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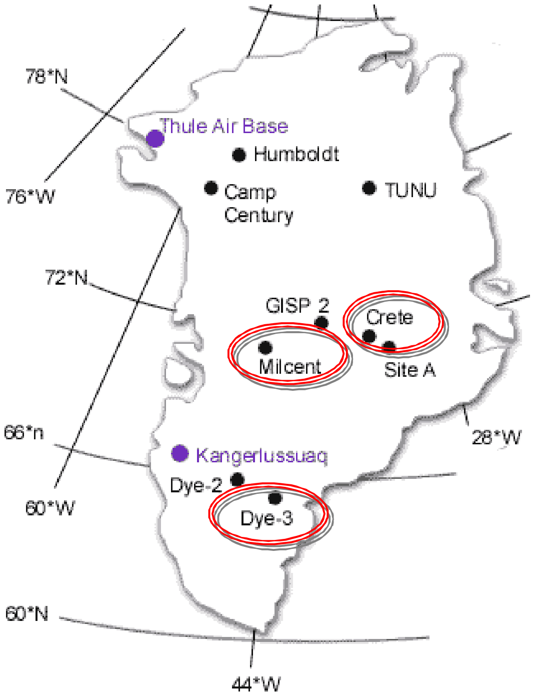
Climatic changes, the Norsemen and the modern man



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Introduction

Through centuries, mankind lived with a very close contact to nature. Good harvests, nice weather, but also famines, very cold seasons or epochs remain in the stories of Norse people, either in oral folklore or written sagas, or poems. Nowadays, new technologies and equipment allow scientists to read data about climate changes recorded in sea or glacier ice. The purpose of this report is to link these two knowledges, to check if they match, and to understand what they can bring to each other.

Firstly, I will briefly describe the intellectual and technical tools required to understand how to get, to extract and to interpret feature variations of ice. Secondly, I will try to confront climate change data from different Nordic places in order to see how climate changes and if the changes spread in a special way, following special rules. Thirdly, I will compare historical records and facts with ice data about climate change to highlight how science meets history.

I) From ice to data

1) Cycle of water, importance of isotopes

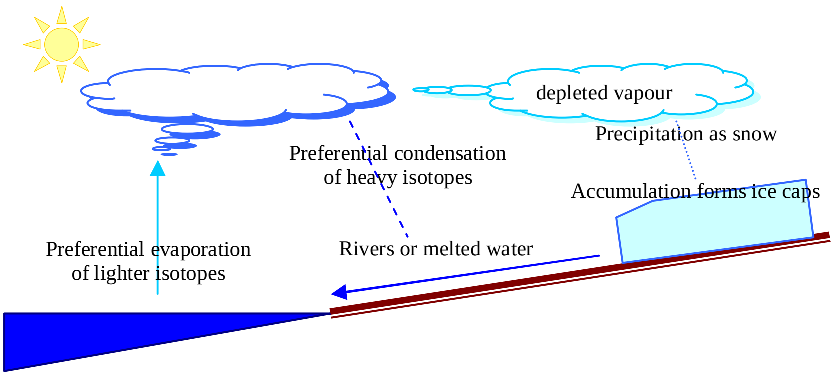
Covering more than 70 % of Earth, water is the witness of each event, natural or human. The main 2 reservoirs (see table below) are the oceans and icecaps.

Water source	Water volume, in cubic miles	% of total water
Oceans	317 000 000	97,24
Icecaps, glaciers	7 000 000	2,14
Ground water	2 000 000	0,61
Fresh-water lakes	30 000	0,009
Inland seas	25 000	0,008
Soil moisture	16 000	0,005
Atmosphere	3 100	0,001
Rivers	300	0,0001
Total water volume	**326 000 000**	**100 %**

Water reservoirs on Earth, Nace, USGS 1967.

Those reservoirs are not passive; exchanges between them happen constantly, powered by the sun. The origin of the water over the continental surface is the ocean. The water evaporated from the ocean is transported by the wind into the atmosphere over the continent and precipitates over the continental surface and finally flows back into the oceans as rivers, or stay as ice in ice caps and glaciers.

The existence of oxygene isotopes influences the composition of the flows. The so-called $^{18}0$ isotope is heavier than the usual $^{16}0$ atom. Thus, when water evaporates, it requires more energy for the $H_2{}^{18}0$ water molecules than for the $H_2{}^{16}0$ ones to be "carried" from a liquid or a solid phase to vapour. The opposite phenomenon happens during condensation.



Parts of the water cycle related to the formation of ice caps and variations in isotope composition.

Preferential evaporation and condensation affect isotope composition of water, and especially ice, which as a solid, keeps its composition constant through time. Therefore, one can characterised ice by its ratio of oxygen isotopes. Scientists use the normalised ratio called "δ^{18}O" (*spl* for sample, *SMOW* for Standard Mean Oceanic Water which is the sample used to normalise isotopic ratios):

$$\delta^{18}O_{spl} = \frac{(^{18}O/^{16}O)_{spl} - (^{18}O/^{16}O)_{SMOW}}{(^{18}O/^{16}O)_{SMOW}}$$

δ^{18}O give information about paleoclimates: at a given location, ice deposited in warm climatic periods has a higher δ^{18}O than ice deposited in cold climatic period. GISP 1 (Greenland Ice Sheet Program, 1970-1974) was launched to collect and to study paleoclimate from cores drilled in 3 different places in Greenland (see locations on front page map):

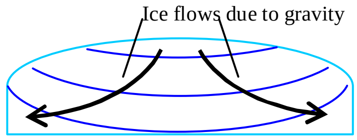
- DYE3, South Greenland, 1971 (another one was drilled in the early 1980s), 400m long
- Milcent, Central Greenland, 1973, 400m long
- Crête, Central Greenland, 1974, 400m long

But how can we match temperature data with time, in order to make a real chronology of climate events?

2) The layering principle and the building of a depth-time scale

Glaciers and ice caps result from the accumulation of snow which has precipitated in non melting areas. As the accumulation occurs from the top, one can use the **layering principle** to say that a layer of material above another one is younger than the one below it.

Nevertheless, it must be taken into account that:
- the layers are moving inside the glacier and therefore tilt the horizontal layering (see picture on the right),
- water from occasionally melted layers can penetrate and mix with underneath layers.

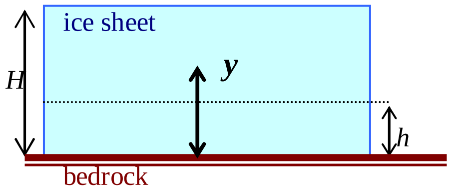


Layering disturbance due to internal ice flow within an ice cap

For GISP 1, the 3 drilling sites were chosen in respect of these conditions. The horizontal layering was good enough to calculate a relatively simple depth-time relation, thanks also to a quite constant accumulation rate of ice at the top of the ice cap (**a**, in *meter/year*). The other parameters are **y** (the height in *meter* from the bedrock of the layer one want to know the age: **t** in *year*), H (the thickness of the ice sheet, in *meter*) and **h** (the height from the bedrock above which the horizontal is assumed to be uniform, in *meter*).

$$t_{(y)} = \left(\frac{2H-h}{2a}\right).\ln\left(\frac{2H-h}{2y-h}\right)$$

$$y > h$$



This formula is very accurate for the ice core drilled in Crête, and we are now equipped with 2 tools: one to measure temperature variations, another one to place those variations on a time scale. This site is exceptional for its high and constant accumulation rate, its simple ice pattern (which makes the former formula precise), its high ice thickness can give a big amount of data and its location close to the main track of North Atlantic cyclones is relevant for climate studies. It is now time to compare data from Crête with other climatic historical information.

3) Other sources of information

Since 1847 for Iceland and since 1690 for England, we have measured data of temperature. But for the time before, data were extracted from systematic ice observation (Iceland) or deduced from historical records (agricultural results, Icelandic *sagas*, private diaries, tree rings, moraines, lake and ocean sediments, pollen strata, deposits of insects…). All these data had been processed through a 60-years low pass filter (except for the “historical data” of England which already cover bigger periods of time) in order to compare more easily smooth curves giving temperature as a function of time.

II) Climate changes through Norse history

1) A delay that suggests that some climate changes travel

a) The Medieval Warm Period (MWP)

During the 12^{th} and the 13^{th} centuries, England, and basically Europe, experienced a quite warm period. It led to good agricultural results. As a clue, we can notice that even the poor population had a rather high meet consumption. A more striking fact is the existence of several vineyards in England: 14 vines were grown commercially.

According to historical facts, the MWP also took place one century before in Iceland (1050-1200), and is clearly recorded in the Crête ice core in Greenland (around the 10^{th} century).

b) The Little Ice Age (LIA)

Even if it is not that obvious in the results of the analysis made on the ice core from Crête, the $\delta^{18}O$ data suggest that a bigger event for its consequences first occurred in Greenland and spread westward over North America and eastward over Iceland, Europe, causing huge troubles in living conditions, agriculture, trade, human settlements: the Little Ice Age.

The Little Ice Age started in the late 14th century in Greenland with an increasing and over spreading amount of sea ice between Greenland and Iceland. Subsequently, ship frequentation decreased, causing delays and then lack of food supplying. The population of famine-ridden Iceland dwindled during the Little Ice Age to half its previous numbers. In 1695, Iceland was completely surrounded by sea ice, which covered sea as far as the Faeroe Islands!

Greenlanders fared even worse. Two different cultures had colonised Greenland: the Vikings (Norse people) who were farmers, and the Eskimos (Inuit people), who were a hunting people. They were affected by the LIA differently. Growing sea ice cut off communication with the outside world beginning about 1370, and when German ships landed in South Greenland (where were settled the Viking settlers), more than a century later, they found a single frozen corpse but no living colonists among the ruins. We do not have many evidences to describe what happened at this time there. As the soil was strongly iced, Vikings might have changed their burial customs, which could explain why only few bodies had been found. Archaeological agricultural sites show that, after farmers left their farms, the soil layer was blanketed by layers where typical Arctic insects replaced those associated with agriculture.

The Eskimos, who were migrating eastward as the Norse moved westward, were better able to cope with the climate chill because they are more versatile and well-adapted to Arctic conditions. Some of them were strong enough to stay, but most of them rowed away to Scotland.

Cold and erratic weather patterns produced numerous crop failures in northerly areas such as Scotland and Norway. Native American tribes such as the Iroquois relocated their villages to escape the cold. These migrations stirred up political conflict among tribes, leading to the creation of non-aggression pacts like the famous League of the Iroquois, adopted in the 1500s.

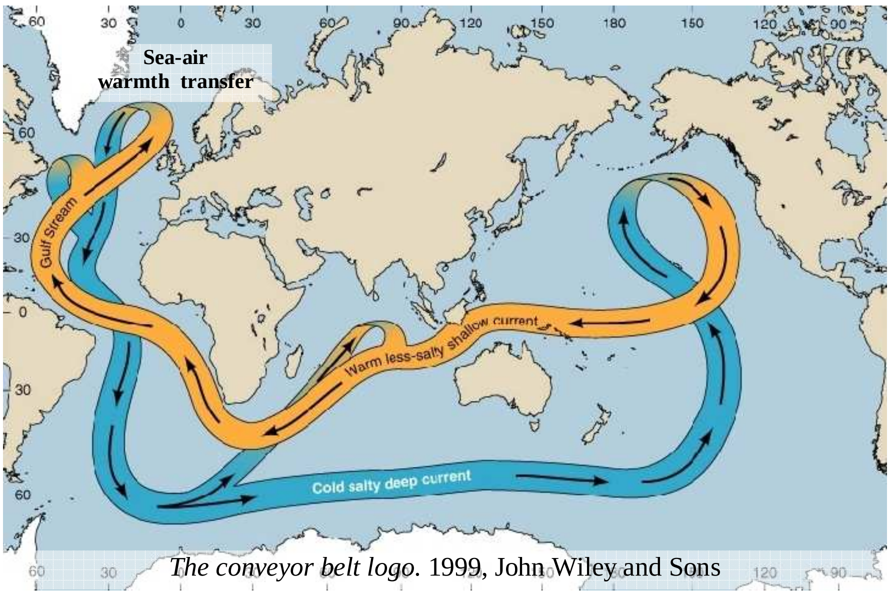
Confirmed by other researchs (ice cores from the Greenland Icecore Project and from the GISP 2), the LIA was a strong climate change which deeply affected both Norse and North American populations. It was also confirmed that this event took place first around Greenland and then moved to Europe and America at the same pace than the MWP. It seems that air mass circulation plays an important role in transporting climate change so fast. What can powered such climatic disturbances? How can such changes like the one between the MWP and the LIA can interfere with Norse History?

2)The Broecker conveyor belt theory, impact on Iceland early History

a) Salinity and warmth power sea currents

Wallace Broecker first stated the conveyor belt theory in 1984. It is based on real facts, observations, and it is supposed to explain that fast climate changes can be triggered by sudden sea current changes.

The great ocean conveyor carries warm water to the region around Iceland where cooling from 12-13°C to 2-4°C by cold Canadian air masses. This cooling densifies the water, allowing it to sink to the bottom. As the Atlantic Ocean is a particularly salted one, it increases again the density of this southward-moving water mass. The flow of water (20 million m^3/second) is equal to 100 Amazon Rivers or the amount of global rainfall!



The conveyor belt logo. 1999, John Wiley and Sons

So immense is the heat released to the atmosphere that it keeps northern Europe 5 to 10°C warmer than it would be if the conveyor shut down. But this release of energy melts glaciers and ice caps; which therefore decreases salinity, disturbs local currents and finally shuts or changes the direction of the conveyor belt. Subsequently, cold climate onsets swiftly with hard conditions of life for Norse populations who live in the usual sea-air warmth transfers area. Could fast climate changes have affected parts of Greenland and Iceland History?

b) The *Landnam* and *Greenlander sagas* – when the weather makes people confused

As far as we know (L*andnam saga*, written in the 13th century), the first farmer who attempted to settle in Iceland was Floki Vigerdason, in 865. He unfortunately lost his cattle in a severe winter, and came home to Norway with tales of "*a fjord filled up by ice*", therefore naming this country Iceland. $\delta^{18}O$ data from the Crête ice core and from other drilling sites agreed on saying that Floki tried to settle at the end of a short cold period in Greenland and probably Iceland as well. Here, ice core data matches *saga*. The $\delta^{18}O$ curve also shows that the climate was really warmer 10 years after, when Ingolfur Arnarson succeeded to settle in Iceland.

According to the *Greenlander saga*, Greenland was re-discovered and called "*green*"land in 982 by Erik the Red, after he was banished for 3 years from Iceland after a killing. It is written that he more or less lied and described this country as a peaceful land covered by grass in order to attract people to go and settle there with him. This nice description of Greenland might have sounded unreal to the unknown writer of this *saga*, especially after the cold periods that both Iceland and Greenland went through (remember that the LIA had likely started in the 12th century, before the oldest written text we can find about those *sagas*). It seems that Erik had found a fjord on the south-west coast, well protected from the sea, warmed by the Gulf Stream and with adequate land for farming.

The ice core thermometer provides accurate clues to assess historical facts or historical written records: they explain why Iceland and Greenland did not get the opposite names. It also reveals that climate can shift in a very short lapse of time, as it did between Floki's attempt and Ingolfur's success. This ten years shift can be partly explained by a disturbance of the conveyor belt.

3) Climate and the modern man

Although climate has a strong impact on human civilisations and on nature in a general view, one must not forget the consequences of human activity on the environment. Speculations can be done on the human responsibility about the fact that there is not long lag anymore between temperature variations in Greenland, Iceland and England. Is it due to pollution? Is it due to climatic changes far beyond the Greenland area?

Other ice core results reveal that human activity has had a big impact on environment since the early civilisations. Copper analysis made by the LGGE (Laboratoire de Glaciologie et Géophysique de l'Environnement) in Grenoble on the ice cores drilled at Summit (GRIP, Greenland, 1990-1992) show that the Greek and Roman civilisations had polluted on a high scale the North Hemisphere atmosphere, 2000 years before the Industrial Revolution.

Even if copper is naturally present in polar ice at low rates, copper concentration had doubled during the Greek-Roman epoch due to copper production. In fact, this production had started 7000 years ago in China. Before the Industrial Revolution, the estimated loss of copper in the air during the process is 15 % (it is around 0,25 % nowadays). The total amount of copper released by human activity in the atmosphere that had fallen on Greenland between 2500 BC and the Industrial Revolution was evaluated to 2800 t, 10 times the amount released from this Revolution until now!

Conclusion

Glaciers and ice caps reveal much more information that one could have expected. It is not just an "ice thermometer" that allows us to read recorded climate changes. The most surprising feature of ice cores is that they also witness, in such blank or virgin area, the signs of human activity. As for paleoclimate, they can be good tools to study paleometallurgy.

Therefore, History can be finally approached either from the point of view of climatic conditions and impacts on civilisations, or from the climate changes subsequently due to human activity. This is also a very burning issue today, as industrialisation has increased and is still increasing so much. Phenomenon, like the catastrophes linked to El Niňo disturbances or the global warming of Earth, are still threatening us. Thanks to new data from ice cores and from theories like the Conveyor Belt one, weather and climate modelling should improve and help us to behave more carefully.

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