Global and Regional Cloud Properties Derived from MODIS Data

B. A. Baum
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia

S. L. Nasiri
Cooperative Institute of Mesocale Meteorological Studies
University of Wisconsin-Madison
Madison, Wisconsin

P. Yang
Goddard Earth Science and Technology Center
University of Maryland
Baltimore, Maryland

Introduction

Current efforts to derive a global cloud climatology from satellite data generally suffer in situations involving multi-layered clouds. In fact, cloud properties are inferred for each imager pixel assuming only single 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 Atmospheric Radiation Measurement (ARM) observations show that clouds often occur in multiple layers simultaneously in a vertical column, i.e., cloud layers often overlap. Our goal is to work towards improving both satellite-derived and surface-derived cloud products under these complex conditions.

The first data from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument arrived in February 2000 following the successful launch on the National Aeronautics and Space Administration (NASA) Terra platform. After a concerted calibration effort by the instrument team, the MODIS atmospheres group has been working towards the goal of operational processing of the aerosol and cloud property retrieval products. The MODIS cloud products include cloud height, thermodynamic phase, optical thickness, and effective particle size. Cloud heights are determined through application of the CO_2 slicing algorithm (e.g., Frey et al. 1999). Cloud thermodynamic phase is inferred using data from the 8.5-μm and 11-μm bands. An example of a global cloud product is shown in Figure 1 for all nighttime data collected on November 5, 2000. In this figure, we relate the frequency of co-occurrence between pixels having cloud top temperatures between 253 K and 268 K in which the clouds are also classified as being composed of liquid water. Note the high frequencies of occurrence of supercooled water clouds in the high latitude storm tracks.

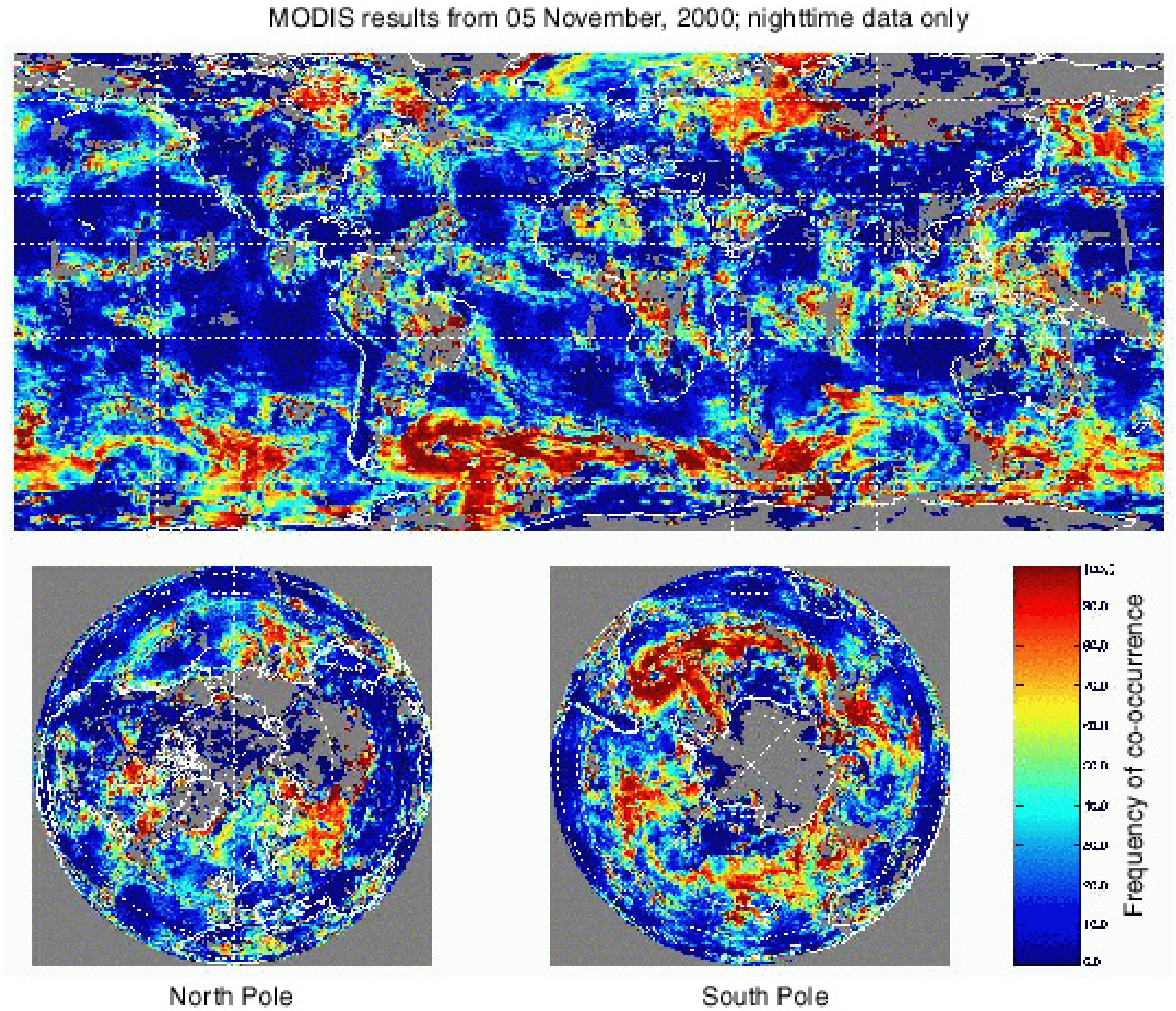

Figure 1. Nighttime MODIS results derived on November 5, 2000, depict the frequency of co-occurrence between fields-of-view having cloud top temperatures between 253K and 268K that also are classified as having water phase clouds. The algorithms for computing cloud top temperature and cloud phase are run independently of each other. Also, each method uses different spectral bands than the other. Note the high frequency of supercooled water clouds in the storm tracks.

As the calibration issues have been largely resolved and the cloud data products are now being produced routinely, our efforts are now turning to comparison of the satellite cloud products with the cloud products developed at the ARM Cloud and Radiation testbed (CART) sites. The detection and analysis of overlapping cloud layers is not yet an operational algorithm. We have developed methodology to determine whether MODIS data contain single-layer clouds or whether the pixels may contain potential cloud overlap (Baum and Spinhirne 2000). Since the successful launch of MODIS, we have been refining our methodology and subsequently comparing the results to data from the ARM Southern Great Plain (SGP) CART site. An example of such an effort to detect and analyze overlapping cloud layers is shown below.

Data and Models

MODIS is a scanning spectrometer with 36 spectral bands between 0.4 and 14.4 µm with spatial resolutions of 250 m (2 visible bands), 500 m (5 bands), and 1000 m (29 bands) at nadir. MODIS is in polar orbit at 705 km. Top of atmosphere reflectances at 1.64, 8.5, and 11 µm from water clouds and ice clouds are modeled using methods described in Baum et al. (2000a). Scattering properties (phase function, single-scattering albedo, and extinction cross section) are derived for water droplet clouds using the Mie theory. Cirrus optical properties are derived for a set ice crystal size and habit distribution based on in situ measurements of cirrus. We are developing improved cirrus models with more size bins and habit distributions based on in situ measurements. The lastest set of cirrus models have been reported by Nasiri et al. (2001) and are based on in-site particle size and habit distributions. Each particle size is discretized to 27 size bins. The cirrus distributions are composed of a combination of hexagonal plates, hollow columns, bullet rosettes, and aggregates. Yang et al. (1997) provides a detailed explanation of the methods used to describe scattering calculations for hollow columns and bullet rosettes, and Yang and Liou (1998) describes calculations involving more complex crystals such as aggregates.

Methodology

Baum and Spinhirne (2000) present a straightforward method to separate pixels that contain a single cloud layer from those that potentially contain overlapped cloud layers based on scatter plots of 1.6-µm near infrared (NIR) and 11-µm infrared (IR) channel data. The idea for their approach was first suggested by Platt (1983). Recently, the NIR-IR method has been enhanced by incorporating a simplified version of the MODIS approach to infer cloud thermodynamic phase (Strabala et al. 1994; Baum et al. 2000b). While an assumption to the method is that thin cirrus overlies a lower-level water phase cloud, we are now able to justify the application of the cloud overlap detection method to any set of pixels with the additional pixel-level information on cloud phase. The MODIS data are analyzed in blocks of 200 by 200 pixel arrays; individual pixels have a nominal 1-km resolution. The clear-sky pixels are identified from application of the MODIS cloud-clearing algorithm (Ackerman et al. 1999). For each data block, the mean and standard deviation values are determined for the clear-sky pixel reflectances and brightness temperatures. Mean and standard deviation values for the upper and lower cloud layers are derived by averaging the radiances for the liquid and ice phase clouds. The result from application of the NIR/IR algorithm is provided in Figure 2 for the MODIS overpass over Oklahoma on October 15, 2000 at 1726 Universal Time Coordinates (UTC). Figure 2a shows the 11-µm image and a false color image is shown in Figure 2b. Areas of thin cirrus overlap are shown in red over the 11-µm image in Figure 2c. ARM CART site millimeter wave cloud radar (MMCR) data are shown in Figure 2d. A visual comparison of Figures 2(a, and b) with Figure 2c, indicates that the method has some ability to capture the areas of thin cirrus overlying a lower-level cloud.

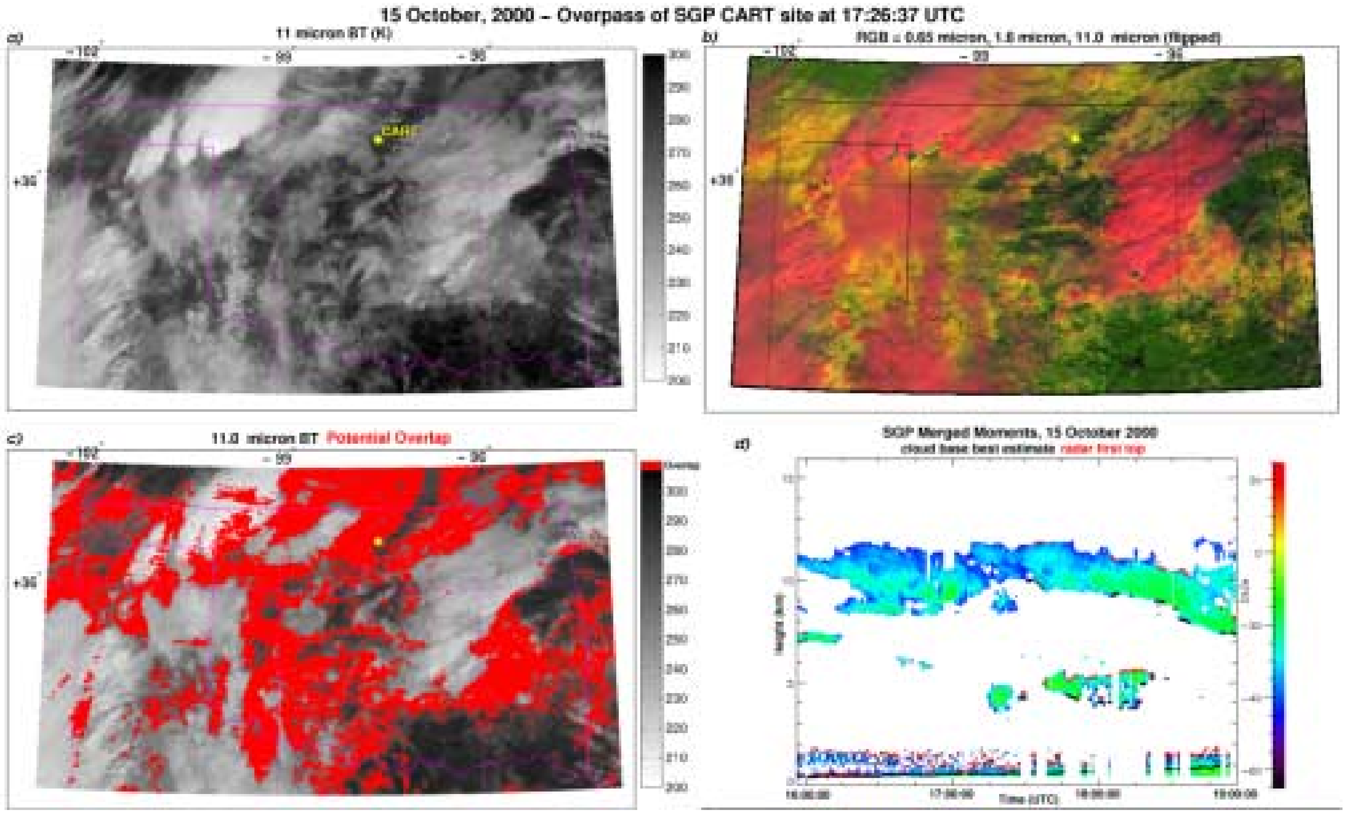

Figure 2. MODIS image recorded on October 15, 2000 over Oklahoma at 1726 UTC. Shown are (a) the scene at 11 µm; (b) a false color representation of the scene where ice clouds are magenta, low clouds are bright white/yellow, and the vegetated surface is green; (c) the results of application of the MODIS overlapped cloud detection algorithm; and (d) ARM SGP site MMCR data showing the presence of multiple cloud layers in the time period surrounding the MODIS overpass.

Future Work

Our immediate goal is to continue collecting cases where overlapping clouds are present in MODIS data over the ARM CART sites. It will take some time to build up a database of useful cases. Once we gain confidence in the ability of the cloud overlap detection method, we will process then apply the method to a full day of global MODIS data. We anticipate that the results of this work will be of use in improving the ability of ARM CART site instrumentation to capture the salient aspects of overlapping cloud data.

Corresponding Author

Bryan A. Baum, bryan.baum@ssec.wisc.edu, (608) 263-3898

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