COMPLEX EMPIRICAL ORTHOGONAL FUNCTION (CEOF) ANALYSIS OF THE HYDROGRAPHY ALONG THE SEWARD LINE FROM 1997 TO 2001: PRELIMINARY RESULTS

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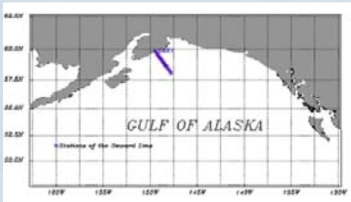

Fig. 1: Map of the Northern Gulf of Alaska showing the Seward Line of hydrographic stations.

INTRODUCTION

Complex Empirical Orthogonal Function (CEOF) Analysis of GLOBEC hydrographic data on 21 cruises along the Seward Line (Fig. 1) from October 1997 to April 2001 has been used for the detection and assessment of the relative magnitudes of stationary and propagating modes on the Alaskan shelf. The data have been interpolated to 33 uniform temporal grids. The interpolated time series are from January 1998 to February 2001, with 10 points for each annual cycle. All the stations of the Seward Line have not been sampled for every cruise. Only stations GAK 1 to GAK 13 have been retained for these analyses. The intermediate stations (1i, 2i, etc.) and GAK 14, GAK 15 have been discarded. The analyses have been performed at the selected depths of 0 m, 10 m, 20 m, 30 m, 50 m, 75 m, 100 m, 150 m and 200 m. For stations with bottom depths shallower than 200 m (GAK 5 and GAK 6), data have been interpolated from the nearest stations at that depth (GAK 4 and GAK 7). For the wavelet analyses, the annual signals have been removed and the data have been scaled with the standard deviation of the time series.

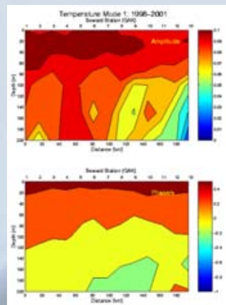

Fig. 2: Amplitude and Phase of the first spatial mode of Temperature from 1998 to 2001.

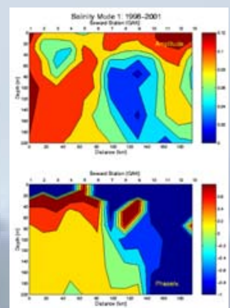

Fig. 3: Amplitude and Phase of the first spatial mode of Salinity from 1998 to 2001.

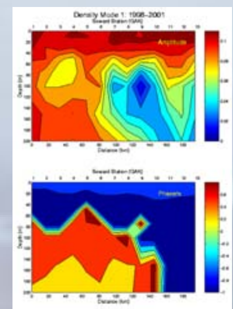

Fig. 4: Amplitude and Phase of the first spatial mode of Density from 1998 to 2001.

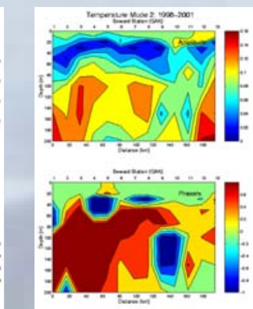

Fig. 5: Amplitude and Phase of the second spatial mode of Temperature from 1998 to 2001.

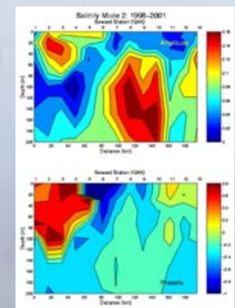

Fig. 6: Amplitude and Phase of the second spatial mode of Salinity from 1998 to 2001.

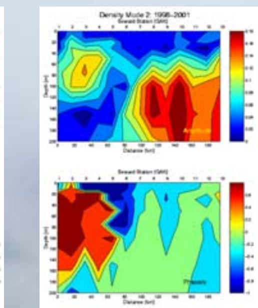

Fig. 7: Amplitude and Phase of the second spatial mode of Density from 1998 to 2001.

COMPLEX EMPIRICAL ORTHOGONAL FUNCTION ANALYSIS

We have chosen to display only the 1st and 2nd modes, which contain 35-50% of the total variance in the hydrographic signals.

SPATIAL MODES

Mode 1

This mode corresponds with the barotropic mode. Temperature mode 1 contains 37.5% of the total variance in the temperature signal. To a depth of 100 m, the amplitude (Fig. 2, top panel) varies with depth but is fairly uniform across the shelf, but deeper, the amplitude varies with both depth and offshore distance. Small amplitudes can also be seen in deep water (deeper than 100 m) off the shelf (beyond GAK 9). The phase (Fig. 2, bottom panel) is also a function of depth rather than offshore distance. Below 120 m, there is some variability across and off the shelf, with the phase at depth lagging the phase higher in the water column.

Salinity mode 1 contains 23% of the total variance in the salinity signal. As expected, there is considerable variability in amplitude with depth and with distance offshore (Fig. 3, top panel). On the outer shelf (GAK 6-10), at depths greater than 60 m, the amplitudes are very small. Over the shelf, the phase (Fig. 3, bottom panel) is a function of depth, but off the shelf (beyond GAK 9), the phase is fairly uniform with depth. The nearshore salinity variations in the upper layer, within the Alaska Coastal Current, are in phase but out of phase with the bottom water. Further offshore, the salinity variations are nearly in phase throughout the water column.
Density mode 1 (30.8% of the total variance) has a vertical gradient of amplitude(Fig. 4, top panel) that is much smaller on the inner shelf (up to GAK 6) than on the outer shelf and beyond the shelf break. Conversely, the phase structure (Fig. 4, bottom panel) has a much greater vertical gradient on the shelf (up to GAK 9) than off the shelf (beyond GAK 9). Between GAK 11 and GAK 13, the complete water column is in phase, demonstrating the influence of a deep, coherent flow - the Alaska Current.

Mode 2

Temperature mode 2 (13% of the total variance) has small amplitudes (Fig. 5, top panel) on the shelf down to 60 m depth, below which the amplitudes increase. However, at the shelf break the amplitude is low all through the water column. Farther offshore, a two-layer structure in the amplitude is seen again, with increased amplitudes below 150 m. The phase (Fig. 5, bottom panel) exhibits depth dependence on the shelf, but off the shelf, there is little phase difference with depth.

In salinity mode 2 (15.5% of the total variance), the largest amplitudes (Fig. 6, top panel) are between GAK 7 and GAK 10, from 40 m depth down to 200 m. This is possibly the boundary between the shelf waters and the Alaska Current, which switches on and off the shelf. There is also a large amplitude signal within the Alaska Coastal Current (GAK 2-3), especially at depths between 10 and 60 m. The phase (Fig. 6, bottom panel) on the outer shelf and shelf break GAK 7-10) is fairly constant. Inshore, there are two distinct layers in both amplitude and phase. The upper 120 m is out of phase with the phase in the salinity below 100 m.

Density mode 2 (15.2% of the total variance) has a two-layer structure in amplitude (Fig. 7, top panel) across the shelf. On the inner shelf (GAK 1-7), largest amplitudes are in the surface layer, to a depth of 100 m. However, beyond GAK 7, smaller amplitudes are in the surface layer to a depth of 40 m and larger amplitudes are found deeper than 60 m. Once again, the boundary between the shelf waters and the Alaska current can be seen, this time below a depth of 60 m, between GAK 7 and GAK 10. The phase (Fig. 7, bottom panel) on the inner shelf (GAK 1-6) leads the phase on the outer shelf and beyond the shelf break.

TEMPORAL MODES

Mode 1

The amplitude of the temperature (Fig. 8, top panel) is greatest in 1999. The 1st modes in salinity and density (Figs. 9 & 10, top panels) are similar in shape, although the peaks in salinity are greater. Again, the annual signal appears to be modified, especially the salinity signal in mid-1998. The calculated frequencies (d(phase)/dt) of the 1st mode of all the hydrographic parameters have a least squares fit of approximately 2 cycles per year. This suggests that the 1st mode captures the annual cycle and this is consistent with the phases of the 1st modes of the hydrographic parameters (Fig. 8, 9, & 10, second panels).

Mode 2

For all the hydrographic parameters, the 2nd mode is more intermittent (Figs. 8, 9, & 10, bottom panels). The temperature has higher amplitudes at the end of 1998 and mid-2000 (Fig. 8, third panel). Salinity has higher amplitudes (Fig. 9, third panel) in the first half of the analysis period than in the second half, reflecting an increased freshwater discharge in late 1997 and very low freshwater discharge in spring 1999. Density mode 2 has fairly uniform amplitude ranges over the period of the analysis (Fig 10, third panel).

SPECTRAL TECHNIQUES

Wavelet analysis is designed to show the frequency/period-time structure of a time series. In contrast to other spectral analysis techniques it can isolate "events" which occur over a portion of a time series by windowing the data with a set of wavelets of varying temporal width.

Figure 11 shows the wavelet spectrum of the density anomaly (trend and annual signal removed) for GAK 8 on the outer part of the shelf but inshore of the shelf break. The near surface anomalies have 30% to 40% of the total variance while at greater depths they contain about 70% of the total variance.

In Figure 11 the wavelet spectrum at the surface and at 20 m depth show a strong signal with a period of about 3.3 years; this may be an El Niño effect. At the surface there is also a weak signal with a period about 0.75 years beginning in mid 1998 and lasting about a year. At 20 m depth this signal is stronger. At 50 m this signal is stronger and another weak signal appears about mid 1999 with an apparent period of 1.5 years. At a depth of 100 m, both of these signals are stronger and the 1.5 year period signal begins earlier and lasts longer than at 50 m. The 1.5 year period signal is even stronger at 150 m but the 0.75 year period one is much weaker. Finally, at 200 m depth the signal with a 0.75 year period has almost vanished and the 1.5 year signal is slightly weaker than at a depth of 150 m.

The wavelet spectra at 50 m depth (Fig. 12) for the even numbered GAK stations have a complex set of signals. Inshore, at GAK 2 and 4, there is a 3.2 year period signal. This signal is absent from GAK 6, 8 to GAK 10, but appears strongly at GAK 12 that is well off the continental shelf. At GAK 2-6 and GAK 10 a 1.5 year signal is strong and appears to have begun prior to 1998, perhaps mid to late 1997. GAK 4 and GAK 8 have a significant 0.75 year signal which is weaker at GAK 6 and GAK 10. In contrast to the other stations, at GAK12 there is a strong signal with a period between 2.0 and 2.5 years which appears in mid to late 1998 and seems to be disappearing as of early 2001.

CONCLUSIONS

The first spatial mode represents the barotropic mode whereas the first temporal mode represents the annual cycle. For Mode 1, the temperature changes across the shelf are greatest nearshore and near to the surface but the surface heating is out of phase
with the deep temperature changes. The salinity changes are greatest nearshore and just offshore of the shelf break, reflecting the influence of the Alaska Coastal Current in both locations. The offshore influence maybe due to the bifurcation of the Alaska Coastal Current around Kayak Island. The phases of these two freshwater lenses are similar but the deep water over the shelf is out of phase with them. Similar comments, as those for salinity, hold for the density structure over the shelf. Mode 2 contains the influences of freshwater discharges, upper layer heating and upwelling processes. For Mode 2, the temperature changes are greatest at depth, both nearshore and off-shelf. The nearshore deep changes are out of phase with the surface fluctuations but the nearshore surface, offshore surface and offshore deep temperature changes are in phase. The greatest salinity changes for Mode 2 are between GAK 1-4 at the surface and GAK 6-10 at depth (near the shelfbreak). The salinity changes within the Alaska Coastal Current (upper 120 m between GAK 1-4) are out of phase with the deep waters beneath it. That is, during times of maximum runoff, the deep salinity is the greatest similar to an estuarine flow. While the upwelling processes also connect changes in the shelf deep waters with offshore influences it is uncertain as to relative strengths of the freshwater (estuarine) and wind forcing. Finally, the Alaska Current can be seen as relatively large amplitudes in salinity and density in the spatial mode 2 near the shelf break.

The technique of wavelet analysis applied to the relatively short (just over 3 years) time series of hydrographic data on the Seward line has shown the presence of a number of distinct strong transient signals, including what may be a manifestation of El Niño. The challenge required for understanding these results is to determine the physics generating these events; perhaps related to meanders of the Alaska Current and the Alaska Coastal Current.

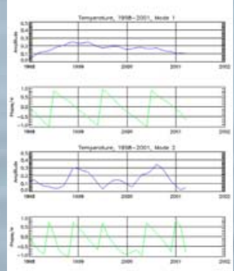

Fig. 8: Amplitude and Phase of the first and second temporal modes of Temperature from 1998 to 2001.

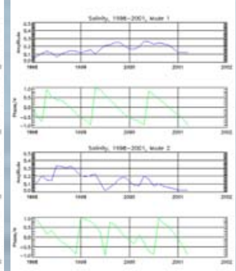

Fig. 9: Amplitude and Phase of the first and second temporal modes of Salinity from 1998 to 2001.

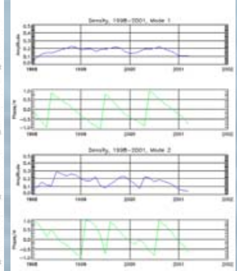

Fig. 10: Amplitude and Phase of the first and second temporal modes of Density from 1998 to 2001.

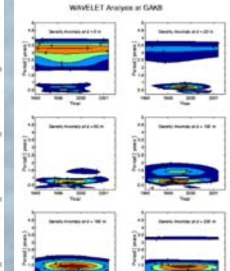

Fig. 11: Wavelet analysis of the Density Anomaly at GAK 8 at selected depths from 1998 to 2001.

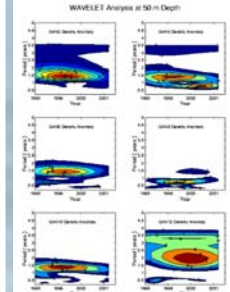

Fig. 12: Wavelet analysis of the Density anomaly at even-numbered stations of the Seward Line at a depth of 50 m, from 1998 to 2001.

REFERENCE

Torrence, C., and G. P. Compo, A Practical Guide to Wavelet Analysis, Bull. Am. Met. Soc., 79, 61-78, 1998.

ACKNOWLEDGEMENTS

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Wavelet software was provided by C. Torrence and G. Compo, and is available at url: http://paos.colorado.edu/research/wavelets/.