CALIPSO SURFACE RETURN FOR ICE AND WATER DETECTION

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ABSTRACT

Since launching in April 2006, the primary objective of the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) mission has been studying the climate impact of clouds and aerosols in the atmosphere. However, recent work has demonstrated that both daytime and nighttime CALIPSO lidar surface returns, specifically the 532 nm depolarization ratio, can be used to infer ocean surface ice-water phase. Depolarization measurements have been long used to discriminate cloud and aerosol types. In this study we will demonstrate an additional relationship between surface echo depolarization and surface ice–water state. Analysis of four years of collocated CALIPSO 532 nm depolarized surface returns and Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E) 12 km resolution ice concentrations have found that a depolarized 532 nm surface return with a value of 0.2 or less indicates a surface water state, while a depolarized 532 nm surface return of 0.55 or larger represents a surface ice state. After briefly recounting the motivation for attempting the retrieval, we describe our methodology for calculating and screening CALIPSO lidar surface returns, matching these lidar surface returns with collocated AMSR-E ice concentration measurements, and finally assess the performance of this methodology with four years of measurements in latitudinal bands between 50° – 90°North and 50° – 90° South. When applying this method we can expect to classify day and nighttime measurements for ice and water with 92% accuracy.

1. INTRODUCTION

Seasonal variability of sea ice concentration and ice extent has been monitored by many of the A-Train satellites such as the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) [1], and the Moderate-resolution Imagining Spectroradiometer (MODIS). From May 2002 until October 2011 AMSR-E provided high-resolution large spatial coverage of the Polar Regions. Unlike MODIS it is not affected by the persistence of cloud cover. AMSR-E has had great success mapping the marginal ice zone and has provided precise locations of the ice edge. We believe the finer resolution of the CALIPSO footprints (90 m diameter, spaced 335 m apart [2]) could assist in this process.

When the CALIPSO orbit transects surfaces covered by ice, be it land or ocean, the signal intensity will be very strong and frequently cause digitizer saturation. This response will be very evident in the altitude region from -0.5 to 8.2 km for the two 532 nm channels (parallel and perpendicular) and when these channels are ratioed, the resulting depolarization values are in the range of 0.55 - 1.1. It is this specific effect that enables the 532 nm depolarization data to be used for ice classification purposes. Figures 1a -1c illustrate this effect. Each browse image is a small section of the nighttime orbit over the Arctic starting at 77N and descending to 73N on December 14 2010 between 17:25 and 17:30 UTC. The altitude range includes attenuated backscatter from 2km below the surface to 15km above the surface. In each of the images the estimated surface elevation, derived from a digital elevation map, is displayed as a red line. Surrounding this red line, the saturated values appear as multi-layered "ribbon". The attenuated backscatter

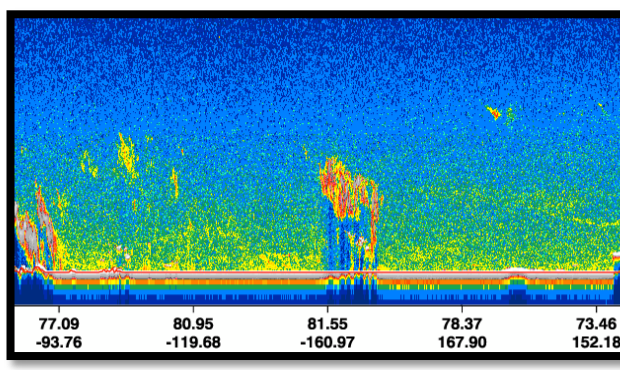

Figure 1a 532 nm Total attenuated backscatter

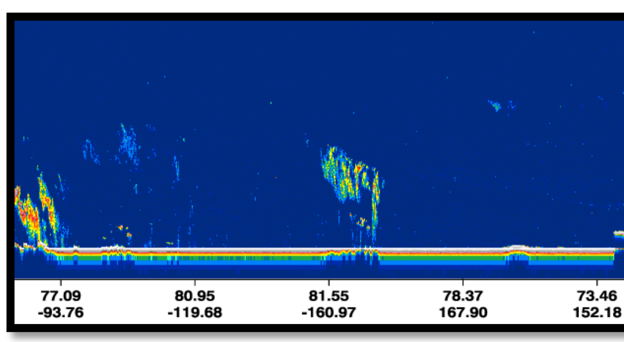

Figure1b 532 nm Perpendicular attenuated backscatter

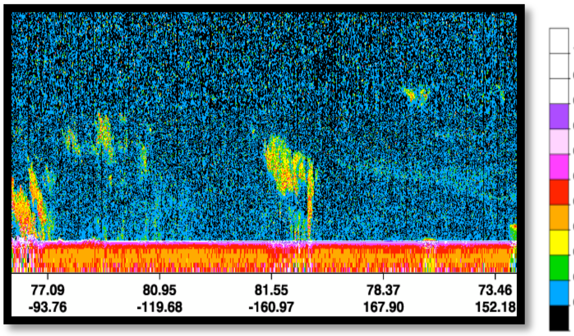

Figure 1c is the 532 nm Depolarization Ratio

samples from this "ribbon" section are the focus for this study.

2. DATA CONSTRUCTION

The 532 nm depolarized surface return is derived from the detected CALIOP surface echo every 335-meters along track. The CALIOP surface detection algorithm [3] uses the digital elevation map (DEM) Global 30 Arc-Second Elevation Data Set (GTOPO30) [4] as the starting point in its search for the lidar surface echo. If a surface spike is detected, the altitudes of the top and base are stored and can be retrieved from the Level 2 CALIPSO layer data products. In this specific study, the top and base altitudes are retrieved from the L2 333 m Cloud Layer product and merged with the Level 1 attenuated backscatter. The 532 nm parallel and perpendicular attenuated backscatter measurements are retrieved from two consecutive altitude bins above the top altitude of the surface spike to five altitude bins below the base of the surface spike, screened for fill values, integrated and ratioed, creating a surface integrated depolarization ratio, defined as follows:

$$\delta_{\text{layer}} = \sum_{k=\text{top}}^{\text{base}} \beta_{\perp}(z_k) \Big/ \sum_{k=\text{top}}^{\text{base}} \beta_{P}(z_k) \qquad (1)$$

Additional surface properties such as DEM altitude, International Geosphere/Biosphere Programme (IGBP) surface classification and National Snow and Ice Data Center (NSIDC) snow and ice coverage (re-averaged to CERES footprint ~30km) are also retrieved as references.

Each of the 333 m CALIPSO 532 nm depolarization measurements is collocated to the AMSR-E Level-3 gridded daily product AE_SI12. The AE_SI12 includes daily averages for sea ice concentrations and snow depth over sea ice at a 12.5 km spatial resolution [5]. The ice concentration, ice concentration uncertainties, and snow depth are retrieved for comparative analysis and validation. Valid samples consist of calculated depolarization ratios between 0.0 and 1.5 with the location of the CALIPSO footprint within the bounds of the 12 km AMSR-E pixel.

3. CONCEPT TESTING

The initial test of our concept was performed using a histogram of the collocated 532 nm depolarization values for 2010. All samples classified by AMSR-E as water, open water, or ice with an ice concentration greater than 30% were retrieved and tested. Figure 2 illustrates a distinctive bimodal histogram with distributions from 0.0 to 0.2 and 0.55 to 1.1. Upon examination, we found that pixels classified as water by AMSR-E correlated to depolarization values in the range of 0.0 to 0.2, and pixels classified as ice correlated to depolarization values in the range of 0.55 to 1.1.

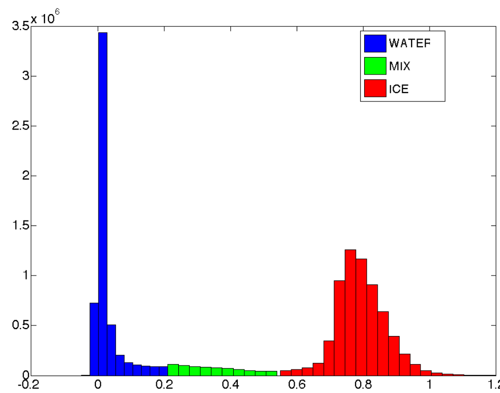

Figure 2: The CALIPSO 532 nm Depolarization ratio distribution for 2010 when a surface echo was detected and the AMSR-E 12km pixel is classified as water or ice.

Using this newly-defined ice and water classification criteria, samples from 2006 through 2010 were retrieved and grouped for additional testing. Each depolarization value was compared to its corresponding AMSR-E classification, generating statistics for tracking the level of agreement for this classification methodology. First we looked at the consistency of the ice classification for samples in the northern latitudes. As seen in Figure 3, a seasonal trend is evident with the higher percentage of agreement in the winter months and a lower percentage of agreement in the transitional summer-fall months. For 53 of the 54 months of our data sample, when AMSR-E classified the pixel as ice, the calculated depolarization values fell in the range of 0.55 to 1.1 at a rate of 90% or higher. The one month that did not measure above 90% agreement was August 2007, when the rate was 89.2%.

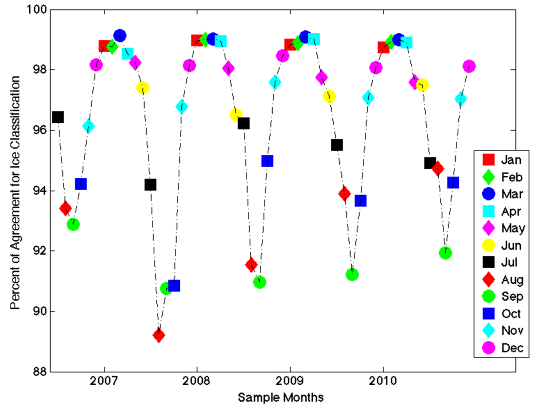

Figure 3: Northern Latitudes for 2006 to 2010 monthly percentage of agreement when AMSR-E classified the pixel as ice, the calculated depolarization values fell in the range of 0.55 to 1.1.

Next we looked at the consistency of the water classification for samples in the northern latitudes. As seen in Figure 4, a seasonal trend is also evident with the higher percentage of agreement in the winter months and a lower percentage of agreement in the summer months. For 44 of the 54 months, when AMSR-E classified the pixel as water, the calculated depolarization values fell in the range of 0.0 to 0.2 at a rate of 90% or higher. For 51 of the 54 months the agreement was 85% or higher. The summer months, specifically June and July of 2007 through 2010 showed the lowest agreement.

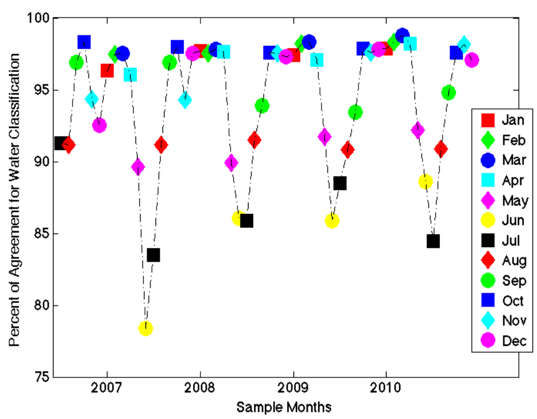

Figure 4: Northern Latitudes for 2006-2010 monthly percentage of occurrence when AMSR-E classified the pixel as water, the calculated depolarization values fell in the range of 0.0 to .02

Though the summer and transitional months recorded the lowest percentage of scene classification agreement for both of the two classification test cases, it does highlight the possibility of CALIPSO's depolarization values providing fractional scene classification. A maximum of 36 CALIPSO 335 m surface depolarization samples could fall within each 12 km AMRS-E pixel and provide additional information about sea surface classification. When examining the collocated records that indicated a mismatch for ice classification, it was found that 85% of those records contain AMSR-E pixels with ice concentrations in the range of 10% to 80% indicating a mix-phase scene of ice and water. When examining the non-matching collocated records for water classification it was found that 80% of those records also contained ice concentrations in the range of 10% to 80%. The non-matching due to a mixed-phase scene was not unexpected. In this study our scene matching criteria required 100% agreement between the classification reported by AMSR-E and the newly-defined CALIPSO ice and water classification. It would not be expected that each of the 335 m CALIPSO samples collocated with a 12 km AMSR-E pixel have 100% scene classification agreement.

Additional analysis was performed to determine if cloud cover contributed to the mismatch in scene classification. Data from the October 2009 ice classification data set was selected for the initial test. It contained 805,656 valid collocated samples and had 94% agreement between the CALIPSO and AMSR-E scene classifications. 40% of these matching scenes contain one or more cloud layers, whereas 60% of the matching scenes were classified as clear sky. (Checking for aerosols was not performed during this test sequence but will be added at a later date). The remaining 6% of October 2009 ice classification valid samples had been classified as non-matching with 68% having clear sky and 31% having one or more cloud layers. Tables 1a and 1b list the percentages of cloudy and clear sky samples for each month of 2009.

Table 1a: The percentage of cloudy and clear sky samples for matching ice classification scenes for each month of 2009.

2009		Matching		
Month	Total Samples	Fraction Matching	Cloudy Percent	Clear Percent
01	2676542	98.84	26.02	74.98
02	1595342	98.88	22.15	77.85
03	1965518	99.09	16.69	83.31
04	2821549	99.03	17.90	82.10
05	1103272	97.75	27.42	72.58
06	1008496	97.11	20.93	79.07
07	810873	95.51	14.61	85.39
08	356005	93.89	23.69	76.31
09	367008	91.21	36.99	63.01
10	805656	93.66	39.20	60.80

11	1682248	97.06	34.05	65.95
12	2260717	98.07	27.55	72.45

Table 1b: The percentage of cloudy and clear sky samples for non-matching ice classification scenes for each month of 2009.

2009		Non-Matching	
Month	Fraction Non-Matching	Cloudy Percent	Clear Percent
01	1.16	27.56	72.44
02	1.12	29.42	70.58
03	0.91	28.45	71.55
04	0.97	23.04	76.96
05	2.25	18.43	81.57
06	2.88	17.94	82.06
07	4.49	11.30	88.70
08	6.11	15.61	84.39
09	8.79	25.46	74.54
10	6.34	31.32	68.68
11	2.94	28.60	71.40
12	1.93	27.42	72.58

The similar distributions of cloudy and clear sky samples for the matching and non-matching ice classification scenes as seen in Tables 1a and 1b strongly suggests that clouds do not contribute to the mismatch in scene classification.

From our analysis the prevailing reason for a mismatch in the scene classification is not due to cloud cover, but attempting to match a 335 m CALIPSO sample to an AMSR-E pixel comprised of a mixed-phased scene. The ability of CALIPSO to successfully provide surface scene classification when cloud layers are present is a feature from which the passive sensor community could benefit.

4. Summary

In this paper we propose a new application of the CALIPSO 532nm attenuated backscatter data to provide additional observations in the Polar Regions. We have shown that the retrieval of the 532 nm surface depolarization provides an accurate classification of the sea surface scenes. This retrieval can be performed with samples acquired during the CALIPSO day and nighttime orbits, and with samples that contain one or more cloud layers.

The AMSR-E 12 km L3 ice concentration data products provided the standard for our comparison of the newly defined CALIPSO surface ice-water classification technique. After analyzing 54 months of collocated samples we found that our method accurately classified the surface scene at a rate of 90% or higher. We note that our success rate had a seasonal variance, with a higher percentage of matching during the height of winter and lowest during the summer and transitional months. This was especially the trend during the summer of 2007 when the arctic experienced one of the largest melts in recent history. We believe that our scene classification methodology produced from the 335 m footprint could be an asset during these transitional months. The ability to detect the changing ice-water composition at a finer detail would provide an enhanced detailed scene composition. Additionally, with CALIPSO's measurements not being limited to daytime or clear sky conditions it could provide a "fill-in" measurement where other data products are limited due to instrument characteristics or have the practice of masking land surfaces. Prediction Models may also benefit from the finer resolution in discriminating ice boundaries.

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