0.1 Ice Cores as a Window to the Past

The studies of ice cores have revealed much information and knowledge about the dynamics of the world's past climate, atmosphere and geology through measured proxies such as isotopic and chemical compositions, and conductivity. By disclosing information about our past, the analysis of ice cores leads us to a greater understanding of the behaviors of the Earth system, which opens up for possibilities of modeling and predicting the future that lies ahead of us.

When analyzing ice cores it is most important that a relationship between depth and age is accurately established, as these timescales are of the essence for building empirical models and reconstructing paleoenvironments. Dating of ice cores can be attempted through a variety of methods: visual inspection of annual layers in data, known volcanic events detected in the ice or radiocarbon dating, to name a few.

A difficulty, that arises when dating ice cores, is the effects of diffusion through the firn column. Both gas and water molecules can diffuse through the firn which presents a number of obstacles for the continued dating. First of, the diffusion of gases in firn, through air pockets connected to the atmosphere, makes the age of the gas in the ice younger than the age of the firn at the same depth. Secondly, the diffusion of solid state molecules present in the firn, like water molecules, erases some of the signal, when measuring different properties of the ice. This erasure is commonly described through the average diffusion length of a molecule at a given depth, σ. This work focuses in particular on the densification and diffusion processes affecting water isotopic ratios in the firn.

The diffusion length σ is affected by a variety of parameters: the depth, the annual average accumulation, the ice flow and - especially interesting - the temperature. By understanding which parameters influences the behavior of σ, it might be possible to use this signal erasure obstacle to gain more knowledge about paleoconditions: if it is possible to empirically estimate a diffusion length at a given depth, it may be achievable to reconstruct the temperature for this time interval.

0.2 A Rare Gem of Knowledge

Some measured signals in the ice cores contain annual cycles. For example, the water isotopes in the firn are sensitive to temperature, leading to a clear

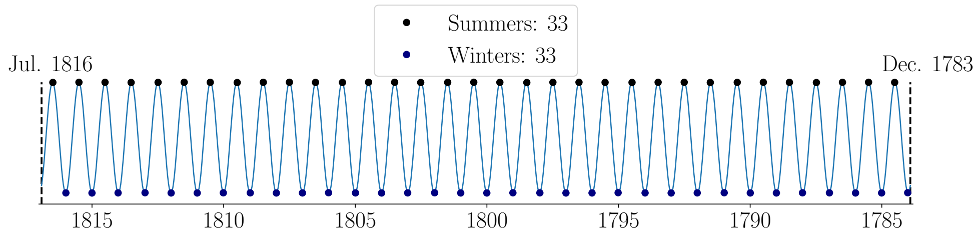

Figure 0.1: Visualization of pattern of summers and winters in the time span between the Laki and Tambora volcanic depositions in Greenland.

summer-to-winter cycle. This makes it relatively easy to date shallow ice cores as the cycles can be counted, but as diffusion takes place in the firn column, some of this signal is washed away. Luckily, another method can be utilized to date the ice: detection of known volcanic events through electrical conductivity measurements. This reveals a quite unique gem of knowledge: By knowing the time of a certain volcanic event, either through historical observations or through previous ice core synchronization, and matching this with the depth of the detected event in the ice, it is possible to set some very certain dates on the timescale of the ice.

An example of this type of event dating is by examining the volcanic eruptions of the Icelandic volcano Laki in 1783 and the Indonesian Volcano of Tambora in 1815. Both eruptions are very well historically documented and are visible and detectable in a great number of ice cores. The deposition in Greenlandic ice cores has been estimated to be in December 1783 for Laki and in July 1816 for Tambora, yielding 33 summers and winters between the two events, see Figure 0.1. This does not only make it possible to generally date and synchronize different ice cores, but it also allows for in depth analysis of the diffusion and densification processes in the ice.

0.3 Utilizing the Rare Gem

By considering an isotopic depth series situated between two volcanic events, it is possible to back diffuse this series over the known time span in years - or even months - using the diffusion length as a tuning parameter. This is an optimal way to empirically estimate the diffusion length of a given depth interval which makes it possible to obtain a temperature reconstruction of this interval, as σ is temperature sensitive.

The goal is thus to reconstruct the lost signal by a back diffusion scheme, tuning σ of the diffusion process, until the known actual number of winters/summers between the events can be counted as peaks and valleys in the depth signal. Then the estimated optimal diffusion length can be used to make a temperature estimate of the given interval. The back diffusion method is built on both empirical models and signal analysis of the measured data. A simplified flowchart of the general idea is illustrated in Figure 0.2.

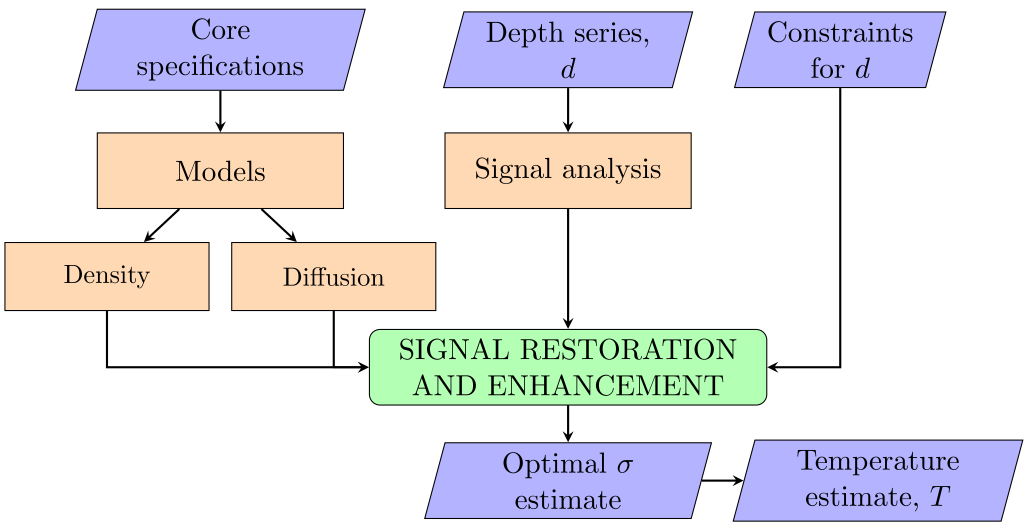

Figure 0.2: Illustration of the general idea, restoring signal by tuning the diffusion length until the expected number of years is detectable in the depth interval.

In this thesis an introduction to diffusion of water isotopes in ice cores is firstly presented along with methods for modeling densification and diffusion profiles. Following is a brief examination of different experimental methods for detection of volcanic deposited material and which methods has been used for the data under inspection. The chosen data are then presented along with an argumentation of why they were selected. Then a thorough presentation of data and signal analysis along with important computational methods are presented. These different tools are then combined in the method description, depicting a walk-through and testing of the final algorithm developed for estimating the diffusion length given the specific number of years. The final method is tested and further developed and fine tuned, and results given the last iteration of the method are presented. On the basis of these results, finally, a temperature reconstruction of the examined depth intervals for the ice cores is attempted.