Diurnal, seasonal, and geographical variability of air temperature limits of snow and rain

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ABSTRACT

The critical temperature, Tcrit, is defined as the air temperature at which the likelihood of snow equals the likelihood of rain. Data from 47 synoptic weather stations in Iceland reveal Tcrit to be between 0.5°C to 2.1°C. The lowest values of Tcrit are in the central highlands, and the highest value is at the northwest coast of Iceland. Tcrit is in general higher during daytime than in the night, and it is also higher in the spring and early fall than in the middle of the winter.

1. Introduction

Although of significant practical use, there is rather limited literature on the connection between the temperature close to the ground and the phase of precipitation. Decades ago studies of this kind entered the meteorological literature, whereas now this kind of investigations are perhaps more likely to end up in internal reports for domestic use. In two of these old studies, Lamb (1955) and Murray (1952) investigated the connection between the limits between rain and snow and the 1000-500 hPa and 1000-700 hPa thicknesses. These studies aimed at providing rules for weather forecasting which was in these years heavily based on thickness charts. As numerical prediction has become more sophisticated and automatic temperature measurements are available from a dense network of stations it is more practical to link the precipitation phase to the 2 m temperature than to thickness values that represent the mean temperature in a thick layer of airmass that may reach far above freezing level.

In this study, thirty years of data (1970-1999) from 47 synoptic weather stations in Iceland is analyzed in order to establish a link between the temperature at two meters height and the phase of precipitation. First, a critical temperature, Tcrit, is defined at which the frequency of snow is equal to the frequency of rain. In the following, the diurnal, seasonal and spatial variations of Tcrit are explored and explained. Finally, the applications of Tcrit are discussed and an example of snow-pack simulations with different values of Tcrit is presented.

2. Definition of the critical temperature Tcrit

Observed phase of precipitation at temperatures in the range from 0°C to 3°C in Reykjavík (WMO no. 04030) is shown filtered in Fig. 1. Not unexpectedly, snow is the dominating precipitation phase at temperatures below 0.5°C, while for temperatures above 2.5°C precipitation is in most cases in the form of rain. At 1.45°C the snow curve crosses the rain curve and we shall refer to this point as the critical temperature for the phase of precipitation, Tcrit. At this point sleet is the most common form of precipitation, being almost as frequent as the sum of observations of snow and rain.

3. Diurnal and seasonal variations of Tcrit

Figures 2 and 3 show the diurnal and seasonal variations of Tcrit at the coastal station Reykjavík and at the inland station Hveravellir (Fig.4). The diurnal cycle reflects the impact of solar radiation on the stability of the lowest part of the atmosphere, giving highest Tcrit in the unstable afternoon airmass, while the nocturnal stability results in a lower Tcrit. The amplitude is about 0.5°C for both stations, suggesting little difference between coastal and inland areas.

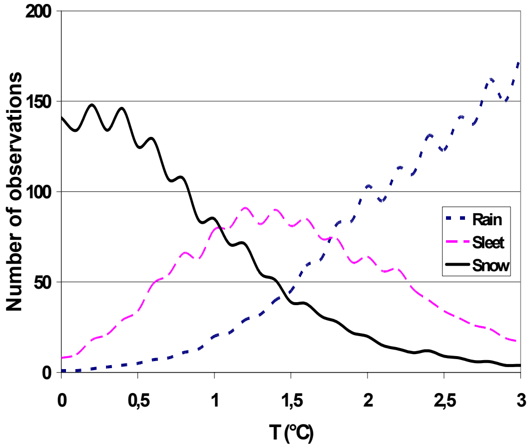

Figure 1. Number of observations of rain, sleet and snow 1970-1999 in Reykjavík, at the southwest coast of Iceland.

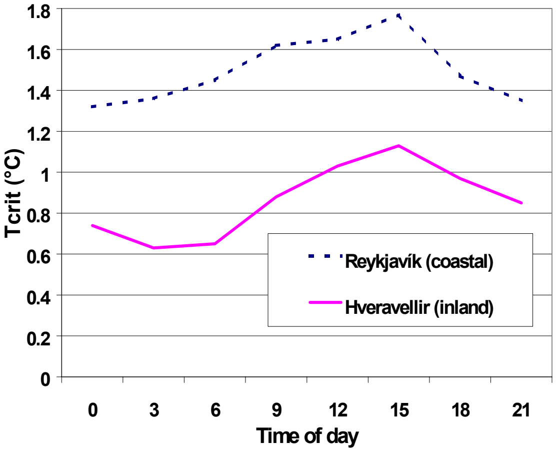

Figure 2. Diurnal variation of Tcrit in Reykjavík and Hveravellir 1970-1999.

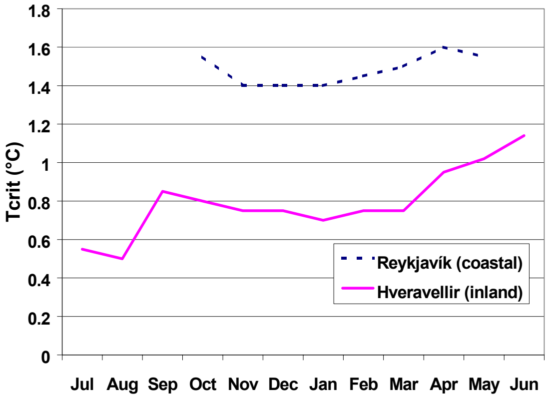

Figure 3. Seasonal variation of Tcrit in Reykjavík and Hveravellir 1970-1999.

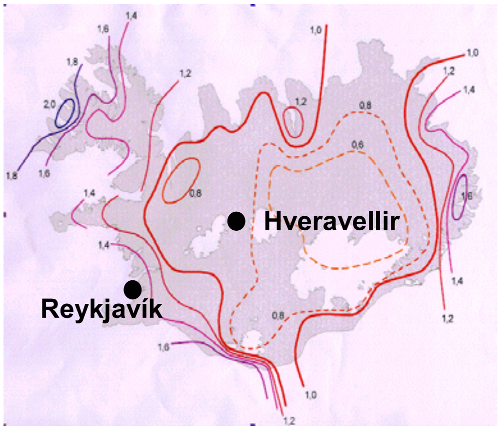

Figure 4. Average Tcrit in Iceland based on observations at 9 UTC and 18 UTC 1970-1999.

The seasonal variations are also significant (Fig. 3), giving in Reykjavík lowest values from November to January, while in April Tcrit is about 0.2 °C higher. Similar pattern can be found in Hveravellir, apart from extremely low values in July and August. High Tcrit in the early autumn and late in the spring relate to high sea surface temperatures and strong relative impact of solar radiation. Both these factors contribute to destabilizing the low level airmass and thereby increasing the average Tcrit. July and August in Hveravellir do however not follow this pattern. Both these months have extremely low Tcrit. This can be explained by the fact that snow in July and August is rare, and snowfall occurs almost exclusively at nighttime in stable airmass.

4. Geographical variation of Tcrit

The data reveals substantial and surprising geographical variation in the value of Tcrit (Fig. 4). The southwest and west coast together with the easternmost parts of the island figure the highest values, ranging from about 1.4°C to about 2.1°C, while in the north, in the southeast and in inland areas, Tcrit is in most cases well below 1.2°C. The lowest values are found in the central northern highlands and in the lowlands in the west part of North Iceland. A general large-scale feature is that Tcrit in coastal areas is higher than in inland areas. The only stations that are situated well above sea level are also far away from the coast, and consequently it is difficult to draw conclusions on the impact of altitude alone on Tcrit. On a smaller scale, local maxima appear in the fjords in the northwest, in the north and in the east. The difference between the highest and lowest values of Tcrit is more than 1.5°C, which is indeed a significant difference.

The explanation of the large geographical variations in Tcrit must lie in variations of stability of the lowest part of the atmosphere when precipitation occurs, but how can this stability vary to such a great extent? As previously mentioned, heating or cooling by sensible heat flux at the surface is the dominating factor in determining the low-level stability. The surface may be solid ground heated by solar radiation or warm sea surface. Although a diurnal cycle is detected in Fig. 2, heating by contact with the sea surface may be expected to be of greatest importance for two reasons. Firstly, precipitation at 0-3°C is most common in wintertime and under cloudy conditions, of which neither is favourable for solar radiation. Secondly, precipitation in general occurs in moderate or strong winds that are predominantly from the ocean. If the sea surface temperature (SST) is warmer than the air, heat flux from the surface contributes to destabilize the airmass. As we are mainly considering precipitation in the temperature range 0.5-2°C, warmer SST will contribute to a destabilization of the airmass and higher Tcrit. The geographical variations may also be explained by different frequency of convective vs. stratiform precipitation. Snow in Southwest- and West-Iceland falls typically in convectively unstable airmass, whereas in other parts of the country convective precipitation at temperatures around 1°C may not be as frequent.

At the north- and northeast coast of Iceland the SST is often close to the Tcrit while at the south- and west coast the SST is often several degrees higher. If the air temperature is 1-3°C, the sea contributes to destabilize the airmass at the southeast, south- and at the west coast, while at the north- and the northeast coast this effect is much less, if any at all. This explains however not the low values observed in Southeast-Iceland. A plausible explanation for this is orographic blocking of cold surface air. That corresponds to frequent occurrence of wet snow icing in the area (Ólafsson et al., 2002).

5. Applications of Tcrit

A primary application of the results of this study lies in the guidance it gives for forecasting. Statistical processing of numerical weather prediction model output – or even direct model output provide reasonably accurate forecasts of the 2 m temperature and it is therefore practical to use this parameter as a first indicator of whether the precipitation will fall as snow or rain.

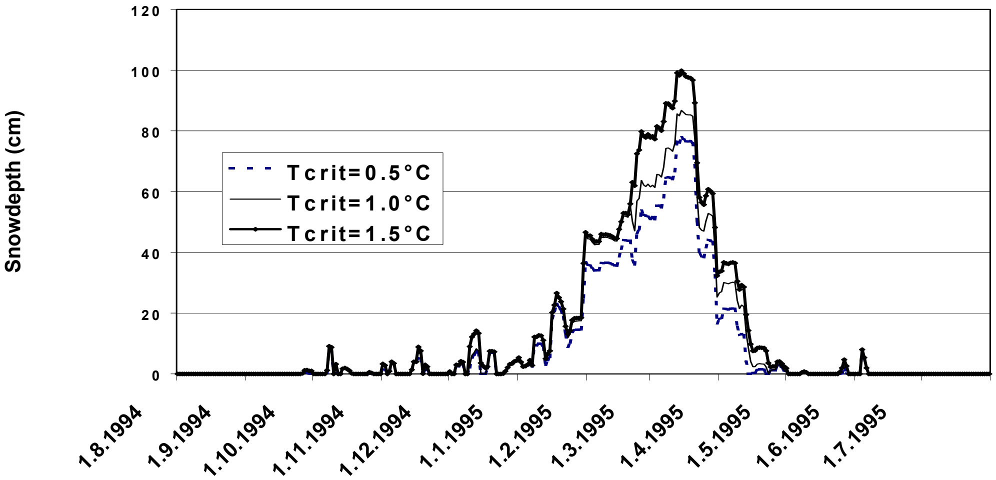

Figure 5. Simulated snowdepth at Sauðanesviti, North-Iceland with different values of Tcrit.

Simulations of snow cover can be very sensitive to the value of the critical temperature. Figure 5 shows such a test carried out for Sauðanesviti at the north coast of Iceland with the SAFRAN-Crocus simulation system (Haraldsdóttir et al., 2001). By increasing Tcrit from 0.5°C to 1.5°C, the maximum simulated snowdepth increases about 30%. Tcrit is also a parameter in hydrological models that simulate the water budget on the ground and the runoff. Finally, the distribution of Tcrit may turn out to be useful for cross-validation of historical weather data where both temperature and type of precipitation have been observed.

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