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A novel experimental study of aeolian snow transport in Adelie Land (Antarctica)

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ABSTRACT

None of the previous aeolian snow transport campaigns in Antarctica meet the requirements in terms of temporal resolution, long-term series and qualified instruments for evaluations of meteorological and climate models including parameterization for aeolian snow transport. Consequently, determining the quantity of snow transported remains a challenge. A field campaign was therefore launched in January 2009, in Adélie Land, Antarctica, to acquire new model-evaluation-oriented observations within the European ICE2SEA project, with the logistical support of the French polar Institute (IPEV). The available aeolian snow transport sensors are reviewed and the sensor that best suited our specific needs was chosen: FlowCapt™ acoustic sensors. Three automatic weather stations were deployed with FlowCapts™ close to the coast. The stations' locations are distinct, ranging from 1 to 100 km inland, one of them with a 7-m mast with six levels of anemometers and thermohygrometers. The fluid and impact threshold friction velocities recorded were 0.48 ± 0.09 m s^{-1} and 0.4 ± 0.09 m s^{-1}, respectively, with a high standard deviation of 0.12 ± 0.03 m s^{-1} and 0.13 ± 0.03 m s^{-1}, respectively. The aeolian snow transport frequency in Adélie Land was very high with seasonal variation of transport occurring with minima during the austral summer. Seven percent of the aeolian snow transport events were drifting snow (maximum particle's height, <1 m above the surface). The snow quantity transported was above 1 kiloton per year in the first meter above the surface.

1. Introduction

The surface mass balance (SMB) of the Antarctic ice sheet is probably the only significant negative contribution to the mean sea-level rise (Agosta et al., 2013; Ligtenberg et al., 2013). The SMB is the sum of precipitation ($P > 0$), evaporation/sublimation of the surface ($E > 0$ or < 0), runoff to the ocean ($R < 0$) and deposition, erosion and sublimation of snow due to wind (BS >0 or <0): SMB $= P + E + R +$ BS (e.g., Agosta et al., 2013). The terms "blowing snow" and "drifting snow" are sometimes used to characterize the aeolian snow transport. They are distinguished from one another based on the maximum height reached by the snow particles lifted from the surface by the wind, with the drifting snow being the lower transport event of the two. The value of the height, which separates them, varies from the eye-height (Leonard et al., 2011) to 2 m for the American meteorological society. We have fixed this height at 1 m, which is close but lower than the former definitions (see subsection 4.2 Transport occurrence). While the long-term mean Antarctica SMB is relatively well known from glaciological observations (Arthern et al., 2006), the individual terms are not. Meteorological and climate models all account for P and E and most models account for runoff because seasonal snow affects large regions of the Earth. Aeolian snow transport, on the other hand, is largely ignored. However, in Antarctica, snow accumulation (Eisen et al., 2008) and modeling of aeolian snow transport (Agosta et al., 2013; Gallée et al., 2005; Lenaerts et al., 2012) suggest that it is a significant term in the mass balance equation. Indeed, blowing snow occurrence is very frequent due to the strength and persistence of the katabatic winds close to the coast. Blown snow can be exported to the ocean at the coastlines. As a consequence, the average contribution of BS to the SMB is most probably negative, yet this is still unknown. While satellite laser altimetry may provide information on the height reached by snow particles (Palm et al., 2011), the current measurement techniques combined with the logistic constraints make it impossible to observe aeolian snow mass fluxes over the entire ice sheet. Therefore obtaining the term BS in the Antarctic SMB equation is currently impossible. Only regional or general models may offer this information. However, before

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any estimation, models should be evaluated and calibrated against observations.

Observations of aeolian snow transport started in the earliest days of Antarctic exploration, well before models existed. Yet, the objective was already to evaluate the processes of aeolian snow transport and to assess the quantities involved. Table 1 provides a synthetic review of past aeolian snow transport observation campaigns, starting with the first Australian exploration expeditions at the beginning of the 20th century. The locations of previous measurement campaigns are shown in Figs. 1 and 2. Such campaigns have been carried out in many places and over a range of seasons and time periods. However, their design was not necessarily tuned for the evaluation of models; most particularly, no meteorological and climate models with parameterization for aeolian snow transport have been used. The requirements for this type of target would be:

- obtaining data on the meteorological variables (including wind in the first place), which are important for aeolian snow transport process;
- obtaining meteorological and aeolian snow transport profiles to capture gradients near the surface, which results from the surface processes and atmospheric turbulence that lift the snow into the atmosphere;
- measuring the above vertical profiles with an accurate temporal resolution (<1 h) to evaluate models;
- verifying that field data are representative at the scale of the model grid box (5–20 km);
- collecting long-term series for a representative sample of variability at hourly to interannual time scales;
- using qualified instruments and methods for the measurements;
- defining robust model validation methods.

Although they all have contributed highly valuable data and breakthroughs, none of the previous campaigns listed in Table 1 were fully designed to fulfill all these requirements. In addition, the use of a wide range of methods and instrumentation makes any intercomparison difficult. No systematic review and discussion of the various methods and instruments for estimating aeolian snow transport in Antarctica with respect to model evaluation are available at this time. Section 2 in this paper intends to fill this gap. In Section 3, we present a new aeolian snow transport observation campaign in Adélie Land. To the extent possible considering logistical difficulties and limitations, this campaign, started in 2009, was designed to optimally evaluate and improve models. There are therefore up to 4 years of data collected, which allow for a preliminary presentation and analysis of the results the first 3 years, presented in Section 4. General conclusions are given in Section 5.

2. Measuring aeolian snow transport: A review

Aeolian snow transport has been studied since the first explorations in Antarctica, because explorers were struck by the frequency and the intensity of the transport episodes. During those expeditions, basic traps were constructed on site to evaluate the snow quantity

Table 1
Previous field campaigns where specific aeolian snow transport sensors were used: locations and instruments used, observation periods, and references.

Location	Latitude, longitude and altitude	Period	Instruments used	Publications
Cap Denison station	67° 01′ S 142° 41′ E 31 m	Years 1912 and 1913	Collecting device	(Madigan, 1929)
Port Martin station	66° 49′ S 141° 23′ E 14 m	Years 1950 to 1952	Collecting device	(Boujon, 1954; Prud'homme and Valtat, 1957)
Dumont D'Urville station	66° 39′ S 140° 00′ E Between 6 and 21 m	Year 1958	Collecting device	(Lorius, 1962)
Charcot station	69° 22′ S 139° 01 E 2400 m	Years 1958 and 1959	Collecting device	(Garcia, 1961, 1960)
Byrd station	80° 01′ S 119° 32′ W 1553 m	Years 1962 and 1963	Rocket traps on 8 levels	(Budd et al., 1966; Mellor and Fellers, 1986)
Mizuho station	70° 42′ S 44° 20′ E 2230 m	Year 1973 March 1982 to January 1983 October to November 2000	Cyclone-collector Rocket traps on 5 levels, cyclone-collector Optical SPC-S7 on 4 levels	(Kobayashi, 1978) (Takahashi, 1985) (Nishimura and Nemoto, 2005)
Amundsen–Scott station	90° S 2835 m	May to July 1982 Mid 1999 to end of 2002	Optical Terrestrial lidar	(Wendler, 1989a) (Mahesh et al., 2003)
D47 point, Adélie Land	67° 23′ S 138° 43′ E 1560 m	Austral summer 1985–1986	Optical	(Wendler, 1987, 1989b)
Halley station	75° 36′ S 26° 42′ W 33 m (ice shelf)	Year 1991 (only 26 days)	Optical on 6 levels	(Dover, 1993; Mann, 1998; Mann et al., 2000)
Svea station	74° 11′ S 10° 13′ W 1250 m	January to February 1998	Piezoelectric on 2 levels	(Bintanja et al., 2001)
Kohnen station	75° 00′ S 0° 04′ E 2892 m	January to February 2002	Piezoelectric on 3 levels	(Lenaerts et al., 2010; van den Broeke et al., 2002)
Larsen glacier near Terra Nova Bay	74° 57′ S 161° 46′ E 1350 m	January 2006 to January 2008	Acoustic on 6 levels	(Scarchilli et al., 2010)
McMurdo station	77° 52′ S 168° 59′ E 66 m (ice shelf)	October 2006 to January 2007	Optical piezoelectric	(Leonard et al., 2011)