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ICEBERGS IN A LARGE GREENLAND GLACIAL FJORD

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INTRODUCTION

In general the Greenland Ice Sheet serves as a significant fresh water source to the ocean, contributing about 0.7 mm/year to global mean sea level rise (*Rignot et al*. 2011). About a quarter of the total sea level rise in the latest 20 years has been estimated to be due to the mass loss of marine-terminating glaciers of Greenland (*Straneo & Heimabck, 2013)*. This contribution is about two times bigger than the one due to the glacier melting in Antarctica. The fresh water input at high latitudes occurs through two main mechanisms. The first one is the direct melting of glaciers, which are a point source of fresh water. Instead the second one is due to the melting of icebergs broken off by glaciers (calving). They move in Greenland fjords and in the open ocean, thus they are a diffuse sources of fresh water. Evidences suggest how fresh water flux in Greenland, including the one due to iceberg melting, increased in the early 2000s (*Enderlin et al*. 2014). Moreover this flux at high latitudes strongly influences thermohaline circulation and deep-water formation (*Stouffer et al*. 2006). A freshwater cap, diffuse sources (e.g., melting of drifting icebergs), or point sources (e.g., melting at the heads of fjords) likely have different impacts on the thermohaline circulation.

The goal of this research thesis is to study the forcings which influence motion and melting of icebergs in a Greenland fjord. The fjord is Sermilik, located in the south-east of Greenland. At the head of Sermilik Fjord there is one of the biggest marine terminating glacier in the Northern Hemisphere, Helheim.

INSTRUMENT AND METHOD

It is possible to exploit a new methodology of an existing technology to observe icebergs, as well as sea-ice. The instrument is the pressure inverted echo sounder, PIES. It is designed to sit on the sea-floor and meausures the acoustic travel time τ between the transducer and strong reflectors, like sea-surface or water-ice interface (icebergs or sea-ice). One PIES was placed in Sermilik Fjord in 2011 by scientists of Woods Hole Oceanographic Institution, for one year.

Its high sampling frequency allows to detect icebergs, to value their speed and a range for their draft. The analysis shows that during the summer the signal was too noisy to detect icebergs, likely due to biological reflections (macro-plankton). In particular, in order to gain the iceberg speed, it's possible to exploit the "reflection curve", namely the curve that identifies an iceberg transit (Figure 1.a). It describes the time (t) variation of the travel time τ, due to an iceberg transit over the PIES. From the slope of the linear fit of τ^2 as function of t^2, it is possible to calculate the iceberg speed (*Andres et al., 2014, Figure 1.b*).

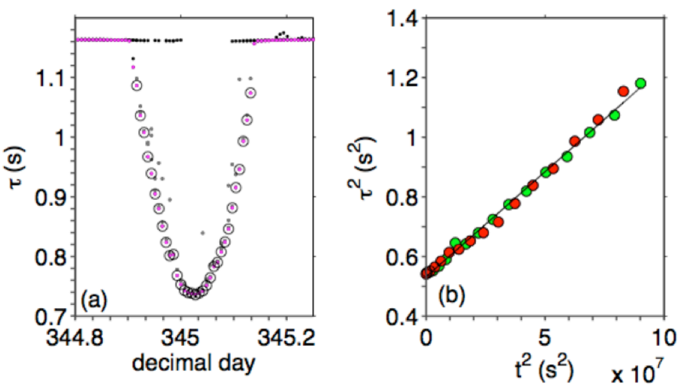

Figure 1: a) Example of a *reflection curve*, indicating an iceberg transit over the PIES. On the y-axis it is represented the acoustic travel time τ (s), while in the x-axis the time (in decimal day), namely when the signal is acquired by the instrument. b) Linear fit, τ^2 (t^2), of the same iceberg transit illustrated in figure 1.a.

RESULTS AND INTERPRETATIONS

Thanks to this work, it has been possible to evaluate the speed of hundreds of icebergs. The speed distribution is Gaussian, with average of 0.2 m/s and standard deviation of 0.1 m/s. Furthermore icebergs, on the average, are deeper than 100 m.

The two main forces which act on icebergs are the air drag (F_A) and the water drag (F_W). Sea-ice is rarely present in the fjord and therefore the friction that it could exert on icebergs is not relevant. For Archimede's principle about 90% of the iceberg volume is under water. As a consequence, the surface exposed to water drag is much bigger than the one exposed to air drag.

In order to study the weight of winds and marine currents, we couple iceberg speed with currents and wind speed data in the fjord. The correlation with the marine currents is strongly significant, while the one with the winds is not. Therefore water drag seems to be dominant. Another confirmation to this hypotesis is that the ratio between F_A and F_w is small (<1/e) in more than 80% of the measuraments. Indeed winds, in order to generate the same drag produced by currents, have to be at least two orders of magnitude faster than the currents. Marine currents have a speed of 15–20 cm/s in the first 200 m, where most of the icebergs move.

Therefore wind speed has to be around 15-20 m/s in order to have a significant impact on iceberg dynamics. However, in fjords, only katabatic winds can reach these values, but they are rare and their duration is brief.
The last part of this work is dedicated to study the iceberg melting. There are two main mechanisms which cause the melting. The first one is the wave erosion. Unfortunately there are not data regarding waves in Greenland and we can't value this contribution. The second one is due to the turbulence which is generated at the ice-ocean interface, because icebergs and the surrounding water have different speed. The consequence is that a turbulent layer is created at the interface, which causes a turbulent heat transfer through the iceberg: the result is the iceberg melting. In order to estimate the melting speed due to the turbulence, namely the turbulent melt rate (M_T), we can exploit the equations used by *Silva et al.* (2006). They describe the iceberg melting in Antarctica. The result of our analysis show how M_T depends on the relative speed between iceberg and water v_r and on the water temperature T_w (figure 2).

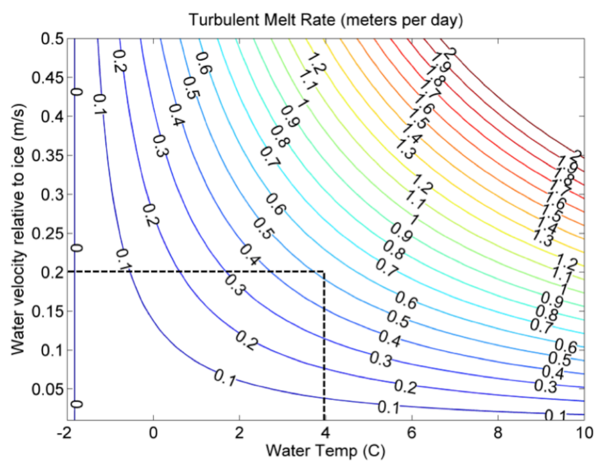

Figure 2: Counter plot of the iceberg turbulent melt rate (m/day) as a function of relative speed between iceberg and water (m/s) and water temperature (°C). Values underneath the dashed box indicate the values that can found in Sermilik Fjord.

Using data about T_w and v_r in the fjord, we obtain that typical values of M_T vary between 0.1 and 0.2 m/day. These values are similar to the melt rate estimated for Helheim glacier (*Sciascia et al.,* 2013). This outcome is very important: in fact it expresses tha fact that iceberg contribution to fresh water flux it's not negligible. In order to evaluate the actual contribution we need to multiply the melt rate by the total surface exposed to melting. In order to do that, we need to know the number of icebergs in the fjord, as well as the surface of each single iceberg. Unlikely we don't have data nor about the actual number nor about each single surface. A goal of scientists in the future is definetely to evaluate this surface (along with the contribution of wave erosion), in order to estimate the impact of iceberg melting in the North-Atlantic. The primary goal is to insert icebergs into climate models, ameliorating our projections on future climate. In the Northern Hemisphere their contribution could be very important, even more relevant than the one due to the glacier melting at the interface with ocean. Indeed the number of icebergs in Greenland fjords is of the order of thousands and the exposed surface to melting is probably much bigger than the one of glaciers. For example, in Antarctica, a recent work of *Silva et al.* (2006), shows that fresh water discharge due to iceberg melting is of the same order of magnitude of precipitation and much bigger than the one due the ice-shelf melting. It is possible that also in Greenland icebergs play an essential role.

CONCLUSIONS

The work done in this thesis allowed to show the effectiveness of the instrument (PIES) for iceberg study in Sermilik Fjord. Hundreds of icebergs has been analyzed, much more than in the past. Indeed, before this work, the few available data has been collected by oceanographic cruise: icebergs were followed during their path. Obviously this method is very expensive and few icebergs can be analyzed.
The outcomes show how icebergs are driven by marine currents within the fjord. The iceberg turbulent melt rate is comparable to the Helheim glacier one. Therefore the iceberg contribution to fresh water is not negligible and it has to be estimated in the future.
This work represents the first dynamical and thermodynamical study based on field data of icebergs in Greenland. Its importance lies in the fact that this methodology can be applied also to other areas, as in the open ocean, due to the low costs.

This work, conducted at Woods Hole Oceanographic Institution, is the object of a scientific paper regarding method and instrument (*Andres, Silvano, Straneo & Watts,* 2014). I'm currently writing a second paper regarding the results of the data analysis (*Silvano, Straneo & Andres).*

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