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Abrupt Climate Change and Thermohaline Circulation

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This study explores the role of thermohaline circulation (THC) in climate change, based upon the results from a simple coupled ocean-atmosphere model developed at the Geophysical Fluid Dynamics Laboratory/NOAA. Using the coupled model, the first part of the study (Manabe and Stouffer, 2000) investigates the mechanisms, which are responsible for the abrupt climatic changes associated with the so-called Younger Dryas event, that occurred approximately 12,000 years ago.

In response to the freshwater discharge into the high North Atlantic latitudes over the period of 500 years, the THC in the Atlantic Ocean weakens (Fig. 1a), thus reducing the surface air temperature over the northern North Atlantic Ocean, the Scandinavian Peninsula, western Europe, and the Circumpolar Ocean of the Southern Hemisphere. Upon termination of the water discharge on the 500th year, however, the THC begins to intensify, regaining its original intensity within a few hundred years (Fig. 1a). In addition, the sudden onset and termination of freshwater discharge induces multidecadal oscillations of the THC intensity and associated convective activity (Fig. 1d), generating large multidecadal fluctuations in both the sea surface temperature and salinity of the North Atlantic Ocean (Figs. 1b and c). Such fluctuations yield almost abrupt change in climate, which involves a rapid rise and fall in the surface temperature within a few decades (Fig. 1b).

In the second experiment, in which the same amount of freshwater is discharged into the subtropical North Atlantic over the period of 500 years, the THC and climate evolve in a manner qualitatively similar to the first experiment. However, the magnitude of the THC response is 4–5 times smaller. It appears that freshwater is much less effective in weakening the THC, if it is discharged outside the high North Atlantic latitudes.

A Similar but weaker oscillation of the THC on a multidecadal time scale is also evident in the control integration of the coupled model without freshwater discharge (e.g., Delworth *et al.*, 1997; Manabe and Stouffer, 1999). Associated with the fluctuation in the THC, the North Atlantic Current seesaws with the East Greenland Current on a multidecadal time scale, yielding the evolution of surface salinity anomalies, which resembles the so-called Great Salinity Anomaly event. The multidecadal fluctuation in the surface temperature in the Nordic seas and the surrounding regions has been identified in the records of tree rings and ice cores.

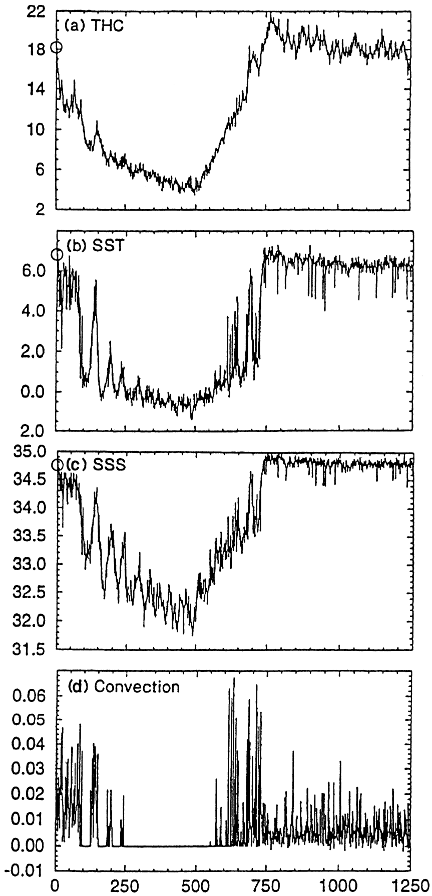

Fig. 1. 1,250-year time series of annual mean values of (a) intensity of the THC (in units of Sv, i.e., $10^6\ m^3s^{-1}$) defined as the maximum value of its streamfunction in the North Atlantic Ocean, (b) sea surface temperature (SST) in units of °C, (c) sea surface salinity (SSS) in psu, (d) rate of SST change (Cd^{-1}) due to convective adjustment at a location in the Denmark Strait (30.0W, 65.3N) over the 1,250-year period (abscissa) of the numerical experiment. The initial values of THC, SST, and SSS are enclosed by circles (from Manabe and Stouffer, 2000).

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