



Improving cloud modelling in climate simulations: the stochastic approach in a coupled atmospheric-ocean model

Damien Lecarpentier

Using DEISA resources within the DECI framework, the SSSC (Stochastic Subgrid-Scale Clouds) project, directed by Heikki Järvinen and Petri Räisänen, researchers at the Climate and Global Change research unit of the Finnish Meteorological Institute (FMI), experimented with a new approach to cloud modelling which enables a better representation of the crucial interaction process between clouds and radiation in climate models.

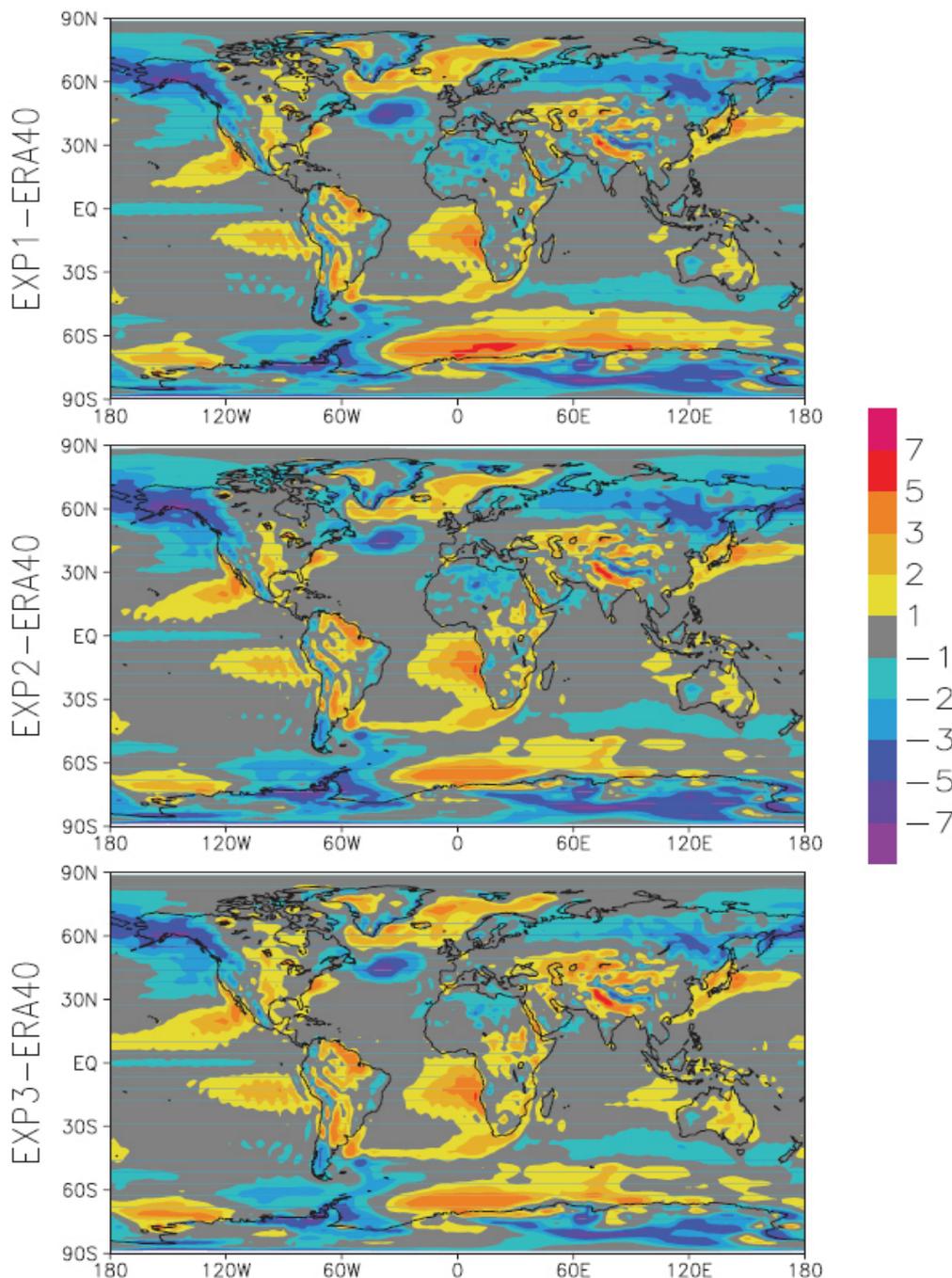
Climate modelling has become a crucial tool for research on climate and global change. However, many important processes that occur in the atmosphere, such as the interaction of clouds with the radiation emitted by the Earth-atmosphere system, are still unresolved by current computer-driven models.

“Atmospheric General Circulation Models (GCMs) – which model the atmosphere – are the basic modelling tools used in climate research and climate simulation”, Järvinen explains. “However, the representation of clouds and their interaction with radiation remains a major issue, due to the coarse spatial resolution of this particular model: a grid cell typically covers an area of 200 km by 200 km in the horizontal. This implies that many cloud features important for radiation cannot be explicitly resolved. These interaction processes are essential to the Earth’s radiation budget which, in turn, largely determines the Earth’s climate. Correct representation of clouds in climate models is thus a research question of great importance. One could even say that a biased cloud scheme can ruin a climate simulation resulting from an otherwise accurate climate model”.

Stochastic cloud modelling in a coupled climate model

“In climate models, clouds are usually computed using grid box average quantities, such as grid box mean temperature and humidity. In

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Comparison of simulated time-mean near-surface air temperature (in Kelvin) to the ERA40 reanalysis data produced by the European Centre for Medium Range Weather Forecasts. EXP1 = standard version of the ECHAM5-MPIOM coupled model. EXP2 = Tompkins cloud scheme included. EXP3 = Tompkins cloud scheme included and subgrid-scale cloud information utilized in radiation calculations through the stochastic cloud generator and Monte Carlo Independent Column Approximation.

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our study, cloud formation is described as a stochastic process. It mimics the chain of events as they occur in nature but is inherently random. The need to preserve the grid-box mean quantities, however, represents a powerful constraint on the process”.

“Our study is based on several recent developments – from our own work, and that of other scientists – that enable us to address cloud subgrid-scale variability in climate models. The *Tompkins* cloud scheme (a statistical cloud scheme developed by Adrian *Tompkins* for data assimilation) allows us, for example, to derive the magnitude of subgrid-scale variations in cloud water amount in a physically consistent fashion. The *Monte Carlo Independent Column Approximation (McICA)* (a recently developed method for computing domain-average radiative fluxes) and the stochastic cloud generator enable a flexible description of subgrid-scale cloud structure in GCM radiation calculations.”

“This model setup would have been impossible for us, using the resources available to us at our Institute in Finland alone, to conduct this experiment to the extent made possible by the DEISA resources.”

“The *SSSC* project represents the first test of these approaches in long integrations within a coupled atmosphere-ocean GCM”, *Järvinen* points out.

“The first tests with the stochastic subgrid-scale cloud modelling have been successful. In these tests, the atmospheric GCM used the observed sea surface temperature and sea-ice cover, which implies a forcing of the atmospheric simulation towards the observed evolution of the climate. In the *SSSC* project, the atmospheric GCM was coupled with an oceanic GCM and these were run in a coupled mode. In this case, there is no forcing towards the observed climate evolution, excepting perhaps the observed atmospheric CO₂ concentration. A coupled atmosphere-ocean GCM was particularly required for our study, in order to avoid use of fixed sea surface temperature of an atmosphere-only GCM, which would have limited the validity of the simulations”.

“In a nutshell, our study aimed at exploring the use of an advanced treatment of subgrid-scale cloud radiation effects in climate models, by using a coupled atmospheric-ocean

model. Its scientific objectives were twofold: first, to test and demonstrate the viability of the stochastic approach for the sub-grid-scale cloud and radiative transfer parametrizations; and second, to use this approach to improve the representation of cloud-radiation interaction in GCMs.”

Computational resources

In order to carry out this study, a large amount of computational resources was required. Experiments were conducted in 2008 on the *NEC-SX-8* at the High Performance Computing Center (*HLRS*) in Stuttgart, Germany, where the Finnish team coupled the general atmospheric circulation model *ECHAM5* to the general ocean circulation model *MPIOM*, two models that were developed by the *Max-Planck-Institute for Meteorology (MPI-M)* in Hamburg, Germany.

“*ECHAM5* allows us to represent the atmosphere at horizontal resolution *T63* (roughly 200 km resolution in grid point space) with 31 layers in the vertical, while the *MPIOM* ocean model has a nominal resolution of 1.5 degrees, with 40 layers. Model hydrodynamic equations were integrated forward in time with time steps of 12 min for *ECHAM5* and 72 min for *MPIOM*. *ECHAM5* and *MPIOM* were coupled on a daily basis via a specific coupler module (*OASIS3*)”, explains *Järvinen*.

“This model setup is very time-consuming for any computer and, in practice, it would have been impossible for us, using the resources available to us at our Institute in Finland alone, to conduct this experiment to the extent made possible by the *DEISA* quota”, *Järvinen* acknowledges.

“Three 240-year long experiments were carried out with three specific model configurations. The first experiment involved the standard version of the *ECHAM5-MPIOM* coupled atmosphere-ocean GCM; the second used a version employing the *Tompkins* cloud scheme; and the third a version employing the *Tompkins* cloud scheme together with *McICA* radiation calculations and the stochastic cloud generator”.

“On the *NEC-SX-8* processors, each run took between 3 and 4 hours per simulated year. Unexpected problems regarding the parallelization of the coupled model across several 8-processor nodes precluded the use of a larger number of processors, but the experiments were completed successfully nevertheless”, says *Järvinen*.

Unexpected results

The results, however, proved to be quite unanticipated for the research team: “Perhaps surprisingly, the modifications tested here had overall a relatively small effect on simulated climate. Given that this new cloud modelling method represented quite a significant change compared to the standard model, we had anticipated that it would have a larger impact. Nothing major was detected, however, and this was rather unexpected” (see Figure 1).

These unexpected results did not, however, mean that the experiment was worthless; quite to the contrary: “While this might seem like an unexciting result, it is actually an important indicator of the feasibility of the proposed stochastic approach in state-of-the-art climate models”, *Järvinen* points out. “It shows, in particular, that the new cloud modelling method can be safely included into the coupled climate models, and that its benefits can begin to be exploited. The new approach improves substantially the internal physical consistency of the model, and allows also us to produce a stable model climate. It is therefore a viable option for application in multi-century climate simulations”.

“We are now equipped with convincing evidence of the applicability of our approach within GCM implementations. Hopefully this work will contribute towards improving the models that will be used in the 5th assessment report of the Intergovernmental Panel on Climate Change (*IPCC*)”.



Fig. 2. *SSSC* project director Heikki *Järvinen*

Call for Expressions of Interest: DEISA Virtual Community Support Initiative

Within the current FP7 DEISA2 project, the well-known DEISA Extreme Computing Initiative (DECI) for single project support is complemented with starting the support for Virtual Communities, in particular organised scientific communities and suitable EU FP7 projects from computational science.

This extended initiative of DEISA2 will benefit from and build on the experiences of the scientific Joint Research Activities of DEISA1 (FP6) where selected computing needs of various scientific communities and a pilot industry partner were addressed.

Now DEISA has started a call for expressions of interest from Virtual Communi-

ties from all science areas for collaborative actions and support through the new DEISA Virtual Community Support Initiative in 2009 (see www.deisa.eu/communities/call) Communities and projects can benefit from access to some of the most powerful computing facilities in Europe and HPC consulting from experts based at the participating national HPC centres.

Science communities / EU FP7 projects with HPC needs from the following science areas are especially encouraged to contact us: Climate/Earth System Research, Astrophysics/Cosmology, Life Sciences, and Materials Sciences. Support for the European Fusion Community and an EU Life Science project has already started.

Communities with pan-European HPC needs who are interested in establishing a collaboration with DEISA and asking for support through the DEISA infrastructure and its services, are invited to send an "Expression of Interest". The template is available for download from the DEISA web page.

In case of questions, please contact Hermann Lederer (RZG, Germany) from DEISA External Relations: lederer@rzg.mpg.de

DEISA Extreme Computing Initiative Awards 2009

Forty two scientific projects have recently been awarded supercomputing resources through DEISA, the EU's unique infrastructure of supercomputing systems. The awards, totalling more than 49 million processor hours, collectively comprise the largest amount of supercomputing resources ever allocated at a pan-European project call.

These DEISA Extreme Computing (DECI) projects will each have access to resources at one or more of the 11 DEISA partner sites, including 12 of the Top 100 most powerful supercomputers in the world. Through DECI, now in its fourth year, scientists are tackling a wide range of scientific challenges. Successful projects are chosen for their potential to achieve ground-breaking scientific results through the use of supercomputers, enabling them to run more detailed and accurate simulations of scientific problems than was previously possible. Multi-national proposals are especially encouraged and the latest projects to be supported include col-

laborations involving scientists from three continents, although the vast majority of the participants are based in Europe. Staff from DEISA will work closely with the researchers, providing applications support to enable and deploy the codes on the most appropriate architecture.

Alison Kennedy, Coordinator of DECI said, "DEISA is delighted to be able to provide compute resources and applications enabling assistance to such a wide range of researchers in so many innovative projects. It's very exciting to see the impact that DECI has in advancing scientific knowledge and competitiveness in Europe."

Professor Gernot Muenster, the Principal Investigator of the Nf1 DECI project to study fundamental issues in quantum field theory said, "In order to attain the goals of our project and to arrive at conclusive results, we need computational resources which exceed our previous approvals. Thanks to DEISA, we will be able to perform simulations in suffi-

ciently large lattice volumes and sufficiently small lattice spacings to obtain relevant results. Also, the support of our calculations by DEISA staff members, concerning implementation and optimization of our program codes, is of very high value for our project."

Professor Simon Portegies Zwart, the Principal Investigator of the Gravitational Billion Body Problem (GBBP) DECI project related to cosmological studies on Cold Dark Matter said, "Thanks to the available compute resources and the excellent network facilities of DEISA we can now make a breakthrough in computational science, especially in our understanding of the dark matter distribution in the Universe".

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DEISA at SC08 in Austin, November 15-21, 2008

GENIUS and DEISA at SC08

Stefan Zasada, Steven Manos, UCL

Cardiovascular disease is the cause of a large number of deaths in the developed world. Cerebral blood flow behavior plays a crucial role in the understanding, diagnosis and treatment of the disease; problems are often due to anomalous blood flow behavior in the neighborhood of bifurcations and aneurysms within the brain. The GENIUS project, a finalist in the Analytics Challenge at the recent Super Computing 2008 (SC08) conference, is concerned with performing neurovascular blood flow simulations in support of clinical neurosurgery. Simulation offers the possibility of performing patient-specific, virtual experiments to study the effects of courses of treatment with no danger.

GENIUS uses a bespoke lattice-Boltzmann code, HemeLB, designed to simulate fluid flow in the sparse topologies of the brain. Models derived from patient-specific brain x-ray angiography scans are used as input to the simulator. Real time visualisation and computational steering allow clinicians to interact with simulations as they run, investigating the possible effects of various surgical investigations.

Simulating whole brain blood flow is a compute intensive task, and as such GENIUS project researchers make use of an advanced federated international grid infrastructure comprising resources from DEISA, the US TeraGrid and the UK NGS. To do this they exploit a standard job submission interface, based on OGSA BES, coupled with their own Application Hosting Environment middleware tool, to allow clinicians to seamlessly interact with some of the worlds biggest supercomputers from their operating theatre, and to steer simulations in real-time.

Demonstrations of interactive real-time blood flow simulations were shown at SC'08 in Austin on several stands on the show floor over 3 days. This included a detailed presentation at the booth of DEISA partner FZJ, where the Application Hosting Environment was used to simultaneously launch HemeLB across the TeraGrid NCSA cluster the DEISA IBM Power6 machine at RZG and the DEISA IBM BlueGene/P machine at FZJ, demonstrating interoperation between these HPC infrastructures from a common interface for the first time.

GIN and DEISA at SC08

Morris Riedel, FZJ

Annually, the Grid Interoperation Now (GIN) group (<http://forge.ogf.org/sf/projects/gin>) of the Open Grid Forum (OGF) demonstrates achievements in Grid technology interoperability and interoperation of infrastructures at Supercomputing conferences with a particular focus on use case applications that require resources in more than one infrastructure.

At SC08, members of GIN have shown numerous demonstrations such as the interoperation of different storage technologies using the Storage Resource Broker (SRB) and a wide variety of Storage Resource Manager (SRM) OGF standard implementations. Other demonstrations include the interoperability between NorduGrid technologies (i.e. A-REX) with technologies of DEISA (i.e. UNICORE) and EGEE (i.e. CREAM).

Members of DEISA actively steered (co-chair position) and contributed to the success of these demonstrations. Most notably, DEISA was involved in two GIN pre-production demonstrations in the research field of e-Health. While the first leads to faster drug discovery jointly using EGEE and DEISA, the second is about neurosurgical imaging using large-scale simulations across resources from DEISA, TeraGrid in the US and the National Grid Service (NGS) in the UK.

UNICORE 6 and DEISA at SC08

Achim Streit, FZJ

The latest version of the UNICORE Grid Technology used in the DEISA infrastructure, was successfully presented and demonstrated at SC08. It is planned to replace UNICORE 5, which is currently in production in the DEISA infrastructure, in mid 2009. Indeed, pre-production tests are in their final phase. Some application Use Cases, that employ UNICORE 6 within DEISA, were successfully demonstrated at SC08.

Major improvements over UNICORE 5 include: use of standards (OGSA, WS-RF 1.2) enabling interoperability of DEISA with other Grid infrastructures for the users' benefit, security enhancement for optional proxy and Virtual Organisation support, and additional clients (command line tool, API). At the same time UNICORE 6 preserves UNICORE's key features, such as workflow support and application integration, as well as support for commonly used operating and batch systems.

A further benefit for DEISA and its users is the close link to the UNICORE core developers at the Jülich Supercomputing Centre (JSC), which enables short response times to feature requests.

European HPC Infrastructure and DEISA at SC08

Hermann Lederer, RZG

DEISA was invited to give talks about the European HPC Infrastructure at SC08.

At the booth of JSC at FZJ, Andreas Schott (RZG) was giving a talk on "DEISA – Towards a European HPC Infrastructure", after a presentation about PRACE by Thomas Eickermann (FZJ).

On the booth of the Oak Ridge National Laboratory (ORNL), Hermann Lederer (RZG) gave a featured presentation on "DEISA and

the European HPC Ecosystem". ORNL, a DOE leadership compute facility, had just installed the second PetaFlop/s system worldwide, and the first system of this kind for open scientific research, on which the Gordon Bell Prize 2008 on application performance was achieved. With the inclusion of the new NSF system at the University of Tennessee, ORNL was proud to report an accumulated peak performance of 2.5 PetaFlop/s.



DEISA at ICT2008 in Lyon

Hermann Lederer, RZG

Europe's most important biennial event on Information and Communication Technology (ICT) took place in Lyon from Nov 25 to Nov 27.

DEISA was represented with an Information Stand in the "ICT Connect" exhibition village (booth J18). Five experts from the various technical fields (applications, networks, operation, technology) and the DEISA dissemination team from three DEISA sites (CSC/Finland, FZJ/Germany and RZG/Germany) were demonstrating the benefits of a unified European Supercomputing Infrastructure with video material on the DEISA infrastructure and supercomputer simulation results from different scientific fields including cosmology and supernova research, fusion energy research, and life sciences.

In addition, the complex integration of the various services was explained in talks about the DEISA dedicated 10 Gbit/s network, the technological configuration, as well as grand challenge applications. There was a huge interest in the DEISA book "Advancing Science in Europe" and the brochure "DEISA Digest 2008". About 200 printed publications were distributed in addition to electronic copies on memory sticks. Not only international visitors with scientific background in supercomputing were interested in details, but also visitors active in politics such as mayors from various European countries.



Fig. 3. Ralph Niederberger FZJ, Heli Autere, CSC and Hermann Lederer, RZG at DEISA booth at ICT2008 Conference in Lyon

Next DEISA events:

Two DEISA Training courses

13-14 January, 2009
FZJ, Jülich, Germany

DEISA Symposium and joint DEISA-PRACE scientific workshop

11-13 May, 2009
Amsterdam, The Netherlands

www.deisa.eu/news_press/