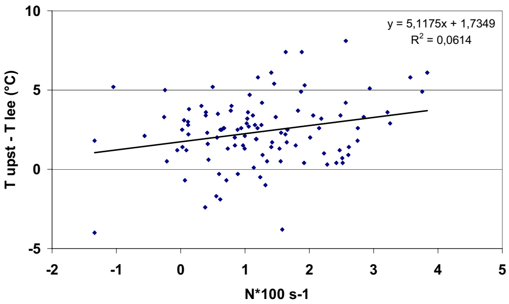

Figure 5. Temperature difference between the lee and upslope (T_{AK}- T_{HJ}) as a function of the Brunt-Väisälä frequency (N*100 s^{-1}) in October-March. N is calculated between the surface and 925 hPa

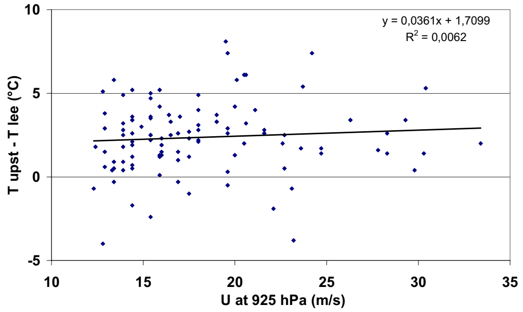

Figure 6. Temperature difference between the lee and upslope (T_{AK}- T_{HJ}) as a function of the wind speed (U) at 925 hPa in October-March.

3. DISCUSSION AND CONCLUSIONS

There is indeed a large spread in the data presented in this paper. A substantial part of the spread is presumably related to the upstream and upper air observations not being fully representative (in time and space) for the airmass leading to the surface conditions at AK. However, some indications of the source of the heat in the foehn in N-Iceland can indeed be seen. Figure 2 indicates strongly that the release of latent heat is quite irrelevant for the downstream heating. In fact, heavy precipitation is favoured at high N (not shown) and if that effect is corrected for, the result would be an inverse correlation between precipitation and downstream heating. As expected, there is a positive correlation between Nh/U and N on one hand and the downstream heating. The cases with greatest downstream warming are mainly clustered at high Nh/U and high N, indicating that the origin of the downslope surface airmasses is at higher levels in these cases. The lack of correlation between the downslope heating and the wind speed calls for an explanation. Here, there are presumably two different processes at stake. At low wind speeds, the low level cold flow tends to be blocked, giving room for potentially warm air to descend to the downstream surface. At high wind speeds there is more vertical mixing and less probability of low level inversions on the downstream side. In other words: at low wind speeds, the warm air is brought down in the lee as a result of a blocking upstream, while at high wind speeds, vertical mixing over rough surface is producing a similar effect. The seasonal cycle of the downstream-upstream temperature difference indicates great importance of solar heating. This may however not be quite so simple, since only little heating at the surface may lead to strong heating of the low-level air through increased vertical mixing, if the airmass is very stable in the first place.

The data that has been used for this study indicates that in the summer, solar radiation is of substantial importance in keeping up higher temperatures downstream than upstream of Iceland. In the winter, high static stability of the low level airmass contributes to warmer air in the lee. Precipitation observations do not indicate that the release of latent heat is of any importance for heating of the downstream surface airmasses. There is only little and inverse correlation between the low level wind speed and the temperature difference between the downstream and the upstream temperatures. The results of this study should encourage authors of meteorological textbooks to lay less weight on latent heating as an explanation of the heat of the foehn and more weight on potentially warm air from upper levels being brought down to the surface, either by mountain-scale divergence in the lee (associated with an upstream blocking) or by vertical mixing in strong winds over rough terrain. Heating through solar radiation in the cloud-free lee should also not be neglected.

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