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The Impact of Precipitation and Sublimation Processes on Snow Accumulation: Preliminary Results

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INTRODUCTION

The need for climate change prediction has focused attention on the Surface Mass Balance (SMB) of the Antarctic continent and on how it influences the sea level.

The SMB of the Antarctic plateau is governed by the equilibrium between precipitation and ablation processes such as sublimation and wind-borne snow redistribution. At scales of hundreds of kilometres snowfall variability dominates the snow accumulation process (Dery and Yau, 2002); at smaller scales, post-depositional process such as wind-borne redistribution, surface sublimation and snowdrift sublimation becomes more important. In recent years the sublimation phenomenon has received much attention from the glacial-meteorological community, and some theoretical studies have tried to model it (Bintanja, 1998; Dery & Yau, 2001b; Frezzotti, 2004). There are two different types of sublimation: surface sublimation and blowing snow sublimation. Surface sublimation is mostly determined by the continual exchange of water between the air (in the vapour phase) and the snow pack (in the solid phase) due to solar irradiance. Blowing snow sublimation is possibly the more effective of the two sublimation processes. It occurs when snow particles at the surface are blown by winds exceeding a certain threshold value. Particles suspended in the sub saturated Atmospheric Boundary Layer (ABL) sublimate at a relatively fast rate, cooling air mass transported by the wind and increasing the local atmospheric moisture content. When the first few meters of the ABL are completely saturated, the process is dumped. It takes a long time to meet this condition because katabatic winds transport saturated air masses to the coast, thereby reactivating sublimation.

The role of sublimation in snow accumulation and its high variability at local scales are not fully understood due to the few available measurements in Antarctica. Further study and field experiments are required.

FIELD CAMPAIGN AND SITE CHARACTERISTICS

Mid Point (MdPt), a fuel depot halfway along the Terra Nova Bay – Dome C route, lays 2500 m a.m.s.l. and has an average slope of 2 ‰ . An Italian Automatic Weather Station (AWS, No ID 89648) is located at the site since 1997; it produces detailed time series data of surface height and meteorological parameters on an hourly basis. The very low temperatures and moderate-high wind velocities with high directional constancy (Fig. 1) are such that this site is representative of meteorological conditions on the Antarctic plateau. MdPt accumulation time series data, measured using a sonic sensor, seem flat but very sensitive to snow transport by constant high winds, especially during winter (Fig. 1).

Recent snow radar profiles have revealed the high local-scale variability of snow accumulation; the presence of different surface features such as sastrugi and wind crusts make MdPt a suitable site for studying the impact of sublimation on SMB. Moreover, the presence of logistic and support supplies for the fuel depot facilitates research under such extreme climatic conditions.

The goal of the Antarctic field campaign is to obtain a detailed meteorological and thermal characterization of two adjacent sites with different morphological features for better understanding differences in ice/atmosphere and snow/atmosphere heat exchanges. To this end, two AWS were placed at sites with different accumulation values and dissimilar surface characteristics; site selection was based on snow radar analysis of the field and on a morphological survey.

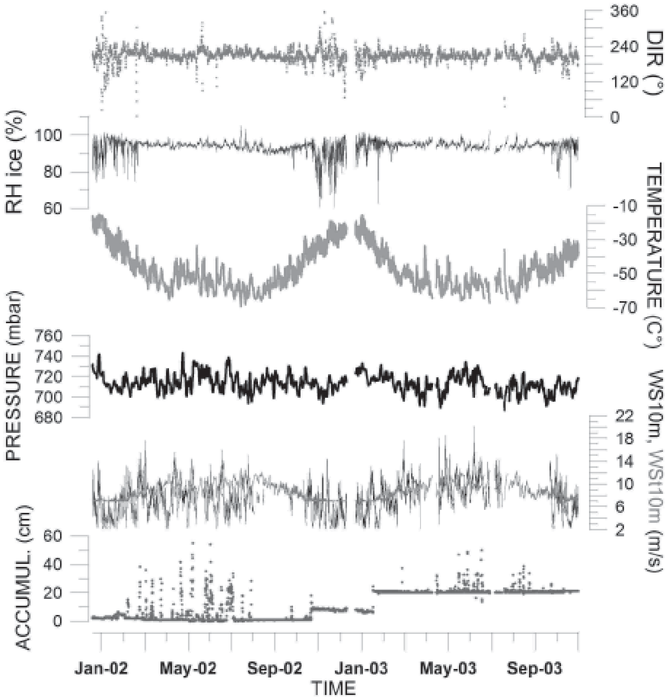

Fig. 1 - Time series of meteorological parameters: relative humidity with respect to ice (black) temperature (grey), pressure (black), wind speed (black), threshold wind speed (grey), surface snow accumulation (grey).

METHODS

Analysis of MdPt 89648AWS could provide some information on sublimation processes. Preliminary results were obtained by processing data from active instruments. Figure 2 shows sublimation values for the 2001-2002 summer months (November, December and January). Turbulent latent heat fluxes were calculated using a profile method and considering neutral atmospheric stability conditions according to Van den Broeke et al. (1997) and Dery et al. (2001) due to the lack of many surface parameters; sublimation was derived from these fluxes. The blowing snow sublimation rate was calculated through a parameterization based on the “PIEKTUK” sublimation snowdrift model, Dery et al. (2001), which predicts the mixing ratio of suspended snow by solving a prognostic equation that takes into account diffusion settling and sublimation of blowing snow particles.

Accumulation time series are apparently highly sensitive to wind speed transport, so that it is impossible to identify precipitation events using surface data only and without accurately defining atmospheric parameters. A possible solution is to consider the precipitation term as an unknown in the SMB equation.

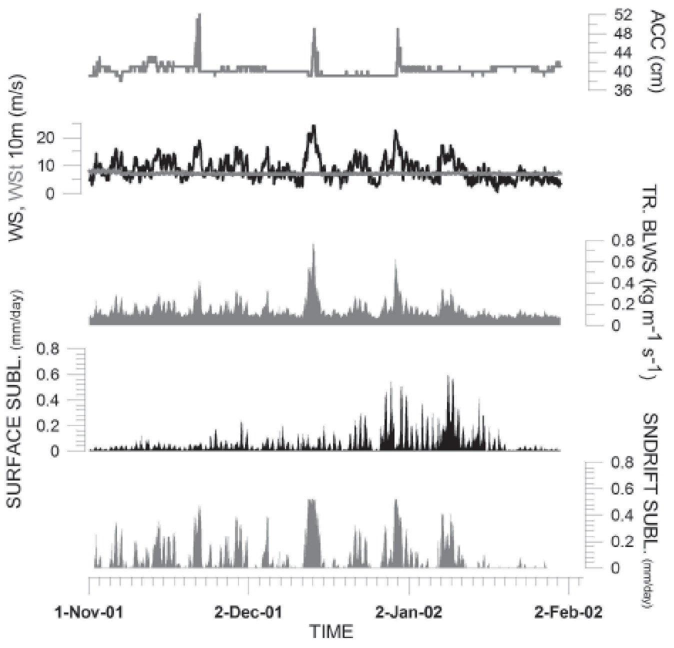

Fig. 2 - Snow accumulation (grey), wind speed and threshold (black and grey respectively). Examples of derived time series parameters for Antarctic summer months: blowing snow sublimation rate (grey), surface sublimation rate (black), wind-borne snow (grey).

RESULTS AND DISCUSSION

Summer blowing snow sublimation rates are highly wind-dependent; they are stable below 0.1-0.2 mm/day, except for sparse peaks in the medium-high wind speed regime which reach values of up to 0.5 mm/day. Surface sublimation seems to depend more on temperature and humidity conditions than on wind velocity, and rates are generally less than 0.2 mm/day. During intense high wind events surface sublimation tends to cease, probably due to the greater moisture saturation produced by blowing snow sublimation in the first meter.

The annual result was produced by applying the sublimation calculation process to data from November 2001 to November 2002. Blowing snow sublimation removes approximately 7 mm w.e.: 6.2 mm w.e. during 10-15 m/s winds, 1 mm w.e. for 15-20 m/s winds, and 0.8 w.e. for low wind speeds of 5-10 m/s. Surface sublimation eliminates 2.3 mm w.e. during 5-10 m/s winds, 1.2 mm w.e. during 10-15 m/s winds and 0.6 w.e. for wind speeds of 0-5 m/s. The greatest removal of snow occurs for medium winds (17% of the total duration of wind events); under these conditions the two sublimation processes act together.

A value of 11 mm w.e. is obtained for the total annual ablation considered as the sum of surface and snowdrift sublimation. Note that during the few high wind events (1% of the time) snowdrift sublimation accounts for ~9% of this annual value.

The mean accumulation value measured at stakes in MdPt for the same period is ~ 36 mm w.e.; it is therefore possible to estimate an annual precipitation of 47 mm w.e. by summing ablation and accumulation terms.

As mentioned above, these are preliminary results that require validation. In this study, calculations do not take into account the effect of turbulent flows on stability. Lastly, detailed ABL meteorological data will allow more complete blowing snow model initialization.

At this time it is difficult to compare our results to those presented in the literature. However, our calculated mean latent heat flux of -1.1 W/m^2 for a high plateau site in January and February is consistent that reported by Van As et al. (2005); our blowing snow sublimation values are also comparable to those in Bintanja et al. (1998 and 2001).

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