9.5 STUDY OF LARGE ENSEMBLE OF CLOUD SYSTEMS FROM EOS SATELLITE OBSERVATIONS FOR CLOUD MODEL EVALUATION

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1. INTRODUCTION

Clouds play an important role in the Earth's climate system by modulating the exchange of energy between Earth and space. However, recent IPCC report strongly indicates representation of clouds and their radiative feedback processes as being one of the weakest components of current global climate models (GCMs). In order to improve the predictive capability of current GCMs, better methods for evaluating and improving cloud representations in GCMs are needed. Traditional methods of improving cloud parameterization usually employ detailed case studies using data collected during intensive campaigns over a limited area and a short duration. The non-linearity of cloud processes requires that observations be made on all relevant cloud modeling scales. Limited data from such field campaigns are clearly not adequate. A conventional method of evaluating the performance of cloud parameterization in GCMs is to verify the simulation of GCM using monthly mean global and regional satellite, surface, and atmospheric data. Another technique is to validate the results of the single column model (SCM) version of GCM with field programs. These validation techniques are again not sufficient to isolate the errors associated with cloud parameterization from those associated with other components of GCMs.

In this study, a new method of analyzing satellite data is developed to evaluate the performance of cloud parameterization in GCMs, numerical weather prediction models, and cloud resolving models (hereafter referred to as cloud models). Instead of gridding satellite data to some standard GCM grid, this new technique classifies them into distinct cloud systems (hereafter referred to as cloud objects) defined by their types (i.e., trade cumulus, stratus, and deep convective system). These cloud objects are then matched with nearly simultaneous atmospheric state from European Centre for Medium-Range Weather Forecasts (ECMWF) data. The atmospheric state data (e.g., temperature, water vapor, wind and advective tendency fields) are used to provide initial conditions and forcing information for cloud model simulations. The merged satellite/ECMWF cloud object data are saved as a function of cloud types. The advantage of this new data analysis technique is to take cloud model evaluation beyond the traditional methods into tests of large statistically robust ensembles of matched atmospheric state -> cloud model -> satellite cloud object data comparisons. For example, frequency distributions of various cloud and radiation parameters for a given atmospheric state and cloud type deduced from the satellite cloud object analysis can be directly compared with those of ensemble cloud model simulations. The results of these comparisons can be used to further improve cloud model performance. The improved cloud models can then be used to cultivate better cloud representations in GCMs, which can lead to further advances in the predictive capability of these global models.

This paper reports some preliminary results on satellite analysis of cloud object using this new classification method. Cloud modeling activity using these cloud data are currently underway and will be reported in future meetings. The satellite dataset and the cloud objective analysis technique used in this study are outlined in section 2 and 3, respectively. Section 4 shows some preliminary results for large tropical deep convective system. Summary and future work are given in section 5.

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2. SATELLITE DATA

The Single Scanner Footprint Top-of-the-Atmosphere/Surface Fluxes and Clouds (SSF) dataset from the National Aeronautic and Space Administration (NASA) Clouds and the Earth's Radiant Energy System/Tropical Rainfall Measurement Mission (CERES/TRMM) is used in this study. This dataset contains CERES data for a single scanner instrument. The SSF combines instantaneous CERES observations at satellite footprint resolution with scene information from higher resolution imager on Visible/Infrared Scanner (VIRS) on TRMM. Scene identification and cloud properties are defined at the higher imager resolution and these data are averaged over the larger CERES footprint. For each CERES footprint, the SSF contains the number of cloud layers and for each layer the cloud amount, height, temperature, pressure, optical depth, emissivity, ice and liquid water path, and particle size information. The SSF also contains the CERES filtered radiances for the total, shortwave (SW), and window (WN) channels and the unfiltered SW, longwave (LW), and WN radiances. The SW, LW, and WN radiances at spacecraft altitude are converted to Top-of-the-Atmosphere (TOA) fluxes based on the imager defined scene. These TOA fluxes are used to estimate surface fluxes. The data volume for one month of CERES/TRMM SSF data is 190 GigaBytes.

3. CLOUD OBJECTIVE ANALYSIS METHOD

For this study, the satellite data are analyzed to group cloud property and radiative flux observations into a contiguous region of the earth with a single dominant cloud type. These regions can be thought of as snapshots of cloud objects. They can range in diameter size from as small as a single CERES footprint (tens of km) to more than 1000 km. The shapes and sizes are determine by the data itself, and by the cloud property selection criteria used to defined the cloud object types. The process to determine these cloud objects (i.e. an area of the earth with a given cloud type) is generalization of an algorithm developed in Wielicki and Welch (1986) to determine the size distribution of cumulus cloud fields using Landsat satellite data. The algorithm is simply to: 1) define each satellite field of view as belonging to one of N classes of cloud type based on the cloud and radiative flux properties of the field of view, 2) group all adjacent fields of view of the same class into distinct objects, 3) complete cloud object when no further adjacent fields of view can be found in the same class, and 4) determine the final statistical characteristics of each cloud object. This algorithm has been modified to accept the CERES SSF data product as its input data, and to allow cloud object types to be defined as a function of any cloud or radiation property in the SSF data product. For example, the criteria for large tropical deep convective cloud system are 1) cloud height of at least 10 km, 2) optical depth of at least 10, 3) cloud amount of 100 percent, 4) latitudes within 25^o of the Equator, and 5) size of at least 300 km in diameter. Once the cloud objects have been identified, their radiative and macro-physical properties can be saved to a database with matching ECMWF atmospheric state data. Given sufficient number of cases, these combined cloud object/atmospheric state data can then be analyzed to produce robust statistical information about these cloud systems and their sensitivity to the background environment (e.g., SST and boundary layer inversion strength)

4. PRELIMINARY RESULTS

Using the criteria defined in section 3 for large tropical deep convective cloud system, cloud objective analyses are performed on a full month of CERES/TRMM SSF data for March 1998. Preliminary results indicate that at least 58 cases of cloud object are identified as matching the criteria for large tropical deep convective cloud system. These systems come in different size and shape, ranging from of 300 km to larger than 500 km in length.

Figure 1 show an example of a large tropical deep convective cloud system that were identified by this new cloud objective analysis classification technique in the form of cloud LW radiation and cloud effective temperature. It is apparent from this figure that the variability of cloud LW fluxes for this large tropical deep convective cloud system is closely related with the variability in its cloud effective temperature fields. The variability of the SW fluxes (not shown), on the other hand, is tied to variability in cloud optical depth (not shown).

Another way of examining the satellite cloud object information is to look at their statistical representation in term of probability density function (PDF). Figure 2 shows the corresponding PDF for cloud LW fluxes and cloud effective temperature derived from the same cloud object shown in Fig.1. While the cloud effective temperature has a Gaussian shape, the distribution for cloud longwave radiation is slightly skewed with a longer right-hand tail. With sufficient number of cloud object cases, statistically robust PDF representation of these cloud variables can be easily constructed and saved for cloud model comparisons.

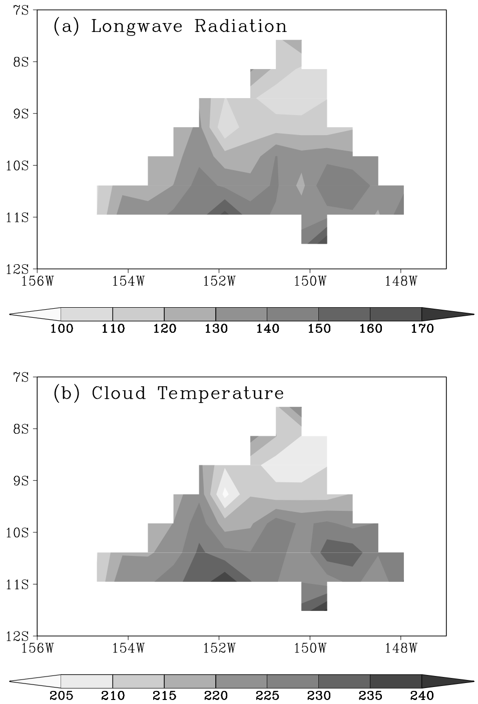

FIG. 1. Example of a large tropical deep convective cloud system, identified by the satellite cloud objective analysis classification system, showing spatial variability of (a) cloud longwave radiation (Wm^{-2}) and (b) cloud effective temperature (K).

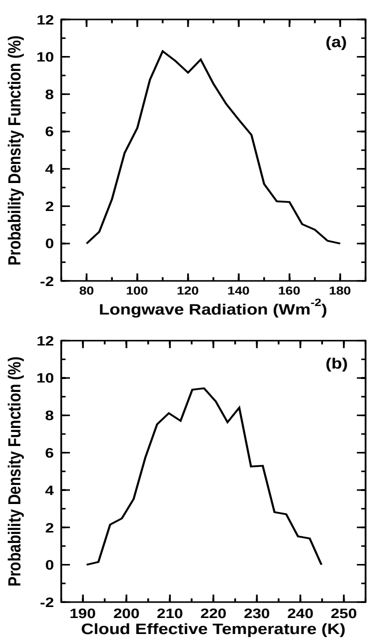

FIG. 2. Example of probability density function for (a) cloud longwave radiation (Wm^{-2}) and (b) cloud effective temperature (K) for the large tropical deep convective cloud system shown in Fig. 1.

5. SUMMARY

A new method for evaluating and improving cloud representations in GCM has been described to go beyond traditional methods of improving cloud models based on limited case studies from intensive campaigns and evaluating cloud representation based on gridded monthly mean satellite, surface, and atmospheric data comparisons. Instead of gridding satellite data to some standard GCM grid, this new technique classifies the satellite data into distinct cloud systems or cloud objects based on pre-defined cloud or radiation property in the satellite data. Once the cloud objects have been identified, their radiative and macro-physical properties can be saved to a database with matching ECMWF atmospheric state data. Given sufficient number of cases, these combined cloud object/atmospheric state data can then be analyzed to produce robust statistical information (e.g., PDF) about these cloud systems and their sensitivity to the background environment. These statistical information can be used directly to verify and improve statistical results produced from ensemble cloud model simulations. It is hoped that the improved cloud models can then be used to cultivate better cloud representation in GCMs, which can lead to further advances in the predictive capability of these global models.

Some preliminary satellite analyses based on CERES/TRMM SSF data for large tropical deep convective system have been shown to illustrate the results of the cloud classification technique. Future works include construction of statistical robust PDF for different cloud types based on large number of cases derived from the CERES SSF dataset and comparison with statistical results from ensemble of cloud model simulations, as well as, SCM cases.

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