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Direct measurements of heat and mass transports through Fram Strait

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To determine volume and heat transports through Fram Strait, an array of current meter moorings was maintained in the Strait between 1997 and 2001, with annual redeployments. The transports obtained by averaging the monthly means from the first 2 years were 9.5 Sv to the north and 11.1 Sv to the south ($1 Sv = 10^6 m^3 s^{-1}$). The net transport over the 2 years was 4.2 Sv to the south, taking into account that there is some recirculation from the eastern to the western side of the transect which has a meridional offset of 10 nmi. The northward transport consists of about 50% of Atlantic Water, of which about 65% recirculates north of the transect. The northward heat flow, 85% of which is by Atlantic Water, is 16TW (1997/1998) and 41TW (1998/1999).

Keywords: Arctic Ocean, Atlantic Water, Fram Strait, measurements, transports.

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Introduction

Exchanges between the North Atlantic and the Arctic Ocean result in the most dramatic water mass conversions in the world ocean: warm and saline Atlantic waters flowing through the Nordic Seas into the Arctic Ocean are separated by cooling and freezing into shallow fresh waters (and ice) and saline deep waters. The outflow from the Nordic Seas to the south provides the initial driving of the global thermohaline circulation cell; the one to the north is of major impact to the large-scale circulation of the Arctic Ocean. Measuring these fluxes is a major requirement to quantify the turnover rates within the large circulation cells of the Arctic and the Atlantic Oceans and a basic condition for understanding the role of these ocean areas in climate variability on interannual and decadal scales.

Data

With the aim of assessing the accuracy of the transport estimates which can be obtained by direct measurements, 14 current meter moorings were deployed in Fram Strait from September 1997 until August 2001, with replacements in September of 1998, 1999, and 2000 (Figures 1, 2). The recovery of the present array is planned for 2002 after a 2-year deployment period. From 1999 to 2000 the 3 central moorings (F7, F8, and F9) were omitted. The moored instruments covered the water column from 10 m above the seabed to approximately 60 m below the surface. Three moorings in the East Greenland Current were equipped with upward-looking Doppler Current Meters reaching to the sea surface. In the horizontal the measurements extend from 6°51′W (the eastern Greenland shelf break) to 8°40′E (the western shelf break off Spitsbergen), on a line along 78°50′N on the eastern part and along 79°N on the western part of the transect. The flow field through the Strait was compiled by interpolation based on the records of 40 current meters for the first year and 45 for the second. The temperature and salinity distributions were obtained with significantly higher spatial resolution by CTD measurements during the cruises.

Results

Monthly volume transports were calculated from the velocity field interpolated over the cross-section of Fram Strait. Because of the superimposed eddy field, 1 month is the shortest period for sufficient averaging to reduce aliasing by eddies and still to resolve the seasonal variation (Fahrbach *et al.*, 2001). The transports obtained by averaging the monthly means from the 2 years were 9.5 Sv to the north and 11.1 Sv to the south (1 Sv = 10^6 m^3 s^{-1}). However, it has to be taken into account that the eastern and western parts of the section are meridionally shifted by 10 nmi (Figure 1). The average recirculation across this 10-nmi-wide section is 2.6 Sv to the west on. Taking into account this recirculation, the net transport over the 2 years is 4.2 Sv to the south (Fahrbach *et al.* 2001). The monthly transports reveal an intensive seasonal variation with large northward transports in winter and weaker ones in summer. This is reflected in the net transport time-series with southward transports in May/June and northward ones in February and April. Strong semi-annual fluctuations are superimposed. The results of transport calculations depend strongly on the applied schemes, which take into account the non-linear character of transports with a variable regional extent. Uncertainties due to different interpolation schemes and the way gaps caused by failing instruments are closed in the time-series are in the range of 1 to 2 Sv. This uncertainty affects the estimates given below in the range of 20%.

Forty-five percent (1997/1998) and 55% (1998/1999) of the northward transport across the transect consists of Atlantic Water defined by water with a temperature above 1°C. From the Atlantic Water 80% (1997/1998) and 50% (1998/1999) recirculates. The northward heat flow of Atlantic Water (rather temperature flow relative to –0.1°C due to the

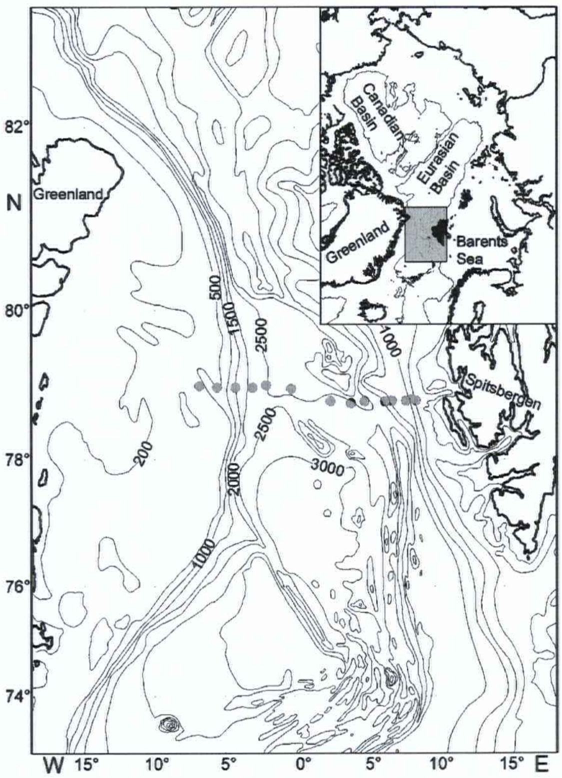

Figure 1. Map of Fram Strait with the positions of moorings deployed during VEINS and until 2001.

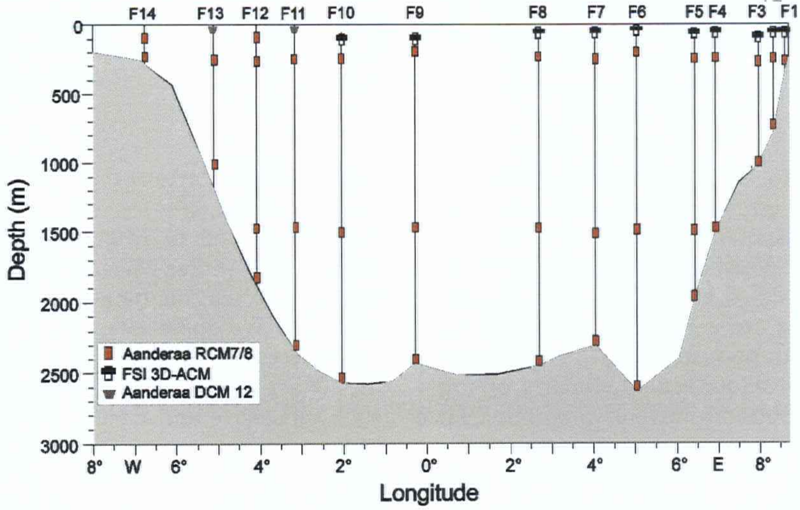

Figure 2. Vertical transect across Fram Strait with the moored instruments deployed from September 1997 to September 1999.

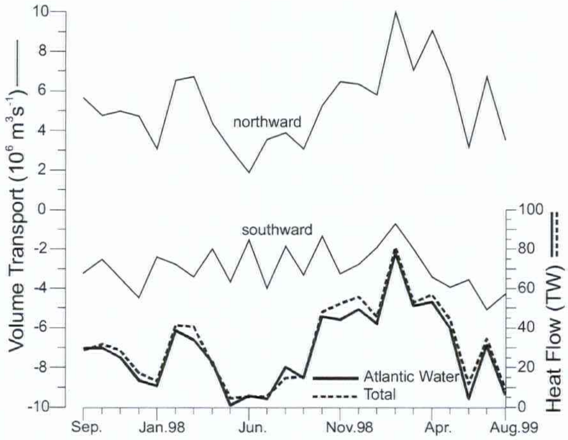

Figure 3. Monthly averages of volume transports through Fram Strait by Atlantic Water (temperature above 1°C) and of associated temperature transports (relative to –0.1°C) determined from the data of the moored instruments as an indicator of the heat transport.

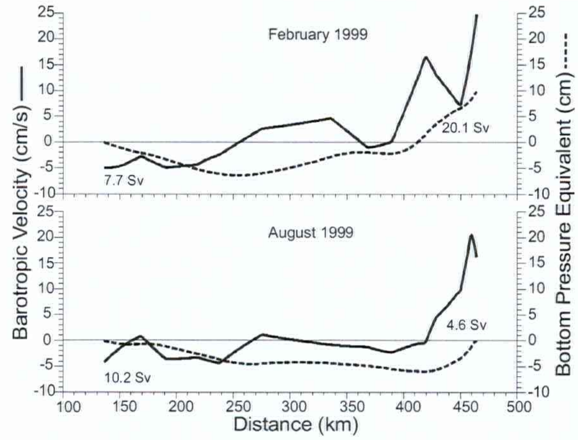

Figure 4. Monthly averages of the barotropic velocities (solid line) along the transect across Fram Strait determined from the moored instruments for February (top) and August 1999 (bottom) and the associated northward (left) and southward (right) volume transports given as numbers (1Sv = $10^6\,m^3\,s^{-1}$). The dashed line indicates the equivalent bottom pressure profile, which is derived from the barotropic currents relative to the western end of the transect and expressed in sea-level elevation (cm) under the assumption of geostrophic equilibrium.

unbalanced volume flow) across the complete section results as 16TW (1997/1998) and 41TW (1998/1999) (Figure 3). In both years, 85% of the heat transport is caused by the flow of Atlantic Water. The reference temperature of –0.1°C was selected in agreement with Aagaard and Greisman (1975) and Simonsen and Haugan (1996) to obtain results which can be compared with earlier work. The obtained range of heat transports suggests an interannual variation of 50%. During both years the transport was within the range of previous estimates (e.g. Simonsen and Haugan, 1996). The transport has its maximum in winter and varies by about 50% within the annual cycle. The variance is mainly due to volume transport variability and only to a minor extent to temperature fluctuation. The time-series is still not long enough to address decadal time-scales. However, it gives a hint on the effort which is needed to eliminate seasonal and interannual variations before longer time-scales can be assessed properly.

It is planned to continue the measurements to obtain a reliable estimate of the interannual variability of the transports and the effect on the Arctic Ocean. Different possibilities will be examined to reduce the number of instruments and moorings. Since the currents are highly barotropic, measurements with bottom pressure recorders, after careful calibration, might allow better estimates of transport variations. Bottom pressure variations related to transport variations can be expected under the assumption of a geostrophically balanced barotropic current. Their seasonal range is derived from current meter records by calculating the horizontal profile of bottom pressure relative to western end of the transect for two seasons (Figure 4). It is in the range to be measured by available pressure recorders, which were deployed in the meantime. Omitting moorings in the recirculation area in the centre of the Strait does not seem promising, since 30% of the volume transport will then not be captured. Correlation of transport time-series with monthly mean zonal current velocities at selected locations seems promising. However, results based on 2-year long time-series cannot simply be transferred onto longer periods, since the present time-series are dominated by the annual cycle. Consequently a longer evaluation period is needed.

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