Atmos. Chem. Phys. Discuss., 7, S4518–S4526, 2007
www.atmos-chem-phys-discuss.net/7/S4518/2007/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Characterization of Polar Stratospheric Clouds with Space-BorneLidar: CALIPSO and the 2006 Antarctic Season" *by* M. C. Pitts et al.

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Received and published: 30 August 2007

Formal Response to Referee #1

The authors would like to thank the reviewer for his careful critique of our manuscript.

Our response to his comments is provided below.

Referee's general concerns:

1. "I understand that the paper has a substantial scope in dealing exclusively with the Antarctic. However, the polar Arctic is a region of great relevance, and there is one full PSC season already recorded by CALIPSO. Auth do not make any attempt to scope in the Arctic, or even present a plan for that in future work. I hope auth consider

addressing this by either a referee response or perhaps even inclusion in the paper."

The overall goals of this paper are to describe our initial PSC detection algorithm and demonstrate its viability. We feel that the analysis of the 2006 Antarctic season presented in the paper is sufficient for meeting these goals. We agree that the Arctic is of great relevance and we are in the process of writing a second paper that will include results from the 2007-07 Arctic season.

2. "What is the rationale for reducing noise by horizontal averaging? Is there a known horizontal component to the instrument noise? Is the "noise" instrument-related, or geophysical variability. It would be valuable to read a fuller description of this issue, or have a citation to which to refer."

The CALIPSO lidar design was optimized for studying tropospheric aerosol and clouds; hence the stratospheric data have relatively low signal-to-noise ratios (SNR). As a result, the single profile data appear very noisy compared to high SNR measurements such as those from the SAM II and POAM II/III solar occultation instruments. The measurement noise we refer to is dominated by shot noise which is a well-known phenomenon associated with most optical and electronic measurement systems. Shot noise is random, electronic white noise (not of any geophysical nature) and, as a result, averaging the data will reduce this noise component roughly in proportion to the square root of the number of measurements averaged. So the horizontal averaging is applied to reduce this noise component and enhance the detection of the weaker stratospheric signal at the cost of some spatial resolution. The initial smoothing of the data to 5-km horizontal resolution is performed to put the data onto a common horizontal scale. The horizontal resolution of the Level 1b data changes with altitude (1-km between 8-20km and 5/3 km between 20-30km) and 5 km is the smallest common denominator. The additional averaging to 25- and 75-km horizontal resolution is applied to further reduce the measurement noise and allow more optically-thin clouds to be detected above the noise. This is similar to the approach used in CALIPSO's operational feature finder algorithm for tropospheric clouds and aerosols.

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3. “While I understand the utility of a temperature marker for the PSC detection, I am perplexed at the primary use of temperature in the algorithm, in particular using T=198K as a threshold for segmenting background aerosols. This seems like a sort of circular logic, a reversion to the early method of Poole and Pitts (1994) that more recent PSC-detection algorithms (for instance Fromm et al. 2003) sought to avoid. I would ask auth to address this concern and discuss whether this aspect of CALIPSO PSC detection is considered fundamental (i.e. necessary), or perhaps just step in the evolution to the eventual, more sophisticated algorithm that auth envision.”

We spent many months struggling to find a robust method for CALIPSO PSC detection. Our fundamental approach is to characterize the optical properties of the background aerosol apart from clouds and then define a threshold where all points above it are statistical outliers of this background population. By nature, these detection algorithms are empirical, especially the choice of the thresholds for the outliers. We examined many different methods including the Fromm et al. 2003 approach before settling on the approach described in the paper. The noise characteristics of the lidar data presented some new challenges and it is not clear that an assumption of a Gaussian-shaped background aerosol distribution (as used by Fromm et al. 2003) is valid for CALIPSO data. In fact, the noise on the background population has a distinct positive tail and a Gaussian approximation for its shape produces questionable results. In our approach, temperature is only used as a crude filter to exclude clouds from our background ensemble of points and it appears to be very effective. The real heart of the approach is the determination of the scattering ratio thresholds that we use to define the outliers. This was very much trial and error, but the proof is in the pudding and we believe the detection algorithm works extremely well. That being said, this is our initial version of the algorithm and as we gain more experience with the CALIPSO data we expect that the algorithm will indeed evolve and become more sophisticated.

4. “An additional concern is that auth use a vertical domain of 20 km (10-30 km), over which the canonical Tpsc varies on the order of 10K. Again, it strikes me as a reversion

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to older PSC-detection methods (to employ a single temperature value), which risks aliasing the results in altitude. An additional risk is that in the (approximately) lowest 3km of their domain, significant "contamination" by the upper troposphere is possible. Tropopause heights are typically below 10km, but on any given day in the polar region it is likely that anticyclones lift the tropopause above that level. Moreover, it is well established (e.g. Tuck, 1989) that tropospheric flow disturbances (in particular, anticyclones) force stratospheric cooling leading to PSC formation/intensification. It is also well observed that (especially) late-season PSCs form in the very lowermost stratosphere, just above the tropopause. For all these reasons, the choice of a fixed lower altitude limit combined with no accounting for tropospheric bulges (with concomitant increases of condensible gases, cirrus , etc) above 10 km is a weakness of this method. I would ask auth to address this issue, either in discussion form, or through a more altitude-sensitive treatment of Tpsc and tropopause height."

Two points are to be made here. First, temperature is used in our detection algorithm only as a crude filter to exclude clouds from the background ensemble, NOT as a threshold for defining cloud formation. The detection algorithm is not sensitive to PSC formation temperature or the formation mechanism. As long as the PSC exhibits an enhancement in scattering ratio relative to the background ensemble, it should be identified regardless of temperature. Any possible bias with altitude is also minimized by our choice of scattering ratio as the variable. Even though the mean backscatter coefficient for the background ensemble decreases significantly with altitude, the mean scattering ratio remains close to 1.

Secondly, we made no attempt in this initial analysis to discriminate between troposphere and stratosphere. We simply identified all features that occurred above 10km and with temperatures $<$ 198K as 'clouds'. Clearly some cirrus will leak into our statistics and yes this is a weakness of our method, but we think this is a minor issue and will not impact the overall conclusions of the paper in any significant way. In the future, we will implement measures to better discriminate between tropospheric and stratospheric features.

5. “Considering that this is a first, standard-setting paper on CALIPSO stratospheric cloud detection, it seems both natural and important to include some comparison with other validated data giving PSC/aerosol profiles, for instance ground-based lidar. There are to my knowledge multiple aerosol lidars that have been operated in Antarctica (e.g. McMurdo). Why have auth not performed such comparisons, or if they have, not included them in this paper? In my opinion, this paper must contain a discussion (or analysis) on this topic.”

We are not attempting to validate the CALIPSO lidar backscatter coefficient measurements or the altitude determination in this paper. This type of critical validation activity is ongoing utilizing comparisons with airborne lidar systems and the first validation results are in press (McGill et al. 2007, JGR). Given the high spatial variability of PSCs, individual comparisons with ground-based lidar measurements have limited value for validation unless you happen to have a perfect coincidence. Even if the CALIPSO overpass is only 20 km away from a ground-based location, the observed cloud structure can be significantly different and interpretation of these differences is difficult. We have compared CALIPSO PSC observations with measurements from the ground-based lidar at McMurdo and many of them are in good agreement, especially given the amount of separation (50km or so at the closest). But we don’t see how including these comparisons adds additional value to the paper other than confirming that CALIPSO does indeed observe clouds at about the same altitude as the ground-based system. A more instructive analysis would be comparisons of seasonal statistics from CALIPSO and the ground-based lidar systems. We are actively collaborating with a number of groups on comparison studies, such as the MIPAS group and some ground-based lidar groups, and we anticipate that there will be future papers written describing these results.

6. “Did auth do any vortex discrimination? If so, did they attempt an analysis like Figure 4 to determine if CALIPSO is sensitive to background aerosol differences in and out of

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the vortex? This might be a useful test, for instance, in order to evaluate the swelling of the population of backscatter ratio at low temperature they present. It also would be generally useful to assess statistically the CALIPSO response to the extra-vortex aerosol as a sort of control data set for the in-vortex studies."

We did not have sufficient resources (e.g., full met data) available to include any vortex discrimination in this first paper. We hope to add this in future analyses.

7. 7943, L8. It is not clear to me what auth mean by "forced to live with this behavior." It appears they are describing a real, natural, geophysical feature of stratospheric aerosols. It looks like a slight swelling of aerosol–whether due to a process akin to deliquescence, or something else–a small signal to which CALIPSO is sensitive. This is a good thing! Presumably the tail of the distribution–that which auth are focusing on for distinguishing cloud from aerosol–is still resolvable by their method. It is a challenge in all cloud studies to decide on what is meant by a cloud "edge", or cloud just forming, or cloud just before evaporating. The answer will alway be elusive. Thus I am not sure what is unique about this shifting-backscatter feature that deserves the special comment quoted above. This may be an example of how a comparison of the inside-vortex and outside vortex BSR statistics could be used to assess the inherent uncertainty in precisely pegging a cloud-no-cloud boundary, and showing CALIPSO's value in characterizing these transition regions. Regardless of how auth decide do deal with this, it seems they could use this information as a quantitative constraint on the uncertainty of CALIPSO cloud detection."

The comment was meant as an acknowledgment of the fact that one of our primary assumptions (we can characterize the background aerosol population at cold temperatures by using measurements at warm temperatures) was not strictly true because the aerosol size distribution does indeed shift towards larger values as the temperature cools, but that's the nature of the physics and we have to live with it. The violation of our assumption, however, appears minor and doesn't impact our results significantly.

Technical Concerns/comments:

1. 7937,L18. Presumably the 333m horizontal resolution mentioned here is along track. If so, state that and give the across-track resolution.

The horizontal sampling resolution of the lidar is 333 m. This means that a lidar profile is obtained every 333 m along track (corresponding to the 20 Hz pulse rate). The actual footprint of the lidar is about 70 m diameter on the Earth's surface. We have clarified this in the text.

2. 7940, L4-8. This last sentence is out of order in this paragraph in my opinion. I suggest movning it up near the lead part of the paragraph.

Done.

3. 7940, L8. Why 540m for vertical averaging? Why not use a round number like 500m?

The standard CALIOP lidar data altitude bins are 60 m for altitudes between 8.2 km and 20.2 km and 180 m for altitudes between 20.2 km and 30 km. As discussed in the data preparation section 3.1, we averaged all data below 20.2km to 180-m vertical resolution. At this point in the processing, all the data will then have 180-m vertical resolution. Although it would be possible to average the data to other vertical resolutions, any additional averaging would naturally occur in increments of 180 m. To further reduce measurement noise, we chose to apply 3-point smoothing to the data, resulting in 540-m vertical resolution (3 x 180 m).

4. 7940, L11. "radiation induced" should be hyphenated.

Done.

5. Figure 3. Please consider remaking fig 3 in terms of BS ratio, to make it consistent with the terms of the detection algorithm. This would aid the reader by reducing the data units to assimilate.

Figure 3 is illustrating how the differing vertical resolutions can produce apparent discontinuities in the standard Level1B backscatter data products and how additional averaging can significantly reduce these effects. We specifically call attention to this (and the fact this effect can be seen in the Level 1B browse images) to aid users of the Level 1B backscatter data. For this reason, we would prefer to leave the figure in backscatter units.

6. Any plans for graduating to daytime CALIPSO? Can these be mentioned in this paper?

There is a brief discussion of PSC detection using daytime CALIPSO data on p7938, L22-26. Currently, we have no specific plans for analysis of daytime data, but will consider it in the future.

7. Are auth aware of Maturilli et al., ACP, (2005)? This paper may be especially relevant for forthcoming CALIPSO studies of PSC composition and Arctic PSCs.

Yes.

8. 7945, L20. What is NAT "haze"? The employed quotation marks by auth suggest that this needs to be either cited or described in more detail.

By NAT “haze”, we are attempting to provide a descriptive name to NAT clouds that have very low number densities. Instead of a visible cloud, these may appear as a haze or actually be sub-visible similar to the persistent NAT ‘background’ observed above McMurdo most seasons (Adriani et al., 2004). We revised this in the text and now refer to this as NAT ‘background’ and provide a citation.

9. 7946, L20. Redundant statement in one paragraph regarding record ozone mass deficit.

The text has been revised.

10. 7947, 26. "inner core" seems redundant.

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We changed this to just “core”.

11. Map figures. Give Greenwich longitude a label.

Done.

12. Fig 10 and 11. The color scales are different, but no color bar is shown for Fig 11.

Color bar has been added to Fig. 11.

13. Fig. 12. Caption needs a little more detail re. contour interval/labeling...they are difficult to read.

Color bars have been added to Fig. 12.

14. Fig 13. Mention SAM II in caption.

Done.

15. Figs w/ time series. Consider using calendar dates on axis labels.

Month names have been added to x-axis on Fig. 12-18.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 7933, 2007.