TEF-ZOOM Research Project

(LMD-CIRED-LE, September 2003)

Reciprocal influences between environment and human society are the topic of many national and European research projects (as ENSEMBLES). These projects are built from the questions of interest for decision-makers, who have to make development choices (concerning sustainable development, governance, fair trade, North-South relationship) to cope with social problems due to climate change. It is well known that these problems involve strong methodological problems, concerning the scientific understanding and control of models and the understanding of the underlying phenomena : a precise definition of the Climate-Economy problem has still to be built. This project is to propose to build a new approach, based on methods we developed in Engineering Sciences and Climatology.

1 A proposal to use the TEF-ZOOM framework in order to deal with the Climate-Economy issue

- The Climate-Economy issue requires the use of models to analyse interactions between both fields. The difficulty comes from the high complexity of each domain and from the fundamentally different natures of the involved objects (in particular concerning Time, Human behaviour modelling and uncertainty accounting).
  It is already difficult to establish a relevant simplification level in a homogeneous disciplinary field. The difficulty is here increased since we have to cope with numerous fields, based on different approaches and different concepts. To overcome this problem, we chose to put the stress on the interface, in order to focus on the objects through which the inter-influences act.
  However, the definition of interfaces between climatic and economic system is made difficult by i) spatial and temporal scale differences ; ii) the multiplicity of reciprocal influence modes ; iii) conceptual differences between physical science models and economic models.
- The Climate-Economy problem requires both *prediction models* (detailed ; realistic ; exhaustive) and *analysis models*, which aim at identifying critical mechanisms, particularly those that are difficult to integrate in prediction models. In other terms, it is necessary to be able to simulate correctly the system evolution, but also : i) to assess the system sensitivity to changes in any unknown parameter (for instance in the future productivity growth) and to changes in any elements on which mankind has a direct influence (for instance in the cultivated area surface or in deforestation) ; ii) to analyse the system response to shocks, coming from the climate system (for instance a bifurcation as the collapse of the thermohaline circulation), from the economic system (as the reach of a profitability limit in a sector), or from a political choice (as a change in

the energy policy).
Debates concerning climate change have shown that the temporal patterns of the responses to such shocks are essential in the building of efficient politico-economic decisions aiming at adapting or at preventing global change damages. This is why the prediction and public decision processes necessitate the knowledge of characteristic times involved in elementary natural processes or in conceivable political actions.

- Studying such systems, that are complex and opaque systems involving strongly coupled processes, requires methods using sensitivity analysis and feedback loop analysis. For instance, the IPCC-2001 report describes the climate system as a set of feedback loops, which enables a simple description of the system response to solicitations and to understand essential mechanisms. However, usual feedback analysis techniques ignore dynamical aspects. As a consequence, dynamical aspects are handled much more awkwardly and are thus ill understood.
  We propose to use the TEF-ZOOM framework, a method that proved useful in many instances in the fields of engineering and climate sciences. It enables the design and analysis of intermediate complexity models (i.e. with no more than a few thousand equations) and is thus not in competition with high complexity model coupling systems. It allows, while performing simulations of the time evolution of a system, to analyse the dynamical response to a shock, to quantify couplings between model elements and to describe dynamically feedback loops present in the system.

2 Project work-plan

The project aims at designing a method for building coherent climatic and economic scenarios (i.e. scenarios in which the expected economic development is actually possible in the simulated climate, a constraint which is not taken into account in SRES scenarios). Meeting this goal will require software developments (model developments and improvements of ZOOM software environment), theoretical and formal developments concerning coupling and feedback analysis.

2.1 Designing coherent scenarios

The program will comprise three steps. The first two (feedback loop analysis, first separately in climatic and economic fields, then in the coupled system) constitute the very core of the project. The third one will assess the method performances by actually building coherent scenarios.

1. **Assessment of the relevance of feedback loop analysis** (using simple models of climate and economy). Review of the IPCC-2001 report, assumed to be a state of the art analysis of the economy and climate systems. Some results have already been obtained in the climate field, concerning the water-vapour feedback loop. Applying the same type of analysis in economics is much more innovative. First tests have been performed using a simple projection model of macroeconomic equilibrium (French programs GICC

2000 and 2002) ; these tests proved the possibility of using TEF-ZOOM method in economics.

2. **Study and analysis of the main components of the interface coupling economy and climate** (using simple models of climate, economy and impacts). Exhibiting and describing economy-climate feedback loops. Assessment of the importance of these feedback loops in the dynamics of the coupled system. Design of a method for building coherent climatic and economic scenarios.
3. **Assessment of the method by actually building up coherent scenarios**. Climate simulations will use the IPSL coupled model. Economic simulations will use a multi-sector multi-region macroeconomic model. Impact models are still to be determined (e.g. food and water resource model).

These work-packages necessitate three tasks to be developed in parallel :
- Implementing simplified models of climate and economy under the ZOOM computer environment
- Implementing in ZOOM diverse macro-economic models already existing at CIRED
- Further development of tools for feedback, sensitivity, coupling mechanisms analysis, stability analysis. Design of a specific software to simplify the implementation of models.

Available computer tool facilities will be searched for to look for the most simple ways of addressing the preceding development. It is thus necessary to identify the different components of ZOOM in its present state, specify its functional characteristics, in the objectives of being able to evaluate whether new software facilities might bring improvement. Such a specification of ZOOM should also facilitate interactions with scientists from other fields, concerning numerical sciences, computer sciences, and experts in computer tool development.

2.2 Theoretical and formal developments

Numerous theoretial and formal developments will be simultaneously carried out concerning :

- **Feedback mechanisms** : using the Linear Tangent System to characterise the full system dynamics and its stability. Search for optimal numerical methods. A theoretical project has been submitted to the European 6thFP concerning these problems with a mathematician team (cf. http ://prism.enes.org/capri/CAPRI_sub_pdf.tar).
- **Sensitivity analyses to diverse sources** : initial conditions, known to bring information on systems evolution and possible bifurcation toward existing attractors that can be met along a trajectory ; modification of the system parameters, either intrinsic or stemming from interfaces with other systems or boundary conditions. Such analyses are useful to grade the role of the different physical mechanisms which are driving the system behaviour.
- **Analysis of the non-linearity of models** : in climatology, using perturbed trajectories brings insight of the effect of non-linearities, depending upon the temporal scale of analysis. Linear analyses along the trajectories can be matched with full model behaviour. This is thought as tentative development.

- **Alternative approaches using System Dynamics Theory and spectral analysis**
- **Heuristic approaches** : use of TEF-ZOOM facilities to characterise summary functions of full systems (as in Lyapunov exponent methods). Characteristics time of the system can be recovered from the summary functions, feed-back loops can be specified to match time-responses with physical mechanisms, etc.
- **Use of the adjoint system**. The forward Jacobian matrices computed along the system trajectory in ZOOM environment is used to build the adjoint of the system. The adjoint allows to compute the sensitivity of any global or local variable to system parameters or initial conditions, given any (eventually large) number of them. The adjoint is also classically used in identification and fit problems, which offers solutions to the classical calibration problem of climatic and economic models.

3 Description of participants

1. **Laboratoire de Météorologie Dynamique**
   (Director : Hervé Le Treut) Founded in 1968, the "Laboratoire de Météorologie Dynamique" of C.N.R.S. employs some 150 persons spread over three sites : l'École Polytechnique, l'École Normale Supérieure, and l'Université Pierre et Marie Curie. Its research program consists in studying the mechanisms, the evolution and the prediction of meteorological and climatic phenomena.

   The CeMCOEP (Director : Michael Ghil) is a new unity depending on LMD in Ecole Normale Supérieure. Its research fields concern the Climate-Economy issue in its methodology and mathematic (particularly system dynamics) components.

   Up to now, 3 researchers and 1 engineer use TEF/ZOOM as their modelling tool and about 20 researchers are interested in the Climate-Economy issue.

   Alain Lahellec is the person to contact in LMD (alain@lmd.jussieu.fr).
2. **Centre International de Recherche sur l'Environnement et le Développement**
   (Director : Jean-Charles Hourcade) CIRED was founded in 1973 by Professor Ignacy Sachs in order to study tensions between environment, natural resources long term management, and economic development. In the seventies, CIRED pioneered the eco-development approach, aiming at reducing and preventing these tensions by acting on three main groups of variables : consumption patterns, technological choices, and space management. The themes presently dealt with cover environmental economy and management.

   Up to now, 2 PhD students use TEF/ZOOM as their modelling tool and about 15 researchers are directly concerned by the Climate-Economy issue.

   Stéphane Hallegatte is the person to contact in CIRED (hallegatte@centre-cired.fr).
3. **Laboratoire d'Énergétique**
   (Director : Richard Fournier)

   The LE depends on the Paul Sabatier university in Toulouse. Its research fields are convection and thermic environment ; Radiation and corpuscular transport ; and diphasic systems and phase change phenomena. More generally, the laboratory has a

strong capacity in complex system dynamics and numerical simulations.
4 researchers of the LE are involved in this TEF/ZOOM project.
Jean-Louis Joly is the person to contact in LE (jlj@sphinx.ups-tlse.fr).