ARTIC SNMR PROJECT

Water content assessment in glaciers

Research, development and innovative project

UNESCO

Fundació Privada Marcel Chevalier

Water content in glaciers and climate change

Glaciers are widely spread on polar and sub-polar regions but also on middle latitude mountains, where cold-dry type glaciers, polythermal glaciers and temperate-wet glaciers are respectively present. Assess their water content is capital to understand the ice dynamics and how is related with the climate change.

How assess the water content in glaciers

Since water content and its distribution also exert a strong control on radar propagation velocity and attenuation, this provides a potential remote technique for assessing ice-water content, being the surface ground-penetrating radar (GPR the standart method to obtain indirectly water content data in glaciers. Nevertheless the uncertainty in calculate water content by small amounts of impurities (for example sulfates, dust and saline compounds from marine aerosols) is, however, significant in terms of ice dynamics, meaning that alternative methods of assessing water content are required to provide the input for predictive models of glacier flow and evaluate the effects of the climate change on glaciers, see for example Murray et al (2007). In the other hand surface nuclear magnetic resonance (SNMR), a non-invasive groundwater-exploration method that allows a direct determination of the water content and eventually the estimation of discharge, has been recently used in glaciers as an alternative method (Walbrecker et al. 2008; Hertrich & Walbrecker 2008, Turu 2009 and 2011). In some cases (Walbrecker et al. 2008 and Turu 2011) data from GPR are greather than data from SNMR and for that reason surface nuclear magnetic resonance in some places of low electromagnetic noise be a good tool to evaluate the water content on glaciers, like Artic and Antartic glaciers.

Figure 1: *From left to right electrical resistivity measurements in glacier. Magnetic Resonance Suonding on top of the crystal cave tunnel inside the glacier. Tuva and Crystal cave areas in Hansbreen glacier.*

Project main goals

In some cases (Walbrecker et al. 2008 and Turu 2011) data from GPR are greather than data from SNMR and for that reason surface nuclear magnetic resonance in some places of low electromagnetic noise be a good tool to evaluate the water content on glaciers, like Artic and Antartic glaciers. Looking at the GPR data from Moore et al. (1999) from Hansbreen, Turu (2011) demonstrates that combining both data (GPR and SNMR) is possible to enlarge the information about the state of the water content in glaciers and type of ice, what is not possible to do only with GPR data. So the main goal is to enlarge the 2009 Svalbard experience, with a second SNMR survey using a new pulse sequence. The previous field campaign was the first study in a Polar region using SNMR techniques, now we are able to select the best sites in Hansbreen polythermal glacier and investigate about the different kinds of water content on ice. In particular polythermal glaciers are the best ones to investigate with SNMR, because have a cold-ice layer (temperature below the pressure melting point) overriding a temperate-ice layer, so in a single glacier is possible to study different water contents on ice (seepage, inclusions, crevasses and moulins, major water conduits). For that a new pulse sequence will record the water signals in a large time range than in the previous survey and enlarge also the recording time. That new data is needed in order to assess the best protocol to obtain the water content on glaciers.

SNMR Experience in glaciers

While the efficiency of the MRS applied to groundwater related studies is already proved in developed counties, only few experiences were carried out in glaciers: Antartica (Callaghan et al. 1999; Ripeka et al. 2005), Swiss Alps (Walbrecker et al. 2008; Hertrich & Walbrecker 2008), Svalbard (Turu 2009, 2011). As has been explained before the MRS technique use the natural Earth's magnetic field to energize the free hydrogen atoms in the nature, and in nature, only water and hydrocarbons molecules have such free hydrogen atoms, so in theory if any NMR signal is detected, that would be originated mostly from water (subglacial water, wet ice, groundwater). The Magnetic Resonance Sounding (MRS) technique is specially designed to detect subsurface water, in which the possible water molecules are energized by pulses of alternating current at the proper frequency (Larmor frequency) transmitted into a loop laid on the glacier surface. The information obtained allows to detect the water content at different depth and the mean pore size, both parameters are useful to determine the melting state of glaciers.

Figure 2: *On point 1 of the aerial view Hansbreen calving ice-cliff, a tidewater grounding glacier at Siedleckivika bay on Hornsund fjord, September 2009. On point 2 the Polish polar station and in 3 the Crystal cave entry at the confluence between the main glacier and the tributary one (Tuvabreen)*

To interpret MRS datasets it is assumed that the glacier is stratified at the scale of the loop dimensions. For inversion a set of field data are necessary to compute a matrix giving the theoretical response of thin water layers located at various depths. This matrix take into account the general configuration of the measurements: loop dimension, Earth's magnetic field inclination, ice electrical resistivity, and total moment of pulses. The inversion procedure, which requires noise filtering and regularisation parameters, is performed to solve the water content equivalences, because a same signal can be obtained by different water contents and wet ice thicknesses. So any previous knowledge of the glacier structure is helpful, in that sense GPR data at the same place is suitable.
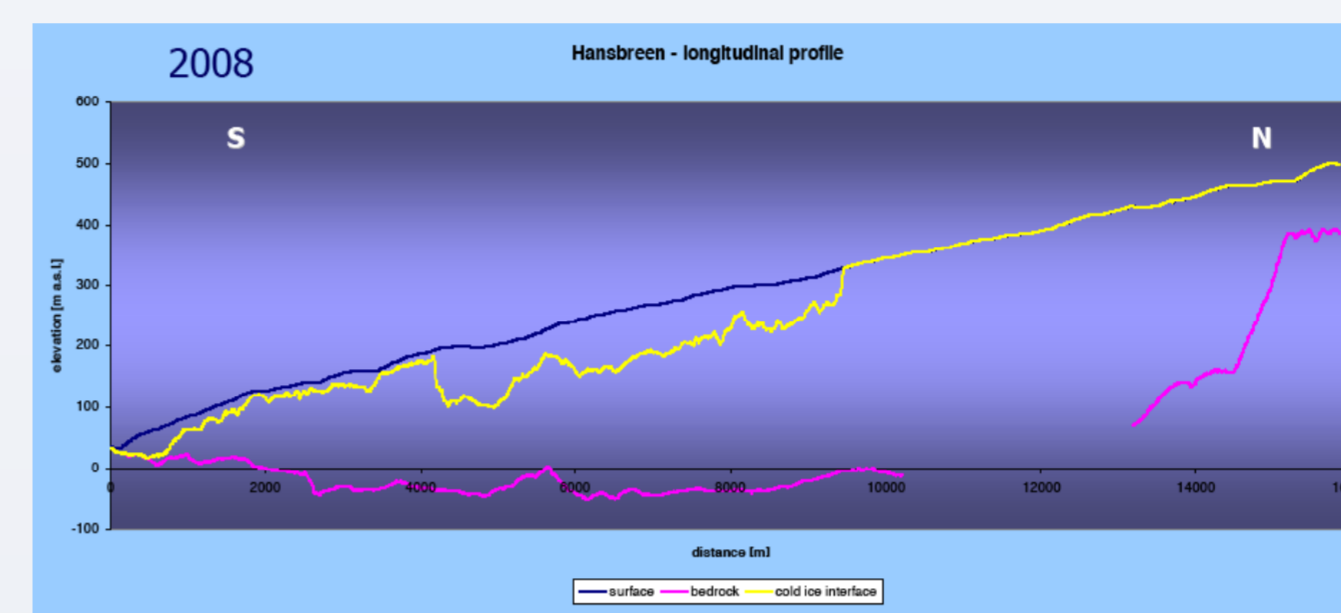

Figure 3: *GPR longitudinal profile from Hansbreen in the 2009 field campaign from Mariuzs Grabiec* http://water.iopan.gda.pl/projects/AWAKE/Grabiec_Sopot.pdf

SNMR technology versus others techniques

Traditional methods like electrical resistivity measurements, UHF and low frequency radio-echo sounding, ground penetrating radar (GPR) are classified as indirect methods because they measure a physical property linked to the probable presence of water on ice, but can't detect the water itself. In the other hand, SNMR techniques had less than twenty years experience outside the ancient USSR and is classified as a direct method, because it detects directly the response of the water (H+ protons) to a electromagnetic exciting pulse. So this method guarantees the existence or not of water while traditional methods cannot.

The non linearity behaviour between the measured signal and the energizing pulse intensity is a particularity of NMR physics, so it means that doubling the pulse current does not mean doubling the signal amplitude: instead it increases the depth of investigation for the same Earth's magnetic field. Nevertheless the signal is linearly related to the water content, which makes the interpretation quite quick.

SNMR Specyfic questions to solve in Hansbreen

Which procedure should be taken to investigate in glaciers (logistics, pulse sequence, ...). In the 2009 SNMR survey at Hansbreen only free induced decay (FID) pulse sequence was done. With FID mode is possible to obtaining T^*_2 relaxation time but to obtain T_2 or T_1 variables other kind of pulse moment sequences are needed.
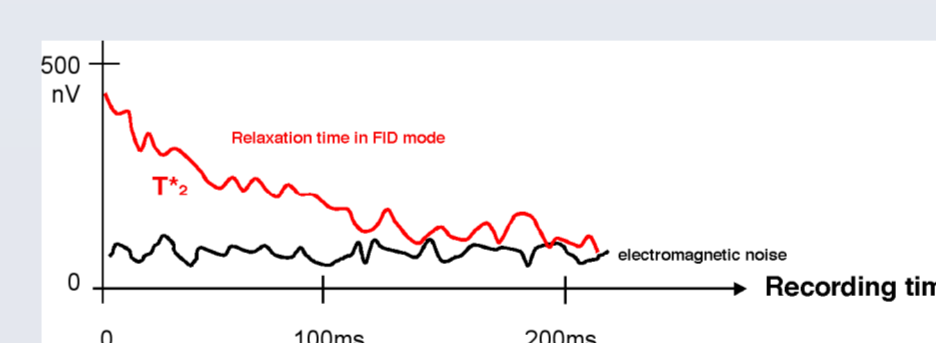

Figure 4: *Energy time decay in FID mode. T^*_2 is correlated with pore size (microfracturation, wet ice, ...) and permeability (seepage, connected conduits or microfractures in ice) but also influenciated by the presence of magnetic geology. If some magnetism is present on surrounding rocks more complex pulse moment sequence are needed to obtain T_2 or T_1 relaxation times. Nevertheless is suitable to obtain the whole NMR relaxation times in Hansbreen glacier to assess if there is any differences related with the glacial environment.*

MRS pilot study in Hansbreen

Previous experience in Hansbreen allow us to know about the technical and metodological problems with SNMR geophysics, the device choice and hardware configuration. That is specialy important in the case of polar and sub-polar regions because the high strength of the Earth's magnetic field encourage the use of light SNMR devices like the Numis Lite one. Nevertheless the death time existing between pulses is too big (40 ms) to determine mobile and bound water together with the Numis system, as has been observend in 2009, and a more advanced device is needed (GMR system) in order to compare GPR and SNMR data; if not Numis system is only to be able to detect mobile water on ice and systematic differences in water content exist between GPR and SNMR data (GPR water content data > SNMR water content data). Also from the 2009 SNMR survey is known that different relaxation times from water signals has been observed in 2009 and should be confirmed by this new powerful device.

Estimated budget

The project monitoring will be done by the Marcel Chevalier P. Foundation, given to the local Unesco commissions of all the related counties invited to be involved in that project (Norway, Finland, Germany, Poland, Spain and Andorra). The best moment is between the end of August and the beggining of September because glacial ablation season is major at that moment. Presentation on the possibilities of the SNMR technology for water content in glaciers for the Polish Faculty of Earth Sciences of the Silesia University, the Artic Centre of the University of Lapland (Finland), the Polytechnical University of Madrid, all of them related with the SvalGlac project in Svalbard (http://svalglac.eu/index.html)

OUTGOINGS		INCOMINGS	
Equipment	$11234,81	UNESCO	$11234,81
Field work and final report	$29032,08	Fundació Marcel Chevalier	$29032,08
TOTAL	$40266,89		$40266,89