Modern mass balance observations at the Greenland ice sheet margin

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ABSTRACT: An automatic mass balance station (AMS) concept has been developed over the recent years and is continuously being improved. It is a system optimized for use at the GIS margin which is probably among the most difficult areas of the world to carry out ablation studies at a larger scale. We have eliminated the need for ablation stakes and instead use pressure sensors and strings. The combination of solar power supply and satellite transmission in principle makes the system fully automatic.

1. INTRODUCTION

1.1. *Background*

Studies of the climate system and particularly climate change are in focus presently. Glaciers are well recognized as climate indicators since retreat of glacier tongues indicates increased melting. An area of increased focus is the active role of glaciers and ice sheets on the global climate system. Particularly glaciers around the north Atlantic are interesting due to the deep water formation in this area. In this region the Greenland ice sheet (GIS) is by far the largest ice mass. On the GIS half the mass loss is by iceberg calving and the remaining half by surface melting. As opposed to the accumulation zone, which is nearly in balance the ablation zone particularly in the south show signs of thinning, which may increase the fresh water production Thomas et al. (2001). But, ablation observations are difficult to collect which is the reason for the sparse ablation observations from the GIS.

1.2. *Earlier methods*

The former GGU (Geological Survey of Greenland) and presently GEUS (Geological Survey of Denmark and Greenland) have been carrying out ablation studies for more than 25 years on the GIS. The studies were initiated by a need for hydropower investigations and later the studies shifted to climate related studies. In the early days monitoring along a transect across the ablation zone needed more than 10 man months for establishing by having three persons continuously in the field from May until September. And, the same staff was required during the following years to continuously collect data and maintain the profile of stakes.

1.3. *Aim*

Here we present the latest development in an automatic and cost efficient way of doing mass balance and surface climate observations. We have developed a fully automatic mass blance station (AMS). The system is fully automatic, self sufficient with power and uses satellite transmission back to Denmark. It can be transported by small helicopters and can be installed at the ice sheet margin in a matter of 1-2 hours. Such a cost efficient system is needed on order to enable ground monitoring of even parts of the Greenland ice sheet margin, which is approximately 5000 km long.

2. PHYSICAL SETTING AND SET-UP

Ablation rates on the GIS range from 1 to 10 meters of annul melting with a general decreasing trend to the north. Under low ablation areas such as in North-East Greenland a climate station can conveniently be mounted on ablation stakes which are drilled into the ice. However, in high ablation areas ablation stakes are not practical to use since the free melt result in bending and breakage of the stakes due to the persistent katabatic winds.

2.1 *Limitations*

Logistically the ablation zone belongs to the most difficult part of the GIS since walking distance is too long and a rough surface combined with frequent crevasses prevent both snow scooter operations and the use of fixed wind airplanes. Only small helicopters have proven practical to use, which are expensive in operations, have limited payload and volume capacity and are highly weather sensitive. For ablation observations at the GIS margin the following criterion have been identified:

- Component which are simple, cheap and easy to maintain.
- Dimensions which secures easy handling and transport with the smallest helicopters.
- Application of commercial standard components to the highest degree, which will be easily replaceable.
- The shortest possible installation time to optimize the efficiency in the field.

2.2. *Design of tower*

In the south where annual ablation rates can be as high as 10 meters per year the only solution for a stable station design is to have the station installed on top of the ice. A tripod design has been developed (fig. 1) with the use of a combination of 32 mm aluminum poles, 4 mm wires and “kee klamps” which connects poles and wires. The tripod is designed in the lightest and strongest way possible and a battery box hanging below it secures a low point of gravity nearest possible to the ice surface. On a horizontal bar at 3 m above the ice surface sensors are mounted for measuring the turbulent fluxes for the energy balance. For the radiation fluxes a lower bar at 1.5-meter elevation carries sensors for incoming long wave radiation, short wave incoming- and reflected radiation. During melting conditions the temperature of the ice surface, the vapor pressure and the wind speed is known. Hence for determination of the turbulent fluxes only one level of observations is needed.

A solar panel collects energy mainly in the summer period and a battery capacity of 75 AH secures storage sufficient for power consumption during the darker periods of the year. This combination secures a year-round power supply with no need for battery replacement or external recharging.

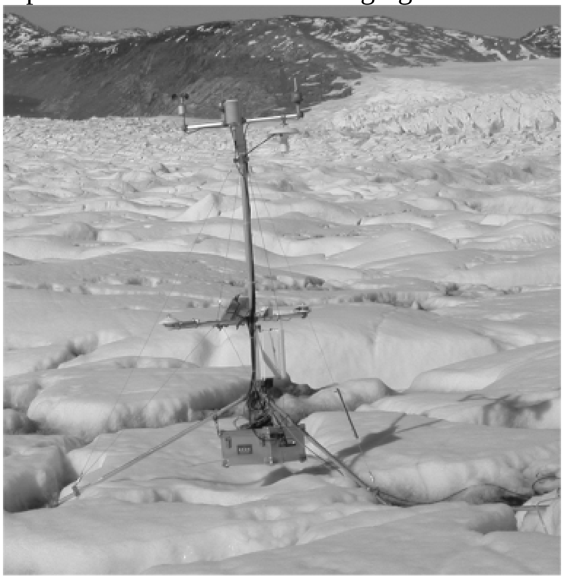

Figure 1. Station setup in the ablation zone of the GIS

All connections to the data-logger box are made by waterproof- and gold covered plugs. This greatly reduces the installation time and reduces the risk of making wrong or improper connections.

2.3. *Ablation sensor*

The system developed consists of a 14 mm diameter ventilated stainless steel pressure transducer (Ørum & Jensen, type NT 1400) (see Fig. 2) connected to a 12.8 mm diameter, fibre reinforced PVC hose filled with a commercially available 93% vol. alcohol/water mixture (Bøggild et al, accepted). The upper end of the hose is connected to a soft polyethylene bag (bladder) to prevent the mixture from evaporating and to catch the surplus anti-freeze during borehole freeze in. The system is lowered into a 25-mm.-diameter borehole and weighed down by a 1-kg iron rod. The polyethylene bag lies on the glacier surface. The pressure observed at the sensor is the hydrostatic pressure plus the atmospheric pressure. However, by means of ventilation inside the pressure sensor, the atmospheric pressure is automatically compensated. The small dimensions of the transparent blatter (approximately 150 by 100 mm) prevent the formation of a pedestal or hollow of the ice beneath the blatter.

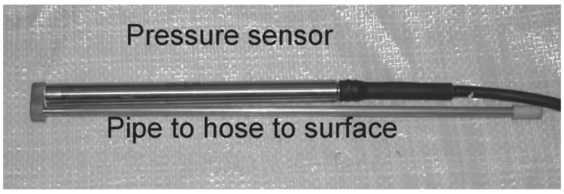

Figure 2. The pressure sensor applied for automatic ablation monitoring.

3. STEAM DRILL

The system consists of a manual injection pump, a steam generator, a system of hose, pipe and nozzle to deliver the steam for melting fig. 3. In order to avoid long preheating time the size of the water chamber inside the generator has been minimized in volume (Bøggild et al, submitted). This reduces the volume of water, which needs to be heated to the boiling point before drilling can start. Instead a steady supply of cold water is provided with a manual pump which easily generates higher pressures than the maximum steam chamber pressure. This concept also allows us to drill continuously until the final depth without stopping for re-filling water.
The steam chamber is constructed by use of commercially available cast iron lamella tubing which increase the heat contact by a factor 3.5 as compared to the surface of the tube without the lamellas. Dual propane burners heat the steam chamber from below. A combination of forced and free heat convection up along the lamella tubing secures a heat flow around the steam chamber with a maximum contact surface. To avoid overpressure in the system the maximum pressure is set to 900 kPa by means of a safety valve. A total of five 10 meter hoses are available. Each hose is 14 x 10-mm in diameter made of PTFE with an outer stainless steel mesh. The drill rods consist of two pieces of 1 meter lengths and 25mm diameter stainless steel cover. Inside is an inner steel tube of 10mm diameter, which carries the steam. The lower rod is additionally filled with lead between the two tubes in order to provide weight sufficient to secure a vertical drilling profile. Since drilling is likely to occur in ice temperatures of down to –20 °C heat loss through the wall of tube and rods is made high enough to prevent water freezing on the outside of the tube and the drill rod.

Figure 3. The steam drill in operation in the field.

The dimensions of the drill are 0.9x0.58x0.18 m and the weight of 41 kg of the main drill unit makes it possible to transport over shorter distances e.g. within 100 m range by two persons. It can easily be on and offloaded from a helicopter. And, for longer manual surface transport it can conveniently be mounted on a sled.

4. SATELLITE TRANSMISSION

The station described so far enable automatic data collection for a period only limited by data storage capacity of the data logger and lifetime of the pressure sensor deployed into the ice. However, data stored in the field is of little scientific use unless available in the office. Investigation on the commercial marked has shown that Inmarsat-C is among the cheapest systems with respect to price per byte transmission. Thrane and Thrane is among the most experienced in providing hardware solutions for Inmarsat transmission. We found that the EasyTrack transceiver was best suited for the present purpose. Application programs to interface the EasyTrack with the Campbell CR10X data logger have been specifically developed for this AMS concept.

5. DISCUSSIONS

We have developed a system for cheap, efficient and fast installable operation, which to our knowledge does not exist similar in the field of glaciological mass balance studies. In this process specific considerations have been addressed which will be discussed here.

As mentioned earlier a system design fixed by stakes drilled into the ice is only practical in low ablation areas i.e. with less than 2 m annual ablation. Where the annual ablation is higher which is the major part of the outermost ice sheet margin the station concept with a tripod sitting on top of the ice becomes superior. But, due to differential melting rates of the surface the station may tilt in different direction during the melting season, which may affect particularly the radiation measurements. This problem has been addressed by installing tilt meters and a compass whereby a tilt correction of the measurements can be performed.

A next specific problem of automatic data collection in cold remote areas is the power consumption of sensors data logger and satellite transmission. Since battery capacity reduces under cold conditions and little ablation occur under such conditions we have decided to stop measurements during the period from Julian day 300 until day Julian 100 i.e. from late October until mid April. In the period from day 100 until day 300 where measurements are made, data are only transmitted every 6 hours and the transceiver is turned off shortly after transmission.

A third problem addressed is finding the station in springtime under high snow accumulation conditions where the station may become buried – and has proven difficult to locate despite navigation with a GPS. We have added a Barryvox beacon to the system of the type used for avalanche hazard rescue. The beacon transmits a pulse signal at 457 kHz which can penetrate several meters thick snow pack. By use of a receiver of the type Barryvox VS 2000 Pro the station can be traced within a distance of up to 180 meters. In order to save power the beacon only transmits in the period from Julian day 100 until Julian day 200 and only in the day time from 9 AM until 4 PM which is the normal operation time for helicopters in Air Greenland. Furthermore, in order to avoid interference with sensors the beacon is turned off when measurements are made.

6. CONCLUSIONS

An automatic mass balance station (AMS) concept has been developed over the recent years and is continuously being improved. It is a system optimized for use at the GIS margin which is probably among the most difficult areas of the world to carry out ablation studies at a larger scale. Over the 25 years where GEUS has been studying ablation at the GIS the installation time for a profile has reduced from more than 10 man-month to just one day. We have eliminated the need for ablation stakes and instead use pressure sensors and strings which can be installed 30-40 meters deep into the ice and thus has a life-time of several years before reinstallation is needed. The combination of solar power supply and satellite transmission in principle makes the system fully automatic. Only by use of fully automatic AMS stations the ground monitoring of the GIS can be performed in an operational way. The AMS is equally suited for other remote areas outside Greenland.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Bøggild, C. E., O. B.Olesen, A. P. Ahlstrøm, P. Jørgensen. In Press. Automatic glacier mass balance observations using pressure sensors. (*In Press J. Glaciol*.)

Carl Egede Bøggild, C. E., Mayer, C., Olesen, O. B., Ahlstrøm, A.P. Submitted. A high pressure steam drill for glaciological mass balance investigations (*Submitted to Cold Reg. Sci Technol*.)

Thomas, R. H. and PARCA investigators. 2001. Program for Arctic Regional Climate Assessment (PARCA): Goals, key findings, and future directions. *J. Geophys. Res.* Vol 106. D24. 33,691-33,705