We would like to thank the two Referees for their valuable input. Please find out point-by-point replies to the initial comments and the follow-ups below. Referee comments are given in black, our answers are given in blue.

Anonymous Referee #1, initial comment

The paper addresses the representativeness of ground-based lidar measurements in the Polar regions with respect to CALIOP (and MIPAS) observations of polar stratospheric clouds. The main conclusion of the paper is the identification of the best sites for PSC observation. To my opinion, the title is not adequately describing the main goal of this work. I would suggest something like "How to find the best locations for ground-based PSC observations", which better expresses the conclusions and recommendations of the authors.

We thank the Referee for this suggestion. It is indeed an outcome of the paper to define the best locations for ground-based PSC observations. Nevertheless, we think that the current title is appropriate as we show results for the entire Arctic and Antarctic, respectively, in Figures 2, 3, 5, and 6. These maps provide information that goes further than just the locations of existing research stations.

The comparison of the two CALIOP datasets (troposphere and PSC v2) and the ground-based lidar observations might produce many interesting results. The paper does not fully explore the potential of this method and also is not considering possible biases due to the different measurement protocols of CALIOP and ground-based lidars. It would be useful to specify the different categories of ground-based lidars; those measuring in a continuous mode, others "randomly" and still others in a CALIOP-synchronous mode". The authors should also explain that CALIOP is NOT a continuous mode lidar at a certain location, but has overpass frequencies in the order of days at specific local times. This might cause a bias in the statistics.

We are sorry that our description was not as clear as intended. The scope of this study is to explore the effect of tropospheric cloudiness on what would be observed from ground. The basic assumption is that the CALIPSO lidar can observe all PSCs along its laser beam while tropospheric clouds might attenuate the laser beam before it can reach PSC altitudes. In other words, we look at the same observation from two directions, i.e. from ground and space. In terms of the measurement protocol of a ground station, this implies CALIPSO-synchronous mode. We then separate between scenarios in which measurement at ground are performed (i) during each CALIPSO overpass and (ii) only one third of all CALIPSO overpasses. The first scenario can be realised both with a continuously operating lidar and with a system that is operating during each CALIPSO overpass with downtime in between but only if there is no interference by tropospheric clouds or measurement-inhibiting factors such as maintenance, downtime, or operator availability. The second scenario also refers to CALIPSO-synchronous measurements with the caveat that interfering factors reduce the number of observations to one third. This latter scenario is much more realistic for most polar lidar stations.

We agree that the labelling of a continuously operating lidar and a manually operated lidar was misleading. Accounting for this and the fact that we really only consider the CALIPSO-synchronous scenario, we have dropped the reference to continuously operating and manually operated instruments. We have also revised the text in Section 2.4 to:

"*The matched observations of tropospheric and stratospheric clouds allow for a direct comparison of individual PSC profiles as well as long-term PSC statistics as seen from ground and space independent of the considered instruments. Specifically, the same profile can be evaluated from two perspectives, i.e. from space as well as from the point of view of a ground-based instrument. In that context, the* *latter perspective translates to a CALIPSO-synchronous measurement protocol at a ground station. True PSC statistics unaffected by tropospheric cloudiness, i.e. during all-sky conditions, at a certain location can only be obtained with a spaceborne lidar. In contrast, filtering with respect to tropospheric cloudiness is applied to emulate the likely conditions for meaningful ground-based PSC measurements in the CALIPSO data set. Specifically, we assume that a ground-based lidar would only provide meaningful results during conditions with no clouds or only transparent clouds that would not already attenuate the laser beam before it can reach PSC altitudes. This is referred to as the ground-based view of the CALIPSO data set. It provides sampling that is dependent on the CALIPSO return rate and must not be confused with actual ground-based measurements that can provide localised PSC observations in the time range from hours to weeks.*

We subsequently separate the ground-based view of the CALIPSO data set into two scenarios for which (i) all cases of the ground-based view are considered and (ii) one third of the profiles of the ground-based view was randomly selected. The first scenario corresponds either to a continuously operating lidar or a manually operated system that is active during every single CALIPSO overpass with possible downtime in between without any interference by tropospheric clouds or measurement-inhibiting factors. The second scenario also refers to CALIPSO-synchronous measurements with the caveat that interfering factors reduce the number of measured lidar profiles to one third of what would ideally be possible. This latter scenario is much more realistic as (i) most ground-based lidar instruments are operated manually and on campaign basis, (ii) the decision to start a measurement, i.e. the assessment of tropospheric cloudiness, is made subjectively by the operator, and (iii) infrastructural challenges (e.g. system downtime, logistical problems, and lack of personnel) affect the operation of a ground-based lidar at a remote location and under harsh conditions.

To assess the representativeness of ground-based PSC measurements, PSC statistics are obtained for boxes of 2° latitude by 2° longitude around the sites in Figure 1 and Table 1."

Having at disposition both data sets the authors might also explore the possible correlation between tropospheric cloudiness and PSC occurrence (as they mention in lines 240-247).

The investigation of the connection between tropospheric and stratospheric cloudiness has actually been our motivation from the outset. The present study turned out to be a by-product of this work and we decided to publish it first as makes for a nice stand-alone publication.

They also might quantify the bias introduced by prohibitive meteorological conditions, such as cloud cover in the ground-based dataset, by comparing the PSC occurrence, as observed by CALIOP, with and without cloud cover. I suppose that this could be easily done.

This is actually the scope of the manuscript. We use the matched CALIPSO observations of tropospheric and stratospheric cloudiness to show what PSC statistics look like during (i) all-sky conditions (spaceborne view, not possible with ground-based instruments), (ii) situations with tropospheric cloudiness that would still enable PSC observations from ground (view of a ground-based lidar with CALIPSO-synchronous measurement protocol operated during every single CALIPSO overpass), and (iii) situations in which CALIPSO-synchronous operation of a ground-based instrument is affected by cloudiness and other measurement-inhibiting factors. We have revised the description of the data analysis in Section 2.4, the caption of Figure 4, and the discussion of Figures 4 for clarity. We have also made revisions throughout the text to clearly state that the purpose of this work is exactly to quantify the bias introduced by prohibitive meteorological conditions, though we refer to them simply as tropospheric cloudiness.

An important flaw of the paper is that they apparently are not aware of the fact that a lidar observatory is active at Concordia station since 2014 (see e.g Snels, ACPD 2020 and https://tmf.jpl.nasa.gov/testLidar/NDACC_LWG/sites/dome_c.html). This is particularly relevant, since the authors recommend Concordia as one of the best sites to perform PSC observations.

We thank the Referee for making us aware of this publication and the measurements at Concordia station. The paper has been added and the Figures and discussion have been revised to account for the existence of PSC measurements at Concordia (see also replies below).

The authors consider the CALIOP observations as a reference system for the ground-based lidar. When they speak about representativeness they refer to the agreement of the statistics of the ground-based lidar measurements with respect to the CALIOP observations. This is generally speaking an acceptable concept, but there are some caveats. CALIPSO is performing 14-15 orbits per day, which means that the orbits have a separation in longitude of about 180/15 = 12 degrees (we have ascending and descending overpasses). At a latitude of 70(80) degrees. 12 degrees of longitude means 450 (225) km of distance between successive overpasses. The authors use boxes of 2 x 2 degrees lat-lon boxes to do their statistics, this means that several days are needed to “fill the boxes”. Experience shows that tropospheric clouds and PSCs are not constant over days, often they change during the day. The CALIOP overpasses in a box occur at fixed local times and thus are biased wrt to the random ground-based observations. Synchronized ground-based observations eliminate this bias. If one considers only average statistics, one should take into account the biases present in the comparison of ground-based lidar observations wrt to CALIOP, due to the different measurement times. Some stations (McMurdo in the past, Concordia in the present, maybe also Belgrano) synchronize their observations with CALIOP overpasses, and this makes the comparison more reliable. I would suggest that the authors comment on the opportunity to perform synchronized measurements with CALIOP overpasses. The synchronized measurements do not improve the occurrence statistics necessarily, but they make comparison with CALIOP more reliable.

Please see our reply to your other comments regarding the possible measurement protocols at ground stations. We have now clarified that our data set corresponds to a CALIPSO-synchronous measurement protocol at ground stations. We have also dropped the misleading reference to continuously and manually operated instruments at ground and replaced the corresponding statements with more accurate ones.

Snels, ACPD, 2020: Snels, M., Colao, F., Shuli, I., Scoccione, A., De Muro, M., Pitts, M., Poole, L., and di Liberto, L.: Quasi-coincident Observations of Polar Stratospheric Clouds by Ground-based Lidar and CALIOP at Concordia (Dome C, Antarctica) from 2014 to 2018, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2020-972, in review, 2020.

Thank you. The paper has been added to the list of references.

Other comments:

Abstract. Line 8. What do the authors mean by representativeness ? Is it wrt to the CALIOP observations in a lat-lon box or wrt to the overall occurrence statistics in the Northern or Southern Hemisphere ?

The term representativeness in our study refers to the statistics derived without and with the effect of tropospheric clouds and other measurement-inhibiting factors that can affect the findings of ground-based lidar instruments. The statement was changed to: “*CALIPSO observations during the boreal winters from December 2006 to February 2018 and the austral winters 2012 and 2015 are used to assess the effect of tropospheric cloudiness and other measurement-inhibiting factors on the* *representativeness of ground-based PSC observations with lidar in the Arctic and Antarctic, respectively.*"

Line 12. These findings are rarely in agreement with polar-wide results..... Why would one expect an agreement with polar-wide results? Each location is different. It would be more interesting to have an agreement with a "box-region" observed by CALIOP

One might not expect an agreement with polar-wide results at each site but it is reasonable to assume that some sites are more representative of the larger-scale conditions than others. The agreement in a box region is basically what we do for the selection ground sites.

Line 15. Concordia is already a NDACC lidar observatory since 2014. Data are available on the NDACC web-site.

The Referee is correct. The statement has been changed to "and Mawson, Troll, and Vostok in the Antarctic". We rate Mawson over Jang Bogo due to the proximity of the latter to McMurdo.

Line 33 "calculations with" should read "calculations considering..."

Changed to: "*light-scattering calculations that consider spherical and non-spherical particle shapes*"

Line 43: representativeness see comment on line 8

Revised as in the reply to comment regarding line 8.

Line 47 : I would prefer "ground stations" instead of "ground sites", "site" already implies "ground"

Ground site has been changed to ground station throughout the text. However, we still use the term site when referring to locations.

Lines 81-83, This line is not very clear for readers that are not familiar with CALIOP data and should be written in a more "reader friendly" way. The 4 digits in the height are not significant and mentioning the bin number is irrelevant.

Thank you for this comment. The section was revised to: "*Because of CALIPSO's top-down viewing geometry, profiles start with the uppermost height bin down (bin 1) to the lowermost height bin (bin 583). Profiles in the PSC mask v2 product extend down to 8.2 km. They can therefore contain contributions of upper-tropospheric cirrus, as visualised in Figures 13 and 20 of Pitts et al. (2018). To exclude the contribution of such cirrus clouds from our analysis, only height bins above 14.9 km (smaller than bin 85) and 13.1 km (smaller than bin 96) are considered to represent Arctic and Antarctic PSC, respectively.*"

Line 92 ..if this type....

Following a comment of the other reviewer, we have revised the statement to:

"A CALIPSO profiles is referred to as containing a certain a PSC composition (e.g. STS-containing or ICE-containing) if the respective component is identified in at least one of the PSC height bins."

We have also replaced the reference to PSC type with PSC composition after the introduction.

Line 101 . the 2x2 degrees boxes correspond with 220 x 76 km at 70 degrees of latitude and 220x38 km at 80 degrees latitude. This implies that the box dimensions change with the locations. Does this create a bias on the statistics ?

We don't think that this has much of an effect on the statistics as the smaller box sizes at higher latitudes are compensated for by the higher CALIPSO return rate at higher latitudes.

Line 108: I would add (iii) ground-based observations synchronized with CALIPSO overpasses.

Please see our earlier replies regarding the reference to ground-based measurements and the revisions of Section 2.4.

Line 108-113. The authors want to estimate potential biases due to the mode of operation of the ground based stations. The answer is apparently in the small numbers in Figure 7. To my opinion these numbers do not address adequately the question they posed in the introduction, since the difficulties encountered while recording ground-based measurements cannot be simply translated in doing random measurements. (implicating that non-random measurements would give different results..). "(ii) a manually operated system for which one third of the cases of the ground-based view was randomly selected." What does this mean and how it works? In most cases the number in the third column is about 1/3 of the second column, except for Tiksi. Why is that? What is the rationale between taking a random 1/3 or just divide by three ?

We are sorry about the confusion. We have revised Section 2.4 and hope that it is now more comprehensible. We do refer the bias to the available data coverage but erroneously assumed this could be synonymous to certain modes of operation. We actually only include what would be CALIPSO-synchronous measurements when we consider a CALIPSO lidar profile from the spaceborne and ground-based perspective. We then screen the data set to find those profiles in which tropospheric cloudiness was unlikely to have attenuated the lidar beam if it was coming from ground (no or only transparent clouds). This corresponds to the optimum data yield for ground-based measurements. However, we know that there is a wide range of factors that reduce the amount of collected data from the optimum data yield. We estimated that even under the worst of circumstances, a ground-based instrument should not provide less than one third of the maximum possible measurements. To get to this sub-set of observations, we randomly selected one third of those CALIPSO profiles that represent what would be observable from ground, i.e. the optimum yield. The statistics were derive subsequently from that subset of profiles. The numbers in Figure 7 refer to the number of PSC height bins in the corresponding category. Because the amount of PSC height bins can vary from profile to profile, the scaling is only about one third and not exactly one third.

Line 201. It is not clear what the 1:1 line means, and also the other grey lines like 1.0:1.6 are not clear. The authors write "the grey lines mark the ratios....." But which ratios ?

We agree that the grey lines in Figure 8 were confusing. We have removed all but one and revised the figure caption to: "*The grey line marks a scale PSC coverage defined as (10000 - x)/10000. Stations to the right of this line show a combination of tropospheric cloudiness and PSC coverage that indicates favourable conditions for ground-based lidar measurements*."

We have also revised the discussion of Figure 8 accordingly.

Line 202 add Concordia

done

Line229 understanding of processes.

of has been added

Figure 4 shows the occurrence rate of the different PSC classes as seen by CALIOP, by the ground-based lidar (continuously operating) in clear sky conditions and for manually operated ground-based stations. This figure is not clear for what concerns the small numbers written in the coloured columns. It would be better to have a Table with these numbers. Then the number of continuously operating lidars is very small.

We state in the figure caption that the numbers refer to the total amount of considered PSC height bins per configuration. The purpose of these numbers is to give an idea about the amount of data that went into the respective bars. We have increase the size of the figure to improve readability. Please see our previous replies clarifying what was meant with the reference to continuously and manually operated ground-based instruments.

Figure 2 . The longitudes in fig b are wrong! / Figure 5 the longitudes are wrong in fig a / Figure 6 the longitudes are wrong

Thank you for spotting this mistake. It has been corrected.

Table 1. mark Concordia with existing datasets (see NDACC) The authors might indicate in Table 1 (or in a new Table limited to PSC observing stations) which lidars are continuously operated, which are randomly operated (whenever it suits the operator) and which are synchronized with CALIOP overpasses.

A corresponding marker has been added to Concordia in the table. We have also changed the marker style of Concordia in Figure 1b from open blue circle to filled magenta circle and in Figure 8 from open to filled circle to denote that it is a research station with published PSC measurements.

Anonymous Referee #1, follow-up comment

The answers of the authors to my first comments have been all addressed in a satisfactory way and appropriate corrections have been made. I still have some minor remarks, however.

Thank you for the positive feedback.

I still find the title not very descriptive. I think that the title I suggested does not exclude any locations. The best locations can be determined from Figures 3 and 6, without specifying existing stations.

We have thought about the title suggested by the Referee (*How to find the best locations for ground-based PSC observations*) and propose to change our original title (*Location controls the findings of ground-based PSC observations*) to ***On the best locations for ground-based PSC observations.***

Among the reasons for performing or not performing a measurement from the ground, the authors mention "(ii) the decision to start a measurement, i.e. the assessment of tropospheric cloudiness, is made subjectively by the operator ", While the other two reasons are "random" with respect to the possibility to observe PSCs, the decision of the operator to perform the measurement in absence of tropospheric clouds is not random, since it already selects a favourable condition.

We agree with the Referee that point (ii) is not as random as the other two points, as an operator is generally capable of identifying cloud-free conditions. What we are referring to here, however, is related to our own experience on deciding whether or not to start a measurement with a manually operated instrument in the presence of clouds. In particular, a measurement could be started in the presence of tropospheric clouds that inhibit PSC observations. An operator might decide to stop the measurement if this cloud deck does not dissolve as expected and the clouds might dissolve after the end of the measurement.

"we randomly selected one third of those CALIPSO profiles that represent what would be observable from ground, i.e. the optimum yield". I don't understand why the authors randomly select one third of useful measurements, taking into account the number of pixels where PSCs are present. It would be sufficient to state that the ground based lidars should be able to perform at least one third of the optimum yield.

The rational for picking the factor of one-third is indeed that we assume that a ground based lidars should be able to perform at least one third of the optimum yield. The intention of sub-sampling the CALIPSO-observations related to the optimum yield, however, is to asses if random sampling of the optimum yield, i.e. subsampling of the dataset in an effort to account for the inhibiting factors imposed on a real-world ground station, would lead to any changes in the overall statistics on PSC type occurrence. Figures 4 and 7 show that this could be the case at some ground stations.

In Figures 4 and 7 two kinds of information are mixed. The first is the relative number of possible observations by CALIOP, ground-based lidar and one third of the latter. The second is the relative occurrence rate of the different PSC types at the various stations, as observed by CALIOP (the other columns are derived from CALIOP data). The question is if the small differences of the relative occurrence rates between the three columns is "real" or just "casual".

The figures provide the occurrence rate of different PSC types related to the three considered conditions viewpoints (all cases of all-sky conditions, all cases of transparent or no clouds, and one third of all cases of transparent or no clouds). The numbers that refer to the amount of considered PSC height bins provide complementary information that allows to assess the representativity of the measurements, i.e. the statistics become less trustworthy is the number of considered cases falls below a certain level. Our best assessment of the Referee's question is that differences between the first column (all-sky conditions) and the other two columns are real as they describe the effect of tropospheric cloudiness on the obtained statistics. We already state in the discussion of Figure 4: "*The localised view for 15 ground stations in the Arctic reveals the impact of tropospheric cloudiness on the statistics on PSC microphysical properties as expected from Figure 3.*"

In an ideal world, there should be no difference between the second and third column and differences should be casual. Nevertheless, there are stations with a considerable difference in those columns. For such stations (e.g. Igloolik or Tiksi) the sub-sampled data set becomes too small to conclude that the differences are real.

We also realised that the numbers in Figure 4 were mixed up for the different stations. This has now been corrected.

The caption of Figure 6 should read "Same as Figure 3 but for the Antarctic."

Correct. Changed as suggested.

Vincent Noel (Referee #2)

In this paper, the authors combine two CALIPSO cloud datasets to evaluate the amount of stratospheric clouds (PSCs) that could be detected by ground-based lidars at various polar locations, taking into account the optical obstruction of the lidar laser beam by tropospheric clouds.

The concept behind this study is simple and smart, relatively straightforward to apply once the datasets are made coincident in time and space, and in this study provide results that will be definitely useful to inform installations of lidar instruments in polar locations. In other words, I think the authors had a very good idea. For the most parts, they executed that idea well: generally the paper is clear and well-written, the figures convey the important points well, and the conclusions are useful. The article is short, which I appreciate, but perhaps a bit too short. I have a few questions for which I could not find answers in the paper, and I think some of the paper's results could be made clearer (see below).

Thank you for the overall positive feedback. Please find our detailed replies below.

Major points

1. My first major point is that while I think I understand how the authors processed profiles with stratospheric clouds and no tropospheric clouds, I'd like a clarification on how the authors decide, when tropospheric clouds are present, whether these clouds are transparent enough for a ground-based lidar to detect the PSC above (L. 105)? I expect the authors apply a threshold criteria on some integrated property of tropospheric clouds within the profile – is it on the geometrical thickness of the tropospheric clouds, on their optical depth, on something else? The value of the threshold might change from one ground-based lidar to the next, since one lidar with higher SNR might be able to penetrate further than another lidar with a smaller SNR.

We are sorry that this important point was not clear. Our approach is actually much simpler and doesn't require the use of threshold values or any information on cloud geometrical and optical thickness. For every matched profiles of tropospheric and stratospheric cloud observations, we check the cloud types in the 05kmCPro Vertical Feature Mask. We consider a profile as representing conditions under which a ground-based measurement could be performed, if the Vertical Feature Mask (i) shows no tropospheric clouds at all, (ii) shows only altocumulus (transparent), i.e. cloud type (v) in Section 2.2, (iii) shows only cirrus (transparent), i.e. cloud type (vii) in Section 2.2, or (iv) shows both altocumulus (transparent) and cirrus (transparent). As soon as any other type of tropospheric clouds in present in a profile (any of the four low-level cloud types, altocumulus (opaque), or deep convective (opaque), see Section 2.2), we consider this profile to represent conditions that are unsuitable for a ground-based measurement. Our definition of transparent clouds is already given in Section 2.2. For clarity, we have revised the first paragraph in Section 2.4 to:

"Information on cloud type from the Vertical Feature Mask in the 05kmCPro.v4.10 cloud profile product is used to sum up the number of height bins with different tropospheric cloudiness for each CALIPSO profile. This information is used to identify cloud-free conditions (a total of zero counts for each of the eight cloud types) and situations with only transparent tropospheric clouds that would still enable meaningful PSC observations with a ground-based lidar, i.e. altocumulus (transparent), cirrus (transparent), or a combination of the two. In addition, all-sky refers to the use of all profiles independent of tropospheric cloudiness."

Also, given a semi-transparent tropospheric cloud with a specific optical depth, a given lidar might be able to detect a relatively bright (larger backscatter) PSC beyond, but not detect a thinner one. Could you comment on how these considerations affect your results, or if they do not affect them at all?

Maybe discussing the distribution of opacities of tropospheric clouds the ground-based lidars are supposed to go through would help evaluate if this is an important issue or not. These considerations might lead to location-dependent uncertainties of the approach, according to the distribution of opacities of tropospheric clouds and backscatter of stratospheric clouds over a given location.

These considerations have no effect on our results as we don't consider geometrical thickness of opacity of the tropospheric clouds. Instead, we rely on the CALIPSO cloud typing which depends on feature altitude (cloud top height) and opacity (whether or not clear sky can be detected below a feature). Because the CALIPSO laser emits less power than most ground-based lidar instruments for PSC observations, we are confident that a cloud that is transparent in a CALIPSO measurement would also be transparent in a ground-based observation.

2. My second point relates to the presentation of the results by location. Once I understood the premise of the study, the first thing I looked for is a figure presenting the amount of PSCs detectable by a ground-based lidar at each location (taking into account obstruction by tropospheric clouds), relative to the amount of PSCs actually present in the profile (and observable from space). That information might be present in Figure 1 (the numbers in each bar?), or Figure 8 (the y-axis?), but I'm not sure.

This is indeed the central information we want to convey by this work. We are sorry to hear that it was hard to figure out the actual numbers. The information on the fraction of PSCs that are observable with a ground-based lidar at a certain location can be taken from (i) the maps in Figures 2b and 5b (occurrence rate of favourable tropospheric cloud conditions for ground-based lidar measurement), (ii) the ratio of the numbers in Figures 4 and 7 (number of PSC height bins during conditions with no tropospheric clouds or transparent clouds only (middle bar) divided by number of PSC height bins during all-sky conditions (left bar)), and (iii) the y-axis in Figure 8 (ratio of ground-based to all-sky view, this was calculated following (ii)).

We have revised the text throughout the manuscript so that the information can be extracted more straightforwardly.

Regarding Figure 8, I am not sure I understand it correctly. I am under the impression the authors tried to create a single figure that somehow sums up the potential of each location for ground-based lidar observation of PSCs, but this attempt might be at the cost of ease of interpretation. For instance, the meanings of the grey lines is lost on me. Could you make it clearer somehow if that information is present somewhere in the paper, or add it if it's not there? I understand there is value in having a single figure that ranks locations according to their ground-based performance, but maybe the authors could consider spreading the information it contains on several figures to make it easier to discuss and digest?

We are sorry for the confusion regarding Figure 8. We agree that the interpretation of this figure was not straightforward. Following the suggestion of the other referee, we have already removed all but one of the grey lines and revised the figure caption to: "*The grey line marks a scale PSC coverage defined as (10000 - x)/10000. Stations to the right of this line show a combination of tropospheric cloudiness and PSC coverage that indicates favourable conditions for ground-based lidar measurements*."

We have revised the discussion of Figure 8 accordingly. We chose the display in Figure 8 as it nicely presents the two factors that define the rate of success for PSC measurements at a certain ground station: (i) the effect of tropospheric cloudiness (How often can we measure up to the stratosphere (while PSCs are present)?) and (ii) the occurrence rate of CALIPSO profiles that contain PSCs (How often will there be PSCs?). All stations to the right of the grey line are those that we consider to perform particularly well. This shows for instance that at Ny Alesund, the high PSC occurrence rate compensates for the low occurrence rate of favourable conditions for ground-based PSC measurements – leading to an overall favourable station location.

The information in Figure 8 can be used to produce a simple ranking of stations by multiplying the x and y values. The stations listed in the Abstract and the third paragraph of the Summary are based on such a ranking.

3. Another information I'd like to see: given a particular location, if we take the spaceborne-retrieved PSC fraction over a given location as the "truth", how off are the fractions retrieved from the incomplete ground-based retrievals at the same location? This would quantify the error or uncertainty in ground-based PSC retrieval from a given location. Depending on the seasonal variability of PSCs over a given location, it might provide a different way to rank the locations. A location with the best sampling might be affected by a larger error than another with a poorer sampling, if the PSCs over that last location do not change much.

We might have misunderstood the Referee's comment but the outcome of the PSC classification at different sites for different conditions of tropospheric cloudiness is exactly what is shown in Figures 4 and 7. These figures show the occurrence frequency of different PSC constituents for all-sky conditions (the "true" values), for favourable conditions for ground-based lidar measurements (the ground-based instrument measures whenever tropospheric clouds allow), and for conditions where external circumstances allow for only one third of the optimally possible measurements. We find different effects of tropospheric cloudiness. We also see that locations with poorer sampling tend to show a larger difference between the spaceborne and ground-based view. However, we are only looking at the long-term distribution of PSCs with different composition here and did not consider any seasonal variation.

In any case we would like to ask the Referee to confirm that this is what was meant by the comment.

Minor comments

1. L.26: "Today, we are confident..." I'm not sure we are that confident. There is definitely a consensus in recent studies that study PSCs to focus on three possible particle types (ICE/STS/NAT), but I'm under the impression this consensus has less to do with actual evidence showing that all PSCs are made of these particle types (meaning in-situ measurements) and more with a standardization around dominant retrieval algorithms and datasets. Please use a less confident statement, or correct my impression with references.

Thank you for pointing out that the availability of PSC in-situ measurements is still low. We have mitigated the statement to: *"Today, there is consensus that…"*

2. L. 77: "only the austral winters of 2012 and 2015 are are included in the analysis of Antarctic PSCs": Why is that? Why not use the same record for both poles? If one dataset is 3 years long and the other 12 years long, how does it affect our confidence in the results from both poles? (Also "are" is said twice)

This is a fair comment. We started looking at the coincidence of PSCs and tropospheric clouds in the Arctic based on the full data set for this pole. We later realised that a comprehensive documentation of the method and results in a research publication should consider both poles and this is what we did. However, the much larger amount of CALIPSO PSC observations translates into an increased amount of available data which is further doubled because we consider CALIPSO profiles for both tropospheric and stratospheric clouds, i.e. APro and PSCMask files. We started with two years of Antarctic measurements and found that those actually include more CALIPSO PSC profiles than the entire Arctic data set. So on the one hand, the volume of data is comparable at both poles. On the other hand, we checked that the Antarctic observations are in line with *Pitts et al.* (2018, https://doi.org/10.5194/acp-18-10881-2018). This means that we are confident that including a longer time series of Antarctic observations does not affect the overall conclusions regarding the assessment the representativity of long-term lidar measurements from ground.

Also, we have deleted the second are.

3. L. 93: "Maps of the occurrence..." Which maps are we talking about here? If this refers to the upcoming figures, why not wait until the figures are introduced to discuss the maps?

The normalisation is part of the data analysis methodology which is why we present it in Section 2.4. However, we have moved the statement to the next paragraph after data gridding is mentioned. In addition, we have added a reference to the figures for which the normalisation has been applied to:

"Maps of the occurrence of the accumulated number of height bins related to different PSC composition are normalised by the total number of PSC height bins per considered grid box (see Figures 2, 3, 5, and 6)."

4. L. 92 "a certain a PSC", "this types was"

The statement has been revised to:

"A CALIPSO profiles is referred to as containing a certain a PSC composition (e.g. STS-containing or ICE-containing) if the respective component is identified in at least one of the PSC height bins."

We have also replaced the reference to PSC type with PSC composition after the introduction.

5. Like another reviewer, I do not think the title is a clear description of what this article is about. Without reading the article it is unclear what the authors did. I understand the authors wanted the title to be more about PSCs and less about location ranking, but I find the current title to be less interesting than what the paper describes. It sounds almost obvious: "Location controls the findings of observations" is always true. The contents of the paper go beyond that, and the title might do the article a disservice. I'm not sure what a better title would be though.

Following the concern of both reviewers, we have revised the title to: ***"On the best locations for ground-based PSC observation."***

6. The approach presented by the authors here has, in my opinion, applications beyond the polar regions. It could be used to rank the potential of locations to provide ground-based observations of high clouds in other regions (eg Tropics), or evaluate the best use of mobile observation setups during campaigns, etc. Maybe the authors could include a comment to this effect in the conclusion.

The Referee is correct. The methodology can be adapted to find suitable locations for observations of mid-level or high clouds or elevated aerosol layers at which the effect of measurement-inhibiting low clouds is minimal. A corresponding statement has been added to the Conclusions:

"In addition, the methodology presented here can be easily adapted to assess the effect of low-level clouds on tropospheric observations. For instance, it can be used to find locations for measurement campaigns or long-term observatories at which the measurement-inhibiting effect of opaque clouds has a minimum impact on the observational cover of mid-level or high clouds and elevated tropospheric and stratospheric aerosol layers."

Vincent Noel (Referee #2)

I am satisfied with most of the answers to my original comments.

The comment in which I request for a result was not clear. I'll try to do better below.

When PSC measurements are available from a ground-based site, I would expect the first result (before PSC speciation) presented to be the PSC Fraction, which would be defined (by analogy with tropospheric clouds) as the ratio of the number of lidar profiles in which a PSC can be detected, divided by the number of lidar profiles that sample the stratosphere over that location. 100% would mean that all sampled profiles contain a PSC, 50% half of the sampled profiles contain a PSC, etc. This number would inform on the ubiquity of PSCs over the considered area.

Using the authors' methodology, it should be possible to document, over a given location, the actual PSC Fraction (by considering all the profiles sampled by CALIPSO over that area), and the PSC Fraction that would be retrieved from a ground-based lidar (by considering only the profiles that would see the stratosphere considering the presence of opaque tropospheric clouds). From these results one could document the error in retrieved PSC Fraction over all the considered locations. That error might provide an additional data point to rank locations, as locations with smallest errors would enable the most accurate representation of PSC frequency. The numbers retrieved in this fashion would probably align with the accuracy of PSC speciation by location.

We would like to thank Vincent Noel for the follow-up comment. We now understand what the Referee was looking for. Right now, our statistics are restricted to those CALIPSO profiles for which PSCs have been detected. The Referee would like to see what the findings would look like if we were to normalise by the total number of CALIPSO profiles rather than only the number of CALIPSO profiles that show PSCs. Such plots have now been added to Figures 2 and 5. Figures 2b and 5b now show the ratio of all CALIPSO PSC profiles versus all CALIPSO profiles (i.e. the PSC occurrence rate) while Figures 2d and 5d show the ratio of PSC profiles with suitable tropospheric cloudiness for ground-based lidar measurements versus all CALIPSO profiles.

We understand the rationale of the Referee's question regarding the effect of PSC occurrence rate. However, our own experience with running a manually operated ground-based lidar for PSC observations shows that PSC occurrence rate is an ambiguous measure. First, it can only be defined properly in terms of a reference number for normalisation if a ground-based instrument is run continuously or according to a schedule with fixed measurement times. This is often complicated for a manually operated system run by a small team as measurement times are adapted to PSC occurrence. Second, measurements might not be performed if PSCs are absent to save laser lifetime, to perform calibration measurements, or to simply give the operator some time to rest. Finally, PSC statistics are generally obtained only for those lidar profiles that show PSCs.

Nevertheless, we appreciate the Referees suggestion and have revised Figure 2 and 5 accordingly so that the readers can also get an impression of PSC occurrence rates from the polar-wide plots. In addition, we have added the effect of PSC coverage for additional guidance towards finding the best location for ground-based PSC measurements as colour coding to Figure 8. This addition complements the current discussion of Figure 8 but doesn't change the conclusion of the analysis.

Figures 2 and 5 now look like this:

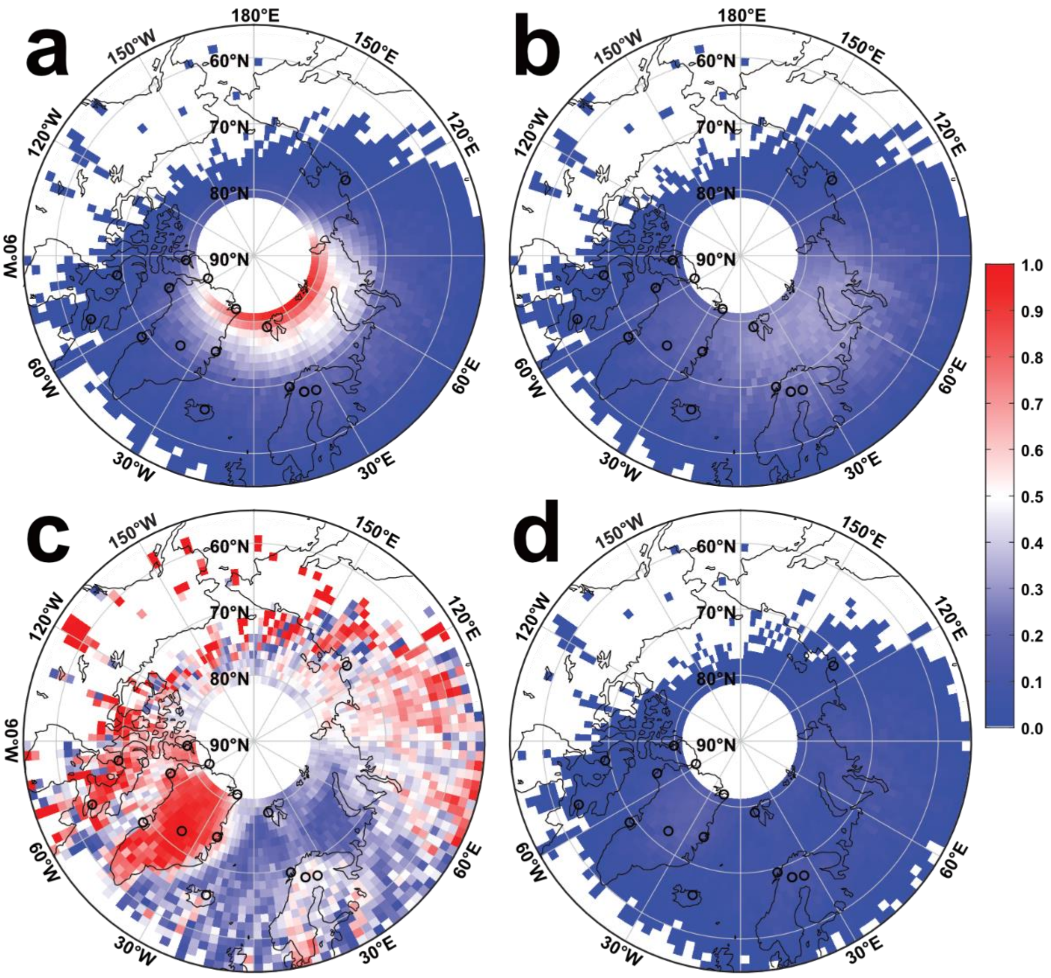

Figure 2. Normalised number of CALIPSO profiles with PSCs detected over the Arctic (a, scaled to maximum count of 2478), ratio of CALIPSO profiles with PSCs detected versus all CALIPSO profiles (with and without PSCs detected) for the same time period (b, PSC occurrence rate), ratio of CALIPSO profiles with favourable tropospheric cloud conditions for ground-based lidar measurements (no or only transparent clouds) and PSCs detected versus all CALIPSO profiles with PSCs detected for the same time period (c), and ratio of CALIPSO profiles with favourable tropospheric cloud conditions for ground-based lidar measurements and PSCs detected versus all CALIPSO profiles for the same time period (d). Black circles mark the locations of lidar ground stations shown in Figure 1 and listed in Table 1.

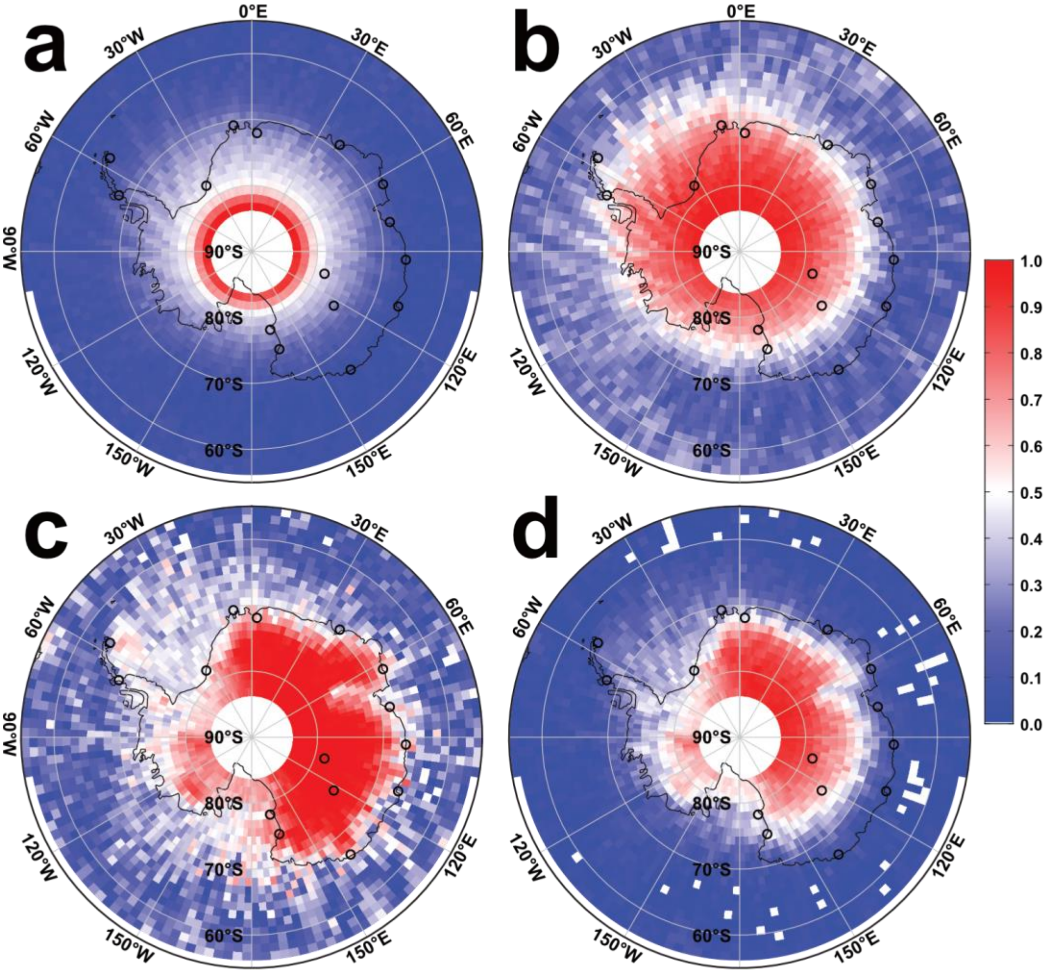

Figure 5. Same as Figure 2 but for the Antarctic. The display in (a) is scaled to a maximum count of 2001.

We have revised the discussion of Figure 2 accordingly and clarified that the closer look at PSC chemical composition only considers those CALIPSO profiles for which PSCs have been observed. New text is marked bold:

The absolute number of observed PSC profiles (normalised to a maximum count of 2478) and the PSC occurrence rate (the ratio of observed CALIPSO PSC profiles versus all CALIPSO profiles) are shown in Figure 2a and b, respectively. The absolute number of PSC observations is largest at highest latitudes due to the high CALIPSO return rate at those locations. The effect of the return rate is compensated for in the PSC occurrence ratio in Figure 2b. Overall, *Arctic PSCs are most abundant between 30°W and 90°E and north of 70°N. The pattern of the CALIPSO-derived PSC occurrence rate resembles the MIPAS-based findings in Figure 6b of Spang et al. (2018). Note that Pitts et al. (2018) derived PSC occurrence frequencies for fixed altitudes of Θ = 500 K (around 20 km) and that the PSC area in their Figure 24 is thus smaller than inferred from considering all PSC height levels as done here. Figure 2a and b also show that the geography of the Arctic means that most ground stations are located in areas of relatively low PSC occurrence. This is levelled by the normalised occurrence rate of suitable conditions for ground-based observations presented in* ***Figure 2c and d. The difference between the two displays is that Figure 2c is normalised to the number of all PSC-containing CALIPSO profiles while Figure 2d is normalised to all CALIPSO profiles.*** *The region of highest PSC occurrence rate over the north Atlantic coincides with the highest occurrence of opaque tropospheric clouds. While Ny Ålesund could potentially observe the most PSCs in the Arctic, the occurrence rate of good conditions for ground-based lidar measurements is much lower than at* *the other Arctic stations. In contrast, sites on Greenland and in the Canadian Arctic show almost no opaque clouds but - with the exception of Villum - also feature a low occurrence rate of PSCs. A similar situation though with a generally lower rate of suitable conditions for ground-based observations is found for Alomar, Esrange, and Sodankylä. However, these sites provide much easier access than the other more remote locations. Tiksi is a station that could potentially provide information on PSCs over the Siberian Arctic.*

The occurrence rate of PSCs with different chemical composition in the Arctic for all-sky conditions is shown in Figure 3. Here and in the following closer look at Arctic PSCs, normalisation is done with respect to all CALIPSO profiles that contain PSCs (analogous to Figure 2c) rather than all CALIPSO profiles (as in Figure 2b and d). The Figure 3 *reveals that STS and NAT mixture are most abundant with a region of maximum STS occurrence over the north Atlantic and southern Greenland. The occurrence rates of NAT enhanced and ICE are well below 10% and neither shows an area of pronounced occurrence. The distribution of wave ICE in Figure 3e shows that this composition is restricted regionally to south-eastern Greenland, around Iceland, southern Svalbard, the Scandinavian mountain range, and Novaya Zemlya.*

The discussion of Figure 5 was revised to refer to the correct plots in new Figure 5.

The revised Figure 8 looks like this:

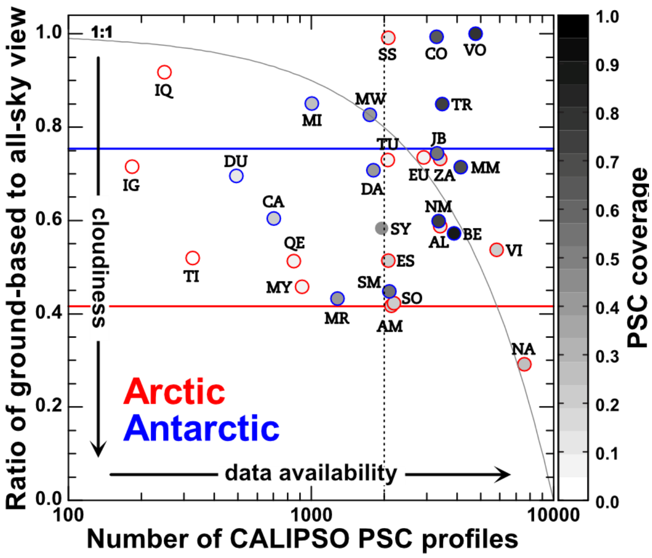

Figure 8. Number of CALIPSO PSC profiles in the 4◦×4◦ grid box centred around the Arctic (red) and Antarctic (blue) ground stations listed in Table 1 versus the ratio of PSC height bins as observed by a ground-based and a spaceborne lidar (columns 3 and 6 in Table 1). The colour coding refers to PSC coverage (ratio of PSC-containing profiles to all profiles) as shown in Figures 2b and 5b. Horizontal lines mark the values for the entire Arctic and Antarctic, respectively. The vertical dashed line separates stations with more than 2000 CALIPSO PSC profiles from those with fewer observations. The grey line marks a scaled PSC coverage defined as (10000 - x)/10000. Stations to the right of this line show a combination of tropospheric cloudiness and PSC coverage that indicates favourable conditions for ground-based lidar measurements. Stations abbreviations and markings for sites with published PSC climatologies are given in Table 1.

The discussion of Figure 8 has been revised to:

"Figure 8 combines the information on the absolute and relative occurrence of PSCs with the occurrence rate of tropospheric conditions that support PSC observations with ground-based lidar.

This display helps to assess the likelihood for obtaining suitable amounts of data for studying PSCs from ground-based lidar observations at the sites considered in this study. For the sites to the left of the dashed line that marks 2000 available CALIPSO PSC profiles, the number of PCS profiles in combination with the PSC occurrence rate is too low to consider the establishment of a new lidar station for PSC observations. To the right of the dashed line, further separation is provided by the grey line that represent a scaled PSC coverage. The most suitable stations for PSC observations from ground can be found to the right of this line because they combine a high PSC occurrence rate and a large number of identified PSC profiles with a high rate of favourable conditions for PSC observations from ground (upper right corner). Of the established PSC observatories only Concordia, Eureka, and McMurdo fall into this category. At Ny Ålesund, the large number of PSC profiles together with the high PSC occurrence rate (see Figure 2a and b, the PSC coverage of 0.29 at Ny Ålesund is the largest of all Arctic station) balances the measurement-inhibiting effect of a high occurrence rate of tropospheric clouds. Note that the assessment in Figure 8 is based entirely on atmospheric conditions and does not consider infrastructural challenges such as the accessibility, power supply, or availability of facilities at the respective sites; or the training and work load of the stationed personnel. It is because of this that most of the established PSC observatories fall into a region that could be considered as less suitable for establishing a ground station for PSC observations. Nevertheless, the trade-off between PSC occurrence and tropospheric cloudiness at those sites still creates conditions that allow for meaningful amounts of PSC observations — as witnessed by the available literature. If new PSC observatories were to be established, the most suitable choices – based solely on atmospheric conditions – would be Villum, Summit, Zackenberg, Thule, and Alert in the Arctic; and Vostok, Troll, Jang Bogo, Belgrano II, and Neumayer III in the Antarctic."

~~Location controls~~ On the ~~findings of~~ best locations for ground-based PSC observations

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Abstract. Spaceborne observations of Polar Stratospheric Clouds (PSCs) with the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite provide a comprehensive picture of the occurrence of Arctic and Antarctic PSCs as well as their microphysical properties. However, advances in understanding PSC microphysics also require measurements with ground-based instruments, which are often superior to CALIOP in terms of, e.g. time resolution, measured parameters, and signal-to-noise ratio. This advantage is balanced by the location of ground-based PSC observations and their dependence on tropospheric cloudiness. CALIPSO observations during the boreal winters from December 2006 to February 2018 and the austral winters 2012 and 2015 are used to assess the effect of tropospheric cloudiness and other measurement-inhibiting factors on the representativeness of ground-based PSC observations with lidar in the Arctic and Antarctic, respectively. Information on tropospheric and stratospheric clouds from the CALIPSO Cloud Profile product (05kmCPro version 4.10) and the Polar Stratospheric Cloud (PSC) mask version 2, respectively, is combined on a profile-by-profile basis to identify conditions under which a ground-based lidar is likely to perform useful measurements for the analysis of PSC occurrence. It is found that the location of a ground-based measurement together with the related tropospheric cloudiness can have a profound impact on the derived PSC statistics and that these findings are rarely in agreement with polar-wide results from CALIOP observations. Considering the current polar research infrastructure, it is concluded that the most suitable sites for the expansion of capabilities for ground-based lidar observations of PSCs are Summit and Villum in the Arctic and ~~Concordia~~Mawson, Troll, and Vostok in the Antarctic.

1 Introduction

The existence of Polar Stratospheric Clouds (PSCs) is of critical importance for stratospheric ozone depletion during polar winter. They provide the surface for heterogeneous reactions which transform stable chlorine and bromine species into their highly reactive ozone-destroying states (Lowe and MacKenzie, 2008; Solomon, 1999). PSC formation requires low temperatures that support the condensation of stratospheric water vapour and nitric acid vapour onto the available stratospheric aerosol particles. These conditions are generally found from December to February in the Arctic and between late May and early October in the Antarctic (Pitts et al., 2018).

Since the early 1990s, airborne and ground-based lidar remote-sensing observations of PSC optical properties have been used to classify PSCs into different types according to their size, shape, and chemical composition (Achtert and Tesche, 2014). Detailed observations of PSC occurrence and composition are also available from passive remote-sensing observations with the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) instrument (Spang et al., 2018). Today, ~~we are confident~~ there is consensus that PSC particles consist of supercooled liquid ternary solutions (STS), nitric acid trihydrate crystals (NAT), or water ice (ICE); and that PSCs are made up of different mixtures of those three ~~compositions~~components.

Ground-based lidar observations of PSCs are generally performed at the mercy of tropospheric clouds. Since its launch in June 2006, the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) aboard the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) satellite (Winker et al., 2009) has been providing a pole-wide view of Arctic and Antarctic PSCs that is unaffected by tropospheric cloudiness. The initial CALIPSO PSC classification scheme employs light-scattering calculations ~~with~~ that consider spherical and non-spherical ~~particles~~ particle shapes to relate sets of optical parameters to microphysical properties (Pitts et al., 2009, 2013). Recently, the CALIPSO PSC mask version 2 was introduced to correct deficiencies of the initial CALIPSO PSC classification and to improve composition discrimination (Pitts et al., 2018).

Traditionally, two approaches are used to match ground-based lidar measurements to spaceborne observations. Either statistics from a time series of ground-based measurements are compared to those obtained from averaging spaceborne observations for a specific grid-box around the ground ~~site~~ station or individual ground-based observations are matched to the data of the closest CALIPSO approach (Snels et al., 2019). Both methods can introduce biases as a result of imperfect temporal or spatial collocation. In addition, ground-based and spaceborne lidar observations of PSCs are often analysed with customised retrieval algorithms that can vary in their definition of different PSC types (Achtert and Tesche, 2014). The combined data set of CALIPSO cloud observations in the troposphere and stratosphere during the Arctic winters from December 2006 to February 2018 and the Antarctic winters 2012 and 2015 presented here allows for an assessment of the effect of tropospheric cloudiness and other measurement-inhibiting factors on the representativeness of ground-based lidar measurements of PSCs in a novel way. This paper starts with a description of the data and methods in Section 2. Results are presented and discussed in Section 3 and conclusions are drawn in Section 4.

2 Data and methods

2.1 Ground ~~sites~~stations

Figure 1 and Table 1 provide an overview of the Arctic and Antarctic research stations considered here. The sites were selected because they are accessible, manned year-round, and assumed to provide the necessary infrastructure for ground-based lidar measurements. Sites are also selected to minimise overlap with other research stations. Emphasised are the established PSC observatories Esrange, Sweden (Blum et al., 2005), Eureka, Canada (Donovan et al., 1997), Ny Ålesund, Svalbard (Massoli et al., 2006), and Sodankylä, Finland (Müller et al., 2001) in the Arctic and Belgrano II (Córdoba-Jabonero et al., 2013), Concordia (Snels et al., 2020), Dumont d'Urville (David et al., 1998; Santecesaria et al., 2001), McMurdo (Adriani et al., 2004; Snels et al., 2019), and Syowa (Shibata et al., 2003) in the Antarctic. Also highlighted are stations with a record of lidar measurements that are not specifically dedicated to PSC observations: Alomar (Langenbach et al., 2019), Iqualuit, and Summit (Neely et al., 2013) in the Arctic and Davis in the Antarctic.

2.2 Cloud Profile data

Information on tropospheric clouds is taken from the CALIPSO level 2 version 4.10 cloud profile product (05kmCPro.v4.10) which provides information on the vertical extent of different cloud types as well as profiles of the optical properties of clouds with a resolution of 5 km along the CALIPSO ground track and 30-m height bins below 8.2 km height (60-m height bins between 8.2 and 20.2 km height). The extracted parameters are time, latitude, longitude, and the cloud type as provided in the Vertical Feature Mask.

Features that are identified as clouds in the CALIPSO retrieval are further classified into eight cloud types (Liu et al., 2009): (i) low overcast, transparent, (ii) low overcast, opaque, (iii) transition stratocumulus, (iv) low, broken cumulus, (v) altocumulus (transparent), (vi) altostratus (opaque), (vii) cirrus (transparent), and (viii) deep convective (opaque). Ground-based equivalent CALIPSO observations are those that show an absence of tropospheric clouds or only transparent clouds for which a human operator would likely consider performing a ground-based measurement, i.e. transparent altocumulus, cirrus, or a combination of the two. An overview of the number of considered CALIPSO profiles with PSC observations for different tropospheric cloudiness is presented in Table 2.

2.3 PSC mask version 2

The CALIOP version 2 PSC detection and composition classification algorithm (CALIPSO PSC mask v2) separates stratospheric cloud features into STS, NAT mixture, ICE, NAT enhanced, and wave ICE. The PSC mask product has an along-track resolution of 5 km, identical to the tropospheric CALIPSO products, and a vertical resolution of 180 m. The new PSC mask corrects known deficiencies in previous versions (Pitts et al., 2009, 2013) and is described in detail in Pitts et al. (2018). A first evaluation with ground-based measurements at Antarctica is presented in Snels et al. (2019).

While all boreal winters from December 2006 to February 2018 are considered in the analysis of Arctic PSCs, only the austral winters of 2012 and 2015 are ~~are~~ included in the analysis of Antarctic PSCs. However, the generally higher occurrence rate of Antarctic PSCs means that a larger number of individual PSC profiles was observed during the two Antarctic winters compared to the 12 considered Arctic winters (see Table 2).

Because of CALIPSO's top-down viewing geometry, profiles start with the uppermost height bin (bin 1) down to the lowermost height bin (bin 583). Profiles in the PSC mask v2 product extend down to 8.2 km. They can therefore contain contributions of upper-tropospheric cirrus, as visualised in Figures 13 and 20 of Pitts et al. (2018). To exclude the contribution of such cirrus clouds from our analysis, only height bins above ~~14.9127~~14.9 km (~~down to~~ smaller than bin 85) and ~~13.1140~~13.1 km (~~down to~~ smaller than bin 96) are considered to represent Arctic and Antarctic PSC, respectively.

2.4 Data analysis

Information on cloud type from the Vertical Feature Mask in the 05kmCPro.v4.10 cloud profile product is used to sum up the number of height bins with different tropospheric ~~cloud types~~ cloudiness for each CALIPSO profile. This information is used to identify cloud-free conditions (a total of zero counts for each ~~cloud type~~of the eight cloud types) and situations with only transparent tropospheric clouds that would still enable meaningful PSC observations with a ground-based lidar~~.~~, i.e. altocumulus (transparent), cirrus (transparent), or a combination of the two. In addition, all-sky refers to the use of all profiles independent of tropospheric cloudiness.

The PSC mask v2 is processed analogous to the Vertical Feature Mask for tropospheric clouds by accumulating the number of height bins with different PSC ~~types~~ composition for each CALIPSO profile. PSCs that extend over just one height bin are excluded from the analysis. ~~Profiles are~~ A CALIPSO profiles is referred to as containing a certain a PSC ~~type, for instance STS, if this types was~~ composition (e.g. STS-containing or ICE-containing) if the respective component is identified in at least one of the PSC height bins. ~~Maps of the occurrence of the accumulated number of height bins related to different PSC types are normalised by the total number of PSC height bins per considered profile or grid box.~~

To enable a combined analysis of cloudiness in the polar troposphere and stratosphere, the data extracted from the 05km-CPro.v4.10 and PSC Mask v2 products are temporally matched and reduced to only those profiles with detected PSCs. The data set is then filtered according to the occurrence of (i) tropospheric clouds and ~~different PSC types~~(ii) PSCs with different composition. The filtered data is gridded into cells of 1.25° latitude by 2.50° longitude for visualisation of PSC occurrence. Maps of the occurrence of the accumulated number of height bins related to different PSC composition are normalised by the total number of PSC height bins per considered grid box (see Figures 2, 3, 5, and 6).

The matched observations of tropospheric and stratospheric clouds allow for a direct comparison of individual PSC profiles as well as long-term PSC statistics as seen from ground and space independent of the considered instruments. ~~To assess the representativeness of~~ Specifically, the same profile can be evaluated from two perspectives, i.e. from space as well as from the point of view of a ground-based ~~PSC measurements, PSC statistics are obtained for boxes of 2° latitude by 2° longitude around the sites in Figure 1 and Table 1~~instrument. In that context, the latter perspective translates to a CALIPSO-synchronous measurement protocol at a ground station. True PSC statistics unaffected by tropospheric cloudiness, i.e. during all-sky conditions, at a certain location can only be obtained with a spaceborne lidar. In contrast, filtering with respect to tropospheric cloudiness is applied to emulate the likely conditions for meaningful ground-based PSC measurements in the CALIPSO data set. Specifically, we assume that a ground-based lidar would only provide meaningful results during conditions with no clouds or only transparent clouds that would not already attenuate the laser beam before it can reach PSC altitudes. This is referred to as the ground-based view ~~.~~ of the CALIPSO data set. It provides sampling that is dependent on the CALIPSO return rate and must not be confused with actual ground-based measurements that can provide localised PSC observations in the time range from hours to weeks.

We subsequently separate ~~between observations of~~ the ground-based view of the CALIPSO data set into two scenarios for which (i) ~~a continuously operating ground-based lidar for which~~ all cases of the ground-based view are considered and (ii) ~~a~~

~~manually operated system for which~~ one third of the ~~cases~~ profiles of the ground-based view was randomly selected. The ~~two ground-based configurations are used to account for sampling effects related to the fact that~~ first scenario corresponds either to a continuously operating lidar or a manually operated system that is active during every single CALIPSO overpass with possible downtime in between without any interference by tropospheric clouds or measurement-inhibiting factors. The second scenario also refers to CALIPSO-synchronous measurements with the caveat that interfering factors reduce the number of measured lidar profiles to one third of what would ideally be possible. This latter scenario is much more realistic as (i) most ground-based lidar instruments are operated manually and on campaign basis~~and that~~ , (ii) the decision to start a measurement, i.e. the assessment of tropospheric cloudiness, is made subjectively by the operator~~. The purpose is hence to provide an estimate of the potential effects of,~~ , and (iii) infrastructural challenges (e.g. system downtime, logistical problems, and lack of personnel~~(to list just a few infrastructural challenges in operating a~~) affect the operation of a ground-based lidar at a remote location and under harsh conditions~~) on the inferred PSC statistics~~.

To assess the representativeness of ground-based PSC measurements, PSC statistics are obtained for boxes of 2° latitude by 2° longitude around the sites in Figure 1 and Table 1.

3 Results and discussion

3.1 Arctic observations

The ~~normalised~~ absolute number of observed PSC profiles (normalised to a maximum count of 2478) and the PSC occurrence rate (the ratio of observed CALIPSO PSC profiles versus all CALIPSO profiles) are shown in Figure 2a ~~shows that~~ and b, respectively. The absolute number of PSC observations is largest at highest latitutes due to the high CALIPSO return rate at those locations. The effect of the return rate is compensated for in the PSC occurrence ratio in Figure 2b. Overall, Arctic PSCs are most abundant between 30°W and 90°E and north of 70°N. The pattern of the CALIPSO-derived PSC occurrence rate resembles the MIPAS-based findings in Figure 6b of Spang et al. (2018). Note that Pitts et al. (2018) derived PSC occurrence frequencies for fixed altitudes of $\Theta = 500$ K (around 20 km) and that the PSC area in their Figure 24 is thus smaller than inferred from considering all PSC height levels as done here. Figure 2a and b also shows that the geography of the Arctic means that most ~~ground-sites~~ ground stations are located in areas of relatively low PSC occurrence. This is levelled by the normalised occurrence rate of suitable conditions for ground-based observations presented in Figure 2~~b. The~~ c and d. The difference between the two displays is that Figure 2c is normalised to the number of all PSC-containing CALIPSO profiles while Figure 2d is normalised to all CALIPSO profiles. The region of highest PSC occurrence rate over the north Atlantic coincides with the highest occurrence of opaque tropospheric clouds. While Ny Ålesund could potentially observe the most PSCs in the Arctic, the occurrence rate of good conditions for ground-based lidar measurements is much lower than at the other Arctic ~~sites~~stations. In contrast, sites on Greenland and in the Canadian Arctic show almost no opaque clouds but - with the exception of Villum - also feature a low occurrence rate of PSCs. A similar situation though with a generally lower rate of suitable conditions for ground-based observations is found for Alomar, Esrange, and Sodankylä. However, these sites provide much easier access than the other more remote locations. Tiksi is a ~~site~~ station that could potentially provide information on PSCs over the Siberian Arctic.

The occurrence rate of ~~different PSC types~~ PSCs with different chemical composition in the Arctic for all-sky conditions is shown in Figure 3. ~~The figure~~ Here and in the following closer look at Arctic PSCs, normalisation is done with respect to all CALIPSO profiles that contain PSCs (analogous to Figure 2c) rather than all CALIPSO profiles (as in Figure 2b and d). Figure 3 reveals that STS and NAT mixture are most abundant with a region of maximum STS occurrence over the north Atlantic and southern Greenland. The occurrence rates of NAT enhanced and ICE are well below 10% and neither ~~type~~ shows an area of pronounced occurrence. The distribution of wave ICE in Figure 3e shows that this ~~type~~ composition is restricted regionally to southeastern Greenland, around Iceland, southern Svalbard, the Scandinavian mountain range, and Novaya Zemlya.

Figure 4 provides a local quantification of the Arctic-wide display in Figure 3 for the selected Arctic sites in Table 1 in the form of the occurrence rate of different PSC ~~types~~ compositions as seen by a spaceborne instrument (all-sky conditions, same as in Figure 3), a ~~continuously operating~~ ground-based ~~instrument~~ lidar with CALIPSO-synchronous measurement protocol operated during every single CALIPSO overpass (no or only transparent clouds are present in the troposphere), and a ~~manually~~ CALIPSO-synchronously operated ground-based instrument that is affected by cloudiness and other measurement-inhibiting factors (one third of randomly selected CALIPSO profiles in the presence of no or only transparent clouds). For the entire Arctic, the spaceborne view gives a smaller fraction of NAT mixture compared to the ground-based view because the regional minimum in the occurrence rate of NAT mixture (Figure 3b) covers the location of most of the considered ground ~~sites~~stations. This is balanced by a larger fraction of STS for the entire Arctic compared to most ground ~~sites~~stations. The occurrence rates of NAT enhanced, ICE, and wave ICE are marginal with a total contribution of less then 10% of all observed PSC height bins. Tropospheric cloudiness would allow for ground-based observations in only about 42% of all Arctic CALIPSO PSC profiles. This causes the slight difference between the three bars related to Arctic-wide observations in Figure 4.

The localised view for 15 ground ~~sites~~ stations in the Arctic reveals the ~~different~~ impact of tropospheric cloudiness on the statistics on PSC microphysical properties as expected from Figure 3. Alert and Eureka in the Canadian Arctic and Summit, Thule, and Villum on Greenland, where the conditions for ground-based observations are best (see Figure 2~~b~~c), show little difference between the spaceborne and the ground-based view. Differences in PSC statistics at those site would more likely be related to the imperfect sampling of a ~~manually operated instrument~~ ground-based instrument related to cloudiness and other measurement-inhibiting factors (ground-based scenario 2). The smallest amount of observed CALIPSO PSC profiles is found for Igloolik (183), Iqualuit (249), Myvatn (918), Qeqertarsuaq (848), and Tiksi (326) compared to the other sites where this number ranges from 2080 for Esrange to 7573 for Ny Ålesund. Consequently, PSC statistics at these sites are much more sensitive to cloudiness and further sub-sampling. A considerable difference between the spaceborne and ground-based view is found in the European Arctic, particularly at Myvatn and Sodankylä. The occurrence rate of STS (ICE) is underestimated (overestimated) at Esrange, Myvatn, and Sodankylä while the opposite is found at Alomar and Ny Ålesund. The ratio of the number of PSC height bins representing the ground-based versus the spaceborne view is given in the third column of Table 1 and allows for the ranking of the ground ~~sites~~ stations with respect to the occurrence rate of suitable conditions for ground-based measurements.

Apart from the different effect of tropospheric cloudiness, Figure 4 also reveals that statistics of PSC microphysical properties can vary with location. Alert, Eureka, and Thule show STS (NAT mixture) occurrence rates below (above) the Arctic mean of about 30% (60%) while the opposite is the case at Alomar, Esrange, Iqaluit, Myvatn, Ny Ålesund, and Summit where the occurrence rate of STS exceeds 40% and that of NAT mixture stays below 40%. The highest and lowest occurrence rates of NAT enhanced are found at Igloolik and Alomar, respectively. The other sites show values that are mostly in line with the Arctic mean. ICE is most abundant at Myvatn, Qeqertarsuaq, Sodankylä, and Zackenberg and rarely observed at Alert, Alomar, Eureka, Thule, and Tiksi. Contributions of wave ICE are noticeable only at Myvatn, Sodankylä, and Zackenberg (see Figure 3e) and negligible at the other sites.

3.2 Antarctic observations

Figure 5a ~~shows~~ and b show that CALIPSO PSC profiles in the Antarctic are nearly equally distributed around the pole with a higher occurrence rate at higher latitudes. The same is found in the MIPAS climatology (Spang et al., 2018). Tropospheric cloudiness related to conditions that support ground-based lidar measurements (Figure 5~~b~~ c and d) is most abundant inland whereas the majority of Antarctic stations is located at the coast to keep logistics manageable. As for the Greenland ice sheet, the elevation of the better part of Antarctica translates into a complete absence of low-level clouds – the biggest antagonist to atmospheric lidar measurements. Cloudiness is largest upwind from the Antarctic Peninsula. The final column in Table 1 confirms that the lowest occurrence rate of favourable conditions for ground-based lidar measurements of PSCs is found at Marimbio (43%) and San Martín (45%), which are located on the Antarctic Peninsula. The opposite, i.e. an occurrence rate of unity, is true for Concordia and Vostok on the Antarctic Plateau.

The maps of the occurrence rates of different PSC ~~types~~ compositions in the Antarctic during all-sky conditions in Figure 6 show that STS and NAT enhanced are rather homogeneously distributed. A regional minimum in the occurrence of NAT enhanced is found over the West Antarctic Ice Sheet, the Weddell Sea, and parts of Queen Maud Land. This is compensated by higher occurrence rates of ICE. As in the Arctic, wave ICE occurs more locally and is restricted to the Antarctic Peninsula and the border between the Ross Sea and Victoria Land. Despite their layer-based approach on PSC occurrence frequency, Figure 19 in Pitts et al. (2018) presents similar findings regarding the distribution of STS, NAT, and ICE.

The statistics of Antarctic PSC microphysical properties are shown in Figure 7 and vary with location. There are, however, two noticeable differences compared to the situation in the Arctic. Firstly, there is generally little difference in the statistics related to the spaceborne and ground-based view. This is because opaque clouds are less abundant in the Antarctic compared to the Arctic. It is therefore more likely to find reasonable agreement between ground-based an spaceborne PSC observations at Antarctic ~~sites~~ stations (Snels et al., 2019) and to observe the same long-term statistics for Antarctic PSCs from ground and space. Secondly, sites such as McMurdo and Vostok show statistics that resemble those obtained for the entire Antarctic. The largest occurrence rates of STS are found at Marimbio, Neumayer III, San Martín, and Troll. However, these values don't exceed those for the entire Antarctic by more than 10 percentage points. The lowest occurrence rate of STS is found at Casey with a difference of also about 10 percentage points compared to the Antarctic mean. Casey is also the station with the highest occurrence rate of NAT mixture followed by Mirny. In addition, these two stations show almost no ICE PSCs. The lowest rate of NAT mixture and the highest rate of ICE (45%-50%) is found at Belgrano II, as this is the only site located in the regional minimum (maximum) of the occurrence rate of NAT mixture (ICE) revealed in Figure 6. All other sites show ICE occurrence rates below the Antarctic average. Wave ICE is found only at Jang Bogo (1%) and McMurdo (0.5%).

3.3 Location assessment

Figure 8 combines the information on the ~~occurrence rates of PSC and~~ absolute and relative occurrence of PSCs with the occurrence rate of tropospheric conditions that support PSC observations with ground-based lidar. This display helps to assess the likelihood for obtaining suitable amounts of data for studying PSCs from ground-based lidar observations at the sites considered in this study. For the sites to the left of the dashed line that marks 2000 available CALIPSO PSC profiles, the number of PCS profiles in combination with the PSC occurrence rate is too low to consider the establishment of a new lidar station for PSC observations. To the right of the dashed line, further separation is provided by the grey ~~lines that represent different ratios of cloudiness versus data availability~~line that represent a scaled PSC coverage. The most suitable stations for PSC observations from ground can be found to the right of ~~the 1:1~~ this line because they combine a high PSC occurrence rate and a large number of identified PSC profiles with a high rate of favourable conditions for PSC observations from ground (upper right corner). Of the established PSC observatories only ~~Eureka, McMurdo, and Ny Ålesund~~ Concordia, Eureka, and McMurdo fall into this category. At Ny Ålesund, the ~~high occurrence rate of tropospheric clouds is levelled by the also~~ large number of PSC profiles together with the high PSC occurrence rate (see Figure 2~~)~~a and b, the PSC coverage of 0.29 at Ny Ålesund is the largest of all Arctic station) balances the measurement-inhibiting effect of a high occurrence rate of tropospheric clouds. Note that the assessment in Figure 8 is based entirely on atmospheric conditions and does not consider infrastructural challenges such as the accessibility, power supply, or availability of facilities at the respective sites; or the training and work load of the stationed personnel. It is because of this that most of the established PSC observatories fall into a region that could be considered as less suitable for establishing a ~~ground-site~~ ground station for PSC observations. Nevertheless, the trade-off between PSC occurrence and tropospheric cloudiness at those sites still creates conditions that allow for meaningful amounts of PSC observations~~ –~~, as witnessed by the available literature. If new PSC observatories were to be established, the most suitable choices – based solely on atmospheric conditions – would be Villum, Summit, Zackenberg, Thule, and Alert in the Arctic; and Vostok, ~~Concordia,~~ Troll, Jang Bogo, Belgrano II, and Neumayer III in the Antarctic.

4 Summary and conclusions

There is a rich literature on airborne and ground-based PSC measurements going back to the 1980s. The thus collected time series have been used to obtain statistics of microphysical properties of PSCs in the Arctic and Antarctic. While the impact of using different PSC classifications schemes has been assessed in the past (Achtert and Tesche, 2014), there as not yet been an evaluation of the comparability and the representativeness of the available time series and statistics of ground-based PSC observations. Here, CALIPSO lidar observations of clouds in the troposphere and stratosphere are used to compare statistics of PSC microphysical properties as observed (i) from space and ground and (ii) at different ground ~~sites~~stations. The data set shows a strong dependence of PSC microphysical statistics on the location of a ground ~~site~~ station in both the Arctic and the Antarctic. In the Arctic, there is the additional combined effect of the inhomogeneous distribution in the occurrence of both PSCs and tropospheric clouds on the representativeness of ground-based PSC observations with respect to all-sky conditions.

The combination of the occurrence rate of PSCs and of suitable conditions for ground-based PSC observations allows to assess the suitability of a ground ~~site~~ station for long-term lidar measurements of PSCs. This suitability is related solely to atmospheric conditions and does not consider challenges with respect to logistics, personnel, or training. According to this definition, measurements at more suitable sites will require less measurement effort to obtain a data set that can be used to infer statistically significant PSC data. This knowledge is important as ground-based lidars are generally more advanced than spaceborne instruments and allow to independently retrieve backscatter and extinction coefficients as well as the particle linear depolarisation ratio at multiple wavelengths and at a better signal-to-noise ratio. Their measurements are therefore invaluable for a better understanding of processes related to PSC formation and persistence.

Of the established PSC observatories only Concordia, Eureka, McMurdo, and Ny Ålesund are found to fall into a category that provides a good balance between PSC occurrence and tropospheric cloudiness. Dumont d'Urville is at the lower end of available PSC observations while Esrange, Sodankylä, and Syowa all show only about 1000 CALIPSO PSC profiles during conditions for ground-based measurements. The occurrence rate of PSCs in the Arctic is much lower than in the Antarctic. Hence, the assessment prevented here is particularly important for Arctic sites. Considering only atmospheric conditions, it is found that Villum, Summit, Zackenberg, Thule, and Alert would be the best choices for establishing new PSC observatories with state-of-the-art lidar instruments the Arctic. In the Antarctic, this is that case for Vostok, ~~Concordia, Troll,~~ Troll, Mawson, Jang Bogo, Belgrano II, and Neumayer III.

The strong dependence of PSC formation on temperature suggests a crucial role of processes that enhance local cooling (Carslaw et al., 1998; Teitelbaum et al., 2001). These include synoptic or mesoscale events that are generally linked to specific types of tropospheric cloudiness. It is therefore reasonable to expect a connection between tropospheric cloudiness and the occurrence of PSCs and maybe even ~~different PSC types~~PSCs of different chemical composition. Initial studies focussed on individual winters in the Arctic (Achtert et al., 2012) and Antarctic (Wang et al., 2008; Adhikari et al., 2010) show that particularly high and deep-convective cloud systems have a strong effect on PSC formation. This indicates that tropospheric meteorology might be an important driver for the interannual variability in PSC formation and ozone hole recovery. While CALIPSO is operational since 2006, there has not yet been a thorough assessment of the dependence of the occurrence of different PSC ~~types~~ compositions on tropospheric cloudiness. In the future, the combined CALIPSO data set of clouds in the troposphere and stratosphere presented here will be used to investigate this connection. In addition, the methodology presented here can be easily adapted to assess the effect of low-level clouds on tropospheric observations. For instance, it can be used to find locations for measurement campaigns or long-term observatories at which the measurement-inhibiting effect of opaque clouds has a minimum impact on the observational cover of mid-level or high clouds and elevated tropospheric and stratospheric aerosol layers.

Data availability. CALIPSO Cloud Profile data were obtained from the ICARE Data and Services Center (http://www.icare.univ-lille1.fr/). CALIPSO PSC Mask v2 data are available from Michael C. Pitts upon request.

Author contributions. MT and PA conceived the study, developed the methodology, and analysed the data. CALIPSO PSC Mask v2 data were provided by MCP. All authors contributed to the discussion of the data and the preparation of the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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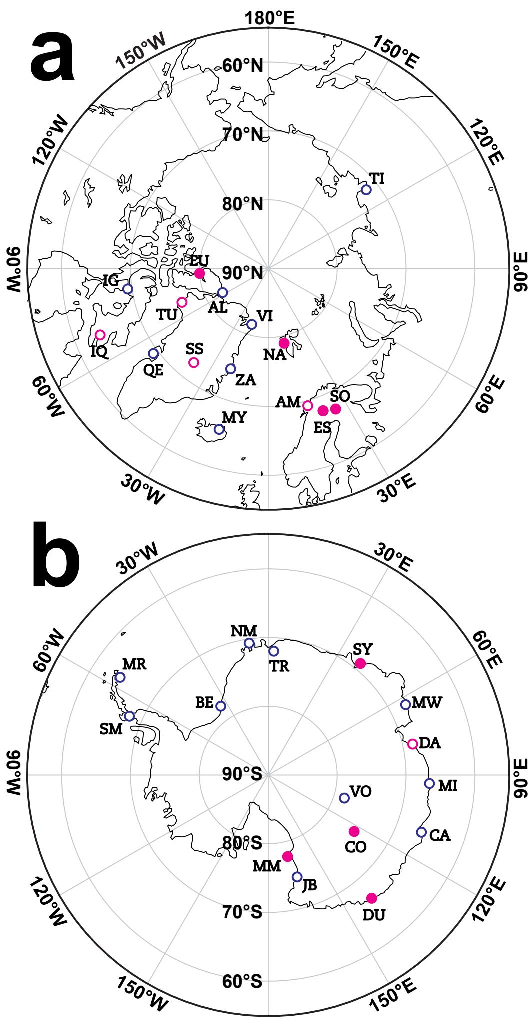

Figure 1. Locations of research stations in (a) the Arctic and (b) the Antarctic and their respective abbreviations are listed in Table 1. Red open circles mark stations with atmospheric lidar measurements while red filled circles refer to stations with published PSC measurements. Other stations of potential interest for ground-based PSC observations are marked by blue open circles.

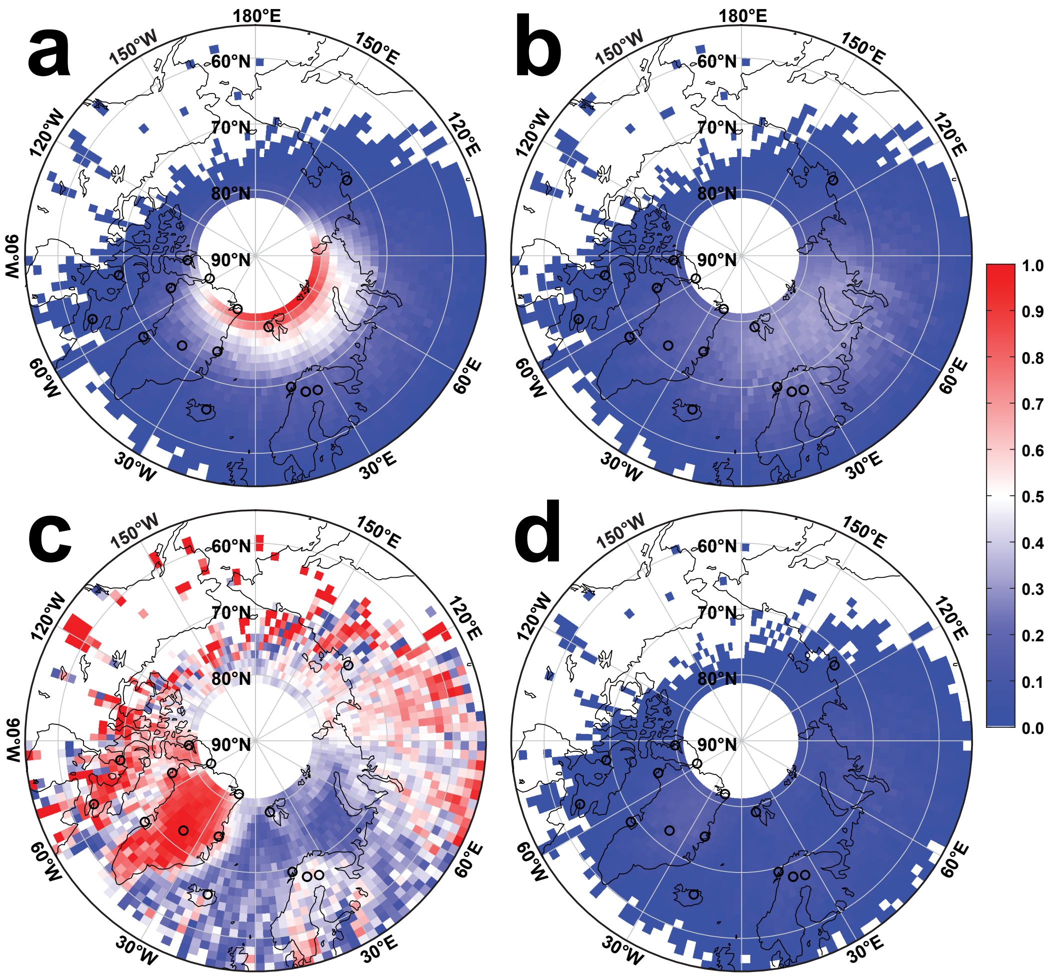

Figure 2. Normalised number of CALIPSO profiles with PSCs detected over the Arctic (a, scaled to maximum count of 2478)~~and~~ , ratio of CALIPSO profiles with PSCs detected versus all CALIPSO profiles (~~b~~with and without PSCs detected) for the same time period (b, PSC occurrence rate), ratio of CALIPSO profiles with favourable tropospheric cloud conditions for ground-based lidar measurements (no or only transparent clouds) and PSCs detected versus all CALIPSO profiles with PSCs detected for the same time period (c), and ratio of CALIPSO profiles with favourable tropospheric cloud conditions for ground-based lidar measurements and PSCs detected versus all CALIPSO profiles for the same time period (d). Black circles mark the locations of lidar ground ~~sites~~ stations shown in Figure 1 and listed in Table 1.

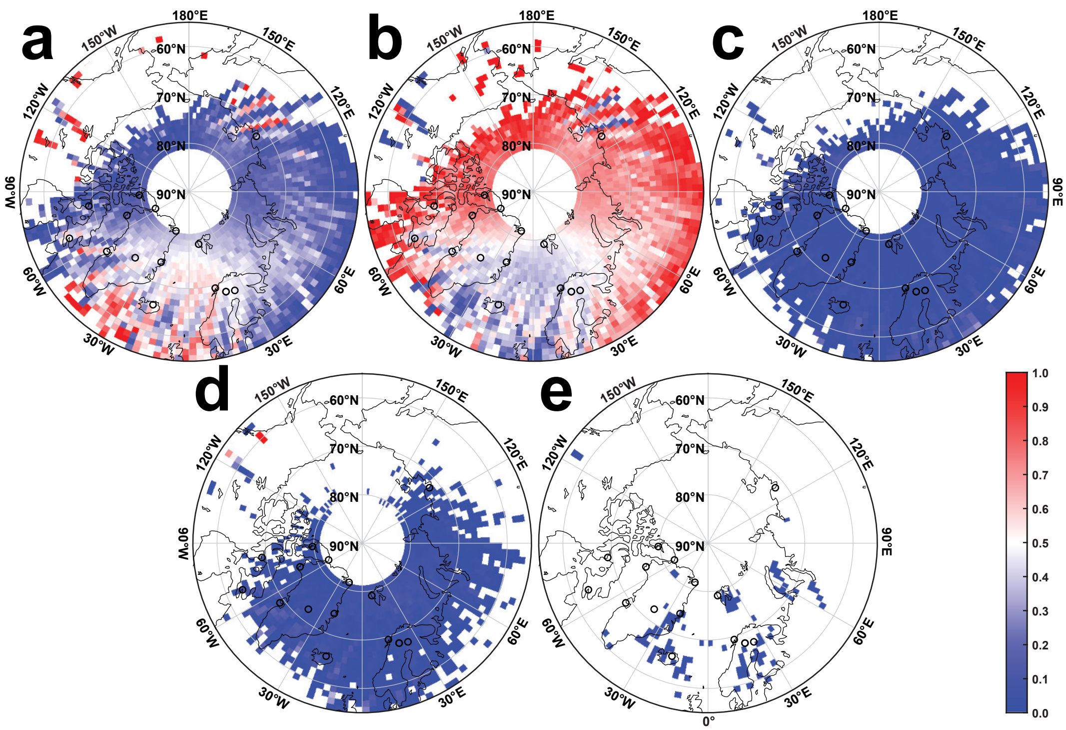

Figure 3. Normalised occurrence rate of CALIPSO height bins that contain (a) STS, (b) NAT mixture, (c) NAT enhanced, (d) ICE, and (e) wave ICE for all-sky conditions in the Arctic.

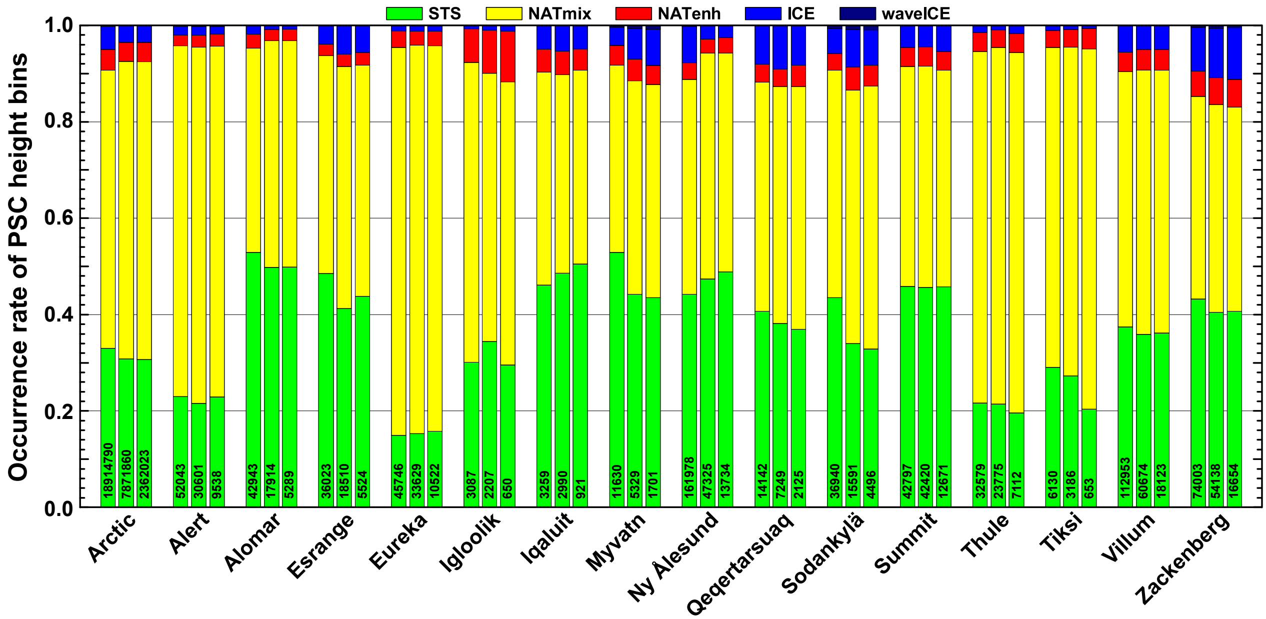

Figure 4. Occurrence rate of STS (green), NAT mixtures (yellow), NAT enhanced (red), ICE (blue), and wave ICE (dark blue) for the entire Arctic as well as for the Arctic ground ~~sites~~ stations listed in Table 1. The three bars per site refer to (i) all-sky conditions in the troposphere (the view of a spaceborne lidar, left, not possible with ground-based instruments), (ii) conditions with no tropospheric clouds or transparent clouds only (the view of a ~~continuously working~~ ground-based lidar with CALIPSO-synchronous measurement protocol operated during every single CALIPSO overpass, middle), and (iii) one third of randomly selected profiles from observations with no tropospheric clouds or transparent clouds only (the view of a ~~manually~~ CALIPSO-synchronously operated ground-based ~~lidar~~instrument that is affected by cloudiness and other measurement-inhibiting factors, right). Numbers refer to the total amount of considered PSC height bins per configuration.

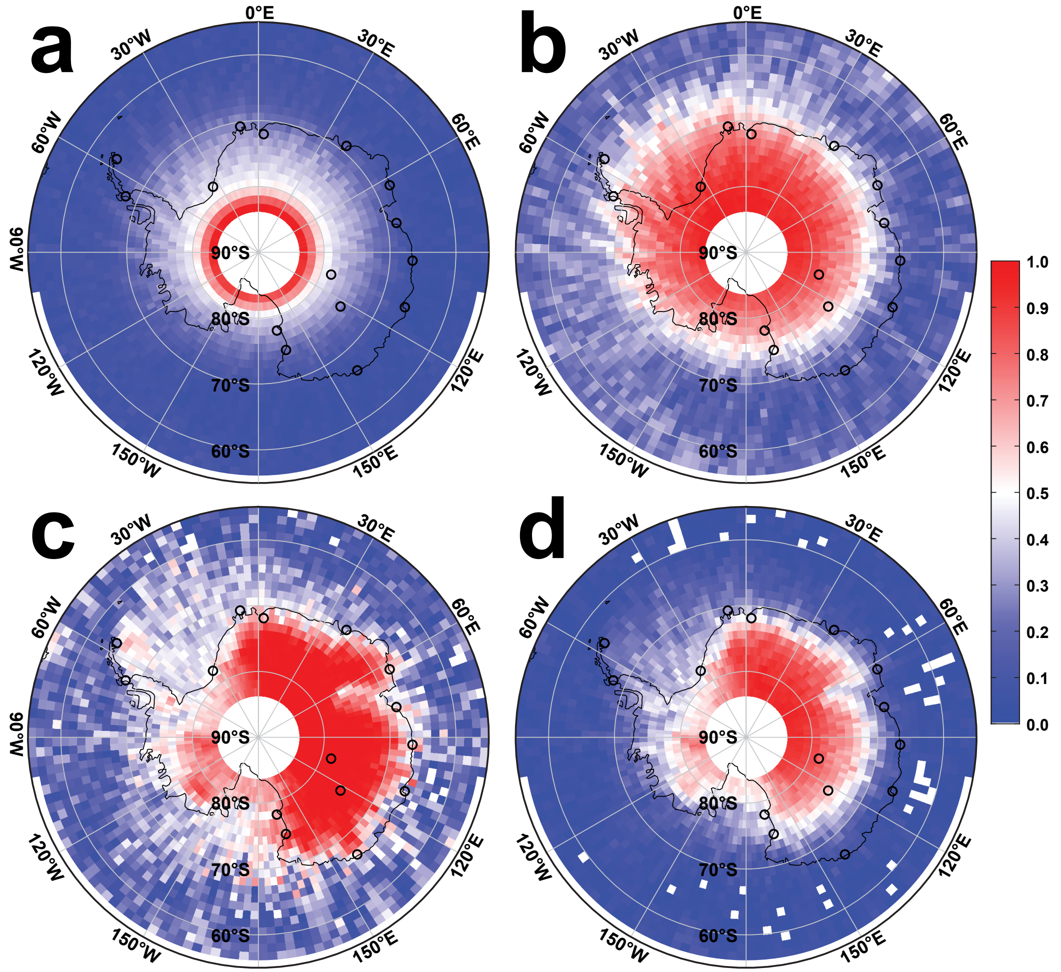

Figure 5. ~~Normalised number of CALIPSO profiles with PSCs detected over~~ Same as Figure 2 but for the Antarctic. The display in (a~~,~~) is scaled to a maximum count of ~~2001) and (b) the occurrence rate of favourable tropospheric cloud conditions for ground-based lidar measurements (no or only transparent clouds). Black circles mark the locations of lidar ground sites shown in Figure 1 and listed in Table 1.~~2001.

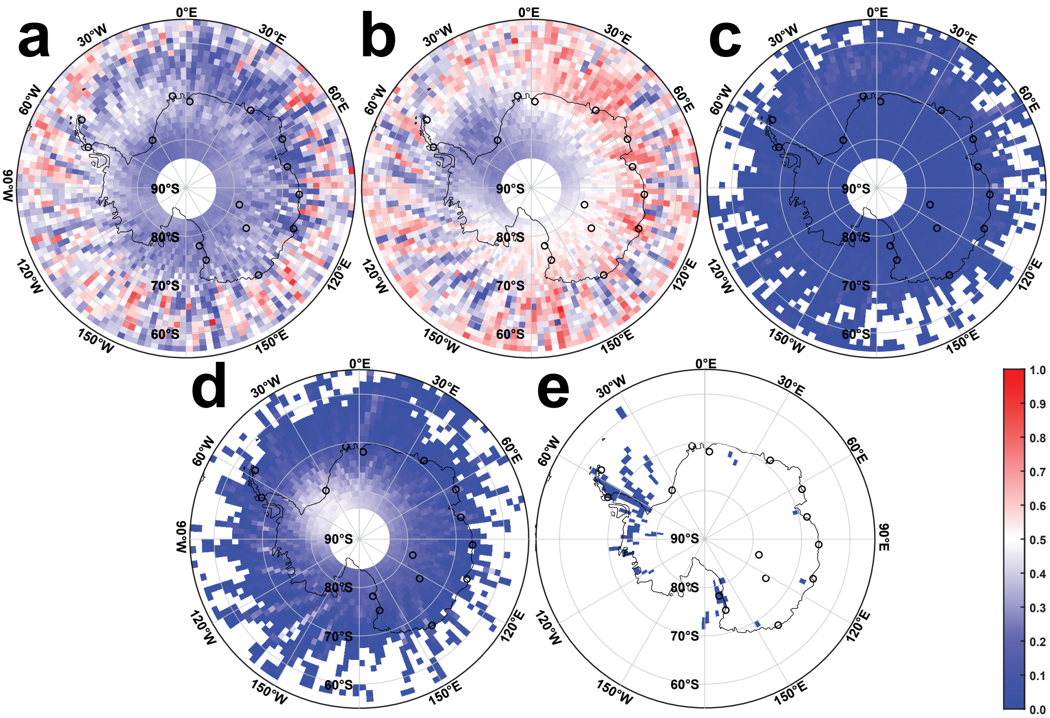

Figure 6. Same as Figure ~~7~~ 3 but for the Antarctic.

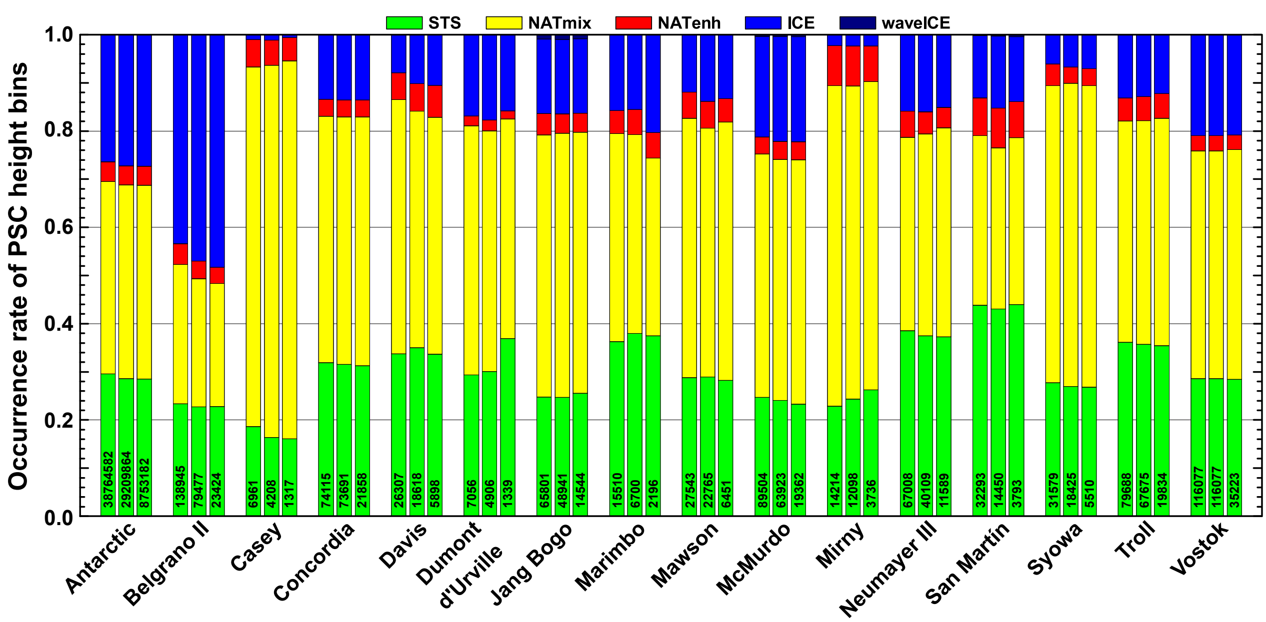

Figure 7. Same as Figure 4 but for Antarctic observations.

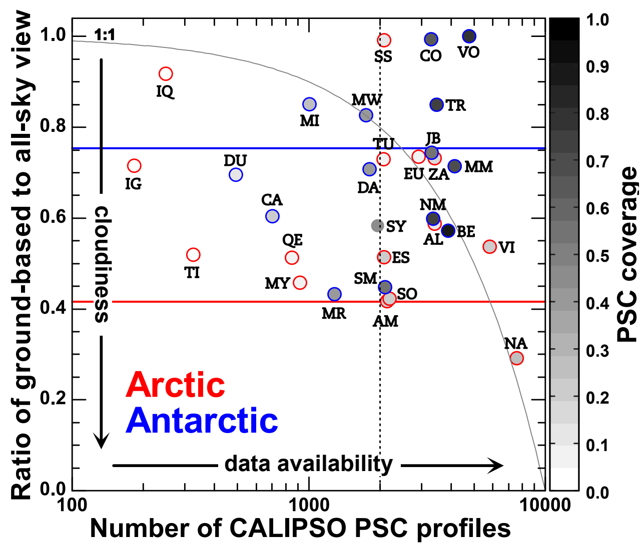

Figure 8. Number of CALIPSO PSC profiles in the $4^\circ \times 4^\circ$ grid box centred around the Arctic (red) and Antarctic (blue) ground ~~sites~~ stations listed in Table 1 versus the ratio of PSC height bins as observed by a ground-based and a spaceborne lidar (columns 3 and 6 in Table 1). ~~Filled symbols mark sites with published~~ The colour coding refers to PSC ~~climatologies~~coverage (ratio of PSC-containing profiles to all profiles) as shown in Figures 2b and 5b. Horizontal lines mark the values for the entire Arctic and Antarctic, respectively. The vertical dashed line separates stations with more than 2000 CALIPSO PSC profiles from those with fewer observations. ~~Grey lines mark~~ The grey line marks a scaled PSC coverage defined as (10000 - x)/10000. Stations to the ~~ratios 0.6:1.0, 0.8:1.0, 1.0:1.0, 1.0:1.2, 1.0:1.4,~~ right of this line show a combination of tropospheric cloudiness and ~~1.0:1.6~~PSC coverage that indicates favourable conditions for ground-based lidar measurements. Stations abbreviations and markings for sites with published PSC climatologies are given in Table 1.

Table 1. Overview of the location of Arctic and Antarctic research stations. Station abbreviations in columns 1 and 5 are used to mark the corresponding sites in Figures 1 and 8. Stations with a deployment of atmospheric lidar instruments are marked with ♣ while those with existing PSC data sets are marked with ♠. R gives the ratio of PSC height bins for tropospheric cloudiness that relates to the data coverage of a ground-based (cloud-free and transparent clouds) and a spaceborne lidar (all-sky).

Arctic station		**Location**	**R**	**Antarctic station**		**Location**	**R**
AL	Alert, Canada	82°N, 62°W	0.59	BE	Belgrano II, Coats Land ♠	78°S, 35°W	0.57
AM	Alomar, Norway ♣	69°N, 16°E	0.42	CA	Casey, Vincennes Bay	66°S, 111°E	0.60
ES	Esrange, Sweden ♠	68°N, 21°E	0.51	CO	Concordia, Antarctic Plateau ♠	75°S, 123°E	0.99
EU	Eureka, Canada ♠	80°N, 86°W	0.74	DA	Davis, Princess Elizabeth Land ♣	69°S, 78°E	0.71
IG	Igloolik, Canada	69°N, 82°W	0.71	DU	Dumont d'Urville, Aélie Land ♠	66°S, 140°E	0.70
IQ	Iqaluit, Canada ♣	64°N, 69°W	0.92	JB	Jang Bogo, Terra Nova Bay	75°S, 164°E	0.74
MY	Myvatn, Iceland	66°N, 17°W	0.46	MR	Marambio, Marambio Island	64°S, 57°W	0.43
NA	Ny Ålesund, Svalbard ♠	79°N, 12°E	0.29	MW	Mawson, Mac Robertson Land	68°S, 63°E	0.83
QE	Qeqertarsuaq, Greenland	69°N, 54°W	0.51	MM	McMurdo, Ross Island ♠	78°S, 167°E	0.71
SO	Sodankylä, Finland ♠	67°N, 27°E	0.42	MI	Mirny, Davis Sea	67°S, 93°E	0.85
SS	Summit Station, Greenland ♣	73°N, 39°W	0.99	NM	Neumayer III, Atka Bay	71°S, 8°W	0.60
TU	Thule, Greenland ♣	77°N, 69°W	0.73	SM	San Martín, Barry Island	68°S, 67°W	0.45
TI	Tiksi, Russia	72°N, 129°E	0.52	SY	Syowa, Queen Maud Land ♠	69°S, 40°E	0.58
VI	Villum, Greenland	82°N, 17°W	0.54	TR	Troll, Queen Maud Land	72°S, 3°E	0.85
ZA	Zackenberg, Greenland	75°N, 21°W	0.73	VO	Vostok, Antarctic Ice Sheet	78°S, 106°E	1.00

Table 2. Number of considered CALIPSO profiles with PSC observations for different tropospheric cloudiness in the Arctic (December 2006 to February 2018) and the Antarctic (winters of 2012 and 2015). The sum of cloud-free conditions and profiles with transparent clouds makes up the view of a ground-based lidar.

Tropospheric cloudiness	**Arctic**	**Antarctic**
all-sky	1000572	1676986
cloud-free	218553	402630
transparent	225600	740952
ground-based	444153	1143582