NOAA Technical Report ERL 452–PMEL 42

Water Properties Over the Bering Sea Shelf: Climatology and Variations

R.K. Reed

May 1995

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Environmental Research Laboratories

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Seattle, Washington

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U.S. Department of Commerce
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Contribution No. 1652 from NOAA/Pacific Marine Environmental Laboratory

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Abstract. This study examines climatological water properties over the southeastern Bering Sea shelf during 1974–90. Maps of surface and bottom temperature, surface and bottom salinity, and mixed-layer depth are derived and presented for winter, spring, summer, and fall. Surface temperatures range from about –1 to 10°C over the year. Bottom temperatures range from about –1 to 7°C but are colder than surface temperatures except in winter. The patterns of bottom temperature and salinity indicate the path of inflow from Unimak Pass. Surface salinities vary from ~31.2 to 32.5‰; bottom salinities range from ~31.4 to 33.0‰. Mixed-layer depths are deepest (>50 m) in winter and fall and shoalest in summer (<15 m). Waters inshore of 50 m are not always well mixed, in contast to findings in other studies. The most extreme bottom water temperatures (3°C colder than normal) occurred in 1976 as a result of extensive ice cover in winter.

1. INTRODUCTION

The continental shelf of the southeastern Bering Sea (Fig. 1) is a vast area that constitutes about one-third of the entire sea south of 60°N. On the western or Russian side of the sea, however, the shelf (depths <200 m) is relatively narrow. The deep basin, to the west of the area in Fig. 1, has maximum depths of ~4000 m; its circulation system is mainly dependent on northward inflows, through deep passes in the Aleutian Islands, of the westward-flowing Alaskan Stream (Favorite, 1974; Stabeno and Reed, 1994). The shelf area in Fig. 1 is largely decoupled from the oceanic circulation. Instead, circulation results from an inflow of relatively warm, fresh coastal water through Unimak Pass, with some influence from oceanic flow on the outer shelf. The most striking feature about the circulation over the shelf is its very weak net speeds, which range from about 1 to .5 cm s^{-1} (Schumacher and Kinder, 1983; Coachman, 1986). This extremely weak circulation permits the atmosphere to have the dominant influence on shelf-water properties (Niebauer and Day, 1989).

Water properties (temperature and salinity) over the shelf vary greatly, mainly in relation to season and bottom depth (Reed, 1978; Kinder and Schumacher, 1981). In winter, temperature and salinity are nearly homogeneous in the vertical in depths ≤100 m. This results from minimal insolation and strong winds, which vigorously stir the water column and also induce large latent and sensible heat fluxes. In summer, the opposite extreme occurs; winds are weak, and the water heat budget is dominated by absorption of solar radiation (Reed, 1978). In depths ≤50 m, however, there is a yearlong semihomogeneous water column as a result of overlapping wind and near-bottom tidal stirring (Kinder and Schumacher, 1981). In depths between 50 and 100 m, except in winter, there is a two-layer temperature and salinity structure because the wind and tidal mixed layers do not overlap. Farther offshore, water structure is essentially oceanic in all seasons.

At present, the Fisheries Oceanography Coordinated Investigations (FOCI) program of the National Oceanic and Atmospheric Administration (NOAA) is actively engaged in research on walleye pollock and the environment in the shelf area shown in Fig. 1. As part of FOCI, a climatological summer circulation was derived for the shelf area (see Fig. 1). Data on water properties are also needed, especially for the 1970s and 1980s when most of the fisheries data were obtained. The present study is thus an effort to derive climatological thermohaline conditions over the shelf during 1974–90, and also to examine year-to-year variations from climatology. It is hoped that this will establish a useful baseline of environmental conditions that can aid fisheries research.

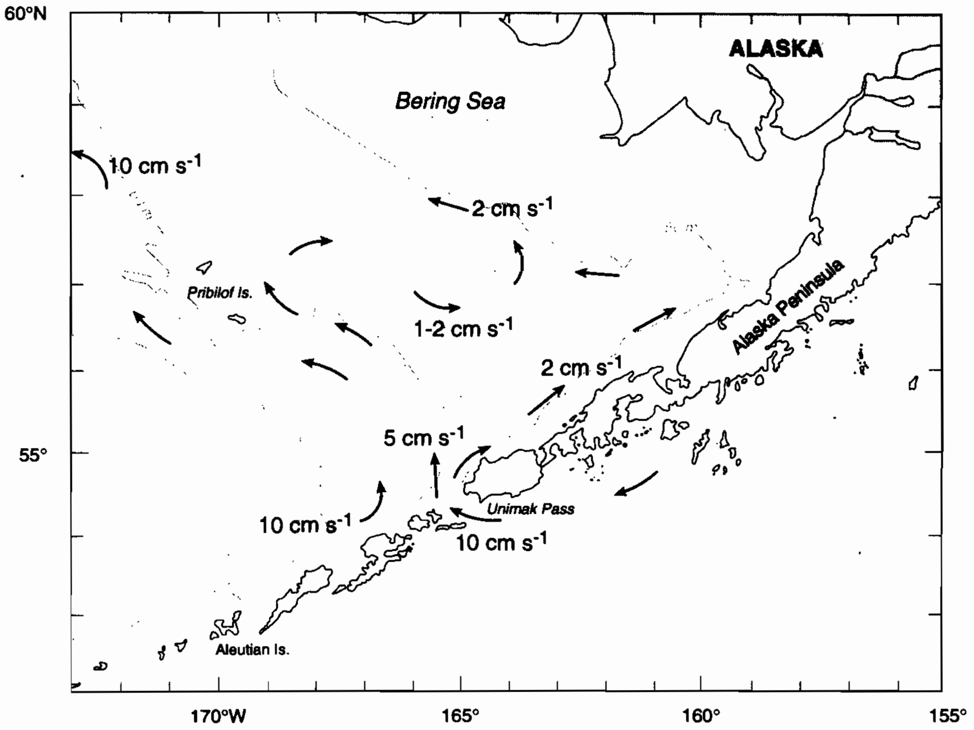

Figure 1. Location of the study area, showing the typical net circulation and the 50-, 100-, and 1000-m isobaths.

2. DATA AND METHODS

The data file used was from the National Oceanographic Data Center; it contained data from conductivity, temperature, depth (CTD) sensors. The data are available for 1974–90 for the eastern Bering Sea shelf. These data generally have better resolution or accuracy than earlier data from bottle casts or bathythermographs. Hence only this CTD data file was used here.

Data from each CTD cast were examined for quality. No data were used from casts that appeared to have spurious values of temperature or salinity. No casts were used that did not start within 5 m of the sea surface or reach within 20 m of the bottom (as determined from listed bottom depths or estimates). A few casts were rejected as a result of implausibly large density inversions.

Data were averaged over areas of 0.5° latitude by 1.0° longitude (~50 × 50 km). This is a compromise between spatial resolution and data availability. There are no data in this file for the month of December, and data for January and November are very sparse. It was decided to produce seasonal distributions by averaging over the following periods: winter (February–March); spring (April–May); summer (July–August); and fall (October–November). Note that data from June and September were not used even though they are fairly abundant. Values in these months were quite variable and appear to reflect year-to-year differences in the seasonal cycle so that, for example, June in one year might be more typical of spring but in another year might be closer to summer conditions. Use of the 2-month seasons tends to produce fairly homogeneous data sets.

Within each 0.5° × 1.0° area for each season, a logical method had to be chosen for averaging over time. Data from 25 time series (at 13 individual sites), generally of 6- to 25-h duration,

Table 1. Seasonal mean standard errors of estimate (and their standard deviations) of surface and bottom temperature, surface and bottom salinity, and mixed-layer depth, using independent estimates as discussed in the text, for 1974–90

	Winter (Feb.–March)	Spring (April–May)	Summer (July–Aug.)	Fall (Oct.–Nov.)
No. of areas with three or more estimates	23	48	37	16
Surface temperature (°C)	0.7 (0.3)	0.7 (0.4)	0.6 (0.4)	0.5 (0.2)
Bottom temperature (°C)	0.6 (0.4)	0.4 (0.4)	0.7 (0.4)	0.5 (0.2)
Surface salinity (‰)	0.08 (0.05)	0.11 (0.06)	0.11 (0.06)	0.10 (0.12)
Bottom salinity (‰)	0.09 (0.06)	0.07 (0.03)	0.08 (0.05)	0.09 (0.04)
Mixed-layer depth (m)	11 (13)	6 (4)	3 (2)	8 (3)

The standard deviations of the standard errors of the estimates are given in parentheses.
For depths >100 m, values at 100 m are used as bottom values.

indicated small variations. The mean standard errors for these time series (standard deviations divided by the square root of the number of values) were as follows: surface temperature, 0.14°C; bottom temperature, 0.04°C; surface salinity, 0.04‰; bottom salinity, 0.02‰; and mixed-layer depth, 7 m. It is thus apparent from these small values that data taken closely together in time are probably highly correlated and are not likely to be independent estimates. (There is also an implication that tidal effects, on the water properties used here, are small.) It was therefore decided to consider an "independent estimate" as the mean of all values within an area in an individual month, such as August 1980. (Means from time series stations were considered as single values.) The standard errors of these independent estimates are given in Table 1. The mean values for temperature and salinity are ~0.6°C and ~0.1‰, respectively. Thus contour intervals of 1.0°C and 0.2‰ were used for the climatology. In general, the values in Table 1 reflect year-to-year or interannual variability; except for surface temperature and bottom temperature in shallow water, the interannual variability is greater than the seasonal variability discussed in Secs. 3.2–3.4.

The number of independent estimates for each area for each of the four seasons is shown in Fig. 2. (Each area used had at least three independent estimates.) The number of estimates varied from 3 to 11. The mean numbers of estimates per area were 4.0, 5.5, 4.8, and 3.2 for winter, spring, summer, and fall, respectively (Fig. 2). The number of areas with three or more estimates were 23, 48, 37, and 16 for winter, spring, summer, and fall, respectively. The total number of CTD stations used was 2239, with 269, 1330, 475, and 165 being in winter, spring, summer, and fall, respectively.

3. CLIMATOLOGY

Seasonal maps of surface temperature, bottom temperature, surface salinity, bottom salinity, and mixed-layer depth are shown in this section and discussed. The data used extend over the period 1974–90. In water depths >100 m, temperature and salinity values at 100 m are used, rather than actual bottom values, to allow more reasonable comparisons with near-bottom data in inshore waters.

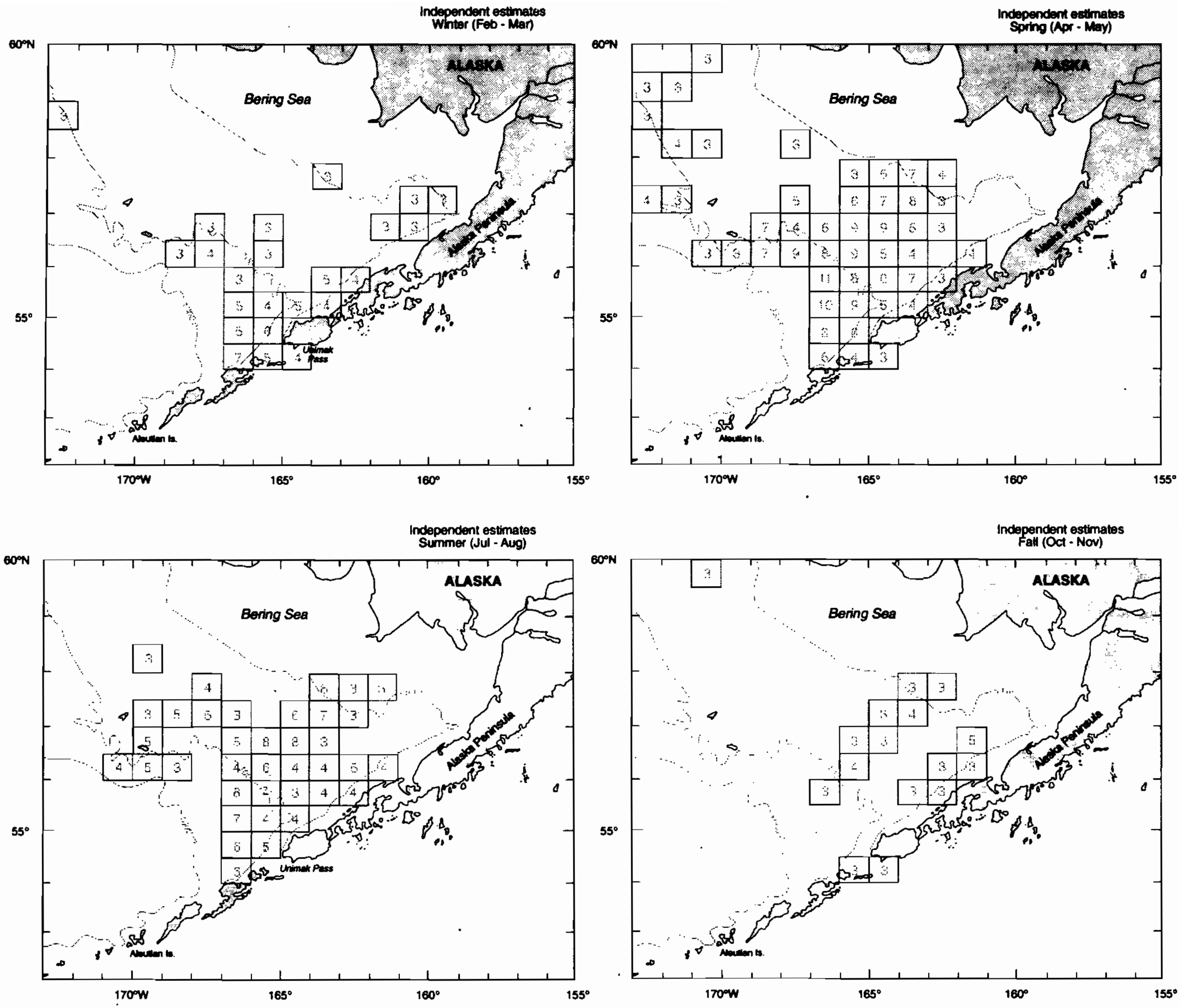

Figure 2. Number of independent estimates in winter, spring, summer, and fall, 1974–90.

3.1. Surface Temperature

Surface temperature distributions for the four seasons are shown in Fig. 3. In all seasons, data are sparse north of 58°N; in winter and fall, there are numerous data gaps elsewhere as well. In winter, temperatures vary from about –1 to 3°C, with the highest temperatures being near the Aleutian Islands. In spring, temperatures vary from about –1 to 4°C. Although spring temperatures north of 57°N are similar to those in winter, waters to the south are ~1°C warmer than in winter. In summer, temperatures vary only from about 8 to 10°C. The warmest water is near 56°N, from 163 to 165°W. Fall temperatures vary only from about 7 to 8°C, except for one cool value north of 59°N.

3.2. Bottom Temperature

South of 56°N, bottom water temperatures (Fig. 4) in winter are slightly warmer than surface temperatures. North of 57°N near the 50-m isobath, temperatures at the two levels are similar. In spring, bottom water temperatures vary from about –1 to 4°C; they are slightly cooler than surface temperatures south of 57°N. Note the alignment of the 3°C isotherm along the Alaska Peninsula and similar features in summer and fall. This reflects advection of warm subsurface water through Unimak Pass and along the north side of the Alaska Peninsula (see Fig. 1; Schumacher and Kinder, 1983; Coachman, 1986). Bottom temperatures in summer vary from about 1 to 5°C. Note the large region of temperatures <2°C. In fact, some of the temperatures here are colder than in spring. This very likely results from substantial amounts of the summer data, but not the spring data, being from 1976, which was a very cold year (discussed in Sec. 4). Another interesting feature in the summer data is that bottom temperatures inshore of 50 m near ~57.8°N (Fig. 4) are ~2–3°C colder than at the surface (Fig. 3); shoal waters near the Alaska Peninsula have even more pronounced differences. This is surprising because of the consensus (Kinder and Schumacher, 1981; Coachman, 1986) that waters inshore of 50 m are generally well mixed because of combined tidal and wind stirring. Closer examination of their results, however, shows that small vertical gradients are not atypical. Fall has the warmest bottom waters (about 4 to 7°C, except for 1.8°C north of 59°N), but they are typically 1–2°C cooler than the surface waters. The waters inshore of 50 m are warmer than 7°C, which may result from both advection and enhanced vertical mixing in the shoal water.

3.3. Surface Salinity

Surface salinities are shown in Fig. 5. Crowding was avoided by omitting the first digits of the values listed (that is, 2.00 is actually 32.00‰). The winter values range from about 31.4 to 32.4‰; ranges and values in other seasons are similar, except both the range and the mean value in fall are smaller. The pattern of isohalines indicates low-salinity water in Unimak Pass extending northeastward along the Alaska Peninsula. This results from low-salinity coastal water from the Gulf of Alaska flowing through the pass (Royer, 1981; Schumacher et al., 1982); this water has lowest salinity in fall, as indicated in Fig. 5.

3.4. Bottom Salinity

Salinities near the bottom (Fig. 6) also show the effects of the low-salinity inflow through Unimak Pass. Salinities during the four seasons do not differ markedly. The range is typically from 31.4 to 32.8‰, which is slightly larger than at the surface. Near the 100-m isobath, bottom values are generally about 0.5‰ greater than surface values. The highest bottom salinities (or values at 100 m in greater depths), 33.1‰, are present west of Unimak Pass in summer. One speculation is that this might represent an enhanced inflow of oceanic water to the inner slope.

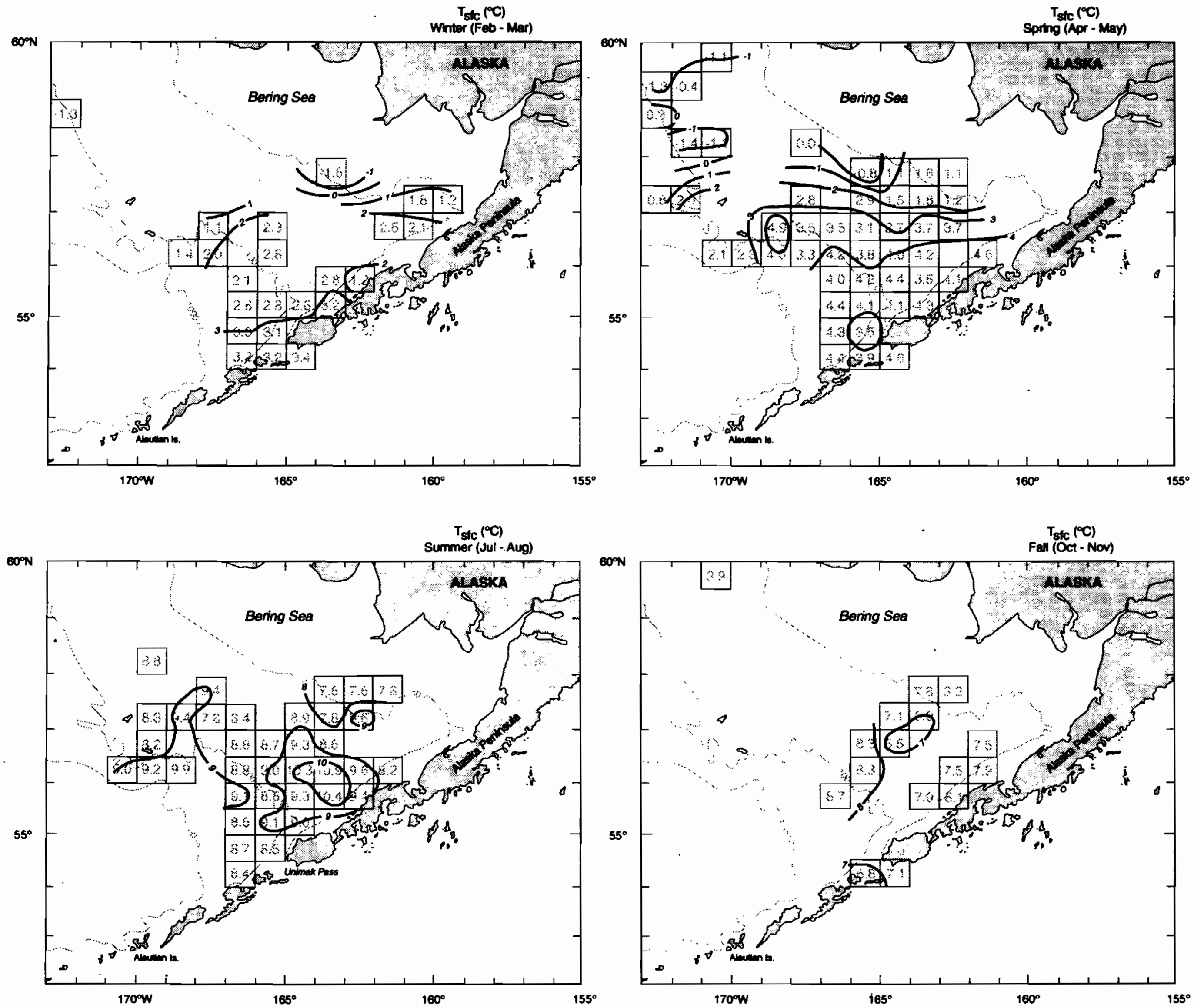

Figure 3. Sea surface temperature (°C) in winter, spring, summer, and fall, 1974–90.

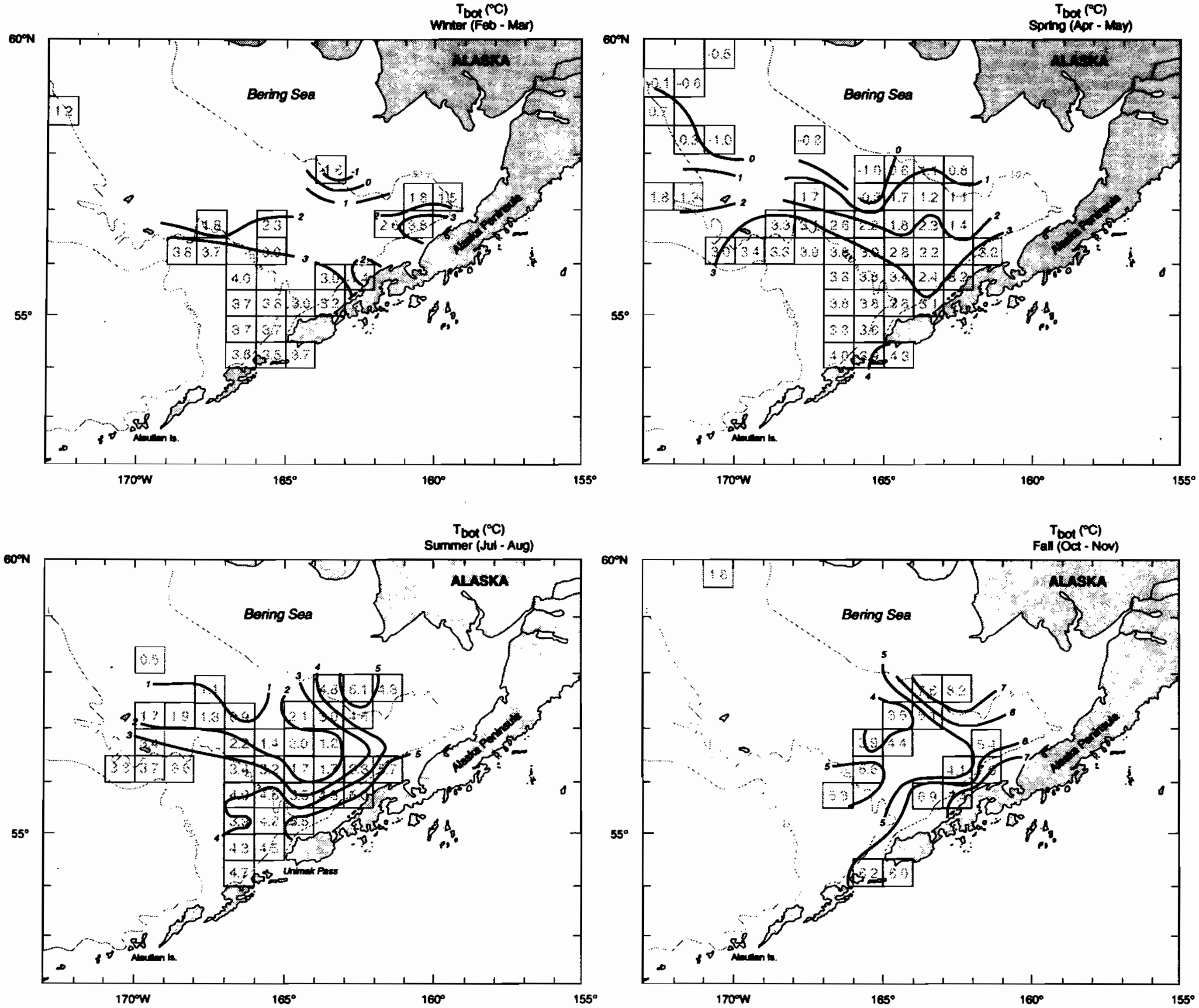

Figure 4. Bottom (or 100-m; see text) temperature (°C) in winter, spring, summer, and fall, 1974–90.

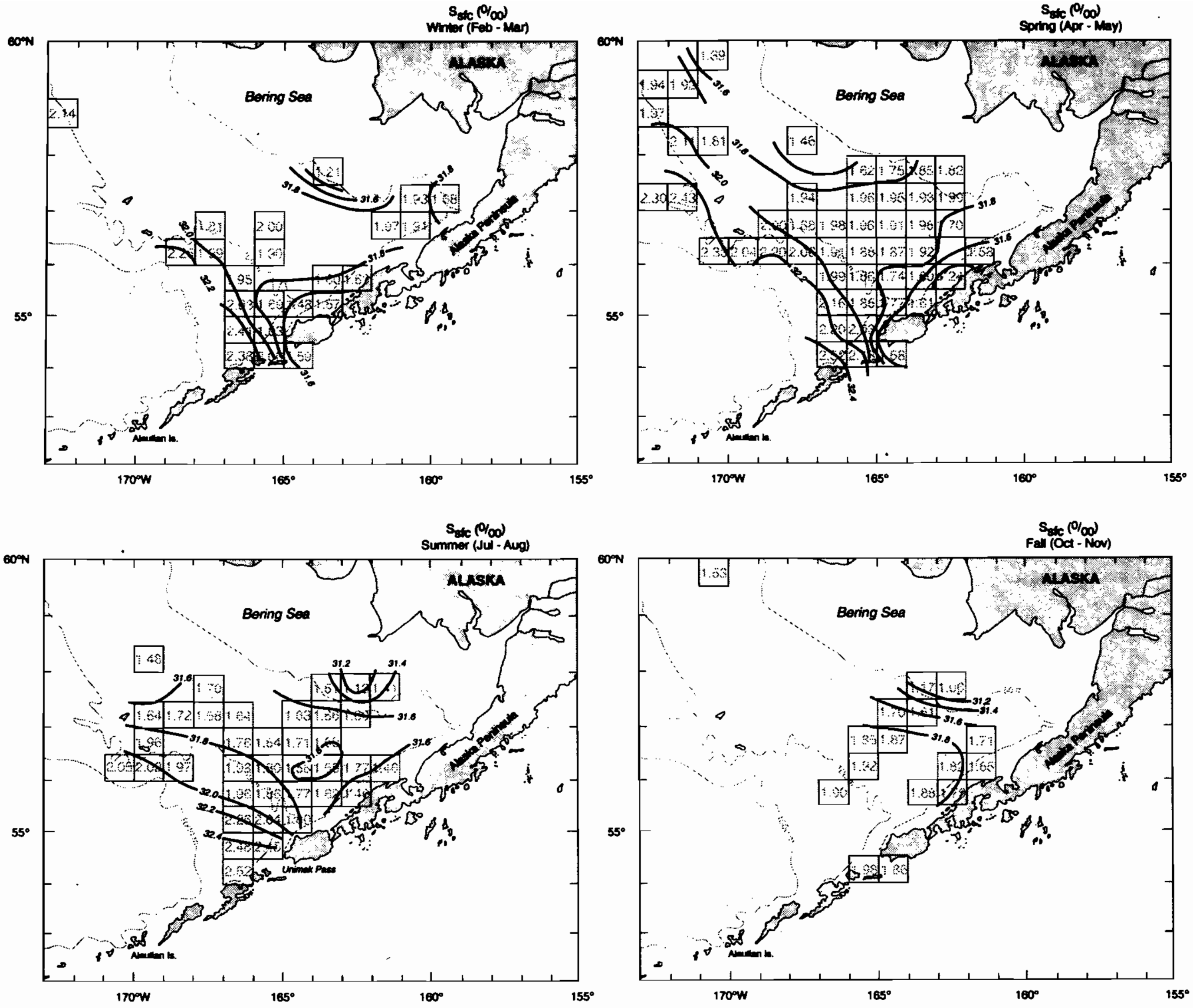

Figure 5. Sea surface salinity (‰) in winter, spring, summer, and fall, 1974–90. The first digit of each value was omitted; i.e., 2.00 is actually 32.00‰.

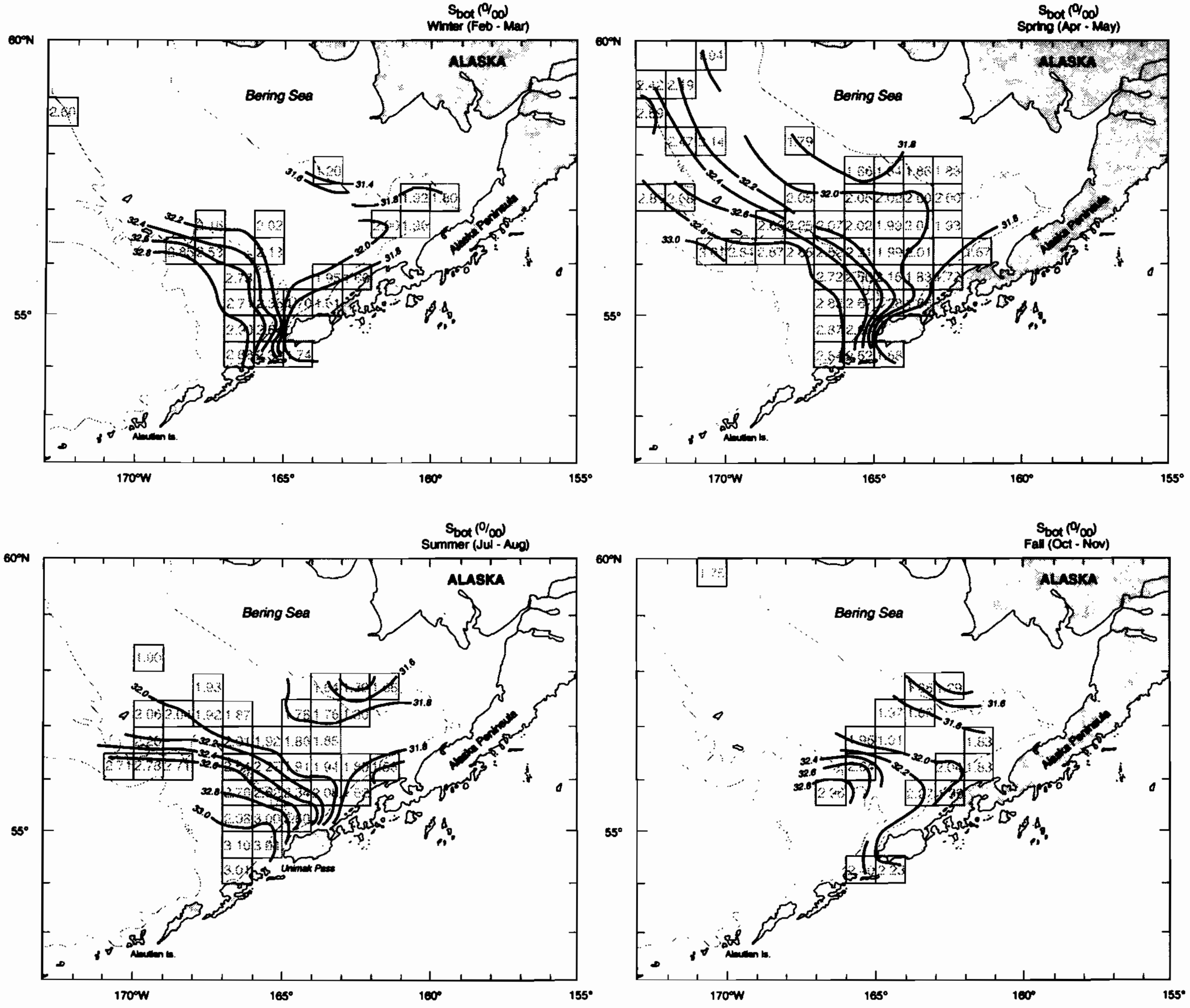

Figure 6. Bottom (or 100-m; see text) salinity (‰) in winter, spring, summer, and fall, 1974–90. Notation is as in Fig. 5.

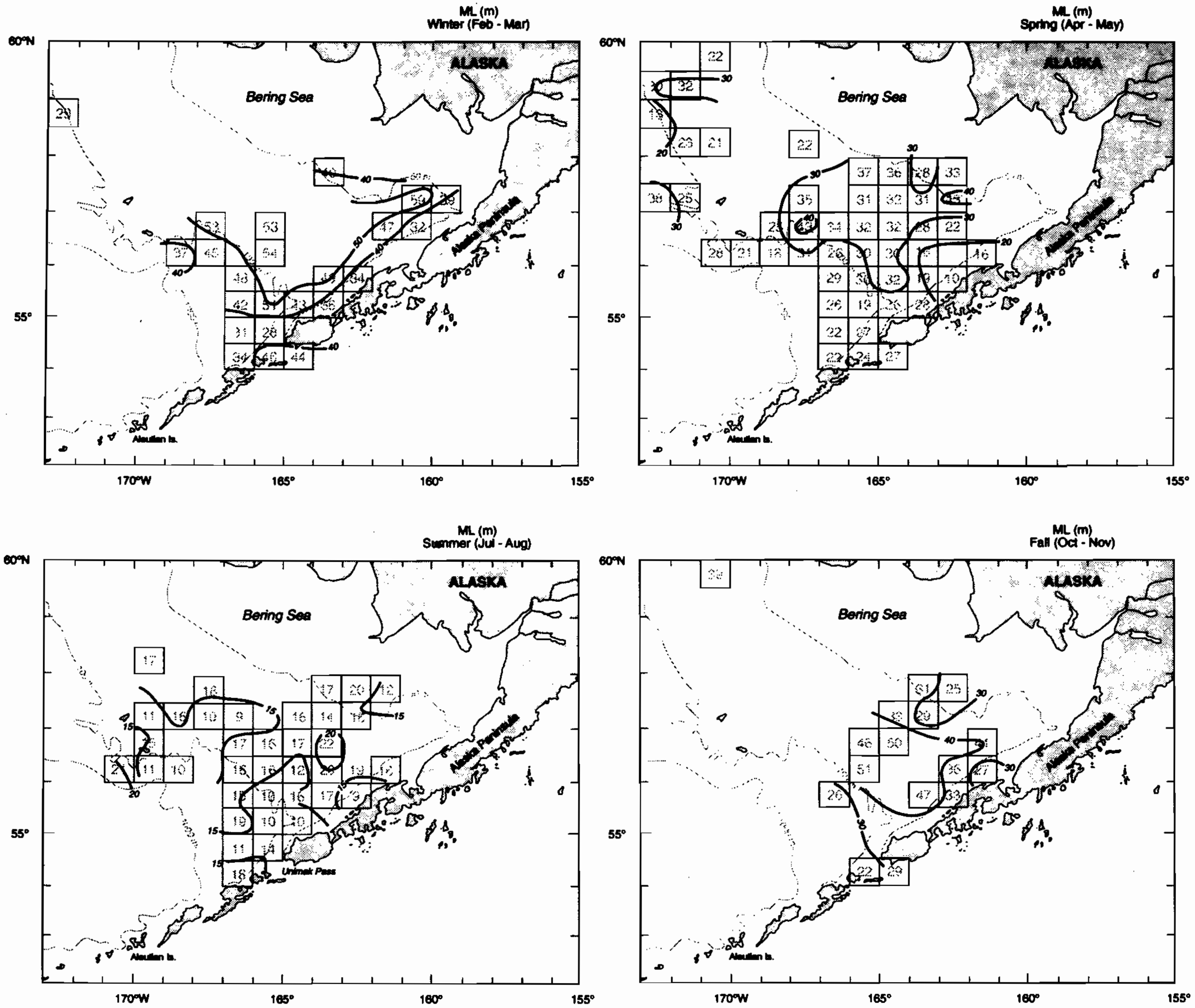

Figure 7. Mixed-layer depth (m) in winter, spring, summer, and fall, 1974–90.

3.5. Mixed-Layer Depth

The depth of the mixed layer is defined here, according to Coachman (1986), as that depth at which sigma-t density increases from its surface value by 0.020 units. This definition has been used because of the importance of density structure to water column stability and possible impacts of tidal and wind stirring. Note that this level may not coincide with a thermal mixed layer.

In winter (Fig. 7), the mixed layer is from ~30 to 60 m; the greatest values are in the central region, and the least are near the Alaska Peninsula. In spring, the mixed layer is shoaler, ranging from ~15 to 40 m. As expected, the shoalest mixed layers are in summer (from ~10 to 20 m). In fall, the mixed layer ranges from ~25 to 50 m, a rapid deepening from summer and generally deeper than in spring. As discussed above, mixed-layer depths near the 50-m isobath also indicate that the entire water column is not always mixed from top to bottom.

4. VARIATIONS

Although climatological mean conditions are relevant to many problems, conditions during extreme years are also quite important. The year-to-year or interannual variability of water properties is examined here for the summer season. (Although more data are available overall for spring, they are concentrated over fewer years, of shorter duration, than for summer in the areas of interest.) Figure 8 shows the locations of the two areas used for generating time series of the year-by-year values of water properties in summer. Area 1 is between the 50- and 100-m isobaths, and area 2 is offshore in water deeper than 100 m, where slope waters may intrude.

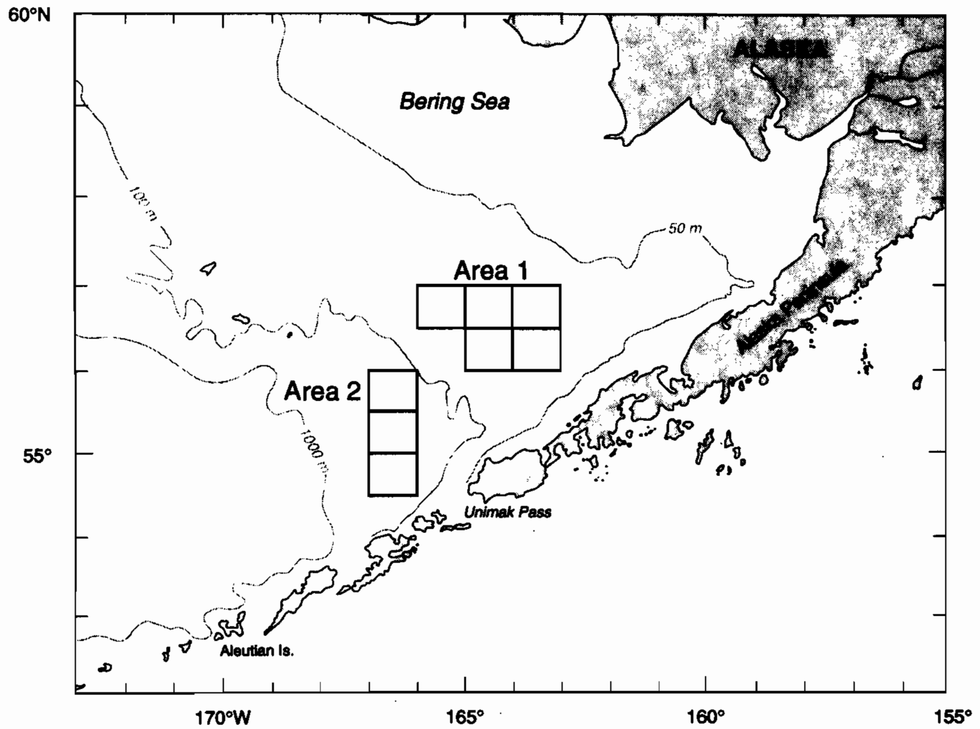

Figure 8. Locations of two areas used to examine interannual temperature variations in summer, 1975–84.

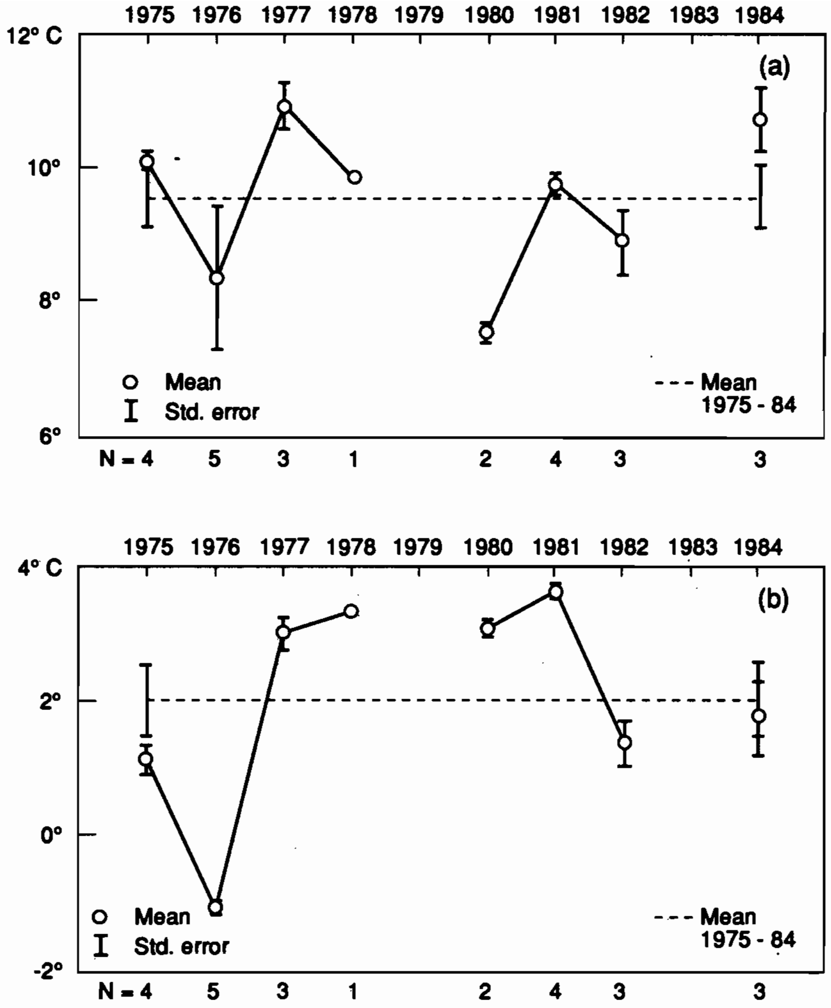

Figure 9. Interannual temperature (°C) variations in summer at (a) the sea surface and (b) the bottom, in area 1 (see Fig. 8), 1975–84.

The mean summer surface and bottom water temperatures in area 1 are shown in Fig. 9. Surface temperatures are somewhat variable, but only one year (1980) has means that depart from the 1975–84 mean (dashed line) by as much as 2 °C. Bottom water temperatures are more variable than surface temperatures; six of the eight values have significant departures from the long-term mean. Four years (1977, 1978, 1980, and 1981) are somewhat warmer than normal. The most striking feature, however, is the very cold conditions in 1976. Bottom temperatures then are >3 °C below normal. The abnormally cold spring and summer 1976 conditions were discussed by Reed (1978), Ingraham (1981), and Coachman (1986); these were attributed to extensive ice cover the previous winter. Salinity data in this area (not shown) indicate that the only noteworthy anomaly was low surface salinity (by ~0.5‰), but not bottom salinity, in summer 1976, which very likely resulted from addition of melt water from the ice that year.

Mean summer temperatures for 1975–84 in area 2 (Fig. 8) are shown in Fig. 10. Water depths here are from 100 to ~400 m; as noted above, 100-m temperatures are used rather than bottom temperatures. In Fig. 10, few of the surface or bottom temperature means are significantly different from the 1975–84 mean. Comparison of Figs. 9 and 10 demonstrates clearly the lack of convection of cold surface waters below ~100 m in either normal winters or very cold ones like 1976.

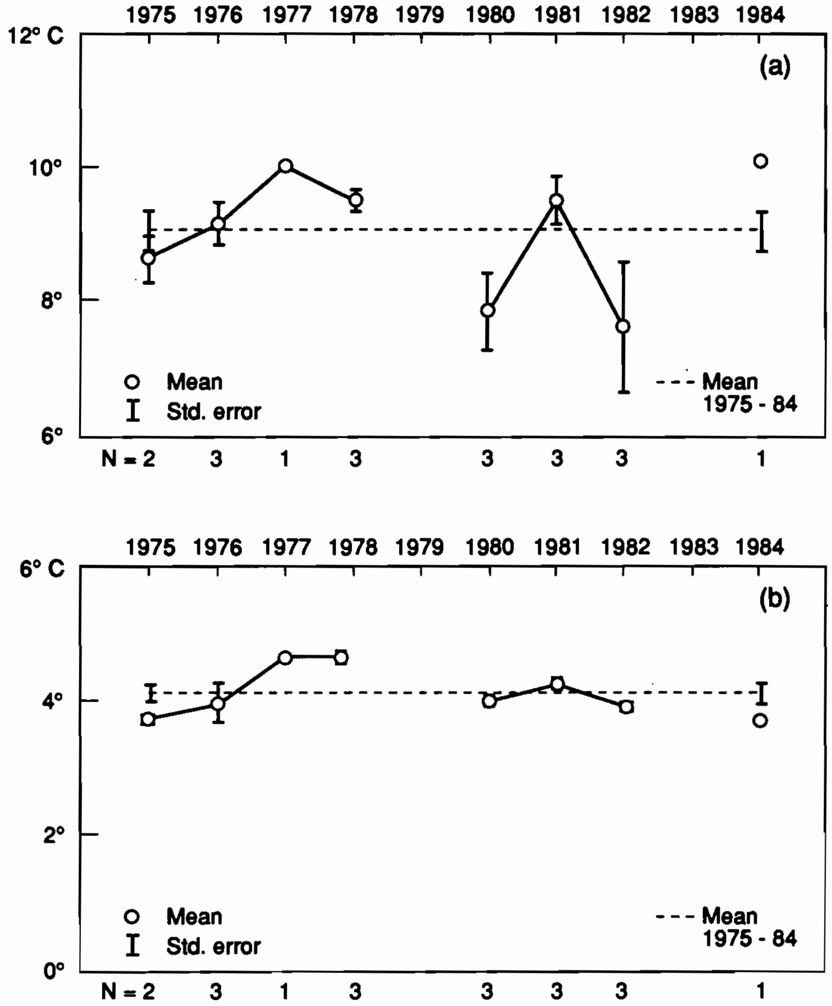

Figure 10. Interannual temperature (°C) variations in summer at (a) the sea surface and (b) 100 m, in area 2 (see Fig. 8), 1975–84.

Specifically, 100-m long-term mean temperature in area 2 is >2°C warmer than in area 1, and 100-m temperature in 1976 is not significantly colder than normal in area 2.

5. DISCUSSION AND CONCLUSIONS

It is not entirely clear how well the maps of climatological mean properties, based on 1974–90 data, represent longer-term (over several decades) conditions. Ingraham (1981) presented climatological maps based on data from 1932 to June 1979, although a considerable portion of the data was for after 1955. His maps show somewhat colder conditions at the surface and bottom than those here in winter and spring; in summer and fall, however, the climatologies are similar. A similar comparison of salinity maps shows good agreement; his contour intervals are 1.0‰ though. Thus it seems likely that the maps here are not greatly different from long-term means.

Swan and Ingraham (1984) presented bottom water temperature anomalies for 1950–82. For the region shown here, their time series indicated the coldest water (anomaly of −2.2°C) was in 1976;

1971 and 1972 were next coldest (anomalies of –1.4 and –1.5°C). During the 1950s and 1960s bottom temperatures were normal or above; in the early and middle 1970s quite cold conditions prevailed; and warm conditions were typical in the late 1970s and early 1980s. At any rate, 1976 appears to be the most extreme cold year since 1950.

Extremely cold water is produced by abnormal winter ice conditions (Reed, 1978; Coachman, 1986; Niebauer and Day, 1989). Niebauer and Day (1989) concluded that extreme ice production is caused by atmospheric, not oceanic, forcing. The winter position of the atmospheric Aleutian Low is the main factor. It, however, is linked to El Niño–Southern Oscillation (ENSO) events, which explain 30–40% of the variability in the Bering Sea. Thus extreme, aperiodic changes occur that are induced by an atmospheric teleconnection.

6. ACKNOWLEDGMENTS

I thank D. Kachel for preparing data products. J. Overland, J. Schumacher, P. Stabeno, P. Dell'Arciprete, and N. Bond provided support and advice. S. Stillwaugh helped obtain the data. This is contribution FOCI-B 237 to the Fisheries Oceanography Coordinated Investigations and is part of the Coastal Ocean Program of NOAA.

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*U.S. GOVERNMENT PRINTING OFFICE:1995-673-018/00110