What happens with the Arcto-Norwegian cod if the thermohaline circulation slows down?

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A reduction of the thermohaline circulation (THC) might have a strong impact on the Northeastern Atlantic ecosystem. We address this potential challenge by studying the effects of THC changes on larval drift and development of Arcto-Norwegian Cod (ANC), as several studies have shown that there is a close link between the condition of cod at the 0-group stage and the year class strength of the 3-group fish. The approach taken is that of a modelling study supported by analysis of existing data on fish stocks and climate. A regional model (ROMS) is forced by a global climate model in which the hydrological cycle of the Nordic Seas is perturbed. The impact of the anomalous circulation and ocean temperature on ANC in its habitat, as simulated by ROMS, is investigated by using an individual based model to simulate growth of the larvae and juveniles along their resulting drift paths. The Nordic Seas are dominated by the near surface inflow of warm and salt Atlantic Water (AW), driven by prevailing southwesterly winds (Furevik and Nilsen, in press) and thermohaline circulation (THC) (Broecker, 1991). That is, ocean circulation driven by density differences. The relative importance of winds versus density differences is, however, not yet clear (Hansen and Østerhus 2000; Blindheim, 2004). Because of the massive heat transport by the AW, atmospheric and oceanic cold fronts are pushed northwards giving a maximum deviation of air temperature from the latitudinal mean in the northeastern North Atlantic of about 10°C. Sediment cores have revealed that the THC has undergone major changes in the past (Sarnthein *et al.* 1994; 1995). In this regard several authors have discussed the possibility of non-linear behaviour of the THC (Manabe and Stouffer, 1988; Rahmstorf, 1994). A THC collapse is now widely discussed as one of a number of "low probability – high impact" risks associated with global warming (Integration – www.pik potsdam.de/~stefan/Projects/integration/). More likely than a breakdown of the THC, which only occurs in very pessimistic scenarios (Rahmstorf and Ganopolski, 1999), is a weakening of the THC by 20–50%, as simulated by many coupled climate models (Rahmstorf, 1999).

Significant changes of the THC will affect ecological processes across a broad range of temporal and spatial scales. Atlantic cod (*Gadus morhua* L.) is one of the major North Atlantic fish resources and Arcto-Norwegian cod (ANC) is the larger of these cod stocks. By existing data on ANC and climate it has been well documented that weak year classes always occur during cold years, and that strong year classes occurs during warm years (Sætersdal and Loeng, 1987; Ellertsen *et al.*, 1989; Ottersen and Sundby, 1995; Ottersen and Loeng, 2000). This relationship between recruitment and temperature is partly, directly through feeding intensity and metabolic rates (Otterlei *et al.*, 1999), and partly, indirectly through lower trophic layers, as temperature in the Barents Sea is a proxy for the advection of zooplankton-rich AW from the Norwegian Sea and onto the shelves, e.g. the Barents Sea and the shelf off Norway (Skjoldal and Rey, 1989; Helle and Pennington, 1999; Sundby, 2000). Existing knowledge on cod and climate may be used to infer the consequences of a permanent change in the physical state of the environment occupied by cod.

A regional ocean model system (ROMS – http://marine.rutgers.edu/po/models/roms/) is set up for the habitat of ANC. ROMS is forced with initial- and boundary conditions from a simulation with the Bergen Climate Model (BCM), in which the hydrological cycle is perturbed, resulting in a weakened THC from 18 to 12 Sv (1Sv equals 1mill. m^3/s) and a subsequent reduced inflow of AW to the Barents Sea. As a consequence, the temperature in the Barents Sea is reduced by up to 3°C. ROMS simulates transport of larvae and juveniles, while keeping a record of the individual temperature histories enabling calculation of temperature dependent growth, from spawning until settlement at the nursery grounds. Temperature-growth relations from two studies were included (Otterlei *et al.*, 1999 and Björnasson and Steinarsson, 2002). What are the qualitative and quantitative effects of a substantial reduction of the THC on growth, distribution and recruitment of ANC?

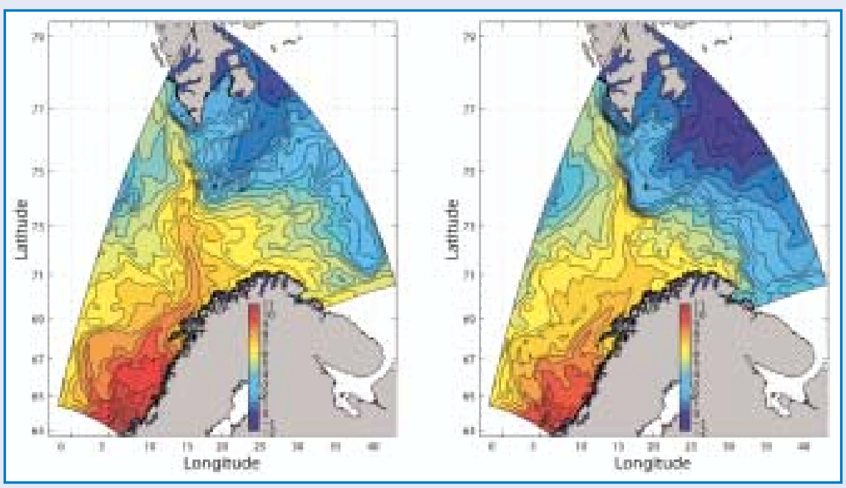

Figure 1. Temperature averaged for May, June and July at 100m depth for simulated fields with forcing fields from the BCM control run (left panel) and the BCM perturbed run (right panel).

In conclusion, the present description of a reduction in the THC by 35% results in:

1) An increased flow west of Spitsbergen, while the inflow to the Barents Sea is considerable reduced.
2) A southward and westward shift in the distribution of cod year classes from the Barents Sea onto the narrow shelves of Norway and Svalbard.
3) A reduced individual growth of the pelagic juveniles with a subsequent poorer year classes, most probably less than 10% of the strong year classes of today (Ellertsen *et al*., 1989).
4) An increasing number of larvae and juveniles advected towards the western parts of Spitsbergen and possibly further into the Arctic Oceans where they are unable to survive.

A southward shift of the spawning areas along the Norwegian Coast will enhance this development (Sundby and Nakken, submitted).

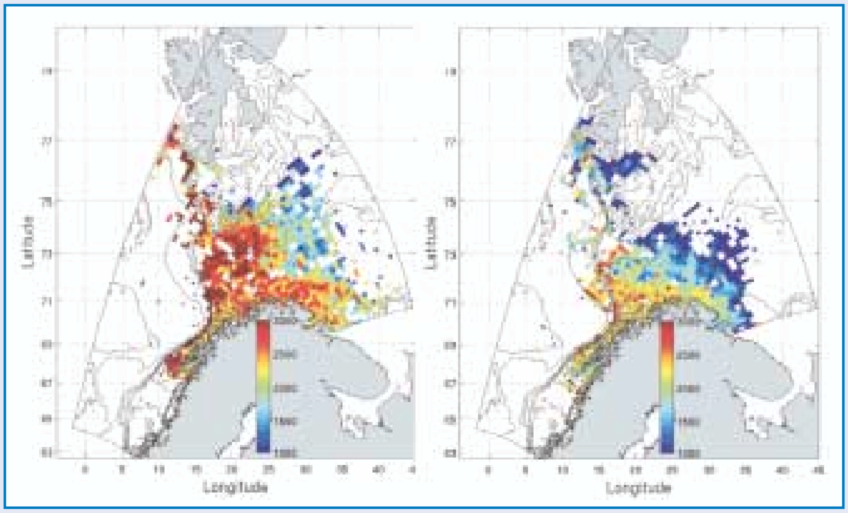

Figure 2. Simulated distribution of 0-group cod late August, 4 to 6 months old depending on time of spawning, with ocean and atmospheric forcing from the ctrl run (left panel) and +50 run (right panel). All particles are released inside the Vestfjorden, the main spawning site. The colour scale indicates wet weight in milligram.

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