Recent technical developments at the IMAU: a new generation of AWS and wireless sub-glacial measurements

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Introduction

Two technical developments are presented: a new generation of AWS and a wireless subglacial measurement system. Both systems build on the experience of the IMAU in developing GPS systems (Den Ouden *et al.*, 2010). Combining methods to minimize energy consumption and wireless communication form the basis of the new systems described here.

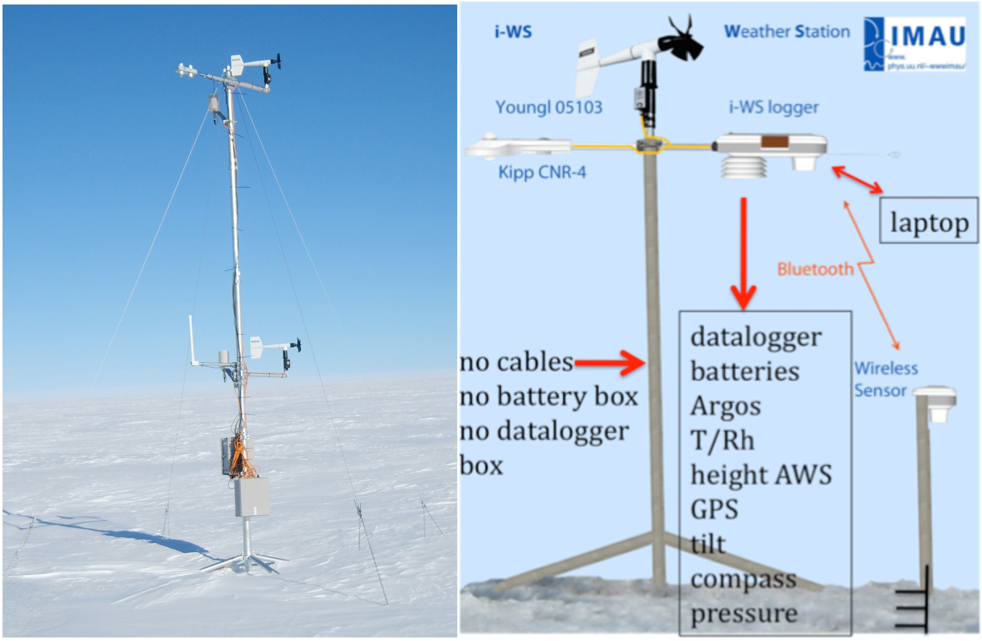
A new IMAU AWS

The current AWS design originates from the early nineties, and its success is for a large part based on the use of lithium batteries and Campbell dataloggers. Currently the IMAU operates 18 AWS on glaciers (Antarctica 9, Greenland 4, Norway 3, Svalbard 1, Switzerland 1). An AWS typically is powered by 96 lithium batteries for 3 years of continues operation. The transportation rules for these batteries become increasingly strict and their cost price is high. Additionally, Campbell Scientific recently stopped producing the CR10X datalogger which is used in all IMAU AWS. In the light of these developments, the rising costs and problems with the uniformity and the operation and maintenance of an increasing number of AWS, the IMAU decided to start the development of a completely new type of AWS.

The core of the new AWS design is an IMAU developed logger unit that is customized to our requirements. Its main characteristics are minimal energy use, small size, wireless communication and easy handling. In Figure 1 the current and new AWS design are compared.

The logger unit is small (dims. 18x32x12 cm) and integrates the energy supply (2 batteries, a capacitor and a small solar panel), the datalogger, Bluetooth for wireless communication and ARGOS communication electronics. Furthermore, it includes sensors for temperature, humidity, pressure, GPS (time and position), tilt, compass and instrument height. As with the current AWS, ablation and possibly sub-surface temperatures are measured at a separate stake. The new AWS uses Bluetooth instead of a cable for the data transmission. In Figure 2 a schematic diagram of the logger unit and part of its internal components is shown.

A complete AWS of the new generation constitutes a logger unit, a Young wind vane, and a KIPP CNR4 radiation sensor all fixed to a single



a. **b.**

Figure 1. a) The current AWS design that is used in Greenland (two measurement heights). Close to the surface the datalogger and battery box are fixed to the mast while all instruments for wind speed/direction, temperature/humidity and radiation are fixed at the two mast extensions (2 and 5 m high). The lower mast extension also carries an antenna for ARGOS data transmission. b) The new AWS design has one mast extension at 4 m height carrying all instruments, cables, ARGOS antenna, datalogger and batteries. If needed, a second sensor arm can be attached.

mast extension (Fig. 1) that fits in a standard Explorer case. The new design maintains the currently used 4-legged foot with telescopic pole that is used for the current AWS. Replacement of the complete AWS instrumentation is therefore much faster and easier than with the current design, while Bluetooth allows wireless data transfer between the logger unit and e.g. a laptop. Fast sampling of wind speed and temperature (using an additional thermocouple) are also foreseen, allowing the derivation of turbulence fluxes using the variance method (De Bruin and Hartogensis, 2005). A field experiment is currently carried out to assess the quality of this method for use with AWS data.

Current status of the new IMAU AWS

At the moment single logger components are tested and a complete version of the new logger is expected to become available in the spring of 2012, if funding is obtained. First tests are foreseen in the Netherlands and Switzerland (Morteratch Glacier).

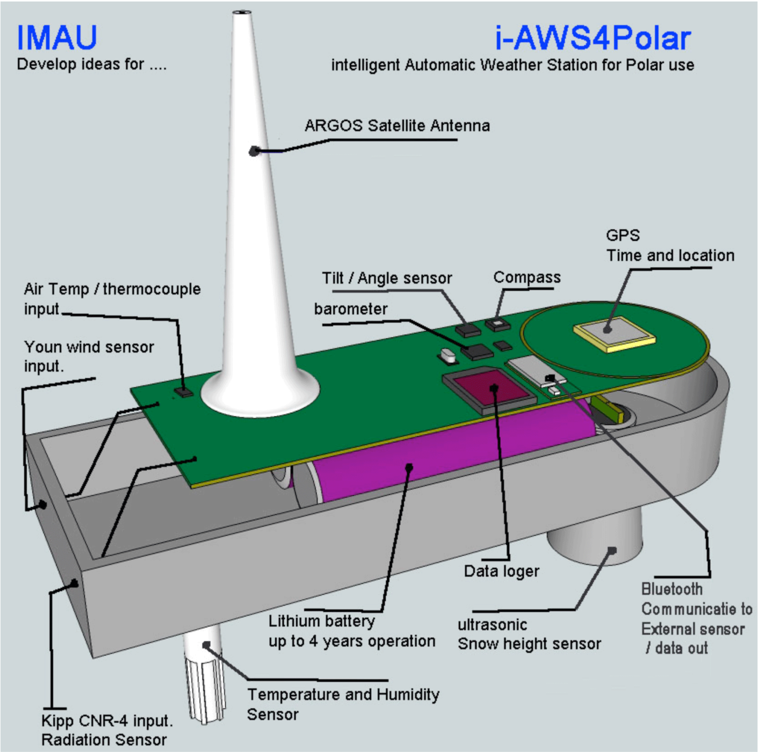


Figure 2. Detailed schematic of the logger unit and its internal components.

A wireless subglacial probe system for deep ice applications

Another technological development at IMAU concentrates on englacial measurements in ablation zones. A problem with this type of measurements is that the internal shearing may corrupt electrical cables preventing long term observations at depth. Here, we present the design and first results of a wireless subglacial probe system that is able to transmit data through at least 600 m thick ice without signal cables running from the instruments to the surface. The motivation to develop this type of system originated from the study of the role of surface melt water in the dynamics of ice sheets and ice caps. Melt water percolates in the snow and firn in the accumulation area, where it partly refreezes. In the ablation area, the meltwater partly runs off at the surface and partly reaches the glacier base through crevasses and moulins, where it has the potential to increase basal sliding via increased basal water pressure. Recently the role of melt water has been identified as influencing the motion of larger ice caps and even ice sheets in Iceland, Svalbard and Greenland (e.g. Zwally *et al.*, 2002; Van de Wal *et al.*, 2008; Benn *et al.*, 2009; Sundal *et al.*, 2011). At present, a lack of information on subglacial water pressure hampers a better fundamental understanding of this process and its importance for the long term evolution of the ice sheet.

The wireless system is designed to penetrate through thicker ice (up to

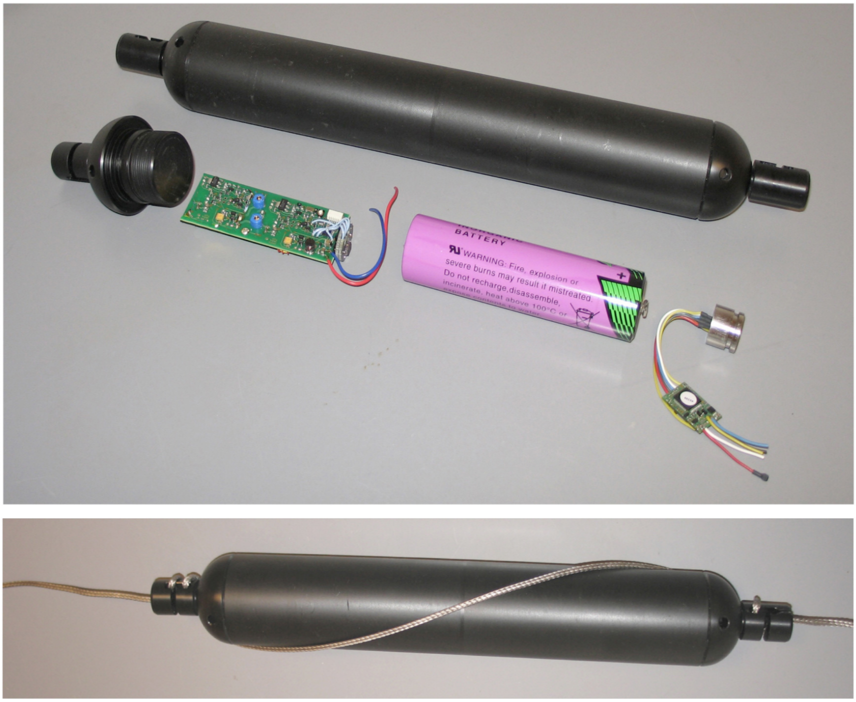


Figure 3. a) A probe and its internal components (the transmitter, lithium battery and a pressure sensor) and b) a probe attached to the 3 mm kevlar rope.

about 1000 m) than previous systems (Harrison *et al.*, 2004; Hart *et al.*, 2006). The receiver/datalogger system is mounted on a small 4-legged mast that stands freely on the ablating ice surface. This is in contrast to previous wireless systems which installed their receiver somewhat below the ice surface while it was connected via a serial/power cable to the datalogger at the ice surface to avoid signal losses occurring in the upper part of the glacier resulting from the presence of liquid water.

Figure 3 shows the internal components and the connection to the kevlar rope that is used to lower the wireless probes in a hole. The upper panel displays the custom made black housing of the probe and its internal components. The housing is composed of the technical plastic Delrin®. It has high mechanical strength and rigidity, excellent resistance to moisture and has a wide end-use temperature range. The housing of the prototype has an outer(inner) diameter of 50(40) mm, a length of 350 mm and was designed to resist 200 bar of pressure. The probe contains three main components (upper panel, Fig. 3) with, from left to right, the 100 mW transmitter working at a frequency of 30 MHz, a lithium battery (3.6 V, 35 Ah, Tadiran batteries), and a pressure transducer (working range 0-100 bar, maximum peak pressure 300 bar). The energy consumption of the wireless probe is minimized and continuous operation can be maintained for more than 5 years, while measuring and logging data every 2 hours. The current prototype of the probe contains 1 sensor at a time but future versions are foreseen to include multiple sensors. The probe is attached to a 3 mm kevlar rope that is used to lower the probes in a hole (lower panel, Fig. 3). At the outer ends of the housing rope clamps enable easy fixation of a probe to the rope.

At the ice surface, an antenna configuration is fixed horizontally to a wooden/plastic frame. The antenna is connected to the receiver/datalogger system, which is powered by a pack of lithium batteries and mounted on a small 4-legged mast. Currently, one receiver/datalogger system is able to monitor 32 probes simultaneously. Each probe sends out a coded set of real time data at approximately every 3 minutes (each probe uses a slightly different time interval). Once every 2 hours the receiver starts to gather the data from all probes during 10 minutes.

The test experiment was conducted at site SHR along the K-transect at Russell glacier in South-West Greenland near Kangerlussuaq, just north of the Arctic Circle. The K-transect was established in 1990 by the IMAU and currently constitutes eight locations with mass balance and GPS measurements and three locations with AWS; the latter have been operational since August 2003 (Van de Wal *et al.*, 2005; Van den Broeke *et al.*, 2009a). Location SHR lies about 15 km from the front of Russell Glacier and was chosen because there the summer speed-up is the largest along the K-transect (Van de Wal *et al.*, 2008). The experiment combined the measurement of subglacial pressure, surface velocity and surface melt water production with best possible precision at hourly resolution.

Two holes were drilled with the hot water drill from the Alfred Wegener Institute (AWI, Bremerhaven, Germany), to the ice sheet bottom in the marginal ice zone, approximately 620 m deep. In one hole, a wireless pressure and tilt probe were lowered to the base of the glacier, while a temperature profile consisting of 23 probes was installed at a distance of 1.5, 5.5, 10.5, 15.5 m and ongoing at intervals of 25 m from the base. In the second hole a wired pressure/temperature probe was lowered to the base for reference. Five GPS receivers were operated at and around the drill site, together with an automatic weather station (AWS). First data were retrieved in August 2010 and at that time the wireless system was still operating as it was left in July, receiving data from 26 wireless probes. The second dataset was obtained in June 2011 and showed that the receiver battery was drained in February 2011, but that all wireless sensors were still operational. During this last visit, batteries were exchanged and we hope to capture the remaining part of the melt season.

First results from the wireless subglacial system

Figure 4 shows the first results for the July-August 2010 campaign. We find good agreement between the timeseries of subglacial pressure measured by the wireless and wired systems. The absence of data gaps demonstrates that the wireless system is well capable of transmitting data continuously through at least 600 m thick ice, with only a limited number of

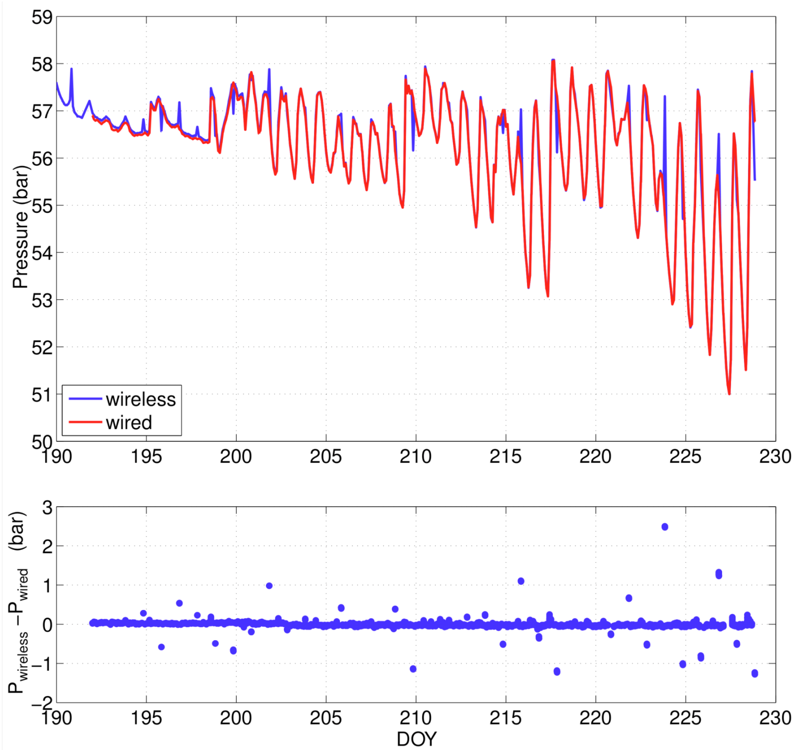


Figure 4. a) A probe and its internal components (the transmitter, lithium battery and a pressure sensor) and b) a probe attached to the 3 mm kevlar rope.

outliers. For a proper comparison, we only selected data that were simultaneously measured by both probes within a time window of 30 minutes. Hole 2 was approximately 22 m deeper than hole 1, and to correct for this we offset the wireless pressure data by +2.2 bar. The lower panel of Figure 4 shows the pressure difference; besides a few spikes in the wireless data set (less than 1%) the standard deviation of the differences between both timeseries is 0.2 bar including all spikes (or 0.05 bar excluding the most obvious spikes). The small random differences are probably to be explained by the subglacial pressure variations within the 30 min time window.

Current status of the wireless subglacial system

Future experiments will involve testing a modified version of the wireless system with higher transmission power (i1000 mW transmitter and a 400 bar probe housing) in the 3000 m deep drill hole at the NEEM site in June 2011, to obtain a maximum depth range for the wireless system. Furthermore, we hope to capture the 2011 melt season at SHR with the currently installed wireless system, together with simultaneous measurements of the surface velocity by GPD measurements and surface energy balance from a nearby AWS.

Acknowledgements

The development of the wireless probe system is part of research performed within ice2sea work package 2.2 and dedicated to the basal lubrication by surface melt. We acknowledge the ice2sea project, funded by the European Commission's 7th Framework Programme through grant number 226375, ice2sea manuscript number 037.

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