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ATLANTIC WATER TRANSPORT FROM LONG TERM CURRENT MEASUREMENTS IN THE SVINØY SECTION

by

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ABSTRACT

The Svinøy section just to the north of the Faroe-Shetland Channel cuts through the core of the Atlantic inflow to the Norwegian Sea. Recent investigations show that the different branches of the Atlantic inflow merges through confluence in the shelf break area off Svinøy, making this site very suitable for monitoring the Atlantic inflow. This study deals with transport investigations of the inflow based on long-term current measurements from 9 current meters on 3 mooring lines during April 1995 to August 1996. To achieve a significant estimate of the transport during typical winter conditions, an extensive program was performed in March-April 1996, with 24 current meters on 5 mooring lines. A similar extensive program is in progress for the period September-October 1996, for typical summer conditions. Our findings show that the Atlantic inflow occurs as a 30 km wide, nearly barotropic current trapped over the steepest slope between depths of 200 m and 900 m . Current records in the core of the inflow show a very stable along-isobatic flow towards north-east with yearly mean of 40 cm/s, standard deviation of 18 cm/s and maximum of 100 cm/s. Transport estimates based on a linear regression model show an inflow with strong variabilities between 12 Sv and 0 Sv and a fluctuating time scale ranging from a few days to two months. The annual mean transport is estimated to 5.3 Sv with a standard deviation of 1.9 Sv. The two months moving averaged transport estimates have a standard deviation 0.6 Sv, indicating small variabilities. This figure corresponds with the time series which show small seasonal variations in contrast to the common accepted annual cycle with winter maximum and summer minimum.

1. Introduction.

During the last decades, much attention has been drawn to the inflow of Atlantic water to the Norwegian Sea, an issue still under debate. This is because variabilities of this inflow of warm and saline water are assumed to be an important factor for climate, ecology and biological production in Northern areas. To monitor this Atlantic inflow, a current measuring program was initiated for the Svinøy section (Fig 1) in April 1995 for a 3 years period, as a part of the Mare Cognitum program. The Svinøy section runs north-westwards from the Norwegian coast at 62 deg north and cuts through the core of the Atlantic inflow just to the north of the Faroe-Shetland Channel. The objective is to survey this inflow by estimating the volume transport on the base of long term current measurements.

Hydrographic observations in the Faroe-Shetland Channel and the Svinøy section show water properties of the Atlantic inflow as a warm and saline, wedge-shaped, baroclinic current. Based on hydrographic observations and sparse current measurements volume transport estimates of the inflow have then been worked out by many scientists. The most relevant estimates are summarized by Gould (1985) and Hopkins (1991) and ranges from 2.0-8.0 Sv (Sverdrup). Generally, there is little information on the seasonal variability of the transport, but it has been a common comprehension of seasonality with maximum transport in winter and minimum in summer. Monthly mean calculations by Blindheim (1993) for instance, gave a winter maximum of 7.9 Sv in January and a summer minimum of 2.9 in September, with a annual mean in 1990 of 5.5 Sv.

Worthington (1970) estimated volume transports based on mass balance considerations and ended up with a total Atlantic inflow of 9 Sv. The most extensive transport estimates based on year long direct current measurements on the continental slope northwest of Shetland were made by Gould (1985). Based on 4 moorings sited between 400 m and 1100 m, the calculations show an annual average of 7.5 Sv. He also indicated seasonality with maximum in winter. Recent investigations have used satellite altimetry to obtain estimates of the inflow. Pistek and Johnson (1992) and Samuel et al. (1994), worked out mean transports of 2.9 Sv/2.7 Sv, and they both show a strong annual cycle with summer to winter variations of about 100 percent.

Recent investigations by Poulain et al. (1996) show that the major part of the Atlantic inflow over the Scotland-Greenland ridge is trapped by the bottom topography at depths of the order of sill-depth i.e. 500-700 m. The inflow over the Faroe-Island ridge for example, turns eastwards and follows along the isobaths over the steep slope to the north and east of Faroe Islands, then turns northward after a cyclonic turn in the Faroe-Shetland Channel and merges with the Faroe-Shetland inflow through confluence in the Svinøy area. Just to the north of the Svinøy section, the inflow splits into a minor coastal and a major shelf edge branch flowing northward along the Norwegian shelf edge as the Norwegian Current, before spreading into the Barents Sea, the Arctic Ocean and Norwegian Sea. The drift-experiments also show that the slope area in the Svinøy section catches the major part of outflow from the North Sea. Drifters deployed in the Norwegian trench indicate a flow pattern trapped by bottom topography along the 200-300 m isobaths. Because of the shallow Møre Plateau with depths less than 200 m, the main flow is forced offshore towards northwest and presumably passes through the slope area in the Svinøy section. There seems to be small northward transports over the Møre Plateau, making this area suitable as spawning area. The merging through confluence of the different branches of the Atlantic inflow in the Svinøy slope area, make this site a key position for monitoring the inflow.

Transport estimates presented in this study are based on direct current measurements from 9 current meters on 3 mooring lines (S1, S2 and S3) in the Svinøy section from April 1995 to September 1996, sited in the steep continental slope area between depths of 480 m and 1000 m.

The monitoring program was extended with 2 moorings (E1 and E2) in between S2 and S3 for a one month in March-April 1996, for typical winter conditions. Fig 3 shows the 5 mooring sites with the 24 current meters between depths of 480-1000. A similar extensive program is in progress for September-October 1996, for typical summer conditions. Service operations on 6 months intervals with R/V "Håkon Mosby" have been combined with ship board ADCP observations and standard CTD transects.

Based on 24 current records, the monthly volume transport will be estimated. And in order to reveal applicability of the long term measurements in transport investigations, each current meter will be correlated towards estimated transport. Based on the best suitable current record, a linear regression model will then be worked out to obtain relation between volume transport and long-term current measurements.

2. Measurements and data processing

The measurements were made using Aanderaa RCM-4/7 current meters on subsurface mooring lines. For the long term measurements, in each position, the instruments were deployed at standard depths of 100 m, 300 m and 5 m or 20 m above sea bed. Pressure sensors on uppermost meters measured vertical movements of the moorings. During the extensive period each mooring were equiped with extra current meters at 500 m, 700 m and 5 m and 20 m above sea bed. The data were hourly sampled and afterwards filtered by 25 hours and 168 hours (1 week) moving average filters. Additionally the long-term records have been filtered by using moving averages over 2 weeks, 4 weeks(1 month) and 8 weeks (2 months) period. For the extensive period, monthly mean velocities have been calculated for each of the 24 records and presented as contour plot for the velocity perpendicular to the section in Fig 4.

CTD observations are presented as standard sections for temperature, salinity and sigma-t (Fig 2). Bottom tracked ADCP records with extension down to bottom depth of 600-700 m are processed for stick-plot and contour-plot presentation. They are used as basis for extrapolations of the lateral current profile between the shallowest mooring S1 at 480 m depth and the shelf edge at 200 m, but will not be presented here.

3. Transport calculations and correlation analysis.

The 24 current meter records during March-April 1996 are used to calculate the volume transport across the Svinøy section by assigning each current meter to a cross section area surrounding it (Fig 3). The transports are presented as 168 hours (one week) moving average time series in Fig 5. For control, the monthly mean transport is also calculated based on the contoured velocity field in Fig. 4. In order to apply our long term current measurements in transport investigation, a linear regression model is worked out to obtain a relation between transport as dependent variable and current observations from one current meter as independent variable. To deduct the optimal current meter position for monitoring the inflow, each of the 24 data series are correlated towards calculated transport. The highest correlation coefficients were figured out for the current meters at 300 m depth on mooring S1 at 500 m depth and mooring S2 at 700 m depth, respectively. The figures were 0.66 and 0.87 for 25 hours moving average data; 0.88 and 0.92 for 168 hours moving average data. Based on the fact that we have a complete time series over 17 months for mooring S1 and lack in data recovery for mooring S2, the current meter S1 at 300 m depth has been selected for long term transport estimates. Also transport estimates based on current meter S2 at 300 m will be presented for comparison.

4. Results

The hydrographic observations along the Svinøy section in March 1996 (Fig 2), exhibits the warm and saline Atlantic inflow as a wide wedge-shaped baroclinic current extending westward from the 200 m deep shelf edge. Maximum salinity is observed over the slope at 1000 m depth and may be interpreted as the core of the inflow. However, the monthly mean current field in Fig 4 reveals the inflow as a 30 km wide current with nearly barotropic vertical structure. The narrow current occurs as a topographically trapped current over the steepest slope between depths of 200 m and 900 m. The topographic trapping is also documented in the vertical integrated transport in Fig 4, exhibiting a maximum transport and thus the core of the inflow at about 600 m depth. There seems to be little coincidence between the baroclinic field and the flow field and it is a paradox that the area of maximum salinity, the so-called core of the inflow, is located in the area of insignificant currents. Most likely the salinity maximum is a manifestation of the distribution of mixing intensity.

For the moorings S1 and S2, the time series for each current meter record show a very stable along-isobath flow towards north-east through the water column., with monthly means of about 40 cm/s, standard deviation of 18 cm/s and maximum of 100 cm/s. In the site of mooring E1 at 900 m depth, the flow is moderate and variable with insignificant monthly mean currents in accordance with Fig 4. Further westward in area of moorings E2 and S1, the records show variable currents with a moderate mean flow towards west. The monthly mean transport based on Fig 5 turns out as 4.9 Sv with a standard deviation of 1.1 Sv. The calculated transport based on the monthly mean contour field in Fig 4 is 4.6 Sv, i.e in good accordance.

For long term transport investigations, time series from the linear regression model for the period 22 April 1995 to 31 August 1996 is shown in Fig 6. The estimates are presented as hour mean values, 25 hours moving average values and 1 week, 2 weeks, 4 weeks (1 month) and 8 weeks (2 months) moving average values. Based on the 25 hours moving average transport estimates, the long term time series reveals an inflow with strong variabilities, with a fluctuation time scale ranging from a few days to months. Maximum estimated transport is 12 Sv and minimum 0 Sv. The annual mean transport over one year cycle is 5.3 Sv with a standard deviation of 1.9 Sv. Comparing the 2 weeks and 4 weeks moving average time series, they show significant periodicity of one and two months, where the transport ranges between 3 Sv and 8 Sv. However, considering the 2 months moving average time series, the transport show no systematic seasonal signal. To some extent the time series indicate a winter maximum in December-January of about 6 Sv and a minimum in April-May of 4 Sv, a period known for stable northerly winds in western Norway. The transport for the period June-November is very stable about 5 Sv and disrupt the common accepted comprehension of an annual cycle with summer to winter variations of 50 percent of the means; inferred from hydrography (Blindheim, 1993), satellite altimetry (Pistec and Johnson , 1992) and direct measurements (Gould, 1985). The feature of the estimated inflow showing insignificant seasonality corresponds well to Dickson et al.,(1990). His successful current records of the overflow from Nordic Seas show fluctuations of a few days period with little seasonal and inter-annual variations. He estimated the annual-mean overflow to 5.6 Sv. The transport estimates based on current meter S2 at 300 m in Fig 7 show mean transports of the same order (about 5 Sv) as Fig 6, for the period November 1995-June 1996. The standard deviations indicate less variabilities in the transport. Concerning the 2 months moving average time series ,the standard deviation is only 0.2 Sv. This very stable pattern of about 5 Sv ; confirms our findings of small seasonal variabilities of the Atlantic inflow.

5. Concluding remarks

The merging of the different branches of the Atlantic inflow through a confluence process in the Svinøy slope area makes this site very suitable for monitoring the Atlantic inflow to the Norwegian Sea. It is a paradox that while hydrographic observations in the Svinøy section reveal the Atlantic inflow as a about 300 km wide and wedge-shape baroclinic current while our current measurements show that the inflow occurs as a 30 km wide current with nearly barotropic structure trapped over the steepest slope between 200 m and 900 m depth. It is also a paradox that transport estimates based on radically different schemes, achieve more or less comparable values, for example Blindheims (1993) geostrophic calculations and our findings which both turn out with a annual mean just above 5 Sv.

Our transport estimates based on a monthly extensive program with 24 current meters and long term estimates by a linear regression model, reveal that the inflow show strong variabilities with fluctuation time scale ranging from a few days to 2 months, with maximum of 12 Sv and minimum close to 0 Sv. However the 2 month moving average filtered series show very small seasonal variabilities compared with common comprehension of strong seasonality of the inflow. This inflow pattern is also confirmed by our estimates based on current meter S2 (300 m), which shows a stable transport of about 5 Sv over the period November-April.

Acknowledgment

The Svinøy program is run as a part of the joint Norwegian research program Mare Cognitum and is funded by the Norwegian Research Council. Øystein Skagseth is now engaged in the program and we thank him for excellent computer work. Also thanks to the technical staff at our institute and the crew on board R/V"Håkon Mosby". Their positiveness and engagement have been an important factor for our successful current measurements.

6. References

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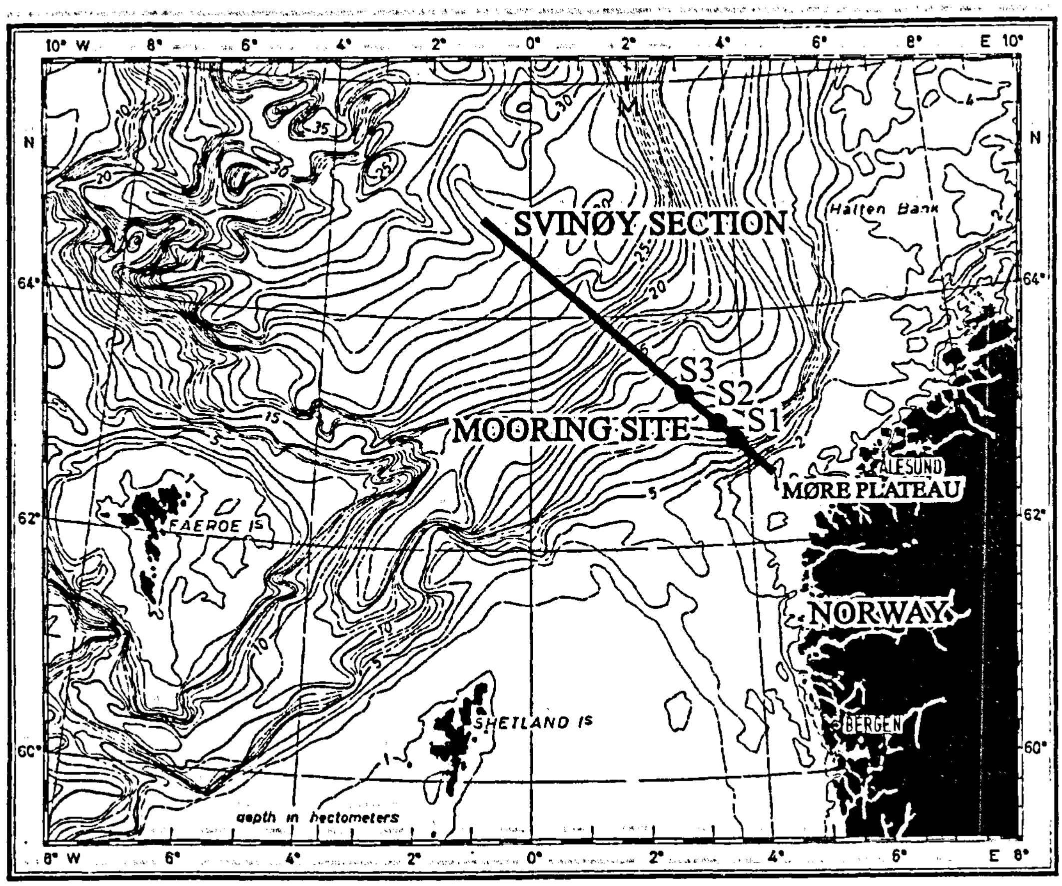
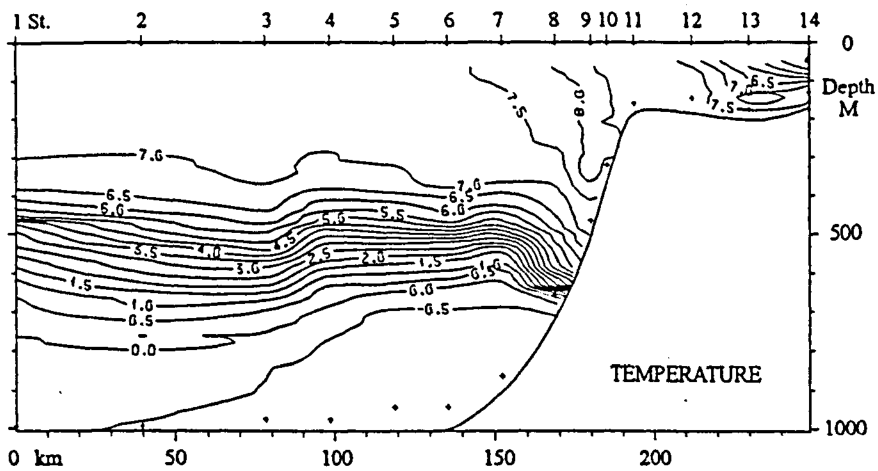


Fig 1. Topographic chart of the investigation area
The Svinøy section, mooring site and Møre Plateau are indicated on the figure.



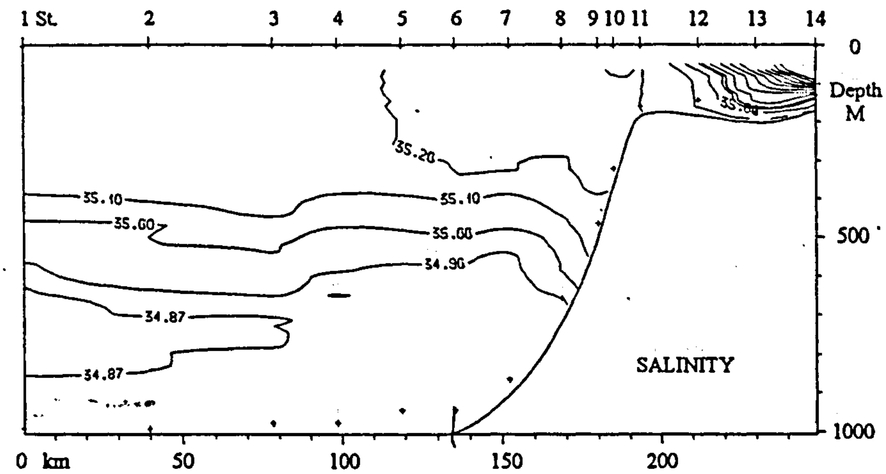


Fig 2. Hydrographic transect, the Svinøy section, March 1996.

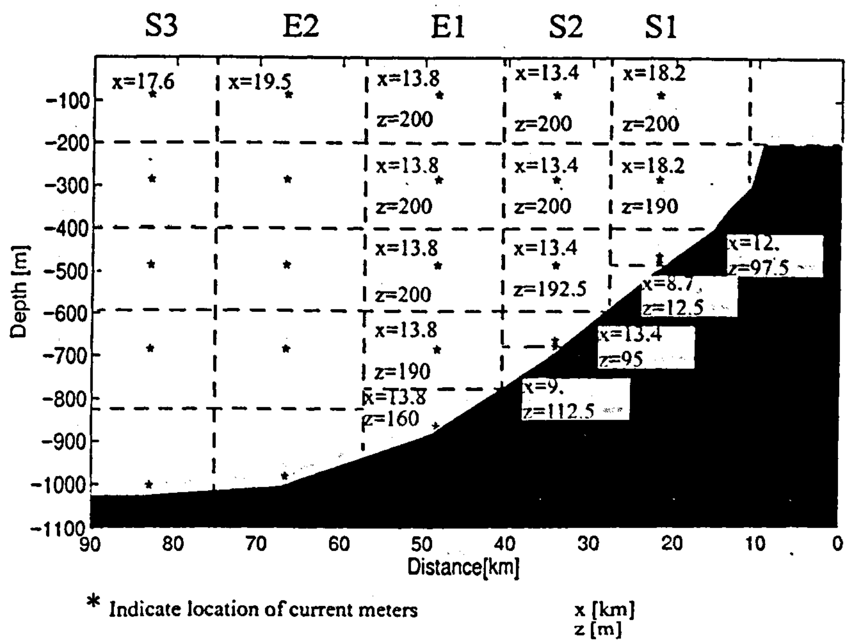


Fig 3. Mooring sites in the slope of the Svinøy section.

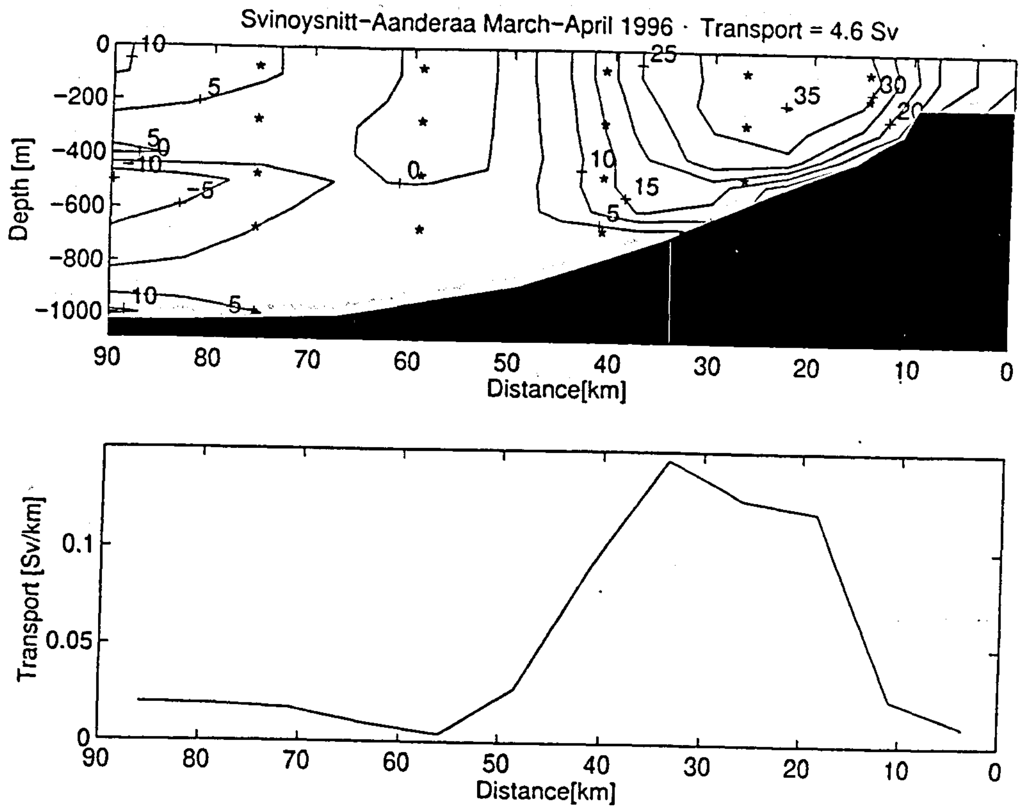


Fig 4. Contour plot of monthly mean velocity field and vertical integrated transport, March-April 1996

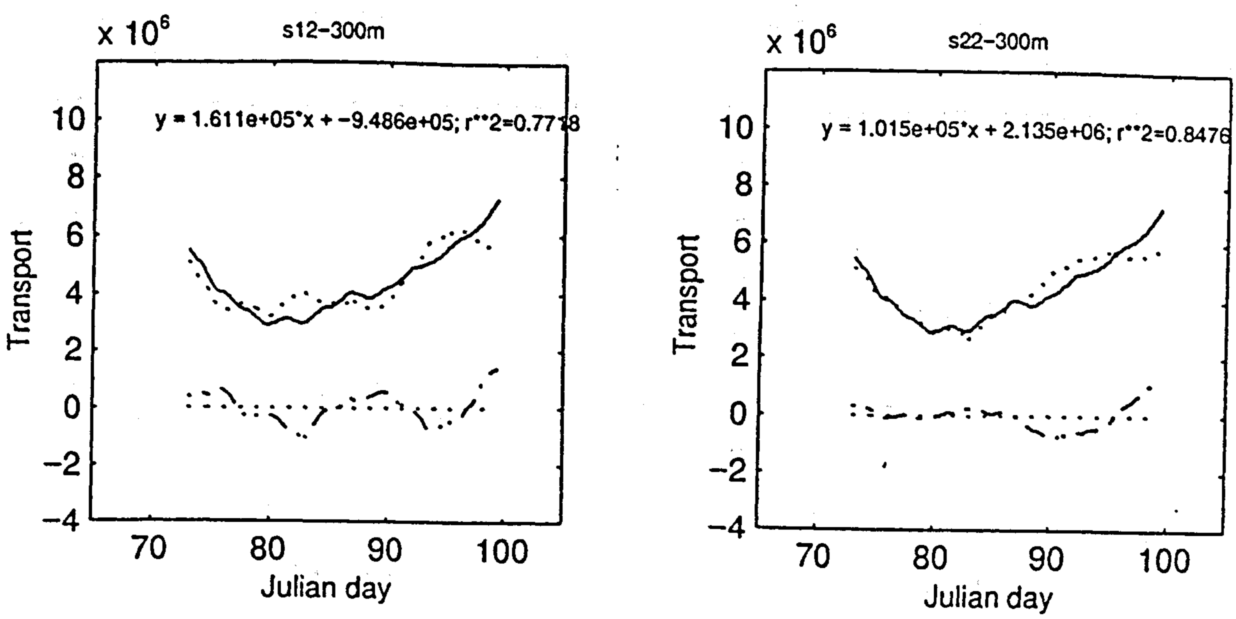


Fig 5. One week moving average time series of calculated volume transports (full line) and linear regression estimates based on current meter S1-300 m and S2-300m (dotted line), March-April 1996.

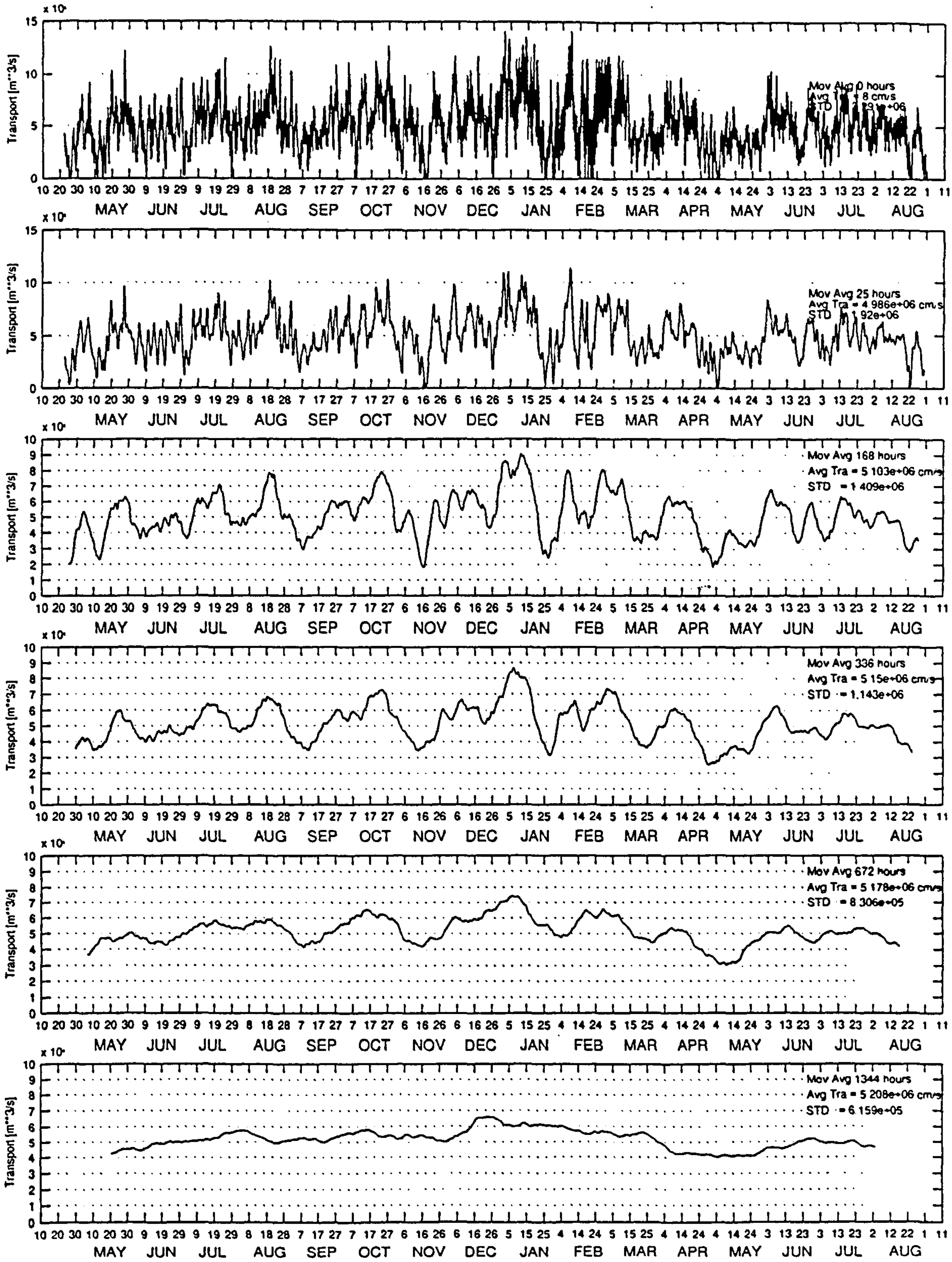


Fig 6. Time series of estimated long-term volume transports for S1-300 m, 22 April 1995-31 August 1996

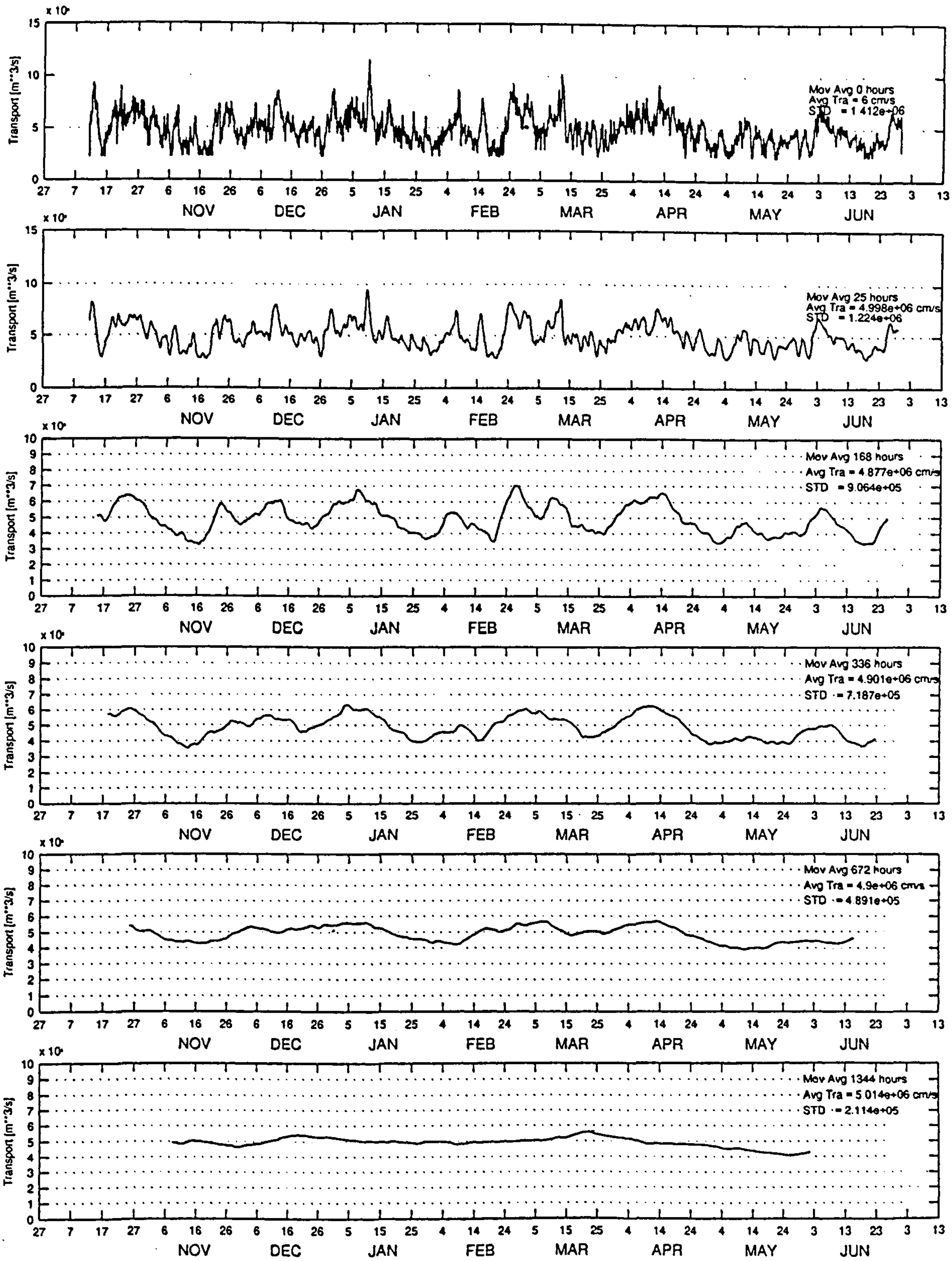


Fig 7. Time series of estimated long-term volume transports for S2-300 m, November 1995- June 1996