CERFACS: Scientific Report

"Climate Modelling & Global Change" Project

1992 - 1993

October 25$^{\text{th}}$ 1993

1 INTRODUCTION (Olivier Thual)

An important event has attracted the focus and interest of the French climate community during this past year: *the first significant coupled simulations of French oceanic and atmospheric GCMs* (General Circulation Models) focusing on the Tropical Pacific Ocean, where El Niño and the Southern Oscillation take place. This good news is now starting to diffuse in the European and international climate community, which had already reached this stage several years ago.

The "Climate Modelling & Global Change" project has played a key role in this achievement, after two years of intensive efforts concentrated on this goal. More importantly, the creation of this young ocean-atmosphere coupling project at CERFACS has catalyzed the expected collaboration between the well settled laboratories responsible for the oceanic and atmospheric components of the coupled model: the LODYC (Laboratoire d'Océanographie DYnamique et de Climatologie), the CNRM (Centre National de la Recherche Météorologique) and the LMD (Laboratoire de Météorologie Dynamique).

Of course, extra efforts are still necessary to complete the spin-up phase of the project, and numerous obstacles remain to be overcome. We need to carefully analyze the 10 year ocean-atmosphere coupled run of the Tropical Pacific Ocean that we have recently completed. The post-processing of the huge amount of data generated by these experiments is an important task. For the global ocean coupling, the first year of simulation is about to be launched. But several steps are necessary before we can defend a prediction of the global warming of the next century, with a state-of-the art climate model.

Based on these actual and potential achievements, the Global Change CERFACS project is now recognized as a real player in the French climate community, which itself can now join the table of the "coupling models countries".

1.1 Participants to the project

There are presently eight participants to the Climate Modelling & Global Change project, including one project leader (Olivier Thual), one senior (Laurent Terray), one post-doc (Véronique Taverne) and four Ph.D. students (Laurence Fleury, Gilles Garric, Sophie Belamari —ex Pelletier— and Marc Pontaud). The first three positions are funded by CERFACS, while two Ph.D. students are funded by MRT (French Research Ministry) and two by Météo-France. We welcome one visitor (Stéphane Godet-Thobie) from GRGS, also former participant of the Parallel Algorithms project. We have also welcomed one training student (Dan Davidson) from the "Informatic Department" of the Toulouse IUT (Institut Universitaire de Technologie), during four months. Three persons have quitted the project during this past year (Norman Barth, Baosuo Wu and S. Dhivakar), so that the number of participants to the project has stayed constant compared to last year (Figure 1).

PUT FIGURE 1 HERE
PUT FIGURE 2 AFTER THE NEXT PAGE

List of the participants of the Global Change project

Name	Position	Period
O. Thual	Project leader	1991/09 — Present
L. Terray	Senior	1990/10 — Present
V. Taverne	Post-doc	1993/03 — Present
L. Fleury	Ph.D. student	1992/10 — Present
G. Garric	Ph.D. student	1992/10 — Present
S. Belamari	DEA student (IT)	1992/10 — 1993/06
	Ph.D student (IT)	1993/07 — Present
M. Pontaud	DEA student (IM)	1993/01 — 1993/06
	Ph.D. student (IM)	1993/07 — Present
S. Godet-Thobie	Post-doc visitor	1993/03 — Present

From the actual repartition between experienced scientists and students, one can notice a strong imbalance, due to the lost, this year, of one senior position. Our principal goal now is to fill this position, either by recruiting an experienced scientist well trained in the subject, or by promoting a post-doc whose involvement in the project justifies it. We also strongly need a research engineer to help us to handle the huge amount of data generated by our coupled experiments.

1.2 Project management

A project involved in the research field of general circulation modelling needs to rely on a real team work. Each participant depends strongly on the work of the other members of the group. One of the leaders of the early generation of the general circulation models, Smagorinsky (1969) stated:

> ...a scientist entering this field must have a capacity for deep involvement and a temperament of unrelenting commitment; also he must have or develop a multi-disciplinary consciousness and an ability to function as a member of a team. In return, his institution must fulfill his human need for individual recognition. Although such demands are relatively new in meteorology, other fields, such as space exploration, have evidently learned to cope on a far larger scale.
>
> When one is in the midst of such long-term projects, months and even years can slip by without encountering a natural publication milestone. Yet in the prevailing environment of publish or perish, there is an impatience on the part of the scientist as well as the institution that supports him. ...

General circulation modelling needs to be undertaken in a stable institution which can fulfill its medium-term engagements. More fundamental projects are flexible and can survive in a fluctuating environment. Applied research, such as climate modelling, requires long term planning in human activity as well as in funding. Figure 2 shows the work plan which has been tuned through various proposals to the CERFACS structure and the climate community. This planning relies on a level of resources which is low compared to other groups in Europe and in the world, competing on the same subject. During the last two years, in a critical spin-up phase of the project, this level has not been reached, in spite of the numerous contracts that we have generated. But instead of revising our work planning to less ambitious goals, for instance more fundamental research, the CERFACS Direction and the Scientific Council have encouraged us to keep going in the original direction, anticipating a catching up in 1994.

This seems a reasonable strategy since the amount of resources needed to avoid the present slow-down of the project is in fact small. Moreover, the five year project that the CERFACS Direction has proposed for the renewal of the GIP, should avoid the errors that we have made so far because of the lack of medium term planning of the resources. The imbalance in the repartition between students and experienced scientists has been due to a bad anticipation of the CERFACS position evolution and fewer students should have been recruited. Now, a coherent evolution of the project composition has been settled in the CERFACS five year project. Two years ago, we have chosen an equipment policy in which each researcher would work on a cheap workstation instead of a network with a big server and X-terminals. This policy has been suspended half way, with a vanishing equipment budget for the present year. Until an homogeneous informatic equipment is reached, the two year efforts spent, so far, to build a coherent software environment, will remain unused. The catching up of this equipment delay is the first priority of the CERFACS five year plan.

The participation of at least one research engineer in projects dealing with general circulation models is a rule which has seldom been violated elsewhere. We have expressed this need since the beginning, but administrative reasons have delayed the realization of such a recruitment. In a coherent informatic network, the task of such a person would be first to implement the post-processing of the huge amount of data coming out of our first climate experiments, with an adequate set of softwares which still remain to be purchased. At last, a starting project like ours needs numerous interactions with other groups already experienced in the subject. This can only be done through participation to conferences, visits to other laboratories and welcoming of experienced visitors. In the same spirit, documentation is also a key point which needs to be reinforced. For instance, all the travels of the new coming students, planned to initiate their scientific subject with our collaborating laboratories, have been suspended during eight months, disturbing their settlement in the project. With the five year project of CERFACS, such difficulties will not be reproduced and we will start to be competitive in the international community.

1.3 Scientific achievements

The more visible achievements of the Climate Modelling & Global Change project this year are the numerical simulations performed by matching together the Tropical Pacific oceanic model OPA of LODYC (CNRS and Paris VI University), and the atmospheric climate model ARPEGE from CNRM (Météo-France):

1. A ten year integration of OPA forced by the fluxes of ARPEGE obtained in the framework of the intercomparison program AMIP (1979-1988), with the observation of two El Niño events (see Section 3.1).
2. A ten year integration of OPA and ARPEGE in coupled mode (see Section 3.2).

These simulations are based on the use of the Global Change coupler OASIS (see Section 2), which has been further improved during this last year. The message passing procedures, based on UNIX signals, have been upgraded to allow the parallelization of the atmospheric or oceanic codes, which are independent UNIX processes (see Section 2.1). In this new version, it is also possible to choose between several grid-to-grid interpolations depending on the particular type of coupling performed (see Section 2.2).

The achievements related to the coupling of ARPEGE with the global ocean version of OPA will be more visible when at least one year of simulation is reached. Deep involvement has been needed to set-up ingredients of this complex coupling. In collaboration with the LODYC, we have converged on a strategy in which the degrees of freedom of the oceanic model are released step by step (see Section 4.1 and 4.2).

In connection with the settlement of these heavy General Circulation Models experiments, we have maintained a theoretical approach based on simplified models. We have undertaken an exhaustive exploration of the literature dealing with the dynamics of El Niño and the Southern Oscillation, and found new analytical results on the instabilities which can explain this phenomena (see Section 3.3). The coexistence of this simplified approach with the interpretation of the Tropical Pacific coupled GCM's experiments has significantly enriched the dynamism of the whole project. The same synergy is expected between the theoretical studies of the thermohaline oceanic circulation when the first runs of the global oceanic model are performed. Indeed, the high latitude deep water formation of the ocean, driven by the atmospheric heat and fresh water, has been recognized as a key factor in global change climate experiments. We have pursued the study of simple 2D models which exhibit multiple stable equilibria of this circulation, and extended the analysis towards the coupling with simple atmosphere and sea ice models (see Section 4.3).

At last we have put some more bricks for the building of our "Experiment Manager". This word denotes all the software environment necessary to launch climate experiments and perform the post-processing of the huge amount of data that are generated. The implementation at CERFACS of OPA7, the oceanic model of LODYC, has been performed with the active help of the authors of this GCM (see Section 5.1). We have developed a set of procedures and programs for the post-processing of the surface fields which are used in the coupling, i.e. the atmospheric fluxes and the sea surface temperature (see Section 5.2). We have continued our study and exploration of visualization softwares for the post-processing of climatic data, and have used them in operational mode. We have also upgraded, for climate oriented applications, an existing software called Visuo and written in collaboration with ONERA-CERT (see Section 5.3).

In the framework of the Global Change project, Marc Pontaud and Sophie Belamari have defended their DEA (Diplômes d'Etudes Approfondies) at the Paul Sabatier University in Toulouse (UPS), and successfully achieved their research training period of the National Meteorological School (ENM).

1.4 Interactions with the climate community

One strong motivation for the creation of the Climate Modelling & Global project at CERFACS has been the need for an ocean-atmosphere climate model coupling two GCMs in the French climate community, when countries like the USA, Germany or the UK had already performed anthropogenic climate change experiments. Because of its European future and its competence in scientific computing, CERFACS has been chosen to host the working forces necessary to fill the gap of the climate community.

Our scientific goals are thus strongly linked to a joint effort gathering the CNRM (Centre National de la Recherche Météorologique), the LODYC (Laboratoire d'Océanographie DYnamique et de Climatologie) and the LMD (Laboratoire de Météorologie Dynamique). This common project is centered around climatic experiments with coupled GCMs. During the past two years, we have settled our position inside this joint project by reinforcing the interactions with our partners. This has been achieved through various meetings and scientific exchanges, as well as the participation to joint projects funded by various instances: Conseil Régional Midi-Pyrénées (CRMP), Commissions of the European Communities (CEC), Ministère de la Recherche et de la Technologie (MRT), Centre National de la Recherche Scientifique (CNRS) and others. Our project has been included in the scope of interest of the GIP MEDIAS (Regional Research Network for the Mediterranean Basin and Subtropical Africa) to which CERFACS participates as a partner. We have also started to extend our insertion in the climate community towards European centers like the Max Planck Institute in Hamburg or the Hadely Center in Braknell. We have also developed significant connections with NCAR and UCLA in the US.

Today, CERFACS is recognized by the various partners, as a key point in the design of the community climate model. This settlement work has required an exceptional and additional cost of energy during the past two years, due to the starting stage of the project. The following years will benefit from this organizational investment and the priority will be put on scientific achievements in collaboration with our partners.

1.5 Settlement in the CERFACS structure

Its integration in the climate community being successful, the Global Change project has been able to concentrate more deeply on its settlement in the CERFACS structure. Like for the previous year, this action has coincided with fluctuations in the organization of this structure. Indeed, the original plans mapping the personnel expansion of the project and the project resources (equipments, travel and other expenses) have been modified, leading to perturbations in the scientific plan of the project. Nevertheless, we have been able to reinforce our interactions with the other CERFACS projects.

At first, we have tried to build common projects with the *Visualization & Post-processing* project in CERFACS. The treatment of climatic data with advanced visualization and post-processing concepts is indeed a growing activity all around the world, and CERFACS has chosen to play a role in this subject. However, the investments needed by the ambitious goals of the Visu project will take time to converge and, so far, we have supported our own visualization needs on our own resources. We are confident that it will be possible in the future to follow the recommendations of the Scientific Council for a tight collaboration between the Global Change and the Visu project.

The collaboration with the *Parallel Algorithm* project is now entering a new phase with the initiation of the GPMIMD2 project, in which four meteorological centers will port their codes on the Meiko CS-2. This project will motivate in CERFACS the structuring of a group specialized in the adaptation of large codes on parallel machines and we are willing to participate to this effort. There are, indeed, a strong motivation for ocean and atmosphere GCMs porting on these machines, and an urgent need of expertise for this work. We want to be actively involved in this process and contribute to improve CERFACS excellence in this domain. We also follow the coordination of Météo-France and the European Center for Medium range Weather Forecasts (ECMWF) which has already started to work on these topics.

Another collaboration with the *Parallel Algorithm* project has taken place, and has to do with coupling techniques. In the previous CERFACS scientific report, we had detailed how two couplers had been developed in the framework of the Global Change project. One of them, developed by N. Barth in collaboration with the *Parallel Algorithm* project, is based on PVM. This message passing software is a powerful tool used for the parallelization of codes on MIMD machines or clusters of workstations. It has been applied to the coupling between the atmospheric model of the LMD and the oceanic model OPA. Because it relies on PVM, this coupler is particularly suitable for a generalization to applications wider than climate modelling. It has been decided that this generalization would be undertaken in the framework of the Algo project, which competences are particularly appropriated for this topic. The Global Change project is still using the other coupler OASIS which we only have implemented in the OPA/ARPEGE coupling. For manpower reasons it has not been possible to mix the two prototype couplers into a single version, as originally planned, and the priority has been put on the performance of the climate simulations. But in the future, we plan to pursue our collaboration with the Algo project and benefit from the coupling techniques improvements that will be generated.

The modelling of the atmosphere and oceanic models share a lot of common problems with the ones that the *Computational Fluid Dynamics* deals with. These problems range from the numerical methods used to integrate the Navier-Stokes equations, to the parametrizations of the turbulent processes which are crucial in the design of climate models. In addition, the CFD project is willing to use the coupling techniques that we have developed for combustion problems in which the dynamics must be coupled to the chemistry. In collaboration with the Algo project, we will do our best to share our experience in this domain.

We have benefited from the help of the *Computer Support Group* of CERFACS. For instance, this group supported us in providing us various kind of CERFACS unused terminals for the newcomers of the project, which has ended several weeks of severe shortage. The general software cleaning of the network, e.g. the generalization of `automount`, has been welcomed with a great relief by all. We are confident that the impetus of the GP-MIMD2 project will help the CSG to continue in this good direction.

These last two spin-up years have coincided with a repeated evaluation of the CERFACS projects by the CERFACS *Administration*. Five, three and one year project proposals have been submitted, and presented several times to the Scientific Council. These submissions, the management of four scientific contracts or other items such as the diffusion of the project publications have generated a huge amount of administrative work. We are confident that the request of the project leaders for specific access to secretariat services will be eventually fulfilled. In this expectation, the actual secretary task force have done their best to take in charge the most urgent needs.

1.6 Internal organization of the project

About ten scientific articles have been written in the internal journal of the Global Change project, also called "Epicoa" (Exchange of Projects and Ideas for Coupling Ocean and Atmosphere). The second year of existence of this journal has been concretized by the edition of Volume II. This is also the case of the other journal called LogBook (Climate Modelling & Global Change Team LogBook) which records the important administrative events concerning the project (budget, equipments, work plans, etc...). The list of diffusion of the Global Change project has been registered by the library, and the delay in the sending of the project publications is being repaired.

The weekly meetings of the Global Change project, also called Astm (Administration and science team meetings), have contributed to the good communication between the participants of the project. In these meetings, discussions about project planning are followed by an unformal presentation on selected scientific topics by one participant of the project or an invited speaker. These presentations have generated productive scientific debates.

The "Climate Modelling & Global Change Internal News System" (GlobNews), which is a simple but convenient system of E-mail internal news, has enabled a fast communication of a broad variety of topics (miscellaneous events, new release of the project softwares, etc...). Due to the lack of availability in secretary work power during this past year, this system has decreased a little the important time spent to purely administrative tasks.

The "Climate Modelling & Global Change Numerical Laboratory" (NumLab) gathers all the softwares developed by the participants of the project, in a format that can be used or upgraded by everyone. The organization and efficiency of this NumLab would greatly benefit from the presence of one research engineer in the project. Until such a position is filled, every participant spends a significant part of his research time to enrich this numerical laboratory.

After two years of structuring, the internal organization of the project is now solidly settled (Epicoa, LogBook, Astm, GlobNews, NumLab) and contributes to facilitate the interactions between all the participants. The existence of scientific interactions assumes individual attitudes oriented towards mutual enrichments and collaborations. As stated by Smagorinsky (1969) "the ability to function as a member of a team" is essential in the research field of general circulation modelling.

2 THE OASIS COUPLER

In order to realistically simulate many features of global climate, variability, and climate change, the major components of the Earth climate system (atmosphere, ocean, sea-ice and cryosphere) have to be dynamically coupled together. Some inherent unstable coupled modes in the climate system such as some features associated with the El Niño-Southern Oscillation result directly from the interactive coupling of the atmosphere and the ocean. Recent advances in computing power and climate modelling techniques in the past few years have allowed coupled ocean-atmosphere General Circulation Models (GCM) to be run synchronously (i.e ocean and atmosphere communicate at least once a day). In order to ease the realization of these simulations, there is a strong need for a general and flexible interface to be developed between atmospheric and oceanic models. Such an interface, let us call it coupler, can be used to interchange models easily or to test a hierarchy of coupled systems within the same framework. The OASIS coupler described in the next section is the first step towards this universal coupling module.

2.1 General architecture of the OASIS coupler (Laurent Terray)

OASIS ([1]) is a set of fortran routines which enables the coupling of oceanic and atmospheric models for instance General Circulation Models (GCM) or simpler ones. In the following we use GCM as a generic term for an ocean or an atmospheric model whether it is a real GCM or a simpler model. OASIS main concepts are the following:

- The three programs are considered as different processes in the UNIX sense and so synchronization is done using fortran extensions of few C-library routines dealing with processes. The GCM's and the coupler run concurrently in batch mode on a Cray computer.
- The coupler does ALL the coupling which is basically to provide boundary conditions for each model on its own grid when they are needed. The only job the models have to do is to put under a given format the data which need to be transfered to the coupler. Conversely they must be able to read the data they need (their own boundary conditions) coming from the coupler. Fortran units connected with files shared by the coupler and the two models are used to exchange (i.e read and write) data between the three programs. The common format can be either simple binary or a format specific to the GCM.
- The package is extremely modular, each routine has a well defined task separated from the rest of the code. For instance, there are in the actual version several interpolation packages (Lagrange, splines, nearest-neighbor...) and one can switch between these different methods by changing namelist parameters.

This framework has important implications:

- ANY atmospheric model can be coupled to ANY oceanic model via OASIS with very few changes in both models. In particular, it is possible to use a dataset as a passive atmospheric model to force different OGCM's for intercomparison purposes.
- Other interpolation packages can be used as long as they have a similar calling sequence.
- Models structure is entirely preserved (i.e multitasking options, I/O scheme...). There is no constraint on the computing aspect (i.e for instance on the number of CPU's devoted to each program)
- There is no " hidden variables"; everything is written in fortran following the DOCTOR norm([2]) from ECMWF and can be understood quickly by the user.

A complete description of OASIS can be found in ([1]). OASIS has been used extensively in forced or coupled simulations which have shown its robustness and flexibility ([3-4]).

References

[1] L. TERRAY , The OASIS Coupler User Guide Version 1.0, *CERFACS Technical Report* , **CERFACS TR/CMGC/93-33**, (1993).

[2] J.K.GIBSON, The Doctor System - A DOCumentary ORiented programming system, *ECMWF Technical Memorandum* **No. 52** , (1982)

[3] S. BELAMARI, Variabilité inter-annuelle simulée dans l'océan Pacifique tropical, *CERFACS Technical Report* , **CERFACS TR/CMGC /93-30** , (1993).

[4] L. TERRAY, O. THUAL, " Coupled Ocean-Atmosphere Simulations " in: High Performance Computing in the Geosciences, Proceedings of Les Houches Workshop June (1993), F.X. Le Dimet, Ed., Kluwer Academic Publishers B.V.

2.2 Grid-to-grid interpolation (Véronique Taverne, Olivier Thual and Laurent Terray)

The coupling of two GCM's (General Circulation Models) requires to examine the important question of temporal synchronization between the models and, as importantly, the way spatial information is exchanged between these models. This is easily understandable but becomes rapidly difficult to handle as soon as the numerical implementation is considered. Indeed, each GCM has its own grid definition and, in particular, a quite different resolution. This leads to different definitions of the land/sea borders (the "mask" problem) but also to the problem of going from one type of representation, on the "source" grid, to another type of representation, on the "target" grid, in a smooth way. Furthermore, it should be desirable that this transfer be done in a physically consistent way, in the sense that what we know about the physics of our system, such as energy flux conservation, should be verified when going from one grid to the other.

Designing an interpolation that would satisfy all these requirements is a difficult optimization problem. Before going into such complexity, simple interpolations have been considered with the goal of being able to perform coupled runs as soon as possible. A first interpolation, "the closest neighbours" interpolation, has been studied and detailed in 91-92 CERFACS Scientific Report. Let's just remind that, in this method, the physical quantities at each target point are weighted averages of the values at the d closest source points, the weights becoming small as the distance gets large. Although simple and cheap, in terms of number of operations, this method has the disadvantage of smoothing the fields.

Improvement of this method was necessary and has led us to develop what we call the "mesh interpolation". This interpolation remains simple and cheap, but achieves a more coherent weighted average, adapted to the local distance of the grid points. Each (target or source) point is now supposed to control a certain surface around itself. On a regular latitude-longitude grid, for instance, the borders of the control surface associated to a point will be determined by 4 values: the average latitudes or longitudes between that point and its direct neighbors. The neighbors that will be taken into account in the interpolation, are those whose associated surface has a non-zero intersection with the surface controlled by the target point and the weight is directly proportional to the value of that intersection. Given two grids, these neighbors and weights are fixed once and for all and need to be calculated only once at the beginning of the coupled simulation. It is easy to understand that this method will work fine in the case of the interpolation from a fine grid to a coarser grid, the other way around leading to too few neighboring points.

This "mesh" method is now being used in the "Pacific Ocean-Atmosphere" coupled simulations (see Section 3.2: "OPA/ARPEGE coupled simulations") in order to interpolate the values of the temperature at the sea surface (SST) from the fine oceanic grid to the coarser atmospheric grid. For the exchange of the various fluxes from the atmospheric grid to the oceanic grid, both bilinear and bicubic interpolations are used. Although well-known, let us note that these last interpolations are here generalized versions, which have been written by Y. Chartier et al. from RPN (Canada) and are adapted to meshes that are regular or not and periodic or not. The final goal of the project being the coupling of the LODYC global ocean GCM with METEO-FRANCE's atmospheric GCM (ARPEGE), such a generalization has to be applied to our "mesh interpolation" as well. Indeed, the general OPA grid does not have a regular latitude-longitude definition anymore and one has to take into account the deformation of that particular coordinate system with respect to the usual spherical coordinate system in order to compute the surface elements and their intersections properly. Furthermore, the ARPEGE version intended for the study of climate has a "reduced" grid definition, in the sense that as one approaches the poles, the number of longitudinal points decreases gradually in a non regular fashion. This reduction of the number of points is important since it can bring a gain of 30% in the total computation time but it has to be taken into account for the local surfaces calculation.

Besides the development of this "mesh" interpolation for the global coupling, we intend to study the behavior of various interpolations by coupling a simplified ocean model and a statistical atmosphere model. This project would also give us the opportunity to consider the coupler in a simpler frame and to realize a larger number of tests.

PUT FIGURE 3 HERE

PUT FIGURE 4 AND 5 AFTER THE TWO NEXT PAGES

PUT FIGURE 6 at PAGE 19

PUT FIGURE 7 at PAGE 22

PUT FIGURE 8 IN FRONT OF SECTION 5.2
PUT FIGURE 9 IN FRONT OF SECTION 5.3

3 PACIFIC OCEAN AND ATMOSPHERE COUPLING

We have coupled a fully nonlinear ocean general circulation model (OGCM) OPA of the Tropical Pacific Ocean to a global spectral model of the atmosphere (AGCM) ARPEGE, in order to study interannual climate variability. We have focused our study on El Niño and the Southern Oscillation. The oceanic model OPA, from the LODYC (Laboratoire d'Océanographie Dynamique et de Climat) and the atmospheric model, which is the climate version of forecasting model ARPEGE-IFS from Météo-France and ECMWF, are the components of the French Climate Community Model.

In a first stage, we have forced the oceanic model over a 10 year period (see Section 3.1) with the surface fluxes generated by the atmospheric model in the framework of the AMIP experiment using observed SST (Sea Surface Temperature) as boundary conditions. This experiment is used as control run for the coupled experiment that we have conducted over a 10 year period (see Section 3.2). In connection with these experiments, we have undertaken a theoretical study using simpler models (see Section 3.3), and achieved mutual enrichments between the two approaches.

3.1 Ocean forced by the AMIP fluxes of ARPEGE (Sophie Belamari and Laurent Terray)

Since September 1992, the CNRM (Centre National de Recherche Météorologique) disposes of ten years of surface fluxes data issued from the atmospheric model ARPEGE. These fluxes were calculated during an experiment performed by the MGEC group of the CNRM, in the framework of the AMIP project (Atmospheric Models Intercomparison Project) [1], using observed SST (Sea Surface Temperature) as boundary conditions. We use five surface fluxes (zonal and meridian components of the wind stress, fresh water flux, total heat flux and solar heat flux) to force the Tropical Pacific version of the oceanic model OPA for ten years. This work, which relies on a tight collaboration with M. Déqué from Météo-France and P. Delecluse from LODYC, strongly benefited from the work done by Ph. Dandin at LODYC [2]. One of their achievements is the forcing of the Tropical Pacific version of the OPA oceanic model with the AMIP fluxes of the previous version of the atmospheric model from Météo-France called EMERAUDE, for the period 1979/1986. We repeat this experiment with the ARPEGE fluxes and with the informatic structure of the coupler OASIS [3], for the full AMIP period (1979/1988) including two El Niño events (1982/1983 and 1986/1987), and also the cold event La Niña 1988, which was particularly intense. As in Ph. Dandin and P. Delecluse's work, a correction in the heat flux is applied: $Q = Q_{Arpege} + C(SST - SST_{ColaCac})$, where $SST_{ColaCac}$ is the temperature which has forced the ARPEGE AGCM in the AMIP experiment, and C a coefficient calculated from the derivation of the heat flux bulk formula with respect to the SST, and approximated by a constant (-40) over the tropical Pacific ocean domain. The numerous data provided by this decadal simulation have been analyzed to study the interannual tropical variability of the Pacific ocean, a low-frequency variability caused by complex interactions between the atmosphere and the ocean which is expressed in an irregular interannual fluctuation between warm El Niño and cold La Niña states.

This preliminary run provided very promising results: the simulated fields are in very good agreement with the available data, and the behaviour of the tropical Pacific ocean is correctly reproduced [4]. The comparison between the simulated SST averaged on the full period 1979/1988 and observed SST (Reynolds data) shows relatively small differences in the Pacific, except for the eastern part of the Pacific along the peruvian coasts where the simulated SST is too warm (Figure 3a). The seasonal cycle is also correctly reproduced as shown by the latitude/depth sections at 150° West (Figure 3b): the equatorial upwelling is minimal (cf depth of the iso-26°C) during the spring, and is maximal in fall. At last, this good behaviour of the oceanic model during the full period 1979/1988 is shown by Figure 3c, which represents the evolution of the SST anomaly versus time. This anomaly is averaged over different zones of the tropical Pacific called "boxes Niño 3 and 4", centered on the equator and representative of the thermal structure of the equatorial Pacific ocean.

This ten year simulation — a necessary step before the coupling with ARPEGE, and a first validation of the coupler OASIS into an operational mode —, constitutes now a reference run, which will be very much needed to understand and analyze coupled model results.

References

[1] J.F. MAHFOUF, L'expérience d'intercomparaison AMIP : simulation du climat 1979-1988 avec le modèle EMERAUDE, note **CNRM/GMGEC/UDC**, (1992).

[2] Ph. DANDIN, Variabilité Basse Fréquence Simulée dans l'Océan Pacifique Tropical, *PhD thesis University Paris VI* (1993).

[3] L. TERRAY , The OASIS Coupler User Guide Version 1.0, *CERFACS Technical Report*, **CERFACS TR/CMGC/93-33**, (1993).

[4] S. PELLETIER, Variabilité inter-annuelle simulée dans l'Océan Pacifique Tropical, *CERFACS Student Report*, **CERFACS STR/CMGC/93-30**, (1993).

3.2 OPA/ARPEGE coupled simulations (Laurent Terray, Sophie Belamari and Olivier Thual)

We have performed the first coupling experiments using the atmospheric general circulation model (AGCM) ARPEGE ([1]) from Météo-France and the oceanic general circulation model (OGCM) OPA ([2]) from LODYC-CNRS. The two models have been coupled without any correction using the OASIS coupler ([3]) developed at CERFACS. They interact only over the Pacific ocean in the region 40S-48N. The ocean model is forced by the surface wind stress, the heat fluxes (total and solar), and the fresh water flux simulated by the atmospheric model, which in turn is forced by the sea surface temperature (SST) simulated by the ocean model. Outside the coupling region, boundary conditions are prescribed from climatology. The deep ocean is relaxed towards the Levitus climatology. Information is exchanged between the two models every day (i.e, every 24 and 96 time steps respectively for the OGCM and the AGCM). The only external forcing is the seasonally varying solar radiation. The oceanic initial conditions are those simulated by a 10-year uncoupled simulation ([4]) of the Pacific ocean forced with ARPEGE fluxes coming from an AMIP simulation ([5]) of the ARPEGE model forced with observed SST's. The atmospheric conditions were taken from this same AMIP run. The initial date is july first 1985 and the simulation continued for two years in order to realize a prediction experiment about the 1987 El Niño event. First results show an initial warming in the ocean for the first two months; then the coupled model drifts in a warm state (in particular, eastern pacific warms up significantly) with little variability. The cold tongue is almost non existent along the equator in northern summer and the Inter Tropical Convergence Zone is south of the equator during southern summer. Detailed analysis is underway; yet two factors might be invoked to explain the observed behaviour of the coupled model. There is a large excess of incoming solar radiation in all subtropical high pressure regions and in particular in the south eastern pacific ([6]) (on the order of $100\mathrm{W}/m^2$). This extra insolation can increase stratification leading to heat accumulation in the upper layers of the ocean. This is a common flaw in most AGCM's due to a poor representation of low level stratus clouds. The second and probably related factor may be the low mixing in the upper 300 meters of the ocean.

Since then, we have modified our interpolation procedure and a new version of the AGCM is now available (main difference lies in the fact that the fluxes at the top of the atmosphere are now balanced in an annual mean sense). We have recently achieved a new simulation over a ten year period, in order to simulate the mean state, the seasonal cycle and to study potential interannual variability in our coupled system. The results of this simulation, which are very encouraging, are part of an intercomparison between several coupled models worldwide and was initiated during a recent workshop in Paris. This work is a close collaboration between CERFACS, CNRM (Météo-France) and LODYC (CNRS).

References

[1] P. COURTIER, C. FREYDIER, J. F. GELEYN, F. RABIER, M. ROCHAS, The ARPEGE project at METEO-FRANCE, *Note de Travail "ARPEGE"* **N^o 22** (1991).

[2] P. ANDRICH, P. DELECLUSE, C. LEVY, G. MADEC: "A multitasked general circulation model of the ocean" in: Science et Engineering on Cray Supercomputers, Proceedings of the fourth International Symposium, Minneapolis, Minnesota, USA, October 1988, A Cray Research Inc. book, 407-428.

[3] L. TERRAY, The OASIS Coupler User Guide Version 1.0, *CERFACS Technical Report* , **CERFACS TR/CMGC/93-33**, (1993).

[4] S. BELAMARI, Variabilité inter-annuelle simulée dans l'océan Pacifique tropical, *Rapport de stage de DEA* , **CERFACS STR/CMGC /93-30** , (1993).

[5] J.F. MAHFOUF," L'expérience d'intercomparaison AMIP: simulation du climat 1979-1988 avec le modèle EMERAUDE ", note **CNRM/GMGEC/UDC** , (1992).

[6] L. TERRAY, O. THUAL, " Coupled Ocean-Atmosphere Simulations " in: High Performance Computing in the Geosciences, Proceedings of Les Houches Workshop June (1993), F.X. Le Dimet, Ed., Kluwer Academic Publishers B.V.

3.3 Simplified models of the Tropical ocean-atmosphere dynamics (Marc Pontaud and Olivier Thual)

In the absence of exact solutions of the ocean-atmosphere system equations, the exact understanding of the climate and its evolution requires numerical calculations with General Circulation models which are the roots of the Global Change project foundation. In order to understand and isolate basic phenomena observed in these big numerical simulations, simplified models of ocean-atmosphere are developed. Simplified numerical and analytical calculations are based on models like the "Zebiak and Cane" model [1]. The ocean is represented by the evolution of the thermocline (shallow-water equations) and by the instantaneous adaptation of a thin surface layer driven by the wind stress. The evolution of the SST (Sea Surface Temperature) is an equation for a passive scalar advected by the surface current. This surface current comes from the contributions of the thermocline layer and from the thin surface layer. The atmospheric model represents crudely a slave first baroclinic mode and gives instantaneously a wind stress from the SST field.

In collaboration with the LODYC, we have run such a simplified model, and forced it with AMIP fluxes of the ARPEGE model. This study has opened the path to unexpensive coupled experiments where the atmospheric model is obtained from a statistical regression of long time series of surfaces fluxes provided by an atmospheric GCM (e.g. ARPEGE). These cheap coupled models are also perfect tools to test particular features of the coupler such as the grid-to-grid interpolations or the temporal synchronization.

This kind of simple coupled models is the raw material for analytical calculation. Asymptotic developments give an unstable coupled mode (the SST-mode) which seems to give some insights on El Niño mechanism, but in some specific limits [2]. The projection of a simplified version of the Zebiak and Cane model on the equatorial oceanic modes shows an unstable coupled mode (SST-Kelvin mode) akin to the SST-mode but all the mechanisms are well identified [3]. This mode seems to explain different characteristics of the start up of El Niño events.

The information gained from the analytical and numerical calculations made with simplified coupled models helps the comprehension of the tropical ocean-atmosphere coupling and gives some insights either for the realization of fully coupled experiments or the analysis of the numerical results.

References

[1] S.E. ZEBIAK and M.A. CANE : A model El Niño-Southern Oscillation, Mon. Wea. Rev.,115, 2262-2278, 1987.

[2] J.D. NEELIN : The slow sea surface temperature mode and the fast-wave limit : analytical theory for tropical interannual oscillations and experiments in a hybrid coupled model, J.A.S.,48, 584-606, 1991.

[3] M. PONTAUD : El Niño, une approche analytique simplifiée. CERFACS STR/CMGC/93-32 ,1-44, 1993.

4 GLOBAL OCEAN AND ATMOSPHERE COUPLING

The human activities induce some modifications in the environment. One of the most significant on a global scale is the release of gases in the atmosphere, principally CO2, which induces an increase of the green-house effect. This green-house effect modifies the climatic balance of the ocean-atmosphere system (global warming, general circulation, precipitations, ...). The consequences of such a climate change are likely to be important (economy, ecology, geography, ...). Various possible scenarii in the increase of CO2 during the next century are considered. The big challenge of climate modelling is to predict the global changes induced by these various scenari. It is currently recognized that this challenge is only possible through the simulation of the coupled global ocean-atmosphere system with General Circulation Models.

The ultimate goal of the Climate modelling & Global Change project is to participate to the achievements of such coupled simulation, in collaboration with the climate community. We have started the coupling between the global version of the LODYC oceanic model OPA7 (see its bathymethry on Figure 7) with the ARPEGE model. Various steps are necessary before the undertaking of climate change experiments. We have started two coupled experiments in which the dynamics of one specified part of the ocean is free to interact with the atmosphere, the remaining domains being relaxed to climatology. In the first experiment (see Section 4.1) only the tropical regions are free, while in the second one (see Section 4.2) the interaction with mixed layer and sea ice in the high latitudes are considered. Theoretical approach of the thermohaline circulation, which is a key phenomena of the global ocean coupling, is pursued (see Section 4.3).

4.1 Tropical dynamics of the Global OPA/ARPEGE coupling (Marc Pontaud, Laurent Terray and Olivier Thual)

The tropical interannual variability is characterized by the severe and abnormal warming of the equatorial Pacific ocean. This events are called El Niño and occur every two to ten years. They induce large modifications in the tropical circulation (Hadley cells and Walker cells) and some at high latitudes (teleconnections).

To focus on this phenomenon, the OGCM is relaxed to climatology from 50^o N & S to the poles, and between 50^o N & S only under 300 meters. The dynamic of the tropical oceans from the surface to the thermocline is free. A first comparison will be performed with the results of the tropical Pacific version (see 3.2).

The global version relaxed at high latitudes should give some new information about the initiation of El Niño events. The more accurate bathymetry enable the communication of the Pacific ocean with the Indian ocean. This improvement should give some insight about the preference between the two theories in the swim, the "delay-oscillator" and the "coupled modes". The "delay-oscillator" theory is based on the reflection of the oceanic waves on the west border of the Pacific ocean (a good bathymetry is important) [1,2]. The "coupled modes" theory is based on equatorial waves which are destabilized by positive feed-back between ocean and atmosphere [3,4,5].

References

[1] P.S. SCHOPF and M.J. SUAREZ : Ocean wave dynamics and the time scale of ENSO, J. Physical Oceanography,20, 629-645, 1990.

[2] D.S. BATTISTI and A.C. HIRST : Interannual variability in a tropical atmosphere-ocean model ;

influence of the basic state, ocean geometry and nonlinearity, J.A.S.,46, 1687-1712, 1989.

[3] A.C. HIRST : Slow instabilities in tropical ocean bassin-global atmosphere models,J.A.S.,45, 830-852,i 1988.

[4] J.D. NEELIN : The slow sea surface temperature mode and the fast-wave limit : analytical theory for tropical interannual oscillations and experiments in a hybrid coupled model, J.A.S.,48, 584-606, 1991.

[5] M. PONTAUD : El Niño, une approche analytique simplifiée. CERFACS STR/CMGC/93-32 ,1-44, 1993.

4.2 High latitudes processes of the Global OPA/ARPEGE coupling (Gilles Garric, Laurent Terray and Olivier Thual)

In high latitudes sea ice constitutes an important component of ocean-atmosphere interactions. It induces modifications in radiative budget, weakens heat exchange and inhibits chemical constituants exchange (CO2 for example) between ocean and atmosphere.

In order to take into account this new element in global coupling processes, we have started to investigate the coupling of a thermodynamic-dynamic sea ice model, the Ocean General Circulation Model (OGCM) OPA7 and the Atmospheric General Circulation Model (AGCM) ARPEGE. The sea ice model has been developed at the Université Catholique de Louvain by T. Fichefet and M. Morales Maqueda and was initiated at Météo-France by S. Planton and C. Bellevaux. Written in spherical coordinates, this model is a large scale one where both dynamics and thermodynamics are incorporated [1]. Several features of this sea ice model can be summarized :

- the simulation of leads within the ice pack, assuming an area of ice free in each grid square,
- the modelling of ice resistance by a viscous-plastic rheology with no shear strength,
- and the storage of sensible and latent heat inside the ice.

With this global coupling we also intend to study one paradigm of the sea-ice, ocean and atmosphere coupling characterized by the decadal variability of the deep-water formation in the North Atlantic, which feeds the conveyor belt. It is believed that this variability is due to a coupling with atmospheric winds. This paradigm would then be as important for the high latitude coupling phenomena than the "El Niño" paradigm for the tropics.

Preliminary experiments are necessary before the stage of fully coupled ocean, atmosphere and sea ice models is reached. In collaboration with G. Madec from LODYC-CNRS, we agreed that the first step should consist in coupling in an interactive way the oceanic model OPA with a "free" mixed layer in high latitudes, i.e. there are no damping terms in ocean superficial layers but tropical band is relaxed to climatological terms . This experiment is complementary of the experiment of tropical coupling processes (see previous section 4.1).

References

[1] FICHEFET Th., MORALES MAQUEDA M. A., PLANTON S. and BELLEVAUX C., A Global Sea-Ice-Upper-Ocean Model: Some Preliminary Results, *Submitted for publication in "The role of the Polar Oceans in Shaping the Global Environment"(Geophysical Monograph, AGU)*

4.3 Thermohaline oceanic circulation (Laurence Fleury and Olivier Thual)

The thermohaline oceanic circulation is driven by the density forcing at the ocean surface, whose two components — the heat and fresh water fluxes — have antagonistic effects. Colder temperatures in high latitudes favor sinking near the poles, while fresh water fluxes there tend to prevent it. Several recent studies, numerical [1-2] as well as analytical [3], have shown that the competition between thermal and saline forcings results in multiple equilibria. The differences in direction and intensity between two modes of circulation induce changes in the poleward heat transport, and thus has a significant effect on global climate.

A 2D fluid model of the thermohaline convection, based upon the Boussinesq approximation in a rectangular pole-to-pole meridional basin and forced by mixed boundary conditions at the surface (i.e. temperature field and freshwater flux imposed), is studied numerically in [1] and analytically in the small aspect ratio limit in [3]. In [3], the 2D fluid model is thus reduced to a 1D evolution equation which describes quantitatively the catastrophe structure of the thermohaline convection detailed in [1], but only one equilibrium is globally defined in the box. To obtain multiple equilibria defined in the whole domain, we have considered an other asymptotic path associated with a slightly reshaped surface temperature forcing. This new asymptotic expansion enables the description of the multiple equilibria observed in [1] and satisfies the exact superposition principle (i.e. a pole-to-pole circulation is the exact superposition of two half symmetric circulations, a thermally driven equilibrium in one hemisphere and a salinity driven equilibrium in the other one). We are presently checking the validity of our asymptotic expansion by pushing down the asymptotic path as far as numerically possible. We wish moreover to study the evolution of fronts according to various asymptotic paths .

The asymptotic approach can be extended to simple models of the atmosphere- ocean coupling: more realistic salinity and temperature forcings , presence of a momentum surface forcing (i.e. wind), rotation, coupling with a simple atmospheric model (energy balance model (1D) or large scale convection model (2D)).

Another interesting outcome of this asymptotic analysis is the connection between fluid and box models. In the limits of large N and fast temperature relaxation times, a N-box model, connected by pipes whose section varies linearly with the flow rate, satisfies dynamical equations which are exactly the discretization of our 1D asymptotic equation.

Other types of numerical investigations have been undertaken with the 2D code described above: influence of anisotropic viscosity or/and diffusivities, study of the variability of the model under a time dependent forcing, ...

The last step of this thermohaline study will be experiences with an Ocean Global Circulation Model (OPA from LODYC-Paris). We will then consider this model in both forced and coupled configurations. Our strategy is to explore ranges of parameters in which basic phenomena can be observed, and connect them to the realistic parameters. Otherwise, the comparison between the behavior of this complete model and those of the simpler models cited above will provide a key in the practical question of the choice of a model for a type of study.

This activity is performed in the framework of an european contract (MAST- CT92-0034) in collaboration with P. Cessi from the FISBAT-CNR institute (Bologna, Italy).

References

[1] O. THUAL, J. C. MCWILLIAMS, The catastrophe structure of thermohaline convection in a two-dimensional fluid model and a comparison with low-order box models, *Geophys. Astroph. Fluid Dyn.* **64** (1992) 67-95.

[2] A.J. WEAVER, J. MAROTZKE, P.F. CUMMINS, E.S. SARACHIK, Stability and variability of the thermohaline circulation, *J. Physical Oceanography* **23** (1993) 39-60.

[3] P. CESSI, W.R. YOUNG, Multiple equilibria in two-dimensional thermohaline circulation, *J. Fluid Mechanics* **241** (1992) 291-309.

5 DEVELOPMENT OF THE EXPERIMENT MANAGER

All the groups involved in big computing experiments must assemble a set of procedures and tools to performed three tasks: the launching of the runs, the control of their execution and the post-processing of the generated data. The set of these softwares, which deals with the big atmospheric or oceanic codes, is what we call the "Experiment Manager". In order to constitute it, we have settled a "Numerical Laboratory" structure, in which each participant of the project puts the results of his software developments in a form that can easily be used by others. This organization has been useful, especially since there is no research engineer in the project. We only report here some significant achievements in the building of this Experiment Manager.

5.1 Implementation of OPA7 at CERFACS (Stéphane Godet-Thobie, Gilles Garric, Marc Pontaud, Laurent Terray and Olivier Thual)

In collaboration with LODYC, we have installed the oceanic GCM OPA7 at CERFACS, and the launching procedures that go with this code. This installation makes possible the preparation of Cray jobs on a frontend workstation in such a way that the file transfers to the Cray-2 and the compilation time are minimized. We also ported the OPA7 model from Cray-2 to IBM RS/6000 workstations at CERFACS, keeping the possibility to manage efficiently the code by means of the **UNIX** Source Code Control System (i.e. the `sccs` command). Various computation and visualization routines and shell scripts have been adapted for this purpose.

The OPA model was developed and implemented by M. Chartier (see [1]) and P. Delecluse at the LODYC. The model was totally rewritten in 1988 to be used in a multitasked way and run in central memory on a Cray-2 (see [2]). The last version OPA7 has been released in 1992 (see [3]). In collaboration with LODYC, we intend to provide a distributed version (using PVM: see [4]) which will first run on an IBM RS/6000 cluster, and then on the Meiko CS-2 and the IBM SP/1.

In the framework of his activity at the Spatial Geodesy Research Group (OMP/GRGS), S. Godet-Thobie has used OPA7 to do some comparisons with other OGCMs based on the same Primitive Equations model.

References

[1] Michel Chartier (1985), "Un modèle numérique tridimensionnel aux équations primitives de circulation générale de l'océan", Ph.D. thesis, University Paris VI.

[2] Patrick Andrich, Pascale Delecluse, Claire Lévy et Gurvan Madec (1988), "A multitasked general circulation model of the ocean", in *Science and Engineering on Cray Supercomputers; Proceedings of the Fourth International Symposium*, Cray Research Eds, 407–428.

[3] Pascale Delecluse, Maurice Imbard, Claire Lévy et Gurvan Madec (1993), "OPA, Ocean General Circulation Model, Reference Manual".

[4] A. Beguelin, J. Dongarra, A. Geist, R. Manchek and V. Sunderam (1991), "A Users' Guide to PVM Parallel Virtual Machine", Tech. Rep. ORNL/TM-11826, Oak Ridge National Laboratory, September.

5.2 Post-processing and visualization of climate fields (Olivier Thual, Laurent Terray, Sophie Pelletier, Gilles Garric)

We have built a software environment for the post-processing and the visualization of the climate fields generated by our experiments. Lacking specalized support for these topics, the researchers of the project have devoted an important part of their scientific work to fulfill the gap. We were constrained to base our developments upon free softwares, which implied an intensive search, and even had to contribute to the development of one of them (see Section 5.3).

We have created a database called VAIRMER and several UNIX scripts to extract the climate fields and put them into the various formats required by our visualization softwares. This database presently contains two AMIP experiments (10 years of simulation of atmospheric GCMs) performed with the atmospheric GCM ARPEGE by CNRM and by LMD with their model. These efforts have allowed an intercomparison study between the two atmospheric GCMs, in collaboration with the CNRM and the LMD, which have welcomed our initiative.

We have explored a large variety of visualization softwares and selected three of them for operational purposes in the post-processing of our data. One important requirement for our activity is the display of coast lines superimposed to the climate fields. For paper output (see Figures 6 and 9), we have installed and retained GMT, a free software developed by the University of Hawai and the Scripps Institution of Oceanography [1]. For screen visualizations and animations we have explored and retained REC (see Figure 5), developed by the Atmospheric Environment Service of Canada [2]. We also retained VISUO [3] for very fast animations, and 3D representations (see also Section 5.3). The visualization software Ncar Graphics was also convenient for our needs, but we still cannot afford to buy it at CERFACS, in spite of its low price. We have explored a lot of other visualization softwares (UNIRAS, AVS, SGI-EXPLORER, KHOROS, APE, etc ...) by testing them with our data. Some of them were not appropriate to our needs, the others had to be purchased and are kept in mind for future software budget.

This selection of three visualization softwares (GMT, REC and VISUO) is convenient for our purposes provided that every participant to the project has access to a Silicon Graphics worsktation. Until this stage is reached, we will have to find an alternate solution which is suitable even for monochrome X terminal. This will be a difficult task since most of the free softwares available on the network and suitable for geophysic visualizations assume a minimum of informatic comfort.

We have written various small programs and scripts to convert our data between the various formats of the visualization software that we use. The integration of all these "Numerical Laboratory" (NumLab) items into a coherent structure is a necessary step that we will have to face soon.

[1] P. WESSEL, W. H. F. SMITH, Free software helps map and display data, *EOS. Trans. AGU,* **72, 441** (1991) 445-446.

[2] Y. CHARTIER, M. LEPINE, M. VALIN, Rêver En Couleurs v 3.15, Div. de Recherche en Prévision Numérique, Environment Canada, Dorval, Quebec (1992).

[3] D. ASTRUC, D. DAVIDSON, Visuo 3.0; guide de l'utilisateur, CERFACS Internal Report 26 juillet (1993).

5.3 VISUO 3.0 (Dan Davidson, Dominique Astruc, and Olivier Thual)

During the early stage of the evaluation of several visualization software packages (see Section 5.2.), Visuo, originally developed by D. Astruc at Onera/Cert/Dermes in Toulouse which is one of CERFACS's partners, proved to be well-suited for climatic data visualization and very efficient in animation on the available hardware platforms. Unfortunately, Visuo was at the beginning designed to visualize CFD databases and one important feature for climatic purposes, namely the ability to display coast lines, was lacking.

Therefore, we decided to upgrade the original version of Visuo by including in the software some new features (see Figures 4, 7 and 9). This work has been done with D. Davidson (Student from Institut Universitaire Technologique de Toulouse, Computer Science Department) during a three month training period in the Global Change team. All the improvements have led to visuo 3.0 a new major release of the software.

Roughly, we have:

- added several important new features: coast lines, vectors, video-oriented labels,
- improved the internal coding: dynamic memory allocation, hardware compatibility,
- and improved the released material: install procedure, printable manual, defaults resources.

This new version is currently used by the Global Change project to visualize the climatic fields but it has already been installed in several other laboratories including some of our partners (LODYC) and some regional laboratories (Institut de Mécanique des Fluides de Toulouse, Onera/Cert/dermes). We should add that this software is available to the research community.

CONFERENCES AND SEMINARS PARTICIPATED BY THE CLIMATE MODELLING & GLOBAL CHANGE PROJECT

September 92

La Londes les Maures, CNES Summer school "Les Climats subtropicaux et leur évolution". Invited talk: "ocean-atmosphere coupling, design of a coupler", O. Thual.

December 92

Toulouse, Atelier de Modélisation de l'Atmosphère. Communication: "Deux coupleurs et le modèle communautaire", réunion des modélisateurs du modèle communautaire français. O. Thual.

Mars 1993

Bruxelles, MAST DAYS. Poster: "Multiple equilibria of the thermohaline oceanic circulation". L. Fleury and O. Thual.

May 1993

Université Paul Sabatier. Seminar: "Scientific activities of the Climate Modelling & Global Change project at CERFACS". O. Thual.

June 1993

Les Houches, High Performance Computing in the Geosciences, Invited talk: " Coupled Ocean-Atmosphere Simulation". L. Terray.

June 1993

Braknell, Invited talk: "Anthropogenic Climate Change: the joint CERFACS/LODYC/CNRM/LMD project". O. Thual.

Slides of the talks and seminars

All the slides of the talks and seminars given by members of the Climate Modelling & Global Change project are gathered each year in an internal document:

COMPILATION Volume A, Conference and seminar slides, Climate Modelling & Global projet, *Internal Report* , CERFACS IR/CMGC/93-June (1993).

PUBLICATIONS BY MEMBERS OF THE CLIMATE MODELLING & GLOBAL CHANGE GROUP.

L. TERRAY, O. THUAL, "Coupled Ocean-Atmosphere Simulations" in: High Performance Computing in the Geosciences, Proceedings of Les Houches Workshop June (1993), F.X. Le Dimet, Ed., Kluwer Academic Publishers B.V. (1993).

L. TERRAY , The OASIS Coupler User Guide Version 1.0, *CERFACS Technical Report,* **CERFACS TR/CMGC/93-33**, (1993).

S. BELAMARI, *Variabilité inter-annuelle simulée dans l'Océan Pacifique Tropical*, Rapport de stage du DEA "Astrophysique, Géophysique et Techniques Spatiales", *Student Report*, CERFACS STR/CMGC/93-30 (1993).

M. PONTAUD, *El Niño, une approche analytique simplifiée* Rapport de stage du DEA "Astrophysique, Géophysique et Techniques Spatiales", *Student Report*, CERFACS STR/CMGC/93-32 (1993).

G. GARRIC, *Validation d'un modèle thermodynamique-dynamique de banquise*, Rapport de stage du DEA "Astrophysique, Géophysique et Techniques Spatiales, *Student Report*, CERFACS STR/CMGC/93- (1993).

EPICOA Volume II, Climate Modelling & Global Change projet, *Technical Report* , CERFACS TR/CMGC/93-August (1993).

EPICOA JOURNAL

The *Epicoa* letters (Exchange of Projets and Ideas for the Coupling of Ocean and Atmosphere) constitute the internal journal of the "Climate Modelling & Global Change" project. The format of these letters is unformal and can range from a quick presentation of an unelaborated scientific idea or technical detail, to a worked-out preprint preceeding a publication in an international journal. These letters are concerned with the scientific aspects of the ocean-atmosphere coupling activity of the project, and its interactions with the climate community. Joint publications with other scientists of this community are seeked.

Each year, a new volume of the Epicoa letters is edited and distributed to a list of diffusion which can be updated by the CERFACS library upon request by the receivers.

Volume II

L. TERRAY, O. THUAL, Real test on OPA Pacific coupling. Part A: the communication procedure, *Epicoa* **0803** (1992) 1-11 .

P. CESSI, O. THUAL, Multiple equilibria in the thermohaline ocean circulation, a FISBAT-CERFACS work program, *Epicoa* **0824** (1992) 12-22.

O. THUAL, L. TERRAY, Approaches of the ocean-atmosphere coupling, *Epicoa* **0930** (1992) 23-37.

O. THUAL, Four students scientific subjects in the Global Change project, *Epicoa* **1117** (1992) 38-61.

O. THUAL, J. SALVANO, P. LAMBOLEY, M. DEQUE, D. ASTRUC, Testing visualization tools for climate. Part I: the butterfly experiment data. *Epicoa* **1210** (1992) 62-67.

L. FLEURY, O. THUAL, An asymptotic expansion explaining the catastrophe structure of the thermohaline oceanic convection, *Epicoa* **0107** (1993) 68-83.

L. FLEURY, O. THUAL, Box models and the asymptotic expansions of the thermohaline convection, *Epicoa* **0218** (1993) 84-90.

O. THUAL, L. TERRAY, M. PONTAUD, S. PELLETIER, G. GARRIC, L. FLEURY, April 93 scientific trajectory of the climate modelling & global change project, *Epicoa* **0422** (1993) 91-101.

LOGBOOK JOURNAL

The *LogBook* letters (Climate Modelling & Global Change Logbook) are internal notes adressing our team administrative questions. They present an interest only for the teams which share close administrative links with us.

Volume II

Couplage d'un modèle de glace à un modèle global Atmosphère-Océan *LogBook* **0710** (1992).

Dossier de demande de temps calcul sur la CM-5 *LogBook* **0720** (1992).

Proposition pour un stage de recherche IM: couplage OPA Pacifique / ARPEGE et systèmes dynamiques, *LogBook* **0801** (1992).

Offices and terminal repartition, *LogBook* **0903** (1992).

1993 budget proposal for the Climate Modelling & Global Change team: september 92 version, *LogBook* **0927** (1992).

1991 and 1992 budgets of the climate modelling & global change team, *LogBook* **1001** (1992).

Couplage OPA Pacifique / ARPEGE, proposition de stage de DEA, *LogBook* **1007** (1992).

October 8th scientific steering committee, *LogBook* **1008** (1992).

Changement climatique global anthropogénique *LogBook* **1022** (1992).

Une nouvelle version de visuo pour le climat *LogBook* **0112** (1993).

Rapport d'activité intermédiaire du projet "Climate Modelling & Global Change" pour la convention CNRM - CERFACS 1992/1993. *LogBook* **0404** (1993).

April 93 offices and terminal repartition *LogBook* **0409** (1993).

Dynamique tropicale du couplage ARPEGE climat / OPA global. proposition de sujet de formation complémentaire par la recherche IM 1993-1995. *LogBook* **0417** (1993).

May 1993 five year plan of the Climate Modelling & Global Change project, *LogBook* **0510** (1993).

Trace de vecteurs dans le logiciel visuo, plan de travail a un mois, *LogBook* **0608** (1993).

Personnel evolution 1993-1998 for the climate modelling & global change project. *LogBook* **0608** (1993).

Parallel computing softwares and couplers subject proposal for a recite training period, *LogBook* **0729** (1993).