

Interactive comment on “CALIPSO polar stratospheric cloud observations: second-generation detection algorithm and composition discrimination” by M. C. Pitts et al.

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Final Response

Included below are our responses (in bold italics) to the comments from the two referees of our ACPD paper. We appreciate all of their suggestions for clarification and improvements to our paper.

Anonymous Referee #1

General comments

This paper presents a second-generation PSC detection algorithm and composition
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discrimination. The method presented shows improvements in comparison with the original algorithm, although it is still necessary to be validated by more in situ measurements. The application of the algorithm and composition classification scheme presents the useful and impressive information on the properties of PSCs over the Arctic and Antarctic. The paper also mentioned the inter-comparison of the results with the other observations such as MLS data, which shows a high degree of consistency. In this regard, further validation by in situ measurements will lead to further improvement of current algorithm and more understanding of PSC composition and formation mechanisms. The paper is well written and will interest the scientific community with the promising application in PSC detection and composition discrimination using satellite measurements.

We agree that comparisons of CALIOP data with coordinated in situ measurements would be particularly valuable for exploring more fully the information content of the CALIOP data with regard to PSC microphysical characterization.

Specific comments

1. Page 8132-8133, the authors present the theoretical calculation of optical properties for STS, STS-NAT, STS-ice by different particle number density and effective radius. It will be interesting to give the summarised typical particle size and number density of mixtures found from satellite observational data analysis.

Particle number density and effective radius are difficult parameters to retrieve directly from satellite observations. Although in situ particle measurements of PSCs are limited, we felt it was more prudent to use these to establish the typical range in particle size and concentration for our optical model calculations of NAT and ice mixtures. Large NAT particles have been measured in situ by Fahey et al. (2001) and Northway et al. (2002) with diameters from 5-20 μm and particle number densities between 10^{-5} and 10^{-3} cm^{-3} . In situ measurements of ice (i.e., Type 2) PSCs are very rare. Dye et al. (1992) measured particles at sub-frost-

point temperatures with diameters greater than $4 \mu\text{m}$ and concentrations from 10^{-3} to 10^{-2} cm^{-3} . STS particle size is calculated as a function of temperature (assuming a lognormal size distribution with $N=10 \text{ cm}^{-3}$ and $\sigma=1.6$) directly from the equilibrium condensed STS volume, which is specified from the relationship of Carslaw et al. (1995). The Carslaw et al. (1995) results were shown to match very well the STS volumes observed by Dye et al. (1992).

We added text to Section 3.1 stating that we based our particle size and number density ranges on in situ observations.

2. Page 8134-8135, how about the thin PSCs of the very large NAT particles with low number density? Is it possible to detect them?

PSCs characterized by low numbers of large NAT particles (so-called NAT 'rocks') will produce significant enhancements in perpendicular backscatter (and aerosol depolarization), but only very small enhancements in scattering ratio. Although these clouds were likely missed with our v1 algorithm, the second generation algorithm may be able to detect these clouds through enhancements in the perpendicular backscatter. Our optical model calculations indicate that CALIOP observations of these clouds would fall near the left edge of the Mix 1 domain shown in Fig.7. It should be noted, however, that NAT 'rock' detection by CALIOP can only be confirmed through coordinated comparisons of CALIOP data and in situ particle measurements.

3. Page 8136-8138, it will be helpful if the authors can give some uncertainty analysis of the second-generation algorithm and scheme.

A formal uncertainty analysis for our PSC detection and composition classification is difficult due to the empirical nature of the algorithms. Validation of our PSC data products is also problematic due to a lack of corroborative data sets. Instead, we have attempted to identify the predominant sources of uncertainty in our PSC detection and composition analyses. We have defined the de-

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tection thresholds conservatively to ensure that cloud elements are confidently identified with minimum false positives. Analyses of the CALIOP Antarctic PSC database from early May and late October (when no PSCs observations are expected) indicate that the false positive rate is less than 0.1%. The detection threshold for STS is at a scattering ratio of about 1.3, which is similar to that used in other lidar PSC analyses (e.g., Toon et al., 2000). However, the transition from background stratospheric aerosol to STS is continuous rather than an abrupt shift. Thus, our threshold approach will by its very nature exclude a subset of the evolving liquid aerosol population. Therefore, the PSC area calculations are likely lower limits on true PSC coverage. We estimate the error in mapping the CALIOP PSC observations into areal coverage is generally less than 5% during most of the season when PSCs are widespread, but is larger when PSC coverage is limited such as very early and late in the Antarctic season and in the Arctic.

Based on our theoretical optical calculations, we made the arbitrary choice of four composition classes for CALIOP PSC data. Measurement noise will clearly introduce uncertainty in assigning an observation to one particular composition class, especially if the data point lies near the boundary between two classes. However, our confidence in our PSC composition classification scheme has been boosted by a comparison with coincident PSC observations by MIPAS (Höpfner et al., 2009) which shows a high degree of consistency between both PSC detection and composition derived from the two instruments. This comparison study was published since we submitted the original version of this paper.

We have added text in Sections 2 and 3 to describe the various uncertainties related to PSC detection and composition discrimination.

Anonymous Referee #2

GENERAL COMMENTS: This paper reports a detailed study of the capabilities and performances of CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) lidar sys-

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tem onboard the CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) spacecraft in measuring polar stratospheric cloud (PSC) optical properties. The authors go through an extended description of an improved method for the detection of PSC, the new algorithm allows the classification of the observed PSCs in the classical scheme: Supercooled Ternary Solution (STS), ice, nitric acid trihydrate (NAT) and mixtures of STS with NAT. The CALIOP/CALIPSO PSC observations also show the peculiar differences between Antarctic and Arctic PSC on global geographical scale and along multiannual periods. The authors claim that the seasonal and altitudinal variations in Antarctic PSC composition are related to changes in HNO₃ and H₂O observed by the Microwave Limb Sounder on the Aura satellite.

The message occurring at a “standard” reader (e.g., who is interested to the general PSC microphysical properties) is very appealing: this, very extended, classification of PSC could have a strong impact on to the (polar region) stratospheric studies, but a more clear discussion of the indetermination (systematics and statistics, paragraph 2) could improve the scientific weight of the paper.

We have added text in Sections 2 and 3 describing uncertainties in PSC detection, composition discrimination, and the calculation of PSC areas.

On the other hand, a “technical” reader (for example, a lidar-oriented scientist) could find the paper of interest, if the CALIOP data significance and limitations (I am thinking to the retrieval of backscatter coefficients, the depolarization, and the estimation of their “cut-off”/threshold values) are presented in more schematic way.

Our analyses are based on standard CALIOP Level 1B data products. The retrieval of the Level 1B data products, lidar calibration, and data quality have been discussed in detail elsewhere in the literature (e.g., Powell et al., 2009; Hunt et al., 2009; Winker et al., 2007; McGill et al., 2007) and we feel that it is beyond the scope of this paper to present these details here. We have added citations to these papers for the more “technical” readers. We have also added text to clar-

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ify the definitions of all optical parameters used in our analyses that have been derived from the standard Level 1B data products.

In such form, the paper induces an high attention; and, (I think that) these capabilities and results of a space-lidar are worth of interest for the atmospheric scientific community. In summary (according to the generic review rules): the study has an high degree of originality; the inferences, interpretation and mathematical analysis are correct; the presented results and material could be interesting in the field of cloud studies; the abstract is quite clear; the general policy on the issue of SI units is fulfilled.

Below, I will try to evidence few critical points in the different parts of the current form of the paper, hoping that these can be useful for the authors.

DETAILED COMMENTS: Abstract Is it possible to insert a sentence stating which impact has the evaluated increase (about 15%) in PSC areal coverage on the PSC key-role within the chemical/dynamical processes of the polar stratosphere?

Most of the additional ~15% PSC areal coverage can be attributed to our increased sensitivity to low number density NAT mixtures. Although these optically-thin NAT mixtures would have a minimal impact on chlorine activation due to their relatively small particle surface area, they may play a significant role in denitrification and therefore are an important component of our overall PSC area. We have added a sentence to the abstract and in Section 5 (summary and conclusions) stating this impact.

2. Second-generation detection algorithm 2.1 Data preparation Does the data smoothing affect the PSC classification? 5km horizontal - 180m vertical grid could average out the very peculiar features of “mountain wave” PSCs (strong variations of perp. and paral. backscatter) that develop over smaller scales.

The resolution of the CALIOP Level 1B data is 60-m vertical and 1-km horizontal for altitudes between 8.2 km and 20.2 km and 180-m vertical and 1.67-km hori-

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zontal for altitudes between 20.2 km and 30 km. This change in averaging scales produces a distinct difference in the noise characteristics of the data across the 20.2 km altitude boundary and combining data across this boundary would produce unpredictable results. We chose to apply additional spatial averaging to closely match the resolutions of the two altitude regimes and produce a single dataset with consistent resolution and noise characteristics over the entire altitude range of interest. The smallest common multiple of the vertical and horizontal scales is 180 m and 5 km, respectively, so this is the starting resolution for our PSC analyses. In general we don't believe the smoothing significantly impacts our current PSC composition classification. Small scale gravity wave and mountain wave PSCs are typically optically-thick ice clouds that produce very large enhancements in scattering ratio. Although the initial smoothing may reduce the absolute magnitude of the scattering ratio somewhat, it will likely remain above the scattering ratio threshold for ice clouds and be properly classified as an ice PSC. However, the smoothing will clearly affect the details of the optical properties of these clouds. An alternate approach would be to treat the two altitude regimes separately for cloud detection and retain the inherent resolution of the Level 1B data. However, this would add significant complexity to the algorithm and is beyond the scope of this paper. We will investigate this option in future studies.

2.2 Cloud detection lines 10-22 This procedure, in some way, accentuates the "smoothing effects" cited in the previous point.

It is true that the spatial coherence test will exclude PSCs that occur in isolation on spatial scales of less than about 20-km horizontal by 540-m vertical. However, it is also very effective at filtering out false positives due to radiation-induced noise spikes that are very common in the data. Without the spatial coherence test, the level of false positives would be unacceptable.

3. PSC composition discrimination A naïve question: the inherent simplicity of a Monte

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Carlo approach, could give a more significant picture when performing the optical calculations for PSC discrimination?

It is not clear to us what type of Monte Carlo approach the referee envisions we would use in our optical calculations. We assume that he/she is suggesting that we could use a Monte Carlo approach to add measurement noise to our calculated scattering and aerosol depolarization ratio, resulting in "fuzzy" or blurred curves for each particle mixture rather than sharply defined curves. This is beyond the scope of our present work, but it is a good suggestion that we will consider implementing in future versions of our algorithm. We have added text in section 3.2 to emphasize that the boundaries between our PSC composition classes are somewhat arbitrary and that there is uncertainty in the classification of data points lying near the boundaries.

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