AWS measurements at the Belgian Antarctic station Princess Elisabeth, in Dronning Maud Land, for precipitation and surface mass balance studies

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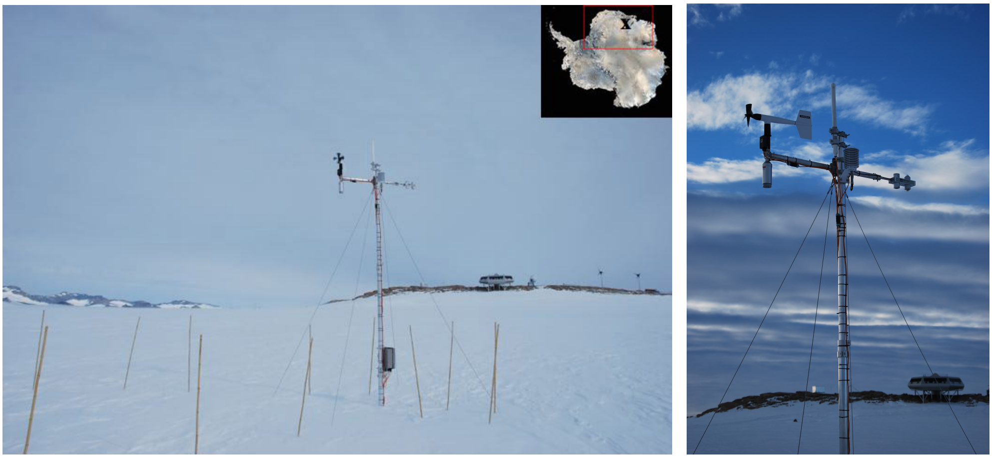
Introduction

The Antarctic mass balance and the hydrological cycle of the entire planet are tightly linked together. Evaporation from the ocean surface in the tropical and middle latitudes, poleward moisture and energy transport, changes in the midlatitude atmospheric dynamics, cloud formation microphysics - all these processes determine the amount of precipitation in Antarctica. The main objective of our project is to improve the understanding of the atmospheric branch of the hydrological cycle of Antarctica covering the chain from evaporation/sublimation at the surface via cloud formation to snowfall. As there is a lack of data on the clouds and precipitation processes in the Antarctic, the first goal is to establish a new database that can be used for local process studies and large-scale model evaluation. The base for our measurements is the new Belgian Antarctic station Princess Elisabeth (PE) built on the Utsteinen Ridge in Dronning Maud Land, East Antarctica (71°57’ S and 23°20’ E, ~1400 m asl, 180 km inland). Princess Elisabeth station is located in a nearly thousand kilometer wide "data gap", where no long-term measurements of the surface mass balance have been done up to date and where regional climate models show large differences in snow accumulation estimates.

Measurements

The meteorological data have been collected by an Automatic Weather Station (AWS) installed 300 m east from the Utsteinen ridge in February 2009 (Fig. 1, Tab. 1). The AWS provides hourly mean data of near-surface air temperature, relative humidity, pressure, wind speed and direction, up and downward directed broadband short-wave and long-wave radiative fluxes, snow height changes, and a 1 m snow temperature profile. In addition, ground-based cloud and precipitation remote-sensing instruments have been operating during several months, from which characteristics of cloud properties and individual storms have been derived. Information



a. **b.**

Figure 1. Automatic Weather Station installed as part of the HYDRANT project near the Belgian Antarctic station Princess Elisabeth. The AWS is designed by the IMAU group (Link). (a) Photo of the AWS in February 2010; (b) zoom on the instrument yard.

about the instruments and measurement campaigns can be found on the project website (Link).

Method of filtering the snow height data

Measurements of snow height changes using ultrasonic altimeter sensor provide hourly data with 0.01 m accuracy (Tab. 1). The measurements are highly sensitive to the air temperature and correction is applied using the AWS near-surface air temperature measurements assuming isothermal temperature profile. In addition, prior to computing daily accumulation

Table 1. Configuration of the AWS installed as part of the HYDRANT project at the Belgian Antarctic Princess Elisabeth base.

Variable	**Sensor**	**Range**	**Accuracy**
Temperature	Vaisala HMP35AC	-80 to +56 °C	0.3 °C
Relative Humidity (with respect to liquid)	Vaisala HMP35AC	0 to 100%	2% (RH<90%) 3% (RH>90%)
Wind Speed	Young 05103 propvane	0 to 60 m/s	0.3 m/s
Wind Direction	Young 05103	0 to 360°	3°
Pressure	Vaisala PTB101B	600 to 1060 hPa	4 hPa
Shortwave radiation	Kipp CNR1	305 to 2800 nm, 0 to 2000 W/m^2	2%
Longwave radiation	Kipp CNR1	5 to 50 μm, -250 to +250 W/m^2	15 W/m^2
Height above snow	SR50	0.5 to 10 m	0.01 m or 0.4%
Power supply	SL-790 Lithium batteries		
Data transmission	ARGOS		

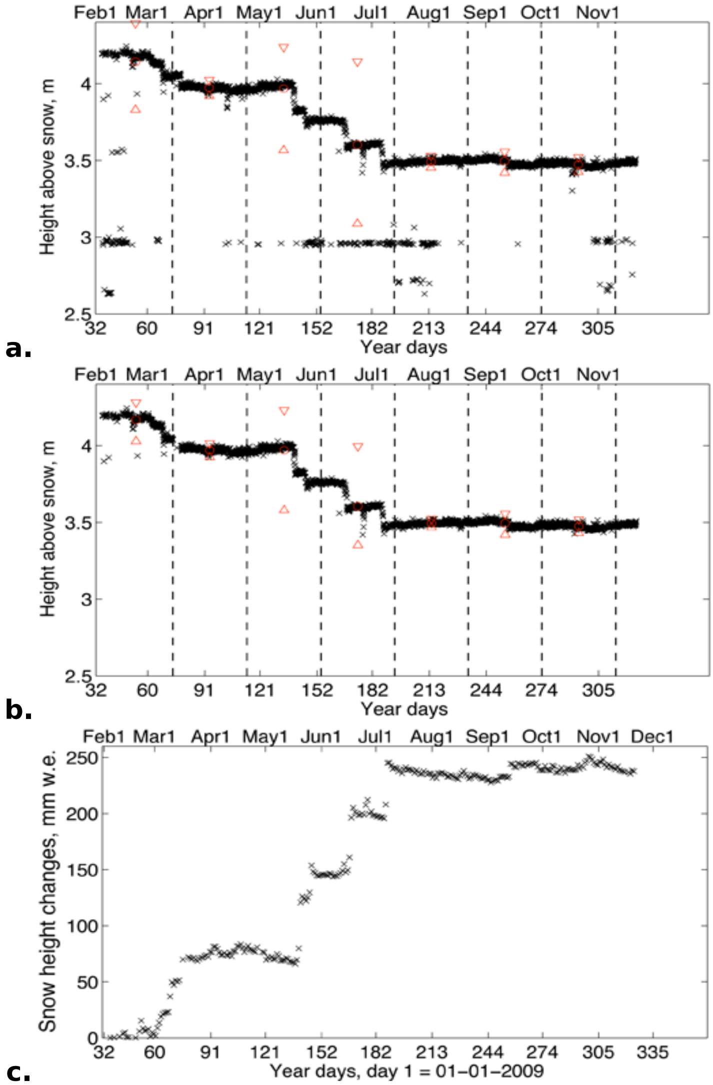


Figure 2. Filtering method for the height above snow measurements during 2009: (a) original 2-hourly data with red triangles showing the upper and lower demarcation lines for the outliers based on the inter-quartile range; (b) 2-hourly data with the outliers rejected after the first filter with the new demarcation lines; (c) daily accumulation data calculated based on the filtered 2-hour snow height values, converted to mm w.e. (water equivalent) using local measured snow density (Tab. 2).

values, the original hourly measurements of height above the snow surface were subject to filtering to eliminate false reflections. During snowfall there are possible reflections from individual snowflakes. There are also some parts of the AWS mast, which can be giving false signals. This problem was discussed intensively during the workshop and apparently is a challenge for many AWS observations on glaciers and ice sheets. After trying out various techniques, we found a reliable statistical method of

Table 2. Annual mean values of major meteorological variables measured by the AWS at Utsteinen (standard deviations and extreme values are based on daily means).

	2009		2010	
	Feb 2 - Nov 21		Jan 12 - Dec 31 *	
Variable	**Mean±std**	**Min/Max**	**Mean±std**	**Min/Max**
Air temperature (K)	254.0 ± 5.4	240 (Aug) / 267 (Feb)	253.7 ± 7.1 *	237 (Jul) / 269 (Jan)
RH (%) with respect to ice	61 ± 22	18 / 102	48 ± 19 *	16 / 101
Specific humidity (g/kg)	0.58 ± 0.37	0.1 / 2.1	0.52 ± 0.51 *	0 ** / 2.6
Pressure (hPa)	827 ± 8.7	802 / 857	842 ± 10.3	802 / 850
Wind speed (m/s)	5.3 ± 3.4	0.1 / 17.3	4.6 ± 2.6	1.3 / 17.5
Total accumulation (mm w,e,) ***	235		26	

* A gap exists in air temperature and humidity data from Oct 17 to Dec 22 2010.
** Specific humidity less than 0.1 g/kg is below the measurement accuracy of Vaisala humicap (Table 1).
*** accumulation calculated from snow height difference between the first and the last day of each year using the snow density = 335.7 kg/m^3 measured Feb 2009 near the AWS.

data filtering taking into account variability during quasi-monthly period (40 day) for the year with large step-wise accumulation events, and yearly variability (yearly mean ±3σ) for the year with nearly zero total accumulation. As the accumulation can vary quite drastically over time and space, a filtering method can differ for various locations and even for different years at one location depending on the accumulation variability patterns, amounts and the height of the snow sensor above the snow. Thus, special scrutiny is required for accumulation data based on the knowledge of local processes.

For the year 2009 with large step-wise accumulation events, the quartile filter was applied to the height above snow data (Fig. 2). The original 2-hour time series was divided into 40-day intervals, and quartiles were calculated for each interval. The demarcation line for the outliers was calculated as Q3+1.5*IQR for the top and Q1-1.5*IQR for the bottom whisker, where Q3 is the upper quartile, Q1 is the lower quartile, and IQR is the inter-quartile range (Tukey, 1977). For 2010, the inter-quartile range was found to be very small, restricting the snow height change variability beyond physically possible values. Thus, the 3σ filter was applied to the 2010 hourly values. Daily mean snow height change values were calculated from the filtered hour data. Daily accumulation was computed as the difference between snow height values of the two consecutive days. In the final verification of the filtered data set, the daily accumulation data were checked for closure, i.e. difference between the total sum of all positive and all negative daily accumulation values should be nearly equal to the difference between the first and the last daily mean snow height for each year.

Some meteorology and accumulation characteristics

The AWS measurements during 2009-2010 showed that the Utsteinen site is characterized by relatively mild meteorological conditions (Tab. 2). The minimum daily mean near-surface air temperature observed during 2009-2010 was 237 K and the maximum daily wind speed was 17 m/s (maximum hourly wind speed of 30 m/s was recorded during 2009 winter). The AWS is located north of Sør Rondane mountains, east of the Utsteinen ridge, in a valley, at the tongue of the outlet glacier Gunnestadbreen. This glacier is believed to channel the katabatic wind at PE (Pattyn *et al.*, 2010). Indeed, a small percentage of high wind speeds at Utsteinen was associated with cold temperatures indicating enhanced katabatic wind. Despite these rare channeling events, the large scale katabatic flow, typically limited to 500-1000 m above the surface in the Antarctic escarpment zone (Parish and Bromwich, 2007), is blocked by the mountain range reducing the katabatic wind speeds in the AWS locality. Wind speeds stronger than 5 m/s are restricted to the E-SE direction and are mostly associated with cyclonic activity in the near-coastal ocean region. Cluster analysis has shown that the warm periods with strong wind speeds are associated with increased cloudiness and accumulation, while cold periods have calm wind speeds and either zero accumulation or slight net ablation (by sublimation or wind erosion). Few strong accumulation events were responsible for the majority of the total yearly accumulation during 2009 (Fig. 2c). The ongoing research using the AWS data includes analysis of synoptic controls of precipitation, and estimates of sublimation rates at Utsteinen compared to other Dronning Maud Land stations.

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