**Snow measurement methods intercomparison and nature-based solutions in avalanche prevention in Iceland**

STSM, Iceland

3-24 February, 2018

Katalin Gillemot

The proposed STSM had three main objectives: i) to complement the COST ES1404 HARMOSNOW Action field campaigns with new measurements, ii) to investigate possible research into nature-based solutions for avalanche risk reduction and iii) to generate video material for the dissemination activities of the COST ES1404 Action. For this purpose a visit at Reykjavik University in February 2018 for the period of three weeks was conducted.

The primary objective of the STSM was to complement and support the intercomparison efforts on manual snow density and snow water equivalent (SWE) measurements done within the HARMOSNOW network. The analysis of the results from the previous field campaigns conducted in Iceland (2017) and Erzurum (2016) concluded that in order to get more comprehensive results and a systematic understanding on the error induced by the different devices (or observers) more data would be necessary. Within this STSM specific snow measurements were repeated/carried out in order to fill some existing gaps, complement and increase the available dataset for the instrument intercomparison. The exact measurement details were worked out in collaboration with the leading researchers of this task, namely Leena Leppänen, Juan Ignacio López Moreno, Pavla Dagsson Waldhauserova, Ladislav Holko and David C. Finger.

4 full fielddays were carried out within this task. From these on one day ($15^{th}$ of February) students from Reykjavik University (enrolled in the course of David C. Finger) have also participated in the field campaign to do extra measurements on snow depth.

The measurements were carried out at 4 different locations due to the varying snow conditions. From these two were close to Reykjavik, one up in Northern Iceland and one in South-West Iceland. Detailed data of the sites will be available in the final report on the measurements. At 2 of the sites only density measurements were carried out, while at the 2 other sites only snow depth was measured. At all 4 sites a snow pit was dug to measure detailed parameters of the snowpack (thickness, temperature, density, crystal structure for each layer, etc.). Altogether 3 different snow coring tubes were used for the density measurements. Originally the use of 5 different instruments was planned, but due to some unforeseen issues one didn't arrive, while one other was broken during the measurements (due to the plastic aging).

The weather was very unfavorable, as right after our arrival a big rain followed by warm weather has washed over the country and had melted much of the snow, especially in the South-Western part of the country. This was followed by some snow events, however these were once more followed by heavy rain. This has left quite a small weather window for the measurements. The situation was also further aggravated by the fact, that where the snow hasn't fully melted, it ended up -after several melt-freeze cycles- with a 12cm thick hard crust, that even the most versatile Federal sampler was not able to penetrate through with any normal force applied. This has meant that doing the originally planned experiments with the instruments by sampling the average snow density down to the ground became nearly impossible (we didn't dare to risk applying a too large force as due to the number of measurements planned this may have meant breaking one of the instruments or doing measurements with a huge error). This has led us to redesign the original experiments to match the current circumstances, so we made an intercomparison where each instrument was used to sample the same depth of snow each time. As at both testsites for the density the uppermost 50-60cm of the snow was above the frozen layer, we did comparison between the instruments when only sampling the top $h$ cm ($h=20, 30, 40, 50$) of the snowpack. At each testsite for each depth with each instrument 5 measurements were carried out, adding up to 100 measurements altogether. The testsites were chosen to be flat spaces with a size of ca. 5m x 5m, and the distance between the measurements was 50cm. All measurements were carried out by a single person.
At each measurement the tube was penetrated very slowly and very carefully into the snowpack (in order not to squash the snow beneath) until it has reached the required depth (the depth was always measured by the scale on the side of the instrument). Once at the required depth, the tube was very carefully excavated on one of its sides, and then a very thin metallic plate was pushed under the instrument in order to separate the snow inside the tube from the underlying snow layer. Once the tube was excavated, it's weight was measured by the scale belonging

to the instrument, or in some cases with both the scale belonging to the instrument and a scale belonging to another tube.

Figure 1. shows the measurement results for the average snow density, while Figure 2. shows the SWE. The points on both curves are the average of the 5 measurements carried out with the same instruments, while the error bars correspond to the standard deviation of the average calculated from the 5 measurements (multiplied by the value of 1.15 for $t$ due to the low number of measurements with each instrument). Loc1 and Loc2 mean the two different locations used for the density measurements, while 20-50cm are the different depth tested.

If we compare the different instruments (measured by their own scales) at each location and depth (green, blue, purple dots) we can conclude the following: there is a significant difference in the results, however -even though to some extremes- but all results are within the error bars. Also as noted elsewhere in the literature for the Federal sampler the less the snowdepth is, the larger the error gets. This is however not the case for the Hungarian sampler 2, that has a diameter similar to that of the Federal sampler. This implicates that the errorsource may not be as simple as the diameter, and the situation may not be simply solved by using long tubes for deep snowpacks, while thicker tubes for shallower snowpacks.

Furthermore we can also clearly see that if we use different scales to measure the same weight we get highly differing results, and this is especially so in the case of the Federal sampler. Here one should note that the Hungarian scale is used to measure the tubes at their end, and not in the middle as with the scale of the Federal sampler. However if we compare the results measured with the same scale but different instruments we can see that the errors are always consistent and it's also the largest if we measure the Federal sampler with the Hungarian scale. Hopefully this means that the error induced by the scaling method is the smallest when each instrument is used with it's original scale. The results also highlight, that the scale induced error is valid and relatively large, but is a consistent error source, meaning that the variance in the results can't only come for the scaling method, but is as suggested a mix of all sorts of erros sources.

Further analysis of the data and the results of the snow depth measurements will follow in the final report to Leena Leppänen.

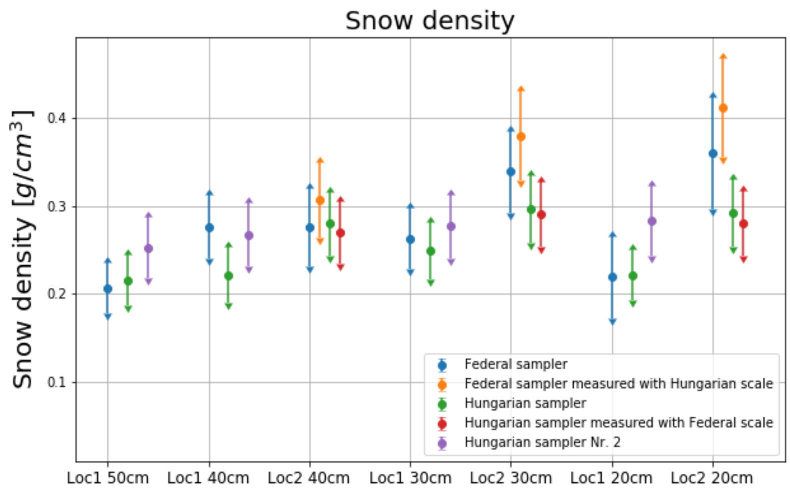


***Figure 1.*** *Average snow density at the different testsites and for different snowdepth measured*

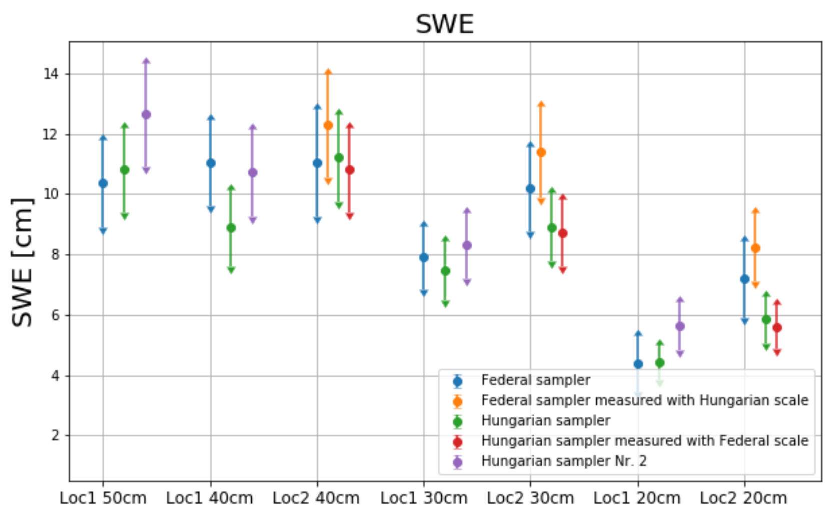


***Figure 2.*** *SWE at the different testsites and for different snowdepth measured*

The second objective of the STSM was to determine the effect of the Icelandic forests on the stability of the snowpack. In Iceland only 1.5% of the area of the country is forested, however these are in numerous cases considered as defenses against avalanches. These forested areas are usually neighbored by open areas that have the same elevation, aspect, slope angle and large scale wind patterns as the forests itself, meaning that comparing the snow stability in the open areas next to the forested areas and inside the forested areas could gain us very valuable insight into how do forests influence the snow stability. However the weather was not in favour of the measurements. The original idea was to make the measurements in South-West Iceland, however the large rain just on the second day of the campaign has melted most of the snow in the lower regions where the forests are located. During the next weeks there was some snowfall, however it was not significant enough to build the interesting layering patterns for the measurements. Thus we have decided to move the measurements to the northern side of the country, where the weather was more stable, and there was more hope for snow. This has turned out to be true, however the considerable avalanche danger in the area and the very large winds only allowed us to make a very small number of measurements in the 4 days spent there. Thus in order to answer the original research question and to get more reliable results we will need to do further measurements in the future. However in order to answer the question from another perspective we have started to analyze and find the correlation between GIS based data on the vegetation cover with the data on reported avalanches collected by the Icelandic Met Office. Currently we are working on using GRASS GIS and specific statistical methods in order to find possible correlations between the local vegetation cover in specific areas of the country and the recorded avalanche path.

The third aim of the STSM was to make small videos on the measurement procedures applied within the STSM. This was done in cooperation with dr. Glenda Garcia-Santos from Alps-Adria-University in Klagenfurt. During the field campaigns short videos on both the SWE measurements, on the snow stability measurements and on the student's field day were recorded. These are currently being edited and will be available later for the COST HARMOSNOW webpage.

Within the frame of the STSM I have also participated on the II. ICEDUST workshop (supported by COST HARMOSNOW) on the 14th of Feburary organised by Dr. Pavla Dagsson Waldhauserova, where we have presented the poster "*Pilot study to predict contamination drift on snow surface*" (Garcia-Santos, G., Piz, J., Gillemot, K., Dagsson, P., Meinander, O., Djordjevic, D., Finger, D.). Furthermore I have have presented a lecture at the Reykjavik University on SWE measurements for 3rd year Environmental engineering students, followed by helping out in their field day on the 15th of February. During my stay we have collected snow and water samples from 10 different locations for impurity analysis for Dr. Dragana Đordevic from Belgrade University.