Temporal and spatial variations of the snow stratigraphy beside the Tarfala Research Station, Sweden

Marcel Nicolaus

The Tarfala Field Course 2001

The EU GlacioEuroLab No. 2 took place from April 1st 2001 to April 8th 2001 at the Tarfala Research Station, Sweden. This station is located in northern Sweden about 100 km western of Kiruna in Lapland at an altitude of about 1230 m. The area of investigations included the Storglaciären, one of the glaciers beneath mountain Kebnekaise (1982 m).

The major goal of the course was to introduce students with glaciological subjects to methods of field measurements. To this aims a variety of glaciological and climatic relevant parameters were exemplary recorded.

Snow pit studies

To investigate the material properties (e.g. temperature, density, layering, crystallisation) of snow and firn one of the most obvious and classical methods is do dig snow pits and inspect their stratification depending on their depth. This proceeding allows to describe as well spatial as chronological relations. If no mixing by wind or other kind of movement (horizontal flow, avalanches) occurs, the chronology is a function of depth, because new snow always accumulates on top of previous older layers. Snow pits are an extremely simple and cheap "tool" in glaciology but nevertheless they have to be used accurate and carefully.

Before digging the pit it has to be reflected which sides of the pit-box should later be probed, because these should not be stepped on or thrown with the removed material. If thin snow walls are planned they should stand perpendicular to the sun ray direction, because finally the sun should translucent it.

If the pit has reached the maximum depth a vertical smooth wall has to be prepared and a reference surface level has to be chosen. All following depth measurements are related to this zero level. One possibility to fix a reference level is to use the bottom of a ski, laying across the edge of the pit.

Further methods to investigate the vertical snow and firn layering are GPR- (ground penetrating radar) measurements or firn coring. The results of these studies are presented in other reports.

A completely different use of snow pits is to check out the avalanche risk at inclined locations. This is necessary for scientists to care for their own safety in snowy mountains. Therefore we searched for layers, which are tending to slide down if (surface) forces appear. This kind of pits might be explained in an other report, as well.

Methods

The first probing in each pit was to create a regular, vertical temperature profile with an about 20 cm long thermometer. Every 5 or 10 cm the probe was pushed horizontally into the snow and remains there for about 30 sec until the temperature reached a constant level.

For the measurement of snow density a defined volume of snow was separated and weighted. The density derives from the geometry and the weight in the post-processing. To get this defined volume of snow two alternative forms of containers were used: A square metered "Swedish box" (about 1000 ml) and a cylinder (about 500 ml), which was easier to handle. The results I am presenting below were mainly calculated from the use of the cylinder but (assuming precise probing) the geometry of the container should not effect the results itself.

To complement the interpretation of temperature and density profiles it is proposed to describe the visible stratigraphy. (Unfortunately we did not pay attention to this regularly.) There are some obvious differences of the "colour" (reflection of light) and the crystal size, which is related to the mentioned properties.

Thin, about 2 cm thick, snow walls are showing all the different layers, due to changing optical properties. They are created by continuing two pits towards each other until just a thin wall is dividing them. The most impressive results are visible by translucent light of the sun.

Field Measurements

During the field course several snow pits at different places were dug. I will present the results of four pits from the valley because they should show sufficiently comparable results. Further snow pits were sited on Storglaciären and on the slope down to the research station

The four pits can be grouped in two pairs of location and time. The first pits (N1 and F1, N: narrow to the mess, F: far from the mess) were measured on April 4th and the later ones (N2 and F2, 1: early, 2: late) after two days of heavy snow fall and strong winds on April 7th. The location of the narrow pits was about 100 m apart from the Tarfala Research Station while the far pits were about 200 m north of the station along the stakes line. Both sites are marked on the photo (fig. 1). The later pits were created close the prior locations, but we cared for not digging in the earlier affected area. These locations and times were chosen to better relate the results in space and time. If such measurements should be used for extensive studies (and not just as field course demonstration and practice) it is quite obvious that much more pits are needed to get clearer relations.

At the N2 - site a photo of the snow stratigraphy through a thin snow section were taken (see below: Results)

Results

Snow depth:

One of the most obvious and surprising results of the snow pits is that the total snow depth is not increased after the heavy snowfalls. All pits reached the bottom of the snow layer, the bedrock, so the maximum depth equals the total snow cover. Pits N1 and N2 show about 1.10 m snow, F1 and F2 have 1.40 m. This difference of 30 cm should be explained with local effects, mainly the varying bedrock topography. Further the locations are not exposed to huge wind caused accumulation or ablation as it was visible close to the huts. The pit areas are not effected by any above snow surface topography changes and especially not by the influence of the buildings (see other reports). But it is realistic to assume changes in the surface layering caused by the wind and the precipitation.

Temperature:

The results of the surface temperatures measurements are very different and certainly (partly) incorrect (fig. 2). We already thought about the large variations during the field course and concluded, that mistakes at the measurements itself were made. Nevertheless the measurements show that the uppermost 20 cm of the snow are dominated by weather conditions. Further downwards all profiles show the expected trend of getting warmer with depth. The bedrock is frozen at temperatures between - 4°C and -1.9°C.

The profiles of both sites approach to each other with increasing depth because of the decreasing influence of surface conditions. The deeper the snow is buried, the less it is affected by short time temperature variations (e.g. caused by the actual sun radiation) at the surface. Only the measurements at the F position are constantly approaching each other and end up at common - 1.9°C. At both sites the second measurements are predominating warmer than the first profiles.

Density:

The results of the density measurements (fig. 3) of both locations are much more similar than those of the temperature distribution. They represent a layering structure which is conserved over the three days between the probing. The reason is certainly, that densities are not affected (in the same way and amplitude) from surface conditions. Even the new snow did not just accumulate and compress the layers below. This should be explained with the (already above mentioned) additional strong wind. At the F pits the depth between - 1,0 m and -1,4 m gives a pronounced alternation between lighter (about 230 kg/m^3) and denser (about 320 kg/m^3) layers. Around -0,8 m both stations differ of about 150 kg/m^3. The N pits have an additional light layer while the far ones are still continuing the nearly linear increasing of density with depth. All profiles show such an increase from near surface values approximately at 100 kg/m^3 to 350 kg/m^3 below 60 cm. This attitude is the expected consequence of compression due to the pressure of the overlaying snow masses.

Layering:

In this paragraph I would like to take a closer look to the N2 profile. From this pit a photo of a thin section against the sun was taken. It reflects the density profile down to 70 cm. The photo just reaches down to 70 cm because the thin section ended there. The reason for this is, that a very hard (icy, conclusively dense) layer followed next, overlaying a light layer with huge snow crystals. It was probably, that continuing downwards might damage this thin snow wall.

The photo of the snow wall (fig. 4) shows a shiny layer in 0.25 m depth, which compares to the light layer (of 95.8 kg/m³) in the density function at the same depth. The darker part above this layer might be influences and regulated by wind stress the days before. The under laying part is the already described increase caused by snow induced pressure.

Further the photo shows vertical structures, which cross the chronological layers. They might be induced by melting or evaporating events. Those may appear at the surface if the sun is warming the snow. The uppermost structures are caused by the shuffle.

Uncertainties and deviations in all these density values are mainly based on the effectively measured volume of snow. Mainly in layers with loose, large crystals it is possible that not the whole volume of the probe cylinder was filled and so the weight is lower than the true value. Mistakes towards too high densities are probably rare.

Conclusions

Temperature depth functions are dominated by the influence of the bottom and surface temperature, which leads to increasing values with depth. Variations from this trend are related to changing weather conditions between the moment of snow accumulation and the measurement. The differences between the two profiles at the same station are decreasing with depth, but I expected a more obvious equality in the two pairs of temperature - depth functions.

The density is generally increasing downwards due to the overlaying snow masses. Local variations in the layering were even in details nearly constant over time (3 days) and characteristics have been preserved.

The comparison of field observations concerning changing densities and the brightness variations of the thin wall photo with measured served the same results. It is possible to use one of the methods to justify or calibrate one of the others.

The combination of all methods we used to analyse snow structures and deformations is certainly ideal to receive well founded results. Further it is necessary to describe as many observations as possible directly in the field. In this special case the knowledge of how the thin wall was made helped to explain layering shown on the photo.

More stations and / or repeated measurements with an unique proceeding are guaranteeing serious data and qualitatively higher results.

My personal Results

This field course was a great experience in teamwork with many different students having such different knowledge in various disciplines. I learned essential things beside the applied methods. Mainly the necessity of safety in mountains, the use of equipment and how important reliable team mates are for good results and safe working conditions.

Surely I applied some new methods and learned how to use them and interpret the results. I realised once again that it necessary to make a lot of (useless) mistakes yourself just avoid them the next time. This is the well known "learning by doing" - effect.

Even if it was not the intention of such a course I learned two "basic principles of glaciology":

"Red light is bad light, and green light is good light" and "snow depth depends on time and location".

Acknowledgements

Finally I would like to thank all participants of this course for a great time at Tarfala. I enjoyed to work and live with them for that week in the snow even if the weather was not that good. But it could have been even worth. Most of the data I presented above were measured by different members of this field course.

Thanks to the EU for financing such field courses and giving me a chance to participate for this week. I am convinced that we all learned a lot even if the real scientific data we collected could have been better.

Last but not least I am thanking John for teaching me a lot and for being very patient with our group during this time.

Figures

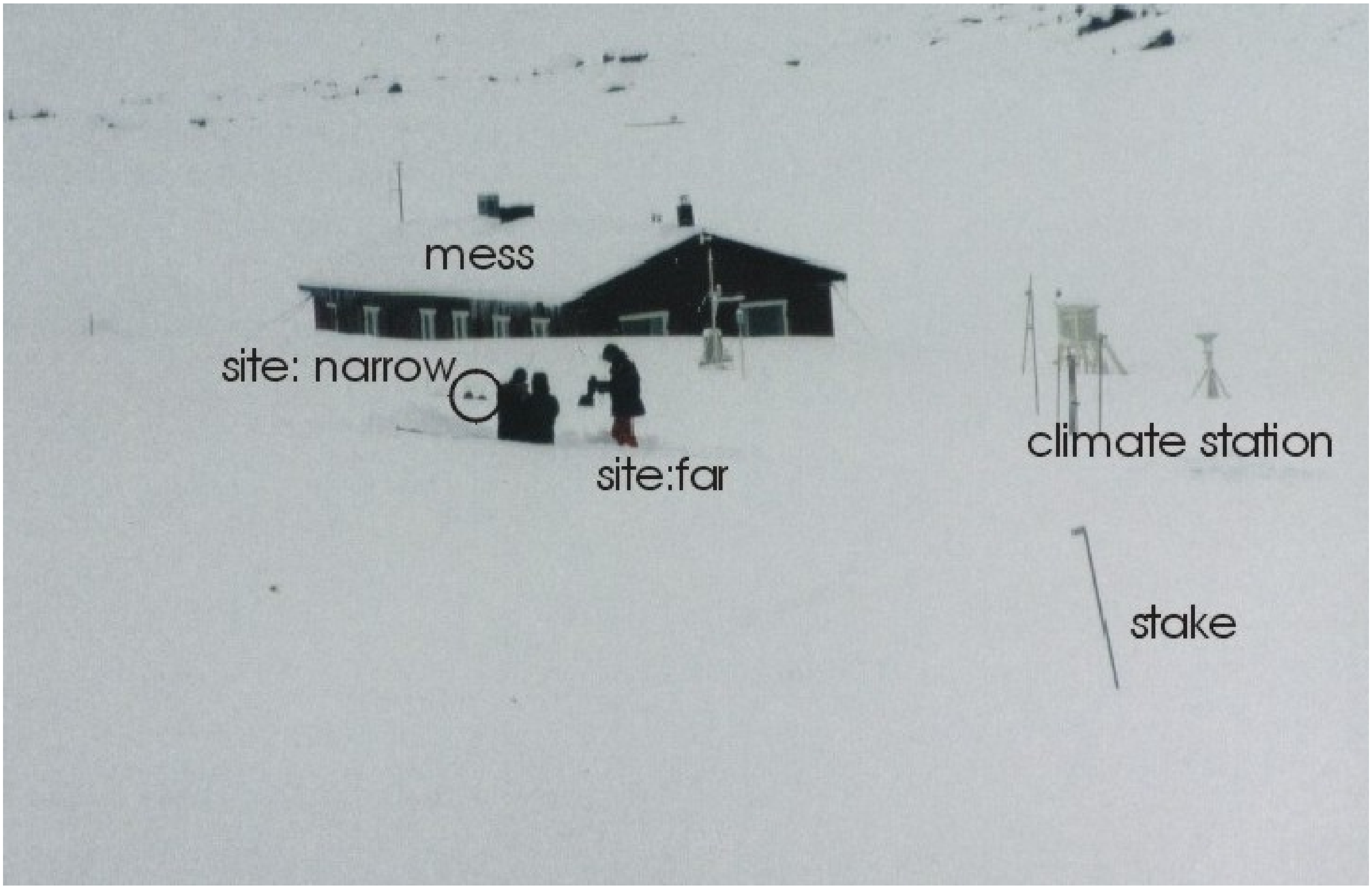
1: Photo with the two snow pit locations. At the F (far) station the three measuring persons are visible, at the N (narrow) site only the heads of two working group members are marked with the circle. The mess, the stakes line and the climate station are labelled for a better orientation.

2: Diagram of the four compared temperature profiles. The sites relate to those in fig. 1, the early data were recorded April 4th, the later ones April 7th.

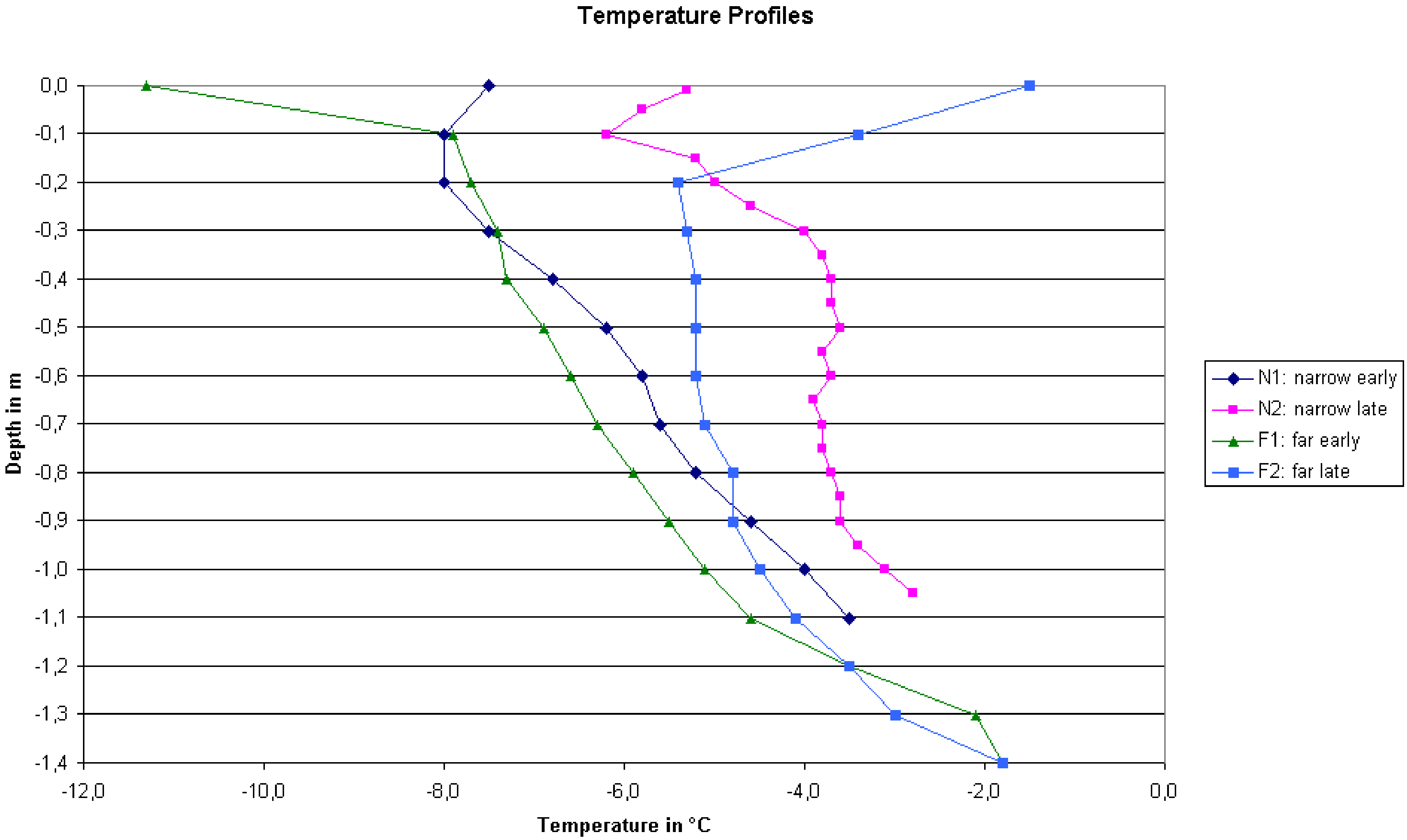
3: Diagram of the four compared density profiles. The sites relate to those in fig. 1, the early data were recorded April 4th, the later ones April 7th.

4: The photo shows the upper 70 cm of the thin snow wall at site N2. The most obvious layer is the light one at about 25 cm depth.

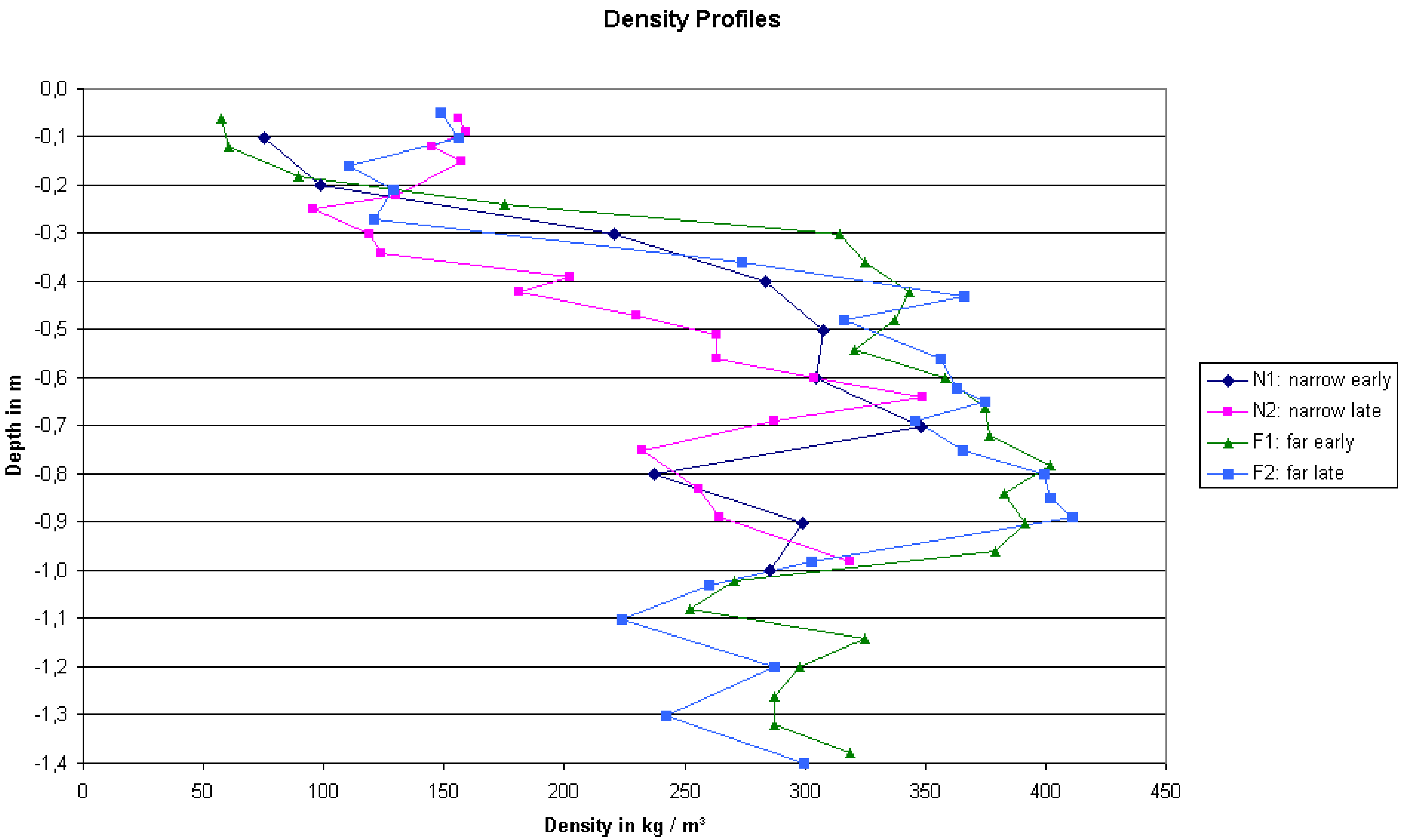
Temperature



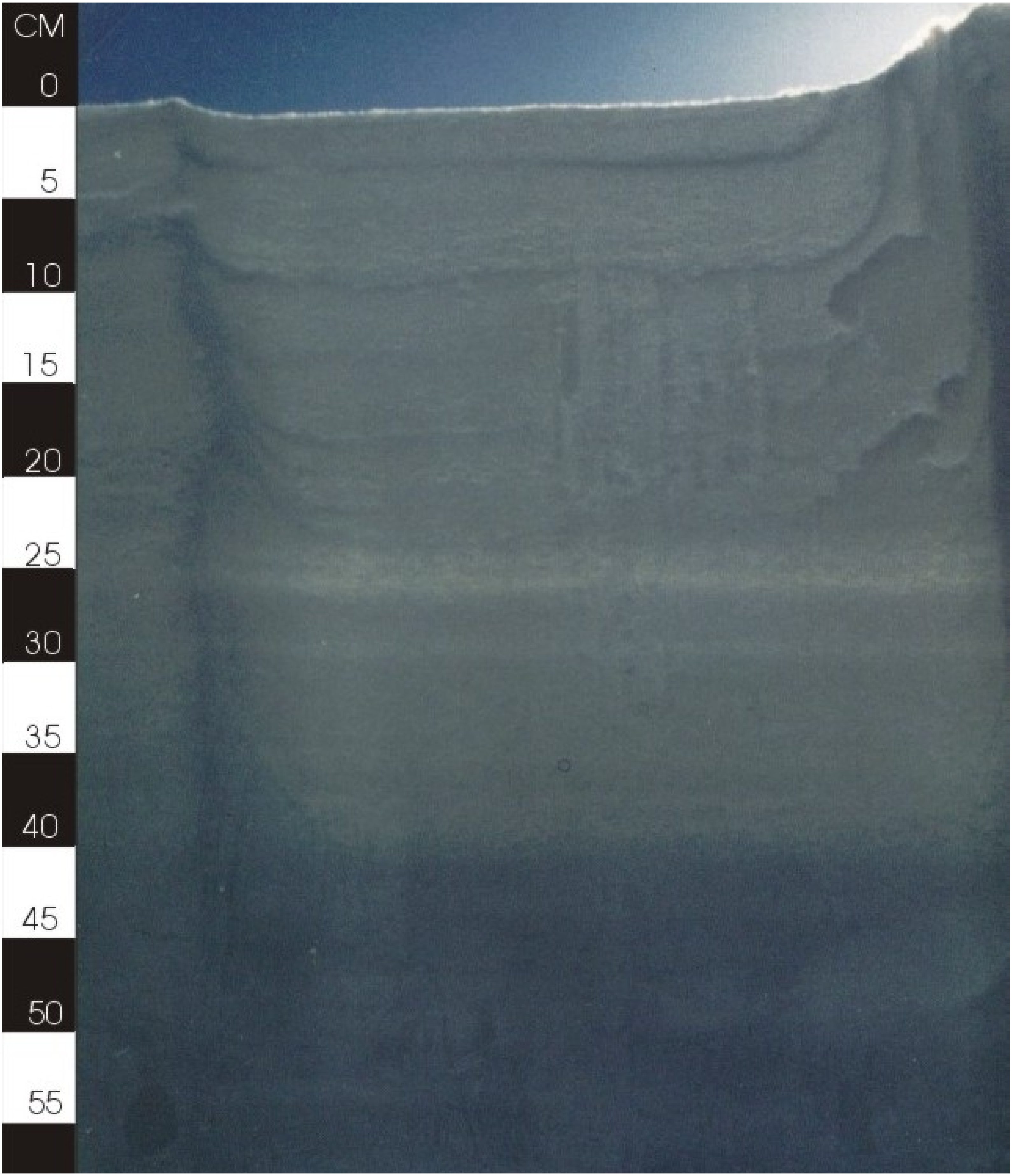
Temperature



Density


Density Profiles
Depth in m
Density in kg / m³
0,0
-0,1
-0,2
-0,3
-0,4
-0,5
-0,6
-0,7
-0,8
-0,9
-1,0
-1,1
-1,2
-1,3
-1,4
0
50
100
150
200
250
300
350
400
450
N1: narrow early
N2: narrow late
F1: far early
F2: far late

Temperature




60
65
70