Dana, vol. 8, pp. 69-82, 1989

The North Sea and the climate

Jan O. Backhaus
Institut für Meereskunde der Universität Hamburg, FRG

Abstract

The North Sea is situated in the transition between the maritime climate of the northeastern North Atlantic and the continental climate of the hugest continent on the globe. As such the transition is characterized by a very high variability, which depends on the respective dominance of one of the two climatic regimes. The variability covers time scales (periodicities) ranging from some days to several years, up to decades. In contrast to the inertia of the deep Atlantic Ocean, which reacts on atmospheric fluctuations and long-term climatic changes with time-scales of the order of decades up to centuries the North Sea reflects almost directly the variability of the atmosphere.

Some examples of the present variability of the North Sea are presented. These were computed by means of a numerical simulation model, which was fed with actual observed atmospheric data (winds, air-pressure) and information about the tides and the distribution of temperature and salinity. The model is a sophisticated computer programme, which performs a dynamical interpolation of the input data, based upon our knowledge about the physical processes in the sea. The result of the simulation is an estimate of the marine climate of the North Sea (currents, water elevations, stratification) for a time span of more than a decade.

In terms of climatic time-scales the duration of the simulation must be compared to the flicker of an eyelid and therefore it only reflects the present state of the marine climate and its high frequency oscillations (climate-noise). However, the dynamical fluctuations of the North Sea, the seasonal and interannual variability of the circulation, may have a considerable influence on the marine environment and on life within the sea. Some examples of this variability will be given.

Once such a simulation model has been set up it can be used to carry out 'science fiction' in the very sense of the wording. Hence, some simulation-estimates of a climate-change scenario for the North Sea will be presented. A number of crude simplifications needed to be made for this study which certainly limits the realism of the estimates. But presently this is true for any of our climate predictions. However, one conclusion can definitely be drawn from the results: let us hope that the present state of our climate remains as long as possible ...

The North Sea regime

The North Sea, a semi-enclosed basin within the north-west European shelf sea, is one of the most productive regions of the world ocean. Obviously the environmental conditions, if not disturbed by human activity, are ideal for marine life. In a shallow shelf sea the environment, the 'marine weather', which stands for temperature and salinity, turbulence and currents, almost directly reflects the activity of the atmosphere. This is in contrast to the deep ocean, which reacts to atmospheric disturbances (climate variability and/or changes) with a time-lag of some decades, or even centuries.

An important factor for the marine weather of the North Sea are the inflowing water masses from the Atlantic and the continental fresh water run-off. The salty Atlantic water and the fresh water drained via a number of rivers and via the Baltic

Sea from the huge hinterland of western Europe are merged and mixed by the action of the tides and of the atmospherically induced turbulence of waves and currents. This permanently ongoing mixing process maintains a lateral stratification, which has a considerable influence on the dynamics of the North Sea, as will be demonstrated later. The haline stratification (influence of the salinity on the density of the sea water) is present throughout the year but it shows an annual variation due to changes in the precipitation over the land and due to the changing Atlantic inflow. The role of the precipitation over the North Sea itself is as yet poorly investigated; in general it is assumed that it is balanced by evaporation.

The radiative solar heat input into the sea accounts for a thermal stratification, which is most pronounced in the vertical. During summer wide areas of the North Sea form a two-layer system with a sharp interface, the thermocline, which separates heated surface water from the bottom water. The latter tends to keep the temperature of the previous winter season, because it is thermally isolated from the surface heat input by the surface layer. In autumn and winter this stratification breaks down as a consequence of tidal and of of increased wind and wave induced mixing and due to convective cooling at the sea surface. Then the two-layer system reduces to a vertically well mixed water column of uniform temperature. In addition to the vertical thermal stratification during summer, also a lateral thermal stratification is present throughout the year. This is caused by the gradual transition between the strong annual variations of the continental waters and the weaker thermal variations of the oceanic water masses in the north.

Both, the atmospheric and the marine weather are characterized by the transition between the oceanic and the continental mid-latitude climate regimes. The temporal and spatial changes in the respective dominance of the regimes accounts for a considerable annual, sub-annual and inter-annual variability of the weather in the atmosphere and in the sea, respectively.

The main focus of this contribution will be on the dynamics of the sea, because it reflects the influences of both, the direct forcing of the atmosphere (wind and air pressure) and the internal distribution of mass, formed by the thermal and the haline stratification. Spatial changes in the density of the sea water create pressure differences within the sea, which in turn will accelerate the flow. The resulting currents are an effective transport medium for dead and living matter in the sea (for example: nutrients and biomass) and as such they play an important role for the productivity of the sea.

The atmospheric weather

The dominant atmospheric forcing of the North Sea is provided by the space-time distribution of the winds and the air pressure. Climatological means of these parameters are shown in Fig. 1 for the summer and the winter season. The distributions were computed from a 28 years record of six-hourly data compiled and kindly provided by the Norwegian Meteorological Institute. Each of the two plates in Fig. 1 contains contours of the wind-stress east- and north-component (the tangential force exerted by the winds at the sea surface), the air pressure and the wind-stress curl. The latter is a measure of the rotation of the wind field relative to a vertical axis. This pa-

A, Summer
(August)

B, Winter
(December)

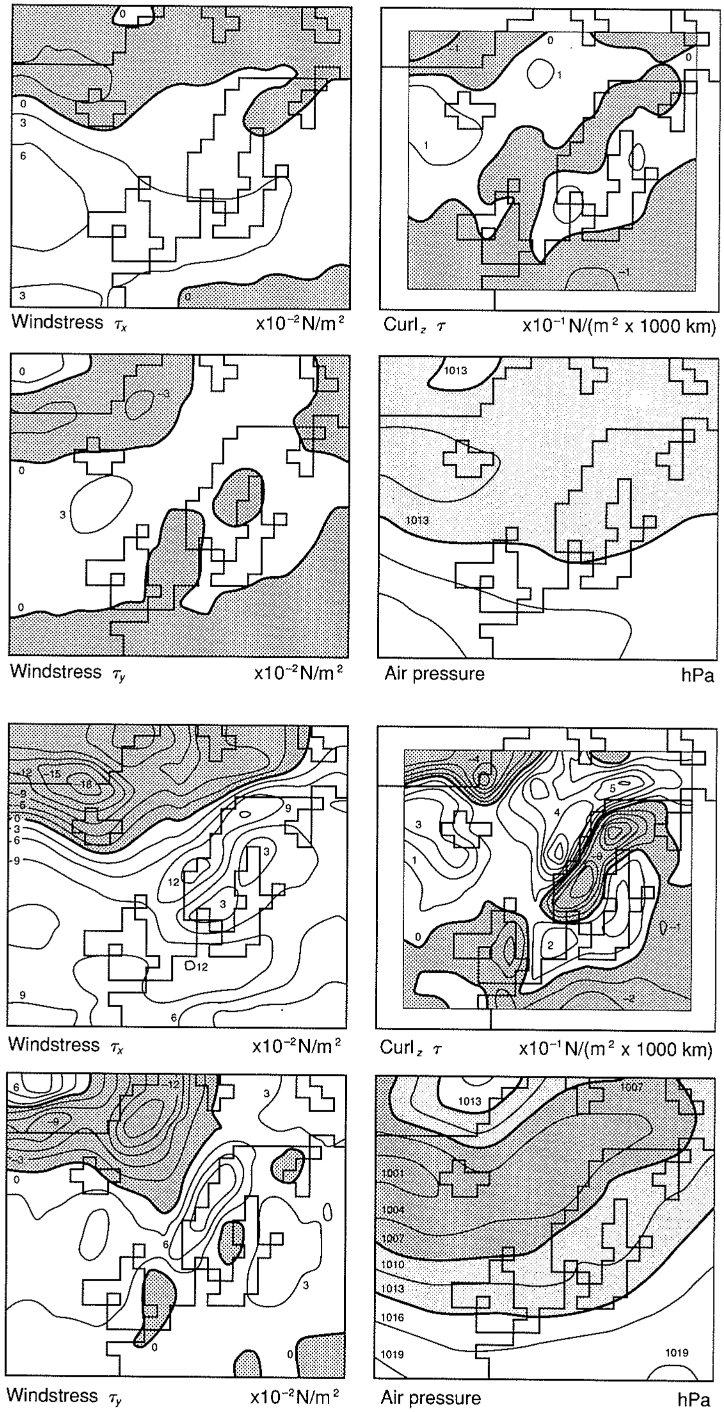


Fig. 1. Climatological means of weather patterns over northern Europe. A, summer; B, winter.

rameter is especially important for the long-term flow within the sea. The display of Fig. 1 gives an impression of the range of the mean annual changes of these parameters. Clearly, the most energetic situation is found in winter, which verifies the personal experience of any North-European. Later in this presentation Fig. 1 will be needed in order to reflect weather anomalies against the mean situation.

The marine weather

As already reasoned above, the marine weather of the North Sea will be demonstrated by means of the currents, or the circulation. The only means to compile a consistent picture of the circulation of a sea in view of the quality of the presently available oceanographic data, which is scattered in space and in time, is a numerical model.

The following results were computed by means of a three-dimensional numerical circulation model, which combined data of the tides, the distribution of tempera-

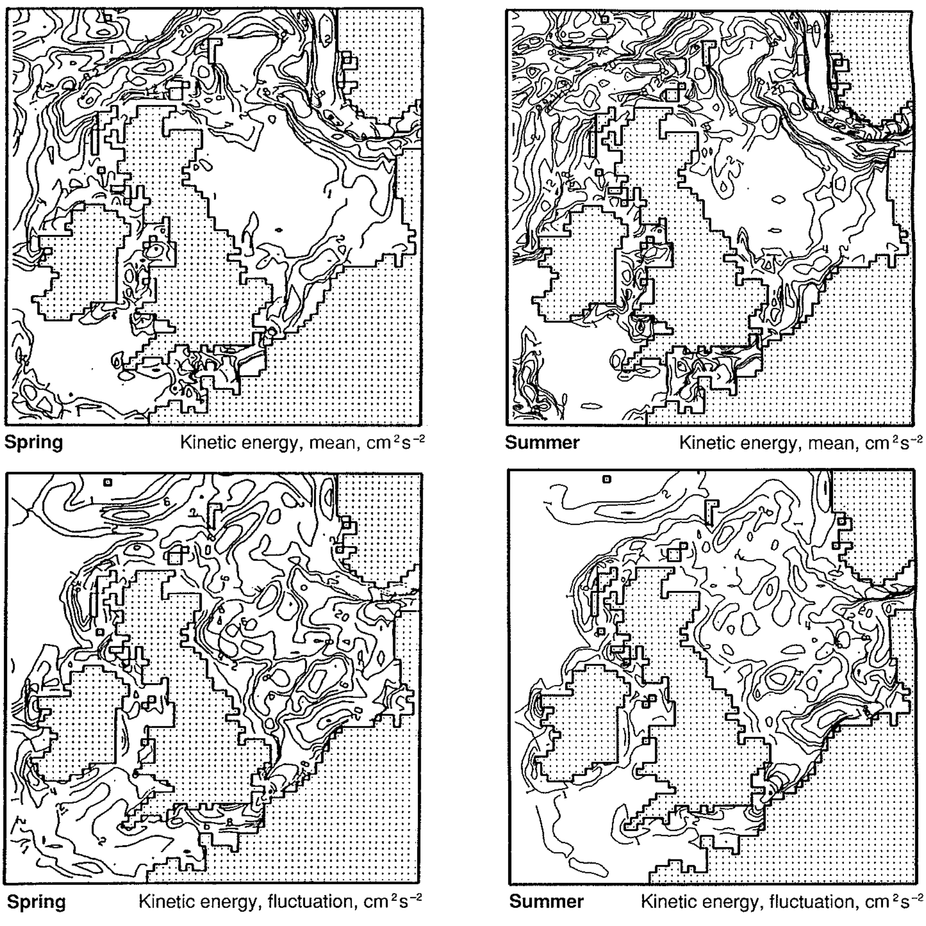


Fig. 2A. Seasonal means of the energy of the mean flow and of flow-fluctuations within the season.

ture and salinity (and hence, the density of the sea water) and the atmospheric forcing. A further important input is the shape of the sea basin, its topography, which was prescribed in a 1:1 scale on a rectangular grid system (cf. Fig. 3A). Since the North Sea covers a latitudinal extent of almost ten degrees and since its dimensions are huge enough to allow the flow to be influenced by the effect of the earth rotation, the model accounts for the so-called Coriolis acceleration and its latitudinal variation. The numerical model is a sophisticated computer coding, which needs a powerful mainframe computer. It can be regarded as an interpolation tool for oceanographic data, based upon the laws of hydrodynamics.

The marine weather is displayed in Fig. 2 by means of the kinetic energy of the depth averaged flow. For the summer and the winter season the kinetic energy of the respective seasonal mean of the flow and the mean energy of dynamical flow-fluctuations within each season are shown. The general direction of the circulation varies only little between the seasons so that only one picture of the directional pat-

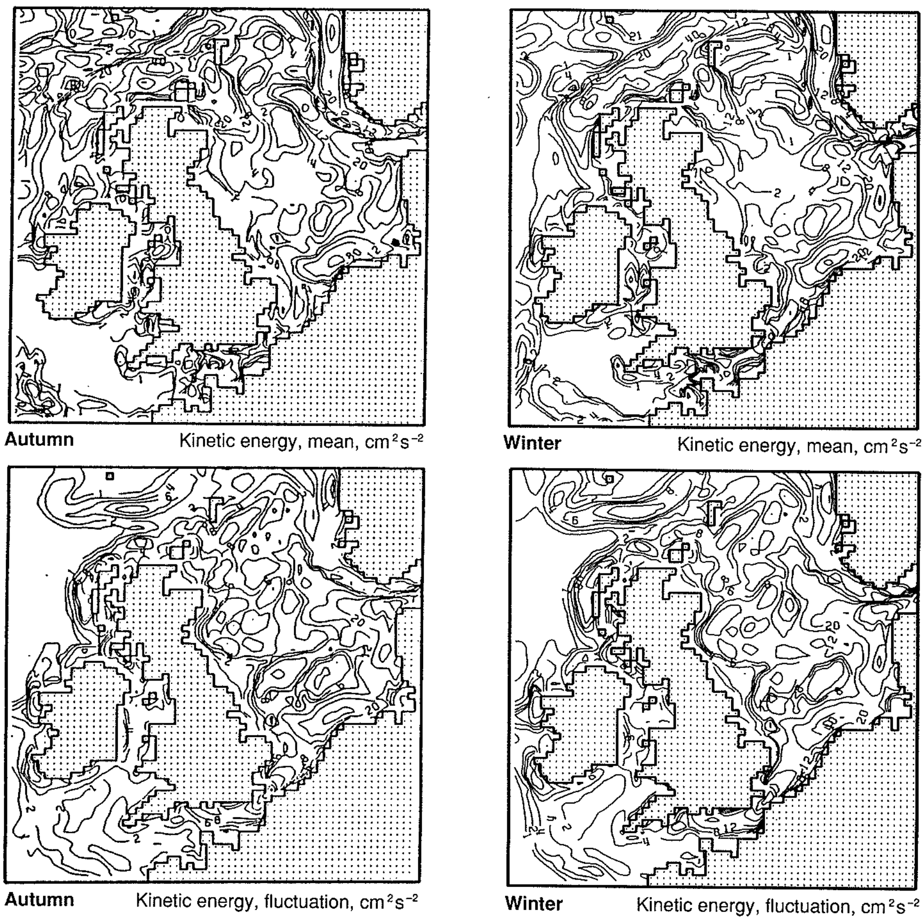
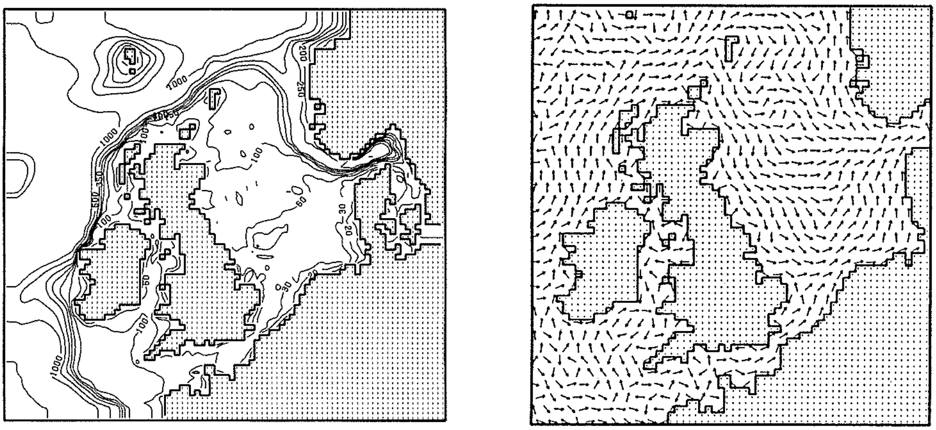


Fig. 2B. Seasonal means of the energy of the mean flow and of flow-fluctuations within the season.



A Topography (M), ISO = DZ(J) B Velocity field, direction

Fig. 3. A, topography of the North Sea and adjacent regions defined on discrete model grid (raster). B, mean direction of the flow within the North Sea (unit vectors).

tern is given in Fig. 3B. It shows the cyclonic (contra sole) sense of rotation of the large-scale, basin wide flow, which is characteristic for the North Sea.

The display of Fig. 2 not only provides an impression of the annual variations of the long-term circulation and of its fluctuations but also of the considerable regional differences of the circulation. It becomes evident that for both, mean and fluctuation the most energetic dynamics in the shallow southern portion are to be found in the south-eastern North Sea (German Bight) and in particular off the coast of Jutland. The Great Fisher and the Dogger Bank, both fertile fishing grounds in the North Sea, are also regions of very high fluctuation dynamics. This gives rise to the assumption that the variability of the marine climate may favour biological productivity.

The transport-ways of water masses of different origin in the North Sea are given in Fig. 4. Contours of the so-called transport-streamfunction indicate the various routes, taken by the water masses. The contours are given in units of 1 million cubicmeters per second (1 Sverdrup unit in oceanography); the density of the contours is a measure of the magnitude of the flow. This display shows that those Atlantic water masses, which enter the North Sea from the north do not reach the continental coastline because they gradually turn eastward towards the Jutland coast and the Skagerrak where they merge with the southern Atlantic inflow through the Channel. All water masses leave the North Sea via the Norwegian Trench off the west coast of Norway. Obviously there are two main water mass regimes within the North Sea indicated by the streamfunction contours. Along their way through the North Sea the oceanic water masses are transformed by mixing with the fresh water run-off from the continent. The result of the mixing and movement of water masses is demonstrated by the surface salinity distribution, given in Fig. 5. It shows the pronounced lateral haline stratification along the continental coastline.

With the help of the numerical model an analysis of the circulation of the North Sea in relation to variations of the direction of the mean wind forcing revealed, that

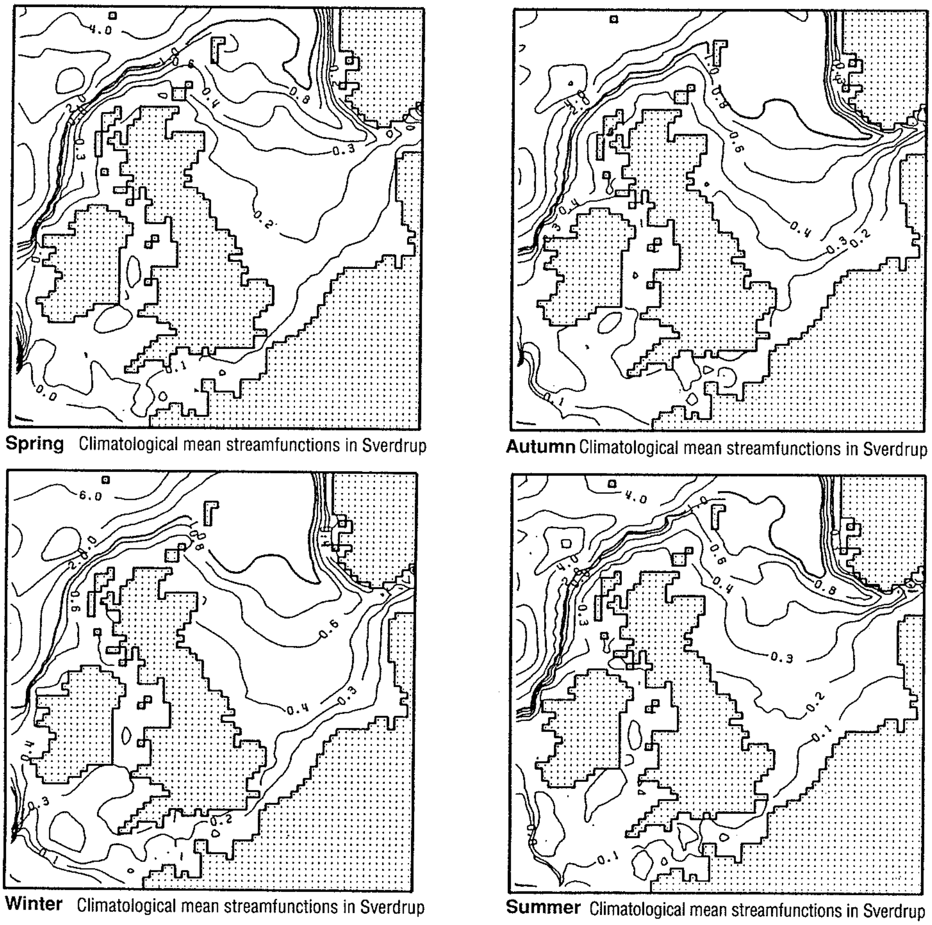


Fig. 4 (above). Mean annual cycle of the water mass transport within the North Sea (in million cubic-metres per second). The contours indicate the routes of the water masses, their density are a measure for the speed of the flow.

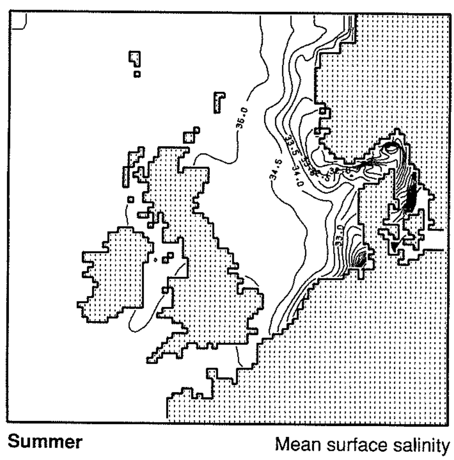


Fig. 5 (right). Salinity (practical salinity units) for the summer as derived from 20 years of observational data.

the present climate situation leads to an optimum water mass exchange within the North Sea basin. The average cyclonic rotation (positive curl) of the windstress over the North Sea (cf. Fig. 1) significantly favours the water mass exchange.

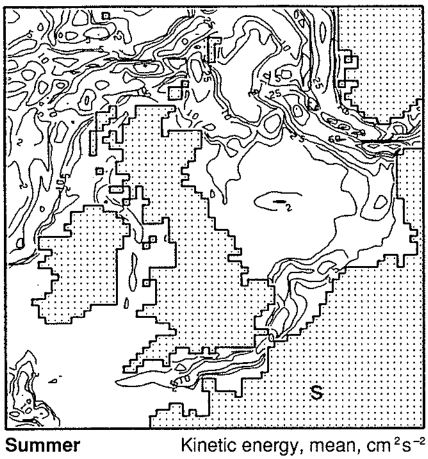
In regard to the anthropogenic pollution of the North Sea, which gives reason for increased concern, the present climatic situation of the North Sea must be regarded as a fortunate coincidence.

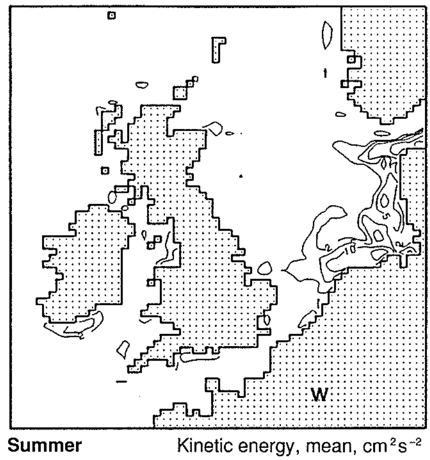
It is merely a philosophical question to consider what would have happened to the dump-site North Sea if the marine climate would have been less favourable....

Decomposition of the marine dynamics

The above figures represent the combined dynamical effect of the components of the marine weather (tides, stratification, winds, air pressure). They do not allow to quantify the regional and temporal contributions of the respective weather components to the dynamics of the sea.

In order to estimate these contributions to the overall patterns given in Fig. 2 the





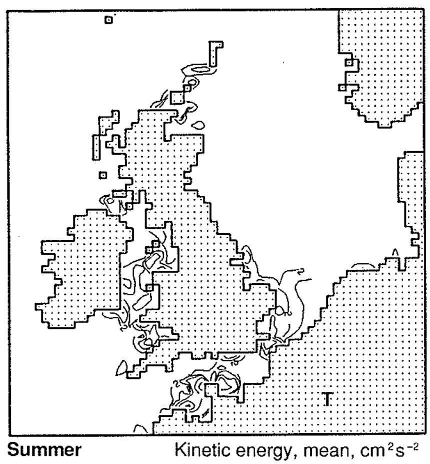
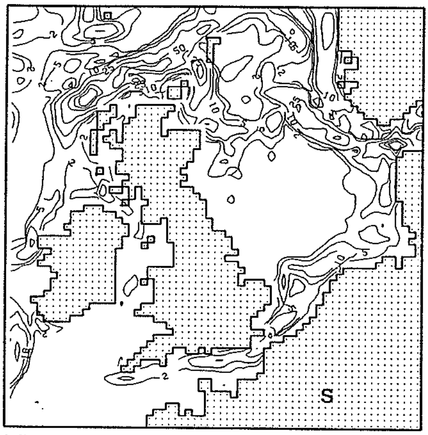


Fig. 6A. Decomposition of flow components in summer. T: tidal; S: stratification; W: wind contribution to total kinetic energy of the mean flow.

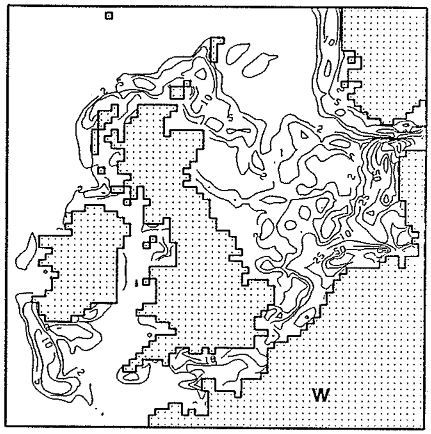
single components were fed separately into the model. This decomposition of the marine climate is displayed in Fig. 6 for the marine summer and winter weather, respectively, again by means of the kinetic energy of the flow. In this figure T stands for the contribution of the tidally induced long-term flow, the so-called tidal residual flow (not for the energy of the tide). Further, S stands for stratification and W for winds and air pressure.

The most striking result of this decomposition was that the contribution of the tidal long-term flow compared to that of winds and stratification is almost negligible. Only in regions with a very strong tidal flow (e.g. Channel and Irish Sea) a significant contribution was obtained. However, it would be the wrong conclusion to assume that the effect of the tide can be neglected, because it interacts non-linearly with the other components, as was deduced from further model studies.

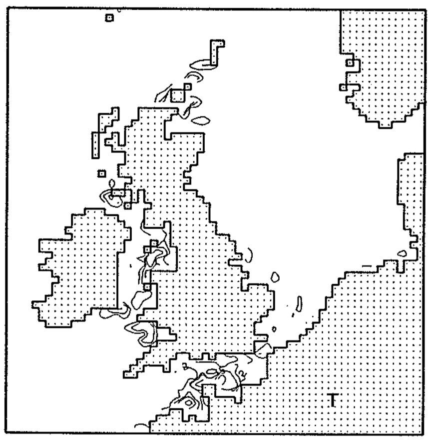
Another striking feature (as yet not fully accepted by some North Sea oceanographers) is that during summer the influence of the stratification on the long-term flow dominates for wide areas in the North Sea, especially in the north. For quite a



Winter Kinetic energy, mean, cm^2s^{-2}



Winter Kinetic energy, mean, cm^2s^{-2}



Winter Kinetic energy, mean, cm^2s^{-2}

Fig. 6B. Decomposition of flow components in winter. T: tidal; S: stratification; W: wind contribution to total kinetic energy of the mean flow.

long time it was assumed that the influence of the stratification was unimportant. Only in the winter season the wind forcing clearly dominates the dynamics. In the shallow southern North Sea a pronounced difference between the western and the eastern parts of the basin is evident.

Outstanding weather events

The consequences of climate variability on the dynamics of the North Sea shall be demonstrated by two outstanding weather events. In Fig. 7 the simulated water mass transport through a control-section off Jutland (near Hanstholm) is displayed for the years 1969 to 1981. Fluctuations of the flow with time-scales (periodicities) above one month are given by the black curve, whereas shorter term fluctuations appear as a shaded variance around the curve. The section cuts the converging stream lines shown in Fig. 4; it represents a region where water masses from the northern and the central North Sea and from the German Bight are merging to form the Skagerrak inflow. Positive values in Fig. 7 represent an inflow, negative values a southwestward directed (out-) flow.

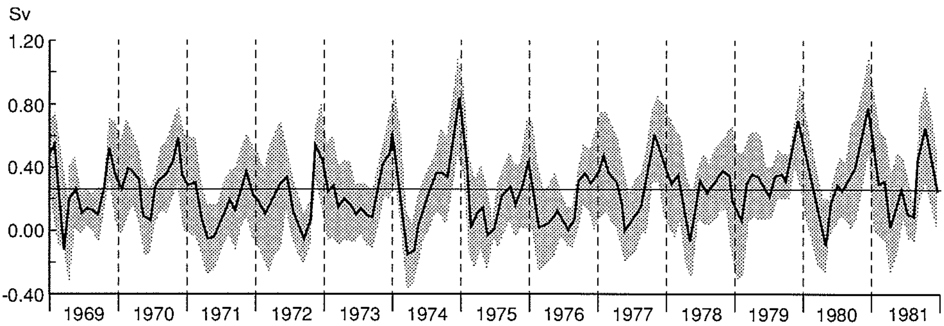


Fig. 7. Water mass transport through control section off Jutland in Sverdrup(in million cubic-metres per second). Shading indicates high frequency fluctuations of the flow.

In 1974 two distinct extrema of the flow are present. The first is a negative marine climate anomaly, which lasts for more than two months in spring 1974. It appears in conjunction with a pronounced and persistent high air pressure system over the central North Sea (increased continental influence).

The second event in the winter 74/75, which is the overall extreme of the record shown in Fig. 7, coincides with a considerable increase of a cyclonic low air pressure situation over western Europe (increased oceanic west-wind activity). In Fig. 8 the spatial distribution of the marine climate parameters (directional flow pattern and anomalities of the energy of the mean flow, cf. Fig. 2) are shown together with the respective anomaly of the air pressure distribution (cf. Fig. 1).

The two examples were chosen on purpose, because they provide an impression about the present range of the variability of the marine weather on the one hand, and on the other hand about the consequences of a change in the dominance of the oceanic or the continental climate regime, respectively.

Note that in the negative event (high air pressure anomaly and unfavourable anti-cyclonic windstress rotation) the directional pattern of the flow has changed entirely). This situation leads to a far less effective flushing of the water masses within the North Sea. On the other hand the extreme positive event has at least doubled the energy of the mean flow and the directional pattern of the flow shows that it is favourable for the flushing of the North Sea. However, if such a situation would prevail in the course of a climatic change this would imply very drastic changes especially along the coasts of the German Bight and Jutland (cf. Fig. 8). For instance sand and sediments might be transported at much higher rates than now, with the danger of an increased coastal erosion.

Since the circulation of the North Sea is 'used' by a number of fish species as a vehicle for the transport of eggs and larvae any climatic change of the circulation would inevitably induce drastic changes in the recruitment of fish.

A climate-change scenario

The results presented above provide an impression about the consequences of changes of the wind and air pressure fields over the North Sea. In the following a crude estimate of the consequences of a change in the salinity distribution, depicted in Fig. 5, will be presented.

This estimate is based upon the assumption that the haline stratification of the North Sea is solely produced by the mixing of fresh continental with salty oceanic waters and that precipitation over the North Sea is balanced by evaporation. It is further assumed that a change in the continental fresh water run-off will not modify the general, overall pattern of the lateral stratification created by the water mass mixing. Finally also the advection of fresh water (its transport) with the currents is neglected in the experiment.

With these restricting and simplifying assumptions it is easy to compute the local amount of fresh water at any position within the North Sea in relation to a reference Atlantic salinity of, say 35 (cf. Fig. 5). An artificial increase or decrease of the local amount of fresh water would then reflect a climate change of the precipitation in the west European hinterland of the North Sea. If the new salinity distribution is fed into the model, it will produce an estimate of the resulting change in the dynamics of the flow, which depends on the modified haline stratification.

For this climate-change scenario the amount of continental fresh water was doubled. The estimated consequences on the salinity distribution in the North Sea are shown in Fig. 9 by means of an anomaly related to the present distribution, given in Fig. 5. According to the original pattern in Fig. 5 the most drastic changes are to be expected along the continental coastline. Indeed, due to the doubling of the fresh water, the salinity decreases by up to 5 psu (practical salinity units) in the German Bight and the Kattegat and of the order of 2 psu along the Jutland coast and in the Skagerrak. Such a change might increase the abundance of sea-ice production in the coastal regions during winter. However, also for marine life a long-term climatic change of the order of some salt units implies a severe impact, which could lead to a change in the distribution of species within the regions affected.

The scenario represents a shift in the transition between Atlantic and coastal water masses. The most drastic changes for the dynamics of the flow occur in those

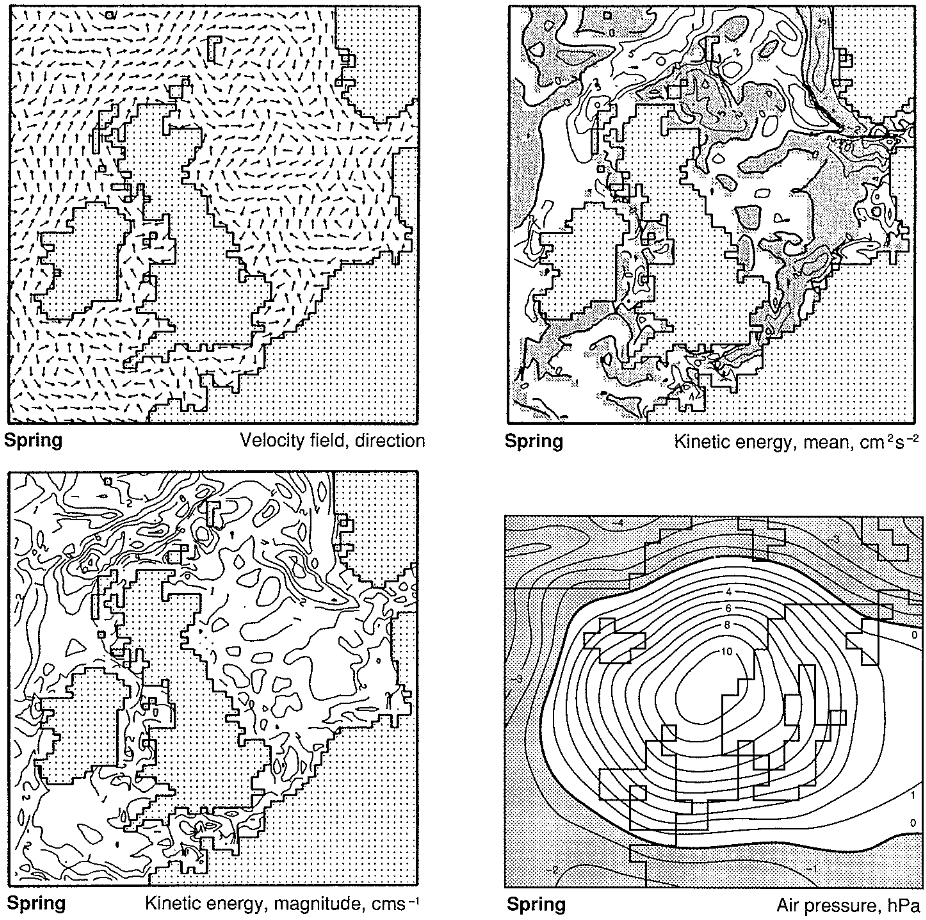
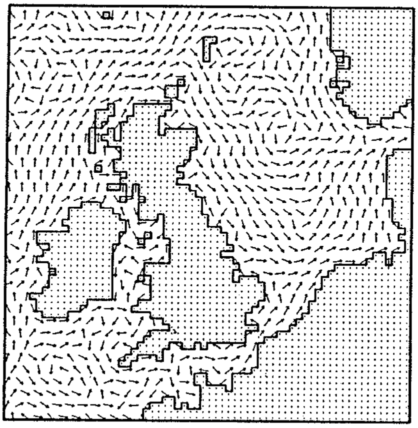


Fig. 8. Circulation and weather (lower right) anomalies; A (above): spring 1974, B (opposite, top): winter 1974/75 (cf. Fig. 7).

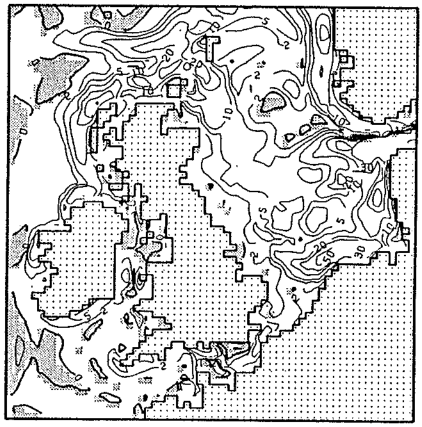
regions, where the gradients of the density are increased. The modified haline stratification affects the dynamics in the German Bight, along the Jutland coast and in the Skagerrak and Kattegat. In the very shallow coastal regions of the eastern North Sea (German Bight) the changes are less pronounced, although the local salinity change is large, because they are damped out by the energy dissipation at the sea bed, which increases with decreasing water depth.

Due to the very simplifying assumptions the result of this simulated scenario should be regarded with care. It is a crude zero order estimate. From observations of the long-term dispersion of radioactivity released at nuclear reprocessing plants and from dispersion simulations for the North Sea we know that the average time

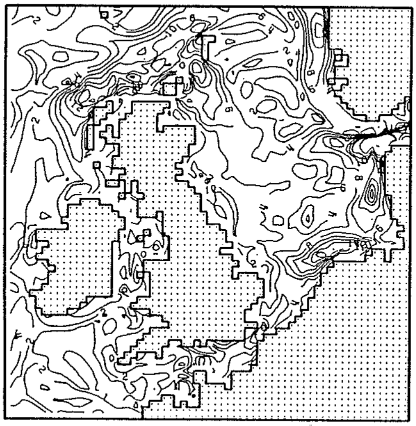
Fig. 9 (opposite, bottom). Estimated reduction of salinity in the North Sea (cf. Fig. 5) due to a doubling of the continental fresh water run-off.



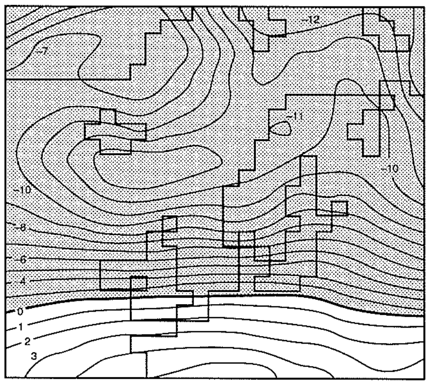
Winter Velocity field, direction



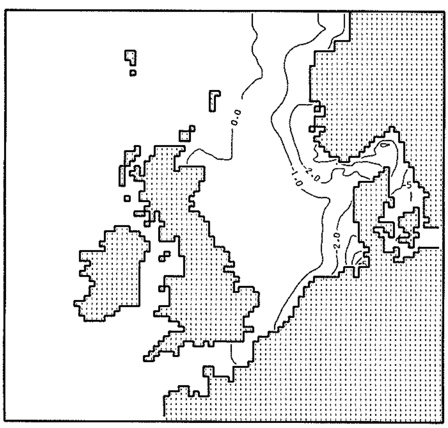
Winter Kinetic energy, mean, cm^2s^{-2}



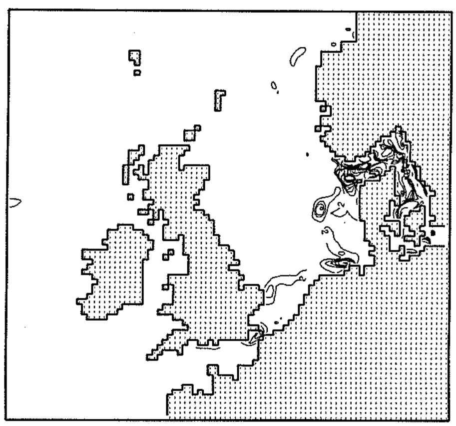
Winter Kinetic energy, magnitude, cms^{-1}



Winter Air pressure, hPa



A Surface salinity anomaly



B Kinetic energy, anomaly, cm^2s^{-2}

for a total exchange of the North Sea water masses is of the order of 3 to 5 years. Hence, if a climate change, which affects the distribution of water masses, should occur, the North Sea would react with the above time-scale to the disturbance. This is extremely fast in contrast to the at least ten-fold slower response of the deep ocean. However, in view of the very high variability of the marine climate of the North Sea, it will be rather difficult to discriminate between a real change and the normal climatic variability described in 'The marine weather' section.

Final remarks

The climatic-change scenarios discussed above are highly speculative, because as yet the consequences, for instance of the greenhouse effect, on the North Atlantic and the North Sea are unknown. However, already the assumption that some of the above shown events, which presently occur as climatic noise (short-term changes, order of weeks to months), may last for longer periods (i.e. months to years) implies a drastic impact to the marine climate of the North Sea. The changes would affect life in the sea as well as the dispersion of living and dead matter (biomass, pollutants, nutrients, sediments, etc.), but also people living near the coast, because of the likelihood of increased icing or coastal erosion once the dynamics become more energetic. Since the present average water mass exchange of the North Sea is an optimum, any deterioration of this situation might increase the hazard of pollution due to lacking dilution. In conclusion, there is good reason to hope that the present marine climate should not change.

Acknowledgement

The results presented here were carried out in cooperation with my colleagues J. Bartsch, P. Damm, D. Hainbucher and T. Pohlmann. The research was funded by the German Federal Ministry for research and Technology under grant no. BMFT-MFU0545.