# The Paleoclimatic Record from a 345 m long Ice Core from the Hans Tausen Iskappe

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*Abstract*

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The 345 m long ice core retrieved from the Hans Tausen Ice Cap in 1995 (82,5°N, 38°W) in Western Peary Land was sampled in situ for later paleoclimatic $\delta^{18}O$ measurements in Copenhagen.

The upper 125 m covers a little more than 1000 years and indicates strong persistent warming from the late 1920-ties, a maximum warming in the early 1960-ties and a variable climate with no particular trend since the 1960-ties. The δ record over the past 100 years shows similarities with the temperature records from the Greenland west coast stations, Iceland, and the Faroe Islands.

The 20th century is the warmest in the entire record, while the periode 1700-1900 A.D. is the coldest during the past 2000 years. A maximum of warm climate seems to be reached around 900-1100 A.D. which then declines to the colder conditions around 1700 A.D.

The climatic interpretation of the deepest 105 m of the δ record is more complicated due to the non-steady state of the ice cap: The implication for the paleoclimatic interpretation will be discussed. No glacial ice is present in the bottom ice.

*Keywords:* Climate; ice cores; North Greenland; Arctic; greenhouse effect; global changes.

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## Introduction

The Hans Tausen Ice Cap (82.5°N, 38°W) in western Peary Land is believed to be located in a region of high climate varialibility and its position on a 1000 m high rock plateau north of the present margin of the Greenland Ice Sheet makes it an evident object for paleoclimatic research. It is also the most northern ice cap in the Arctic, but little is known about its stability and history.

The nordic Hans Tausen project (1993-1997) investigated the ice cap and its surroundings in order to obtain paleoclimatic environmental data and to model the dynamic pattern of the ice cap. Part of the project was to drill through the ice cap to obtain an ice core to the bedrock at a suitable drill site. The drill site was chosen after an intensive survey over the years 1993-1994 (see Gundestrup *et al.* 2001). An overview of the Hans Tausen project is found in Hammer and Højmark (1998).

Below we will concentrate on the main features of the Hans Tausen $\delta^{18}O$ profile along the ice core in order to infer the paleoclimate as far back in time as the core allows.

The preliminary dating of the core (Clausen *et al.* 2001) and other information from the project indicated that the present ice cap is not older than 3500-4000 years, and that the region around the drill site is still growing 4 cm per year (Keller *et al.* 2001), i.e. the ice cap is not yet in a dynamically steady state.

## Material and Techniques

The core was sampled in situ for later $\delta^{18}O$ masspectrometric measurements in Copenhagen. Density- and ECM-measurements were also performed in situ; the latter profile has been used to establish a chronology for the past 2000 years by using volcanic reference horizons (Clausen *et al.* 2001; M. Stampe, 1997). The δ sampling was made in the following way:

- From 0-345 m depth each 0.55 m.
- From 0-22 m depth each 0.025 m.
- At various selected depth ranges each 0.025 m in order to investigate the diffusive aspects of the δ profile.

Also a second drilled shallow core down to 35 m and a 2 m pit were sampled for $\delta^{18}O$ in order to estimate the influence of glaciological noise on the δ record and to secure a correct sampling of the upper low density part of the firn surface.

## Results

The over all δ profile (0.55 m samples) is shown in Fig. 1. The profile exhibits a number of characteristic features, which can be clearly seen in the figure.

From 345-280 m the δ values are nearly 2‰ lower than the average value over 260 m to the surface. From 260 to around 100 m the values vary around –27‰ but between 60-20 m the δ values are almost 1‰ lower. The upper 10 m represent the highest δ values in the entire record.

Before interpreting the record in terms of past climate changes it is, however, nescessary to invoke other information from the Hans Tausen project.

In Fig. 2 a smoothed version of Fig. 1 is presented along with the timescale established by Clausen *et al.* (2001). This timescale is presently only established back to 244 BC even though we know that the bottom ice is approximately 4 kyrs old. As can be seen from the dates there is nearly no decrease of the annual layer thickness with depth, which indicates that the central dome area must have experienced very low strain rates over a substantial part of the ice caps existence.

Apparently the dome area is presently in a transitionary state approaching steady state as indicated by the findings of Keller *et al*. (2001). The annual accumulation over the past 200 years is 10.8 cm of ice equiv./yr, not much different from the annual layer thickness around 2000 BP.

If the growth rate of the dome area had been equal to the annual accumulation over the past 2000 years, the ice cap would have added some 200 m to its thickness. This estimate is of course too high, because the dome area presently only grows 4 cm/yr. Let us instead assume that the ice cap has grown some 100 m over the past 2000 years (the exact figure is not important in the following). Then the most likely effect on the δ values should be a decrease of the order of some 0.7‰ i.e. if the δ profile in Fig. 2 were to be corrected for elevation changes it would enhance the difference

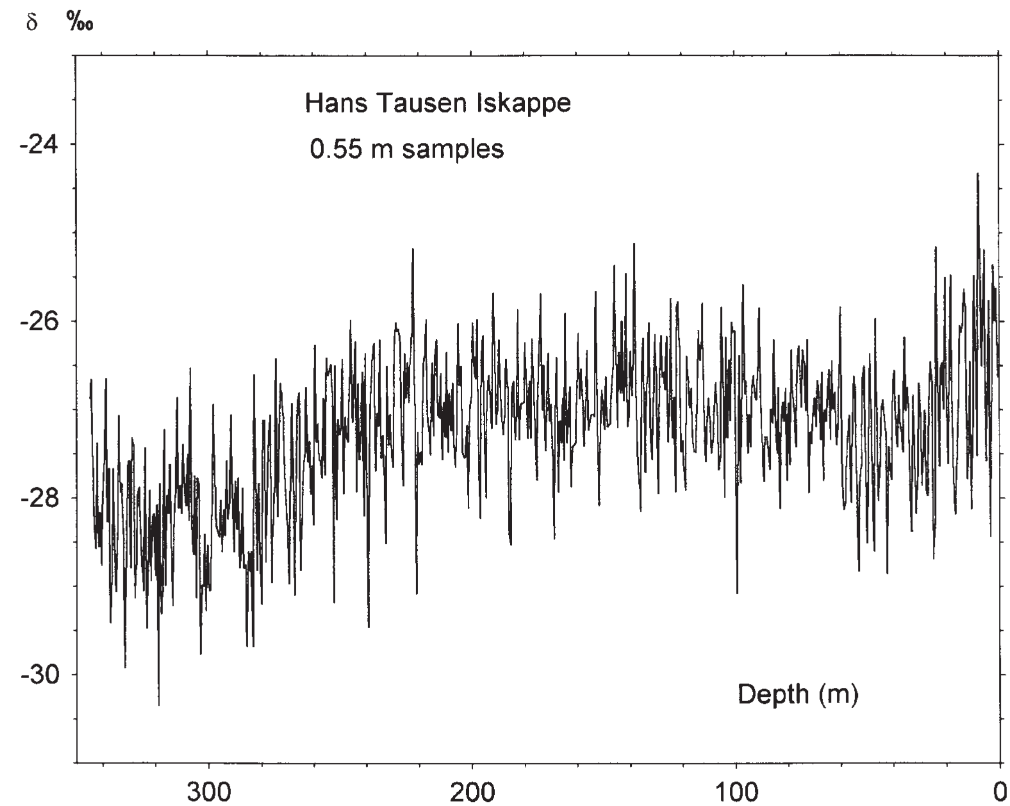



*Fig. 1.The Hans Tausen profile versus depth; shown as 0.55 m average samples. Note the high values at 10-20 m and the rather low values over the bottom 60-70 m.*

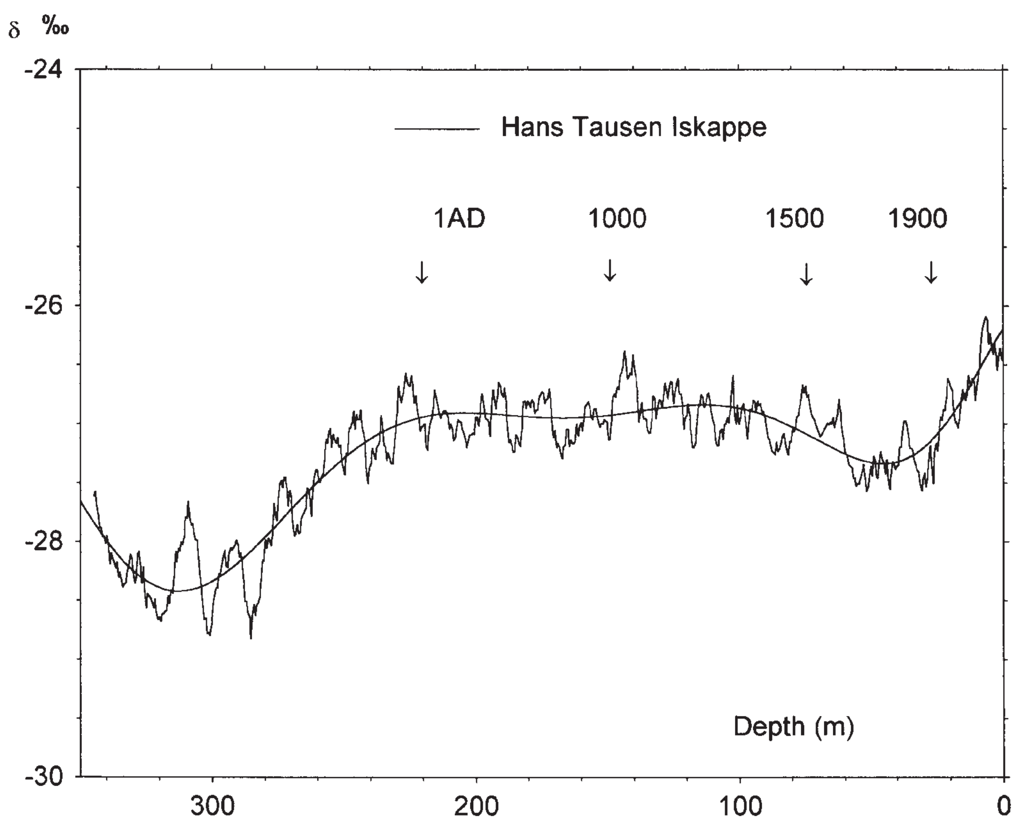



*Fig. 2. A smoothed version of Fig. 1 (10 point sliding averages plus a fitted polynomium). Selected dates are indicated (see Clausen et al. 2001).*

between the δ values around 2000 years ago and those covering the past century. In other words, the δ values covering the past century would be even higher compared to the values of the older periods.

It is therefore possible to interprete the δ profile, back to 2000 BP, in terms of past climate changes as long as the interpretation concentrates on the qualitative changes. An interpretation in terms of quantitative temperature changes would be rather uncertain both due to our poor knowledge of the orographic influence on the snow deposition, the dynamic history of the rebuilding ice cap and the often forgotten a priori assumption that the seasonal pattern of snowdeposition remains unchanged over time. The latter is especially important for areas of low annual snow accumulation (where a change in the frequency of substantial individual snow deposition events can strongly influence the annual average δ value (Hammer, in press). It should also be remembered that climatic data from ice cores from regions of high summer melt must be interpreted with caution (Koerner 1997) Even with these reservations the Hans Tausen δ record presents us with some intriguing interpretations of relevance to climate research as discussed below.

## Interpretation of the δ record

Evidently, it is difficult to relate the deeper parts of the Hans Tausen ice core δ profile to past climate changes. Also there must be a transitionary sequence of the δ profile between the deeper parts up to the layers around 2000 BP old. We have therefore chosen to divide the δ profile into 3 sections, which will be treated independently.

*The bottom ice, 345-240 m*

While the drill-site is presently on a dome in a fairly "simple" flowregime, this was not the case for this site during the early milleniums of rebuilding. First of all the rebuilding of the ice cap several thousands of years after the Climatic Optimum must have been a wet "summer-affair" during the first few thousand years.

Between 280 m and 250 m the melt-layer percentage in the core is still around 60-70%, and the percentage only falls below some 40% around 200 m depth: The present melt percentage is 8%; increasing with depth to 20% around 120 m. The loss of summer snow accumulation by run-off in the flat dome area is hardly likely, if the melt percentage is below some 30-40% and we therefore assume, that the δ profile reflects climate changes from the surface and down to 220 m depth (of course with the earlier mentioned reservations concerning the growth of the surface elevation).

We must stay clear of interpreting the δ profile below some 220 m in terms of a record of climate change; rather it represents a record related to the rebuilding history of the Hans Tausen Iskappe. It might be possible in the future to extend the usefulness of the δ profile as a climate indicator back to some 260 m, but that would require a substantial amount of new information e.g. from another deep ice core some 5 km from the present drill-site.

## 1 AD – 1900 AD (200 m – 20 m)

From 1 AD to 1900 AD the smoothed δ profile in Fig. 2 exhibits semi-cyclic variations. The highest values are confined to a short period around 140 m depth while the lowest values are in the depth range 60-20 m (1700-1900 A.D.). How does this compare to the information on the past climate from the Greenland Ice Sheet proper and the Northern Hemisphere in general?

In 1980 only a few ice cores from the Greenland Ice Sheet existed, which reached back to 2000 BP, but an attempt was made to establish a normalized climatic index for the ice sheet back to 550 AD (Hammer *et al.* 1980). This old index concur somewhat with the δ profile of the Hans Tausen ice core i.e. relatively high values until 1300 A.D., followed by declining values until a minimum from 1650-1700 A.D. and general low values between 1700-1900 A.D. The match is not perfect, but the spline in Fig. 2 illustrates the general trend of the δ profile. Hammer *et al.* (1980) also attempted to construct a Northern Hemisphere temperature index, which differed from the ice core index by having a pronounced medieval warm maximum around 1100-1300 A.D.

Since 1980 several new drillings to intermediate depths have been accomplished and the GRIP and GISP2 drillings at the Summit area have added to the climate archive (Greenland Summit Ice Cores 102, C12, 1997). The recent NORTH GRIP drilling 315 km north-north west of the Summit drillings has added yet another δ profile representing the Greenland Ice Sheet.

With all these data it should be possible to compare the δ profile from the Hans Tausen Iskappe to the main features of the Greenland Ice Sheet δ profiles. For the period 1 AD – 1900 AD this is, however, problematic. One could of course normalize the profiles and stack them all together. This has actually been done by Fisher *et al.* (1996), who also included the Canadian ice cores from Devon Island and the Agazzis Ice Cap. The NORTH GRIP core and the Hans Tausen data did not exist at that time. Even though the stacked profile of Fisher *et al.* (1996) explain some of the variance by the EOF technique (Empirical Orthogonal Functions), they reach no firm conclusion as to why the Central Greenland ice cores GISP2 and GRIP show no trend in the Holocene; Fisher *et al.* (1996) link this problem to "the smaller problem" of the past 3000 years. This leads us to a crucial question: Can we a priori assume, that the seasonal distribution of snow fall has not changed over time? There is also the possibility that high and low elevation sites respond differently to climate chances.

In the case of the GISP2, GRIP, and Dye-3 ice cores paleotemperatures obtained from borehole temperature measurements (Cuffey *et al.* 1997; Dahl-Jensen *et al.* 1998) indicate a temperature low some 2000 years ago; high temperatures around 500-1200 A.D. and two minima at approximately 1500 A.D. and mid 19th century; finally ending with a maximum in the 20th century.

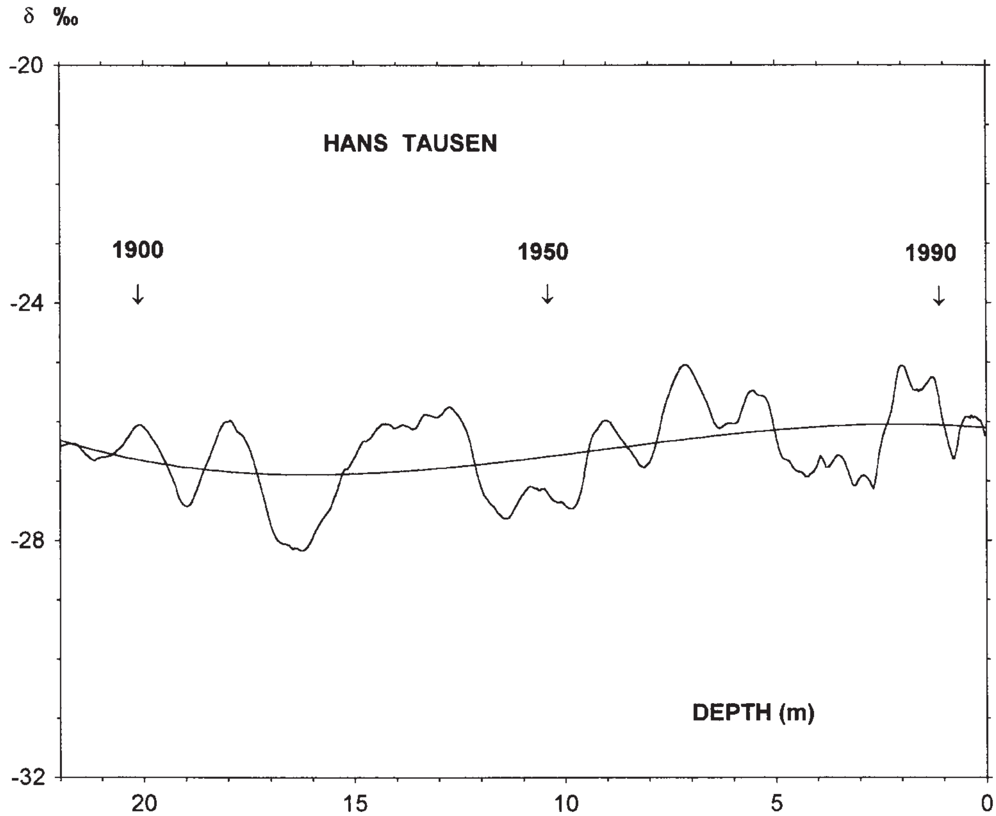
The Hans Tausen δ record exhibits some of the same characteristics i.e. high values during the first millenium and low values around 1700-1900 A.D., but it is certainly not a perfect match to either the data from Central Greenland or the stacked data of Fisher et al.

## The 20th Century

The number of ice cores from Greenland and Canada covering the past century is substantially higher than the number of cores reaching several thousand years back in time. Also the existence of temperature data from coastal Greenland meteorological stations add to our knowledge of the climatic development during the 20th century in the Greenland region.

In Fig. 3 the Hans Tausen profile (smoothed) covering the periode 1900-1995 A.D. is shown. If we compare this profile to the earlier mentioned data of Hammer *et al.* (1980), Fisher *et al.* (1996), and Dahl-Jensen *et al.* (1998) and the coastal temperature data (from the Danish Meteorogical Institute) we get a much more consistent picture as for the periode 1900-1995 A.D. i.e. cold temperatures (or low (s) in the beginning of the century, higher temperatures (or high δs) during the late 20-ies to 1940 and high values again in the mid 60-ies; finally a slight trend of cooling since the

*Fig. 3. The upper 22 m of $\delta^{18}O$; smoothed but based on 2.5 cm samples. A fitted polynomium curve of the data is also shown. Dating is based on seasonal variations of $\delta^{18}O$ and a reference horizon from the Katmai eruption 1912 A.D.*




mid 60-ties. This is substantiated by a second shallow ice core from the Hans Tausen Southern Dome, i.e. it is not caused by glaciological noise.

More recent ice core data from the GISP2 and GRIP were analyzed by White *et al.* (1997), who also concluded that their stacked δ profiles from 6 ice cores actually reflected several observed features of the 20th century North Atlantic climate.

So we are left with the impression, that the δ profiles in fact do reflect the temperature history at an ice core drill-site in the Greenland-Canadian region. If we analyse the data further back in time the interpretation is harder. Of course this does not change the fact that the δ profiles along deep ice cores indicate glacial periods or the Dansgaard-Oeschger events observed during the last glacial (Dansgaard *et al.* 1993), but it does point to the fact that the δ method is based on certain assumptions.

When dealing with climate changes of the Holocene some of the assumptions do not hold and this can have serious consequences for the δ-T (temperature) relation. It should be noted that Dansgaard's and Johnsen's empirical relation between δ-T for Greenland ice cores (Dansgaard, 1964; Johnsen *et al.* 1989) was established by means of shallow ice cores i.e. while a linear relation was found between δ and T it did not nescessarily mean that it would hold for older ice-strata.

## The anthropogenic "Greenhouse effect"

In this paper we have tried to briefly present the Hans Tausen δ profile and its relation to other ice core data from the Greenland and Canadian region. We have also indicated some of the problems involved in relating δ and temperature, but perhaps one of the most exciting findings of the Hans Tausen project does not require a complete quantitative analysis of the δ profile!

From Fig. 2 it can be clearly seen, that the highest δ values in the Hans Tausen record are observed during the 20th century; the values of the 1930-ies and 1960-ies are even higher than the values of the first millenium and Medieval times. "Is this just a statistical fluctuation over 2000 years or is it indicating that the present human activity is now changing our climate?"

Even though the climate "trend" of the Greenland region since the mid 60-ies has been toward cooling, this "trend" is based on not more than 30 years; could it be that the cooling is just part of a coincidental variation in the semi-cyclic pattern seen in Fig. 2? Actually the low δ values between the 60-ies and the 90-ies are as high as the δ values around medieval times i.e. the 20th century climate seems to be really unique, when compared to the climate changes over the past 20 centuries.

Is there any reason to expect unusual warm conditions since the 1920-ies? There are at least two natural causes which come into play:

1) The absence of volcanic eruptions of climatic significance between 1912 to 1963 A.D. and
2) The Sun's activity (see e.g. ESF project: Solar output and climate during the Holocene, 1995).

While the latter is a highly controversial subject there is no doubt that 1920-1962 A.D. was a period representing a rather clear upper atmosphere (especially stratosphere). It is, however, difficult to explain the high δ values in the Hans Tausen record since the mid 1960-ies without including an anthropogenic "greenhouse effect". If an anthropogenic greenhouse effect is not the explanation we are left with two very complex causes for the high δ values: Either the past 30 years are due to chance fluctuations in the Earth Climate System or some, perhaps oceanic, memory effect of the warm temperatures between the end of the 1920-ies and to the mid 1960-ies is acting in some unknown way.

If compared to all the other information on the Earth climate during the 20th century we feel heavily inclined to accept that human activity in the second half of the 20th century has indeed an effect on the climate.

## Conclusions

We have demonstrated that the Hans Tausen ice core δ profile does indeed, in a qualitative way, concur with the general climate change in the Greenland-Canadian region as obtained from other ice core data in the region.

It is, however, clear that the record, as all the ice core records from the region, is not varying entirely in phase. There are good reasons to believe that they should not vary exactly in phase even though the various profiles do indeed show some similar long term trends. We suspect that the differences between the various profiles are partly due to real climatic differences and partly due to a presently unknown change in the seasonal snow deposition pattern.

For the past 100-200 years the δ profile apparently reflects the actual temperature changes in the Greenland-Canadian region rather well. The unusual high δ values during the 20th century seems to be related to both low volcanic activity and since the 60-ies to the anthropogenic greenhouse effect. The latter conclusion could be tested and partly verified by extending the Hans Tausen δ profile i.e. to sample the past 5 years of snow accumulation at the southern dome of the Hans Tausen Iskappe. Only 5 years have passed since the samples from the ice cap were collected, but if the δ values of the past 5 years (1995-2000 A.D.) would still remain as high as during medieval times – or higher – it could be an important verification of the anthropogenic greenhouse effect. If not, we would be forced to be much more cautious in our interpretation. In other words we would need many more ice core data from the Greenland-Canadian region combined with intensified and improved regional climate modelling to get a more firm basis for our conclusions.

We do, however, base our present conclusion, regarding the anthropogenic greenhouse effect, on the fact that the 20th century data are outstanding when compared to the past 2000 years. It is not proving that the δ profile from the Hans Tausen Iskappe over the 20th century is really unique, but it certainly suggest that the present odds are not in favour of a simple "stastistical fluctuation" of the Earth climate system.

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