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ATLANTIC INFLOW TO THE NORWEGIAN SEA

AS DEDUCED FROM CURRENT METER OBSERVATIONS AND NUMERICAL MODELLING.

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Abstract

The main aim of a new project is to quantify transports in the Svinøy section, a confluence region of the Norwegian Current with pronounced bottom topography. The representativeness of each current meter position has been tested by a re-examination of current observations in 1969. The transport estimates based on 26 current meters show great variability with an monthly average of 3.3 Sverdrup. It is also shown that the transport is adequately represented by two current meter recordings. The transport is compared with results from a numerical model (POM), showing an monthly average transport of 3.0 Sverdrup.

Introduction

The main entrance of warm, salty North Atlantic waters to the Norwegian Sea is through the Faeroe-Shetland Channel. North of the Faeroe-Shetland Channel this inflow merges with the inflow between the Faeroe Islands and Iceland and also with a branch of the Irminger Current which enters through eastern Denmark Strait and turns east. The Norwegian Current is the northern extension of the North Atlantic Current, and it is following close to the Norwegian continental slope on its way northwards. The temporal and spatial structure of the current have been discussed by Sælen(1963). The small scale variations, 30-60 km, are according to Mysak and Schott (1977) due to waves induced by baroclinic instability. The variations of the Norwegian Current have a great impact on the ocean climate in the Nordic Seas.

The inflow to the Norwegian Sea has been discussed since the beginning of this century, and is still under debate. Estimates from budget calculations by Worthington(1970), McCartney and Talley(1984) and Mauritsen(1993) are in the range 6.8-9 Sv (Sv=10^6 m^3/s) while use of satellite altimeter data by Samuel(1993) and Pistek and Johnson(1992) show values of 1-5 Sv. Volume fluxes estimates based on measurements by Dooley and Meincke(1981), Gould et al(1985) and Blindheim(1993) gave an inflow of 3.3, 7.5 and 2-8 Sv, respectively. Most works indicate an annual cycle with maximum inflow during winter and minimum in summertime. Major results are summarized in Hopkins(1991).

In this paper, observations from an expedition in 1969 will be re-examined to improve our knowledge of the volume flux in the region, and in the vertical distribution of current. In addition, an attempt to compare the observations with results from a numerical model will be made.

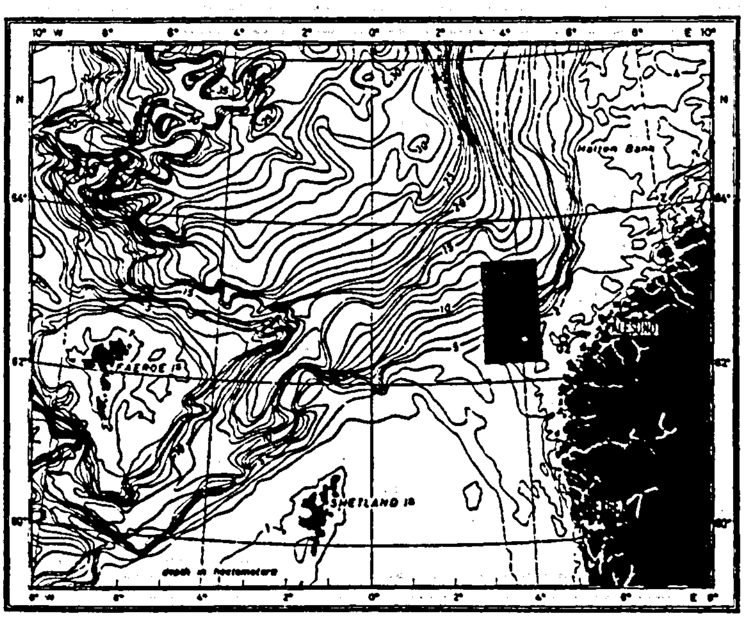

FIGURE 1. Investigation area of "Norwegian Sea 1969" (from Dietrich and Horn(1973))

Flux calculations from current meter observations

In summer 1969, the "Norwegian Sea-Expedition 1969" (Dietrich and Horn (1973)) took place, covering the rectangular shaded area in Figure 1. Among other measurements the expedition deployed four moorings in the Storegga-area, oriented normal to the continental slope in water depths from 500 to 870 m. A total of 26 current meters where mounted on the moorings, covering a period of 12 to 43 days, starting at July 21, 1969. Common recording time interval was 10 min. The time series were first averaged to 3 hourly means and next filtered by a low-pass filter with a cutoff period of 24 hours to eliminate the fluctuations of tidal and internal wave periods. Progressive vector diagrams shown in Horn and Schott (1976) show mean current direction of about 60 degrees to the northeast, although for shorter periods of time there are small deviations from this direction in the deeper instruments at the outermost mooring. The local topography at the mooring sites is approximately oriented east-west. The time series of current showed strong fluctuations with periods of 2-3 days.To determine the flux of inflowing water we associate an cross sectional area with each current meter. The uppermost area is taken to the surface, and the lowermost is taken to the bottom. The position of each of the current meters and the area associated with each instrument are shown in figure 2. By combining the areas with the east-west component of current from the filtered records and summing the results, time series of the inflow is derived and presented in figure 3 as the solid line. The range is between 1.6 and 5.5 Sv with a standard deviation of 0.7 Sv, and the mean value for the 43 days period is 3.3 Sv. Different kinds of error sources must be considered: measurement errors by instrument inaccuracies and mooring motions, and uncertainty by the method chosen for volume flux estimate. Concerning the measurement errors, three different types of current meters were used. However, as discussed in Schott and Bock (1980), only small deviations exist. Mooring motions were found by Horn and Schott (1976) to be small in the periods considered here. Measurement errors are therefore neglected. Different methods for choosing the area to represent each current meter in calculating the volume flux through a section were tested, and gave results within 5% of the results presented in figure 3.

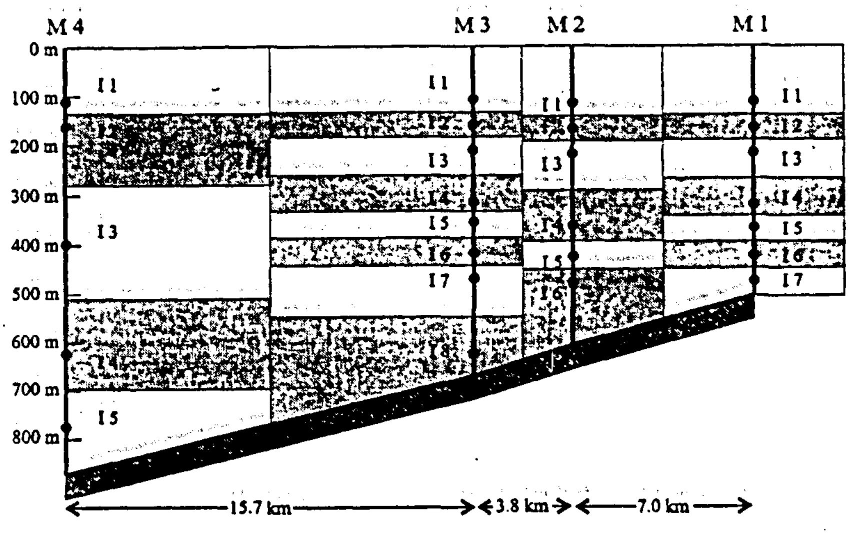

FIGURE 2. The four moorings and the area associated with each current meter.

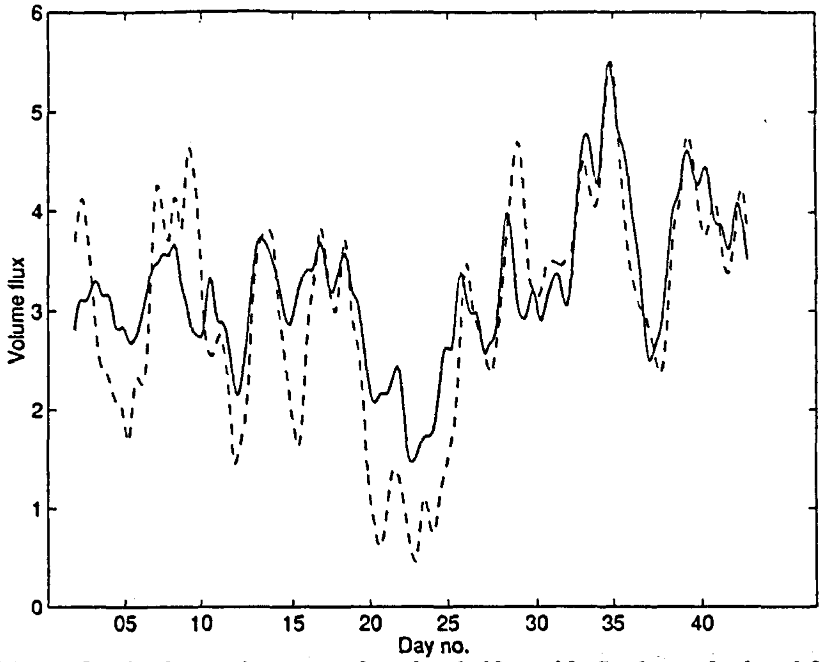

FIGURE 3. Volume flux in the section normal to the shelf outside Stad as calculated from observations (solid line) and from regression line analysis (dotted line). Horizontal axis shows time in days, starting at July 21, 1969. Vertical axis shows volume flux in Sverdrups.

Flux calculations from regression analysis

Velocity recordings at 20 of the instruments (i.e those recording all 43 days) where correlated against the volume flux estimate from the current meters, and the results are given in Table 1. There are three current meters with relatively high correlation: instrument M3-I4, M3-I5 and M2-I3, corresponding to depth 312, 353 and 219 meter. The correlation coefficients are 0.69, 0.71 and 0.63, respectively. Choosing the two latter instruments to represent the total flow, assuming them to be within the core of the current, a linear relationship between velocity and total volume flux gave the following regression line for transport U:

$$U = 5.72 \cdot 10^6\,m^2 \cdot u_1 + 9.47 \cdot 10^6\,m^2 \cdot u_2$$

u_1 and u_2 are the velocities (in m/s) from M3-I5 and M2-I3. U is depicted as the dashed line in figure 3. The range of the regression line transport is 0.5 to 5.5 Sv, with a mean of 3.0 Sv, and the standard deviation gives a variability of 1.1 Sv. Correlation coefficient between fluxes derived from all observations and regression analysis based on two current meters give a correlation coefficient of 0.80.

Mooring \ Instr	I1	I2	I3	I4	I5	I6	I7	I8
M 1	0.46	0.43		0.09			-0.21	
M 2	0.62		0.63	0.50		0.31		
M 3	0.53	0.57		0.69	0.71	0.63	0.55	0.34
M 4	0.31	0.35	0.18	0.30	0.15			

TABLE 1. Correlation coefficients between each current meter recordings and total volume flux calculated from 26 current meter recordings.

Flux calculations from a numerical model

The model used in this study is the time-dependent, three-dimensional, estuarine and coastal circulation model of Blumberg and Mellor (1987) commonly referred to as the Princeton Ocean Model (POM). The prognostic variables are the free surface elevation, velocity, temperature, salinity, turbulent kinetic energy and turbulent length scale. The model uses a σ-coordinate system, and the grid points are arranged in a Arakawa C-grid. The area in this experiment covers the Nordic Seas, the North Sea, Skagerrak and the Barents Sea, with a horizontal resolution of 20 km in both directions. The model set up includes 17 σ-layers, at 0, 2, 5, 10, 25, 50, 100, 150, 200, 300, 400, 500, 600, 700, 800, 950 and 1000m when normalized to 1000m. As initial values we use climatological values of velocity, salinity, temperature and water elevation for May, allowing a 50 day spin-up period. At the open boundaries, the flow relaxation scheme of Martinsen and Engedahl (1987) has been implemented. Driving forces are hindcast six-hourly atmospherical forcing from The Norwegian Meteorological Institute and monthly mean river runoff. In addition a weak relaxation toward climatological values in depth are used. We make use of the embedded turbulence closure scheme to calculate vertical mixing processes. External and internal timestep is 900 and 30 s, respectively. In the Smagorinsky diffusion formulae the parameter C (degree of horizontal diffusion) is 0.1. Minimum vertical diffusion is $2.0 \cdot 10^{-5}$ m^2/s.

Volume flux were calculated by choosing a section representing the same area and part of the shelf as the observations covered. Due to sparse model resolution, the section occupies only a few gridpoints, but testing different combinations of points along and across the section yield practically no differences, and a resulting curve for volume flux is shown in figure 4 as the dotted line. The minimum, maximum and mean values of the model volume flux are -0.9, 5.5 and 3.1 Sv, respectively. The standard deviation is 1.3 Sv. The solid line is the volume flux calculated from the current meter recordings, as in figure 3.

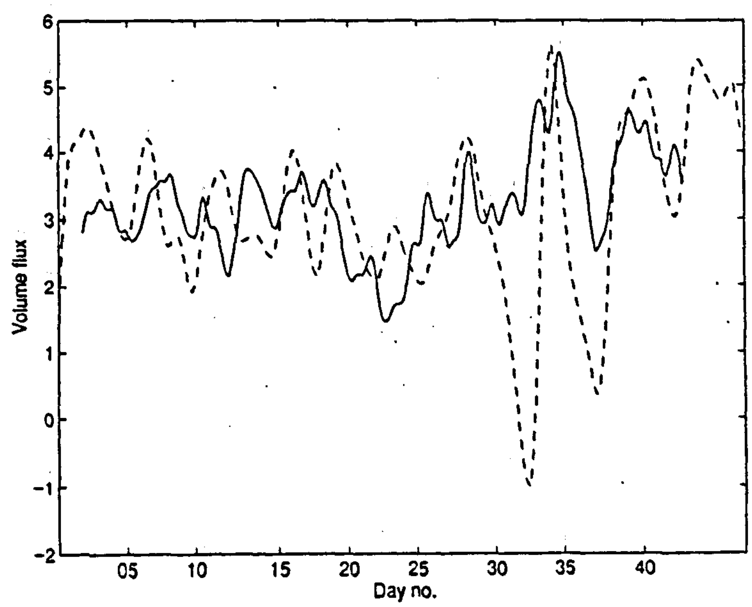

FIGURE 4. Volume flux in the section normal to the shelf outside Stad as calculated from observations (solid line) and from a numerical model (dotted line). Horizontal axis shows time in days, starting at July 21, 1969. Vertical axis shows volume flux in Sverdrups.

Discussion

From the current meter recordings we arrive at a volume flux of 3.3 Sv for the summer situation which is considered to be the season of minimum inflow. From combined use of hydrography and altimeter signals Pistek and Johnson(1992) arrived at a mean flux of 2.9 Sv, with a seasonal variation of about 50% of the mean, for the years 1987-1989, which indicate about 1.5 Sv as a minimum. Samuel(1993) based his calculations on altimetry and numerical ocean circulation models and arrived at a mean value of 2.7 Sv, with annual cycle of about 1.8 Sv for the same period. Our estimate is somewhat higher than these estimates. By geostrophic calculations based on a level of no motion at 1000 m, Blindheim(1993) arrived at a volume flux through the Svinøy section of 4.6 Sv both in August 1990 and 1991, which is somewhat higher than our estimate. However, the differences in all cases are not greater than what may be expected considering the observed variability and the different methods of transport calculations.

The measured transport may be adequately represented by velocity recordings at two depths within the core of the current. The relative (0.80) high correlation coefficient between observed and regression analysis volume flux (0.80) indicate that the core of the current is found above the 600 m isobath.

Comparing observed and model volume flux, we can divide our considerations in two parts: mean values and variability. Phase differences between the to time series exist, but are not closer examined. Mean values of volume flux are very close for observations and model results: 3.3 against 3.0 Sv. From fig. 4 its evident that the first 30 days of the time series would have given even closer mean flux values. After day 30, corresponding to August 20, there are some larger disagreements which may be caused by the model response to a sudden change in windspeed and direction. Focusing on the variability of the volume flux, the standard deviation is greater in the model flux than in the observed volume flux time series, but the difference is small. Disagreements between numerical model results and in situ measurements may have many reasons; the lack of sufficient spatial resolution and influences from outside the model domain being the most obvious. Thus, the present work is considered as an exercise and will be followed up by new extended measurements and modelling.

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