SPECIAL PROJECT INTERIM REPORT

Interim Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	1st half of 2006
Project Title:	Stochastic sub-grid scale parametrizations for coupled earth system models
Computer Project Account:	
Principal Investigator(s):	Prof. Heikki Järvinen
Affiliation:	Finnish Meteorological Institute
Name of ECMWF scientist(s) collaborating to the project (if applicable)	
Start date of the project:	1.1.2006
Expected end date:	31.12.2008

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	-	-	191,000	0
Data storage capacity	(Gbytes)	-	-	1620	0

Summary of project objectives

(10 lines max)

1) to test and demonstrate the viability of the stochastic approach for the sub-grid-scale cloud/radiative transfer parametrizations
2) to use this approach to improve the presentation of cloud-radiation interaction in ECHAM5

Summary of problems encountered (if any)

(20 lines max)

Test runs with the atmosphere-only model were succesfully run on the FMI computer. Allocated ECMWF computing resources were not used due to delay (technical difficulties) with the implementation of the coupled atmosphere-ocean model.

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

Please see the attached full report.

List of publications/reports from the project with complete references

Summary of plans for the continuation of the project

(10 lines max)

It is expected that within 2006, runs with a coupled atmosphere-ocean GCM (ECHAM5 atmospheric GCM combined with the MPI-OM ocean GCM) will be initiated. The initial focus of these tests will be the impact of McICA noise, which has never before been tested in a coupled GCM environment. Comparisons to the standard (non-McICA) version of the model will also be performed.

Stochastic subgrid-scale parametrizations for Coupled Earth System Models

(interim report 10 May 2006)

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1 Introduction

Interaction of clouds with radiation is strongly influenced by unresolved cloud features, that is, features which are smaller than the GCM grid cell (e.g., Barker et al. 2003). Within the current paradigm of modelling radiative transfer in GCMs, assumptions about the unresolved cloud structures are embedded deep within the radiative transfer codes. This complicates the radiative transfer codes, makes them more difficult to modify, and opens the door for biases in radiative fluxes and heating rates.

As a radical alternative to the current paradigm, Pincus et al. (2003) introduced the Monte Carlo Independent Column Approximation (McICA). The McICA approach extricates the description of unresolved optical structure from the radiative transfer solver, which allows much more flexible, and eventually more accurate, description of unresolved cloud features than is possible for typical GCM radiation codes. Furthermore, and importantly, McICA is *unbiased* with respect to the full Independent Column Approximation (ICA), which means that for every situation, the expectation values of radiative fluxes and heating rates equal those for ICA. However, as a potential weakness of the approach, McICA's results contain conditional *random errors*, whose magnitude depends on cloud and atmospheric properties, characteristics of the radiation code etc. (Räisänen and Barker 2004).

McICA operates on subcolumns that are horizontally homogeneous and either cloud-free or overcast. Thus, in order to apply McICA in GCMs, a set of subcolumns needs to be provided for every GCM column. They can be produced using a stochastic cloud generator (Räisänen et al. 2004).

In the current work, the McICA approach is being tested in the Max Planck Institute for Meteorology's (MPI) ECHAM5 GCM. The work is part of Finland's contribution to the COSMOS Earth System Modelling consortium led by the MPI.

2 Work performed until now

The work on ECHAM5 started in FMI in January 2005. The McICA approach and the stochastic cloud generator have been implemented to ECHAM5 and have been tested in a set of ensemble simulations. In these initial tests, ECHAM5 has been run in uncoupled mode, that is, using prescribed distributions of sea surface temperature (SST) and sea ice. A brief summary of the most important results is given below. A more detailed report will be given in Räisänen et al. (2006).

2.1 Impact of McICA random noise

McICA's conditional random errors ("McICA noise") are a potential problem for the use of McICA in GCMs. The concern is that the random errors could lead, through nonlinear interactions, to systematic effects on model climatology. If such effects were substantial, this would put a serious question mark on the applicability of McICA.

The impact of McICA noise in ECHAM5 was tested in a set of ensemble simulations with differing noise levels. Each simulation consisted of 10 six-year runs at horizontal resolution T42, with 31 layers in the vertical. In Figs. 1 and 2, results are shown for three simulations (for terminology, see Räisänen and Barker (2004) or Räisänen et al. (2005)): (1) REF denotes a computationally expensive reference simulation, in which McICA noise has been suppressed by heavily increased sampling. (2) CLDS is an example of a reasonable GCM implementation of McICA. (3) 1COL is a degraded version of McICA which maximizes the noise level. Roughly speaking, the random errors in radiative fluxes and heating rates for REF are $\approx 80\%$ smaller than those for CLDS, while those for 1COL are 2–3 times larger than for CLDS.

The most significant effect of McICA noise noted in the simulations was a slight reduction in low cloud fraction (Fig. 1), with related effects on radiative fluxes (i.e., shortwave cloud radiative effects (CRE) at the top of the atmosphere (TOA) and at the surface, and longwave CRE at the surface). This echoes, with some differences in details, the results of Räisänen et al. (2005) for NCAR CAM. While the reduction in low cloud fraction compared to REF is fairly distinct in the 1COL simulation, it is much smaller for the CLDS simulation. In terms of global means, the difference to REF was -0.013 for 1COL but only -0.001 for SPEC. Similarly, for example, the global mean difference in shortwave CRE at the TOA between 1COL and REF was 1.56 W m^{-2}, while that between CLDS and REF was 0.20 W m^{-2}.

Zonal mean temperature differences between CLDS and REF (see Fig. 2) are very small and mostly statistically insignificant. The 1COL$-$REF differences are, as expected, somewhat larger, with most notable differences at high northern latitudes and

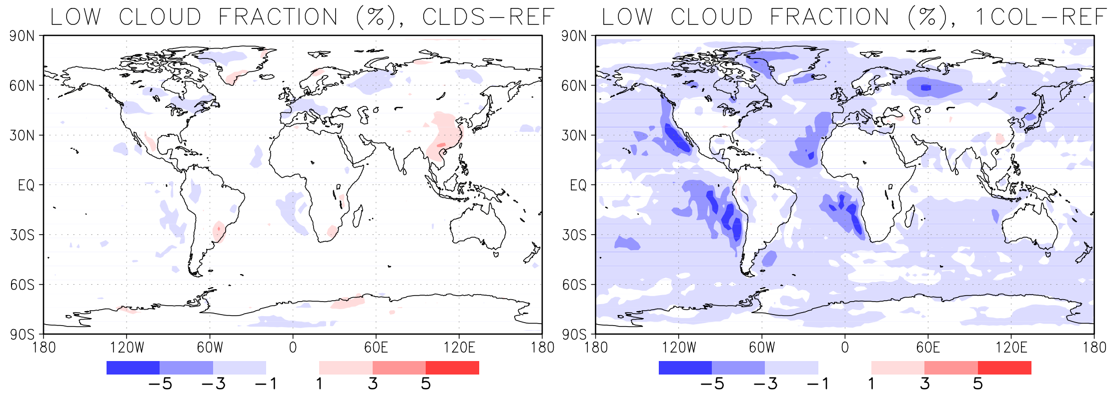

Figure 1: Differences in low cloud fraction (in percentage) between (a) the CLDS and REF simulations and (b) the 1COL and REF simulations. The 1COL−REF differences are statistically significant at the 99% level over most ocean areas.

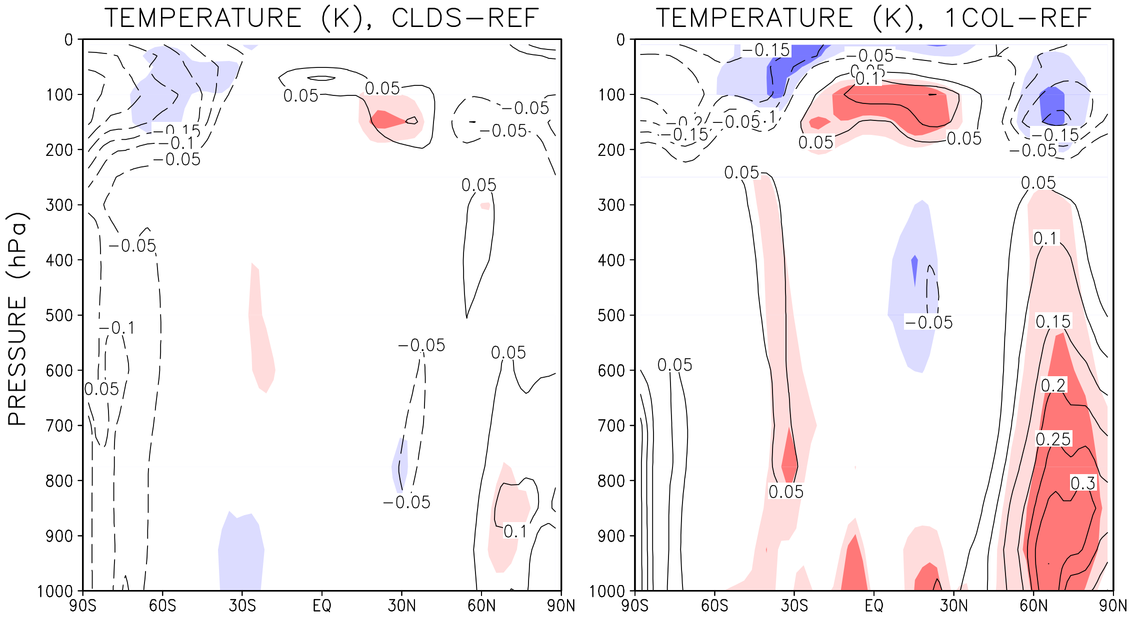

Figure 2: Zonal mean temperature differences between (a) the CLDS and REF simulations and (b) the 1COL and REF simulations. Light (dark) shading indicates differences that are statistically significant at the 10% (1%) level.

in the stratosphere.

In summary, while McICA noise has some effects on the climate simulated by ECHAM5, these effects can be kept very small by a reasonable implementation of McICA (e.g., the CLDS approach). Thus, McICA appears to be a viable method for use in ECHAM5.

2.2 Evaluation of cloud variability for ECHAM5's cloud scheme

A unique feature of ECHAM5 is that it carries prognostic variables for the probability distribution function (PDF) of total water (water vapour + cloud condensate) within each GCM grid cell. A beta distribution is assumed (Tompkings 2002):

$$P(q_t) = \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} \frac{(q_t-a)^{\alpha-1}(b-q_t)^{\beta-1}}{(b-a)^{\alpha+\beta-1}}, \tag{1}$$

where q_t is the mass fraction of total water and Γ is the gamma functon. In standard ECHAM5, this approach is only used to determine cloud fraction, but it can also be utilized to derive the PDF of cloud condensate amount needed by the cloud generator (Fig. 3).

Preliminary comparisons with ISCCP satellite data and with cloud-system resolving model (CSRM) data suggest that ECHAM5 clouds derived from the beta distribution of total water are, on average, somewhat too homogenous. As an example, Fig. 4 displays the relative standard deviation of cloud condensate amount for ECHAM5 and for the global 2D CSRM data set considered by Räisänen et al. (2004).

3 Future plans

It is expected that within 2006, runs with a coupled atmosphere-ocean GCM (ECHAM5 atmospheric GCM combined with the MPI-OM ocean GCM) will be initiated. The initial focus of these tests will be the impact of McICA noise, which has never before been tested in a coupled GCM environment. Comparisons to the standard (non-McICA) version of the model will also be performed.

4 Note on use of computer resources

The simulations discussed in this report have been performed using computer resources available at the Finnish Meteorological Institute. Thus, ECMWF resources have not

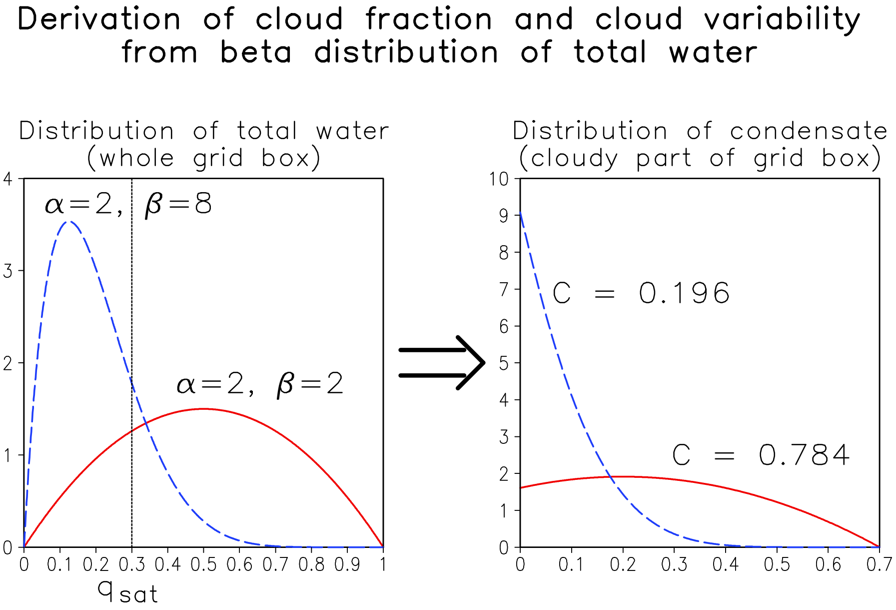

Figure 3: The cloud fraction C and the PDF of condensate amount q_c can be derived from the PDF of total water q_t, subject to the assumption that the saturation specific humidity q_{sat} is constant within the grid box. Those points with $q_t < q_{\text{sat}}$ are cloudy and have condensate amount $q_c = q_t - q_{\text{sat}}$. In this schematic example, $a = 0$, $b = 1$, and $q_{\text{sat}} = 0.3$.

yet been used. However, when experiments with a coupled GCM are initiated, our need for computer resources will likely increase substantially, making the availability of the ECMWF resources critical for the project.

References

[1] Barker, H. W., and 31 co-authors, 2003: Assessing 1D atmospheric solar radiative transfer models: Interpretation and handling of unresolved clouds. *J. Climate*, **16**, 2676–2699.

[2] Pincus, R., H. W. Barker, and J.-J. Morcrette, 2003: A fast, flexible, approximate technique of computing radiative transfer for inhomogeneous clouds. *J. Geophys. Res.*, **108**, 4376, doi:10.1029/2002JD003322.

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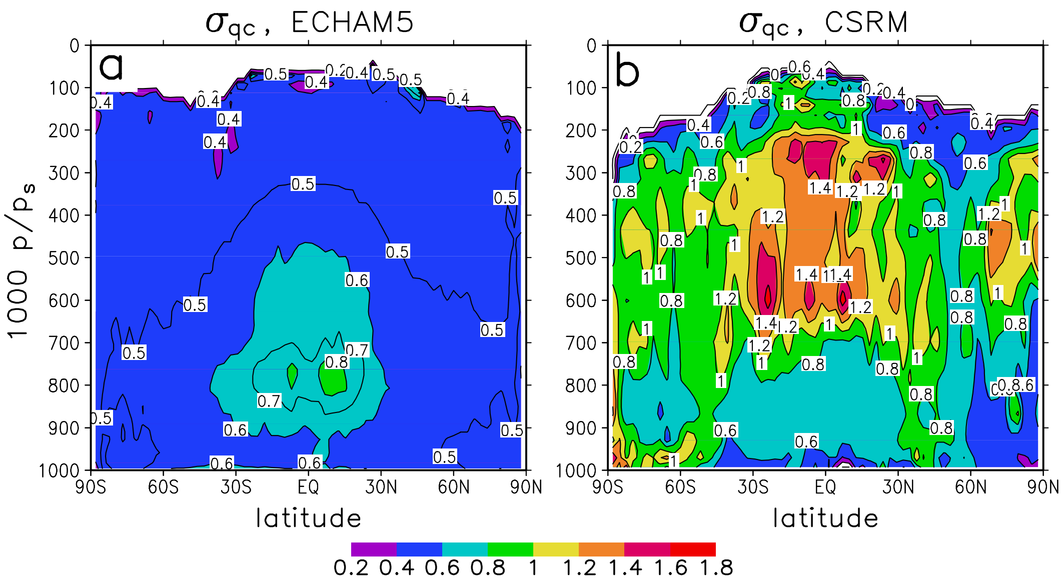

Figure 4: Zonal-average relative standard deviation of cloud condensate amount σ_{q_c} (i.e., standard deviation divided by mean, for the cloudy part only) for (a) the ECHAM5 dataset and (b) the global 2D CSRM dataset used by Räisänen et al. (2004).

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