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Synergetic use of POLDER and MODIS for multilayered cloud identification

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ABSTRACT

The purpose of this study is to investigate the possibility of identifying overlapping clouds that contain thin cirrus overlying a lower-level water cloud by synergetic use of POLDER-3 (Polarization and Directionality of the Earth Reflectance) and MODIS (MODerate resolution Imaging Spectroradiometer) data. When thin cirrus clouds overlap the liquid cloud layer, the liquid information may be obtained by POLDER observations and the presence of the cirrus may be inferred from the MODIS CO_2-slicing technique. An initial comparison of the POLDER cloud phase and the MODIS cloud-top pressure for one scene over East Asia also shows that a large portion of clouds declared as liquid water clouds by POLDER-3 correspond to the lower cloud-top pressures derived from MODIS. As a result, an overlapped cloud identification method is proposed under the assumption that the multilayered cloud would be present if the POLDER cloud phase is liquid water and the MODIS cloud-top pressure is less than 500 hPa. For the studied scene, the comparison of the multilayered cloud identification results with CloudSat and CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) observations illustrates that the proposed method could detect multilayered clouds when the upper cirrus has a visible optical thickness of less than 2.0. Then the identification results are compared with the MODIS Cloud_Multi_Layer_Flag. It is indicated that the consistency between the multilayered clouds from the proposed synergy and MODIS-operational algorithm increases gradually from over 40% to nearly 100% with the increase of the confidence level of the MODIS multilayered clouds from the lowest to the highest. Further analysis suggests that the majority of multilayered clouds falsely classified as single-layered clouds by the proposed method may correspond to relatively thick cirrus covering lower-level water clouds. Additionally, an index by using the multilayered cloud detection differences from the two methods is proposed to provide some information on the optical thickness of the cirrus covering lower-level water cloud. Finally, quantitative comparisons are extended to four other scenes at different locations by using active measurements. The results also show that the mean visible optical thickness of the high-level clouds of the multilayered clouds detected by both methods (1.57) is remarkably less than that by only MODIS-operational method (2.84), which means that the differences between the results from the two methods are mainly caused by the different sensitivities to the visible optical thickness of the high-level cloud and could be used to indicate the range of the visible optical thickness of the cirrus clouds covering the lower-level water clouds.

1. Introduction

Surface and satellite observations have shown that overlapping cloud layers exist frequently. Cirrus overlying low cloud occurs in about half of all cloud observations (Hahn et al., 1982, 1984; Warren et al., 1985; Tian & Curry, 1989; Mace et al., 2009). Multilayered clouds occur commonly in the vicinity of fronts and deep tropical convection. Over tropical oceans, thin cirrus often overlies broken boundary layer clouds. Accurate knowledge of the vertical and horizontal distributions of clouds is critical for improving and verifying weather and climate models. Current operational algorithms are designed to infer cloud properties for each imager pixel from satellites under the assumption that only single-layered cloud (SC) is present. Many satellite observations of clouds are affected by radiation from multilayered clouds. If multilayered cloud (MC) exists in a vertical column and single-cloud-layer assumption is imposed on cloud parameter retrievals, the retrieved cloud microphysical and optical properties may be incorrect (Chung et al., 2000; Davis et al., 2009). Thus, it is very important to be able to automatically identify cloud overlap situations and monitor them from space. Additionally, a global climate model study suggests that different cloud overlapping schemes make significant differences in top-of-atmospheric net long-wave (short-wave) radiative fluxes (Stubenrauch et al., 1997).

Some studies have been performed to infer the presence of multilayered clouds from passive satellite observations. Sheu et al.

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(1996) and Lin et al. (1998) combined satellite-based passive microwave and multi-spectral data to identify overlapped (or multi-layered) clouds over oceans. Baum et al. (1995) determined the cirrus heights using the CO_2 slicing technique (Menzel et al., 1983) and low cloud heights using spatial coherence. Baum and Spinhirne (2000) demonstrated a bi-spectral method to detect imager pixels containing possible cloud overlap when an optically thin cirrus cloud overlies a lower-level water cloud. Nasiri and Baum (2004) modified this method and exploited differing visible and infrared spectral signatures unique to cloud overlap from MODIS (MODerate Resolution Imaging Spectroradiometer) data. Pavolonis and Heidinger (2004) and Pavolonis et al. (2005) developed an automated method to detect multilayered clouds from satellite imagery, for the Advanced Very High Resolution Radiometer (AVHRR) and the Visible Infrared Imager Radiometer Suite (VIIRS). Chang and Li (2005) proposed a new method to detect cirrus overlying water clouds and determine their optical properties. Cimini et al. (2005) used the differences between infrared and microwave cloud-top temperature to detect multilayered clouds. Naud et al. (2007) presented that the synergy between the difference in MODIS-MISR cloud-top height analysis and the MODIS cloud-typing method could improve overlap detection for thin cirrus over low cloud situations and provide additional information on the cloud-top height of two distinct layers. Wind et al. (submitted for publication) used the MODIS 0.94 µm water vapor band along with CO_2 bands to obtain two above-cloud precipitable water retrievals, the difference of which, in conjunction with additional tests, provides a map of where multilayered clouds could potentially exist.

The constellation of satellites called A-Train includes passive and active sensors specifically dedicated to the study of cloud and aerosol properties from a three-dimensional perspective, exploiting the simultaneous and collocated multi-sensor observations (Stephens et al., 2002). Since the satellites in the constellation fly in close formation to each other, measurements from the sensors on the different platforms can be easily compared to each other or merged into combined measurements. Among the instruments in the A-Train, two active instruments: CloudSat, the “first radar” in space and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) onboard CALIPSO, a depolarization lidar, and in particular the combination of the radar and lidar give very detailed vertical profiles of cloudiness. Mace et al. (2009) gave for the first time a global survey of the co-occurrence of different cloud types. Although the two active instruments can tell us when multilayer clouds are present no matter the type of cloud, they are non-scanning, nadir-pointing instruments and provide a very limited across-track sample. Therefore, multilayer cloud detection with passive instruments with significantly greater coverage should be pursued especially for retrieving cloud parameters, while the active measurements can play important roles in the validation of results from passive methods.

The POLDER (POLarization and Directionality of the Earth Reflectance) and MODIS instruments in the A-Train take advantage respectively of spectral multi-directional and polarized passive measurements and of multi-spectral measurements to improve our knowledge of cloud and aerosol properties on a global scale (Platnick et al., 2003; Parol et al., 2004). The synergetic use of different instruments onboard the A-Train for deriving cloud and aerosol properties has been widely considered (Reidi et al., 2007; Waquet et al., 2009). Maximal exploitation of the above two instruments is highly desirable, which is one of the motivations of this investigation. Furthermore, although some studies (Goloub et al., 2000; Riedi et al., 2001) have shown that multilayered clouds may cause the false cloud-top phase for cirrus by using POLDER measurements, no further papers have used this kind of false detection results to detect multilayered clouds and evaluate its performance.

This study is dedicated to investigate the possibility and evaluate the performance of identifying overlapped clouds that contain thin cirrus overlaying a lower-level water cloud by synergy between POLDER-3 and MODIS instruments operating in the framework of the A-Train mission. Firstly, the POLDER cloud phase results are compared with the MODIS cloud-top pressures on one scene. Then an overlapped cloud identification method is proposed based on an assumption and validated by active measurements. Furthermore, the identification results are compared with multilayered cloud products from MODIS. Finally, further quantitatively extensive comparison and validation are conducted on other scenes at different locations.

2. Data

2.1. POLDER cloud phase

POLDER-3 in the A-Train was launched on the PARASOL microsatellite developed by the French space agency (CNES) in December 2004. It is a multi-spectral imaging radiometer–polarimeter composed of a two-dimensional charged coupled device (CCD) detector array, wide field of view telecentric optics and a rotating wheel carrying spectral and polarized filters. The dimension of the CCD detector array (242 × 274) provides a moderate spatial resolution (about 6 km at nadir), and a multi-angle viewing capability. When the satellite carrying POLDER passes over a target, up to 14 different images can be acquired in several narrow spectral bands of the visible and near-infrared spectrum. The most original characteristic of POLDER is its ability to measure the directionality and polarization of sunlight reflected by the Earth–atmosphere system. It allows for determining cloud properties (Parol et al., 2004), like cloud thermodynamic phase, which is an important cloud parameter for climate models.

According to both theory and observations (Bréon & Goloub, 1998; Goloub et al., 2000; Chepfer et al., 2001), the polarization features of clouds depend strongly on the particle shape and size. Considering a cloudy system observed from satellite, the polarized component of the upward radiance is mainly formed in the upper cloud layer. Around 80% of the single-scattered radiation reflected by the cloud arises from the upper hundred meters of the layer. Thus, the polarization features mainly governed by single scattering are preserved in the polarized reflectance. Within the range of scattering angles observed by POLDER, clouds composed of liquid spherical particles show a strong maximum in the polarized component (Lp) at about 140° (primary rainbow). Liquid clouds exhibit a polarization value of zero (i.e., a neutral point) at around 90°, and supernumerary bows for angles greater than 145°. These features make possible the discrimination with clouds composed of ice particles, which exhibit positive polarization that decreases as the scattering angle increases. Unambiguous discrimination between ice particles and liquid water droplets can be made using these polarization differences. The algorithm of POLDER cloud phase identification consists of three tests on the polarized radiance at 0.865 µm, using three specific angular ranges. Molecular contribution is neglected because it is rather weak at this wavelength. A complete description of this algorithm is given by Goloub et al. (2000). The cloud phase results are included in the RB2 (Radiative Budget Level 2) given at pixel resolution of approximately 19 km (Parol et al., 2004).

However, the major limitation of the method is that thin cirrus overlapping the low–middle-level clouds can be misidentified as liquid water clouds. In the case of ice clouds located above the thick water clouds, the simulation performed by Goloub et al. (2000) illustrates that for the cirrus optical thickness less than 2, the liquid cloud signature is still present in the polarized reflectance in the rainbow scattering angle region (around 140°). In other words, the POLDER observations can be used to obtain the characteristics of the water cloud in the case of an ice cloud with the optical thickness less than 2 covering a thick water cloud. Additionally, mixed phase clouds are also obviously problematic for this method. When liquid spherical droplets coexist with ice particles, they can produce a rainbow feature that will toggle liquid phase detection in the polarization test (Reidi et al., 2007).