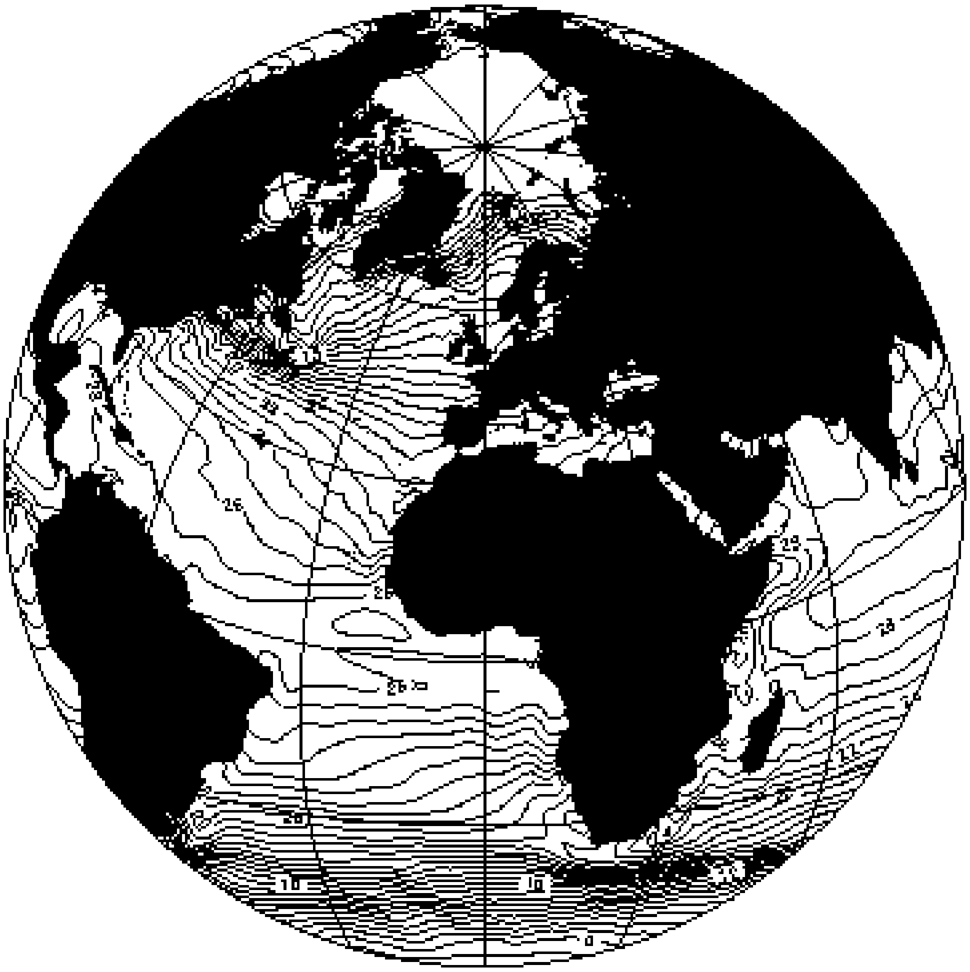
"Climate Modelling & Global Change" Team :

1994 Scientific Report

April 1995



Contents

1 Introduction

1.1 Three successful coupled experiments

The year 1994 has been very rewarding for the "Climate Modelling & Global Change" team. The long term investments in scientific expertise and software developments have led to the first climate experiments in which a global oceanic model (OPA) is coupled with an atmospheric general circulation model (ARPEGE). We have successfully achieved a **50 year simulation** with the low resolution version of the model (T21 for the atmosphere) and a **25 year simulation** with the high resolution version (T42). In parallel, we have thoroughly analyzed the **10 year simulation** of the Tropical Pacific Ocean version of OPA coupled with ARPEGE. These three experiments have been welcomed with emphasis by the French climate community, who had expected these achievements for several years. These good results have benefited from the quality of the General Circulation Models (GCMs) developed by METEO-FRANCE (atmosphere) and the LODYC[1] (ocean) in addition to the coupling efforts that the "Climate Modelling & Global Change" team has undertaken to master these two codes and make them communicate in the proper way.
In addition to these visible realizations, the scientific competences of the team participants in the field of climate modelling have significantly improved. We not only have fulfilled our computer software goals, but we have also become specialists in the field of climate experiments, combining with equal weight the expertise in oceanic and atmospheric modelling. It might be noticed that, contrarily to all the French groups involved in General Circulation Model activities, these heavy experiments (7000 hours of CRAY-2 and 500 hours of CRAY C-90 in 1995) have been launched and analyzed without the support of a research engineer. Despite this heavy handicap, we have been able to combine computer duties with high quality science in a new field.

1.2 Participants of the team

In 1994, there has been twelve participants to the Climate Modelling & Global Change project, including one project leader (Olivier Thual), one senior (Laurent Terray), two post-docs (David Stephenson and Marie Angèle Filiberti), five Ph.D. students (Laurence Fleury, Gilles Garric, Marc Pontaud, Eric Guilyardi and Jorge Macías), two research engineer students (Sophie Belamari and Eric Sevault) and one administrative assistant (Isabelle Moity). We have also welcomed one student for a DEA training period (Thierry Moliner) and two engineer students for software development (Dan Davidson and Jean-Charles Frances).
Six positions are funded directly by CERFACS (team leader, 1 senior, 1 post-doc, 2 Ph.D. students and 1 administrative assistant), one through a EC[2] contract (1 post-doc), two by the MESR[3] (2 Ph.D. students) and three by METEO-FRANCE (1 Ph.D. student, 2 engineer students). One participant (O.Thual) is also working as a Professor at the IMFT[4] of INPT[5]. One post-doc position (M. A. Filiberti) has been given to LODYC in order to help this laboratory to develop the sea-ice model that we will eventually include in our coupled model. This is why this activity is only briefly mentioned in this report (in Section ??).
The present repartition shows that there is a great number of students compared to the number of confirmed researchers. This deficit is compensated by the fact that Ph.D. students have now gained great

[1] Laboratoire d'Océanographie Dynamique et de Climat
[2] European Commission
[3] French Research and Education Ministry
[4] Institut de Mécanique des Fluides de Toulouse
[5] Institut National Polytechnique de Toulouse

Name	Position	Period
O. Thual	Project leader	1991/09 —
L. Terray	Senior	1990/10 —
D. Stephenson	Post-doc	1993/12 —
M. A. Filiberti	Post-doc	1993/11 — (1995/10)
L. Fleury	Ph.D. student	1992/10 — (1995/12)
G. Garric	Ph.D. student	1992/10 — (1995/12)
M. Pontaud	Ph.D. student (IM)	1993/07 — (1995/08)
E. Guilyardi	Ph.D. student	1993/10 —
J. Macías	Ph.D. student	1993/10 —
E. Sevault	Engineer student (IT)	1994/09 — (1995/02)
S. Belamari	Engineer student (IT)	1992/09 — 1994/08
I. Moity	Adm. Assistant	1993/10 —

Table 1.1: List of the participants of the Global Change project

autonomy and an important part of the team activity is relying of them. Nevertheless, there is an urgent need for a research engineer to optimize the management of software development and data processing.

1.3 Contracts

Since its creation, the "Climate Modelling & Climate Change" team activity has been able to fulfill a large part of its resources through contracts. For instance, all the workstations and terminals used by the team have been bought through contracts with the Midi-Pyrénées (MP) Region. Most of the computing time of the team is provided by METEO-FRANCE or IDRIS through scientific projects.

Funding agency	Program	Topic
EC	Environment	Anthropogenic Climate Change
EC	MAST II	Thermohaline Oceanic Circulation
Region MP	Environment Pole	French Community Model Development
METEO-FRANCE	Community Model	Coupled Climate Simulations
EDF/DER	CATHODe	Distributed Computing
CNRS	PNEDC	Climate Modelling

Table 1.2: Contracts of the "Climate Modelling & Global Change" team

1.4 Scientific achievements

The team achievements that are reported for 1994 are consistent with the working plan that has been elaborated three years ago, at the beginning of the project, and summarized in Figure 1.1. This project has started with software developments which are the necessary basis of following scientific activities. The latter activities are now the core of the project, even though the former ones are still going on.

Among the purely scientific activities, the coupled modelling of the Tropical Pacific Ocean has reached a stage in which deep analysis is being performed (see Chapter 2). The data from the 10-year simulation achieved in 1993 have been extensively processed and used, so far, for two major accepted publications. This experiment is motivating sensitivity studies which are also fruitful. This tropical activity also includes the development of a hybrid coupled model, in which the atmospheric GCM is replaced by a simplified model based upon a statistical study.

The coupled experiments with the global ocean model OPA are at the earlier stage where the data of the 50 years (low resolution) and 25 years (high resolution) experiments are just coming out of the computer (see Chapter 3). However, the first-order sets of analysis of these present climate experiments reveal

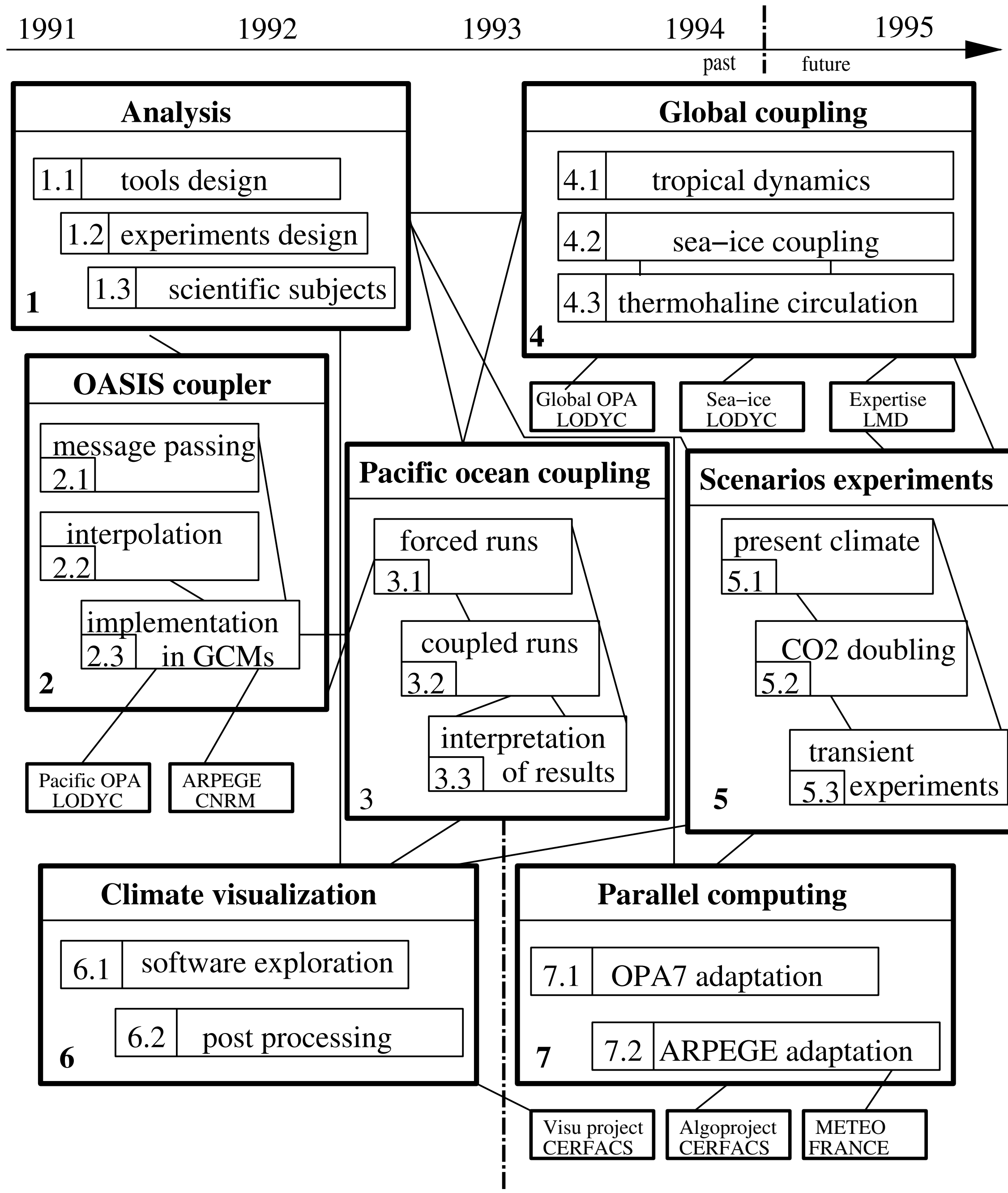


Figure 1.1: Working plan fo the "Climate Modelling & Global Change" project.

interesting information about the drift of the coupled model, which is low compared to other groups. These results are very encouraging for the scenarios experiments that are planned next.
But prior to these climate prediction experiments, the implementation of a sea-ice model in the ocean-atmosphere coupling is necessary. Two steps are conducted in parallel to achieve this goal (see Chapter 4). One step consists in coupling ARPEGE with a sea-ice model, and we use the one developed at UCL[6]. The other step is conducted at LODYC and directly includes a new sea-ice model into the oceanic model OPA.
In connection with these GCM heavy experiments, simplified models are developed to study climate paradigms such as the instabilities at the root of the El Niño Southern Oscillation phenomenon or the variability of the thermohaline oceanic circulation (see Chapter 5).
Computer science developments have been pursued in 1994, motivated by the needs of the climate experiments (see Chapter 6). The OASIS coupler has been adopted by several international laboratories, and extensions have been brought in to adapt it to specific needs. The VAIRMER Experiment Manager is also becoming a standard for climate communities, and has been extensively used and improved this year. The new software CLIM has been designed to integrate PVM[7] in the coupling procedure. It has been tested in the framework of the CATHODe project, in which two distant supercomputers, hosting either the ocean or the atmosphere, were communicating through the network. At last, we have pursued the development of VISUO to enable quick animations of the climate fields coming out the computer.
In conclusion (see Chapter ??), we predict that 1995 will achieve the transition from the ending spin-up phase and a fully established scientific phase. The number of presentations in conferences (see Chapter 8) and publications (see Chapter 9) shows that this orientation is a reasonable one.

2 Coupled modelling of the Tropical Pacific Ocean

2.1 A 10-year coupled simulation of the tropical climate

Large-scale ocean-atmosphere interaction plays a crucial role in natural climate variability on a broad range of time scales and in anthropogenic climate change. The development and validation of coupled ocean-atmosphere models is thus essential for simulating, understanding and predicting the global climate system. In particular, there is now strong evidence that ocean-atmosphere interaction is responsible for the El Niño/Southern Oscillation (ENSO) phenomenon. Intense research effort is being devoted to the simulation of tropical climate anomalies with tropical coupled general circulation models (GCMs) [4].
We have performed the first French coupled experiment with a global atmospheric model and a tropical Pacific oceanic model. The atmospheric component is the climate version of the Météo-France global

[6] Université Catholique de Louvain la Neuve
[7] Parallel Virtual Machine software

forecasting model, ARPEGE [2]. The oceanic one is the Laboratoire d'Océanographie DYnamique et de Climatologie (LODYC) oceanic model, OPA, [1] which is dynamically active over the tropical Pacific. The two GCMs have been coupled over a 10 year period with the CERFACS coupler, OASIS, [6] in order to simulate the mean state, the seasonal cycle and to study potential interannual variability of the coupled system.

The climatological mean state and seasonal cycle are well simulated by the coupled model [5]. In particular, the oceanic surface current pattern is accurately depicted and the location and intensity of the Equatorial Undercurrent (EUC) are in good agreement with available data. The seasonal cycle of equatorial sea surface temperature (SST) captures quite realistically the annual harmonic (see Figure 2.1).

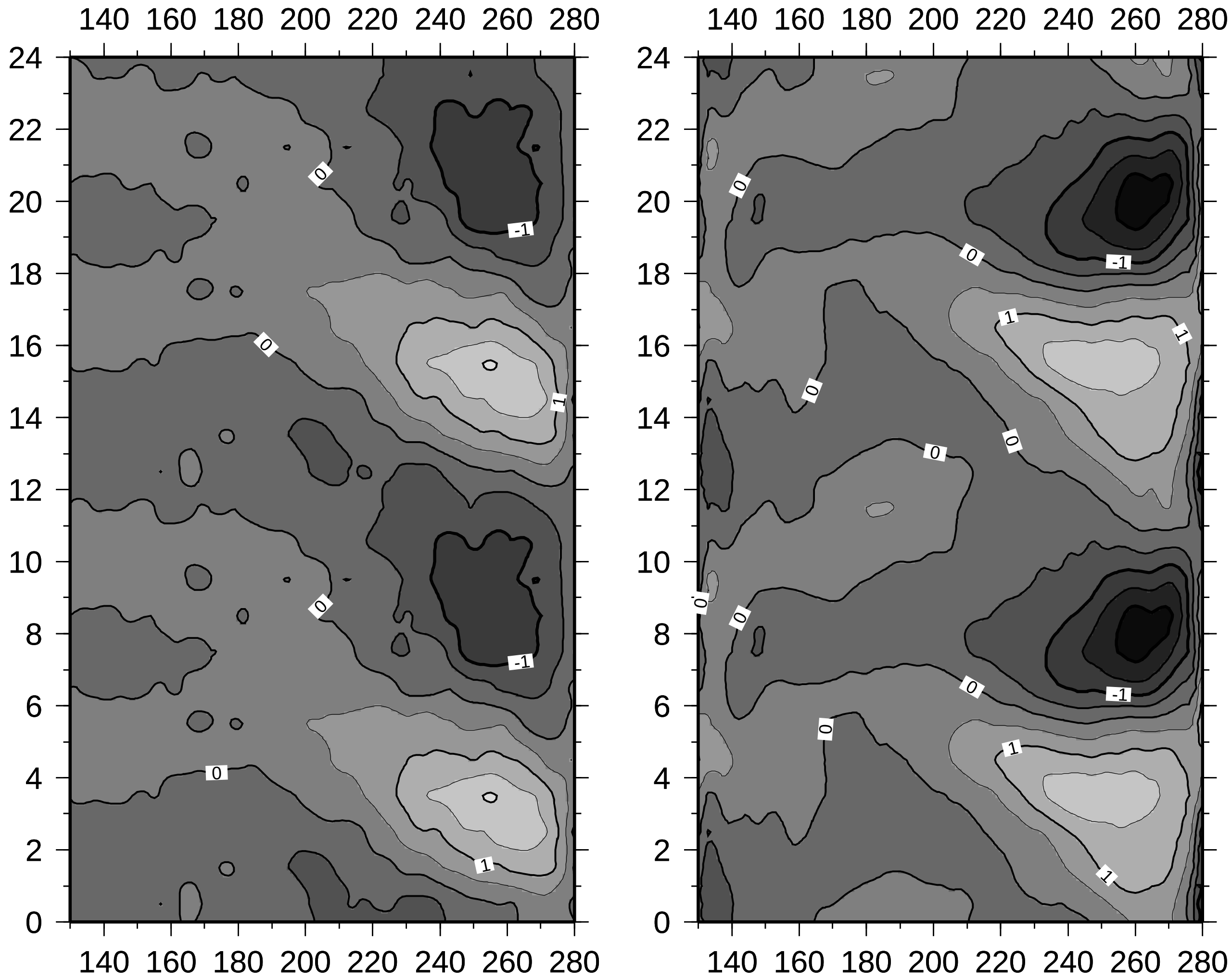


Figure 2.1: SST Seasonal cycle: (left) COADS and (right) coupled run.

Some deficiencies remain, including a weak zonal equatorial SST gradient, underestimated wind stress over the Pacific equatorial band and an additional inter-tropical convergence zone (ITCZ) south of the equator in northern winter and spring. Weak interannual variability is present in the equatorial SST signal with a maximum amplitude of 0.5°C. The simulation is part of an international intercomparison exercise about tropical GCMs [3]. The next sections describe further specific analysis as well as some sensitivity experiments carried out with the coupled model.

[1] P. Delecluse, G. Madec, M. Imbard, and C. Lévy, (1993), OPA version 7 Ocean General Circulation Manual, Tech. Rep. 93/05, LODYC, Paris, France.

[2] M. Déqué, C. Dreveton, A. Braun, and D. Cariolle, (1994), The ARPEGE/IFS atmosphere model: a contribution to the French community climate modelling, *Clim. Dyn.*, **10**, 249–266.

[3] C. Mechoso, A. Robertson, N. Barth, M. Davey, P. Delecluse, P. Gent, S. Ineson, B. Kirtman, M. Latif, H. L. Treut, T. Nagai, J. Neelin, S. Philander, J. Polcher, P. Schopf, T. Stockdale, M. Suarez, L. Terray, O. Thual, and J. Tribbia, (1995), The seasonal cycle over the tropical Pacific in coupled ocean-atmosphere general circulation models, *Mon. Wea. Rev.*, In press.

[4] D. Neelin, M. Latif, and F. Jin, (1994), Dynamics of coupled ocean-atmosphere models: the tropical problem, *Annu. Rev. Fluid Mech.*, **26**, 617–659.

[5] L. Terray, O. Thual, S. Belamari, M. Déqué, P. Dandin, P. Delecluse, and C. Lévy, (1995), Climatology and interannual variability simulated by the ARPEGE-OPA coupled model, *Clim. Dyn.*, In press.

[6] L. Terray, (1994), The OASIS coupler user guide version 1.0, Tech. Rep. TR/CMGC/94-05, CERFACS, Toulouse, France.

2.2 Short-term variability studies

Temporal variability on time scales of intraseasonal (30-60 days), seasonal and interannual have been examined in the 10 year coupled Pacific simulation and compared with observations.
On the intraseasonal timescales, realistic westerly wind bursts occur in the model results causing surface cooling of up to 1K as noted in the TOGA-COARE observations. Examination of the upper level velocity potential indicates that these events are part of a larger eastward propagating signal similar to the Madden-Julian oscillation [1]. Currently a collaboration is being developed with Simon Tett at the UKMO and Julia Slingo at the University of Reading to further study these phenomena in global coupled experiments.
New diagnostics on the seasonal variability in the Pacific such as an Ekman pumping parameter valid globally, have been developed in order to understand the oceanic dynamics involved and the NMC ocean analyses have been retrieved for comparison [2].

[1] D. Stephenson, (1994a), In *TOGA-COARE workshop*, Toulouse.

[2] D. Stephenson, (1994b), In *GEWEX conference*, London.

2.3 Climate drift sensitivity studies

Climate drift can be defined as the departure of the coupled GCM climatology from the observed one as well as from the climate simulated by the GCMs in uncoupled mode [1]. In the case of high resolution tropical GCMs, it usually appears as a fast adjustment (over a period of few months) towards an equilibrium state which can significantly differ from the observed one. Analysis of the initial phase and of the error at equilibrium are both necessary to understand the model biases.
Sensitivity of climate drift to selected convection and cloudiness parameters has been investigated with a coupled ocean-atmosphere general circulation model. The dependence of the coupled model climatology upon parameterizations of convective entrainment and strato-cumulus cloud cover has been studied. Furthermore, the coupling initial phase was carefully analyzed for the different performed simulations. The methodology relies upon short uncoupled (1 year) and coupled (4 years) simulations. The model climatology as well as the initial drift is very sensitive to both parameterizations. For instance, the air-sea interface mean state can be too warm or too cold depending on the profile of the convective entrainment rate. The model sensitivity is found to be the result of complex feedbacks between convection, cloud processes, sea surface temperature (SST) and large-scale ocean-atmosphere dynamics [2].

[1] D. Neelin, M. Latif, and F. Jin, (1994), Dynamics of coupled ocean-atmosphere models: the tropical problem, *Annu. Rev. Fluid Mech.*, **26**, 617–659.

[2] L. Terray, (1995), Sensitivity of climate drift to physical parameterizations in a coupled ocean-atmosphere general circulation model, *Mon. Wea. Rev.*, To be submitted.

2.4 Hybrid Coupled Models.

The aim of the work described in this section is to develop a hybrid coupled model (HCM) in which the ocean component is constituted by the OPA ocean general circulation model and a simplified empirical atmosphere will be constructed. To develop this empirical atmosphere, a collaboration with Prof. D. Anderson at Oxford University and Dr. M. Balmaseda at Alcalá de Henares University has been established through an ECCN (European Climate Computer Network) project. This project covers the period from January 1995 to June 1996. At the present moment the following steps to build this empirical atmosphere and perform the subsequent coupled experiment have been carried out:

-Preparation of FSU wind data: interpolation and extrapolation onto the OPA grid. The data and programs were provided by Dr. M. Balmaseda.

-A second step has consisted of forcing OPA model in its tropical Pacific version with this 33-year period wind data. The objective of this forced experiment is to obtain a consistent Sea Surface Temperature (SST) over the same 33-year period (1961-93) in order to be used, together with the wind data, to construct the empirical atmosphere. This forced experiment will serve as a reference for coupled experiments by being the first forced with observational data.

- The mean state, seasonal and interannual variability simulated in this experiment have been studied in order to validate the model results. This has generated two atlases, one containing the mean state and the second the seasonal cycle of this experiment (named OF1). Other atlases were done to compare OF1 results against observations (Levitus Climatology atlas and COLA-CAC observations) and against other experimental results developed at CERFACS: forced experiments (F8C mean state validation atlas) or coupled experiments (CO1 mean state validation atlas). Finally, a statistical study of the results has been started by means of a Principal Component Analysis (PCA) of the SST and wind data in order to examine the interannual variability in the results.

The simulated interannual variability in OF1 experience were summarized in [7, 8].
This team activity also forms the thesis subject for the Ph.D J. Macías. In parallel, J. Macías is collaborating with a group in Málaga University working on the development of a mesoscale oceanic model [2, 5, 4, 1, 6, 3].

[1] M. Castro and J. Macías, (1994), *Modelo Matemático de las Corrientes Forzadas por el Viento en el Mar de Alborán*, vol. 5, Publicaciones del Grupo de Análisis Matemático Aplicado de la Universidad de Málaga. 350pp, ISBN:84-7496-252-8.

[2] M. Castro, J. Macías, and C. Parés, (1993), Numerical modelling of the Alboran sea, In *Proceedings of the VIII Int. Conf. on Finite Elements in Fluids*, Barcelona, CIMNE/ Pineridge Press.

[3] M. Castro, J. Macías, and C. Parés, (1994a), Numerical modelling of the water mass exchanges through the Gibraltar strait, In *Report of the Workshop on Fluxes through Straits and Passages*, Publicaciones del Instituto Español de Oceanografía.

[4] M. Castro, J. Macías, and C. Parés, (1994b), Un modelo multicapas de aguas poco profundas. Aplicación al Mar de Alborán, In *Proceedings del Simposio sobre Modelado de Sistemas en Oceanografía, Climatología y Ciencias Medio-Ambientales: Aspectos Matemáticos y Numéricos*, Publicaciones del Grupo de Análisis Matemático Aplicado de la Universidad de Málaga, vol. 6.

[5] M. Castro, J. Macías, and C. Parés, (1995), A multilayer shallow water model. Applications to the modelling of the Alboran Sea and the Strait of Gibraltar, Amsterdam, J.L. Lions and I. Díaz eds. Springer Verlag.

[6] J. Macías, M. Castro, and C. Parés, (1995), Numerical modelling of water mass exchanges through the Strait of Gibraltar, *Revista GAIA*, **9**. Universidad de Lisboa. ISSN: 0871-5424.

[7] J. Macías, D. Stephenson, L. Terray, and S. Belamari, (1994), Description and results of the OPA/FSU forced experience (OF1), Epicoa Letters 1215, CERFACS, Toulouse, France.

[8] J. Macías, D. Stephenson, L. Terray, and S. Belamari, (1995), Interannual variability simulated in the tropical Pacific, Amsterdam, J.L. Lions and I. Díaz eds. Springer Verlag.

[9] J. Macías, (1993), Modelo shallow-water de dos capas del océano ecuatorial. Comparación del modelo no lineal con su versión linealizada, In *Actas del XIII CEDYA/ III Congreso de Matemática Aplicada*, Madrid.

3 Coupled experiments with the Global Oceanic Model

3.1 Motivations

The study of global climate variability requires the development of global coupled ocean-atmosphere models. This last year has seen the outcome of the previous years of development with the first global coupled experiments with the AGCM ARPEGE-Climat (CNRM/Météo-France) [2] and the OGCM OPA (LODYC) [1]. Two main scientific goals were proposed in order to both analyze and improve this new global model.

First, the study of the interactions of the 3 tropical oceans and their possible contributions to the interannual variability (with a focus on El Niño events). The PhD subject of M. Pontaud is inserted in this work and it is completed with a theoretical approach (see Section 5).

Second, an analysis of the global-scale water masses in the ocean in order to assess the role of the oceanic physical parameterizations in the formation, the circulation and the ventilation of these water masses in coupled mode. The Ph.D. Subject of E. Guilyardi is included in this study.

[1] P. Delecluse, G. Madec, M. Imbard, and C. Levy, (1993), OPA version 7: Ocean General Circulation Model Reference Manual, Tech. Rep. Internal Report LODYC, Université Paris VI, Paris, France.

[2] M. Déqué, C. Dreveton, A. Braun, and D. Cariolle, (1994), The climate version of Arpege/IFS: a contribution to the French community climate modelling, *Clim. Dyn.*, **10**, 249 266.

3.2 Reference experiments

A first stage was the realization of a few forced mode experiments for both models. These were necessary, first, to establish "reference" experiments, and, second, to build the initial state for the coupled experiments.

The AGCM ARPEGE was forced with the observed SST for the period 1979-1993 (experiment BF5 from CNRM). This experiment has been used to validate the version 1.0 of ARPEGE-Climat and is now a reference. Another 15 year run (GA2) [1] was made with a seasonally varying albedo, as a test case for a new vegetation scheme.

The OGCM OPA was forced (experiment FG2 - 15 years) by the daily averaged energy, momentum and water fluxes generated by experiment BF5. The model was run in *robust diagnostic* mode: observed temperature and salinity were restored below the thermocline and outside the tropics. The SST obtained from this integration is close to observations (good seasonal cycle) and shows a realistic interannual variability. Global energy transports agree fairly well with observations. This experiment reproduced (but for the interannual variability) the results obtained by the LODYC team and is a good reference for coupled experiments.

The ice parameterization only involves a test on the SST, and, in the presence of ice, imposes fixed heat flux to the ocean.

[1] E. Guilyardi, (1994), A Reference Atlas for the ARPEGE-Climat AMIP Forcing GA2 Experiment, Epicoa Letters 0604, CERFACS, Toulouse, France.

3.3 Coupled experiments

The ARPEGE and OPA models have been coupled with the OASIS coupler. Used by several modelling groups, flux correction techniques help reduce climatic drift in long term simulations [2] but introduce artificial variability. Here, the coupled model is kept free from any adjustment to ensure the coherency of the global system.
Two coupled experiments were made: the first for tropical studies integrated for 25 years; the second for water masses studies integrated for 50 years.
For the first coupled experiment (CG3) [3] a T42 spectral truncation was used for the atmosphere. The ocean initial state comes from the uncoupled simulation (FG2) and the initial atmospheric state is taken from the integration BF5 of the atmosphere model.
The second coupled experiment (CA1) [1] used a T21 spectral truncation for the atmosphere. The ocean initial state comes from an uncoupled simulation where the ocean was forced by climatological air-sea fluxes and constrained to the Levitus climatology for temperature and salinity. The constraint is released as soon as the coupled integration begins. The initial atmospheric state is a January 1^{st} of an integration of the atmosphere model forced by observed SST over the 1979-1988 period.

[1] E. Guilyardi, (1994), Coupled Experiment CA1: Reference Atlas, Epicoa Letters in preparation, CERFACS, Toulouse, France.

[2] G. Meehl, (1994), Workshop on global coupled general circulations models, *Bulletin of American Meteorological Society*, submitted.

[3] M. Pontaud, (1994), Coupled Experiment CG3: Reference Atlas, Epicoa Letters in preparation, CERFACS, Toulouse, France.

3.4 Results

The variation of the zonal SST field shows an initial tropical warming (within a few months) leading to a stable mean state after 10 years (see Figure 3.1). The warm waters, initially located in the western Pacific, spread over the entire equatorial belt due to a feedback process between the tropical SST zonal gradient and the trade wind system. The mid-latitudes reach a stable state within 2 years while high latitudes present the same biases as most coupled models: warming in Antarctica with total melting of the sea-ice within 25 years and cooling in Arctica. Thus, the stability of both coupled models at the air-sea interface after 15 years is very promising. Furthermore, the thermohaline circulation is well maintained in the ocean and the global oceanic secular drift is relatively small (Temperature drift: +0.4 Celsius/century; Salinity drift: +0.05 g/kg/century).
The zonal mean atmospheric temperature mirrors the SST pattern: warming in the tropics (2 ^oC), cold bias in Arctica and warm one in Antarctica. The meridional circulation becomes more symmetric: the Inter Tropical Convergence Zone (ITCZ) is shifted southward as is the rain belt associated to the Indian monsoon. The jet streams location is correct but the intensity of stratospheric jets has increased due to a stronger meridional SST gradient.
In the tropical ocean, the simulated thermocline is tight and shows a marked "W" structure. These features are usually not represented by coupled models which have a smooth and diffuse thermocline.
Coupling an ocean to the atmosphere model (CG3) has improved the summer monsoon simulation giving more realistic precipitation with less of a precipitation maximum over Sumatra. In the two simulations CG3 and CA1, the interannual variability is marqued in the equatorial Pacific ocean. The SST signal is concentrated in the eastern part. The amplitude is around $\pm 2°C$ in CG3, and $\pm 4°C$ in CA1. A westward propagation of the anomalies occurs sometimes, until the date-line.

Figure 3.1: Latitude-time diagram of SST in CA1 and CG3 coupled experiments.

$\boxed{4}$ Sea-ice Coupling

4.1 Coupling of a sea-ice mixed-layer model with an atmospheric GCM

Sea-ice is an essential element of the world climate which, both affects present-day climate and responds sensitively to climatic changes. Aside from direct effects (Earth surface albedo, insulator between ocean and atmosphere), sea-ice phase changes act upon surface-water salinity and play a major role in the deep and bottom water formation. A realistic simulation of high latitude sea-ice is thus widely regarded as essential for long-term climate simulations with global coupled models.

We have investigated the coupling of a sea-ice mixed-layer model developed at l'Université Catholique de Louvain-La-Neuve (UCL) [1] with the Météo-France/CNRM ARPEGE model. The sea-ice model domain is global and its grid is identical to the T42 gaussian grid used by the spectral atmospheric GCM. In the ocean, the vertical and salinity profiles are stored on a 12-layer grid. The sea-ice model has representations of both ice thermodynamics and dynamics.

Control runs with the surface thermal forcing and wind stress, provided by an AMIP(1979-1993) atmospheric run, have been performed with both the thermodynamic and dynamic versions. The simulated ice thickness and velocity fields are in general agreement with observations. In particular, the ice edge position during winter months is reasonably well simulated by the model. The first coupled attempt revealed some problems in the treatment of the air-sea-ice interface due to the presence of both ice and open-water within the same grid-point area. The problem has been identified and work is in progress to have a consistent treatment of turbulent and radiative fluxes in the sea-ice and atmospheric models.

[1] T. Fichefet, M. M. Maqueda, S. Planton, and C. Bellevaux, (1994), A global sea-ice-upper-ocean model: some preliminary results, In *Proceedings of the 93's International Symposium on on Sea Ice, Beijing*, Beijing, China, China Ocean Press, 64–77.

$\boxed{5}$ Simplified Models of Climate Paradigms

5.1 El Niño: Interaction Wave/Basic State

Linear approachs of the tropical coupling Ocean-Atmosphere show that coupled modes can become unstable [2, 3, 4]. In one of the approaches, a coupled mode, called T_K, seems to explain the onset of the El Niño [4]. The T_K-mode becomes unstable when the basic zonal SST gradient overcomes the damping effect of the mean upwelling.

A dynamic system has been developed to simulate the interaction of this T_K-mode with a basic state supposed to reproduce the behavior of the large structure of the equatorial Pacific ocean [1, 5]. In this first attempt, the damping effect of the upwelling has been fixed constant. Then the unstable behavior of the T_K-mode was driven only by the SST gradient. The first simulation was made without seasonal cycle in the basic state. Then, the T_K-mode appears periodically with a four and a half year frequency. The characteristic time of the warming generated by the T_K-mode is around one year. When the seasonal cycle is added in the basic state, the occurrence of the warming becomes more chaotic, without phase locking with the seasonal cycle. This result gives credit to the recent idea that the chaotic occurrence of El Niño is linked to the seasonal cycle forcing.

It has been noticed in the forced simulation FG2 of OPA, that around the date-line, the upwelling decreases each year around September, and mainly when El Niño occurs. Then the grow rate of the T_K-mode also would increase, and that could explain the phase locking of such events with the seasonal cycle. This observation has motivated the extension of the study, which will include the temporal evolution of the upwelling damping effect.

[1] T. Moliner, (1994), Etude du phénomène El Niño à l'aide d'un modèle simplifié de l'océan Pacifique équatorial, Tech. Rep. Stage de DEA, Université Paul Sabatier, Toulouse, France.

[2] D. Neelin, (1991), The Slow Sea Surface Temperature Mode and the Fast-WaveLimit: Analyical Theory for Tropical Interannual Oscillations and Experiments in a Hybrid Coupled Model, *J. Atmos. Sci.*, **48**, 584–606.

[3] M. Pontaud and O. Thual, (1994), Some Effects of a Mean Zonal Thermocline Gradient on Planetary Equatorial Waves, *Annales Geophysicae*, submitted.

[4] M. Pontaud, (1994), El Niño, une approche analytique simplifiée, Tech. Rep. STR/CMGC/93-32, CERFACS, Toulouse, France.

[5] O. Thual and M. Pontaud, (1994), El Niño - Southern Oscillation: from coupled GCM's to box models, In *20th International Conference on Mathematical Geophysics*, Villefrance, France.

5.2 Thermohaline oceanic circulation

The thermohaline circulation is forced by horizontal buoyancy contrasts at the ocean surface as a result of fluxes of heat and freshwater exchanged with the overlying atmosphere, sea ice, or the adjacent land through river run-off. Operating at large spatial scales and transferring laterally substantial amounts of heat, water and chemical tracers, the thermohaline circulation plays a major role in climate system.

Both simplified and general circulation models are useful to study the sensitivity of the thermohaline circulation to the competing effects of heat and fresh water forcing and its variability (see, for example, [7, 3]).

The model considered here is a bi-dimensional (latitude-depth) model based upon the Boussinesq approximation in a rectangular basin with flat bottom and forced by a temperature field and a freshwater

flux imposed at the surface. Numerical simulations of this model are performed and their results are compared to analytical results in the thin layer limit. The asymptotic expansion is described in [1, 4].
A geometric interpretation of the asymptotic equations has been given in [5]. The domain where multiple equilibria and fronts are susceptible to exist, and a parametric plot reliable to the forcings can be drawn on the same plane. The intersection of the different curves indicate the topological structure of the equilibria.
The validation of the asymptotic expansion has been performed with two types of forcings. Following the geometrical construction, the first one enables the presence of multiple equilibria, the second one is designed to generate the presence of stationary fronts between two counteracting loops of the circulation. The solutions observed correspond qualitatively to these predictions [6].
More precisely, in the presence of multiple equilibria, the asymptotic equations are almost fulfilled. We observe that the streamfunction is of low intensity, which validates the asymptotic approach. In the case of fronts, the same observation is made, except in the vicinity of the fronts, where the asymptotic hypothesis of thin layer is wrong (i.e. the horizontal scale of the fronts is of similar magnitude as the depth). On the other hand, the asymptotic expansion is unable to predict the precise location of the fronts.
Of course, this validation of the asymptotic expansion has been performed with relatively strong aspect ratios ($k = .2$ and $.1$), because of numerical reasons. The investigation of very low aspect ratios will be performed during the next months in the University of Utrecht, using a steady solver software, developed by H. Drijska.

Some attention has been given to the implementation of the rotation, parameterized by an orthogonal velocity vector, in both code and asymptotic expansion [2]. This work will be pursued in collaboration with P. Cessi from the FISBAT-CNR Institute (Bologna, Italy). This activity is performed in the framework of an European contract (MAST-CT92-0034).

[1] P. Cessi and W. Young, (1992), Multiple equilibria in two-dimensional thermohaline circulation, *J. Fluid Mechanics*, **241**, 291–309.

[2] P. Cessi, L. Fleury, and O. Thual, (1994), A symmetric model of the thermohaline circulation with rotation and wind stress forcing, Epicoa Letters 1612, CERFACS, Toulouse, France.

[3] T. Delworth, S. Manabe, and R. Stouffer, (1993), Interdecadal variations of the thermohaline circulation in a coupled ocean-atmosphere model, *J. Climate*, **6**, 1993–2011.

[4] tech. rep.

[5] L. Fleury and O. Thual, (1994a), Detailed comparison of numerical simulations and asymptotic predictions, Epicoa Letters 1512, CERFACS, Toulouse, France.

[6] L. Fleury and O. Thual, (1994b), The regional structure of multiple equilibria of the thermohaline oceanic circulation, Epicoa Letters 1006, CERFACS, Toulouse, France.

[7] O. Thual and J. McWilliams, (1992), The catastrophe structure of thermohaline convection in a two-dimensional fluid model and a comparison with low-order box models, *Geophys. Astrophys. Fluid Dynamics*, **64**, 67–95.

6 Computer Science Developments

6.1 OASIS: a general and modular coupling software for climate simulations

The OASIS coupler [3] is a set of fortran routines which enables the coupling of oceanic and atmospheric general circulation models (GCMs) on a supercomputer. OASIS is extremely modular as each routine has only one well defined task. It respects the GCMs structure as very few changes have to be implemented in the two models being coupled. In particular, the specific options of each model (multitasking, I/O, number of CPU used...) are left untouched. Furthermore, the three programs are considered as different processes in the UNIX sense and so synchronization is done using message passing with special files (named pipes). The coupler performs all the coupling stages sequentially which allows a quick understanding of its structure. It offers many options regarding interpolation schemes, I/O formatting and the type of models being coupled.
The current version (1.1) of OASIS has been validated and used quite extensively during 1994. Current efforts regard implementation of the Coupling Library for Interfacing Models (CLIM) [2] within the OASIS program [1]. This library will allow distributed coupled simulations as well as the coupling of parallel models on MPP machines. Version 2.0 (release date: June 1995) will have these features as well as some changes in the code structure (use of the cpp C-preprocessor, portability to workstation, dynamic definition of the coupling fields).

[1] E. Sevault, P. Noyret, L. Terray, and O. Thual, (1994), Distributed and coupled ocean-atmosphere modelling, In *In Proceedings of the Sixth ECMWF Workshop on the Use of Parallel Processors in Meteorology, ECMWF, November 21-25*, Shinfield Park, Reading UK, ECMWF, In press.

[2] E. Sevault, (1994), CLIM: Coupling Library for Interfacing Models. User's Guide and Reference Manual, Version 1.0, Technical Report TR/GMGC/94, CERFACS, Toulouse, France.

[3] L. Terray, (1994), The OASIS coupler user guide version 1.0, Tech. Rep. TR/CMGC/94-05, CERFACS, Toulouse, France.

6.2 VAIRMER: the experiment manager

The aim of the VAIRMER Experiment Manager is to provide a set of tools for the launching, the control and the post-processing of numerical climate experiments. As of today, such experiments involve the coupling of several General Circulation Models (ocean-atmosphere-ice). In charge of the design of the community "coupler" OASIS, the Global Change team of CERFACS has been faced face with the need of an *integrated* package that could handle the numerical tools of an heterogeneous climate research community. This need is now filled with the present version of VAIRMER . The post-processing part, being the most urgent, was developed first. VAIRMER provides an efficient and homogeneous environment to store, analyze, compare and visualize experiments done with the community General Circulation Models (ARPEGE-Climat and LMD AGCM, OPA6 and OPA7 OGCMs and the Louvain Ice model). It requires little time investment, no specific computer knowledge and is together simple and powerful. VAIRMER is an open system: its modular UNIX structure makes it easy for the user to implement new models and new functionalities.
VAIRMER is now used routinely by the climate community (CERFACS, CNRM, LMCE, LODYC, LMD, ...) for storage, analysis and visualization purposes.

[1] E. Guilyardi, L. Terray, and O. Thual, (1994), The VAIRMER Experiment Manager. Part I: A description of the project, Epicoa Letters 0222, CERFACS, Toulouse, France.

[2] E. Guilyardi, (1994), The VAIRMER Experiment Manager. User's Guide and Reference Manual, Version 2.1.1, Technical Report TR/GMGC/9404, CERFACS, Toulouse, France.

6.3 CLIM: the coupling library

CLIM (Coupling Library for Interfacing Models) [1] provides an easy way for coupling independent models running on various plateforms under PVM. To build this tool, some specifications have been gathered :

- Clim allows to couple parallel codes even if the parallelism is expressed outside of the temporal loop.

- Programs should remain independent Unix processes without any hierarchical dependence.

- Reliability is of major importance. Therefore, multiple checks are performed before any communication operation. Time-out control and detailed trace file are provided as well as two level of error codes.

- The global configuration of the coupled application is hidden as most as possible and should be fixed only at execution time. Real-case simulations have been carried out : CLIM was used in OASIS to couple the atmospheric model ARPEGE to the ocean model OPA.

CLIM is available as compressed archive file by anonymous ftp to orion.cerfacs.fr in the /pub/algo/softw directory.

[1] E. Sevault, P. Noyret, and L. Terray, (1994), Coupling Library for Interfacing Models. User's Guide and Reference Manual, Version 1.0, Technical Report TR/GMGC/94, CERFACS, Toulouse, France.

[2] E. Sevault, P. Noyret, L. Terray, and O. Thual, (1994), Distributed and Coupled Ocean-Atmosphere Modelling, In *Proceedings of the VI ECMWF Workshop on the Use of parallel processors in Meterology*, Reading, England, ECMWF.

6.4 CATHODe: a distributed computing project

We have conducted a collaboration with EDF/DER on the exploration of real size distributed computing, on the example of ocean-atmosphere coupling. We have benefited from the support of the GLPP team, in the person of P. Noyret, and from the expertise of the Algo team.
The goal of the so-called CATHODe project [2] (Couplage Atmosphère Océan Distribué) is to run the atmosphere and the ocean General Circulation Models (GCMs) on two different supercomputers communicating through the network. We have performed a **two year simulation** in which ARPEGE was running on the CRAY C-90 of EDF/DER and the global version of OPA on the CRAY C2 of METEO-FRANCE, the two codes communicating through the RENATER network. Each day of simulation (about 5mn of elapsed time), the two codes exchange their fluxes which are interpolated from one grid to another by an independent code. We have tested and compared two coupling procedures based on the PVM (Parallel Virtual Machine) software. One procedure is based on the general purposes coupler CALCIUM [1] developed at EDF/DER that we had to apply to the ocean-atmosphere example. The other procedure is based on the software CLIM developed at CERFACS (see Section 6.2) that we have included in the OASIS coupler. Experiments have also been performed in which the two CRAY computers of METEO-FRANCE were communicating.
These achievements have demonstrated that distributed computing was possible for big codes, but has also pointed out a number of needed improvements. Detailed measurements of the computing time have been performed [3]. These experiments open the way for further applications in which the localization of the code environment is a critical factor.

[1] D. Beaucourt and C. Caremoli, (1994), A new tool for codes coupling, In *Proceedings of the Fall CUG 94, October 10-15.*

[2] J. Cahouet and D. Beaucourt, (1994), le projet CATHODe, tech. rep., Internal Report EdF/DER, Clamart, France.

[3] E. Sevault, P. Noyret, L. Terray, and O. Thual, (1994), Distributed and Coupled Ocean-Atmosphere Modelling, In *Proceedings of the VI ECMWF Workshop on the Use of parallel processors in Meterology*, Reading, England, ECMWF.

6.5 VISUO 3.1: the animation software

For the second year, we have continued the development of the visualization software VISUO [1], in collaboration with Dominique Astruc, former participant of the CERFACS Visualization team in 1993 and now working at the ENSL (Ecole Normale Supérieure de Lyon). We have welcomed back Dan Davidson as a student engineer for a one month period to upgrade VISUO to the 3.1 version [1].
VISUO, originally developed by D. Astruc [3], proved to be well-suited for climatic data visualization and very efficient in animation on the available hardware platforms. In 1993, we have decided to upgrade the original version of Visuo by including in the software some new features (coastlines, superposition of scalar and vector fields, new interface, etc.), leading to VISUO 3.0 [2], a new major release of the software.
This year, the 3.1 version has brought new features such as workstations compatibilities (SGI or IBM, 8- or 24-plans graphic cards, etc.), automatic launching, and synchronous animations between two VISUO processes. The user manual has been updated, and the software has been distributed to various laboratories, among which are LODYC[1] and IMFT[2].

[1] D. Astruc and D. Davidson, (1994), VISUO. User's Guide and Reference Manual, Version 3.1, Technical Report TR/GMGC/94, CERFACS, Toulouse, France.

[2] D. Astruc, D. Davidson, O. Thual, A. Rompteaux, and J. L. Estivalezes, (1994), VISUO 3.0 for flow visualizations, Tech. Rep. 0716, Epicoa Letters, CERFACS, Toulouse, France.

[3] D. Astruc, (1990), Visuo 1.0: un manuel pour l'utilisateur, Tech. Rep. 25 juillet, ONERA/CERT/DERMES, Toulouse, France.

[1] Laboratoire d'Océanographie Dynamique et de Climat
[2] Institut de Mécanique des Fluides de Toulouse

7 Conclusion

After four years of intensive efforts and human investments, the quality of the achievements realized this year shows that this project is a complete success. Starting from scratch, the team has been able to combine advanced software developments with an ambitious experiment planning while reaching a good scientific level in climate studies. The creation of such a team in the French climate community, at the interface between atmospheric and oceanic modelling, has enabled the development of a climate coupled model which compares to those of other European and international countries. The quality of the three coupled experiments that are detailed in the present report shows that the ARPEGE-OASIS-OPA coupled model opens the way for pertinent climate studies, in coordination with other laboratories.
As far as the organization of the "Climate Modelling & Global Change" is concerned, the planning of Figure 1.1 will be eventually replaced by a more conventional scientific program, articulated around thematic studies rather than an integrated project. We have started a brain storming to determine how this program could be structured. We plan to prepare its implementation during 1995 which can be seen as a transition year between the original "project-like" planning and the future scientific program. This transition takes into account the fact that three Ph.D. students will defend their thesis at the end of 1995 and that the new structure will rely on the activities of the five remaining researchers (see Table 1.3). This program is based on the following research axes:

- Coupled model development
  - Impact of physical parameterizations
  - Hybrid coupled models
- Short term variability (< 10 years)
  - El Niño and the Southern Oscillation (ENSO)
  - Seasonal cycle in the Indo-Pacific region
  - High frequency Madden and Julian (MJ) oscillations, blocking and storms
- Decadal to secular variability (> 10 years)
  - Water mass formation and abyssal circulation
  - Sea-ice coupling
  - Climate change scenarios.
- Software development
  - OASIS (the coupler)
  - VAIRMER (the experiment manager)
  - VISUO (a visualization tool)

In addition to these already launched scientific subjects, the "Climate Modelling & Global Change" team is ready to use its double competence in scientific computing and climate modelling, to tackle new fields, such as the assimilation of altimetric data in global climate models. The investments which are necessary to fulfill this type of scientific objectives are of the order of magnitude of the ones which have been needed to create the "Climate Modelling & Global Change" team. We expect that the means will be in good adequation with the objective, in order to maintain the quality of our scientific activities.

8 Conferences and seminars of the "Climate Modelling & Global" Team

January 94

Fuengirola (Málaga, Spain), workshop on "Fluxes through Straits and Passages", Fuengirola (Málaga). Chairman and rapporteur (J. Macías).

Torremolinos (Málaga, Spain), Simposium "Modelado de Sistemas en Oceanografía, Climatología y Ciencias Medio-Ambientales: Aspectos Matemáticos y Numéricos", January 24-26, 1994. Organizing committee (J. Macías). Invited talk : "Ocean-atmosphere coupling at CERFACS" (O. Thual).

February 94

Toulouse, METEO-FRANCE/CNRM, Workshop on "Arpège Climat", February 8-11, 1994. Attended (J. Macías, E. Guilyardi, M. Pontaud, L. Fleury, S. Belamari). Organization of the the coupling day (11, 1994) (L. Terray, O. Thual).

March 94

Lyon, ENSL, GDR "Fluides Géophysique". Communication: "Thermohaline Convection and Multiple Equilibria" (O. Thual).

Toulouse, METEO-FRANCE/CNRM, March 31, 1994 seminar. Invited talk: "Modélisation du Climat et de son Changement Global" (O. Thual).

April 94

Grenoble, XIX General Assembly of the European Geophysical Society (EGS), April 25-29, 1994. Communications: "Catastrophe Structure and Asympotic Expansions of Thermohaline Convection" (L. Fleury), "Seasonal and interannual variability in the tropical Pacific simulated by the ARPEGE-OPA coupled model" (L. Terray) and "Interannual variability simulated in the tropical Pacific Ocean" (S. Belamari). Posters: "GCM simulation of the southern oscillation and its dependence on the model horizontal resolution" (D. B. Stephenson), "The Tk-mode and the Onset of El Niño" (O. Thual) and "High latitudes processes of a global OGCM / AGCM coupling" (G. Garric).

June 94

Villefrance, "20th International Conference on Mathematical Geophysics", June 19-24, 1994. Invited speaker: "El Niño - Southern Oscillation: from coupled GCM's to box models" (O. Thual).

July 94

Noordwijkerhout (the Netherlands), "International Conference on Nonlinear Dynamics and Pattern Formation in the Natural Environment". Invited speakers: "Catastrophe Structure and Asympotic Expansions of Thermohaline Convection" (O. Thual)

London (United Kingdom), Royal Society "European conference on the global energy and water cycle". Invited speaker : "Moist processes in a 3D coupled ocean atmosphere model" (D. Stephenson).

August 94

Oxford (United Kingdom) University, Monday, 8 August 1994. Invited talk: "Pacific variability in the CERFACS coupled run" (D. Stephenson).

Toulouse TOGA-COARE international data workshop, Météo-France, 1-11th August 1994. Communication : "Westerly wind bursts in the CERFACS coupled run" (D. Stephenson).

Reading (United Kingdom) ECMWF Research Department, thursday, 18 August 1994. Invited talk: "Coupled modelling at CERFACS" (L. Terray).

September 94

Sevilla (Spain), VI Escuela Hispano-Francesa de Simulación en Mecánica y Física. Attended (J. Macías).

October 94

La Jolla (California), Scripps workshop on "Global coupled general circulation models". Invited talk: "Global coupled modelling at CERFACS" (D. Stephenson).

Athens (Greece), "Advanced Course on Computational and Modeling Aspect of Oceanography" School, 3-21 October 1994. Lecturer (M. Pontaud).

November 94

Toulouse, Workshop of the "CATHODe" contract with EDF. Organization (O. Thual). Communications: "Ocean-atmosphere coupling" (L. Terray) and "CLIM: a coupling software" (E. Sevault).

Lisboa (Portugal), 1^o Simpósio sobre a Margem Continental Ibérica Atlantica. Chairman and invited talk: "Numerical modelling of water mass exchanges through the Strait of Gibraltar (J. Macías)

Paris, LODYC, November 29th 1994 seminar. Invited talk: "Une Etude Analytique des Ondes Equatoriales Libres et Couplees" (M. Pontaud).

Fort-de-France (Martinique), SMIR-Antilles-Guyanes. Seminar: "Le Couplage Ocean-Atmosphere ; observation, theorie et simulation" (M. Pontaud).

December 94

Paris, IDRIS Scientific Committee, December 9, 1994. Participation to the Environnement Program Committee (O. Thual).

Chatou, EDF/DER, Worskop of the "Anthropogenic Climate Change" EC contract. Communication: "First results of the long climate coupled experiments at CERFACS" (O. Thual).

Cambridge (England), visit to the Fluid Mechanics Department of Schlumberger. Invited talk: "The Climate Modelling & Global Change Project at CERFACS" (O. Thual).

GRGS, Toulouse (France). Invited talk: "Climatologie et variabilité interannuelle simulées par le modèle couplé ARPEGE-OPA" (L. Terray).

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 B, Conference and seminar slides, Climate Modelling & Global team, *Internal Report* , CERFACS IR/CMGC/94 (1994).

9 Publications of the "Climate Modelling & Global Change" Team

9.1 Journals

[1] E. Guilyardi, G. Madec, L. Terray, M. Déqué, M. Pontaud, M. Imbard, D. Stephenson, M. A. Filiberti, D. Cariolle, P. Delecluse, and O. Thual, (1994), Simulation couplée océan-atmosphère de la variabilité du climat, *C. R. Acad. Sci. Paris*, in press.

[2] C. Mechoso, A. Robertson, N. Barth, M. Davey, P. Delecluse, P. Gent, S. Ineson, B. Kirtman, M. Latif, H. L. Treut, T. Nagai, J. Neelin, S. Philander, J. Polcher, P. Schopf, T. Stockdale, M. Suarez, L. Terray, O. Thual, and J. Tribbia, (1994), The seasonal cycle over the tropical Pacific in general circulation models, *Monthly Weather Review*, in press.

[3] M. Pontaud and O. Thual, (1994), Some Effects of a Mean Zonal Thermocline Gradient on Planetary Equatorial Waves, *Annales Geophysicae*, submitted.

[4] D. Stephenson and J.-F. Royer, (1994a), GCM simulation of the Southern Oscillation from 1979-88, *Climate Dynamics*, in press.

[5] D. Stephenson and J.-F. Royer, (1994b), Low-frequency variability of TOMS and GCM total ozone stationary waves associated with the El Niño/Southern Oscillation for the period 1979-88, *Journal of Geophysical Research*, in press.

[6] L. Terray and O. Thual, (1994), Le couplage océan-atmosphère, *La Météorologie*, submitted.

[7] L. Terray, O. Thual, S. Belamari, M. Déqué, P. Dandin, C. Lévy, and P. Delecluse, (1994), Climatology and interannual variability simulated by the ARPEGE-OPA model, *Climate Dynamics*, to appear.

9.2 Publications in proceedings

[1] J. Macías, D. Stephenson, L. Terray, and S. Belamari, (1994), *Interannual variability simulated in the tropical Pacific*, J.L. Lions and I. Díaz eds. Springer Verlag, Amsterdam.

[2] P. Noyret, E. Sevault, L. Terray, and O. Thual, (1994), Ocean Atmosphere Coupling, In *Proceedings of the Fall CUG 94, October 10-15.*

[3] M. Pontaud, (1994), Part 1: Numerical Techniques and Part 2: Physical Processes and Simulations, In *Advanced Course on Computational and Modeling Aspects of Oceanography, Athens, 3-21 October 1994*, National Technical University of Athens, Athens, Greece, European Communities, in press.

[4] E. Sevault, P. Noyret, L. Terray, and O. Thual, (1994), Distributed and Coupled Ocean-Atmosphere Modelling, In *Proceedings of the VI ECMWF Workshop on the Use of parallel processors in Meterology*, Reading, England, ECMWF.

[5] L. Terray and O. Thual, (1994), Coupled Ocean-Atmosphere Simulations, In *Proceedings of the workshop "High Performance Computing in the Geosciences", Les Houches, June 1993*, F.X. Le Dimet, Ed., Kluwer Academic Publishers B.V, Netherland, NATO, in press.

[6] O. Thual and L. Terray, (1994), Ocean-atmosphere coupling at CERFACS, In *Proceedings of the Symposium "Modelado de Sistemas en Oceanografía, Climatología y Ciencias Medioambientales: Aspectos Matemáticos y Numéricos", Málaga, 24-26 January 1994*, Spain, Publicaciones del Grupo de Análisis Matemático Aplicado de la Universidad de Málaga, vol. 6, 141–147.

9.3 Technical Reports

[1] E. Guilyardi, (1994), The VAIRMER Experiment Manager. User's Guide and Reference Manual, Version 2.1.1, Technical Report TR/GMGC/9404, CERFACS, Toulouse, France.

[2] T. Moliner, (1994), Etude du phénomène El Niño à l'aide d'un modèle simplifié de l'océan Pacifique équatorial, Tech. Rep. Stage de DEA, Université Paul Sabatier, Toulouse, France.

[3] M. Pontaud, (1994), El Niño, une approche analytique simplifiée, Tech. Rep. STR/CMGC/93-32, CERFACS, Toulouse, France.

[4] E. Sevault, P. Noyret, and L. Terray, (1994), CLIM: Coupling Library for Interfacing Models. User's Guide and Reference Manual, Version 1.0, Technical Report TR/GMGC/94, CERFACS, Toulouse, France.

[5] L. Terray, (1994), The OASIS Coupler User Guide Version 1.0, Tech. Rep. TR/CMGC/94-05, CERFACS, Toulouse, France.

9.4 Epicoa Letters

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" team. 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 prior to 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 sought.
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. The letters of Volume III, which have appeared in 1994 are listed below.

[1] tech. rep.

[2] P. Cessi, L. Fleury, and O. Thual, (1994), A symmetric model of the thermohaline circulation with rotation and wind stress forcing, Epicoa Letters 1612, CERFACS, Toulouse, France.

[3] tech. rep.

[4] L. Fleury and O. Thual, (1994a), Detailed comparison of numerical simulations and asymptotic predictions, Epicoa Letters 1512, CERFACS, Toulouse, France.

[5] L. Fleury and O. Thual, (1994b), The regional structure of multiple equilibria of the thermohaline oceanic circulation, Epicoa Letters 1006, CERFACS, Toulouse, France.

[6] G. Garric, E. Guilyardi, and M. Pontaud, (1994), A serie of figures from the ARPEGE C11 AMIP FORCING GA1 Experiment, Epicoa Letters 0110, CERFACS, Toulouse, France.

[7] E. Guilyardi, L. Terray, and O. Thual, (1994), The VAIRMER Experiment Manager. Part I: A description of the project, Epicoa Letters 0222, CERFACS, Toulouse, France.

[8] E. Guilyardi, (1994), A Reference Atlas for the ARPEGE-Climat AMIP Forcing GA2 Experiment, Epicoa Letters 0604, CERFACS, Toulouse, France.

[9] J. Macías, D. Stephenson, L. Terray, and S. Belamari, (1994), Description and results of the OPA/FSU forced experience (OF1), Epicoa Letters 1215, CERFACS, Toulouse, France.

[10] M. Pontaud, (1994a), Lecture notes of the MAST program, Epicoa Letters 1109, CERFACS, Toulouse, France.

[11] M. Pontaud, (1994b), Moyennes Mensuelles des SST COLA-CAC sur la période 1979 à 1993, Epicoa Letters 0430, CERFACS, Toulouse, France.

[12] M. Pontaud, (1994c), Quelques Notes sur l'Afrique et son Climat, Epicoa Letters 0310, CERFACS, Toulouse, France.

[13] M. Pontaud, (1994d), Quelques Notes sur l'Océan Indien et les Moussons, Epicoa Letters 0224, CERFACS, Toulouse, France.

[14] D. Stephenson, (1994a), COADS and the Oberhuber flux climatologies now available in VAIRMER format, Epicoa Letters 1118, CERFACS, Toulouse, France.

[15] D. Stephenson, (1994b), Precipitation climatologies now available in VAIRMER format, epicoa letters, CERFACS, Toulouse, France.

[16] O. Thual, L. Terray, D. Stephenson, M. Pontaud, J. Macías, E. Guilyardi, G. Garric, L. Fleury, and S. Belamari, (1994), The CERFACS participation to the EGS conference, Epicoa Letters 1505, CERFACS, Toulouse, France.