ABSTRACT: A small innovation company in Iceland, POLS Engineering, has developed the SM4 automatic snowpack sensor that is currently installed at over 30 locations in Iceland and Norway as a tool for avalanche forecasting. POLS and the Icelandic Meteorological Office are collaborating in the development project Fjallasnjórar (e. Mountainsnow) on further developing the instrument and the utilisation of data for avalanche forecasting. Within the project, new methods of installation in avalanche starting areas are being tested, the snowdepth algorithm is being improved, a method of monitoring the crystal growth rate in the snowpack is developed, and the control unit of the SM4 has been improved to allow for data transfer independent of GSM coverage as well as connection with other instruments such as anemometers.

KEYWORDS: avalanche forecasting, snow sensor, automatic warnings, snow crystals, snow depth, facets

1. INTRODUCTION

The SM4 automatic snowpack sensor has been developed in Iceland and is currently installed at over 30 locations in Iceland and Norway. The goal was to develop an instrument that is robust and simple to install, and provides important information for avalanche forecasting (Ingolfsson and Grimsdottir, 2008 and 2012).

The instrument consists of thermistors mounted with a fixed interval on a pole. The basic output is a temperature profile and the snowdepth is calculated with an algorithm that distinguishes buried thermistors from the ones in open air based on fluctuations in temperature. The results are displayed in a user website, www.snowsense.is, where the visualisation of data is under constant development with the user in mind.

The Icelandic Meteorological Office (IMO) and POLS Engineering are currently collaborating in the development project Fjallasnjórar (e. Mountainsnow) on further developing the instrument and the utilisation of data for avalanche forecasting.

2. INSTALLATION IN HARSH CONDITIONS

Real-time data on snow, directly from the avalanche starting areas, are highly relevant for avalanche forecasters. Installation of instruments in steep slopes high in the mountains can be problematic since they may be exposed to icing conditions, high wind speeds, snowcreep, snow avalanches and rockfall.

Technical solutions of installing relatively light poles in mountainous areas are being developed within the Mountainsnow project. The Icelandic Meteorological Office monitors snow accumulation and avalanche danger above settlements in Iceland. One of the tools are 4.5 m long wooden poles that are installed vertically within avalanche starting areas, covered by white and blue plastic tubes. Steel wire stays are used to stabilize them. The snowdepth is read manually with binoculars. Simple poles like these can be used to install the SM4 snowsensor.

The experience with the wooden poles is quite good, they are inexpensive and only require manpower for installation up in the mountains. The biggest problem, however, is that both the wood and the steel wires are relatively stiff. If the deformation due to e.g. snowcreep and avalanches is too big, the poles or the wires tend to break. In addition, they are sometimes damaged by rockfall and strong winds.

Within the project, experiments are done on increasing the flexibility of such simple installations.
Foundation made of a strong metal spring bolted to the ground, with a flexible pole (such as a wind-surf mast) attached to it, have shown promising results. The masts are in some cases mounted down with two wires that may be equipped with smaller springs to increase flexibility. However, the system should not be too flexible because the mast will then give in to snow creep and lie down horizontal under the snow, making it useless. Ideally, it should be just flexible enough to give a little in to snow creep and other forces rather than breaking, but always returning to the original position.

3. IMPROVED TECHNOLOGY

3.1 Connection to anemometer

Within the Mountainsnow project, the SM4 control unit has been modified to allow for connection with other instruments, such as anemometers. SM4 sensors with anemometers of common types, such as Young, have already been installed in a few places. The best experience has been with relatively small anemometers with black coating that resist icing. Since the idea with SM4 is to have a simple instrument that can be installed in the backcountry and is not power-intensive, a heating system is not considered an option in most cases.

A new type of ice tolerant wind sensor is also being developed and tested within the project, with the needs of avalanche forecasters in mind. SM4 sensors with anemometers can obviously not be attached to a flexible foundation, since the anemometers require a stable position.

3.2 Data transfer

The SM4 sensor currently uses the GSM system to transfer data. The GSM coverage is constantly improving and, in most cases, this solution works well. However, places are still found without GSM coverage, especially in vast backcountry areas. The new version of the control unit also makes it possible to use methods independent of GSM for data transfer, and such instruments are under development.

4. UTILISATION OF DATA

The basic data output from SM4 is a temperature profile with either 20 cm or 10 cm interval. An algorithm distinguishes buried thermistors from the ones in open air based on fluctuations in temperature. The algorithm has been further developed within this project using different methods, including statistical methods. An improved data collection unit also makes it possible to increase the data processing within the instrument itself and to
have greater temporal resolution of data, making it possible to improve the algorithm.

Since the basic data from SM4 consist of a temperature profile, it gives the option of automatically monitoring the temperature gradient in the snowpack. The growth rate of crystals depends on the temperature gradient. The critical temperature gradient to produce faceted forms in alpine snow is about 10°C/m; below this value rounded forms tend to appear (McClung and Schaerer, 2006). The degree of faceting is calculated with empirical laws that were developed for the Crocus snowmodel (Brun, David, Sudul, Brunot, 1992; Vionett et al., 2012). Colored lines represent the degree of faceting in the snowdepth graph on the user interface at www.snowsense.is. The first attempt to indicate the likelihood of faceting was to let colored lines show up in the snowdepth graph when the gradient is above the critical value between two thermistors.

![Image: Example of data visualisation. The black line shows changes in snowdepth with time. Coloured lines show the degree of faceting between the thermistors, based on methods from the Crocus snowmodel.](Image)

4.1 **Automatic warnings**

No automatic method is known that performs better than an experienced avalanche forecaster, when it comes to predicting avalanches. However, tools for assisting forecasters in their decision making are important, and different ways to decrease the possibility of human errors are being used. Within the Mountainsnow project, the possibility of sending automatic warnings to avalanche forecasters is under development. When a threshold level of snowdepth increase or degree of faceting has been reached, the SM4 instrument can send a warning e.g. as a predefined text message to the cell phone of the avalanche forecaster. The threshold level is different from place to place and should be defined by the user. For some locations in Iceland, a threshold level of snowdepth increase of 50 cm/24 hrs may be used as a rule of thumb in avalanche forecasting, when predicting large natural storm snow avalanches.

5. **SUMMARY**

Real-time data from avalanche starting areas are a valuable input to avalanche forecasting. The Mountainsnow project deals with methods and technical solutions of installing snow sensors in steep mountain slopes and utilising the data in best possible way for avalanche prediction.

6. **ACKNOWLEDGEMENTS**

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**REFERENCES**


