Ice Busters

full length

Proposal of an experiment for
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1. Introduction

There are two most popular associations with the word “glacier” . The first one is an harsh monumental ice desert that covers hundreds or maybe even thousands of square kilometres. The other one is quite different – huge masses of ice torn off the mother ice causing the avalanche or they fall into the ocean. Obviously, both of these scenes are correct. However, we - group of young people fascinated with glaciers and everything which is connected with them, are going to focus on glaciers located in the Arctic zone.

First we need to differentiate between types of glaciers. We can divide them according to their form and their thermal state. In the first division we have continental glaciers (also known as ice sheets) and mountain glaciers. In the second one there are warm and cold glaciers. What characterizes warm glaciers is their constant temperature in the whole volume equalling the melting temperature of ice. The temperature in cold glaciers is lower than the melting temperature and it is also different in further parts of their depth. What is also important, the bottom part of these glaciers is “welded” to the rock on which the glacier is based. It also contains no water. Forces bounding ice with the ground are bigger than ice binding forces and that is the reason why these glaciers are motionless.

The above mentioned features of glaciers generate a number of questions. How exactly does the glaciers look exactly like? Is the pressure of the glaciers? What do air bubbles and cracks appearing and disappearing in ice exactly mean?

The above features of glaciers generate a number of questions. How exactly does the ice in the glaciers look like? Is ice pressure the only cause of changes in the structure of glaciers? What exactly are the air bubbles and cracks appearing and disappearing in the ice?

Figure . 1.1. Russell Glacier located in central-western Greenland.

2. Model of polar glacier

Following the information available on Internet and data given to us by V. Y. Lipenkov[1] from Arctic and Antarctic Research Institute, we have created an model of cold polar glacier 3 km high.

We distinguish four main layers of glaciers – snow, firn, white (bubbled) ice and blue (clear, transparent) ice. Between each two parts there is a transition zone.

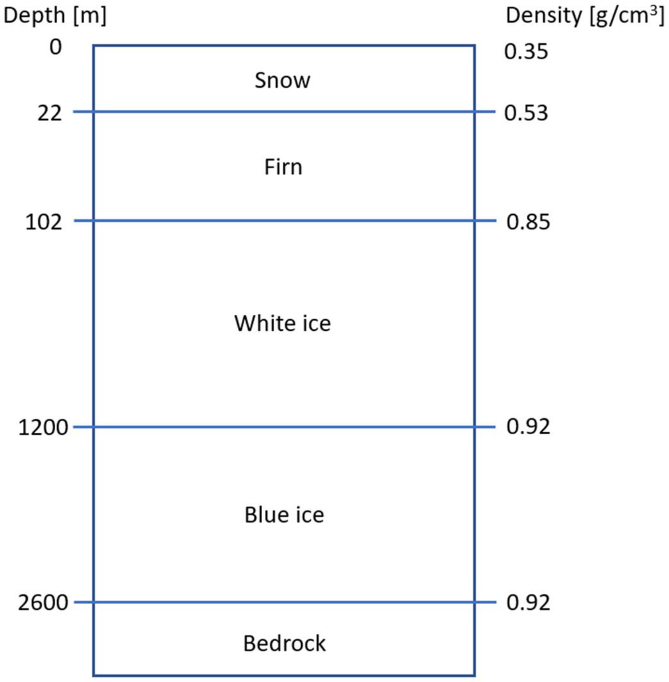

Figure 2.1. Model of polar glacier.

Snow cap 50 cm-thick creates a weakly heat transmissive layer. We have carried out measurements of temperature and humidity of snow on the depth from 50 cm up to 1 m in order to confirm this thesis experimentally. The measurements were made on Kamieńska Mountain near Bełchatów. A sensor examining the aforementioned parameters was created by students of the Warsaw University of Technology in Płock, members of Chemistry Club. The temperature outside was 7°C, air humidity – 76%. On the depth of 50 cm underground the temperature was 1°C and air humidity – 70%. This type of snow is customary called “wet snow” because of its high water content.

The layer of firn under the snow layer consists of compacted snow. It turns out that this firn layer have also new important feature. On the basis of the newest satellite measurements of the Larsen C ice shelf (carried out by Holland’s team) we know that during the settlement of firn the air is pushed out from the firn. Holland’s team estimates that “thickness of firn is decreasing at a pace of 4 cm a year”.

Two lowest parts of glacier – white ice and blue ice – also have very fascinating features. After analysing two neutrino detectors – AMANDA and Ice Cube – located in Amundsen - Scott South Pole Station, we estimate that white ice creates itself on the depth up to 1km. The above mentioned detectors are located from 1.45 km to 2.82 km underground. We assume that ice is transparent couple of hundred meters higher than 1.45 km.

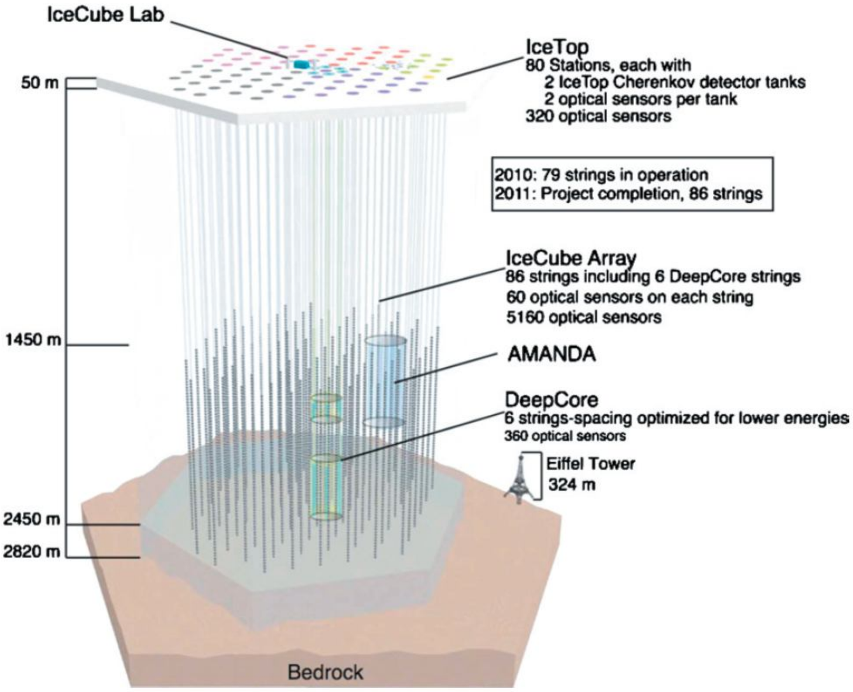

Figure 2.2. Ice Cub's architecture diagram.

Each model is a kind of simplification of reality. This also applies to the glacier model presented above. Reality is more complicated. The air bubbles inside the glacier have very different sizes. We have so-called normal air bubbles and micro air bubbles differing significantly with their average radii (see Fig. 2.4). The appearance of these bubbles at a depth of 250 below the surface of the glacier at Lake Vostok can be seen in Fig. 2.3a. The number of bubbles observed inside the glacier varies with depth. It achieves for the so-called normal (large bubble) maximum at a depth of about 500m below the surface of the glacier. The number of air bubbles then decreases with depth.

From the depth of about 500 m, crystals of air hydrates (see Fig. 2.3b) begin to appear which dominate from a depth of over 1250 meters (see Figure 2.4). Up to a depth of 1250 meters, there is experimental data on the decreasing number of normal bubbles and micro bubbles in the glacier. On the other hand, the number of air hydrate crystals begins to dominate and their number changes with depth in a similar way to cosine. Other characteristics: medium rays and their variations fluctuate slightly with depth.

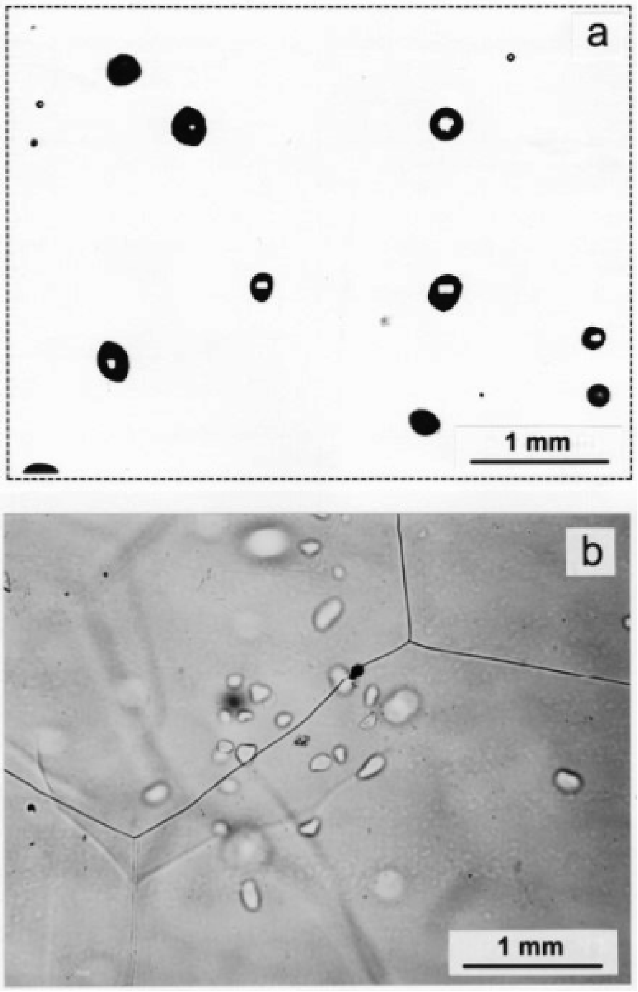

Figure 2.3 Air inclusions in the fresh Vostok ice core[2]: (a) “Normal bubbles and microbubbles in ice recovered from a depth of 250 m. (b) a group of air clathrate-hydrate crystals (2500 m.)

At great depths, glaciers are free of ordinary air bubbles. However, air hydrate crystals begin to dominate in them. Their role is not entirely clear. Ice in glaciers is transparent at great depths. At the same time, the temperature of the ice and its pressure increase with the depth in the glacier. On the other hand, ice density remains practically constant, starting at a depth of about 500 meters. This density of ice is about 0.92 g/cm^3 up to a depth of 2,500 meters.

It may also be worth noting here that you can easily buy ice in large blocks having a density of 0.95 g/cm^3.

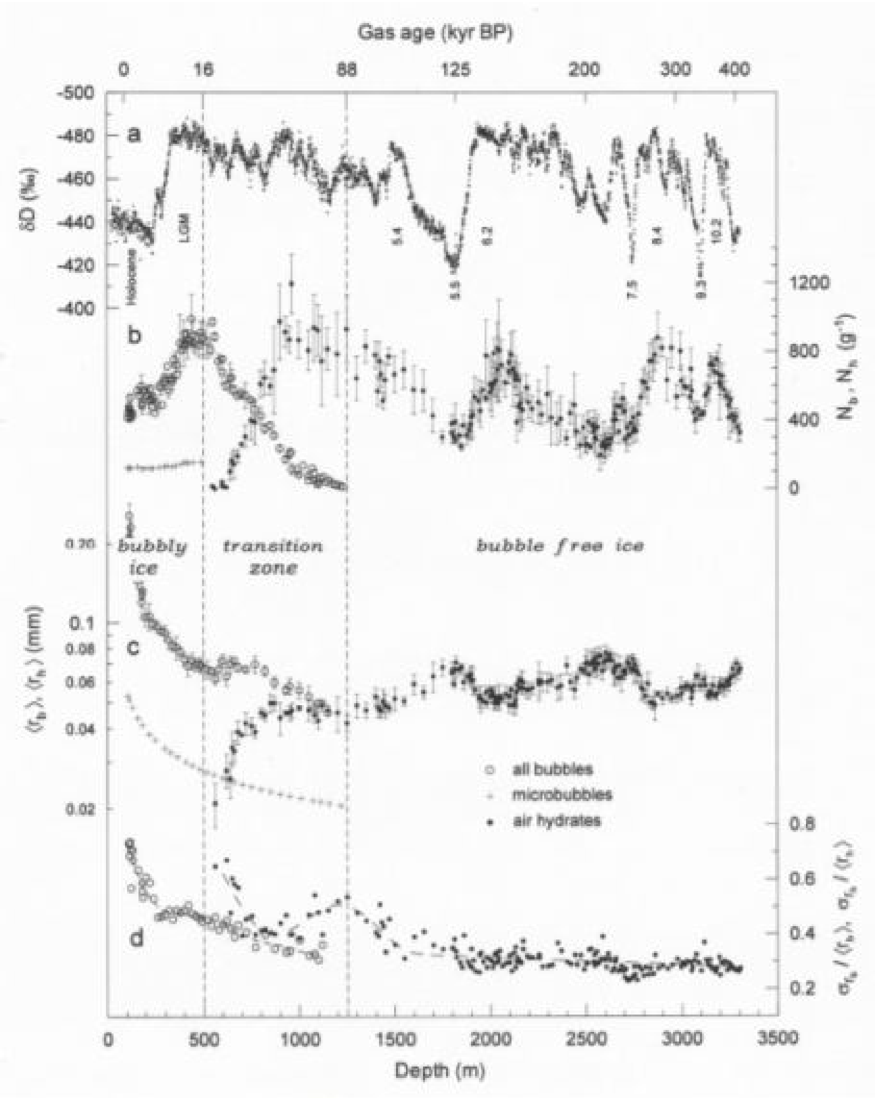

Figure 2.4 The experimental data obtained from the Vostok ice cores [3]. (a) The deuterium record, (b) Number of air bubbles (N_b) and air hydrate crystals (N_h) in 1 g of ice. Vertical bars indicate the variability inclusion concentration within the 9 cm core increment. (c) Mean radii of air bubbles ($<r_b>$) and air hydrate crystals ($<r_h>$). The radii of microbubbles were calculated from the data of microbubbles from the 183 m depth. (d) The relative variance of the bubbles and air hydrate radii.

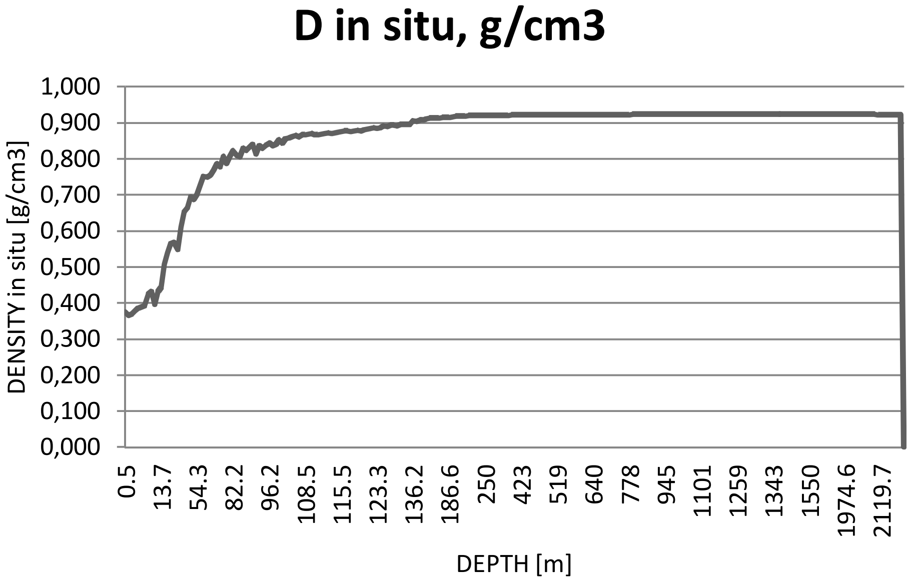

Figure 2.5 Experimental data of ice density measurements in the glacier at Lake Vostok at various depths. From a depth of about 200 meters, the ice density is constant[4]

3. Blue (transparent) ice

From our everyday experience and observations of nature surrounding us, we are aware that transparent ice is the result of cyclic melting and freezing of ice[5].

Figure 3.1. Blue ice seen in Iceland in 2012.

Energetic/ energy-related (approx. 273K):

Heat of fusion of water:

$$C_f = 6.01\,kJ/mol$$

Heat of evaporation of water:

$$C_e = 45.05\,kJ/mol$$

Thus heat of sublimation can be estimated as follows:

$$C_s = C_f + C_e = 51.06\,kJ/mol$$

We estimate the amount of heat needed for one molecule of water to sublimate from the surface of ice for:

$$\frac{C_s}{N_A} = 0{,}53\,eV/molecule$$

This energy is not high compared with discussed further on the energy of muons and electrons in question.

4. Heat conduction between ground and ice on 3km depth

Heat conduction through a slab of material of thickness Δx and cross-section S. Opposite faces are at temperatures T_1 and T_2.

$$\frac{\Delta Q}{\Delta t} = kS\frac{T_2 - T_1}{\Delta x}; T_2 > T_1$$

If we choose the same thickness Δx of ground and ice layers, we will receive:

$$k_g S(T_g - T) = k_I S(T - T_I)$$

By reducing S, we receive a formula for the temperature in contact between ice and ground:

$$T = \frac{k_g T_g + k_I T_I}{k_g + k_I}$$

where:

T_g- ground temperature
T_I- ice temperature

In warm glaciers the temperature fluctuates around 0°C. Rock, on which the glacier is based, is often floated by warm currents (both in Antarctica and in the Arctic). In cold glaciers the easiest solution is to assume that in the contact between ice and ground k_g □ k_l and there is the same temperature in the area around that contact.

The maximum value of this temperature is defined by the melting temperature of ice on the depth of 3km. The pressure on this depth indicated by h we can calculate from the following formula: (assuming that the ice density is constant and equal ρ):

$p = \rho g h.$

If a glacier was made only of blue ice ($\rho = 0.917 g/cm^3$) then the pressure would be equal to around[6] 27 MPa. And if the glacier was made only of white ice , then the pressure on the depth of 3km would be equal to only around 19 MPa.

Following the data from Internet, the melting temperature of ice in contact between ice and ground fluctuates around -2, -1.5°C. This means that in cold glaciers every temperature below -3°C is possible. However, there is the lower limit. The lowest temperatures were noted in Antarctica in 1983 (-89.2°C, the measurement made with a thermometer) and in 2010 (-92.9°C, the satellite measurement).

In turn, water in Vostok Lake (around 4km under the glacier, fresh water) has the temperature of -2,6°C, and in Ellsworth Lake (around 3km under the glacier, salt water) the temperature is around -13°C. We can assume that these temperatures are equal with the temperature of ice in glaciers.

5. Our hypothesis

We do not believe that bubbles and cracks in ice "disappear by themselves". We do not believe that they are filled only with air.

We suppose that inside a bubble there is water vapour, which under certain pressure becomes saturated. We postulate that muons surrounded by delta electrons (which are described in further part of this paragraph) are responsible for turning white ice into blue ice.

Following the data given to us by A.W. Wolfendale[7], this stream of muons equals at 800m of water:

$$3 \cdot 10^{-6} cm^{-2} s^{-1} sr^{-1}$$

Following the information available on Internet, at the depth of 1km of water ANTARES 2007 gives the intensity of muons around

$$1 \cdot 10^{-6} cm^{-2} s^{-1} sr^{-1}$$

Explorers of glaciers say that white ice needs around 150-180 years (!) to turn into blue ice.

$$150 years = 4.73 \cdot 10^{9} s$$

If we assume the time equals 150 years, this means that on every 1cm^2 falls 4730 muons. To this number we should also add electrons struck out in the process of ionization surrounding atoms.

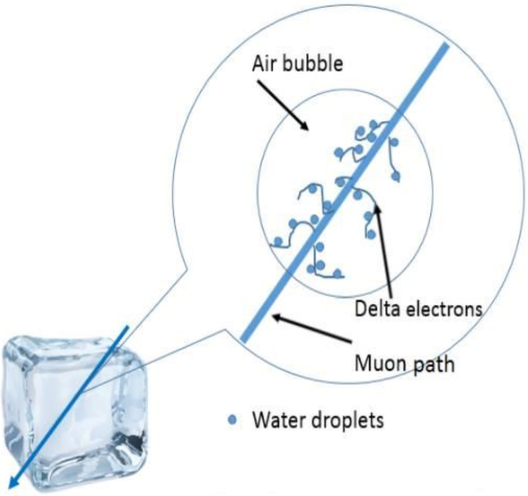

Figure 5.1. Scheme of muon passing through the ice.

While going through ice, muon loses its energy to ionize molecules of ice. During this process electrons with different energy levels are struck out.

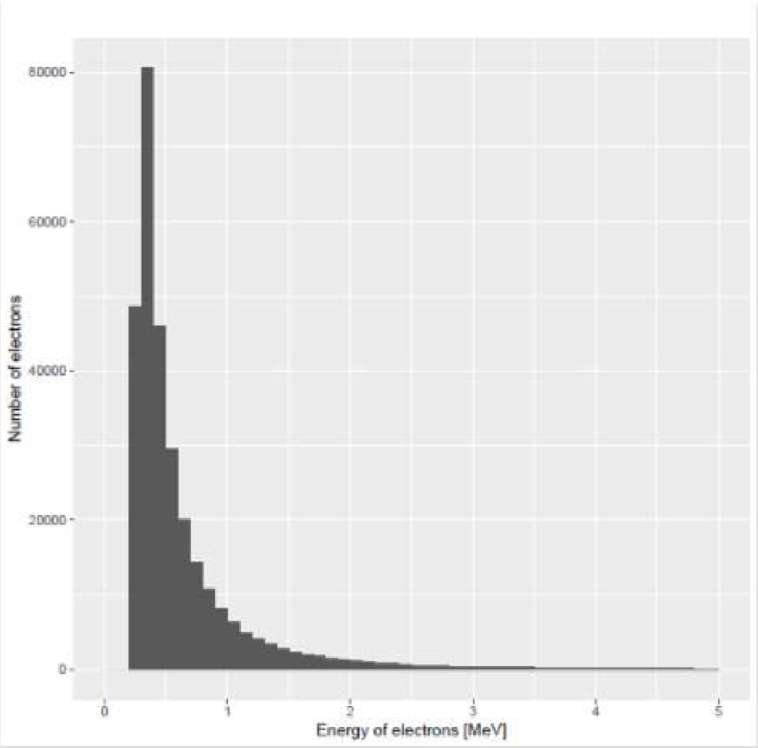

Figure 5.2. Number of electrons compared with their energy.

In the picture above there is presented an energetic spectrum of so called electrons delta that are able to go through minimum 1 mm of ice of the thickness of 1 meter . Those electrons are able to go into a bubble in white ice. Just like muons, on the trace of such electrons can appear droplets of liquefied vapour. If inside such a bubble there is temperature for example -10°C, those droplets turn into ice.

We can imagine this mechanism as follows: muons and electrons while going through the bubbles of saturated vapour cause the condensation of vapour on the trace of particle (similar effect like in Wilson's Chamber) and its freezing. This process lasts until most of the vapour is condensing and its freezing. In cracks the process can be similar, if there is saturated water vapour. If not, it is possible for water molecules from the surface of rupture to sublimate and to fill the crack.

In the case of hydrate of air crystals, they may break down and release air.

6. Planned experiment

Experiment details:

- Ice blocks in the size of 1 m x 0.2 m x 0.2 m, source of light, photomultiplier, measuring detector of number muons or protons and pions, (ice during the experiment must be kept low temperature to prevent melting of the ice). In order to obtain low temperatures, similar to those that prevail inside glaciers, you can cover our block of ice with blocks of dry ice.
- The measurement with lead layer on top of ice (the imitation of pressure in glacier)
- Proper conditions need to be ensured to upkeep constant temperature during the experiments.
- The use of dry ice - It's being planned to expedition to Mars in order to rebuild its atmosphere. Cosmic-ray protons and nucleons will interact with the atoms in the Mars atmosphere. Produced pions will decay into muons. The stream of muons will increase proportionately to the increasing thickness of the atmosphere of Mars . The muons will also permeate the CO_2 glaciers on Mars. What could be the outcome of that?
- In addition to measurements concerning the role of muons to structural changes in glacial ice at large depths, we plan to perform the exposure of the ice block at low depths with a mixed beam of protons and mesons produced in the interaction of protons with the target. In this way we want to recreate what is happening in the ice at small ice depths. At low depths, the ice density is small, around 0.8 g / cm^3 for depth around 90 m. This means that at these depths we have ice (firn) with a large number of bubbles filled with water vapor next to the air.

7. Expected results

- If irradiation of ice with particle beams will cause ice cracks to seal and air bubbles disappear, then the absorption of light should be gradually reduced (the light stream reaching the photomultiplier and its signal should be higher and higher). We should easily measure it.
- If irradiation of the ice with a muons beam will cause changes in the crystals of the air hydrate, then the absorption of light may also change (the hydrate cell will be destroyed).
- It may be possible to record the change in humidity in the ice gap using a humidity sensor (we tested the effect of this sensor in firn).
- Which role (if any) will the muons play while passing through the dry ice glaciers on Mars? We would like to measure this by replacing a block of ordinary ice with a block of dry ice.

Sources of pictures

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Pictures not specified above were created by authors.

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