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NIGHTTIME CLOUD OVERLAP USING MODIS DATA

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Clouds play an important role in our weather and climate. Formed as water vapor condenses onto tiny particles of dust, soot, or chemical compounds, clouds change the radiative heating of our planet, which in turn drives the conditions in which the clouds form. As global climate models (GCMs) are extremely sensitive to cloud parameterization, we need to study clouds to better understand how they affect our world, to better our modeling, and in turn, the prediction of changing weather and climate.

To improve our knowledge of clouds, the International Satellite Cloud Climatology Project (ISCCP) was conceived. ISCCP uses data at two wavelengths, 0.6 and 11 microns, from international geostationary and polar orbiters to retrieve information every three hours on cloud top temperature and pressure, cloud optical thickness (only in daytime), and cloud type (also only in daytime), for example (Rossow and Schiffer, 1999). To retrieve the cloud properties, several assumptions are made. Each pixel is assumed to be wholly cloudy or clear, and if cloudy, there is only one cloud layer. Until 1992, all clouds were treated as a distribution of water droplets having an effective radius of 10 microns. Clouds at night are assumed to be opaque, which results in cloud top pressures being high by about 75 hPa. Since an ice model (a "fractal polycrystal" with an effective radius of 30 microns) has been introduced, nighttime cloud top pressures have been corrected such that they are only about 45 hPa too high. The wavelengths ISCCP uses have difficulty detecting high, optically thin cirrus clouds, perhaps missing 5-10% of cirrus because the radiance threshold is too high for detecting them (Rossow and Schiffer, 1999). This problem is exacerbated at nighttime, since during the day both wavelengths are available, but at night only the 11 micron channel is available. Considering that infrared optical thicknesses are about half the value of visible optical thicknesses, this makes ISCCP's detection of thin cirrus at nighttime tenuous at best.

A more sensitive method uses the High resolution Infrared Radiation Sounder (HIRS) on the National Atmospheric and Oceanic Administration (NOAA) polar orbiting satellites. Wylie and Menzel (1999) describe a CO_2 slicing technique that uses radiation from wavelengths from 13 to 15 microns to calculate cloud level, optical thickness, and effective emissivity. Effective cloud amount (the cloud fraction multiplied by the cloud emittance) is also inferred from a ratio of the radiance of the observed cloud to the radiance of an opaque cloud at the same level. A cloud at levels less than 3 km is assumed to be opaque, since the wavelengths used cannot detect radiation that far down into the atmosphere--there is a high signal-to-noise ratio below 3 km. Another assumption made is that there is only one cloud layer in each field of view--if there is a scene with multiple cloud layers, the method retrieves a mean height and emissivity.

GCMs have different assumptions about how to treat cloud overlap. Hogan and Illingworth (2000) used 71 days of cloud data over the United Kingdom from a 94 GHz high vertical resolution radar to investigate how GCMs treat cloud overlap. The most common cloud overlap assumption used in GCMs is the "maximum-random" assumption, such as discussed in Chou et al. (1998). There are also other assumptions for cloud association used in GCMs. These include random overlap, in which clouds are assumed to be randomly distributed horizontally at each level; mixed overlap, in which all clouds are randomly overlapped except for convective clouds, which are maximally overlapped; full overlap, in which all clouds are overlapping as much as possible; and combinations of these overlap assumptions. In the maximum-random assumption, vertically continuous clouds are assumed to be maximally overlapped, while clouds separated by levels without clouds are assumed to have random overlap. Tian and Curry (1989) noted that the maximum overlap assumption closely followed observations of vertically continuous cloud scenes. From their high-resolution radar data, Hogan and Illingworth found that for vertically continuous clouds, when the separation between cloud layers increases, the random overlap assumption fits better than the maximum overlap assumption. Most GCMs assume maximum overlap for all vertically continuous clouds, no matter how far they are apart from other layers. However, the GCM assumption of random overlap for vertically non-continuous clouds is in agreement with their data. Which assumption is used in a GCM affects the results of the model (Weare, 2001, also Chen, 2000), making the basis of the assumption critical for radiative feedback and heating calculations and other sensitivities.

In a remarkable collaboration among 19 different GCMs, Cess et al. (1990) found that in a simulated climate change, the variation of the global sensitivity parameter of the GCMs is almost three times more than the variation of the clear-sky sensitivity parameter. Since the global sensitivity parameter is shown to be linearly related to the cloud feedback parameter, cloud feedback is the source of the variation among the GCMs. Six years later, in a follow up paper (Cess, 1996) found that the

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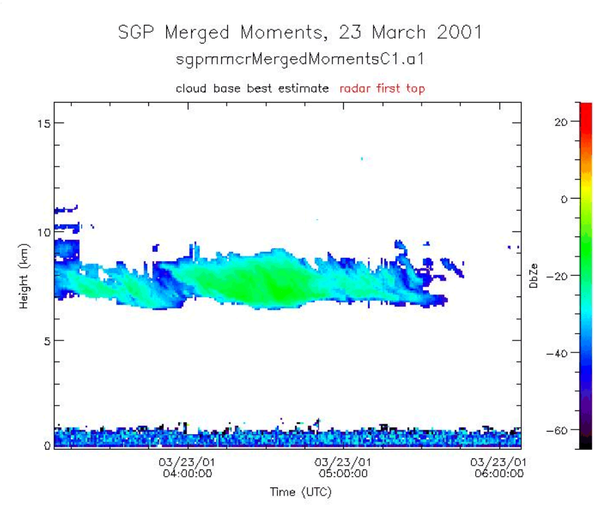

Fig. 1. Radar/LIDAR composite showing cloud layers.

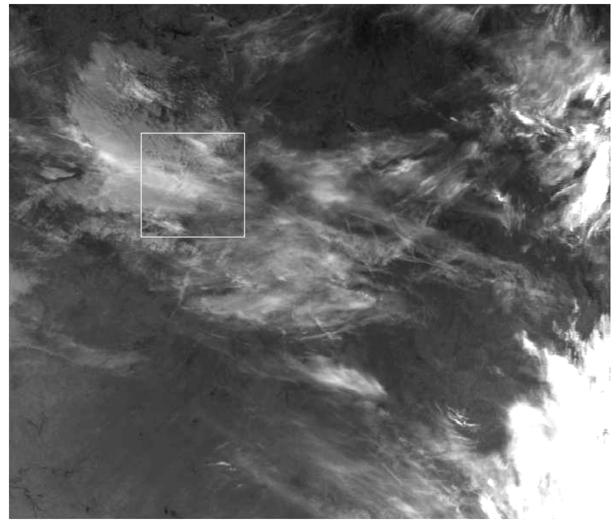

Fig. 2. Scene from MODIS overpass at 5:35 UTC over ARM SGP site. 11 micron brightness temperatures are shown, with white being the lowest and black being the highest values.

variation among the GCMs decreased because a few of the models had changed aspects of their cloud parameterizations, such as cloud optical properties. However, there still is a range of the cloud feedback parameter of about 1.2 among the GCMs. This range suggests that as there is so little agreement among a large number of climate models, more research needs to be done in cloud parameterizations. An important aspect of cloud parameterizations is the treatment of overlapping cloud layers.

The focus of this work is the detection of overlapping clouds at nighttime using three IR bands of MODIS data: 3.78, 8.5, and 11 microns. Samples of MODIS granules are chosen for detailed analysis over the Department of Energy's (DOE) Atmospheric Radiation Measurement Clouds and Radiation Testbed (ARM CART) at the southern great plains (SGP) site that were found to have cloud overlap by radar and lidar data. Single-layer clouds are modeled using a discrete ordinate radiative transfer model (DISORT). An algorithm is applied to subtract out the modeled single-layered clouds from the satellite data, leaving pixels that are potentially of overlapping clouds. We assume that there are no more than two cloud layers in each region used in this study. This assumption is supported Tian and Curry (1989) in general, and more specifically by ARM data. We also limit our cases to scenes with optically thin cirrus (11 micron optical thickness is less than 2), which ISCCP has difficulty detecting. Our approach may prove to be even more useful than previous studies in the formation of GCM parameters and assumptions, because of the resolution of the MODIS instrument. The channels used in our study (20, 29, and 31, corresponding to 3.78, 8.5, and 11 microns) all have resolutions of 1 km.

Surface-based observations are provided by Drs. Ken Sassen and Jay Mace of the Facility of Atmospheric Remote Sensing, at of the University of Utah. Additionally, they have compiled cloud data using lidar and radar measurements over the various ARM sites. Figure 1 shows such data--at the time of the 23 March 2001 MODIS overpass over the ARM SGP site at 4:35 UTC, there is a low cloud with a top at about 1 km, and the high cloud is between 7 and 9 km in altitude. Part of that MODIS granule is shown as Fig. 2, with a box around the sample data set. This image was obtained using Interactive Visualizer and Image Classifier (IVICS) software developed by Todd Berendes of the National Space Science Technology Center. With IVICS, a sample dataset was taken that had two cloud layers along with potentially overlapping cloud pixels. The two cloud layers were modeled in DISORT. We found that the low cloud was a water cloud at 272 K with particles having an reff of 4 um. The high cloud corresponded to the cold cirrus model, at a temperaure level T = 228 K. Figure 3 shows the sampled data set with the DISORT-derived curves for each cloud layer.

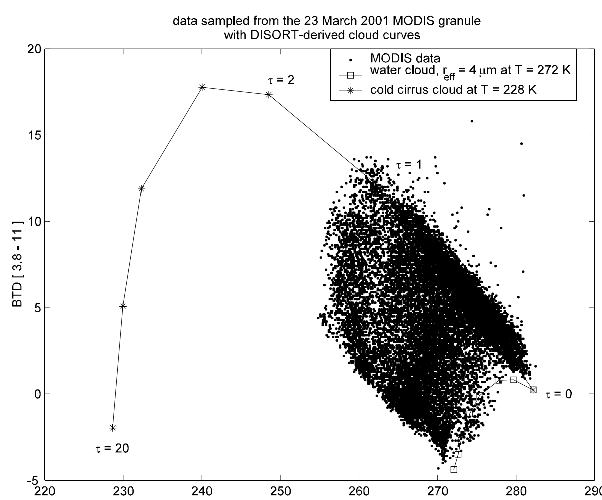

Fig. 3.

We have been able to reasonably identify the individual cloud layers in order to isolate the potentially overlapping cloud pixels. Our goal is to show that our method of nighttime cloud overlap identification using MODIS data is unique and very useful, as cloud climatology projects such as ISCCP and the HIRS CO_2 slicing technique assume, among other things, only one cloud layer per field of view, and cloud overlap is a critical aspect of cloud parameterizations needed in GCMs.

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