Fisheries and Oceans Canada
Science

Pêches et Océans Canada
Sciences

C S A S

Canadian Science Advisory Secretariat

S C C S

Secrétariat canadien de consultation scientifique

Research Document 2002/071

Document de recherche 2002/071

Not to be cited without
permission of the authors *

Ne pas citer sans
Autorisation des auteurs *

Trends in Stratification on the inner Newfoundland Shelf

Tendances de la stratification dans la partie intérieure du plateau de Terre-Neuve

J. D. C. Craig and / et E. B. Colbourne

Department of Fisheries and Oceans
P. O. Box 5667
St. John's Newfoundland, Canada A1C 5X1

* This series documents the scientific basis for the evaluation of fisheries resources in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the Secretariat.

This document is available on the Internet at:

* La présente série documente les bases scientifiques des évaluations des ressources halieutiques du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au Secrétariat.

Ce document est disponible sur l'Internet à:

http://www.dfo-mpo.gc.ca/csas/

ISSN 1480-4883

Abstract

The time series of the stratification at Station 27 shows a continuation of the increasing trend first seen in the early 1990s, reaching near record levels in recent years. The increase in stratification appears to be in response to reduced salinity. Increased stratification over the last decade of the new (1971-2000) reference period resulted in a higher mean stratification than that for the old (1961-1990). As a result, the anomalies are about 0.002 kg m^{-4} lower with respect to the new reference period. The mean annual signal for this period was broader and about 7 percent higher than the previous one.

Increased stratification over the past year was a result of almost equal contributions of reduced salinity and increased temperatures during the summer and fall of 2001. A long term decreasing trend in salinity was observed.

Résumé

La série chronologique de données sur la stratification à la station 27 révèle que la tendance à la hausse observée pour la première fois au début des années 1990 continue, la stratification ayant atteint des niveaux presque records dans les dernières années. L'accroissement de la stratification semble être le résultat d'une baisse de la salinité. La stratification accrue observée au cours de la dernière décennie de la nouvelle période de référence (1971-2000) a donné lieu à une stratification moyenne plus marquée que pendant l'ancienne période de référence (1961-1990). En conséquence, les anomalies sont d'environ 0,002 kg m^{-4} moins élevées en ce qui concerne la nouvelle période de référence. Le signal moyen annuel pour cette période était plus large, étant d'environ 7 pour 100 plus élevé que le signal précédent.

La stratification accrue observée au cours de la dernière année est le résultat de contributions presque égales d'une baisse de la salinité et d'une élévation des températures pendant l'été et l'automne 2001. On a aussi observé une tendance à la baisse de la salinité à long terme.

Introduction

Density stratification has a strong effect on the nutrient transport, distribution and biological process in the water column, Mann and Lazier, (1996), Platt et al. (1994). Monitoring stratification is important in attempting to understand and predict plankton distribution. For instance, the dynamics of the spring bloom is believed to respond to the density structure of the water. For this reason, an effort has been made to closely monitor stratification, along with nutrient and plankton distributions at Station 27, Pepin and Maillet (2001), Craig et al. (2001).

Station 27 has been sampled since 1946 and approximately 50 times a year over the past decade. No other site on the Newfoundland shelf has been sampled as intensely. The site is generally representative of the entire shelf in terms of biological and physical processes.

In the present paper, recent trends in the stratification index are examined. The effects of the recently adopted 1971-2000 reference period on the anomaly calculations of stratification and the mean annual stratification cycle are outlined.

Sources of data

Data at was obtained from the Station 27 atlas maintained at the Northwest Atlantic Fisheries Centre (NAFC). All measurements were taken within a 2 nautical mile radius of the station (47° 32.8'N 52° 35.2'W) which is located near St. John's.

Sampling at station 27 before the 1980s was usually at the standard depths of 0, 10, 20, 30, 50, 100, 125, 150 metres and the bottom at approximately 176 metres. From about 1990 to present, sampling was at intervals of approximately 20 cm, as determined by the deployment speed of 50 metres/minute, the instrument sampling frequency of 8 Hz, and some degree of quality control of the raw data. The accuracy of the measurements was maintained to within 0.005°C for temperature and 0.005 Seimens/metre or better, for conductivity. Pressure measurements were accurate to 0.25 percent. Density was calculated from the salinity, temperature and depth using the standard 1982 UNESCO equation of state.

Analysis

The stratification index was calculated using a two-point method similar to that of Drinkwater et al. (1999), i.e.: the difference in densities of water at 50 metres and at the surface divided by 50 metres. Stratification is expressed in kg m^{-4} or alternately, g/ml/m (1 kg m^{-4} =10^{-3} g/ml/m). Because of the high variability of the surface water, the surface density was taken as that nearest but less than or equal to 5 metres. The other value was the first available density falling between 48 and 53 metres. By taking the quotient of difference in densities and the difference in the corresponding depths, the density gradient was obtained. This was not done for profiles without density data in the zero to 5-metre range. Monthly averages of the stratification index were prepared for the reference periods and these were subtracted from the monthly means to yield the anomaly time series. For each year, the mean anomaly was calculated from the monthly anomalies. Although there were instances when there was no data available for a given month, these were rare and no weighting of the monthly means was used in computing the yearly means. These calculations were performed for the 1961-1990 and 1971-2000 reference periods (per the World Meteorological Organisation and Northwest Atlantic Fisheries Organisation standards).

Harmonic analysis with 4 harmonics (Craig et al. 2001) was used to prepare the mean annual cycle curves for each reference period.

Stratification trends

Time series plots were very similar for the two reference periods (Figs. 1 and 2) with the most apparent difference being generally lower anomalies in the more recent reference period. The difference, about 0.002 kg m^{-4} was due to the increased stratification in the last decade. Because this was now included in the new reference period, the mean stratification was higher, resulting in a lower anomaly. There appeared to be an increase in variability of stratification over the last 20 years

The heavy line in Figs. 1 and 2 was calculated as a 5-year running mean to effectively low-pass filter the annual anomalies. The filtered anomaly showed a clear and fairly consistent increasing trend over the past decade and appeared to be approaching record levels in recent years. This trend, as reported earlier on the Newfoundland shelf, Craig et al. (2001) and the Scotian shelf, Drinkwater et al. (2001) persisted into 2001. The trends in the salinity of the surface waters of the Scotian and Newfoundland shelves are so similar (Fig. 3) that Drinkwater et al. (2002) suggested that they may originate with advection of the water from the Newfoundland to Scotian shelves. They note, however, that there was no phase delay in the signals as might be expected if the water were advected from the Newfoundland shelf.

Seasonal Analysis and the Origin of the 2001 anomaly

Surface temperature and salinity anomalies (Figs. 4 and 5) showed contrasting trends over the past decade. Although the salinity remained below normal during this period, it exhibited high variability but the 5-year running mean remained relatively constant. The filtered temperature time series, on the other hand, consistently increased from below normal to about 0.5 degrees above normal over the same period. This suggested that the increase in the stratification anomaly was temperature-driven, but this was not consistent with previous findings that indicated it was due to fresher surface waters. In the first half of the last decade, the mean salinity was driven down by strong negative anomalies in 1991 and 1995. The temperature was colder than normal during most of this period so that there was only a slight effect on the density anomaly. The second half of this period was characterised by slightly fresher and much warmer surface water. An increase in stratification in this period occurred with warmer surface water.

The density of cold water depends almost exclusively on salinity, but temperature becomes a significant factor in water over about 10 ^{o}C. In this region of the TS diagram for Station 27, Craig et al. (2001), an increase in temperature of 1 ^{o}C will reduce the density about the same as a 0.2 ppt decrease in salinity. The summer and fall temperatures for 2001, (Figs. 6 and 7) show anomalies in the +1 ^{o}C range whereas the corresponding salinity anomalies are in the –0.2 ppt range. Because the temperature during this period was above 10 ^{o}C, the lower density of the surface water was due to approximately equal contributions of warmer and fresher surface water. Water properties at 50 metres were relatively stable, so the variation in the stratification is due almost entirely to changes in the density at the surface. The stratification anomaly in 2001 is therefore the result of fresher and warmer than normal surface waters in the summer and fall.

For 2001, the stratification was examined on a seasonal basis to determine which seasons were contributing to the anomaly. The winter, Fig. 8, was a period of relatively little stratification because the water column is well mixed. Anomalies in this period are therefore very small. In the months from March through June, the water column became more structured and there was the potential for more variability in the stratification. By summer and fall, the stratification reached its seasonal maximum. Anomalies were more pronounced in this part of the annual cycle. The summer stratification anomaly exhibited the same increasing trend observed over the past decade for the annual anomaly time series, while the fall signal was dominated by a strong positive anomaly in 1991.

Comparisons of the Annual Cycles

Anomalies are now calculated based on the 1971-2000 reference period. As shown in Figs. 1 and 2, the adoption of a new reference period resulted in subtle changes to the anomaly calculations, primarily a reduction in their values. Annual cycles were prepared by a harmonic regression based on each observation in the respective reference periods, Fig. 12. The cycle corresponding to the later period was about 7 percent greater and somewhat broader. There appeared to be a small shift of a few days in the phase of annual cycle since 1946. The small peaks seen in the winter of each curve could be eliminated by range restricting the data before the regression, suggesting they are the result of random noise.

Annual cycles for the surface water were plotted on a standard TS diagram Fig. 13. These showed that for the new reference period, the surface water was fresher and less dense during the entire cycle.

Origin of the long-term trends in stratification

It appears that stratification is decreasing over the past several decades. Unlike the recent trend, this feature does not seem associated with an increase in temperature, rather a decrease in the surface salinity. Such a trend has been described by Dickson et al. (2002) particularly with respect to the deeper waters in the North Atlantic. The change in salinity of the Labrador Sea Water for instance was reported as –13 ppm/decade. However, they have noted both a freshening and cooling of the entire water column of the Labrador Sea Water over the past several decades. A similar analysis, Fig. 14, where annual salinities were calculated from monthly means for the surface water at station 27 showed a substantially higher rate of freshening corresponding to a change in salinity of -56.7 ppm/decade over the past 4 decades. The similarity of the trends and the possibility of advection of fresher water from the north is perhaps evidence that they may originate with changes in larger scale processes in the North Atlantic circulation.

Conclusions

The increasing trend in stratification that started in the 1990's has continued into 2001. Fresher and warmer than normal surface water during the summer and fall were responsible for the 2001 increase. The adoption of the new 30-year reference period has effectively reduced stratification anomalies by about 0.002 kg m^{-4}.

Subtle differences were apparent in the annual cycles for each of the reference periods, notably an increase in its maximum value. Other slight differences were seen and may be artefacts of the sampling regime. Warmer and fresher water caused the 2001 stratification anomaly, however the lower density of the surface water in the new reference period appears to be due to lower salinity.

Acknowledgements

We are very grateful to the technicians and students at the NWACF and Memorial University who assisted with the data acquisition, processing and archiving of the Station 27 data, to Garry Maillet for interesting and inspiring discussions and to Dr Joanne Morgan for her helpful suggestions in reviewing this manuscript.

References

Craig, J. D. C., E. B. Colbourne and G. L. Maillet, 2001. Preliminary Studies of Density Stratification and Fluorescence on the Newfoundland Shelf. DFO Canadian Science Advisory Secretariat Research Document 2001/085

Dickson, Bob, Igor Yashayaev, Jens Meincke, Bill Turrell, Stephen Dye, Juergen Holfort, 2002. Rapid freshening of the deep North Atlantic Ocean over the past four decades, Nature 416 832-837

Drinkwater, K., E. B. Colbourne and D. Gilbert 1999. Overview of Environmental Conditions in the Northwest Atlantic in 1998, NAFO SCR Doc. 99/36, 1999

Drinkwater, K.F., B. Petrie and P.C. Smith. 2002. Climate variability on the Scotian Shelf during the 1990s, ICES Mar. Sci. Symp. Ser. (accepted)

Drinkwater, K., B. Petrie, R. Pettipas, L. Petrie and V.Soukhovtsev. 2001. Physical oceanographic conditions on the Scotian Shelf and in the Gulf of Maine during 2000. DFO Canadian Science Advisory Secretariat Research Document 2001/055

Mann K. H., J.R.N. Lazier, 1996. Dynamics of Marine Ecosystems, Blackwell Sciences Inc.

Pepin, P. and Maillet, G.L., 2001. Biological and Chemical Oceanographic conditions on the Newfoundland Shelf during 2000 with comparisons with earlier observations. DFO Canadian Science Advisory Secretariat Research Document 2001/073

Platt, T., J.D. Woods, S. Sathyendranath and W. Barkmann, 1994. Net primary production and stratification in the ocean pp 247-254 In Johannessen, D.M. Muench and D.E. Overland. The Polar Oceans and their Role in shaping the Global Environment. Geophys. Monograph 85 AGU Washington 525 pp.

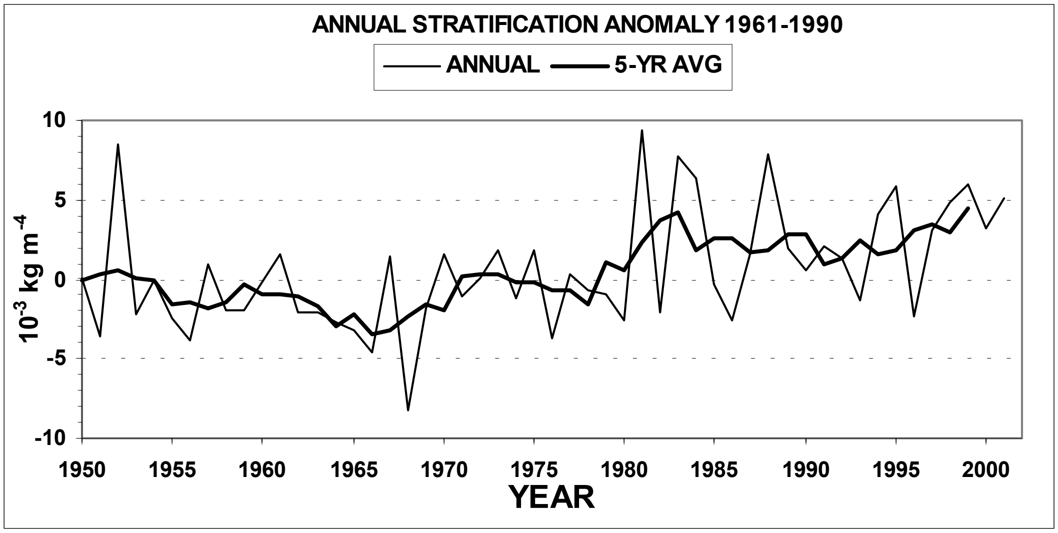

Fig.1 Annual stratification anomaly time series using the 1961-1990 reference period.

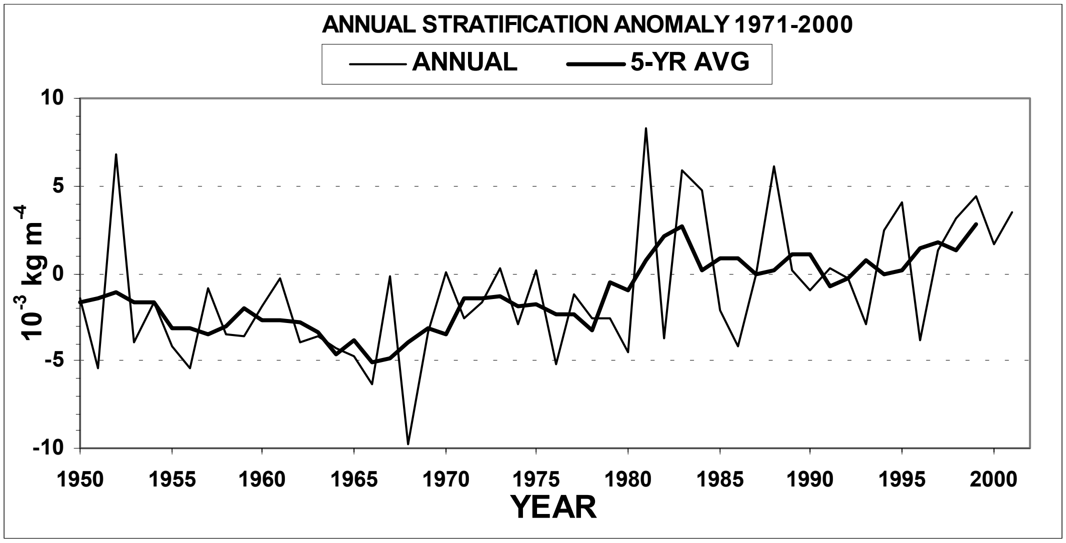

Fig. 2 Annual stratification anomaly time series using the 1971-2000 reference period

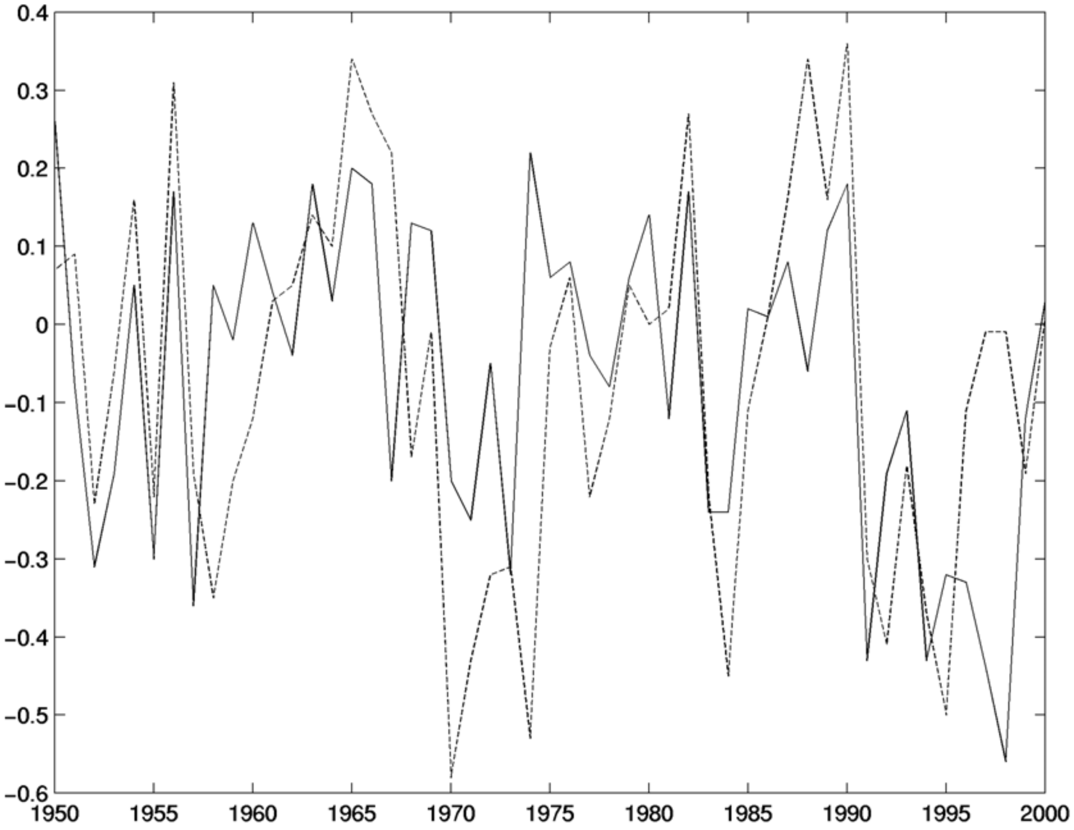

Fig 3 Salinity anomalies for the Scotian Shelf (solid) and Station 28 (broken line). From Drinkwater et al. (2002)

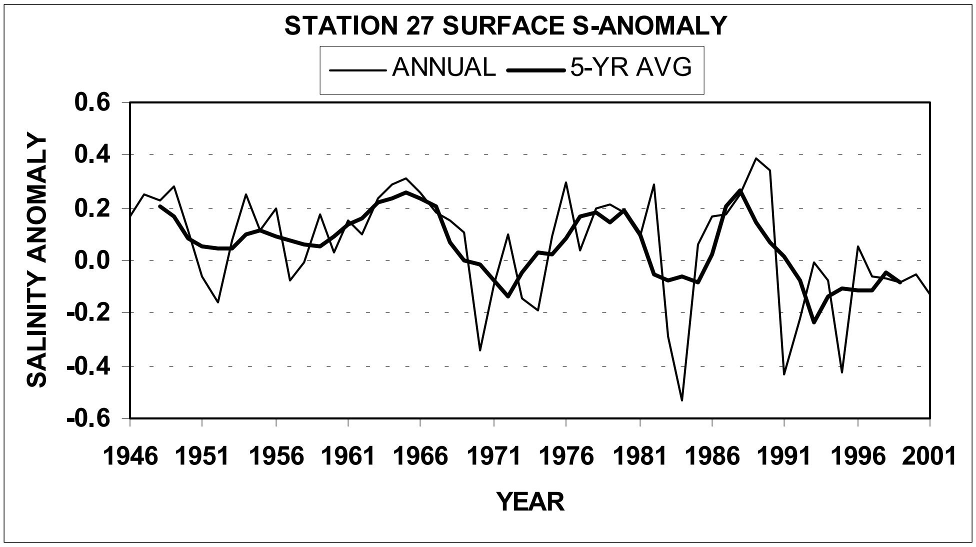

Fig 4. Surface salinity anomaly

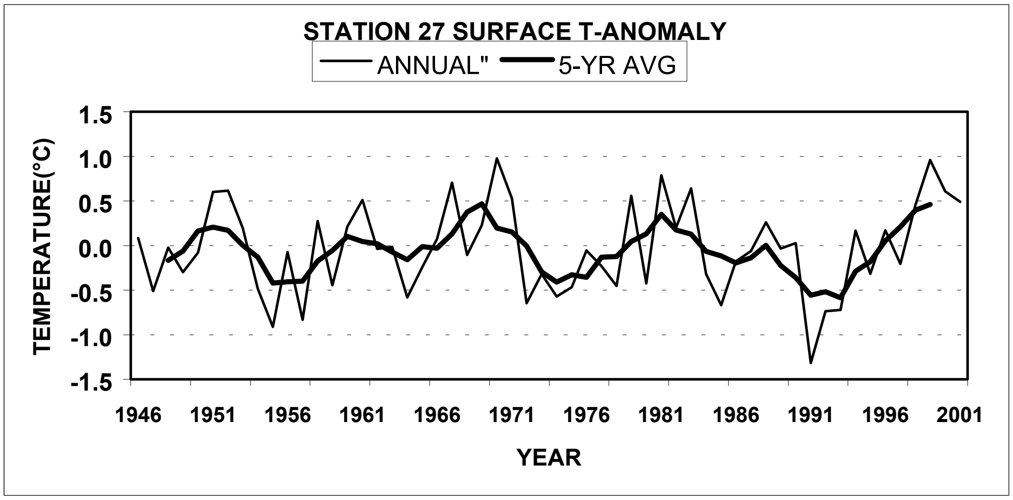

Fig 5. Surface temperature anomaly

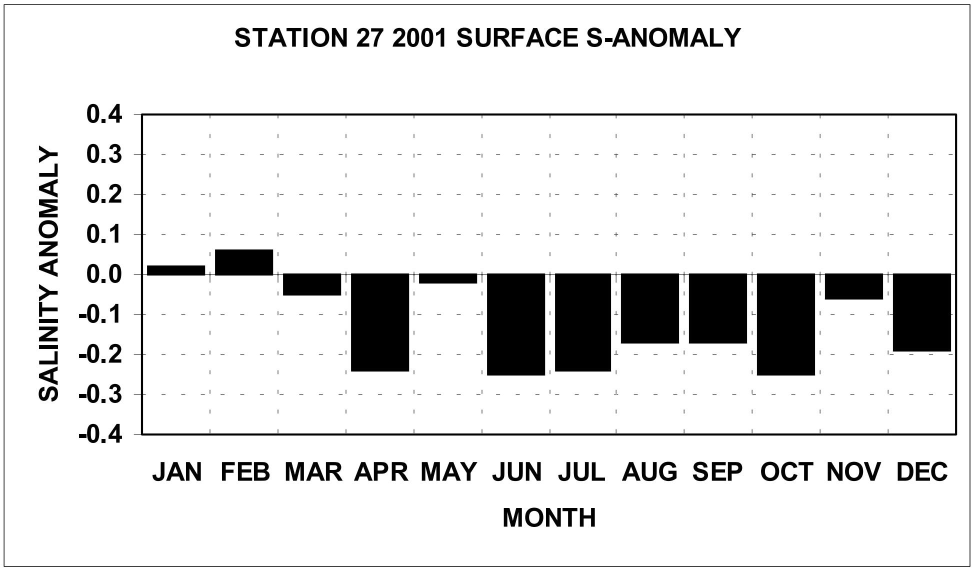

Fig.6 Surface salinity anomaly for 2001

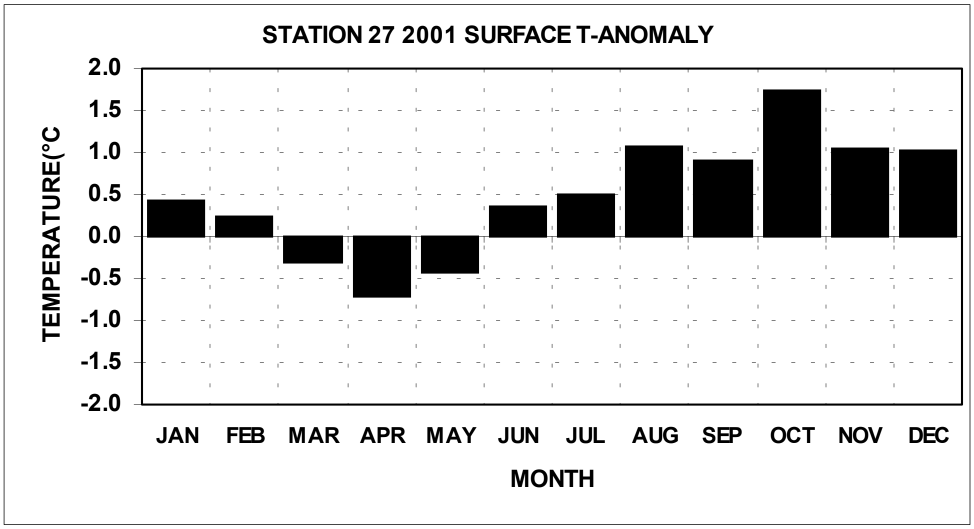

Fig.7 Surface temperature anomaly for 2001

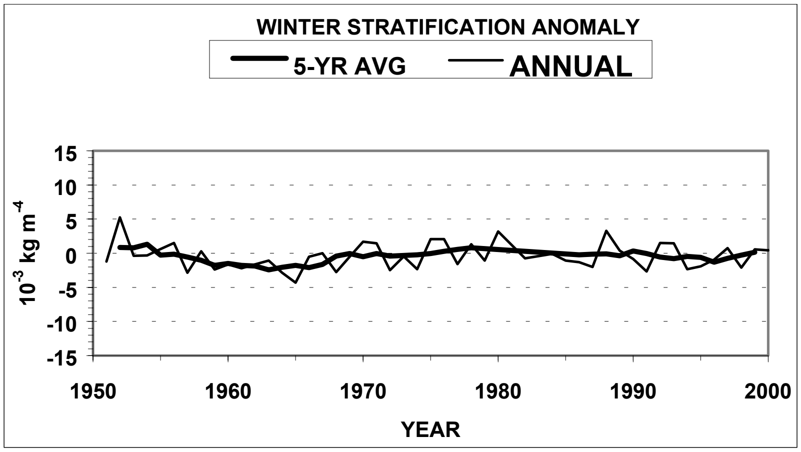

Fig. 8 Winter stratification anomaly

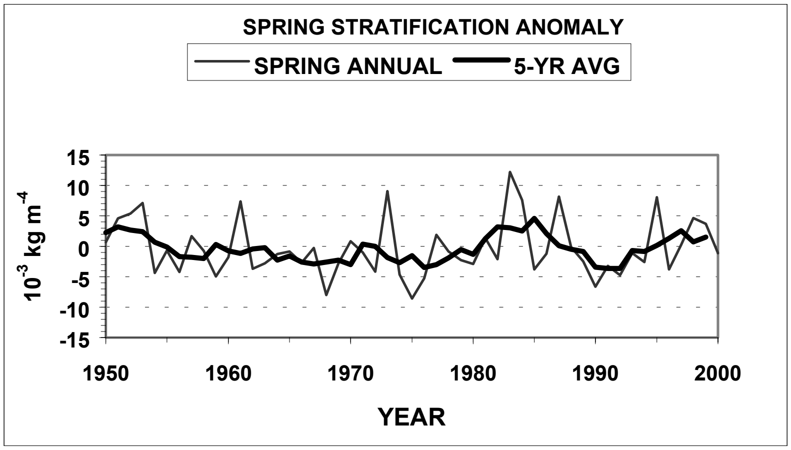

Fig. 9 Spring stratification anomaly

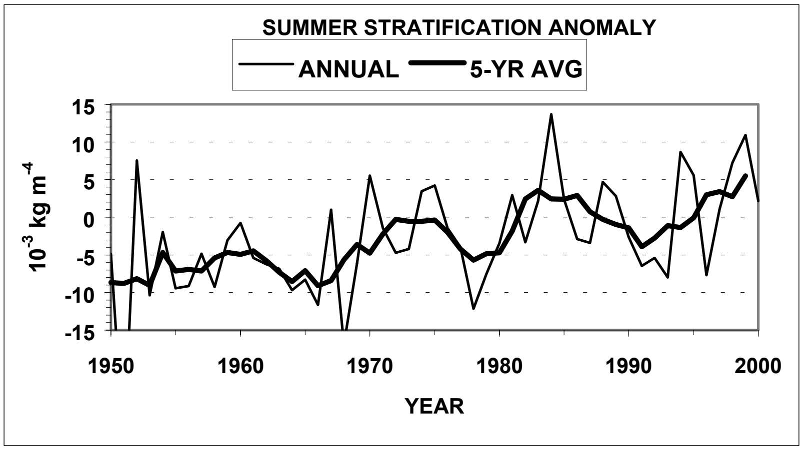

Fig. 10 Summer stratification anomaly

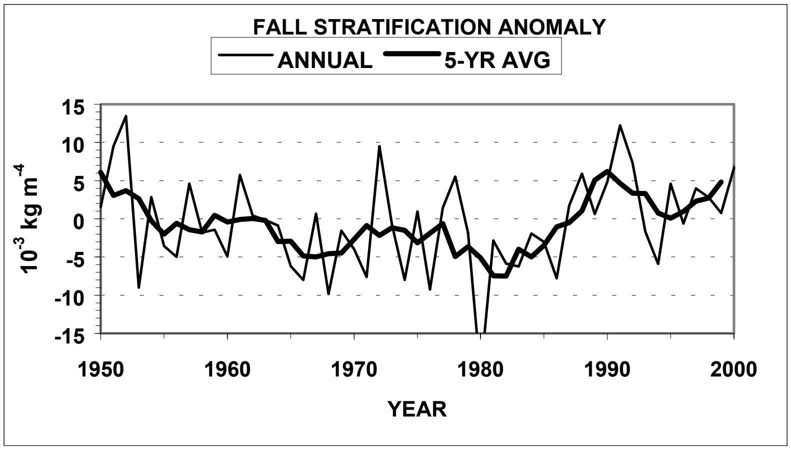

Fig. 11 Fall stratification anomaly

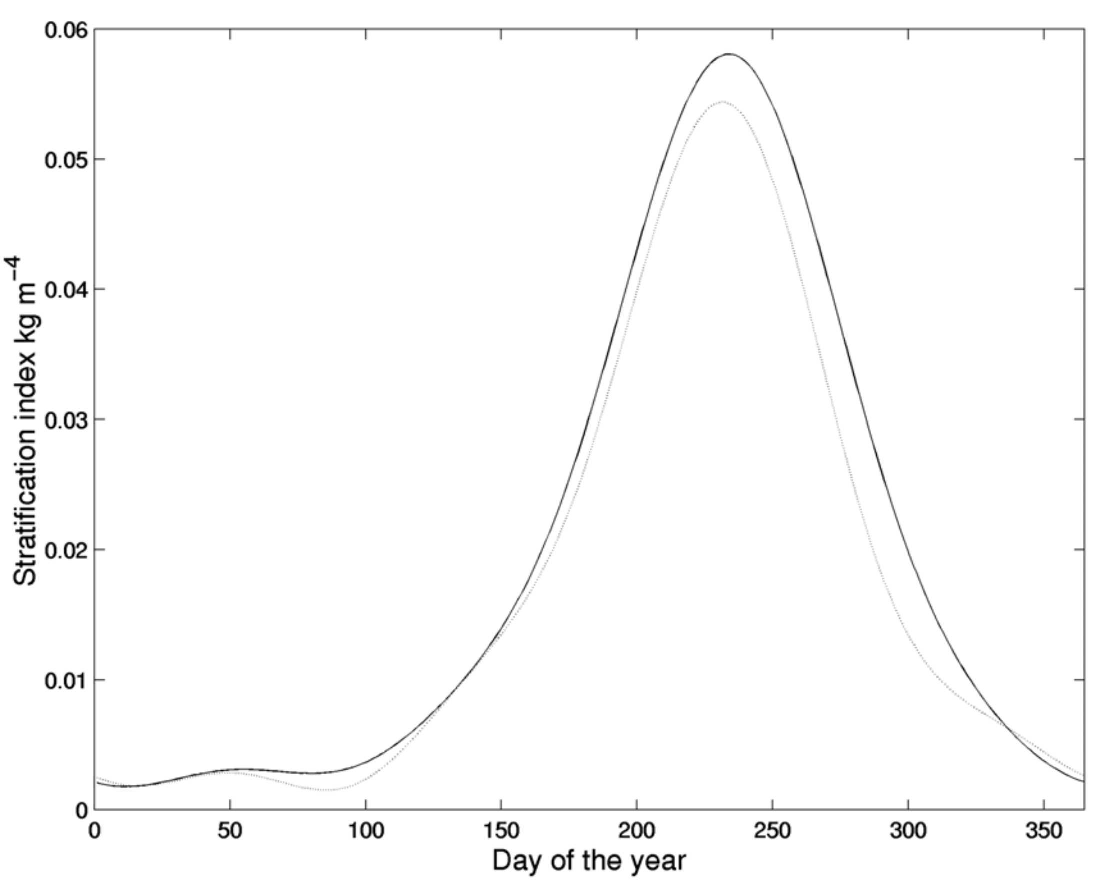

Fig. 12 Comparison of annual signals derived from the 1961-1990 (dotted line) and the 1971-2000 (solid line) standard reference periods.

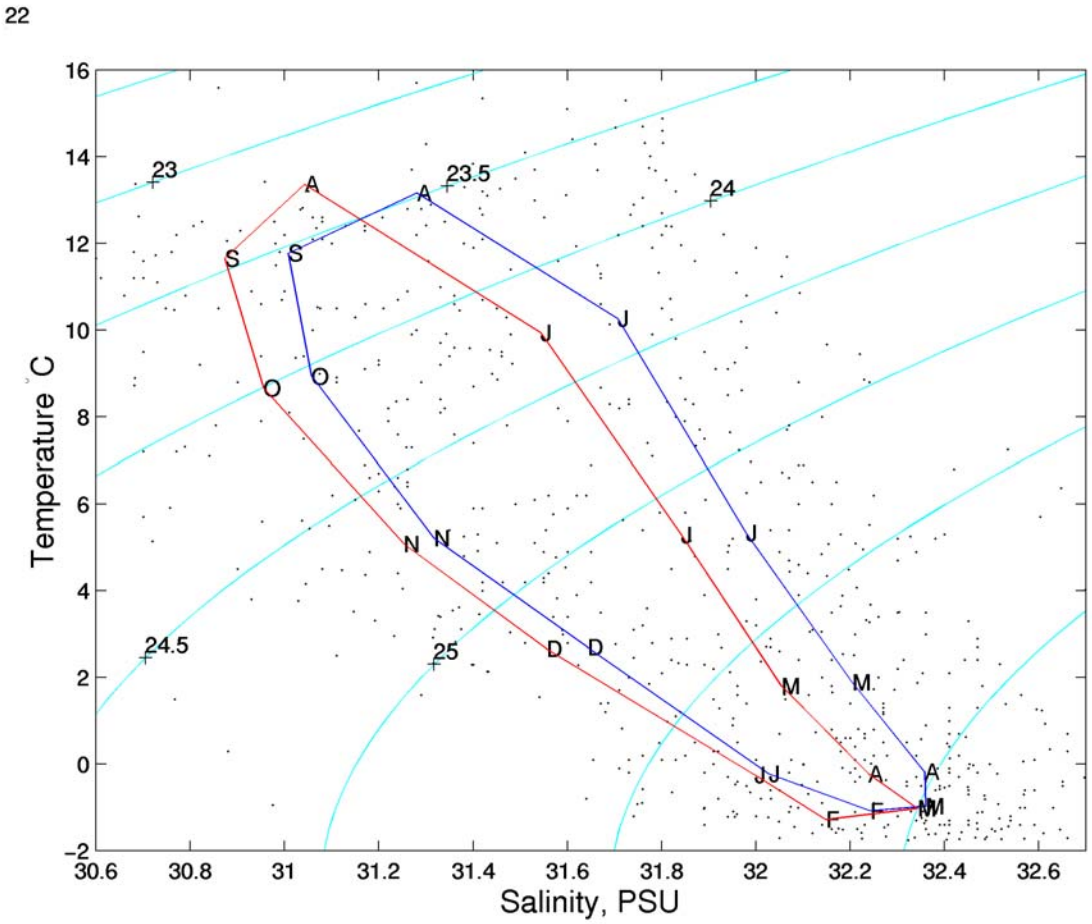

Fig. 13 Annual cycles for the surface water at Station 27 for the 1971-2000 (left) and 1961-1990 reference periods.

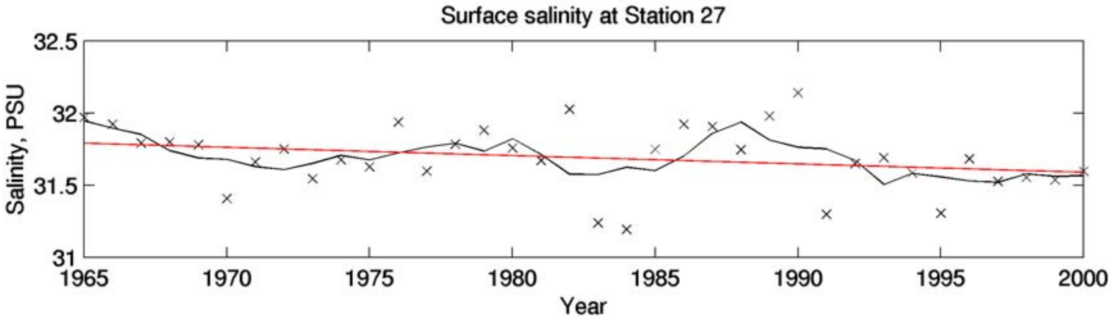

Fig 14 Long term trend in salinity at Station 27. The decline was 57.6 ppm/decade or about 0.18%/decade.