To the Polish National Commission for UNESCO

Artic SNMR Project
Marcel Chevalier
Private Science Foundation

Principality of Andorra

Main goals and fundings

2012

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Andorra la Vella 6th July 2012

M. Chevalier

To the Polish National Commission for Unesco
Dear Sirs and Madams

I'm glad to present our scientific project to be developed on the Polish Polar Station of Hornsund in Svalbard (http://hornsund.igf.edu.pl/index_en.php), to improve the methodology to study some aspects of the cliimate change effects in glaciers :

SNMR Surface Magnetic Resonance Sounding, a New Approach to Assess Englacial and Subglacial water content in sub-polar glaciers. Study on Hansbreen Polythermal Glacier (SW Spitsbergen, Norway)

Glaciers are sensitive to the effects of the climate warming increasing their melting. Glaciers are also 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. How quick is their melting is crucial to prevent related natural hazards (brutal openings of subglacial and ice dammed lakes), major calving events (affecting warm ocean currents), major glacial retreats and landscape change (Kilimanjaro glaciers), water mass balance (melting increasing), and a long *et cetera*.

Assess their water content is capital to understand the ice dynamics and how is related with the climate change. Since water content and its distribution also exert a strong control on different physical parameters (radar and seismic propagation velocity, electrical resistivity) a huge of non invasive remote techniques has been developed for assessing water content in ice. Nevertheless the uncertainty in calculate water content with non direct techniques spread the scientific efforts and butgets from their main goal (http://jeeg.geoscienceworld.org/content/12/1/87.short).
Our project in 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 : (http://www.meetingorganizer.copernicus.org/EGU2011/EGU2011-1946.pdf)

Hansbreen in Hornsund (SW Spitsbergen) is our field laboratory. This glacier has been studied from different scientific teams and good knowlede about its thermal structure has been published. Previous experience in 2009 demonstrates that combining both methods (non-direct and direct remote techniques) enlarge the information beyond the traditional remote techniques. Because the direct remote technique (SNMR) is under development, more field campaign is needed in order to assess the best protocol using that technique on glaciers. For that reason I encourage you to support our project and I'm sure that you will look for the best way to participate in that mission.

For that reason I demand from your commission to contact the Department of Polar Research from the Institute of Geophysics of the Polish Academy of Sciences (for example Dr. Piotr Glowaki, glowacki@igf.edu.pl), to intercede for that project get out of transport and accommodation expenses for two persons (that can be quoted by Wlodzimierz Sielsk, Head of the Logistics and Public Procurement Department, Institute of Geophysics; sielski@igf.edu.pl). In the other hand we offer freely to the Polar Research Dpt. the access to the final repport of our results and a training staying for one Polish student in Hornsund.

Sincerelly yours

Valenti Turu i Michels
Scientific chief

(a) Description of the **project**:

A.0 Main goal

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. 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 standard method to obtain indirectly water content data in glaciers. Nevertheless the uncertainty in calculate water content by small amounts of impurities (for example sulphates, 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 greater 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 Antarctic 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.

Murray et al (2007): http://jeeg.geoscienceworld.org/content/12/1/87.short

Moore et al. (1999): http://arcticcentre.ulapland.fi/docs/jmoore/mooreJG1999.pdf

Turu 2009: http://www.igeotest.ad/Altres/Descarregues/N%20008.08.09%20MRS%20Svalbard%205.pdf

Turu 2011: http://www.meetingorganizer.copernicus.org/EGU2011/EGU2011-1946.pdf

Walbrecker et al. 2008; Hertrich & Walbrecker 2008:
http://www.cosis.net/members/meetings/abstracts/file.php/49/105215/pdf/EGU2008-A-06663-1.pdf

A.1 Technology and industry:

Surface nuclear magnetic resonance is a non-invasive groundwater-exploration method that allows a direct determination of the water content and eventually the estimation of discharge. The very first Magnetic Resonance Soundings (MRS) was carried out between 1979 and 1981. Since 1982 the method was already used in the USSR for practical purposes and intensively tested in different geological settings and in different countries. The fall of the Berlin wall in 1990 and the end of the USSR in 1992 provides to the western Europe a brain gain from eastern Europe and the knowledge about MRS was firstly fixed in France by the BRGM (Bureau de Recherches Géologiques et Minières). The joint venture between BRGM and OYO corporation (Japanese instrumental factory for ground studies) built Iris-Instruments factory on Orléans (France), with the objective to commercialize generic BRGM geophysical devices and develop a commercial version of the MRS device. The arrival of this new geophysical method initiated intensive scientific discussions and exchange of experience. In 1996 a new generation of equipment became commercially available and Iris-Instruments was the only one factory on the world to commercialize MRS devices for groundwater exploration since 2006. On that year the American Vista-Clara Co. introduced the multi-channel surface NMR instrumentation (GeoMRI) and quickly (in 2009) a second generation of handle transportable devices (know as GMR) have become commercial from USA. Beside of traditional geophysical meetings these exchanges are occurring through specialized International workshops: Berlin, 1999; Orléans, 2003; Madrid, 2006; Grénoble 2009 and next one will be take in Germany at the end of September 2012. Nowadays the number of MRS users is continually increasing in EU and USA, because the two only factories in the world (Iris-Instruments & Vista-Clara) are on those regions.

A.2 The MRS technique and experience:

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: Antarctica (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 pulses of alternating current at the proper frequency (Larmor frequency) transmitted into a loop laid on the glacier surface energize the possible water molecules. The information obtained allows detecting the water content at different depth and the mean pore size; both parameters are useful to determine the melting state of glaciers.

Callaghan et al. (1999) http://www.sciencedirect.com/science/article/pii/S0165232X99000245

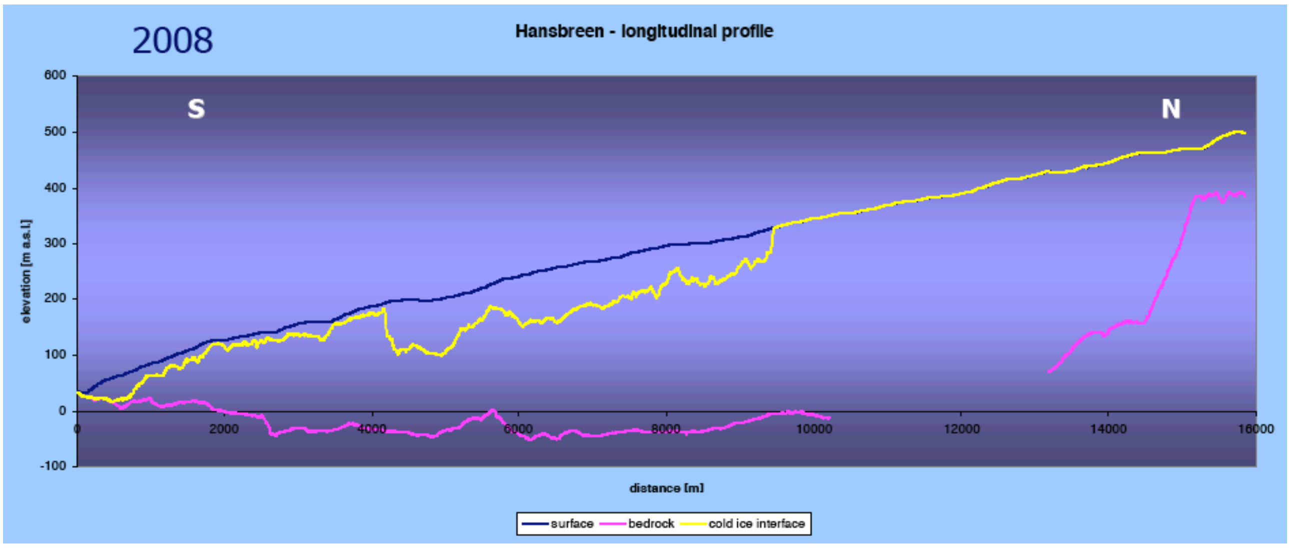
Ripeka et al. (2005) http://www.sciencedirect.com/science/article/pii/S0165232X04001624

Turu (2009) http://ssf.npolar.no/pages/news338.htm

Turu (2011) http://presentations.copernicus.org/EGU2011-1946_presentation.pdf

During the acquisition the operator, using the PC, monitors the NMR signal curve (the envelop of the proton response, which is an exponentially decaying curve), and the background electromagnetic noise curve stacked in the same conditions as the NMR ice water signal curve. The theory states that the investigation depth of a measurement varies with the moment of the excitation pulse (product of the intensity of current in the loop at the Larmor frequency by the pulse duration). It is therefore possible to sound the ground, the aim of the MRS technique, with surface NMR measurements. Besides, it can be shown that the decay time constant of the relaxation field is related to the pore size, which potentially permits to distinguish between pore free water and bound water.

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. These matrixes 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.



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

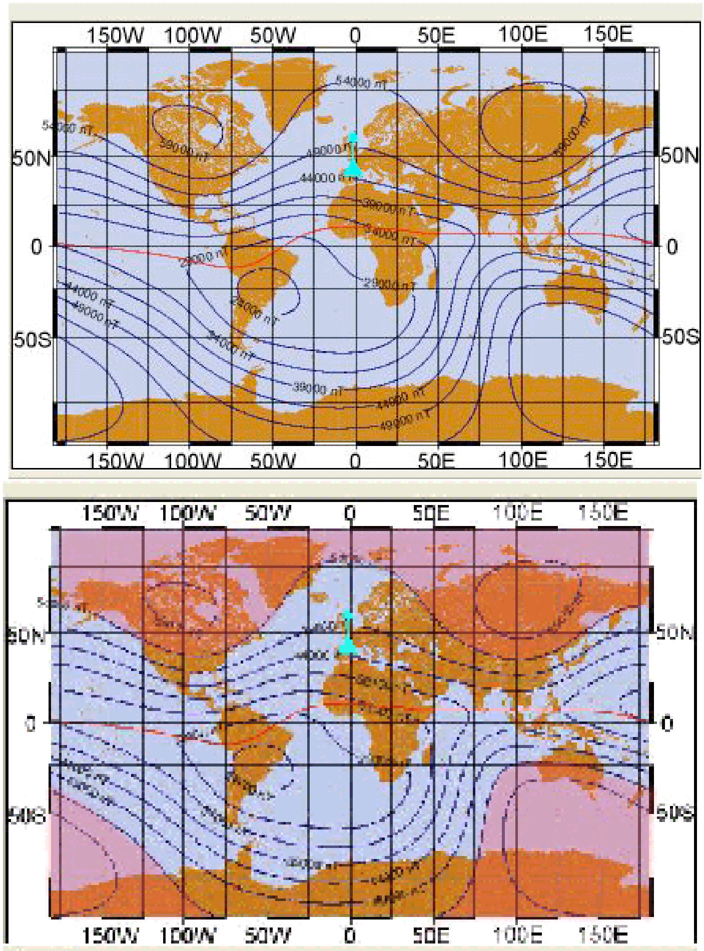
A.3 MRS versus other geophysical techniques:

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 an 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.

A.4 The Earth's magnetic field and SNMR equipment

Two commercial SNMR devices are available. A Numis system from Iris-Instruments and a GMR system from Vista-Clara. The Numis system offers now two products, a light Numis Lite device that can survey up to 60 m depth and a heavy MRS device, the Numis Poly that can survey more than 150 m depth. The last one is equivalent to the Vista-Clara's device, but GMR represents a technological leap. Both systems can be specifically configured for places where the Earth's magnetic field is high (more than 54,000 nT). In theory the light device, Numis Lite, can operate also in high Earth's magnetic field if the loop area is increased (more depth) exciting more amounts of water and consequently an increased of the water signal. In the SNMR field campaign on Svalbard a Numis Lite device was used until its maximum loop surface of 120 x 120 m, reaching an investigation depth of 180 m.



Earth's magnetic field distribution in nano Tesla (nT), shaded zone corresponds to high magnetic field. Note that all the Artic (Svalbard included) has more than 54,000nT.

A.5 The SNMR hydrogeophysical survey

Two phases are needed for a hydrogeophysical campaign. First, traditional techniques are needed to characterize indirectly the subsurface geology. Usually, the availability of electrical resistivity data of the investigation area of GPR data is helpful to accomplish the second study phase. In situ Earth's magnetic field and magnetic susceptibility background from surrounding rocks are also highly recommended. Previous electromagnetic noise measurements reduce final loop installation time. Secondly a MRS survey can be done using one of the three commercial instruments (GMR, Numis Lite and Numis Plus or Poly). So, the standard equipment we should have the devices listed on Table 1:

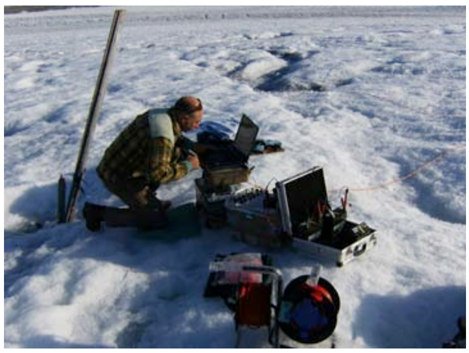
Phase 1				**Phase 2**
Subsurface	Earth's magnetic field	Magnetic Susceptibility	Electromagnetic noise	MRS
VES or GPR	Magnetometer	Susceptibility meter	Reduced MRS antenna	GMR or Numis

Table 1: Devices needed for a full complete hydrogeophysical SNMR survey.

VES device

Proton magnetometer device

Reduced MRS antenna

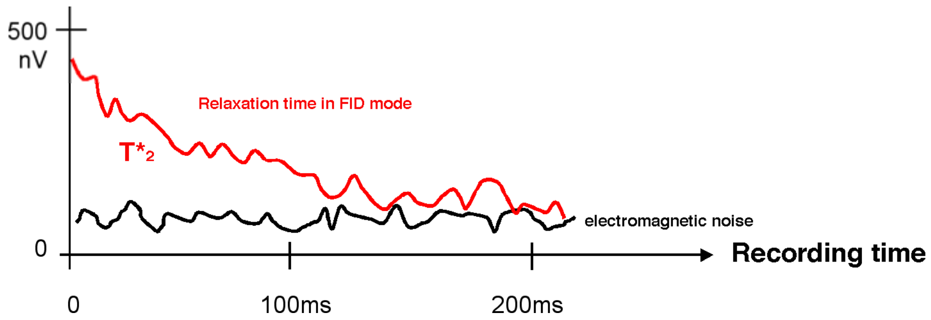


MRS device (Numis Lite system

Field basics (Schmidt hammer, GPS, compass, magnetic susceptibility meter)

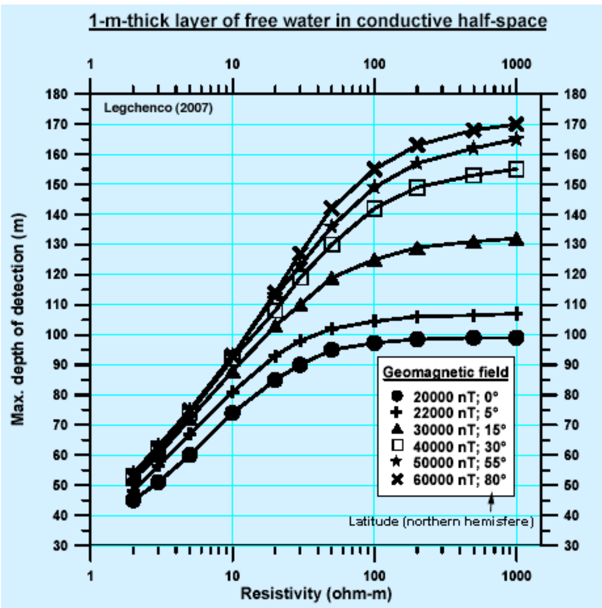
A.6 Specific questions to test SNMR in Hansbreen glacier

* 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.



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 influenced 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 are any differences related with the glacial environment.

* What will be the limitations in depth (skin depth versus configuration depth).



Svalbard

Different theoretical SNMR detection depth regarding the Earth's magnetic field and the electrical resistivity in the subsurface (skin depth). But investigation depth also depends on the configuration of the loop (depth is one and half times the square root of the loop area) and the power of the used device. In Svalbard more than 170 m depth is expected, that is more or less the maximum available depth for Numis Lite device.

* How to proceed if magnetic rocks are present is also a major question in NMR surveying. The relaxation time decay in FID mode is reduced, so T^*_2 can be even undetectable with devices like Numis system. Magnetic rocks are widely spread on areas with metamorphic geology like in Hornsund. To correct the effects of magnetic rocks a particular pulse moment sequence is required called « spin echo » to obtain T_2. In the 2009 field SNMR campaign in Hansbreen no available data from the magnetic susceptibility of Hornsund substrata. The new survey will include this kind of measurements.

A pocket device can measure the magnetic behaviour of rocks. Some rocks samples were taken from Svalbard in 2009 to assess the magnetic susceptibility in the continent, some of the samples had a medium to high values that makes convenient to carry out that king of data from the surroundings of Hansbreen in a new field campaign.

* Compare the SNMR data with the GPR available data and analyse the differences between the two methods. Previous published GPR data from Hansbreen (Moore *et al.* 1999) show systematic positive differences in comparing with SNMR data from 2009.

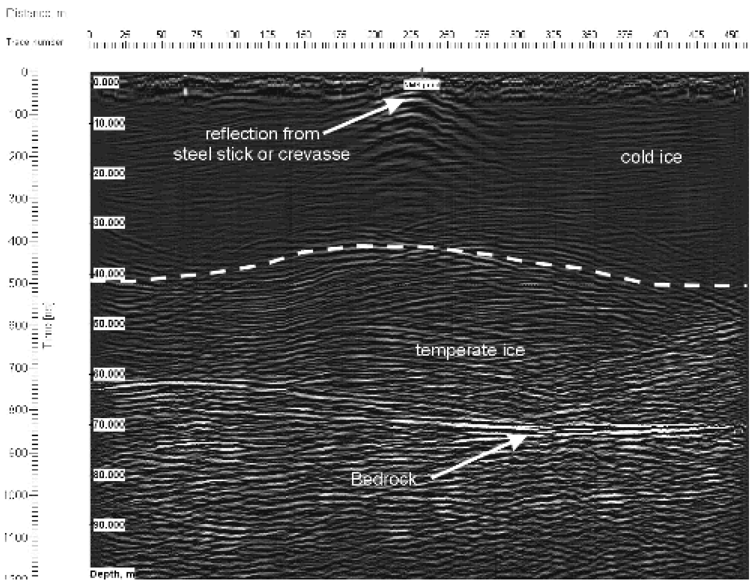


Figure of the internal structure from a portion of Hansbreen glacier. Unpublished GPR data from 2009 is available from Mariusz Grabiec (Slaski University from Poland) that show different internal reflexions also detected by the 2009 SNMR campaign.

http://water.iopan.gda.pl/projects/AWAKE/Grabiec_Sopot.pdf

* How changes in the Earth magnetic field can disturb the SNMR measurements. Variations of the ionosphere can be very strong close to the poles due to solar electromagnetic storms. Such variations influence the external component of the geomagnetic field, causing changes during the time needed to make a full MRS. If those variations exceeds more than 10 Hz from the excitation pulse frequency resonance conditions of measuring fails. For that reason the MRS survey should been done in parallel with Earth magnetic field measurements and in Hornsund the Polish polar station do that kind of measurements. However the HRN polar station reported no strong variations of the magnetic field during the 2009 SNMR survey:

Geomagnetic field at the HRN station		
Date:	**Hour**	**Total magnetic field**
29/08/09	17H43	54 384 nT
29/08/09	17H53	54 386 nT
2/09/09	16H28	54 363 nT
2/09/09	16H36	54 355 nT
5/09/09	18H12	54 376 nT
5/09/09	18H20	54 378 nT
09/09/09	18H01	54 396 nT
09/09/09	18H25	54 389 nT
Average	54 378,4 ± 13,64 nT	

Total Earth magnetic field measurements at HRN Polish Polar station (77º00'14''N 15º33'02''E) and the magnetic field inclination is 81° 57'.

HRN Polish polar station (http://en.wikipedia.org/wiki/Polish_Polar_Station,_Hornsund)

A.7 SNMR pilot study in Hansbreen

Previous experience in Hansbreen allow us to know about the technical and methodological problems with SNMR geophysics, the device choice and hardware configuration. That is especially 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 observed 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.

A.9 For whom are destined the SNMR survey and schedule

If wanted, a 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), also to the Norwegian universities of Oslo and Unis in Lonyearbyen.

1. John Moore (Finland)
2. Mariusz Grabiec and Jacek Jania (Poland)
3. Francisco Navarro (Spain)
4. Jon Ove Methlie Hagen (Norway)
5. Others that can be interested (Germany, Scotland, ..)

Hansbreen schedule

The best moment is between the end of August and the beginning of September because glacial ablation season is major at that moment.

Hansbreen schedule				
2012	August 13 -	August 31 – September		December
Material transport				
Geophysical Phase 1 Geophysical Phase 2		SNMR survey		
interpretation				
Hydrogeopysical rapport (SNMR)				SNMR rapport