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Frontal Oscillations on the NE Newfoundland Shelf

by

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Abstract

An examination of the temperature and current measurements from the NE Newfoundland Shelf indicates significant frontal variability at 7 day period during the months of June - September, 1989. These oscillations are found to be non-locally generated, and are coherent with oscillations in the inshore branch of the Labrador Current off Hamilton Bank and Cape Bonavista. Significant variability in the position of the shelf water/slope water front in the Bonavista area is also found between years and within the same year. Time series measurements also indicated that the transition from winter to summer conditions in the inshore region may be occuring during late July to early August. This may have a significant effect on the analysis of interannual variability based on NAFO transect data.

1. Introduction

A dominant oceanographic feature on the Newfoundland and Labrador Shelves (Fig. 1) is the shelf edge temperature/salinity/density front, separating the colder and fresher shelf waters from the warmer and saltier Labrador Sea waters (Fig. 2). The location of this front in relation to the slope region, its strength as characterised by the cross-isopycnal gradients, and the slope of the front vary both spatially and temporally. Inshore of this front, a subsurface layer of water at subzero temperatures, referred to as the Cold Intermediate Layer (CIL), is found during the summer and fall seasons.

The seasonal variability in the T/S properties on the continental shelf results from a combination of horizontal and vertical mixing processes (Lazier, 1987). The winter storms induce vigorous mixing on the shelf to generate a thick near uniform water mass in the upper layers of the water column. In March 1988 on the NE Newfoundland Shelf, Fissel et al. (1989) found the layer to be approximately 90 m thick at -1.75°C and a salinity of 33.4 psu; in 1989, when the winter was more severe, the mixed layer extended to the bottom. Ice-melt and surface mixing increase the surface stratification isolating the intermediate depth waters, which remain cold throughout the summer. As the surface layer is cooled in the autumn, upper layer density is increased enabling the shelf slope front to surface.

Variability at weather-band frequencies was also found to be significant on the Newfoundland/Labrador Shelves. LeBlond (1982) reported satellite observations of the ice edge undulations off Labrador, with an estimated wavelength of 49 km and a time scale of 4.4 days for the Hamilton Bank region. A comprehensive analysis of current measurements from the Labrador Shelf by Narayanan et al. (1990) highlighted the spatial differences in the response characteristics of the Labrador Shelf to wind forcing. They found that the current variability on the banks of the Shelf was dominated by 2.8 - 5.6 day (0.18 - 0.36 cpd, band 2) oscillations whereas in the marginal trough where the inshore branch of the Labrador Current is located, most of the variability was within 5.6 - 11.1 day (0.09 - 0.18 cpd, band 1) period; in the slope region, variance in these two bands were comparable. Further south on the Grand Bank, Mountain (1980) noted that the weather-band variability in the Labrador Current off the southeastern edge was domianted by an 8-12 day period oscillation that is coherent with local wind stress, followed by a second one at 4-6 day period.

The primary purpose of this paper is to examine the current and temperature variability at the edge of the NE Newfoundland Shelf and relate it to the variability observed in the inshore region, and in the marginal trough and on the slope off Hamilton Bank. The analysis will be restricted to bands 1 and 2 mentioned above. The principal kinematic structures within the data are examined using an empirical orthogonal function (EOF) analysis in the frequency domain. We also examine the time of occurence of the winter to summer transition in the water column on the NE Newfoundland Shelf and its effects on the analysis of interannual variability based on NAFO transects. Since exploratory analysis of the fish catch data and the water temperatures has indicated a positive relationship between the inshore catch and the temperature within the CIL (Lear et al., 1986), the evolution of the CIL during the summer months is of great interest.

2. Data Analysis

2.1 Time series

The current meter and thermistor chain data examined in this study were obtained from four moorings, two on the NE Newfoundland Shelf and two on Hamilton Bank (Fig. 1, Table 1); the Hamilton Bank moorings were part of the Labrador Current variability study by the Bedford Institute of Oceanography (Lazier, personnel communication). The wind data used in this analysis were collected from a coastal station at Cape Bonavista by the Atmospheric Environment Service. Both the wind and the current velocity vectors were decomposed into alongshore and onshore components; at BB1 and BB2 on the NE Newfoundland Shelf, and for the winds, alongshore and onshore directions are southward and westward respectively whereas at H1 and H2, these are 131° True and 221° True. Prior to the analysis and presentation in this paper all time series were low-pass filtered using a filter with a half-amplitude frequency of 0.72 cpd, to remove the subdiurnal components of the signal. The time series were also high-pass filtered prior to EOF analysis using the same type of filter but with a half-amplitude frequency of 0.11 cpd, thus we focus on weatherband frequencies.

The low-pass filtered time series of the velocity components are compared to the thermistor chain data in Fig. 3 to demonstrate the presence of frontal oscillations on the NE Newfoundland Shelf; wind data from the Cape Bonavista land station is also shown in the diagram. The contours indicate large vertical excursions of the isotherms superimposed on a slow warm-up at the intermediate layers; these excursions may be induced by the onshore-offshore movement of the front, by frontal oscillations passing over the mooring site or by instabilities in the frontal region. Four oscillations appear at the mooring during a 28 day period thus indicating an average period of approximately 7 days. Furthermore, it appears that there is some degree of correlation between the bottom currents and the shelf edge oscillations and that the onshore currents appear to lead the temperature by about 2 days; correlation with the winds is not obvious.

Superimposed on this oscillation is the seasonal warming-up of the water column. Figure 4, showing the temperatures recorded at the two Bonavista moorings indicate that the near bottom temperatures at the shelf edge more or less increased linearly with time at a rate of 0.008°C/day from June to September. At the inshore site on the other hand, the intermediate layers started warming up at about mid-August and continued to do so until the moorings were recovered. A similar pattern was indicated in the monthly means of temperature and salinity for the inshore region on the NE Newfoundland Shelf given in Drinkwater and Trites (1986) and reproduced in Fig. 5.

2.2 Power Spectra

Each of the band-pass filtered time series was Fourier transformed to estimate the power spectra and the variance in selected frequency bands, namely, bands 1 and 2 mentioned above; for the analysis, we use only the July - September data. Interestingly, the current variances in these two bands are approximately of the same magnitude at the offshore locations on the NE Newfoundland Shelf and off Hamilton Bank (Fig. 6a). However, at the inshore moorings off Bonavista and off Hamilton Inlet, variance in band 1 far exceeded that in band 2. Thus, as far as the current variance is concerned the inshore site on the NE Newfoundland Shelf resembles the marginal trough on the Labrador Shelf, whereas the offshore site resembles the slope region on the Labrador Shelf (see Narayanan et al., 1990). The variance in the temperature field at the offshore site (Fig. 6b), on the other hand, was dominated by the band 1 oscillations, whereas those at the inshore site were considerably lower in both bands (but still dominated by band 1: $2. \times 10^{-3}$ to $3. \times 10^{-4}$ $(°C)^2$, in band 1; $2. \times 10^{-4}$ to $6. \times 10^{-4}$ $(°C)^2$, in band 2.

2.3 EOF Analysis

Since the primary purpose of this paper is to examine the frontal oscillations during the summer and since band 1 variance dominated the intermediate layer temperature field, we focus our attention on this band. To examine the kinematic relationships between the temperature field, currents and the winds we apply the EOF analysis in the frequency domain (Webster and Narayanan, 1990). As was discussed in Webster and Narayanan (1990), the terms corresponding to the forcing time series in the coherence matrix, namely Bonavista winds, were multiplied by a sufficiently small factor (0.001) so that the structure of the EOF was determined by the oceanographic variables alone; the EOF phasor corresponding to the wind time series then measures that part of the wind forcing coherent with the EOF.

EOF analysis is equivalent to a series expansion using orthogonal functions so that each successive term (referred to as modes) contributes less to the total structure than the previous one. Figure 7 shows the fraction of the variance represented by the two dominant EOF modes. EOF 1 clearly represents most of the frontal variability in frequency band 1 at the offshore location on the NE Newfoundland Shelf. This mode appears to be strongly correlated with the bottom currents at this location and with the mid-depth currents at the inshore site off Cape Bonavista. Interestingly, the variance associated with this mode at the slope station on Hamilton Bank is very small whereas at the inshore location, the EOF 1 variance is about 24%. EOF 2 dominates the Hamilton Bank current variance. Even though this mode represents about 28% of the current variance at the inshore location on the NE Newfoundland Shelf, only about 15% (18%) of the current (temperature) variance at the offshore site is represented by EOF 2. Both EOF modes appear to be uncorrelated with the Bonavista winds.

Figure 8 shows the first two EOF modes represented as phasor diagrams. The length and direction of the phasor signifies the amplitude and phase of the component of each time series coherent with the EOF. The amplitudes are given in the original units for each time series and the phases are measured counterclockwise such that a positive phase angle means the corresponding component leads the reference component phasor. All temperature phasors from the thermistor chain data at BB1 fall within the shaded area in the diagram.

The statistical uncertainty in the determination of the EOF vectors, arising through uncertainty in the coherence between the component and the EOF may be estimated as in Webster and Narayanan (1990). The expected amplitude variance σ_a^2 and the expected phase variance σ_p^2 of the coherency estimator (Jenkins and Watts, 1968) can be estimated as

$$\sigma_a^2 = (1 - C^2)^2/(2R), \quad \sigma_p^2 = 2C^2(1 - C^2)^2/R \qquad (1)$$

where C is the coherence amplitude and R is the number of frequency bands used for band averaging (R = 6 for band 1). A measure of the uncertainty would be a circle of radius $\Delta = [(\sigma_a^2 + \sigma_p^2)/2]^{1/2}$ L about the head of the phasor, where L is the length of the phasor (see Fig. 8).

If the frontal oscillations represent a balance between onshore advection of heat and temperature increase, then the onshore current is expected to lead the temperature signal by 90°. The EOF 1 phasor diagram shows that the phase difference between the bottom onshore currents at BB1 and the intermediate depth temperature field ranged between 115° (at 94 m) and 95° (at 170 m). Since the error estimates associated with the EOF 1 phases lie within 10° - 15°, it is reasonable to conclude that the onshore currents lead the temperature by approximately 90°. The phasors also indicate that the currents at the shelf edge lead those near the coast by 58° and 90° for the onshore and alongshore components respectively. As was expected, the portion of the currents coherent with this EOF at H1 is very small, perhaps due to the fact that the offshore mooring was placed along 1000m isobath, far offshore of the front. The alongshore component at H2, on the other hand is almost in phase with that at BB1 in spite of the station separation. This will be reasonable if the shelf edge oscillations on Hamilton Bank lead those near the coast as was the case on the NE Newfoundland Shelf.

EOF mode 2 represents the current oscillations at H1, offshore of Hamilton Bank, and a significant portion of the alongshore currents at H2. Furthermore, the EOF amplitudes corresponding to the velocities appear to decrease with depth. On the NE Newfoundland Shelf, the currents at the inshore site are partially represented by EOF 2 whereas only a small portion of the variability (approximately 18%) was represented by this mode at BB1.

3. Discussion

The time series measurements taken from the NE Newfoundland Shelf clearly indicate significant frontal oscillations at approximately 7 days periods. These oscillations were correlated with currents in the inshore region of the Shelf, but not with local winds. Since, these oscillations were also correlated with the currents in the inshore branch of the Labrador Current off Hamilton Bank, these may have been generated on the Labrador Shelf. Ou (1984), using a two-dimensional model has shown that significant frontal oscillations can be generated by winds that force surface waters in the frontal region to move offshore; thus strong frontal oscillations correspond to deep onshore flow. The measurements concur with Ou's findings.

The temperature oscillations on the NE Newfoundland Shelf edge appear to be poorly correlated with currents offshore of Hamilton Bank. Since Ou's model indicates that these oscillations are more or less confined to the frontal region, if Station H1 was located far offshore of the front on Hamilton Bank and in much deeper waters, then the strength of these oscillations measured by the current meters will be small. Unfortunately, the Seal Island NAFO CTD Transect could not be occupied in 1989 because of logistical problems; hence the location of the front is not known in 1989. However, T/S data collected in 1988 (Fig. 2) indicate that the front on Hamilton Bank was located between 200 m and 300 m isobaths, suggesting that H1 mooring may be approximately 100 km offshore of the frontal region. This conclusion is also in agreement with the average frontal location for July estimated from all available archived data by Petrie et al. (1988). Furthermore, LeBlond(1982) estimated, based on an analysis of satellite imagery, that the onshore-offshore meander amplitudes of the front (characterised by the ice-edge in the imagery) was less than 50 km off Hamilton Bank. Thus it may be reasonable to conclude that the currents at H1 may not be influenced significantly by the frontal oscillations.

The frontal zone on the NE Newfoundland Shelf appears to have significant spatial variability. Along the White Bay transect in July (Fig. 2), the offshore temperature gradient at 150 meter depth was approximately 0.1°C/km, whereas along the Bonavista transect, the gradient was only 0.05°C/km. Furthermore, the 3°C isotherm (representing the offshore edge of the frontal zone) was located at the shelf slope off White Bay, while the corresponding one off Bonavista was more than 50 km inshore from the slope region. To verify whether the location of the front in July, relative to the slope off Bonavista varies from one year to the next, the historical July temperature data set from the Bonavista Transect was examined. Results from this analysis indicated that the position of the 3°C isotherm varies significantly from one year to another. For example, in 1965, the anchor location of this isotherm was 125 km inshore of the slope whereas in 1985, it was right at the slope; at 200 m depth, the position of the 3°C isotherm was located at approximately 80 km inshore of the shelf edge in 1965, and at 50 km offshore of the shelf edge in 1985. Since the

NAFO transects are occupied only once-a-year (in July/August) and more or less during the time period when the water temperature starts to increase on the shelf, it is difficult to estimate the extent of bias in the data, and thus the interannual variability in the front's position.

4. Summary

In this study, time series of temperature and currents from the edge of the NE Newfoundland Shelf were analysed to examine frontal oscillations during summer period. The principal results of this study are as follows:

1. Strong frontal oscillations at 7 day periods occur along the shelf edge off Bonavista during the summer. The oscillations recorded in 1989 data appeared to have propagated into the region from the Labrador Shelf. The forcing that generated these on the Labrador Shelf appears to have generated oscillations in the inshore branch of the Labrador Current off Hamilton Bank which propagated into the near shore region off Bonavista.

2. The warming of the intermediate depth waters on the NE Newfoundland Shelf appeared to commence in late July to early August. Since the annual occupation of the NAFO lines falls during this time slot, the NAFO CTD data may be significantly aliased.

3. The position of the thermal front off Bonavista appeared to shift significantly from year to year and seasonally; in some years the bottom layers of the outer half of the shelf may be warmer than 3°C.

Acknowledgements

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Table 1. Data Summary

Station	Water Depth m	Sensor Depth m	Data Type
BB1	343	316	Currents, T
		94 - 170	11 T time series at approx. 7 m intervals
BB2	233	70	Currents, T
		86 - 186	11 T time series at approx. 10 m intervals
H1	1000	200	Currents, T, S
		400	Currents, T, S
		986	T
H2	192	190	Currents, T, S

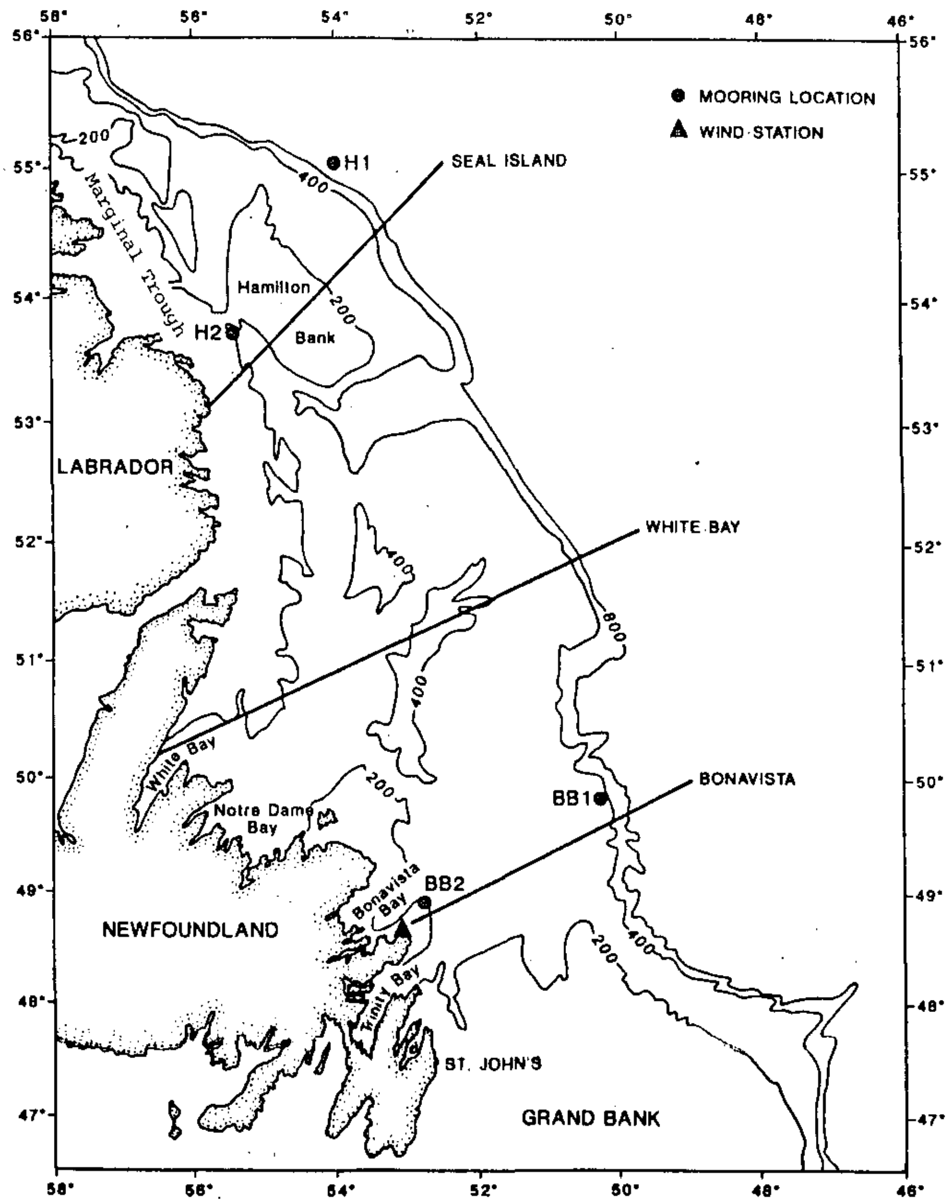

Figure 1. Area map showing measurement locations.

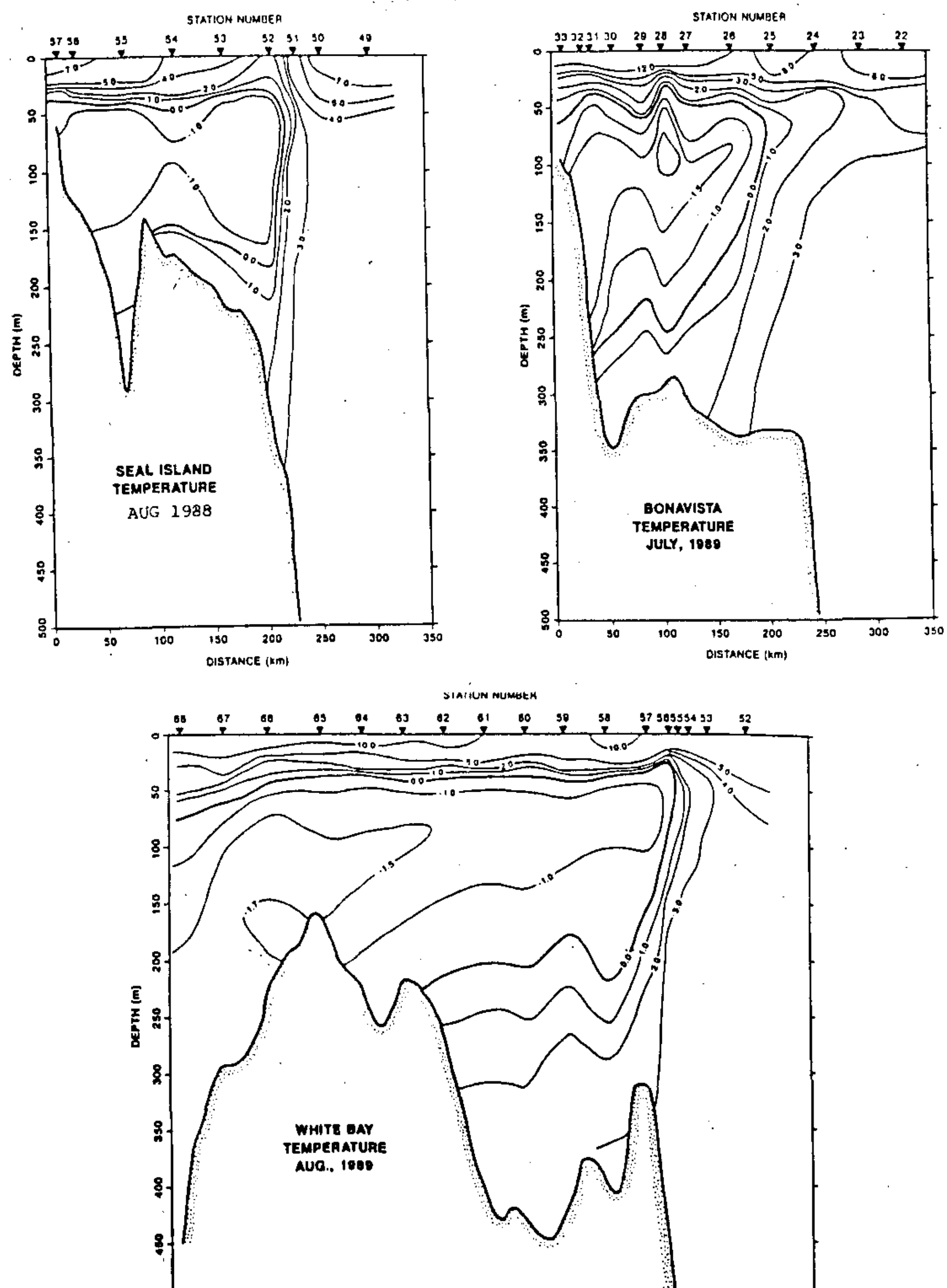

Figure 2. Temperature transects from the NAFO lines, Seal Island, White Bay and Bonavista.

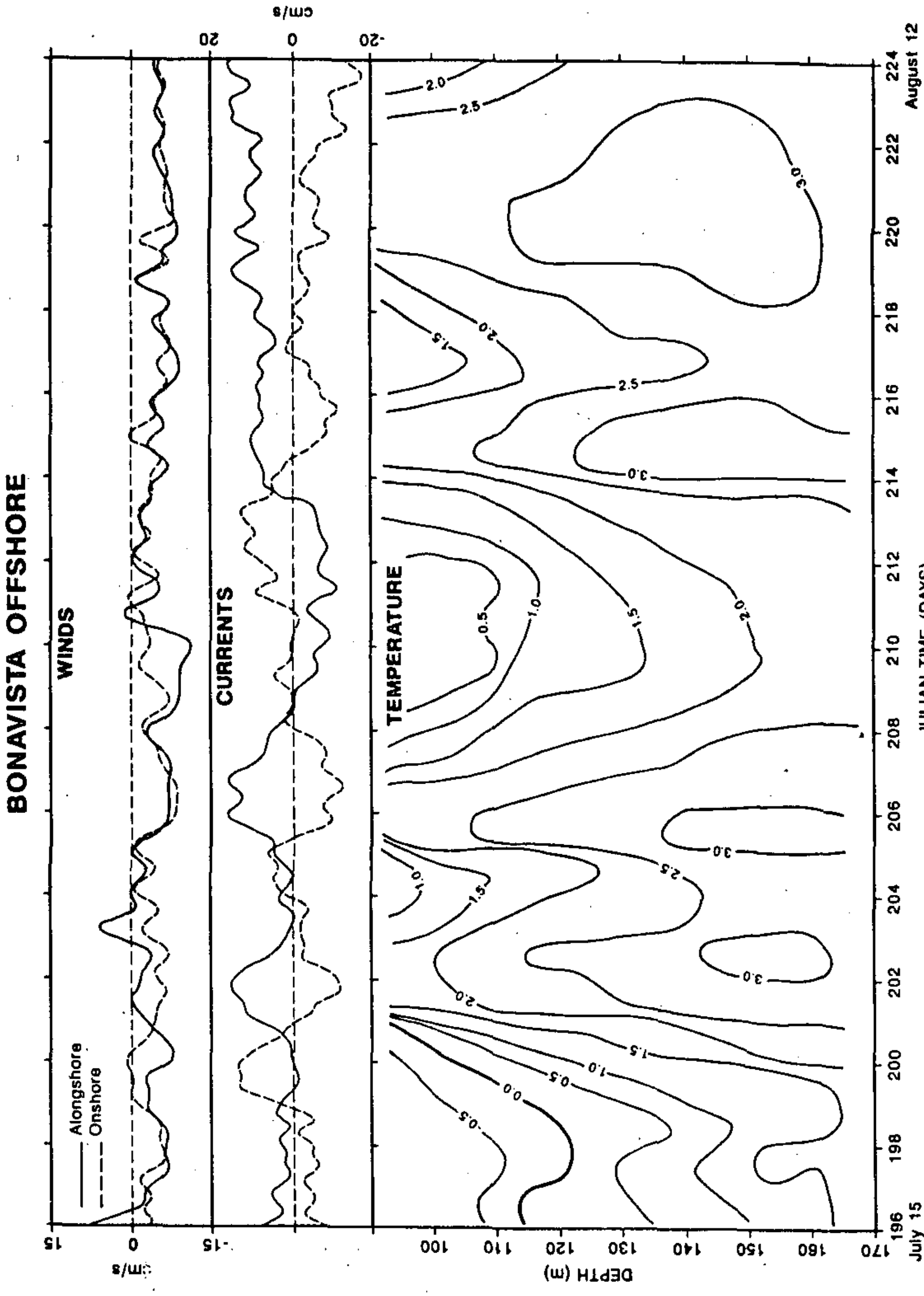

Figure 3. A comparison of shelf-edge temperature oscillations with currents and winds.

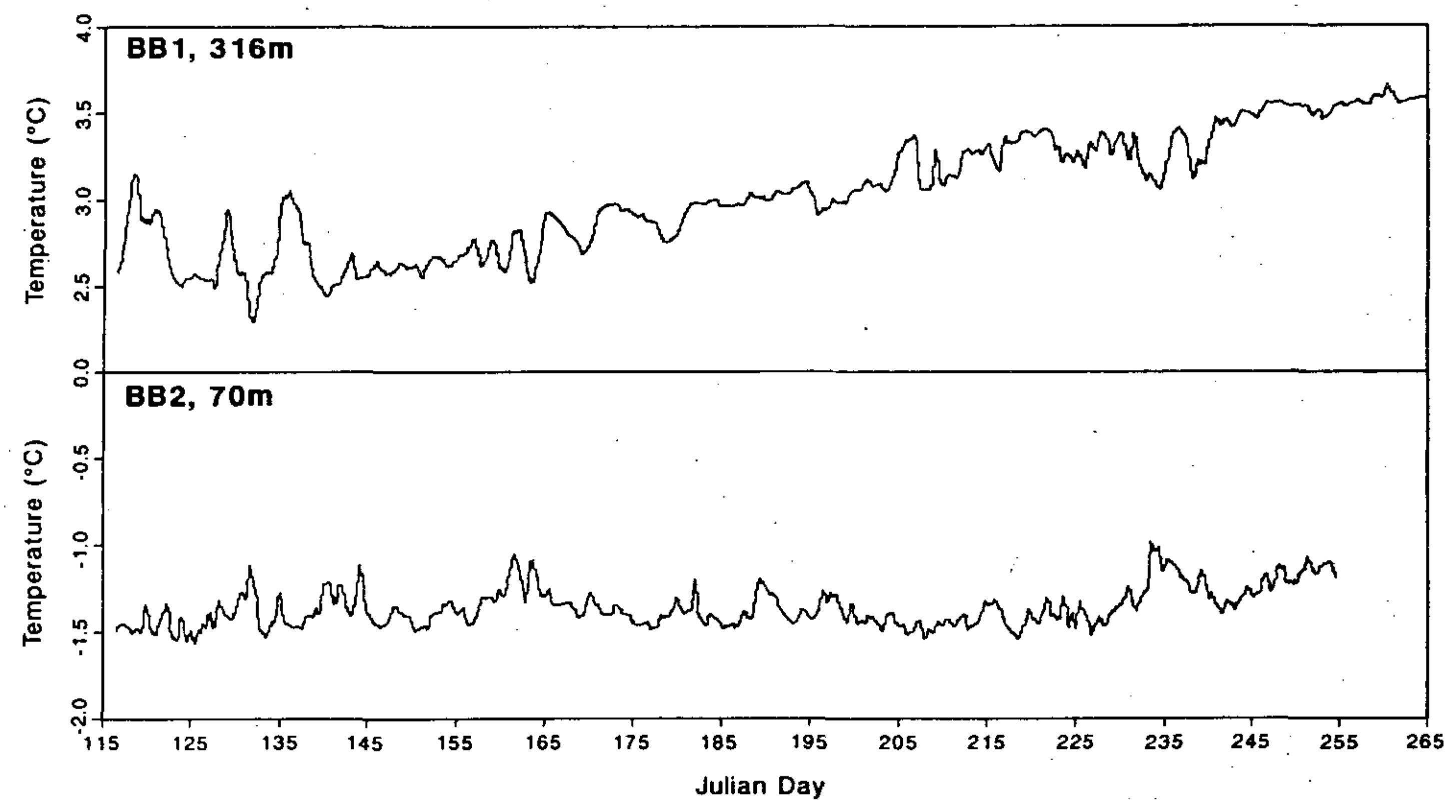

Figure 4. Comparison of shelf-edge bottom temperature with near shore intermediate depth temperature.

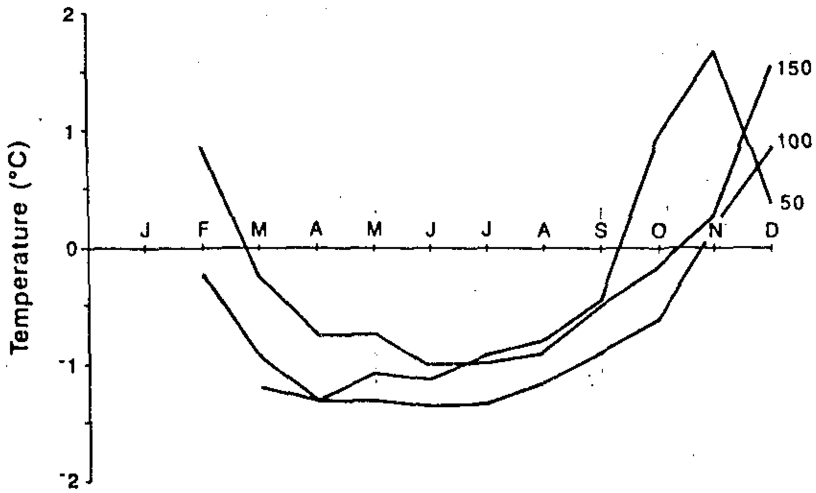

Figure 5. Monthly means of temperature at selected depths in the inshore region (area 1 in Drinkwater and Trites, 1986).

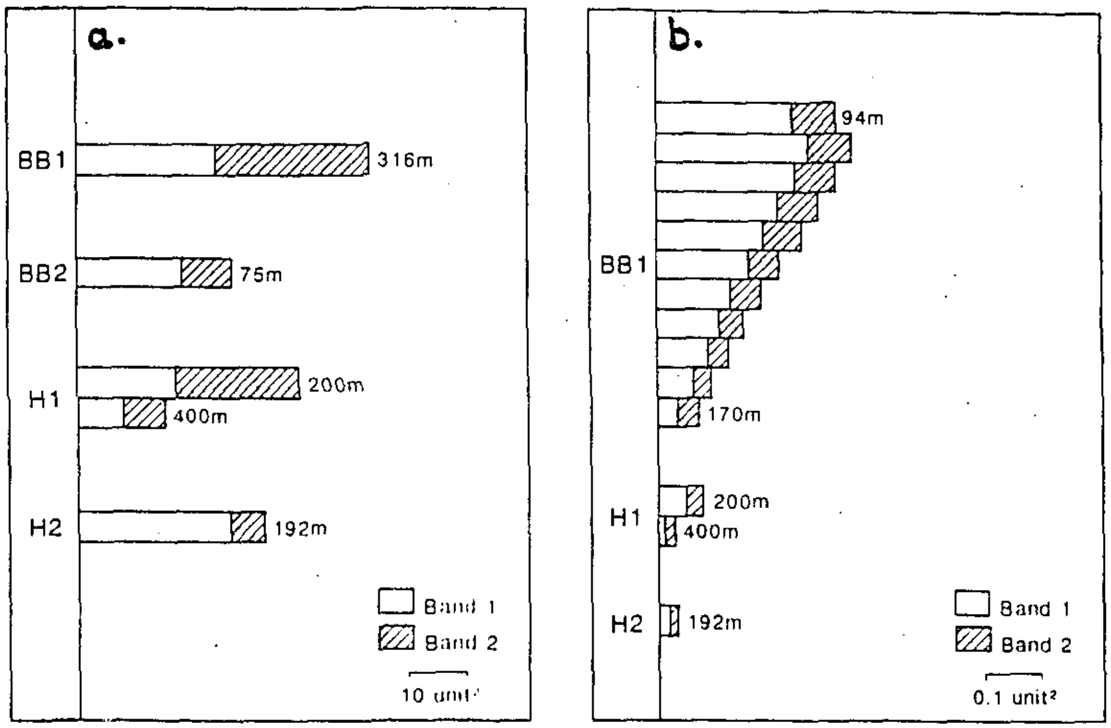

Figure 6. Variances in bands 1 and 2 of: a) currents, b) temperature.

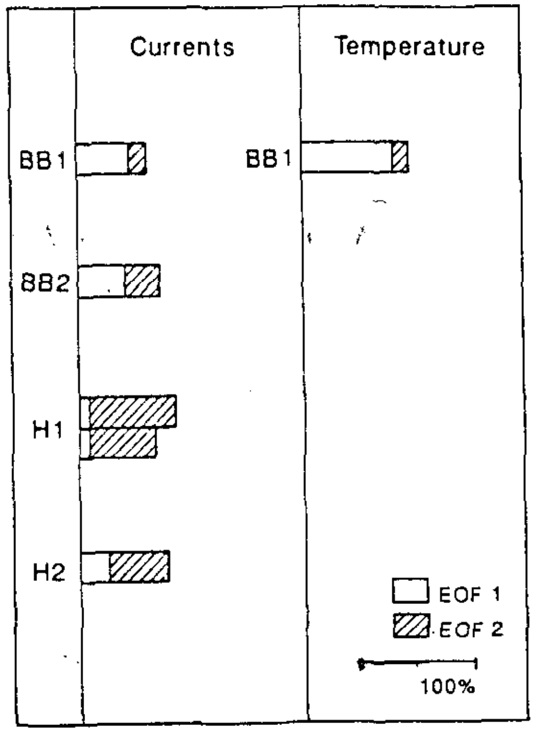

Figure 7. Fraction of variance represented by EOF modes 1 and 2. Temperature variance is the average of the 11 thermistor time series.

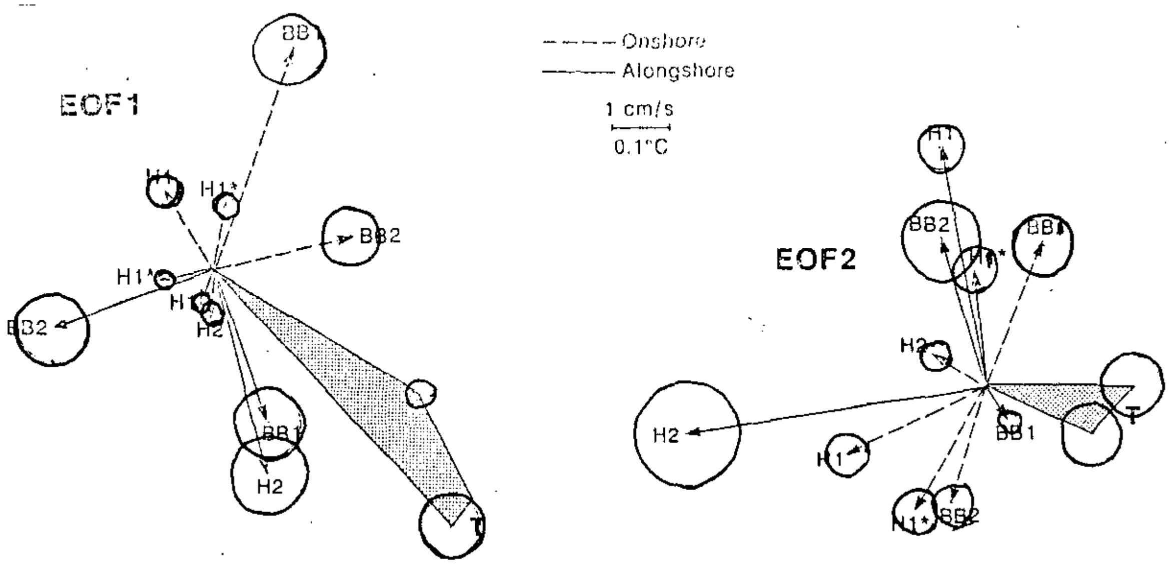

Figure 8. Temperature and current phasors corresponding to EOF modes 1 and 2. The circles are of radius Δ.