Version 6, 19 December 2019

Manuscript Title: *Supercooled Liquid Water Clouds observed and analysed at the Top of the Planetary Boundary Layer above Dome C, Antarctica* **by Ricaud et al.**

RESPONSES TO THE EDITOR

→ Both reviewers requested structural changes to the paper, as well as provided line edits. The line edits were made before large passages were moved around. In response to suggestions from the reviewers, a section focused on the impact of the SLW clouds has been created as well as a Discussion section. As suggested by the reviewers, we have created a supplementary file where additional information has been inserted. Specific changes have been made in response to the reviewers' comments and are described below. The reviewers' comments are recalled in blue and changes in the revised version are highlighted in yellow. We have acknowledged the two anonymous reviewers. A sentence has been inserted in the Acknowledgements.

> `We would like to thank the two anonymous reviewers for their beneficial comments.`

Note that Figures and Table are labelled as follows:

Figs. 1-18: Figures shown in the revised manuscript
Figs. Supp1-Supp14: Figures shown in the Supplementary Materials
Figs. R1-R4: Figures only shown in the Replies to the Reviewers
Table R1: Table only shown in the Replies to the Reviewers

Anonymous Referee #1

Review of “Supercooled Liquid Water Clouds observed and analysed at the top of the Planetary Boundary Layer above Dome C, Antarctica” by Ricaud et al. (acp-2019-607)

→ Both reviewers requested structural changes to the paper, as well as provided line edits. The line edits were made before large passages were moved around. In response to suggestions from the reviewers, a section focused on the impact of the SLW clouds has been created as well as a Discussion section. As suggested by the reviewers, we have created a supplementary file where additional information has been inserted. The reviewers’ comments are recalled in blue and changes in the revised version are highlighted in yellow. In the following responses, note that Figures and Table are labelled as follows:

Figs. 1-18: Figures shown in the revised manuscript
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Table R1: Table only shown in the Replies to the Reviewers

Summary:

The paper investigates the water budget (cloud, water vapour) in relation to the thermal structure of the boundary layer at Concordia Station, Antarctica. It describes two distinct cases studies from the summer 2018-2019 campaign and highlight the impact of the misrepresentation of supercooled liquid cloud in the ARPEGE model on the surface radiative budget. This study shows that the warmer and wetter episode with cloud leads to radiative biases larger by a few tens of W m-2 than for a more typical configuration of the PBL with colder and drier conditions at “night”, when biases of 20- 30 W m-2 are already measured. The authors show that this is mainly due to the longwave part of the spectrum, and conclude on the possibly large impact of the misrepresentation of SLW layers on Antarctica’s surface energy budget.

Relevance of the paper and overall comment:

The paper presents very interesting observations of the Antarctic boundary layer, combining cloud, water vapour, and thermodynamic measurements. It clearly demonstrates large biases related to supercooled liquid water (SLW) misrepresentation using a model configuration of ARPEGE (ARPEGE-SH) zoomed in over Dome C. Interestingly, it distinguishes between two PBL regimes, showing that wetter and warmer conditions lead to even larger radiative biases, still related to a misrepresentation of the SLW. To me this dataset allows to address an important question of the link between the modelling of cloud properties (and not just the overall cloud cover) and the surface energy biases measured in Antarctica, which still remain to be 1) understood 2) corrected in NWP models. Moreover, most of the in-situ studies have mostly concentrated on coastal Antarctica so far, and in-situ observations of SLW on the continent are rarely analysed. This study is well in the scope of ACP. I am in favour of its publication in the journal provided improvements are brought to the presentation and discussion of the results. (Minor revision).

→ Thank you for your positive comments.

Main comments:

My three main points are:

1) Say how the two case studies are representative of the whole summer campaign and please better introduce first the two PBL conditions at once (see my comment on L119 – section 2) and give the synoptic scale context for both cases.

→ Based on the NCEP data sets, the temperature fields at 600 hPa above Antarctica have been investigated both during the two case studies and climatologically during the YOPP campaign (December 2018-January 2019) and over 10 years in summer (December-January) from 2009 to 2019 (Figure 1). Climatologically the Dome C station temperature at 600 hPa is less than 245 K. This is consistent with the temperature analysed on 24 December 2018 during the case study labelled as "typical". On 20 December 2018 (case study labelled as "perturbed"), warm air parcels (temperature greater than 260 K) are issued from the coast opposite in longitude (30°W) of the Dome C station creating an elongated tongue of warm air (temperature greater than 250 K) with maxima of 255 K on 21 December 2018 at 00:00 UTC above Dome C.

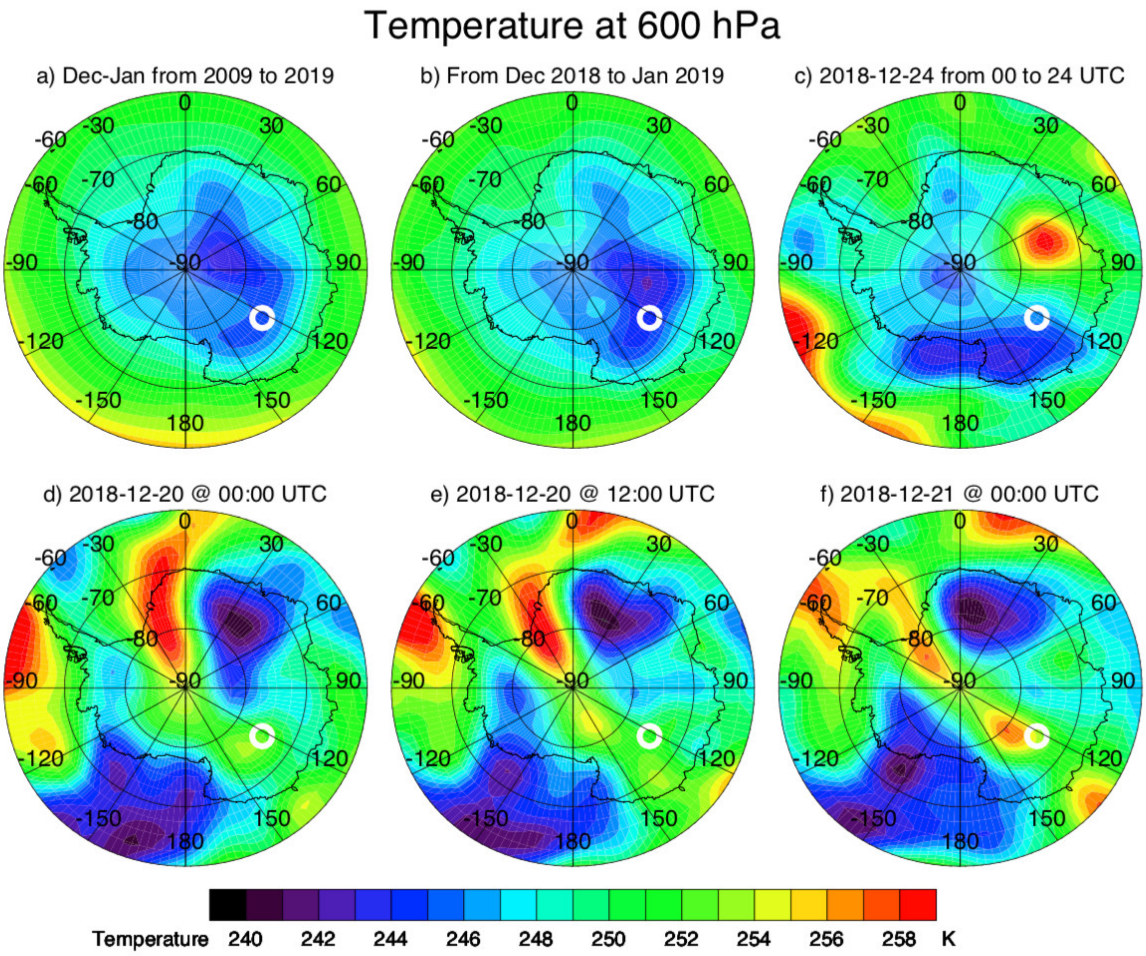

***Figure 1:** Temperature fields from NCEP at 600 hPa: a) decadal average over December-January from 2009 to 2019, b) YOPP average over December 2018-January 2019, c) daily average over 24 December 2018, d) 20 December 2018 at 00:00 UTC, e) 20 December 2018 at 12:00 UTC, and f) 21 December 2018 at 00:00 UTC. The white circle represents the position of the Dome C station.*

This is also confirmed by the calculations by HYSPLIT of 10-day back-trajectories originated from the Dome C station at 500 and 1000 m above ground level on 20 and 24 December 2018 at 12:00 UTC. Trajectories are initiated from the Antarctic continent during the typical case of 24 December 2018 whilst, during the perturbed case of 20 December 2018, they are initiated from the oceanic Antarctic Coast opposite in longitude to the Dome C station. This perturbed case brings warm and wet oceanic airmasses to the Dome C station atmosphere.

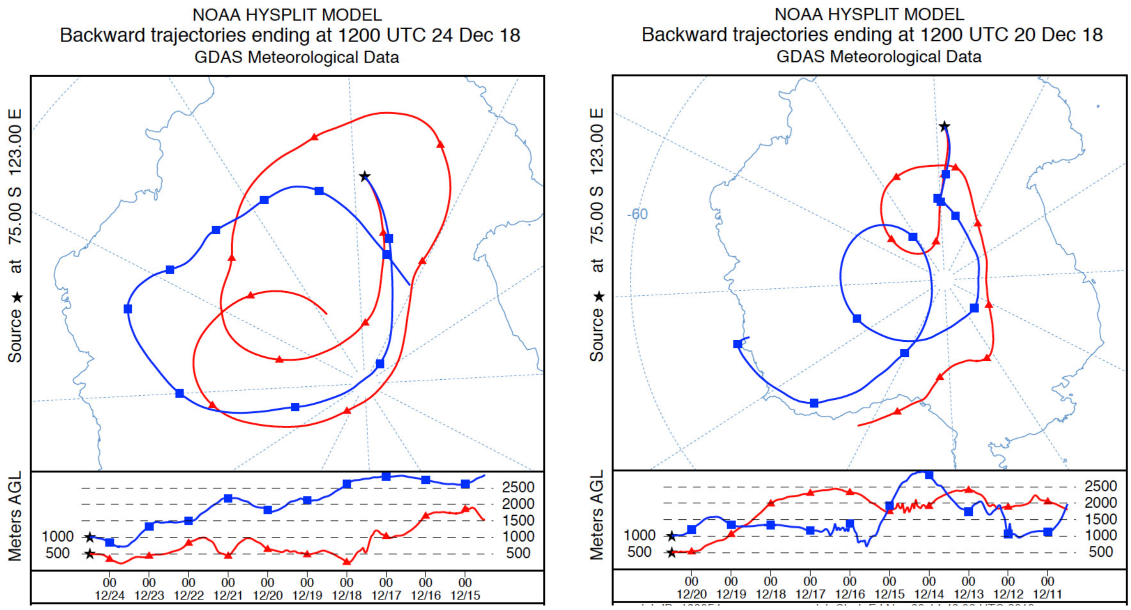

Figure Suppl1: *Ten-day backtrajectories calculated by HYSPLIT originated from the Dome C station at 500 (red) and 1000 m (blue) above ground level at 12:00 UTC on 24 December 2018 (left, typical case study) and 20 December 2018 (right, perturbed case study).*

We have inserted a new section and 2 new Figures.

3. Methodology

In this article, we present two case studies from the SOP-SH that illustrate the occurrence of low-level supercooled liquid water clouds at Dome C. Both cases occurred in December 2018, within 5 days of each other, which allows direct comparison between the cases without concerns for seasonal variations in radiation.

The first case study has been fixed on 24 December 2018 and is representative of a climatological summer atmosphere. The second case study is on 20 December 2018 when the atmosphere is very different from a climatological summer atmosphere. We have considered in Figure 1 the temperature fields from the National Centers for Environmental Prediction (NCEP) at 600 hPa to highlight the state of the atmosphere above Antarctica with a focus over the Dome C station at different periods: a) decadal average over December-January from 2009 to 2019, b) YOPP average over December 2018-January 2019, c) daily average over 24 December 2018, d) 20 December 2018 at 00:00 UTC, e) 20 December 2018 at 12:00 UTC, and f) 21 December 2018 at 00:00 UTC. The climatological summer temperature field at 600 hPa has been calculated by averaging the December and January data from 2009 to 2019 and the mean synoptic state of the YOPP campaign during the summer 2018-2019 has been calculated by averaging data from December 2018 to January 2019. The synoptic state of the first case study was selected on 24 December 2018 averaged from 00:00 to 24:00 UTC and for the second case study on 20 December 2018 at 00:00 UTC and 12:00 UTC, and on 21 December 2018 at 00:00 UTC. Firstly, the summer atmosphere during YOPP was very consistent with the decadal climatological state of the atmosphere both over Antarctica and the Dome C station (temperature less than 245 K). Secondly, the synoptic state of the atmosphere on 24 December 2018 (1st case study), although warmer (> 258 K) over some parts of the Antarctic Plateau (60°E-90°E) is, over Dome C, consistent with the YOPP summer synoptic state and the climatological summer temperatures of ~246 K. Thirdly, on 20 December 2018 (2nd case study), on tongue of warm air (254-260 K) originated from the oceanic coast in the sector 0-30°W (00:00 UTC) reaches Dome C 24 hours later with temperatures increasing from 252 to 256 K, about 10 K greater than on 24 December 2018. Ten-day back trajectories (see Figure Suppl) initiated at Dome at 500 and 1000 m above ground level are restricted to the Antarctic Plateau on 24 December 2018 (1st case study) and are originated to the oceanic coast in the sector 0-30°W on 20 December 2018 (2nd case study). This is consistent with previous studies (Ricaud et al., 2017) showing that inland-originated air masses bring cold and dry air to Dome C whilst ocean-originated air masses bring warm and wet air to Dome C.

In the following, we will label the 1st case study on 24 December 2018 as typical case and the 2nd case study as perturbed case. We will show that, in the typical case, the SLW cloud occurred over a 24-hour period that it characterized by a typical summertime, diurnal PBL cycle, where the boundary layer develops over the course of the day and the top height of the boundary layer is stable and then collapses to the surface toward the end of the day, around 12 UTC (Ricaud et al., 2012). The first case provides insight into the impact of SLW cloud layers on the local radiative fluxes. The perturbed case provides a contrasting situation where the diurnal cycle of the PBL was perturbed by the sudden arrival of very moist and warm air of oceanic origin (see Ricaud et al., 2017). We analyse how this episode affected the presence and evolution of SLW clouds and their influence on the energetic surface fluxes. Note that, in the remaining of the article, we will present the altitude above ground level (agl) unless explicitly shown as above mean sea level (amsl).

We have also introduced both NCEP and HYSPLIT data in the dataset section as follows.

2.7. The NCEP temperature fields

In order to assess the synoptic state of the atmosphere during the two case studies above Dome C against the climatological state of the atmosphere in summer over Antarctica, we have used the temperature fields at 600 hPa from the National Centers for Environmental Prediction (NCEP) from 2009 to 2019 (Kanamitsu et al., 2002). These are NCEP-Department of Energy (NCEP/DOE) Atmospheric Model Intercomparison Project (AMIP-

II) Reanalysis (Reanalysis-2) 6-hourly air temperature at 2.5°x2.5° horizontal resolution over the globe.

2.8. The HYSPLIT back-trajectories
In order to assess the origin of airmasses associated to the two case studies, ten-day back-trajectories originated from the Dome C station at 500 and 1000 m above ground level have been calculated on 20 and 24 December 2018 at 12:00 UTC from the Hybrid Single-Particle Lagrangian Integrated Trajectory model (HYSPLIT) model (Stein et al., 2015; Rolph et al., 2017) (https://www.ready.noaa.gov/HYSPLIT.php).

We inserted the following sentences in the acknowledgements.

We acknowledge the NCEP_Reanalysis 2 data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/ and the NOAA Air Resources Laboratory to have accessed the HYSPLIT model through https://www.ready.noaa.gov/HYSPLIT.php.

We inserted the following sentences in the "Data availability" section.

The NCEP data are available at https://www.esrl.noaa.gov/psd/ and the back-trajectory calculations can be performed at https://www.ready.noaa.gov/HYSPLIT.php.

We inserted the associated references.

Kanamitsu, M. W. Ebisuzaki, J. Woollen, S-K Yang, J.J. Hnilo, M. Fiorino, and G. L. Potter. NCEP-DOE AMIP-II Reanalysis (R-2), Bulletin of the American Meteorological Society, 1631-1643, Nov 2002. https://doi.org/10.1175/BAMS-83-11-1631.

Rolph, G., Stein, A., and Stunder, B., (2017). Real-time Environmental Applications and Display sYstem: READY. Environmental Modelling & Software, 95, 210-228, https://doi.org/10.1016/j.envsoft.2017.06.025.

Stein, A.F., Draxler, R.R, Rolph, G.D., Stunder, B.J.B., Cohen, M.D., and Ngan, F., (2015). NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., 96, 2059-2077, http://dx.doi.org/10.1175/BAMS-D-14-00110.1.

2) Provide with a discussion section, which is currently lacking and/or spread over section 3,4,5, in order to provide the reader with a more synthetical views of what is presented in 3 and 4, before concluding in 5.

→ A discussion section (Section 7) has been created, moving text from sections 3, 4, and 5. The discussion section is separated into 3 subsections:

7.1. SLW Clouds vs Mixed-Phase Clouds
7.2. SLW Clouds and PBL
7.3. SLW Clouds in ARPEGE-SH

For instance, you do not discuss the possible bias due to the water vapour (as GHG) vs. the one due to SLW. Given the data-to-model comparison you show, could we say that both are acting as factors biasing the modelled radiations, rather than pointing at SLW only?

→ This is a very interesting question that has not been directly investigated in the model runs. Water vapour (WV) is of course the main greenhouse gas (GHG) impacting the net radiation budget at global scale. We can argue that WV amounts above Dome C are one of the smallest values around the planet with precipitable water (vertically-integrated water vapour) of about 1-2 mm in summer and 0.5 mm in winter, to be compared to values of 1-50 cm at middle latitudes. So, we do not expect the variability of WV at Dome C to deeply impact the radiation budget. Nevertheless, we can estimate the possible impact of WV on the longwave downward surface radiation (LW↓) by considering periods of measurements when SLW clouds are observed and periods when SLW clouds are absent.

The period of 20 December 2018 (Figure 16) is probably the most suitable for this kind of analyses since prior to 12:00 UTC, all the observations show a clear sky whilst, after 13:00 UTC, our analysis tends to show the presence of a SLW cloud. On the other hand, on 24 December (Figure 9), although our analysis tends to show the presence of a SLW cloud after 09:00 UTC, the observations performed prior to 07:00 UTC highlight some high-altitude cirrus clouds. Consequently, we will only consider the measurements on 20 December 2018.

In the presence of SLW clouds after 13:00 UTC, the difference (BSRN − ARPEGE-SH) between the LW↓ surface radiations from BSRN and ARPEGE-SH is ranging 60-100 W m^{-2} whilst, before 12:00 UTC (no SLW clouds), the difference is only about 10 W m^{-2}.

Table R1. *Differences between observations and ARPEGE-SH on IWV, LWP and Net Surface Radiation on 20 December 2018 at 14:00 and 20:00 UTC and on 24 December 2018 at 14:00 UTC.*

	20 Dec 14:00 UTC	20 Dec 20:00 UTC	24 Dec 14:00 UTC
Obs-Arp IWV (kg m^{-2})	1.4	0,5	0.02
Obs-Arp LWP (g m^{-2})	50	20	2.6
Obs-Arp Net Surf Rad (W m^{-2})	70	40	-20

We understand that it is difficult to be sure that the bias is mainly due to the absence of SLW. However, if we compare for both cases (Figures 3 and 12 and Table R1), the bias on the net surface radiation and the underestimation of IWV and LWP, we can think that probably LWP has more impact than the IWV on LW↓ due to the small quantities of specific humidity at Dome C. We thus agree to discuss this point.

Furthermore, the tests performed with ARPEGE-SH considering a new ice partition function more favourable in producing liquid water at temperature less than -20°C give more insight on this topic since SLW clouds can be estimated by ARPEGE-SH in this test mode, and surface net radiations on 24 December from the model are very consistent with those from observations.

Nevertheless, on 20 December 2018, the surface net radiations from the model in test mode still differ from observations (see also Replies to the Reviewers#2).

Please discuss the fact that the model shows even larger biases in the perturbed (warmer and wetter) case. Is this because the wetter environment allows for a thicker SLW layer to form (hence larger LWP values) and/or also because larger water vapour biases are measured that day? A discussion should compare both case studies.

→ The new Figure 12 (see Replies to the Reviewer#2), with the different forecasts, shows almost no improvement with the analysis especially at 12:00 or 18:00 UTC for the IWV bias, the increase of the humidity (probably large-scale advection) seems not well captured by ARPEGE-SH. The 4Dvar analysis is not able to correct the dry bias especially during the case of 20 December 2018. We have mentioned this point in the Discussion section (7.3 SLW Clouds in ARPEGE-SH).

Can the vertical resolution of the model be responsible for the poor modelling of SLW through failure of simulating enough supersaturation and the right PBL structure? (one would expect higher vertical resolution to allow to better simulate temperature and supersaturation, for instance).

→ The partition function between liquid and ice for cloud condensate is given as a function of temperature in the model (see the Figure Supp8 in replies to the comments of the Reviewer#2). For temperature below -20°C, all the cloud condensate is in the form of ice whatever the vertical resolution of the model. The vertical resolution of the model may indeed impact the total cloud water (liquid + ice), consequently ice, but not SLW.

Are there any comments to make regarding instrumental/observations biases from the LIDAR and/or the HAMSTRAD instrument that could somehow affect the conclusions of the study? For instance, the fact that HAMSTRAD is measuring non- null LWP will LIDAR is not seeing any SLW layer in the first case study is interesting. Can the radiometer-derived LWP be biased somehow for instance when large particles of ice precipitate below the SLW layer? (Is this answered in a previous paper e.g. Ricaud et al. 2010b)

→ As clarified in the revised version (see section 2.1 of the replies to the reviewer#2), the LWP observations performed at the Pic du Midi were the first ever published in Ricaud et al. (2010a) and were not validated (not presented in Ricaud et al., 2010b) because we were not expecting to observe liquid water in Antarctica. Consequently, the HAMSTRAD LWP data presented in the present article are qualitatively compared to an external data set (namely LIDAR) for the first time. We cannot rule out some biases in the HAMSTRAD observations as for instance non-null LWP when the LIDAR does not detect SLW. As the reviewer states, these biases might be related to differences in the observation wavelengths employed (submicrons for the LIDAR and microwaves for HAMSTRAD) that could favour large particles (HAMSTRAD) against thin particles (LIDAR). Biases might also be due to the observing geometry that differs between the LIDAR (zenith viewing) and HAMSTRAD (atmospheric scan at different elevations from zenith to ~3° elevation). We have addressed this point in the discussion section that is also presented in the responses to the reviewer#2.

Also, have the authors tried to change some settings in ARPEGE in order to allow for more SLW simulation to happen? Is the model not representing SLW because it converts all the vapour into ice or is this rather that it does not even capture the water vapour right? Or both? What can be discussed regarding that matter by comparing both case studies' simulations?

→ We have performed a sensitivity test with ARPEGE-SH by modifying the ice partition function. A long discussion is detailed both in the Replies to the Reviewer#2 and in the revised manuscript (section 7.3 SLW Clouds in ARPEGE-SH). It might also be that the partition function depends on the concentration of aerosols and some additional and long-lasting tunings in the microphysical scheme will thus be necessary.

Would you say the radiation biases spotted for the two case studies are representative of the biases for the entire campaign?

→ We have not considered the analyses of the radiation during the 2-month campaign in line with the observation of the SLW clouds. This is an interesting question that will be treated in a forthcoming analysis and hopefully in a forthcoming paper more focussed on a climatological analysis of SLW clouds and their impact on surface radiations.

I was also wondering whether you were seeing any aerosol with the lidar that could impact the SW radiations, and that would not be considered in the model?

→ For another study (not yet published) on the stable boundary layer at Dome C (GABLS4), some sensitivity tests have been performed with and without the operational profile of aerosols used in ARPEGE. The impact on the atmospheric state (humidity, temperature and winds) was very small. However, during GABLS4, the sky was rather clear with limited interactions between aerosols and clouds.

3) I recommend to reorganise a little bit the paper by:

- introducing a Method subsection in 2. where you present both types of PBL cases and justify why these two are of particular interest (e.g. representative of most of the campaign?) and give the larger – synoptic – scale context (see comment about L119)

→ Section 2 has been renamed to "Datasets", a new section "3. Methodology" has been created to describe the case studies and motivate their selection.

- moving both radiation subsections together in separate (sub)section after the descriptions of both case studies in terms of cloud, temperature, water vapour etc. (see my comment of Line 350 - section 3.4.). In doing so, the main and final aspects of this study (the effect of SLW on radiation budget) would come at once, at the end of the results section. Both Figures 9 and 16 are very interesting and showing pictures of the cloud cover at the same time is a very good idea.

→ These sections were moved into a new section, section 6 (6. Impact of SLW Clouds on Net Surface Radiation), with a subsection for each case study.

- adding a discussion section (cf point 2. above)

→ We added a discussion section, section 7 (see above -point 2 - for the subsections).

Line by line comments:

Title – I would rather say Supercooled liquid "layers" (not "clouds") as the examples shown here appear more to be mixed-phase clouds (SLW layer + ice in/below the layer). (see e.g. my comment to L392-393)

→ This is an interesting comment. We have analysed in more detail the LIDAR observations and we have shown that the clouds observed were SLW clouds and not mixed-phase clouds. (see discussion 7. 7.1. SLW vs Mixed-Phase Clouds and point 4 below). Consequently, we did not change the term SLW cloud in the revised manuscript and have kept the title the same.

Abstract

L39 –I would start the sentence with "The second case study takes place on..."

→ The recommended change has been made.

L42 and L44 – Since you already said at L31 what you define by a "typical" PBL you do not need these quotation marks here, I think.

→ The quotation marks have been removed.

L46-48 – I am not convinced by this sentence which is very general compared to the text above and suggests that SLW is absent from all NWPs model over Antarctica, which might to some extent be true, but still this is not shown in the present paper. The verb "indicate" is also not very clear. I would suggest to rewrite this sentence by simply stating that the correct modelling of SLW layers appears crucial to achieve the correct representation of the surface energy budget of the polar atmosphere on the continent.

→ The last sentence of the abstract was changed following the reviewer's suggestion to:

> Accurately modelling the presence of SLW cloud layers appears crucial to correctly simulate the surface energy budget over the Antarctic Plateau.

1. Introduction

L58 – There are other papers to cite here:

- the Bromwich et al. 2012 cited above

→ this has been inserted.

Listowski, C., Delanoë, J., Kirchgaessner, A., Lachlan-Cope, T., and King, J.: Antarctic clouds, supercooled liquid water and mixed phase, investigated with DARDAR: geographical and seasonal variations, Atmos. Chem. Phys., 19, 6771–6808, https://doi.org/10.5194/acp-19-6771-2019, 2019.

→ This reference was added after the Bromwich paper. It was already incorporated in the paragraph after (L68). It was previously cited as Listowski et al. 2018 (in review). We have updated the reference to above.

L59 – “(<30%)”: This is what Adhikari et al. say in their abstract but please note in winter, when the cloud cover increases over the Plateau, it is more than 30% over at least half of the Plateau (in all of the studies cited above). However, it is indeed less than 30% almost year-round in the area where Dome C sits. You may then want to rephrase a little bit the sentence here.

→The sentence was rewritten as follows, based on the information shown in figure 4 of Adhikari et al. (2012):

> Based on spaceborne observations, Adhikari et al. (2012) observed that low-level cloud occurrence over the Antarctic Plateau is consistently between 20-50% with the highest values occurring in winter and the lowest values consistently occurring over the Eastern Antarctic Plateau.

L63: “...near the coast (Listowski et al. 2019)” Their paper demonstrate this using satellite observations.

→ The Listowski et al. (2019) reference was added as suggested.

L65-66 – The whole Antarctic region, not only the continent I think.

→ This sentence was modified to:

> The time and geographical distribution of tropospheric clouds over the Antarctic region has been recently studied using the raDAR/liDAR-MASK (DARDAR) spaceborne products (Listowski et al., 2019).

L61 – “Some measurements exist”: Yes, and papers that are lacking from the current bibliography investigated the microphysical properties and provided new constraints to modelling. They should be cited here. These are papers dealing with the analysis of airborne measurements:

> Grosvenor, D. P., Choularton, T. W., Lachlan-Cope, T., Gallagher, M. W., Crosier, J., Bower, K. N., Ladkin, R. S., and Dorsey, J. R.: In-situ aircraft observations of ice concentrations within clouds over the Antarctic Peninsula and Larsen Ice Shelf, Atmos. Chem. Phys., 12, 11275–11294, https://doi.org/10.5194/acp-12-11275- 2012, 2012.

→ This reference has been added to the article.

> Lachlan-Cope, T., Listowski, C., and O’Shea, S.: The mi-crophysics of clouds over the Antarctic Peninsula – Part 1: Observations, Atmos. Chem. Phys., 16, 15605–15617, https://doi.org/10.5194/acp-16-15605-2016, 2016.

→ This reference has been added to the article.

O'Shea, S. J., Choularton, T. W., Flynn, M., Bower, K. N., Gallagher, M., Crosier, J., Williams, P., Crawford, I., Fleming, Z. L., Listowski, C., Kirchgaessner, A., Ladkin, R. S., and Lachlan-Cope, T.: In situ measurements of cloud microphysics and aerosol over coastal Antarctica during the MAC campaign, Atmos. Chem. Phys., 17, 13049–13070, https://doi.org/10.5194/acp-17-13049-2017, 2017.

→ The Grosvenor et al. (2012) and Lachlan-Cope et al. (2016) papers describe in situ observations over the Western Antarctic Peninsula, while the O'Shea et al. (2017) one focuses on flights over the Weddell Sea, providing insight into ice particle concentration and sizes, as well as formation mechanism. The passage was modified to read:

Nevertheless, some in situ aircraft measurements exist particularly over the Western Antarctic Peninsula (Grosvenor et al., 2012; Lachlan et al., 2016) and nearby coastal areas (O'Shea et al., 2017) that provide ice mass fraction, concentration and particle size relative to cloud temperature, cloud type and formation mechanism which have provided new insights to polar cloud modelling. These studies also highlighted sea-ice production of ice-condensation nuclei, which is important in winter both coastally and at Dome C (Legrand et al., 2016).

Also note that Grazioli et al. (2017) observed microphysical properties and shapes of precipitating crystals at DDU (aggregates, rimed particles etc):

Grazioli, J., Madeleine, J.-B., Gallée, H., Forbes, R. M., Genthon, C., Krinner, G., and Berne, A.: Katabatic winds diminish precipitation contribution to the Antarctic ice mass balance, P. Natl. Acad. Sci. USA, 114, 1858–10863, https://doi.org/10.1073/pnas.1707633114, 2017b.

→ The Grazioli et al. (2017) PNAS paper focuses on the snow precipitation that is sublimated due to interaction with katabatic winds. We therefore assume that the reviewer meant the Grazioli et al. (2017) Crysophere paper which combined radar, precipitation gauge and multi-angle camera to observe precipitation characteristics at DDU. This paper is now included in the article as follows:

Additionally, Grazioli et al. (2017) observed precipitating crystal characteristics at Dumont d'Urville using a combination of ground-based radars and in situ cameras and precipitation sensors and looked at the role that the katabatic winds play in the formation, modification and sublimation of ice crystals.

Grazioli, J. and Genthon, C. and Boudevillain, B. and Duran-Alarcon, C. and Del Guasta, M. and Madeleine, J.-B. and Berne, A.: Measurements of precipitation in Dumont d'Urville, Adelie Land, East Antarctica, The Cryosphere, 11(4), 1797-1811, 2017.

L74 – It is also or rather King et al. 2015 that should be cited here, where the authors show the large radiative biases in three high-resolution models and hypothesize the link with the lack of simulated SLW by showing the little liquid amounts formed by these models.

> King, J. C., Gadian, A., Kirchgaessner, A., Kuipers Munneke, P., Lachlan-Cope, T. A., Orr, A., Reijmer, C., Broeke, M. R., van Wessem, J. M., and Weeks, M.: Validation of the summertime surface energy budget of Larsen C Ice Shelf (Antarctica) as represented in three high-resolution atmospheric models, J. Geophys. Res.-Atmos., 120, 1335–1347, https://doi.org/10.1002/2014JD022604, 2015.

→ This reference has been added. The old reference has been kept due to relevance of study area.

A recent study that should appear in the introduction used the above-mentioned aircraft measurements to specifically show the link between poor/better SLW modelling and poor/better radiation modelling at the surface:

> Listowski, C. and Lachlan-Cope, T.: The microphysics of clouds over the Antarctic Peninsula – Part 2: modelling aspects within Polar WRF, Atmos. Chem. Phys., 17, 10195–10221, https://doi.org/10.5194/acp-17-10195-2017, 2017.

→ This paper has been added to the references in this portion of the paper.

These studies above, that deal more with a coastal environment stress even more the importance of the findings of the present paper, which address the continental environment, which has been less investigated so far with respect to links between SLW modelling and radiation biases.

→ Thank you. We added the following sentence to emphasize this point.

> In the present study, we explore these biases further, moving the focus to the modelling and simultaneous observations of low-level supercooled liquid clouds and surface radiation over the Eastern Antarctic Plateau, specifically at Dome C.

You should also say here that Lawson and Gettelman (2014) conducted a study of SLW observations on the Plateau at South Pole with a MPL. However, if they did look at the radiation changes at the surface by changing some model parameters to simulate more SLW in their model, they did not analyse simultaneous radiation measurement I think (please double-check). You are doing this and this is a big plus of your study compared to theirs in terms of ground-truth radiation budget investigation (and you could emphasise this in your introduction).

→ Lawson and Gettelman (2014) focus on mixed-phase and all-ice clouds, modelling locally with a single-column model and regionally with GCMs. They do not mention simultaneous radiation observations. We added the following sentence:

> The year-long study of mixed-phase clouds at South Pole with a micropulse LIDAR presented in Lawson and Gettelman (2014) showed that SLW occur more frequently than observed in earlier

aircraft studies, and are underestimated in models leading to biases in the surface radiation budget.

L75 – Rather say for instance: "...impacting the radiative budget of the Antarctic and beyond" or something like this, since the Antarctic (including the SO) is the region mainly investigated by Lawson and Gettelman (2014) in their modelling experiments.

→ This change was made.

L84 – Is there any document or reference describing this project, which could be cited here? Or is the present paper aimed at being the first reference of this project?

→ We have inserted an internet link to the initial document endorsed by YOPP (https://apps3.awi.de/YPP/pdf/stream/52).

L115 – "The method employed and data sets used in our study are..." (see below comment on L119)

→ This textual change has been made.

L117 – As suggested in my main comment, there should be a discussion section gathering information from 3 and 4 and coming before section 5 (conclusion).

→ A new Discussion section, section 6, has been created.

2. Datasets

L119 – I recommend section 2 explaining not only the dataset used but also the method, i.e. the fact of choosing two scenarios of PBL regimes, and state how representative these two scenarios are for instance (perhaps citing previous work like Ricaud et al. 2012, etc.), with a presentation of both larger synoptic scale contexts. The authors could think of one figure demonstrating the clear difference between the two cases by overplotting temperature e.g. at two different altitudes (surface and 500m?) and IWV for both cases. This would better introduce the results for the two case studies. Ideally this would have been event better to compare both atmospheric conditions with the corresponding average+/-std of the whole summer campaign (I am thinking of the representativeness of the two case studies.)

→ Section 3 presents the methodology employed and show some climatological temperature fields together with a presentation of the case studies at global scale above Antarctica (see point 1 above).

L137 – Does this wet bias takes into account any possible dry bias of the sondes?

→ We have clarified this point. Consistently with our previous study on diamond dust (Ricaud et al., 2017), the RS92 radiosonde data have been used without any correction of sensor heating or time lag effect. On humidity, the corrections performed on the radiosonde data measured in 2009 according to Miloshevish et al. (2006) showed a weak impact (with a maximum of +4 % on IWV) on the vertical profiles (Ricaud et al., 2013).

L. 137: We have modified the incriminated sentence into:

IWV has been validated against radiosondes at Dome C between 2010 and 2014 showing a 5-10% wet bias of HAMSTRAD compared to the sondes (Ricaud et al., 2015) that were uncorrected for sensor heating or time lag effect that may produce a 4% dry bias (Miloshevish et al., 2006).

The reference to Miloshevish et al. (2006) has been inserted in the revised version.

Miloshevich, L. M., Vömel, H., Whiteman, D. N., Lesht, B. M., Schmidlin, F. J., and Russo, F.: Absolute accuracy of water vapor measurements from six operational radiosonde types launched during AWEX-G and implications for AIRS validation, J. Geophys. Res., 111, D09S10, doi:10.1029/2005JD006083, 2006.

L. 166: We have also clarified this point in the section (2.4. Radiosondes) by inserting this new sentence.

The radiosonde data were taken using the standard Vaisala evaluation routines without any correction of sensor heating or time lag effect. The sondes are known to have a cold bias of 1.2 K from the ground to about 4 km altitude (Tomasi et al., 2011 and 2012) and a dry bias of 4% on IWV (Miloshevish et al., 2006), mainly between 630 and 470 hPa, with a correction factor for humidity varying within 1.10–1.15 for daytime (Miloshevish et al., 2009).

The reference to Miloshevish et al. (2009) has been inserted in the revised version.

Miloshevich, L. M., Vömel, H., Whiteman, D. N., and Leblanc, T.: Accuracy assessment and corrections of Vaisala RS92 radiosonde water vapour measurements, J. Geophys. Res., 114, D11305, doi:10.1029/2008JD011565, 2009.

L138 – Do you mean studied or validated?

→ We changed the word to "studied". A detailed explanation of the qualitative validation of LWP at Dome C is provided above in the response to the reviewer, along with some discussions in the associated section. We changed the associated reference from Ricaud et al. (2010b) to Ricaud et al. (2010a).

L178 – Please say here which version of the CALIOP product you are using.

→ We have used version V3.40. We have clarified this point in the text and in the associated Figure caption into:

We have used version V3.40 data retrieved from https://www-calipso.larc.nasa.gov/.

L188-189 – what is the vertical resolution of the model configuration, at least in the PBL? 7.5 km stands for the horizontal resolution.

→ We clarified this point by inserting a new sentence:

> The horizontal resolution during the SOP-SH period was 7.5 km at Dome C. The vertical resolution during the SOP-SH period was constituted by 105 vertical levels, the first one being set at 10 m, with 12 levels below 1 km and 35 levels below 3 km.

L190 – Since you show cloud fraction in some figures, please recall here how this cloud fraction is defined? What do the values shown in Figure 2a exactly mean?

→ The cloud fraction is computed differently whether the cloud is resolved in the grid of the model or within a sub-grid. For each of the model vertical level, the value of the cloud fraction ranges between 0 and 1 and is defined as the fraction of the cloud within the model horizontal grid box. The total cloud fraction at each level is a combination between the resolved cloud, the cloud from the shallow convection and the cloud from the deep convection. The resolved cloud is based on a pdf function with critical relative humidity profile. The shallow convection cloud (below 4000 m) is based on the cloud water/ice tendencies computed by the shallow mass flux scheme with a maximum value at 0.3. For the deep convection, the cloudiness is computed with the vertical divergence of the precipitation flux.

We have inserted a new sentence.

> For each of the model vertical level, the value of the cloud fraction ranges between 0 and 1 and is defined as the fraction of the cloud within the model horizontal grid box. The total cloud fraction at each level is a combination between the resolved cloud, the cloud from the shallow convection and the cloud from the deep convection. The resolved cloud is based on a pdf function with critical relative humidity profile. The shallow convection cloud (below 4000 m) is based on the cloud water/ice tendencies computed by the shallow mass flux scheme with a maximum value at 0.3. For the deep convection, the cloudiness is computed with the vertical divergence of the precipitation flux.

3. Typical diurnal cycle of the PBL

L198 – Here you could build on the Method already given in section 2 as recommended in my comment of Line 119, instead of just saying a “typical” PBL cycle, which is not necessary transparent to a reader non familiar with Antarctica.

→ A new section (3. Methodology) has been created that develops and clarifies this point. Furthermore, we have introduced the issue by inserting a paragraph in the section 4. Typical diurnal cycle of the PBL.

> As described in Ricaud et al. (2012), the typical summer boundary layer at Dome C is very similar to that described by Stull (1988). Although sunlight is present throughout the day, the variation in magnitude is enough to allow a stable boundary layer from 18:00 to 06:00 LST, similar to a stable nocturnal boundary layer. There is then a transition from a stable boundary layer to a mixed layer around 06:00 LST with

the increase in the solar irradiation, which reaches a maximum around solar noon. Then around 18:00 LST, the stable boundary layer starts to form again, with a quasi-mixed layer about it. The height of the summertime boundary layer at Dome C typically ranges between 100 and 400 m. The presence of SLW clouds at the top of the PBL together with the diurnal evolution of the PBL will be discussed in the section 7.2.

L203 – “LIDAR cloud backscatter” is redundant with saying that it “indicates that clouds,..” are present. Just say: LIDAR backscatter, and use beta. No need for beta_c here, I think, as long as you refer to “high values” of beta (clearly defined as >100*beta_mol)).

→ We removed the world “cloud” from “LIDAR cloud backscatter” and the subscript from beta_c.

L211-212 – I recommend rather saying a “SLW layer” because what we would call “cloud” here would rather appear to be the combination of the SLW layer at the top and ice below (and probably in) the SLW layer (hence a mixed-phase cloud). Please change here and everywhere in the text, where relevant.

→ As already explained above, careful scrutiny of these two cases has shown that these are not mixed-phase clouds and so the language has not been modified.

L214 – See my comment of Figure 2 (end of this review) for the choice of colour, which is not the best here I think.

→ The text and color of the cloud layer was modified to be more visible on the image.

L218 – I would say: the cloud is mainly confined

→ This grammatical change was made.

L225-227 – The modelled SLW shows very low mmr: 5 10-9 kg/kg = 5 10-6 g/kg ~ 4 10-6 g/m3. Compare this to typical values to Antarctic/Arctic stratus (on coastal areas) of about 0.1 g/m3. (cf. O’Shea et al. 2017, Lachlan-Cope et al. 2016 / Young et al. 2016).

→ The following text was added:

The modelled values of liquid water (~4 10^{-6} g/m^3) are very low, far lower than the observed values of 0.1 g/m^3 observed for coastal polar stratus clouds (cf. O’Shea et al. 2017, Lachlan-Cope et al. 2016, Young et al. 2016).

First two were cited above, the third one (as an example) :

Young, G., Jones, H. M., Choularton, T. W., Crosier, J., Bower, K. N., Gallagher, M. W., Davies, R. S., Renfrew, I. A., Elvidge, A. D., Darbyshire, E., Marenco, F., Brown, P. R. A., Ricketts, H. M. A., Connolly, P. J., Lloyd, G., Williams, P. I., Allan, J. D., Taylor, J. W., Liu, D., and Flynn, M. J.: Observed microphysical changes in Arctic mixed-phase clouds when transitioning from sea ice to open ocean, Atmos.

Chem. Phys., 16, 13945–13967, https://doi.org/10.5194/acp-16-13945-2016, 2016.

→ This was added. Thank you for the complete reference.

When saying " presence of SLW cloud almost all day long in ARPEGE-SH compared to SLW clouds from 08:00 to 22:00 UTC in the observations" you are not comparing very similar things. The "all day long" SLW layer in the model has very low concentrations, that would – if real at all – be missed by the lidar, especially if it forms above the precipitating ice detected during the first half of the day by the instrument. These very low values should probably be mentioned before comparing things.

→ We modified and clarified this point into:

It is obvious that ARPEGE-SH fails in estimating: 1) the vertical distribution of liquid water (a thin layer is observed around 500 m whereas the modelled cloud layer extends from the surface to 800 m); 2) its temporal evolution (presence of SLW cloud almost all day long in ARPEGE-SH compared to SLW clouds from 08:00 to 22:00 UTC in the observations); and 3) the liquid vs. ice mixing ratio, the former being in the model several orders of magnitudes lower than the latter, in contrast to the observations.

Since you speak of the SLW in this paragraph you should also point to the LWP comparison between HAMSTRAD and ARPEGE (Fig. 3b) to give a more quantitative estimate of the difference between both. The sentences of the next paragraph (L228- 241) speaking of LWP should be moved to here I think and the next paragraph would only focus on ice and water vapour.

→ For a sake of simplicity, we think that it is better firstly to discuss about the vertical distribution of different parameters and secondly to consider vertically-integrated products. So, we have not modified the two incriminated paragraphs. Furthermore, the sentence "The ARPEGE-SH LWP is on average 10^3 times lower than that observed by HAMSTRAD, underlining the fact that ARPEGE-SH misrepresents features of the SLW clouds over Dome C." already gave a quantitative comparison between HAMSTRAD and ARPEGE-SH LWP.

About Fig3b – Interestingly the lidar detects some SLW at 9UTC while HAMSTRAD LWP increases only very slightly but was already non-null before. Why is that? Could it be that at earlier times the lidar is not seeing SLW because of the obscuration by the ice below it (Fig1a)? HAMSTRAD sees non-null LWP values. Are these real? If they are, then you could say that the model is right in continuously simulating SLW (although very small amounts) after all, since HAMSTRAD does continuously detect non-null LWP (as opposed to the LIDAR).

→ Discussions about biases and errors of HASMTRAD LWP are detailed in the replies to the reviewer#2 and a paragraph has been inserted in the revised version of the manuscript.

L240-241 – I am not sure why this is recalled here since this was already said before (see my previous comment to line 137).

→ This sentence was removed from the manuscript.

L242-247 – I would rather say that CALIOP complements (and not validate) the ground observation since it observes from the layer top downwards, and the ground-based LIDAR from the bottom upwards. Also note that both will not have the same field of view at all so that features seen by the ground based lidar could be missed by CALIOP. The ground lidar will be more prone to detect finer structures and ice below the SLW (since CALIOP signal will get extinguished by the SLW layer). Besides, in the VFM of CALIOP note that SLW is spotted by the space lidar but no ice is detected, while the LIDAR does detect some (Fig. 1a shows that there is ice below the SLW layer). This is most probably due to CALIOP signal getting extinguished because of the presence of SLW. This should probably be commented on in the paper at some point, to help the reader understand the observations.

→ The first sentence of this paragraph was changed to read:

> Observation of clouds from space-borne sensors has two main advantages: 1) it complements the ground-based cloud observations at Dome C (namely ice/liquid water), and 2) it provides an estimate of the vertical and horizontal extents of the detected cloudy layers.

Since CALIOP is a nadir-viewing instrument, the presence of a thick cloud can extinguish the signal underneath. This has already been observed in Ricaud et al. (2017) when analyzing 2 episodes of a thick 5-km deep cloud and of diamond dust (ice crystals in suspension close to the surface). Such a thick cloud was also present in the vicinity of the Dome C station on 20 December 2018 around 13:00 UTC preventing the observation of SLW clouds underneath. The presence of SLW clouds seems not to alter too much the signal underneath since backscattering attenuated signals (total and perpendicular) were able to reach the surface on 24 December 2018 on the two orbits at 14:00 and 16:00 UTC (see Figures TTT and UUU). Consequently, if ice was present underneath the SLW cloud, CALIOP could have probably been able to detect it.

A sentence has been inserted to address this issue.

> However, the presence of a thick cloud may extinguish the CALIOP signal underneath as it was already presented in Ricaud et al. (2017) when studying episodes of thick (5-km deep) clouds and diamond dust (ice crystals in suspension close to the surface).

In Fig4a – Note that the feature detected by CALIOP seems almost to lie on the surface (I am not sure what the green colour is in Fig4a – see my comment about Figure 4 regarding this matter). What is the measured height of this feature compared to the surface? How can we say this is not an artefact? Can SLW missdetections happen very close to the surface within the CALIOP product that is used here?

→ The Vertical Feature Mask (VFM) image provided by the CALIOP/CALIPSO team does not show a high vertical resolution. Since we know that liquid water clouds are detected around 77.6°S and 121.2°E (in the vicinity of Dome C), we also provide the maps of LIDAR total attenuated backscatter at 532 nm (km^{-1} sr^{-1}) and LIDAR perpendicular attenuated backscatter at 532 nm (km^{-1} sr^{-1}), that is to say the Level 1 data from which the Level 2 VFM data are produced (Figure Supp2). We clearly notice that the SLW cloud under consideration (from -73°S to -

75°S) is located between 3.7 and 3.8 km above mean sea level, that is to say a height of 450 to 550 m above ground level. This is consistent with our observations at Dome C.

We have inserted 2 new sentences to clarify this point.

> Considering the CALIOP total and perpendicular attenuated backscatter data at 532 nm on 24 December 2018 at 16:00 and 14:00 UTC (Figures Supp2 and Supp3, respectively), we can note that: 1) the SLW cloud is located between 3.7 and 3.8 km amsl, that is to say a height from ~450 to ~550 m agl, and 2) since the CALIOP signal is able to reach the surface underneath the SLW cloud, ice is not detected by the space-borne instrument. This is consistent with the observations performed at Dome C.

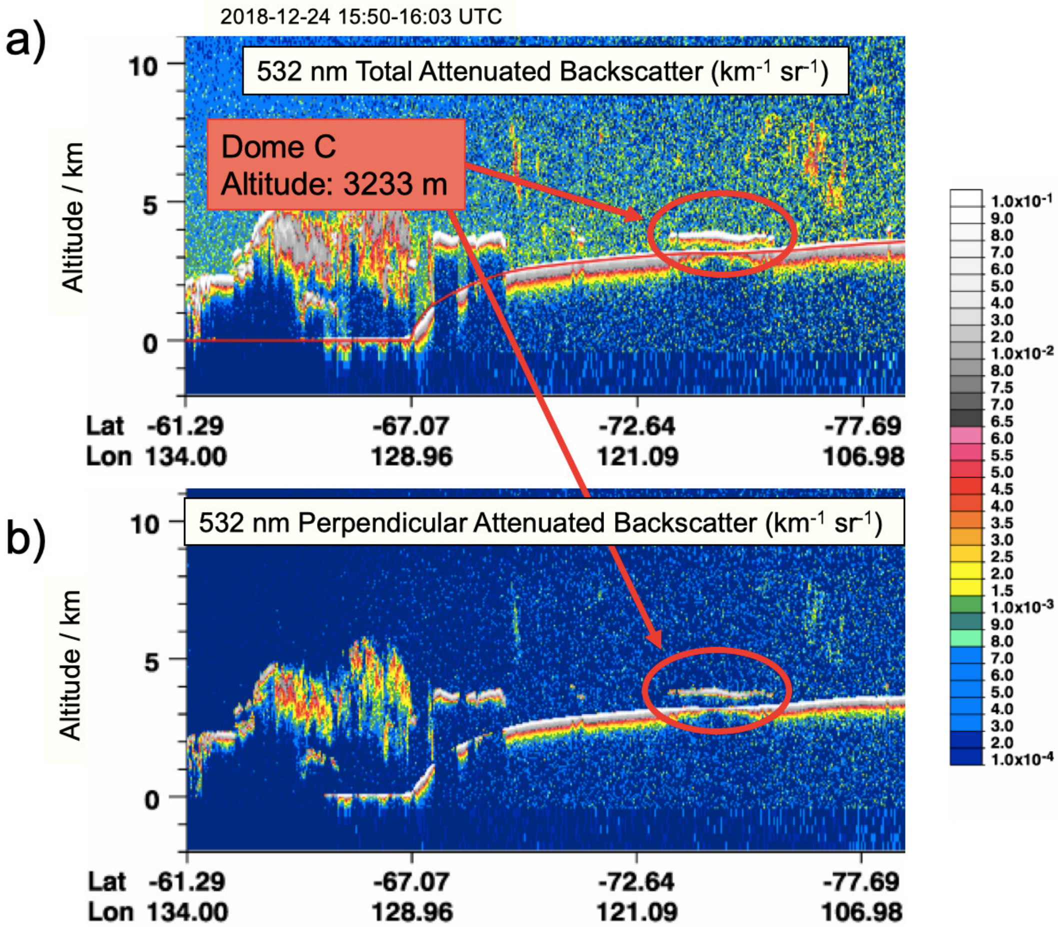

Figure Supp2: *CALIOP/CALIPSO spaceborne LIDAR observations at 532 nm version V3.40 along one orbit on 24 December 2018 (15:50-16:03 UTC) in the vicinity of Dome C (75°S, 123°E) of: (a) the Total Attenuated Backscatter (km^{-1} sr^{-1}) and (b) the Perpendicular Attenuated Backscatter (km^{-1} sr^{-1}). The red circle represents the cloud investigated in our analysis.*

The same conclusions can be drawn for the second orbit not shown in the manuscript (24 December 2018 on 14:11-14:25 UTC) but in the replies to the reviewer#2, that is to say the SLW cloud is located around a height of 450 to 550 m above ground level (Figure Supp3). We have updated the relevant sentence into:

```
The other orbit from 14:11 to 14:25 UTC (Figure Supp4) is
slightly more distant than the one shown in Figure 5 (~360
km), but it exhibits a similar SLW cloud located between ~450
and ~550 m agl, over an even greater horizontal extent of
~700 km along the orbit track.
```

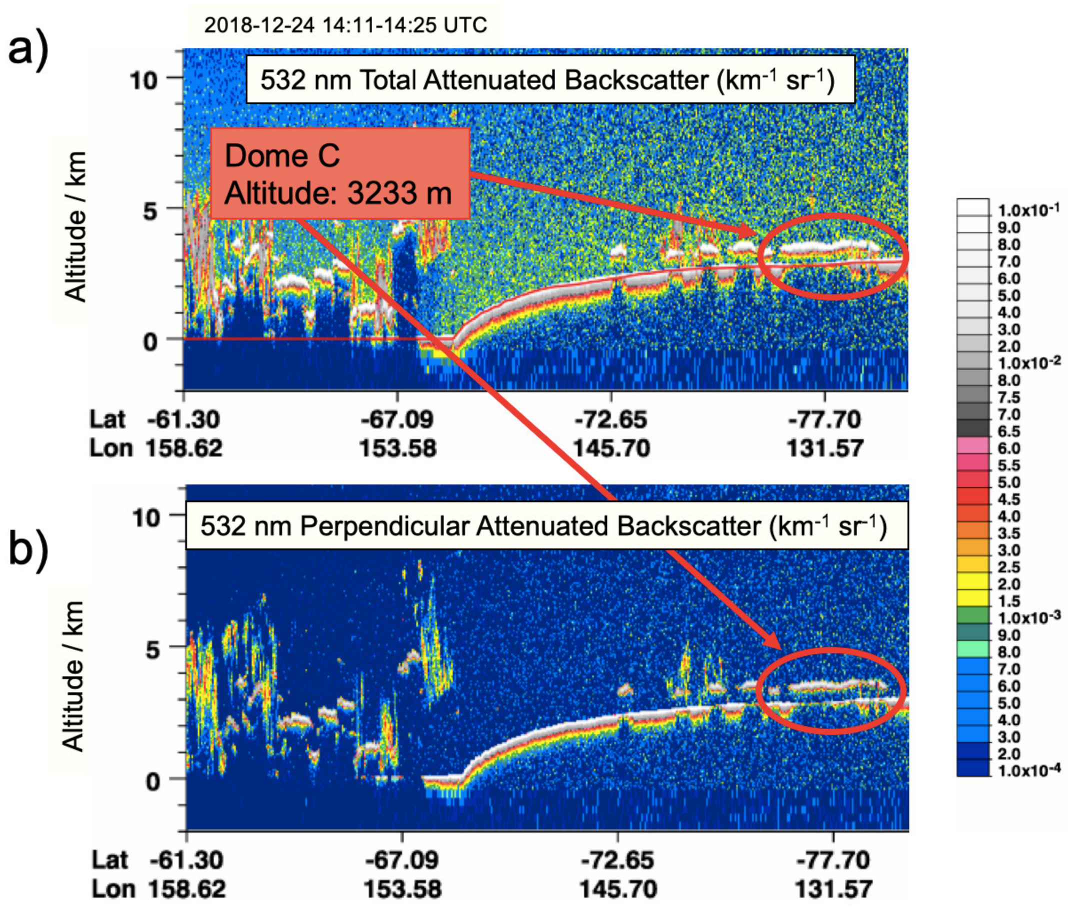

***Figure Supp3**: Same as Figure Supp2 but for one orbit on 24 December 2018 (14:11-14:25 UTC).*

L251 – How close? How does this distance compare to the typical dimension of the SLW layer in the other direction (the 280km of horizontal extent you mention later). We are not necessarily observing the same layer here, after all.

→ At 16:00 UTC, the closest distance between the satellite track where SLW is detected and the Dome C station is ~220 km. The horizontal extent of the SLW cloud along the orbit track is ~450 km. We modified the text accordingly.

```
We show the vertical feature mask and ice/water phase from
the pass closest to the station (~220 km), from 15:50 to 16:03
UTC (Figures 4a and b, respectively). (…) Furthermore, we can
state that this SLW cloud is not a local phenomenon but has
a horizontal extent of ~450 km along the orbit track.
```

L261 – same remark about the distance

→ At 14:00 UTC, the closest distance between the satellite track where SLW is detected and the Dome C station is ~360 km. The horizontal extent of the SLW cloud along the orbit track is ~700 km. We modified the text accordingly (see paragraph above).

L264 – I would suggest a title saying "vertical profiles of temperature and water vapour" since you already speak of water vapour in the previous section. The title, for now, suggests that water vapour was not mentioned before.

→ The title of the section was changed.

L291-293 – This explanation about how the PBL is derived should come in section 2 in the subsection dealing with ARPEGE. Actually, the PBL height is already superimposed in all Figures 1a-c and 2a-c without explaining how it was derived.

→ This explanation was added to the end of section 2.6 as follows:

> The diurnal variation of the top of the PBL is calculated by ARPEGE-SH as the level where the turbulence kinetic energy becomes lower than 0.01 $m^2 s^{-2}$.

In addition, we deleted the sentence here and combined it partially with the last sentence of the paragraph above as:

> The time evolution of the SLW cloud (Fig. 2c) and the diurnal variation of the top of the PBL as calculated by ARPEGE-SH are superimposed on all the panels of Figure 6.

L295 – Shouldn't you cite King et al. 2006 here?

→ Yes, and we have added King et al. (2006) to the list of references in this line.

L300-302 – I am not sure to understand this. What is exactly meant by "elsewhere in the surrounding environment"? Plus, on the figures, the SLW layer after 12UTC seems to remain in a colder (not "warmer") environment (Fig5a and 5b). Then, the model suggests a dryer (not wetter) environment (Fig 5c) and the observation a wetter environment (Fig 5d). I might be missing something here.

→ Yes indeed, the Figure 5 is confusing. The figure caption on Figure 5 is incorrect, although the labels on the panels are correct, which may add to the confusion. However, the reviewer is correct that after 12UTC the air is colder, but the cloud layer persists in a layer that is less cold than air just above and below it. We agree that model suggest a drier environment at the altitude of the observed SLW layer, while the observations show a wetter one. The text for this point has been changed to:

> The SLW cloud persisted after 12:00 UTC in a layer that is cooler than earlier in the day, but slightly warmer than the air above and below it. However, the model shows that this layer is drier while the observations suggest it is wetter.

The erroneous Figure caption was corrected together with the Figure itself (see below).

Figure 6: Time-height cross section on 24 December 2018 (UTC Time) of a) the temperature anomaly (K) calculated by ARPEGE-SH and b) observed by HAMSTRAD, c) the water vapour relative anomaly (%) calculated by ARPEGE-SH and d) observed by HAMSTRAD. Superimposed to all the Figures are the SLW cloud altitude (grey area) deduced from the LIDAR observations (see Fig. 1c) and the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Two vertical green dashed lines indicate 12:00 and 00:00 LT.

L307 – Please define residual mixed layer.

→ The definition of the Residual Layer taken from the American Met. Society (http://glossary.ametsoc.org/wiki/Residual_layer) is:

"The middle portion of the nocturnal atmospheric boundary layer characterized by weak sporadic turbulence and initially uniformly mixed potential temperature and pollutants remaining from the mixed layer of the previous day.

Below the statically neutral residual layer is the stable boundary layer in contact with the radiatively cooled ground, and above it is the capping inversion that separates boundary layer air from free-atmosphere air."

We modified the incriminated sentence and have inserted a new one to clarify this point.

Even if the PBL gets thinner after 12:00 UTC, a residual mixed layer remains above (see e.g. Figure 1.7 of Stull, 2012; Figure 12 top of Ricaud et al., 2012 and definition of a residual layer from the American Meteorological Society at http://glossary.ametsoc.org/wiki/Residual_layer). This layer, where turbulence is sporadic or even absent, lies above the surface-connected stable layer, and can be viewed as a fossil of the mixed layer developed during the previous mixing period.

L315-316 – The SLW layer is just below, and not coinciding with, the local max. of dtheta/dz. As it is a bit difficult to see this local maximum on the Figure 6, can you give its height and value in the text?

→ We have modified and clarified the incriminated paragraph into:

Figure 7 shows $\partial\theta/\partial z$ field and the evolution of the mixed layer top, both computed from ARPEGE-SH output – the latter defined according to whether the turbulent kinetic energy exceeds a defined threshold – and the observed SLW cloud superposed. Black areas correspond to neutral conditions ($\partial\theta/\partial z \sim 0$), whereas the coloured ones relate to stable stratification according to the colour scale in the Figure. The SLW cloud, once appeared at the top of the PBL around 08:00 UTC, persists after 12:00 UTC in a layer around 500-600 m coinciding with the top of the residual mixed layer (see above for the definition) even after the ARPEGE-defined mixed layer top collapses down to the surface.

L317 – I would plot the RS for the potential temp. gradient starting at 100m above the surface, to avoid the unnecessary features/artefacts at the bottom of the red curves.

→ Done for the two incriminated Figures.

L323-324 – Since ARPEGE cannot reproduce the fine vertical structure of the theta gradient I would say this as such, instead of saying “broadly consistent”, because it seems that this fine structure may in the end be one reason for the wrong simulation of SLW. To me, just saying “broadly consistent” suggests that this is ok and we don’t need to further pay attention to this.

→ This clarification is helpful and the change was made in the text as:

ARPEGE-SH cannot reproduce the fine vertical structure of $\partial\theta/\partial z$. For example, the calculated maxima (…)

L327 – You speak about colocation. Can you add on Figure 7 a horizontal line giving the height of the SLW layer as obtained from the LIDAR? This would help locate this layer vs. the altitude of the dtheta/dz maximum.

→ Done for the 2 incriminated Figures.

Also I would rather speak of a colocation of the positive dtheta/dz “with the SLW layer”, not “with the height of the SLW layer”.

→ This change was made.

However, here, you speak about the colocation of the positive dtheta/dz with the layer while, before, you were rather speaking of the colocation of the maximum of the dtheta/dz with the layer. Do you mean to say both or just one of both? Please remain consistent within this subsection.

→ We added “the maximum in the potential temperature gradient” for clarification.

L332-333 – Can you recall for the reader the definitions of these zones by e.g. describing a bit more your Figure 8, rather than just referring to previous papers?

→ The definition of the Entrainment Zone taken from the American Met. Society (http://glossary.ametsoc.org/wiki/Entrainment_zone) is:

(Also called entrainment layer.) A layer of intermittent turbulence and overshooting thermals at the top of the convective mixed layer where the free atmosphere is entrained into the top of the boundary layer.

The entrainment zone is thinner when a stronger temperature inversion caps the boundary layer and thicker when turbulence and thermals are more vigorous.

We have modified the incriminated paragraph together with the incriminated Figure.

The definition of the Capping Inversion Zone can be found at: http://glossary.ametsoc.org/wiki/Capping_inversion.

The colocation of the positive potential temperature gradient with the height of the SLW clouds is consistent with the schematic representation of the diurnal variation of the PBL illustrated by Stull (2012) and adapted by Ricaud et al. (2012) for the Eastern Antarctic Plateau. Figure 8 is a modified version of Figure 12 from Ricaud et al. (2012) to take into account the impact of the clouds on the PBL structure. Starting with the simplest, cloud-free case, we have during the convective (mixing) period a mixed layer at the top of which is located the “entrainment zone”, so-named because air parcels coming from the above free troposphere are entrained into the mixed layer below under the effect of overshooting thermals and compensating descending currents. When clouds form at the top of the PBL (boundary-layer clouds), we consider that the PBL locally (i.e. where clouds are present) extends to the top of these clouds. The PBL is clearly separated from the above stable free troposphere by the so-called capping inversion. The cloud layers as well as the capping inversion zone are thin, of the order of 100 m. When the stable layer forms close to the surface, the SLW cloud may persist over the residual mixed layer, as may persist the capping inversion zone which can also be qualified as “residual”. The stable layer is then progressively eroded, when the incoming available energy becomes large enough to ensure turbulent mixing from the surface. The new mixing layer thus grows through the previous stable layer and residual mixed layer, up to it reaches the residual capping inversion. The stratification of the different layers is characterized by the simplified potential temperature profiles in Figure 18.

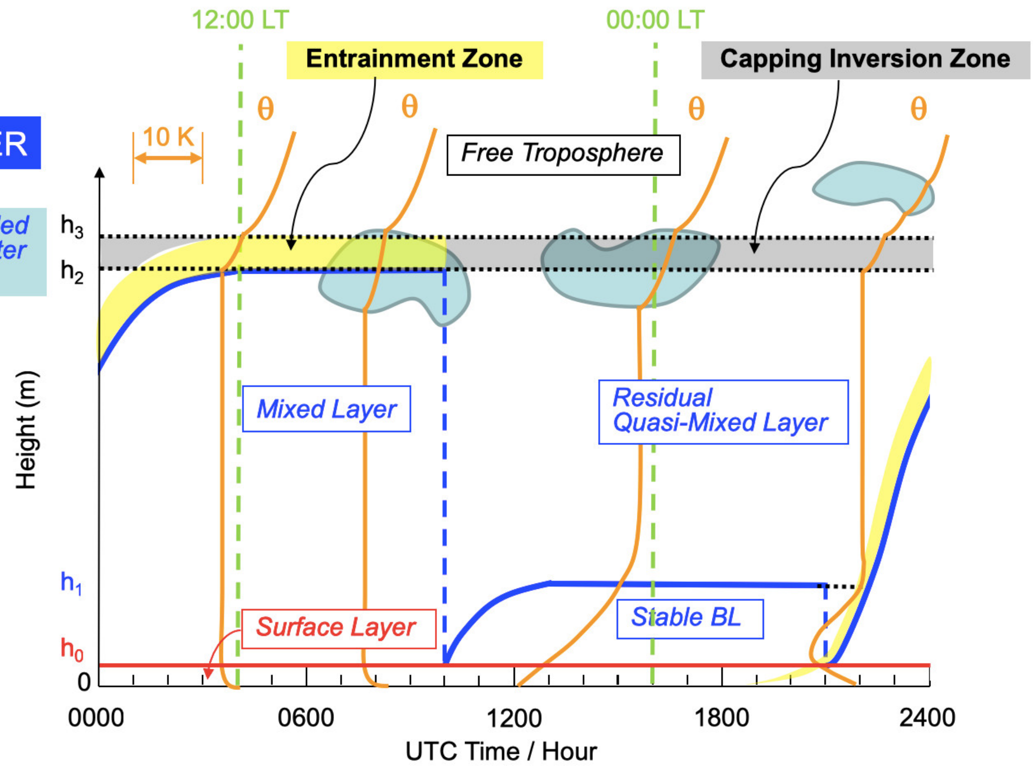

Figure 18: *Figure modified and updated from Fig. 12 of Ricaud et al. (2012) showing the diurnal evolution (UTC Time) of the different layers in the Planetary Boundary Layer (PBL) with h0 the top of the surface layer, h3 the daily overall top of the PBL, and h1 the top of the intermediate stable layer within the PBL. The orange lines symbolize the vertical profiles of*

potential temperature θ, and the light blue areas the SLW clouds. The layer between h2 and h3 is named "capping inversion zone". The yellow area represents the "entrainment zone" at the top of the (cloudy or cloud-free) mixed layer. When the mixed layer is fully developed, the entrainment zone coincides with the capping inversion zone. Note that LT = UTC + 8 h, midnight and noon in the local time reference being indicated by the green dashed lines.

We have inserted a new subsection in the Discussion section (7.2. SLW Clouds and PBL) that deals with the statistics of SLW clouds over the summer periods that includes the YOPP campaign and the SLW cloud development within the PBL (see also replies to the Reviewer#2).

7.2. SLW Clouds and PBL

During the YOPP intensive observing period (SOP-SH), SLW clouds were observed in the LIDAR data for 15 days in December (49% of days) and 13 days in January (47%), which is a similar rate of occurrence to other years (53% in December 2016 and 2018; 51% in January 2018 and 2019) (Figure 17). A day is flagged with a SLW cloud occurrence when a SLW cloud has been detected in the LIDAR observations for a period longer than 1 hour. The presence of SLW clouds in the atmosphere is strongly dependent on the temperature field. From Fig. 2.33 of Pruppacher and Klett (2012), the percentage of clouds containing no ice becomes non-negligible at temperatures greater than -35°C, although SLW clouds have been observed at lower temperatures over Russia (-36°C) and the Rocky Mountains in the USA (-40.7°C). Recent laboratory measurements show that liquid water can exist down to -42.55°C (Goy et al., 2018).

Considering that the SLW clouds at Dome C are so thin, they resemble stratocumulus, as can be observed at middle latitudes. The diurnal cycle of the SLW cloud also evokes that of oceanic stratocumulus, with a trend to fragmentation and/or dissipation during the "day" (local noon) because of solar absorption and to a solid deck state during the "night" (local midnight) because of reversed buoyancy due to cloud top longwave cooling. We use here the "night" and "day" terms for convenience, though solar radiation remains positive 24-hr long at this period of the year. During the SOP-SH, SLW clouds were observed in the LIDAR data for approximately 48% of days but it is not yet evident whether they were formed during the "day" (local noon) when the mixed layer becomes thick enough to reach the condensation level, and vertically broadened during the "night", or created during the "night" (local midnight) and then dissipated during the coming "day". Complementary observations would be needed, in particular turbulence profiles from the surface to above the top of boundary-layer clouds, to determine what is the coupling/decoupling diurnal cycle of these clouds.

The diurnal evolution of the top of the PBL is consistent with previous studies carried out at Dome C (e.g. Argentini et al., 2005; King et al., 2006; Ricaud et al., 2012; Casasanta et al., 2014), with a top higher when there is a relatively warm mixed layer than in cool stable conditions.

The colocation of the positive potential temperature gradient with the height of the SLW clouds is consistent with the schematic representation of the diurnal variation of the PBL illustrated by Stull (2012) and adapted by Ricaud et al. (2012) for the Eastern Antarctic Plateau. Figure 18 is a modified version of Figure 12 from Ricaud et al. (2012) to take into account the impact of the clouds on the PBL structure. Starting with the simplest, cloud-free case, we have during the convective (mixing) period a mixed layer at the top of which is located the "entrainment zone", so-named because air parcels coming from the above free troposphere are entrained into the mixed layer below under the effect of overshooting thermals and compensating descending currents. When clouds form at the top of the PBL (boundary-layer clouds), we consider that the PBL locally (i.e. where clouds are present) extends to the top of these clouds. The PBL is clearly separated from the above stable free troposphere by the so-called "capping inversion". The cloud layers as well as the capping inversion zone are thin, of the order of 100 m. When the stable layer forms close to the surface, the SLW cloud may persist over the residual mixed layer, as may persist the capping inversion zone which can also be qualified as "residual". The stable layer is then progressively eroded, when the incoming available energy becomes large enough to ensure turbulent mixing from the surface. The new mixing layer thus grows through the previous stable layer and residual mixed layer, up to it reaches the residual capping inversion. The stratification of the different layers is characterized by the simplified potential temperature profiles in Figure 18. Considering both the potential temperature gradients and the vertical extent of the SLW cloud, these layers are quite thin, less than 100-m deep.

We have also inserted a sentence in the Abstract and in the Conclusions.

The analysis shows that SLW clouds were present from November to March, with the greatest frequency occurring in December and January since ~50% of the days in summer time exhibited SLW clouds.

L336-348 – In this paragraph you speak about observations over the entire YOPP campaign while it was only about a specific case study so far. This is confusing. Please remove this paragraph. It rather belongs to the discussion section, like the one I am recommending to add in my main comment at the beginning of this review.

→ The paragraph was moved to the new discussion section, section 6.

L350 - Section 3.4 – I recommend presenting the second case study of SLW layer here. After, you could have a subsection dedicating to surface radiations for both case studies at the same time. It is better not to separate both SLW/PBL case studies so much so that the reader can compare them easily. Surface radiation considerations can very well be moved to a common part, later in the paper and it would be better to show Figures 9 and 16 at the same time, so that – again – both cases can be paralleled.

→ The two radiation sections were moved into a new section, section 5 "Impact of SLW Cloudy Layers on Net Surface Radiation"

L353: Figure9 (top)

→ We added in the clarification "(top)" to the text.

L365-368. "As the SLW... over Antarctica". This sentence would better go in the discussion section that I am recommending to add. Focus on the case study here. Also, you don't necessarily know whether what CALIOP sees is exactly the cloud you see from the ground. Plus, note that it is 280 km along the satellite track and you don't know about the cloud cover in the perpendicular direction (unless the second orbit you are not showing gives info about cloud cover size along a different direction?).

→ This was moved to the discussion and combined with a reference to the Lawson and Gettelman (2014) paper.

L370: you only mention the increase in downward LW radiation. In theory you should also detect a decrease in SW because small droplets are very efficient in reflecting sunlight. And, actually, you do see this in your plot. Around 12UTC you see a reduction in down/upward surface SW, because of the SLW layer reflecting sunlight, hence reducing the upward SW (reflection by the icy or snowy surface) as well. Please refer to this as this satisfyingly shows the opposite effects of the SLW layer in both parts of the spectrum. (see my similar comment of L475-476, for Figure 16)

→This is a good point and the following sentences have been inserted:

> The reflective impact of SLW layers can also be seen after 12:00 UTC: unlike observed SLW clouds, ARPEGE-SH simulates ice clouds, and therefore too high SW↓ values. The difference between observed and simulated values of this parameter thus increases, as can be seen on the Figure. But because of the high values in surface albedo, a compensating effect occurs on the surface reflected SW fluxes, and the resulting impact on net radiation is quite weak (the time series of the observed – simulated difference in incoming and reflected SW flux follow each other quite well). The major impact on net radiation is therefore related to the longwave fluxes.

L373: What is meant by "at a level higher"?

→ The sentence was rewritten to:

> Thus, SLW clouds tend to radiate more LW radiation toward the ground (like greenhouse gases) than more transparent clouds, like cirrus, do.

4. Perturbed diurnal cycle of the PBL

L377-380: this info could go in the "method" subsection I was recommending to add, to introduce at once both PBL cases investigated here (and possibly say something about their representativeness).

→ This has been done both in the "Methodology" (Section 3) and in the introduction of the subsection relative to the perturbed case (Section 5) by inserted anew sentence.

On the second case study, 20 December 2018, the diurnal cycle of the PBL was perturbed by the sudden arrival of very moist, warm air of oceanic origin.

L392-393 – I am not sure to understand why it is said that the LIDAR does not detect a mixed-phase as well. Your LIDAR mask indicates SLW but this does not mean there is no ice at the same time. Does it? Fig10a suggests ice forms/falls below SLW layer I suppose and again it could be ice precipitating from the SLW layer where little crystals would have also already formed (as it is often the case for low-level mixed-phase clouds). Unless you demonstrate this, I don't think you can say here that your observed cloud is not a mixed-phase one.

→ We have addressed this very important issue by considering the raw measurements acquired by the LIDAR. For the two dates under consideration (Figures Supp6 and Supp7 relative to 24 and 20 December 2018, respectively), we have represented (top) the P signal as the signal received with the same polarization as the laser (unpolarized component). Any suspended object can contribute to P signal. We have also represented the S (cross-polarized) LIDAR signal (bottom) that is only produced by non-spherical (obviously frozen at Dome C) particles and, to a smaller extent, by multiple scattering in water clouds.

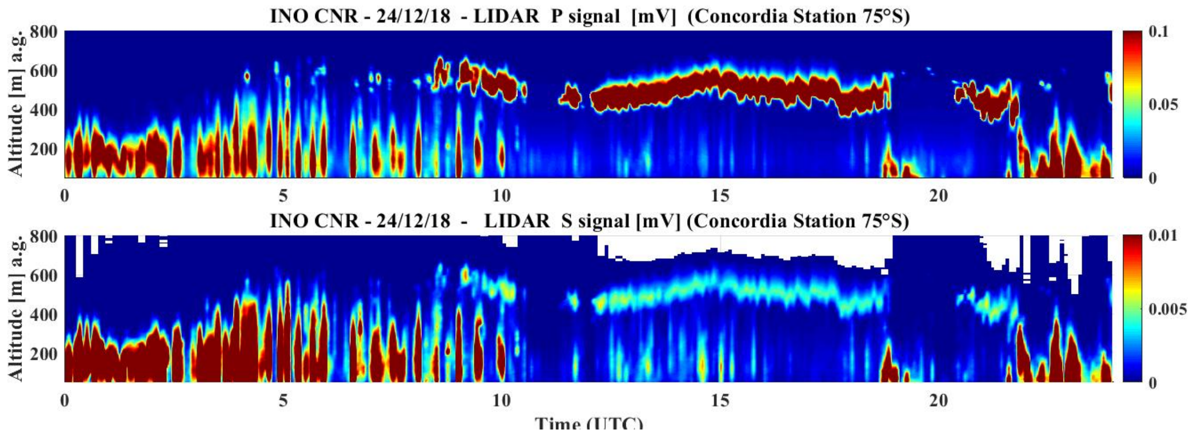

Figure Supp6: *Time-height cross-section on 24 December 2018 (UTC Time) of the raw signals acquired by the LIDAR: (top) the LIDAR P signal (mV) and (bottom) the LIDAR S signal (mV). The P signal is the signal received with the same polarization as the laser (unpolarized component). The S (cross-polarized) signal is only produced by non-spherical particles.*

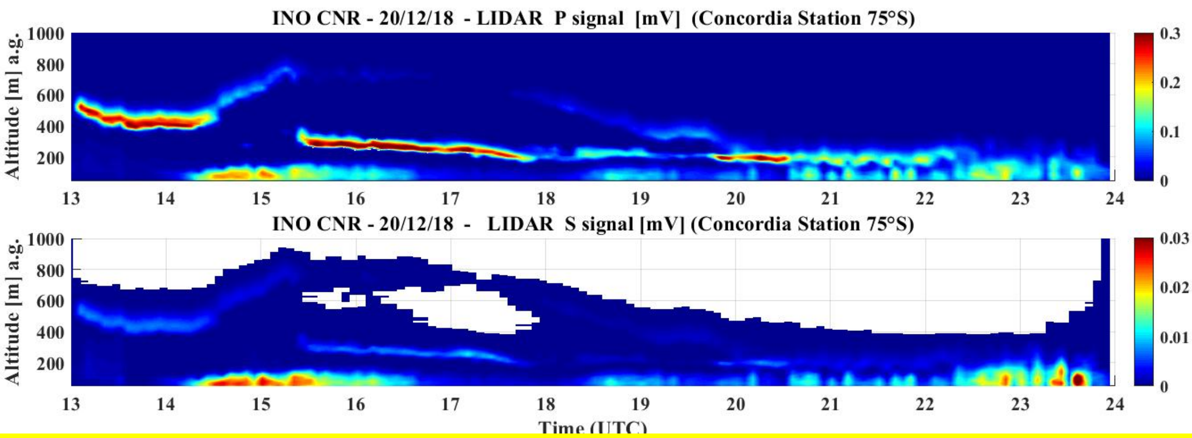

Figure Supp7: *Same as Figure Supp6 but focusing on the period 13:00 – 24:00 UTC when clouds are present.*

First of all, an elevated P signal above ~400 m on 24 December 2018 (P ≥ 0.1 mV) and above ~200 m on 20 December 2018 (P ≥ 0.3 mV) is associated to a cloud as shown in the manuscript. Inside these clouds, the S signal is always very low: S ~0.003 mV on 24 December 2018 and ~0.01 mV on 20 December 2018. Consequently, the S signal is very weak and corresponds to a maximum of ~3% of the corresponding P signal. Some S signal is nevertheless present in the cloud and could be given by both multiple scattering inside the truly liquid water cloud or by the effective presence of ice particles.

When considering the LIDAR depolarization diurnal evolutions presented in Figures 2b and 9b in the manuscript associated to the 2 dates, ice particles could have been disappeared in the low depolarization ratio S/P of the SLW layer because the P signal inside the SLW cloud is very high compared to the S signal. But when considering the P and S signals distinctively (Figs Supp6 and Supp7), the S signal remains very weak in the SLW cloud compared to the P signal whatever the date considered. Consequently, even if the presence of some ice particles scattered within the SLW layers cannot be excluded from the S signal plot, the very low depolarization of the layers leads to classify them as a liquid cloud.

The important point is that the optical properties of the layer, relevant for the radiative budget in the shortwave, such as optical extinction, optical depth, asymmetry factors, etc. are bound to the P signal, being e.g. optical extinction in the visible proportional to the lidar P signal. Thus, the shortwave radiative characteristics of the cloud are driven by the P signal, and thus by liquid water. The layer is thus a truly SLW layer, being its ice component, even if present, irrelevant under the radiative point of view.

We have inserted a new section in the Discussions and Figures in the Supplementary File.

7.1. SLW vs Mixed-Phase Clouds

In order to check whether the observed cloud is constituted of liquid and/or mixed phase water, we have considered the raw signals recorded by the LIDAR. For the two dates under consideration (Figures Supp6 and Supp7 relative to 24 and 20 December 2018, respectively), we have represented (top) the P signal as the signal received with the same polarization as the laser (unpolarized component). Any suspended object can contribute to P signal. We have also represented the S (cross-polarized) LIDAR signal (bottom) that is only produced by non-spherical (obviously frozen at Dome C) particles and, to a smaller extent, by multiple scattering in water clouds.

First of all, an elevated P signal above ~400 m on 24 December 2018 (P ≥ 0.1 mV) and above ~200 m on 20 December 2018 (P ≥ 0.3 mV) is associated with a cloud as shown in the sections 4.1 and 5.1. Inside these clouds, the S signal is always very low: S ~0.003 mV on 24 December 2018 and ~0.01 mV on 20 December 2018. Consequently, the S signal is very weak and corresponds to a maximum of ~3% of the corresponding P signal. Some S signal is nevertheless present in the cloud and could be given by both multiple scattering inside the truly liquid water cloud or by the effective presence of ice particles.

When considering the LIDAR depolarization diurnal evolutions presented in Figures 2b and 9b associated to the

2 dates, ice particles could have been disappeared in the low depolarization ratio S/P of the SLW layer because the P signal inside the SLW cloud is very high compared to the S signal. But when considering the P and S signals distinctively (Figs. Supp6 and Supp7), the S signal remains very weak in the SLW cloud compared to the P signal whatever the date considered. Consequently, even if the presence of some ice particles scattered within the SLW layers cannot be excluded from the S signal plot, the very low depolarization of the layers leads to classify them as a liquid cloud.

The important point is that the optical properties of the layer, relevant for the radiative budget in the shortwave, such as optical extinction, optical depth, asymmetry factors, etc. are bound to the P signal, being e.g. optical extinction in the visible proportional to the lidar P signal. Thus, the shortwave radiative characteristics of the cloud are driven by the P signal, and thus by liquid water. The layer is thus a truly SLW layer, being that its ice component, even if present, is irrelevant from a radiative point of view.

L400: the simulated cirrus cloud is above the area where the SLW layer is. This is not just a matter of sensitivity. This is most probably because the SLW layer extinguishes the lidar signals which cannot reach the cirrus cloud. The top right part of Fig10a suggests so (no signal).

→ Agreed. We modified the sentence to:

We note the presence of high altitude cirrus (ice) clouds calculated by ARPEGE-SH after 12:00 UTC around 3-4 km height, while not observed likely because of the LIDAR is attenuated by the SLW layer.

L393 – As for the previous case study, please do clearly highlight the very little amounts formed (in g/kg) clearly showing that the model forms virtually no liquid at all...

→ We added the sentence:

In all occurrences, the liquid water amounts produced by the model are extremely small, nearly non-existent.

L401 - SLW layer

→ No, as mentioned previously, for these case studies the clouds are not mixed-phase clouds so the language was not altered.

L429 - Please avoid the use of "model data". You could say e.g. "the model output" or "the model simulates a moistening..."

→ We utilized "the model simulates a moistening…".

L449 - When you say "This is broadly..." it is not clear what "This" is referring to since you then speak about the events "prior the warm episode", while "This" seems to refer to all three profiles. Please rewrite. I am not comfortable with this "broadly consistent" expression (see my previous comment on L323-324). Obs-Model differences in Fig15b and c appear even more larger here than in the previous case study.

→ Several clarifications were made in this paragraph. In addition, the vertical axis of Figure 15 was adjusted, similar to that of Figure 7.

L458 - Figure 16 (top)

→ This change was made.

L472 - the maximum of LWP appears rather to be 45 g m-2 at 13h00 UTC. However, it seems that you smoothed the data here – when comparing with Fig.12b where we see the maximum is 50 g m-2 indeed. Please make Figure/text consistent with each other.

→ We have redrawn the two incriminated Figures (9 and 16, now 15 and 16 in the revised manuscript) with no smoothing of the LWP.

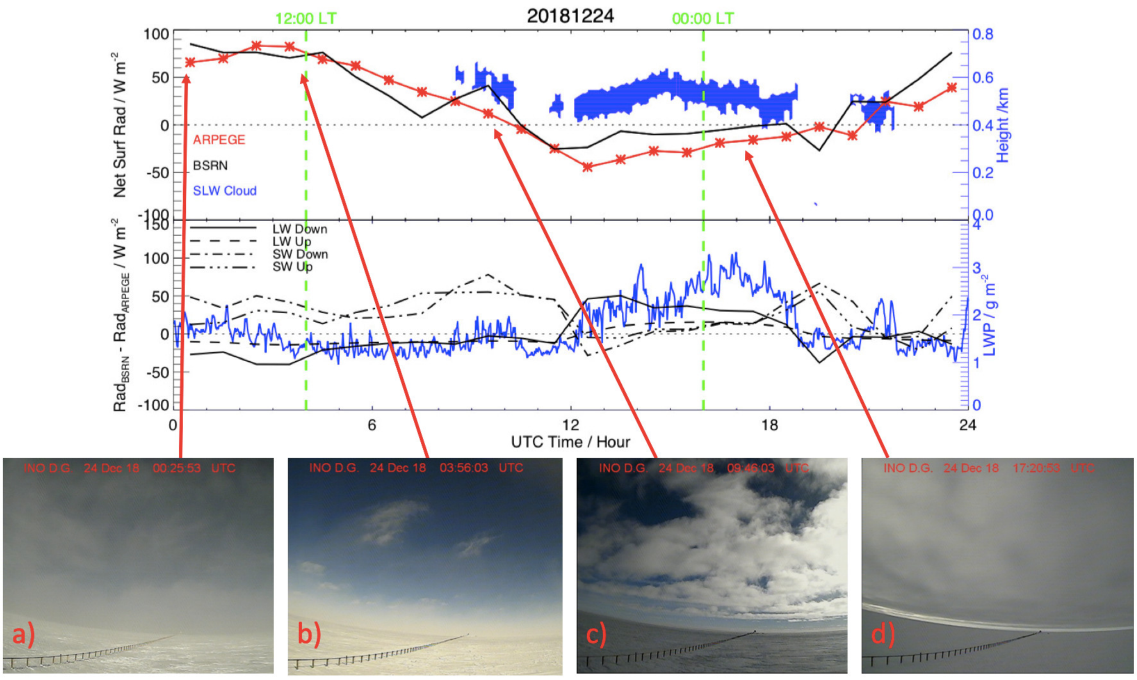

Figure 15: *(Top) Diurnal variation of the net surface radiation (W m^{-2}) observed by BSRN (black solid line) and calculated by ARPEGE-SH (red crossed line) on 24 December 2018 in UTC Time. Superimposed is the SLW cloud altitude (blue) deduced from the LIDAR. (Middle) Diurnal variation of the difference between surface radiation (W m^{-2}) observed by BSRN and calculated by ARPEGE-SH on 24 December 2018 for longwave downward (black solid), longwave upward (black dashed), shortwave downward (black dashed dotted) and shortwave upward (black dashed triple dotted) components. Superimposed is LWP (blue) measured by HAMSTRAD. (Bottom) Four webcam images showing the cloud coverage at: a) 00:25 UTC and b) 03:56 UTC (cirrus clouds, no SLW cloud), c) 09:46 UTC (SLW cloud) and d) 17:20 UTC (SLW cloud). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

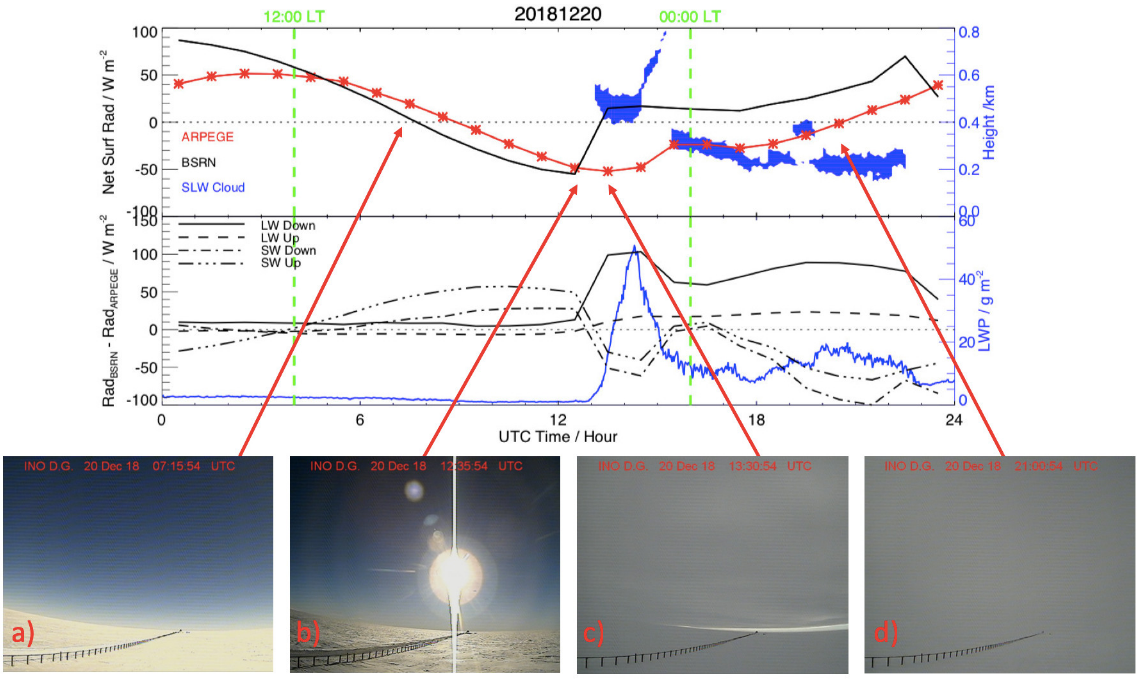

Figure 16: *Same as Figure 15 but for 20 December 2018 whilst the 4 webcam images were selected at: a) 07:15 and b) 12:35 UTC (clear sky), c) 13:30 and d) 21:00 UTC (SLW cloud).*

L475-476 - As for the previous case-study you can note the decrease in SW up/down because of the reflection of sunlight by the SLW layer. Compared to previous case, however, SW up/down is continuously decreasing. Why is that? It seems, according to the pictures and the LIDAR detection that the cloud deck is thickening (hence the largest LWP values) and the cloud base lowering, preventing always more radiations to reach the ground, while for the previous case study, the cloud seemed more broken (see your pictures) and the cloud base altitude constant (see the LIDAR detections).

→ The following sentence was added to this section:

> The SW↓ and SW↑ also decrease due to the high reflectivity of the SLW layer seen at 13:00 UTC and again at 21:00 UTC.

The LIDAR data in former Figure 10 (now Figure 9) may suggest the presence of precipitating ice crystals and possibly blowing snow which may add to the decreased SW flux and also to the decreased visibility shown in the webcam image in Figure 16d.

The meteorological diurnal evolutions of surface temperature, humidity, wind speed and direction from the Automated Weather Station (AWS) at Dome C for 24 and 20 December 2018 (typical and perturbed cases, respectively) are presented on Figures R1 and R2. For both periods, wind was rather slow (3-10 m s^{-1}) and few traces of snow drift (characterized by red spots on the depolarization Figure) may have been detected by the LIDAR on 20 December 2018 after 17:00 UTC just around 20 m agl.

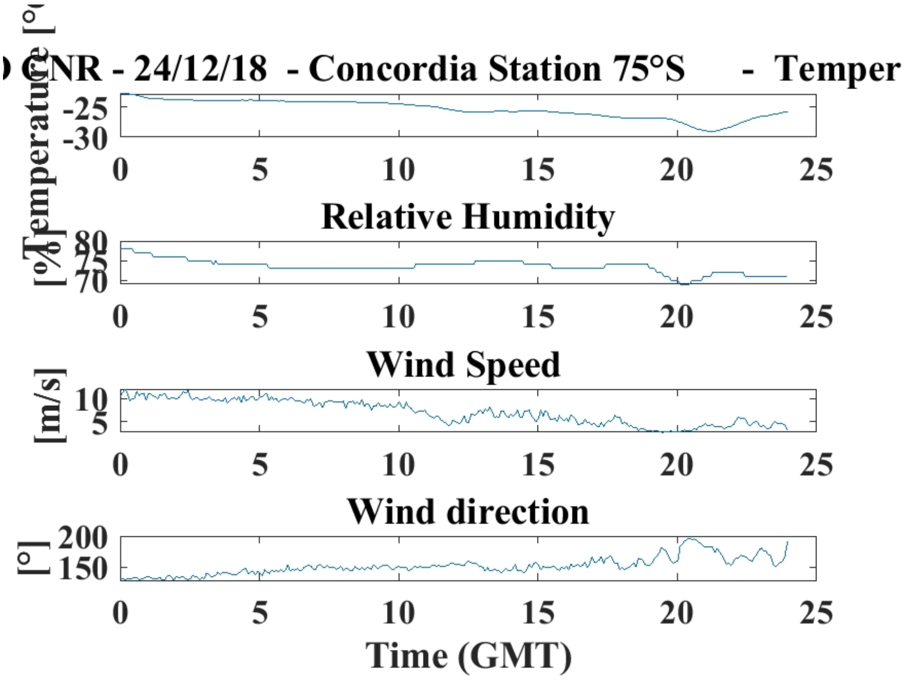

Figure R1: *Diurnal variations of surface temperature, relative humidity, wind speed and direction measured by the Automated Weather Station (AWS) at Dome C on 24 December 2018.*

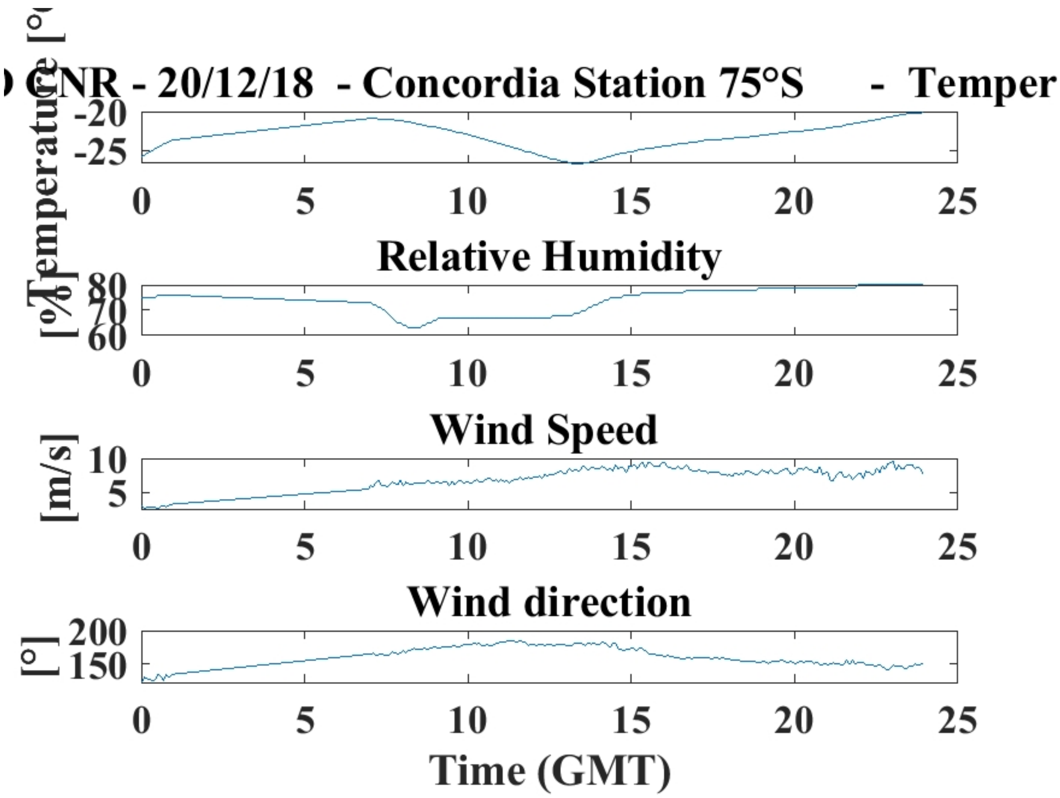

Figure R2: *Same as Figure R1 but for 20 December 2018.*

A sentence was added that states:

Both SW components decrease after 17:00 UTC. Some of this may be due to: 1) increasing LWP, and 2) the presence of precipitating ice crystals and/or blowing snow (characterized by red spots on Figure 9b) that are increasing optical depth and decreasing transmission/visibility (webcam images in Figure 16d) although surface wind was rather weak (3-10 m s^{-1}, not shown).

These types of observations should be commented on, here or in the discussion section. Please make the most of the combination of radiation measurements, cloud measurements, and visual observations. Again, rearranging the paper so that Figure 9 and 16 are in a same unique section about radiation would help.

→ This has been done.

Also, you don't comment on the fact the water vapour bias is clearly appearing in this case study so that you could expect also bias in LW radiations from water vapour since it is a strong GHG. Perhaps this can explain the larger biases observed in the second case study (in addition to the thicker SLW layer observed). What do you think? These are matters to discuss in a discussion part...

→ This point has been discussed in detail above. Some sentences have been modified and others have been inserted in the revised version.

5. Conclusions

L496 - you have not mentioned any CALIPSO overpass for the 20th of December so far, only for the 24th. Both overpasses you were mentioning (although you only showed one) were for the 24th.

→ On 20 December 2018, after 13:00 UTC when SLW have been detected at Dome C, the CALIPSO overpasses are both far away from Dome C and, for the closest overpass at 13:17 UTC (closest distance to Dome C is 500 km), shows a very thick ice cloud at about 3 km above ground level that prevents the LIDAR radiation to reach the surface (Figure Supp5). Unfortunately, no meaningful information can be grabbed from the spaceborne observations on that day relevant to SLW clouds in the vicinity of Dome C.

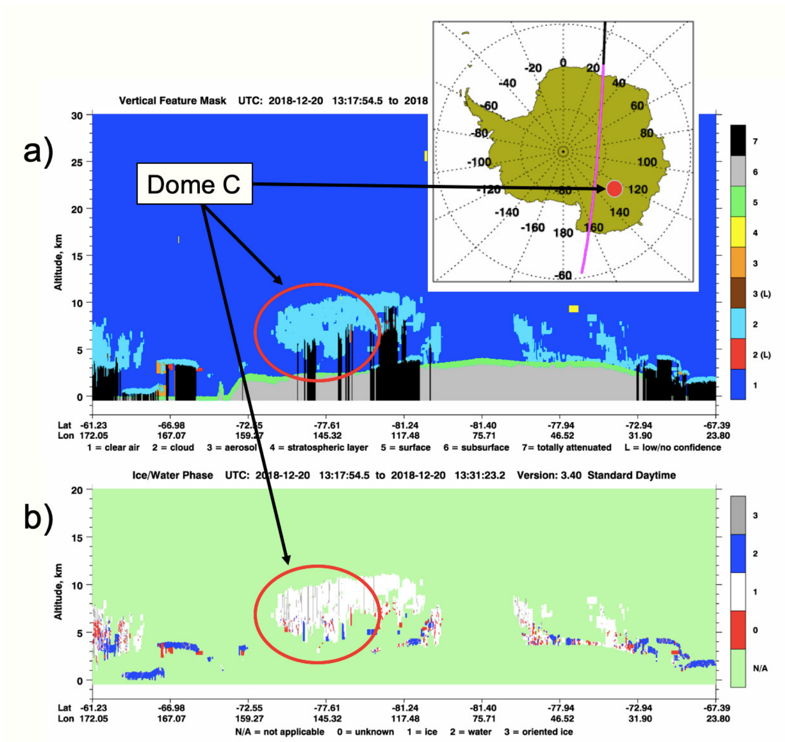

Figure Supp5: *CALIOP/CALIPSO spaceborne LIDAR observations version V3.40 along one orbit on 20 December 2018 (13:17-13:31 UTC) in the vicinity of Dome C (75°S, 123°E): a) the Vertical Feature Mask highlighting a cloud (light blue) near the surface (red circle) and b) the Ice/Water Phase Mask highlighting a SLW (dark blue) cloud near the surface (red circle). The ground-track of the sensor (pink) has been embedded at the top of the Figure, with the location of Dome C marked (red filled circle). Note that the altitude is relative to the sea surface, with the height of surface of Dome C at an elevation of 3233 m amsl. Figure adapted from the original image available at https://www-calipso.larc.nasa.gov/products/lidar/browse_images/std_v34x_showdate.php?browse_date=2018-12-20.*

L498: underestimated – say by how much.

→ The phrase "by a factor 1000" was added to this sentence.

L505 - BSRN LW or net values?

→ The sentence is correct as written, these are LW values.

Figures.

Figure 1 – one cannot see the red text, especially on the coloured background. Please adapt the color, and put the text a bit higher. For Figure 1c, use the blue colour for the "SLW layer".

→ We modified the incriminated Figure (now Figure 2) according to the comments of the reviewer.

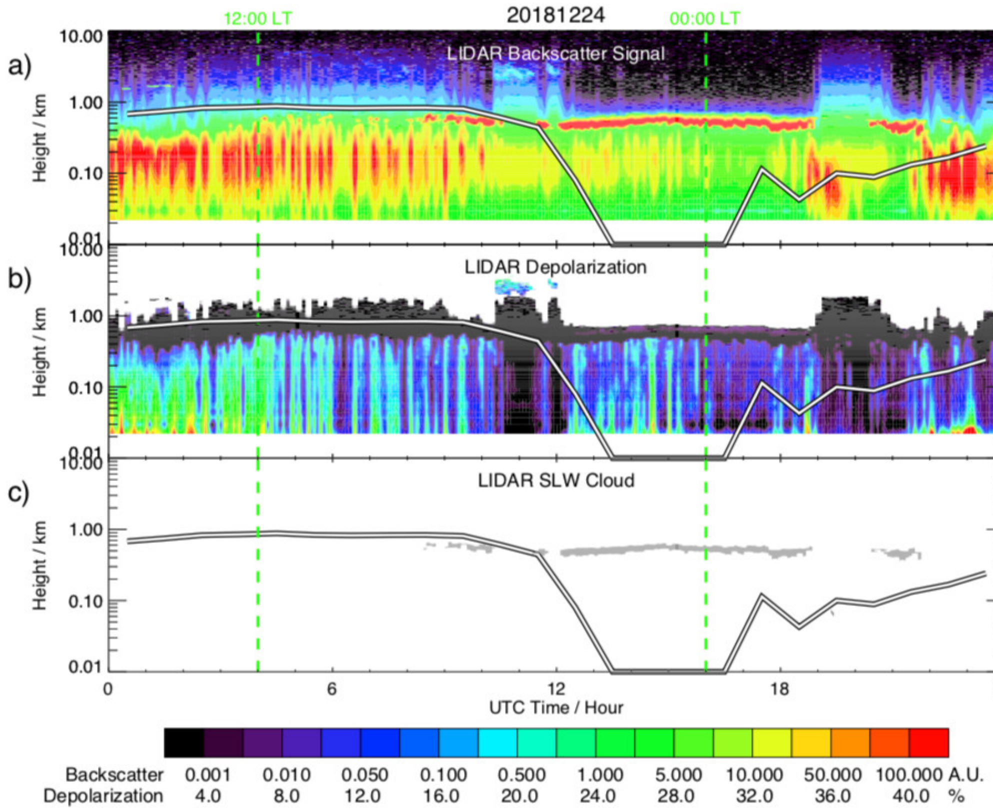

Figure 2: *Diurnal variation on 24 December 2018 (UTC Time) along the vertical of: a) the backscatter signal (Arbitrary Unit, A.U.), b) the depolarization ratio (%) measured by the aerosol LIDAR, and c) the Supercooled Liquid Water (SLW) cloud height (grey) deduced from the aerosol LIDAR ($\beta_c > 100\ \beta_{mol}$, depolarization < 5%). Superimposed to all the Figures is the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

Figure 2 – Please use a different color for the text in the plots. Also, this is confusing to have “liquid water” written in red, with that colour being used for the lidar observation as well (while also being part of the colour scale...) Could you perhaps use grey colour to indicate the SLW layer observation? Also: using white colour instead of black-red would help seeing the curve for PBL height more clearly.

→ We modified the incriminated Figure (now Figure 3) according to the comments of the reviewer.

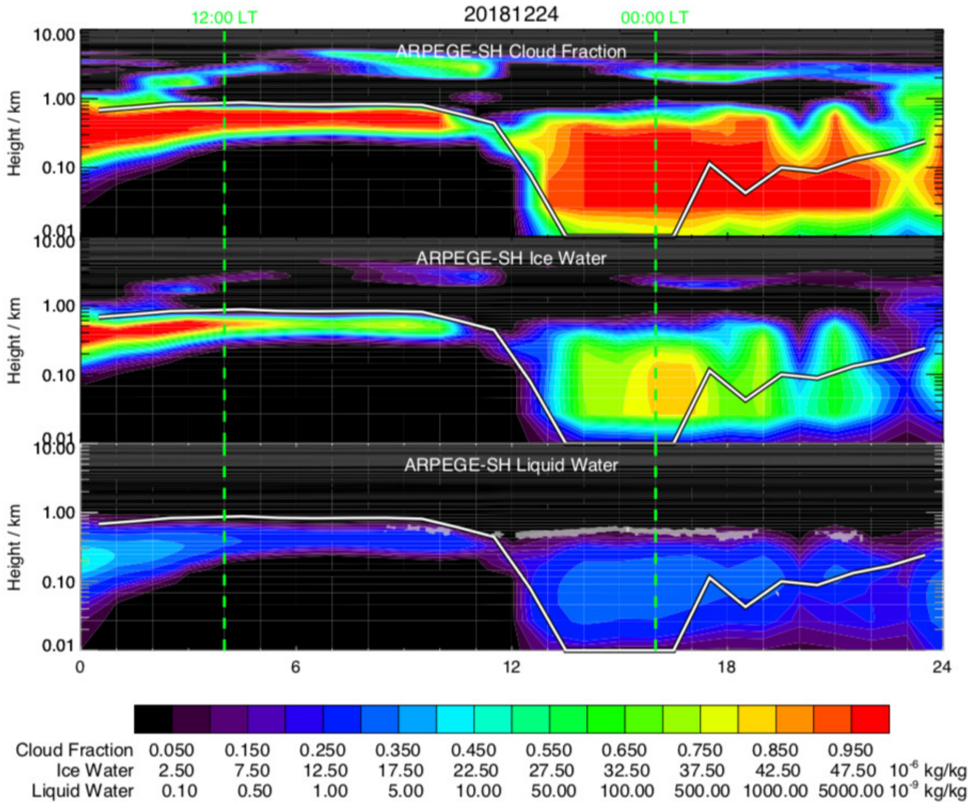

Figure 3: *Time-height cross section on 24 December 2018 (UTC Time) of: a) the Cloud Fraction (0-1), b) the Ice Water mixing ratio (10^{-6} kg kg^{-1}) and c) the Liquid Water mixing ratio (10^{-6} kg kg^{-1}) calculated by the ARPEGE-SH model. Superimposed to all the panels is the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Superimposed in panel c is the SLW cloud (grey area) height depth deduced from the LIDAR observations (see Fig. 1c). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

Figure 4 – Can you put the names of the categories on the colour bars instead of numbers that are not explained in the Figure caption? If this Figure is a quicklook obtained from another source, this should probably be said.

→ We modified the incriminated Figure (now Figure 5) according to the comments of the reviewer and the comments from the reviewer #2.

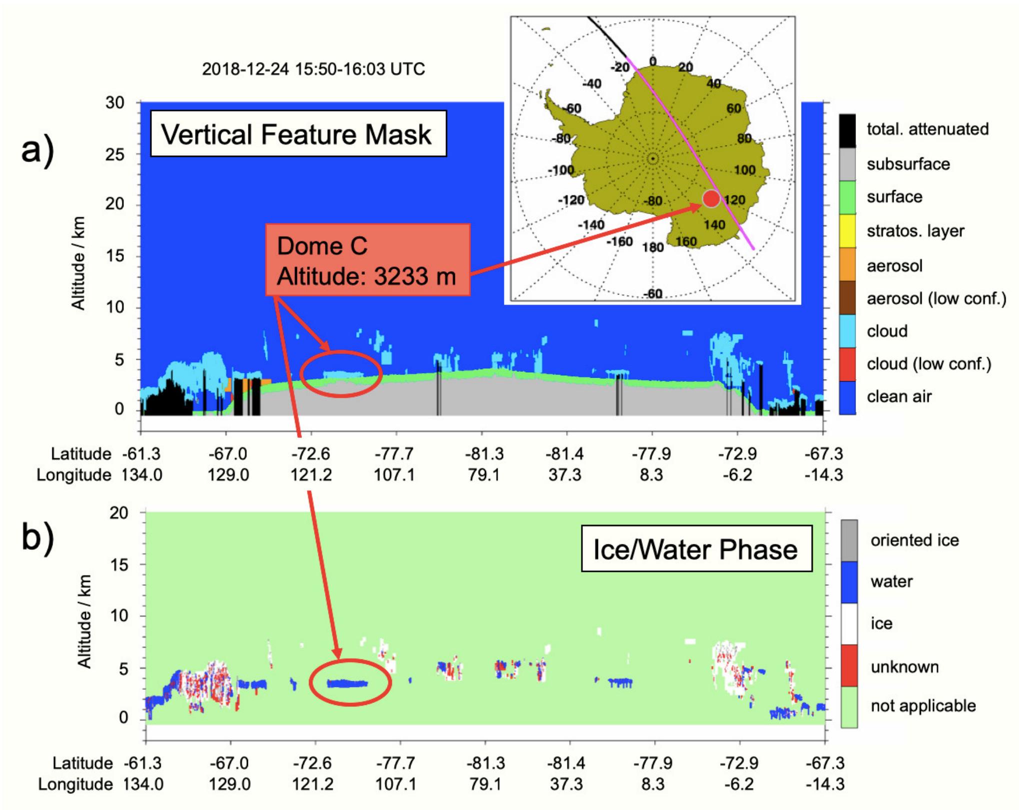

Figure 5: *CALIOP/CALIPSO spaceborne LIDAR observations version V3.40 along one orbit on 24 December 2018 (15:50-16:03 UTC) in the vicinity of Dome C (75°S, 123°E): a) the Vertical Feature Mask highlighting a cloud (light blue) near the surface (red circle) and b) the Ice/Water Phase Mask highlighting a SLW (dark blue) cloud near the surface (red circle). The ground-track of the sensor (pink) has been embedded at the top of the Figure, with the location of Dome C marked (red filled circle). Note that the altitude is relative to the sea surface, with the height of surface of Dome C at an elevation of 3233 m amsl. Figure adapted from the original image available at https://www-calipso.larc.nasa.gov/products/lidar/browse_images/std_v34x_showdate.php?browse_date=2018-12-24.*

Figure 5 - Please use a color other than red for text.

→ We modified the incriminated Figure (now Figure 6) according to the comments of the reviewer and the comments from the reviewer #2.

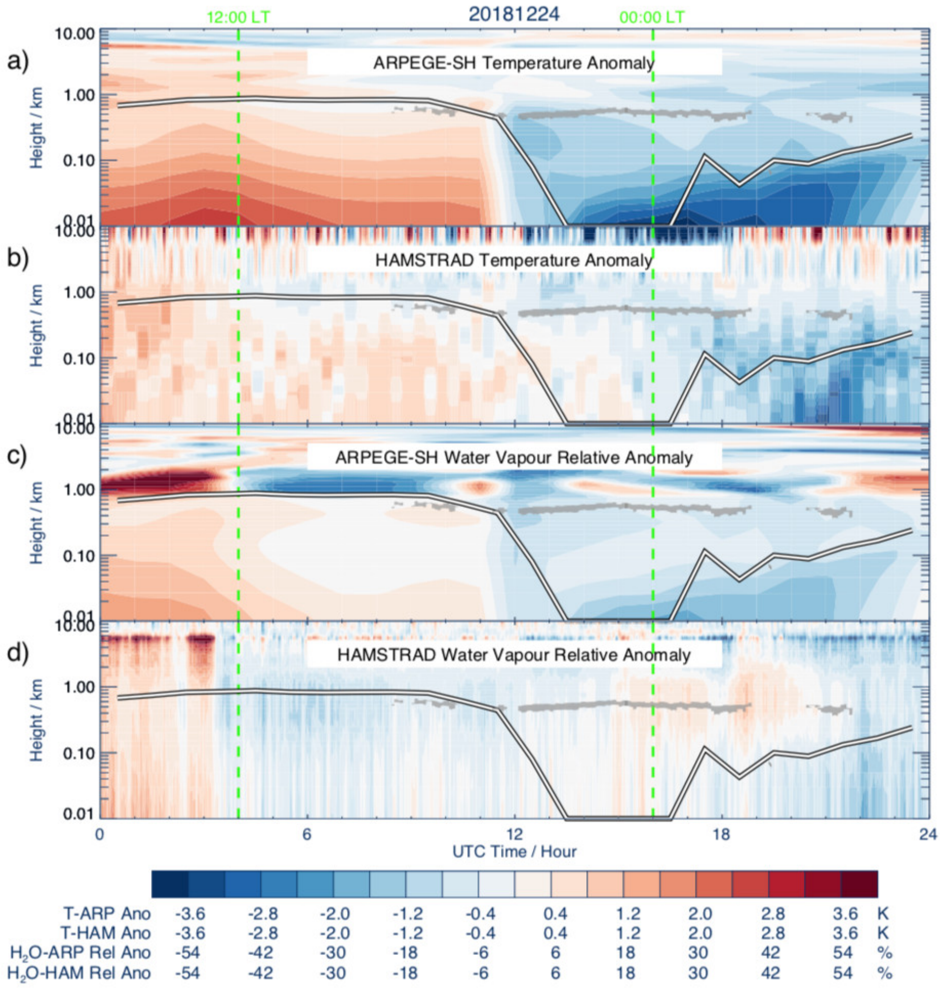

Figure 6: *Time-height cross section on 24 December 2018 (UTC Time) of a) the temperature anomaly (K) calculated by ARPEGE-SH and b) observed by HAMSTRAD, c) the water vapour relative anomaly (%) calculated by ARPEGE-SH and d) observed by HAMSTRAD. Superimposed to all the Figures are the SLW cloud altitude (grey area) deduced from the LIDAR observations (see Fig. 1c) and the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

Figure 6 - Please use other color for observed SLW as it is the same red as in the colour scale.

→ We modified the incriminated Figure (now Figure 7) according to the comments of the reviewer.

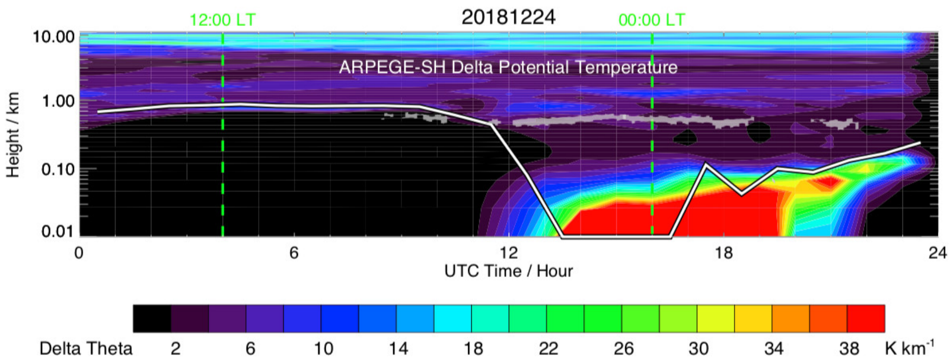

***Figure 7:** Time-height cross section of ∂θ/∂z (K km^{-1}) calculated from ARPEGE-SH temperature on 24 December 2018 (UTC Time). Superimposed are the SLW cloud altitude (grey area) deduced from the LIDAR observations (see Fig. 2) and the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

Figure 9 – “simulated with” rather than “calculated by”?

→ We have modified the relevant Figure (now Figure 15) caption accordingly.

Figure 15: (Top) Diurnal variation of the net surface radiation (W m^{-2}) observed by BSRN (black solid line) and simulated with ARPEGE-SH (red crossed line) on 24 December 2018 in UTC Time. Superimposed is the SLW cloud altitude (blue) deduced from the LIDAR. (Middle) Diurnal variation of the difference between surface radiation (W m^{-2}) observed by BSRN and simulated by ARPEGE-SH on 24 December 2018 for longwave downward (black solid), longwave upward (black dashed), shortwave downward (black dashed dotted) and shortwave upward (black dashed triple dotted) components. Superimposed is LWP (blue) measured by HAMSTRAD. (Bottom) Four webcam images showing the cloud coverage at: a) 00:25 UTC and b) 03:56 UTC (cirrus clouds, no SLW cloud), c) 09:46 UTC (SLW cloud) and d) 17:20 UTC (SLW cloud). Two vertical green dashed lines indicate 12:00 and 00:00 LT.

Figure 11 – It might be better to use white colour for the PBL height.

→ We modified the incriminated Figure (now Figure 10) according to the comments of the reviewer and former Figure 10 (now Figure 9) to be consistent with Figure 2 and the comments from the reviewer #2. Also we started to show the LIDAR data from 20 m agl consistently with the description of the LIDAR instrument (section 2.2.).

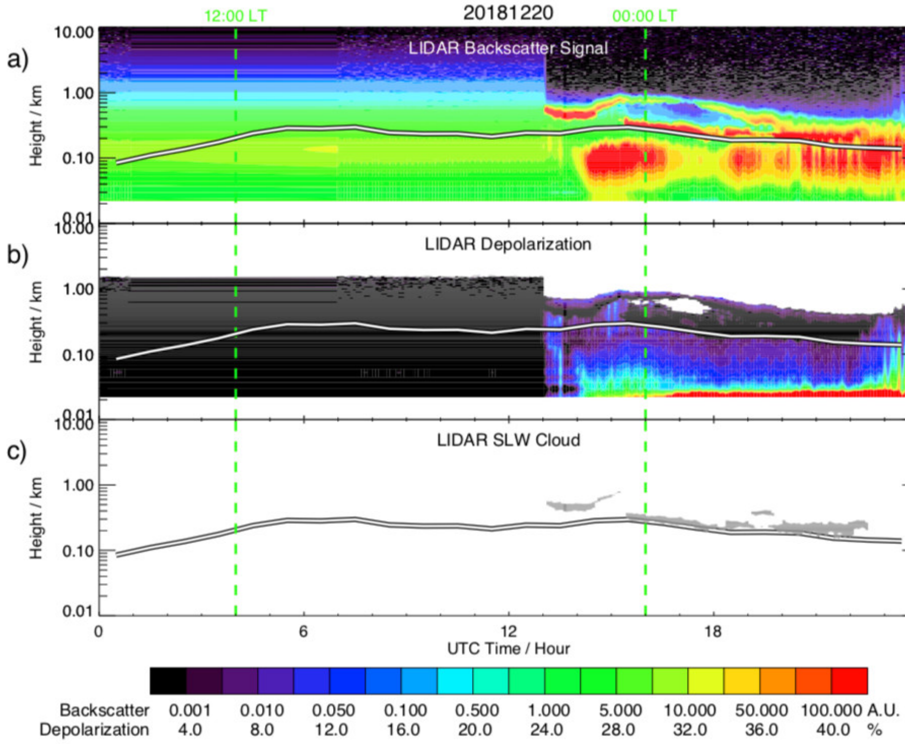

Figure 9: *Same as Figure 2 but for 20 December 2018.*

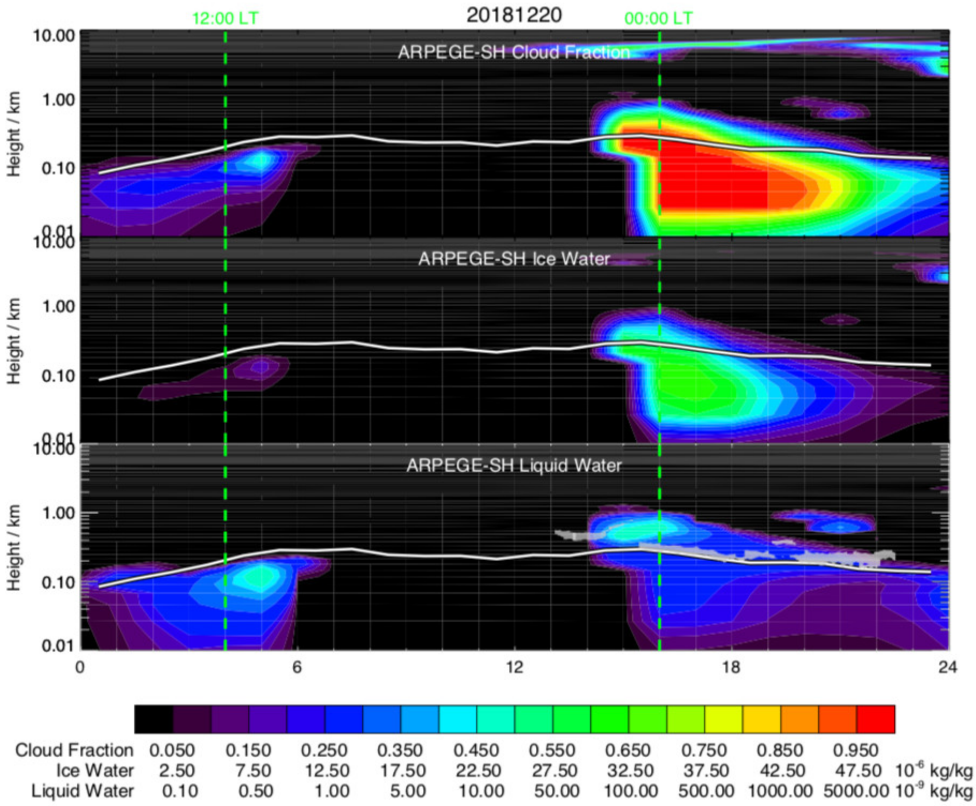

Figure 10: *Same as Figure 3 but for 20 December 2018.*

Figure 13 - red text is not visible. Also, the red colour chosen to show the presence of the SLW observed by the LIDAR is the same red as the colour scale. Please change this. This was not so problematic in Figure 5 but it is here.

→ We modified the incriminated Figure (now Figure 12) according to the comments of the reviewer and the comments from the reviewer #2.

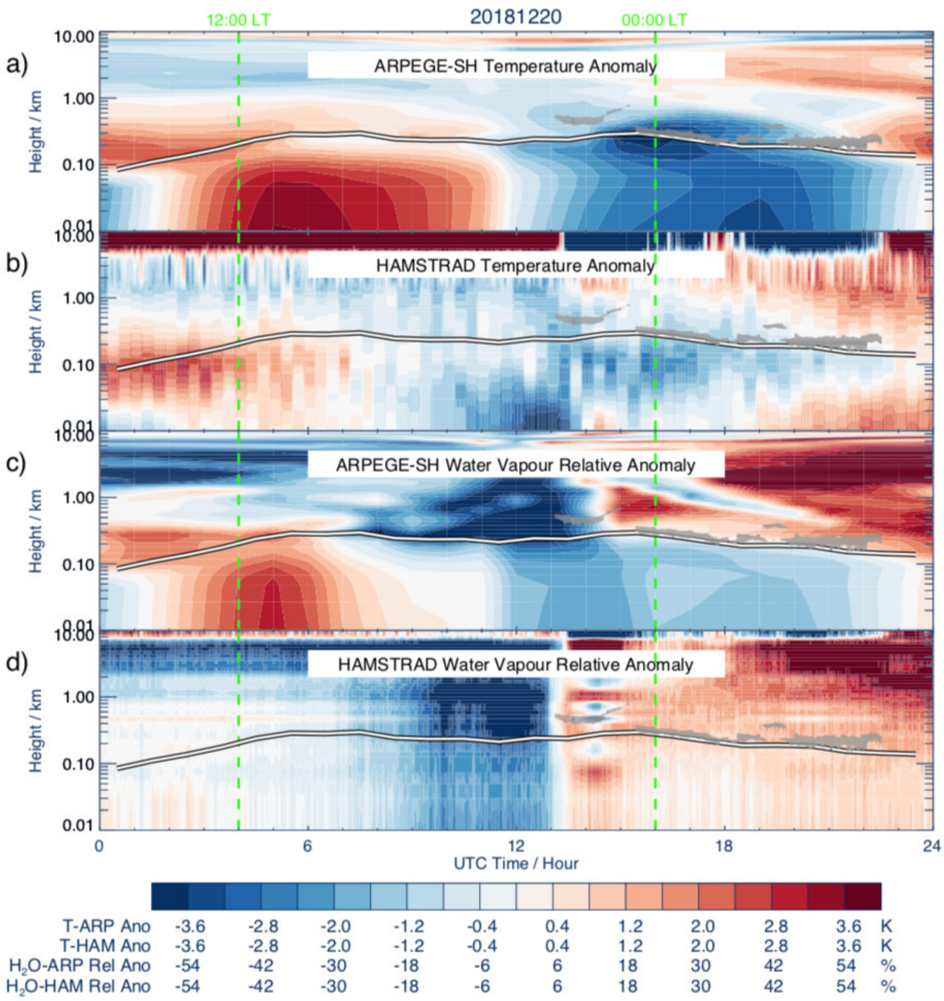

Figure 12: *Same as Figure 6 but for 20 December 2018.*

Figure 14 - using red colour for SLW and the same red for the colour scale should be avoided.

→ We modified the incriminated Figure (now Figure 13) according to the comments of the reviewer.

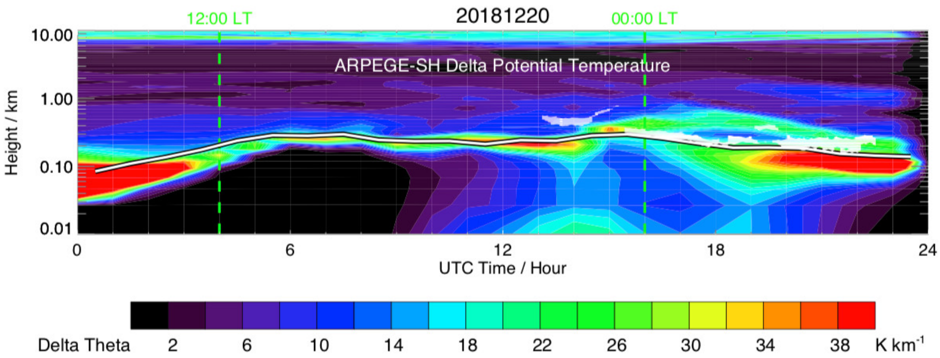

***Figure 13**: Same as Figure 7 but for 20 December 2018.*

Anonymous Referee #2

Review of "*Supercooled Liquid Water Clouds observed and analysed at the Top of the Planetary Boundary Layer above Dome C, Antarctica*" by Ricaud et al.

→ Both reviewers requested structural changes to the paper, as well as provided line edits. The line edits were made before large passages were moved around. In response to suggestions from the reviewers, a section focused on the impact of the SLW clouds has been created as well as a Discussion section. As suggested by the reviewers, we have created a supplementary file where additional information has been inserted. The reviewers' comments are recalled in blue and changes in the revised version are highlighted in yellow. In the following responses, note that Figures and Table are labelled as follows:

Figs. 1-18: Figures shown in the revised manuscript
Figs. Supp1-Supp14: Figures shown in the Supplementary Materials
Figs. R1-R4: Figures only shown in the Replies to the Reviewers
Table R1: Table only shown in the Replies to the Reviewers

Ricaud et al. present a very nice study of two cases of supercooled liquid water cloud layers measured using a suite of remote sensing instruments at Dome C, Antarctica in the summer of 2018. Exemplar cases of a "typical" and a perturbed boundary layer are detailed to show what cloud and boundary layer properties may be expected in the region and how these properties can be affected by warm moist oceanic air masses. The authors show that these perturbed boundary layers can greatly change the radiative properties of the clouds which form within them and thus affect the surface energy balance.

Comparisons with the ARPEGE-SH model show that the model fails to capture key observed characteristics of the clouds and boundary layer structure in both scenarios; specifically, the model severely underpredicts cloud supercooled liquid water and exhibits almost systematic biases in temperature and water vapour with respect to the observations. The failure of the model to capture cloud presence and phase distribution the both cases is very important to highlight to the community. The difference between observed and modelled net surface radiation in the perturbed case (up to 50 W/m^2) is particularly striking.

The study is well explained and provides clear figures to support the conclusions drawn from the observation-model and inter-case comparisons. It will provide an excellent resource as a reference study for future observation-model comparisons focusing on boundary layers on the Antarctic Plateau. The authors operate with transparency by providing access to all data used within the study, which is fantastic to see. I recommend publication subject to some minor comments and restructuring.

→ Thank you for your positive comments.

General comments:

I appreciate that statistical analyses of PBL properties measured/modelled at Dome C is within the future work remit of this study; however, it would be useful to provide the reader with an estimation of how representative each of these two cases were for e.g. the summer of 2018/19. It would be useful to know how typical is "typical" with perhaps an estimation of occurrence percentage. Also, it would be helpful to have some synoptic overview of the two cases presented, perhaps as a supplementary to the manuscript, with some reference to the mean synoptic state over e.g. the summer of 2018/19.

→ We have added in CLW occurrence statistics for the YOPP period as well as more general statistics from data available at Dome C over the past several years. The new text appears in the Discussion section (7.2. SLW Clouds and PBL) together with a new Figure 17.

We have both assessed reanalysis data and performed a preliminary analysis of synoptic states for this time period. This is presented in the new section 3. Methodology.

See replies to the Reviewer#1 for a detailed description of both new sections.

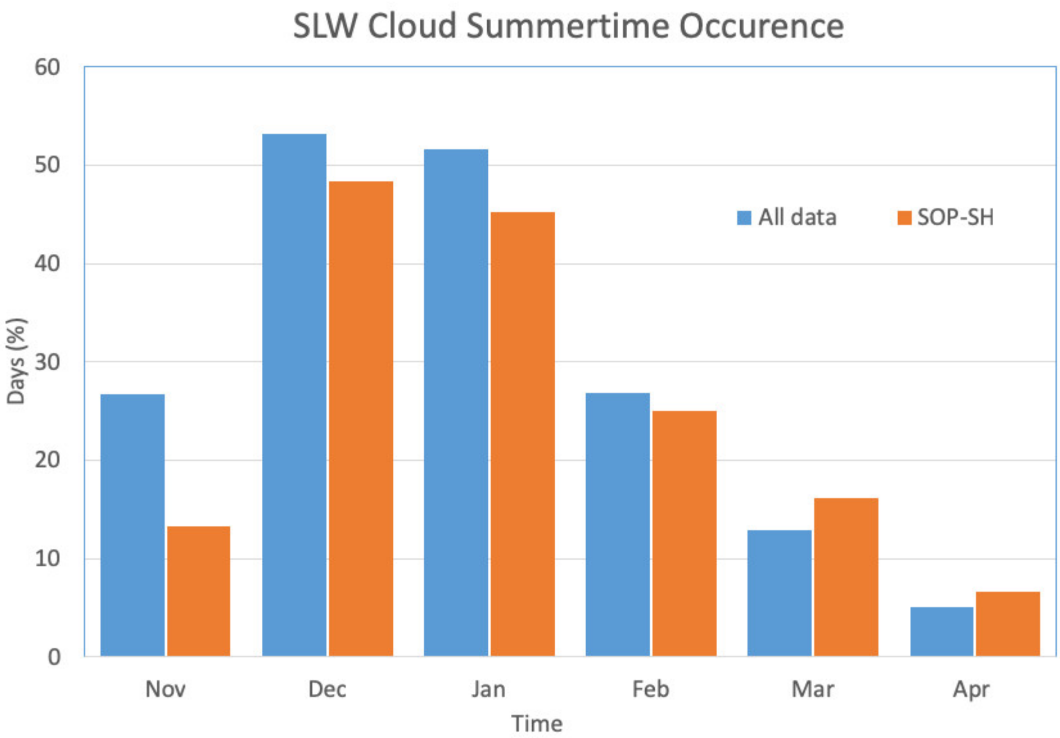

Figure 17: *Percentage of days per month that SLW clouds were detected within the LIDAR data for more than 1 hour per day over the following summer periods: all data (blue) represent the following months November (2016-2018), December (2016-2018), January (2018-2019), February (2018-2019) and March (2018-2019) whilst SOP-SH (orange) represent the YOPP campaign (November 2018 to April 2019). A day is flagged with a SLW cloud occurrence when a SLW cloud has been detected in the LIDAR observations for a period longer than 1 hour.*

The authors mention that model 24-h model forecasts and meteorological analyses were provided, where 4D-VAR data assimilation of the latter took place every 6 h. It is stated that most of the model- observation comparison uses the forecasts, while the analyses are used at 0000 UTC and 1200 UTC (understandably due to radiosonde ingestion improving the comparison and providing a "best guess" at these times). What is unclear to me is the combination of these two datasets, and this should be made clearer in the manuscript. When are the forecasts initialised? Are they initialised every 12-h (0000 UTC or 1200 UTC) or once per day? Are they 24-h in total, or are 24 hours of each forecast (which may be for longer) used for comparison with the observations? Or, are they 24-h in total, initialised twice daily at 0000 UTC or 1200 UTC, providing the latter 12 hours for comparison with the observations (to avoid any spin up issues)?

→ When the manuscript was initially submitted, two analyses at 00:00 and 12:00 UTC were available together with hourly forecasts, initialized by these two analyses, from 01:00 to 11:00 and from 13:00 to 24:00 UTC, respectively.

We have inserted a new sentence when describing ARPEGE-SH.

> Two analyses at 00:00 and 12:00 UTC were represented in the present study together with hourly forecasts initialized by the two analyses from 01:00 to 11:00 and from 13:00 to 24:00 UTC, respectively.

Since the submission of the initial manuscript, four hourly forecasts became available, initialized with the analyses at 00:00, 06:00, 12:00 and 18:00 UTC and covering 78, 6, 78 and 6 hours, respectively. Only a 6-h forecast is performed at 06:00 and 18:00 UTC as required for the 4Dvar cycle.

Figures R3 and R4 are an update of the former Figures 3 and 12 initially presented in the manuscript where we have highlighted the ARPEGE forecasts initialized from the analyses at 00:00 (red asterisks), 06:00 (green crosses), 12:00 (orange circles) and 18:00 UTC (blue diamonds).

It is interesting to note that the underestimation of the SLW in ARPEGE is not significantly modified when considering the 4 forecasts and the 4 analyses. This can be explained by the fact that: 1) the underestimation of liquid water is mainly a physical problem in the model related to the ice/liquid partition function vs. temperature (see e.g. Fig. Supp8) and 2), since cloud water is not a model control variable in the 4DVar scheme, cloud water cannot be analyzed. A micro-physical adjustment is nevertheless performed in the forecast atmospheric state (humidity, temperature and wind). As an example, on 24 December 2018 at 12:00 UTC, some differences of Total Column of Ice (TCI), Liquid Water Path (LWP) and Integrated Water Vapour (IWV) are obviously depicted between the analysis at 12:00 UTC and the forecasts initialized at 00:00 and 06:00 UTC.

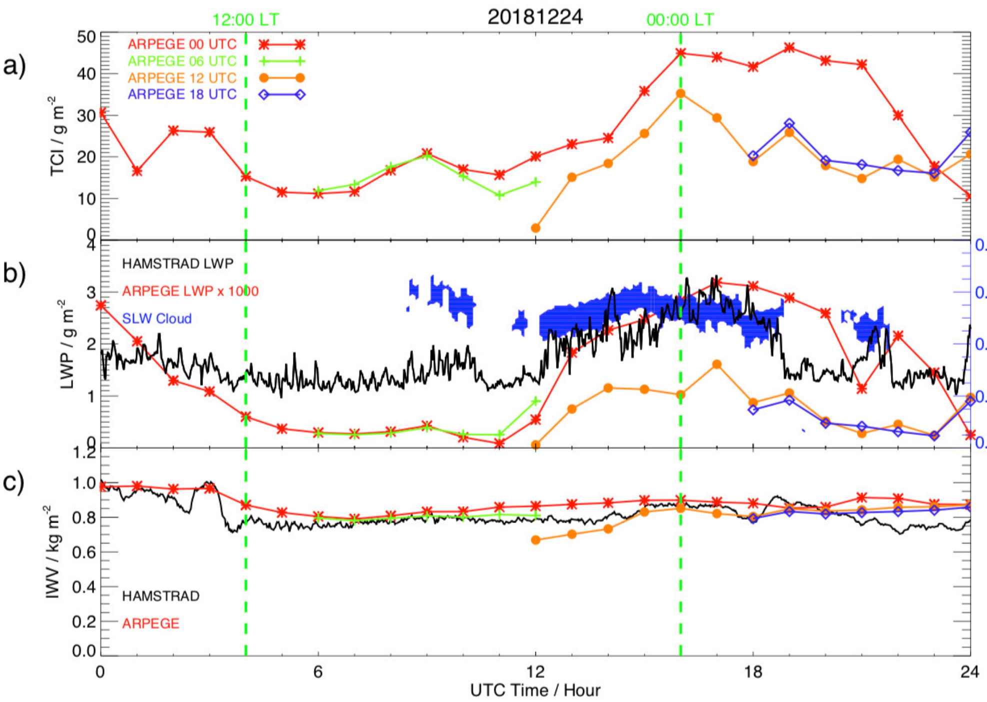

Figure R3: *Diurnal variations on 24 December 2018 (UTC Time) calculated by ARPEGE-SH, from the analyses at 00:00 UTC (red line with asterisks), 06:00 UTC (green line with crosses), 12:00 UTC (orange line with filled circles) and 18:00 UTC (blue line with diamonds), of: a) the Total Column of Ice (TCI) (g m^{-2}), b) the Liquid Water Path (LWP) (x1000 g m^{-2}, black solid line) and c) the Integrated Water Vapour (IWV, kg m^{-2}). Superimposed to panel b) are the LWP measured by HAMSTRAD (g m^{-2}, black solid line) and the SLW cloud thickness (blue area) deduced from the LIDAR observations (see Fig. 1c) (blue y-axis on the right of the Figure). Note that LWP from ARPEGE-SH has been multiplied by a factor 1000. Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

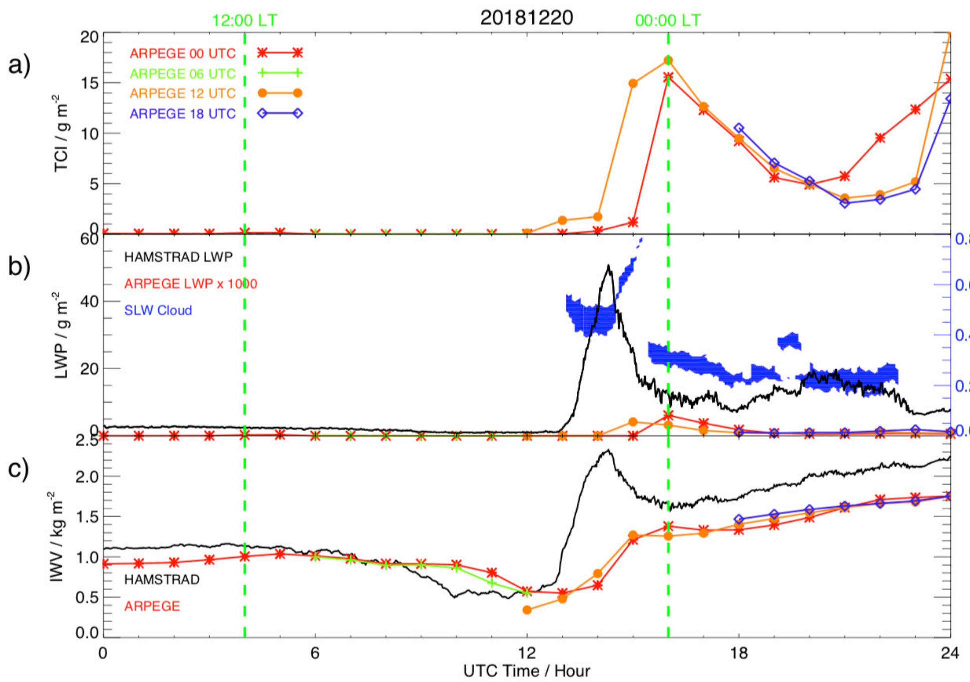

Figure R4: Same as Figure R3 but for 20 December 2018.

Indeed, if 12-h subsets of the 24-h forecasts are used, with each beginning at either 0000 UTC or 1200 UTC, then the sharp transitions at 1200 UTC would be somewhat expected from this re-initialisation as the model is effectively brought from maximum divergence back to the “best guess” of the atmospheric state. The authors mention the poor agreement in cloud properties at 1100 UTC and 2300 UTC in Section 3.1, so I am inclined to believe this is how the model is being operated. One would expect improved agreement with the observations at these re-initialisation times (albeit there may still be some discrepancies with the observations which should be emphasised). If I have misunderstood, please accept my apology; however, I feel that the model use and implications of using it in forecasting mode should be discussed in greater detail with a focus on how this re-initialisation (if conducted) may be affecting any of the conclusions drawn with respect to the transitions between wet/dry conditions. Additionally, if this is the case, there is scope for more discussion on model deficiencies: if the model diverges so strongly within the forecast comparison window, it may suggest severe parametrization deficiencies within the model.

→ This point is discussed above with appropriate Figures.

Following from this last point, the study would benefit from more discussion on why the model fails to capture the SLW layers, perhaps with specific reference to which cloud microphysical parametrizations are used within the model. Did the authors look into the process parametrizations and identify which may need to be changed to remedy the poor model-observations comparison? E.g. are the deposition freezing / Wegener-Bergeron-Findeisen mechanisms too efficient? To what extent can the SLW deficiency be caused by the poor agreement in temperature / water vapour?

→ First of all, we have considered the ice partition function (ice/liquid water vs temperature) actually used in the ARPEGE-SH NWP model (Figure Supp8) to perform analyses and forecasts. We noticed that, for temperature less than -20°C, water was only present in the solid form in the model. A test has been performed for two dates with ARPEGE-SH on 20 and 24 December 2018 by considering a new ice partition function allowing the presence of liquid water for temperature less than -20°C down to -40°C (Figure Supp8).

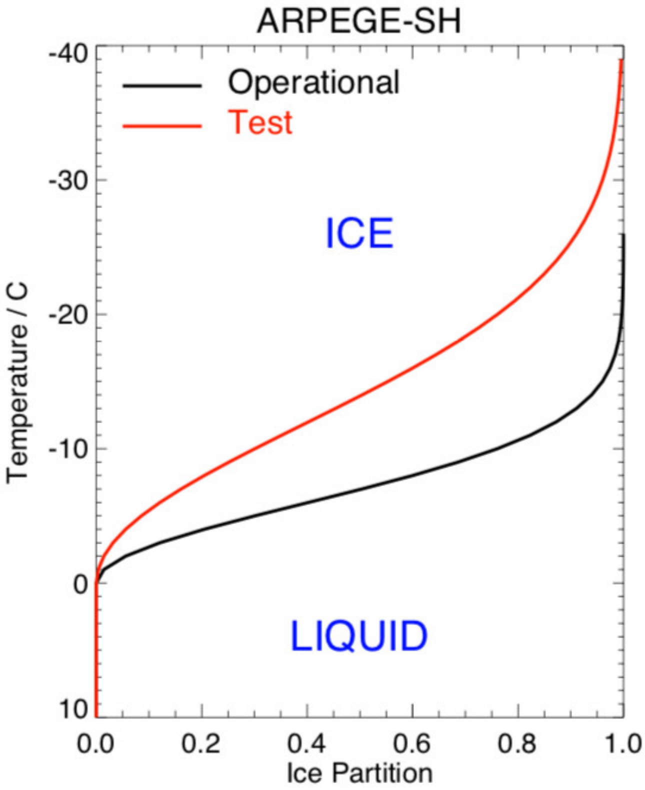

Figure Supp8: *Ice/Liquid Water partition as a function of temperature used in the ARPEGE-SH NWP operational model (black) and in the "test" modified version (red).*

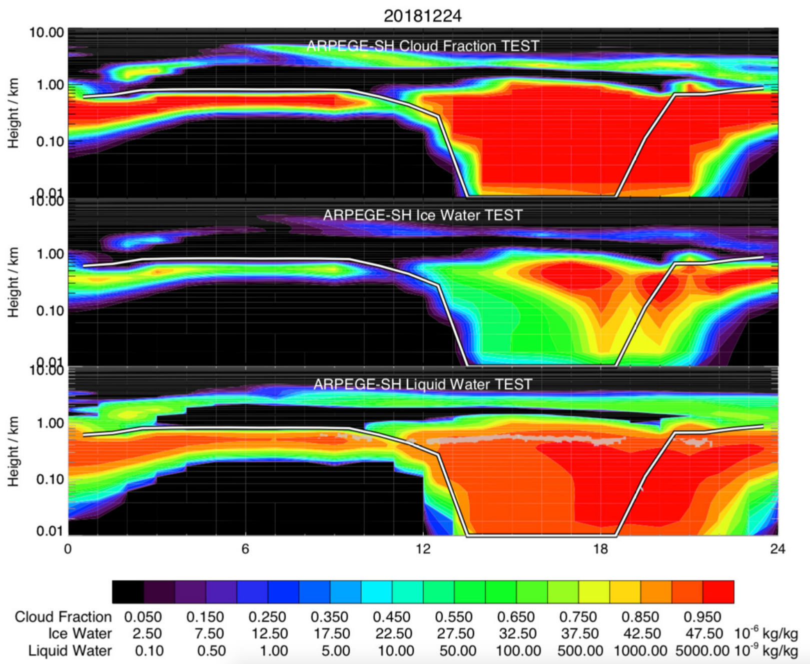

Figure Supp9: *Time-height cross section on 24 December 2018 (UTC Time) of: a) the Cloud Fraction (0-1), b) the Ice Water mixing ratio (10-6 kg kg-1) and c) the Liquid Water mixing ratio (10-6 kg kg-1) calculated by the ARPEGE-SH model in test mode (new ice partition function). Superimposed to all the panels is the top of the Planetary Boundary Layer calculated by the ARPEGE-SH model (black-white thick line). Superimposed in panel c is the SLW cloud (grey area) height depth deduced from the LIDAR observations (see Fig. 2c).*

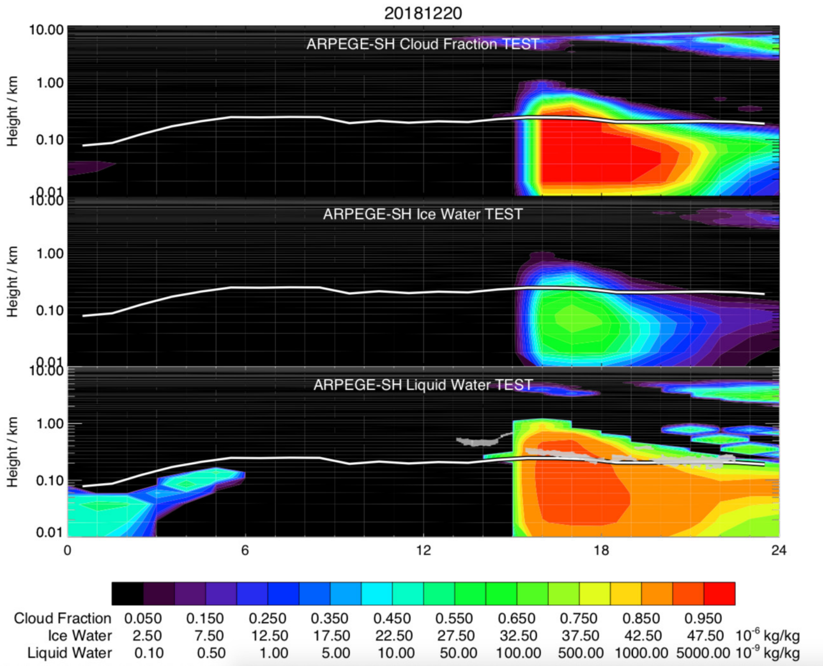

Figure Supp10: *Same as Figure Supp9 but on 20 December 2018 (UTC Time).*

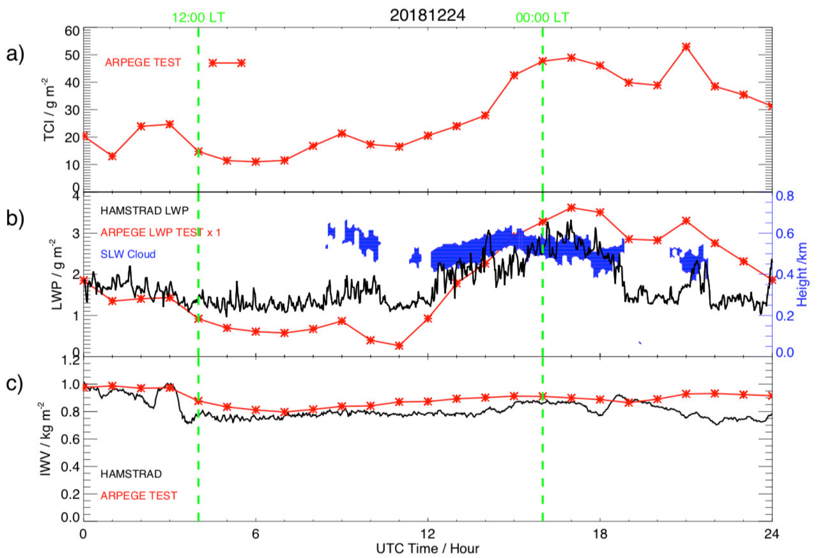

Figure Supp11: *Diurnal variation on 24 December 2018 (UTC Time) of: a) the Total Column of Ice (TCI) (g m^{-2}) calculated by ARPEGE-SH in test mode (red crossed line), b) the Liquid Water Path (LWP) measured by HAMSTRAD (g m^{-2}, black solid line) and calculated by ARPEGE-SH in test mode (-no scaling- g m^{-2}, red crossed line) and c) the Integrated Water Vapour (IWV, kg m^{-2}) measured by HAMSTRAD (black solid line) and calculated by ARPEGE-SH in test mode (red crossed line). Superimposed to panel b) is the SLW cloud thickness (blue area) deduced from the LIDAR observations (see Fig. 1c) (blue y-axis on the right of the Figure). Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

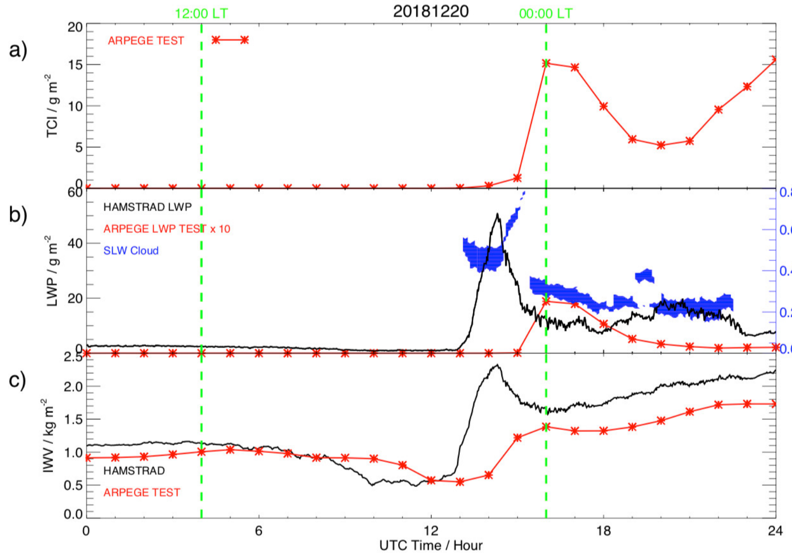

Figure Supp12: *Same as Figure Supp11 but on 20 December 2018 (UTC Time) and LWP from ARPEGE-SH in test mode has been multiplied by a factor 10.*

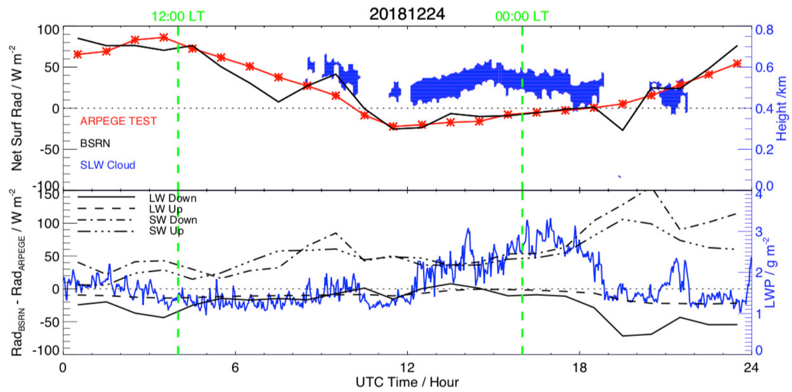

Figure Supp13: *(Top) Diurnal variation of the net surface radiation (W m^{-2}) observed by BSRN (black solid line) and calculated by ARPEGE-SH in test mode (red crossed line) on 24 December 2018 in UTC Time. Superimposed is the SLW cloud altitude (blue) deduced from the LIDAR. (Bottom) Diurnal variation of the difference between surface radiation (W m^{-2}) observed by BSRN and calculated by ARPEGE-SH in test mode on 24 December 2018 for longwave downward (black solid), longwave upward (black dashed), shortwave downward (black dashed dotted) and shortwave upward (black dashed triple dotted) components. Superimposed is LWP (blue) measured by HAMSTRAD. Two vertical green dashed lines indicate 12:00 and 00:00 LT.*

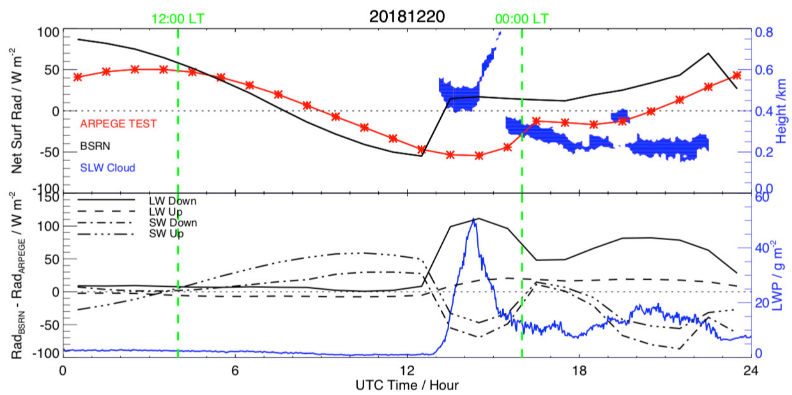

Figure Supp14: *Same as Figure Supp13 but on 20 December 2018 (UTC Time).*

Secondly, we have not yet looked at the the process parameterizations. However, thanks to the test with the modified ice partition function, the causes of the deficiencies in producing SLW clouds for the two dates are probably not the same. On 24 December 2018 (typical case), the new function improves significantly the SLW, together with the surface net radiation. Unfortunately, on 20 December 2018 (perturbed case), even if the impact on SLW clouds is important (SLW multiplied by a factor 100), the underestimation factor of modelled vs observed LWP is still 10. For this later date, the increase of the IWV at 13:00-14:00 UTC is not well captured by ARPEGE-SH, even if we start the forecast at 12:00 UTC.

Thirdly, the deposition freezing / Wegener-Bergeron-Findeisen mechanisms are not explicitly parameterized in the simple micro-physics of the ARPEGE-SH NWP.

Fourthly, the poor agreement in temperature/water vapour of the model cannot be totally ruled out to correctly capture the SLW cloud, particularly during the perturbed case of 20 December 2018 when observation-model differences in LWP and surface net radiations are obviously highlighted.

The above discussion and associated Figures are presented in the Discussion subsection (7.3 SLW Clouds in ARPEGE-SH) and in the Supplementary Materials, respectively.

A new section has been inserted in the revised manuscript within the Discussion Section.

7.3 SLW Clouds in ARPEGE-SH

In comparison with observations, ARPEGE-SH consistently underestimates the liquid cloud condensate by several orders of magnitude. This is due in part to how the partitioning of cloud condensate into liquid and ice in the model is a simple function of temperature such that below -20°C all cloud particles are ice. The inability of ARPEGE-SH to reproduce the observed liquid water content of the cloud leads to an underestimate of the simulated downwelling longwave radiation relative to observations, and an overestimate of both upwelling and downwelling shortwave flux. This effect is particularly notable in the perturbed PBL case study where the high moisture content leads to an enhanced longwave effect. As the SLW horizontal extent in the first case study is about 280 km and persists over more than 12 hours (section 3.1), the discrepancy in the net surface radiation between observation and NWP model may have a strong impact on the calculation of the radiation budget over Antarctica. Lawson and Gettelman (2014) showed that better representation of liquid water in modelled mixed phase clouds in Global Climate Models led to an increase of the 7.4 $W.m^{-2}$ in the cloud radiative effect over Antarctica.

Furthermore, even when considering analyses of ARPEGE-SH at 00:00, 06:00, 12:00 and 18:00 UTC and associated forecasts (not shown), the underestimation of the SLW in ARPEGE-SH is not significantly modified, both in IWV and LWP. The 4Dvar analysis is not able to correct the dry bias especially during the case of 20 December 2018 probably because it is induced by large-scale advection. The underestimation of the SLW in ARPEGE-SH can be explained by the fact that: 1) the underestimation of liquid water is mainly a physical problem in the model related to the ice/liquid partition function vs temperature (see below) and 2), since cloud water is not a model control variable in the 4DVar scheme, cloud water cannot be analyzed.

We have thus tried to modify the ice partition function (ice/liquid water vs temperature) used in the ARPEGE-SH operational model (Figure Supp8). We noticed that, for temperatures below -20°C, water was present only in the solid form in the model. A test has been performed for 20 and 24 December 2018 with ARPEGE-SH by considering a new ice partition function allowing the presence of liquid water for temperature between -20°C and -40°C (Figure Supp8). The analyses were done at 00:00 UTC and the forecasts from 01:00 to 24:00 UTC. This run was labelled as ARPEGE-SH-TEST.

For 24 December 2018, and consistently with Fig. 3, we have drawn on Fig. Supp9 the diurnal evolutions of different variables calculated by ARPEGE-SH-TEST: a) the Cloud Fraction, b) the Ice Water mixing ratio and c) the Liquid Water mixing ratio. Similarly, and consistently with Fig. 4, Figure Supp11 presents: a) the ARPEGE-SH-TEST TCI, b) the LWP measured by HAMSTRAD and calculated by ARPEGE-SH-TEST and c) the IWV measured by HAMSTRAD and calculated by ARPEGE-SH-TEST. Eventually, and consistently with Fig. 9, Figure Supp13 presents the net surface radiation observed by BSRN and calculated by ARPEGE-SH-TEST, and the difference between surface radiation of longwave downward, longwave upward, shortwave downward and shortwave upward components observed by BSRN and calculated by ARPEGE-SH-TEST. In the same manner, for the case of 20 December 2018, Figs. Supp10, Supp12 and Supp14 echo Figs. 11, 12 and 16, respectively.

On 24 December 2018 (typical case), the new partition function improves significantly the SLW, with liquid water about 1000 times greater in ARPEGE-SH-TEST than in ARPEGE-SH, and LWP varying from ~0 to ~3 g m^{-2} consistently with HAMSTRAD to within ±0.5 g m^{-2}. The impact on the net surface radiation is obvious with an excellent agreement between ARPEGE-SH-TEST and BSRN to within ±20 W m^{-2}. Unfortunately, on 20 December 2018 (perturbed case), even if the impact on SWL clouds is important (liquid water multiplied by a factor 100), LWP is still a factor 10 less in ARPEGE-SH-TEST than in HAMSTRAD. ARPEGE-SH-TEST still fails to reproduce the large increase in liquid water and IWV at 13:00 UTC since the local maximum is calculated 2 hours later. The impact on the net surface radiation is weak with ARPEGE-SH-TEST underestimating the net surface radiation by 50 W m^{-2} compared to observations, mainly attributable to longwave downward surface radiation from BSRN being 100 W m^{-2} greater than that of ARPEGE-SH-TEST.

Finally, the bias on the net surface radiation and the underestimation of IWV and LWP of the model compared to the observations is strongly reduced when using a new ice partition function in ARPEGE-SH-TEST. This tends to show that probably LWP has more impact than IWV on LW↓ due to the small quantities of specific humidity at Dome C.

We have also inserted a new paragraph in the Conclusions.

The ice/liquid partition function used in the ARPEGE-SH NWP has been modified to favour liquid water at temperatures less than -20°C down to -40°C. For the two study cases, the model run with this new partition function has been able to generate SLW clouds. During the typical case, modelled LWP was consistent with observations and, consequently, the net surface radiation calculated by the model agreed to measurements to within ±20 W m^{-2}. During the perturbed case, modelled LWP was a factor 10 less than observations and, consequently, the model underestimated the net surface radiation by ~50 W m^{-2} compared to observations.

We have also inserted 2 new sentences in the Abstract.

The model was run with a new partition function favouring liquid water below -20°C down to -40°C. In this test mode, ARPEGE-SH has been able to generate SLW clouds with modelled LWP and net surface radiation consistent with observations during the typical case but, during the perturbed case, with modelled LWP a factor 10 less than observations and a modelled net surface radiation by ~50 W m^{-2} less than in the observations.

The study is well written; however, it could benefit from a distinct Discussion section for the case and literature comparisons. For example, the 1st paragraph and point (1) of the last paragraph of Section 3.2, 4th and 5th paragraphs of Section 3.3 etc. read like a discussion and should be presented separately from the main study results.

→ We agree, and we have moved these passages, and other appropriate ones to a new "Discussion" section.

Also, the following additional references could be of benefit to the study:

- O'Shea, S. J., Choularton, T. W., Flynn, M., Bower, K. N., Gallagher, M., Crosier, J., Williams, P., Crawford, I., Fleming, Z. L., Listowski, C., Kirchgaessner, A., Ladkin, R. S., and Lachlan-Cope, T.: In situ measurements of cloud microphysics and aerosol over coastal Antarctica during the MAC campaign, Atmos. Chem. Phys., 17, 13049–13070, doi:10.5194/acp-17-13049-2017, 2017.
- Grosvenor, D. P., Choularton, T. W., Lachlan-Cope, T., Gallagher, M. W., Crosier, J., Bower, K. N., Ladkin, R. S., and Dorsey, J. R.: In-situ aircraft observations of ice concentrations within clouds over the Antarctic Peninsula and Larsen Ice Shelf, Atmos. Chem. Phys., 12, 11275-11294, doi:10.5194/acp-12-11275-2012, 2012.
- Young, G., Lachlan-Cope, T., O'Shea, S. J., Dearden, C., Listowski, C., Bower, K. N., et al. Radiative effects of secondary ice enhancement in coastal Antarctic clouds. Geophysical Research Letters, 46. doi:10.1029/2018GL080551, 2019.
- King, J. C., Gadian, A., Kirchgaessner, A., Kuipers Munneke, P., Lachlan-Cope, T. A., Orr, A., Reijmer, C., Broeke, M. R., van Wessem, J. M., and Weeks, M.: Validation of the summertime surface energy budget of Larsen C Ice Shelf (Antarctica) as represented in three high-resolution atmospheric models, J. Geophys. Res. Atmos., 120, 1335–1347, doi:10.1002/2014JD022604, 2015.

→ All of these references were added to the text, along with some additional ones suggested by the other reviewer.

Specific comments:

Page 2, line 29: Please define ARPEGE-SH as an acronym at first point of use.

→ The definition of ARPEGE-SH (Action de Recherche Petite Echelle Grande Echelle – Southern Hemisphere) was added at this location in the manuscript.

Page 5, line 89: Please define YOPP SOP as SOP-SH to avoid confusion with SOPs 1-3 in the northern hemisphere. This is described in more detail in Section 2.6, but it would be beneficial to move these specific dates up to this point (or just repeat).

→ This change was made at this location and the usage of YOPP-SH was changed to SOP-SH in section 2.6. The dates were already present in this section, but we corrected a difference in the starting date between this location and section 2.6.

Page 5, line 95: Here, it is not clear what the authors mean by the "adjustable time resolution" statement, as it is not clear whether 7 mins was chosen as the time resolution or whether it is the limit of what is achievable by the instrument. However, this becomes clear within the Methods section. Please rephrase for clarity or remove.

→ We have clarified this. The integration time is adjustable. During YOPP, it was fixed to be 60 seconds. An automated internal calibration is performed every 12 atmospheric observations and lasts about 4 minutes. Consequently, the atmospheric time sampling is 60 seconds for 12 atmospheric measurements followed by 4 minutes. We have thus performed 2 changes.

L. 95: we have modified the sentence into:

> (…) with an adjustable time resolution fixed at 60 seconds during the YOPP campaign.

L. 126: idem for this line.

> The time resolution is adjustable and fixed at 60 seconds during the YOPP campaign. Note that an automated internal calibration is performed every 12 atmospheric observations and lasts about 4 minutes. Consequently, the atmospheric time sampling is 60 seconds for a sequence of 12 atmospheric measurements and a new atmospheric sequence is performed after 4 minutes.

Page 6, line 117: typo (synthesizes)

→ This typo was corrected.

Section 2.1: can the authors comment of whether you would expect instrument functionality to be affected by the altitude difference between Pic du Midi and Dome C?

→ The radiometer functionality is better adapted for the Dome C site than for the Pic du Midi site. It has been designed and developed for measuring water vapour in very dry and cold environment such as those encountered at the Dome C station all year long. At the Pic du Midi, these kinds of environment can only be found during the wintertime period. At Dome C, the instrument is located inside a dedicated shelter at room temperature between 10°C and 20°C. At the Pic du Midi, the instrument was installed outdoors at temperatures from -20°C to +20°C, and could not operate during snow tempests because of snow accumulation on the observational window of the radiometer. The altitude of the site does not affect the functionality of the instrument itself but, on average, the higher the altitude the drier the atmosphere and the better the instrument sensitivity. Regarding LWP, it has not been possible to validate this parameter at the Pic du Midi station. This is a unique opportunity to perform such a qualitative validation against Lidar observations of SLW. We have commented this point by inserting the following sentences.

L.140: We inserted a new paragraph.

> Because the instrument has been designed and developed for measuring water vapour in very dry and cold environments such as those encountered at the Dome C station all year long, the radiometer functionality is better adapted for the Dome C site than for the Pic du Midi site. It has not been possible to validate LWP observations at the Pic du Midi station. The H_2O-DC project has thus provided a unique opportunity to perform such a qualitative validation against LIDAR observations of SLW.

Section 2.2 (and throughout): The authors often refer to measurements with respect to mean sea level; however, given the high altitude of Dome C, this is misleading to the reader. Please could measurements made at Dome C be rephrased to "above ground level"? This would avoid any confusion.

→ The choice to use above mean sea level (amsl) is to compare to the satellite retrievals which are measured amsl. However, where possible, we converted to above ground level (agl) to decrease confusion. This has been carefully checked in the revised manuscript. We have inserted this sentence.

> Note that, in the remaining of the article, we will present the altitude above ground level (agl) unless explicitly shown as above mean sea level (amsl).

Section 2.6: How many model levels were within the PBL? Can the authors comment on whether the vertical resolution of the model may limit its ability to capture the ~100m thick SLW clouds observed? Additionally, the spatial resolution is quite coarse: Young et al., 2019 (full reference above) found that resolution can affect cloud modelling skill, can the authors comment on whether this may be affecting their comparisons?

→ Regarding the vertical resolution of the model, there are 12 levels below 1 km and 35 levels below 3 km, as indicated in the revised manuscript. This might be indeed a limiting factor since the vertical level size is of the same order as the SLW cloud thickness. However, as shown above, the ability of the model to represent the SLW clouds is mainly coming from the ice partition function used, and the major improvements are expected from a better formulation of this function.

Page 11, lines 222-223: Is it not only the SLW from the lidar that is shown in Figure 2?

→ Yes, you are correct. We removed "ice" from this sentence.

Page 11, lines 232 – 234: Small values are presented from the HAMSTRAD, what is the measurement accuracy of this instrument?

→ The 1-σ RMS error on the 7-min integration time HAMSTRAD IWV is 0.05 kg m^{-2} or ~ 5% (Ricaud et al., 2013). In general, the summer bias (~ 0.1 kg m^{-2}) is on average twice that of the winter bias (~ 0.05 kg m^{-2}) mainly because IWV is twice as great in summer (~0.6–0.7 kg m^{-2}) as in winter (0.3 kg m^{-2}) (Ricaud et al., 2015). We have inserted the following sentence in the revised manuscript.

> The 1-σ RMS error on the 7-min integration time IWV is 0.05 kg m^{-2} or ~5% (Ricaud et al., 2013).

Regarding LWP, as stated above, this is the first time some validation process is performed. From the diurnal evolution of the 1-min integration time of LWP presented in former Figs. 3b and 12b (now Figs. 4b and 11b), we can estimate the 1-σ variability of LWP to be ~15%. Biases are much more difficult to assess because external observational data sets are needed in coincidence (time and space) with HAMSTRAD measurements. We did get these pieces of information neither at the Pic du Midi nor at Dome C. We noticed that HAMSTRAD LWP was not strictly null in the absence of liquid water, either actually measured by the LIDAR at Dome C, or by the absence of clouds of any types at the Pic du Midi. We cannot rule out that these biases might also be related to a certain extent to differences in the observation wavelengths employed (submicrons for the LIDAR and microwaves for HAMSTRAD) that could favour large particles (HAMSTRAD) against thin particles (LIDAR). Biases might also be due to the observing geometry that differs between the LIDAR (zenith viewing) and HAMSTRAD (atmospheric scans at 10 angles from zenith to ~3° elevation). From the comparisons between the HAMSTRAD LWP and the LIDAR observations of SLW clouds during the YOPP campaign, we can argue that the LWP bias is about 1.0 g m^{-2}. We have inserted the following sentence in the revised manuscript.

> The 1-σ RMS error on the 1-min integration time HAMSTRAD LWP can be estimated to be ~15%. Based on the comparisons between the HAMSTRAD LWP and the LIDAR observations of SLW clouds during the YOPP campaign, we can estimate that the LWP bias is about 1.0 g m^{-2}. We cannot rule out that these biases might also be related to a certain extent to differences in the observation wavelengths employed (submicrons for the LIDAR and microwaves for HAMSTRAD) that could favour large particles (HAMSTRAD) against thin particles (LIDAR). Biases might also be due to the observing geometry that differs between the LIDAR (zenith viewing) and HAMSTRAD (atmospheric scans at 10 angles from zenith to ~3° elevation).

Page 12, line 260: Second pass of CALIOP/CALIPSO not shown – please consider adding figure in supplementary material to the manuscript.

→ We have produced the relevant Figure in the Supplementary Materials.

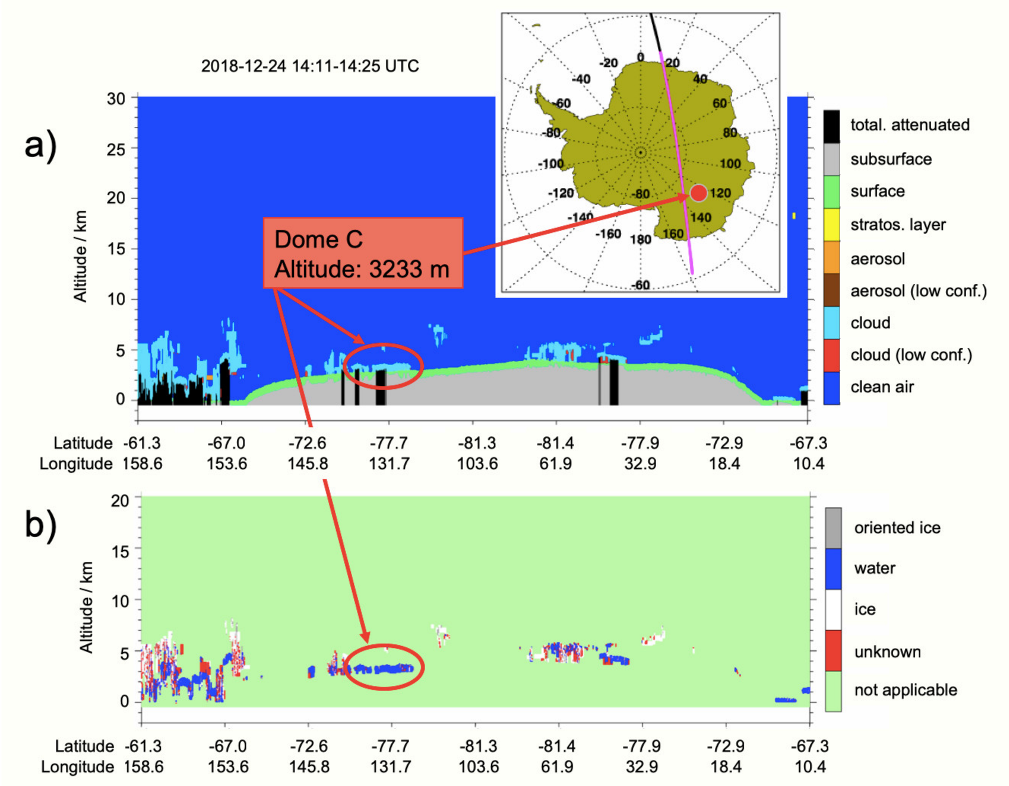

Figure Supp4: *CALIOP/CALIPSO spaceborne LIDAR observations version V3.40 along one orbit on 24 December 2018 (14:11-14:25 UTC) in the vicinity of Dome C (75°S, 123°E): a) the Vertical Feature Mask highlighting a cloud (light blue) near the surface (red circle) and b) the Ice/Water Phase Mask highlighting a SLW (dark blue) cloud near the surface (red circle). The ground-track of the sensor (pink) has been embedded at the top of the Figure, with the location of Dome C marked (red filled circle). Note that the altitude is relative to the sea surface, with Dome C at 3233 m amsl. Figure adapted from the original image available at https://www-calipso.larc.nasa.gov/products/lidar/browse_images/std_v34x_showdate.php?browse_date=2018-12-24.*

Page 12, line 266: Please include reference edition number for Pruppacher and Klett as figure numbering may change between editions.

→ We have updated the incriminated references.

> Pruppacher, H. R., and Klett, J. D.: Microphysics of Clouds and Precipitation: Reprinted 1980. Springer Science & Business Media, Second revised and enlarged edition, 2012.

Page 14, lines 313 – 316: mention that this positive gradient indicates a stable layer, as previously explained. As currently written, the authors are leaving it to the reader to make this conclusion and should be explicitly emphasised.

→ We have inserted a new sentence.

Black areas correspond to neutral conditions ($\partial\theta/\partial z \sim 0$), whereas the coloured ones relate to stable stratification according to the colour scale in the Figure.

Figures:

- The description of the model BL calculation is included for the first time in the introduction to Figure 5 on page 13. As this BL height is used for the first time in Figure 1, it should be introduced at this first point of use (page 10).

→ We have restructured the revised manuscript with a Methodology section that explains the reasons why the two case studies were selected along with some information about the PBL. Furthermore, the following sentence was added in the Methodology section.

The diurnal variation of the top of the PBL is calculated by ARPEGE-SH as the level where the turbulence kinetic energy becomes lower than 0.01 m^2 s^{-2}.

- I would suggest using a different colourmap between observations and modelling results to make it clear to the reader which data are being presented.

→ To clarify, on each panel (sub-Figure), we have highlighted the origins of the data: either model results (ARPEGE-SH) or observations (LIDAR or HAMSTRAD).

- Figure 4: Could benefit from (a) larger tick labels / different labels to explain phase masks rather than providing the number allocation; (b) indicating the altitude of Dome C to illustrate cloud layer altitude relative to ground level.

→ Done. See replies to the comments from the reviewer #1.

- For anomaly figures (5 and 13), please consider using a diverging colourmap with white at 0 (e.g. blue-white-red) to ease readability. Changing the colormap may make the sub-figure headings clearer, which would also be useful.

→ Done. See replies to the comments from the reviewer #1.

- Figure 7: it may be useful to adapt the scale to make the subtle maxima easier to see.

→ We have modified the former Figures 7 and 15 (now Figs. 8 and 14) to highlight the gradients and the small maxima.

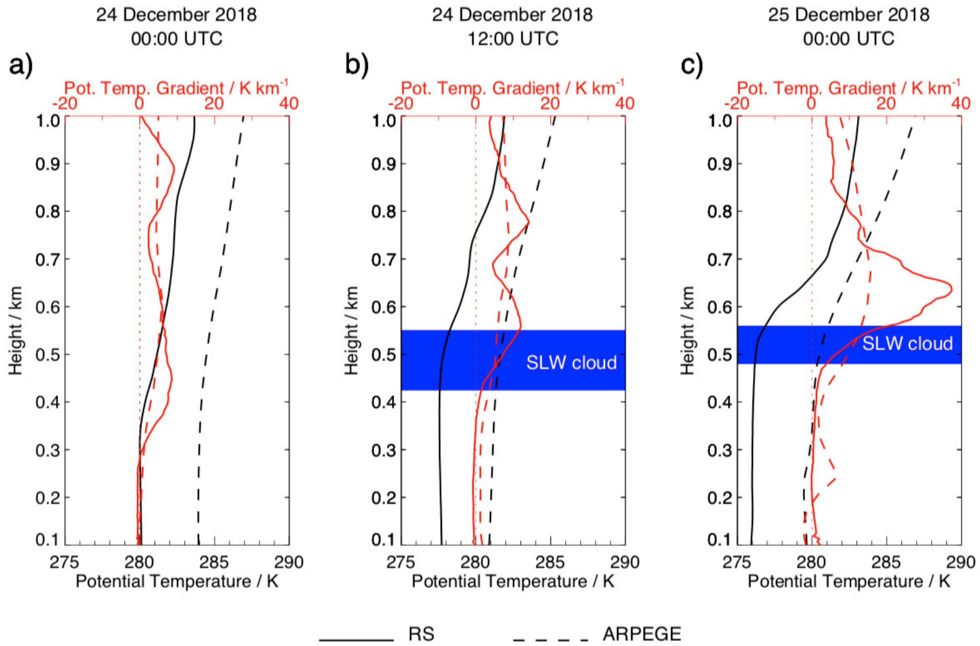

***Figure 8**: Vertical profiles of potential temperature θ (black) and the gradient in potential temperature ∂θ/∂z (red) as calculated from temperature measured by the radiosondes (solid line) and analysed by ARPEGE-SH (dashed line) at Dome C on 24 December 2018 at a) 00:00 and b) 12:00 UTC, and c) on 25 December 2018 at 00:00 UTC. The presence and the depth of the SLW cloud detected from LIDAR observations are indicated by a blue area.*

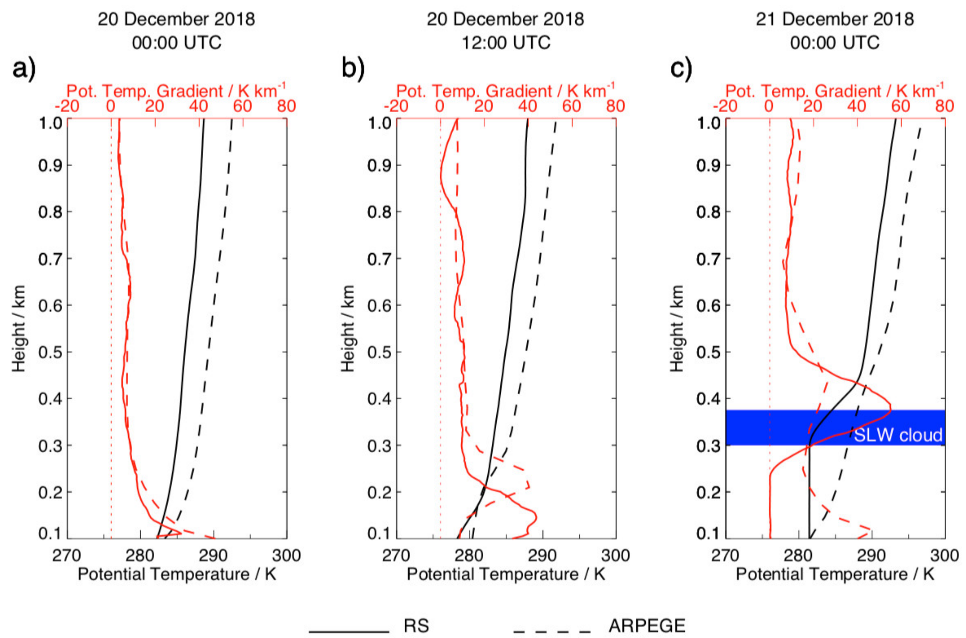

***Figure 14**: Same as Figure 8 but on 20 December 2018 at a) 00:00 and b) 12:00 UTC, and c) on 21 December 2018 at 00:00 UTC.*

- Figure 14: it's quite hard to see the measured SLW cloud layer (red) on top of the high values of delta Theta (red), perhaps changing the colour (maybe white?) of the measurements would make this easier to distinguish.

→ Done. See replies to the comments from the reviewer #1.

- Side note: Figures 9 and 16 are fantastic, the webcam images do a great job at illustrating the different cloud conditions between the two cases. The radiation values alone don't truly convey how different cloud distribution can be, so these images are invaluable to emphasise this.

→ Thank you.