Daytime Overlapping Cloud Detection in MODIS Data

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Introduction

Current efforts to derive a global cloud climatology from satellite data generally suffer in situations involving multilayered clouds. In fact, cloud properties are inferred for each imager pixel assuming only one cloud layer is present. Currently available satellite cloud climatologies provide a horizontal distribution of clouds, but need improvement in the description of the vertical distribution of clouds. The single cloud layer assumption is unfortunate because surface observations show that clouds often occur in multiple layers simultaneously in a vertical column, i.e., cloud layers often overlap.

Multiple cloud layers occur in about half of all cloud observations and are generally present in the vicinity of midlatitude fronts and in the tropics (Hahn et al. 1982, 1984; Warren et al. 1985; Tian and Curry 1989), where cirrus anvils may spread hundreds of kilometers from the center of convective activity. In a millimeter cloud radar (MMCR) study performed over a 2-month period at State College, Pennsylvania, in the autumn of 1994, Mace et al. (1997) present statistics of cirrus overlying lower cloud layers. Over the 2-month period, cirrus was observed in 32% of the observations collected over 899 hours of observation. Of those observations in which cirrus was present, lower clouds were also present 52% of the time. Mace et al. (1998) report that of all cirrus events recorded during April, May, and June 1997 over the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) Cloud and Radiation Testbed (CART) site, lower-level cloud layers were present 27%, 29%, and 36% of the time, respectively. Dr. G. Mace (personal communication, 1999) has provided statistics for the time period from December 1996 through November 1997, for which the annual average of cirrus was 22%. Of those cirrus observations, lower clouds were also present 21% of the time on average. It is our understanding that a methodology has not been developed for the retrieval of microphysical cloud properties (optical thickness, cloud thermodynamic phase, effective particle size) at the ARM CART sites when multilayered, overlapping clouds are present. Our goal is to work towards improving both satellite-derived and surface-derived cloud products under these complex conditions.

We are developing and testing methodology to determine whether imager pixels contain single-layer clouds or whether the pixels may contain potential cloud overlap in moderate resolution imaging spectroradiometer (MODIS) imagery. The groundwork for our research may be found in Baum et al. (2000a, b) and Baum and Spinhirne (2000). The techniques have been tested using MODIS Airborne Simulator (MAS; King et al. 1996) aircraft for a case of thin cirrus overlying a lower-level water phase cloud such as stratus. As MODIS data are now becoming available, these methods, and the resulting Earth Observing System (EOS) MODIS and Clouds and Earth's Radiant Energy System (CERES) data products, await systematic comparison to overlapping cloud properties inferred from active lidar/radar measurements at the ARM CART sites.

Data and Models

MODIS is a scanning spectrometer on the EOS Terra platform. It has 36 spectral bands between 0.4 μm and 14.4 μm with spatial resolutions of 250 m (2 visible bands), 500 m (5 bands), and 1000 m (29 bands) at nadir. The MAS is a scanning spectrometer flown on the National Aeronautics and Space Administration (NASA) ER-2 aircraft and has 50 spectral bands between 0.55 μm and 14.2 μm. The scan rate is 6.25 s^{-1}. Each scan line contains 716 earth-viewing pixels with a maximum scan angle extending approximately 43° on either side of nadir. The spatial resolution is 50 m at nadir at a nominal ER-2 altitude of 20 km. The entire set of MAS bands is described by King et al. (1996).

Top of atmosphere radiances from water clouds and ice clouds are computed using the Discrete Ordinate Radiative Transfer (DISORT) model. Scattering properties (phase function, single-scattering albedo, and extinction cross section) are derived for water droplet clouds using Mie theory. Cirrus optical properties are derived for a set ice crystal size and habit distribution based on in situ measurements of cirrus. The cirrus models used by Baum et al. (2000a,b) are based on a 5-size bin discretization with a fixed habit distribution for all cirrus models. The cirrus distributions are composed of a combination of hexagonal plates, hollow columns, bullet rosettes, and aggregates. Yang et al. (1997) provide a detailed explanation of the methods used to describe scattering calculations for hollow columns and bullet rosettes, and Yang and Liou (1998) describe calculations involving more complex crystals such as aggregates. More detail regarding the treatment of clear-sky gaseous absorption, ice cloud scattering properties, and water cloud scattering properties may be found in Baum et al. (2000a). We are in the process of developing improved cirrus models based upon in situ measurements of particle size and habit distributions.

Methodology

Based on scatter plots of 1.6-μm near-infrared (NIR) and 11-μm infrared (IR) channel data, we have developed a straightforward method that separates pixels that contain a single cloud layer from those that potentially contain overlapped cloud layers. The separation of single-layered from overlapped pixels is an extension of ideas presented in Platt (1983). To illustrate the physical relationship between the NIR and IR data for clouds at various altitudes, we use as an example MAS data collected over Oklahoma at 2000 Universal Time Coordinates (UTC) on April 21, 1996 (ER-2 Flight Track #11). On this date, much of Kansas and Oklahoma was covered with a broken low cloud layer and a simultaneous cirrus veil (see Figure 1).

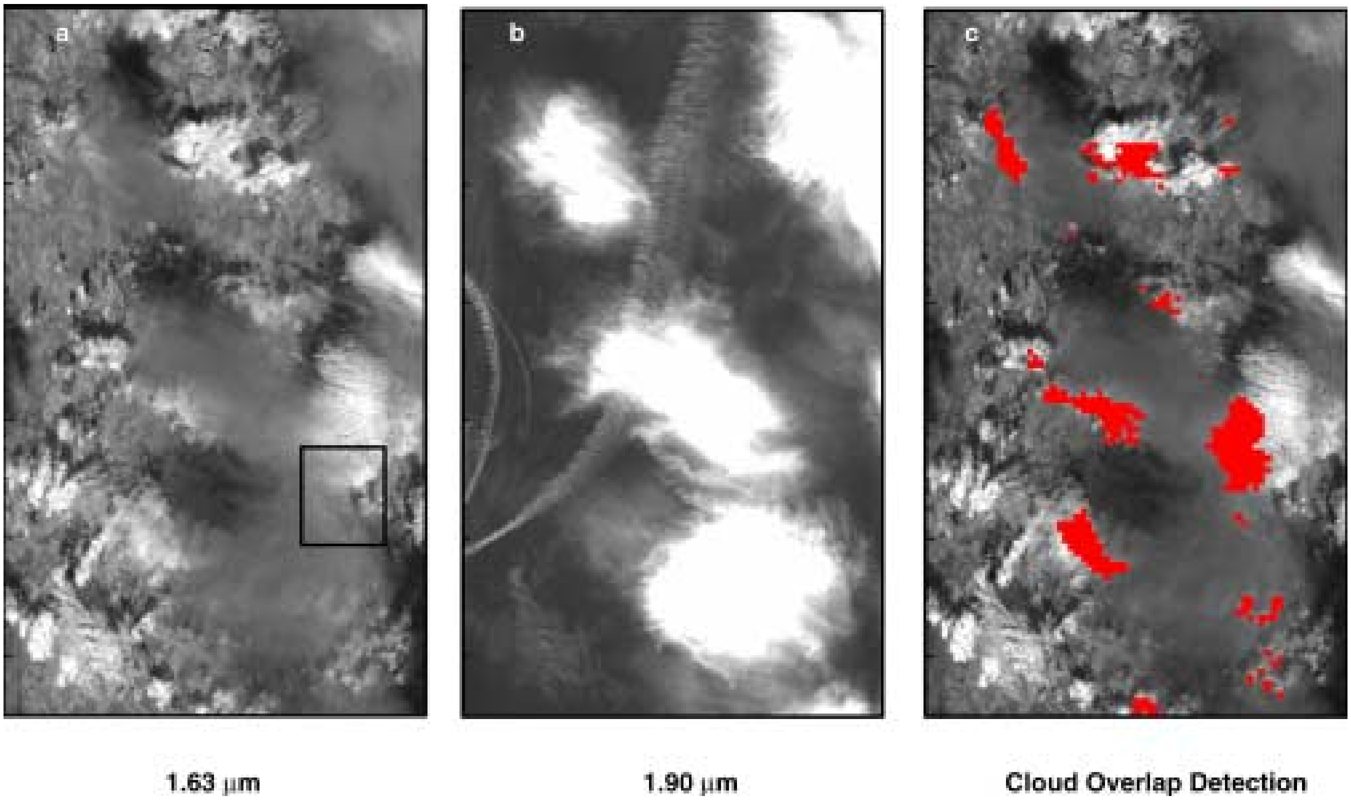

Figure 1. MODIS Airborne Simulator (MAS) image recorded on April 21, 1996, over Oklahoma during ER-2 Flight Leg #11 between 1959 and 2002 UTC. Shown are (a) the scene at 1.63 µm; (b) the scene at 1.9 µm; and (c) the results of the MAS overlapped cloud detection algorithm. The scale of the image is 37.5 km cross track by 50 km along track.

The MAS data are analyzed in blocks of 300 scan lines at a time (~15 km along track) and approximately 500 pixels per scan line (~25 km cross track), corresponding to data within a viewing zenith angle of 30°. The pixels free of cloud are determined from application of the MAS cloud clearing algorithm as described in Ackerman et al. (1998). For each data block, the mean and standard deviation values are determined for the clear-sky pixel reflectances and brightness temperatures. The presence of cloud shadows throughout the imagery acts to increase the standard deviation of the clear-sky values, thereby decreasing the ability of the algorithm to classify with any certainty those pixels containing very thin cloud, i.e., pixels displaying little thermal or reflectance contrast with the mean clear-sky values. The cloud overlap detection algorithm uses the clear-sky statistics calculated for each data block.

The result from application of the NIR/IR algorithm (Baum and Spinhirne 2000) is provided in Figure 1c, where areas of thin cirrus overlap are shown in red over the 1.63-µm image. The cloud overlap detection process was performed on all data within a viewing angle of 30° from nadir. A visual comparison of Figures 1a and 1b with Figure 1c indicates that the method has some ability to capture the areas of thin cirrus overlying a lower-level cloud. It is interesting to note that the method does identify an area (upper central portion of the image) where a contrail overlies a highly reflective lower-level cloud. The contrail is apparent in the 1.90-µm image but not in the 1.63-µm image.

Future Work

MODIS cloud products are, at the time of this writing, in the beginning stages of production. Our immediate goal is to design and implement a system to subset the MODIS cloud products over the ARM CART sites (Tropical Western Pacific, SGP, North Slope Alaska) and compare satellite-retrieved cloud properties with those obtained from surface measurements, for all satellite overpasses.

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Referenced unpublished papers can be found in PDF format at http://arm1.ssec.wisc.edu/~shaima/publications.html

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