MODELING REPORT TO OCSEAP

by

J. A. Galt and G. Watabayashi

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratories
Pacific Marine Environmental Laboratory
3711 15th Avenue N.E.
Seattle, Washington 98105

Current address:
Hazardous Materials Response Branch (N/0MA34)
Ocean Assessments Division
Office of Oceanography and Marine Assessment
National Ocean Service, NOAA
BIN C15700
7600 Sand Point Way N.E.
Seattle, Washington 98115

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I. Introduction

Over the last year modeling experiments have been carried out for two areas of the Alaskan Outer Continental Shelf as part of the work done on RU 140. The first study area was in the vicinity of Kodiak Island; the second study area covered the Fairweather Ground region. Both of these studies made use of oceanographic data obtained in other components of the OCSEAP program and a diagnostic circulation model developed previously under RU 140.

The circulation model and its use have been described elsewhere (RU #140 - Report to OCSEAP September 1978) so a detailed description of those procedures will not be presented here. To briefly summarize the techniques for obtaining current estimates, we proceed as follows:

1) The flow is assumed to be quasi-steady;

2) The dynamics are assumed to be controlled by a combination of geostrophic and Ekman flows;

3) The geostrophic flow is separated into two components;

4) The first component is baroclinic and is forced by the internal mass distribution and, as such, requires oceanographic data. The"resolution will depend upon available station spacing and may be noisy in the sense that detailed current features may be poorly resolved or aliased;

5) The second geostrophic component is barotropic and represents the large-scale effect of wind set-up of the sea surface. This component of the flow is density independent and is assumed to be in dynamic balance with the regional wind.

6) These two components of the geostrophic flow added together with a simple non-divergent surface Ekman layer are then assumed to represent the regional surface currents.

The diagnostic circulation model is solved using a finite element technique and a bases set of first order triangular elements. The dependent variable is the elevation of the sea surface. Results are presented as either vector arrows over the region in question or maps of sea surface elevation which can then be taken to represent stream-lines of the surface flow.

II. Kodiak Regional Study

The Kodiak Regional Study covered the continental shelf area surrounding Kodiak Island. It extended from the Kenai Peninsula in the northeast to Chirikof Island in the southwest. Within this regional study special emphasis was put on the area just offshore and east from Kodiak Island. This is a complex region of banks and troughs which is identified as Portlock Bank, Marmot Bank, and Albatross Bank. This particular section of the continental shelf has extremely complex topography, and thus, required a high resolution system of grid points or triangular finite elements to resolve the region in sufficient detail. To cover the region over 400 vertices were used with subsections being run independently and then analytically combined. Figure 1 represents the general area of the study and Figure 2 represents the bathymetric features which were resolved within the model. For purposes of description, we see that the northeast section of the region is covered by Portlock Bank. Stevenson Entrance leads in towards Cook Inlet and around to Shelikof Strait, which separates Kodiak Island from the mainland. Offshore from Kodiak is a series of complex banks which are collectively referred to as Marmot and Albatross Banks. To the southeast of Kodiak Island are the Trinity Islands and beyond that, the outflow from Shelikof Strait which moves toward Chirikof Island.

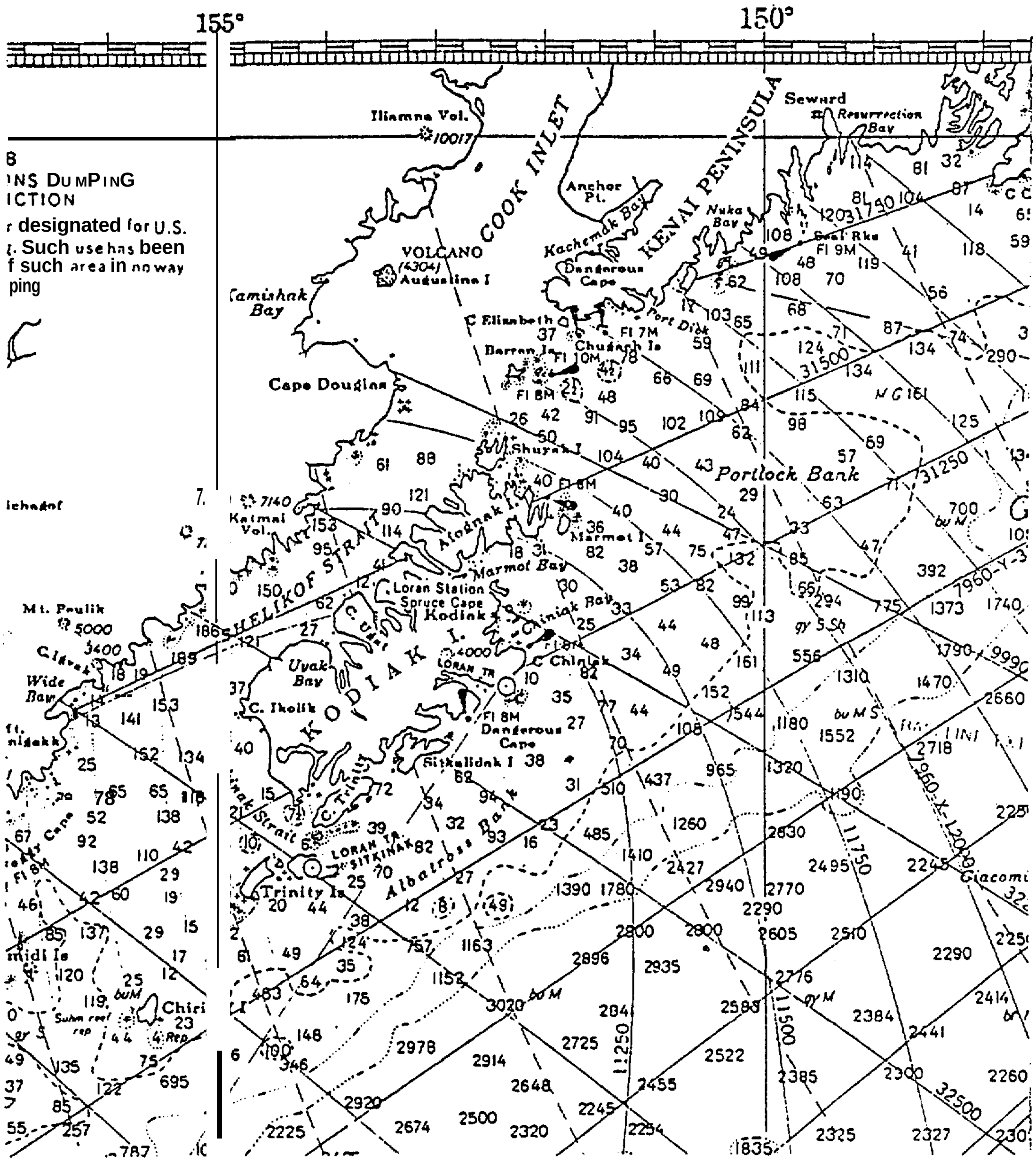

Figure 1. General area covered by the Kodiak Island modeling studies.

Figure 2. Shelf bathymetry resolved during the barotropic mode studies for the Kodiak region. Shaded areas represent the coastline of Kodiak Island and the Alaskan Peninsula. Contour intervals (m) (20, 40, 60 . . . .1200)

Barotropic Mode

The first component of the flow to be considered is the barotropic circulation. It is assumed that thfs flow results from the set-up of the sea "surface by the regional winds. In this case, the regional wind stress was assumed to be in bathystrophic balance along the northeast boundary of the model with the sea surface sloping upwards toward the Kenai Peninsula. With this as boundary conditions, the four regional sub-models were run and the results combined to derive the current pattern shown in Figure 3. Figure 3a shows the computed vector arrows at triangle centroids and Figure 3b shows the current vectors evaluated on the standard cartesian grid. This is representative of the flow patterns that can be expected given this large-scale regional forcing. The actual magnitude associated with these currents will depend on the magnitude of the wind stress. For moderate to strong wind cases, characteristic velocities are on the order of 1 knot. From a study of this figure, a number of features of the barotropic flow can be identified:

1) A general flow is seen to be southwest through Shelikof Strait. This is fed in part by flow from Cook Inlet, and in part from flow through Stevenson Entrance;

2) In the vicinity of Portlock Bank flow is generally to the southwest along the coast. Major cross-shelf intrusions of water are identified with the trough regions. Onshore flow is along the eastern and deeper part of the trough, then there is a subsequent offshore flow along the western edge of this trough. Further to the southeast, between Portlock Bank and Marmot Bank, cross-shelf flow is again seen in the trough that separates these two areas;

3) In the area of Albatross Bank just offshore from Kodiak the current is again seen to reflect the bank and trough bathymetry. The flow is seen to move onshore along the northeast side of the troughs, and offshore along the southwest section of the troughs. This is a region where a deep channel exists close to the shore and a coastal current is seen to flow toward the southwest through this region;

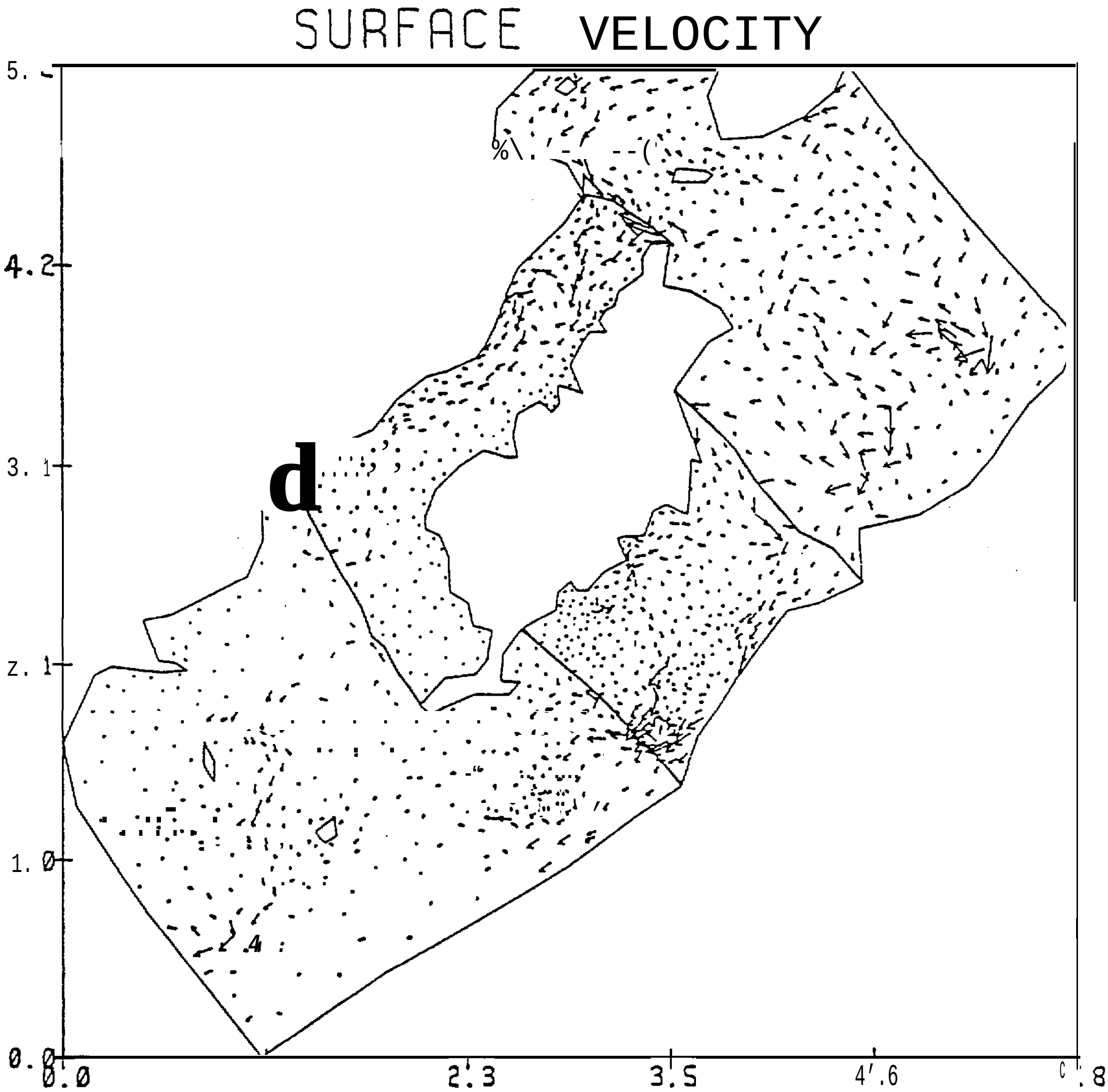

Figure 3a. A delineation of the four subregions used in the Kodiak Island study with vector arrows plotted at the centroids of the triangular bases set. The arrow spacing gives an indication of the resolution used in various parts of the model.

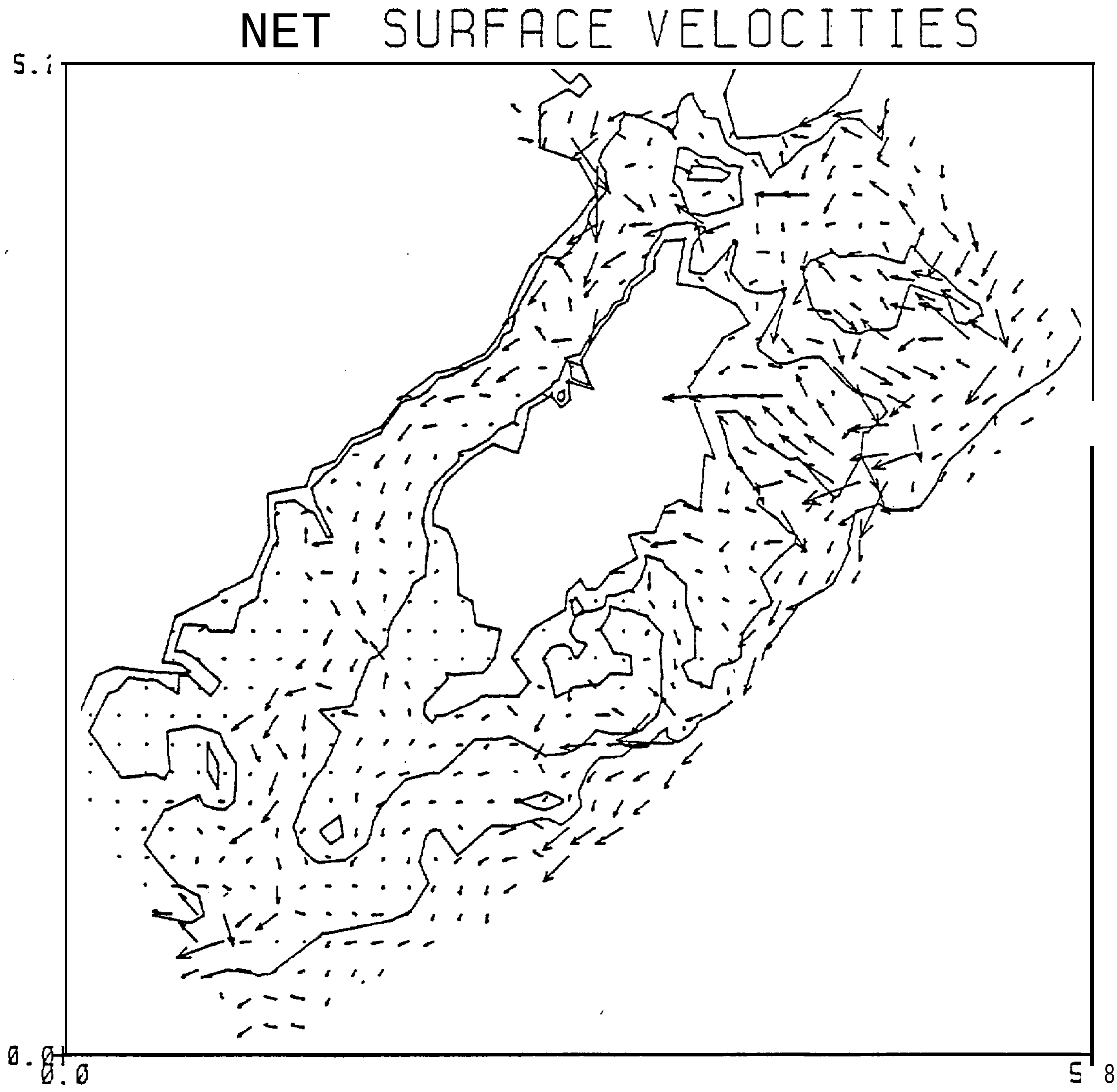

Figure 3b. Barotropic current vector arrows evaluated on a regular cartesian grid for the Kodiak Island study area.

4) To the southwest of Kodiak Island the flow is seen to continue in a southwest direction and be joined by the outflowing currents from Shelikof Strait.

Baroclinic Mode

The baroclinic component of the geostrophic flow was estimated using data from oceanographic cruises. For the Kodiak region, six cases were available. These cases cover the periods:

1. May 1976
2. September 1977
3. November 1977
4. April 1978
5. May 1978
6. June 1978

Each of these oceanographic cruises covered slightly different areas and has variable station spacing. For the model study, they were considered separately and, in each case, the baroclinic component of the current was calculated for regions where it was defined by sufficient oceanographic data. For purposes of comparison, all cases have been plotted on the same overall map with currents evaluated on a regular cartesian grid which has been superimposed over the triangular bases sets used computationally in the model. Figure 4 shows the results of these baroclinic studies.

Figure 4a shows the results from the May 1976 cruise. Of the six cases studied, this one had the most general coverage and the most complete set of oceanographic data. One can notice a strong baroclinic current southwest through Shelikof Strait and strong currents along the outer continental shelf edge offshore from Kodiak Island. Previous model studies have indicated a sensitivity in the model results due to poorly resolved information along the shelf edge, and it is possible that these strong currents seen along the outer edge of the model may represent noise in the data.

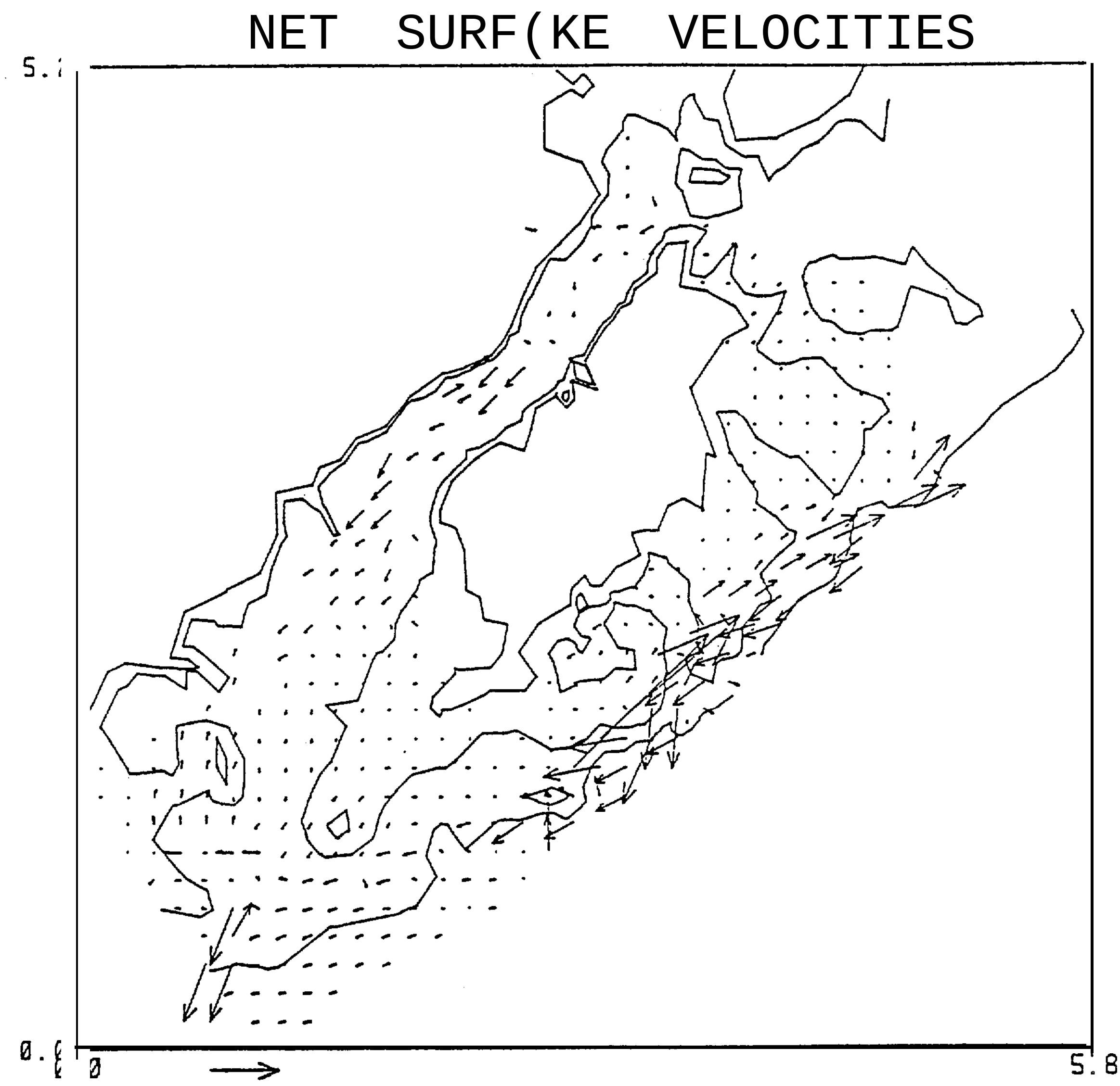

Figure 4a. **Baroclinic** current vectors plotted on a regular cartesian grid derived from data collected during May 1976. Scale arrow indicates 1 m/see current.

It is also obvious that the strong currents shown in the extreme southwest corner of the model domain are the result of one hydrography station that appears to have anomalous density data. As these vector arrows are questionable and at the extreme limit of the calculations they should be disregarded for future composites of currents.

Figure 4b represents the baroclinic currents resulting from the September 1977 oceanographic data. This study covered the Portlock Bank and northeast section of Albatross Bank. A general southwest set to the baroclinic currents over the continental shelf is seen and, once again, stronger currents along the outer edge of the continental shelf with the possibility of poorly resolved eddies or streams.

Figure 4c shows the results of November 1977 oceanographic data concentrating on the Albatross Bank region. Once again, a general southwesterly baroclinic component to the current is seen over the shelf with higher velocities seen along the outer edge of the shelf.

The next three figures result from data collected during the spring of 1978. These figures run through the sequence April-May-June. Figure 4d represents the April data and covers Portlock Bank and along the outer edge of Kodiak down to approximately the area of the Trinity Islands. The April case shows very little baroclinic current over the shelf itself. Marmot Bank and Albatross Bank are nearly devoid of baroclinic flow. Along the outer edge of the shelf, stronger currents are observed, particularly offshore from the Trinity Islands region. In detail, these stronger currents appear as a clockwise eddy but it is also obvious that the spatial pattern is poorly resolved by the data.

Figure 4e shows the same region the following month (May 1978). In this, it can be seen that baroclinic currents are beginning to develop over

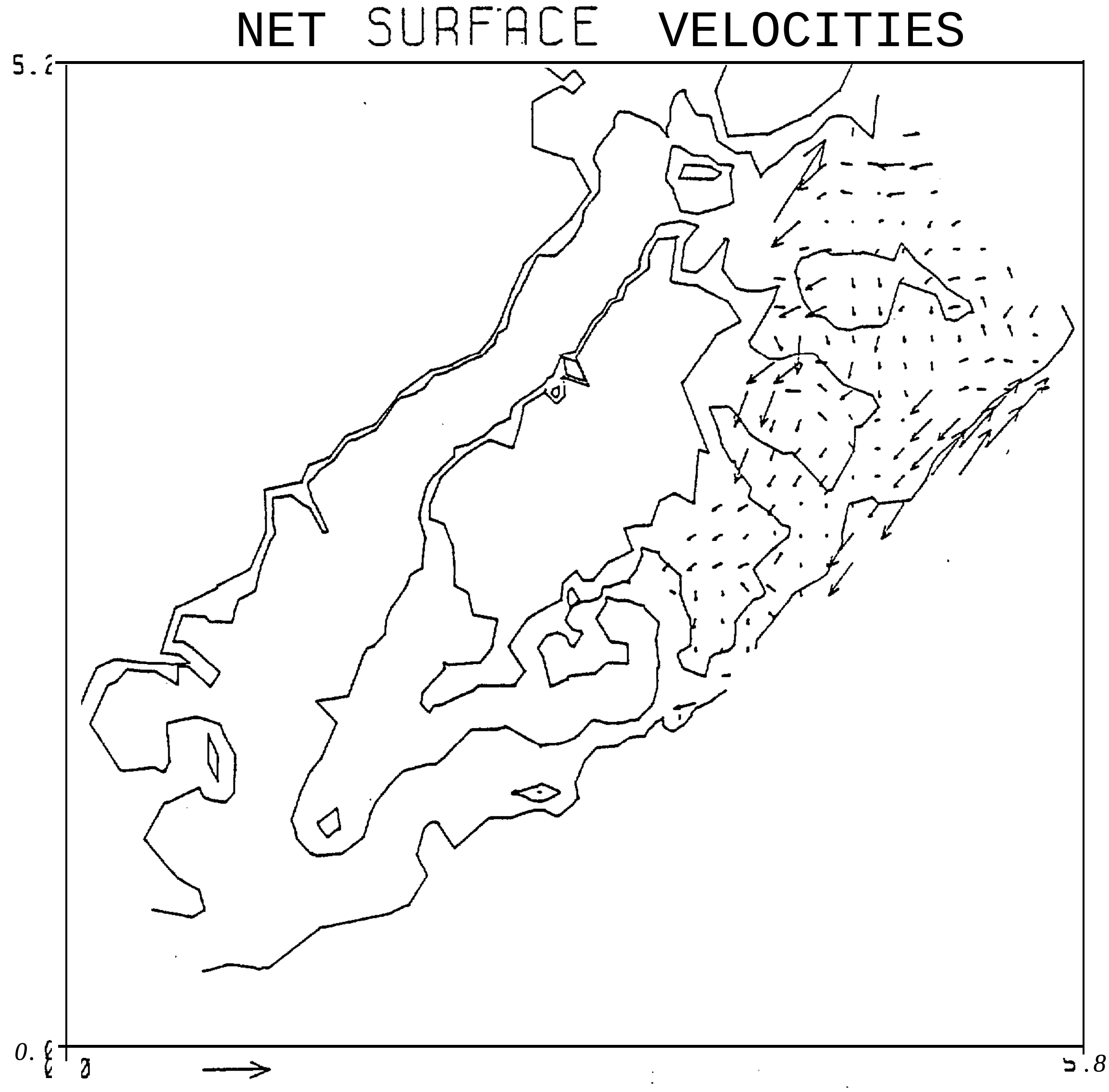

Figure 4b. Baroclinic current vectors plotted on a regular cartesian grid derived from data collected during September 1977. Scale arrow indicates 1 m/see current.

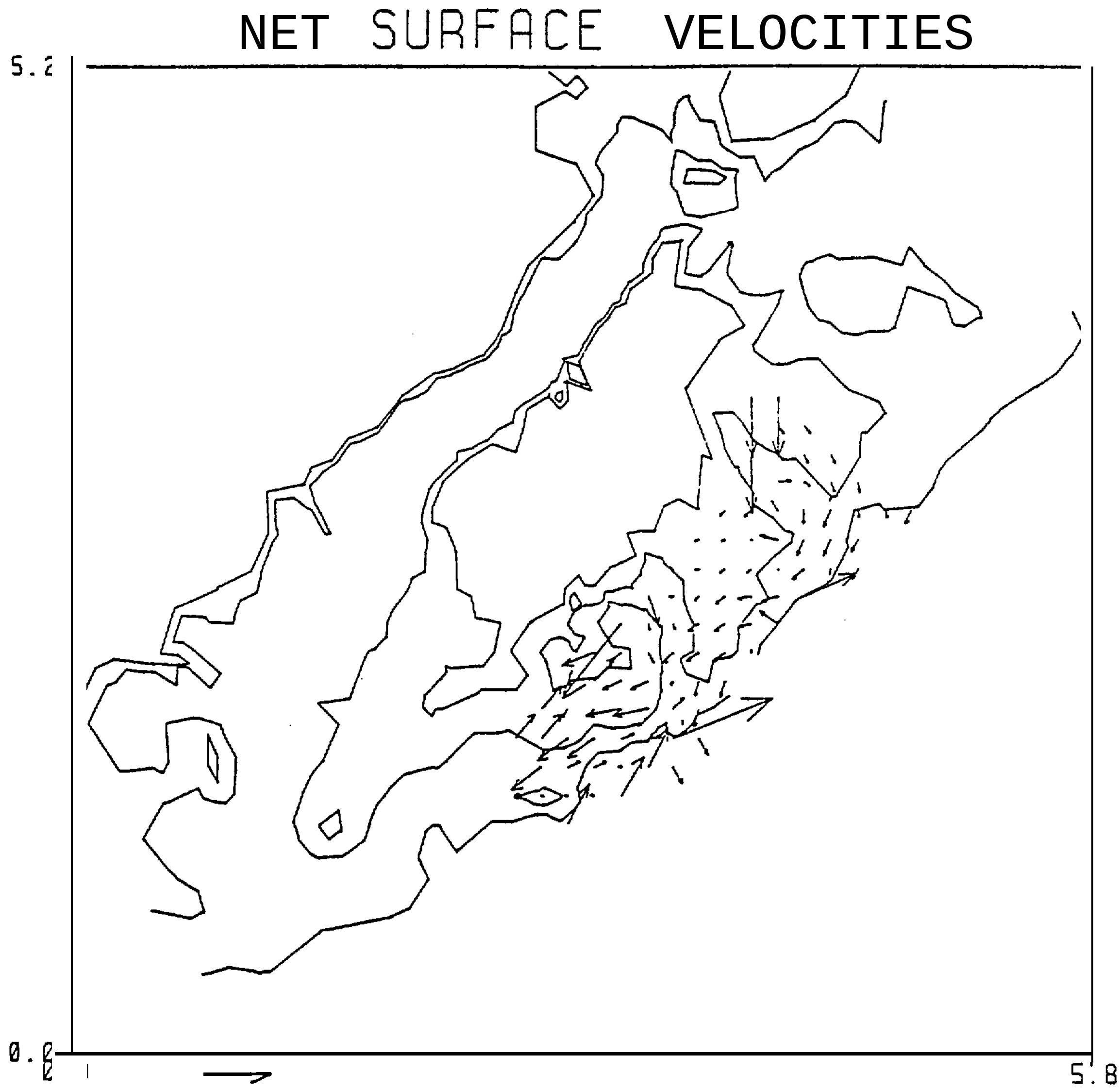

Figure 4c. Baroclinic current vectors plotted on a regular cartesian grid derived from data collected during November 1977. Scale arrow indicates 1 m/see current.

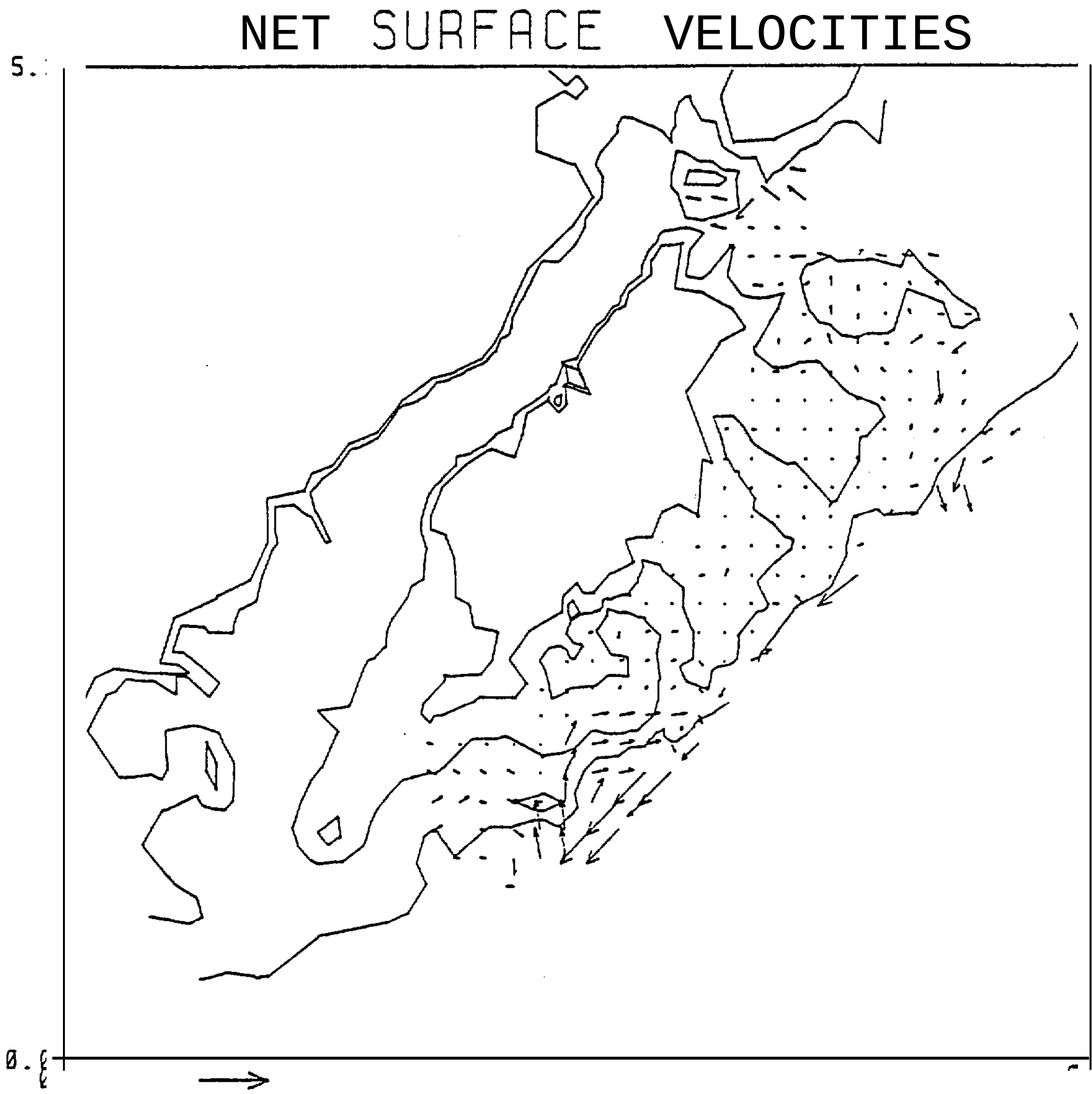

Figure 4d. Baroclinic current vectors plotted on a regular cartesian grid derived from data collected during April 1978. Scale arrow indicates 1 m/see current.

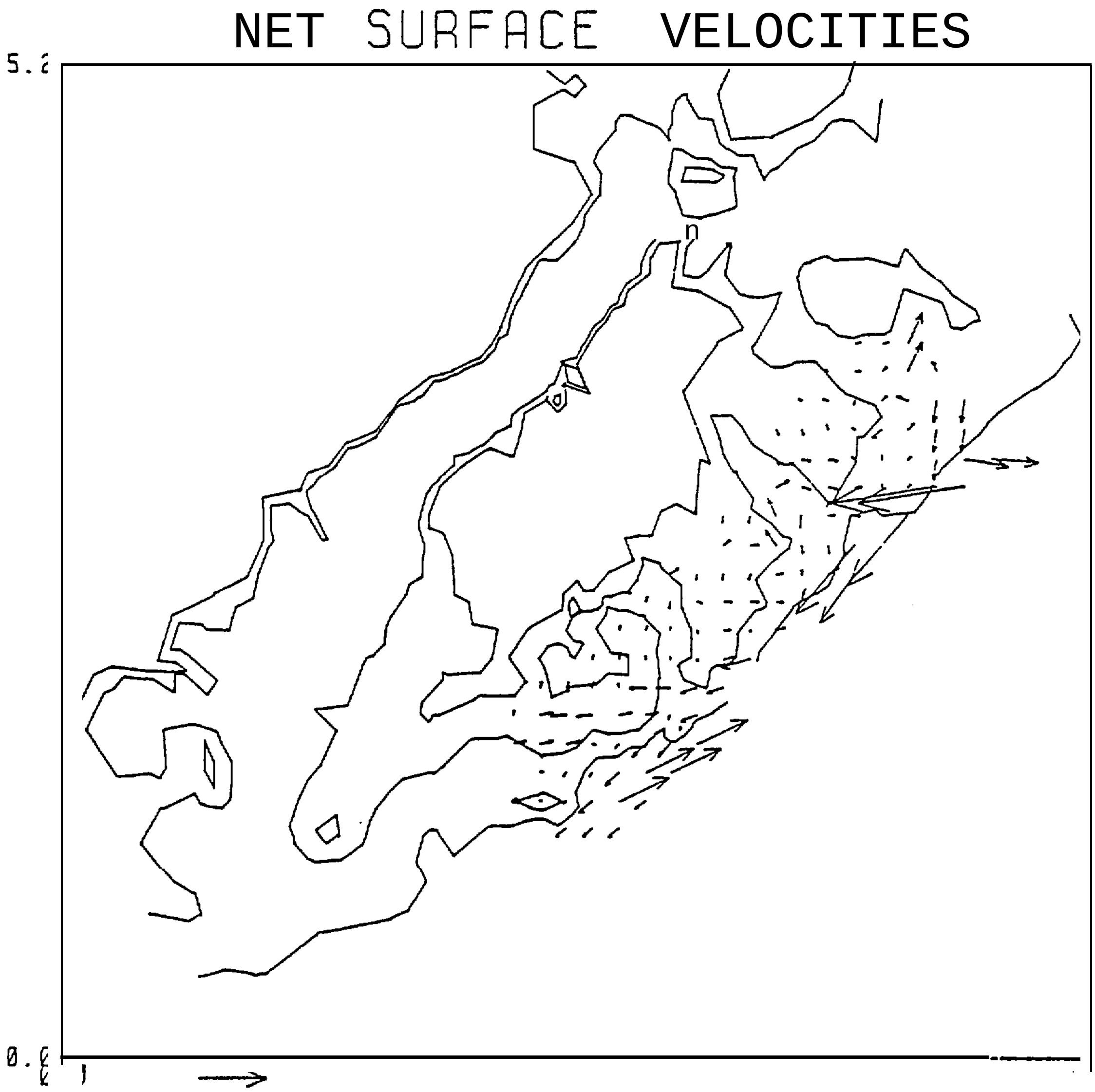

Figure 4e. Baroclinic current vectors plotted on a regular cartesian grid derived from data collected during May 1978. Scale arrow indicates 1 m/see current.

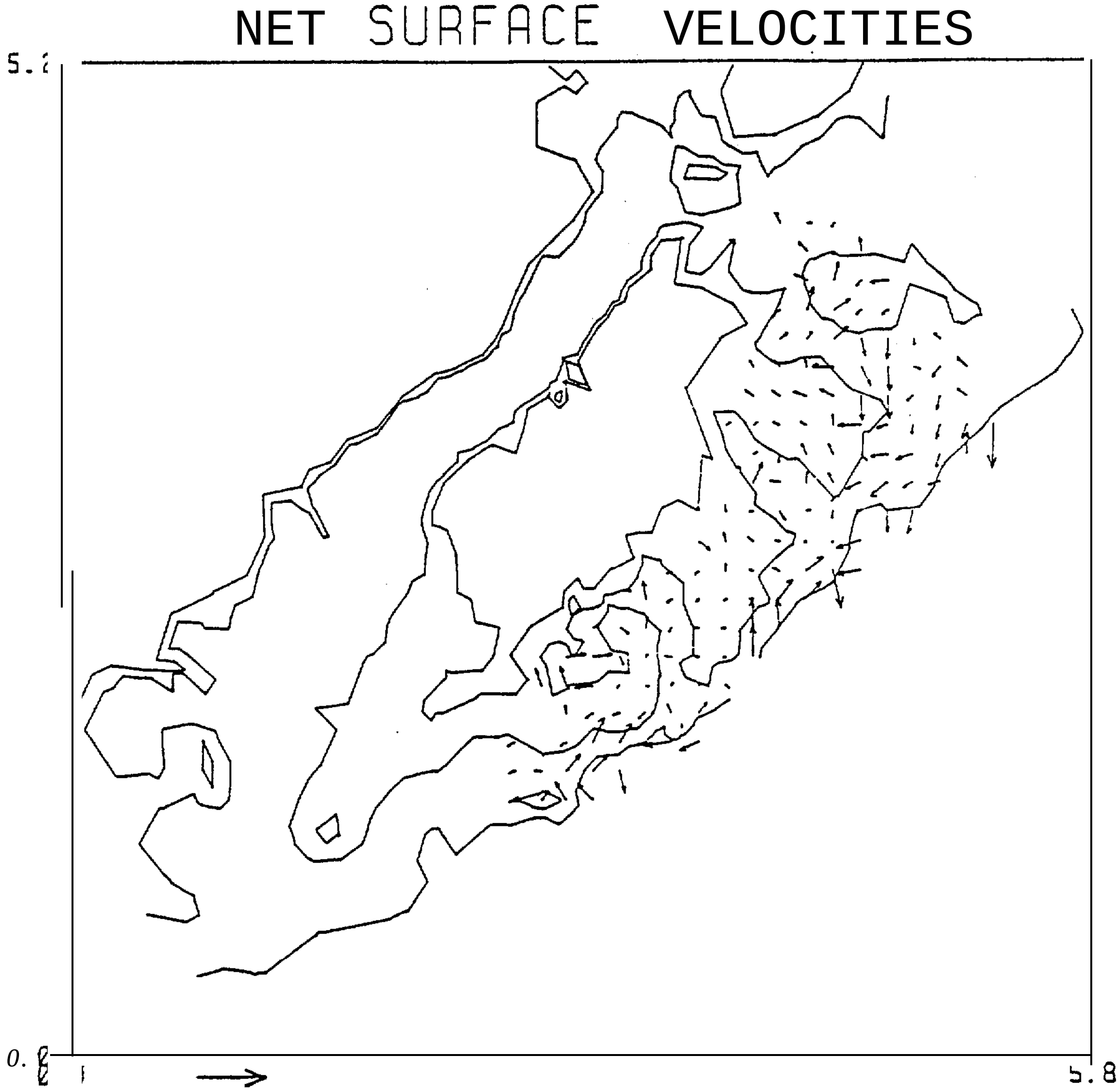

Figure 4f. Baroclinic current vectors plotted on a regular cartesian grid derived from data collected during June 1978. Scale arrow indicates 1 m/see current.

the shelf itself, and circulation is seen over the trough area between Marmot and Albatross Banks. In addition, some baroclinic flow is seen over the southwest edge of Albatross Bank. Stronger currents are once again observed along the outer edge of the shelf, but they do not appear to be coherent with the pattern seen a month earlier.

Figure 4f shows the results of June 1978 data and covers essentially the same region as the previous two cases. By this time, the baroclinic currents are even stronger over the shelf region with an onshore component in the vicinity of Marmot Bank and a general clockwise circulation seen over Kiliuda Trough and the southwest edge of Albatross Bank.

Having looked at a number of cases of baroclinic flow certain characteristics of the regional dynamics have become apparent. There appears to be seasonal differences between the baroclinic flow over the shelf; stronger baroclinic currents are observed during the fall while decreased baroclinic currents are observed during the spring. In addition, the data collected does not appear to be able to resolve the details of the stronger flows seen along the edge of the outer continental shelf.

Averages of Baroclinic Modes

In order to get a better understanding of how the actual mean flows may look, it is instructive to consider averaging the baroclinic fields from these six cases. By doing this the stronger currents, due to poorly resolved baroclinic signatures along the edge of the shelf, should average out and a more realistic mean flow can be expected. To consider this problem in more detail, we can look at Figure 5, which indicates the area of coverage shown in the six cases considered in Figure 4. From this, it can be seen that all six of the cases cover the region between Portlock Bank and the

Figure 5. Composite overlays of the coverage from each of the six baroclinic data sets presented in Figure 4. Scale arrow indicates 1 m/see current.

Trinity Islands. The Kiliuda Trough-Albatross Bank region is, in fact, covered by all six cases: whereas the Shelikof Strait and southwest section of the model was only covered once, in May of 1976. Figure 6a represents the total baroclinic flow or the average of all six cases. This was calculated by taking the total number of estimates for each grid location and dividing by the number of estimates. Regions where there was only one case (as in the Shelikof Straits) were computed as the value given from the May 1976 data whereas regions over Kiliuda Trough were the average of all six cases. As expected, Figure 6a shows smoother flow with southwest currents through Shelikof Straits and a general southwest drift over the outer continental shelf region. The region of the outer continental shelf break is once again an area of stronger currents, but appears definitely less noisy than before. It is interesting to note that even with all six of the cases averaged, a counterclockwise circulation region is seen along the shelf edge offshore from the Trinity Islands.

Figure 6b shows the average of the two fall cases (September and November 1977). These two cases show the flow as southwest over most of the region with stronger current nearshore in the vicinity of Marmot Bank and weaker currents over the central area of Albatross Bank. It is interesting to note that the fall case shows a relatively strong baroclinic signature over the shelf. This appears to reflect the increase in baroclinic structure that develops over the summer period.

Figure 6c represents the average of the spring cases (May 1976 and April-May-June 1978). From this data the flow is seen to be generally weak over the shelf with stronger currents along the shelf break, In this case the relatively weak signature seen in the spring is presumably the result of a general breakdown of baroclinic structure over the continental shelf in the wintertime.

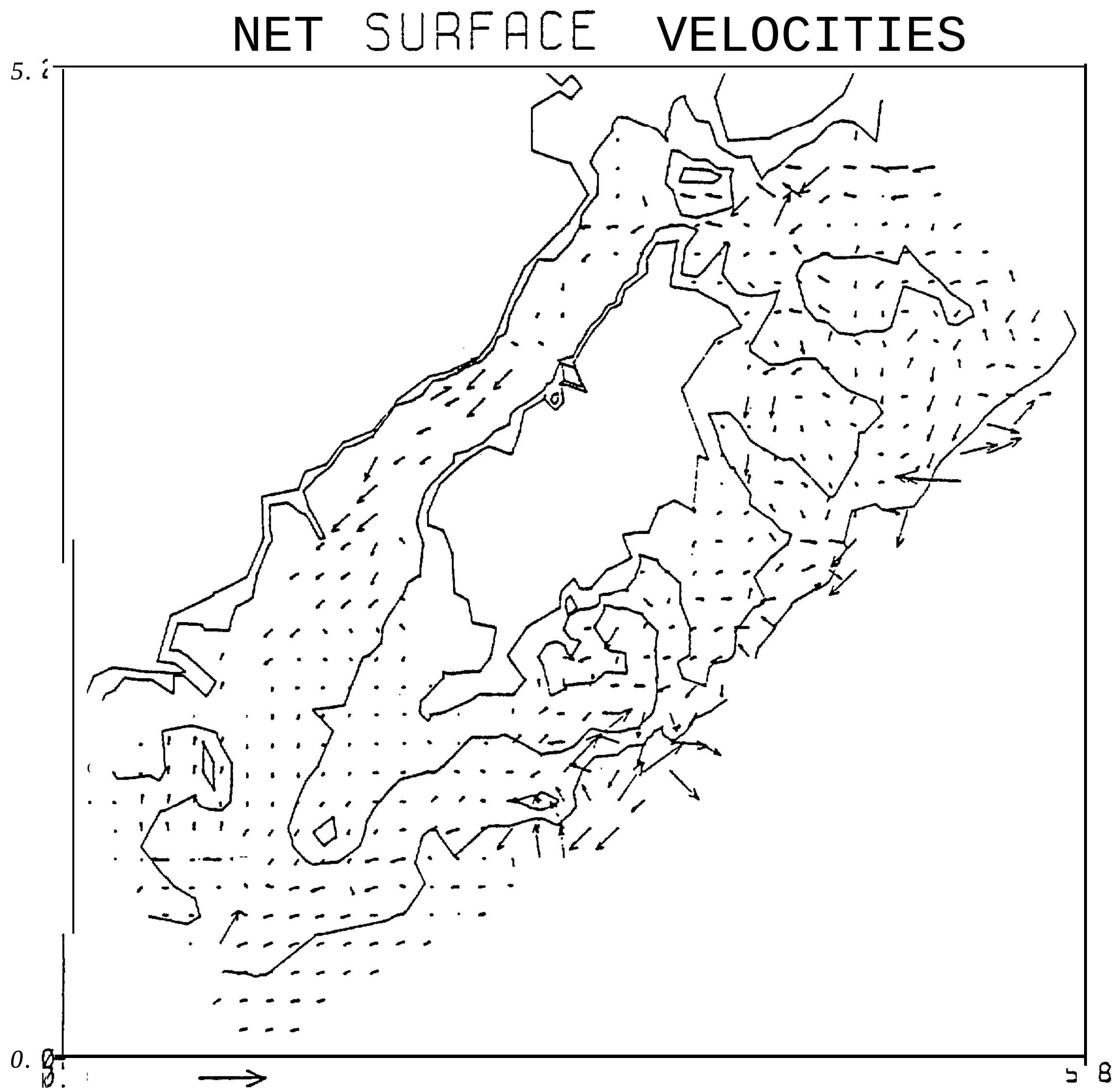

Figure 6a. Average baroclinic currents derived from all six baroclinic data sets. Scale arrow indicates 1 m/see current.

NET SURFACE VELOCITIES

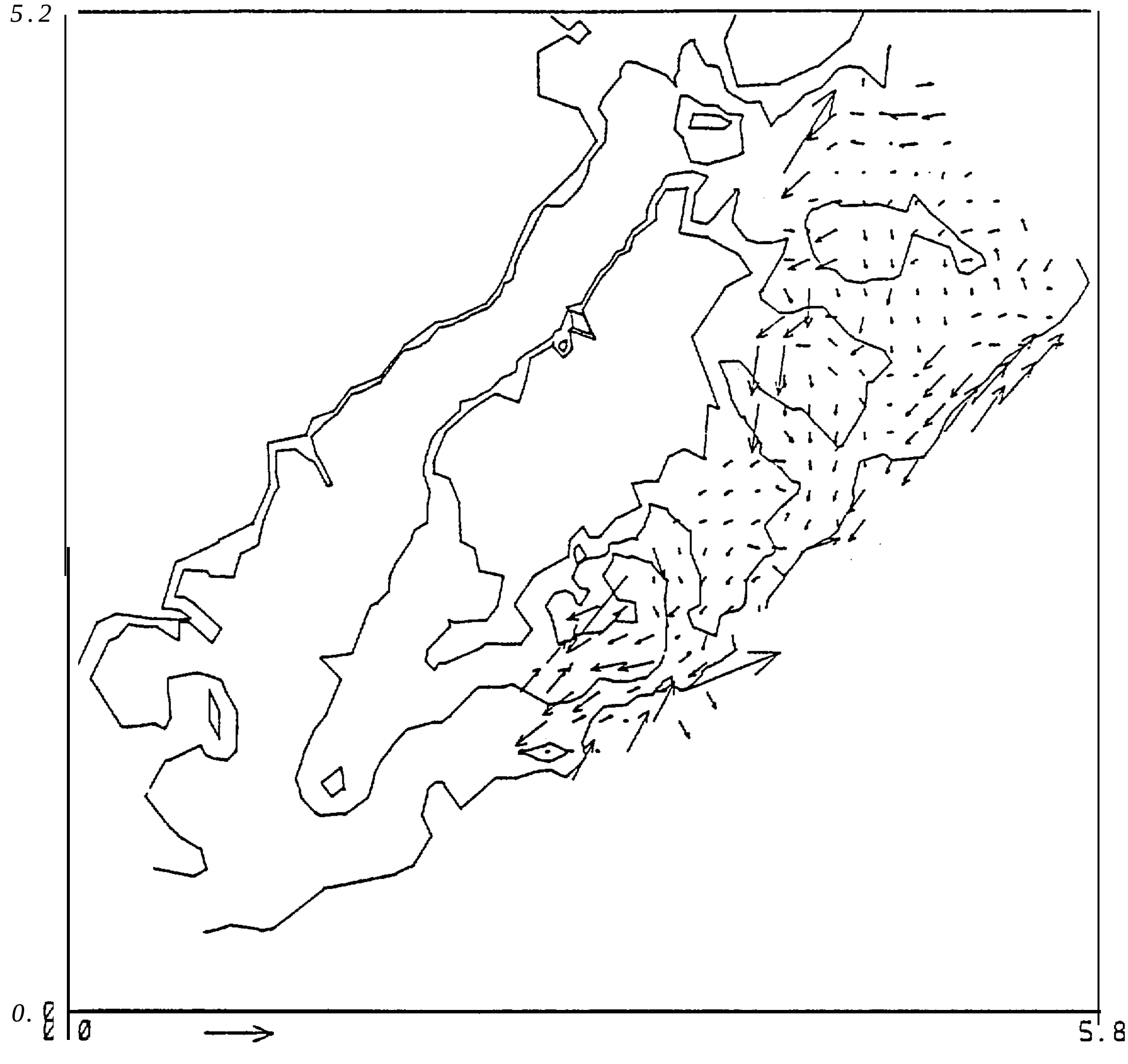

Figure 6b. Fall average baroclinic currents derived from September 1977 and November 1977 data. Scale arrow indicates 1 m/see current.

NET SURFACE VELOCITIES

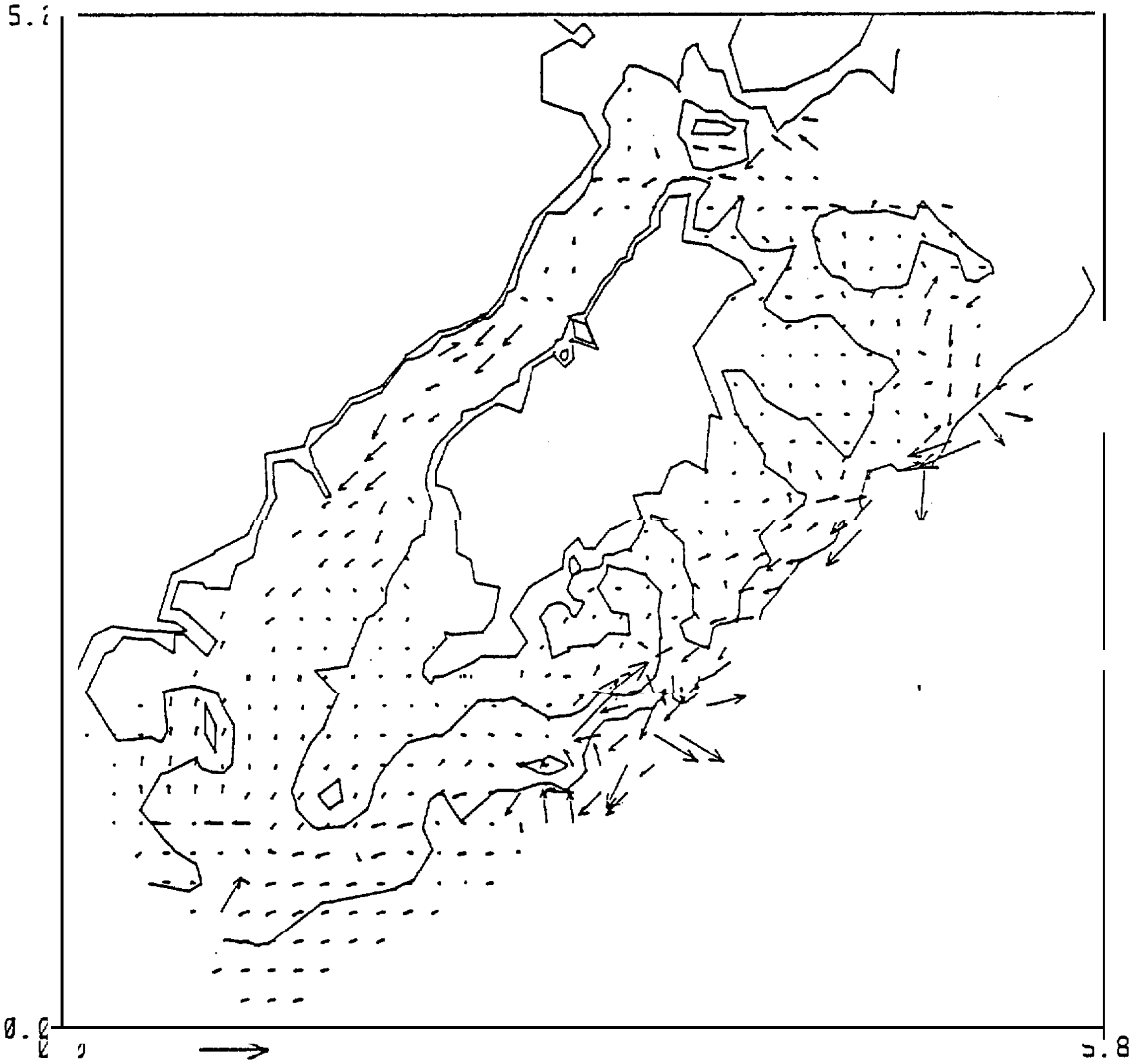

Figure 6c. Spring average baroclinic currents derived from May 1976 and April, May, and June 1978 data. Scale arrow indicates 1 m/see current.

Composite Currents

We are now in a position to consider the total surface current estimates for the Kodiak region. The total current will be the algebraic sum of the baroclinic modes and the barotropic pattern. To combine these currents, we must assign a magnitude to the barotropic component of the flow. This can be done based on estimates of the winds set up along the coast; a number of different cases are considered. Figures 7a, 7b, and 7c represent examples of the barotropic mode plus the average baroclinic flow. Figure 7a represents a moderate wind case that results in the onshore set-up of the sea surface. This would correspond to a large-scale wind pattern which had a southwest component to the wind. Such patterns are relatively common in the Gulf of Alaska, and are associated with low pressure and cyclonic atmospheric circulation over the central Gulf.

Figure 7b shows the expected pattern for increasing southwest wind components. This would be like the previous case but for a stronger wind regime.

Figure 7c is present for completeness and indicates what would be expected for a wind condition that depressed, or set down, the sea surface. This would correspond to a large-scale weather pattern that led to northeast winds along the coast.

Figure 8 represents the composite currents derived from the averaged fall data and the pattern information from the barotropic study. Figure , 8a represents a moderate set-up of the sea surface associated with cyclonic circulation in the Gulf. Figure 8b represents an increased wind event or flow driven by stronger southwest winds. Figure 8c represents the set-down conditions associated with cyclonic flow over the Gulf or a weak northeast wind along the coast.

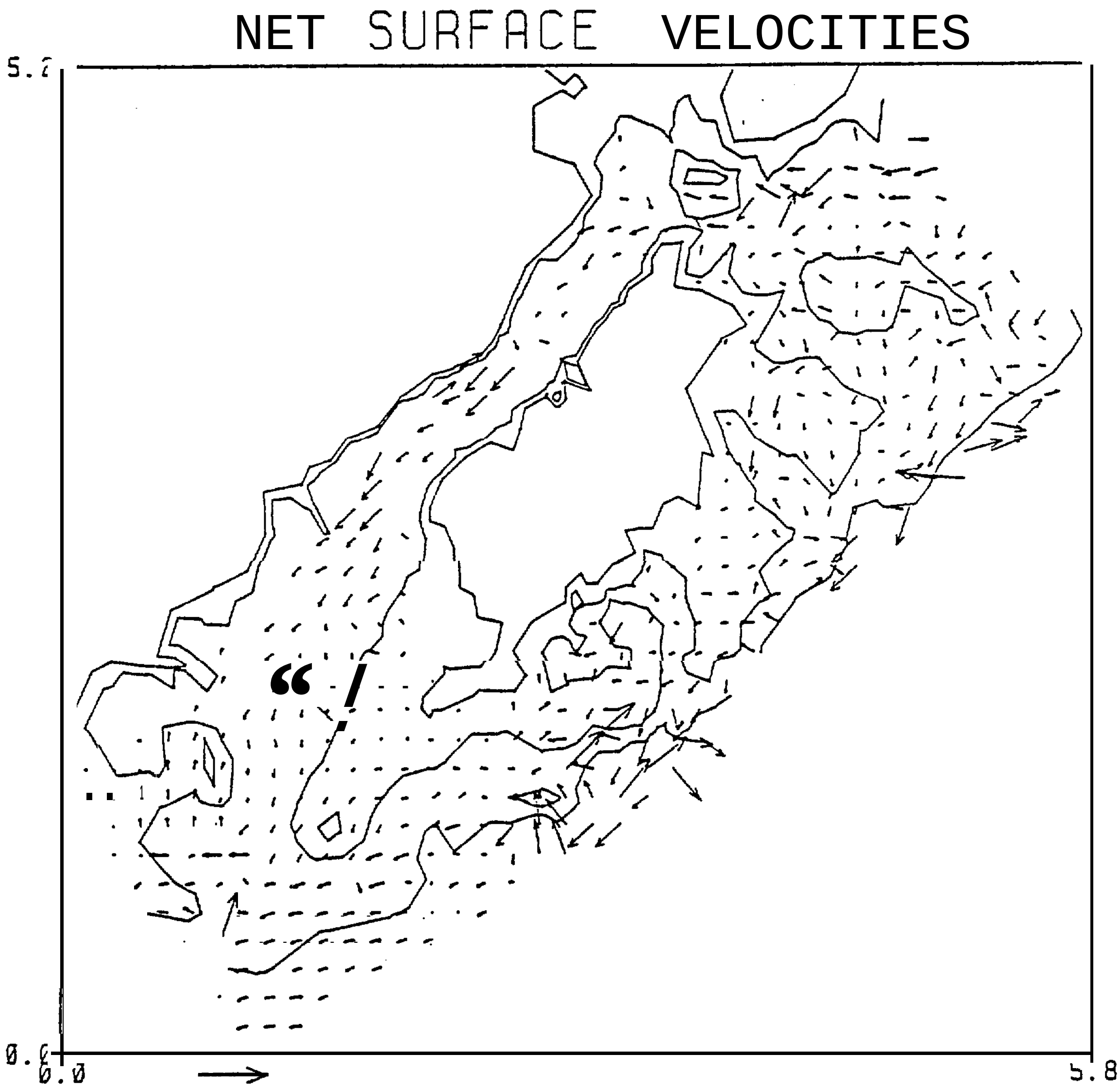

Figure 7a. Composite current vectors showing the sum of the average baroclinic mode and a moderate barotropic mode. Scale arrow indicates 1 m/see current.

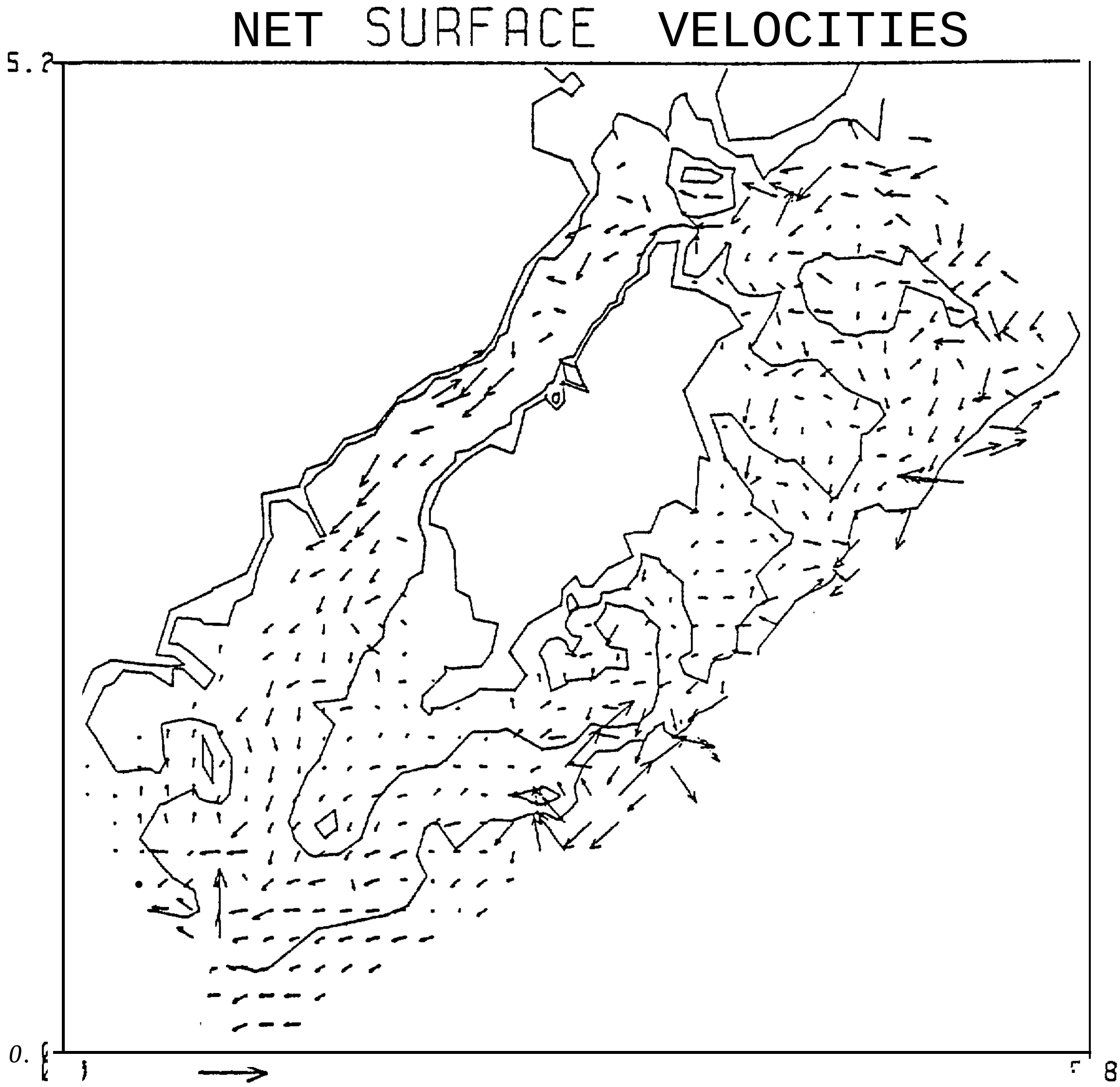

Figure 7b. Composite current vectors showing the sum of the average baroclinic mode and a large to intermediate barotropic mode. Scale arrow indicates 1 m/see current.

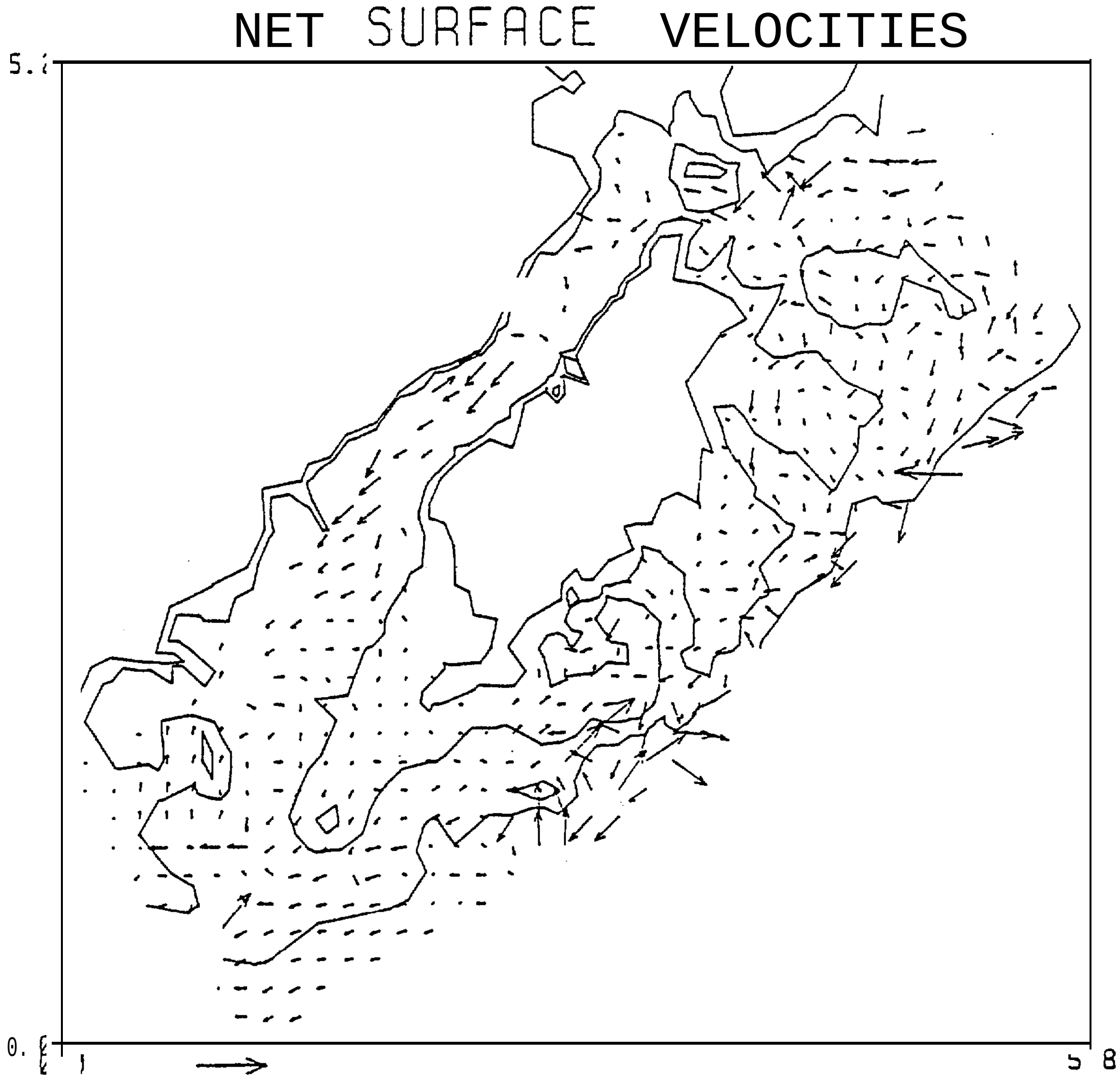

Figure 7c. Composite current vectors showing the sum of the average baroclinic mode and a weak negative barotrop c mode. Scale arrow indicates 1 m/see current.

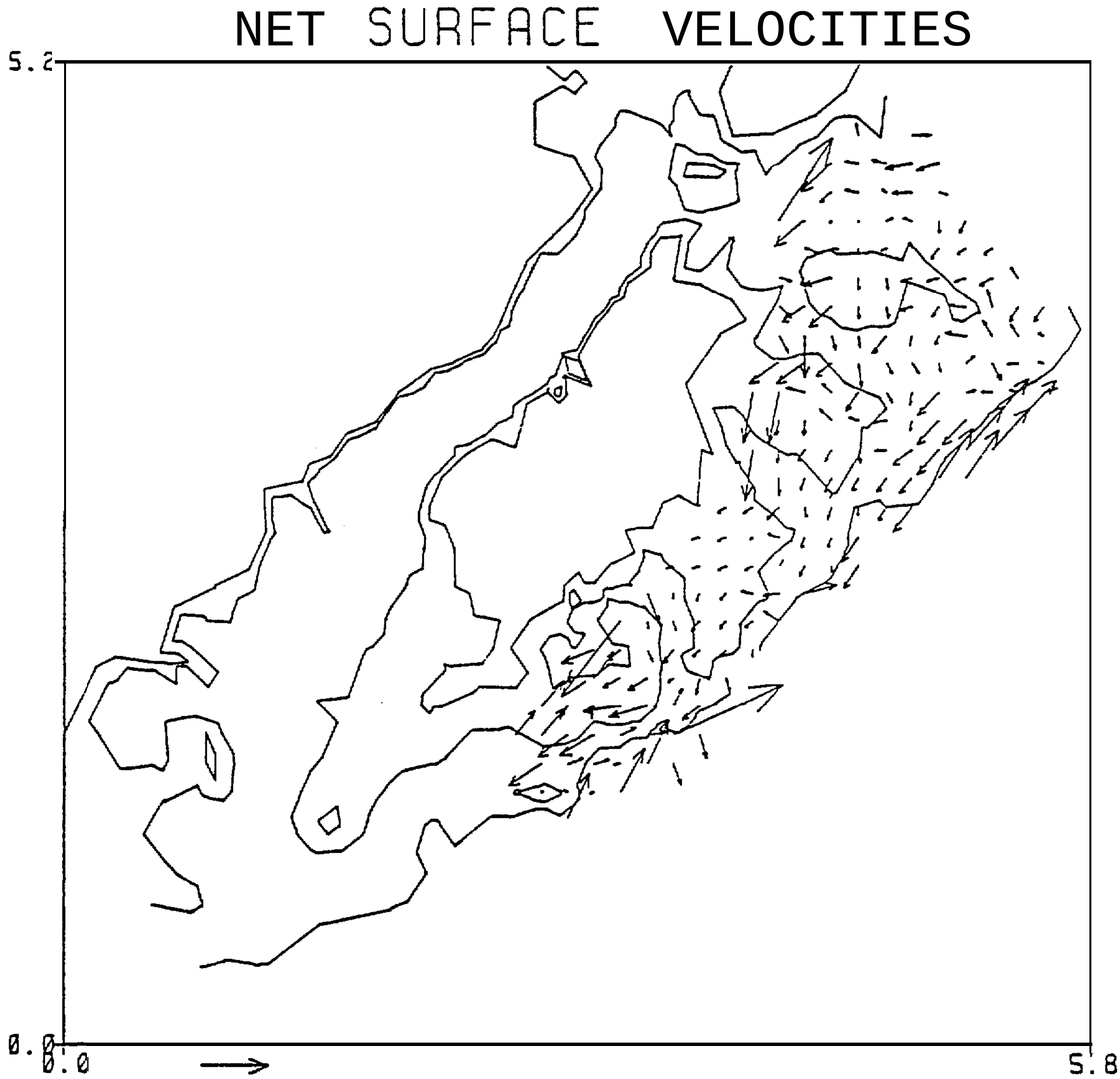

Figure 8a. Composite current vectors showing the sum of the fall average baroclinic mode and a moderate barotropic mode. Scale arrow indicates 1 m/see current.

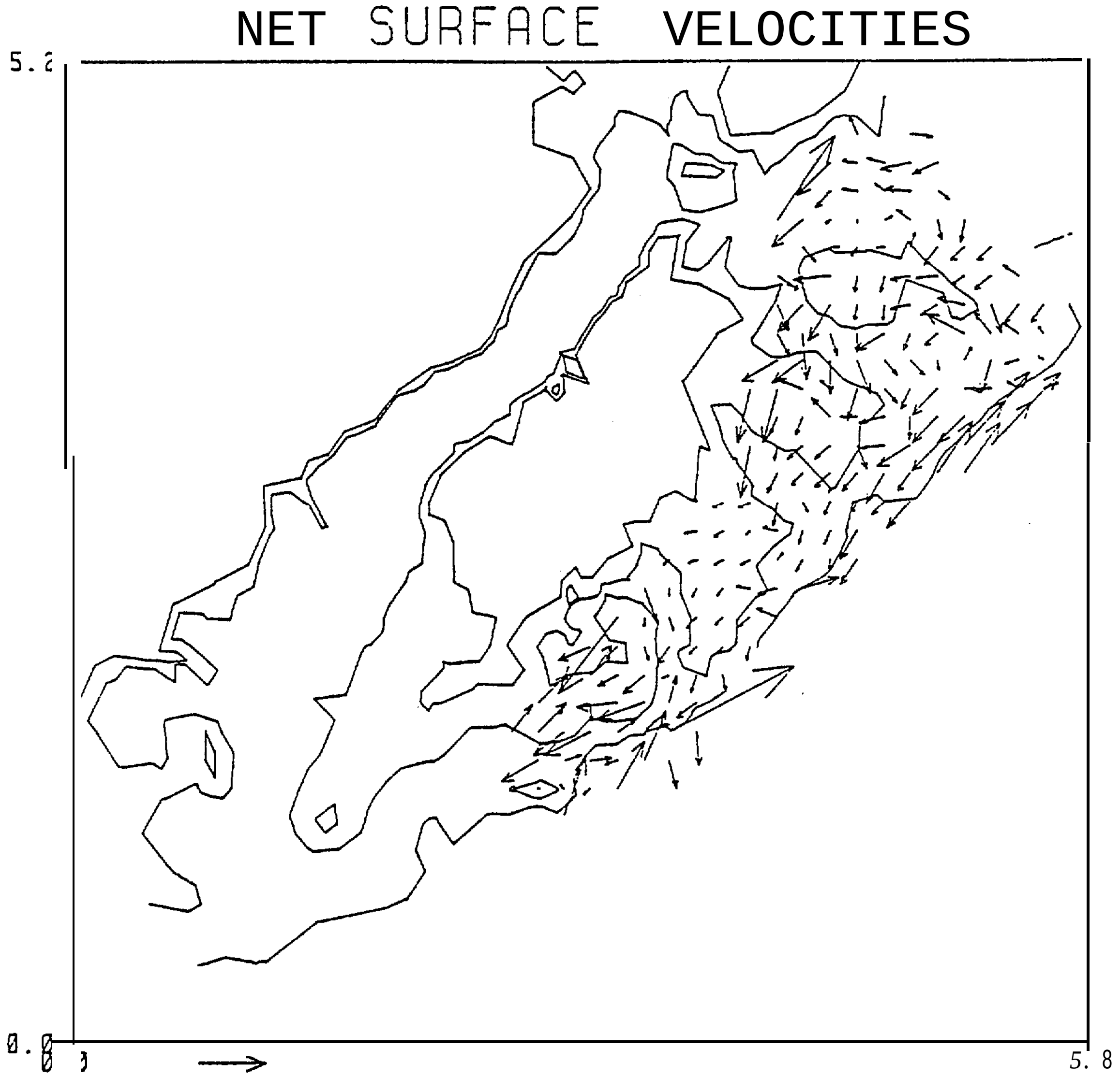

Figure 8b. Composite current vectors showing the sum of the fall average baroclinic mode and a large to intermediate barotropic mode. Scale arrow indicates 1 m/see current.

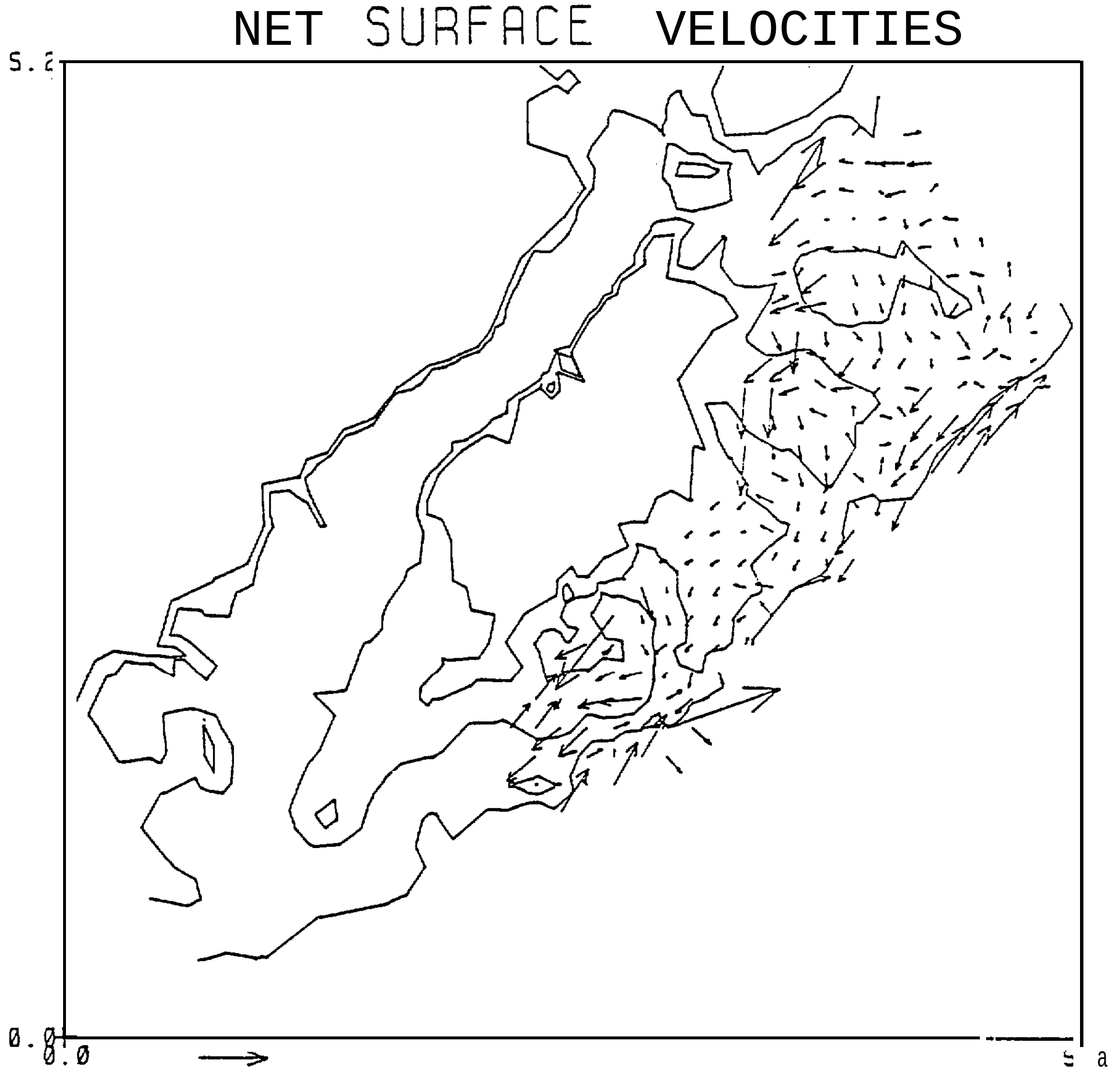

Figure 8c. Composite current vectors showing the sum of the fall average baroclinic mode and a weak negative barotropic mode. Scale arrow indicates 1 m/see current.

Figure 9 is a composite of the four springtime baroclinic fields and the barotropic pattern information. Figure 9a represents a moderate cyclonic circulation pattern for the region (winds towards the southwest over the Kodiak region at approximately 10 knots), and Figure 9b represents the results of a stronger cyclonic wind event (winds toward the southwest over the Kodiak region at approximately 20 knots). Finally, Figure 9c represents the weak northeast winds along the coast (winds towards the northeast over the Kodiak region at approximately 10 knots).

The model studies of the Kodiak region have produced current patterns which include the baroclinic data from a number of different oceanographic observation sets, as well as the dynamic constraints that are associated with the barotropic set-up of the sea surface along the coast. Although this is an extremely complicated domain, a number of features of the flow have been identified, and appear to be consistent with observations and recognized regional dynamics. A persistent southwest flow through Shelikof Strait appears to be fed jointly from outflow from Cook Inlet and flow northwest through Stevenson Entrance. Along the outer edge of Kodiak Island the currents set to the southwest with major perturbations and convolutions in the flow pattern associated with the complex bank and trough topography. In particular, the troughs between Portlock Bank, Marmot Bank, and the various components of Albatross Bank, are all seen to affect the flow. The dynamics of this appear to be related primarily to the barotropic mode where the planetary vorticity interacts with the bathymetry. This suggests that the model dynamics represent an appropriate way to extrapolate current information over this complex region. The baroclinic data is seen to be generally consistent when averaged over seasonal values but flow along the outer edge of the continental shelf is apparently not resolved by the available data.

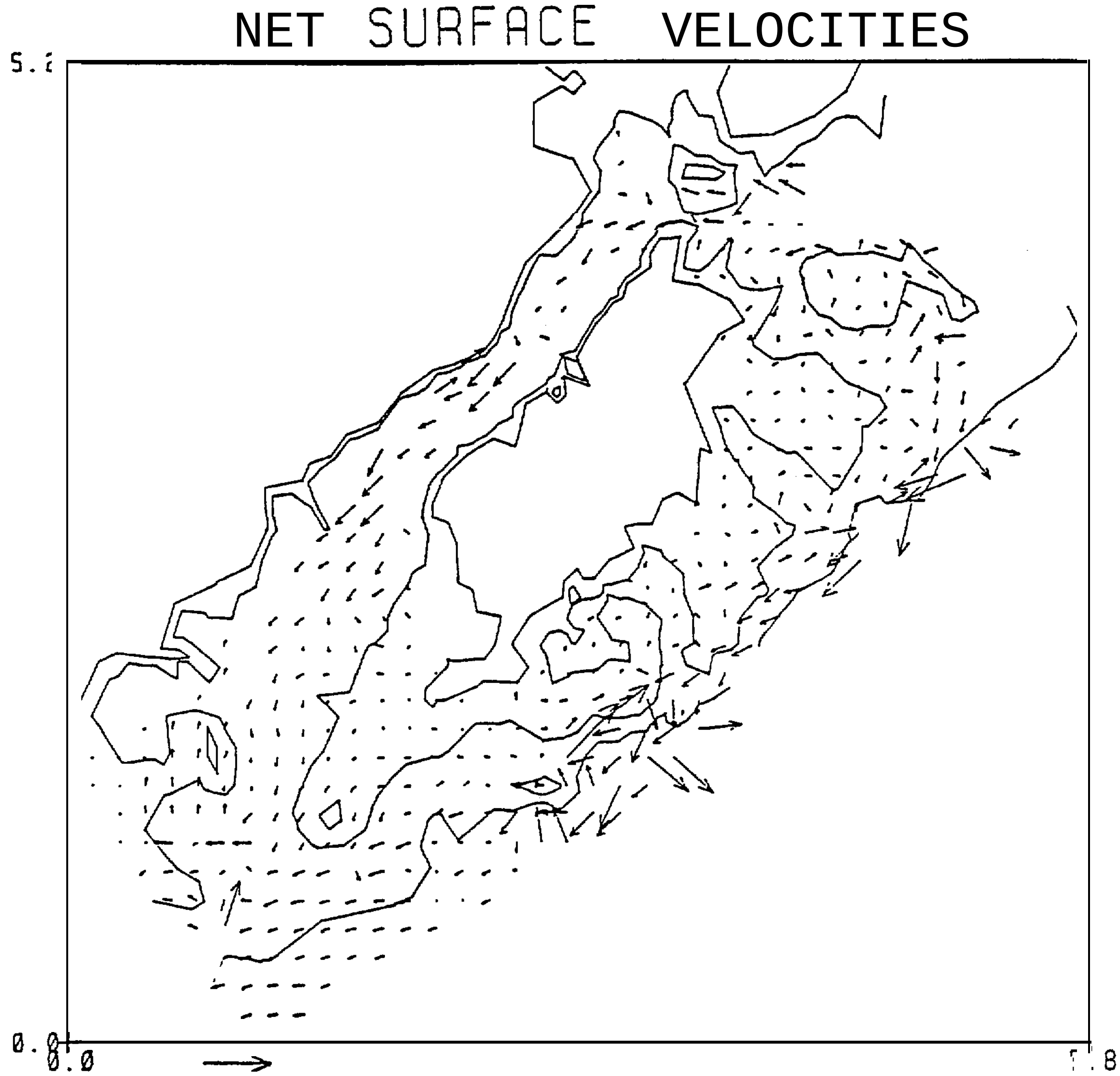

Figure 9a. Composite current vectors showing the sum of the spring average baroclinic mode and a moderate barotropic mode. Scale arrow indicates 1 m/see current.

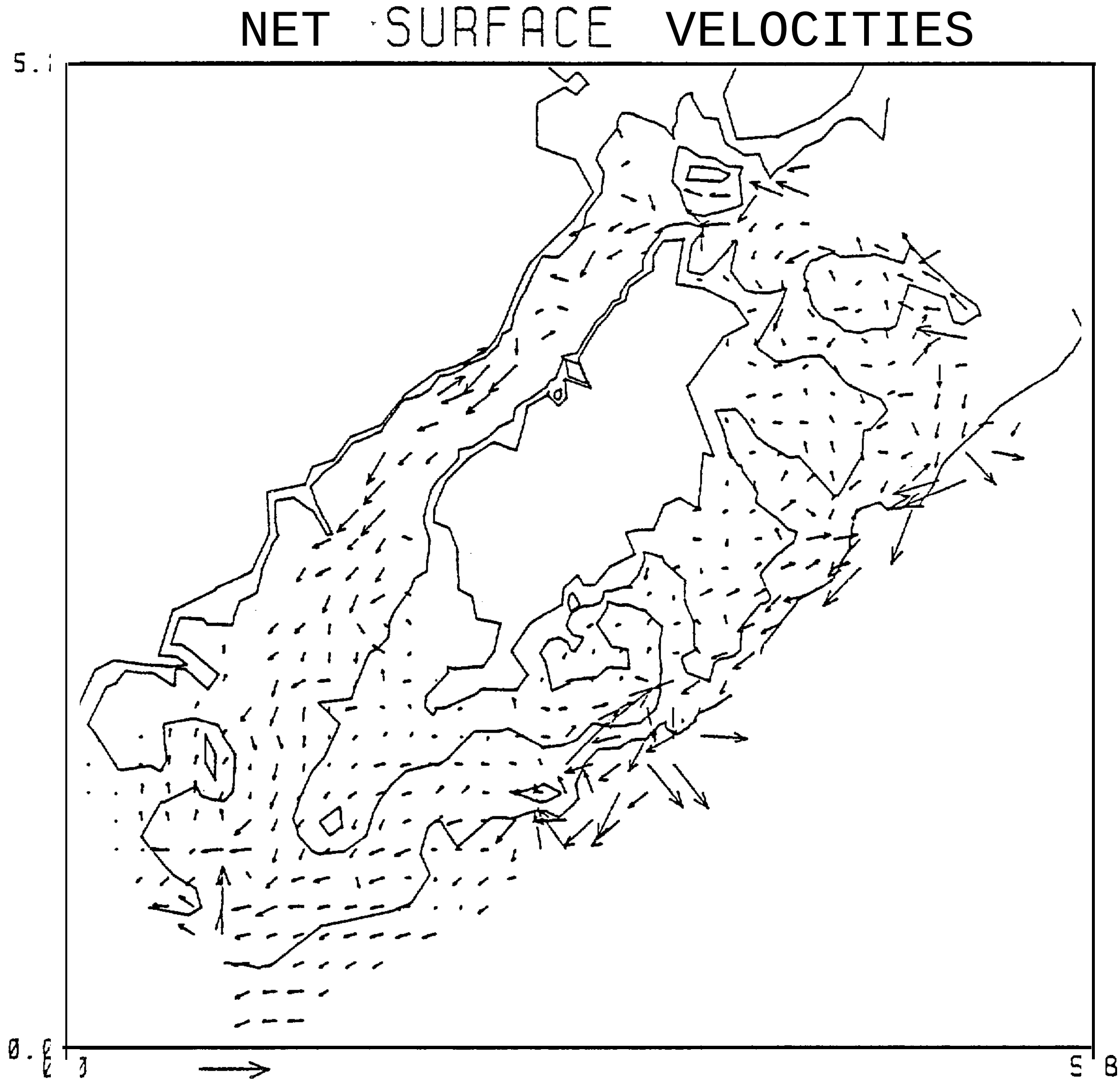

Figure 9b. Composite current vectors showing the sum of the spring average baroclinic mode and a large to intermediate barotropic mode. Scale arrow indicates 1 m/see current.

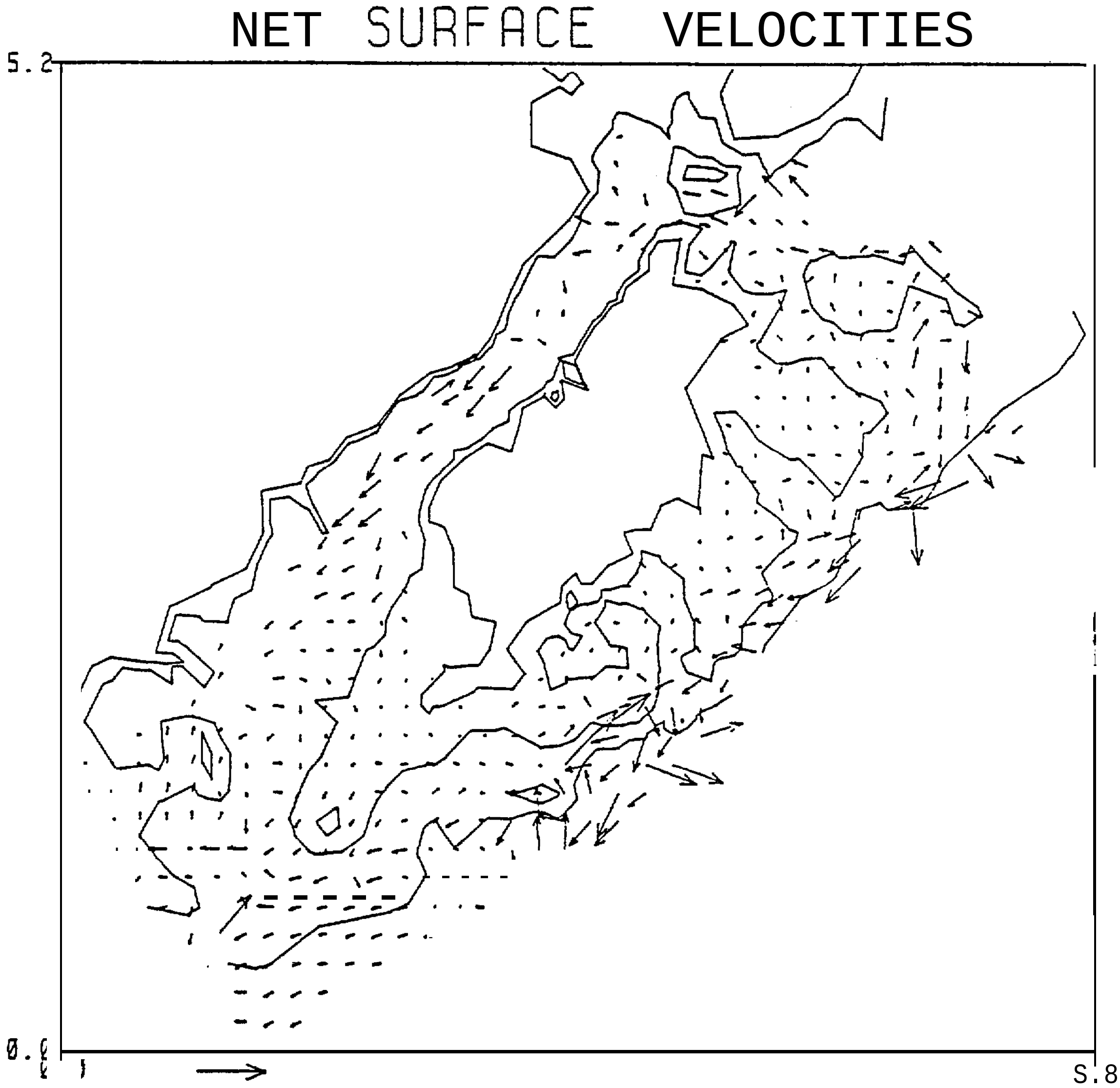

Figure 9c. Composite current vectors showing the sum of the spring average baroclinic mode and a weak negative barotropic mode. Scale arrow indicates 1 m/see current.

The baroclinic data is seen to separate into summer and winter cases with the build-up of baroclinic currents throughout the summertime reflecting higher stratification for the region over the shelf. As the baroclinic fields develop, they tend to enhance the southwest flow over the shelf region off Kodiak, and this flow adds on to the barotropic mode which is basically in the same direction. In summary, Figures 8 and 9 represent the present best estimates of the expected circulation patterns for the Kodiak region. These composites should represent the regional response over a large variety of wind cases and seasonal baroclinic adjustments.

All of the individual baroclinic current patterns as well as the barotropic current pattern for the Kodiak region were forwarded to the USGS' assessment modelers (K. Landfear, USGS, Reston, Vs.) for input into their impact statement considerations. These could obviously be combined into whatever linear combinations make the most sense in the context of their model.

Comparison of Observed Current Features and Model Results

It is of some interest to compare the results of these model studies to observational data that has been collected for the Kodiak region. As a point of departure we may consider the work of Favorite and Ingraham (On Flow in Northwestern Gulf of Alaska, May 1972, Journal of the Oceanographic Society of Japan, Vol. 33, No. 2). In this work, the authors examine the results of an oceanographic cruise and consider some sea bed drifter returns.

The first conclusion of Favorite and Ingraham's work is that the Alaska stream occurs as a strong but narrow current over the outer part of the continental shelf. Average currents are a knot with two knots as the maximum.

The currents are baroclinic and as such would show up in the baroclinic calculations. Earlier studies with the diagnostic model (Third Annual Report to OCSEAP on RU 140, pp. 3-19) specifically considered Favorite and Ingraham's data and completely reproduced this feature, which is not surprising since the baroclinic mode in the diagnostic model degenerated into the classical dynamics heights calculation for deep water cases and the two techniques should give identical results when using the same data. Comparing those earlier results to Figure 6c, it can be seen that for the six cases considered, the data does not extend seaward enough to adequately define the features of the strong Alaska Stream.

A second feature of the regional circulation identified by Favorite and Ingraham relates to the movement of sea bed drifters and their implication on bottom currents. Their Figure 6 indicates the release and recovery points of drifters over Portlock Bank, Marmot Bank, and the northeast sector of Albatross Bank. With the decomposition of the diagnostic model as defined in last year's RU 140 report (Appendix C), the barotropic mode contains all of the bottom currents and the appropriate figure to refer to is Figure 3b. From this we see the model predicts onshore movement over all the banks, consistent with all of the observations. In addition, releases off Dangerous Cape would be projected to move southwest and onshore with good qualitative agreement between the model and observational results. The only bottom drifter release that showed a northeast trend was in the trough south of Marmot Island. In this vicinity the model shows weak bottom flow with a divergence. Close to Marmot Island the flow is predicted to be northeast whereas closer to Kodiak and Chiniak Bay the bottom flow trends southwest.

A third feature identified by Favorite and Ingraham is a gyre over the continental slope south of Albatross Bank. Looking at Figures 6a, 6b, and 6c it can easily be seen that this feature appears in various averages of the baroclinic data and corroborates the results derived from the May 1972 data.

A second study of circulation in the Kodiak region (Circulation and Hydrography Near Kodiak Island September and November 1977, NOAA Technical Memorandum ERL PMEL-13, J. D. Schumacher, R. K. Reed, M. Grigsby, and D. Dreves) can be compared briefly with the model results. This work by Schumacher et al. notes irregular gyre-like patterns over the troughs separating the various sections of Albatross Bank. Figures 3a and 3b clearly show the influence of these features with the general southwest flow over the shelf interrupted by the troughs. In the model results the dynamics associated with these meanders is related to conservation of potential vorticity and closed gyres are not seen. In particular, the flow tends to follow f/d contours with some cross isobath flow due to friction. Within the expected accuracy of either the hydrographic coverage or the model these detailed differences are not resolvable. The general aspects of the flow, however, do agree.

A second observation made by Schumacher et al. described a relatively strong baroclinic current along the Kenai Peninsula. The model did not have data covering that region so no additional insights can be added to their information due to these model studies.

A third study of circulation in the Kodiak Island area (Winter Circulation and Hydrography Over the Continental Shelf of the Northwest Gulf of Alaska, NOAA Technical Report ERL 404-PMEL 31, J. D. Schumacher, R. Sillcox, D. Dreves, and R. D. Muench) presented data on flow through Shelikof Strait and around the complex trough and bank region.

Considering the flow through Shelikof Strait, Schumacher et al. suggest a strong southwest flow that is barotropic. Model results support this view.

Figure 4a indicates that in the spring the baroclinic mode in the northeast sector of the straits is weakly developed, while Figures 3a and 3b show a strong down straight barotropic flow. The amplitude on the barotropic mode is arbitrary and depends on the assumed set-up of the bathystrophic cross shelf pressure gradient. The pattern information, however, is correctly represented and it can be seen from Figure 3a that the magnitude of the flow through Shelikof Strait is comparable to flows over the outer continental shelf, which are known to be on the order of one half to one knot.

Schumacher et al. also discussed current meter observations from Kiliuda Trough and concluded that flow tended to follow isobathic contours (Figure lo). As mentioned earlier, this is also a feature of the model-generated currents.

In summary, the key features of the three observational studies were all supported in the model results where the data covered the region or period of comparison. The basic dynamics and formulation of the model for the Kodiak region appears to successfully reproduce much of the observed flow characteristics as well as offer a means of interpolating the results to regional patterns.

III. Fairweather Ground Study

The second area studied with numerical modeling techniques this year on the Alaskan outer continental shelf was the Fairweather Ground region. The studied area extended from Cross Sound to Yakutat Bay. This section includes a fairly straight but high and rugged coastal region. The shelf varies in width with the major feature being the shallow Fairweather Ground which is made up of a shore area extending some 40 nautical miles offshore. To the northwest of the Fairweather Ground region, a deep trough cuts across the shelf with the hundred fathom isobath coming to within ten miles of shore. Figure 11 indicates the general study area.

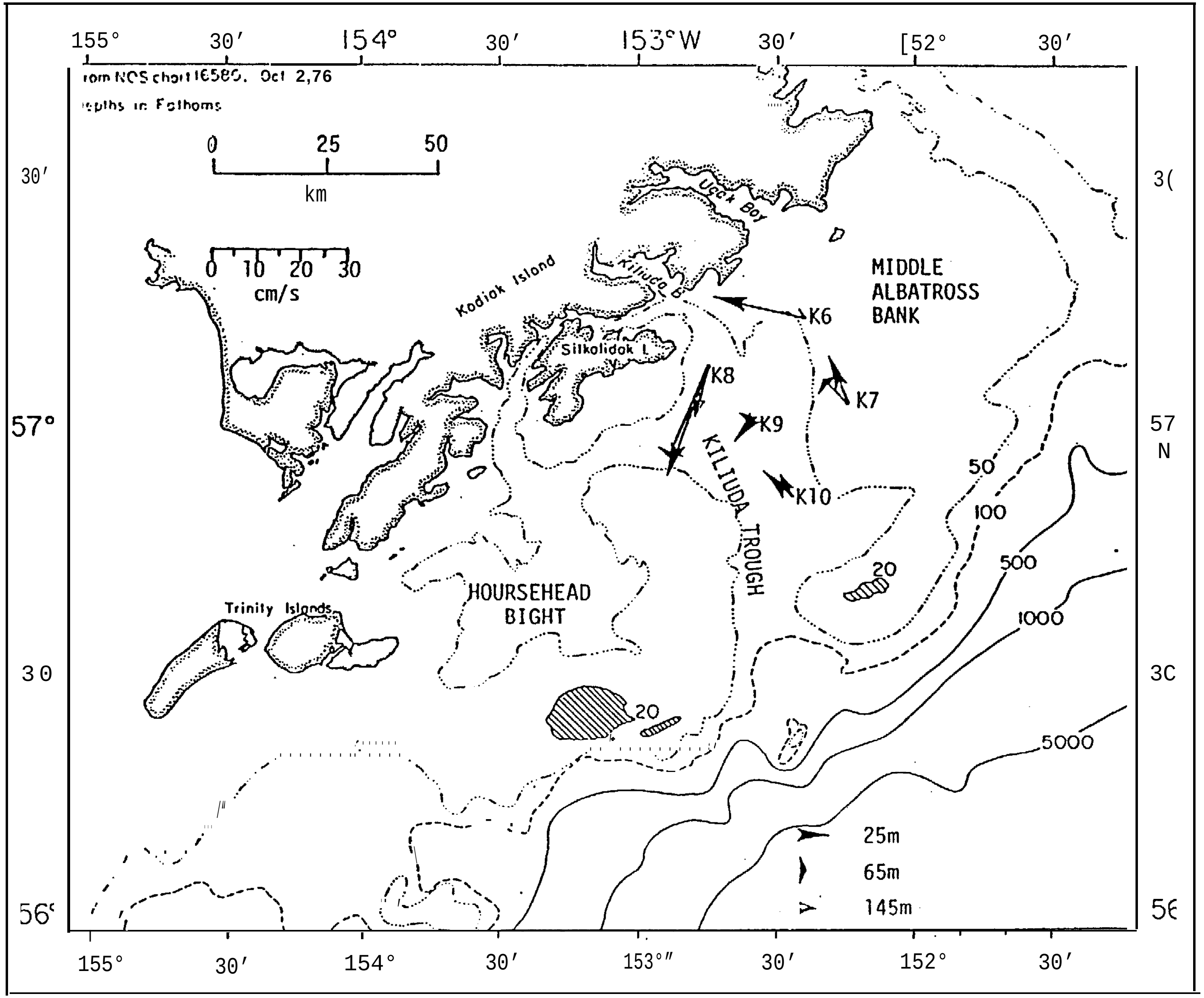

FIGURE 10 **MEAN FLOW** VECTORS FOR OBSERVED CURRENTS: OCTOBER 1977 - MARCH 1978.

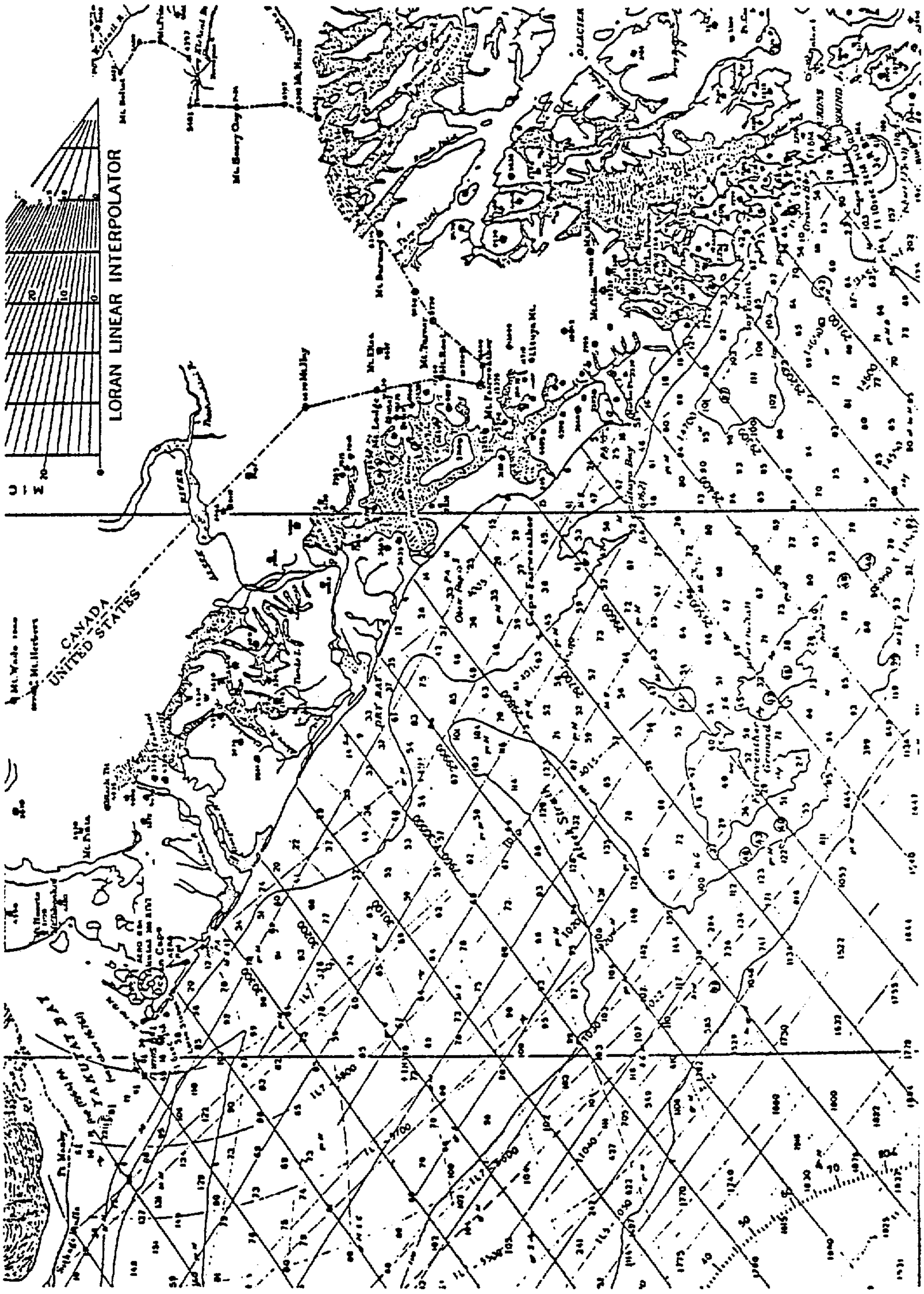

Figure 11. General region covered by the Fairweather Ground study.

Barotropic Mode

The first aspect of the Fairweather Ground study was to obtain estimates of the barotropic current. To do this, a number of vertices were placed over the area to resolve the major bathymetric features and provide the triangular bases for the finite element mode. To do this, a grid of 132 vertices was utilized. The typical or characteristic station spacing was less than five nautical miles. On this grid, a wind set-up perpendicular to the coast was assumed to be in bathystrophic balance. The actual line along which this boundary condition was applied extends perpendicular to the shore cutting off a small section the southeast corner of the domain. This condition resulted in an alongshore circulation pattern which satisfied the basic model dynamics and accounted for the flow over the complex bathymetry. In previous model studies carried out in both real and hypothetical domains questions have arisen as to the fundamental balance between the frictional dissipation in the model and the constraints imposed by conservation of potential vorticity. As one might expect under conditions of strong friction, the flow is smooth and small details in the bathymetry are not significant in causing variations in the flow. A secondary and more fundamental aspect of increasing friction is the decrease in sea surface elevation along the shoreline. Under conditions of high friction, the sea surface will drop as one moves in an along-current direction down the coast. This alongshore gradient in the pressure is probably a fundamental characteristic of the regional flow and plays an important role in determining how to impose the bathystrophic balance conditions for the model.

For the present model study the relative effect of the frictional parameter and the alongshore pressure gradient was investigated in a series of tests. This was done by running the model repeatedly with variations in the frictional parameter. The results of the flow can easily be seen in the surface elevation contour plots presented in Figure 12. Figure 12a represents the surface elevation contours plotted for the minimum frictional case. Figures 12b, 12c, and 12d each represent successively higher frictional values. Several characteristics of the flow are immediately obvious. For the low friction case, the flow has considerably more spatial details and small scale variations in the bathymetry results in perturbations of the flow direction. Some regions of the bathymetry cause closed eddies or gyres. This is particularly apparent south of the Fairweather Ground. A second aspect of the increased frictional cases is the drop is sea surface elevation as you progress from southeast to northwest along the coastline. A third aspect of the barotropic flow patterns is the general tendency for northerly flow across the Fairweather Bank region followed by a loop in the current nearshore which turns in a counterclockwise direction and then leads offshore along the northern edge of Alsek Strath. This northerly flow across the Fairweather Ground and return flow appears to be independent of the frictional parameter and is a consistent feature for any reasonable value.

Figure 13 shows a vector plot corresponding to the sea surface elevation contours shown in Figure 12. Figure 13a represents the minimum frictional case with Figures 13b, 13c, and 13d corresponding to increasing frictional values. It is obvious that increasing the frictional parameterization leads to smoother flow patterns and the northerly flow across the Fairweather Ground and recirculation or counterclockwise circulation around Alsek Strath is clearly seen for all cases.

Baroclinic Mode

To estimate the baroclinic component of the flow for the Fairweather

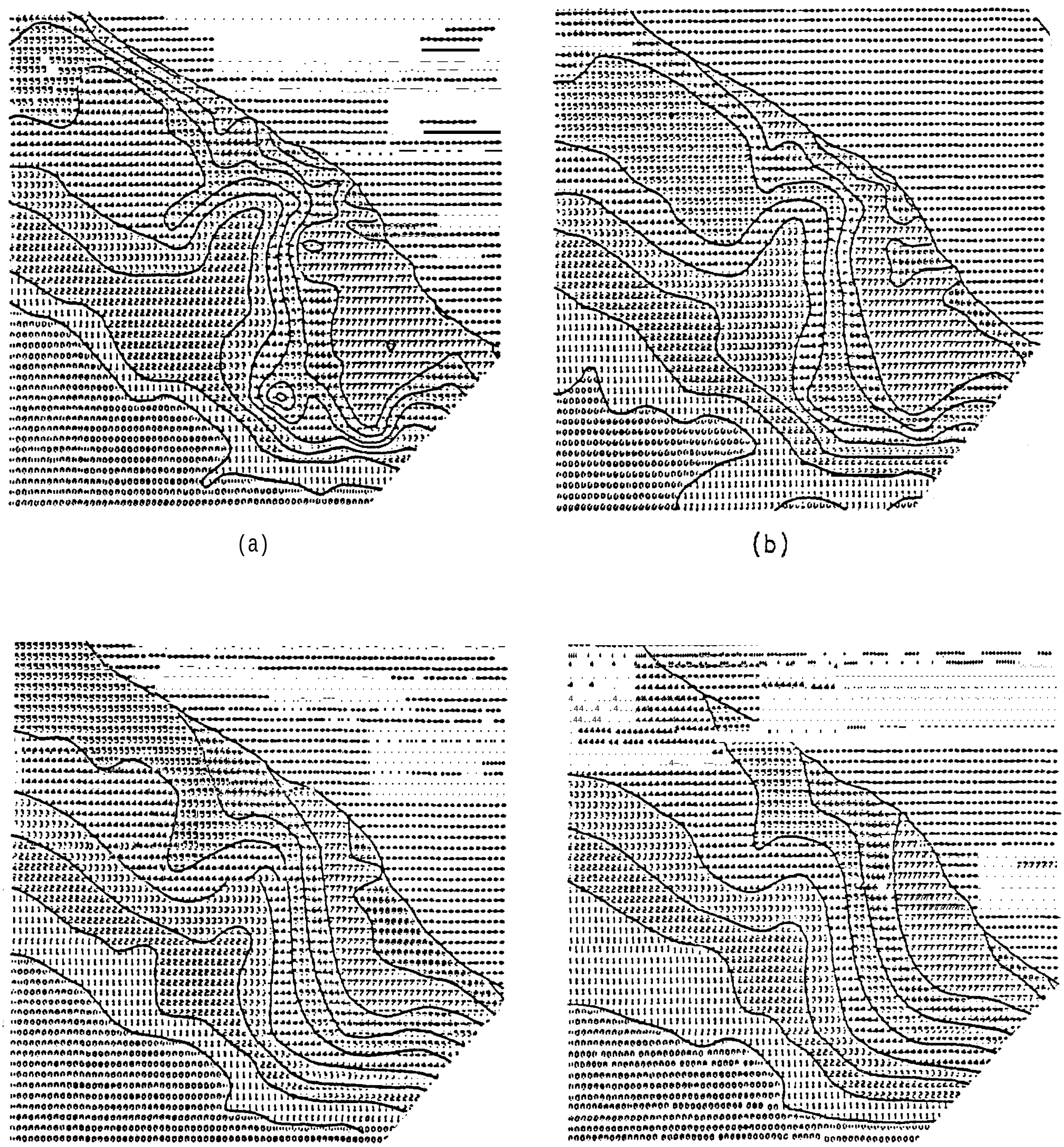

Figure 12

Sea surface elevation contours for the FairWeather Ground barotropic mode. The four figures correspond to increasing frictional effects with the minimal friction seen in case a and the maximum friction seen in case d.

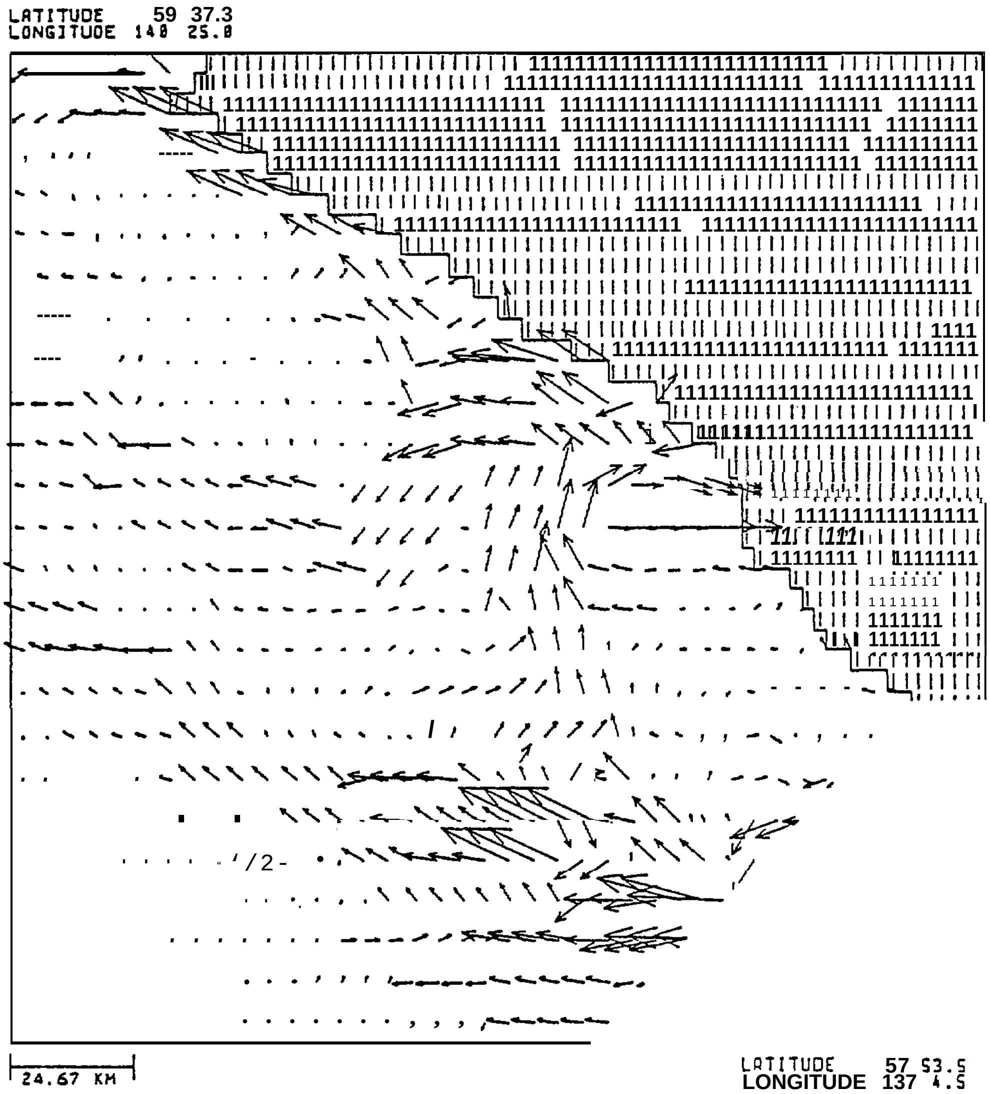

Figure 13a. Current vector arrows for the Fairweather Ground barotropic mode minimum frictional case.

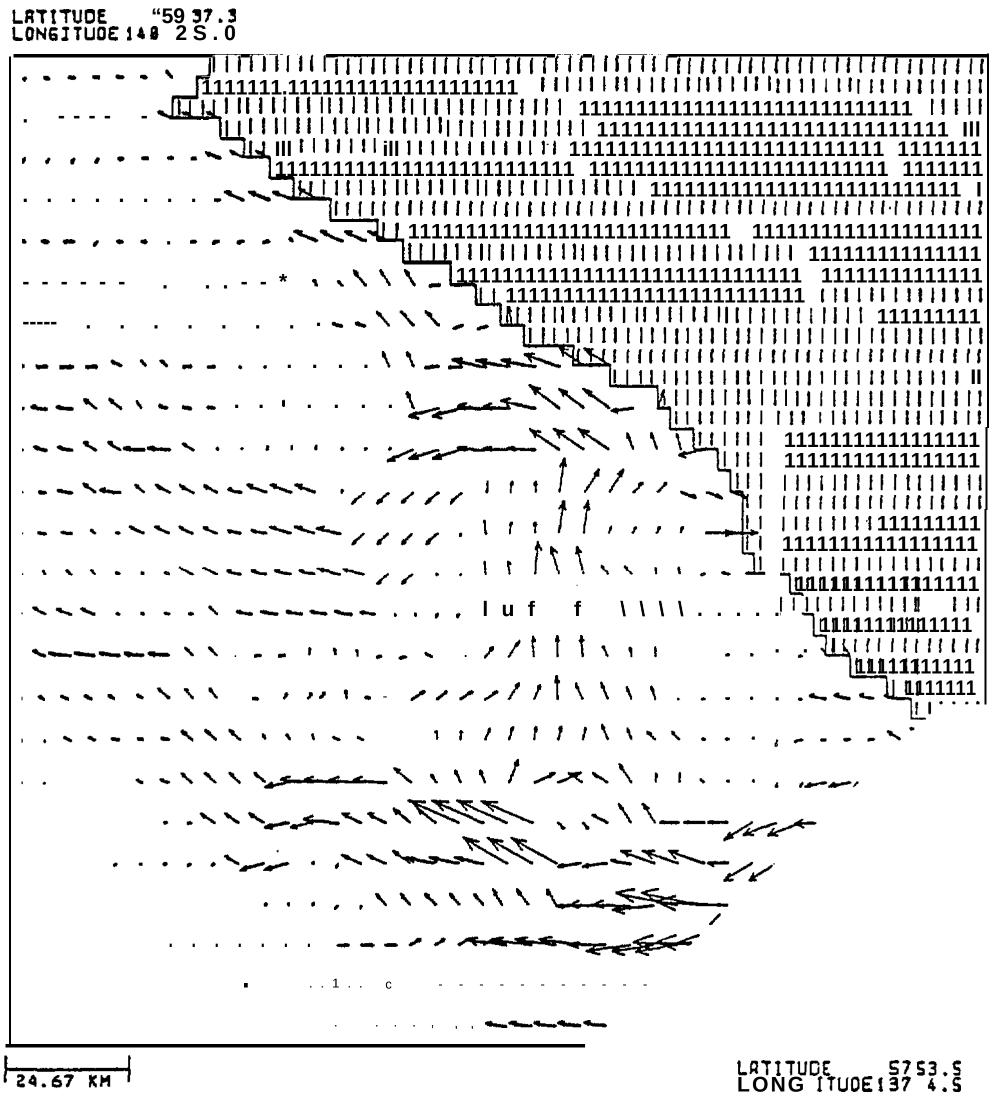

Figure 13.b. Current vector arrows for the Fairweather Ground barotropic mode low frictional case.

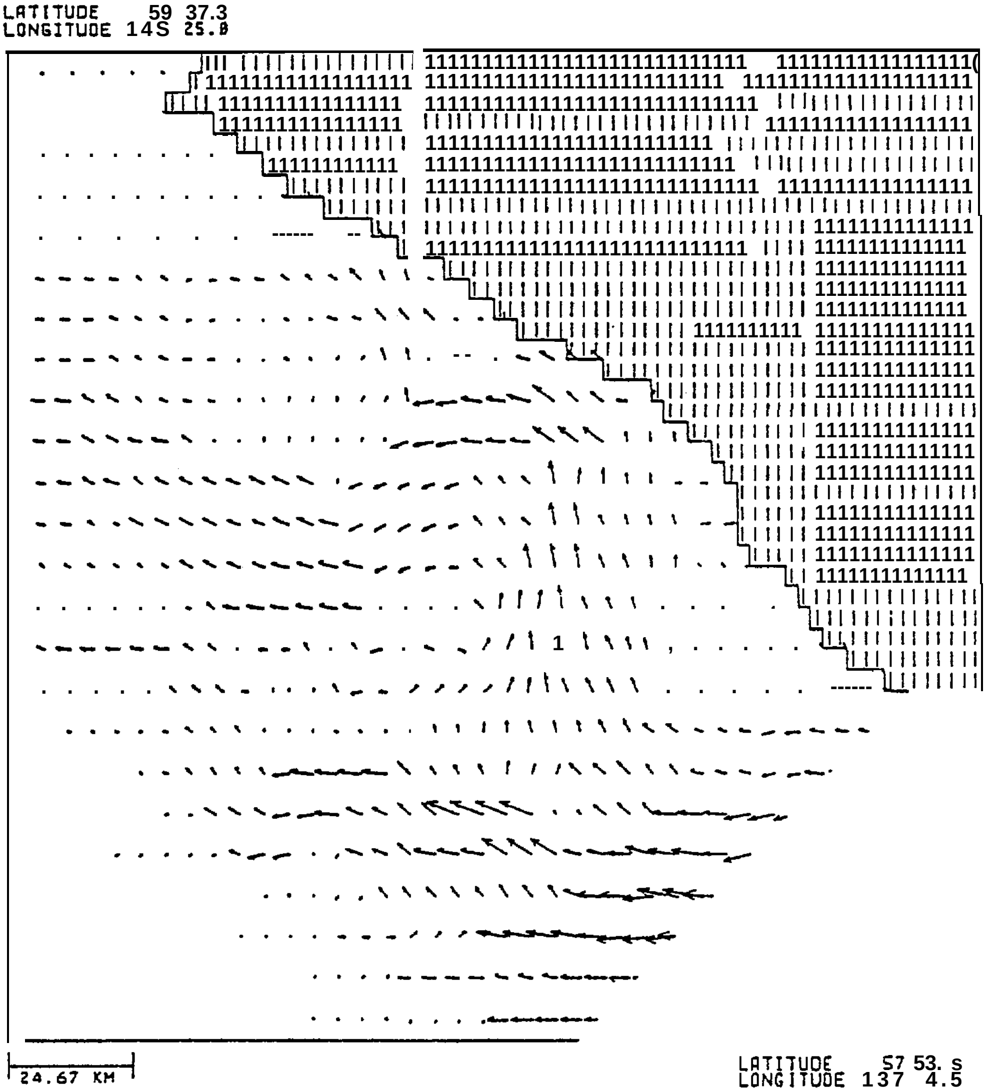

Figure 13c. Current vector arrows for the Fairweather Ground barotropic mode moderate frictional case.

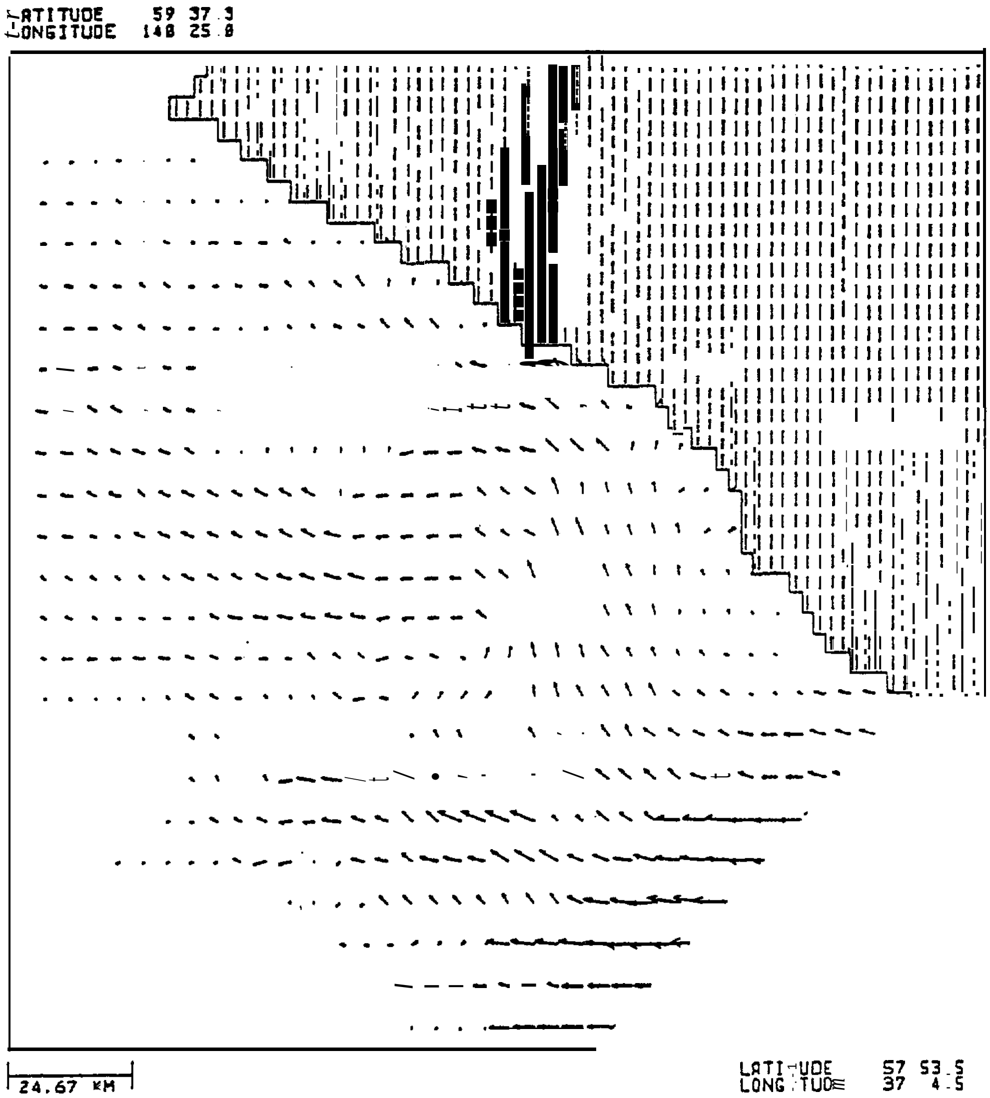

Figure 13d. Current vector arrows for the Fairweather Ground barotropic mode maximum frictional case.

Bank region, a data set from March 1979 was used. At the time of the study, this was the only available set of density stations. One hundred and seven stations were available and their relative coverage and the finite element triangular mesh associated with this data set are shown in Figure 14. Calculations of the baroclinic components of the current are shown in Figure 15. Several characteristics of this flow may be noted: 1) The Alaskan Stream is clearly evident in the southwest corner of the region. Here, a fairly uniform current is seen to move to the northwest along the outer edge of the shelf region and over the continental slope. Typical speeds of this current appear to be in excess of one knot; 2) Over the shelf region itself flow is generally weak but baroclinic currents do appear to develop over the Alsek Strath region with a general tendency for anti-cyclonic flow to the north of the Strath and cyclonic flow south of the Strath and cyclonic flow south of the Strath and in the vicinity of the Fairweather Bank region; 3) A third characteristic of the baroclinic flow pattern is the relative"ly noisy appearance of the current along the shelf break region. As notedin previous studies, it is difficult to obtain sufficient data to resolve the strong baroclinic field and bathymetric interactions that take place along the shelf break.

Composite Regional Currents

The composite current for the Fairweather Ground region will be represented by a combination of the baroclinic and barotropic fields. The barotropic pattern information was seen to depend on a choice of frictional parameter which related to the relative balance between the bottom frictional effects and the constraints associated with conservation of potential vorticity. These also depended on the alongshore pressure gradient.

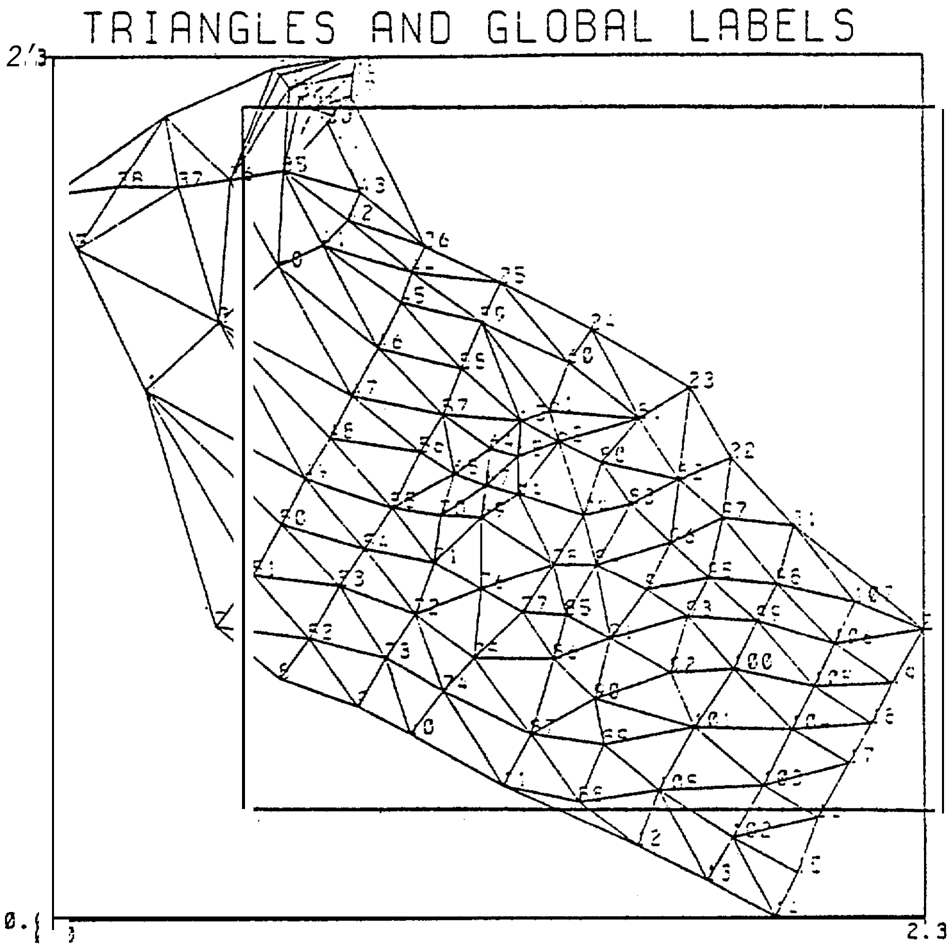

Figure 14. Representation of triangular grid used to calculate baroclinic currents for Fairweather Ground study area. Inner rectangle shows area covered by barotropic mode calculations.

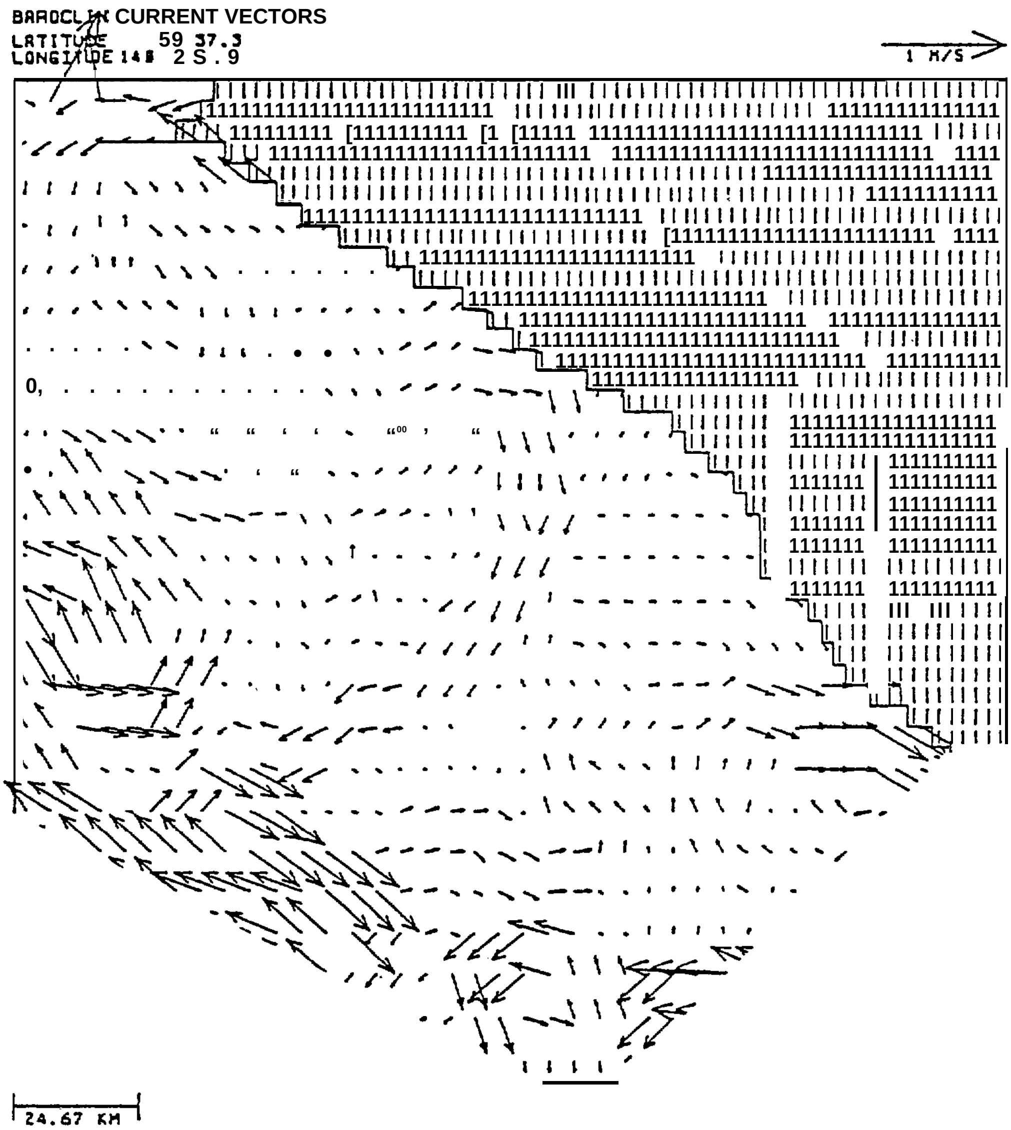

Figure 15. Baroclinic current vector arrows for Fairweather Ground study region based on March 1979 data.

For the present study, it was assumed that the flow pattern represented in Figures 12c and 13c was the most realistic realization for the barotropic current field. Figure 16 represents a combination of this barotropic pattern and the baroclinic information shown in Figure 15. Figure 16a corresponds to an onshore set-up of the sea surface as would be typical of a wind stress to the northwest along the coast. The implied bathystrophic balance at the southeast edge of the model indicates an upslope along the model edge as one proceeds onshore. Figures 16b and 16c correspond to decreasing wind stress cases. These are obtained by decreasing the amplitude of the barotropic pattern as it is algebraically added to the baroclinic flow pattern. Figure 16d represents a wind case where the alongshore component of the wind stress is to the southeast. To relate these figures back to more characteristic weather patterns the flow shown in Figures 16a, 16b, and 16c would correspond to a typical cyclonic circulation over the Gulf of Alaska that would be characterized by an atmospheric low pressure over the central Gulf. Figure 16d would correspond to a weaker, possibly summertime pattern associated with anti-cyclonic flow in the atmosphere over the Gulf of Alaska. In general, these composite current fields shown in Figure 16 can be taken as current estimates which span the likely variations expected in the flow. For pollutant trajectory work these current patterns represent the total surface flow less whatever Ekman or Stokes drift is assumed appropriate for the pollutant in question.

IV. Conclusions

Modeling studies have been carried out for two outer continental shelf regions of Alaska. Techniques developed over the five year history of RU 140 were applied to obtain estimates of the flow suitable for trajectory assessment experiments.

The general circulation patterns developed for the Kodiak Island region include information from six oceanographic cruises. These data sets appear to give a reasonable definition of the baroclinic mode for the flow during spring and fall periods. In addition, a three month series of cruises in the spring of 1978 gives an indication of the summer buildup of the regional baroclinic fields. The general cycle of the baroclinic flow for the region is seen to build up during the springtime with higher stratification effects in the late summer or early fall. During the wintertime, the baroclinic structure breaks down with lower baroclinic currents occuring in the late winter or early spring. Repeated sets of data indicate a clockwise gyre in the vicinity of the shelf break south of the Trinity Islands. The general direction of the baroclinic flow tends to be southwest at the surface over the region of the continental shelf offshore of Kodiak Island. This flow direction tends to enhance the barotropic mode for the region.

The barotropic mode for the Kodiak Island region was studied with a high resolution finite element mesh. In general, the alongshore flow is controlled by the bathymetry with the bank and trough system as the dominant steering features. The general flow is to the southwest with onshore meanders in the currents associated with the northwest or leading edge of the troughs. As the stream continues, offshore flow is seen on the downstream or southwest regions of the troughs. This is particularly apparent over the Kiliuda Trough region which is situated southwest of Middle Albatross Bank.

West of the Marmot Bank region, a deeper trough extends parallel to the shore of Kodiak Island. A southwesterly current is seen to be present here under the dominant influence of cyclonic atmospheric conditions in the Gulf of Alaska.

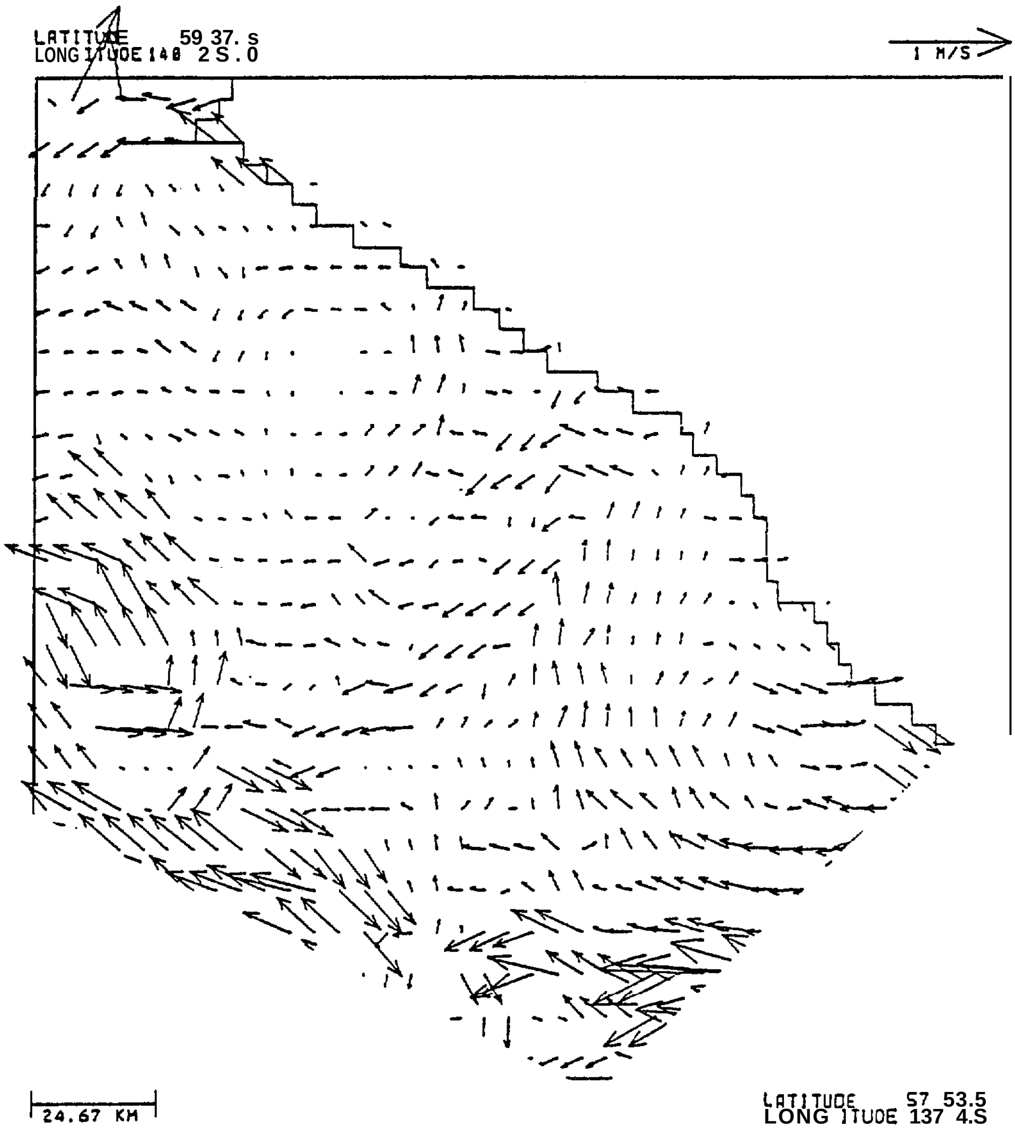

Figure 16a. Composite current vector arrows showing the sum of the baroclinic mode for March 1979 plus the strong barotropic mode.

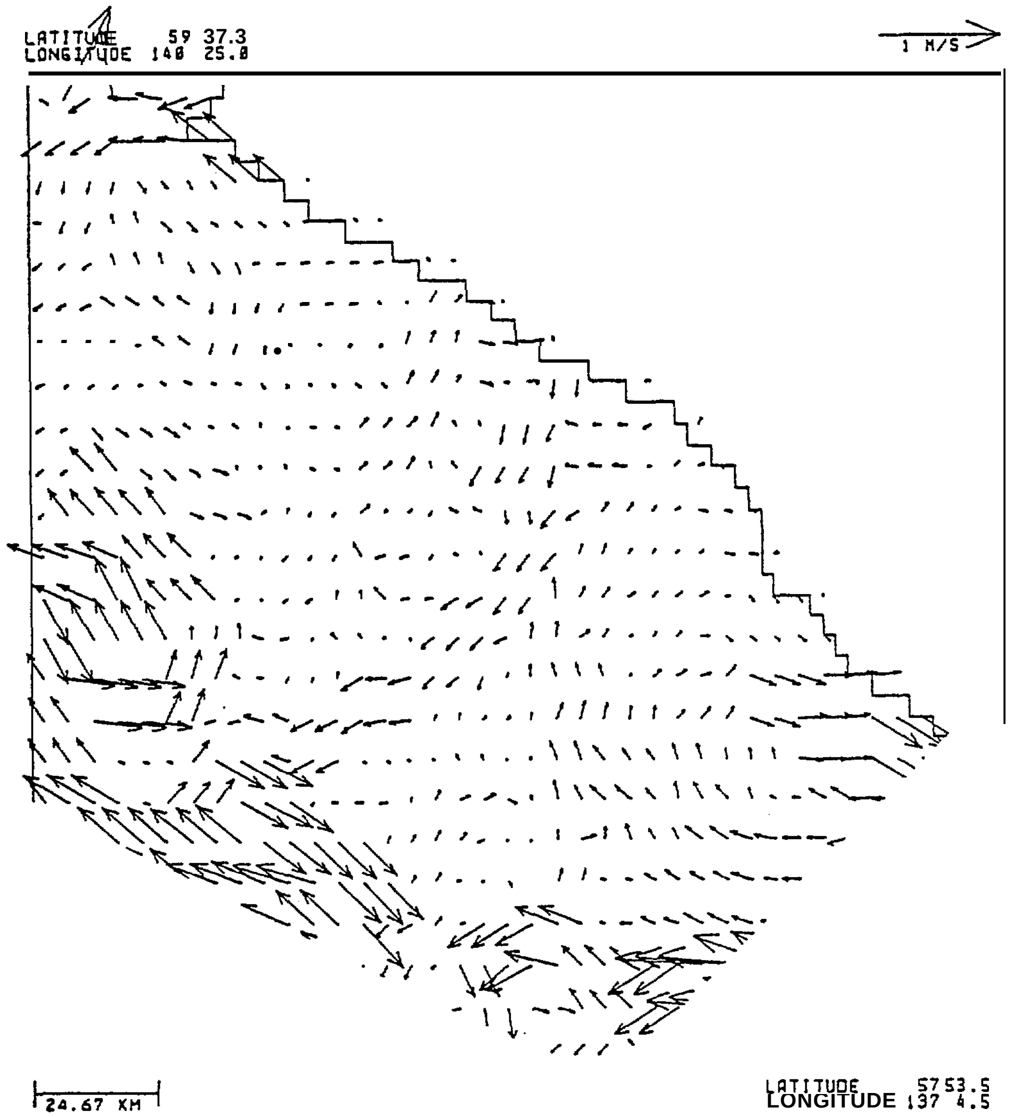

Figure 16b. Composite current vector arrows showing the sum of the baroclinic mode for March 1979 plus the moderate barotropic mode.

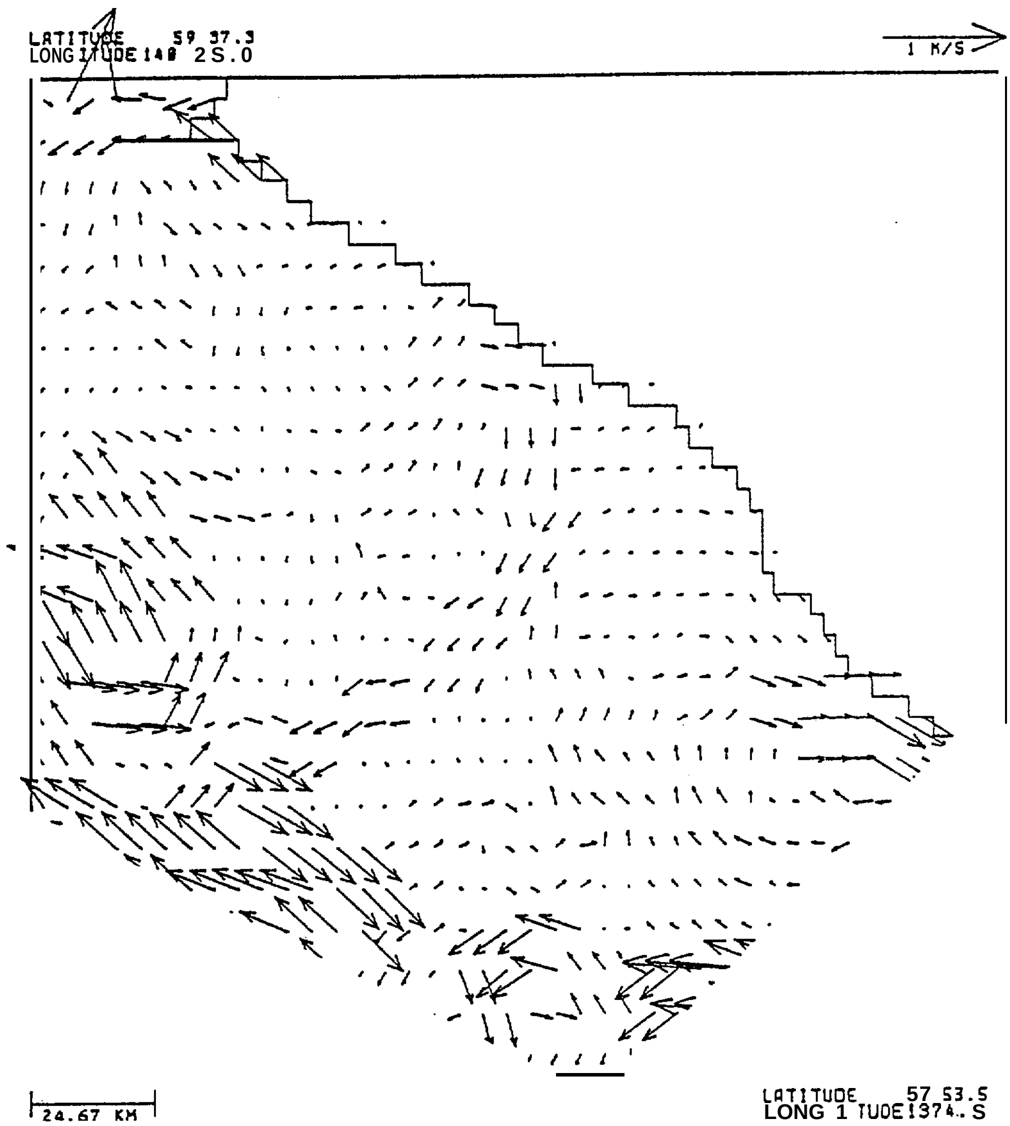

Figure 16c. Composite current vector arrows showing the sum of the baroclinic mode for March 1979 plus the weak barotropic mode.

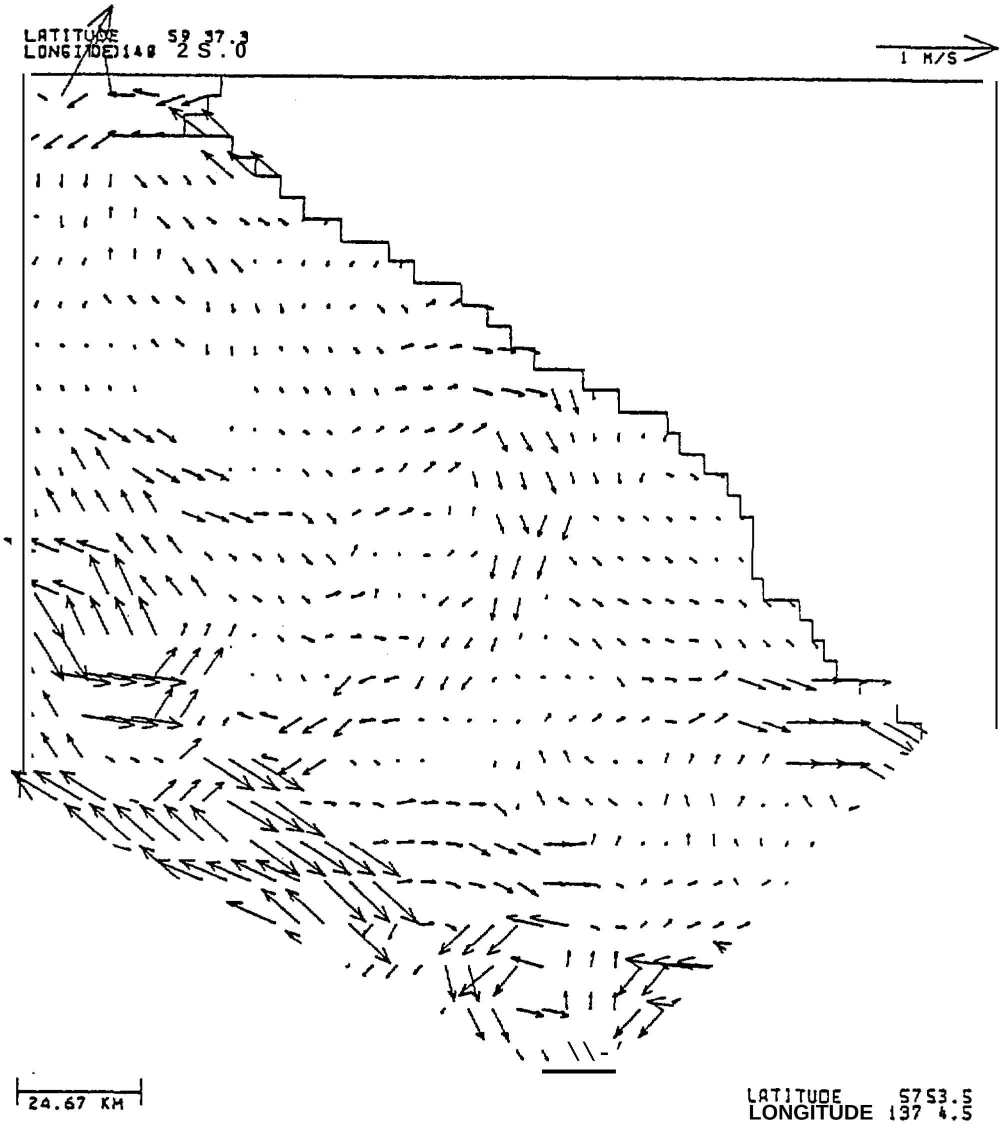

Figure 16d. Composite current vector arrows showing the sum of the baroclinic mode for March 1979 plus the small negative barotropic mode.

The amplitude associated with the barotropic mode depends on the regional wind stress. The dominant or characteristic flow direction is to the southwest resulting from low atmospheric pressure in the Gulf of Alaska. In general, the winter patterns are expected to be stronger than the summertime patterns because of the increased intensity of this characteristic low pressure circulation in the atmosphere over the Gulf of Alaska. This tends to compensate for the decreased baroclinic mode which weakens during the winter period. The genera? balance, then, appears to be dominated by barotropic flow conditions during the winter period and a combination of baroclinic and barotropic forcing during the summertime. Under nearly all conditions, the flow tends to be to the southwest and the influence of the bank and trough bathymetry is clearly seen.

Comparisons of observational studies and model output indicate that mean flows in the Kodiak area are well represented by the derived patterns.

The Fairweather Ground region was studied with the use of one set of oceanographic data which was collected during the spring of 1979. The baroclinic field was dominated by the Alaskan Stream which flowed to the northwest along the outer edge of the continental shelf. A secondary baroclinic circulation was seen to result in a clockwise circulation over the Alsek Strath and northern section of the Fairweather Ground.

The barotropic mode for the Fait-weather Ground was studied with a parametric exploration of the effects of friction on the flow patterns. It was seen that the relative importance of the frictional terms could be related to the alongshore gradient in the pressure. For all of the cases considered, a northerly flow was seen over the Fairweather Ground region. This extended towards the inshore end of Alsek Strath, at which point a counterclockwise circulation develops in the flow. This counterclockwise curvature extends the current around the end of the Strath and back out across the shelf to the north. For the one case studied, the baroclinic mode tended to dominate the flow along the outer edge of the continental shelf with the barotropic mode dominating over the shelf proper and in the vicinity of the Fairweather Ground and Alsek Strath region.

Current estimates for the Fairweather Ground region have now been processed in OSSM (On-Scene-Spill-Model) which is used routinely for trajectory model experimental studies. In this format, the data can be easily used to study pollutant distributions for the region.