Northwest Atlantic Fisheries Organization

Serial No. N411

NAFO SCR Doc. 81/IX/107

THIRD ANNUAL MEETING - SEPTEMBER 1981

Year-to-year Seasonal Dynamics of Water Masses on the Nova Scotia and New England Shelves from Observations Obtained at Standard Hydrographic Sections

by

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Abstract

In this paper seasonal year-to-year fluctuations in calculated transport at characteristic locations of the Scotian and New England Shelves are considered. Transport values are calculated using a dynamic method which had already been applied to the shelf regions. Intrayear variations of water transport with main flows are shown to increase in winter and spring in terms of calculated transport and to reduce in summer and fall. In summertime, in both regions, the transport intensity in a cold intermediate layer and warm near-bottom water approach the equilibrium. Some time intervals in a series of years over 1965 to 1976 display a tendency to weakening or strengthening of water transport with main flows which is consistent with the fluctuations in thermal regime.

Introduction

Three-layer structure of water masses is a peculiar characteristic of the Scotian and New England Shelves. The surface water mass 30-50 m in depth is formed under the influence of local conditions which involve solar heating, river influx, precipitation, evaporation, wind regime, etc. The intermediate cold layer between 50 m and 120 m is transformed waters of the Labrador Current penetrating from the Gulf of Saint Lawrence through the Cabot strait onto the Scotian and New England Shelves. Below 120-150 m, the near-bottom warm and saline waters extend which are modified Gulf Stream waters (Briantsev, 1963). Because of their ranging mainly along the shelf slope these waters were named "slope" waters. Thus, the water column within the shelf range is primarily represented by the waters of the cold intermediate layer and warm "slope" waters. These water masses generated by two powerful flows of various origin are subject to considerable fluctuations in space and time and determine intrayear and year-to-year changes in oceanographic conditions. Due to varying characteristics and high velocities of transport, these water flows form quasistationary zones of horisontal and vertical gradients, resulting from their interaction, which influence the life cycle of main commercial fish species and invertebrates. For example, massive aggregations of the silver hake in the Scotian and New England Shelves area keep to a border between the cold layer and warm bottom waters. Typically, the spawning of this species takes place in the regions where "slope" waters intrude onto the shelf. It has been observed that a more contrasting gradient zone provides more favourable conditions for aggregation of the silver hake during the feeding and spawning periods. The aggregations of such species as mackerel and shortfin squids are also associated with the outflow of "slope" waters on the shelf. The study of the pattern of the fields of geostrophic circulation of the shelf waters has enabled us to reveal quasistationary zones of rising and sinking waters which are known to affect productivity processes on the shelf (Sigaev 1975,1978). The development of these zones is evidently dependent on fluctuations in the strength of flows of cold Labrador and warm "slope" waters. In this connection, the study of the intrayear and year-to-year variability of the flows is necessitated. Quantitative assessment of year-to-year seasonal fluctuations of water mass transport in various parts of the shelf and the determination of the periods of strong and weaker flows from the calculated water transport at standard hydrographic sections are of interest.

Materials and Methods

The velocities and volume transport were calculated from a long-term observation series of water temperatures and salinity at standard hydrographic sections made during the seasonal oceanographic surveys in 1962 through 1976 by the AtlantNIRO ships (fig.1). In addition, similar data of the US surveys for 1964-1966 were used, namely, the observations made at the stations located near to standard stations occupied by the AtlantNIRO.

Although the observations were made over a long period, many important values are missing. Therefore, most typical and data-provided sections I, VI, III and V (fig.1) have been selected out of 15 for the analysis. A total number of cases considered for four selected sections was 88. Each case corresponds to one section made once a season. If the section was reiterated during the season the calculated water transports were averaged. The year 1974 may be disregarded as the one completely lacking data (1962-1976 observation series). In 1972, the observations were missing at sections I and VI.

A dynamic method was used for calculation of velocities and water transport (Zubov, Mamaev, 1956). In the regions of complicated bottom relief and steep continental slope the dynamic hights over the shelf were counted off the bottom, and beyond the shelf boundaries the reference surface corresponded to a 500 db level. The expediency of using the dynamic method for rough assessment of the water velocities and transport in the shelf area with a complicated bottom topography is examplified by the current velocity values (table 1) calculated using the dynamic method and measured with an instrument during the observations at sea in October of 1970 in the area of the northern slopes of Georges Bank.

As is evident from the table the calculated and observed velocities are consistent in all cases but one, and are fairly similar in many cases. It was assumed that a positive sign corresponds to the transport from the northeast toward the southwest and states that the flow of the Labrador water crosses the section made in normal to the shelf. A negative sign denotes the back transport across the "shelf" water section. For the sections made along the shelf, the positive sign corresponds to the "slope" water advection onto the shelf, and the negative to the outflow of the Labrador water offshore.

Results

For the analysis of the year-to-year seasonal variability of the main flows, their characteristics were presented as the graphs of the resultant calculated transport by season and year for each of the four sections (figs 2,3). A predominant flow of the cold water of the intermadiate layer is shaded. The pattern of graphs indicates considerable seasonal and year-to-year fluctuations in the calculated water transport with the values ranging between some tenths of thousands and some millions of cubic meters per second. The long-term interseasonal changes in the calculated transport in the Scotian shelf area reveal a trend to strengthening of the Labrador water flow during the winter and spring seasons (fig.2), which is especially true of section VI. When the graphs of calculated water transport at sections I and VI are compared it is apparent that at section I the flow of the "slope" water and the Labrador flow at section VI are often predominant, which is evident from the intrayear fluctuations. This difference between the intrayear transport pattern at the two sections can be attributed to geographical positions of the sections. Section I crossing the Laurentian Channel provides a complete control of advection of warm "slope" water on the shelf, and, partially, the flow of the Labrador water, i.e. a southerly part of this flow directed immediately along the channel axis. An inshore branch of the Cabot current directed toward the southwest along the Scotian coast is the uncontrollable part of it. As distinct from section I, section VI crosses perpendicularly almost the entire shelf from the inshore shallow-water area to the depths below 1000 m. This section provides a thorough control of the Labrador water branches and the advection of the "slope" water; however, predominance of the latter in the transport may only result from their intensive advection to the Scotian Trough.

For the intrayear fluctuations of the flows in the New England area, their reduction to the east in summer and to the west in autumn (fig.3) is typical. In graphs of resultant calculated transport at sections III and V a trend toward weakening of the Labrador water flow from spring to autumn can be followed. In autumn , the sign of prevailing transport may change as shown in the autumn graph of the calculated transport at section III. Given year-to-year variations of calculated transport with some gaps in data coverage it is difficult to detect any peculiarities or tendencies over the period 1962-1976, however, some time intervals clearly indicate weakening or strengthening of the flows. So, the advection of the "slope" water predominated in the volume transported through the Laurentian Channel in summer seasons over the period 1963-1966, and the transport of the Labrador water increased in 1967 to 1969. At section VI these waters were prevalent in the winter transport during the 1969 to 1971 period. A graph of the calculated spring transport across section VI is indicative of reduced flux of cold water of the intermediate layer from 1965 to 1967, which was replaced by powerful advection of warm "slope" water in 1968; in 1969 to 1971 the cold water was again predominant in the calculated transport. The summer period is characterized by persistent, although insignificant, predominance of the Labrador water. At sections in the New England area (Georges Bank) certain tendencies can only be observed over some time periods. For example, in spring 1965-1967, the Labrador water predominated in the volume transported, and in the 1968 to 1970 period the advection of the "slope" water intensified. According to a long-term data series a reduced flux of the Labrador water took place beginning in 1964 in winter at section V. In 1967 a sharp change was observed for increased advection of the "slope" water and in 1969 to 1971 again the cold water predominated in volume transport with a tendency to weakening of a flow. The values of the spring calculated transport across section V show considerable predominance of transport in a cold intermediate layer from 1965 to 1971 with an obvious trend to reduction. Any tendency in summer transport volume is less definite from the year-to-year data, however, a certain increase in calculated transport of the Labrador water in 1970 to 1973 can be observed with a subsequent reduction by 1976.

Graphical descriptions of the summer calculated transport at section III and the autumn calculated transport at section V are fairly similar. These are characterized by the presence of predominant cold intermediate water which is insignificant in volume, but stable in time. The pattern of the summer calculated transport along section VI on the Scotian shelf is the same. It can be, therefore, concluded that in summer, in the dynamics of main flows, a state close to the equilibrium sets in in both areas. Along the western boundary of the New England shelf such a state sets in in the fall.

During the period 1962-1976, some cases of the anomalous values of the calculated transport were recorded. Among these, a marked predominance of the Labrador water flux in winter 1970 at section VI and in spring 1976 at section I should be mentioned. The summer of 1963 and winter of 1976 at section I, the winter of 1967, spring of 1968 and fall of 1971 at section VI are also considered as the anomalous cases of advection of warm "slope" waters.

In the New England Shelf area the cases of the anomalous calculated transport of the warm water were recorded in spring and summer 1976 (section V).

The values of current velocities vary between 0.5 and 80 cm/sec, with the highest values of 130-150 cm/sec. In fig.4 the examples of vertical distribution of the velocities at section VI by season are shown which illustrate the ratio of water transport by two flows. The regions with the "slope" water flow are shaded.

Any change in the transport of the Labrador and "slope" waters must influence the water temperatures in the intermediate and near-bottom strata. A qualitative comparison of these characteristics is shown in fig.5 where the graphs of the variability of thermal background at 50 and 75 m depths and off the bottom (Sigaev, 1979) are drawn above the graphs of resultant calculated water transports. The graphs of resultant calculated water transports for section VI (Halifax) are shown in the left part of the figure, and those for section III (Northeast Channel) - in the right part. Shaded regions correspond to predominant cold waters of the intermediate layer in calculated transports. In the majority of examined cases the variations in the water transport performed by two flows are consistent with the thermal background fluctuations. This consistency is displayed both in a long-term data series and in year-to-year changes.

From the analysis of the dynamics of main flows on the Scotian and New England Shelves it can be concluded that:

- values of calculated transports and flow velocities considerably fluctuate;
- intrayear fluctuations tend to increase relative values of calculated water transports in winter and spring and to decrease them in summer and fall;
- a state close to the equilibrium sets in in summer between the cold water flows of the intermediate layer and a "slope" water flow with an insignificant predominance of the Labrador water transport;
- during some time periods between 1962 and 1976 a tendency toward reduction or strengthening of water transport by main flows can be observed which is consistent with the fluctuations of the thermal background of the water in the intermediate and near-bottom layers.

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Table 1 Current velocities (cmc^{-1}) measured and calculated by the dynamic method

Dates, October 1970	14	15	15	15	19	20	20	21	21	22	25
No. of station	5	9	11	15	9	15	9	5	11	15	11
Measured values	50	9	61	10	18	102	60	71	27	40	26
Calculated values	42	4	58	12	12	12	46	29	44	29	29

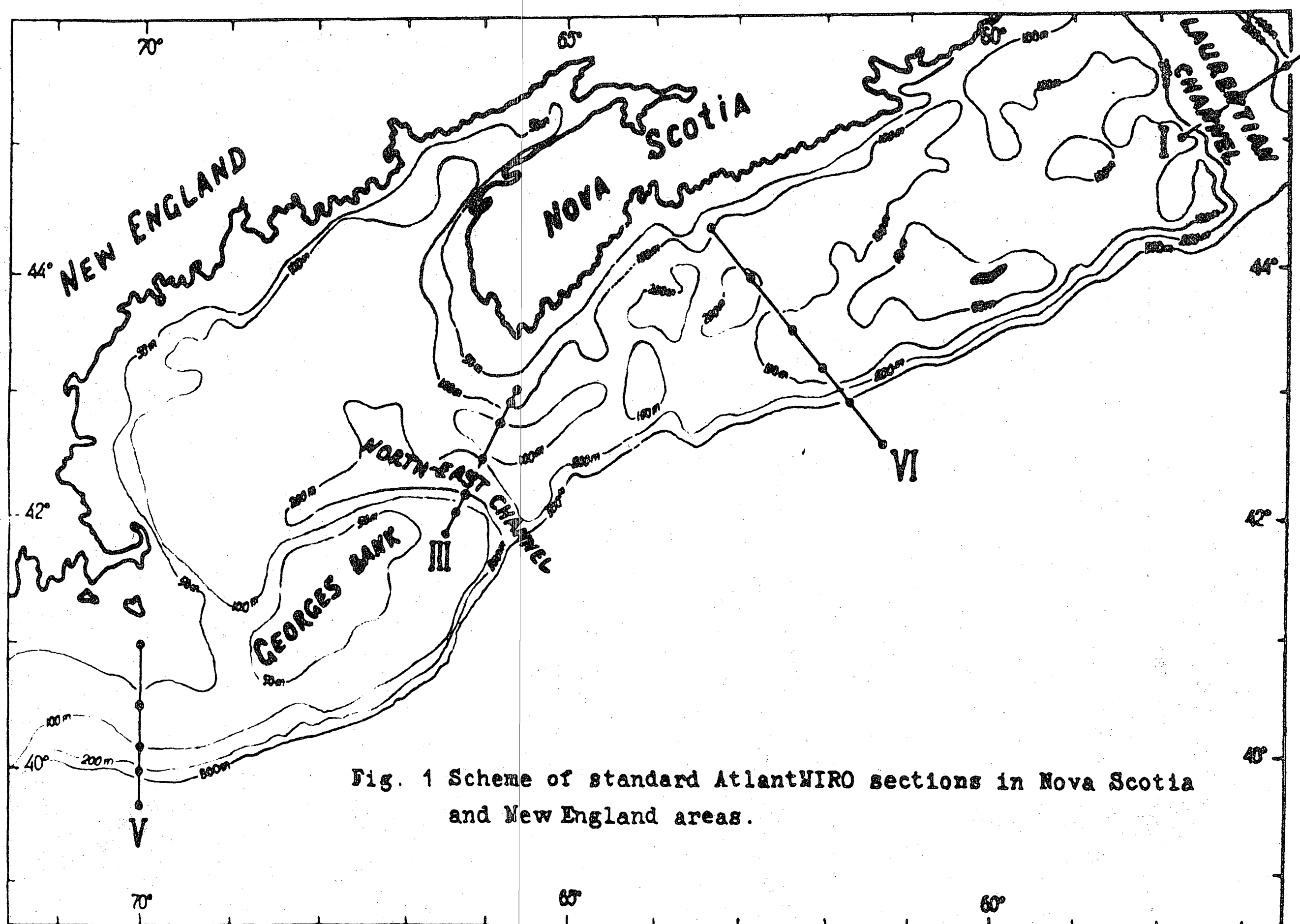

Fig. 1 Scheme of standard AtlantNIRO sections in Nova Scotia and New England areas.

Fig.1. Scheme of standard AtlantNIRO sections in Nova Scotian and New England areas.

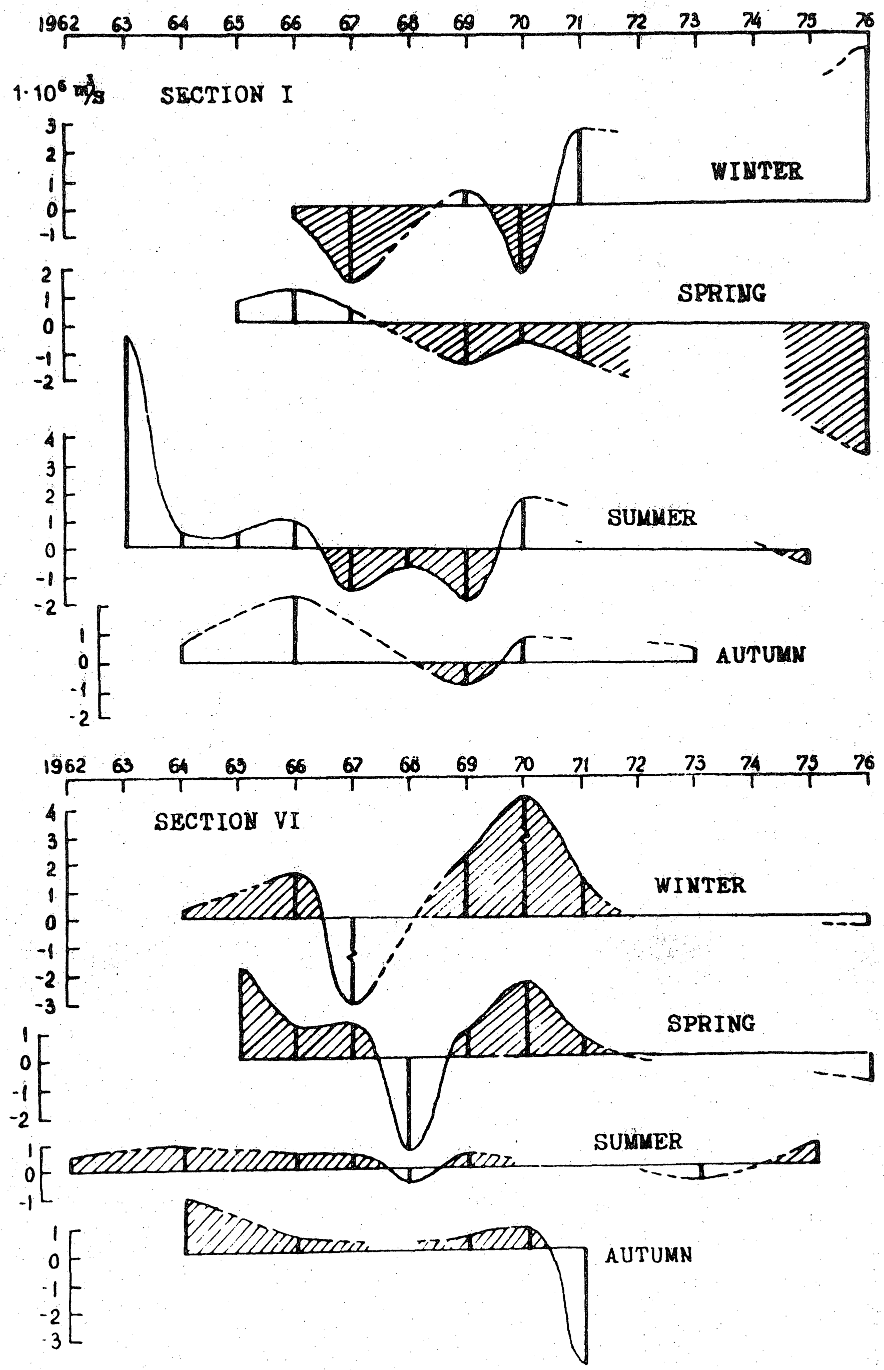

Fig.2. Graphs of resultant values of calculated water transports at sections I and VI (Scotian Shelf).

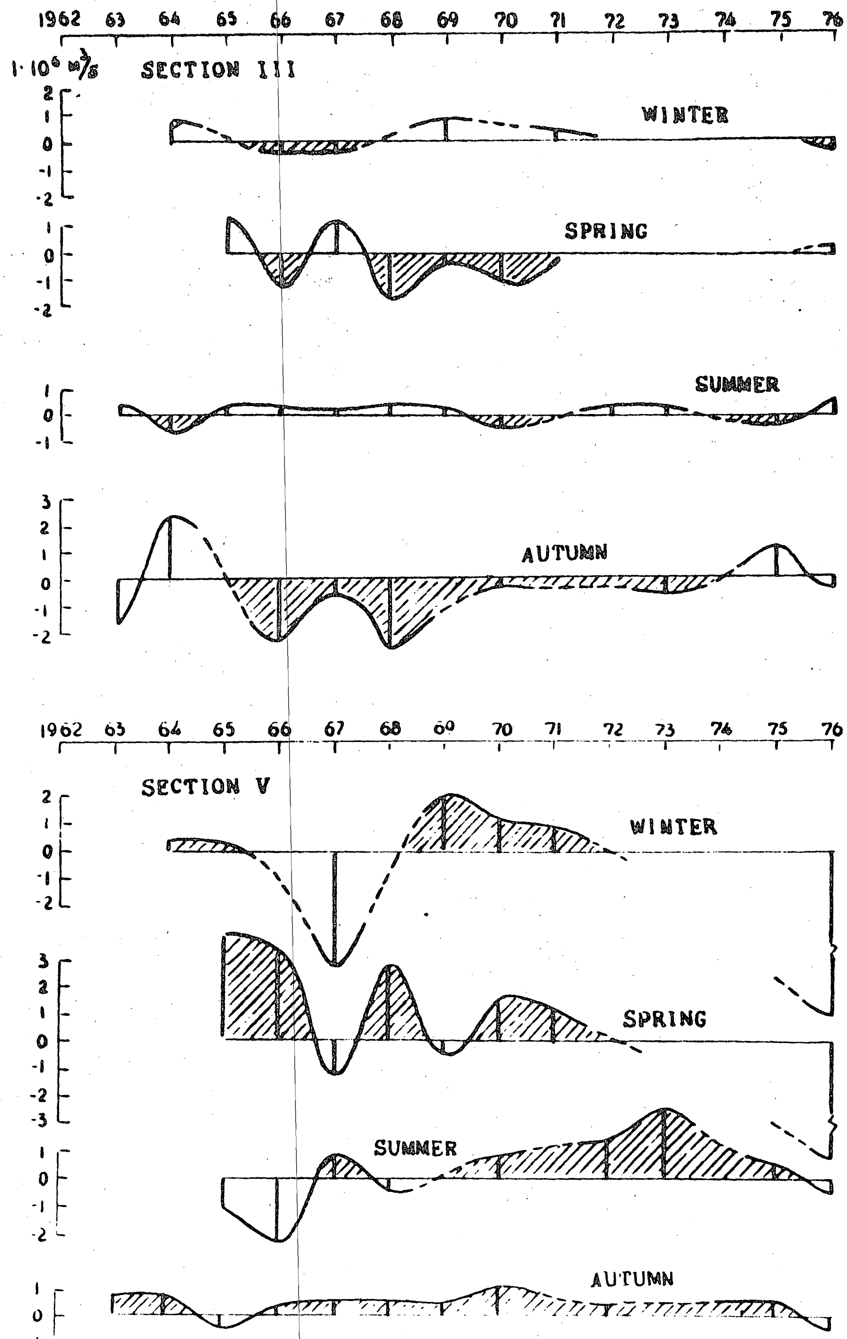

Fig.3. Graphs of resultant values of calculated water transports at sections III and V (New England Shelf).

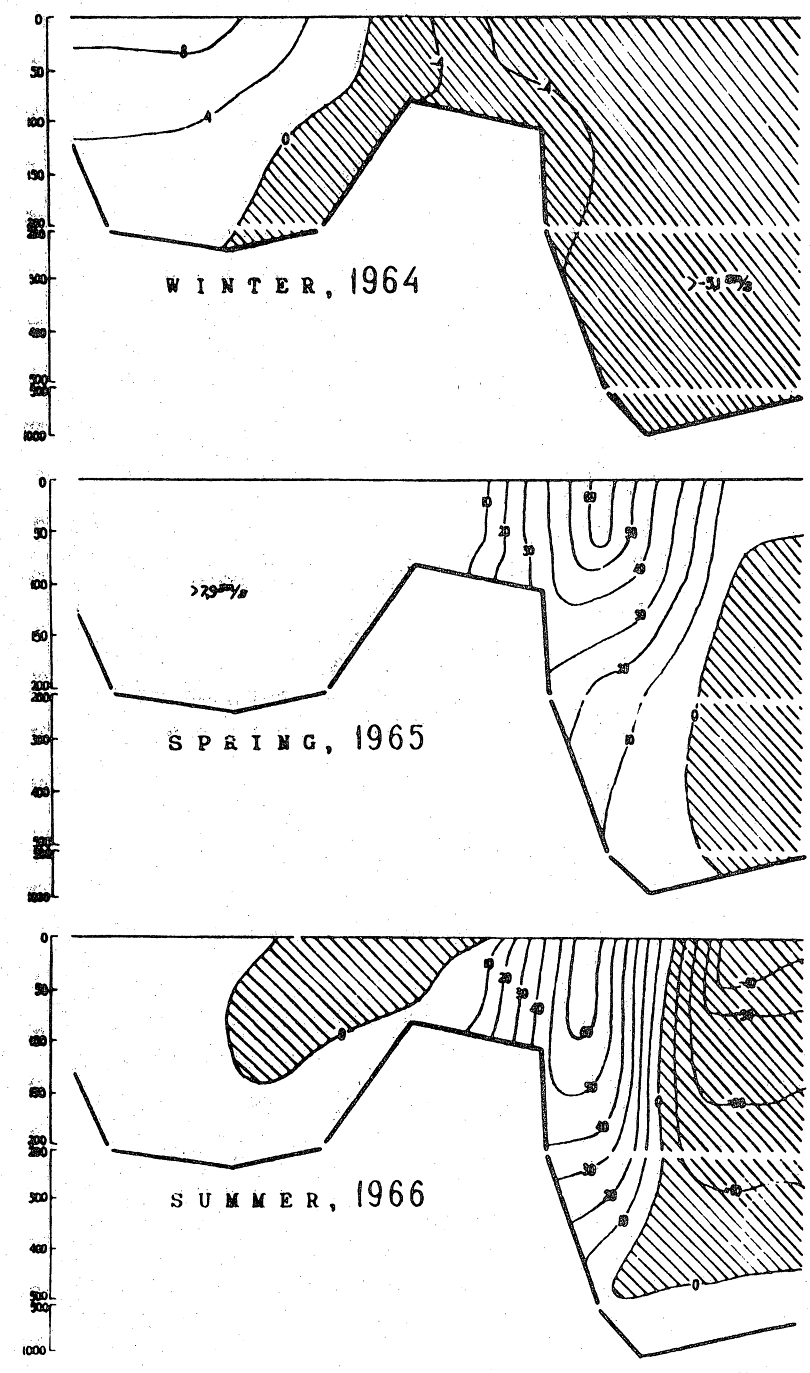

Fig.4. Distribution of flow velocities at section VI.

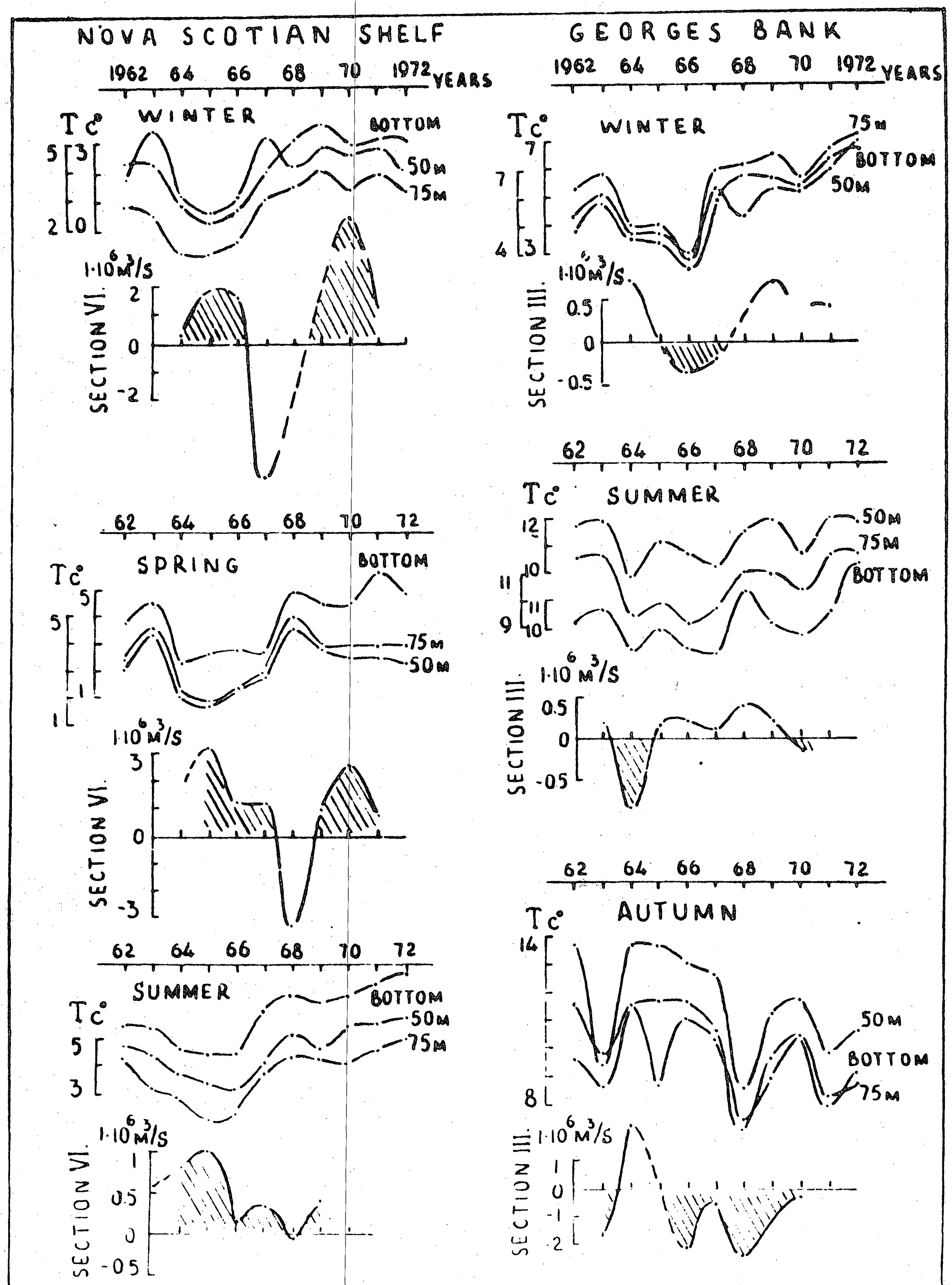

Fig.5. Graphs of year-to-year fluctuations of the thermal background and resultant calculated water transports on Scotian Shelf and Georges Bank.