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Discussions

Interactive comment on "Laser pulse bidirectional reflectance from CALIPSO mission" *by* Xiaomei Lu et al.

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We would like to express sincere gratitude to the Reviewers for their careful reading and thorough comments. The step-by-step answers to the Reviewers' comments are listed below.

Referee #1

comments from Referees: This is a reasonably well written paper presenting significant results employing the CALIPSO lidar response from a hard surface. While others (e.g., Josset, et al., GRL, 2008, Venkata and Reagan, Remote Sens, 2016) have reported on retrievals of aerosol optical depth (AOD) from CALIPSO lidar ocean surface returns, this paper addresses recovering the surface retro reflectance (expressed in terms of

the surface bi-directional reflectance, BRDF, which can be readily compared to MODIS retrieved BRDF'S) for snow and ice surfaces which present challenges in dealing with saturated signals for such bright targets. The authors present an innovative approach for identifying and recovering the saturated signals through use of both the parallel and perpendicular (depolarized) CALIPSO 532 nm lidar channels.

Author's response: Yes, the paper presents an innovative approach to retrieve surface bidirectional reflectance from CALIOP surface laser pulse returns. The saturated signal from snow and ice surfaces are recovered based on surface tail for both CALIOP 532 nm parallel and perpendicular channels.

comments from Referees: As the lidar surface response is proportional to the product of round-trip transmittance to the surface times the surface reflectance, the reflectance can be recovered if the transmittance is known. The authors use the CALIPSO data product estimates of transmittance to recover the surface reflectance for quite clear (nearly Rayleigh) and thin cloud situations. Their retrieved reflectances (BRDF's for lidar backscatter), corrected for saturation or thin clouds, yield values in reasonable agreement with MODIS derived backscatter BRDF's, probably as good an agreement as possible given the likely uncertainty in the MODIS BRDF modeling for backscattering.

Author's response: Right, CALIOP level 2 data products provide cloud optical properties, such as cloud optical depth and two-way transmittance, and CALIOP level 1 data products provide Rayleigh extinction cross-section and molecular number density. As a result, the two-way atmospheric transmittance can be estimated from CALIOP level 1 and level 2 data products. Finally, the surface bi-directional reflectance is obtained from the surface total integrated attenuated backscatter with the known transmittance.

comments from Referees: The authors define their recovered reflectance (eq. 4) in terms of the total observed surface backscattering signal which includes the long 'noise tail' observed in the lidar surface return (e.g., Hunt et al., JAOT, 2009). They could have

alternately defined the reflectance in terms of the total minus tail (eq. 2 minus eq. 3) signal; i.e., main pulse signal. Which is a better/more correct is a matter of conjecture concerning whether the tail is true signal versus after-pulsing noise. The authors do note that over 90% of the surface return signal is contained in the main pulse portion, so either definition for the reflectance would yield about the same result.

Author's response: For an ideal detector, the surface signal will return immediately to its baseline state. However, because of the CALIOP non-ideal recovery of transient impulse response, the surface signal is stretched to a sequence of 30 m resolution bins starting from the bin that contains the surface echo. Comprehensive analyses by the CALIPSO team have determined that more than 90% of the surface return energy is contained in the first three bins, corresponding to the peak signal as well as one before and one after the peak signal. The remaining surface return energy is contained in the tail bins that lies below the three peak bins. As a result, the surface total integrated attenuated backscatter (Eq. 4) is used to obtain the surface bi-directional reflectance. The lidar signal from snow/ice surface is so strong that the signals at three peak bins are often saturated under conditions of clear sky. For the saturated lidar return, the surface total integrated attenuated backscatter is estimated from its surface tail (Eq. 5) which is not saturated.

comments from Referees: In conclusion, this paper presents an innovative approach for recovering the surface BRDF (at backscatter) from CALIPSO surface return signals from snow and ice surfaces, even for saturated signal levels by using the parallel and perpendicular 532 nm lidar channels. The results are new and significant. The paper definitely merits publication.

Author's response: Thanks;