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The Influence of Hudson Bay Runoff and Ice-melt on the Salinity of the Newfoundland Shelf

by

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Abstract

We relate 40 years of salinity data at an oceanographic station on the Newfoundland Shelf to Hudson Bay outflow. Interannual variation in Hudson Bay summer runoff was associated with salinity residuals on Newfoundland shelf the following spring; this indicates that Hudson Bay runoff is not primarily responsible for the seasonal variability in salinity on the Newfoundland Shelf. Ice-melt in Hudson Bay did not appear to be related to interannual variability of salinity on the Newfoundland Shelf.

1 Introduction

The peak discharge of freshwater from river runoff and ice-melt into the Labrador sea through Hudson Strait is on the order of 0.2 Sverdrups (Prinsenberg et al. 1987, Loucks and Smith 1987). This freshwater input has been hypothesized to have an important influence on the strength of the Labrador current and the production of fish and plankton on the Labrador and Newfoundland shelves (Sutcliffe et al. 1983). Large scale engineering projects are now changing the outflow into Hudson Bay (Prinsenberg 1980), it is thus important to know what effects these large scale diversions may have.

Here we investigate the influence of interannual variability of runoff and ice-melt on the salinity at an oceanographic station (Station 27) in the inner branch of the Labrador Current at a bottom depth of 176m. Our purpose is to relate the variability of salinity with observed Hudson Bay runoff and ice melt.

We tested the hypothesis that salinity at Station 27 is reduced by runoff from Hudson Bay. Sutcliffe et al. (1983) noted a 4 month lag between the seasonal cycle of runoff into Hudson Bay and the seasonal cycle of salinity in the upper 50 m at Station 27, and suggested that the time lag was consistent with ocean drift speeds.

Prinsenberg et al. (1987) obtained monthly estimates of the total runoff landward of the mouth of Hudson Strait using time lags that reflected available information on the mean surface-layer circulation. They found no correlation between their their predicted Hudson Strait outflow and the interannual variability of the average annual surface salinity as Station 27. We re-examined the runoff data without using any lags between runoff from different areas. We concentrate on those regions and seasons with maximum runoff.

2 Station 27

2.1 A continental shelf oceanographic station off Newfoundland.

The oceanographic station 2 km off Cape Spear (Fig. 1), known as Station 27 (176 m depth, 47°32.8′N 52°35.2′W) is the twenty-seventh station in a pattern of ocean transects established as a time-series in 1946 (Templeman 1975). The station is occupied by research vessels entering and leaving St. John's harbor, and has been sampled approximately twice monthly since 1950, providing coverage of all the seasons. Our analysis uses data up to and including 1987.

Fig. 1 near here

Until 1959 oceanographic bottle data from Station 27 were collected at 25 m depth increments; since 1959 measurements were taken at the standard oceanographic depths (0, 10, 20, 30, 50, 75, 100, 150, and near-bottom at 175 m). After 1963 an additional level at 125 m was collected. The intended depth was not always achieved, and wire-angle and unprotected thermometer observations were utilized in assigning data to depth classes. After 1977, CTD and XBT data were also collected, and single values for the above depths were extracted from each cast.

About 8180 observations of temperature and salinity were available from Canadian archives. Laboratory and field sheets for about 90 percent of the data was available for checking. Salinity observations were removed from the record if density decreased with depth, or if they were more than 4 standard deviations from fitted seasonal cycles by depth (following) unless they occurred at a time when surrounding residuals were also extreme.

2.1.1 The Seasonal Cycle

Seasonal cycles at Station 27 were fitted to the edited data by a sine and cosine series. The mean and wavelengths of $1, 1/2, 1/3$ and $1/4$ years were fitted by linear regression (Smith 1983). The regression model was

$$\hat{Y}_t = \overline{Y} + \sum_{i=1}^{4} [\varsigma_i \cos(2\pi it/365.25) + \sigma_i \sin(2\pi it/365.25)],$$

where t is the sequential day of the year. The fitted parameters are the mean $\overline{Y}$, and the coefficients ς_i and σ_i. The amplitude and phase of the i^{th} wavelength are $(\varsigma_i{}^2 + \sigma_i{}^2)^{1/2}$ and $\tan^{-1}(\sigma_i/\varsigma_i)$ respectively. Parameters for the first three wavelengths were significant for all depths. Parameters for the 1/4 year wavelength were significant for only 11 of the 20 regressions (α=0.05). *Fig. 2 near here*

The surface surface salinity minimum occurs in August to September, but the corresponding minimum at the bottom (175 m) occurs in February to March (Fig. 2). There is a decrease in the amplitude of the annual cycle with depth that corresponds to this phase shift.

Huyer and Verney (1975) and Keeley (1981) determined the annual cycle at Station 27 by other techniques. The latter applied "objective analysis" to interpolate the data to a 15 day by 10 m grid in each year, and then averaged those grids over years. Comparing our regression analysis with Keeley's (1981) gridpoint estimates indicated that his technique slightly underestimated the amplitude of the seasonal cycle, and heavily smoothed the sharp summer thermocline. Specifically, the maximum and minimum of surface salinity by the harmonic analysis (with day of the year in brackets) were 32.38(84) and 30.97(266). The corresponding values from Keeley (1981) are 32.27(84), and 31.21(282). Some of the discrepancies may be due to the much larger region Keeley(1981) drew his data from, the increased number of harmonics included in our analysis, and our longer time series.

The residuals at each depth from the annual cycle regressions were time-averaged into months by linear interpolation between observations. Months in which no data were collected were treated as missing observations. We use this monthly series of seasonal residuals in the analysis below. Unless we state otherwise, all salinity estimates from Station 27 will refer to these seasonal residuals. We consider three salinity time series in our analysis: the average residuals from the 0, 10, and 20 m series, the average from the 75, 100, and 125 m series, and the average of the 150 and 175 m series.

3 Runoff and Ice-melt Data

We used the Prinsenberg et al. (1987) time series (1963–1983) of summer river runoff into James Bay, Ungava Bay, and Hudson Bay to examine the effect of runoff on salinity at Station 27. James Bay is responsible for 32% of the river input into the Hudson Bay, Fox basin, and Hudson Strait system, and 44% of the river input into Hudson Bay itself. Our total runoff into Hudson Bay includes the runoff from James Bay. Ungava Bay is responsible for (21%) of the runoff that passes through Hudson Strait.

We used the Loucks and Smith (1987) time series (1963–1983) of ice-melt in James Bay and Hudson Bay estimated from weekly ice thickness observations at a network of 11 stations. The annual average volume of ice-melt in the region is 2.4 times the annual river runoff. We were concerned about the reliability of this series because of potential difficulties described by Loucks and Smith (1987). The reliability of this series was tested by correlating it with the annual anomalies in ice cover in the Hudson Bay region, which includes Fox Basin, Hudson Strait, and James Bay, as calculated by Manak and Mysak (1987) from data compiled by J. E. Walsh (described in Walsh and Sater, 1981). We found that the two series correlated reasonably well (r=55, p=0.01, n=21), which indicated that the ice-melt series is probably reliable. *Fig. 3 near here*

The seasonal cycle peaks in June for Hudson Bay and Ungava Bay runoff and ice-melt (Fig. 3). However, the peak runoff from James Bay is in May. We defined summer runoff and summer ice-melt as the sums from May, June, July, and August.

There was no significant autocorrelation among years in summer runoff or ice-melt for any of the time series. Thus, we did not correct significance tests for the effects of autocorrelation. However, autocorrelation may still be present and will inflate the reported significance levels, so they should be interpreted with care.

4 Runoff from Hudson , James, and Ungava Bays

We correlated the summer river runoff into James and Hudson Bays with monthly salinity residuals at Station 27. The results for James Bay were the clearest. There is a maximum negative correlation at 8 months lag for the surface salinity, corresponding to March at Station 27 (Fig 4). The correlation of river runoff with the mid-water and bottom salinity shows a lag of 10 to 11 months, corresponding to May and June at Station 27. The difference in lag correlation between the surface and the the bottom may be caused by the greater velocity of the surface layer in the inshore component of the Labrador Current. *Fig. 4 near here*

The correlations of total Hudson Bay summer runoff to Station 27 salinities show a similar pattern to that observed for James Bay alone (Fig. 4). However, the negative correlations for the Hudson Bay runoff are spread over more time than those for James Bay alone. We tested our results by using a proxy for Hudson Bay runoff for years other than 1963-1983. The Gods River (station 04AC005, Water Survey of Canada, 1985), which drains into southwestern Hudson Bay, was found to be a good proxy to the total runoff into Hudson Bay (r=0.54, p=0.01, n=21). The 1963–1983 data from the Gods River was not used in correlations with Station 27, to allow an independent test of our correlation results. The Gods River annual runoff is negatively correlated with surface salinity at Station 27, at lags of 8–10 months (Fig. 4), which is consistent with our previous result. There is also a decrease in deeper salinity after a lag of about 10 months. The negative correlation with bottom salinity is less than was seen for the James Bay and Hudson Bay discharge data. It is not surprising that the correlation with the Gods River is not as strong as for the total river because the Gods River is only a rough proxy for total discharge. Also, the salinity data at the deeper levels of Station 27 was not sampled as intensively for years before 1963 as later.

Based on the above results, we expected to see an effect of Ungava Bay discharge on Station 27 salinity three to five months after peak discharge in June. However, there was no negative correlation with salinity at Station 27 at the predicted lag (Fig. 5). The absence of predicted salinity decrease could be explained if the summer runoff in Ungava Bay was negatively correlated with meteorological forcing that acted to increase the salinity at Station 27 during September and October. Myers et al. (1988) found that a major source of the interannual variability in both the fall surface salinity at station 27 and the amount of ice cover in the southern Labrador sea, was the North Atlantic Oscillation or NAO (Rogers and van Loon 1979, Rogers 1984, Moses et al. 1987) which results in increased dry, arctic winds over the Labrador Sea.

Fig. 5 near here

We checked the effect of the NAO on runoff in the region using as an index the difference in the winter sea level pressure between the Azores High, as measured at Ponta Delgadas, Azores, and the Iceland Low, as measured at Akureyri, or Stykkisholmur, Iceland (Rogers 1984, Moses et al. 1987). The fall surface salinity at station 27 decreased with increased winds from the arctic, as measured by NAO index (Myers et al. 1988). As anticipated, Ungava Bay runoff was negatively correlated with the NAO index ($r=-0.56$, $p=0.015$, $n=18$). Prinsenberg et al. (1987) arrived at a similar conclusion using local geostrophic winds.

In years in which there are strong winds from the Arctic, there is more ice formed in the Baffin Bay and the Labrador Sea and transported to the southern part of the Labrador Sea. This leads to decreased surface salinity at Station 27. However, in these years there is less runoff into Ungava Bay. There was no significant correlation of the NAO index and runoff in the other regions. Thus, that we did not see the expected decrease in salinity at Station 27 caused by Ungava Bay runoff is not inconsistent with our results for Hudson and James Bay runoff.

5 Ice-melt

We examined the interannual variability in summer ice-melt in a similar manner as described above. We found no consistent evidence of any relationship (Fig. 6). The apparent positive correlation of ice-melt and salinity at some lags is either spurious or caused by correlations of both time series with large scale meteorological forcing. We also examined a similar time series that included the estimated ice-melt from Fox Basin and Hudson Strait as well. The results were very similar to Fig. 6.

Fig. 6 near here

6 Conclusions

Interannual variation in Hudson Bay summer runoff was associated with surface salinity residuals on the Newfoundland shelf the following spring; this indicates that Hudson Bay runoff is not primarily responsible for the seasonal variability in salinity on the Newfoundland Shelf.

We conclude that Hudson Bay runoff does affect the interannual variability in the salinity at Station 27, but in contrast to the Sutcliffe et al. (1983) hypothesis, the effect of peak runoff on Station 27 salinity is in March at the surface, and April to June at the bottom. Evidence to support this conclusion comes from an 11 month long record of salinity at 40 m in Hudson Strait (Fig. 7), that shows the salinity minimum is in December. (However, the decrease in salinity at 40 meters in Hudson Strait may not reflect horizonal advection, but may instead reflect mixing down of lower salinity surface water.) This would imply a 3 month delay between the Hudson Strait salinity minimum and the predicted effect on Station 27 (1800 km away). This results in a surface velocity consistent with the 0.2 ms^{-1} velocity in the upper 100 m of the Labrador Current estimated by Petrie and Isenor (1985). We conclude that the surface salinity minimum at Station 27 is caused by the melt of the seasonal ice cover in the Labrador sea, and is not due to river runoff or ice melt in Hudson Bay. *Fig. 7 near here*

The freshwater pulse appears to take about 5 months to travel the 1000 km from James Bay to Hudson Strait. This gives a current speed of 0.07 ms^{-1}. Prinsenberg (1986) reviewed estimates of current data in Hudson Bay, and concluded that it has a mean cyclonic circulation with a current strength of 0.05 ms^{-1}. Thus, the lag correlation between Hudson Bay runoff and salinity at Station 27 is consistent with other estimates of current velocity.

Although the volume of freshwater from Hudson Bay ice-melt was 2.4 times the volume of freshwater input from rivers, we found no relationship of ice-melt with salinity at Station 27. River input may drive strong thermohaline circulation in Hudson Bay which causes the river input to be transported out of Hudson Strait. A large proportion of the river runoff is concentrated in James Bay and the southern potion of Hudson Bay. On the other hand, ice may melt more uniformly over the surface of Hudson Bay, rather than on the edges, and would not set up horizontal density gradients that would drive thermohaline flow. However, ice is concentrated by wind to some extent on the shore which should drive some thermohaline flow. This matter requires further investigation.

7 Acknowledgments

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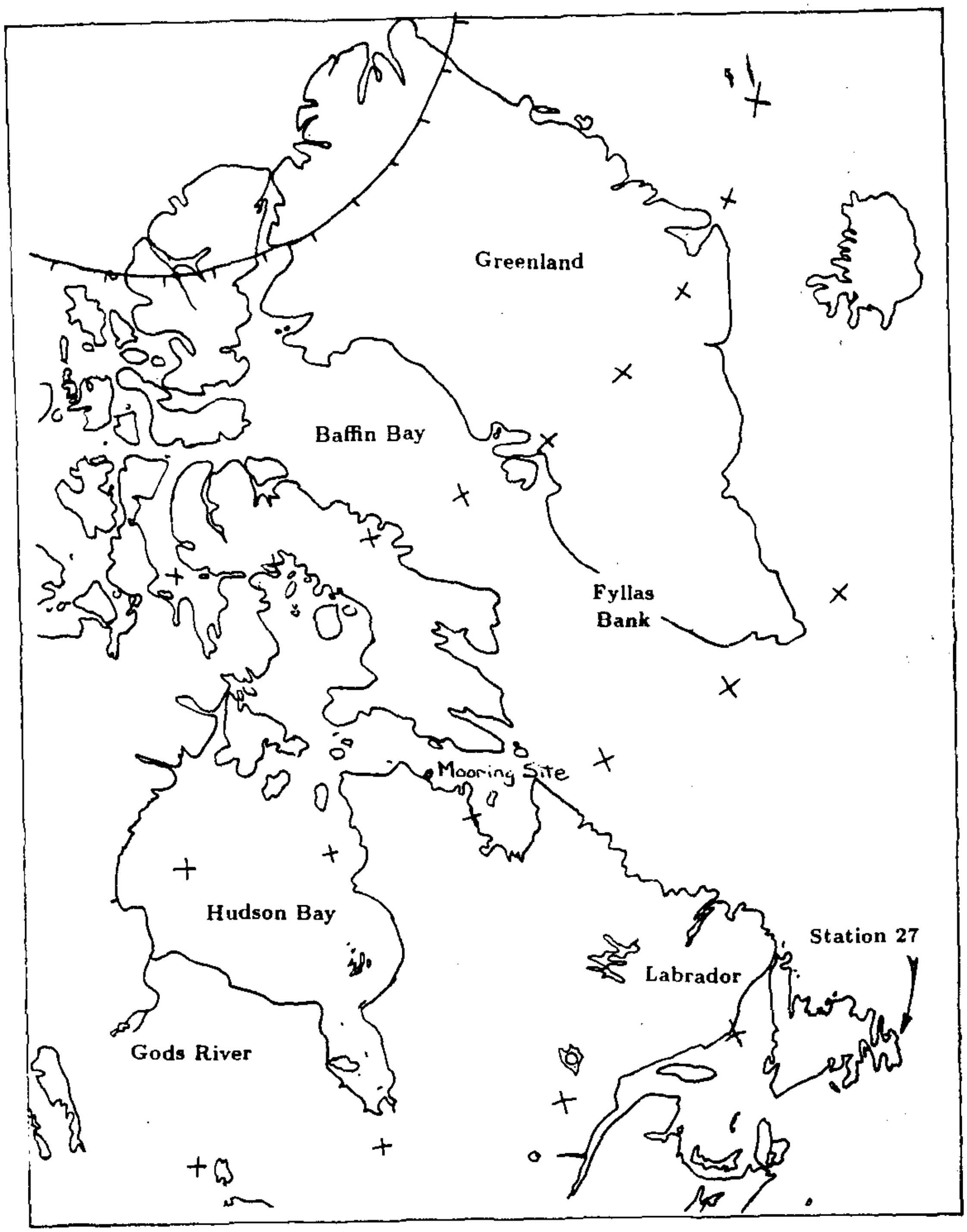

Fig. 1. Location of station 27 and other locations mentioned in the text.

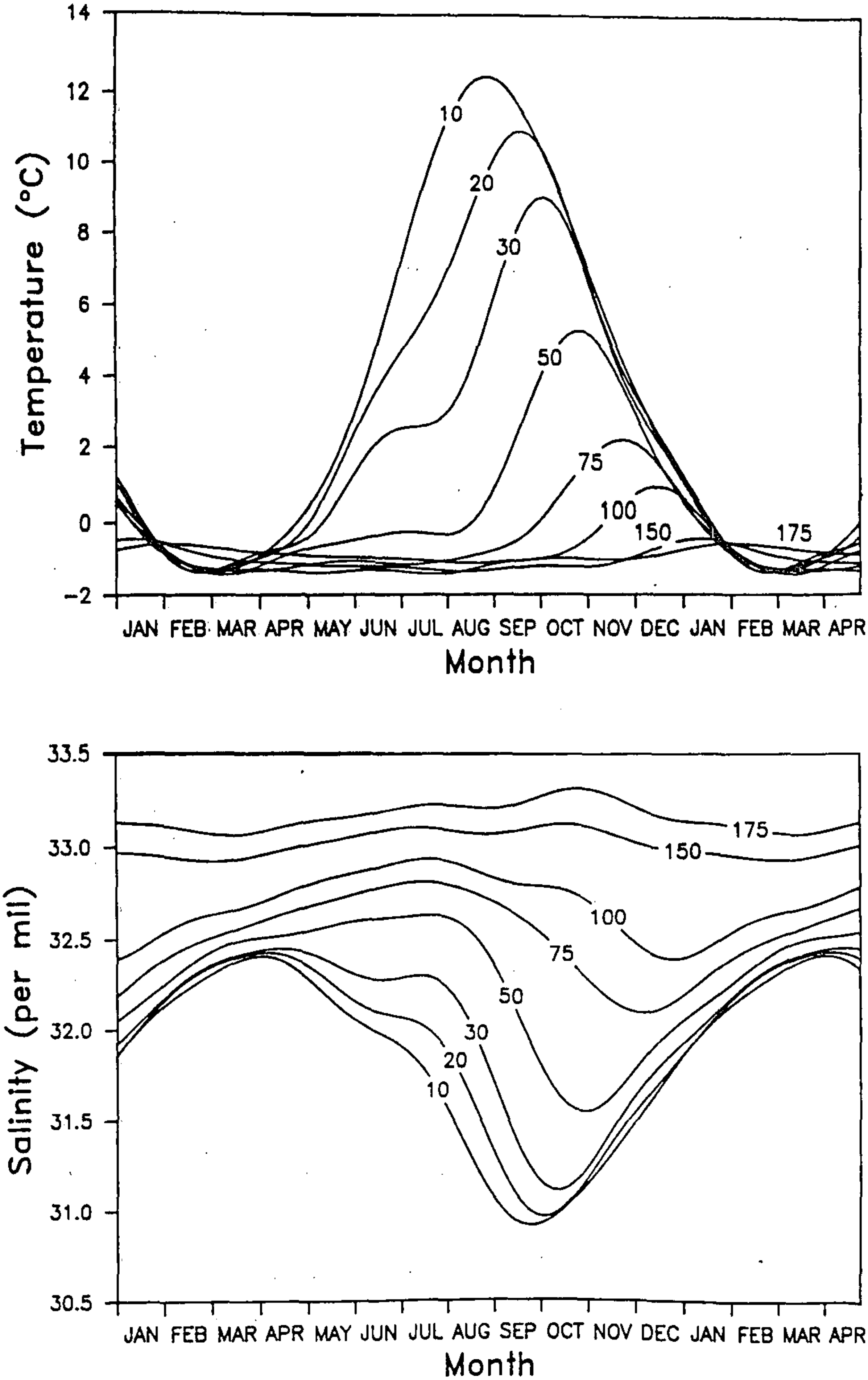

Fig. 2. The seasonal cycle of temperature and salinity at station 27 as a function of depth (in meters).

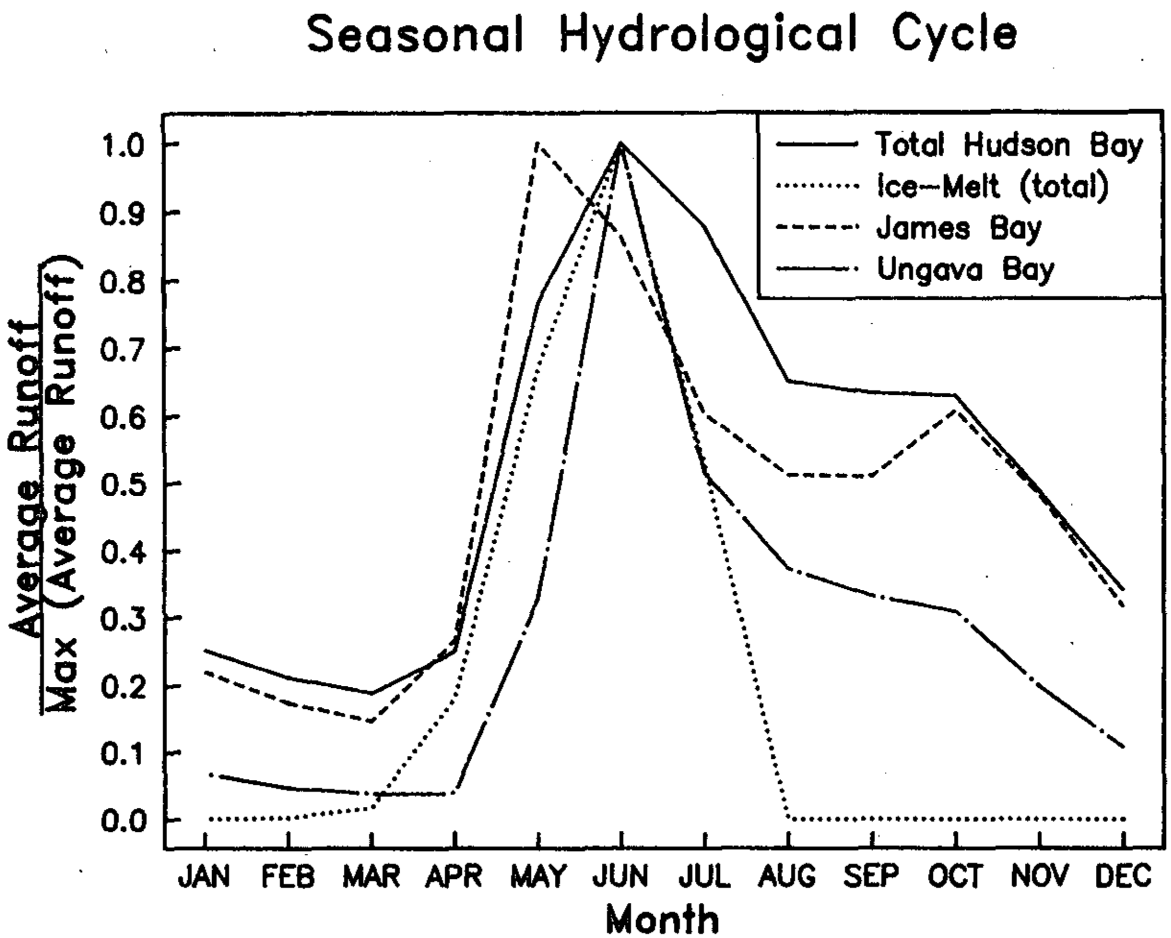

Fig. 3. The average seasonal cycle of runoff into James Bay, Hudson Bay, and ice-melt calculated for the years 1963-1983. Each of the series has been normalized by dividing by the maximum value in each series; these are: $0.39 \times 10^6 m^3 s^{-1}$ for James Bay, $0.82 \times 10^6 m^3 s^{-1}$ for Hudson Bay, and $4.8 \times 10^6 m^3 s^{-1}$ for the ice-melt.

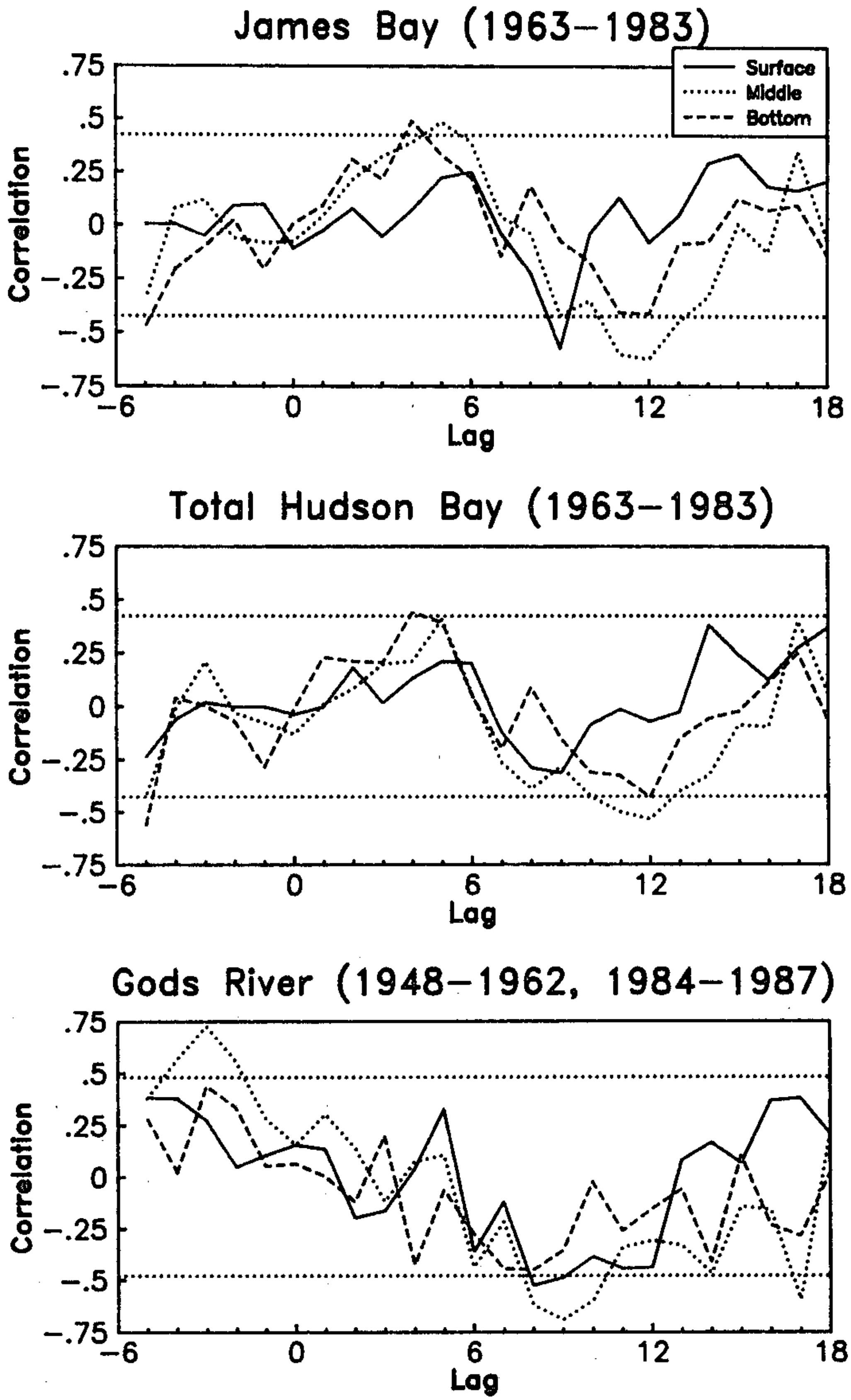

Fig. 4. The correlation of summer runoff into James Bay (1963-1983), total Hudson Bay (1963-1983), and Gods River, (1948-1962 and 1984-1987) with the lagged salinity residuals at Station 27 for three depth zones. The surface salinity is the average residuals over the surface, 10m, and 20m, the middle salinity is the average 75m, 100m, and 125m, and the bottom salinity is the average over 150m and 175m. The lag is referenced to June. The critical values for the hypothesis that the correlation coefficient is equal to zero at $\alpha = 0.05$ are also shown as horisonal lines.

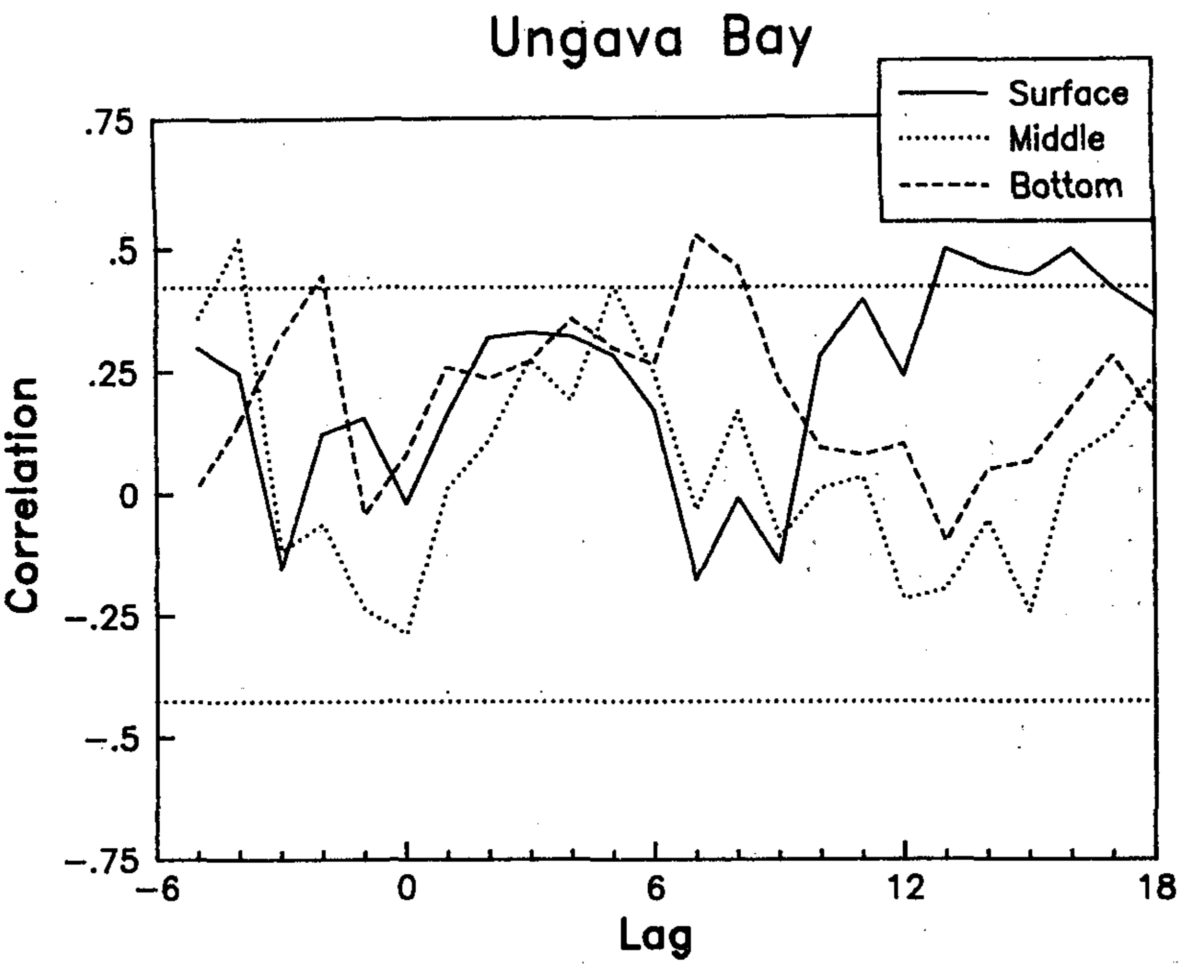

Fig. 5. The correlation of summer runoff in Ungava Bay (1963-1983) with the lagged salinity residuals at Station 27. The lag is referenced to June. See Fig. 4 for details.

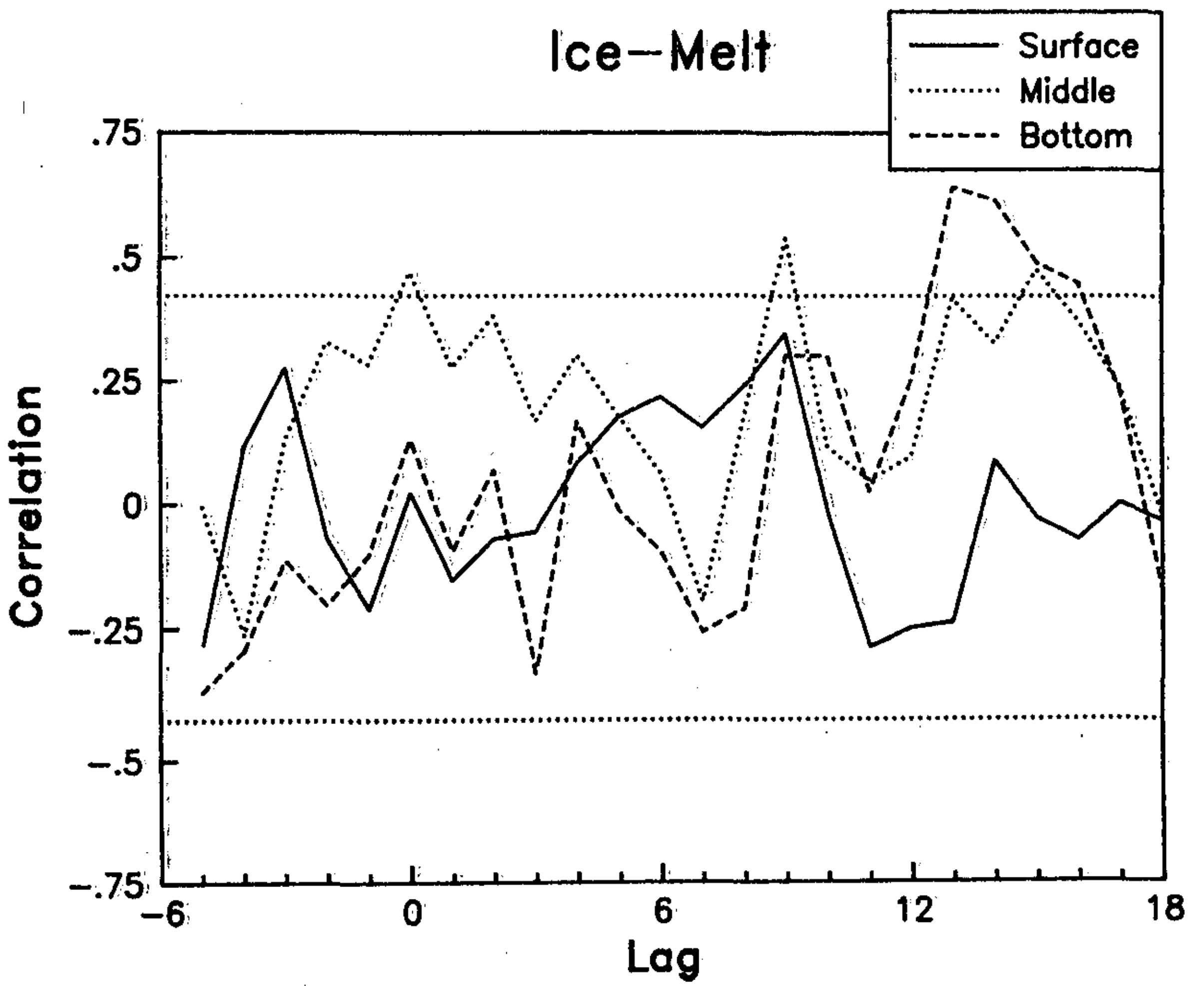

Fig. 6. The correlation of summer ice-melt in Hudson Bay (1963-1983) with the lagged salinity residuals at Station 27. The lag is referenced to June. See Fig. 4 for details.

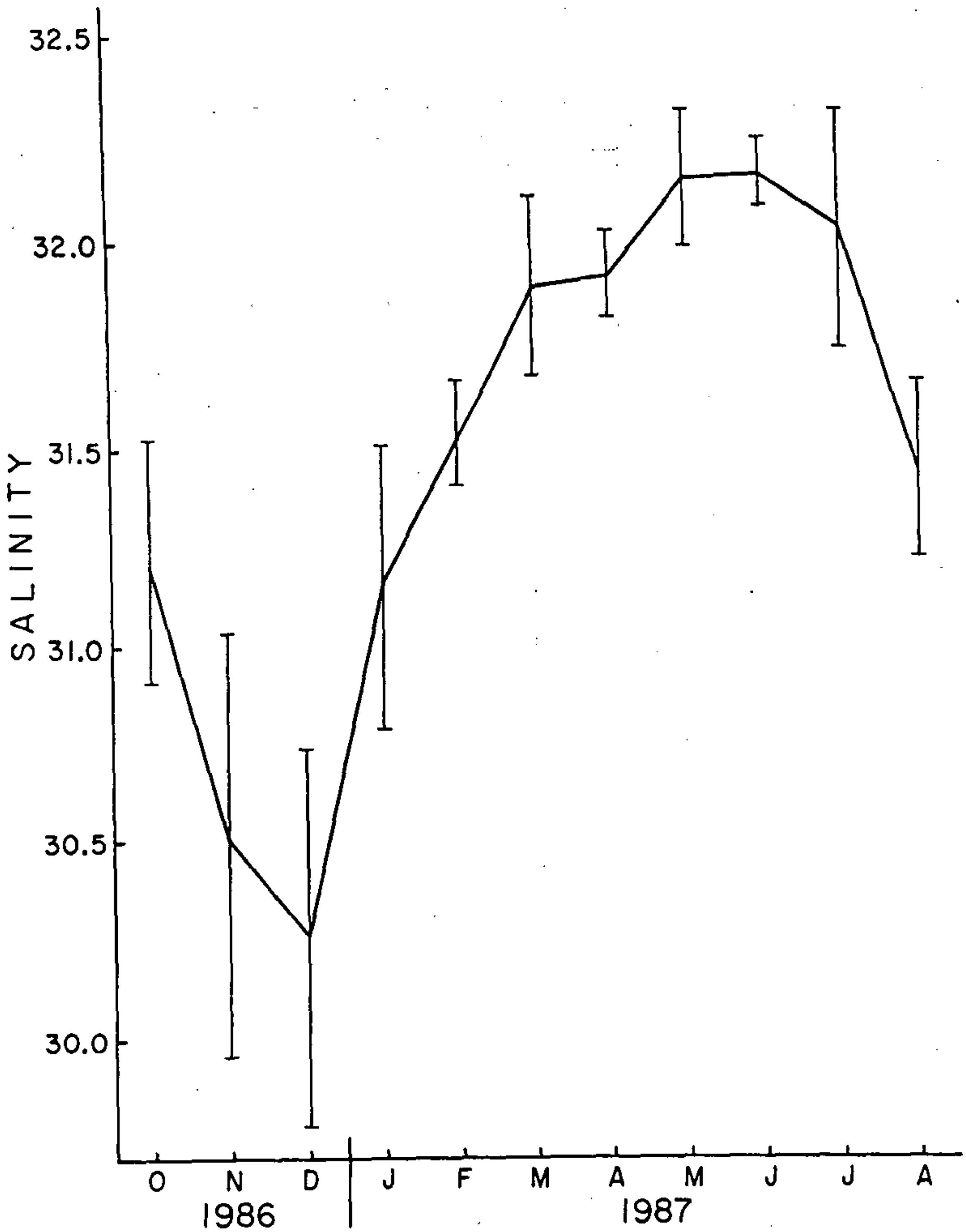

Fig. 7. Salinity (with standard deviations) in Hudson Strait measured at 40 m depth.