AN ATMOSPHERE-OCEAN MODEL FOR INTEGRATED ASSESSMENT OF GLOBAL CHANGE

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Abstract. This paper describes the atmosphere-ocean system of the integrated model IMAGE 2.0. The system consists of four linked models, for atmospheric composition, atmospheric climate, ocean climate and for ocean biosphere and chemistry. The first model is globally averaged, the latter are zonally averaged with additional resolution in the vertical. The models reflect a compromise between describing the physical, chemical and biological processes and moderate computational requirements. The system is validated with direct observations for current conditions (climate, chemistry) and is consistent with results from General Circulation Model experiments. The system is used in the integrated setting of the IMAGE 2.0 model to give transient climate projections. Global surface temperature is simulated to increase by 2.5 K over the next century for socio-economic scenarios with continuing economic and population growth. In a scenario study with reduced ocean circulation, the climate system and the global C cycle are found to be appreciably sensitive to such changes.

Keywords: climate model, atmospheric chemistry, oceanic C cycle, scenario evaluation, integrated model.

1. Introduction

Integrated global modeling of global change involves describing a broad variety of processes like changing energy demands and changing land use, having effects like changing anthropogenic concentrations of greenhouse gases and a change in surface albedo. These changes affect the climate, which in turn may provide feedbacks (positive or negative) to the system (for example, further changes in vegetation, effects on sources and sinks of greenhouse gasses). In this series of processes the characterization of the atmosphere and ocean (consisting of atmospheric chemistry, the atmospheric climate, the ocean climate and oceanic C cycle) can be grouped together in a natural way. This paper describes the atmosphere-ocean system of IMAGE 2.0 (Alcamo *et al.*, 1994a). The atmosphere-ocean system of models consists of four submodels: atmospheric composition, atmospheric climate, ocean climate and ocean biosphere and chemistry. After an introduction to the entire atmosphere-ocean system, each of the component models is described in turn, together with their validation. The linkage of these models is then reported and results from the four linked models are compared to equilibrium General Circulation Model (GCM) results. Finally, results from transient runs are reported.

The emphasis on the atmosphere-ocean calculations in an integrated model depends strongly on the goals of such a model. In a policy oriented model one may be tempted to describe the atmosphere-ocean system quite coarsely, since the management possibilities

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for this part of the system are obviously quite limited. However, to assess the effect of policy measures on "manageable" parts of the system (e.g., fossil fuel emissions, land use changes) one does need to predict the response of other parts. In this respect it is important to note that this response may change over time. For example, a change in the amount of sea-ice or snow cover changes the heat balance of the polar zones, and constitutes one of the many feedbacks in the climate system.

This implies that the atmosphere-ocean system would require a predictive rather than just an empirical ("black box") model. At present, a predictive model based on first principles of physics, chemistry and biology is not possible, both because we don't sufficiently understand these basic principles and because such a "molecular" approach would require too much computer resources. Nevertheless, we can achieve predictive "grey box" models by including a sufficient amount of physical and chemical realism and by checking the model against a variety of observations.

The level of detail depends on the purposes of the individual models, and existing models range from elaborate three-dimensional coupled ocean-atmosphere models to simple zero-dimensional (globally averaged) energy balance models. An example of the latter is the IMAGE 1.0 model (Rotmans, 1990), which is zero-dimensional in its atmosphere and one-dimensional in the ocean. Model experiments with coupled GCM's demand months of computation time on the fastest computers available, while with the simple models experiments can be carried out on a personal computer within a few minutes. In the middle of this range two-dimensional zonally and yearly averaged energy balance models (Peng *et al.*, 1982; Harvey and Schneider, 1985; Peng *et al.*, 1987) play their role with typical running times of one day per hundred years of simulation on a workstation. For our present purpose a zonally averaged 2-dimensional (i.e. latitude and height/depth) model for the atmosphere and ocean has been developed in order to include a number of latitudinally and vertically heterogeneous processes with sufficient realism, for example radiative forcing, precipitation, ocean circulation, etc. A further increase in complexity (e.g., 3-dimensional resolution) was not thought to be necessary as existing 2-dimensional models are generally able to represent the processes relevant for our purpose in sufficient detail.

In fact, apart from its ease of use and analysis, a 2-dimensional model may have a distinct advantage over 3-dimensional models in terms of flexibility of operation. In three-dimensional GCM the linkage between atmosphere and ocean models is a major modeling problem, the solution of which is still in its early stages (Neelin *et al.*, 1992). The atmosphere and ocean models are individually stable when forced by present climate observations. However, when linked together via the surface fluxes at their interface, they often exhibit a climate drift, which quickly deteriorates the simulation. As a remedy, an artificial flux correction has to be introduced to obtain an acceptable simulation of the present climate. In a more aggregated model like the present Atmosphere Ocean System, no flux correction is required and calibration of the linked model can be done more easily.

The system parts have not been selected to be the best available on its terrain. They are to form, when linked, a harmony of models, which enable transient climate projections in the context of policy analysis with IMAGE 2.0. In the following sections of this paper the