RAPID TRANSITIONS OF THE THERMOHALINE OCEAN CIRCULATION

A Modelling Perspective

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ABSTRACT

This chapter discusses the stability of the Atlantic thermohaline circulation with special emphasis on the critical thresholds and state transitions found in model experiments. The thermohaline ocean circulation is a major heat transport mechanism which causes the relatively mild climate in the North Atlantic region (including Europe) in the modern times. The formation of North Atlantic Deep Water and the associated large-scale meridional transports in the Atlantic are maintained by a positive salinity feedback (first identified by Stommel in 1961). A second positive feedback is responsible for the tendency of deep convection to reoccur in the same regions. These two feedbacks are the main reason for the non-linear behaviour of the thermohaline ocean circulation found in models; their characteristic processes, time and length scales are discussed. Simulations of plausible circulation changes during the last glacial maximum and due to future greenhouse warming are presented.

1. INTRODUCTION

The conditions that determine the climate of our planet are ever changing on all time scales. The output of the sun, the Earth's orbit, the distribution of continents, the chemical composition of the atmosphere, the elevation and vegetation cover of the land surfaces, the extent of ice cover and many other factors are variable. It is not possible to find a direct "analogue" for a future climate in the past; history never repeats itself. Therefore there is only one way in which the past can provide a window to the future: we have to dissect and understand the mechanisms of past climatic changes, and then put them together again in models. Reconstructions of past climatic changes, their spatial patterns

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and their timing provide hypotheses about possible mechanisms which can be examined in specific model experiments. Comprehensive climate models need to be tested on past climates; only if past climatic changes can be understood and simulated in models can we make confident projections into the future.

This paper discusses some aspects of this process, focussing on the Atlantic thermohaline circulation. It summarises the understanding of mechanisms of circulation changes gained from a hierarchy of models, and it reports on an early attempt to test a coupled atmosphere-ocean-sea ice model on a past climate that is radically different from the present. The same model is then used for a glimpse into possible futures.

A highly simplified cartoon of the Atlantic circulation is shown in Fig. 1. The observed winter sea ice distribution is one indication of the heating effect of this circulation, visible directly on satellite images. Another indication is the strong warm anomaly

Figure 1. Highly simplified cartoon of the Atlantic circulation: darker shading shows surface currents, lighter grey North Atlantic Deep Water. The warm North Atlantic Current heats north-western Europe, pushing back the winter sea ice margin. From Rahmstorf, 1997.