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INTEGRATED ASSESSMENT OF CHANGES IN THE THERMOHALINE CIRCULATION – INTEGRATION

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Summary

The aim of INTEGRATION is to study the effects of a weakened thermohaline circulation (THC) on various ecosystems in and around the North Atlantic as well as on economy and society. The obtained results and information, together with an uncertainty analysis, are summarized in an Integrated Assessment.

A major THC change might trigger an abrupt cooling in northern and northwestern Europe of up to 5°C within a few decades. Temperatures might even drop below preindustrial levels. Sea level at the North Atlantic shores could rise by 50 cm and more, in addition to the thermal sea level rise. In some climate model simulations such drastic and abrupt changes occur already before the year 2050.

Sea level rise is potentially the heaviest impact of THC changes, requiring costly coastal protection measures. Our results further suggest a strong impact on the whole marine food web in the Northern North Atlantic, from algae to plankton, shrimp, and fish. Norwegian fishery would suffer strongest. While regional socio-economic impacts might be large (yield losses in fishery and agriculture, job losses), damages will be probably small in relation to the national global economies.

The uncertainty about THC risks is still high – we see this in model analyses as well as in the experts' views that we elicited. Still, a growing awareness among stakeholders and experts indicates that the THC risks may well be perceived as "dangerous" (Art. 2 UNFCCC), thus calling for action to avoid them in spite of the uncertainties. Results from our fully coupled THC-climate-economy Integrated Assessment model suggest that the THC in the North Atlantic could be in danger of a serious reduction if no precautionary measures are taken within twenty years from now.

Aim of the research in the framework of DEKLIM and other research activities

The topic of abrupt climate change has gained strongly increasing scientific, political and public attention in the past few years. It has now been recognised that low probability/ high impact risks are an important and policy-relevant aspect of climate change. INTEGRATION focuses on one of such risks: the possibility of a major ocean circulation change in the Atlantic. The scientific and public discussion (e.g. in a Pentagon study and also in a Hollywood movie) shows an urgent need for more scientific information on the THC risks.

INTEGRATION's main research tasks are: (i) The possible effects of oceanic circulation changes in the North Atlantic – and of the accompanying climate changes – on two impact chains, a terrestrial and an oceanic one. We perform these analyses by employing models for various elements like oceanic circulation, phytoplankton, zooplankton, fish, regional climate, agriculture, forestry, and relevant economic sectors. (ii) The uncertainties involved in these impact chains. They are studied systematically in models and by eliciting experts' knowledge through interviews. (iii) The integration of knowledge about the various phenomena and processes involved in a comprehensive assessment. With an integrated assessment model, mitigation policies are determined that could avoid major THC changes.

INTEGRATION responds to several points of the DEKLIM objectives, especially to the topics "climatic sensitivity of ecosystems and socio-economic systems" and "climate-related resilience and governance research". The Integrated Assessment we deliver is an essential complement to other international research into THC risks. Contacts and collaborations exist with e.g. RAPID in the UK, the CMIP model intercomparison, and the EU-project ENSEMBLES.

Principal results and completing activities

Climate scenarios and downscaling

Simulations from the coupled climate model of intermediate complexity Climber-2 (Rahmstorf and Ganopolski 1999) were the basis for some first results. Its successor Climber-3α, equipped with a full 3D ocean has already been used for a couple of studies. The greenhouse gas scenarios we use are based on the IPCC SRES scenarios but extend until 2300 AD, using assumptions about e.g. global mitigation efforts and the development of the world economy (Hare and Meinshausen 2004). The climate scenarios are computed currently. To be applicable for the various impact models, these scenarios are downscaled using an approach that empirically links Climber variables with a high-resolution dataset of observations (CRU). The discussion about the physical driving mechanisms of the THC (e.g. Rahmstorf 2003) was condensed into a review paper (Kuhlbrodt et al. 2005). This knowledge is important to understand how and why the THC could change in the future.

Sea level rise

A model study carried out with Climber-3α (Levermann et al. 2005) revealed that a breakdown of the THC might trigger a sea level rise that adds to the thermal sea level rise. This dynamical sea level rise could amount to more than 50 cm on parts of the eastern shore of North America and on the coasts of northwestern Europe.

The marine impact chain

Plankton

We have coupled an oceanic circulation model (MOM-3) to the biogeochemical model REcoM (basic version, one plankton group). The ocean model is part of the Climber-3α climate model. Results from simulations at the JGOFS-NABE station (47°N, 20°W) showed a good correlation with observations from the North Atlantic Bloom Experiments (NABE). Results from simulations with the 3-D model version of REcoM&Co (two plankton groups) showed that the succession of different groups of algae (coccolithophores, diatoms) is strongly regulated by the ratios of special nutrients like nitrogen or phosphorous (Schartau et al. 2002, 2003; Sprengel et al. 2005). Possible impacts of circulation changes and/or changes within the mixing rates of oceanic surface waters could be the displacement within the ratios of these essential nutrients, following basic changes within the community structure inside the marine ecosystem (reduced primary production, lack of algal blooms). Most impacts for higher trophic levels within the marine food chain would be the lack of and/or the forced migration of small micro-zooplankton prey (copepods) for young fish, shrimps, etc. Consequently, this would induce a reduction or migration of fish and shrimp stocks.

In order to study the impact of THC variations on marine biota the ecosystem model by Six and Maier Reimer (1996, Global Biogeochemical. Cycles) was implemented into Climber-3α. The ecosystem model also includes a carbon cycle model, which enables a fully prognostic computation of the partial pressure of CO_2. Hence, Climber-3α allows studying climate system feedbacks between the ocean circulation and marine biology via the atmospheric CO_2 concentration. Sensitivity studies regarding future CO_2 emission scenarios are in progress (M. Hofmann, in prep.).

Since the regulated community model including the dynamics of coccolithophorids (RecoM &Co) is highly complex (it includes 24 prognostic variables), there is a need to simplify the model in order to become suited to be used in Climber-3α.

Fish stock

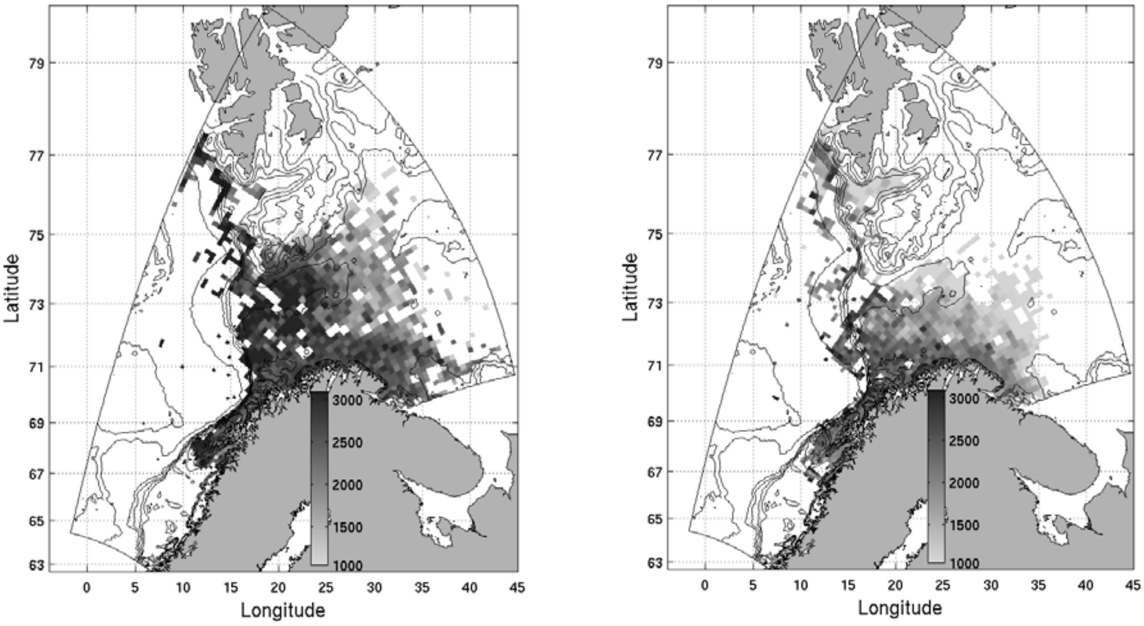

Fig.1. Simulated distribution of 0-group cod in late August, 4–6 months old depending on time of spawning, with oceanic and atmospheric forcing from the BCM control run (left) and from the reduced THC run (right). All particles are released inside the Vestfjord, the main spawning site. The gray scale indicates the young cods' wet weight in milligram. With a reduced THC, the larvae gain less weight, and fewer of them reach the favourable nursery grounds in the Barents Sea.

A regional ocean model system (ROMS) was set up for the habitat of Arctic Norwegian Cod. 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 THC reduction by 35% and a subsequent reduced inflow of Atlantic Water to the Barents Sea. As a consequence, the temperature in the Barents Sea drops by up to 3^oC. 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. The THC reduction results in (Fig.1): (i) An increased flow west of Svalbard, while the inflow to the Barents Sea is considerable reduced. (ii) A southward and westward shift in the distribution of cod year classes from the Barents Sea onto the narrow shelves of Norway and Svalbard. (iii) 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. (iv) An increasing number of larvae and juveniles advected towards the western parts of Svalbard and possibly further into the Arctic Oceans where they are unable to survive

(Vikebø et al. 2005a,b,c,d). A southward shift of the spawning areas along the Norwegian Coast will enhance this development (Sundby and Nakken 2005a,b).

The use of scenarios from Climber-3α is problematic due to the discrepancy in grid resolution. Ongoing work aims at overcoming this obstacle.

Fisheries

We developed a bioeconomic model of the Norwegian cod and capelin fisheries in the Barents Sea. Analyses for two different harvesting strategies (adaptive harvesting vs. profit maximization) were conducted for various extents of changes in the species' reproductive rates and carrying capacities. Reproduction rates are influenced e.g. by fishing, while hydrographic changes lower the carrying capacity (see previous section). Results show that negative developments in the fish species' population dynamics lead to lower stock levels and consequently smaller catch sizes for both harvesting strategies. The effect is more pronounced for changes in the carrying capacity than for smaller reproductive rates. Also, the returns from fishing are adversely affected to a greater extent for profit maximization than for adaptive harvesting strategies. Because of the time lag of sometimes more than a decade between the onset of change in population dynamics and the appearance of pronounced economic impacts on the fisheries, it is hardly possible to adjust to the altered stock dynamics if any of the two harvesting strategies analyzed is employed (Link 2003, Link et al. 2004, Link and Tol 2005).

So far, all analyses with the bioeconomic fisheries model have been conducted using hypothetical scenarios of changes in population dynamics. Currently, tests are conducted to assess whether output from ROMS is suitable to drive the scenarios of the fisheries model. Alternatively to output from ROMS, it seems possible to use the scenarios from Climber-3α directly in conjunction with the fisheries model.

The terrestrial impact chain

Agriculture

To investigate the agro-economic impact of a THC climate change on cultivation and potential yields we use the AEZ (Agro-ecological Zones) model. First results of the potential yield of winter wheat under high standards of farm input, technology, and management conditions for the time span of 2000 to 2300 show an enhanced wheat yield in northern Europe and markedly reduced yields in southern Europe till 2150. After a THC breakdown, the northward movement of the cultivation zone is reversed, reflecting the temperature sensitivity of wheat. Work on driving AEZ with Climber-3α scenarios is in progress.

Carbon cycle and forests

A suite of models (LPJ, EFISCEN, 4C) is used to examine the transient effects of the INTEGRATION scenarios on carbon storage, vegetation dynamics (LPJ), regional wood production (EFISCEN) and sensitivity of single forest stands (4C). The first step has been undertaken with the Climber-2 scenarios. In the global vegetation model LPJ, the tendency of soils to be a net carbon sink during global warming is reversed, so that in the breakdown scenario they temporarily become a net carbon source (Sitch et al., 2003). The full suite of models will be driven with the Climber-3α scenarios. All the preparations for the use of the new downscaled scenarios (including transfer of results from LPJ to EFISCEN and use of a weather generator) are running (Badeck et al., in prep.)

Socio-economic impacts

THC-induced climate change would have various socio-economic consequences. An additional meter of sea level rise would threat coastal cities and lowlands around the North Atlantic, requiring costly protection measures. In terms of gross national product (GNP) losses however, these costs are estimated to be less than 1% of GNP, and hence this threat seems manageable. Still, the sums involved are such that serious political bargaining is to be expected. Concerning fishery, the country most vulnerable is Norway. In the worst case, 2/3 of the Norwegian fishery might disappear. Again, since fishery accounts for 2% of Norwegian GNP, the economic losses are within the usual fluctuations and hence do not appear to be serious. Yet, in some regions where fishery is the main employer, a large amount of lost jobs might be perceived as severe. Other socio-economic impacts of colder temperatures include increased energy use and yield losses in agriculture and forestry.

Uncertainty Analysis

Climber-2 projections may be subject to considerable uncertainty typical of any complex climate model. We use a 110-member perturbed-parameter ensemble of Climber-2 simulations to study the effect of parameter uncertainty on THC scenarios (Schneider von Deimling et al. 2005). Under the application of a global warming greenhouse gas scenario, the ensemble splits in a THC-off and a THC-on branch. All these 110 model runs are downscaled and passed on to the agro-economic model AEZ. In this way, we investigate how the uncertainty from a climate model influences crop yields, i.e. how parameter uncertainty propagates through the impact chain.

Expert Elicitation

INTEGRATION's expert elicitation has the aim to gather the knowledge of THC experts about (i) the current state of the THC, (ii) how it might be affected by future climate change, (iii) the research needs to reduce uncertainty about the THC, and (iv) the possibility of predicting the THC. To collect feedback from the experts and to finish the interview protocol, we held a precursor workshop at the EGU conference 2004. In summer 2004, the 12 interviews were conducted at each expert's home institution, and each lasting for about 7 hours. The evaluation of the interviews has begun (Zickfeld et al., 2005). One of the most interesting results is the experts' answer on the question: "What is the probability that the THC shuts down under different amounts of global mean temperature change in the year 2100?" For instance, given a temperature change of 4°C, the subjective probabilities ranges span an interval from 2% up to 60%.

Risk assessment

Given the large uncertainties in our knowledge of the earth system and its future development, it is clear that in the foreseeable future we will not be able to make reliable forecasts of when or whether global warming might trigger an abrupt climate change event. Action will have to be based on judging uncertain risks, and requires a discussion about risk levels that are acceptable as well as those that are perceived as "dangerous". An important tool to assist this discussion is the Integrated Assessment model INTEGRATION has developed (Rahmstorf and Zickfeld 2005, see below).

In October 2004, the European Climate Forum organized a symposium on the question "What is dangerous climate change?" in Beijing. At this symposium, INTEGRATION put to discussion the dangers of abrupt THC changes, along with the great uncertainty about the future of the THC. It turned out that among the symposium participants – researchers and policy makers from key vulnerable regions around the globe – are well aware of the risks of a major THC change. This implies also that, compared to an earlier stakeholder workshop, awareness has grown to take precautionary measures against such risks.

Integrated assessment

We developed a reduced-form model of the THC suited for the inclusion into optimizing integrated assessment frameworks such as the Tolerable Windows Approach (TWA; Zickfeld et al. 2004, Slawig and Zickfeld 2004). For the calculation of emissions corridors we coupled the THC box model to the reduced-form ICLIPS climate model. The emissions corridors were then derived along the methodological lines of the TWA as described in Zickfeld and Bruckner (2003). The boundaries of the so-obtained corridors demarcate CO_2 emissions limits for the 21st century beyond which either THC changes exceed x% reduction or the mitigation burden becomes economically intolerable. Our results indicate that uncertainties in the physical parameters and the guardrails translate into large uncertainties in the range of allowable CO_2 emissions (Zickfeld and Bruckner 2003, 2005). If probability distribution functions (PDFs) can be attached to the uncertain model quantities, it is possible to calculate emissions corridors obeying the guardrails with a given probability, as demonstrated in Fig. 2.

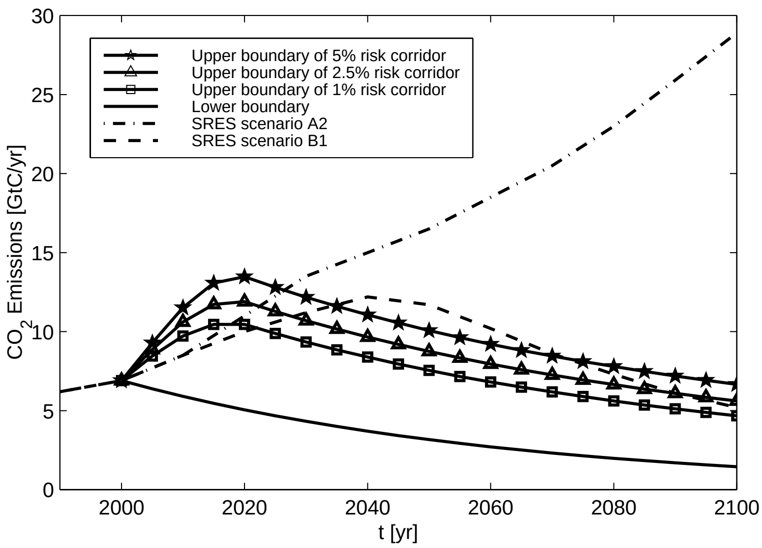

Fig. 2: Emissions corridors avoiding a complete collapse of the THC with a given probability. The corridors were calculated for different values of the climate sensitivity (i.e., 7.7 °C, 8.5 °C, 9.4 °C), corresponding to the 95, 97.5, 99 percentile of the PDF for climate sensitivity determined by Forest et al. (2002, Science 295). Note that any emissions path leaving the x% risk corridor would lead to a collapse of the THC with a probability greater than x%.

Recently, the THC and climate modules have been coupled to a globally aggregated Ramsey-type optimal growth model of the world economy derived from Nordhaus' DICE model. Together, these components create a novel, dynamic, fully coupled, and computationally efficient integrated assessment model (Bruckner and Zickfeld, 2004). The emissions corridors now contain all possible emissions paths that do not endanger the stability of the North Atlantic circulation and that simultaneously obey restrictions on welfare loss arising from mitigation efforts. The results show that, using a conservative calibration of the model, the THC in the North Atlantic may be threatened within two decades in the absence of precautionary mitigation.

Main conclusions and policy relevance

A major change in the THC could mean an abrupt cooling in northern and northwestern Europe of up to 5°C within a few decades. This could even bring temperatures below the pre-industrial level. In addition, a sea level rise of 50 cm and more in regions around the North Atlantic would follow. Some climate models show the possibility of such a major change (but not a complete breakdown) already in the first half of our century.

Sea level rise is potentially the heaviest impact of a THC change, requiring costly coastal protection measures in Europe and North America. Our results suggest a strong impact on fishery and forestry in Northern Europe. Norwegian fishery would suffer strongest, with however only minor effects on the Norwegian national economy. A shutdown of the THC will further have far-reaching effects in the tropics (causing a shift in rainfall belts associated with the intertropical convergence zone) and in the Southern Hemisphere (making it warmer), with adverse effects e.g. in India and northeastern Brazil. Forecasting where and when the THC might weaken is not possible to date. Therefore it is too early to consider specific adaptation strategies.

The tolerable windows approach (TWA) was explicitly conceived to assist climate change decision-making. Its results show that, under conservative assumptions, the North Atlantic circulation may be threatened within two decades from now in the absence of precautionary mitigation. On the global scale, the economic consequences of a major THC reduction are expected to be less than 1% of the gross domestic product. For some regions however the impacts might be serious. It is the question whether the risk of THC changes raises an issue of global stewardship, also in face of the irreversibility of THC changes and the danger of major harm that is unforeseeable by now. In the global policy elite, the voices arguing that avoiding dangerous climate change (Art. 2 UNFCCC) should be a top priority have considerable weight. If one believes that the risks of climate change are too high anyway to be undertaken, the threatened THC is an additional argument for taking action to avoid these risks.

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