

GCSS Precipitating Convective Cloud Systems (WG4) Report

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The goal of the GCSS WG4 is to improve representation of precipitating convective cloud systems in large-scale and global weather and climate models. The Working Group was involved in a number of recent activities and continues to collaborate with DOE's ARM (Atmospheric Radiation Measurement) Program Cloud Parameterization and Modeling (CPM) and Cloud Products (CP) WGs and the European project EUROCS (EUROpean Cloud Systems). The WG4 consists of a large number of scientists involved in several national and international projects, such as ARM, EUROCS, TRMM (Tropical Rainfall Measuring Mission), and IHOP (International H2O Project).

After investigating the maritime tropical convection (Cases 1 and 2; based on the TOGA COARE observations), the focus of the WG4 shifted in recent years toward the continental convection. Case 3, based on the ARM summer 1997 Intensive Observation Period (IOP) data, was extensively used in recent years to explore various aspects of continental precipitating convection, such as convective scaling, diurnal cycle, cloud-radiative interactions, etc. This case was used in extensive comparison among cloud-resolving models (CRMs) and single-column models (SCMs), as documented in two papers published recently in the Quarterly Journal of the Royal Meteorological Society (Xu et al., vol. 128, 2002, p. 593-623; and Xie et al., 128, 2002, p. 1095-1136.). Moreover, CRM results obtained using different case studies (such as Cases 1, 2, and 3 of WG4) have been used to develop and test new convection and cloud parameterizations. Examples (beyond those discussed below) are Chaboureaud and Bechtold (Journal of the Atmospheric Sciences, 2002, vol. 59, p. 2362-2372) and Gregory and Guichard (Quarterly Journal of the Royal Meteorological Society, 2002, vol. 128, p. 625-646).

1. Recent accomplishments.

Data collected at the ARM Southern Great Plains (SGP) site during the Summer 1997 (IOP) continue to be irreplaceable for studying various aspects of continental convection. This dataset was applied in a comprehensive comparison of the CRM and SCM simulations of midlatitude continental cumulus convection, led by Kuan-Man Xu (NASA Langley) and extending the intercomparison published recently. The simulation results from 8 2D CRMs, 2 3D CRMs and 11 SCMs were used. The results were compared as two ensembles (i.e., CRMs versus SCMs), focusing on the mean and the spread among the models. As one might expect from the experience with maritime tropical convection, the spread for any time series and the mean vertical profile was found greater for the SCM group than for the CRM group. There were also significant differences

in the mean vertical profiles of root-mean-square errors for most thermodynamic variables. These results suggest that SCMs as a group have more room for further improvements while some aspects of CRMs also need improvements, for simulating midlatitude continental cumulus convection.

A three-dimensional cloud-resolving simulation of midlatitude continental convection during the ARM Summer 1997 IOP was used by Marat Khairoutdinov (Colorado State University) to study the similarity of several second and third statistical moments and second-moment budgets among five episodes of deep convection. Several parameter scales relevant to deep convection similarity were introduced. The dimensionless vertical profiles of the vertical velocity variance and its third moment, cumulus kinetic energy, the prognostic variables variances and fluxes, their budgets, as well as several triple correlations, clustered together, confirming the dynamical similarity of the simulated convective events. This study yielded several interesting conclusions (for instance, concerning the dissipation time scale for mesoscale circulations) which are important for the physical understanding and the development of improved convective parameterizations.

The same dataset was also used in an extensive comparison between cirrus cloud properties predicted by a cloud-resolving model and observed by a cloud radar. This was a collaborative effort between University of Utah (S. Krueger, Y. Luo, G. Mace) and NASA Langley (K.-M. Xu). One of the conclusions from this study was that large-scale advection of high clouds contributed significantly to the cloudiness observed at the ARM site. This implies that neglecting condensate advection has a detrimental impact on the ability of a SCM or a CRM to simulate cirrus cloud occurrence. The study also suggested that despite the fact that CRM was capable of capturing many features of the observed cirrus, significant weaknesses in model simulations were present; for instance, on average, CRM cirrus clouds occurred at lower heights and with larger physical thicknesses.

The NASA Goddard group (W.-K. Tao, D. Johnson, S. Lang, C.-L. Shie, and J. Simpson) continued to study various aspects of deep convection in a variety of geographical regions (such as South China Sea, Western Pacific, Eastern Atlantic, Continental US), the interaction of convection with the large-scale dynamics, cloud-radiation interactions, and their cumulative impact on the regional energy and moisture budgets. In these studies, datasets originating from major field campaigns conducted over the last several decades (such as GATE and TOGA COARE), as well as more recent field projects (such as the Tropical Rainfall Measuring Mission, or TRMM, Validation Campaigns) provided input for the Goddard Cumulus Ensemble Model and were used to validate model simulations. The studies completed recently included 2D and 3D simulations of GATE and TOGA COARE convection (Cases 1 and 2), SGP ARM site convection (Case 3), and convection during the South China Sea Mesoscale Experiment (SCSMEX). These results are discussed in a number of papers submitted/published recently. Moreover, W.-K. Tao and D. Johnson conducted an intercomparison study of radiative transfer models used in CRMs and SCMs; the results of this intercomparison are being prepared for publication.

An important contribution to the WG4 activities came from the European project EUROCS (EUROpean Cloud Systems, see the web site <http://www.cnrm.meteo.fr/gcss/EUROCS/EUROCS.html>), that - within the area of precipitating convection - focussed on two aspects, namely, the diurnal cycle of continental deep convection and the impact of the free-tropospheric moisture on moist convection. These two aspects are thought to

play an important role in the development and organization of moist convection, but are often poorly captured in large-scale and climate models.

The diurnal cycle of continental deep convection sub-project, lead by Francoise Guichard (CNRM/Meteo-France) and Jon Petch (UK Met Office), considered an idealized case designed with help of the SGP ARM dataset (Case 3 mentioned above). The diurnal cycle case involved a single day, simulated in a perpetual mode for several diurnal cycles. Results from 5 SCMs and 3 CRMs suggest that better results and consistency are found among CRMs than SCMs. For instance, deep convection occurred earlier in many SCMs than it did in CRMs. Moreover, when data on each time step were available (instead of 3-h mean values), convection was often considered as deep in SCM runs, without any transition regime involving shallow cumulus, as in CRMs. This prompted improvements to convection initiation schemes within SCMs, that considered, for example, more realistic evolution of surface and boundary layer characteristics and convection triggering mechanisms. Moreover, CRMs sensitivities to horizontal gridlength, domain size, and subgrid-scale parameterizations (turbulence, condensation) were also quantified.

An idealized humidity case, led by Steve Derbyshire (UK Met Office), considered the impact of the relative humidity above the boundary layer on convective development. The strategy was to verify that CRMs agree in their response to the free-tropospheric moisture (in terms of the sensitivity of model-produced Q1, Q2, and the convective mass flux), and to use the sensitivity observed in simulations using CRMs as a reference for the sensitivity of convective parameterizations applied in SCMs. In this study, 2 CRMs and 5 SCMs participated. The two CRMs were found to agree in their response to the free-tropospheric moisture and their results were used to test and improve the SCMs that initially showed a wide range of behavior.

2. Work in progress and future plans.

Continental deep convection is strongly coupled to the surface and boundary layer processes. The methodology applied by the WG4 is to start with idealized approaches (for instance, by assuming prescribed surface fluxes like in Case 3) and proceed toward more realistic approaches after building physical understanding and developing/improving parameterizations of relevant physical processes. For instance, diurnal cycle of continental convection, with shallow convection early in the day giving way to the deep convection in the afternoon, can be initially studied without considering mesoscale variability of surface fluxes, without considering the impact of surface topography on convective development, and without a land surface model (that will bring, for instance, the issue of the "memory" of the surface energy and moisture budgets to meteorological conditions on the previous day). Moreover, the impact (on convective development) of larger-scale features (e.g., synoptic-scale fronts, dry-lines, etc.), abundant over midlatitude continents and challenging for a single-column modeling framework underlying GCSS approach, has to be addressed as well. Some of the aspects of the problem can be investigated using summer 97 IOP SGP ARM data (like the overall features of precipitating convection over land, as in the EUROCS case). However, issues like the diurnal cycle of boundary layer development over land, the transition from shallow to deep convection during the course of the diurnal cycle, or the coupling of convection with land surface processes, require close ties with dedicated observational campaigns and GCSS working groups focusing on boundary layer cloudiness (WG1) and land/atmosphere interactions (GEWEX Global Land/Atmosphere System Study, GLASS).

Representing diurnal cycle of convection over land in CRMs and SCMs is challenging. For CRMs, grid spacing traditionally applied in studies concerning deep convection is most likely not sufficient to represent boundary layer clouds (this was illustrated in recent studies of Marat Khairoutdinov and Jon Petch), unless sophisticated subgrid-scale modeling of turbulent and cloud processes is included (as illustrated by recent results of Anning Cheng and Kuan-Man Xu). For SCMs, the interaction among boundary-layer, shallow convection, and deep convection parameterizations is the key. To explore these issues, a new case was developed by Wojciech Grabowski (with help from the NASA Goddard group) based on the observations during the TRMM-LBA (Large Scale Biosphere-Atmosphere Experiment) field campaign in Rondonia, Brazil. Currently, this case involves only daytime evolutions of boundary layer and convection. It is planned that the case will be extended into the entire diurnal cycle. Moreover, an attempt will be made to develop an alternative case based on the recent observations during the IHOP project (May-June 2002), which included an ARM IOP over the SGP site.

Finally, results obtained by CRMs over the last several years using case studies concerning deep convection motivated a computational strategy in which a 2D CRM is applied in every column of a global model to represent deep convection and its coupling with radiative and surface processes. This approach was tried by Wojciech Grabowski in idealized aquaplanet simulations and by Marat Khairoutdinov and David Randall in the Community Climate System Model. This approach has become known as the super-parameterization. Although such an approach is arguably an important step in improving the representation of clouds in climate models, the cost of the super-parameterization is extreme when compared to traditional convective parameterizations. An ongoing and planned research within the WG4 explores the cost-benefit aspect of the super-parameterization as applied in a climate model.