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COMPARISON OF LARGE ENSEMBLE OF CLOUD SYSTEMS FROM EOS SATELLITE OBSERVATIONS WITH THE ECMWF PREDICTED CLOUD FIELDS

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1. Introduction

Parameterization of clouds and their radiative feedback processes is still the weakest component of current general circulation models (GCMs). In order to improve the predictive performance of current GCMs, a new method for systematic evaluation and improvement of cloud parameterizations (and cloud models) has been proposed (Xu et al. 2002), which is rather different from the traditional methods using either the limited data from field experiments or the monthly averages of global and regional satellite and meteorological data sets. Specifically, this new technique classifies satellite data into distinct cloud systems defined by their types (e.g., trade cumulus, stratus, and deep convection). These observed cloud systems are then matched with nearly simultaneous atmospheric state data from the European Center for Medium-range Weather Forecasts (ECMWF).

In this new method, the atmospheric data are also used as inputs for cloud model (e.g., single column cloud models, cloud-resolving models and large-eddy simulation models) simulations. The cloud model results are statistically compared with satellite observations. That is, the statistics of subgrid scale characteristics of simulated cloud systems are computed for comparison with observations. In summary, this new approach takes cloud model evaluation into tests of large statistically robust ensembles of matched atmospheric states ==> cloud model ==> satellite cloud system data comparisons instead of using the traditional gridded-mean comparison, emphasizing on evaluating the higher-order distributions of subgrid-scale characteristics of cloud systems between satellite observations and cloud models.

One of the cloud models to be evaluated under this project is the ECMWF cloud parameterization (Tiedtke 1993). The cloud amount and the cloud mass are predicted variables in this parameterization. The evolution of cloud amount and water/ice content is fully determined by advective processes and the sources and sinks due to diabatic processes. The sources and sinks of cloud amount are parameterized for major cloud types, such as frontal, cumulus anvil/cirrus and boundary-layer clouds. This parameterization also includes the explicit link between anvil/cirrus clouds with penetrative cumulus convection.

This paper presents some preliminary results of the comparison of ECMWF predicted cloud fields with tropical convective systems identified by the Earth Observing System (EOS) satellites. The goals are 1) to evaluate the ECMWF cloud parameterization and 2) to present a method for enabling such a direct comparison of predicted grid-mean cloud fields with satellite observations.

2. Satellite data and cloud objective analysis

The satellite data used in this study are from the Single Scanner Footprint (SSF) data set from NASA's Clouds and the Earth's Radiant Energy System (CERES)/Tropical Rainfall Measurement Mission (TRMM) for the March 1998 period, but from the Terra satellite for the March 2000 period. These two periods are chosen because they represent two different tropical climatologies: normal (2000) and El Nino years (1998).

The CERES SSF combines instantaneous CERES broadband radiative flux observations with scene information derived from the Visible/Infrared Scanner (VIRS) cloud imager on TRMM. Major parameters analyzed for this study include cloud amount, height, temperature, pressure, optical depth, emissivity, ice and liquid water path and particle size information, as well as broadband shortwave (SW) and longwave (LW) radiative fluxes from the top of the atmosphere.

The satellite cloud objective analysis uses the CERES SSF data to group cloud properties and radiative flux observations into a contiguous region of the Earth, each with a single dominant cloud type. The shapes and sizes of these cloud systems are determined by the data and the criteria used for identifying different types of cloud systems. For example, the criteria used for identifying tropical convective cloud systems are 1) cloud height of at least 10 km, 2) visible optical depth of at least 10, 3) cloud amount of 100 percent, 4) latitudes within 25° of the Equator. Radiative and optical parameters from the CERES SSF footprint data that fall within the boundary of the cloud systems are used to compute the probability density functions (PDFs) for comparison with ECMWF predicted cloud fields for tropical convective cloud systems in this study. Other major cloud types such as boundary-layer clouds will be studied in the near future.

For the March 1998 period, a total of 29 tropical convective cloud systems have been identified by this cloud objective analysis, with sizes ranging from 300 to 600 km in equivalent diameter. This is a very small number for one month of satellite data because the cloud systems with diameters less than 300 km are eliminated. The main reason for studying the large cloud systems is that the ECMWF model may better predict the large cloud systems with long durations. These twenty-nine cloud systems are then matched with nearly simultaneous ECMWF atmospheric state data. For the March 2000 period, the data are still being analyzed, but they should be available at the time of the meeting.

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3. ECMWF predicted cloud fields

The ECMWF data also contain a set of predicted cloud fields, which includes the vertical profiles of cloud water mixing ratio, cloud ice mixing ratio and cloud fraction. Temperature and water vapor mixing ratio, as well as the three wind components, are also available. Since the ECMWF grid size (0.5625° x0.5625°) is much larger than the CERES footprint size (from 10 km x 10 km and larger), each ECMWF grid needs to be further divided into smaller subgrids in order to properly compare the statistics of ECMWF predicted cloud fields with the satellite observations.

Two major assumptions are made in this study, First, the ECMWF cloud fields within the grid are distributed horizontally and vertically using the maximum-random overlapping (Klein and Jacob 1999). For a given number of subgrids, says, 100, the horizontal (one direction) and vertical location of cloudy subgrids can be determined based upon the given profile of cloud fraction by satisfying the maximum-random overlap requirement. Second, the cloud water and cloud ice mixing ratios are horizontally uniform for every cloudy subgrid at a given height. That is, the subgrid mixing ratio of cloud water/ice is equal to the grid average mixing ratio of cloud water/ice divided by the cloud fraction at the same height.

The broadband radiative fluxes and optical properties of each ECMWF subcolumn are obtained using radiative transfer parameterization from the Fu-Liou radiation codes (Fu and Liou 1993). The major input parameters are the subgrid cloud water and cloud ice mixing ratios, effective diameters of cloud ice and radii of cloud water, as well as the grid average temperature and water vapor mixing ratio. The radius of cloud water is assumed to be 10 microns, while the diameters of cloud ice (small ice) are empirically formulated as a function of cloud ice mixing ratio (Qiang Fu, 2002; private communications). The diameter of large ice (snow) is assumed to be 150 microns. The mass-weighted diameter of small and large ice is used as an input to the radiation codes.

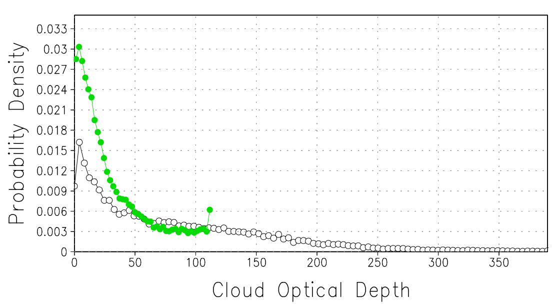

Fig. 1: Probability density functions of cloud optical depths from the ECMWF (open-circle line) and satellite observations (solid-circle line).

Once the cloud optical depths are obtained from the radiation codes, the same criteria used for identifying satellite cloud systems, in particular, the first two criteria described above, are then used to select the ECMWF subgrids of cloud and radiation fields for computing ECMWF PDFs for comparisons with observed PDFs. The cloud top height is the height where the visible optical depth is equal to 2, which is the detectable signal of the satellite. Because a cloud system has a diameter of several hundred kilometers, several ECMWF grids are selected for the calculation described above. Due to the irregular shape of the cloud system identified by the satellite data (see Xu et al. 2002), the rectangle area that composes of several ECMWF grids has to be much larger than the cloud system size determined by its equivalent diameter. A ratio of 3 is chosen in this study so that the large domain can cover the entire cloud system from the satellite observations. This large domain is also used to compute the large-scale advective tendencies for driving cloud-resolving models (CRMs). This choice would provide a consistent three-way comparison among the satellite observations, ECMWF cloud fields and CRM simulations. It should be noted that the statistical results presented below are, however, not sensitive to this ratio.

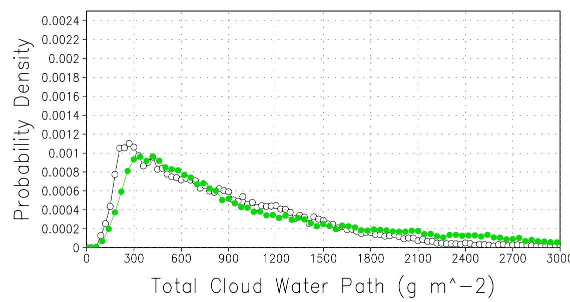

Fig. 2: Same as Fig. 1 except for total liquid water paths.

4. Preliminary Results

We show some comparisons of PDF results for selected parameters, including cloud optical depth (Fig. 1), total cloud water path (Fig. 2) outgoing LW flux (Fig. 3), top-of-the-atmosphere (TOA) SW flux (Fig. 4), cloud top height (Fig. 5), cloud top temperature (Fig. 6) and cloud ice particle diameter (Fig. 7). The last parameter is calculated from a remote sensing formula using the ice optical depth and ice water path as inputs. In all plots shown below, both the ECMWF predicted cloud fields are shown in open-circle lines, while the CERES SSF observed cloud fields are shown in solid-circle lines. The PDFs are computed from all 29 cloud cases combined. The PDFs are not shown for individual cloud systems.

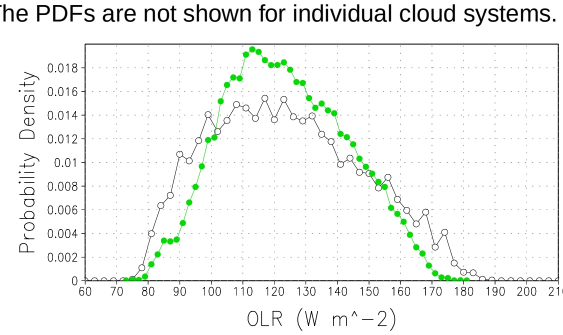

Fig. 3: Same as Fig. 1 except for TOA outgoing LW fluxes.

These figures show strong similarities between CERES SSF and ECMWF predicted cloud fields, but differences are also noticeable in the PDFs of some parameters, as explained in details below.

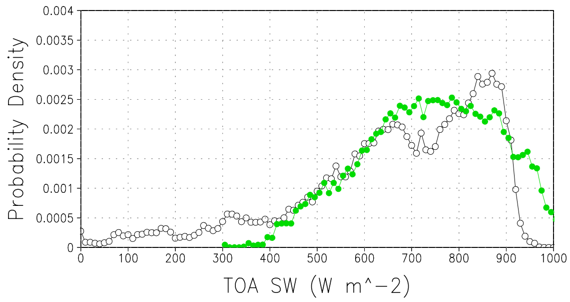

Fig. 4: Same as Fig. 1 except for the TOA SW fluxes.

The similarities include the exponential distributions for cloud optical depth (Fig. 1) and total cloud water path (FIg. 2) and the Gaussian distributions for cloud top height (Fig. 5), pressure (not shown), temperature (Fig. 6) and ice particle diameters (Fig. 7), as well as the top-of-the-atmosphere LW (Fig. 4)and SW fluxes (Fig. 5).

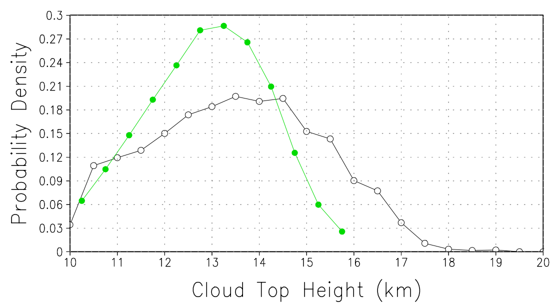

Fig. 5: Same as Fig. 1 except for the cloud top heights.

The significant differences are evident. For example, cloud tops are higher (Fig. 5) and cloud top temperature is lower (Fig. 6) from the ECMWF cloud fields. The outgoing LW fluxes from the ECMWF cloud fields (Fig. 3) are much broader-distributed than those from the satellite observations. The TOA SW fluxes (Fig. 4) have more lower values. This is related to mismatching of the satellite observation time and four times available daily for the ECMWF data. In addition, the cloud ice diameters are slightly smaller than those from the satellite retrievals.

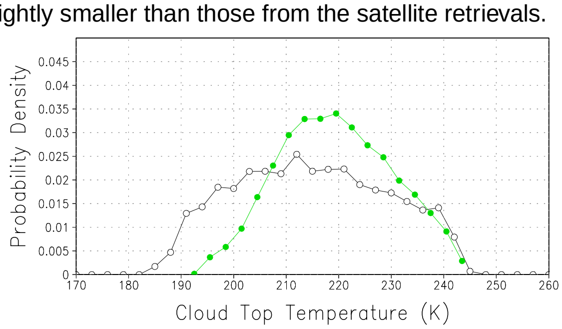

Fig. 6: Same as Fig. 1 except for the cloud top temperatures.

A plausible explanation for the higher cloud tops in the ECMWF predicted cloud fields is that detrainment from cumulus convection is too large and anvil clouds form at higher altitudes. The large detrainment in the upper troposphere is a characteristics of the bulk cloud model used in cumulus parameterization (Yanai et al. 1973), which can be the case in the ECMWF model (Tiedtke 1987).

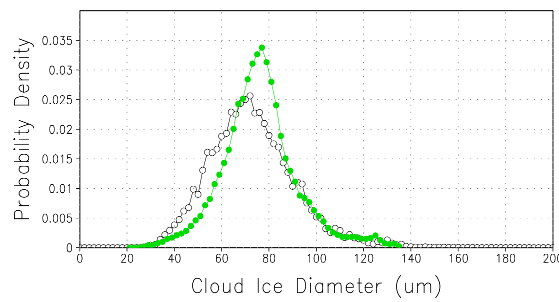

Fig. 7: Same as Fig. 1 except for the ice particle diameters.

5. Summary

This study has presented some preliminary results of a systematic comparison between the ECMWF predicted cloud fields and satellite observations. As far as the PDFs of selected parameters are concerned, the ECMWF predicted cloud fields are very similar to the satellite observations except that the cloud tops are too high, which causes some disagreements for other parameters such as the outgoing LW fluxes. Further studies include the comparisons with cloud-resolving model simulations and sensitivity tests of changing the thresholds for defining subgrid cloud tops from the ECMWF predicted cloud fields.

The uncertainties for calculating the subgrid radiation and optical properties need to be addressed. For example, the cloud overlap assumption may need to be refined although it is consistent with the radiation parameterization employed at the ECMWF model.

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