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 our revised version now includes an additional discussion on saturation conditions in the saltation layer (as requested by M. Lehning), so that we refer to 1 meter instead of 2 meters in the description of Fig. 2 to stay consistent with the typical heights of the saltating particles.
Due to the removal of profiles for which the lowest RH sensor reports values > 100 %, the statistics have been slightly altered but this does not change in any way the conclusions of the paper.

Charles Amory, on the behalf of the two authors

Response to reviewer RC2

We thank the reviewer for its thorough reading of our paper, the very relevant questions and the proposed suggestions that will help to improve the manuscript. Our responses are reported hereafter in red.

General comments

This is a well-written paper with clear figures, and the topic is relevant for The Cryosphere. I do have some reservations about the need for this study to be a separate, brief communication while another study by the same author using the same dataset is presently being considered for publication in the same journal. It must become clearer a) why isolating this aspect of the dataset in a separate publication is warranted and b) whether the conclusions support the title adopted (see below).

Major comments

RC1: Why was this paper presented separately from Amory (2019)? Is there a particular reason to do so? An obvious disadvantage is that the reader is now referred to that paper for a detailed description of the observations, which are at the core of this study.

Authors: While Amory (2019) uses single-level meteorological measurements of the full 9-year dataset to focus exclusively on drifting snow frequency and mass transport statistics and discuss applications for model evaluation, in the present paper we use a part (1 year) of this dataset and extend the analysis to 6-level meteorological profiles to discuss a different, independent topic related to the development of saturated air layers. Although the two papers do have some data in common and share a common context of drifting snow features, note that

1) the analysis proposed here relies on specific requirements that are only met during that specific period (availability of the depth sensor, no dysfunction nor burial of any of the 6 thermo-hygrometers, relative constancy in measurement height along the observation period - see the paragraph dedicated to that aspect of the study from L102 to L110),
2) the specific subject of drifting snow atmospheric interactions and sublimation involve theoretical descriptions that does not fit the objective of Amory (2019), and would have thus require additional out-of-the-scope theoretical background,
3) the meteorological profiles are not presented in Amory (2019).

For the above-mentioned reasons, and because we are 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, we believe that each of the two studies deserve separate papers.
Moreover, the method section of the present paper includes a detailed description of the observations that contains the information (i.e., sensor type, range, accuracy, measurement principle and measurement height) necessary for the self-sufficiency of the paper, and relies on Amory (2019) only for additional, non-essential information about the observation campaign.

RC1: How general are the conclusions? This study only uses a single year of data for a single location. Is this sufficient to support the title of the paper, i.e. that saturation is rare in entire East Antarctica? If maintained, some more effort must go into supporting this claim.
Authors: You are entirely right, Antarctica is wide and diverse. We suggest to change the title to *"Rare ambient saturation during drifting snow occurrences at a coastal location of East Antarctica"*.

RC1: L79: "…in which a local balance between upward turbulent diffusion, gravitational settling and sublimation of windborne snow particles is likely to be attained." Can you be more specific, do the observations allow to assess in a quantitative way whether such a steady state is attained?
Authors: This indeed may have been extrapolated a bit too far, at least in assuming steady-state drifting snow. Answering this question in a quantitative way could ideally be done through a modelling approach but observations alone hardly allows it. This part has been removed from the sentence.

RC1: L114: "Converted values in excess of 100 % were attributed to the limitations of both the instruments and the conversion method and were thus capped to 100 %." Can you provide some statistics, please? How often did this (RH values > 100%) occur?
Authors: RH is the ratio of water vapour pressure to the vapour pressure for saturated air. RH values converted to be given with respect to ice (RH w.r.i.) are necessarily higher than original values given with respect to water (RH w.r.w.), since ice supports a lower saturation vapour pressure than water for a given temperature. A comparison

between raw and converted RH values for the measurement level closest to 2 m is given in Fig. R1. The figure shows that converted RH values slightly exceeding 100 % (up to a maximum of 105%) occur regularly and inevitably account for most of the saturation conditions (considering that saturation is reached at RH >=100 %), as a result of the empirical character and inherent limitation of the widely used Goff-Gratch formulae. As the occurrence of supersaturation is very unlikely at our measurement site (as discussed in the paper from L115 to L118 in the original version), and the conversion of raw sensor records is needed for a matter of rigour, we maintain that Goff-Gratch conversion is a reasonable option and suggest to let the text as it appears in the original version of the manuscript but to add Fig. R1 as Fig. S1 in the supplementary materials.

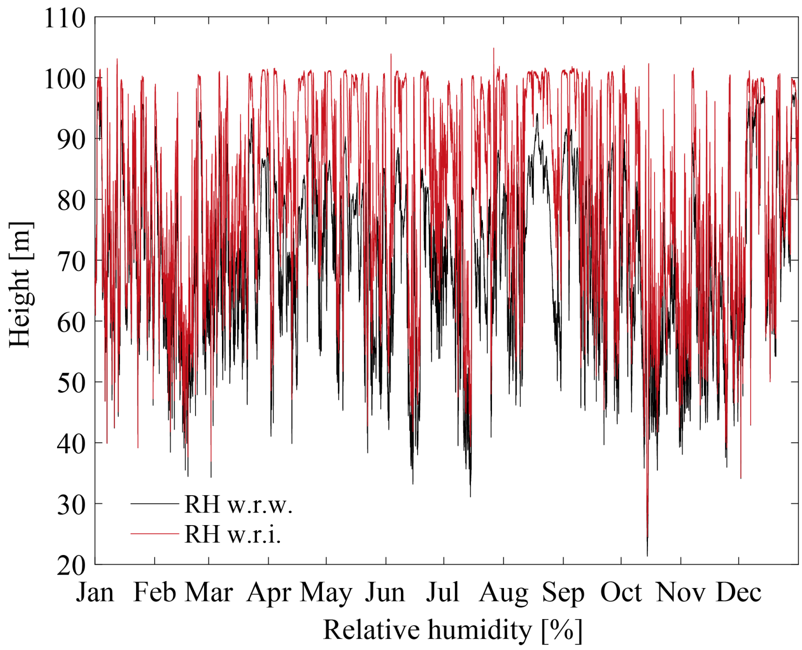

Figure R1. Timeserie of raw (given with respect to water; w.r.w.) and converted (given with respect to ice; w.r.i.) RH values at 2 m height showing the regular occurrence of RH > 100 % due to limitations of the Goff-Gratch formulae used in the conversion.

RC1: Caption Fig. 2: "Frequency of saturation (RH = 100 %). . .": given the uncertainty in the RH sensors, saturation could also occur at measured values well below 100%. Have you investigated the sensitivity of your results to this definition of the observed 'saturation' threshold?
Authors: Accounting for an uncertainty of 3 % in the absolute value of RH as stated by the manufacturer (Table 1 of the original version), the occurrences of a saturated air layer along the whole measurement range rise from 9.7 % to 21.3 % of the drifting snow occurrences if the saturation threshold is lowered from 100 % to 97 %. This twofold increase in the frequency of saturated conditions, also observed for the upper 4 levels (the lowest 2 levels below 1 m are less significantly affected because of initially high frequency values), still accounts for a reduced proportion of the overall drifting snow occurrences and confirm that saturation predominantly occurs within the first two meters above the surface and remains rather infrequent compared to the regular incidence of drift conditions.

We have added the following paragraph at the beginning of the discussion section, and Fig. R2 is now proposed as Fig. S2 in the supplementary materials: "*Examination of the RH profiles revealed that the air is saturated with respect to ice over the entire measurement range in only 8.2 % of the drifting snow occurrences, assuming saturation is reached when RH = 100 %. Because of instrumental inaccuracy, saturation could however occur at measured RH values below 100 %. The sensitivity of the frequency of saturation can be investigated by decreasing the threshold at which saturation is considered to occur. Accounting for an uncertainty of 3 % in the absolute value of RH as stated by the instrument manufacturer (Table 1), the occurrence of a saturated air layer along the whole measurement range rises from 8.2 % to 18 % of the drifting snow occurrences if the threshold for saturation is lowered from 100 % to 97 %. This twofold increase in the frequency of saturation, globally observed for the upper 4 levels (the lowest 2 levels below 1 m are less significantly affected because of initially high frequency values – Fig. S2), still accounts for a reduced proportion of the overall drifting snow occurrences and confirms* *that saturation predominantly occurs within the first two meters above the surface and remains rather infrequent compared to the regular incidence of drift conditions.".*

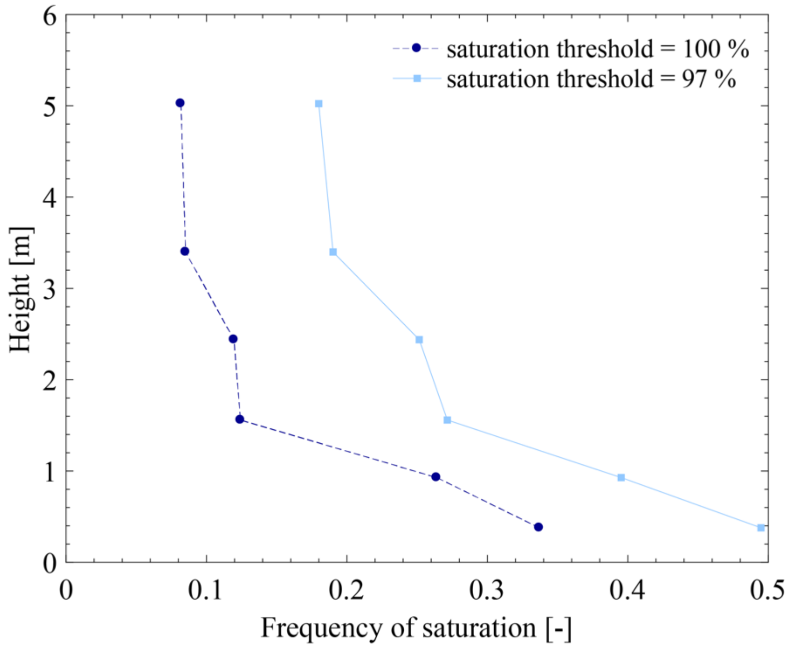

Figure R2. Frequency of saturation in drift conditions at each measurement level assuming that saturation is reached at 100 % (dashed line) and 97 % (sold line). Yearly average instrument heights are used.

The sentence in the conclusion from L214 to L216 in the original version has been completed by mentioning the threshold retained for the computation of the statistics as follows: *"[...]. However, this is shown to be relatively rare (only 8.2 % of the drifting snow occurrences or 6.3% of the time if the RH value at which saturation is considered to be attained is taken as 100 %) at the measurement location and mainly occurs in strong drift conditions (η_1 > 0.2 kg m^{-2} s^{-1}) associated with high wind speeds (U_2 > 20 m s^{-1}).".*

Moreover, by re-investigating the dataset we have also discovered significant occurrences (7% of the data) for which the lowest humidity sensor reports raw RH (with respect to water) above 100 %, most likely due to riming on the probe and/or snow trapped in the radiation shield caused by its proximity with the surface where drift conditions are the most intense. These observations have been removed from the dataset and the (slightly modified) statistics and figures have been corrected accordingly. The following paragraph has been added to the method section: *"Inspection at the dataset revealed a significant proportion of occurrences (7%) for which the lowest humidity sensor reports raw values (i.e., with respect to water) above 100 %. Such values are most likely caused by riming on the probe and/or snow occasionally trapped in the radiation shield due to its proximity with the surface where drift conditions are the most intense. After removal of these erroneous data, 16,289 six-level profiles were available for analysis."* .

RC1: L123: "Before the event begins, only a thin layer near the snow surface is saturated as a result of surface sublimation.": Alternatively, near-surface air could become saturated not by sublimation but simply by cooling. See also L138.
Authors: Yes it is true, a decrease in air temperature can just as likely as surface sublimation cause saturation in the vicinity of the surface. This suggestion has been added in the text as *"[...] saturated as a result of surface sublimation and/or a decrease in air temperature".*
Atmospheric cooling has also been listed as a possible explanation for the persistence of saturated conditions after the cessation of drifting snow events (L138 in the original version).

Minor comments
RC1: L46: "The thermodynamic effects of windborne-snow sublimation are physical limitations to accurate determination of sublimation rates from automatic weather station data. ": This is either an awkwardly formulated sentence or it contains a typo; please reformulate.

Authors: We tried to resume with this first sentence the content of the underlying paragraph, but surely we did it in a clumsy way. We suggest to change the sentence to *"The thermodynamic effects resulting from interactions of drifting snow particles with the atmosphere hinder accurate determination of sublimation rates from classical physical frameworks and automatic weather station data."*

RC1: L52: ". . .raising instrumental accuracy as a large source of uncertainty which strongly amplifies with wind speed": please explain why instrumental inaccuracy amplifies with wind speed; one could also argue that stability corrections become less important during near-neutrality, enhancing accuracy?
Authors: Turbulent mixing and drifting snow promote a weakening in the observed temperature and moisture gradients, to the extent that measurement accuracy are of the order of the existing gradients (Barral et al. 2014). In addition, increasing wind speeds are generally accompanied with an increase in relative humidity (Fig. 3 in the original version), resulting in a strong sensitivity of the profile method to measurement errors, particularly in the case of small gradients in conjunction with strong winds. For further details, we refer to Barral et al. (2014), in particular their section 5.2 and Fig. 12 which show that "*the propagated uncertainties are amplified with wind velocity or decreasing temperature gradients*".
Even if a significant influence of stability corrections in the computation of turbulent fluxes has been demonstrated for stable conditions on the Antarctic plateau (Vignon et al., 2017), a much lower influence can be expected at D17 because the near-surface atmosphere is mostly neutrally stratified throughout the year, and it is more likely that the gradient-induced uncertainty largely offsets the enhanced accuracy due to the decreasing importance of stability corrections with increasing wind speeds.
To improve clarity, we suggest to reformulate the sentence L50 to L53 in the original version as *"In addition, the well-known profile method commonly employed to compute turbulent heat fluxes can become hardly applicable in drifting snow because vertical moisture and temperature gradients are weakened by windborne-snow sublimation and turbulent mixing. As the observed gradients reduce, instrumental inaccuracy becomes important compared to gradients and induces comparatively large flux uncertainties which thus strongly amplify with wind speed (Barral et al., 2014).".*

RC1: L82: ". . .isothermal layer. . .": Strictly speaking, a neutral surface layer implies that potential temperature is constant with height, not temperature.
Authors: Absolutely right. This sentence has been changed to "*Strong turbulent mixing due to frequent katabatic flows induces the nearly-constant presence of an isothermal layer ensuring that vertical changes in relative humidity during transport are mainly governed by particle-air moisture exchanges along the profile*".

RC1: L. 95: emerged -> exposed (?)
Authors: Corrected accordingly.

Amory, C.: Drifting snow statistics from multiple-year autonomous measurements in Adelie Land, eastern Antarctica, The Cryosphere Discuss., https://doi.org/10.5194/tc-2019-164, in review, 2019.

Barral, H., Genthon, C., Trouvilliez, A., Brun, C. and Amory, C.: Blowing snow in coastal Adélie Land, Antarctica: three atmospheric-moisture issues, The Cryosphere, 8(5), 1905–1919, doi:10.5194/tc-8-1905-2014, 2014.

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Response to reviewer RC2: M. Lehning

Dear Michael,
We thank you for your insightful comments that will undoubtedly help to improve the quality of the manuscript. We have adapted the text in several places and included additional discussions to fit your suggestions. Our responses are reported hereafter in red.

General comments
The paper presents an observational study on moisture dynamics at one site in Antarctica with frequent events of strong katabatic winds and associated snow transport. The paper is nicely formulated and timely as the role of sublimation during snow transport is a currently debated problem in meteorology and snow science.

Major comments
RC2: I asked myself whether this rather limited dataset is worth a separate publication but concluded that it helps to shape our understanding of what blowing snow sublimation may look like in these katabatic wind zones. However, I suggest that more complete context and discussion is provided. There have been recent LES simulations on drifting snow sublimation (e.g. Sharma et al., 2018; Huang et al., 2016), which claim that previous efforts in modelling sublimation may have started from wrong assumptions. It would add value and impact to the current paper if the authors could discuss whether their observations are consistent with the new model findings or not.
Authors: Thank you for this very relevant suggestion. We have completed the discussion with the following paragraph in which Fig. 2 is used to discuss our results from the perspective of the above-mentioned model findings: "*In previous efforts dedicated to the modelling of windborne-snow sublimation, the saltation layer has been regarded as saturated at all times and emphasis was primarily placed on the sublimation of suspended snow particles. Recent large-eddy simulations (e.g., Huang et al., 2016; Sharma et al., 2018) have shown from reassessments of physical starting assumptions that sublimation within the saltation layer might be of significant importance in the surface and atmospheric water budgets. In some of these experiments, sublimation within the saltation layer can even exceed sublimation of suspended particles by several orders of magnitude when effective advective transport of moisture can sustain an undersaturated environment in the immediate vicinity of the surface (Huang et al., 2016). Assuming that saturation at the lowest measurement level of ~0.4 m above ground (i.e., well above the saltation layer) also implies saturation down to the surface, Fig. 2 would indicate that saturation at saltation heights is observed in at least one third of the drifting snow occurrences, i.e. 4 times more frequently than saturated conditions at all measurement levels. In these cases, sublimation of saltating particles could indeed be ignored and only sublimation within the suspension layer would likely contribute to the surface-atmosphere moisture exchange. Similarly, limited moisture fluxes from sublimation of saltating snow could be expected in fully developed, deep blowing snow layers in which the contribution of suspension to the total column-integrated mass flux dominates over saltation.*".

A brief mention of this new element of discussion is also made in the conclusion by completing the former sentence "*Although saturation is preferentially confined below 1 metre, low-level atmospheric moistening by the sublimation of […]*" which thus becomes "*Although saturation is preferentially confined below 1 metre likely involving saturation in the saltation layer, low-level atmospheric moistening by the sublimation of […]*".

RC2: One major comment I have is on the overall limitation of sublimation in snow transport clouds. The authors revisit the argument that with stronger wind and snow transport, total snow sublimation may be limited because saturation occurs. This argument has been formulated by Bintanja (2001) based on a model study, in which the author considers a model depth of 10 m to look of blowing snow sublimation. I have always been very skeptical about the conclusion of limited sublimation because I expect in these situations the level of maximum sublimation to be simply lifted to higher elevations such that it is not seen in the first 10 m. If I understand the Bintanja model study correctly, then he only sums up sublimation occurring in the lowest 10 m, which is of course only part of the total sublimation if high winds cause deep clouds of blowing snow. The authors are therefore encouraged to either present clear evidence of total sublimation reduction in stronger winds, or not conclude about this aspect.
Authors: We could not agree more with your comment. We have removed the conclusion about the original argumentation on the peak in sublimation for moderate winds in the Results section and added the following paragraph in the Discussion section "*Figure 3 demonstrates that a layer of near-saturated air inevitably develops along the whole profile in the most extreme wind and drift conditions. Similar results obtained from modelling experiments in which a blowing snow layer of 10 m depth is considered, has been used to hypothesise that total windborne-snow sublimation may be limited with strong winds and snow transport because low-level saturation occurs (Bintanja, 2001b). While both results do imply that further moisture release is inhibited in such conditions through the negative feedback of windborne-snow sublimation in a small portion of the near-surface atmosphere,*

it might also involve that the level of maximum sublimation is lifted to higher elevations when strong winds cause deep blowing snow layers. An important implication could thus be that, despite saturation conditions in the low-level atmosphere, the greatest contribution of windborne-snow sublimation to the total moisture flux might still occur at the highest wind speeds and associated snow transport, as near-surface sublimation is only part of the total atmospheric sublimation.".

As we believe that this reasoning can be of significant relevance for future blowing snow studies, it is also mentioned in the conclusion as: *"[…] during those events for which the occurrence of drifting snow (i.e., < 2 m) and a saturated air layer of several metres is concurrently reported, the height reached by the suspended snow particles, or the depth of the transport layer, likely extends beyond the uppermost measurement level (i.e., > 5.5 m). As this possibly induces significant windborne-snow sublimation in higher atmospheric levels, contrary to previous considerations (Bintanja, 2001b) it is hypothesized that the presence of a low-level saturated air layer would not limit total atmospheric sublimation if the level of maximum sublimation in such conditions is simply moved upwards.".*

Finally we have adapted our last paragraph in the conclusion as: *"Combined dropsonde and satellite measurements have shown that blowing snow can frequently develop into deep layers of several hundreds of metres above the ice-sheet surface in which RH decreases with height through the depth of the layer (Palm et al., 2018), suggesting the existence of a potentially significant atmospheric mass sink through windborne-snow sublimation. However, satellite detection only captures blowing snow layers 30 m or greater in thickness during clear-sky or optically thin-cloud conditions and is limited by the satellite revisit frequency. Synergistic uses of remote sensing, modelling and observation products would help to assess the proportion of missed events when surveying snow transport from space and study the conditions that lead drifting and shallow (< 30 m) blowing snow events to evolve into deep blowing snow layers, to ultimately improve understanding of the links between snow transport and moisture dynamics and better quantify the influence of windborne-snow sublimation on the surface mass balance of the Antarctic ice sheet.".*

Minor comments

RC2: In practical meteorological applications, drifting snow is below 2 m and blowing snow above. Snow scientists, however, would rather define drifting snow as saltation and blowing snow as suspended snow.

Authors: We agree that a standard definition for distinguishing between drifting and blowing snow is still lacking in the scientific community. The formulation of an official consensus may have been hindered by the use of analogous terminologies for the description of diverse meteorological conditions, (without systematic detailed explanations of the semantics used) to the extent that it would, maybe, ideally require a conciliation meeting some day. However, the definition using a standard level of 2 m in height as a distinction criteria has been widely employed over the recent years in publications dealing with snow transport in Antarctica (e.g., Leonard et al., 2011; Lenaerts et al., 2012; Gossart et al., 2017; Trouvilliez et al., 2014; Palm et al., 2017, 2018a,b) while we found no clear evidence of a distinction involving analogy between drifting and saltating snow from one hand and blowing and suspended snow on the other hand, even in the most recent publications dedicated to the characterization of specific aeolian processes (e.g., Aksamit and Pomeroy, 2017; Crivelli et al., 2016; Huang et al., 2016; Huang and Wang, 2016; Comola and Lehning, 2017; Comola et al., 2017; Paterna et al., 2016, 2017; Sharma et al., 2018). In addition, and from our point of view, one could argue that this requires the use of different words for referring to the same mechanism (saltation/drifting and suspension/blowing) which could eventually be a bit confusing in some way. One option could be to mention the existence of the two definitions, and be explicit about the one we choose in the rest of the manuscript. In that case, could you indicate publications in which this definition clearly appears so we can refer to them and then support the proposed definition in the paper?

RC2: L30 (and first sentence in the abstract): I think that it is not proven yet or generally accepted that snow transport and sublimation is the main ablation process over the entire Antarctic ice sheet.

Authors: Yes you're right, this assertion actually relies only on a few modelling studies which have not resulted in a consensual acceptance. We changed the sentence to "*Continent-wide modelling studies suggest that erosion through divergence of drifting and blowing snow transport and concurrent sublimation of particles during transport currently represent important ablation processes on the ice sheet.*".

RC2: L50: Suggest to replace "verified" by "met".

Authors: Changed accordingly.

RC2: L75 vs. L80: You cannot say that D17 is in an accumulation zone and then that you achieve equilibrium horizontal mass flux. This is contradictory.

Authors: This clumsy part has been removed from the sentence.

RC2: L107: Whether or not the vapor pressure really increases towards the surface (or only most often) depends on the air temperature gradient (and the one in the surface snow to a lesser degree).

Authors: The influence of the air temperature gradient on the water vapour gradient decreases with the air temperature gradient itself. Active katabatic winds in the measurement area provide efficient turbulent mixing in the near-surface atmosphere. Figure R3 shows that the air temperature gradient (computed from the temperature difference between the highest and the lowest measurement level) decreases as wind speed increases, and is in most cases below the actual instrumental accuracy of 0.4 °C at -20 °C (see Table 1 in the original manuscript). We can thus expect the actual temperature gradients in the thin portion of the atmospheric boundary layer covered by the meteorological profiles (the first 6 meters above the surface) to be very small (actually below instrumental accuracy), even more in case of moderate to strong winds so we can reasonably make the assumption of the existence of a nearly-isothermal layer. Figure 3 in the original manuscript evidences however the existence of RH gradients above instrumental accuracy for every range of wind speeds that cannot be entirely explained by possible residual temperature gradients; explanations for this gradients have then been proposed from L107 to L110 (in the original version) and used as arguments to justify the importance of relatively constant measurement heights in the statistical analysis of relative humidity. Nevertheless, we have modified slightly the sentence in the revised version of the manuscript and mention instead the proximity with the surface as a influencing factor for RH as :*"This is important for consistent time statistics of relative humidity since (i) the proximity with the snow surface, which acts as a moisture source through sublimation influences the vapour pressure of the air and (ii) the additional moisture loading and atmospheric cooling through windborne-snow sublimation at a given elevation above the snow surface partly depends on the snow mass concentration which is a strongly decreasing function of height."*.

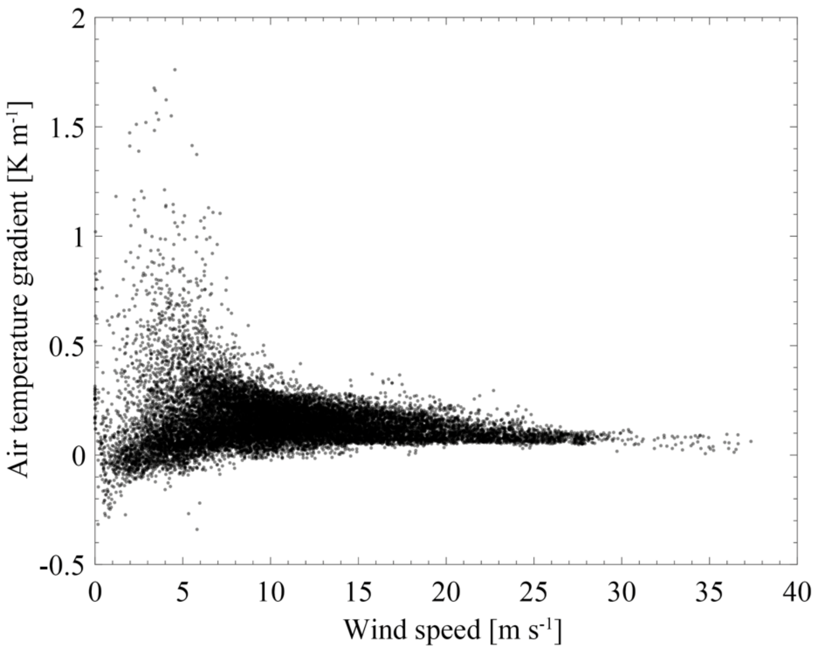

Figure R3. Air temperature gradient (computed from the temperature difference between the highest and the lowest measurement level) as a function of wind speed.

RC2: L161 ff: Mark this as hypothesis/discussion and mention (again) temperature gradients, which are also able to produce moisture gradients.

Authors: This paragraph now includes temperature gradients as a possible explanation for the RH gradients as *"Only surface sublimation, and possibly residual temperature gradients in that case contribute to the vertical moisture gradient and leads RH to increase when approaching the surface."*.

RC2: L175: See major comment above on moving the elevation of maximum sublimation upwards in higher winds. This is what I expect to occur.

Authors: See our response to major comment #2.

RC2: L212: Check wording "preferably".
Authors: We changed to "preferentially".

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Bintanja, R.: Modelling snowdrift sublimation and its effect on the moisture budget of the atmospheric boundary layer, Tellus A, 53(2), 215–232, doi:10.1034/j.1600-0870.2001.00173.x, 2001.

Comola, F. and Lehning, M.: Energy- and momentum-conserving model of splash entrainment in sand and snow saltation, Geophys. Res. Lett., 44(3), 1601–1609, doi:10.1002/2016GL071822, 2017.

Comola, F., Kok, J. F., Gaume, J., Paterna, E. and Lehning, M.: Fragmentation of wind-blown snow crystals, Geophys. Res. Lett., 44(9), 4195–4203, doi:10.1002/2017GL073039, 2017.

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Huang, N., Dai, X. and Zhang, J.: The impacts of moisture transport on drifting snow sublimation in the saltation layer, Atmos. Chem. Phys., 16(12), 7523–7529, doi:10.5194/acp-16-7523-2016, 2016.

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Palm, S. P., Kayetha, V., Yang, Y. and Pauly, R.: Blowing snow sublimation and transport over Antarctica from 11 years of CALIPSO observations, The Cryosphere, 11(6), 2555–2569, doi:10.5194/tc-11-2555-2017, 2017.

Palm, S. P., Yang, Y., Kayetha, V. and Nicolas, J. P.: Insight into the Thermodynamic Structure of Blowing-Snow Layers in Antarctica from Dropsonde and *CALIPSO* Measurements, J. Appl. Meteor. Climatol., 57(12), 2733–2748, doi:10.1175/JAMC-D-18-0082.1, 2018a.

Palm, S. P., Kayetha, V. and Yang, Y.: Toward a Satellite-Derived Climatology of Blowing Snow Over Antarctica, J. Geophys. Res. Atmos., 123(18), 10,301-10,313, doi:10.1029/2018JD028632, 2018b.

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Brief communication: Rare ambient saturation during drifting snow occurrences ~~in~~ at a coastal location of East Antarctica

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Abstract. Sublimation of snow particles during transport has been ~~recognized as the main~~ recognised as an important ablation process on the Antarctic ice sheet. The resulting increase in moisture content and cooling of the ambient air are thermodynamic negative feedbacks that both contribute to increase the relative humidity of the air, inhibiting further sublimation when saturation is reached. This self-limiting effect and the associated development of saturated near-surface air layers in drifting snow conditions have been mainly described through modelling studies and few field observations. A set of meteorological data including drifting snow mass fluxes and vertical profiles of relative humidity collected at site D17 in coastal Adelie Land (East Antarctica) during year 2013 is used to study the relationship between saturation of the near-surface atmosphere and the occurrence of drifting snow in a katabatic wind region among the most prone to snow transport by wind. Atmospheric moistening by the sublimation of the windborne snow particles generally results in a strong increase in relative humidity with the magnitude of drifting snow and a decrease of its vertical gradient, suggesting that windborne-snow sublimation can be an important contributor to the local near-surface moisture budget. Despite a high incidence of drifting snow at the measurement location (~~61.3~~ 60.1 % of the time), saturation, when attained, is however most often limited to a thin air layer below ~~2 meters~~ 1 meter above ground. The development of a near-surface saturated air layer up to the highest measurement level of 5.5 m is observed in only ~~9.6~~ 8.2 % of the drifting snow occurrences or ~~5.9~~ 6.3 % of the time and mainly occurs in strong wind speed and drift conditions. This relatively rare occurrence of ambient saturation is explained by the likely existence of moisture-removal mechanisms inherent to the katabatic and turbulent nature of the boundary-layer flow that weaken the negative feedback of windborne-snow sublimation. Such mechanisms, potentially quite active in katabatic-generated windborne-snow layers all over Antarctica may be very important in understanding the surface mass and atmospheric moisture budgets of the ice sheet by enhancing windborne-snow sublimation.

1 Introduction

Drifting and blowing snow, respectively defined as an ensemble of snow particles raised from the ground at a height below and above 2 meters, occur frequently over windswept areas of ~~the Antarctic continent. Erosion~~ Antarctica. Continent-wide modelling studies suggest that erosion through divergence of drifting and blowing snow transport and concurrent sublimation of particles during transport currently represent ~~the main~~ important ablation processes on the ice sheet ~~(van Wessem et al., 2018)~~(e.g., van Wes

When the effective shear stress exerted by the flow on the snow surface exceeds the threshold value for erosion, particles become mobile and periodically bounce on the surface in a motion mechanism referred to as saltation. In even stronger winds, saltating particles are entrained from the top of the saltation layer by turbulent eddies and enter into suspension without contact with the surface.

The particles transported through saltation and suspension during drifting and blowing snow occurrences interact with the ambient air and influence the thermodynamic structure of the low-level atmosphere. Mass loss experienced by windborne snow particles through sublimation releases water vapour into and removes heat from the surrounding air. Both processes contribute to an increase in relative humidity of the air in an inherently self-limiting fashion (Déry et al., 1998; Mann et al., 2000; Bintanja, 2000), eventually inhibiting further sublimation when saturation is reached. Since the mass concentration of windborne snow particles decreases rapidly with height above the snow surface, windborne-snow sublimation leads to the development of a downward sensible heat flux together with an upward latent heat flux that can balance each other in strong wind conditions (Bintanja, 2001a). Moisture exchange also occurs between the snow-covered surface and the atmosphere through surface sublimation but at much lower rates than windborne-snow sublimation because of the greater exposed surface area and the continuous ventilation of snow particles in the air (Schmidt, 1982).

The thermodynamic effects ~~of windborne-snow sublimation are physical limitations to~~ resulting from interactions of windborne snow particles with the atmosphere hinder accurate determination of sublimation rates from classical physical frameworks and automatic weather station data. The usual Monin-Obukhov similarity theory and related bulk relationships cannot be considered valid in transport conditions since the atmospheric surface layer contains a moisture source and a heat sink (Bintanja, 2001b), implying that the requirement of vertical constancy in turbulent fluxes is not ~~verified~~met. In addition, the well-known profile method commonly employed to compute turbulent heat fluxes can become hardly applicable in drifting snow because vertical moisture and temperature gradients are ~~weak due to~~ weakened by windborne-snow sublimation and turbulent mixing~~, raising instrumental accuracy as a large source of uncertainty which strongly amplifies~~ . As the observed gradients reduce, instrumental inaccuracy becomes important compared to gradients and induces comparatively large flux uncertainties which thus strongly amplify with wind speed (Barral et al., 2014).

The rate of windborne-snow sublimation both affects and depends on the mass concentration of windborne snow particles. It is also interdependent with the temperature and relative humidity gradients across the transport layer, since the water vapour removed from each particle must be compensated by a heat transfer to the particle. In the absence of direct turbulence measurements and despite the instrumental and calculation limitations mentioned above, this suggests that near-surface meteorological profiles can however provide information on the effect of snow transport on the moisture budget of the lowest atmospheric layers.

The development of near-surface saturated atmospheric layers through the negative feedback of windborne-snow sublimation has been mainly described from modelling approaches (Déry et al., 1998; Bintanja, 2001b) and few field measurements of individual blowing and drifting snow events (Mann et al., 2000; Bintanja, 2001a). The relative frequency of such situations in a natural environment is however almost undocumented. This study investigates the relationship between low-level atmospheric saturation and the occurrence of drifting snow based on the analysis of detailed meteorological data collected during year 2013 in Adelie Land, a katabatic wind region of coastal East Antarctica among the most prone to snow transport by wind.

Table 1. Characteristics of the sensors used at the profile station D17.

Sensor	Type	Range	Accuracy
Wind speed	Vector A100LK*	0.2–60 m s^{-1}	0.1 m s^{-1}
Air temperature	Vaisala HMP45A	-39.2–60 °C	0.4 °C at -20 °C
Air relative humidity	Vaisala HMP45A	0–100 %	2 % (RH $<$ 90 %)
			3 % (RH $>$ 90 %)
Snow height	SR50A*	0.5–10 m	0.01 m
Snow mass flux	second-generation FlowCapt™**	-	-

* Manufacturer Campbell Scientific

** Manufacturer IAV Engineering

2 Field area and instrumentation

The detailed meteorological profiles and drifting snow measurements presented in this paper were acquired in the framework of an extensive drifting snow observation campaign that was run on the marginal slopes of Adelie Land in January 2010 (Trouvilliez et al., 2014). The campaign involved three unmanned weather stations (namely D3, D17 and D47) placed at different locations along a 100-km long transect to quantify spatial variations in the area. In this study, only the data collected at site D17 (66.7°S, 139.9°E; 450 m above sea level) is used because vertical profiles have been measured only at this location (see Amory (2019) for a detailed account of the measurements and local meteorological conditions).

D17 is situated in an accumulation zone 10 km inland from the coastline, near the downstream end of a sloping ice field. With frequent, strong and persistent katabatic flows originating almost exclusively from south-easterly directions owing to topographic channeling, D17 benefits from a long unobstructed snow-covered fetch of several hundreds of kilometers. This results in the regular occurrence of non-intermittent, well-developed drifting and blowing snow events (Amory, 2019)~~in which a local balance between upward turbulent diffusion, gravitational settling and sublimation of windborne snow particles is likely to be attained. Due to strong turbulent mixing induced by~~ . Strong turbulent mixing due to frequent katabatic flows ~~, the near-surface atmosphere at D17 is mostly neutrally stratified throughout the year (Amory et al., 2017). The~~ induces the nearly-constant presence of ~~an isothermal layer ensures~~ a quasi-isothermal layer ensuring that vertical changes in relative humidity during transport are mainly governed by particle-air moisture exchanges along the profile.

Wind speed, temperature, and relative humidity were measured at six levels logarithmically spaced (nominal heights 0.8, 1.3, 2, 2.8, 3.9 and 5.5 m above the surface), while changes in elevation due to accumulation and ablation were assessed with a sonic height ranger. The thermo-hygrometers were housed in naturally-ventilated radiation shields. Information on the occurrence and magnitude of drifting snow was retrieved from a second-generation acoustic FlowCaptâ¢ device that was set up vertically and close to the ground to enable detection of the initiation of drifting snow events. The sensor consists of a 1 m long tube containing electroacoustic transducers that convert the acoustic vibration caused by the windborne snow particles colliding with the tube into a snow mass flux (vertically) integrated over the ~~emerged~~ exposed length of the tube. Note that blowing snow may also occur in snow-transport occurrences necessarily identified as drifting snow since in this configuration detection of snow transport is limited to the first metre above ground. To ensure that significant events are detected and electronic or turbulence noise is removed, 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} (Amory et al., 2017). The types and specificities of the instruments installed at D17 are summarised in Table 1. Sampling was done every 15 s and the 30-min statistics were stored on a Campbell CR3000 datalogger.

The meteorological profiles used in this study have been collected continuously from January 1^{st} until December 30^{th} 2013. Although data at D17 is available for a longer period of time (Amory, 2019), this specific year was selected because the thermo-hygrometers remained functional at all levels throughout the year and almost all of the yearly accumulation as recovered by the height ranger occurred in February (Amory et al., 2017), guaranteeing that the measurement heights have undergone relatively little changes during the rest of the year.

This is important for consistent time statistics of relative humidity ~~,~~ since (i) the ~~vapour pressure of the air increases with the proximity of the snow surface~~proximity with the snow surface, which acts as a moisture source through sublimation influences the vapour pressure of the air and (ii) the additional moisture loading and atmospheric cooling through windborne-snow sublimation at a given elevation above the snow surface partly depends on the snow mass concentration which is a strongly decreasing function of height.

The thermo-hygrometers are factory calibrated to provide relative humidity with respect to liquid water rather than to ice for the whole range of measured temperatures. Goff and Gratch (1945) formulae were then used to convert the raw sensor value into relative humidity with respect to ice (RH) for below-freezing temperatures, using the sensor temperature reports in the conversion. Converted values in excess of 100 % (Fig. S1) were attributed to the limitations of both the instruments and the conversion method and were thus capped to 100 %. Although supersaturations have been reported in Antarctica for clean, cold atmosphere devoid of condensation nuclei (e.g., Genthon et al., 2013), they are not likely to be sustained at D17 because of the relatively high temperatures and windborne snow particles providing a large number of condensation nuclei (Barral et al., 2014).

Inspection at the dataset revealed a significant proportion of occurrences (7 %) for which the lowest humidity sensor reports raw values (i.e., with respect to water) above 100 %. Such values are most likely caused by riming on the probe and/or snow occasionally trapped in the radiation shield due to its proximity with the surface where drift conditions are the most intense. After removal of these erroneous data, 16,289 six-level profiles were available for analysis.

3 Results

The evolution of the 2-m wind speed (U_2), snow mass flux integrated from 0 to 1 m above the surface (η_1) and relative humidity profiles with time during a drifting snow event recorded at D17 in May 2013 demonstrates that the near-surface air can readily become saturated in drift conditions (Fig. 1). Before the event begins, only a thin layer near the snow surface is saturated as a result of ~~surface sublimation~~either surface sublimation or a decrease in air temperature. Then, when U_2 rises above 10 m s^{-1}

triggering erosion with drifting snow fluxes rapidly exceeding 2 10^{-1} kg m^{-2} s^{-1}, saturation (RH = 100 %) is observed up to the highest measurement level in less than 3 hours. When drifting snow begins to weaken on JJ 123.25, the saturated air layer progressively thins down to the lowest measurement level during the 12 hours that follow the cessation of the event. The match in timing between the rise in the drifting snow flux and in RH up to 100 % at all measurements levels strongly suggests that windborne-snow sublimation is responsible for the development of the saturated air layer. The absence of precipitation simulated by the regional climate model MAR (Agosta et al., 2019) for the fully continental grid point including D17 over this period provides additional support to this interpretation. In this specific example a timescale of less than 3 hours is necessary for a saturated air layer to grow up to 5.5 m but inspection at the database reveals that for some events ambient saturation can even occur simultaneously to the initiation of drifting snow. Mann et al. (2000) reported similar rapid time delays (1 hour) to reach saturation up to 11 m above the ground during blowing snow episodes at Halley station.

The structure illustrated in Fig.1 is however repeated along only ~~9.6~~ 8.2 % of overall drifting snow occurrences, indicating that saturation, when attained, is most often restricted to the first ~~2 meters~~ meter above the surface (Fig. 2). On the other hand, a large majority (~~80~~ 82 %) of the profiles showing saturation at each measurement level is associated with the occurrence of drifting snow, the rest of them being most likely linked to the prolonged presence of a saturated environment during calm conditions after the cessation of drifting snow events, to atmospheric cooling and/or to maritime air intrusions during cyclonic disturbances (e.g., Gallée, 1996; Kittel et al., 2018). Considering that surface sublimation is less effective at raising the moisture content of the near-surface air than windborne-snow sublimation because of enhanced particle ventilation in drift conditions, Fig. 2 also suggests that, due to the high incidence of drifting snow at D17 (~~61.3~~ 60.1 % of the time), the occurrence of saturation is predominantly caused by windborne-snow sublimation.

Even though the development of a saturated air layer extending up to the uppermost measurement level is relatively rare, the occurrence of drifting snow and high relative humidity values are intimately related (Fig. 3). Binned average profiles of RH are shown for three classes of drift conditions of increasing magnitude, each class being sorted according to three classes of increasing wind speed. When drifting snow does not occur, a general decrease of RH with increasing wind speed is observed at all levels. This results from turbulent mixing and adiabatic warming of near-surface air with the increase in pressure as katabatic flows reach the coast (Gosink, 1989). The saturation vapour pressure of air (with respect to ice) increases strongly with temperature. As the air warms, its saturation vapour pressure increases without substantial changes in moisture content due to the absence of windborne-snow sublimation, and hence its relative humidity decreases. Only surface sublimation, and possibly residual temperature gradients in that case ~~contributes to~~ contribute to the vertical moisture gradient and ~~leads~~ lead RH to increase when approaching the surface. Contrastingly, in drift conditions a reversal is observed; windborne snow particles sublimate and lead to an increase in RH with wind speed all along the average profile, offsetting the katabatic drying effect. This increase is greatest when drifting snow is most pronounced, and the vertical gradient reduces as U_2 becomes stronger and induces more efficient ventilation and turbulent mixing. The residual gradient is then due to surface sublimation and/or vertical gradients of snow mass concentration and thus of windborne-snow sublimation. For the strongest winds speeds ($U_2 \geq 20$ m s^{-1}) associated with strong drift conditions ($\eta_1 \geq 2\ 10^{-1}$ kg m^{-2} s^{-1}), the profiles display ~~saturation~~ nearly saturated conditions up to the highest measurement level. This demonstrates that windborne-snow sublimation can be a significant contributor to the

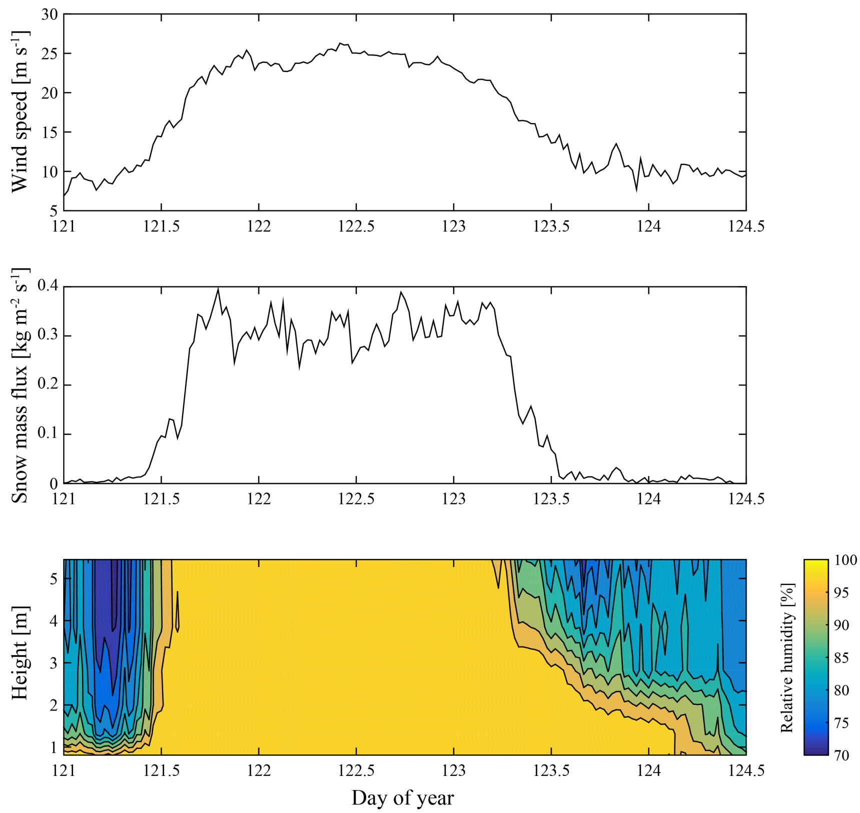

Figure 1. Timeseries of 2-m wind speed (upper panel), snow mass flux (middle panel) and contours of relative humidity with respect to saturation over ice (lower panel) showing the development of a saturated air layer during a drifting snow event in May 2013.

near-surface moisture budget at D17, whose importance increases with wind speed. ~~However, as saturation inhibiting further moisture release (i.e., the negative feedback) is systematically reached in the most extreme wind and transport conditions, the greatest contribution of windborne-snow sublimation to the total moisture flux might occur at moderate wind speeds ($U_2 < 20$ m s^{-1}) when the negative feedback mechanism does not lead to the development of a low-level saturated air layer.~~

4 Discussion

Examination of the RH profiles revealed that the air is saturated with respect to ice over the entire measurement range in only 8.2 % of the drifting snow occurrences, assuming saturation is reached when RH = 100 %. Because of instrumental inaccuracy, saturation could however occur at measured RH values below 100 %. The sensitivity of the frequency of saturation can be investigated by decreasing the threshold at which saturation is considered to occur. Accounting for an uncertainty of 3 % in the absolute value of RH as stated by the instrument manufacturer (Table 1), the occurrence of a saturated air layer along the

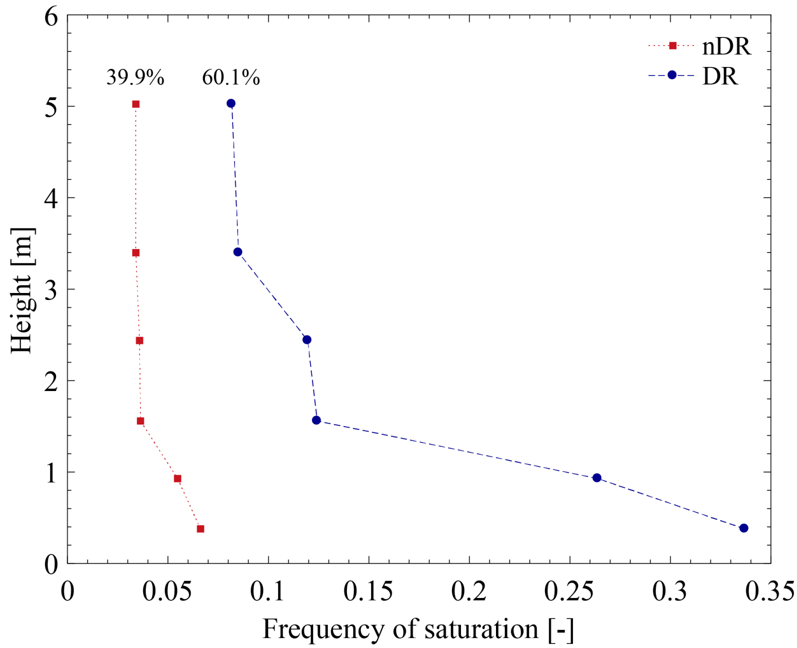

Figure 2. Frequency of saturation (RH = 100 %) at each measurement level showing that the saturated air layer that develops in drifting snow rarely exceeds 2 m in height. Profiles collected during non-drift (nDR: $\eta_1 < 10^{-3}$ kg m^{-2} s^{-1}) and drift (DR: $\eta_1 \geq 10^{-3}$ kg m^{-2} s^{-1}) conditions are treated separately, and their relative proportions are reported at the top of the corresponding curves. Note that saturation frequency values are expressed relative to the total number of profiles for non-drift or drift conditions. Yearly average instrument heights are used..

whole measurement range rises from 8.2 % to 18 % of the drifting snow occurrences if the threshold for saturation is lowered from 100 % to 97 %. This twofold increase in the frequency of saturation, globally observed for the upper 4 levels (the lowest 2 levels below 1 m are less significantly affected because of initially high frequency values – Fig. S2), still accounts for a reduced proportion of the overall drifting snow occurrences and confirms that saturation predominantly occurs within the first meter above the snow surface and remains rather infrequent compared to the regular incidence of drift conditions.

In previous efforts dedicated to the modelling of windborne-snow sublimation, the saltation layer has been regarded as saturated at all times and emphasis was primarily placed on the sublimation of suspended snow particles. Recent large-eddy simulations (Huang et al., 2016; Sharma et al., 2018) have shown from reassessments of physical starting assumptions that sublimation within the saltation layer might be of significant importance in the surface and atmospheric water budgets. In some of these simulations, sublimation within the saltation layer can even exceed sublimation of suspended particles by several orders of magnitude when effective advective transport of moisture can sustain an undersaturated environment in the immediate vicinity of the surface (Huang et al., 2016). Assuming that saturation at the lowest measurement level of 0.4 m above ground (i.e., well above the saltation layer) also implies saturation down to the surface, Fig. 2 would indicate that saturation at saltation

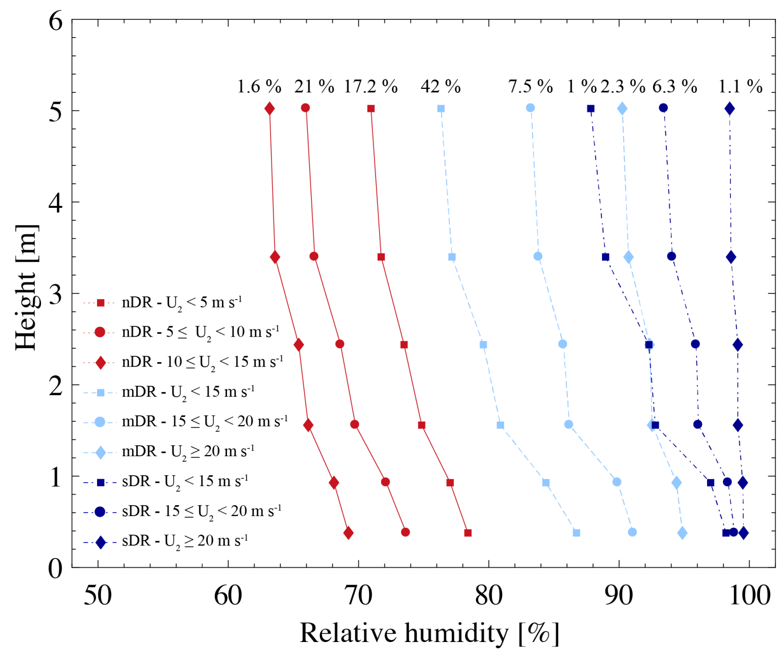

Figure 3. 30-min mean profiles of observed relative humidity (with respect to saturation over ice) averaged into bins of increasing 2-m wind speed (U_2) and discriminated using the snow mass flux (η_1) according to non-drift (nDR: $\eta_1 < 10^{-3}$ kg m^{-2} s^{-1}), moderate drift (mDR: 10^{-3} kg m^{-2} s^{-1} $\leq \eta_1 <$ 2 10^{-1} kg m^{-2} s^{-1} and strong drift (sDR: $\eta_1 \geq$ 2 10^{-1} kg m^{-2} s^{-1}) conditions. The numbers at the top of the average profiles indicate the proportion of observations used to produce each average profile. Yearly average instrument heights are used.

heights is observed in at least one third of the drifting snow occurrences, i.e. 4 times more frequently than saturated conditions at all measurement levels. In these cases, sublimation of saltating particles could indeed be ignored and only sublimation within the suspension layer would likely contribute to the surface-atmosphere moisture exchange. Similarly, limited moisture fluxes from sublimation of saltating snow could be expected in fully developed, deep blowing snow layers in which the contribution of suspension to the total column-integrated mass flux dominates over saltation.

Figure 3 demonstrates that a layer of near-saturated air inevitably develops along the whole profile in the most extreme wind and drift conditions. Similar results obtained from modelling experiments in which a blowing snow layer of 10 m depth is considered, have been used to hypothesise that total windborne-snow sublimation may be limited with strong winds and snow transport because low-level saturation occurs (Bintanja, 2001b). While both results do imply that further moisture release is inhibited in such conditions through the negative feedback of windborne-snow sublimation in a small portion of the near-surface atmosphere, it might also involve that the level of maximum sublimation is lifted to higher elevations when strong winds cause deep blowing snow layers. An important implication could thus be that, despite saturation conditions in the low-level atmosphere, the greatest contribution of windborne-snow sublimation to the total moisture flux might occur at moderate wind speeds ($U_2 <$ 20 m s^{-1}) when the negative feedback mechanism does not lead to the development of a low-level saturated air layer still occur at the highest wind speeds and associated snow transport, as near-surface sublimation is only part of the total atmospheric sublimation.

~~Examination of the RH profiles revealed that the air is saturated with respect to ice over the entire measurement range only 5.9 % of the time, indicating~~ Although the rare occurrence of ambient saturation indicates that the negative feedback effect of windborne-snow sublimation does not dominate the local moisture budget of the atmospheric boundary layer~~. This~~ , this however does not mean that the negative feedback is not at work. Rather it is more likely the result of mechanisms inherent to the katabatic and turbulent nature of the local flow that effectively remove moisture from the transport layer and prevent the formation of a near-surface saturated environment, thereby weakening the negative feedback (Bintanja, 2001b). Examples of such mechanisms are turbulent mixing within the transport layer, downward entrainment of dry air from above the katabatic layer through wind speed and directional shear and both horizontal and vertical advection of dry air through adiabatic warming of the descending katabatic flow. Note that windborne snow particles may also contribute to an increase in temperature, and then to a decrease in saturation vapour pressure in the transport layer through additional absorption of longwave radiation (Yang et al., 2014). These moisture-removal mechanisms have been considered as the physical explanation for the persistence of undersaturated air in the upper portion of deep Antarctic blowing snow layers ($>$ 100 m) revealed from dropsonde measurements (Palm et al., 2018). The influence of such mechanisms down to lower levels of the transport layer would also explain why the near-surface RH profiles are so infrequently saturated (only in the strongest wind and drift conditions) despite large snow mass fluxes and the attenuating effect due to the increase in RH caused by windborne-snow sublimation. Such mechanisms, potentially quite active in the coastal area of Adelie Land, and more generally in katabatic-generated blowing snow layers all over Antarctica (Bintanja, 2001a; Palm et al., 2018) may be very important in understanding the surface mass and atmospheric moisture budgets of the ice sheet by enhancing windborne-snow sublimation. In contrast, RH profiles collected at Halley over a flat ice shelf, therefore in the absence of a katabatic flow, suggest that the negative feedback of sublimation might locally govern the surface-atmosphere moisture flux (Mann et al., 2000), depending on the dynamical origin of the boundary-layer flow.

4 Conclusion

Meteorological profiles and drifting snow mass fluxes collected continuously during year 2013 at site D17 in coastal Adelie Land have been analysed conjointly to characterise the moistening of the near-surface atmosphere during drifting snow occurrences. In snow transport conditions occurring ~~61.3~~ 60.1 % of the time, relative humidity increases and its vertical gradient diminishes with the magnitude of drifting snow, as a result of a major source of moisture from windborne-snow sublimation in the near-surface atmospheric layer. Although saturation is ~~preferably confined below 2 metres~~preferentially confined below 1 metre likely involving saturation in the saltation layer, low-level atmospheric moistening by the sublimation of the windborne snow particles can lead to the rapid development of a saturated environment along the whole measurement range that can even coincide with the initiation of drifting snow. However, this is shown to be relatively rare (only ~~9.6 % of~~ 8.2 % of the drifting snow occurrences or ~~5.9~~ 6.3 % of the time if the RH value at which saturation is considered to be attained is taken as 100 %)

at the measurement location and mainly occurs in strong drift conditions ($\eta_1 \geq 0.2$ kg m^{-2} s^{-1}) associated with high wind speeds ($U_2 \geq 20$ m s^{-1}). The low frequency of ambient saturation despite the high incidence of drifting snow is explained by the likely existence of moisture-removal mechanisms that can counterbalance the negative feedback of sublimation by preventing the near-surface air from reaching saturation, raising windborne-snow sublimation as an important contributor to the local surface mass and atmospheric moisture budgets.

The dataset also demonstrates that the occurrence of snow transport does not necessarily involve saturation of the near-surface atmosphere, and conversely the occurrence of a saturated near-surface air layer is not systematically associated with snow transport. But during those events for which the occurrence of drifting snow (i.e., < 2 m) and a saturated air layer of several metres is concurrently reported, the height reached by the suspended snow particles, or the depth of the transport layer, likely extends beyond the uppermost measurement level (i.e., > 5.5 m). Remote sensing techniques As this possibly induces significant windborne-snow sublimation in higher atmospheric levels, contrary to previous considerations (Bintanja, 2001b) it is hypothesised that the presence of a low-level saturated air layer would not limit total atmospheric sublimation if the level of maximum sublimation in such conditions is simply moved upwards.

Combined dropsonde and satellite measurements have shown that blowing snow can frequently reach heights of 100 m or more (Palm et al., 2018). Since develop into deep layers of several hundreds of metres above the ice-sheet surface in which RH decreases with height through the depth of the layer (Palm et al., 2018), suggesting the existence of a potentially significant atmospheric mass sink through windborne-snow sublimation. However, satellite detection only captures blowing snow layers 30 m or greater in thickness during clear-sky or optically thin-cloud conditions and is limited by the satellite revisit frequency, a comparative study between satellite products and near-surface measurements . Synergistic uses of remote sensing, modelling and observation products would help to assess the proportion of missed events when surveying snow transport from space and study the conditions that lead drifting and shallow (< 30 m) blowing snow events to evolve into deep blowing snow layers. , to ultimately improve understanding of the links between snow transport and moisture dynamics and better quantify the influence of windborne-snow sublimation on the surface mass balance of the Antarctic ice sheet

Data availability. All data presented and described in this study are freely available by contacting the authors.

Author contributions. CA set up the instruments on the field, collected and processed the data, and designed the study. CA and CK wrote the manuscript.

Competing interests. The data presented in this study are freely available by contacting the authors.

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