Surface and snowdrift sublimation estimates at the Belgian Antarctic station Princess Elisabeth, Dronning Maud Land: role in the surface mass balance

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Introduction

In the near-coastal regions of Antarctica, a significant fraction of the snow precipitating onto the surface, is removed again through sublimation – the direct conversion of solid snow particles into water vapour– either directly from the surface or of the drifting snow particles. Meteorological observations from an Automatic Weather Station (AWS) near the Belgian research station Princess Elisabeth (PE) in Dronning Maud Land, East Antarctica, are used to study surface and snowdrift sublimation and to assess their impacts on both the surface mass balance and the surface energy balance. The results for PE are each time compared to three other AWSs in Dronning Maud Land for which longer datasets are available.

Data and Methods

In February 2009, as part of the HYDRANT project (http://ees.kuleuven.be/hydrant), an automatic weather station (AWS 16) was set up near PE in order to record air temperature, pressure, wind speed and direction, relative humidity and down- and upward short- and long-wave radiation fluxes, at a single level, initially approximately 4m above the surface but constantly changing due to snow accumulation and ablation processes.

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The in situ measurements of meteorological variables are used to reconstruct the different ablation components of the surface mass balance (SMB) at PE, following the method described by van den Broeke et al. (2004a), where flux profile relationships derived from Monin-Obukhov similarity theory are used for surface turbulent flux calculations. Three parameterisations derived from complex models were used to determine the total column snowdrift sublimation on the basis of point measurements of wind speed, temperature and relative humidity: parameterisation developed by Bintanja and Reijmer (2001, BR01) after two months of summer observations in Dronning Maud Land, the second parameterisation put forward by Déry and Yau (2001, DY01) and founded on simulations with PIEKTUK-D model in the Arctic, and the third parameterisation proposed by Bintanja (1998, B98), which was derived from simulations with SNOWSTORM model. With the goal of providing a test for the three parameterisations implemented in the SMB model, the numerical snowdrift model SNOWSTORM was applied to the meteorological dataset gathered at AWS 16. The SNOWSTORM model is a surface layer model that can be used to calculate the vertical profiles of snowdrift related quantities (Bintanja 2000).

Results

During the entire measurement period at PE, surface sublimation removed 7 mm w.e. (Fig. 1a). As expected from previous studies, the signal shows a marked seasonality, while most of the sublimation takes place during summer, continuous snow deposition is predicted for the winter months June-October 2009. In 2010 surface sublimation was clearly much higher than in 2009: the process removed less than 1 mm w.e. from February to

November 2009, whereas before September the next year almost 6 mm w.e. was already removed. While in 2009 limited sublimation and significant deposition from June till October almost cancel each other out, sublimation is much stronger during the austral summer 2009-2010 and continues until September. Probably a great deal of ablation is missed during data gap period in summer. The relative humidity values in 2010 (48%) are lower than in 2009 (61%) thus, one could state that the dryer air opens a larger potential to sublimation during the second year. Temperatures and wind velocity, on the other hand, are comparable in both years, so their influence can be thought less important.

Only during high summer the surface specific humidity is significantly larger than the ambient specific humidity, generating an effective upward moisture flux. It is this configuration, which makes surface sublimation a typical summer phenomenon. During prolonged warm, dry and calm periods, this negative humidity gradient can persist for several weeks and even cause net ablation in between two precipitation events.

Surface sublimation attains it highest values in katabatic wind zone (van den Broeke et al., 2004): while only removing 3 mm w.e. yr^{-1} at AWS 9, surface sublimation at AWS 5 and 6 are more or less comparable, with an annual mass flux of -19 respectively -17 mm w.e. yr^{-1}, equivalent to 8% respectively 6% of the total annual accumulation at the station (Fig. 1b).

The snowdrift sublimation (SU_{ds}) at PE was somewhat more important than surface sublimation during 2009-2010, with the average of the three parameterisations estimating that approximately 11 mm w.e. is removed by snowdrift sublimation during the entire measurement period (Fig. 2a). In contrast to surface sublimation, the snow drift sublimation is about as large in 2009 (~6 mm w.e.) as in 2010 (~5 mm w.e.). Moreover, as consistently shown by all three parameterisations, SU_{ds} shows no clear mark of any seasonality; mass is continuously ablated throughout the year, although three major snow drift sublimation events are responsible for important part of the total mass flux. At the Svea site, where relief and meteorological conditions are similar to PE, SU_{ds} removes annually 25 mm w.e., or 8% of the annual solid precipitation (Fig. 2b).

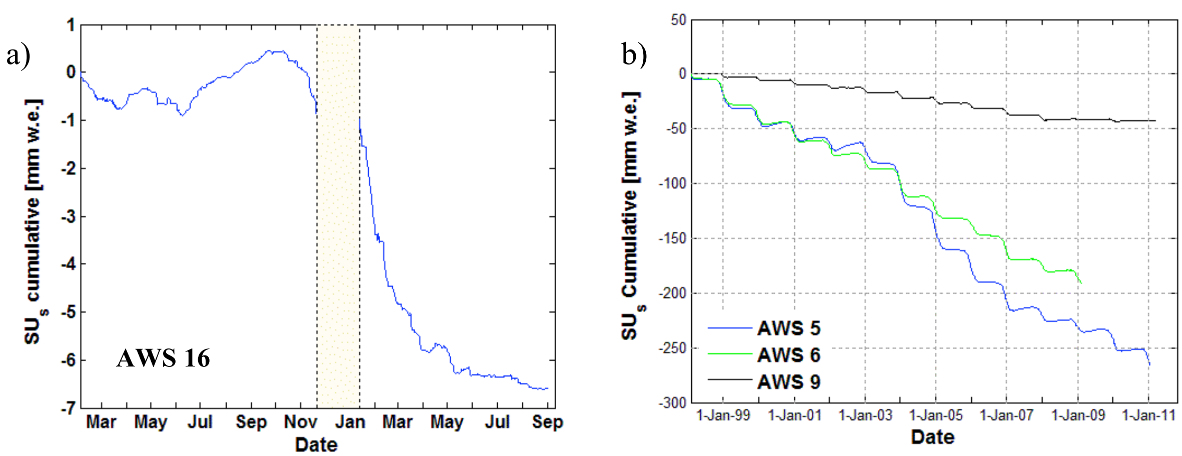

Figure 1. Cumulative surface mass flux due to surface sublimation (SU_s, mm w.e.) at (a) AWS 16 – Princess Elisabeth from 3-Feb-2009 to 1-Sep-2010, and (b) three IMAU AWS (AWS5 - Wasa/Aboa, AWS6 - Svea, and AWS9 - Kohnen) from 1-Jan-1999 to 1-Jan-2011 (except for AWS6 - until 1-Jan-2009). The bar shows data gap for AWS 16.

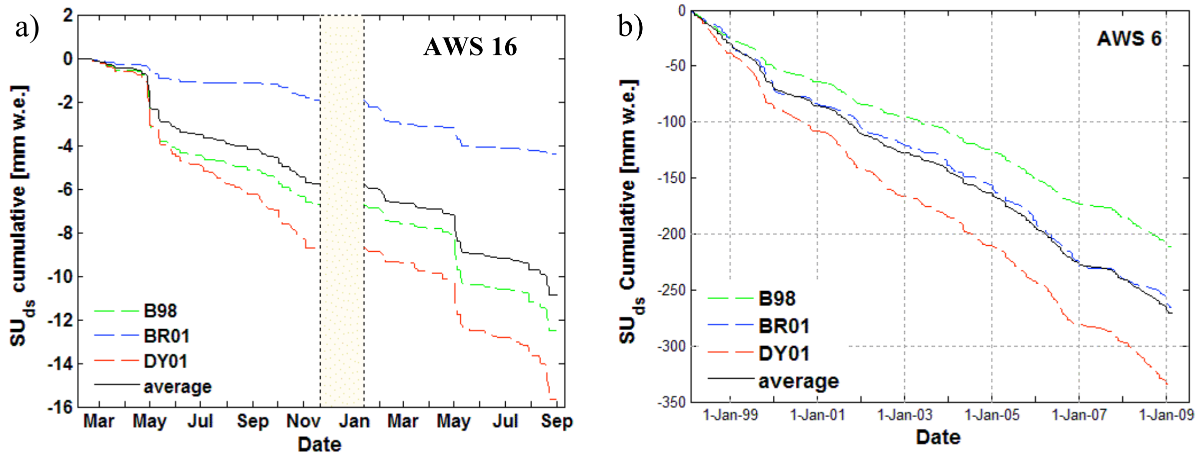

Figure 2. Cumulative surface mass flux due to snow drift sublimation (SU_{ds}, mm w.e.) at (a) AWS 16 – Princess Elisabeth from 3-Feb-2009 to 1-Sep-2010, and (b) AWS6 - Svea station from 1-Jan-1999 to 1-Jan-2009

With the goal of providing a test for the three parameterisations implemented in the SMB model, the numerical snowdrift model SNOWSTORM was applied to the meteorological dataset gathered at AWS 16. According to SNOWSTORM, snow drift sublimation was responsible for a mass removal of 17 mm w.e. during the entire measurement period (Fig. 3). The model is in a good agreement with the estimates by B98 (13 mm w.e.) and DY01 (16 mm w.e.). Furthermore, as well as the three parameterisations, SNOWSTORM captures the three major sublimation events: overall, the cumulative curve of SU_{ds} predicted by SNOWSTORM closely follows B98 and especially DY01.

Sublimation is remarkably lower at AWS 16 than the other stations: both for surface and snowdrift sublimation, annual mass fluxes are three time larger at AWS 6 than AWS 16; at the coastal katabatic AWS 5 they are even 4 times larger. At AWS 16 both the record frame and the data gap in December 2009 are assumed to bias mass fluxes towards winter values, which is especially problematic for the summer phenomenon surface sublimation. On the other hand, since SU_{ds} shows only limited seasonal and inter-annual variability at the IMAU AWSs its signal at AWS 16 might already be without bias. In that case, two reasons can be given for the low values at AWS 16: lower wind speeds and frequent occurrences of humidity inversion.

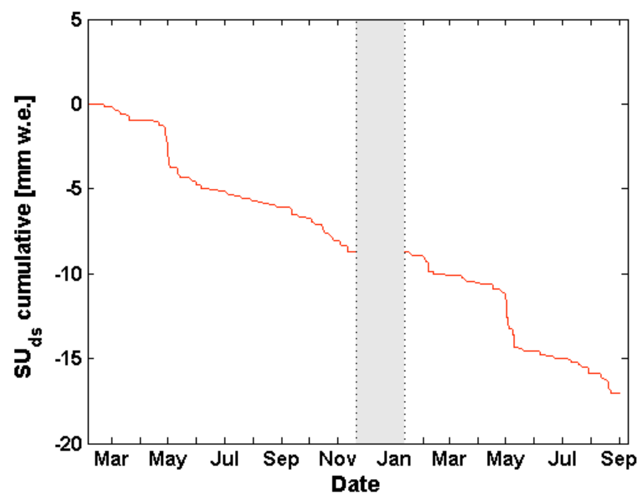

Figure 3. Cumulative snow drift sublimation SU_{ds} (mm w.e.) at AWS 16 – Princess Elisabeth, as calculated by the numerical snowdrift model SNOWSTORM, for the period Feb 2009 to Sep 2010

Discussion

From February 2009 till September 2010, surface and snowdrift sublimation removed a mass equivalent to 17 mm w.e., at Princess Elisabeth, which is 6% of the total accumulation during this period (265 mm w.e.). Considered together, surface and snowdrift sublimation thus have a significant impact on the surface mass balance at AWS 16. Compared to other stations in Dronning Maud Land katabatic zone, however, these values were found relatively low (surface and snowdrift sublimation combined remove 29% and 16% of yearly accumulation at AWS 5 and AWS 6, respectively). The relatively low surface sublimation can be ascribed to the local topography, which protects the station from strong katabatic winds and consequently allows for a strong surface inversion to persist throughout most of the year.

An extended sensitivity analysis revealed that the specific humidity gradient, i.e. the combined effect of ambient relative humidity and the magnitude of the surface inversion, is predominant for both the sign and magnitude of surface sublimation in Antarctica. Temperature and wind speed only represent second order effects. In contrast, snowdrift sublimation is limited by relative humidity, but only when the ambient moisture content is high. Below a RH of ~70-80%, temperature and wind spesed take over as the main controlling variables for SU_{ds}. Of the three negative feedback mechanisms associated with snowdrift sublimation, the snowdrift-turbulence, sublimation-moisture and sublimation-temperature feedbacks, only the former two are found to significantly affect the snowdrift sublimation rate. The efficiency of both significant feedbacks was found proportional to the wind velocity.

Acknowledgements

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