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Global Warming Induced Changes and Their Implications to Fisheries in the North Atlantic

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Abstract

Recent climatic models are considered in terms of their accuracy, errors and assumptions. Matched with observed trends in the world oceans and atmosphere, a latitude dependent global warming is predicted with strong warming trends in the northern latitudes. Models project global sea level rises and reduced ocean circulation in the North Atlantic Ocean. The CO_2 transport at the ocean-atmosphere interface, the stability of ocean strata and potential storm activities are discussed in relation to the possible consequences to the fisheries in the North Atlantic.

Introduction

Climatic changes are considered to have serious impact on mankind in the near future. In recent months various scientific fora have pointed out various scenarios which might be experienced in the next 50 or 100 years. The studies and the predictions are diverse. It is therefore useful to consider possible impact of proposed world climatic changes on the ocean and the fishery. In this report some of the possible impacts are considered along with some currently used climatic models with reference to some of their drawbacks and assumptions.

Climatic Models

Climatic models should ideally be mathematical descriptions of the physical, chemical and biological processes in the entire climate system. Climatic models should therefore cover all components and their interrelations. In reality, however, today atmospheric models which contain the general circulation of the atmosphere are usually coupled with dynamic ocean circulation models (Mikolajewicz *et al.*, MS 1990). At present there are no comparable biological models available, and therefore, only possible scenarios can be deduced for the effects of climate changes on the biological processes.

Errors of Climatic Models

The basic climatic models are equations of continuum physics which are valid for volume elements. These models may derive predictive values for statistical properties such as temperature, but no structures such as turbulence elements are produced (Grassl, 1988). When the equations are averaged over larger volumes with structures, the hydrodynamic-thermodynamic system of equations is no longer closed, since the averaged equations contain unknown correlation products of fluctuating properties. The temporal integration over these partial differential equations, closed in such a manner, result in approximations. The more drastic these approximations are, the less the climatic model resolves spacially. However, with the recent improvements of computer capabilities and the enlargement of the computer memory, the quality of the climatic model has improved.

Climatic Models and Greenhouse-Gas

The overall development of greenhouse-gas concentration in the atmosphere cannot be forecasted. It is dependent on the development of world economics, the anthropogenic activities related to climate as well as the natural variabilities. Subject to the levels of changes of greenhouse-gases, climatic models give general evidence that:

A latitude dependent warming of global temperature is to be expected; relatively moderate warming would occur in the tropics while strong warming would occur in higher (northern) latitudes.

A change of seasonality is to be expected; temperature increase would be very large in the winter season and may reach more than +10° C even in high latitudes.

The Ocean as CO_2-sink

Based on a dynamic global ocean circulation model, Maier-Reimer and Hasselmann (1987) discussed the flux relation of CO_2 at the ocean/atmosphere interface. In general, the model gives a realistic distribution of CO_2 in the ocean surface layer. In biotic productive upwelling areas, however, the model indicates its weakness: the pCO_2 order of magnitude is underestimated by a factor of 1.5. This results from non-consideration of the so-called "biological pump" (see below) because biological sources and CO_2-sinks are not implicated in this model. According to the model results, the crucial point for the effective CO_2-storing capacity of the ocean, is the time slope of anthropogen CO_2-emissions.

Reaction of the Ocean to Greenhouse Warming

Sea Level Rise: Statements on sea level rise differ from author to author, however, the likelihood of a sea level rise is undisputed (Grassl, 1988). The global sea level rise during the past 100 years amounted to 20±5 cm. The increase continues but an acceleration has not been observed clearly. On a global scale a further increase of 20 cm in the next 50 years is expected and for the North Atlantic Ocean the estimated increase amounts to 35 cm. For certain portions of a coast, sea level rises might be even much larger. Reasons for these increases are many-fold: melting of glaciers, expansion of the warming ocean water, global tectonic changes especially through isostatic relief of the large ice shields about 15,000 years ago. Whether the still existing large ice shields of Greenland and Antarctica will contribute to the tectonic rise or not, is unknown.

For model computations concerning sea level rise, the Hamburg large-scale geostrophic ocean general circulation model (for which the acronym OGCM is often used) makes the following assumptions (Mikolajewicz *et al.*, MS 1990):

> Mean global temperature will change according to a linear exponential function, and reach 2.9°C after 50 years (Fig. 1). The model has a dynamic and active sea surface. Changes in the displacement of the surface result from current divergence, thermal expansion and river run-off. A thermodynamic one-layer sea-ice model with advection is also included. This model contains a realistic mean thermodynamic circulation. Surface temperature changes have a poleward increase of temperature gradient during the winter season due to ice-albedo feedback effects. Neglection of atmospheric feedback, anomalous wind stress and fresh water flux, as well as the assumption of time-independent distribution patterns of surface temperature were large simplifications in the experiment based model. The authors stressed, however, that their model is a "Zero-Order-Test" which represents the sensitivity of the oceanic circulation on a specified forcing. The model results yield valuable insights into typical sea level changes which have not been previously presented.

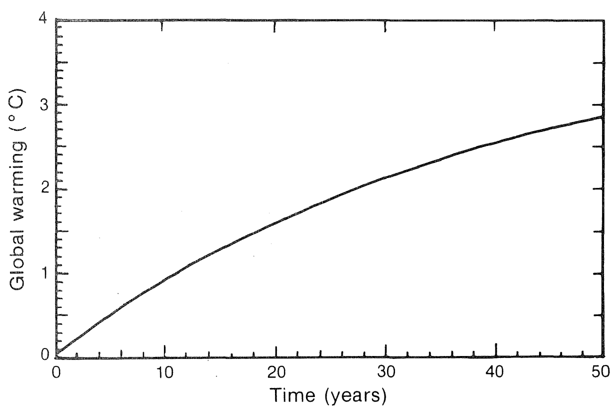

Fig. 1. Time evolution of annual mean globally averaged surface air temperature anomaly imposed on the Ocean General Circulation Model (from Mikolajewicz *et al.*, MS 1990).

The model demonstrates that based on the thermal expansion of water, a global sea level rise of 19 cm in 50 years is expected. This is primarily based on effects of temperature on the oceanic surface layer (0–100 m). Sea level rise in Northwest Europe is estimated at 35 cm, i.e. about twice the global value (Fig. 2). Generally, the sea level rise would vary regionally in relation to the regional differences in warming. It is predicted that in the Antarctic Ocean, *e.g.* in the Ross Sea, the sea level rise would be much less than the global mean.

Changes in Ocean Circulation: According to model results, the thermodynamic circulation of the North Atlantic Ocean would slow down. This suggests that the northward heat transport in the North Atlantic Ocean will be reduced.

Mikolajewicz *et al.* (MS 1990) reveal also significant changes in the oceanic circulation, caused by a global temperature increase as a result of CO_2-increase of the atmosphere. In regions of former deep water formation (*e.g.* Greenland Sea), sea-surface temperature will increase little or may even decrease in comparison to the zonal mean (Fig. 3). The North Atlantic Deep Water formation will decrease much more than the Antarctic Bottom Water formation. The overall consequence in the North Atlantic Ocean is an effective cooling of the deep water layers. This cooling process would be accompanied by a decrease in surface salinity in the North Atlantic and higher surface salinities in lower latitudes (Fig. 4).

The changes in the oceanic circulation is likely to decrease production. The decrease in the global deep water production rates would have a strong implication on the atmospheric CO_2 content. At present, a considerable portion of the emitted CO_2 is transported to the depths of the world oceans via newly formed deep water. If deep water transport and storage mechanisms

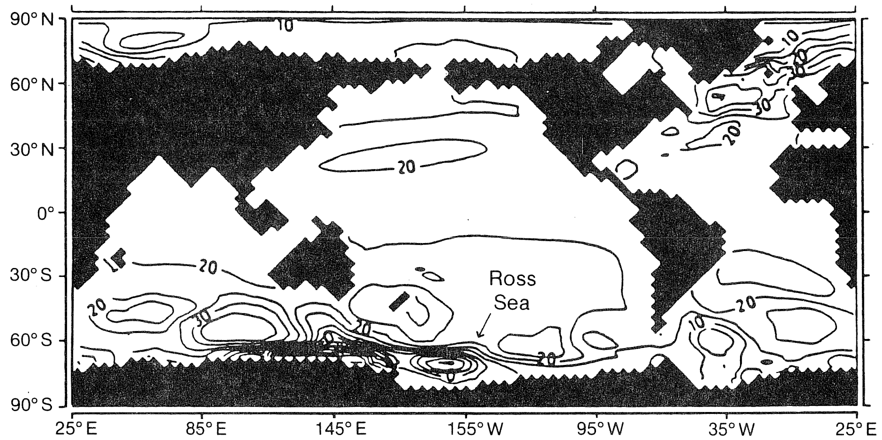

Fig. 2. Pattern of changes in sea-surface elevation (cm) in 50 years relative to the control experiment. Note that changes in the Ross Sea are negative (from Mikolajewicz *et al.*, MS 1990).

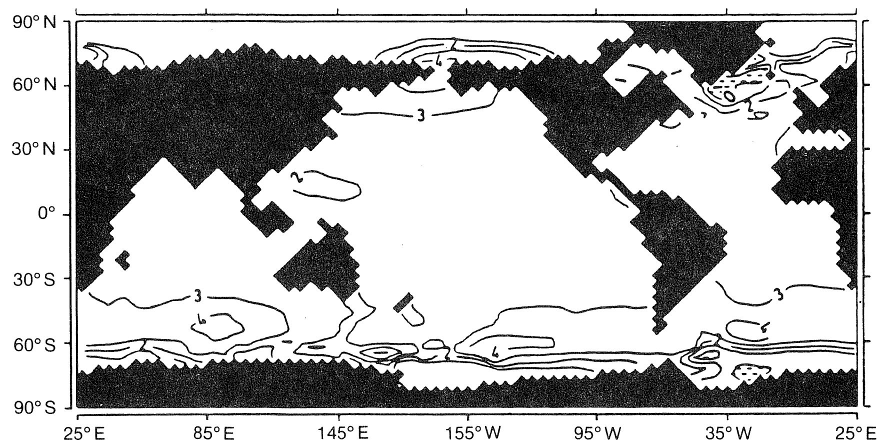

Fig. 3. Geographical distribution of changes in SST (° C) in 50 years relative to the control experiment. Shading indicates negative values (from Mikolajewicz *et al.*, MS 1990).

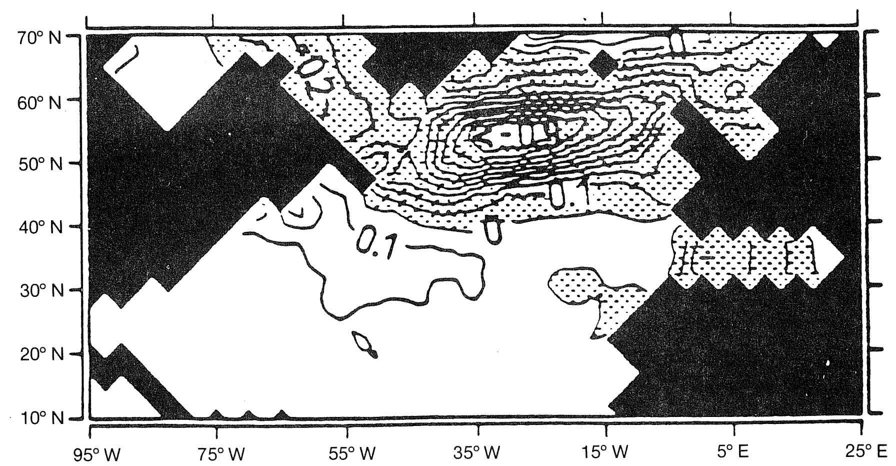

Fig. 4. Geographical distribution of changes in the surface salinity (‰) in the North Atlantic in 20 years relative to the control experiment. Shading indicates negative values (from Mikolajewicz *et al.*, MS 1990).

are reduced, the increase of atmospheric CO_2 will strengthen. Thus Grassl (1988) shows that if there is a reduction in the rate of increase in the use of fossil resources by 50%, the critical point of time when the CO_2 content in the atmosphere is doubled is postponed. Then the main CO_2-sink oceans gets more time to transport CO_2 to the abyssal, and the percentage of CO_2 remaining in the atmosphere (50% at present), is reduced.

Vertical Convection

The forecasted cooling process, accompanied by a decrease of surface salinity in the North Atlantic, is expected to reduce vertical convection. The vertical density stratification will then be characterized more and more by a light surface layer which rests on more saline water. This would lead to higher stability coefficients in the oceanic surface layer. According to Meyer (1968) and Stein and Buch (1985) high stability coefficients in the oceanic surface layer off West Greenland might have negative influences on the development of cod larvae.

Storm Activity

Strong temperature gradients are predicted to occur in the frontal zone of the cooling polar air masses of the North Atlantic Ocean and the warmed air masses of subtropical origin with an increased uptake of latent energy. The two energy sources will level out by the deepening of low pressure systems during winter, which will result in higher frequencies of hurricane force winds. To what degree storm induced variability in the oceanic surface layer influences the general stability of water masses in polar regions, cannot be estimated at present. However, influences on the performance of fishery vessels are to be expected.

Plankton

Through the formation of particle aggregations, the marine plankton forms micro zones in the ocean which have an essential influence on the chemistry of the ocean and atmosphere. Additionally, these aggregations are fast vehicles for the vertical mass transport, especially carbon, and thus play a decisive role in the regulation of the CO_2 balance of the ocean and atmosphere. The sinking of biotic particles from the oceanic surface layer (0–100 m water depth) to the abyssal layers is an essential process for the mass balance of our planet: Planktonic algae grow in the upper euphotic zone and incorporate dissolved carbon (CO_2). It has been assumed that the largest proportion of algae is consumed by the zooplankton, and the organically incorporated carbon is distributed to great depths by feacal pellets. Recent observations have also shown that at times the algae themselves sink in tremendous masses, and thus remove the incorporated carbon from the surface layer. Since the ocean and atmosphere are in an equilibrium state, as the carbon is removed by the algae and exported by fast sinking to greater depths, CO_2 from the atmosphere replenishes the sea surface layers. This process, the so-called "biological pump", is assumed to be the main mechanism for removing CO_2 from the atmosphere. Although the amount of carbon that is buried in this way is at present unknown, the quantities since the beginning of the industrial epoch must be considerable.

The total increment of CO_2 addition to the atmosphere by man-made processes, such as by burning of fossil hydrocarbons, deforestation, etc., is accountable by only 50%. The remainder is probably taken by the ocean via the "biological pump". The ocean has a reservoir of CO_2 which is fifty times larger than that of the atmosphere. It can therefore be assumed that small changes in the ocean CO_2-content, will cause tremendous variations in the atmospheric CO_2-content (Nöthig *et al.*, 1988).[1]

Fish Stocks and Climate Variation

Fish stocks and plankton are relevant indicator organisms of the oceanic ecosystem. Palaeotological, as well as recent, observations indicate that fish and plankton react to climatic variation (Anon.,MS 1990). Investigations in this field are rare, however, the international group of experts that met in Bergen, Norway, in early-1990 to establish a 5-year study, may generate valuable information on the relationship between variability in North Atlantic cod stocks and climatic variations. Three sources of information on cod and environment are available: time-series on cod stock fluctuations; biology, physiology and ecology of larval and adult cod; and global and regional models of the physical environment.

Whereas this study on interrelations between these sources of information has to take into account the other members of the trophic web and their interactions (which is in itself a major problem), it is highly questionable whether the third source of information, the models, are really available on these scales, and if they do, whether their results have an adequate semblance to reality.

[1] With such ocean/atmosphere critical CO_2-equilibrium levels in mind, it seems rather questionable, whether a large-scale model experiment planned in the polar regions by the USA is the right way to tackle the CO_2 problem. The proposal to broadcast tons of iron powder will probably fertilize the surface waters to produce giant plankton blooms. To use this as an anti-greenhouse weapon is a dangerous illusion. Instead of developing means of reducing the CO_2 emissions, man fumbles at our ill planet.

Greenland: Climate Variation and Cod Stocks

With respect to waters off West Greenland, time-series on environmental variation and year-class strength of cod are available (Stein and Messtorff, 1990; Stein and Buch, 1990). The latter authors showed that according to their selected time-window, the conditions in this area are influenced by positive or negative temperature trends in the ocean and the adjacent atmosphere. Although air temperature times-series off Nuuk, Greenland indicate a minimal, linear warming trend for the entire time-series since 1876, it has been dominated by negative temperature trends during the past 30 years, especially during the last decade (Fig. 5). Stein and Wegner (1990) found a warming trend in the ocean surface layer (0–100 m) off West Greenland between 1984 and 1988. In the deep water layers (1,100–1,500 m) of this region the warming trend was not clearly documented. Whereas the warming amounted to 0.1° C/year for the Cape Farewell region (South Greenland), recent observations made by Stein (1990) revealed a negative temperature trend for the 1989 autumn season. This situation may in fact point to the high variability of the ocean/atmosphere climatic system off West Greenland.

Stein and Messtorff (1990) showed that cod year-classes, with respect to the West Greenland cod stock, are linked to warming phases observed in the waters off West Greenland. One recent example cited showed the 1984 and 1985 cod year-classes which essentially contributed to the stock recovery in relation with warm trends, after a period of stock failure in relation to catastrophic cooling by nearly 2° C below normal in the oceanic surface layer (0–200 m) (Fig. 6).

Summary

The climatic scenarios, as shown by the models as well as trends observed in the world oceans and atmosphere (Fig. 7), indicate changes in the hydrosphere and atmosphere. The cooling of surface water masses in the North Atlantic Ocean would imply catastrophic

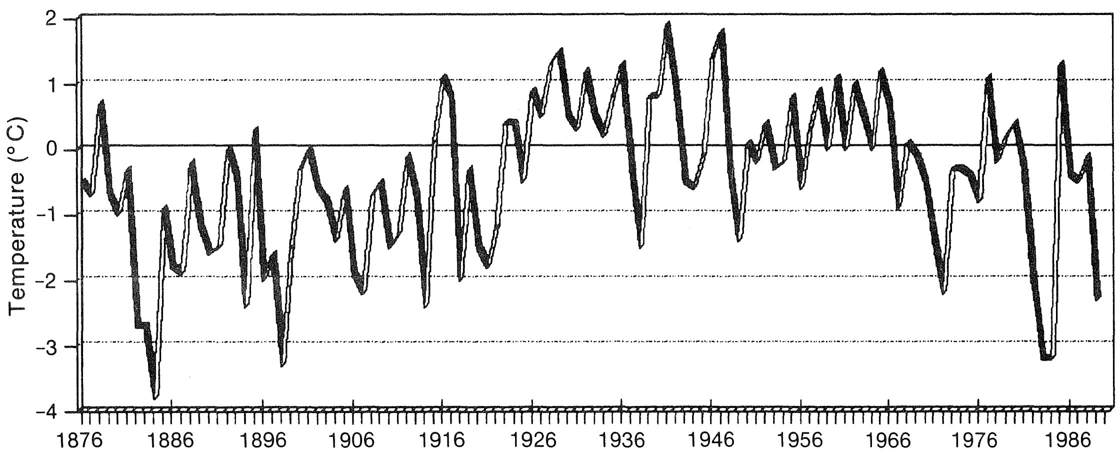

Fig. 5. Year mean air temperature (° C) at Nuuk, Greenland; deviation from the 1951–80 mean.

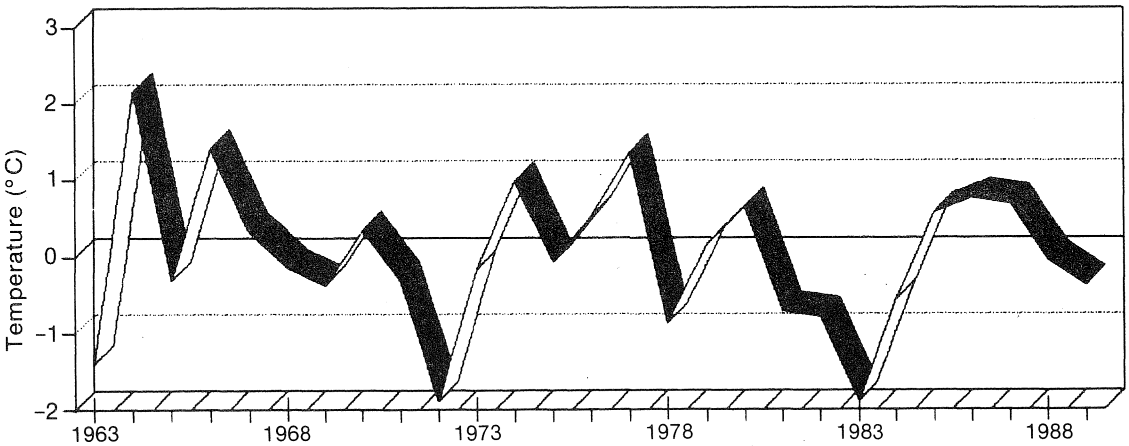

Fig. 6. Fylla Bank temperature anomaly (° C) at the surface layer (0–200 m) in autumn.

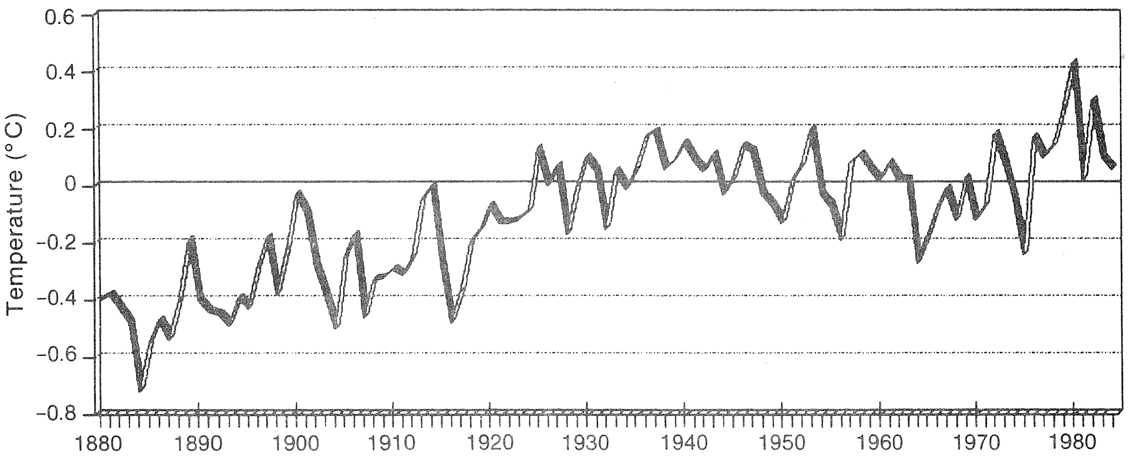

Fig. 7. Global mean air temperature (°C) deviation from the 1950-80 mean (redrawn after Houghton and Woodwell, 1989).

consequences for the fish stocks in that area, especially around Greenland. Observations from the early-1980s showed complete failure of stock reproduction, presumably influenced by the environmental disaster caused by a lethal cooling of the surface layer by 2°C below normal. The cooling trends as forecasted by the models for the area off East Greenland would imply complete failure of recruitment due to changes in stability by cold, diluted surface water masses and increased outflow of polar water through Denmark Strait. As a consequence of reduced vertical convection during winter, the euphotic layers will contain lesser nutrients and hence the food web cannot be built up. The increase of hurricane activities will hamper the Greenland fishery, especially in winter months. Due to cooling of the surface waters in the Northwest Atlantic current system, sea ice formation will increase. This will result in hindrance due to sea ice build up not only off East Greenland, but also off the West Greenland coast and in Labrador/Newfoundland waters.

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