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Regional Differences in Water Types on the Flemish Cap

by

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Introduction

The Flemish Cap Project was conceived in May 1977 to study the survival of fish species living on and around the Flemish Cap. One of the attractions of working in this area was that the cod caught on the Cap are of one species, distinguishable from stocks on the Grand Banks. Because of this, there appeared to be a reasonable opportunity to isolate factors influencing this stock. Three problems were identified which were to be considered. One of these was to understand "... the effect of water circulation patterns ... on the retention and survival of fish larvae on the Flemish Cap" (ICNAF Redbook, 1977, pg. 83). In an attempt to answer not only this question but others, a vigorous program of measurement of temperature and salinity has been carried out since 1978. Coupled with these have been numerous biological and fisheries observations with the hope that these will cast some light on the aforementioned problems. To date, the available data have been used in only simple ways (Akenhead, 1981). Results have not shown clear correlations between biological and physical observations.

The design of the biological sampling program and subsequent data analyses have been based largely on intuitive feelings that there are regional differences in the characteristics of the waters on and around the Cap. This is rooted in the knowledge that the cold, fresher waters of the Labrador Current influence the northwestern area of the Cap and that the warmer, saltier waters of the North Atlantic Current affect the southern and eastern areas. It seems to be felt that the mixing of these waters on the Cap can give rise to regional differences in the properties of the waters on the Cap. Given this mixture of waters, it is thought that this may have some effect on the survival of fish stocks.

There are a number of questions to be asked before answers are to be found. Of fundamental importance is to determine if there are any identifiable regional differences in water characteristics. The mixing of cold, fresh and warm, salty water may primarily occur elsewhere, and therefore the waters on the Cap would be basically uniform. If this is true, other factors, such as aperiodic intrusions of either cold or warm water, may be the important physical processes affecting fish survival. This report is concerned with trying to identify regional differences in the temperature and salinity (T-S) properties of the water on and around the Flemish Cap.

Data Analyses

There has been a substantial amount of data collected from the area of the Flemish Cap in the last few decades. A large portion of these reside in the archives of the Marine Environmental Data Service in Ottawa, Canada. In the area bounded by 46° to 49° N and 43° to 47° W, there are over 3,300 bottle stations in the archive. Since it is differences in water type which is of interest here, it is important to have both temperature and salinity data, and hence only these bottle data have been used in the analyses presented here. These data have been collected over some 70 years, but by far the bulk of the observations occurred in the last 30 years.

The identification of regional water types over the Flemish Cap is not a trivial problem. A manual scrutiny of the data presented on T-S diagrams forces one to partition the graph into water types. This can be done, but may not allow subtle differences to be discerned because of the difficulty in setting partitions. Besides, a manual scrutiny is difficult with such large amounts of data.

There is an alternate way to approach this problem. Initially, it does not matter what the difference is between water types regionally, as long as it is distinguishable. With this in mind, it is not necessary to arbitrarily partition a T-S graph. Instead, automated procedures based on empirical orthogonal functions and cluster analyses can be used.

The use of empirical orthogonal functions to classify data has been presented by Keeley (1980). In brief, it works as follows. The set of T-S profile data is analyzed using eigenfunction analysis techniques. The eigenfunctions or empirical orthogonal functions (EOF's) are ordered from largest to smallest on the precent of the variance in the data for which each accounts. Then, the EOF's are used as a basis set of vectors, and each profile is written as the linear combinations of EOF's. This process calculates coefficients corresponding to each EOF for each profile. This is the point at which the cluster analysis program takes over. The cluster program is supplied with all of the coefficients for every profile, but for one EOF at a time. Each coefficient is assigned to the closest cluster centre based on its Euclidean distance. The analysis proceeds, starting with many centres and sequentially reducing the numbers of centers, one at a time. After each reduction, an F-test based on the increased variance gives the significance of the reduction. Based on this F-test and a choice of the level of significance, the best choice of the number of clusters can be made.

Once the number of clusters is established, it is possible to display the geographic distribution of the members of each cluster. A scrutiny of these distributions can reveal the regional differences. The physical significance of differences in coefficients of the different EOF's can only be gained by examining the EOF's to determine what aspect of the profile each can be identified with. For example, the first EOF, the one which accounts for the largest fraction of the variance, represents the mean profile. Initially, large regional differences will show up in the coefficients of the first EOF, since these are differences from the mean.

Results

The analyses were conducted first on data acquired in April of any year. For this month, there are 697 stations for which EOF coefficients are calculated. As stated previously, the statistical basis for choosing the most appropriate number of clusters is the F-test. But, to aid the interpretation, histograms showing the distributions of the coefficients of temperature and salinity were also displayed. For the April data, two clusters were found at the 96% confidence level. When these are displayed geographically, the clusters separate into waters of the Flemish Pass area and the rest of the region. This is shown in figures 1a and 1b, where "x" indicates the position of a station and the "." show the approximate bathymetry of the region. That the data should split into two clusters is not surprising, since it confirms the knowledge of the water types around the Cap. An examination of the histograms of the coefficients shows that the two water types separate out based on differences in temperature alone.

There is more that can be done, however. If it is acceptable to allow a confidence level of only 78%, then there are six clusters which are present. At this level, there is about a 1-in-5 chance that the clusters are not significant. A display of the geographic distributions of these shows some interesting results. Figure 2 shows a schematic of the regional division of the six clusters with the numbers of stations in each. Cluster number 6 is not well defined by only 10 points, but there are reasons to believe it is distinct.

Figure 3 shows a plot of the coefficients of temperature and salinity for the centres of each cluster. The three extremes are clusters 1, 4 and 6. Clusters 4 and 6 appear to correspond to Labrador Current and Atlantic water respectively. Cluster 1 has the freshness of the Labrador Current but the temperatures of the Atlantic water. Water types 2, 3 and 5 would appear to be mixtures of the three extremes. Of particular interest is cluster 5 because, although it shows up as a separate cluster, types 1, 2, 3 and 4 all have members in the region occupied by type 5. This would suggest that the location describing type 5 is either a region where mixing occurs or at least that the boundaries between the other water types fluctuate through this region. Another interesting aspect is that type 3 water appears to extend off the top of the Cap to the west. Finally, to be noted is that both the northern boundaries of type 1 and type 4 water are not defined.

The temperature and salinity coefficients of figure 3 reflect the typing of water in that large values correspond to higher temperatures of salinities and vice versa. It would be desirable to reconstruct T-S profiles for each of these water types. While normalized T-S curves are available for each water type, the necessary scaling factors of the average means and variances of members in each cluster are not.

It is possible to look at other months to see if this pattern is maintained. March was the next month considered, but there are only 176 stations to deal with. Just as for April, two clusters give the highest confidence level, but this time only at 91%. The definition of four clusters at the 89% confidence level is marginal because of only a few points in each. Water types 2, 3 and 4 do show fairly clearly. Again, there is overlap in the region where type 5 water appears in April, but neither types 5, 1 nor 6 show up in March. The fourth cluster of March is not identifiable with any of April.

The month of May provides 706 stations with the highest confidence level of 89% coinciding with 6 clusters. All of these show the same geographical distribution as those for April, with cluster 5 appearing to extend a little further west into the region of the Flemish Pass. As for April, cluster 6 is defined by only a few stations but is well separable on a plot of coefficients of temperature and salinity.

Summary

Making use of techniques of empirical orthogonal function and cluster analyses, it is possible to discern regional differences in water types in the region of the Flemish Cap. The data from the months of April and May suggest six different regions of the Cap, with about an 85% probability that these regions are different statistically. In particular, one of these regions, directly west of the Cap and east of the Flemish Pass, would appear to be a region of mixed water types.

References

1. Akenhead, S.A. "Local Sea-surface Temperature and Salinity on Flemish Cap." NAFO SCR DOC 81/IX/120.

2. Keeley, J.R. "The Use of Empirical Orthogonal Functions for Checking Data Quality; A Simple Case." Marine Environmental Data Service, Technical Note No. 34, October, 1980 (MEDS 8000904JE).

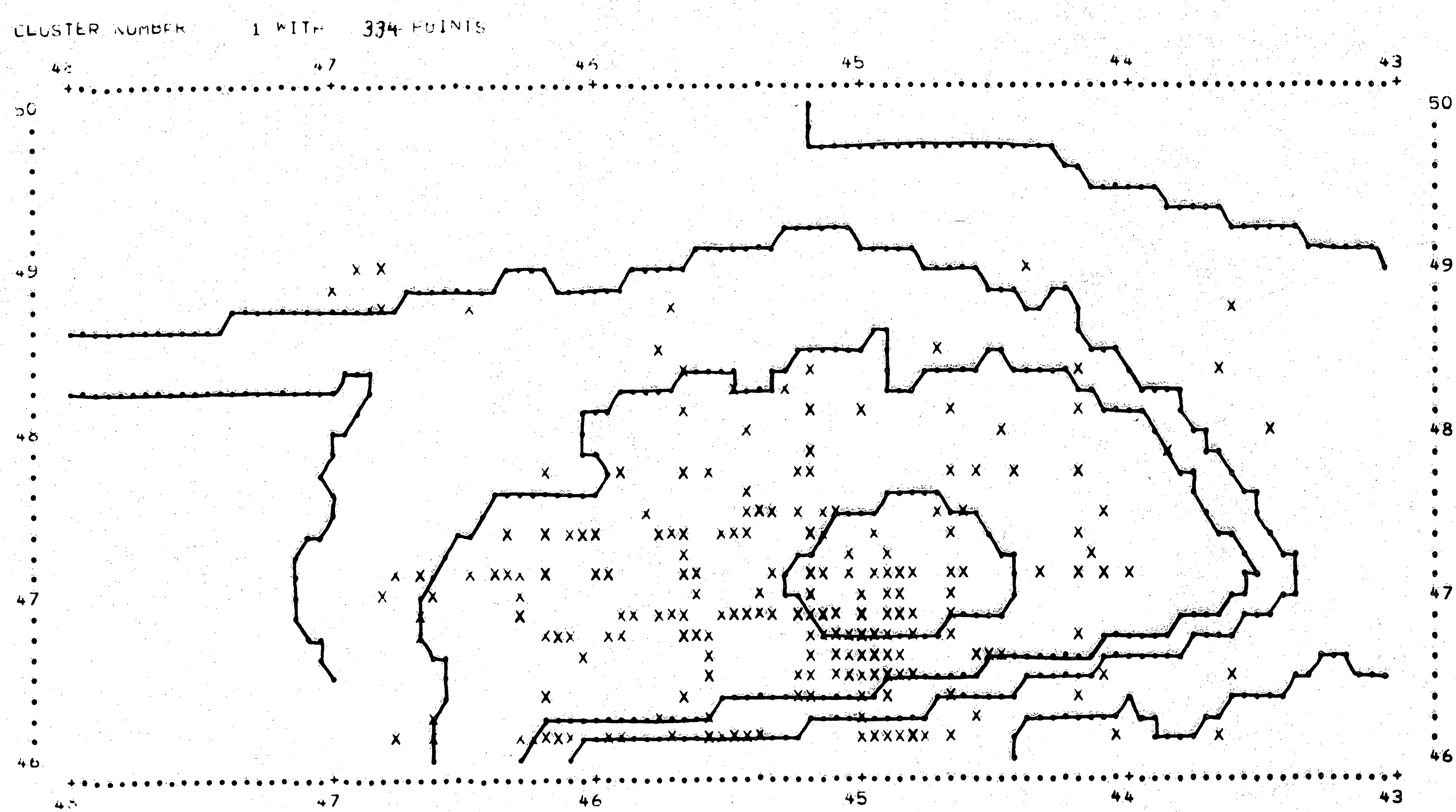

Figure 1a: The geographic distribution of the members of cluster 1 in April.

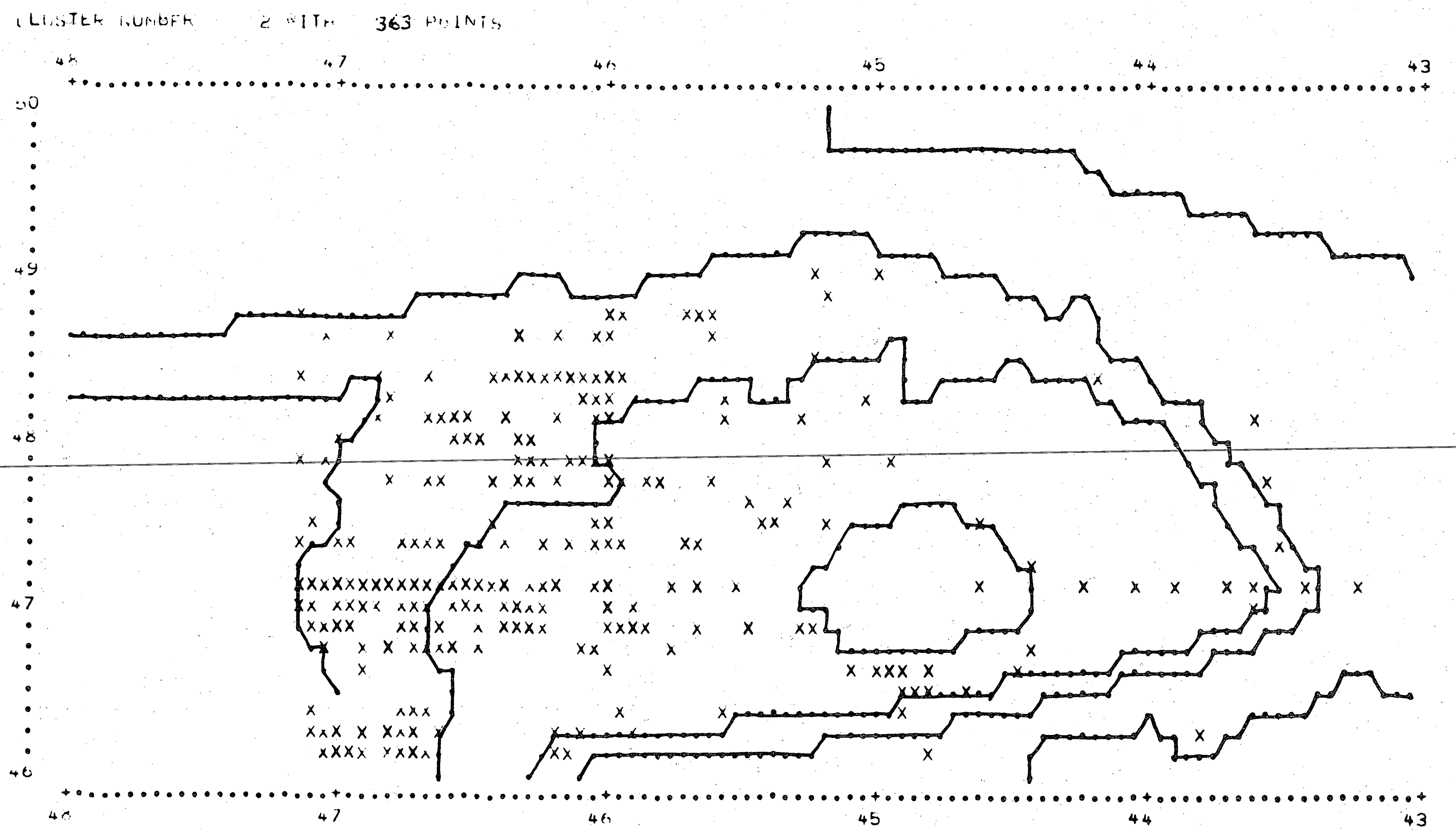

Figure 1b: The geographic distribution of the members of cluster 2 in April.

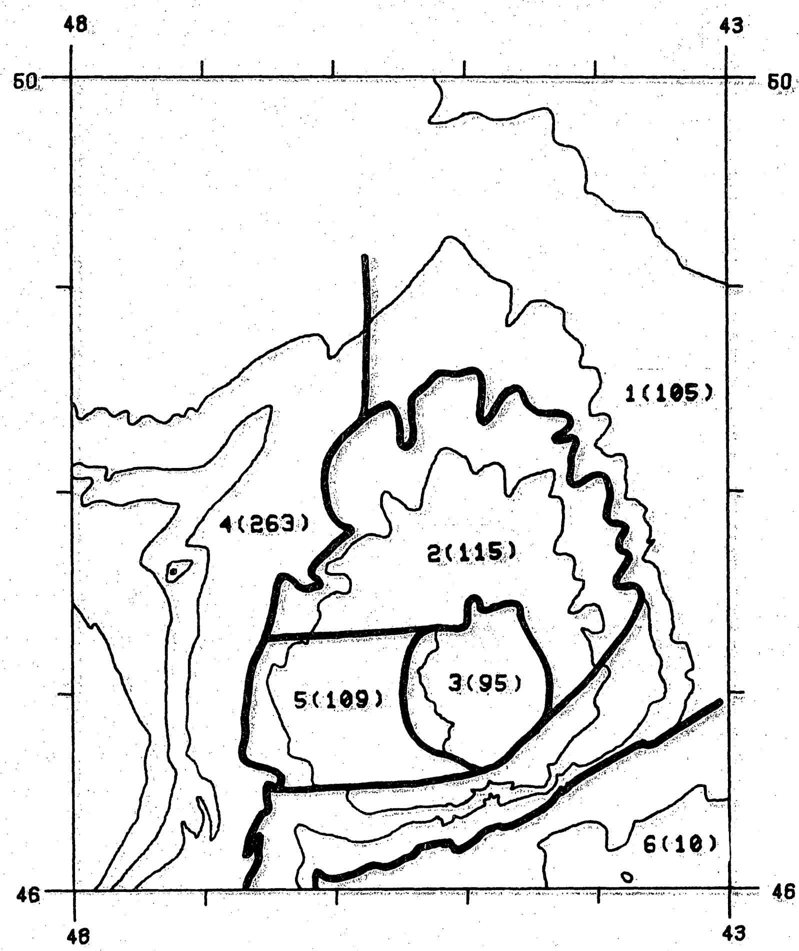

Figure 2: Schematic of the geographic distribution of clusters with numbers of members in brackets.

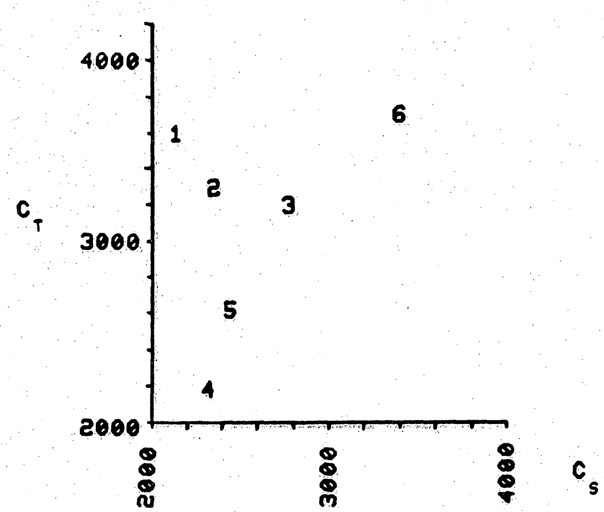

Figure 3: Clusters characterized by their mean temperature and salinity coefficients.