CALIPSO Quality Statements
Lidar Level 2
Polar Stratospheric Cloud Product
Version Release: 1.00

Overall Summary Statement

RELEASE 1 or v1.00: This is the first release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud (PSC) data products.

The CALIOP Level 2 PSC data product ensemble consists of the PSC feature mask, composition flag, and optical properties reported on a uniform 5-km horizontal and 180-m vertical grid. Validation of the Level 2 PSC products is an on-going process. In the absence of simultaneous in situ particle observations, the CALIOP PSC detection and composition classification scheme can only be evaluated through comparison with other remote measurements that provide information on particle composition. All studies to date indicate that, with a few notable exceptions, the PSC detection and composition algorithms are performing well. We have a good understanding of the cause of the minor misclassifications that do occur and are planning to correct these minor deficiencies in our next data release. The status of all PSC data products is Provisional.

Data Quality Statement for the release of the CALIPSO Lidar Level 2 Polar Stratospheric Cloud Product Version 1.00, October 2013

Data Release Date: November 2013
Version: 1.00
Data Date Range: June 13, 2006 to present

PSC Detection

As described in Pitts et al. (2009) (PDF), PSCs are detected using a successive horizontal averaging (5, 15, 45, 135 km) procedure similar to the approach used in the standard CALIOP feature detection algorithm (SIBYL). This approach ensures that optically thicker clouds (e.g., ice and fully developed supercooled ternary solution, STS) are found at the finest possible spatial resolution while also enhancing the detection of tenuous PSCs (e.g., low number density NAT mixtures) that are found only through additional averaging. Prior to PSC detection, CALIOP data between 8.3 and 30.1 km are averaged to a common 5-km horizontal by 180-m vertical grid to account for the change in spatial resolution of the Level 1B data products at the 20.2 km altitude. PSCs are then identified as statistical outliers in either 532-nm scattering ratio, R_{532}, or 532-nm perpendicular attenuated backscatter, β'_{perp}, relative to the daily median background aerosol profile, which is calculated from the ensemble of data at temperatures above 200 K to avoid possible cloud contamination. The inclusion of β'_{perp} is a significant enhancement over the detection approach used in SIBYL that increases the sensitivity to depolarizing, low scattering ratio PSCs and results in an increase in total PSC area of 15% (Pitts et al., 2009). Individual profiles of R_{532} and β'_{perp} are scanned from the top altitude (30.1 km) downward, and a CALIOP observation is assumed to be a PSC if either R_{532} or β'_{perp} exceeds a statistical threshold as graphically illustrated in Fig. 1. The background aerosol population is the vertical ensemble of observations centered near R_{532} = 1.0 (Fig. 1a) and β'_{perp} = 0.0 (Fig. 1b), while PSCs appear as large enhancements in R_{532} and β'_{perp} at temperatures below ~195 K. We define the PSC detection thresholds (black dashed lines in Fig. 1) conservatively as the median of the background aerosol ensemble plus four median deviations (five median deviations for 5-km averaging). The thresholds lie near the upper limit of the noise envelope on the background aerosol and any measurement that exceeds the thresholds is clearly a statistical outlier.

Cloud features identified during the detection process must also pass a spatial coherence test to minimize false positives. False positives are primarily associated with noise spikes that occur as spatially isolated events while clouds typically exhibit coherent structure over spatial scales on the order of hundreds of meters in the vertical and tens of kilometers in the horizontal. The spatial coherence test requires at least 7 of the 15 points in a 5-point horizontal by 3-point vertical box centered on the candidate cloud feature to have been identified as PSCs at a finer averaging scale or a total of 11 points to either exceed the current PSC detection threshold or have been identified as cloudy at a finer averaging scale. While this test is somewhat heuristic, we feel that this combination of requirements balances the desire to eliminate obvious false positives while retaining apparent cloud elements which typically occur near the edges of extensive clouds. Our analyses indicate that the false positive rate is less than 0.1% Pitts et al. (2009) (PDF).

Note that clouds are identified over the entire altitude range between 8.3 and 30.1 km with no explicit attempt to discriminate between 'stratospheric' and 'tropospheric' clouds. The location of the detected cloud relative to the local tropopause (as reported in the GMAO analyses) is provided as part of the PSC Feature Mask. However, the altitude of the tropopause is frequently difficult to resolve in polar regions and should be used with caution.

PSC Composition Classification

The PSC composition classification scheme is based on comparison of CALIOP particulate depolarization ratio, $\delta_{particulate}$, and inverse scattering ratio, $1/R_{532}$, with theoretical optical calculations for equilibrium STS and representative non-equilibrium external mixtures of liquid droplets and non-spherical (ice or nitric acid trihydrate, NAT) particles, assuming 50 hPa atmospheric pressure and nominal mixing ratios of 10 ppbv HNO_3 and 5 ppmv H_2O. CALIOP PSCs are separated into six composition classes: three classes of liquid/NAT mixtures, with Mix 1, Mix 2, Mix 2-enhanced denoting increasingly higher NAT number density/volume; STS (which also includes low number densities of NAT particles whose optical signature is masked by the much more numerous STS droplets at low temperatures); H_2O ice; and mountain wave ice, the latter having high particle number densities (~10 cm^{-3}) but concomitantly small (1.0-1.5 μm radius) particles. Figure 2 shows a composite 2-D histogram for all PSC observations between 2006 and 2010 in the $\delta_{particulate}$ vs. $1/R_{532}$ coordinate system, with the boundaries of the six composition classes denoted by black lines.

Note that the boundaries drawn between PSC composition classes are somewhat arbitrary and do not reflect the inherent uncertainty in the CALIOP measurements. Hence, these boundaries should be considered fuzzy, and toggling between adjacent composition classes on short spatial scales may be simply due to measurement noise rather than a true change in composition. This will be discussed further in the next section.

Also note that since the composition classification scheme in the current release is based on nominal conditions for the mid-stratosphere, composition classification for upper tropospheric clouds should be viewed with caution.

Assessments of the Quality of CALIOP PSC Data Products

Höpfner et al. (2009) (PDF) compared PSCs detected during 2006-2008 by CALIOP and by the MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) instrument on the Envisat spacecraft. During the middle of the Antarctic PSC season, there was around 90% common cloud detection between the two instruments. At the beginning and end of the Antarctic season and in the Arctic, the level of common PSC detection was lower (60–70%), but could be attributed to cloud inhomogeneity and differences in viewing geometry of the two instruments. Höpfner et al. (2009) (PDF) also found a high degree of consistency between CALIOP PSC compositions and those derived from MIPAS data. A finding of particular note was that for PSCs in which the spectral signature of NAT was detected by MIPAS, about 90% of coincident CALIOP data were classified as mixed liquid/NAT PSCs.

More recently, Pitts et al. (2013) (PDF) assessed the robustness of CALIOP PSC composition classification by comparing the temperature-dependent uptake of HNO_3 by CALIOP PSCs from 2006-2011, as observed by the nearly collocated Microwave Limb Sounder (MLS) on the Aura satellite, with modeled uptake for STS and equilibrium NAT. In general, PSCs in the various composition classes conformed well to their expected temperature existence regimes, with some caveats noted. Based on observed overlap in the PDFs of β'_{perp} for STS and the NAT mixture classes, it was estimated that 5–6% of PSCs classified as STS may actually be NAT mixtures, whereas only 1–2% of PSCs classified as NAT mixtures may actually be STS. There is a high degree of confidence in the classification of ice PSCs; median uncertainties in $1/R_{532}$ and $\delta_{particulate}$ for ice PSCs are around 0.03 and 0.13, respectively, and therefore it is unlikely that ice PSCs would be misclassified as NAT mixtures due to measurement noise. There is less confidence in the separation of NAT mixtures into the Mix 1, Mix 2, and Mix 2-enhanced classes. Median uncertainties in $1/R_{532}$ and $\delta_{particulate}$ for NAT mixture PSCs as a whole are around 0.1 and 0.2, respectively, so that toggling between adjacent mixture classes due to random noise is likely.

Pitts et al. (2013) (PDF) also showed that denitrification and dehydration impact the CALIOP classification of ice and Mix 2-enh PSCs. The present composition classification scheme places the Mix 2-enh/ice boundary at the maximum expected value of R_{532} for fully developed STS (R_{532} = 5) assuming 10 ppbv HNO_3 and 5 ppmv H_2O at 50 hPa atmospheric pressure. To properly account for differences in HNO_3 and H_2O with time and with altitude, the Mix 2-enh/ice boundary should be shifted appropriately to different R_{532} values. For the present release, the primary deficiency is that some ice PSCs are being misclassified as NAT mixtures during periods of moderate to severe denitrification, which occur during every Antarctic winter. Future data releases will attempt to correct this deficiency using collocated or climatological HNO_3 and H_2O data from Aura MLS. Future releases will also attempt to reduce noise-induced misclassification through vertical averaging, additional horizontal averaging, or a spatial homogeneity requirement for PSC composition.

References

Höpfner, M., M. Pitts, and L. Poole, 2009: “Comparison between CALIPSO and MIPAS observations of polar stratospheric clouds”, *J. Geophys. Res.*, **114**, D00H05, doi:10.1029/2009JD012114.

http://onlinelibrary.wiley.com/doi/10.1029/2009JD012114/pdf

Pitts, M. C., L. R. Poole, and L. W. Thomason, 2009: “CALIPSO polar stratospheric cloud observations: second-generation detection algorithm and composition discrimination”, *Atmos. Chem. Phys.*, **9**, 7577-7589.

http://www.atmos-chem-phys.net/9/7577/2009/acp-9-7577-2009.pdf

Pitts, M. C., L. R. Poole, A. Dörnbrack, and L. W. Thomason, 2011: “The 2009-2010 Arctic polar stratospheric cloud season: a CALIPSO perspective”, *Atmos. Chem. Phys.*, **11**, 2161-2177.

http://www.atmos-chem-phys.net/11/2161/2011/acp-11-2161-2011.pdf

Pitts, M. C., L. R. Poole, A. Lambert, and L. W. Thomason, 2012: “An assessment of CALIOP polar stratospheric cloud composition classification,” *Atmos. Chem. Phys.*, **13**, 2975-2988.

http://www.atmos-chem-phys.net/13/2975/2013/acp-13-2975-2013.pdf

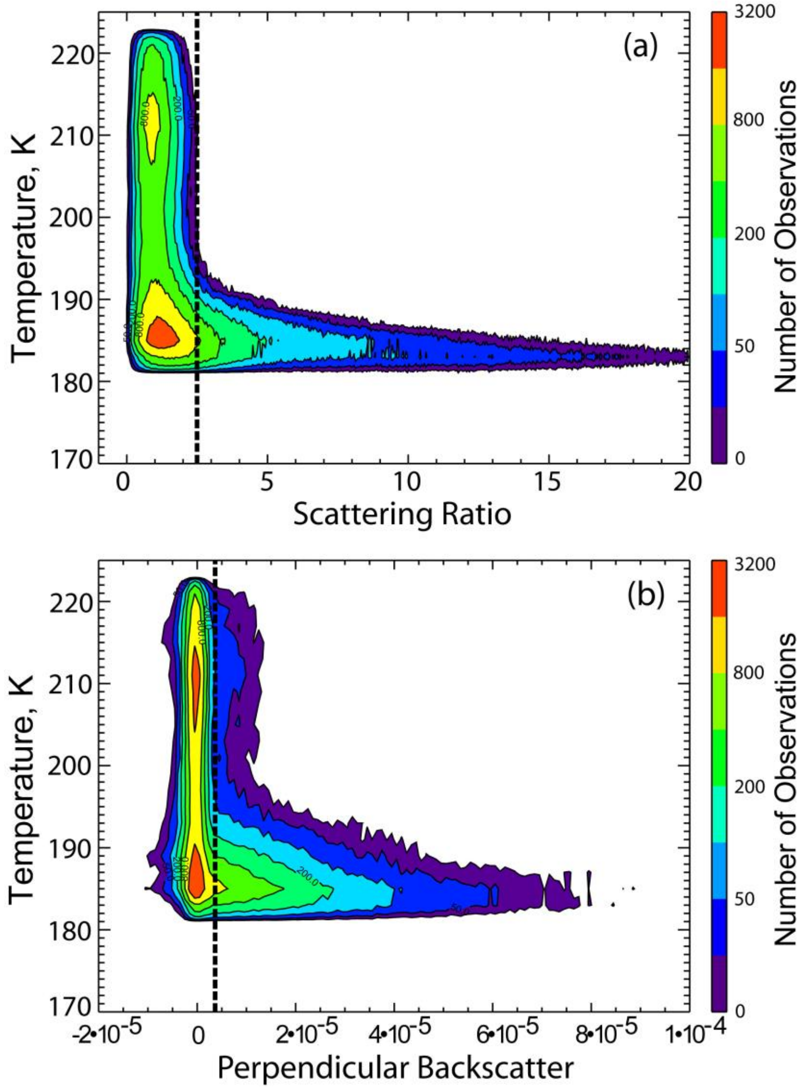

Figure 1. Ensemble of (a) 532-nm scattering ratio and (b) 532-nm perpendicular attenuated backscatter measurements as a function of observed temperature for the 400-500 K potential temperature layer from 1 August 2006. The black dashed lines indicate the scattering ratio and perpendicular backscatter thresholds for PSC detection (reproduced from Pitts et al., 2009) (PDF).

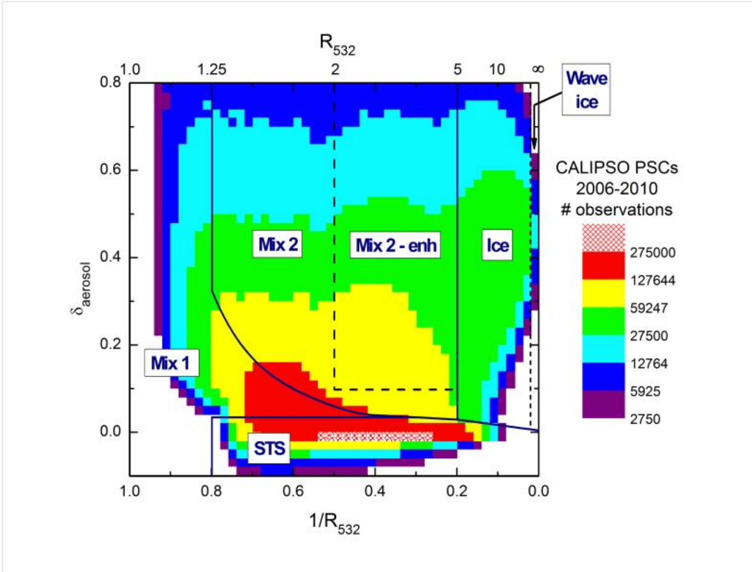

Figure 2. Composite 2-D histogram of all CALIPSO PSC observations from 2006-2010 in the $\delta_{aerosol}$ vs. 1/R532 coordinate system, with the solid/dashed black lines denoting the boundaries of the six PSC composition domains (reproduced from Pitts et al., 2011) (PDF).