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OFFLINE GCSS INTERCOMPARISON STUDY OF CLOUD - RADIATION INTERACTION AND SURFACE FLUXES

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1. INTRODUCTION

Cloud-radiation interactions have ranked as one of the most critical areas in modeling global change scenarios. For this reason, the Global Energy and Water Cycle Experiment (GEWEX) formed the GEWEX Cloud System Study (GCSS) to address such problems. Cloud Ensemble Models (CEMs; also called Cloud Resolving Models - CRMs; or Cloud System Resolving Models - CSRMs) were chosen as the primary approach for carrying out these studies. In addition, Single Column Models (SCMs) have been recommended for use with CEMs to examine cloud parameterizations in General Circulation Models (GCMs) and Climate Models.

In the framework of the GCSS, several CRMs and SCMs were used to simulate a 7-day period in TOGA COARE (19-26 December 1992), which included several episodes of deep convection. The large-scale quantities that were required (initial conditions, upper and lower boundary conditions, large-scale advective tendencies of potential temperature and water vapor; and horizontal winds) were based on observations averaged over the COARE IFA (called a semi-prognostic approach by Soong and Ogura, 1980; and Soong and Tao, 1980). However, large differences in the mean heating and moistening errors were produced by CRMs and SCMs (-1 to -5 K and -2 to 2 g kg^{-1} respectively). Since the large-scale advective temperature and moisture "forcing" are prescribed for this case, a closer examination of two of the remaining external types of "forcing", namely radiative heating and air/sea heat and moisture transfer, are warranted.

This paper examines the current radiation and surface flux parameterizations used in the cloud models participating in the GCSS WG4, by executing the models "***offline***" for a prescribed atmospheric state, then examining the surface and radiation fluxes from each model. The thermodynamic, and microphysical fields are provided by the GCE-derived model output during a period of very active deep convection (westerly wind burst). The surface and radiation fluxes produced from the models are then divided into prescribed convective, stratiform, and clear regions in order to examine the role that clouds play in the flux parameterizations.

2. APPROACH - DATA

The thermodynamic and microphysical fields are provided by the Goddard Cumulus Ensemble (GCE)-derived model output of Case 2 at 5760 min, which is during a time of active deep convection (Johnson *et al.* 2002). Please see web site *http://rsd.gsfc.nasa.gov/users/djohnson/gcssg4* for the GCE simulated fields used as input to the off-line model intercomparison and to examine the results

3. RESULTS

We currently have results from eight participants in the GCSS WG4 Case 2. These include the NASA/Goddard Space Flight Center GCE model (D.

Johnson and W.-K. Tao), University of Utah (UU) CEM (S. Krueger and M. Zulauf), NCAR (Wu), CSU/UCLA (Xu), CNRM (MesoNH, Guichard and Redelsperger), NOAA/GFDL Limited Area Nonhydrostatic model (LAN: L. Donner and C. Seman), and the United Kingdom Metor. Office (UKMO) - Large-Eddy-Model (LEM: J. Petch) and UKMO - SCM (J. Gregory). The GFDL group also submitted three different sets of results with different microphysics options (no graupel included - G-XG, graupel added to rain category - G-G>R and graupel added to snow category - G-G>S).

3.1 Surface Fluxes

The results indicate that the models produce large differences in the sensible and latent surface fluxes. The UKCRM produced the largest latent and sensible heat fluxes in convective regions and consequently, in the domain total. The GFDL model produces very small fluxes when compared to the other models.

For the sensible and latent heat fluxes, mean differences range between 30 and 70% (4-23 W/m^2 for sensible; 10-80 W/m^2 for the latent) with consistent differences in the clear, convective, and stratiform regions. Note that the wind strengths are quite different between the three regions. The GCE model results are in good agreement with those calculated using the TOGA-COARE flux-algorithm.

3.2 Radiation Fluxes

There are two important processes that determine the cloud-radiation interactions parameterized in the SCMs and CRMs. The first one is the radiative transfer process. The simplest radiative radiative transfer model is that used in the MM5 (submitted by the U. of Washington for WG4). This scheme uses a broad band two-stream (upward and downward fluxes) approach for the radiative flux calculations and only requires a very small computation. The GCE model (as well as the UUCEM) uses a broad-bands radiative model. Here, the shortwave radiation models of Chou (1990, 1992) are used to compute the solar heating in the atmosphere/clouds and at the surface. The solar spectrum is divided into two regions: the ultraviolet (UV) and visible region (wavelength < 0.69 um) and the near infrared (IR) region (wavelength > 0.69 um). In the UV and visible spectral region, ozone absorption and Rayleigh and cloud scattering are included. In the near IR region, absorption due to water vapor, and cloud, and scattering due to clouds are included. The UV and visible region is further grouped into four bands, and an effective Rayleigh scattering coefficient are given for each band. The near IR region is divided into seven water vapor absorption bands. The k-distribution method is applied to each of the seven bands for computing the absorption of solar radiation by water vapor and clouds. The four-stream discrete-ordinate scattering algorithm of Liou *et al.* (1988) is used to compute multiple scattering within a cloud layer. The infrared spectrum is divided into eight band to compute the cloud and atmospheric infrared cooling.m The water vapor transmission function is computed using the k-distribution method. The multiplication approximation is used to take into account the effect of overlapping the different gas and cloud absorptions. Overall, the GFDL and UKMO both incorporate the state-of-the-art of radiative model and use multiple broad bands approaches.

The other important physical process, namely cloud optical properties, also need to be parameterized. Almost all of the CRMs use the cloud (liquid/ice) information to calculate the optical depth. Some CRMs also add a few additional layers above their model tops for additional radiation calculations (to eliminate large cooling or heating at the model top). Since the CRMs' resolution is less than 1 km and each grid point is either clear (0) or complete cloudiness (1). Optical depth is only calculated for each cloudy area (each grid point).

The results indicate that the models produce large differences in the radiative fluxes, and radiative heating/cooling rates. The solar heating is quite similar between all five radiative transfer schemes. The differences are mainly caused by the cloudy region. This result implies that different cloud optical properties used in the CRMs and SCMs are the main reason for the differences in shortwave heating. However, the differences in longwave cooling are quite significant even in the clear region. We also note that the differences in the radiative rates in the cloudy or stratiform regions are much more pronounced for shortwave fluxes (310-315 W m^{-2}) than for longwave (9-28 W m^{-2}) at both the surface (downward) and top-of-atmosphere (upward). Differences are also much smaller in the clear regions, but yet significant for the shortwave fluxes (14-29 W m^{-2}) and less so for the longwave (2-5 W m^{-2}).

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