# Review: Sensitivity of the surface energy budget to drifting snow as simulated by MAR in coastal Adelie Land, Antarctica

**General notes**

Please see our answer to R1.Q3 ("Reviewer 1, question 3") and R2.Q3. New model simulations have been computed, consequently all statistics presented in the original manuscript have undergone modifications. Please find at the end of the review the updated figures and tables. The text in the manuscript has been updated accordingly.

**Reviewer 1**

This paper examines the effects of snowdrift on Antarctica in a regional climate model with and without snowdrift physics included, and verified with local observations Adelie Land. Overall it is an interesting paper with useful results, showing that the inclusion of snowdrift physics considerably reduces the bias with observations. I recommend publication provided that the following issues are satisfactorily addressed.

We would like to thank Reviewer 1 for making a constructive review which we believe helped us improve the manuscript and more precisely the scientific discussion involving wind speed modifications.

*R1.Q1*
1. In places, the grammar is quite poor. For instance, there are many errors in the use of plural/singular. I strongly recommend to have the manuscript proofread and check by a native speaker or the like.

We apologize for the grammar errors. We carefully proofread the paper, made the necessary corrections when required, and improved the syntax.  Please find our corrections in the  track-change manuscript.

*R1.Q2*
2. In the model description section, I totally miss how snowdrift affects the momentum balance of the boundary layer. I suspect that the enhanced drag of saltating particles is included (as it should be), but is the buoyancy effect of the suspending particles also included? I recommend adding information on how the model handles these physics,since the authors do show results on wind speeds, which are interesting (see below).

Three processes drive modifications in the momentum balance when accounting for drifting snow in MAR.

Firstly, the weight of suspended snow particles (referred to as "loading" in Fig. S4 in the original manuscript), which increases the density of the air, is accounted for by including the contribution of snow particles in the computation of the potential virtual temperature (Gallée et al., 2001).

Secondly, as atmospheric sublimation contributes explicitly to the energy and mass budget of each model vertical level in which it occurs,  additional sublimation of drifting-snow particles lowers the air temperature by latent heat consumption and contributes to an increase in air density and atmospheric stability. The increase in air density enhances the along-slope pressure gradient force, and is a positive feedback in katabatic flows (Kodama et al., 1985; Gallée and Pettré 1998). A sensitivity experiment is presented in Fig. R1, following the framework detailed in R1.Q3, and demonstrates that decreased potential temperatures in MAR-DR due to sublimation-induced cooling are responsible for an increase in katabatic forcing.

Finally, the drag of saltating particles is not explicitly taken into account in the current version of the model as it is still in development for further studies (see our answer to R1.Q3 regarding modification of statements made in the original manuscript regarding this assumption). However, with the new modifications included in the drifting-snow scheme (please also refer to R1.Q3 for further details), the modeled roughness length for momentum z0 has been calibrated to reproduce the observed seasonal variation in z0, derived from wind speed profiles at D17 (Amory et al., 2020).

We suggest to add the following sentences to the model description (Sect. 2.2 in the original manuscript), after modifications related to R2.Q1:

*"Ultimately, the momentum balance of the boundary layer is mainly affected through three distinct processes when accounting for drifting snow in MAR.*

*Firstly, the increase in air density due to the weight of suspended snow, which is accounted for in the model by including the contribution of suspended snow in the computation of the potential virtual temperature (Gallée et al., 2001), is inherently amplified when eroded particles contribute to the airborne snow mass.*

*Secondly, drifting-snow sublimation and subsequent cooling of the atmosphere is computed at each model vertical level and contributes to increase air density and atmospheric stability, which enhances the along-slope pressure gradient force and is a positive feedback in katabatic flows (Kodama et al., 1985; Gallée and Pettré 1998).*

*Finally, the aerodynamic roughness length z0 is computed following a relationship previously fitted on observed z0 values  in order to take into account the seasonality of surface roughness in a drifting-snow climate as observed in Adelie Land  (Amory et al., 2020). More precisely, z0 is computed as  a function of air temperature (for temperature above -20°C) and set to a constant value of 2 10 ^-4 m representative of inland conditions (Vignon et  al., 2017) for temperatures below -20°C.''*

<u>R1.Q3</u>
3. The effects on wind speed. These are quite interesting and this should be considerably expanded. With snowdrift, wind speed reduces at the surface (due to drag of saltating particles), but increases higher up (owing to stronger cooling associated with enhanced snowdrift sublimation, and the consequent reinforced katabatic forcing). However, a detailed analysis, including a 2D framework, is lacking. Now this is mentioned casually in two sentences (lines 345-347), but this topic warrants an in-depth discussion. One possibility is to include high-level winds in a panel of Fig. 7, and add a discussion on the snowdrift-induced effects of surface drag and katabatic forcing as mentioned above. Another option is to look at the momentum budget of the boundary-layer, and evaluate the friction and buoyancy/katabatic forcing terms. This will shed more light into the (spatial, vertical) variations in e.g. wind speed changes caused by the inclusion of snowdrift.

Following your comments, a deeper and more precise analysis of the model and its core modules was led in order to identify which parameterization could modify directly or indirectly wind speed when drifting snow is activated (see our previous answer R1.Q2).

Firstly, we would like to note that the drifting-snow module should have taken into account a parameterization of the aerodynamic roughness length z0, which has been accidentally kept disabled. As  mentioned  above, this parameterization was initially developed in order to describe the seasonality of surface roughness in a drifting-snow climate as observed in Adelie Land. We refer to R1.Q2 for a detailed description of the parameterization. We consequently relaunched new simulations with the modified parameterization for z0 in the MAR-DR simulation (in addition to a correction of  the computation of sublimation rates for both simulations, see our answer to R2.Q3) and the updated results are now reported.

The corrected z0 shows little influence on the presented results and does not alter the main conclusion despite modifications of the wind speed at the lowest vertical levels of the model. Indeed former results exhibited a small decrease in mean wind speed at the lowest model level (-0.3 m/s) between MAR-DR and MAR-nDR. Such a behavior is not retrieved in the corrected runs where wind speed increases at all model vertical levels in MAR-DR compared to MAR-nDR. As z0 depends on temperature, the air temperature

cooling due to enhanced atmospheric sublimation produces lower z0 values responsible for an increase in wind speed in the lower atmosphere compared to the simulation without drifting snow. Additionally cooling of the atmosphere with drifting-snow sublimation also increases wind speed through an increase in katabatic forcing.

As a consequence, we would like to correct a sentence line 346 in the original version to specify that the consumption of turbulent kinetic energy in order to maintain snow particles in suspension was actually not explicitly taken into account. However, we would like to point out that as the z0 parameterization was calibrated on observed values in Adelie Land, including observations collected during drifting snow events, the z0 computed in the corrected results partly take into account this effect.

We suggest to modify L345-347 to:

*"This effect could be moderated at the lowest vertical model levels by surface-atmosphere interactions, such as the surface drag responsible for a decrease in wind speed"*

Identifying corresponding parameterizations that could influence wind speed and quantifying their marginal effect is a relatively complex task as wind speed is a variable resulting from the interdependence of multiple other variables called at different locations in the model routines. We agree with the reviewer's that wind speed modifications and drifting-snow influence on momentum budget would benefit further investigations. We decide here to frame further discussion on the influence of drifting-snow sublimation on changes in the katabatic pressure gradient force only. Please find below additional information we suggest to add to the supplementary material (including Fig. R2).

*"Mahrt (1982) and van den Broeke and van Lipzig (2003) propose a framework to decompose the downslope momentum budget terms along a low inclination straight slope. This strategy is well suited for studying katabatic wind regimes (e.g. van Angelen et al 2011, van den Broeke et al. 2002, van den Broeke and van Lipzig 2003) and thus the influence of drifting snow on the katabatic forcing at D17. KAT (eq. R1) designates the downslope momentum budget term related to the katabatic pressure gradient force, $\theta_0$ is the background potential temperature, g is the standard acceleration due to gravity (9.81 m s-2) and α is the slope.*

$$KAT = \frac{g}{\theta_0}\Delta_\theta sin(\alpha) \qquad Eq.\ R1$$

*KAT results from a potential temperature deficit $\Delta_\theta$ between the air potential temperature and the background potential temperature, representative of a potential temperature out of the gravity flow (Marht 1982). The latter is obtained by the usual assumption of a linear behavior of potential temperature from the free atmosphere down to the lowest model vertical level. Mean vertical profile of $\Delta_\theta$ are reported on Fig. R1 at D17.*

*Drifting-snow sublimation cools the low atmosphere and increases temperature deficits in MAR-DR. This results in an increased katabatic forcing in the computation of the momentum budget in the model, and favors increasing wind speeds in the downslope direction (Eq. R1).*
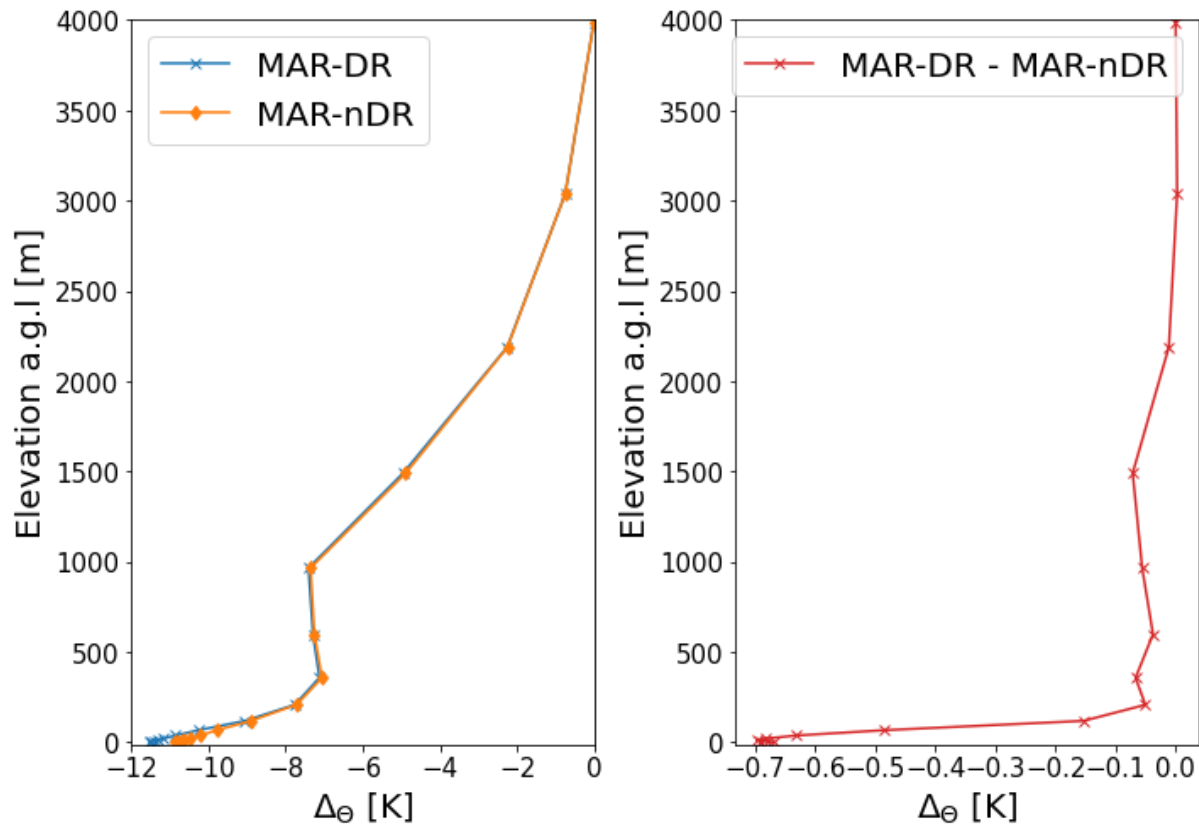


*Figure R1. Sensibility of mean$\Delta_\theta$to the drifting-snow scheme computed with half-hourly outputs between 2010 and 2019. $\Delta_\theta$ is the potential temperature perturbation due to the presence of a gravity (katabatic) flow and is calculated accordingly to van den Broeke et van Lipzig (2003).$\Delta_\theta$decreases in MAR-DR due to drifting-snow sublimation and subsequent cooling of the atmosphere, and is responsible for the enhanced katabatic forcing in the lower boundary layer."*

We would like to summarize this discussion in the main material (L340 to 347) as follow:

*"Wind speed increases in MAR-DR compared to MAR-nDR at D17 (Fig. 6 (g), (h)). The largest increases are found at the sixth and seventh vertical levels (38m and 67m), near the level experiencing maximum sublimation (fourth vertical model level, 12 m). As already suggested (e.g., Kodama et al., 1985), wind speed can increase during drifting snow events because of increased density of the air-snow mixture and an increased stable thermal stratification (Fig. 6 (a)) caused by the atmospheric sublimation-induced cooling, which is a positive feedback on a sloping surface due to the gravitational nature of katabatic winds (Bintanja, 2000). This effect could be moderated at the lowest vertical model levels by surface-atmosphere interactions, such as the surface drag responsible for*

*a decrease of the wind speed Further analysis reveals that incorporating snow particles in the calculation of the virtual potential temperature, in order to simulate the contribution of snow particles to the air density has a small impact on wind speed in MAR-DR (Fig. S4). Finally, a supplementary analysis (Fig. R2) on the sensitivity of the katabatic forcing term to the inclusion of drifting snow is proposed through a computation of the potential temperature deficit in the low-atmosphere at D17, following van den Broeke et van Lipzig (2003). Decreasing temperatures with increasing drifting-snow sublimation modify mean potential temperature in the boundary layer. Such modifications are responsible for an increase in katabatic forcing in MAR-DR.”*

Note that the spatial distribution of wind speed changes induced by drifting snow is presented in  Fig. S2 of the original manuscript. The differences that occured between MAR-DR and MAR-nDR are also retrieved at the scale of  the integration domain. Differences between MAR-DR and MAR-nDR occurring over the all integration domain are not prominent near the surface but peak higher up in the katabatic layer, in accordance with Fig. 6.

Finally, the modified wind values from the corrected runs are reported
both in the tables (Tables 1 and 2) presented in the review and in the manuscript text.

### R1.Q4
4. The changed momentum budget and wind speed feed back on the magnitude of snowdrift transport, saltation and suspension. In essence, the stronger winds in the boundary layer in the case of snowdrifts will enhance snowdrifts (sublimation, suspension), etc. This feedback is worth exploring, as it may vary in sign depending on distance to the surface; this model provides the perfect means to do so.

We followed the reviewer advices and propose to add the following complementary analysis to the main material at the end of the paragraph line 347:

*“Moreover, higher wind speeds have the potential to (i) erode more snow, (ii) advect drifting-snow particles at higher elevations in a warmer and drier environment through turbulent mixing, (iii) increase the residence time of drifting-snow particles in the atmosphere. Consequently, higher wind speeds trigger three factors that could potentially favor more atmospheric sublimation and constitute a positive feedback. We explore this feedback in Fig. R2 (a) where MAR-DR drifting-snow fluxes are computed at each model vertical level and shown as monthly averages. Additionally, we performed the same computation by replacing the wind speed with the one from the simulation MAR-nDR, which is on average lower than in the MAR-DR simulation. We aim here at quantifying the absence of the positive feedback of sublimation on wind speed and its impact on drifting-snow fluxes. Fig. R2 shows that stronger  wind speeds reinforced by additional sublimation in the MAR-DR simulation are responsible for an increase in drifting-snow*

*fluxes. Such drifting-snow fluxes are correlated with atmospheric sublimation in a logarithmic fashion (Fig. R2 (b)): higher wind speeds induce higher drifting-snow fluxes which are in turn responsible for enhanced atmospheric sublimation. Enhancement of sublimation is however limited by the self-limiting feedback of sublimation (Bintanja, 2001), the latter being dependent on the under-saturation of the ambient environment (see colorbar on Fig. 3 (b)). Ultimately, our simulations suggest that the feedback of increased wind speed on atmospheric sublimation could be all the more important at higher elevations (ex: sixth model vertical level, 37m) where the atmospheric sublimation potential is more sensitive to increases in drifting-snow fluxes due to a lower relative humidity.*
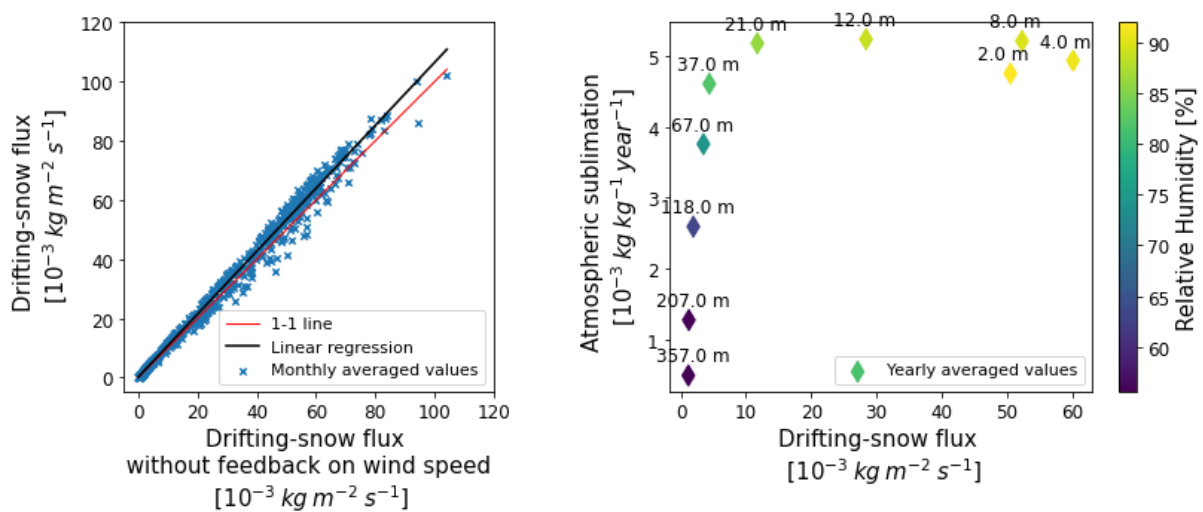


*Figure R2. (a) Comparison between drifting-snow fluxes in the atmosphere calculated in MAR-DR using usual wind speed values (y axis), or using wind speed values retrieved from the MAR-nDR simulation (x axis). The latter is done to approximate drifting-snow fluxes without accounting for the impact of drifting-snow sublimation on wind speeds. All fluxes are monthly averaged values over the period 2010-2018, computed at each of the 10 lowest model vertical levels. The black line denotes the best linear regression. Taking into account the atmospheric sublimation feedback on wind speed enhances drifting-snow fluxes.*

*(b) Atmospheric sublimation as a function of drifting-snow fluxes for the 10 first model vertical levels. Values are averaged yearly to denote the model vertical level elevation (black text). Annual atmospheric sublimation rates are expressed in kg of sublimated snow mass per kg of moist air. The colorbar indicates yearly averaged relative humidity at the considered level. Enhanced drifting-snow fluxes are responsible for increased atmospheric sublimation, until a plateau is reached. This plateau coincides with the occurrence of near-saturated environments, where additional sublimation is limited by the negative feedback of sublimation.''*

5. The comparison with other models should be greatly expanded. In section 4.3 there's a very brief discussion on RACMO, but this is insufficient. Readers would like to know in

We fully agree with the reviewer that important information can be derived from a complete model intercomparison. Referring to other simulations and other models allows one to understand how independent approaches and scientific choices can lead to converging or diverging results. As RACMO was the only regional model to date, and to our knowledge, to provide continent/region scale simulations in Antarctica on timescale close to decades with and without activating drifting snow physics, we decided to refer to the published results and model description to underline specific differences between the two models. We agree that the reader would benefit a further in depth model intercomparison (including RACMO and also other recent drifting-snow models, e.g. Luo et al., 2021) giving insights about the effect of drifting snow on both the surface and the atmosphere. But such a work should ideally be only done by comparing simulations performed under comparable conditions (e.g. same region, comparable horizontal and vertical resolution, same boundary forcing) and we believe such a work is beyond the scope of our study and would benefit a fully dedicated publication. To clarify the position of our study, we propose to delete the paragraph concerning comparisons between RACMO and MAR which is incomplete as it stands. A new section *"4.3 Current limitations"* replaces sections 4.3 and 4.4 in the original manuscript but includes a concise discussion on some key features that differ between MAR and RACMO. The new section also includes modifications relative to points raised by Reviewer 2.

*"4.3 Current limitations*

*The validity of our results is affected, among others, by uncertainties related to the absence of model evaluation concerning surface turbulent fluxes and vertical profiles (Fig. 6), the scarcity of radiative measurements in Adelie Land and the current state of development of the model.*

*The vertical profiles presented in Fig. 6 have only been evaluated at 2 m. a.g.l. therefore, the behavior of the model, and the eventual benefit of accounting for drifting snow in order to capture more realistic atmospheric dynamics in the lower atmosphere still needs to be assessed. Daily radio soundings are operated at the closeby permanent station of Dumont D'Urville. However, sufficient climatic disparity exists between D17 location, situated on the marginal slope of the Antarctic continent and Dumont d'Urville station, situated beyond the continent boundaries on an island approximately 15 kilometers*

northeast of D17. Nevertheless a good agreement with observed values for several meteorological variables (wind speed, relative humidity, temperature, drifting-snow fluxes, incoming and outgoing radiative fluxes) and the fact that the model is well constrained at its boundaries by global reanalysis is an argument in favour of firstly studying model outputs at the first vertical level and then exploring its behavior at higher altitudes. Dropsondes observations near D17 location or operation of radiosoundings from the ground near D17 would help assess model performance and uncertainties at higher elevation in complement of near-surface observations.

Modifications in downwelling atmospheric radiation, induced by the inclusion of drifting snow in MAR, are consistent with former in situ estimates (Lesins et al. 2009, Mahesh et al. 2003, Yamanouchi and Kawaguchi 1984, Yang et al. 2014) of the radiative contribution of suspended particles, suggesting the model simulates a realistic radiative forcing. However, our results might be affected, among other, by limitations in the vertical resolution of the model which does not take into account the large variations of snow particles concentration along the first 2 m of the low troposphere, and the limitations of the current radiative scheme (e.g. Delhasse et al 2020), inherited from the ERA-40 reanalysis product (Uppala et al 2005). Improved/regressed evaluation statistics when accounting for drifting snow can be linked with error compensation elsewhere in the model, independently from the ability of the model to accurately reproduce drifting-snow processes. Radiation measurements are scarce in Antarctica due to the harsh environmental conditions and the difficulty to deploy and maintain measurements sites in remote areas, thus more in situ observations of radiative fluxes and drifting-snow layer properties are needed for a more in-depth evaluation of model results and, in our case, assessment of the temporal and spatial representativity of the interactions described at site D17.

Drifting-snow sublimation, defined here by the difference in atmospheric sublimation between MAR-DR and MAR-nDR over the first 1000m above ground, equals on average 606 mm we/year on the all Adelie Land domain, with higher values reported at D17 (716 mm we/year). These rates are larger than previous in-situ estimates of drifting-snow sublimation held in distinct parts of the continent where the climate differs from the windy and (relatively warm) conditions of coastal Adelie Land. However, Palm et al 2017, through remotely sensed data, and Lenaerts and van den Broeke 2012, by using a regional climate model, report sublimation rates in Adelie Land which are more in agreement with our model estimates, though still twice to three times lower. Finally, the inclusion of newly formed clouds in MAR-DR as discussed in Sect. 2.4 can contribute to the probable overestimation of drifting-snow sublimation rates in MAR-DR. The sublimation rates, as simulated by MAR, have not been yet directly compared to in-situ measurements, although indirect comparisons have been made through the evaluation of near-surface air relative humidity and temperature. Accounting for drifting-snow sublimation in the present study has proven useful to modify the relative humidity of the

*lower atmosphere and help the model matching with observed relative humidity from a timescale of a single event (Fig. 2) to a seasonal scale (Fig. 3). The deployment of eddy-covariance systems including highly sensitive hygrometers could provide complementary atmospheric sublimation estimates to evaluate model simulations during calm to moderate conditions. However, using eddy-covariance devices during strong drifting-snow episodes remains a challenge as drifting-snow particles alter the observed signal and limit their use in Adelie Land (e.g. Bintanja, 2001). Moreover, including drifting snow in MAR shows large impacts on turbulent fluxes which compensate (and sometimes slightly override, e.g. at D17) modifications in radiative fluxes. Such a compensation also needs to be evaluated through comparison with direct in situ measurements of latent and sensible heat fluxes during drifting-snow occurrences to determine if MAR-DR simulates (more) realistic turbulent heat exchanges at the surface. Modeling hypothesis regarding drifting-snow particle distribution and subsequent sublimation rates could be better constrained using information derived from in-situ optical measurements (e.g. Naaim-Bouvet 2013)*

*Additionally, we introduced a method, based on CALIPSO observations to estimate the height of a drifting-snow layer using model outputs. This method allows us to derive an objective criterion concerning snow concentration in the atmosphere to determine the presence (or not) of a drifting-snow layer and its height, during specific meteorological conditions. This method is limited by the fact that it has only been developed for 8 years of CALIPSO observations collected near D17. Future work could focus on other locations in Antarctica to improve the determination of the snow concentration threshold by gathering more remotely sensed observations to be compared to model simulations. This could ultimately lead to an evaluation of modeled drifting-snow layer heights using CALIPSO observations on a specific test dataset. Ultimately, the use of a grounded lidar at D17 could provide complementary information concerning the vertical structure of drifting-snow layers.*

*Finally, we underline that independent modeling approaches lead sometimes to contrasted results, highlighting the uncertainty related to modeling choices. For example, energy exchange following atmospheric sublimation can be accounted for in the surface energy budget (Lenaerts and van den Broeke (2012)) or computed at every model vertical level (this study) and ultimately lead to distinct impacts of drifting snow on the simulated climate. Intercomparing drifting-snow models and related drifting-snow processes could be of a great interest for Antarctica's regional modeling community, and such a work would require simulations performed under comparable conditions* (e.g. same region, comparable horizontal and vertical resolution, same boundary forcing).

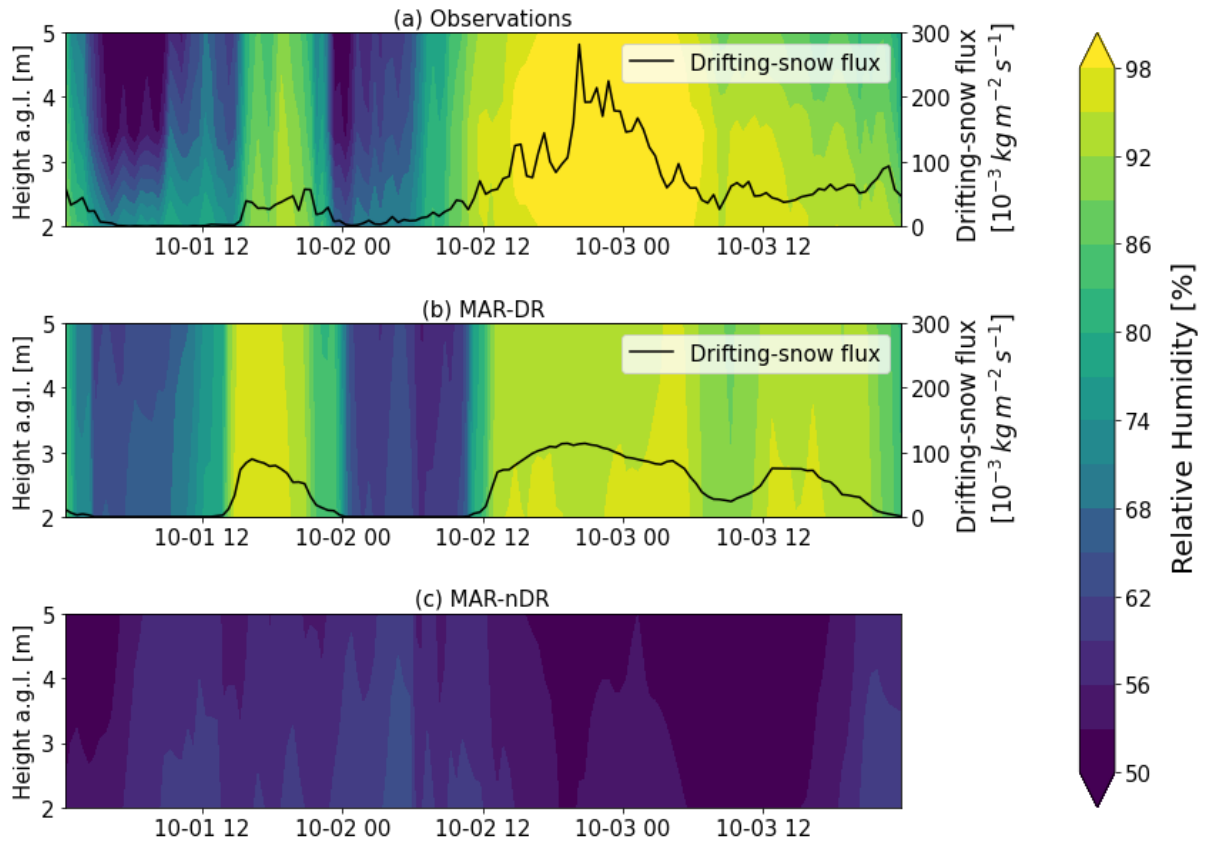## Updated figures and tables



**Figure 2.** *(a) Observed, (b) MAR-DR and (c) MAR-nDR vertical relative humidity profile (with respect to ice, color) and drifting-snow fluxes (from the surface to 2 m a.g.l., black line) between the 1st and the 3rd of October 2017.*
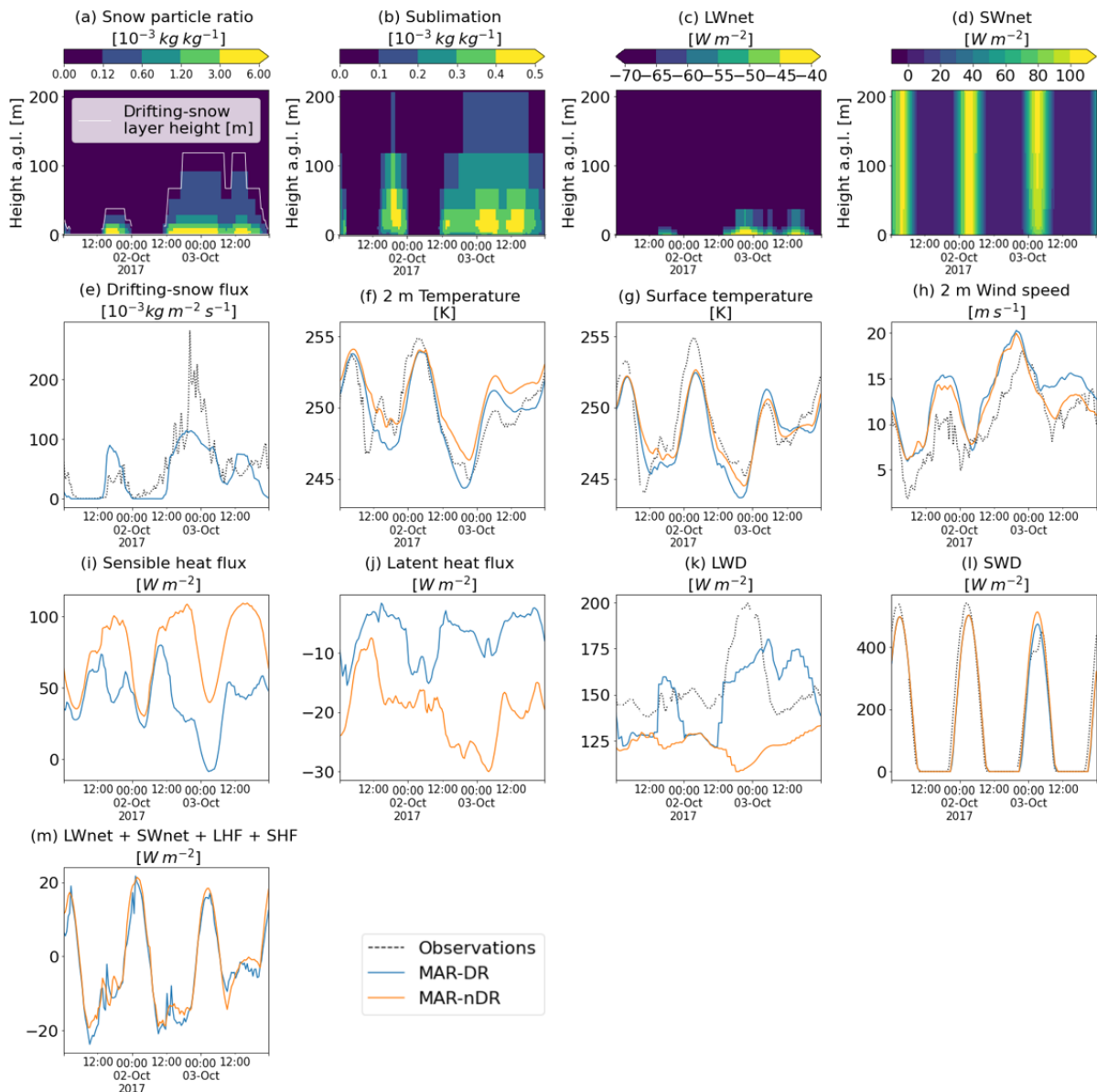
**Figure 3.** *(a) Snow particle ratio, (b) sublimation (expressed in g of sublimated snow per kg of moist air per 30 minutes), (c) SWnet and (d) LWnet vertical profiles as simulated by MAR-DR during a drifting-snow episode occurring between the 1st and the 3rd of October 2017. (e) to (m): 2 m and surface variables as observed and simulated by MAR-DR and MAR-nDR between the 1st and the 3rd of October 2017.*
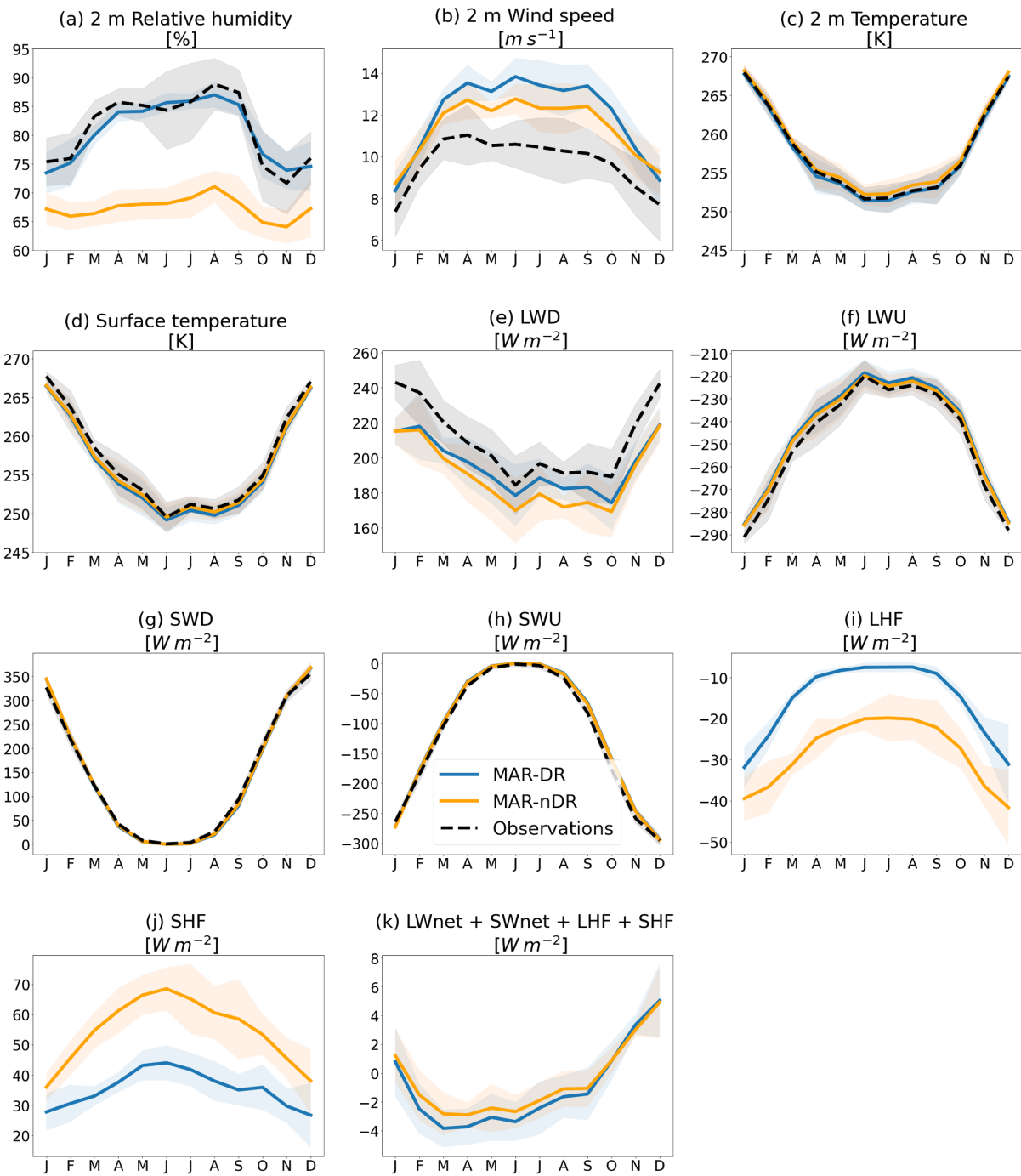
**Figure 4.** *2 m and near-surface variable monthly means as simulated by MAR-DR and MAR-nDR. First, data are aggregated by both months and years. Then means and standard deviations are evaluated within each group aggregated by month. Statistics are performed on 2014–2018 period for radiative fluxes and surface temperature and on 2010–2018 period for near-surface variables and turbulent fluxes.*
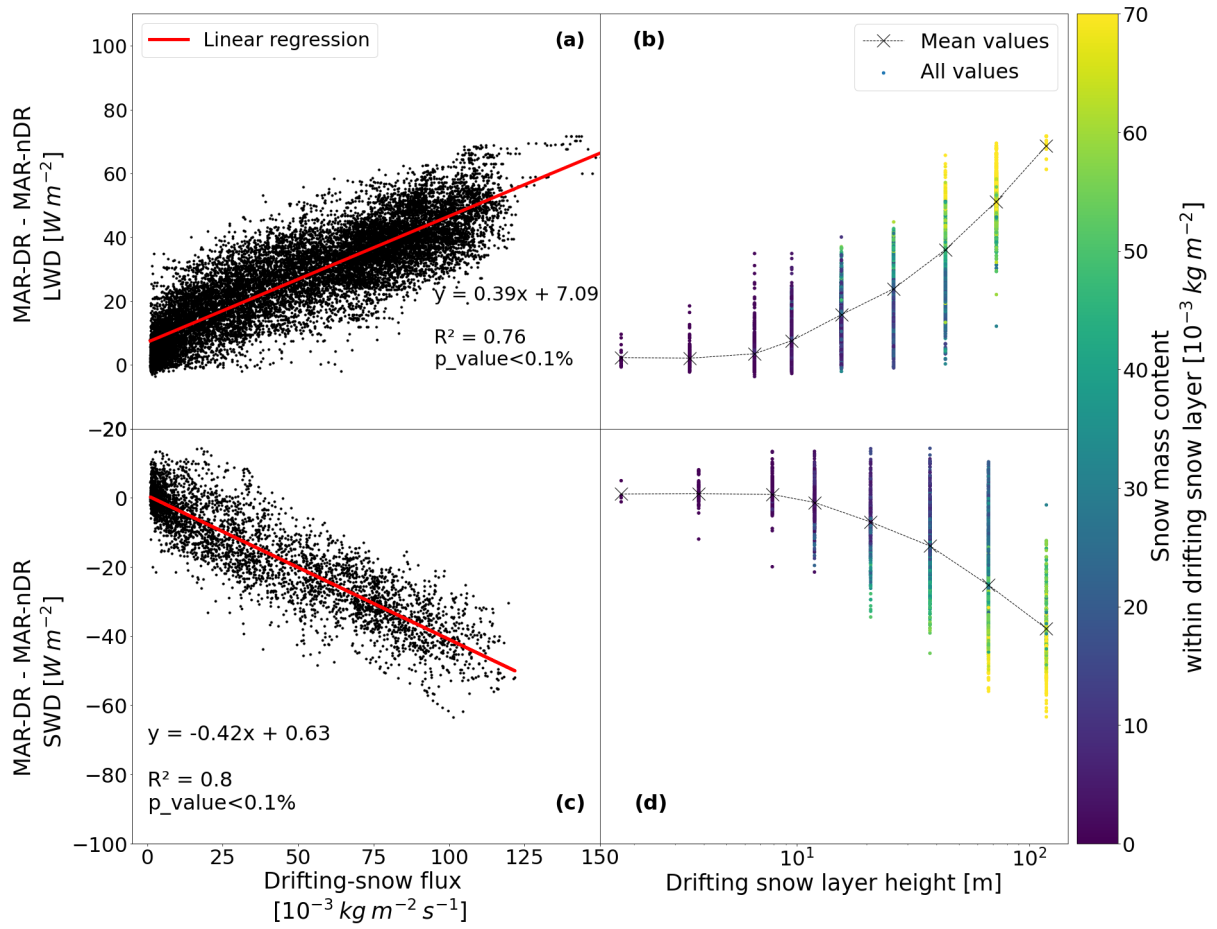
**Figure 5.** *Modifications in (a) LWD and (c) SWD between MAR-DR and MAR-nDR during drifting snow (drifting-snow flux $> 10^3 kg\,m^{-2}s^{-1}$), as a function of drifting-snow flux, for a mean flux calculated between 0 and 2m. The red line indicates the best linear regression between radiative modifications and drifting-snow fluxes. Regression functions and statistics are displayed on the corresponding panels. SWD modifications are computed when MAR-nDR simulates $SWD > 50\,Wm^{-2}$. Data are filtered according to Sect. 2.4.*

*Modifications in (b) LWD and (d) SWD between MAR-DR and MAR-nDR during drifting snow (drifting-snow flux $> 10^3 kg\,m^{-2}s^{-1}$), as a function of drifting-snow layer height. The colorbar indicates the mass of snow contained between the drifting-snow layer height and the surface. Mean values are calculated for the lowest 9 model vertical levels and are represented by a grey mark. SWD modifications are computed when MAR-nDR simulates $SWD > 50\,Wm^{-2}$. Data are filtered according to Sect. 2.4.*
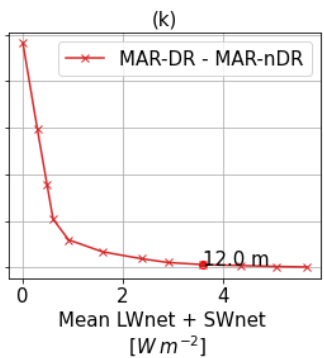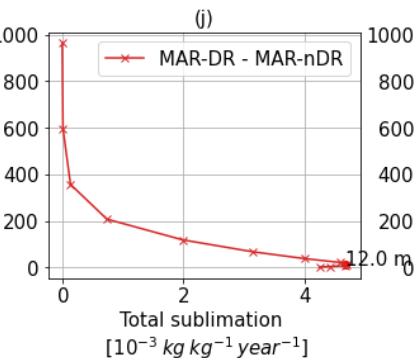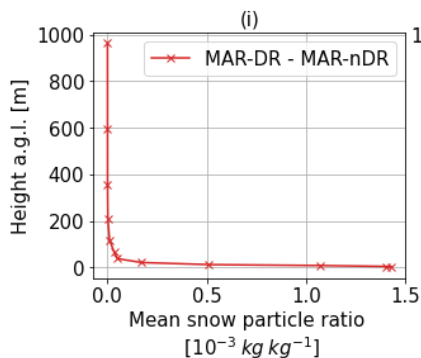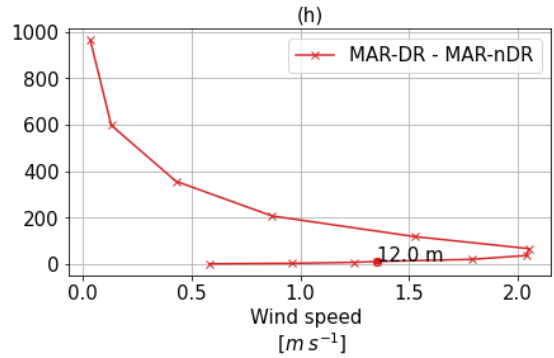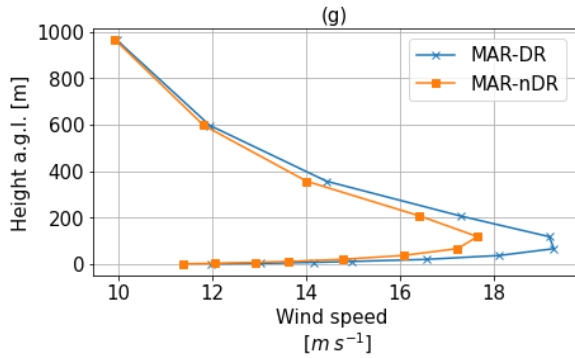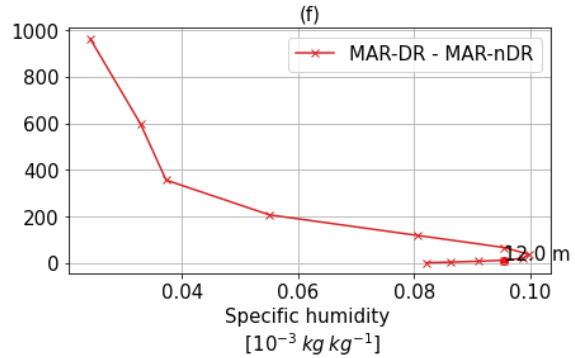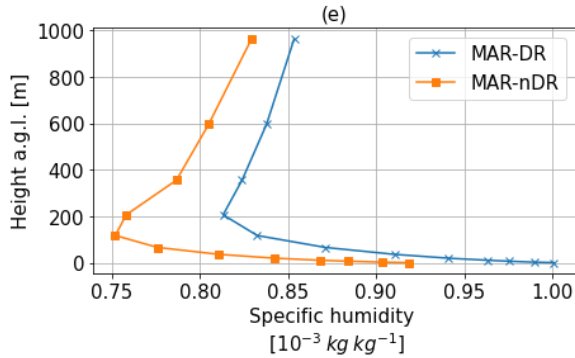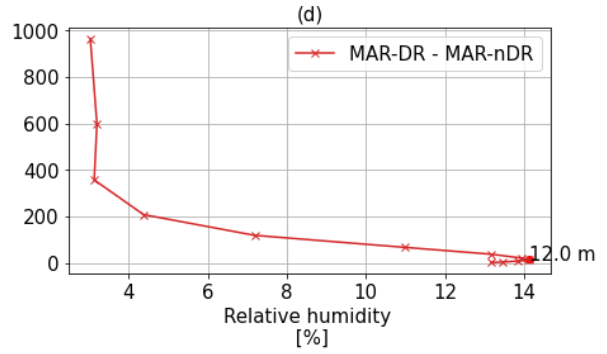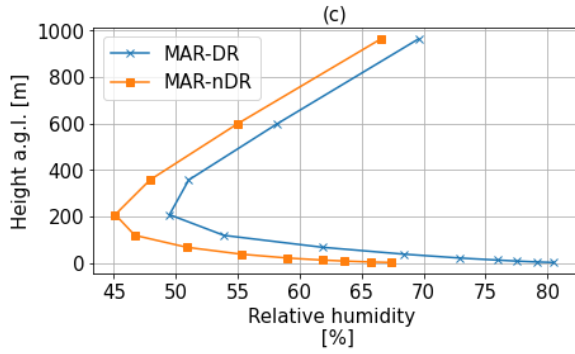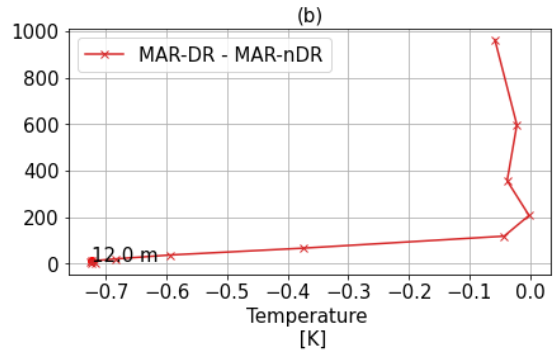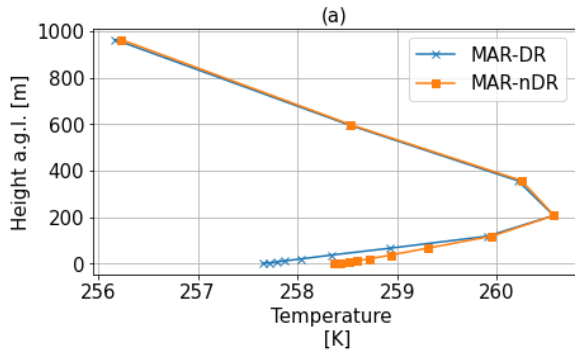
*Figure 6.* *Annual mean (2010-2018) vertical profiles for near-surface and surface variables calculated at D17 on the lowest 12 vertical levels as simulated by MAR-DR, MAR-nDR or corresponding differences between both runs. In (i), sublimation rates are expressed in g of sublimated snow per kg of moist air per year.*
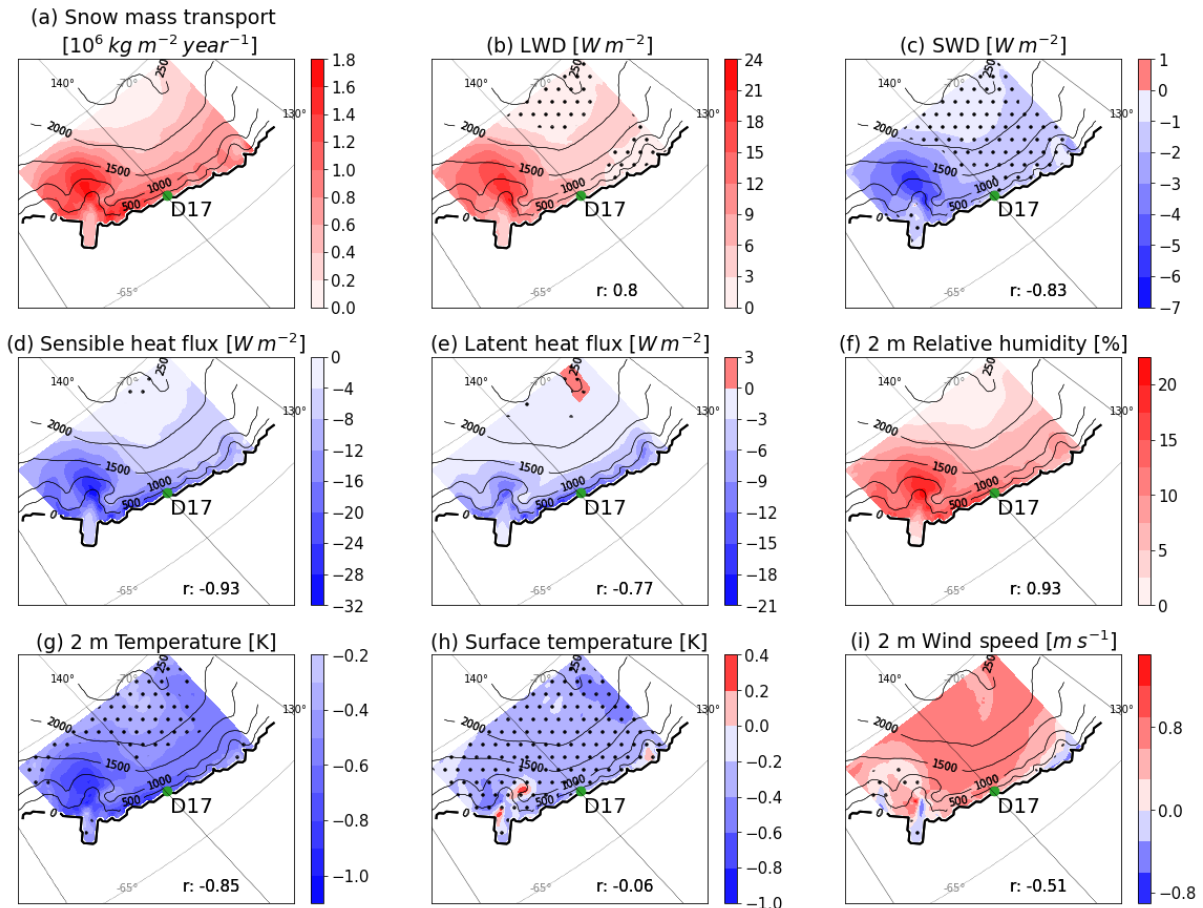


*Figure 8 (Figure 7 in the original manuscript) Annual mean (2010-2018) near-surface and surface variables modifications between MAR-DR and MAR-nDR over the integration domain. Within each panel, r indicates the Pearson correlation coefficient between the snow mass transport anomaly (a) and the considered variable (b to i). Dotted area designate areas where modifications are lower than interannual variability (taken as the standard deviation computed from annual means).*

**Table 2.** Root mean square error (RMSE), Pearson correlation coefficient and mean bias computed at D17 for MAR-DR and MAR-nDR half-hourly simulations in comparison with in situ observations.

|  | r | | RMSE | | Mean bias | |
| --- | --- | --- | --- | --- | --- | --- |
|  | MAR-DR | MAR-nDR | MAR-DR | MAR-nDR | MAR-DR | MAR-nDR |
| LWD [$Wm^{-2}$] | 0.87 | 0.89 | 19.9 | 22.8 | -14.9 | -20.4 |
| LWU [$Wm^{-2}$] | 0.97 | 0.98 | 6.5 | 5.6 | -4.0 | -2.9 |
| SWD [$Wm^{-2}$] | 0.98 | 0.98 | 24.6 | 24.2 | -1.3 | 0.3 |
| SWU [$Wm^{-2}$] | 0.98 | 0.98 | 22.4 | 22.0 | -7.0 | -5.9 |
| Surface temperature [K] | 0.97 | 0.98 | 1.7 | 1.4 | -1.0 | -0.7 |
| 2 m temperature [K] | 0.97 | 0.98 | 1.3 | 1.2 | -0.2 | 0.5 |
| 2 m wind speed [] | 0.78 | 0.82 | 3.0 | 2.5 | 2.3 | 1.7 |
| 2 m relative humidity [%] | 0.62 | 0.51 | 9.5 | 15.8 | -0.7 | -14.0 |

**Table 3.** Half-hourly mean value and standard deviation (STD) for several near-surface and surface meteorological variables computed on Adelie Land with MAR-DR and MAR-nDR. Differences between both model runs are attributed to drifting-snow processes.

|  | MAR-DR | | MAR-nDR | | \|MAR-DR\| - \|MAR-nDR\| | |
| --- | --- | --- | --- | --- | --- | --- |
|  | Mean value | STD | Mean value | STD | Mean value | STD |
| LWD [$Wm^{-2}$] | 162.4 | 22.1 | 156.3 | 20.8 | 6.1 | 1.3 |
| LWU [$Wm^{-2}$] | -205.3 | 22.2 | -206.2 | 22.2 | -0.9 | 0 |
| SWD [$Wm^{-2}$] | 142.6 | 3.4 | 144.4 | 2.8 | -1.8 | 0.6 |
| SWU [$Wm^{-2}$] | -115.4 | 2.8 | -116.0 | 2.4 | -0.6 | 0.4 |
| LHF [$Wm^{-2}$] | -2.7 | 3.0 | -5.8 | 6.2 | -3.1 | -3.2 |
| SHF [$Wm^{-2}$] | 18.1 | 4.3 | 27.0 | 8.9 | -8.9 | -4.6 |
| LWnet + SWnet + LHF + SHF [$Wm^{-2}$] | -0.3 | 0.3 | -0.2 | 0.3 | 0.1 | 0 |
| Surface temperature [K] | 244.6 | 6.7 | 244.9 | 6.7 | -0.3 | 0 |
| 2 m temperature [K] | 245.5 | 6.7 | 246.0 | 6.8 | -0.5 | -0.1 |
| 2 m wind speed [$ms^{-1}$] | 10.6 | 1.8 | 10.1 | 1.8 | 0.5 | 0 |
| 2 m relative humidity [%] | 92.1 | 3.2 | 84.9 | 6.2 | 7.2 | 3.0 |
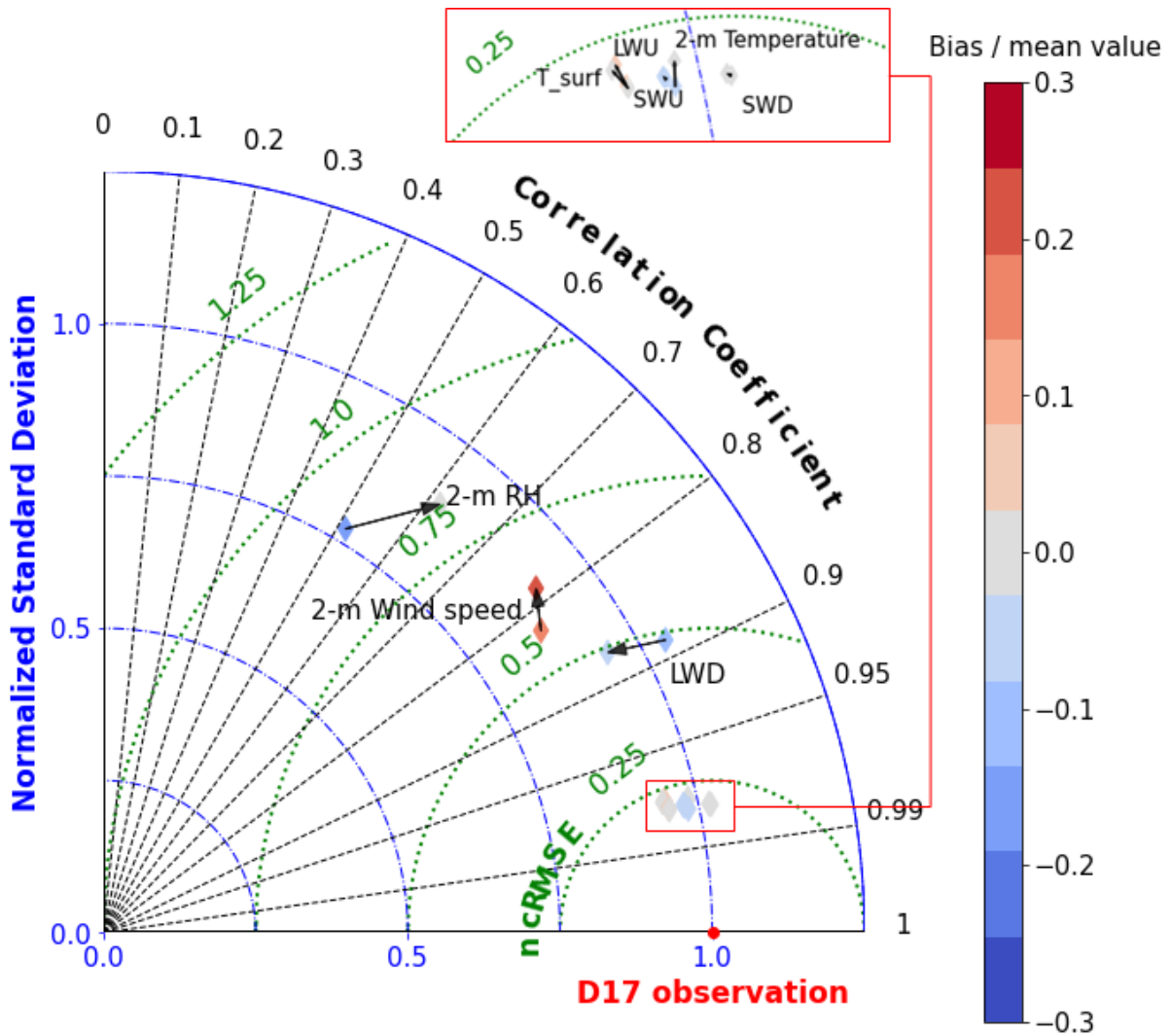
***Figure S1.*** *Taylor diagram at D17 enables visualization of modifications between simulations, using observations as a reference. The radial distance from the origin accounts for the normalized standard deviation (standard deviation of the simulated variable divided by the observed standard deviation). Correlation coefficient is represented by the angular distance from the horizontal. Normalized and centered root mean squared error (ncRMSE) is represented by a green circle centered on the red point. A simulation matching perfectly observations would stand on the red point. The colorbar indicates the mean bias divided by the mean value of observations. The arrows point from MAR-nDR simulations to MAR-DR simulations. 2 m RH designates 2 m relative humidity and T_surf designates surface temperature. Surface temperature is computed using LWD and LWU.*
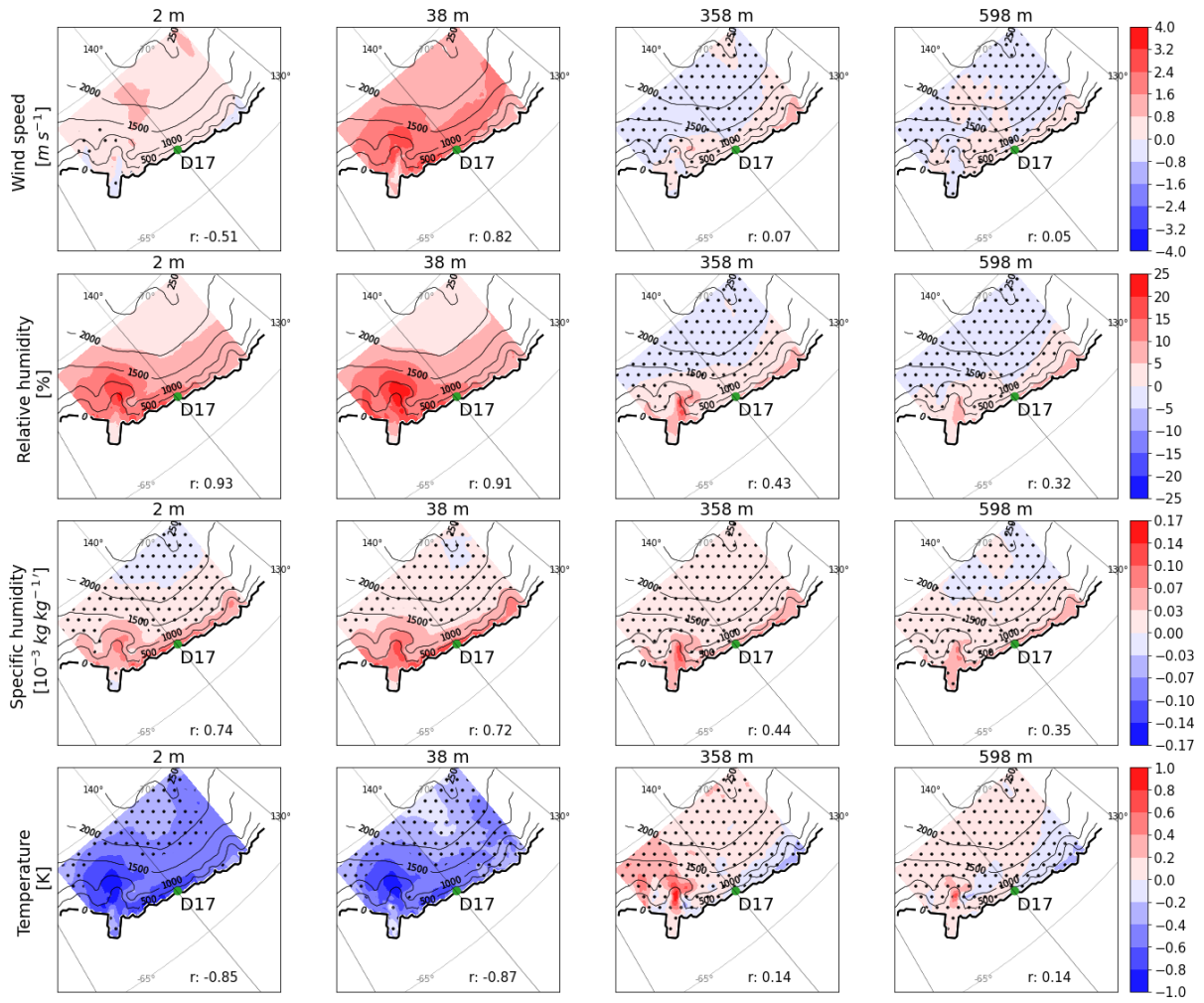
**Figure S2.** *Annual mean (2010-2018) near-surface and surface variables modifications between MAR-DR and MAR-nDR over the integration domain at different vertical levels in the low atmosphere.. Within each panel, r indicates the Pearson correlation coefficient between the snow mass transport anomaly (a) and the considered variable (b to i). Dotted area designate areas where modifications are lower than interannual variability (taken as the standard deviation computed from annual means).*
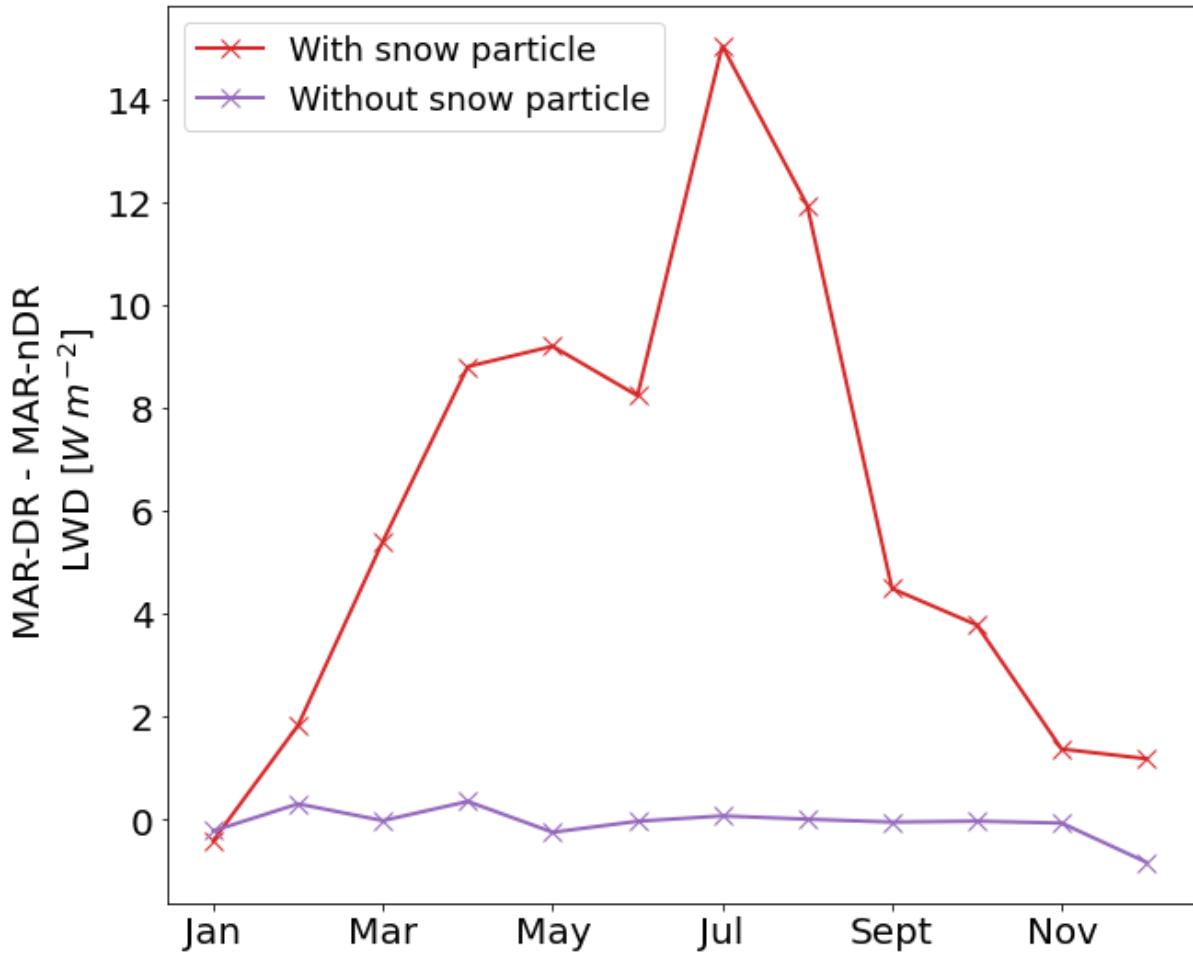
***Figure S3.*** *Time series of LWD modifications between MAR-DR and MAR-nDR at D17 for the year 2017. Two model configurations are compared here: the reference simulation, referred as "With snow particle" includes the snow particle ratio in the LWD computation, oppositely to the "Without snow particle" configuration. LWD modifications between MAR-DR and MAR-nDR are highly influenced by the presence of snow particles in the atmosphere.*
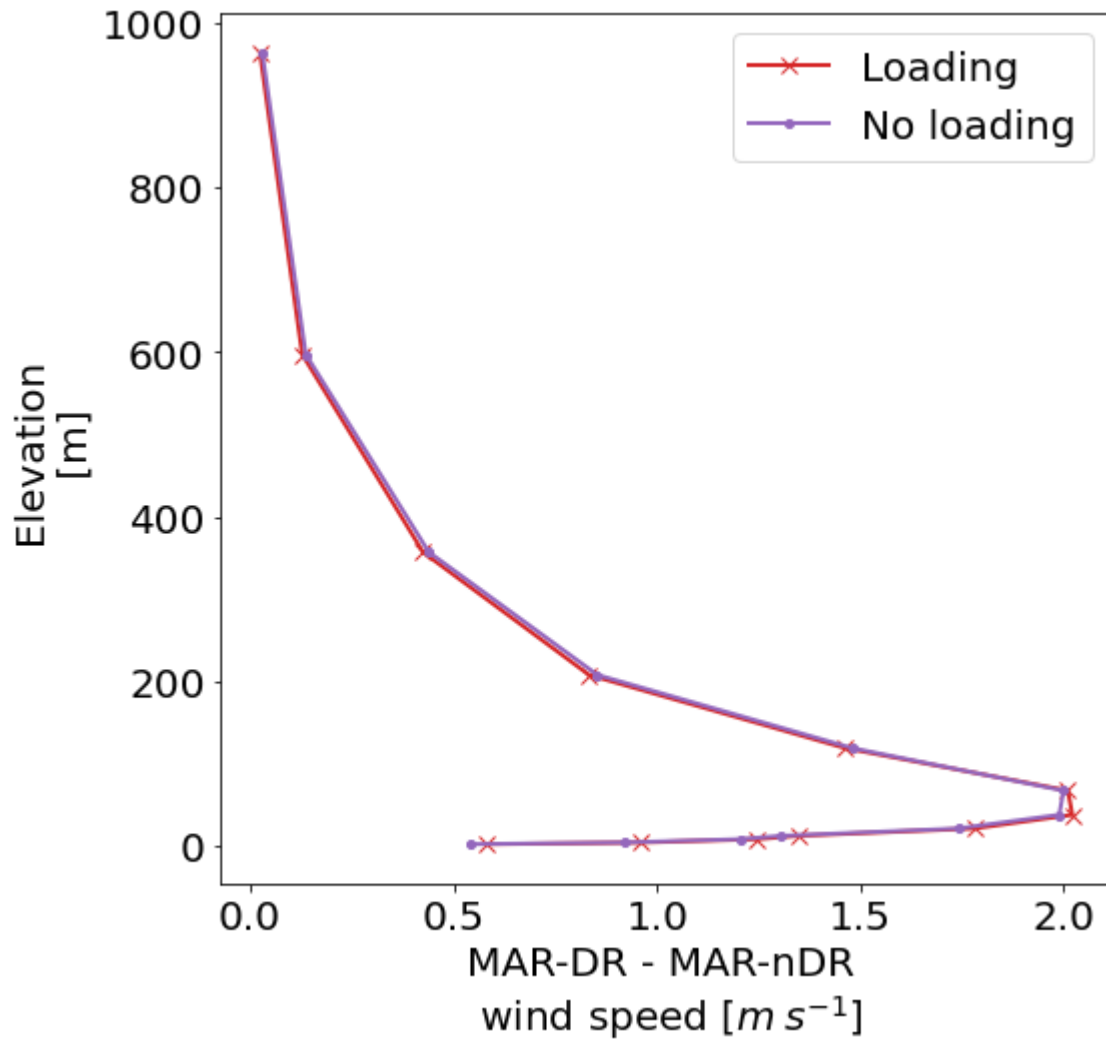
**Figure S4.** *Vertical profile of wind speed modifications between MAR-DR and MAR-nDR at D17 for the year 2017. Two model configurations are compared here: the reference simulation, referred as "Loading" includes the contribution of snow particles to air density, oppositely to the "No loading" configuration. The mass of snow particles is only responsible for limited wind speed modifications when the drifting-snow scheme is activated in MAR.*
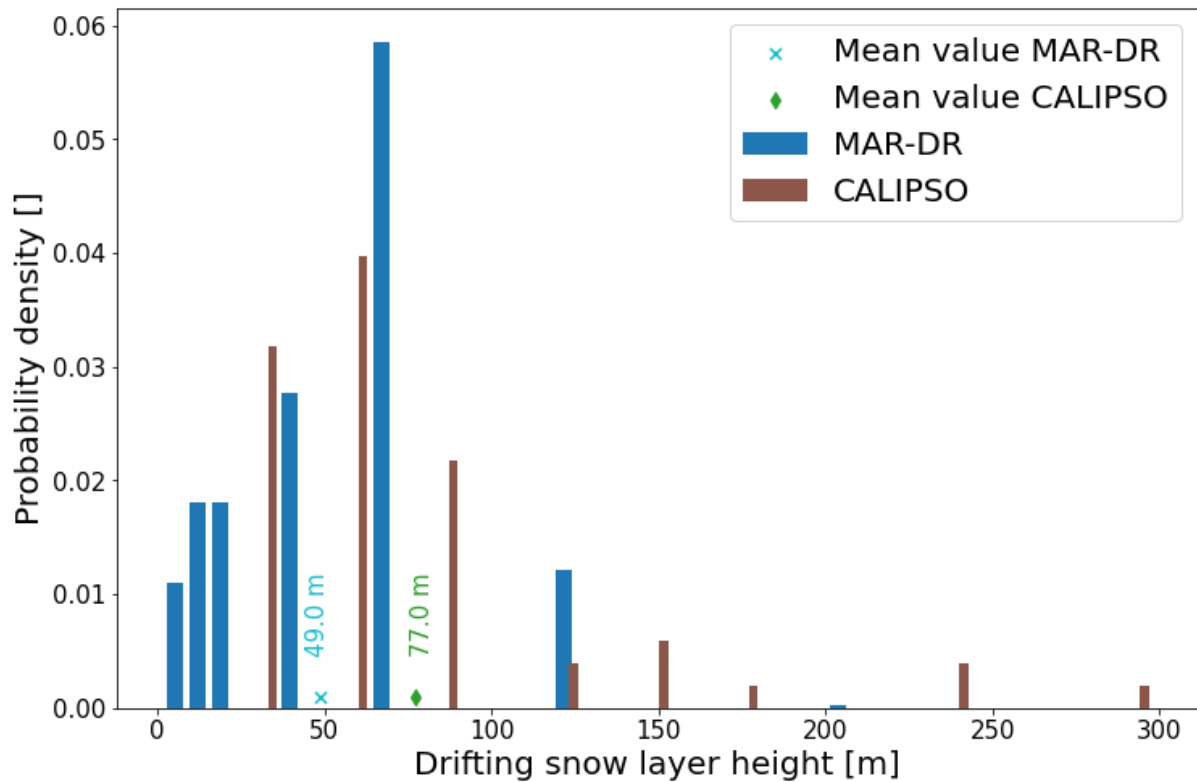
**Figure S5.** *Distribution of drifting-snow layer heights as simulated by MAR-DR (after the filtering process described in Sect. 2.4) and as observed by CALIPSO (Palm et al., 2011). The MAR-DR algorithm for detecting drifting-snow layer height is calibrated on CALIPSO observations. On the 2010–2018 period and after the filtering process, MAR-DR simulates a mean drifting-snow layer height of 49 m while CALIPSO detects for specific occurrences a mean value of 77 m*
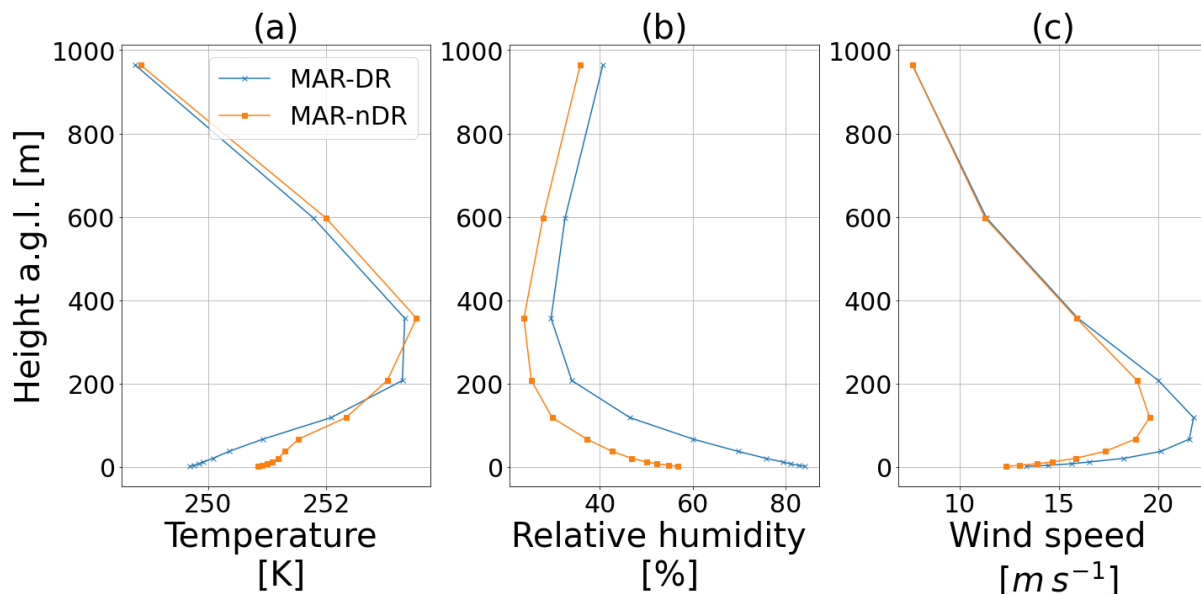


**Figure S6.** *(a) Temperature, (b) relative humidity and (c) wind speed mean profiles calculated during a drifting-snow event between the 1st and the 3rd of October 2017 at D17. Temperature variations are small in the katabatic layer ($0.017\ K\ m^{-1}$ on the first 100 m a.g.l.), relative humidity peaks near the surface, and wind speed increases with elevation in the katabatic layer*

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