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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Comparison of a global-climate model simulation to a cloud-system resolving model simulation for long-term thin stratocumulus clouds" *by* S. S. Lee et al.

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First of all, we would like appreciate the reviewer's comments and suggestions. In response to the reviewer comments, we have made relevant revisions in the manuscript. Listed below are our answers and the changes made to the manuscript according to the questions and suggestions given by the reviewers. Each comment of the reviewer is listed and followed by our responses.

Anonymous Referee #1

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General Comments:

This is a detailed analysis of a case study involving a stratocumulus-to-cumulus transition. The case is modeled using a general circulation model (GCM) and a large-eddy model (LEM). The GCM fails to produce a transition to Cu, as observed, whereas the LEM does. The reasons for failure are related to the facts that 1) the GCM's parameterized turbulent fluxes do not properly represent the deepening-warming decoupling; and 2) the GCM's microphysics produces precipitation that reaches the ocean surface, thereby stabilizing the below-cloud layer. This problem is of great scientific importance. The manuscript is clear and thorough. However, it might have gone further in the two areas mentioned in the Specific Comments below.

Specific Comments:

1... Section 2: I like the authors' approach of running both the CSRM and GCM with the same initial conditions, large-scale forcings, and surface fluxes. However, the CSRM and the GCM used different physical parameterizations. The CSRM contains the microphysics parameterization of Saleeby and Cotton (2004); and the radiation parameterizations of Chou and Suarez (1999), Chou and Kouvaris (1991), Chou et al. (1999), and Kratz et al. (1998). The GCM contains the microphysics parameterizations of Boucher et al. (1995), Tripoli and Cotton (1980), and Beheng (1994); and the radiation parameterizations of Collins et al. (2006). Because the CSRM and GCM use different physical parameterizations, it is difficult to disentangle the effects of different resolutions from the effects of different microphysics parameterizations. In section 6.1, the authors compare the parameterizations for clear-sky and cloudy cases. This is a start, but it does not demonstrate that the microphysics schemes behave the same in both models when clouds are present. Therefore, it is non-trivial to attribute differences to either the change in resolution or the change in physics schemes. This may matter because (p. 12312) "The presence of the surface precipitation in the GCM run throughout the entire simulation period stabilizes the whole sub-cloud layer" whereas (p. 12307) "The surface precipitation is absent in the CSRM run when stratocumulus is a dominant cloud type before the development of cumulus clouds . . . As indicated by Jiang et al. (2002), when precipitating particles evaporate completely before reaching the surface, even the slightly increased evaporation of precipitation around the cloud base can cause the increased instability concentrated around the cloud base (leading to increased updrafts and condensation) in stratiform clouds." Ideally, one would perform the CSRM and GCM runs using identical physical parameterizations. If this is impracticable, it might be of interest to simulate an idealized case that does not produce precipitation, or to shut off precipitation processes in both the CSRM and the relevant region of the GCM. Even running a single column of the GCM with precipitation shut off might be illuminating.

Note that this study examines the role of the different parameterizations of cloud microphysics in the simulation of clouds between the CSRM and the GCM as well as that of the different resolutions; we expected these different parameterizations as well as different resolutions would result in different simulations of cloud properties.

As explained in the text and pointed out by the reviewer here, one of the important differences in the microphysics parameterizations between the CSRM and the GCM is that the microphysics scheme considering spectral information for collections and predicting supersaturation and CDNC for condensation in the CSRM results in smaller condensation and the conversion of cloud liquid to rain than the scheme not considering the spectral information and using a saturation adjustment in the GCM. Larger condensation leads to larger LWP and larger conversion leads to larger rain in the GCM than in the CSRM, making it possible for rain to reach the surface in the GCM. As explained in the text, since the sub-cloud humidity is similar, the larger rain is the main cause of the presence of the surface precipitation in the GCM.

To disentangle the effect of different parameterizations of microphysics from that of different resolutions, the CSRM run is repeated by adopting the microphysics parameterization from the GCM with no changes in the resolutions. We found, in this repeated simulation, precipitation reaches the surface, which stabilizes the entire sub-

cloud layer. Also, the CSRM run with Saleeby and cotton's scheme and the CSRM with the microphysics scheme from the GCM are repeated, respectively, with resolutions in the MBL as low as in the GCM. Comparisons in the results between these two CSRM runs show that the CSRM with the GCM scheme produces the surface precipitation whereas the CSRM with Saleeby and Cotton's scheme produces no surface precipitation. This indicates that the presence of the surface precipitation is controlled by the choice of the microphysics scheme but not by the choice of resolutions.

2... Section 6.3. The authors nicely demonstrate that the transition from Sc to Cu is related to increased latent heat flux (Section 6.3), but the GCM presumably contains this increased latent heat flux, and the authors do not show why the GCM does not respond to the increased latent heat flux. The authors only provide only a few general comments. For instance, the abstract states that "However, in the simulation by the GCM, these interactions are not resolved and thus the transition to cumulus clouds is not simulated." On p. 12311, the manuscript writes "the GCM used here is not able to resolve cloud-scale turbulent motions, which in turn makes it impossible to simulate interactions among latent heat fluxes, buoyancy fluxes, and entrainments in the GCM run." On p. 12314, the manuscript writes "In the GCM run where the interactions between the latent heat fluxes and buoyancy fluxes were not represented explicitly, the deepening-warming decoupling was not simulated." It is useful to know that in one case, at least, the GCM was unable to simulate the transition between Sc and Cu. However, it would be useful to have more guidance on how to fix the GCM's parameterizations. Presumably the GCM contains a shallow cumulus scheme, such as the scheme of Hack (1994). Under what conditions is this scheme triggered? Is the scheme triggered at all in the GCM simulation in the region of interest? If the scheme is triggered, how does it alter subgrid fluxes or turbulence?

Hack's scheme can be triggered when the large-scale moist instability exists. However, in the region of interest here (in the MBL), there is no large-scale instability developing throughout the simulation period. Hence, Hack's scheme is not activated.

Despite no large-scale instability, cumulus clouds develop in the CSRM. This is because the small cloud-scale interactions between latent heat flux and cloud buoyancy flux (described in section 6.3) induce the conditional instability, leading to the formation of cumulus clouds as also described in BW97. In other words, the CSRM is able to generate the instability not from the large-scale forcing but from cloud-scale motions by resolving cloud-scale interactions, which is possible due to the use of high resolutions.

As stated in BW97, in particular, the simulation of deepening-warming decoupling requires the integration of a cumulus parameterization, a cloud microphysics parameterization, and a turbulence parameterization that accurately represents layer cloud feedbacks on boundary turbulence. This integrated parameterization should be able to predict the development of the conditional instability based on the magnitude of surface LH fluxes.

The following is added to indicate the conditional instability developing and the need to develop parameterization to simulate deepening-warming decoupling.

(LL585 in p20) leading to the development of conditionally unstable cloud layer.

(LL862-863 in p29) which generates the conditional instability.

(LL868-872 in p29-30) As stated in BW97, the simulation of deepening-warming decoupling requires the integration of a cumulus parameterization, a cloud microphysics parameterization, and a turbulence parameterization that accurately represents layer cloud feedbacks on boundary turbulence. This integrated parameterization should be able to predict the development of the conditional instability based on the magnitude of surface LH fluxes.

Technical Corrections. p. 12284, line 12: The article refers often to "cloud mass". Does this mean cloud cover? Cloud fraction? Liquid water content? I am not familiar with the term "cloud mass".

To avoid confusion, “cloud mass” is replaced with “LWC” in case cloud mass in the

old manuscript only includes the mass of droplets. In case “cloud mass” indicates the mass of both droplets and rain, “cloud mass” remains; here cloud mass is the sum of LWC and rain water content as indicated in the text (LL648-650 in p22).

p. 12284, line 25: Change "cilimate sensitivity" to "climate sensitivity".

Done

p. 12294: The CSRM uses a horizontal grid spacing of 50 m. Such grid spacings are typical of large-eddy simulations (LES). The authors might want to note early (e.g. in the abstract) that the "CSRM" will be run at fine resolutions typical of LES.

The following is added in the abstract:

(LL27-28 in p2)

Adopts high resolutions which are generally used in large-eddy simulations (LES).

p. 12294, line 27: Change "masoscale" to "mesoscale".

Done

p. 12296, line 18-20: The manuscript writes "In other words, aerosol impacts on cloud particle properties after its activation are only taken into account for both the GCM run and the CSRM run." Is it more accurate to say "In other words, only aerosol impacts on cloud-particle properties after its activation are taken into account for both the GCM run and the CSRM run."?

The sentence pointed out here is replaced with what is suggested by the reviewer here.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 12283, 2009.