Summary

The awareness that anthropogenic activity may change climate has greatly raised the public and scientific interest in the climate system and its components. One of the main issues of present-day climate research is the stability of the global thermohaline ocean circulation. Popularly depicted as a 'conveyor belt', this overturning circulation distributes water, heat and salt world-wide, and is, for instance, responsible for the relatively mild climate in western Europe. Despite its stability during the Holocene, the thermohaline circulation played an essential role in generating the climate fluctuations and switches that characterized the Pleistocene era of ice-ages. The possibility that it attenuates or ceases completely in response to global warming gives rise to concern in view of future climate change scenario's.

The Atlantic plays an essential role in the global overturning circulation. It produces and exports a deep water mass that is known as North Atlantic Deep Water (NADW). NADW is formed by cooling and subduction of surface waters in the Nordic and Labrador Seas, and it is distributed over the entire World Ocean via the Southern Ocean. As compensation, the Atlantic imports upper layer water from the other oceans. This import takes place via two routes of which the relative importance is still a matter of debate. A part of the compensating water enters the Atlantic via the Drake Passage as part of the Antarctic Circumpolar Current ('cold-water route'). This water is cold and relatively fresh. The other part enters the Atlantic south of Africa via a process that is called 'Agulhas Leakage' ('warm-water route'). This intermittent exchange between the Indian and Atlantic oceans is mainly accomplished by large (about 300 km wide) rings that are generated abbout once per two months. Filled with warm and salty Indian Ocean water, these rings influence the stratification in the Atlantic considerably. It has even been suggested that this Indian–Atlantic transfer of salty water stimulates the Atlantic overturning circulation, since it increases the salinity of the Atlantic surface waters and facilitates subduction in the northern North Atlantic. The process of Agulhas Leakage depends strongly on details of the Indian Ocean wind climatology, and may be vulnerable to climate change. Paleoclimatological records suggest that Agulhas Leakage was strongly reduced or even absent during glacial periods. It has been suggested that the re-establishment of Agulhas Leakage at the end of the last ice-age stimulated the restart of the overturning circulation.

In this thesis it is studied how the stability and strength of the Atlantic overturning circulation are affected by the exchange of water between the Atlantic and the rest of the World Ocean. In chapter 2 a summary is given of what is known about interocean

exchange. In chapter 3 an analysis is presented of the interocean exchange in a state-of-the-art Ocean General Circulation Model. The information of these chapters forms the basis of the model studies in chapters 4, 5 and 6. In chapter 4 and 5 a relatively simple model is applied that represents the Atlantic overturning circulation in a 2-dimensional latitude-depth plain. The interocean exchange of heat and salt is represented by lateral fluxes at the southern boundary of the model (chapter 4) and by source/sink distributions (chapter 5). In chapter 6 a more realistic (3-dimensional) global ocean model is used, in which Agulhas Leakage was parametrised by heat and salt sources in the South Atlantic.

The model studies show that the exchange of heat and salt between the Atlantic and the rest of the World Ocean influences the strength of the Atlantic overturning circulation considerably. In particular, the warm and salty input of Indian Ocean water via Agulhas Leakage appears to enhance the overturning strength. Agulhas Leakage also stabilizes the circulation with respect to, e.g., fresh water inflow from the Arctic Ocean (mainly derived from the North Pacific via the Bering Strait). These results indicate that the absence of Agulhas Leakage during the last glacial period may have been partly responsible for the weakness of the glacial overturning state. It may have decreased the stability of the glacial circulation, making it vulnerable to perturbations (like enhanced meltwater events). The re-establishment of Agulhas Leakage at the end of the last ice-age may well have stimulated the restart of the overturning circulation. At present, the variability of Agulhas Leakage is small, so that its direct influence on variations of the western European climate can be neglected. Its importance is that it stabilizes the present-day overturning circulation, and reduces the possibility of catastrophic climate switches.

In both the 2- and 3-dimensional models, the overturning strength is directly related to the north–south pressure difference in the Atlantic. This pressure difference is modified by the buoyancy sources in the South Atlantic. In the 2-dimensional models, however, the buoyancy exchange appears to limit the overturning strength via the energy balance: its supply of potential energy is converted into kinetic energy of the flow, and thus limits the flow strength. Essential for generating response in both 2- and 3-dimensional models is the fact that thermal anomalies are rather rapidly lost to the atmosphere, while saline anomalies are much more persistent. When Indian Ocean water enters the Atlantic, its density anomaly is small, since the effect of the thermal and saline anomalies on the density field almost cancel. However, a density anomaly develops when the water loses its thermal anomaly but retains its anomalous saline anomaly on its way north. The influence of Agulhas Leakage on the density field is therefore largest in the northern North Atlantic. The time-scale on which a change in Agulhas Leakage influences the Atlantic overturning circulation is only a few years. Although it takes about 3 decades for a salinity anomaly to reach the northern North Atlantic, waves modify the North Atlantic density field within a much shorter time.