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NORTHEAST CHANNEL FLOW AND THE GEORGES BANK NUTRIENT BUDGET

by

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ABSTRACT

Two years of current measurements in Northeast Channel show three seasonal flow regimes: a steady inflow in summer, large fluctuations with a net inflow in winter, and a period of low transport in the spring. There is a mean annual influx to the Gulf of Maine below 75 m of about 275 x 10^3 m^3/sec, implying a residence time of about one year for the deep water of the Gulf. Preliminary estimates suggest a nitrogen flux of 4.05 x 10^9 μg-a N/sec, equal to about 40 percent of that required to support primary production on Georges Bank.

RÉSUMÉ

Deux ans de mesures du courant dans le chénal Nord-est démontre trois régimes de flot saionnier: un afflux régulier en été, de grandes fluctuations avec un afflux net en hiver, et une période de transport bas dans le printemps. Il y a un afflux moyenne annuel au Golfe du Maine, plus bas que 75 m, d'environ 275x10^3 m^3/sec, impliquant un temps de résidence d'environ un ans pour l'eau profond du Golfe. Évaluations préliminaires suggère un flot de nitrogène de 4.05x10^9 μg-a N/sec, égal à environ 40 pour cent de celui exiger pour soutenir la production primaire sur le banc Georges.

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INTRODUCTION

Two years of current measurements in the Northeast Channel below 100 m were completed in 1978 by the Northeast Fisheries Center (NEFC), NMFS/NOAA. Northeast Channel, with a sill depth about 230 m, is the only deep passage connecting the slope water of the Northwest Atlantic Ocean with the basins of the Gulf of Maine (Figure 1). The current measurements and associated hydrography were made to test the hypothesis that relatively high-salinity, nutrient-rich slope water flows through the channel into the gulf where it may serve as a source of nutrient replenishment for the highly productive surface waters of the region, particularly over Georges Bank.

Nine vector-averaging current meters (VACMs) were maintained on three moorings set across the channel axis from September 1976 to September 1978 except for a short period in spring of 1977. Preliminary results from the first year of deployment, reported previously (Ramp and Vermersch 1978; Ramp and Wright 1979), emphasized: a) the strong correlation between pulses of inflowing water and northwesterly winds associated with the passage of winter storms; b) the weaker but much more persistent summer net inflow which was not correlated with wind events; and c) steady, mid-depth outflow on the south side of the channel during summer. In this paper we present preliminary estimates of the volume transport and nitrogen flux through the Northeast Channel for the two-year duration of the experiment. Volume transports are presented as two-week averages to show seasonal and interannual variation.

METHODS AND DATA

The current meter moorings were deployed along a southwest-northeast line across the channel just inside the sill, with VACMs at depths of 100 m, 150 m, and 18 m above the bottom. A schematic view of the array looking into the Gulf of Maine is shown in Figure 2. The instruments were set to compute and record at 15-minute intervals the rotor count, compass direction, relative vane bearing, east current component (u), north current component (v), temperature and time. Four six-month deployments were planned but because of logistics problems there was an interval of two and a half months between the recovery of the first array and the setting of the second in spring of 1977. All instruments were recovered except the three on the southernmost mooring (No. 3) from the first deployment.

All data tapes were edited through the standard current meter processing system developed at the Woods Hole Oceanographic Institution (WHOI). One-hour time series of u, v, speed and direction were formed by vector averaging. The coordinate system was rotated counterclockwise 48° so that the v component represented flow along the channel axis (positive in-channel) and u represented cross channel flow (positive north-east). One-hour temperature records were formed by scalar averaging. The hourly records were used to examine tidal and other high-frequency current structure. To examine motions occurring at periods of a day or longer, the one-hour records were low-passed with a digital filter having a half-power point at 33 hours (Flagg et al. 1976).

Wind data were obtained from Fleet Numerical Weather Central (FNWC) in Monterey, California. FNWC supplied six-hourly estimates of geostrophic surface wind and wind stress vectors at 42°N, 66°W (about 18 km south of mooring 3), as calculated from large-scale pressure fields. The wind stress vectors were rotated at NEFC to match the current meter coordinate system. To a very close approximation, the v wind component represents onshore wind and the u component is alongshore wind, positive northeast.

For volume transport calculations the mean flow in (or out) channel was calculated at two-week intervals for each instrument. The cross-sectional area of the channel below 75 m (the upper limit of slope water intrusions) was divided into nine boxes with a current meter at the center of each box. For each two-week interval the mean flow for each instrument was multiplied by the area of the corresponding box. The transports in the individual boxes were then summed to obtain the total net transport for that period. Gaps in the record in individual boxes were filled by taking advantage of the very high coherence between certain pairs of instruments. This close relationship was evident both in the time series stick vector plots and in coherence and phase calculations. If an instrument failed at a given location during any one deployment, then data from that location during the other three deployments were compared with data from adjacent positions to determine how best to estimate the missing values. Overall shear in the water column was also considered, and small adjustments in the magnitude of the estimates were made as needed. For example, Figure 3 compares the middle and bottom instruments on the northeast side of the channel during the third and fourth deployments. The bottom instrument failed during the last two months of array 3 and data from the middle instrument was used to replace it. No effort was made to interpolate across the gap of two and one half months when no instruments were in the water in spring of 1977. However, estimates were made for the three instruments on the southernmost mooring in array 1, which was never recovered. Transport values were obtained for the entire channel for each two-week period with the help of these interpolation techniques.

RESULTS

A surprising consistency emerges when the two-year experiment is viewed in its entirety. Tidal currents varied little over the duration of the experiment, and always contained at least half and sometimes up to 85% of the total current variance, depending on the amount of low-frequency activity. We will not discuss tides further here.

The flow regime can be divided into two sections as shown in Figure 2. The seasonal and annual mean flow is always into the Gulf of Maine on the side of the dotted line marked "in", and is out of the channel on the side marked "out." Axial motions on the "in" side show strong low frequency coherence and move practically as a unit. The two instruments located in the "out" region returned data which were coherent with each other but not with any of the other instruments in the channel. Figure 4 shows an 18-month piece of the data record from 153 m on the northeast side of the channel, and is typical of all records in the "in" region. The current is very steady during the summer months and flows into the Gulf of Maine with a magnitude that does not exceed 30 cm/sec. Large bursts of current on a three-to-eight-day time scale with magnitudes of up to 70 cm/sec characterize the winter flow. Bursts may be in or out, but the inflows tend to be longer and stronger and the net flow is usually into the Gulf of Maine when averaged over a two-week period. Current patterns in the "out" region are the opposite, with a steady outflow in summer and a fluctuating net outflow in winter. The magnitudes of the flow are about the same in both regions in the same season, but the much smaller cross-sectional area in the "out" region almost always leads to a net inflow for the whole channel. Low frequency cross-channel flow was small at all locations throughout the year and was never coherent either horizontally or vertically suggesting space scales of less than 50 m vertically and less than 9 km horizontally for the cross-channel component.

Temperature records from the two regions are markedly different, although both show seasonal trends which diminish with increasing depth. Records from the "in" side of the channel throughout the year typically have dramatic temperature fluctuations of 4-5°C on time scales ranging from 4 to 20 days, representing different water masses being advected past the instruments. As discussed by Ramp and Wright (1979), these masses are probably warm slope water (WSW) and Labrador slope water (LSW) which are alternately present at the channel mouth. Temperature records from the "out" side are much steadier at all times, because the water flowing from Georges Basin has been mixed within the Gulf of Maine.

The net transport for the entire channel below 75 m is displayed in Figure 5 and the mean flow vectors for each of the four arrays are shown in Figure 6. Together these figures reveal three different flow regimes:

1. During the summer months, late May through September, there is a steady net transport into the Gulf of Maine averaging about 350 x 10^3 m^3/sec (0.35 Sv).

2. During the winter months, November through March, the transport varies dramatically from -25 to +700 x 10^3 m^3/sec calculated at two-week intervals, but the net transport is still into the Gulf of Maine at about 260 x 10^3 m^3/sec.

3. During the spring of 1978, April to early June, inflow was at a minimum. There is some suggestion that this may also have been true in spring of 1977 but that was the period when no measurements were obtained.

The seasonal mean transport values are shown in Table 1, along with estimates of the time required to replace all the water in the Gulf of Maine below 75 m. The mean transport for the entire two-year experiment is 276 x 10^3 m^3/sec which gives a replacement time of approximately one year.

DISCUSSION

The net influx through Northeast Channel below 75 m represents water which must ultimately be upwelled to the level of Georges Bank since there are no other passages as deep connecting the Gulf of Maine with the ocean. The amount of water actually reaching the top of the bank with its burden of nutrients cannot be estimated at present. Schlitz and Wright (1980) have identified three situations in which the deeper waters are brought up along the northern edge of Georges Bank: 1) continuous upwelling east of Cape Cod and Nantucket Shoals north of the Great South Channel; 2) upwelling which may be continuous along the Northeast Peak of Georges Bank; and 3) episodic mixing as deep as 200 m by intense winter storms. Garrett and Loucks (1976) have described a centrifugal tidal rectification mechanism by which water from Northeast Channel may be upwelled onto the western Nova Scotia shelf. Some of the nutrients from Northeast Channel undoubtedly contribute to the general productivity of the Gulf of Maine. Nevertheless it is interesting to compare the nutrient input to the Gulf of Maine system with the nutrient demand on Georges Bank.

Systematic nutrient measurements were not made in Northeast Channel during the time our current meters were deployed. However, nitrate values from the slope water region near the channel mouth have been obtained from two sources: historical data (1933-1971) in the files of the U.S. National Oceanographic Data Center (NODC), and recent (1976-1978) data from Georges Bank and vicinity reported by EG&G Environmental Consultants Inc. (EG&G 1977, 1978). Seasonal means for the two data sets for water 100 to 200 m deep, in microgram-atoms of nitrogen per liter (µg-a N/1), are:

	Winter	Summer	Annual
NODC	7.3	15.0	11.1
EG&G	15.7	20.4	17.7
Average	11.5	17.7	14.4

Individual values ranged from 0.9 to 35.7 µg-a N/1. Combining the overall mean of 14.4 µg-a N/1 with the mean annual transport of 276 x 10^3 m^3/sec gives a nitrogen flux of 4.05 x 10^9 µg-a N/sec.

Production is estimated (Cohen and Wright 1978) at 400 to 500 grams of carbon per square meter per year (g $C/m^2/yr$). Using the higher value and an area of 53 x 10^9 m^2 for Georges Bank gives an annual production of 2.65 x 10^{13} grams of carbon, which converts to 8.35 x 10^{11} μg C/sec or 6.96 x 10^{10} μg-a C/sec. Using the Redfield ratio -- C:N:P = 106:16:1 by atoms (Riley and Skirrow, 1975) -- we obtain a nitrogen demand of 10.5 x 10^9 μg-a N/sec. The nitrogen flux into the Gulf of Maine through Northeast Channel, conservatively estimated, is thus roughly 40 percent of the amount needed to support production on Georges Bank. We emphasize however that the partitioning of the flow field inside the Gulf of Maine is not understood, and that the inflowing nutrients cannot all be utilized to support production on the Bank.

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Table 1. Volume transport through Northeast Channel calculated from current meter data.

Array	Dates	Mean transport (x 10^3 m^3/sec)	Replacement time below 75 m (days)
1	23 Sept. 1976 - 21 April 1977	255	338
2	12 June 1977 - 22 Sept. 1977	372	233
3	22 Sept. 1977 - 12 March 1978	284	304
4	12 March 1978 - 15 Sept. 1978	192	448
Mean values		276 (~1/4 Sv)	331 (.91 years)

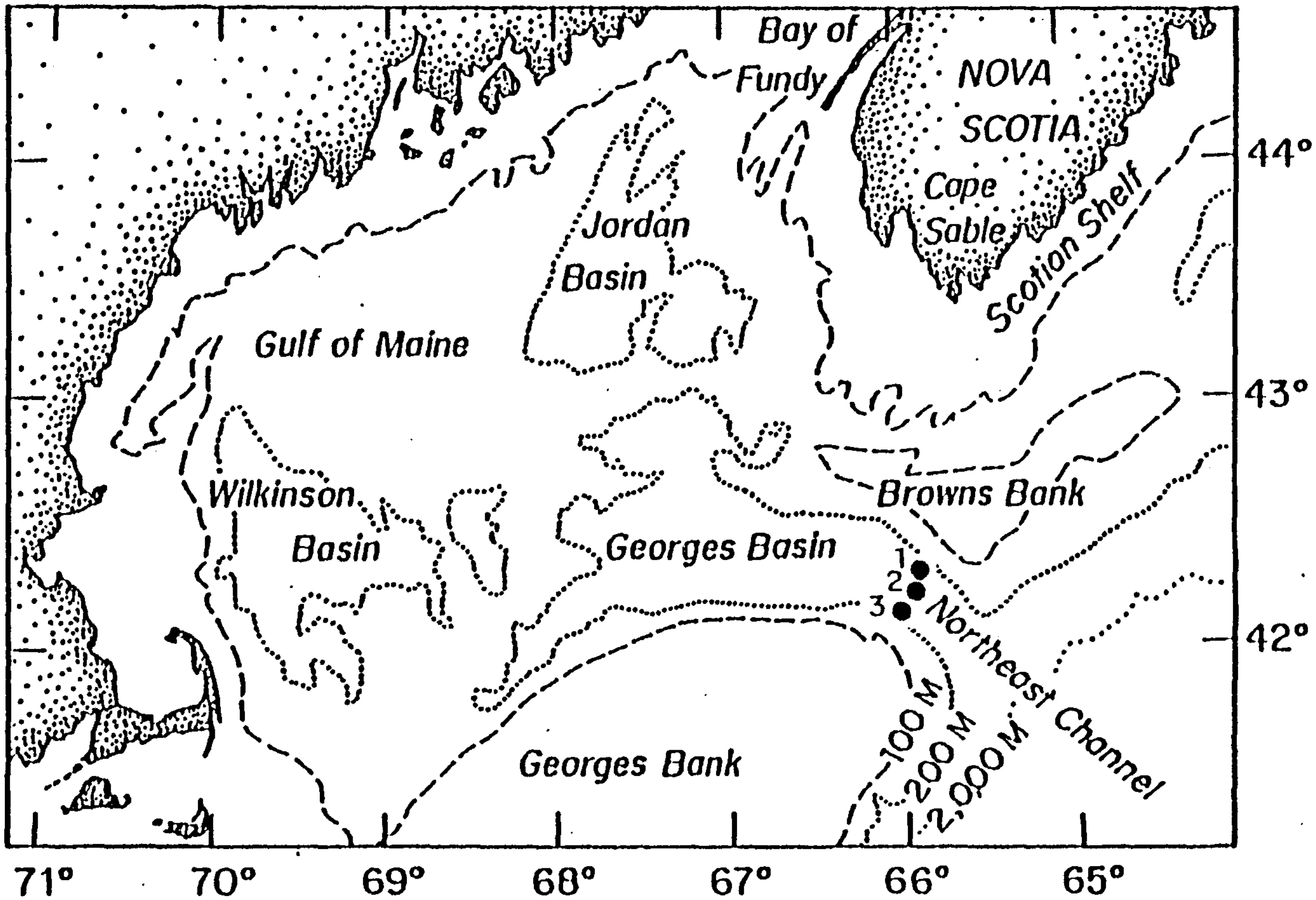

Figure 1. The Gulf of Maine, Offshore Banks, and Northeast Channel, showing mooring positions.

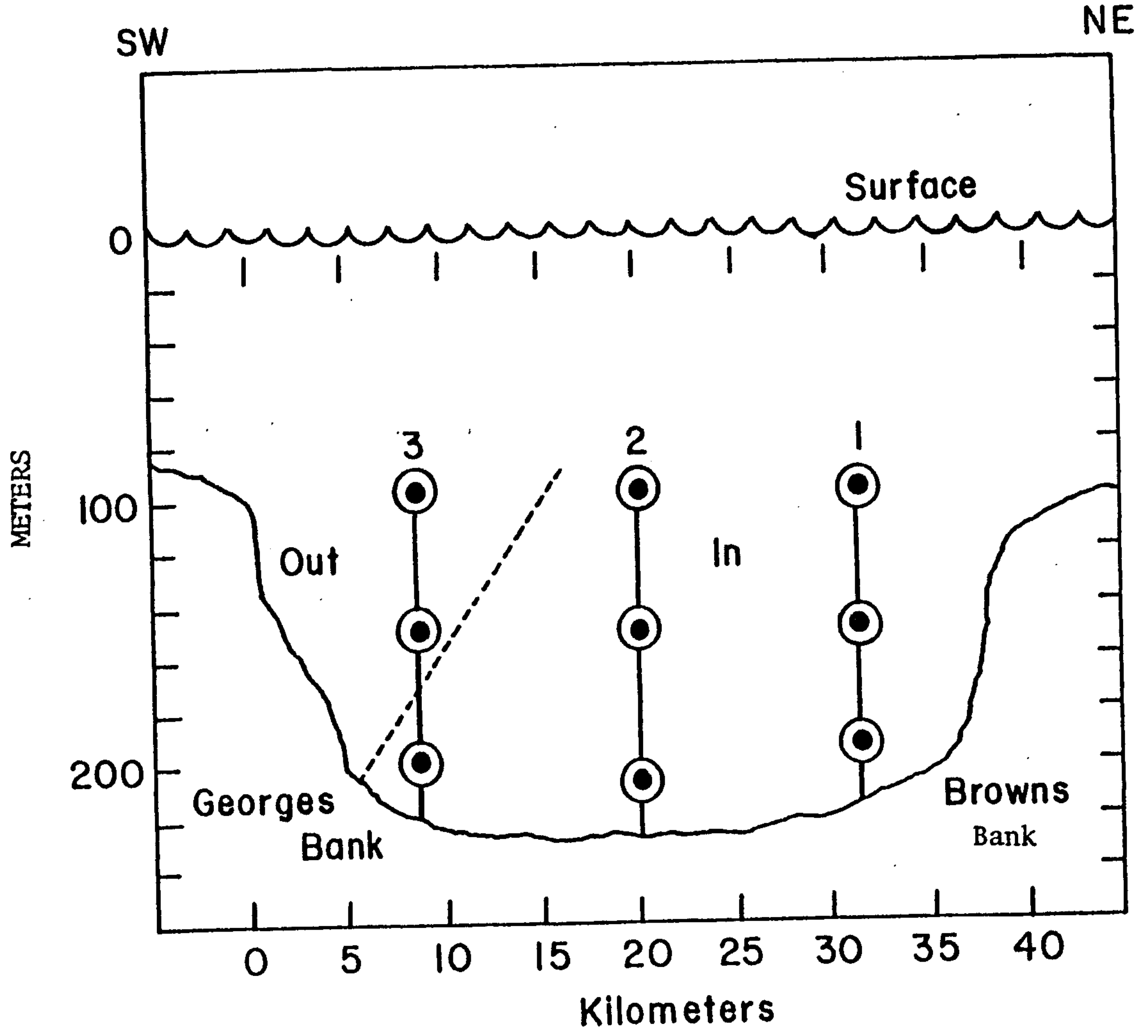

Figure 2. Cross-sectional view of the moored array looking into the Gulf of Maine. The meaning of "in" and "out" is explained in the text.

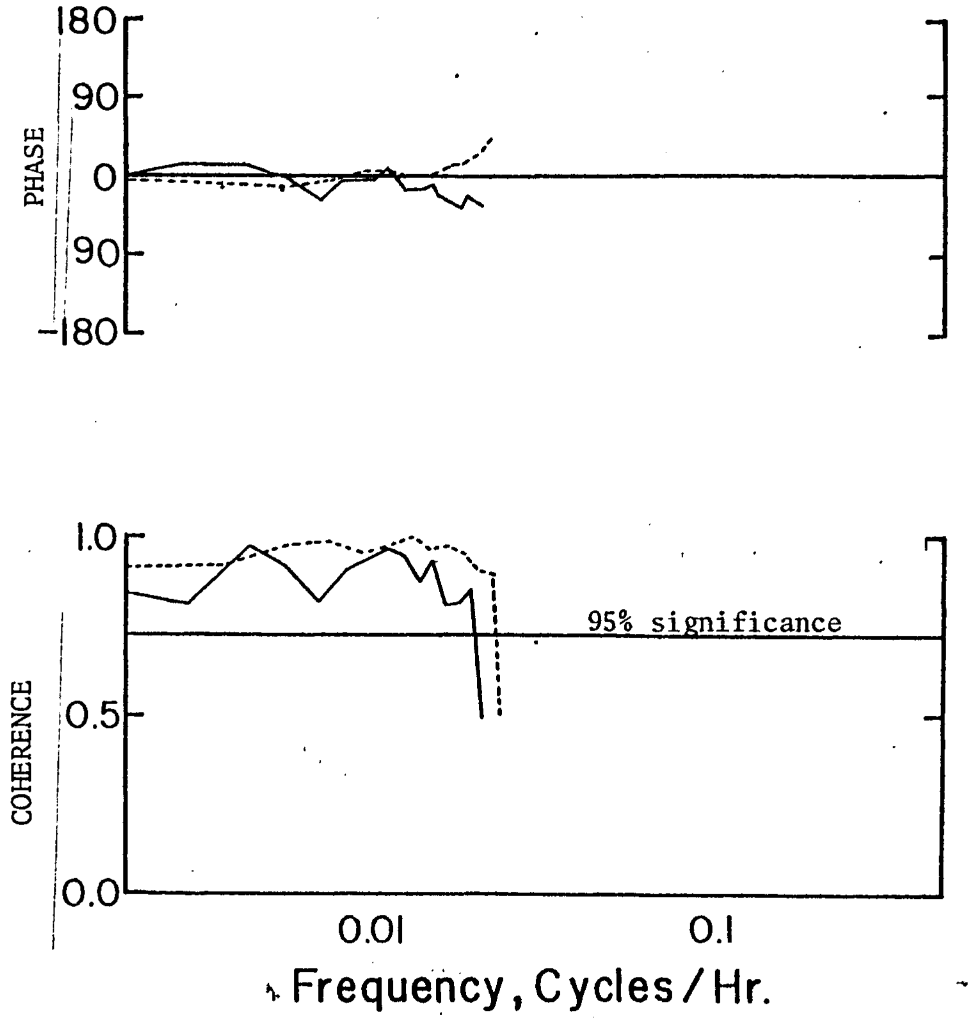

Figure 3. Coherence and phase difference between the middle and bottom instruments on the northeast side of the channel during array 3 (dotted line) and array 4 (solid line).

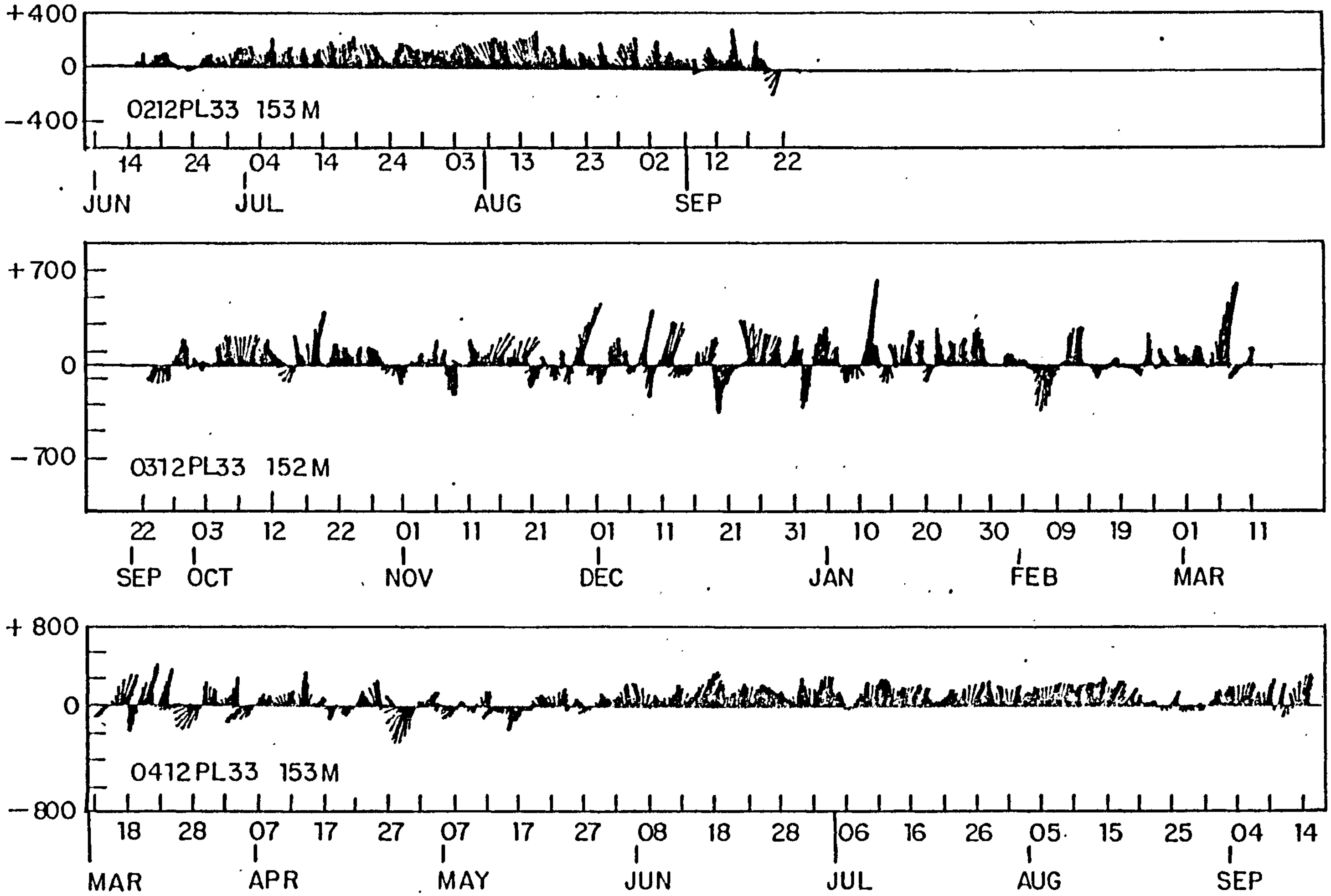

Figure 4. Stick vector plot from the center position on the northeast side of the channel from June 1977 through September 1978. The speed scale is in mm/sec and the "up" direction represents in-channel flow.

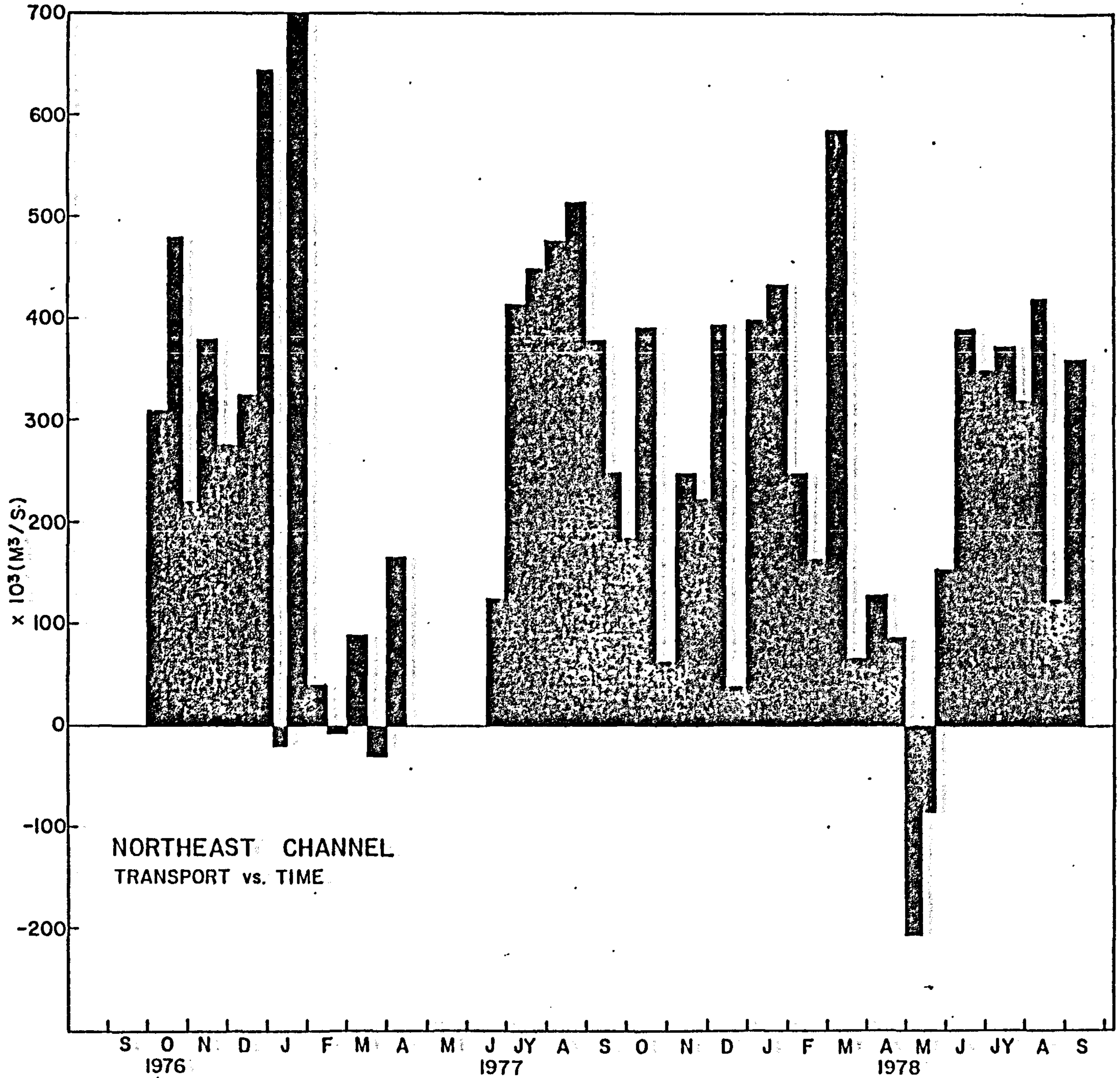

Figure 5. Bar graph of total transport through the Northeast Channel below 75 m versus time. Each bar represents a two-week average. There were no instruments in the water during the gap in spring of 1977. Negative values represent out-channel flow.

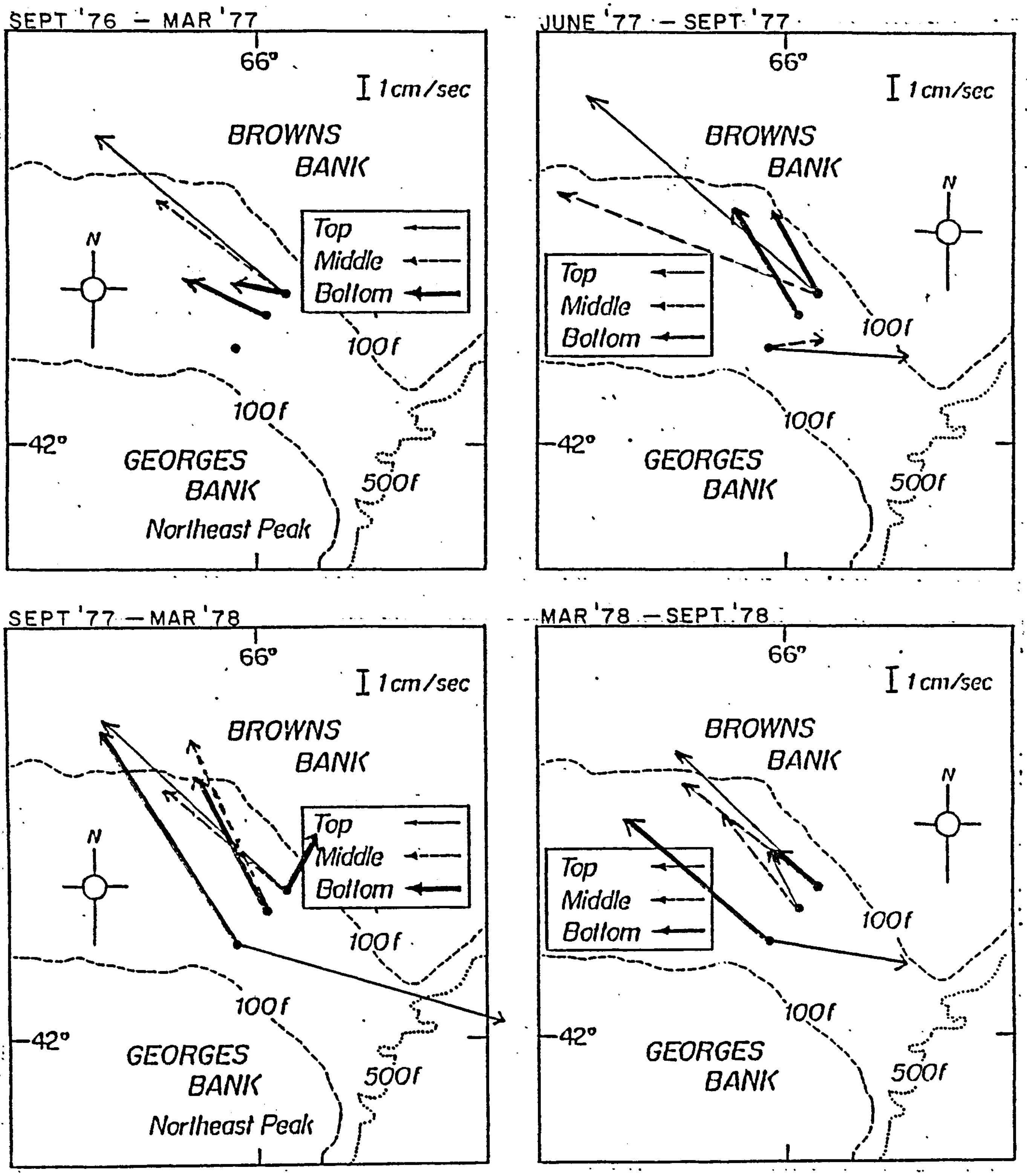

Figure 6. Mean flow vectors in the Northeast Channel for each deployment.