Insulating effect of the winter snowpack on Storglaciären, northern Sweden

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Abstract
Records of winter temperatures were obtained from thermistors installed at different depths within the snowpack of Storglaciären, northern Sweden. This data is used to examine the insulating effect of the snowcover on the penetration of air temperature variations into the snowpack. Time series of thermistor temperatures clearly show this insulating effect, and its variation with depth in the snowpack. Thermistor data such as this has important applications within glaciology, and these are briefly discussed.

Introduction

Thermistors installed at different depths within the snowpack of Storglaciären (a valley glacier in Tarfala valley, northern Sweden) provide a continuous record of snowpack temperature during winter 2002-2003. This data was retrieved during the GlacioEuroLab5 practical study course based at Tarfala Research Station and has been used, along with temperature, stratigraphy and density observations in snow pits, to investigate various properties of the winter snowpack. In this paper, the thermistor records are used to investigate the insulating properties of snow and the resulting temperature patterns found at different depths in the snowpack. Consideration will also be given to the wider applications of such data within glaciology and related sciences.

Background

The winter snowpack acts as an insulator, dampening temperature variations and heat loss at depth within the snowpack and in the ice beneath. While the temperature of the air above may fluctuate widely between extreme cold and warmer daytime temperatures, the influence of these variations on temperatures within the snowpack will decrease with increasing depth beneath the snow surface. Once a sufficient depth of snow builds up, temperatures at the base of the snowpack will acquire a stability which isolates them from the influence of the air temperature above. This insulating effect can be clearly seen in time series of thermistor temperatures, as initially widely varying temperature values (when sensors remain above the snowcover or only thinly covered) give way to smoothed and then unvarying values (as the sensors become snow-covered and buried to greater depth). These temperature series can therefore provide much interesting information about the insulating effect of the snowpack.

Methods

The thermistors (maintained by R. Hock and other researchers from Stockholm University) had been in place prior to the onset of winter snowfall and allowed to snow-in gradually as snow depths increased. The thermistor set-up consisted of a metal stake drilled vertically into the ice surface with five thermistors attached to the ends of 20cm-long poles fixed parallel to the ice surface. This set-up was intended to avoid the unrepresentative temperature values which would be caused by the channelling of percolating melt or rain water along the stake if the thermistors were attached directly to it. Thermistors were located near to the ice surface and at heights of 45, 82, 132, and 179cm above the ice surface.

Temperature measurements were taken by the thermistors every two minutes and hourly averages stored on a Campbell data logger. Data for September onwards was downloaded at the end of March and is considered here.

Thermistor records such as this yield important information about the temperature of the snowpack and can be used to investigate various properties of the winter snowcover. As the height of the thermistors above the base of the snowpack is approximately known, the change in the form of the temperature series can be used to identify the depth of the snowpack at different times, and therefore to reconstruct the snowfall history of the winter, despite no first-hand observations having taken place. Here, thermistor data is used primarily to consider the insulating properties of the snowpack.

Results

The time series of thermistor temperature (Figure 1a-e) clearly show the change between widely varying temperature values, when the sensors are exposed to air temperatures, and progressively smoothed variations, as the insulating influence of the snowcover takes effect, and that this change takes place progressively later in the winter with height above the ice surface, as the snow depth increases and covers more thermistors. These time series can be examined in closer detail to gain more information about the insulating effect of the snowcover.

Analysis

The date at which each thermistor was snowed-in can be derived subjectively from the time series by identifying the start of the smoothing trend at each height. The start of the smoothing trend is taken, and not the point at which the series becomes stable, because the sensors will continue to be affected by temperature variations, although dampened, while the snowcover above them is thin. From this, the following snow-in dates are suggested:

Ice surface	27th October
45cm	21st January
82cm	13th March
132cm	25th March
179cm	30th March (by field observation)

In this respect, winter 2002-2003 seems to have been an unusual one for the Tarfala valley, with the majority of snowfall occurring very late in the winter.

By linear interpolation between these snow-in dates, a graph showing continuous snow depth can be constructed (Figure 2). Again, this shows that the vast majority of accumulation took place very late in the winter. As snow accumulation certainly does not take place in a linear fashion, rather in discrete and irregular episodes, this graph is a considerable abstraction of reality, but is interesting nonetheless. Such a graph could be more confidently created if the thermistors were more closely spaced – as it is they were separated by up to 50cm, allowing for great variations in accumulation rate between snow-in dates. However, the graph provides some useful information regarding snow depth, to be used when considering the snowpack's insulating effect.

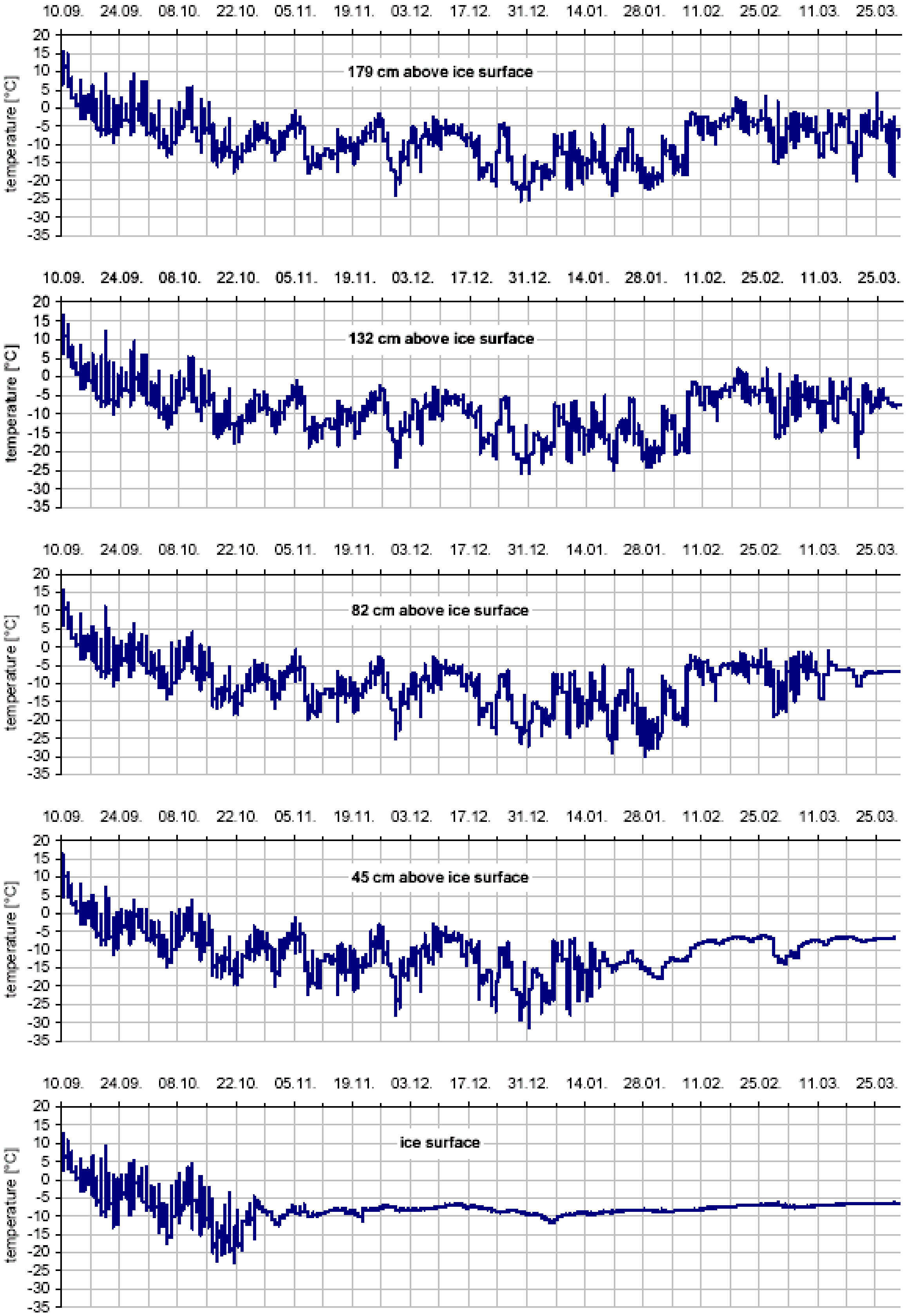


Figure 1a-e: Time series of thermistor temperatures at different depths in the snowpack between September 2002 and March 2003

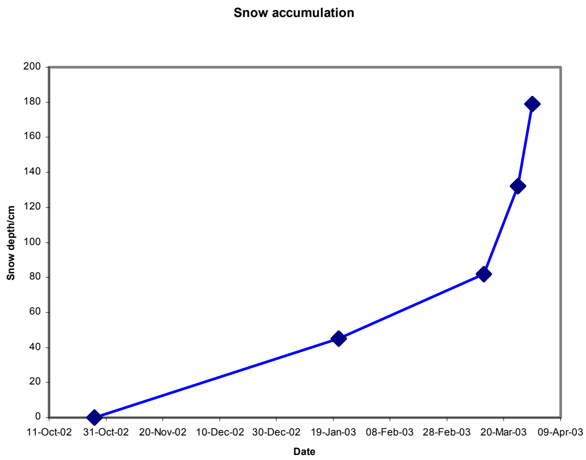


Figure 2: Cumulative snow depth at study site, winter 2003-2003

The insulating effect of the snowpack - March

A subset of this data series can be examined in order to view in more detail the variation of temperature with depth in the snowpack. The month of March (Figure 3) is a particularly interesting period as most snow fell during this time, resulting in the progressive burial of the sensors at 82, 132 and 179cm above the ice surface.

At the beginning of March, the temperature series for the sensor closest to the ice surface has already been significantly dampened by the snowpack above it, and becomes even more steady towards the end of the month. The sensor at 45cm has also been significantly affected and exhibits generally smooth variations, with reduced temperature peaks and longer amplitude variations compared to that at 179cm, which can be taken as air temperature. The time series for the sensor at 82cm follows that of the air temperature at the beginning of the month, but around the 13th of March suddenly smooths, corresponding with the snow-in date derived previously. Only a major temperature event, such as that around the twentieth of March, causes it to significantly respond, and that response lags some time behind the air temperature minimum which triggers it.

The insulating effect of the snowpack – 23rd-29th March

In order to more closely examine the temperature variations at different levels in the snowpack, data from the week immediately preceding the GlacioEuroLab course has been considered. The temperature series for this period are shown in Figure 4.

The data from the thermistor at 179cm above the ice surface is assumed to closely reflect the air temperature throughout this period, as this sensor was observed to be around 4cm above the snow surface on March 30th. This data therefore provides a useful reference air temperature against which to consider the dampened temperature measurements from within the snowpack.

From this graph, it is clear that the sensor at 132cm is already snow-covered, as its temperature series differs from that of the sensor at 179cm. The previously suggested date is therefore slightly incorrect, and this more detailed graph more useful for deriving snow-in dates. In comparison to the air temperature, the sensor at 132cm above the ice surface, in general, shows the same fluctuations in temperature, but of a lower amplitude and more rounded form, due to the insulating effect of the snow above moderating the penetration of air temperatures into the snowpack. Towards the end of the week, the variations in temperature bcome increasingly dampened, as an increasing depth of snow builds up above the sensor.

Throughout this period, during which air temperatures have clearly varied greatly, there nevertheless remains practically no variation in temperature at 82, 45, and 0cm

Figure 3: Time series of thermistor temperatures at different depths in the snowpack during March

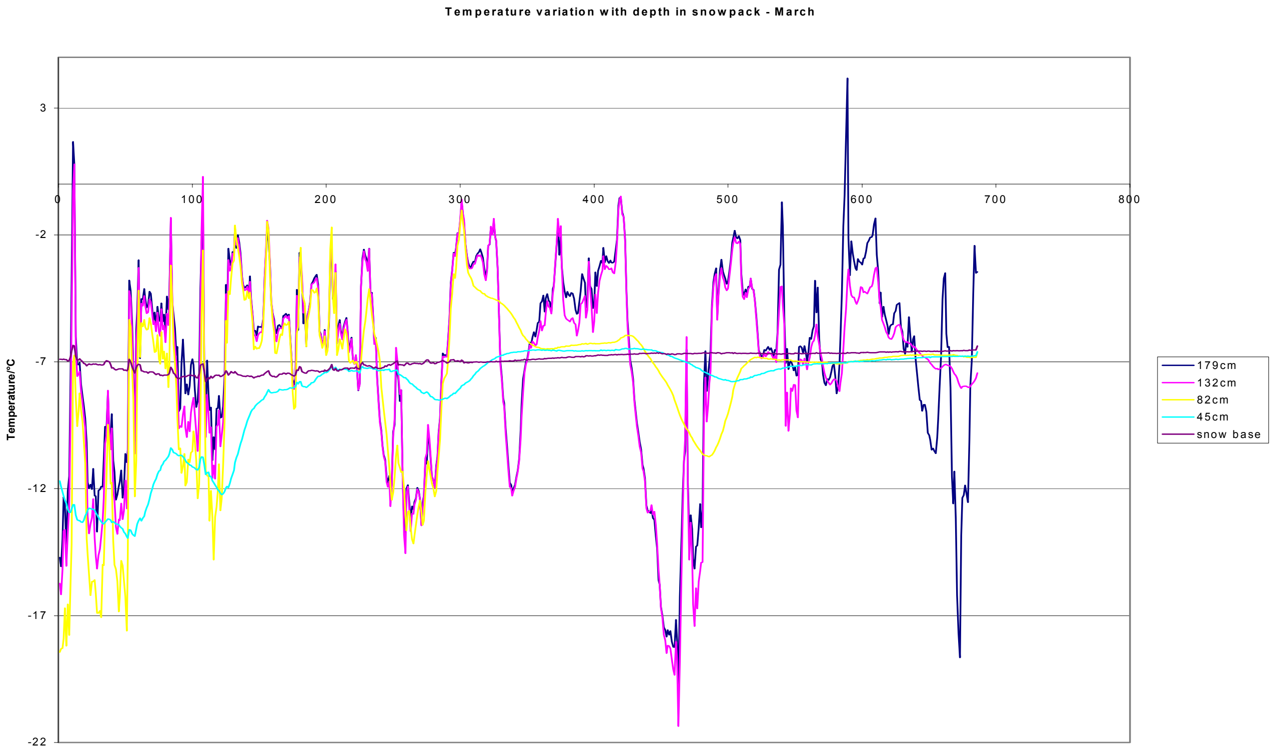
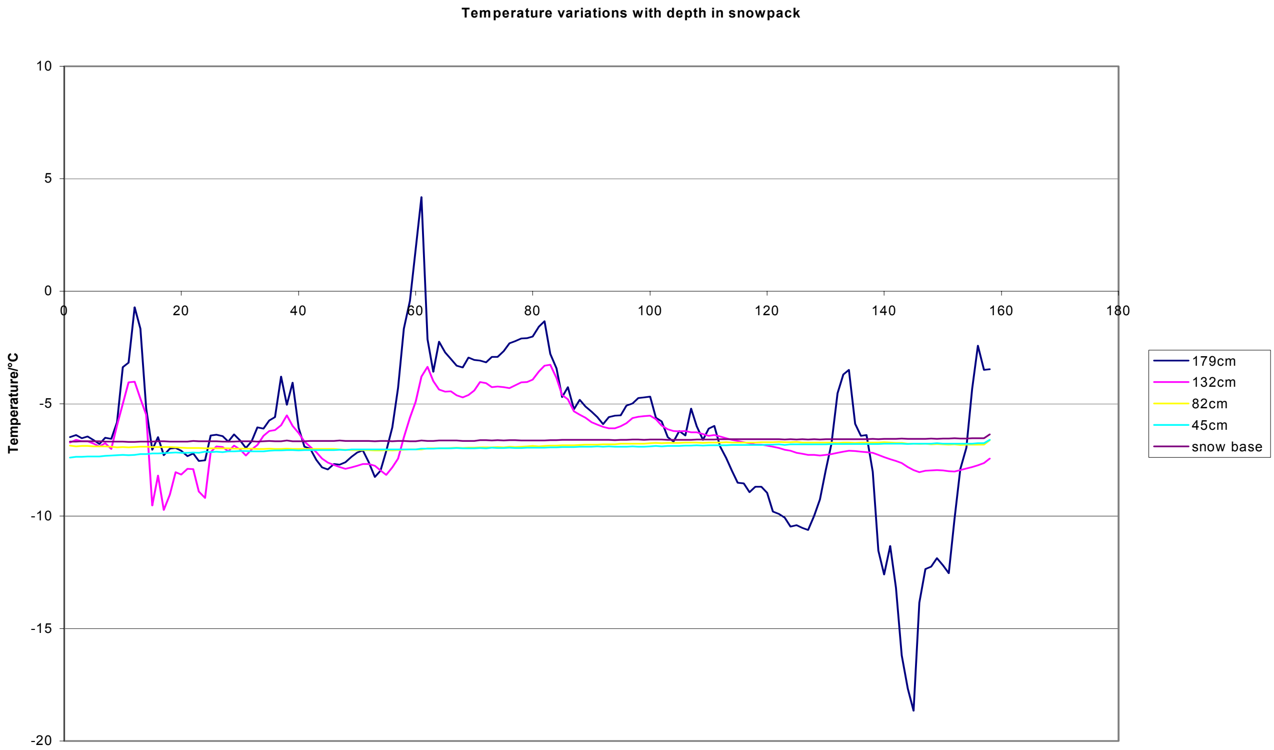


Figure 4: Time series of thermistor temperatures at different depths within the snowpack between March 23rd and 29th.



above the ice surface. This shows that temperature variations are almost completely blocked by a depth of less than 50cm of snow, perhaps considerably less. This could be more reliably identified if temperature measurements were more closely spaced in the vertical dimension.

By the 27th of March, the sensor at 132cm above the ice surface has almost ceased to reflect the variations in the air temperature above, showing that a sufficient depth of snow has accumulated above it to insulate it from temperature fluctuations, at least those on a timescale of 1-10 hours. The exact value of this depth, we can only estimate from Figure 1, as no snow depth data are currently available at a higher resolution (although data from an ultrasonic depth gauge operating nearby throughout the winter should provide useful information to indicate the more exact distribution of snowfall between the snow-in dates used here). Figure 2 suggests that this depth may have been only around 20cm. This estimate is grossly simplified due to the linear interpolation used to construct Figure 2, but provides an interesting indication of the insulating effect of only a few 10s of cms of snow. By considering the last section of the graph it is interesting to note that an air temperature variation of over 15°C is smoothed to one of less than 1°C by only a few 10s of centimetres of snow.

Applications

While thermistor data have been used here primarily to consider the insulating effect of the snowcover, they have many other applications within glaciology and related sciences. Although the data considered here cover only winter months, and therefore do not reflect the change from a cold winter to an isothermal summer snowpack, one important issue which can be addressed using data from thermistors such as these is the movement of water through a melting snowpack. With increasing recognition of the importance of the snowpack in moderating meltwater entry to the subglacial drainage system, and its potential role, therefore, in influencing glacier dynamics, the use of thermistor data in investigating snowpack hydrology may become increasingly valuable.

Acknowledgements

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