The diurnal cycle of shallow Cumulus clouds over land: A single column model intercomparison study

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Geert Lenderink[1], *A. Pier Siebesma*[1], *Sylvain Cheinet*[2], *Sarah Irons*[3], *Colin G. Jones*[4], *Pascal Marquet*[5], *Frank Müller*[6], *Dolores Olmeda*[7], *Javier Calvo*[7], *Enrique Sanchez*[7], *and Pedro M. M. Soares*[8,9]

[1] *Royal Netherlands Meteorological Institute, De Bilt, The Netherlands*

[2] *Laboratoire de Meteorologie Dynamique, Paris, France*

[3] *Met Office, Bracknell, Berkshire, United Kingdom*

[4] *Rossby Center, SMHI, Norrköping, Sweden*

[5] *Météo France (CNRM/GMGEC), Toulouse, France*

[6] *Max-Planck Institut für Meteorologie, Hamburg, Germany*

[7] *Instituto Nacional de Meteorologia, Madrid, Spain*

[8] *DECivil, Instituto Superior de Engenharia de Lisboa, Portugal*

[9] *Centro de Geofísica da Universidade de Lisboa, Portugal*

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[*] *Corresponding author address:* Geert Lenderink, KNMI, 3730 AE De Bilt, P.O. Box 201, The Netherlands. E-mail: lenderin@knmi.nl

Summary

An intercomparison study for single column models (SCMs) of the diurnal cycle of shallow cumulus convection is reported. The case, based on measurements at the ARM Southern Great Plain site on 21^{st} June 1997, has been used in an LES intercomparison study before. Results of the SCMs reveal the following general deficiencies: too large values of cloud cover and cloud liquid water, unrealistic thermodynamic profiles, and high amounts of numerical noise. Results are also strongly dependent on vertical resolution

These results are analyzed in terms of the behavior of the different parameterization schemes involved: the convection scheme, the turbulence scheme, and the cloud scheme. In general the behavior of the SCMs can be grouped in two different classes: one class with too strong mixing by the turbulence scheme, the other class with too strong activity by the convection scheme. The coupling between (subcloud) turbulence and the convection scheme plays a crucial role. Finally, (in part) motivated by these results several models have been successfully updated with new parameterization schemes and/or their present schemes have been successfully modified.

1. Introduction

The representation of clouds in present Atmospheric General Circulation Models (AGCMs) used in climate research and in numerical weather prediction (NWP) is relatively poor, thereby limiting the predictability of cloud feedbacks in a changing climate. In particular, the representation of shallow cumulus (Cu) convection is an important issue. Shallow cumulus clouds are an integral part of the Hadley circulation, increasing the near surface transport of moisture to the ITCZ, thereby intensifying deep convection (Tiedtke 1989). Over land, shallow cumulus convection also plays an important role in the preconditioning for deep convection.

For these reasons shallow cumulus convection has been the subject of many studies, in particular in Working Group 1 (WG-1) of GCSS [GEWEX (Global Energy Water cycle EXperiment) Clouds System Study (Browning 1993)]. In the 4th GCSS WG-1 intercomparison case ("BOMEX") a typical tradewind shallow Cumulus cloud with low cloud fraction was studied (Siebesma et al. 2003). The next case ("ATEX") concentrated on cumulus clouds rising into stratocumulus (Stevens et al. 2001), which is a common cloud regime in the tradewind area near the transition from stratocumulus clouds to cumulus clouds (de Roode and Duynkerke 1997). Finally, the 6th GCSS WG-1 case ("ARM") focused on the diurnal cycle of cumulus clouds over land (Brown et al. 2002).

In all these intercomparisons, the main emphasis was on the comparison of LES results with observations, and the intercomparison of the different LES results. This has been extremely helpful in evaluating the different LES models, giving confidence that LES can be used for these cases as a "substitute" (but no replacement) of reality providing us with a full 3D picture of the turbulent motions where measurements are sparse. This also opens a way to critically evaluate the different parameterizations involved with the representation of convective clouds, like e.g. mass flux schemes and cloud schemes. In particular, the BOMEX case has been very popular in this respect (e.g., Siebesma and Cuijpers 1995;

Siebesma and Holtslag 1996; Grant and Brown 1999; Bechtold et al. 2001; van Salzen and McFarlane 2002; Neggers et al. 2002).

Despite this, relatively little attention has been paid to the critical evaluation and documentation of results from single column models (SCMs) derived from (semi-) operational NWP or climate models. In the last few years, however, it has become clear that this step is essential, and that the whole cycle of intercomparing observations, LES and SCMs (and full 3D AGCM simulations) is critical to actually improve parameterizations in operational models.

This paper studies the representation of the diurnal cycle of cumulus convection in several SCM versions of (semi-)operational models. We use the GCSS WG-1 6^{th} case studying the diurnal cycle of Cumulus clouds (Brown et al. 2002) for the following reason. This case is rather demanding because all the parameterizations in the SCM have to work together in the different regimes capturing the diurnal cycle. What might work well in the mature stage of Cu clouds might not work properly in other stages of the diurnal cycle. Further, many of the parameterizations recently developed have been tuned to the stationary marine BOMEX case, and it is not clear how well they work for this nonstationary continental case.

The first objective of the paper is to show how realistic cumulus clouds are represented by state-of-the-art, operational climate/NWP models. The models considered are: ARPEGE (CLIMAT), ECHAM4, the ECMWF model (hereafter shortly denoted ECMWF), HIRLAM, MESO-NH, RACMO and the UK Met Office model (hereafter METO). These models are described in the Appendix (see also table 1). The second objective is to analyze the behavior of the different parameterization schemes involved. These are the turbulence scheme, the convection scheme and the cloud/condensation scheme. We will keep this analysis as general as possible, not focusing too much into the behavior of one particular model, but attempting to identify typical behavior in classes of models/or parameterizations. In this respect, it is explicitly mentioned that it is not our purpose to distinguish

between good and bad *models*. One bad assumption or bad scheme might jeopardize the solution of an otherwise good model, and relatively good results might be obtained through canceling errors. As part of the analysis we will also show some results of research models, that are not (yet) in operational use, in order to illuminate our findings further. Finally, (in part) motivated by these results several models have been successfully updated with new parameterization schemes and/or their present schemes have been successfully modified. The outcome of these improvements is also documented here. This comparison is part of the EU-funded EUROCS (European Cloud Systems) project, which aims at improving the representation of clouds in climate models.