Dear Editor,

Please find below our point-by-point reply to each reviewer's comment, followed by a marked-up manuscript version explicitly showing the changes made compared to the original version.
More specifically, please note that, as requested by reviewer RC1 (i) in the revised manuscript section 2 (description of drifting snow data) has been expanded and includes a more detailed assessment of the FlowCapt sensors from new data collected in Adelie Land, and (ii) the database described and presented in the paper has been deposited in a public repository via zenodo and is now freely available. Statistics have also been slightly altered due to the redefinition and refinement of some selection criteria based on RC1's comments and have been adjusted accordingly. However, please note that no change has been made according to the short report of reviewer RC2 as it mainly relates to applications that lie, to my opinion, beyond the scope of the paper and have moreover been treated in another manuscript under revision.

Kind regards

Charles Amory

I sincerely thank the reviewer for its thorough reading of the paper, the very relevant questions and the interesting suggestions that will undoubtedly help to improve the paper. My responses are reported hereafter in red.

Response to reviewer RC1

The manuscript describes a unique long dataset of blowing snow observations in Adelie Land, Antarctica, using weather stations that contained FlowCapt sensors for detecting blowing and drifting snow particles. Given that the surface mass balance in Antarctica is dominated by wind erosion and deposition (and thus blowing snow), in-situ measurements are very valuable. It's important that the manuscript is published, describing the setup, and providing some first analysis of frequency of blowing snow events, to increase the value of the dataset. The dataset may become useful for a broad community, including remote sensing and ice sheet (climate) modelling. I think the paper is well suited for TC. I have some minor comments which may help to improve the paper. A major concern I have is that the data is only available from the author on request, whereas I think that the Copernicus Data Policy strongly discourages this. Using for example zenodo and doi versioning, the current dataset could be deposited there, and updated with newer data as a newer version of the data.

The data has been deposited on a public repository via zenodo and can now be downloaded at https://zenodo.org/record/3630497. The section data availability has been modified accordingly.

Please note that the SPC data used for the evaluation of FlowCapt sensors as proposed in the revised version of the manuscript are currently involved in an ongoing publication and have thus not been deposited together with the drifting snow dataset on zenodo.

General comments

1) A better discussion of the accuracy of FlowCapt is required. In section 2.3, L140, the sensor is described as being accurate, and the only reference is Cierco et al. 2017). However, they write: "As a consequence, and even if the sensor provides good information in operational use, a regrettable inaccuracy in the collected data prevents the use of such measurements for research purposes. Nevertheless, a correction algorithm based on a statistical calibration of the sensor is proposed, which should make it possible to use the recorded data for preliminary approximations." In L151-153, it is discussed qualitatively, but can quantitative error margins be established? In any case, this section needs to be expanded, with a more detailed accuracy assessment of FlowCapt sensors.
All the work done by Cierco et al. (2007) on evaluating the reliability of the Flowcapt^{TM} sensor and characterizing its limitations has focused on the first-generation device. The sensors installed at D17 and D47 are of a more recent design (referred to as second-generation FlowCapt or 2G-FlowCapt in the paper) which significantly improves, without necessarily solving, inaccuracy issues with estimating snow mass fluxes (Trouvilliez et al., 2015).
I have reorganized Section 2.3 to better structure the information provided on 2G-FlowCapt^{TM} sensors and utilization of the data. The section is now divided in four parts whose one of them is dedicated to accuracy assessment of the sensors. More specifically I mention results (which I suggest to provide in supplementary materials with further details on the experimental set-up and methodology) from a intercomparison experiment I've led myself in Adelie Land between the 2G-FlowCapt^{TM} and a snow particle counter (SPC-S7), an optical device considered as a kind of reference sensor for estimating snow mass fluxes (Sato et al., 1993). The field experiment took place at site D17 in late January 2014 and focused on a 24 hour long snow transport event. Although more data are necessary to better assess the performance of the 2G-FlowCapt^{TM} in Antarctic conditions, the comparison shows a reasonable agreement between the two types of sensors (Fig. R1; proposed as Fig. S4 in supplementary materials). Reported below is the content of Sect. 2.3 in the revised version of the manuscript entitled "Accuracy assessment" and the related supplementary materials; please refer to the track changes for a complete report of the modifications undertaken in this section:

"[…].

2.3.3. Accuracy assessment

While FlowCapts™ sensors can detect the occurrence of snow transport with a high level of confidence, the ability of the original design to estimate snow mass fluxes is more questionable (Cierco et al., 2007). These accuracy issues, without being necessarily solved, have been significantly improved with the 2G-FlowCapt™, facilitating its use for quantitative applications (Trouvilliez et al. 2015). Although measurement uncertainty is not known, the 2G-FlowCapt™ was shown to generally underestimates the snow mass flux relatively to integrated estimates computed from optical measurements made with a snow particle counter S7 (SPC-S7; taken as a reference in the study) during a winter season in the French Alps, particularly during concurrent precipitation (Trouvilliez et al. 2015). During mixed drifting snow events when erosion occurs simultaneously with snowfall, the density of precipitating particles which have not reached the ground yet is lower than eroded, more rounded snow particles originating from the ground which have lost their original crystal shape and size through collision, sublimation and the thermal processes of metamorphism. For a given snow mass flux, the particles' momentum, and by extension the measured acoustic pressure, is therefore lower during a mixed drifting snow event than during an event predominantly driven by the erosion process. This results in an underestimation of the snow mass flux measured by the 2G-FlowCapt™ during mixed events, with a magnitude depending on the relative proportion of eroded particles against fresh snow particles.

Environmental conditions influence greatly the estimation of the snow mass flux by the 2G-FlowCapt™. The intercomparison experiment in the Alps was done within a range of mass flux values (< 2.5 10^{-2} kg m^{-2} s^{-1}) significantly lower than those encountered in Adelie Land (see Sect. 3.4). In addition, comparatively stronger surface winds and lower temperature on the Antarctic ice sheet favor the breaking and rounding of snow particles. This suggests that the performance of the 2G-FlowCapt™ remains to be assessed in the extreme Antarctic environment, in which large proportions of small, rounded particles can be expected in drift conditions (i.e. within 2 m above ground) even with concurrent precipitating snow (Nishimura and Nemoto, 2005).

A field experiment involving measurements with SPC-S7 and 2G-FlowCapt™ sensors performed during a 24 hour long snow transport event was undertaken at site D17 in late January 2014 (Fig. S3). Strong drift conditions were observed with 2-m wind speeds and snow mass fluxes reaching up to 19 m s^{-1} and 4 10^{-1} kg m^{-2} s^{-1} respectively. Although the statistical representativeness of the results may be small due to the low amount of data collected during only one event, the comparison shows that the snow mass fluxes provided by the two types of sensors are very similar in magnitude (Fig. S4). Further details on the experimental set-up and comparison methodology are provided in supplementary materials (Sect. S1).

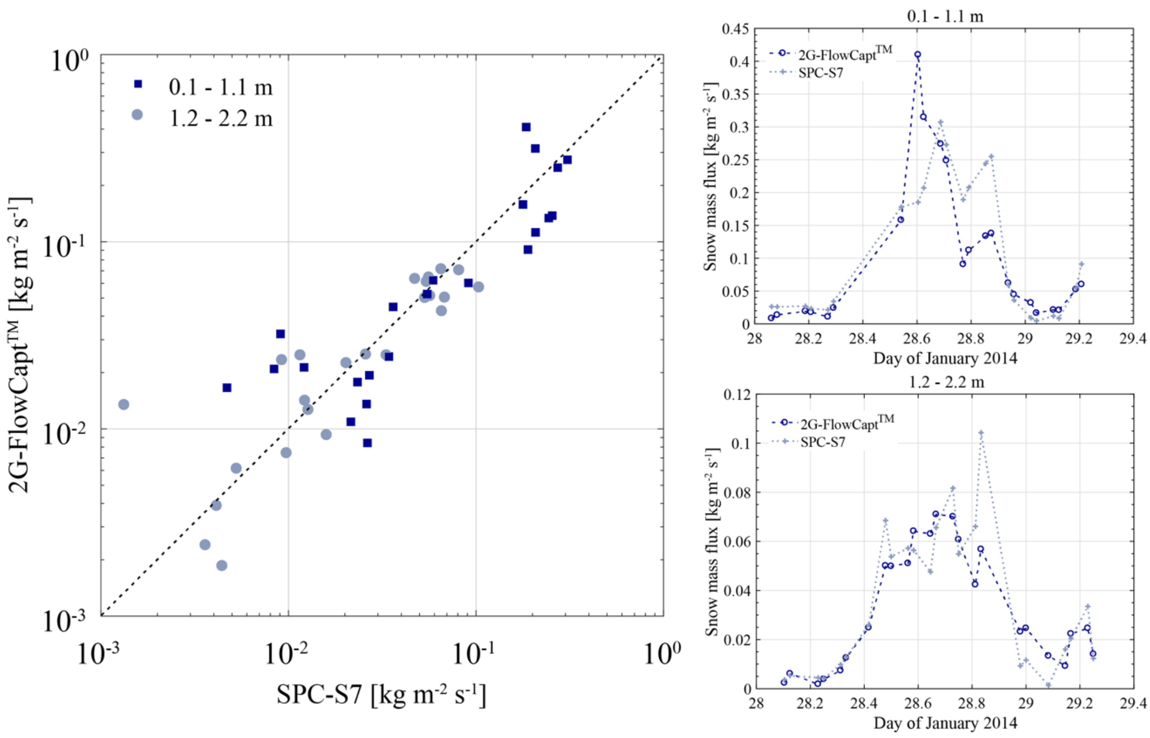

Figure R1. Comparison between snow mass fluxes provided by 2G-Flowcapt™ sensors and computed from measurements made with snow particle counters (SPC-S7) during a snow transport event at site D17 in January 2014. A distinction is made between snow mass fluxes integrated over 0.1 to 1.1 m and 1.2 to 2.2 m above ground.

Supplementary materials:

S1. Intercomparison between snow particle counters S7 and second-generation FlowCapt™ sensors during a drifting snow event in Adelie Land

1.1. Snow particle counters

The measurement principle of the snow particle counter S7 (SPC-S7) follows an optical method based on the strong absorption of the infrared light by the snow. The diameter and number flux of snow particles are detected by their shadows on a super-luminescent diode sensor. Electric pulse signals corresponding to a snow particle passing through a sampling area of 50 mm^2 (2 mm in height and 25 mm in width) and whose voltage is directly proportional to the size of the particle are classified into 32 size bins from ~ 40 to 500 µm (Sato et al., 1993). This means that snow particles smaller than 40 µm remain undetected and snow particles larger than 500 µm are assigned to the maximum diameter class. Thanks to a self-steering vane the SPC-S7 measures perpendicularly to the horizontal wind vector the distribution size spectrum of snow particles every 1 s, from which the horizontal snow mass flux, η, can be computed assuming fully spherical snow particles with a density equal to that of ice as follows:

$$\eta = \sum_{i_d=1}^{32} \eta_d = \sum_{i_d=1}^{32} n_d \frac{4}{3}\pi\left(\frac{d}{2}\right)^3 \rho_i$$

with η_d (kg m^{-2} s^{-1}) the horizontal snow mass flux for the class of diameter d (m), i_d the index and n_d the measured number flux of snow particles (part. m^{-2} s^{-1}) for each of the 32 diameter classes, and ρ_i the particles density (917 kg m^{-3}).

1.2. Experimental set-up

Two SPCs were installed on 28 January 2014 (Fig. S3) a few hours before strong drifting snow occurred in conjunction with strong katabatic winds reinforced by the passage of a low-pressure system off the Adelie Coast. The equipment was removed on 29 January once drifting snow ceased. One SPC was installed at a fixed position 1 m above the ground, while the position of the other was alternatively switched manually between 0.5 et 2 m above the ground every 1-2 hours. This was done in order to study the vertical gradient of the mass flux for two ranges of height (0.1-1.1 m and 1.2-2.2 m) above the snow surface for which 2G-FlowCapt™ measurements are also available for comparison. The high energy requirements of the SPCs (~ 15 W) were fulfilled by an electric generator that was housed together with the acquisition system in a mobile shelter downwind of the measurement structure. Only a few data are missing due to problem with the acquisition system of the SPC at the beginning of the experiment, resulting in an timeseries almost continuous along the event.

1.3. Computation of integrated snow mass fluxes from SPC data

According to the diffusion theory of drifting snow (Radok, 1977), the averaged drifting snow particle density (kg m^{-3}) in the diffusion layer can be approximated by a function of height. When the wind profile follows a power law, an expression for the vertical distribution of the snow mass flux $\eta(z)$ (kg m^{-2} s^{-1}) writes

$$\eta(z) = az^{-b}$$

where a is the calibration parameter and b the exponent independent of height. These parameters were derived by regression from the data measured by the two SPCs (Trouvilliez et al. 2015), alternatively available for the two height ranges. Then, the half-hourly average of the horizontal snow mass flux vertically integrated over the corresponding height covered by the 2G-FlowCapt™ can be estimated. Because (i) snow depth measurements revealed insignificant height change after the event and were affected by the presence of drifting snow particles perturbing the travel of ultrasound pulses along the measuring path during the event, (ii) the two 2G-Flowcapts were respectively installed at 0.1 and 1.2 m above the snow surface at the beginning of the event, and (iii) the heights of the SPCs were regularly checked and manually adjusted along the experiment, constant heights are used in the integration. Finally, data were processed following the procedure described in Guyomarc'h et al. (2019).

Resulting integrated snow mass fluxes are compared in Fig. S4. Although more data are necessary to better assess the performance of the 2G-FlowCapt™ in Antarctic conditions, a high degree of agreement between the two types of sensor is depicted with a correlation coefficient of 0.82 and 0.93 and a rmse of 70 10^{-2} and 13 10^{-2} kg m^{-2} s^{-1} (by taking the SPC-S7 as a reference) for the lower and upper measurement range, respectively.

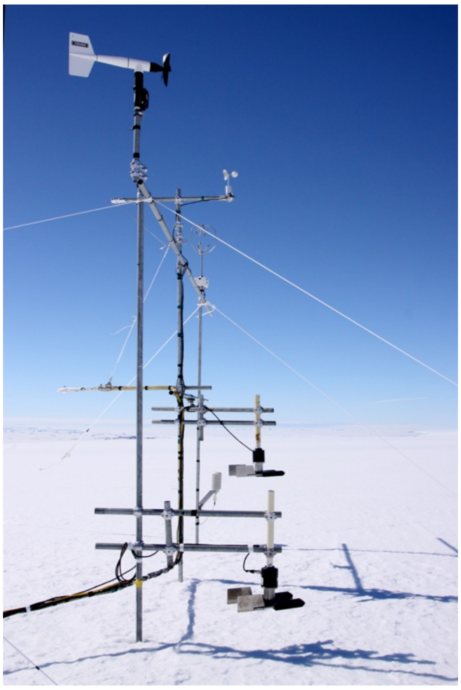

Figure S3. *Picture of the snow particle counters installed at D17 during the intercomparison experiment in late January 2014.*

Figure S4. *See Fig. R1.*

2) It is not clear what the measurement heights were, particularly for D17. Also, it should be made clear throughout the manuscript which measurement level is used for wind speed, temperature and RH, at D17 when plotting or analyzing.

At D17 I've selected the measurement height closest to 2-m as recovered by the snow depth ranger or using the closest original height when no information on snow height is available. This is now explicitly detailed in the manuscript and specified in required places.

3) Fig. 2 shows that drifting snow occurs with lower wind speeds in D17 than in D47. Is this because the surface snow density, or bond strength is lower at this site? Lower average wind speeds can be associated with lower surface density. Or are the two measurement heights not comparable? It would make sense to also discuss the occurrence of drifting snow as a function of friction velocity, as mentioned in L238-239 which is often the variable of interest, determining whether or not snow erosion from the surface occurs. For D17, the profile measurements easily allow for a determination of friction velocity from the 6 measurement heights of wind speed. Similarly, L288, surface roughness could also be quantified from the wind speed profile, which could be used to demonstrate this relationship.

The definition of a drifting snow occurrence in the former version of the manuscript involved a drifting snow mass flux above the confidence threshold at either measurement level. After some reconsideration motivated by your comment on the lack of clarity about the definition of a drifting snow event, I figured out that this may still generate few artificial occurrences when fluxes at the upper level are above the threshold value while fluxes at the lower one are not for small values oscillating around the threshold value. I have then slightly modified the definition of a drifting snow occurrence and redone the analysis with the following definition:

"[…] *drifting snow has been considered to occur when the half-hourly mean of the snow mass flux exceeds a confidence threshold of* 10^{-3} *kg* m^{-2} s^{-1} *as determined from visual observations on the field in Adelie Land (Amory et al., 2017). Note that the same confidence threshold yielded a high level of agreement (98.6 %) between the SPC-S7 and 2G-FlowCapt*^{TM} *in terms of occurrence detection in the comparison study led by Trouvilliez et al. (2015) in the Alps. Since this value remains small compared to snow mass fluxes estimated during drifting snow occurrences (see Sect. 3.4), the confidence threshold is assumed independent on the exposed length of the sensor.*

The sensor is considered unburied as long as at least 10 % (i.e. 0.1 m) of its initial length remain uncovered with snow."

The resulting CRED distribution is presented in Fig. R2. Note that this figure is proposed in replacement of Fig. 2 in the revised version of the manuscript.

Indeed lower surface densities that can be expected at D17 due to lower wind speeds could enable drifting snow to occur at lower wind speeds than at D47. Conversely lower drift-induced compaction at D17 could be compensated by stronger interparticle bonding resulting from higher average temperatures. There is unfortunately no direct way to investigate that aspect, and answering your question in a more exhaustive way would inexorably require knowledge of snow properties at the surface, or at least determination of threshold friction velocities at D47, which are either not available or possible due to the single measurement level at D47. I then suggest to leave this question open for further studies. Anyways, updated Fig. R2 no longer suggests that such processes may be responsible for significant differences in CRED distribution between the two locations despite the actual differences in climate conditions, and indicates that wind speed is the main deriver behind the occurrence of drifting snow.

Accurate determination of friction velocity values from the data collected in the extreme environment of D17 involve several selection criteria (see Amory et al. 2017) that are far from being systematically met along the measurement period, resulting in discontinuous time series that can be additionally biased by an over-representation of climate conditions for which these criteria are met but not necessarily representative of the average climate conditions. In particular, the validity of Monin-Obukhov similarity theory, from which friction velocity and roughness length can be determined using the wind speed profiles, is questionable during drifting snow conditions. Another influent factor in the determination of friction velocity that could impede the generation of homogeneous time series is the number of anemometers available for each wind profile, which varies non-uniformly along the measurement period depending on instrument failure and burial of the lower levels. Note that evolution of the measurement height is also not known before 2013 at site D17. These factors, together with additional parameters such as the choice of the stability correction function, all justify a sensitivity study that lies beyond the scope of the present paper. A non-negligible issue when using the wind profiles at D17 to compute friction velocity values is the artificial roughness created during summer visits and maintenance/replacement operations. This is especially true since summer 2014-2015 when the meteorological mast at D17 was mounted on a sledge that was further buried under the snow. The whole operation, ideally repeated each year, requires excavation of several meters in depth within the snowpack and use of snow trucks that disturb surface roughness in the immediate vicinity of site D17 for an unknown duration.

For all these reasons, and also because site D47 is equipped with only one measurement level thus precluding spatial comparison with D17, I chose to focus on wind speed rather than friction velocity, enabling the discussion of continuous, more homogeneous times series at both locations simultaneously.

Similarly, threshold friction velocity would need to be continuously known all along each drifting snow event to investigate differences with friction velocity, so the theoretical statement made in L288 cannot be illustrated with the present data. It has therefore been removed from the text (see my response to the next comment). Here in the absence of direct measurements of surface snow properties, threshold friction velocity values can only be determined at the onset and end of drifting snow event, when the snow mass flux rises or drops below the confidence threshold value and only if friction velocity can be accurately determined from the wind speed profiles at the same time.

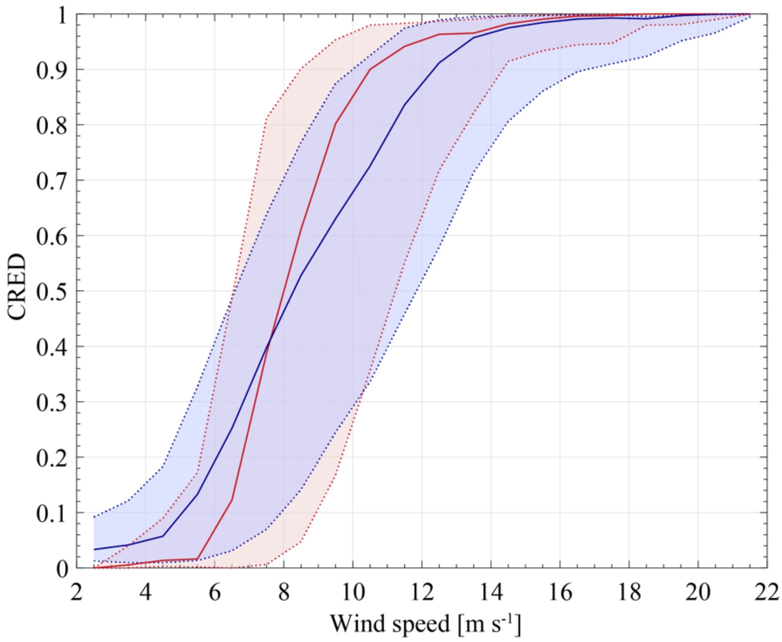

Figure R2. CRED distribution for drifting snow occurrences showing the increasing probability of observing drifting snow with increasing 2-m wind speed at sites D47 (red curve) and D17 (blue curve). Shaded areas correspond to CREDs respectively computed using a relaxed and a stricter confidence threshold of 10^{-4} kg m^{-2} s^{-1} and 10^{-2} kg m^{-2} s^{-1} and are shown as a measure of uncertainty.

4) Eq. 2 confuses me, because the summation symbol lacks what it is summing over. At first, I thought that this was just how to compute half-hourly transported mass, but it seems to be for event transported mass and that the summation is over all the time steps constituting an event. In that case, L276 should introduce the definition of drifting snow event, if it is not each half-hourly data interval. Is the first half hourly interval that drops below the limit considered the end of the event? Nowhere in L262-271 is it introduced that there is a switch to the event based analysis.
Several modifications have been made in order to improve clarity when dealing with the computation of snow mass fluxes and snow mass transport and are reported below:

(i) Derivation of snow mass transport from former Eq. 2 has been re-expressed in a clearer way following two equations, starting from the formulation of the drifting snow mass flux η_{DR} (i.e. vertically integrated between 0 and 2 m over the snow surface) as

$$\eta_{DR} = \begin{cases} \eta_1 + \eta_2, & h_1 + h_2 \geq h_{ref} \\ \eta_1 + \eta_2 \cdot \dfrac{h_{ref}}{h_1 + h_2}, & h_1 + h_2 < h_{ref} \end{cases} \quad (1)$$

where η_i (kg m^{-2} s^{-1}) is the observed snow mass flux integrated over the exposed height h_i (m) of the corresponding 2G-FlowCapt™ sensor, and h_{ref} = 2 m is the sum of two fully exposed, 1 m long 2G-FlowCapt™ sensors. In other words, when $h_1 + h_2 < 2$ m, it is assumed that the measured snow mass flux is constant up to 2 m. To keep consistency with the confidence threshold for the detection of drifting snow occurrences, snow mass fluxes below 10^{-3} kg m^{-2} s^{-1} have been set to 0. The horizontal drifting snow mass transport for a given period of time $[t_0, t_n]$, Q_{DR}, then writes

$$Q_{DR}(t) = \int_{t_0}^{t_n} \eta_{DR}(t)dt. \quad (2)$$

(ii) Following your recommendation, Eqs. 1 and 2 are now introduced in the methods section,

(iii) The definition of a drifting snow event in Sect. 3 has been made clearer and is now presented as "*a period over which snow transport is detected for a minimum duration of 4 hours. That is, an event is considered to start and end when the half-hourly snow mass flux at the lower unburied level* η_i *respectively rises and drops below the confidence threshold of* 10^{-3} *kg* m^{-2} s^{-1}.",

(iv) Complementary information has been given on the threshold used for acknowledging the occurrence of drifting snow in Sect. 2.3 as detailed in my response to general comment #3,

(v) All along the manuscript it is now explicitly mentioned to which snow mass flux (raw sensor output η_i or corrected drifting snow mass fluxes η_{DR}) I refer to.

The relation between snow mass transport and wind speed is now discussed by studying half-hourly drifting snow mass fluxes computed from Eq. (1) as a function of related 2-m wind speeds (Fig. R3 – Fig. 5 in the revised version of the manuscript) instead of mass transport and average wind speed per event, and consists in the following analysis in the paper:

"*The drifting snow mass flux* η_{DR} *typically tends to increase with wind speed in a power-law fashion (Fig. 5). This well-known behavior (Radok, 1977; Mann et al., 2000) is however depicted with significant dispersion and notable differences between the two locations; the data at D17 show that drifting snow mass fluxes can be of greater magnitude than at D47 for similar wind speeds and exhibit a generally higher variability along the range of wind speeds. This illustrates the diversity and spatial variability in factors controlling the windborne snow mass, as mentioned in the previous section. While wind speed can be used to predict the occurrence of drifting snow with a quite similar probability distribution between both locations (Fig. 3), on the other hand Fig. 5 demonstrates that more caution should be taken when scaling drifting snow mass transport with wind speed or related single parameter independent of surface snow properties (e.g. Mann et al., 2000). Such an approach would indeed involve mixtures of power laws to capture the large variability in drifting snow mass flux within the same wind speed interval, particularly at D17 where almost the entire range of values is observed from 15 m* s^{-1}. *Drifting snow is highly non-linear in nature and results essentially from the competitive balance between atmospheric drag and cohesive forces acting on the snow surface. This means that concurrent documentation of turbulence and surface snow properties are required for a better assessment of drifting snow processes and improvements of model predictability (e.g. Baggaley and Hanesiak, 2005; Vionnet et al., 2013).*".

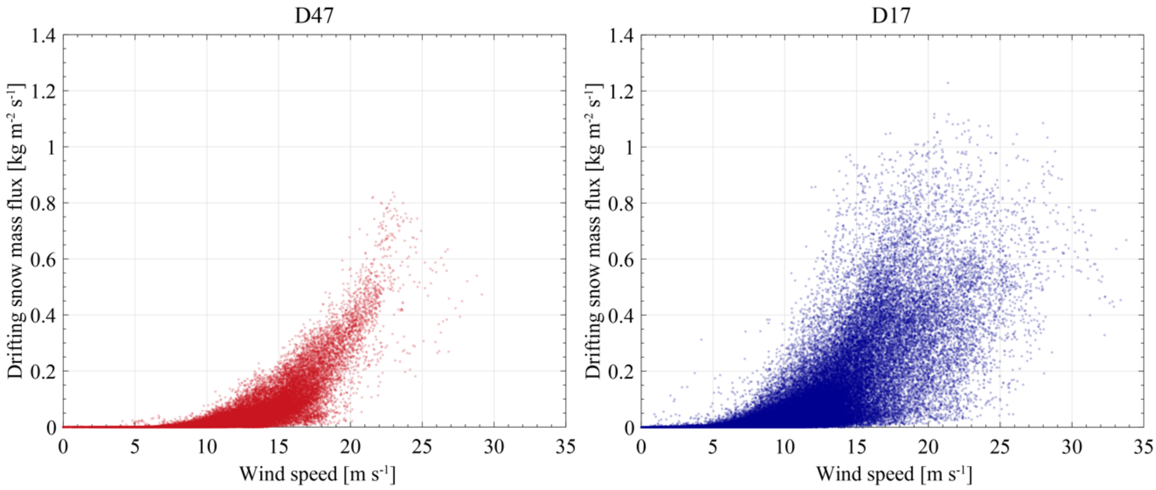

Figure R3. Drifting snow mass flux against 2-m wind speed recorded at D47 (left panel) and D17 (right panel). Only periods for which two 2G-FlowCapt™ sensors were installed and/or the lower sensor was not entirely covered with snow (i.e. $h_1 > 0.1$ m) are considered.

As the definition of a drifting snow event is explicitly given in Section. 3.3, make a recall just a few paragraphs below would thus sound redundant. The paragraph describing the relation between mass transport and event duration introduces the switch to the event-based the analysis in the 2nd sentence: "*Values of* Q_{DR} *have been computed for each drifting snow event identified in the database [...]*".

5) Cierco et al. (2007) mentions that FlowCapt sensors can saturate. Could that be an explanation for the apparent upper bound on snow transport mass (L291-292)?

If saturation of the sensors would be responsible for the apparent upper bound in snow mass transport, it should be apparent from the raw sensor outputs as well. However no evidence of such a behavior is found when plotting the half-hourly snow mass fluxes against wind speed as proposed in the new analysis (see the previous comment - Fig. R3). Note also that the evaluation of Cierco et al. (2007) makes use of the original design of the FlowCapt sensor, and the analysis proposed here relies on a more recent design which significantly improves, although not necessarily solve, inaccuracy issues with estimating snow mass fluxes (Trouvilliez et al., 2015).

6) I'm not sure if the Online Supplement is necessary. It seems that the manuscript would benefit from inclusion of most of the materials in the main text. In particular, I think that the map with location of the stations should be part of the main text.
Yes I agree, the location of the measurement sites is of first importance. The map has been included in the main text. I'd like to stress that I have a limited budget for this publication and inclusion of figures in the main text rather than in supplement goes with significant charges. So I'd like to stick to the very essential material in the main text if it seems reasonable, and leave the rest (Tables S1,S2 and Figs. S2,S2) as supplementary materials since they contain additional information that would surely be beneficial but are not really essential to the analysis.

Minor comments

L7: "hydrological"? Maybe "surface mass balance" is better (see L21-22)?
Thanks for the suggestion. Surface mass balance is the resultant of the hydrological cycle at the surface of the ice sheet, so I'd rather keep this formulation as it is, if it does not result in any misunderstanding.

L8: "punctual" doesn't seem to be the right word here. I suggest: "model and satellite based products".
I simply removed "punctual" and now speak about "model and satellite products".

L13: "The data provided nearly continuously so far constitutes". Maybe add commas for clarification: "The data, provided nearly continuously so far, constitutes"
Corrected accordingly.

L25: It's confusing: wind confluence for me is the *convergence* of wind, unless there is compensating acceleration (which doesn't seem to be the case given that D47 has higher wind speeds than D17), so how does this relate to the horizontal *divergence* of snow?
I agree that these two terms might be confusing when employed together as they may apparently relate to opposite situations. In a general picture, convergence of the wind field is associated with deceleration and thus deposition of snow (or convergence of snow by wind transport). While this is certainly verified over a flat surface, this does not however preclude the occurrence of erosion within steep regions of the confluence area, where katabatic winds converge from a large-scale perspective and still can accelerate locally depending on the slope of the ice surface.
Changes in surface slope play a crucial role in controlling locally the erosion/deposition process through acceleration/deceleration of the near-surface flow. This is illustrated through sub-kilometer spatial heterogeneities in accumulation in, for instance, coastal Adelie Land (Agosta et al., 2012), or alternating ridges and glazed surfaces scattered over East Antarctica (Scambos et al., 2012).
In an even more general picture, erosion occurs at every places where u_* exceeds u_{*t}, whether the near-surface wind field displays a convergent or a divergent character.Wind confluence zones result from the large-scale interactions between the topography and near-surface flow. Cold-air drainage currents converge from a large interior area in smaller areas that thus drain the air from a much wider upstream reservoir. Katabatic confluence areas such as Adélie Land are generally characterized by stronger and more persistent winds (Bromwich and Liu, 1996; Parish and Bromwich, 2007), which can thus lead to enhanced snow transport in these regions, erosion where $u_*>u_{*t}$, or in other words, horizontal divergence of the wind transport of snow.
Nevertheless, for clarity I have removed the terms "divergence" and "convergence" from the paragraph you were confused by, and rewritten the sentence as "*In coastal areas, wind redistribution of snow is responsible for an export of mass beyond the ice-sheet margins.*". Note however that Adelie Land is still introduced as a wind confluence area of East Antarctica in the last paragraph of the introduction.

L26-28: "Sublimation of snow particles ..." Please add citations. There are several good papers on drifting snow sublimation out there which deserve citation here.
I originally intended to have this assertion supported by the several papers I refer to at the beginning of the next paragraph but yes, you're entirely right. I have added 3 significant studies (Mann et al., 2000; Bintanja, 2001; Thiery et al., 2012) highlighting and discussing the role of windborne snow sublimation in Antarctica.

L35: "are to be found" should that not be "are found"?
See our response to the next comment.

L36: "in the absolute values attributed to the relative contribution of these various mechanisms." Sounds vague.
I have reformulated the sentence as "Conversely, contrasting results can be found from one study to another in the absolute values attributed to the contribution of wind-driven processes to the large-scale mass transport."

L40: "3 times fewer" seems to refer to "mass fluxes". But either "3 times fewer" refers to occurrence, or it should be "3 times less".
"3 times fewer" does actually refer to "mass fluxes". I have reversed the sentence and written "3 times larger".

L43: "The degree of plausibility of model-dependant features". I assume "model-dependent", but the sentence is a little vague.
I have reformulated the sentence as "model results as well as the assumptions made in the implementation of wind-driven snow physics need to be carefully assessed with independent observations."

L80-82: It reads as if the experiments were only in January 2010, and it should be highlighted here that the dataset is much longer. I would recommend writing something like: "For long term data acquisition following the measurement campaign, two distinct locations ..."
I have changed the two following sentences to account for your suggestions: *"[...] a field campaign specifically dedicated to drifting snow has been initiated [...]. Two distinct locations, namely D17 and D47 (Fig. S1), were instrumented for long term-data acquisition and equipped with [...]."*

Section 2.1: How is the power supply organized? Can there by a bias in data availability depending on power source? (For example, if the battery tends to be drained towards the end of the winter season).
A power consumption balance has been calculated before installation of each stations according to the whole set of instruments to ensure a continuous power supply throughout the year. Each installation of new instruments (such as for instance, a second 2G-FlowCapt™ sensor and a sonic depth ranger at D17 in late December 2012) came along with installation of new sets of batteries and solar panels to supply for the additional power requirements. The batteries are also checked during each summer visit and replaced when needed. The batteries' voltage is continuously monitored and stored together with the meteorological variables in the datalogger to ensure that the entire system has been designed properly and is sufficiently supplied with energy throughout the winter. Note also that the FlowCapt™ sensors are known to be low-consuming and are moreover continuously solicited by the datalogger (RS232 connection), so we can easily distinguish between instrument failure (absence of response – no data) and data containing null values (absence of drifting snow). Except for the months of May and June at site D47 and a few other instances of malfunction scattered outside of maintenance operations, the dataset is continuous along the measurement periods. I have added the following related lines in the text:

"The FlowCapt™ is low-power consuming and designed to withstand harsh climate conditions without regular human attendance. At each station battery voltage is monitored and stored together with the meteorological variables in the datalogger to ensure that the entire measurement system is sufficiently supplied with energy throughout the winter. The 2G-FlowCapt™ are continuously solicited by the datalogger (RS232 connection), such that instances of instrument malfunction (absence of response and no data) can be

unambiguously distinguished from the absence of drifting snow (data containing null values). A thorough check on the observations was performed and resulted in omission of misleading data wherever necessary. Except for those very few cases, maintenance periods in summer and a major 2-month failure of the lower 2G-FlowCapt™ sensor at D47 in May and June 2012, the dataset is continuous along the respective measurement periods.".

Section 2.1: It would be good to mention here explicitly that D17 is still operative.
It is now explicitly mentioned in the section and in Table 1.

Section 2.1: Fig. S2 in the supplement should show the dates on which the photos were taken.
Done.

L112: "the drainage of the sinking near-surface air" sounds vague to me.
I assumed that the lack of clarity here came from the use of "sinking" and rewrote the sentence as "The local topography controls the drainage of the dense near-surface air as it flows downslope and accelerates […]".

L113: "over an unobstructed"
Corrected accordingly.

L118: "higher incidence of drifting snow", maybe add a reference to Fig. S4?
Done.

L119: "combined with"
Corrected accordingly.

L118-119: I suggest to reference the accompanying Brief Communication here. "Brief communication: Rare ambient saturation during drifting snow occurrences in coastal East Antarctica"
Done.

L160-161: This seems like an appropriate location to introduce Equation 2, instead of Section 3.4. At least, I assume that the same correction is made when part of the FlowCapt was buried as done in Equation 2?
See my response to general comment #4.

L171: Again, I don't think punctual is appropriate here.
The word "punctual" has been replaced with "sporadic".

L194-195: This statement deserves citations.
I refer now to Schmidt (1980) who discusses the importance of inter-particle bonds in the initiation of snow transport and Amory et al. (2017) who discuss the influence of increased threshold friction velocities in summer on snow mass fluxes from data collected at D17 and relate it to the growth of inter-particle bonds.

Fig. 1, as well as Fig. 2: The figure caption should also mention what the gray shaded areas denote (currently it's only explained in the main text).
I have added in the figure caption the meaning of the shaded areas. Note that CRED distributions have been combined into one figure (see fig. R2 and my response to general comment #3) to facilitate comparison between both locations and the figure is now described according to the two main curves only (comments involving shaded areas have been removed) for clarity.

L268: Maybe add: "h_ref = 2 m, which is the sum of two 1 m long FlowCapt sensors."
Done.

L290: This is confusing. Fig 4, right panel should be a non-log (i.e., linear) scale in order for it to show a linear increase of QT and event duration.

The logarithm scale is preferred here because differences of several orders of magnitude in mass transport per event for all the range of drifting snow events decrease significantly readability when using a linear scale (Fig. R4). I suggest to still make use in the paper of the logarithm scale for readability purposes but include the linear regression fits and their respective equation to highlight the linear character of the relationship between mass transport and duration as shown in Fig. R5.

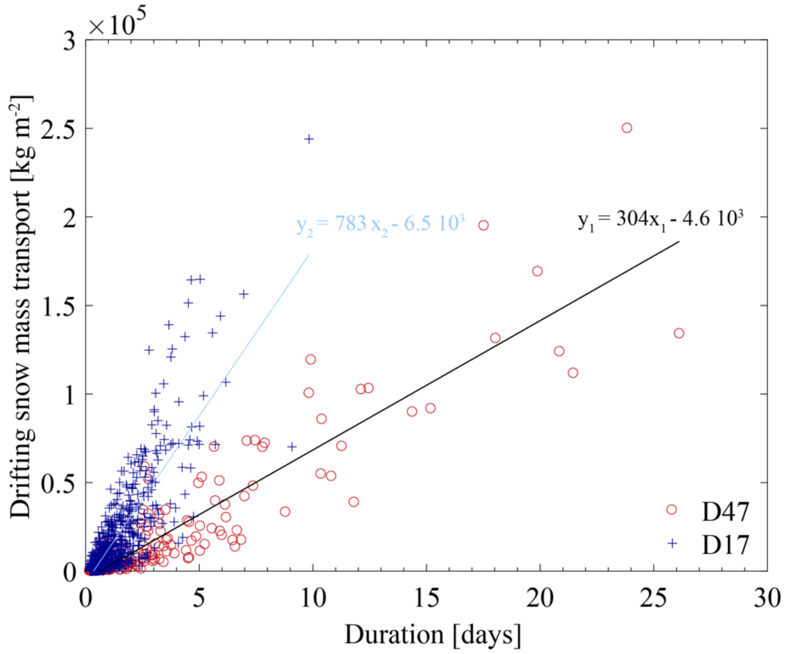

Figure R4. Snow mass transport in drift conditions against duration for each drifting snow event recorded at D47 (red circles) and D17 (blue crosses). Only periods for which two 2G-FlowCapt™ sensors were installed and/or not entirely covered with snow are considered. Linear fits for D47 (black line) and D17 (light blue line) data are also reported on the graph.

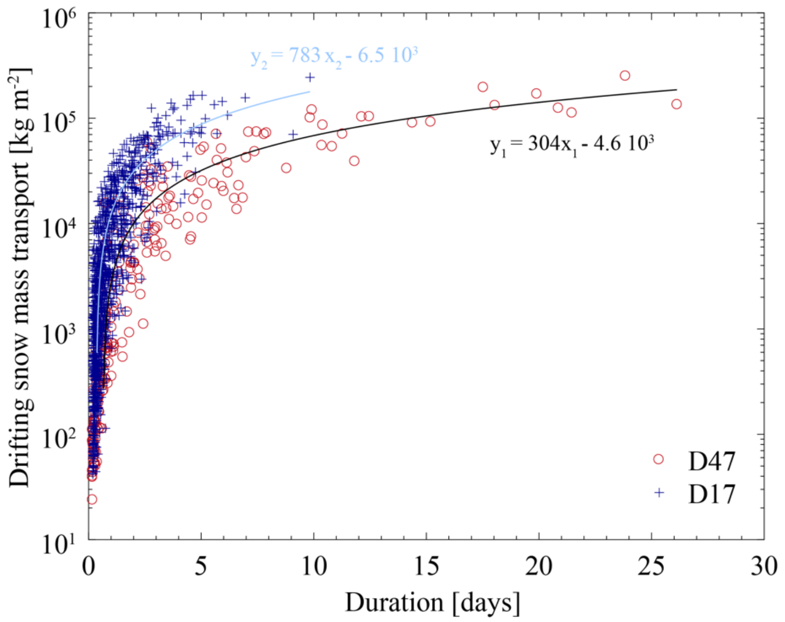

Figure R5. Logarithm of snow mass transport in drift conditions against duration for each drifting snow event recorded at D47 (red circles) and D17 (blue crosses). Only periods for which two 2G-FlowCapt™ sensors were installed and/or not entirely covered with snow are considered. Linear fits for D47 (black line) and D17 (light blue line) data are also reported on the graph.

L296-297: Could this be substantiated by showing the two levels separately?
Unfortunately the contribution of the saltation and suspension layers to the snow mass flux estimates provided by the 2G-FlowCapt™ cannot be distinguished because fluxes are vertically integrated over the exposed length of the sensor, which for the sensor closest to the ground almost always largely exceeds typical saltation heights (~10 cm) over the measurement period. This has been added to the text.

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Response to reviewer RC2

I thank the reviewer for his thorough reading of the paper, the comments and the proposed suggestions. My responses are reported hereafter in red.

This paper presents the analysis of 8 yr field observation of drifting snow at two sites D17 and D47 on Terre Adelie Land (east Antarctica). The main tools used in this study are FlowCapt acoustic sensor and associated Automatic Weather Station. The paper contributes to knowledge concerning the measurement of negative term of surface mass balance driven by wind.

The manuscript subject is appropriate for Cryosphere Journal, well written, data and analysis are very important. The data are partially already presented and analysed in previous paper (Trouvilliez et al, 2014 and 2015) and a paper under review on the Cryosphere (Amory & Kittel, submitted) presents the same data under the aspect of the sublimation that is the main issue not discussed in this manuscript. The interpretations of data acquired are supported by the result and the amount of the good data, but the statistic analysis present in the manuscript are not relevant to support the publication on the high quality Journal such as "The Cryosphere" and the Surface Mass Balance condition from the previous studies are not taken adequately in account. The previous paper on SMB survey at the two sites (D17 and D47) and model on the Adelie Coast are not adequately discussed and reported (example: Pettrè et al., 1986; Bintanja, 1998; Pourchet et al., 1997; Frezzotti el ta., 2004, Genthon et al., 2007; Agosta et al., 2011, Favier et al., 2013, Barral et al., 2014 in the reference but is not taken in account in the manuscript; Goursaud et al., 2017). The manuscript does not analysed the Surface Mass Balance and in particular the extensive presence of the blue ice area in the Coastal Terra Adélie (Favier et al., 2011) and their implication on the drifting snow.

The author does not distinguish drift from blowing snow phenomena and the threshold of snow sublimation, and their implication on the mass transport/sublimation and the difference between the two sites. Blowing and drifting snow are not redistribution process, a significant part of blowing snow sublimate as pointed out by snow radar survey (see Frezzotti et al., 2007; Eisen et al., 2008) or satellite survey (Scarchilli et al., 2010, Palm et al, 2011, 2017; Scambos et al., 2012). The AWS and FlowCapt sensor provide single measurement point for limited number of years and must be analysed in the contest of Surface Mass Balance study derived from other field measurements as stakes, firn cores, snow radar profile and satellite studies.

Although rather concise, many issues are raised in this report and I'll try to address all of them. Note that some of the elements of response provided here are redundant with the information provided in the manuscript but are reported here since they constitute key elements of the argumentation.

One major issue raised by the reviewer is the lacking character of the publication concerning surface mass balance aspects, and the discrepancy between the reviewer's expectations and the content of the paper. If the subject of the paper were to investigate the relations between erosion and variability in the surface mass balance in Adelie Land, I should have indeed considered those points raised by the reviewer, I agree, although one would face some serious complications by doing so, as I will discuss it in the following paragraph. But the objective of the paper in the proposed version is different: I aim here at publishing and presenting the drifting snow database while providing some examples of use of the data through a first statistical (temporal and spatial) analysis of drifting snow mass transport and frequency (made possible by the high sampling frequency and the continuous character over the respective measurement periods) and in which emphasis is placed on aspects relevant to the modelling of drifting snow. The interest of the paper partly relies on the quality and the open-access character of the drifting snow database (which has been deposited on zenodo and can be now downloaded at https://zenodo.org/record/3630497; see my response to reviewer RC1), that compiles new observations which are almost inexistent in the extreme and remote Antarctic environment. By making them freely available to the scientific community without condition, the paper is an opening to a larger field of applications, such as evaluation of climate models, simultaneous analysis of ground-based and remotely sensed data, investigations on polar boundary-layer physics or accumulation/ablation processes, each of them belonging to a specific area of expertise and individually warranting a careful, detailed, equally interesting attention.

It is of crucial importance to understand the possibilities offered by the drifting snow data. In particular, the relation between the snow mass flux and ablation at a given area is far from being direct. Snow mass fluxes do not constitute an estimation of local erosion; rather they are the integrated result of all the mechanisms that contribute to the presence, amount and time residence of snow particles in the air, including notably precipitation and advection from upwind areas. Unfortunately the FlowCapt™ sensor does not distinguish neither the source or the geographical origin of the particles impacting the tube, and how much precipitation contribute to the snow mass transport in Antarctica is still an open research question. Therefore these observations must not be perceived as measurements of "wind-driven negative term of the surface mass balance" and cannot be used to quantify local ablation rates without the use of a complementary approach such as numerical modelling. This is the main reason why all the references mentioned by the reviewer are indeed not discussed in the paper since they would lie beyond the scope of the paper. Some of other major concerns that would arise from the multidisciplinary and quite ambitious approach suggested by the reviewer result from the fact that:

- the transect along which stake measurements are indeed performed in Adelie Land is not aligned with the main slope in the wind direction, so any spatial variability depicted in the local SMB signal might not directly correlate to the magnitude of the snow mass flux.

- the fine spatial resolution of the stake networks in Adelie Land demonstrates a high, sub-kilometre spatial variability that couldn't be supported by analysis of mass fluxes performed at only two distant locations, and whose spatial representativeness cannot be assessed in the absence of other comparable measurements in the area.

- the observations presented in this paper are, as you mentioned, "*single measurements point for limited number of years*", moreover performed over the most recent years. A mismatch in timing of several decades can thus be expected with the information contained in deep snow/ice layers sampled through ice cores and radar stratigraphy.

Moreover, temporal and spatial variability of the SMB in Adelie Land has already been quite well investigated (as demonstrated by the long, non-exhaustive list of references mentioned in your report), while drifting snow mass transport has received much less attention. Documentation of spatial et temporal variability in snow mass transport over Antarctica almost exclusively relies on models whose ability to represent drifting snow processes has been extremely limited owing notably to the current extreme scarcity of drifting snow observations. This justifies, in my humble opinion, an initial and independent documentation of the entire database before exploiting further possible connections with other processes and synergetic uses with other products. For the above-mentioned reasons, and because I'm also deeply convinced that keeping the scientific message of a paper as onefold improves clarity, readability and efficiency and thus prevent the paper from being too long with various scientific messages and disconnected sections, I believe that the various applications mentioned by the reviewer are all interesting subjects for separate papers. Finally, note that SMB-related aspects are discussed in a manuscript that I've submitted to Geoscientific Model Development, in which the data presented in this paper have been used in conjunction with the SMB observations in Adelie Land to evaluate the drifting snow scheme of the regional climate model MAR and its ability to represent the variability in accumulation along the transect.

The following comments gather some elements of responses to the remaining comments of the reviewer:

- The driting snow observations are performed far from the blue ice area (i.e. respectively 10 and 100 km away from the ice margin), which covers the very first hundreds of metres of the ice-sheet margin, and relate to different local (topographical) conditions irrelevant to the objective of the paper in its current form.

- As the sensors are installed at both measurement sites so as to cover the first two meters above ground, which is the height conventionally used to distinguish drifting from blowing snow, they do not enable a distinction between drifting and blowing snow.

- Sublimation of windborne snow is determined by the temperature and humidity gradients across the boundary layer between each snow particle and its environment and is proportional to the undersaturation of the atmosphere (Schmidt, 1982). For a given wind speed, threshold values at which airborne snow sublimation becomes significant can thus be expected to vary significantly depending, among others, on the snow particle concentration and thermodynamic properties and structure of the atmosphere, or the dynamical origin of the boundary-layer flow. From this perspective, as a *"threshold of snow sublimation"* sounds quite vague to me, I also assumed that the reviewer possibly meant "wind speed thresholds for snow transport". A comparison between both measurements sites in terms of occurrence of drifting snow as a function of wind speed is already proposed and discussed in the paper (see Figs. 2 and 3 in the former and revised version of the manuscript, respectively). Moreover, the actual quantity involved in the triggering of drifting snow is the friction velocity, which is only dependent on surface snow properties (Gallée et al., 2001). In the absence of measurements of surface snow properties, and knowing that atmospheric flow conditions would also influence the results, accurate determination of such thresholds can be achieved through turbulence measurements (not available either at D17 or D47) or wind speed profiles using the similarity theory by computing the friction velocity at the onset of drifting snow (e.g., Trouvilliez et al. 2014). However, such an alternative involve a thorough determination protocole (Amory et al., 2017) and selection criteria that are not continuously and homogeneously met at D17 and would result in a discontinuous time series, additionally subject to impeding factors (see my response to general comment #3 of reviewer RC1). For instance, accuracy issues arising from various variable numbers of available anemometers, absence of knowledge of measurement heights, choice of stability correction functions, or the validity of the similarity theory in drifting snow conditions, as well as inclusion of drag effects to the shear stress estimates (e.g., Amory et al., 2016) and artificial roughness created during maintenance operations, are all arguments that would, again, certainly deserve an entire sensitivity study in the form of another publication. Finally, the single measurement level at D47 preclude such determinations, and therefore spatial comparison with D17.

- Limitations in computing sublimation rates from AWS data and drifting snow mass fluxes have already been discussed in a recently published paper (Amory and Kittel 2019). The authors made use of one year of this dataset at site D17 in complement to relative humidity profiles to investigate the development of a near-saturated surface air layer in relation to the occurrence of drifting snow. As also mentioned in that paper, such an exercise involves specific requirements that are only met during a reduced period of time at site D17, justifying its treatment in a separate publication and precluding its application to D47 and outside of the period of study (year 2013). Similarly, strong limitations in the use of the thermo-hygrometers and in the applicability of the Monin-Obukhov similarity theory for retrieving latent heat fluxes at D17 (from which drifting snow sublimation rates could be inferred) have also been discussed in Barral et al. (2014).

- Sublimation of windborne snow has been inferred from accumulation measurements (e.g. Frezzotti et al., 2007; Scambos et al., 2012) but still remained to be confirmed and quantified by measurements of the latent heat flux within the atmosphere and drifting/blowing snow layers, accounting for the physical constraints mentioned above. The usual alternative is the use of gridded model products. Attempts using also satellite data have been made (Palm et al., 2017), but they involve the use of (i) parameterizations for snow particles properties, (ii) snapshots of the atmospheric conditions that are representative of instantaneous conditions only, and (iii) reanalysis produced from model that do not take into account interactions of snow particles with the atmosphere, particularly the negative feedback of windborne snow sublimation thus leading to a dry bias that can result in strong overestimation of sublimation rates and give the role of an infinite mass sink to the atmosphere. Moreover, as discussed in the introduction, strong discrepancy currently remain between the available model products (~100 vs 400 Gt/an), to the extent that the difference between each estimate is one order of magnitude higher than any other ablation term of the surface mass balance as determined from regional models (e.g., Agosta et al., 2019; Mottram et al., 2020). Different model-based approaches have also been proposed in which drifting snow mass transport is believed to be the first-order process with respect to sublimation, because of the low capacity of the atmosphere to hold moisture in the cold environment where accumulation measurements have been performed (Agosta et al., 2019). The role of sublimation during snow transport, particularly as a negative ablation term in Antarctica, is a currently debated problem in meteorology and snow science. I kindly refer to Amory and Kittel (2019) for a more detailed discussion on that matter from D17 data.

- Note that in Trouvilliez et al. (2014) only the initial results of the drifting snow observation campaign (the first 2 years) are presented under different processing criteria relative to a less complete knowledge on the FlowCapt™ capabilities at the time of redaction, and with no accessibility of the data and much less emphasis on drifting snow mass transport.

- Trouvilliez et al. (2015) focus on data collected in the French Alps and their work is not connected to the observations in Adelie Land.

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Drifting snow statistics from multiple-year autonomous measurements in Adelie Land, eastern Antarctica

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Abstract. Drifting snow is a widespread feature over the Antarctic ice sheet whose climatological and hydrological significances at the continental scale have been consequently investigated through modelling and satellite approaches. While field measurements are needed to evaluate and interpret model and ~~punctual~~ satellite products, most drifting snow observation campaigns in Antarctica involved data collected at a single location and over short time periods. With the aim of acquiring new data relevant to the observation and modelling of drifting snow in Antarctic conditions, two remote locations in coastal Adelie Land (East Antarctica) 100 km apart were instrumented in January 2010 with meteorological and second-generation IAV Engineering acoustic FlowCapt™ sensors. The data, provided nearly continuously so far, constitutes the longest dataset of autonomous near-surface (i.e. within 2 m) measurements of drifting snow currently available over the Antarctic continent. This paper presents an assessment of drifting snow occurrences and snow mass transport from up to 9 years (2010-2018) of half-hourly observational records collected in one of the Antarctic regions most prone to snow transport by wind. The dataset is freely available to the scientific community and can be used to complement satellite products and evaluate snow-transport models close to the surface and at high temporal frequency

1 Introduction

Wind-driven transport of snow in Antarctica, organized in drifting (< 2 m above ground level) and blowing (> 2 m above ground level) snow, has important implications for the ice-sheet climate and surface mass balance. Erosive winds redistribute snow at the surface and can form areas of near-zero net accumulation (known as wind glaze areas) or even net ablation (known as blue ice areas) whose presence has a profound influence on the local surface energy balance (Bintanja, 1999; Scambos et al., 2012), possibly enhancing surface melt (Lenaerts et al., 2017). In coastal ~~(wind confluence) areas, the horizontal divergence of snow through wind transport~~ areas, wind redistribution of snow is responsible for an export of mass beyond the ice-sheet margins (Scarchilli et al., 2010). Sublimation of snow particles during transport is a major component of the surface heat and moisture budgets in regions where most of the precipitated snow is relocated by wind (e.g., Mann et al., 2000; Bintanja, 2001; Thiery et al., 2012).

Because of the widespread character of drifting and blowing snow over the vast and remote Antarctic continent, estimates of their hydrological and climatological significances at the ice-sheet scale rely on parameterized methods (e.g., Gallée, 1998; Déry and Yau, 2002; Lenaerts and van den Broeke, 2012; Palm et al., 2017; van Wessem et al., 2018; Agosta et al., 2019). A consensus emerging from these efforts that has persisted for more than two decades suggests that, although significant locally, mass loss through wind redistribution and export into the ocean is of minor importance while sublimation during transport remains the dominant sink of mass when evaluated over the whole ice sheet. Conversely, contrasting results are to can be found from one study to another in the absolute values attributed to the relative contribution of these various mechanismscontribution of wind-driven snow processes to the large-scale mass transport. Latest continent-wide estimations of wind-driven snow sublimation obtained from regional modelling (van Wessem et al., 2018) are lower by a factor of 4 than those computed from a combination of satellite products and meteorological reanalysis (Palm et al., 2017). Modelled snow mass fluxes presented in van Wessem et al. (2018) Agosta et al. (2019) exhibit a similar overall spatial pattern but are more than 3 times fewer larger than those reported in Agosta et al. (2019)van Wessem et al. (2018). Considering the diversity of interactions and the non-linearity of processes involved in the onset, development and magnitude of wind-driven snow occurrences (e.g., Déry et al., 1998; Bintanja, 2000; Amory et al., 2016), model results as well as the assumptions made in the implementation of wind-driven snow physics need to be carefully assessed with independent observations.

Advances in active lidar remote sensing of the atmosphere from space have provided recent insights into the spatial distribution and temporal variability of blowing snow over the last decade independently from modelling approaches. Although of unrivalled interest for studying blowing snow over large temporal, horizontal and vertical scales simultaneously, satellite lidar data provide snapshots of a particular set of blowing snow properties (frequency, layer depth, optical thickness) relatively to the satellite revisit time (Palm et al., 2011). Moreover, satellite detection is restricted to clear-sky or optically thin cloud conditions and relatively deep (> 30 m) blowing snow layers, precluding its application for characterization of shallower (drifting and blowing snow) layers and for model evaluation in the vicinity of the surface. While this last limitation is also shared with ground-based remote sensing techniques (Mahesh et al., 2003; Gossart et al., 2017), measured vertical profiles of snow mass fluxes display however the strongest gradients in the lowest metres of the atmosphere (Budd, 1966; Mann et al., 2000; Nishimura and Nemoto, 2005).

Direct near-surface observations of wind-driven snow in Antarctica are sparse in time and space to the extent that long-term quality-controlled datasets that yet constitute essential development and evaluation bases for parametrization schemes barely exist. The absence of an official standard instrument has led to the use of a wide range of observation techniques from mechanical traps and nets to electronic (optical, piezoelectric, acoustic) sensors (see Leonard et al. (2012) and Trouvilliez et al. (2014) for an extensive review) as well as visual observations carried out at some Antarctic manned stations (Mahesh et al., 2003; König-Langlo and Loose, 2007). However, like satellite products, visual observations are representative of instantaneous conditions only and are additionally dependent on personal appreciation of the observer who might change with time, leading to non-uniform and temporally discontinuous records.

In spite of their disparity, near-surface measurements of wind-driven snow over the Antarctic ice sheet have provided valuable and accurate information that cannot be sensed remotely nor determined visually. This includes, among others, particle size distributions and related dimensionless shape parameters, total particle numbers and snow mass fluxes at different heights. Although the data collected are also relative to the instrument used and can hardly compare to each other, they are eventually useful for modelling experiments. The dimensionless shape parameter and particle number are, for instance, either predicted

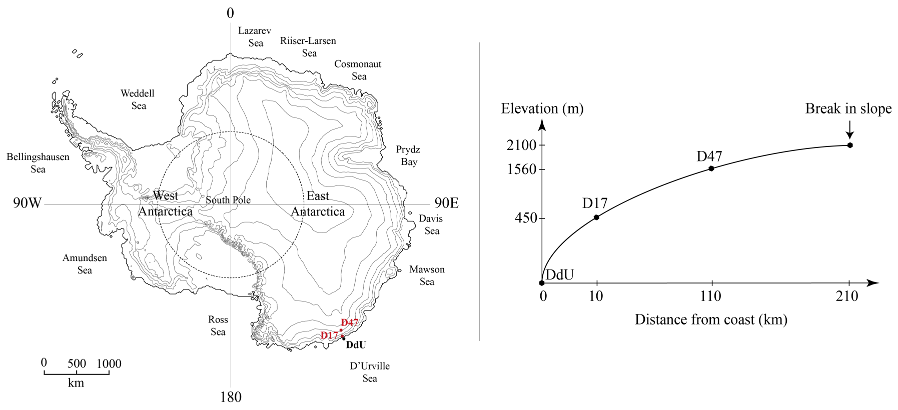

Figure 1. Location of Dumont d'Urville station (DdU) and sites D17 and D47 in coastal Adelie Land and schematic cross-section showing elevation and distance from the coastline for each site. Contours show elevation each 500 m from 0 to 4,500 m.

or prescribed quantities in snow-transport models that compute sublimation rates and snow mass fluxes assuming a gamma distribution of particles (e.g., Déry et al., 1998; Déry and Yau, 1999, 2001; Bintanja, 2000; Nemoto, 2004; Lenaerts et al., 2012). Additionally observed snow mass fluxes can be directly used to assess the ability of models to reproduce wind-driven snow conditions at a specific location in a qualitative (e.g., Lenaerts et al., 2012; Gallée et al., 2013) or a quantitative (e.g., Nishimura and Nemoto, 2005; Yang and Yau, 2007; Amory et al., 2015; van Wessem et al., 2018) perspective. However, even if each dataset is individually valuable regarding the scarcity of observations, in most cases the data were collected at a single location and over a few months, precluding investigations into spatial and temporal (seasonal and interannual) variability.

In order to acquire new model-evaluation oriented observations, a field campaign specifically dedicated to drifting snow has been ~~run~~ initiated in January 2010 in Adelie Land (Trouvilliez et al., 2014), a wind confluence area of East Antarctica. Two distinct locations, namely D17 and D47 (Fig. S1), were instrumented for long-term data acquisition and equipped with second-generation IAV Engineering acoustic FlowCapt™ sensors[1] (hereafter referred to as 2G-FlowCapt™), which are particularly well-suited for continuous monitoring in remote environments and under harsh conditions (Trouvilliez et al., 2015). This study presents an assessment of drifting snow occurrences and snow mass transport from analysis of multiple-year timeseries of meteorological data and snow mass fluxes collected in this framework within a katabatic wind region of the Antarctic ice sheet among the most prone to snow transport by wind.

Table 1. Geographical and climate characteristics of the two measurement locations for the respective observation periods.

Station	~~D47~~ D47*	~~D17~~ D17**
~~Observation period~~ Start of observation	9 Jan. 2010 ~~- Dec. 2012~~	3 Feb. 2010 ~~- Dec. 2018~~
End of observation	27 Dec. 2012	31 Dec. 2018***
Location	67.4°S, 138.7°E	66.7°S, 139.9°E
Altitude	1,560	450
Distance from coast (km)	110	10
Wind speed (m s^{-1})	11.9	9.8
Air temperature (°C)	-25.1	-15.5
Air relative humidity (%)	90.6	81.4
Wind direction (deg)	158	154
Directional constancy	0.95	0.92

*Mean values at sensor level are used.

**Mean values at sensor level nearest to 2 m are used.

***The station at site D17 is still operative.

2 Site characteristics and data

2.1 Instrumentation

The study area consists of a sloping snowfield with a break-in-slope at nearly 210 km inland at about 2,100 m a.s.l., downstream of which D47 and D17 are located (Fig. ~~S1~~1). The two measurement sites are 100 km apart, south-west of the permanent French station Dumont d'Urville (66.6°S, 140°W, 40 m a.s.l.). Because of their remote locations, access and maintenance activities are only possible in summer. At D17, a 7-m high mast is equipped with six levels ~~of~~ logarithmically spaced (initial heights of 0.8, 1.3, 2, 2.8, 3.9 and 5.5 m) of anemometers and thermo-hygrometers housed in naturally ventilated MET21 radiation shields (Fig. ~~S2~~S1, left panel). The ~~wind direction~~ meteorological mast is oriented toward the prevailing wind direction to prevent flow distortion by the measurement structure. The wind direction is sampled at the upper level only. ~~At~~ Site D47 ~~,~~ is equipped with only one level of wind speed and direction ~~,~~ measured at 2.8 m and temperature and relative humidity ~~are measured at only one level~~ measured at 2.2 m (Fig. ~~S2~~S1, right panel). The thermo-hygrometers are factory calibrated to report relative humidity with respect to liquid water. Goff and Gratch (1945) formulae are used to convert to relative humidity with respect to ice for air temperatures below 0 °C, using the sensor temperature reports in the conversion. Ultrasonic depth gauges are used to monitor surface height changes at both sites, from which the elevation of the sensors above the surface is assessed throughout the year. At D17, this information is not available before December 2012 when the height ranger was deployed. The ~~profile initially ranged from 0.8 m to 6.9 m in February 2010~~ station is currently still operative, and the instruments ~~were~~ along the profile are

[1]http://www.flowcapt.com

raised back manually to original heights at the beginning of each summer field campaign. The remoteness and the frequently harsh weather conditions of D47 allowed for limited servicing time, so that summer visits were restricted to the maintenance of sensors without raising operations. As a result the measurement heights decreased from ~~initially 2.8~~ their initial values to respectively 1.5 m for wind speed and ~~2.2~~ direction and 0.9 m for temperature and relative humidity ~~to respectively 1.5 m and 0.9 m~~ in late December 2012 when the equipment was entirely removed. The instrument types and specificities are summarised in Table S1. Data were sampled at 15-s intervals, and stored at a half-hourly time resolution on a Campbell CR3000 datalogger.

2.2 Climate settings

The surface climate in coastal Adelie Land is dominated by intense, frequent and persistent katabatic flows originating from the continental interior where strong temperature inversions develop. The local topography controls the drainage of the ~~sinking~~ cold, dense near-surface air as it ~~converges~~ flows downslope and accelerates toward the steep coastal escarpment over an unobstructed snow-covered fetch of several hundreds of kilometres. Table 1 lists geographical settings and climate information for the two sites. Wind speed and temperature regimes at 2-m height at the two measurement locations follow an annual cycle typical of katabatic wind confluence areas (Fig. S2). Lower temperatures and higher wind speeds are observed in winter as a result of the strong radiative deficit of the surface and increased katabatic forcing. In summer, the absorption of shortwave radiation by the surface diminishes the katabatic forcing, air temperature increases and wind speed reduces. The higher incidence of drifting snow (Fig. S3) and inherent loading of air masses with moisture through sublimation (Amory and Kittel, 2019) combined with lower temperatures in winter account for an increase in near-surface relative humidity compared to summer values. Substantially lower temperatures and subsequent dampened seasonal variations in relative humidity are observed at D47 due to the higher elevation.

Even if D17 is located near the downstream end of the sloping ice terrain where stronger katabatic forcing can be expected, year-round higher wind speeds are consistently observed at D47 some 100 km inland, as already reported by Wendler et al. (1993). Although the question remains open for further study, an explanation for this feature may involve the deceleration and subsequent thickening of the atmospheric boundary layer flow beyond the ice-sheet margins where it is no longer sustained by the buoyancy (katabatic) force. The resulting accumulation of cold air downstream over the ocean leads to the establishment of an upslope pressure gradient force opposing the katabatic flow that is responsible for an additional slowing of the airstream when reaching the coastal area (Gallée and Pettré, 1998), possibly accounting for the lower wind speeds at D17 compared to D47.

Both measurement sites show a very high constancy in wind direction (defined as the ratio of the resultant wind speed to the mean wind speed), reflecting the quasi-unidirectional nature of the flow in coastal Adelie Land (Table 1; Fig. S1). This evidences that topographic channelling strongly controls the surface wind regime, and indicates that cyclonic disturbances do not significantly alter the direction of the main flow.

2.3 Drifting snow data

2.3.1 Measurement principle

At each station the meteorological records were complemented by drifting snow measurements made with 2G-FlowCapt™ sensors. The instrument consists of a 1 m long tube containing electroacoustic transducers that measure the acoustic vibration caused by the impacts of windborne snow particles on the tube. Using spectral analysis, the sensor accurately distinguishes the low-frequency noise generated by turbulence from the high-frequency drifting snow signal, which is proportional to the snow mass flux integrated over the length of the tube (Chritin et al., 1999). This means that the measured acoustic vibration, and thus, the estimation of the snow mass flux depends on the shape, size, density and speed of each individual particle colliding with the tube (Cierco et al., 2007). As precipitating snow particles directly originating from clouds and drifting (saltating and/or suspended) snow particles relocated from the ground cannot be discriminated, measured snow mass fluxes account for all forms of wind-driven snow along the sampling height.

To remove electronic or turbulence noise and ensure that actual occurrences are detected, drifting snow has been considered to occur when the half-hourly mean of the snow mass flux exceeds a confidence threshold of 10^{-2} kg m^{-2} s^{-1} as determined from visual observations on the field in Adelie Land (Amory et al., 2017). In a comparison study between the The 2G-FlowCapt™ and optical measurements made with the SPC-S7 in the French Alps, this criterion yielded a high level of agreement (98.6 %) between the SPC-S7 and 2G-FlowCapt™ in terms of occurrence detection. The integrated snow mass fluxes provided by the 2G-FlowCapt™ were also shown to be underestimated compared to the optical measurements and should thus be considered as lower bound values. can record continuous information as long as it remains partially exposed. This is an advantage over visual observations and satellite products provided at sporadic intervals. Moreover, the ability of these sensors to detect events of small magnitude is particularly interesting, as remote sensing techniques can only retrieve information on blowing snow layers for which the snow particles are lifted at several tens of metres off the surface (Mahesh et al., 2003; Palm et al., 2011; G

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2.3.2 Field installation

In early January 2010 at D47, two 2G-FlowCapt™ were installed and superimposed vertically, with the bottom of the lower sensor located close to the surface (~0.1 m) in order to detect the onset of drifting snow occurrences (Fig. S1). At D17 two sensors were deployed in February 2010 but only one was initially installed close to the surface while the other one was set up at the top of the measurement structure. The upper sensor was removed in January 2011 because of malfunction, and reinstalled after repair in late December 2012 similarly to the configuration adopted for D47.

Burial of the 2G-FlowCapt™ through accumulation of snow affects the estimation of the snow mass flux as it is vertically integrated over the uncovered part of the instrument. This is a matter of concern at both sites since precipitation along the Adelie coast occurs year round almost exclusively in the form of snowfall with a mean accumulation amounting to 362 mm water equivalent per year (Agosta et al., 2012). Like for the other meteorological instruments, the 2G-FlowCapt™ sensors at D17 were reset into their original position with the lower sensor near the surface during each summer visits, except for austral summers 2015-2016 and 2016-2017 during which the pair of instruments was left unchanged. Consequently, substantial burial of the lower sensor took place along the 3-year period from early 2015 to late 2017 depending on snow accumulation and ablation. As no raising operations were undertaken at D47 the measurement structure progressively buried and the lower 2G-FlowCapt™ became entirely covered with snow during the course of the year 2012.

The The FlowCapt™ is low-power consuming and designed to withstand harsh climate conditions without regular human attendance. At each station battery voltage is monitored and stored together with the meteorological variables in the datalogger to ensure that the entire measurement system is sufficiently supplied with energy throughout the winter. The 2G-FlowCapt™ can record continuous information as long as it remains partially emerged. This is an advantage over visual observations and satellite products provided at punctual intervals. Moreoverare continuously solicited by the datalogger (RS232 connection), such that instances of instrument malfunction (absence of response and no data) can be unambiguously distinguished from the absence of drifting snow (data containing null values). A thorough check on the observations was performed and resulted in omission of misleading data wherever necessary. Except for those very few cases, maintenance periods in summer and a major 2-month failure of the lower 2G-FlowCapt™ sensor at D47 in May and June 2012, the dataset is continuous along the respective measurement periods.

2.3.3 Accuracy assessment

While FlowCapts™ sensors can detect the occurrence of snow transport with a high level of confidence, the ability of these sensors to detect events of small magnitude is particularly interesting, as remote sensing techniques can only retrieve information on blowing snow layers for which the snow particles are lifted at several tens of metres off the surface (Mahesh et al., 2003; Palm . the original design to estimate snow mass fluxes is more questionable (Cierco et al., 2007). These accuracy issues, without being necessarily solved, have been significantly improved with the 2G-FlowCapt™, facilitating its use for quantitative applications (Trouvilliez et al., 2015). Although measurement uncertainty is not known, the 2G-FlowCapt™ was shown to generally underestimates the snow mass flux relatively to integrated estimates computed from optical measurements made with a snow particle counter S7 (SPC-S7; taken as a reference in the study) during a winter season in the French Alps, particularly during concurrent precipitation (Trouvilliez et al., 2015). During mixed drifting snow events when erosion occurs simultaneously with snowfall, the density of precipitating particles which have not reached the ground yet is lower than eroded, more rounded snow particles originating from the ground which have lost their original crystal shape and size through collision, sublimation and the thermal processes of metamorphism. For a given snow mass flux, the particles' momentum, and by extension the measured acoustic pressure, is therefore lower during a mixed drifting snow event than during an event predominantly driven by the erosion process. This results in an underestimation of the snow mass flux measured by the 2G-FlowCapt™ during mixed events, with a magnitude depending on the relative proportion of eroded particles against fresh snow particles.

Environmental conditions influence greatly the estimation of the snow mass flux by the 2G-FlowCapt™. The intercomparison experiment in the Alps was done within a range of mass flux values (< 2.5 10^{-2} kg m^{-2} s^{-1}) significantly lower than those encountered in Adelie Land (see Sect. 3.4). In addition, comparatively stronger surface winds and lower temperature on the Antarctic ice sheet favor the breaking and rounding of snow particles. This suggests that the performance of the 2G-FlowCapt™

remains to be assessed in the extreme Antarctic environment, in which large proportions of small, rounded particles can be expected in drift conditions (i.e. within 2 m above ground) even with concurrent precipitating snow (Nishimura and Nemoto, 2005) .

A field experiment involving measurements with SPC-S7 and 2G-FlowCaptTM sensors performed during a 24 hour long snow transport event was undertaken at site D17 in late January 2014 (Fig. S3). Strong drift conditions were observed with 2-m wind speeds and snow mass fluxes reaching up to 19 m s^{-1} and 4 10^{-1} kg m^{-2} s^{-1} respectively. Although the statistical representativeness of the results may be small due to the low amount of data collected during only one event, the comparison shows that the snow mass fluxes provided by the two types of sensors are very similar in magnitude (Fig. S4). Further details on the experimental set-up and comparison methodology are provided in supplementary materials (Sect. S1).

2.3.4 Computation of drifting snow frequency and mass transport

To remove electronic or turbulence noise and ensure that actual occurrences are detected, drifting snow has been considered to occur when the half-hourly mean of the snow mass flux exceeds a confidence threshold of 10^{-2} kg m^{-2} s^{-1} as determined from visual observations on the field in Adelie Land (Amory et al., 2017). Note that the same confidence threshold yielded a high level of agreement (98.6 %) between the SPC-S7 and 2G-FlowCapt™ in terms of occurrence detection in the comparison study led by (Trouvilliez et al., 2015) in the Alps. Since this value remains small compared to snow mass fluxes estimated during drifting snow occurrences (see Sect. 3.4), the confidence threshold is assumed independent on the exposed length of the sensor. The sensor is considered unburied as long as at least 10 % (i.e. 0.1 m) of its initial length remain uncovered with snow.

Changes in the exposed length of the 2G-FlowCapt™ through snow accumulation and ablation affect the estimation of the snow mass flux as it is vertically integrated over the uncovered part of the instrument. This is a matter of concern at both sites since precipitation along the Adelie coast occurs year round almost exclusively in the form of snowfall with a mean accumulation amounting to 362 mm water equivalent per year (Agosta et al., 2012) and frequent, high wind speeds induce frequent erosion/deposition of snow. As a result, the actual sampling height varied substantially and non-uniformly throughout the measurement period preventing direct comparisons of snow transport amounts over time. This is accounted for in a simple way by combining, when available, half-hourly snow mass fluxes from the two measurement levels to derive a standardized estimate of the drifting snow mass flux (i.e. vertically integrated between 0 and 2 m over the snow surface) η_{DR} such that

$$\eta_{DR} = \begin{cases} \eta_1 + \eta_2, & h_1 + h_2 \geqslant h_{ref} \\ \eta_1 + \eta_2 \cdot \frac{h_{ref}}{h_1 + h_2} & h_1 + h_2 < h_{ref} \end{cases} \quad (1)$$

where η_i (kg m^{-2} s^{-1}) is the observed snow mass flux integrated over the exposed height h_i (m) of the corresponding 2G-FlowCapt™ sensor, and h_{ref} = 2 m corresponds to the sum of two fully exposed 1 m long 2G-FlowCapt™ sensors. In other words, when $h_1 + h_2$ < 2 m, it is assumed that the measured snow mass flux is constant up to 2 m. To keep consistency

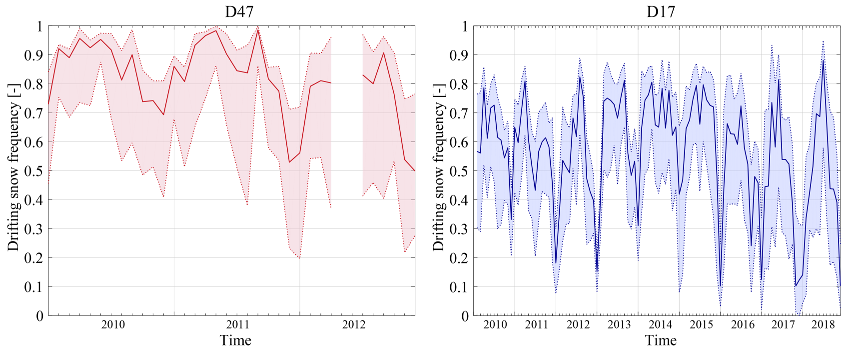

Figure 2. Seasonal variability of drifting snow frequency as recovered by the 2G-Flowcapt™ instruments. Shaded areas correspond to frequencies respectively computed using a relaxed and a stricter confidence threshold of 10^{-4} kg m^{-2} s^{-1} and 10^{-2} kg m^{-2} s^{-1} and are shown as a measure of uncertainty. The absence of data at D47 during May and June 2012 is due to instrument malfunction.

Table 2. Standardized estimates of annual horizontal snow mass transport in drift conditions.

Year	Snow mass transport [kg m^{-2}]	
	D17	D47
2010	-	~~1.93~~ 1.89 10^6
2011	-	~~1.74~~ 1.64 10^6
2012	-	-
2013	~~2.17~~ 2.05 10^6	-
2014	~~2.28~~ 2.42 10^6	-
2015	~~2.87~~ 2.68 10^6	-
2016	~~3.35~~ 2.63 10^6	-
2017	~~2.38~~ 2.12 10^6	-
2018	~~2.33~~ 2.20 10^6	-

with the confidence threshold for the detection of drifting snow occurrences, snow mass fluxes below 10^{-3} kg m^{-2} s^{-1} have been set to zero. The horizontal snow mass transport in drift conditions for a given period of time $[t_0, t_n]$, Q_{DR}, then writes

$$Q_{DR}(t) = \int_{t_0}^{t_n} \eta_{DR}(t)\,\mathrm{d}t \qquad (2)$$

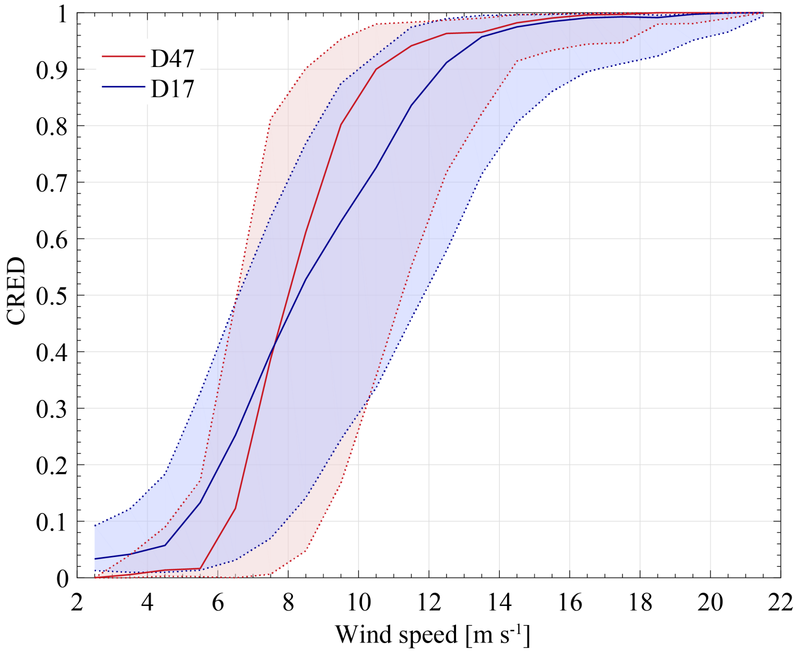

Figure 3. CRED distribution showing the increasing probability of observing drifting snow with increasing 2-m wind speed at sites D47 (red curve) and D17 (blue curve). Shaded areas correspond to CREDs respectively computed using a relaxed and a stricter confidence threshold of 10^{-4} kg m^{-2} s^{-1} and 10^{-2} kg m^{-2} s^{-1} and are shown as a measure of uncertainty.

3 Analysis of observations

3.1 Spatial and temporal variations in drifting snow occurrences

Monthly values of drifting snow frequency at D47 and D17 indicate that drifting snow is a regular feature of the coastal slopes of Adelie Land (Fig. 2; overall averages of ~~0.82~~ 0.81 at D47 and ~~0.66~~ 0.57 at D17). Frequency values have been computed for each month of the observation period as the ratio between the number of half-hourly observations with a snow mass flux at the lower, unburied level η_i higher than the confidence threshold of 10^{-3} kg m^{-2} s^{-1} and the total number of observations in that month. On each panel the shaded area corresponds to the frequency respectively computed using a relaxed and a stricter threshold of 10^{-4} kg m^{-2} s^{-1} and 10^{-2} kg m^{-2} s^{-1} and is shown as a measure of uncertainty. While no particular inter-annual variability is depicted (~~Fig. S4~~annual averages range from 0.73 to 0.85 at D47 and 0.45 to 0.68 at D17), drifting snow frequency varies strongly within the year, with an amplitude that can differ from year to year. Both locations experience a higher incidence of drifting snow in winter (defined here as the 8-month period between 1 March and 1 November) than during the rest of the year, a pattern quite common over Antarctica (Mahesh et al., 2003; Scarchilli et al., 2010; Gossart et al., 2017; Palm et al., 2018). At the end of winter, a gradual decrease in drifting snow frequency is observed

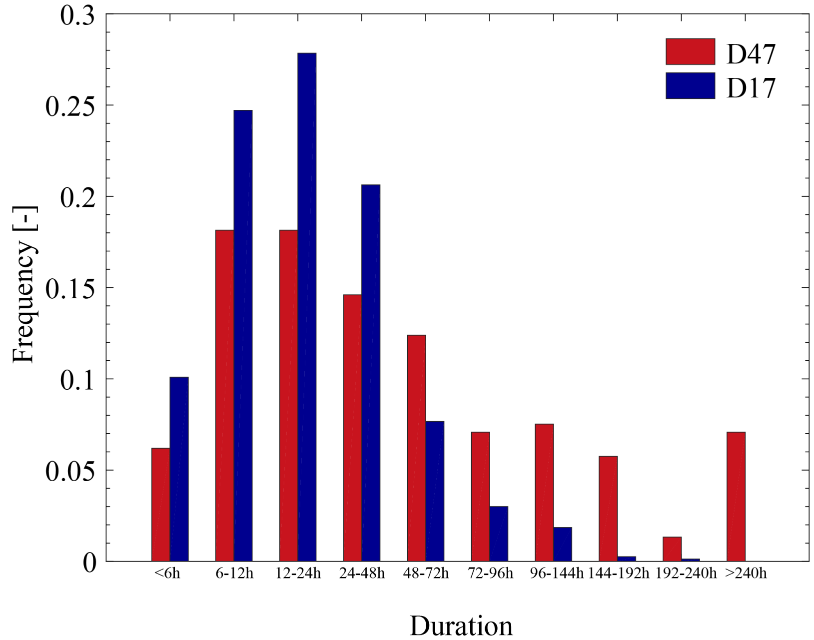

Figure 4. Distribution of durations of drifting snow events at D47 (red) and D17 (blue)~~for the respective observation periods of 2010-2012 and 2010-2018~~. The minimum values of duration and drifting snow mass transport for an event to be retained in the statistics are respectively set to 4 hours and 15 kg m^{-2}.

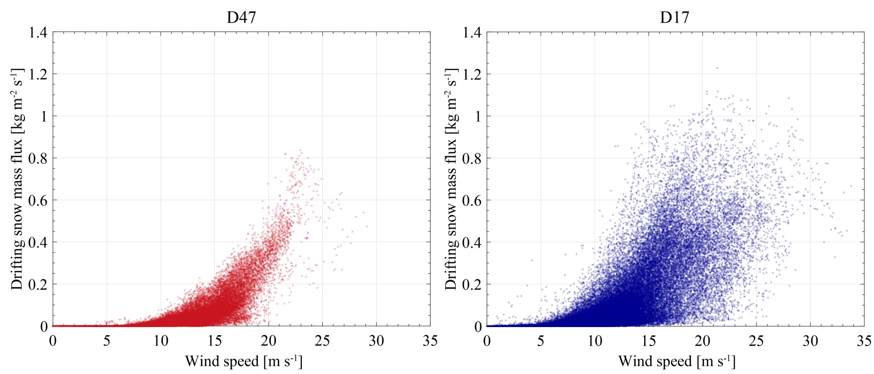

Figure 5. ~~Logarithm of the~~ Drifting snow mass ~~transport in drift conditions (i.e. between 0 and 2 m)~~ flux against ~~mean~~ 2-m wind speed recorded at D47 (left panel) and ~~duration~~ D17 (right panel)~~for each drifting snow event recorded at D47 (red circles) and D17 (blue crosses)~~. Only periods for which two 2G-FlowCapt™ sensors ~~were~~ are installed and/or the lower sensor is not entirely covered with snow (i.e. $h_1 > 0.1$ m) are considered.

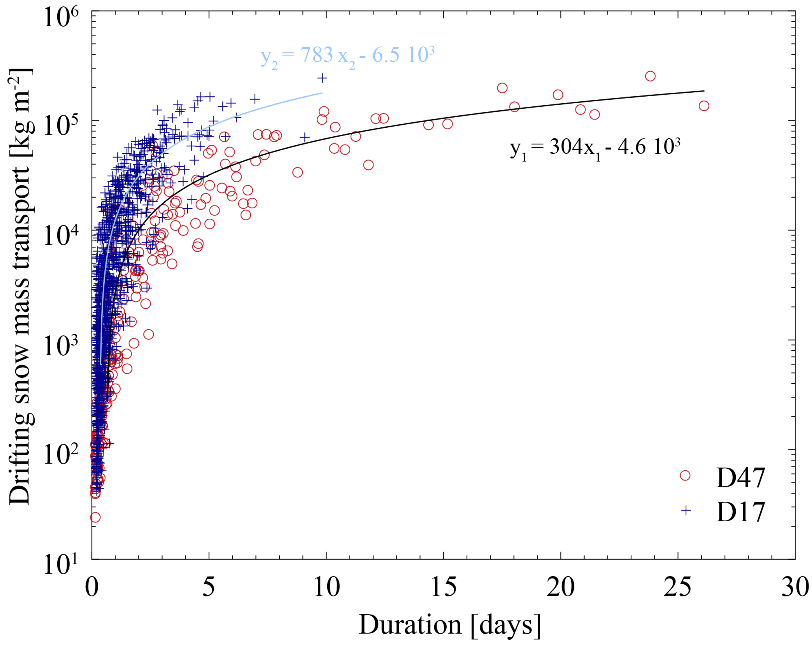

Figure 6. Logarithm of snow mass transport in drift conditions against duration for each drifting snow event recorded at D47 (red circles) and D17 (blue crosses). Only periods for which two 2G-FlowCapt™ sensors were installed and/or not entirely covered with snow are considered. Linear fits for D47 (black line) and D17 (light blue line) data are also reported on the graph, in which duration is expressed in hours.

until a minimum is reached during summer, consistently with the annual course of wind speed (see Fig. S2, upper panel). This seasonal contrast is more pronounced at D17 than at D47 due to the stronger inhibition of erosion in summer resulting from lower wind speeds and higher air temperatures that promote the formation of cohesive bonds holding particles to the surface (e.g., Schmidt, 1980; Amory et al., 2017). Although the use of a lowered threshold does not affect significantly the derived frequency, the stronger sensitivity to the increased threshold evidences the important contribution of occurrences of relatively small magnitude (i.e. < 10^{-2} kg m^{-2} s^{-1} to the overall frequency. This demonstrates the need to specify explicitly the chosen threshold value when computing drifting snow frequency from 2G-FlowCapt™.

Higher monthly values of drifting snow frequency are also systematically observed 100 km inland at D47 than close to the coastline at D17. Analysis of drift conditions documented simultaneously at D17 and D47 for the 3-year period 2010-2012 evidences a significant spatial variability, with almost all drifting snow occurrences at D17 involving drifting snow at D47 while the opposite does not hold true (Table S2). Wind speeds at D47 for which drifting snow is observed at D47 only (28.3 % of occurrences) are generally lower (average of ~~11.3~~ 11.5 m s^{-1} compared to those for which the two locations experience drifting snow simultaneously (average of ~~13.9~~ 13.5 m s^{-1}). This means that the largest occurrences are seen at both sites, and the higher drifting snow frequency at D47 is mainly due to additional occurrences of lesser magnitude for which the reduced wind speed downstream at D17 is not high enough to trigger snow transport.

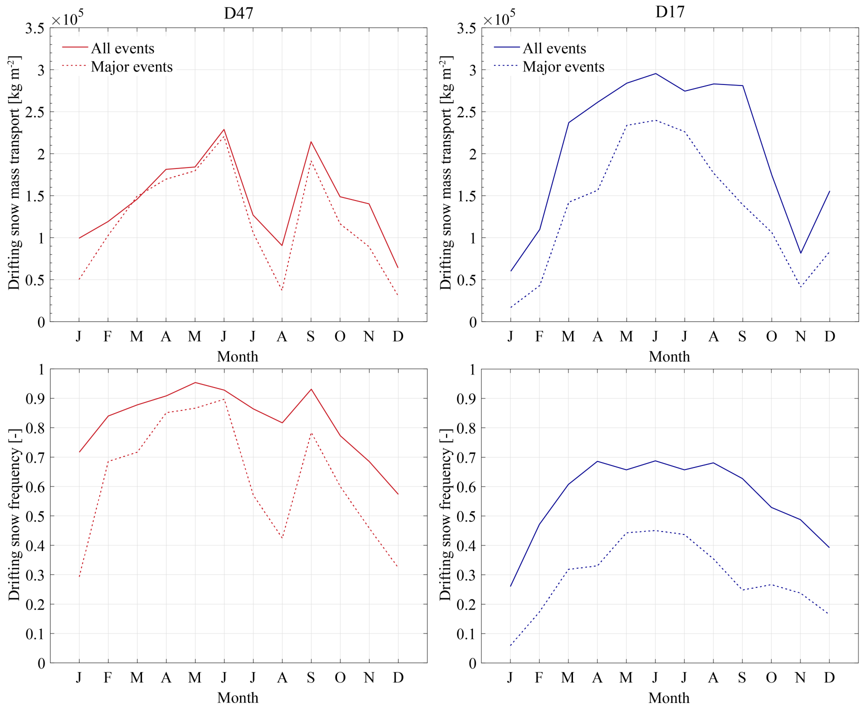

Figure 7. Intra-annual variability of drifting snow mass transport (upper panels) and related drifting snow frequency (lower panels) at D47 (left panels) and D17 (right panels). The relative contribution of major drifting snow events (see text) is highlighted in dotted lines. Summed mass transport and frequency values have been first determined for each month, and averaged within each monthly bin to produce monthly average values. The variability (standard deviation) in not shown due to the short length of the timeseries.

3.2 Frequency of occurrence

Wind speeds at 2-m height for which drifting snow is detected (averages of ~~13~~ 13.1 m s^{-1} for D47 and ~~12.1~~ 12.6 m s^{-1} for D17) are generally higher than those occurring without drifting snow (averages of ~~6.8~~ 7 m s^{-1} for D47 and ~~5.4~~ 6.1 m s^{-1} for D17), although a wide range of similar wind speeds coexists between both categories. Following the approach of Baggaley and Hanesiak (2005) aiming at predicting the occurrence of snow transport from a set of common meteorological parameters, a credibility index (CRED) was used in a simpler approach to provide an estimation of the frequency of occurrence of drifting snow under specific wind conditions

$$CRED = \frac{p}{p+n} \quad (3)$$

where p is the number of occurrences of drifting snow for a given wind speed range and n is the number of non-occurrences within that range. CRED varies from 0 to 1 and reflects the probability of observing drifting snow for a given range of wind speeds. Here a CRED of 0 means that no occurrence of drifting snow was observed for the selected range of wind speeds, while a CRED of 1 indicates that all wind speeds in that range were associated with drifting snow. CRED was calculated from the meteorological dataset within 1 m s^{-1} wide intervals of wind speed. Occurrences observed below 2 m s^{-1} and above 22 m s^{-1} were not considered since their relative proportion within each wind speed interval individually accounted for less than 1 % of the observations. As in Fig. 2 the sensitivity of CREDs to the relaxed and stricter confidence thresholds used for acknowledging the occurrence of drifting snow is illustrated by the shaded areas.

The frequency of occurrence generally increases with wind speed (3) and typically resembles a cumulative normal distribution (Baggaley and Hanesiak, 2005). As the 2G-Flowcapt™ does not provide information on the source of windborne snow particles, CREDs in wind speed intervals lower than 5 m s^{-1} at D17 most likely correspond to rare occurrences detected during snowfall (without necessarily involving erosion of snow) or shortly after the deposition of a loose snow layer easily erodible during light-wind conditions. Then, for higher intervals, small differences in wind speed involve large variations in the CRED. At both sites, the likelihood of observing sigificant drifting snow (> 10^{-2} kg m^{-2} s^{-1}) drifting snow becomes important (CRED > 0.5) when wind speeds rise above 10-11 8 m s^{-1}. Wind speeds above 15 12 m s^{-1} almost systematically produce drifting snow (CRED > 0.9)regardless of the confidence criterion, indicating that threshold (friction velocity) values for snow transport are most often exceeded in such wind conditions. Differences in local climate between the two locations could be expected to affect CRED distributions through their influence on post-depositional processes. Lower average wind speeds at D17 could be associated with lower compaction rates enabling drifting snow to be triggered by lower wind speeds than at D47. Conversely lower drift-induced compaction at D17 could be compensated by stronger interparticle bonding resulting from higher average air temperatures. Accurate investigation of these aspects would inexorably require knowledge of snow properties at the surface. However, Fig. 3 illustrates substantially similar CRED distributions, indicating that wind speed is the main driver behind the occurrence of drifting snow at these locations.

3.3 Duration of drifting snow events

Drifting snow ceases when occurs as long as the effective shear stress exerted on the snow surface by the overlying airstream, or (i.e. the friction velocity, drops below) equals or exceeds the threshold value for erosion. This can either result from a weakening of the flowConcurrent snowfall and advection of snow from upwind areas can also contribute to the windborne snow mass. The incidence of drifting snow depends on (and is affected by changes in) flow dynamics, surface roughness, an increase in aerodynamic roughnesslength, compaction cohesion of exposed surface snow particles or the exhaustion more generally availability of erodible snow, the combination or the individual occurrence of which determining the duration and magnitude of magnitude of snow mass fluxes and the duration of drifting snow events . (Vionnet et al., 2013; Amory et al., 2016, 2017).

Following Vionnet et al. (2013), a drifting snow event has been defined as a period over which snow transport is detected for a minimum duration of 4 hours. An That is, an event is considered to start and end when the half-hourly snow mass flux at the lower unburied level η_i respectively rises and drops below the confidence threshold of 10^{-3} kg m^{-2} s^{-1}. To focus on significant drifting snow events, an additional criterion requires that a snow mass Q_T Q_{DR} of at least 15 kg m^{-2} as recovered by the lower instrument is carried out along the event (corresponding to the snow mass transport (resulting from a mean flux drifting snow mass flux η_{DR} at the confidence threshold of 10^{-3} kg m^{-2} s^{-1} for a duration of 4 hours) was used.

is transported along the event. Note that in case of complete burial of the lower sensor (i.e. $h_1 < 0.1$ m) or in the absence of sensor at the second level, this criterion is applied on the snow mass transport computed from the single available level without correction. By applying this selection procedure to the whole database, ~~1612 and 293~~ 1566 and 226 drifting snow events have been respectively identified at D17 and D47. Most events do not exceed 72 hours at D17 and can reach 10 days at most while a slight proportion (~~5.9~~ 7 %) of events at D47 lasts more than 10 days with a maximum duration of 26 days (Fig. 4). In short, drifting snow events are on average twice as numerous but roughly two times shorter at D17 (yearly average number of ~~180~~ 173 and median duration of 15 hours) than at D47 (yearly average number of ~~92~~ 95 and median duration of 27.5 hours) where stronger winds can sustain longer events. Note that these statistics are not significantly altered if the length of the timeseries considered for D17 is reduced to that of D47.

3.4 Horizontal drifting snow mass transport~~in drift conditions~~

~~Due to snow accumulation and ablation, the sampling height of the lower 2G-FlowCapt™ sensor varied substantially and non-uniformly throughout the measurement period preventing direct comparisons of snow transport amounts over time. This is accounted for in a simple way by combining, when available, half-hourly snow mass fluxes from both sensors to derive a standardized estimate of the horizontal snow mass transport in drift conditions (i. e. between 0 and 2 m), Q_T, such that~~

$$Q_T = \Delta t \cdot \begin{cases} \sum \eta_1 + \eta_2, & h_1 + h_2 \geqslant h_{ref} \\ \sum \eta_1 + \eta_2 \cdot \frac{h_{ref}}{h_1 + h_2} & h_1 + h_2 < h_{ref} \end{cases} .$$

~~where Δt is the storage interval (1800 s), η_i (kg m^{-2} s^{-1}) is the observed snow mass flux integrated over the exposed height h_i (m) of the corresponding 2G-FlowCapt™ sensor and h_{ref} = 2 m. In other words, when $h_1 + h_2 < 2$ m, it is assumed that the measured snow massflux is constant up to 2 m. To keep consistency with the confidence threshold for the detection~~ The drifting snow mass flux η_{DR} typically tends to increase with wind speed in a power-law fashion (Fig. 5). This well-known behavior (Radok, 1977; Mann et al., 2000) is however depicted with significant dispersion and notable differences between the two locations; the data at D17 show that drifting snow mass fluxes can be of greater magnitude than at D47 for similar wind speeds and exhibit a generally higher variability along the range of wind speeds. This illustrates the diversity and spatial variability in factors controlling the windborne snow mass, as mentioned in the previous section. While wind speed can be used to predict the occurrence of drifting snow ~~occurrences (see Sect. 2.2), snow mass fluxes below 10^{-3} kg m^{-2} s^{-1} have been set to zero.~~

~~Values of Q_T have been computed for each drifting snow event identified in the database and plotted as a function of the average wind speed and duration in Fig. ??. Periods during which only one 2G-FlowCapt™ was installed~~ with a quite similar probability distribution between both locations (Fig. 3), on the other hand Fig. 5 demonstrates that more caution should be taken when scaling drifting snow mass transport with wind speed or related single parameter independent of surface snow properties (e.g., Mann et al., 2000). Such an approach would indeed involve mixtures of power laws to capture the large variability in drifting snow mass flux within the same wind speed interval, particularly at D17 ~~(i.e. 2010, 2011 and 2012) or the lower 2G-FlowCapt™ became completely buried at D47 (i.e. 2012) have been ignored because of the absence of information on~~

drift conditions from 1 to 2 m and the inherent overestimation of snow transport produced by Eq. in such cases. The linear relationship depicted in Fig. **??** (left panel) indicates that Q_T increases with wind speed in a power-law fashion, as already evidenced from similar data analyses performed at a higher time resolution (e.g., Mann et al., 2000; Nishimura and Nemoto, 2005; Amory e . Note that the events with the highest average wind speed are not necessarily associated with the largest values of Q_T. This reflects the fact that other factors such as the availability and amount of erodible snow at the surface also influence where almost the entire range of values is observed from 15 m s^{-1}. Drifting snow is highly non-linear in nature and results essentially from the competitive balance between atmospheric drag and cohesive forces acting on the snow surface. This means that concurrent documentation of turbulence and surface snow properties are required for a better assessment of drifting snow processes and improvements of model predictability (e.g., Baggaley and Hanesiak, 2005; Vionnet et al., 2013).

Despite the non-linear behaviour of the drifting snow mass transport. More generally the dispersion can be explained by the diversity of factors governing the occurrence and magnitude of drifting snow through variations in the difference between friction velocity and threshold friction velocity with time, as listed in the previous section.

Figure **??** (right panel) shows that Q_T increases roughly linearly with the event duration and flux illustrated in Fig. 5, Q_{DR} increases linearly with the event duration (Fig. 6). Values of Q_{DR} have been computed for each drifting snow event identified in the database along which data from the two sensors are uninterruptedly available. Linear regression fits are shown and their respective equation are reported on the graph. A logarithm scale is preferred for readability purposes. Figure 6 also shows that Q_{DR} hardly exceeds 10^5 kg m^{-2} even for the longest events, which thus seems to appear as an upper bound value for the mass transported in drift conditions during a single event. This is particularly well illustrated by D47 data. High values of Q_T Q_{DR} for a wide range of durations involve large snow mass fluxes recorded at the two measurement levels, indicating the regular occurrence of well-developed, non-intermittent transport events in which particles are simultaneously carried out through both the saltation and suspension mechanisms. This suggests that events of small magnitude for involving low values of Q_{DR} and/or during which transport in saltation dominates over transport in suspension must be comparatively short-lived. This however cannot be substantiated by studying the two levels separately because snow mass fluxes are vertically integrated over the exposed length and the sensor, which for the sensor closest to the ground almost always largely exceeds typical saltation heights (i.e. .17ex$\sim$0.1 m).

On an annual basis, both kinds of events combine to produce yearly values of Q_T Q_{DR} close to or above 2 10^6 kg m^{-2} at both locations (Table 2). Note that annual values of Q_{DR} decrease only very slightly (less than 5 %) when a stricter confidence threshold is applied (i.e. only snow mass fluxes $\eta_i > 10^{-2}$ kg m^{-2} s^{-1} are considered), a result of large snow mass fluxes well beyond this threshold regularly occurring during drifting snow events. Such high estimates suggest that redistribution of snow by wind together with concurrent sublimation of snow particles during transport are important components of the surface mass balance in Adelie Land (Agosta et al., 2012; Amory and Kittel, 2019).

3.5 Contribution of major drifting snow events

The linear relationship between Q_T Q_{DR} and event duration illustrated in Fig. **??** 6 can be used to distinguish the contribution of the largest events to the drifting snow mass transport from that of the residual events. Major drifting snow events have been defined as the events whose duration is higher than the 75^{th} percentile for each site. Figure 7 shows that such major events, preferably but not exclusively grouped in winter, account for a reduced proportion of the overall events (resp. ~~16 % and 18~~ 22 % and 24 % for D47 and D17) but mainly dictate the variability of ~~Q_T~~ Q_{DR} at the monthly scale, with the largest winter events capable of transporting alone up to ~~13~~ 9 % of the annual quantity. The average monthly frequency resulting only from the occurrence of major events in each month is reported on the graph. As mentioned above, only the periods for which the snow mass flux was measured continuously at two levels have been considered. Note that this requirement is met for distinct periods of time between both measurement locations which thus must not be compared directly.

At D17 (Fig. 7), right panels), major events account for about half of the observed frequency but contribute to a larger part (> 70 %) of the mass transported in drifting snow. Larger monthly values of ~~Q_T~~ Q_{DR} in winter result from an increased occurrence of major events combined with stronger snow mass fluxes (Amory et al., 2017), while drifting snow in summer mainly occurs in the form of residual events of lower magnitude.

The data collected at D47 (Fig. 7, left panels) indicate that major events can contribute to an even larger part (> ~~83~~ 82 %) of the annual transport and bring a different general perspective by showing that ~~Q_T~~ Q_{DR} can be as important in summer than during some winter months, depending on the occurrence of major events. Despite a high and relatively uniform incidence of drifting snow in winter, the sharp decrease in ~~Q_T~~ Q_{DR} from June to August at D47 is due to a reduced occurrence of major events during this period. This demonstrates that high monthly values of drifting snow frequency do not directly relate to the magnitude of snow transport since they can mainly consist of multiple but relatively brief events involving low or moderate snow mass fluxes. This also suggests that, in a modelling perspective, representing these major events rather than the complete range of drifting snow occurrences would be sufficient to capture the bulk of the contribution of drifting snow processes to the local surface mass balance.

4 Conclusion

Meteorological data and snow mass fluxes automatically acquired at two locations 100 km apart in Adelie Land, D17 and D47, have been combined to illustrate the spatial and temporal variability in drifting snow frequency and mass transport in a small portion of the East Antarctic coast. While the equipment at D47 has been dismantled after a period of 3 years (2010-2012), station D17 is still operative and the data provided nearly continuously for a period of 9 years (2010-2018) constitute the longest database of autonomous near-surface measurements of drifting snow currently available over the Antarctic continent. It should be noted that data collection continues at D17 and new measurements will be available in the future. Statistical analysis of the current dataset indicates that the likelihood of drifting snow increases with wind speed. Drifting snow occurred ~~82 % and 66~~ 81 % and 57 % of the time on average at D47 and D17, with maximum and minimum frequency values respectively observed in winter and summer in line with the annual course of wind speed. The higher drifting snow frequency at the more inland location D47 is most likely the result of locally higher wind speeds. Such high incidences of drifting snow and annual mass transport values reaching or exceeding 2 10^6 kg m^{-2} at both sites suggest that drifting snow processes are important components of the local surface mass balance that would require a specific attention in a modelling context. By imposing a minimum duration of 4 hours and a minimum mass transport of 15 kg m^{-2}, 293 and 1612 226 and 1566 drifting snow events have been detected at D47 and D17 over the respective observation periods. Events at D17 typically last 15 hours (median value) and are roughly twice shorter than at D47 where longer events can be sustained by higher wind speeds. The observations also evidence that most of the mass transported annually in drifting snow is carried out through a few major events accounting for less than 20 25 % of all the events and occurring preferably in winter, indicating that modelling the influence of drifting snow on the surface mass balance in this area might primarily rely on an accurate representation of these major events. The instantaneous sampling of blowing snow properties through satellite techniques can be perceived as an undesirable limitation in regard of the mean duration of snow-transport events reported here. The presence of clouds impeding satellite retrieval is additionally responsible for the omission of overcast and/or snowfall conditions during which blowing snow is likely to occur preferentially because of the increased availability of loose snow. This can be particularly restrictive in coastal regions where the occurrence of blowing snow is often associated with synoptic-scale weather systems involving the presence of optically thick clouds (Gossart et al., 2017). The observations presented in this study, while providing spatially limited information, enable a continuous detection of snow-transport occurrences even in the presence of clouds and/or during snowfall. Although likely representative of local conditions, they constitute an original dataset dedicated to a poorly-documented, yet widespread feature of the Antarctic climate that can be used to complement satellite products and evaluate snow-transport models close to the surface and at high temporal frequency. Such exercises are needed to improve our understanding of the links between the occurrence and magnitude of drifting snow and ambient meteorological conditions, and ultimately better quantify the influence of drifting snow on the climate and surface mass balance of the Antarctic ice sheet.

Data availability.

All data presented and described in this study are freely available by contacting the author. The database presented and described in this article (Amory et al., 2020) is available for download at https://zenodo.org/record/3630497 (last access: 29 January 2020). The data of the upcoming years will be added to the database on a yearly basis and made available to the community.

Competing interests. The author declares that he has no conflict of interests.

Acknowledgements. This work would not have been possible without the financial and logistical support of the French Polar Institute IPEV (program CALVA-1013). The author would like to thank all the on-site personnel in Dumont d'Urville and Cap Prud'homme for their precious help in the field, in particular Philippe Dordhain for electronic and technical support. Christophe Genthon and Vincent Favier are also acknowledged for their investment in collecting data and maintaining the observation system in Adelie Land. C. Amory is a Postdoctoral Researcher from the Fonds de la Recherche Scientifique de Belgique (F.R.S.-FNRS).

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Drifting snow statistics from multiple-year autonomous measurements in Adelie Land, eastern Antarctica

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Table S1. Meteorological instruments installed at D47 and D17 along the respective observation periods (sensors marked with * are manufactured by Campbell Scientific, Inc.). Instrument types and specificities are given for the sensors nearest to 2 m as recovered by the ultrasonic depth gauge (2013-2018) or for the nearest original height when information on surface height is not available (2010-2012).

	D47			D17		
	Period	Sensor	Accuracy	Period	Sensor	Accuracy
Wind speed	01/10 - 12/12	Young 05103	$\pm$0.3 m s^{-1}	02/12 - 12/10	RNRG 40C	$\pm$ 0.14 m s^{-1}
				01/11 - 12/18	A100LK*	$\pm$ 0.1 m s^{-1}
Wind direction	01/10 - 12/12	Young 05103	$\pm$ 3 °	02/12 - 12/10	RNRG 200P	$\pm$ 4 °
				12/12 - 12/18	W200P*	$\pm$ 2°
Air temperature	01/10 - 12/12	Vaisala HMP155	$\pm$0.3 °C	02/10 - 12/18	Vaisala HMP45	$\pm$0.4 °C
Relative humidity	01/10 - 12/12	Vaisala HMP155	$\pm$1 %	02/10 - 12/18	Vaisala HMP45	$\pm$2%
Snow height	01/10 - 12/12	SR50A*	$\pm$0.01 m	12/12 - 12/18	SR50A*	$\pm$0.01 m
Snow mass flux	01/10 - 12/12	2G-FlowCapt™	-	12/12 - 12/18	2G-FlowCapt™	-

Table S2. Comparison of drifting snow occurrences at D17 and D47 over the period 2010-2012.

D17 / D47	DR	nDR
DR	53.7%	28.3%
nDR	3.4%	14.6%

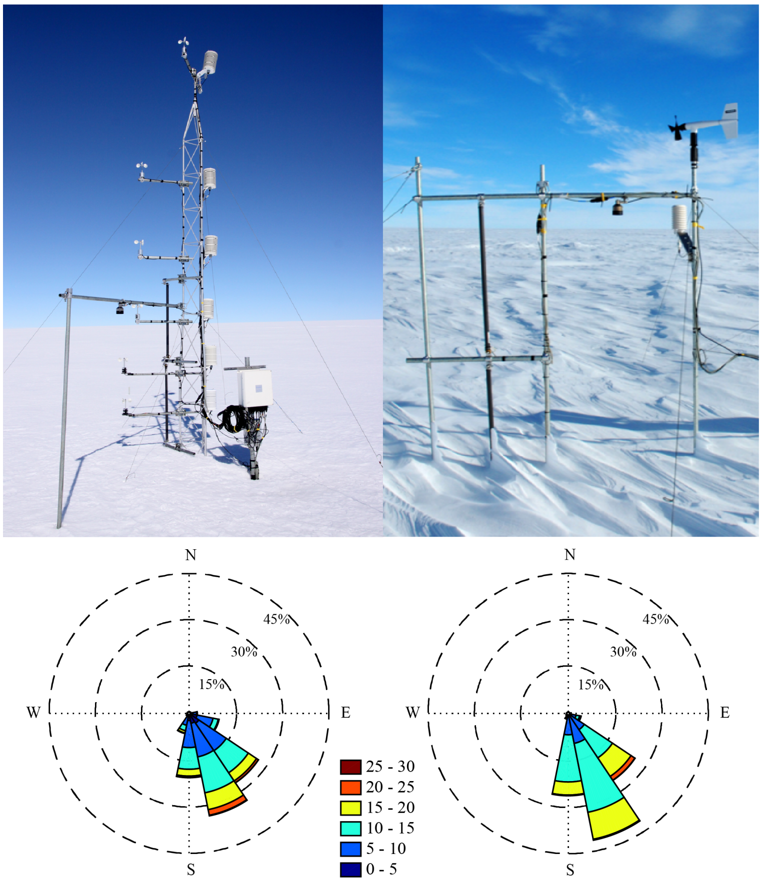

Figure S1. Pictures of the meteorological equipment and wind roses at D17 (left panel) and D47 (right panel) for the respective observation periods. At D17 the wind speed from the measurement closest to 2 m is used while wind direction is taken at the upper level of the meteorological mast. The colours indicate the wind speed ranges in m s-1. The pictures were taken in late January 2014 at D17 and in early January 2011 at D47.

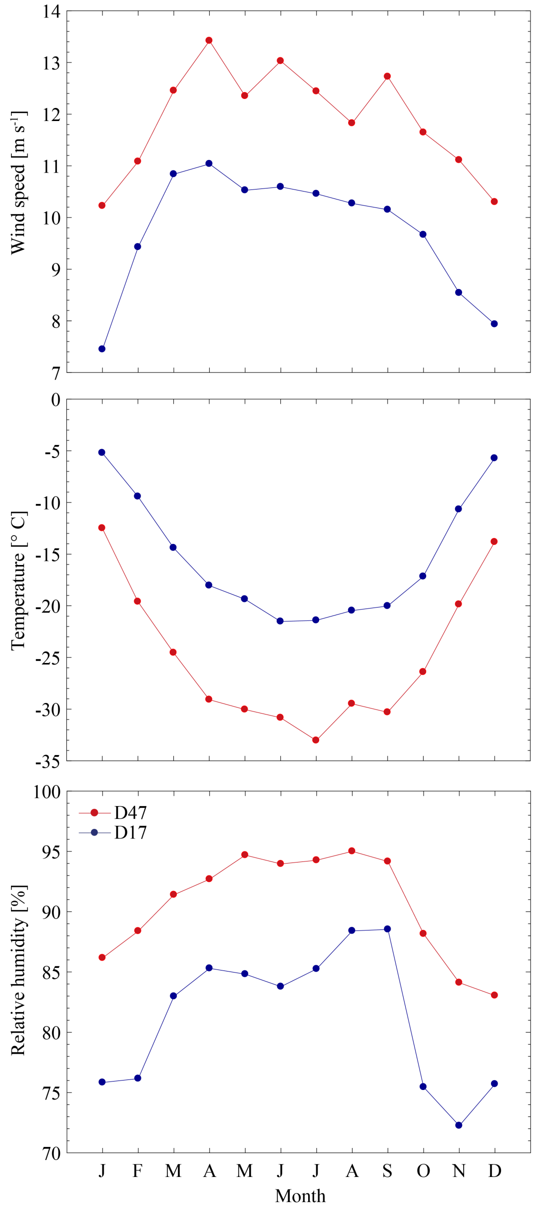

Figure S2. Monthly timeseries of wind speed (upper panel), temperature (middle panel) and relative humidity (lower panel) at 2-m height for D47 (red circles) and D17 (blue squares) for the respective observation periods 2010-2012 and 2010-2018. Mean values for each variable have been first determined from the measurement level closest to 2 m for each month of the observation period, and averaged within each monthly bin to produce monthly average values.

S1 Intercomparison between snow particle counters S7 and second-generation FlowCapt™ sensors during a drifting snow event in Adelie Land

S1.1 Snow particle counters

The measurement principle of the snow particle counter S7 (SPC-S7) follows an optical method based on the strong absorption of the infrared light by the snow. The diameter and number flux of snow particles are detected by their shadows on a super-luminescent diode sensor. Electric pulse signals corresponding to a snow particle passing through a sampling area of 50 mm^2 (2 mm in height and 25 mm in width) and whose voltage is directly proportional to the size of the particle are classified into 32 size bins from ~40 to 500 μm (Sato et al., 1993). This means that snow particles smaller than 40 μm remain undetected and snow particles larger than 500 μm are assigned to the maximum diameter class. Thanks to a self-steering vane the SPC-S7 measures perpendicularly to the horizontal wind vector the distribution size spectrum of snow particles every 1 s, from which the horizontal snow mass flux, η, can be computed assuming fully spherical snow particles with a density equal to that of ice as follows

$$\eta = \sum_{id=1}^{32} \eta_d = \sum_{id=1}^{32} n_d \frac{4}{3}\, \pi (\frac{d}{2})^3 \rho_i \qquad \text{(S1)}$$

with η_d (kg m^{-2} s^{-1}) the horizontal snow mass flux for the class of diameter d (m), id the index and n_d the measured number flux of snow particles (part. m^{-2} s^{-1}) for each of the 32 diameter classes, and ρ_i the particle density (917 kg m^{-3}).

S1.2 Experimental set-up

Two SPCs were installed on 28 January 2014 (Fig. S3) a few hours before strong drifting snow occurred in conjunction with strong katabatic winds reinforced by the passage of a low-pressure system off the Adelie Coast. The equipment was removed on 29 January once drifting snow ceased. One SPC was installed at a fixed position 1 m above the ground, while the position of the other was alternatively switched manually between 0.5 and 2 m above the ground every 1-2 hours. This was done in order to study the vertical gradient of the mass flux for two ranges of height (0.1-1.1 m and 1.2-2.2 m) above the snow surface for which 2G-FlowCapt™ measurements are also available for comparison. The high energy requirements of the SPCs (~15 W) were fulfilled by an electric generator that was housed together with the acquisition system in a mobile shelter downwind of the measurement structure. Only a few data are missing due to problem with the acquisition system of the SPC at the beginning of the experiment, resulting in an timeseries almost continuous along the event.

S1.3 Computation of integrated snow mass fluxes from SPC data

According to the diffusion theory of drifting snow (Radok, 1977), the averaged drifting snow particle density (kg m^{-3}) in the diffusion layer can be approximated by a function of height. When the wind profile follows a power law, an expression for the vertical distribution of the snow mass flux η(z) (kg m^{-2} s^{-1}) writes

$$\eta(z) = az^{-b} \qquad \text{(S2)}$$

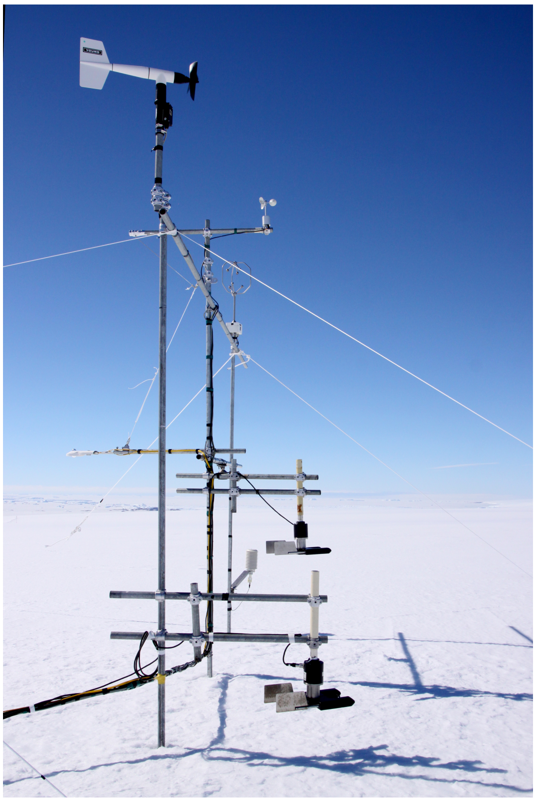

Figure S3. Picture of the snow particle counters installed at D17 during the intercomparison experiment in late January 2014.

where a is the calibration parameter and b the exponent independent of height. These parameters were derived by regression from the data measured by the two SPCs (Trouvilliez et al., 2015), alternatively available for the two height ranges. Then, the half-hourly average of the horizontal snow mass flux vertically integrated over the corresponding height covered by the 2G-FlowCapt™ can be estimated. Because (i) snow depth measurements revealed insignificant height change after the event and were affected by the presence of drifting snow particles perturbing the travel of ultrasound pulses along the measuring path during the event, (ii) the two 2G-Flowcapts were respectively installed at 0.1 and 1.2 m above the snow surface at the beginning of the event, and (iii) the heights of the SPCs were regularly checked and manually adjusted along the experiment, constant heights are used in the integration. Finally, data were processed following the procedure described in Guyomarc'h et al. (2019). Resulting integrated snow mass fluxes are compared in Fig. S4. Although more data are necessary to better assess the performance of the 2G-FlowCaptTM in Antarctic conditions, a high degree of agreement between the two types of sensor is depicted with a correlation coefficient of 0.82 and 0.93 and a rmse of 70 10^{-3} and 13 10^{-3} kg m^{-2} s^{-1} (by taking the SPC-S7 as a reference) for the lower and upper height range, respectively.

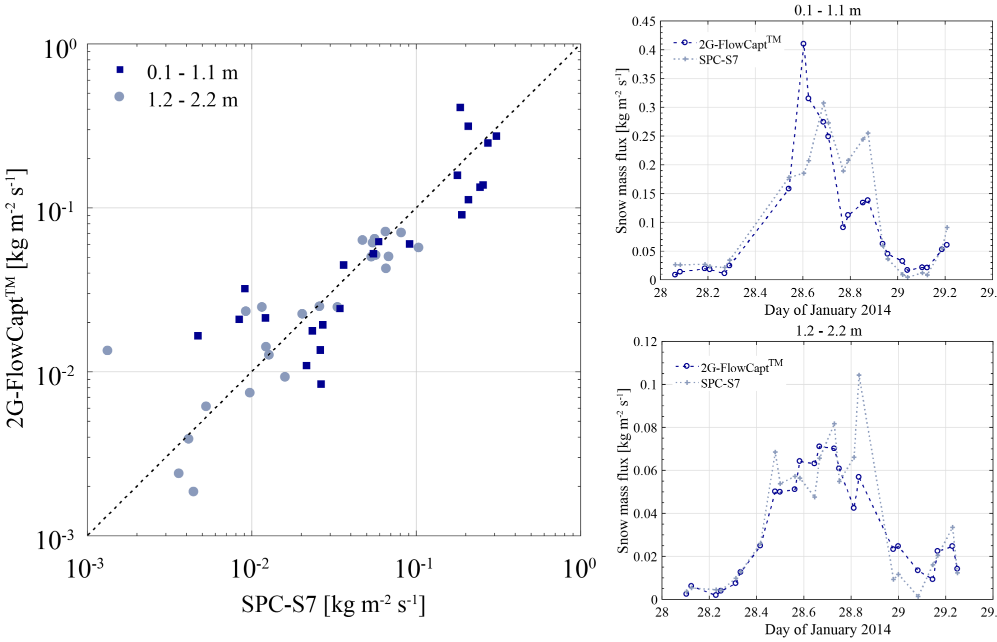

Figure S4. Comparison between snow mass fluxes provided by 2G-Flowcapt™ sensors and computed from measurements made with snow particle counters (SPC-S7) during a snow transport event at site D17 in late January 2014. A distinction is made between snow mass fluxes integrated over 0.1 to 1.1 m and 1.2 to 2.2 m above ground.

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