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Brief communication "Snow profile associated measurements (SPAM) – a new instrument for quick snow profile measurements"

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Abstract

A new instrument concept (SPAM) for snow profile associated measurements is presented. The potential of the concept is demonstrated by presenting preliminary results obtained with the prototype instrument. With this concept it is possible to retrieve rapid snow profiles of e.g. light extinction, reflectance, temperature and snow layer structure with high vertical resolution. As a side-product, also snow depth is retrieved.

1 Introduction

Snow profile measurements have been time-consuming work requiring a snow-pit. Traditionally the data has been collected from distinct depths of the snow-profile wall with a limited vertical resolution. The presented instrument concept makes it possible to collect data rapidly with high vertical resolution without the need of laborous snow-pit excavations. As a profile can be measured in a short time, it is possible to make more measurements to cover the area well to gain information on spatial variability of each measured variable. As the measurement disturbs snow relatively little, collection of time-series from each spot give more natural results.

2 Instrument concept

The idea of the instrument is to obtain snow parameters from the snow-pack easily in short time and with good vertical resolution and repeatability without disturbing the snow as much as is done with traditional snow-pits.

SPAM consists of a shaft, sensor section at the lower-end of the shaft, and a processing and logging unit with range sensor at the top. For low density snow, a thin board is used on top of the snow to give better signal for the range sensor. This basic structure is shown in Fig. 1. The sensors are mounted on the side of the shaft. In some applications (e.g. light extinction, PAR measurements) this needs to be accounted for

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to retrieve the true hemispherical downwelling values. For temperature, reflectance profile and layering this viewing geometry is ideal.

The principle of the instrument is simple:

1. Push the shaft of the SPAM vertically through the snow to the ground level, if applicable.
2. Switch on measurement.
3. Slowly raise the instrument to collect data from the profile.
4. Place the instrument to touch the snow surface or board used as reference level.
5. Switch off data collecting.

The vertical resolution depends on the rate of ascent by the operator, and the sensor reading speed. The temporal sampling interval depends mainly on the sensors that are used. For example, the readout from the acoustic range detector used in the prototype can take up to 10 ms in the case of missing return signal, and for extreme distance (at the level of the snow surface) the two-way time needed is around 6.7 ms. Assuming sampling every 20 ms and a moderate lifting speed of one meter in ten seconds, the average vertical resolution would be 2 mm. For most uses, this gives the possibility to average the data to gain better signal-to-noise ratio with a cost of slightly lower spatial resolution.

2.1 Prototype instrument

The structure of the prototype instrument is shown in Fig. 1. The main parts are 1.1 m long steel shaft, sensor unit at the end of the shaft, and the processing unit at the top with processor, logger, GPS, depth sensor and controls.

This prototype was assembled to test the feasibility of the idea with cheap components and sensors that seemed applicable. The instrument was first tested on 2010

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RASCALS-expedition (Riihelä et al., 2010) at Summit, Greenland. Due to some design flaws, such as missing automatic gain-control of the irradiance sensor, and high amount of other work, only little data were collected. This version also needed a laptop to record the data. The next tests were done in Helsinki, Finland with a refined instrument with AGC for the irradiance sensor and internal data logger fully functional. The sensors and hardware are shown in Table 1.

The logger unit is connected directly to the processing unit, and acts also as a pin-replicator. Also a GPS module is connected to the logger, but the processing unit does not have enough system resources left to process the data. A simplified GPS library and more powerful processing units will be investigated for the next instrument version.

The sensor protocols are simple. The output from the irradiance sensor is a simple pulse, with a pulse length relative to observed irradiance. There are three different sensitivity settings and four scaling factors for the output frequency. With the later, the output signal frequency can be scaled to be within a range readable by the processor. Pulse length is converted to irradiance by

$$I = 100\frac{100}{S}\cdot\frac{f}{R} = 100\frac{100}{S}\cdot\frac{D}{2\tau} \qquad (1)$$

Here S is sensitivity, $R = 0.77\,\mathrm{kHz/(\mu W/cm^2)}$ sensor responsitivity, $f = Df_{\mathrm{out}} = D/(2\tau)$ is de-scaled frequency, D is output frequency scaling factor and τ is length of the output pulse.

The infrared thermometer is connected via SMBus protocol, and the temperature is retrieved in binary format. The emissivity can be adjusted for conversion to physical temperature, but this has not been done and the conversion has been left for post-processing, if seen necessary.

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2.2 Sensors for diverse snow parameters

2.2.1 Snow depth

By far the simplest snow variable to measure is depth. As the length of the instrument, d_0, is constant and known, only one distance is needed:

$$d_{\text{snow}} = d_0 - d_{\text{meas}}. \quad (2)$$

Here d_{meas} is the measured distance between the snow surface and the range sensor. By averaging several samples from one measurement, the random errors (wind, moving snow) can be reduced. This can be done in the beginning of profile measurements. In the case of low density snow, a board is used under the range sensor to give better response. Sturm (1999) presented a self-recording snow depth probe, which incorporated a sliding attachment. The position of the slider was used to give the snow depth. Similar slider was considered also for SPAM, but was not adopted due to possible obstructions to irradiance sensor near the surface, and mechanical difficulties that might have ensued in difficult weather conditions.

2.2.2 Temperature

To retrieve snow temperature, an infrared thermometer can be used. As the IR-thermometer measures brightness temperature, infrared emissivity needs to be used to convert to physical temperature. Thermal emissivity of snow varies between $\epsilon_{\text{snow}} = 0.96 \ldots 1.0$ depending on the grain-size, water content and wavelength, Dozier and Warren (1982). For a broadband sensor, the effective emissivity is controlled mainly by the central wavelength and width of the used band, and a constant value of $\epsilon_{\text{snow}} = 0.99$ can be assumed to be representative for most snow conditions and snow types. Alternatively, the brightness temperature measurements can be combined with measurements of physical temperature to retrieve the true thermal emissivity.

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2.2.3 Light extinction and snow reflectance

For light extinction, some additional calibration is needed, as the viewing geometry differs from the hemispherical measurement of downwelling irradiance. Figure 2 shows one comparison, but further tests are needed to find a general correction method.

With addition of light source, the measurement can be switched from passive to active. By alternating between the passive and active measurement modes, the solar illumination can be reduced from the active measurement, and the resulting relative reflectance of the snow profile should reveal snow layering: different snow types, freeze-melt crusts and ice lenses. With careful calibration, e.g. by comparing against spectrometer reflectances of the spectral band of the used light source, also the absolute value of snow profile reflectance should be possible to be calculated from the relative reflectance values.

3 Preliminary results

In this paper, only some preliminary results are shown. A more detailed study will be made later when there is more data available for analysis.

Figure 2 shows the measured light extinction in snow. The data were measured on 31 March 2011 on a small grass field next to the FMI head-quarters in Helsinki. The snow was hard and thoroughly wet, and the melting was well underway with the snow saturated with water during the afternoon. In Fig. 2, there are three types of irradiance measurements. The solid black lines present eight continuous profiles measured in the way described in Sect. 2 , with the data averaged over one centimeter increments. The red circles show the measured irradiance when the sensor has been inserted horizontally into snow from a snow pit with the sensor pointing upwards. The magenta crosses are measured similarily but with the irradiance sensor pointing horizontally towards the Sun azimuth, ie. otherwise with the same geometry as the profiles, but with the shaft now horizontal. The shift in intensity levels between the profile measurements (black solid lines) and the static horizontally made measurements (magenta crosses) are most probably due to ligth reflecting from the metal instrument shaft, so that there is more light present on the sensor side when the instrument is in vertical orientation, like in Fig. 1. This hypothesis has not been tested yet, but will be during the next snow season.

All the data are scaled with the average value of two measurements of irradiance incident on the snow surface, measured before and after the downwelling extinction and profile measurements. The x-axis is logarithmic. Based on these samples, the light extinction in snow is exponential, apart from the top few centimeters and the deepest parts. In the top layer, the non-exponential behaviour can be explained with the different extinction characteristics of different wavelengths, Warren (1982). A large error source in the top layer is light leakage through a gap between the shaft and the snow. This gap can open when the instrument is raised and the shaft occasionally tilts out of vertical. At the bottom, there are also two main contributors: low dynamic range of the sensor at low light levels, and obstructing vegetation on the ground.

The profiles in Fig. 2 were made with the accompanied blue LED alternating on and off between successive measurements. In that, only the measurements with LED off were used. From these measurements, the reflected part can be retrieved by subtracting the background irradiance (LED off) from the active measurement (LED on). As the light source and the irradiance sensor are not at the same spot, a transfer function is needed to retrieve the actual snow reflectance. This is left for future studies.

In the SPAM prototype, the readings from the infrared thermometer were rendered useless by the steel shaft which conducts heat well. The heat exchange between the instrument and snow changed the snow temperature, but also caused temperature gradients within the thermometer yielding erroneous readings.

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4 Conclusions and discussion

A new instrument for snow profile measurements is presented. The data acquisition is fast, and with later incorporation of GPS location and time, the data will be fully referenced without extra paper logs. The data are stored in easy-to-use text format on a standard SD-type memory card, which can be read without removing it from the instrument.

The results so far are encouraging, albeit some of the measurements have not been proven feasible yet due to non-ideal design. The measurements of snow depth are rapid and repeatable. For light snow, a thin board or similar should be used on the surface to give a good solid target for the ultrasonic range sensor. Without a good return signal, none of the measurements would have a reliable depth reference. Light extinction profiles show expected exponential behaviour below the top-most layer, but some additional calibration and tests are needed to achieve high absolute accuracy.

For the next version of SPAM, some changes are proposed based on the experiences gained so far with the prototype. Instead of steel shaft, a suitable plastic material will be used, so that the temperature data quality would be guaranteed. Also the infrared temperature sensor might need to be upgraded to a model, which has compensation for the internal temperature gradients. To enable the already present GPS, the software library that handles the GPS data stream needs to be made smaller, or the processing board needs to be upgraded to a version with more work memory. The position of the LED will be changed to be at the same level as the irradiance sensor so that the changes in the reflected (and scattered) light will reveal the horizontally oriented layers much better compared to the current vertical positioning, as the illuminated and measured areas would be almost at the same level.

One of the fundamental properties of snow is density. As the speed of sound varies with density (and structural stiffness of the material), acoustic sounder could be used. Marco et al. (1998) conclude their research on acoustic impedance of snow versus density that the measurements of natural snow for density retrievals are difficult at

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best. Later work by Kinar and Pomeroy (2009) describe an acoustic sounder that can be used to determine snow porosity, and therefore density, for each layer of the snow pack with the instrument located on top of the snow. The biggest errors arise when the snow is very wet and liquid water fills the snow pores. Also the underlying vegetation caused significant errors in the lowest layers, and thus also in the overall snow depth that was otherwise retrievable. The applicability of snow density measurements using acoustic sonar with SPAM concept is to be investigated.

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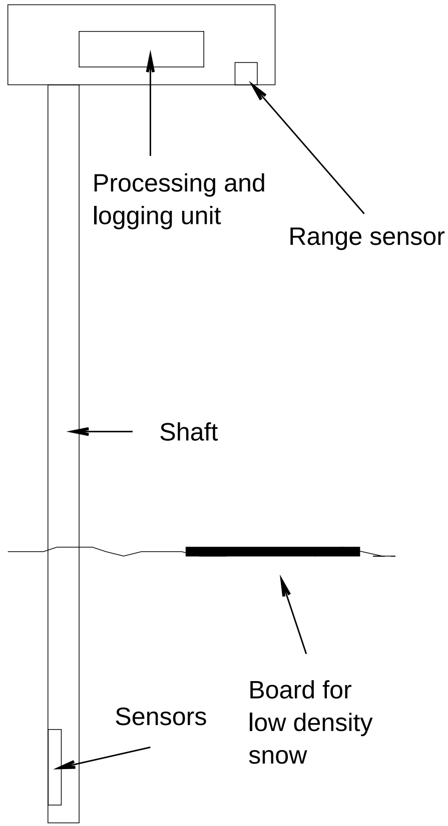

Fig. 1. Basic structure of the SPAM instrument.

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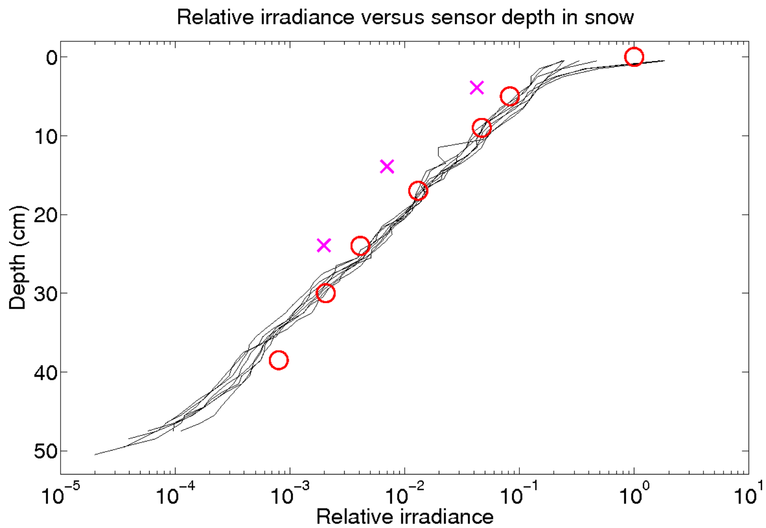

Fig. 2. Light extinction in snow. Black curves: vertical profile measurements, red circles: down-welling irradiance (sensor pointing up, shaft horizontal), magenta crosses: down-welling irradiance (sensor pointing horizontally, shaft horizontal).

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Table 1. Hardware and sensors used in SPAM prototype instrument.

Part	Model
Processing unit	Arduino Duemilanove
Logger	Arduino GPS shield
GPS	USGlobalSat EM-406A (SiRF III)
Height sensor	Parallax Ping ultrasonic range finder
Irradiance sensor	TAOS TSL230R-LF
Light source	Blue (460 nm) LED
Infrared thermometer	Melexis MLX90614ESF-AAA

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