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Variability of Temperature and Salinity in the Middle Atlantic Bight and Gulf of Maine Based on Data Collected as Part of the MARMAP Ships of Opportunity Program, 1978-2001

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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Variability of Temperature and Salinity in the Middle Atlantic Bight and Gulf of Maine Based on Data Collected as Part of the MARMAP Ships of Opportunity Program, 1978-2001

Jack W. Jossi[1,2] and Robert L. Benway[1,3]

Postal Addresses: *[1]National Marine Fisheries Serv., Narragansett Lab., 28 Tarzwell Dr., Narragansett, RI 02882*
E-Mail Addresses: *[2]Jack.Jossi@noaa.gov; [3]Robert.L.Benway@noaa.gov*

U. S. DEPARTMENT OF COMMERCE
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Woods Hole, Massachusetts

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[a] ISO [International Organization for Standardization]. 1981. ISO standards handbook 3: statistical methods. 2nd ed. Geneva, Switzerland: ISO; 449 p.

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Acronyms

GOM = Gulf of Maine
MAB = Middle Atlantic Bight
MARMAP = Marine Resources Monitoring, Assessment, and Prediction Program
NAO = North Atlantic Oscillation
PSU = practical salinity unit
QC = quality control
SOOP = Ships of Opportunity Program
XBT = expendable bathythermograph

ABSTRACT

Monitoring of the Middle Atlantic Bight (MAB) and Gulf of Maine (GOM) has been conducted by the Marine Resources Monitoring, Assessment, and Prediction Program's (MARMAP's) Ships of Opportunity Program (SOOP) since the early 1970s. Portrayals of temporal and spatial patterns of surface and bottom temperature and surface salinity for SOOP transects crossing these regions during 1991-2001, and time plots of anomalous conditions for spatially coherent sections of these transects during the period 1978-2001, are presented. Annual transect averages and departures are presented for both regions.

Lowest average annual surface temperature in the MAB during 1978-2001 and in the GOM during 1978-97 (after which coverage was insufficient) occurred in 1996, departing from baselines in both regions by an average of 1.1°C. Highest average annual surface temperature during the same respective periods occurred in 1995 for the MAB, and in 1991 for the GOM, departing from baselines by 1.3°C for the MAB, and by 0.4°C for the GOM. Three years of consistently low average surface temperatures in the MAB ended in 1999, followed by two more years of positive departures.

Surface salinities in the MAB had their lowest annual averages in 1998, departing from baselines by 1.1 practical salinity units. Four years of consistently low surface salinities in the MAB ended in 2000.

Bottom temperatures in the MAB were lowest in 1994, averaging 1.4°C below the baseline. Bottom temperatures in the GOM were lowest in 1997, averaging 0.5°C below the baseline. From 1999 through 2001, the MAB bottom temperatures were consistently above the baseline, with the maximum departure for the entire period of record of 1.8°C in 1999.

The annual transect average data and the time plots reveal that the magnitude of departures from long-term means was greater for all features and in all regions during the 1990s than during earlier years.

INTRODUCTION

The Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP) Ships of Opportunity Program (SOOP) has been consistently collecting temperature and salinity information between Massachusetts and Cape Sable, Nova Scotia, and from New York City across the continental shelf and slope towards Bermuda, since 1978. A history of the program and variations in surface and bottom temperature and surface salinity through 1990 were summarized by Benway, Jossi, Thomas *et al.* (1993). Included in the latter work were comparisons of time-space conditions with 1978-90 baseline values. Since 1990, annual summaries, in similar format, have appeared as *NAFO* [Northwest Atl. Fish. Organ.] *SCR* [Sci. Counc. Res.] *Documents* (Benway *et al.* 1992; Benway, Jossi, and Griswold 1993; Benway and Jossi 1994, 1995, 1996, 1997, 1998; Benway 1998). However, these post-1990 annual reports did not utilize the consistent baseline of the original 1978-90 summary. For that reason, it was decided to re-analyze the 1991-2001 data and produce a report comparable with the first summary.

This report describes the common methods used during 1978-2001, presents the 1978-90 baseline conditions of surface and bottom temperature and surface salinity for the Middle Atlantic Bight (MAB) and Gulf of Maine (GOM), portrays the 1991-2001 values and their departures from baseline conditions, and presents 1978-2001 time plots of conditions for several spatially coherent sections of the two transects.

MATERIALS AND METHODS

SAMPLING LOCATIONS

The track lines of the ships of opportunity varied on different monthly occupations of a route. For consistency among sampling efforts, two route polygons were developed for analysis and portrayal of the data collected in the two regions. These polygons (Figures 1a and 1b) were based on composites of all sampling locations, such that oceanographic features were assumed to vary along the polygons' long axes, but to vary insignificantly normal to the long axes. Only data collected within the polygons were included in analyses. A standard reference position was chosen for each route from which the radial distance to each sample location was calculated. These reference positions were located at such distances beyond the narrow ends of the polygons so that arcs passing through the sample location had little curvature (see Figures 1a and 1b). The calculation also produced a reference distance which was positive from North America seaward.

The MAB sampling (Figure 1a) originated at Ambrose Tower (40°27.5'N, 73°49.6'W) and extended offshore approximately 500 km towards Bermuda. This route is termed MARMAP Route MB, and the corners of this polygon are defined by the following geographic positions: 40°34'N, 74°00'W; 40°20'N, 74°00'W; 38°30'N, 69°00'W; and 36°44'N, 70°30'W. Sampling generally concluded within the Gulf Stream. Because of the Gulf Stream's varying position, not all sampling transects traversed the entire polygon length. A transect along this route typically passed through shelf, slope, and Gulf Stream water masses, and often crossed a portion of Deep Water Dumpsite 106. The major hydrographic features of this region were summarized by Ingham (1982).

The GOM sampling extended from the Massachusetts coast to Cape Sable, Nova Scotia (Figure 1b), for a distance of approximately 452 km. This route is termed MARMAP Route MC, and the corners of this polygon are defined by the following geographic positions: 43°30'N, 71°00'W; 43°30'N, 65°37'W; 43°00'N, 65°37'W; and 42°00'N, 71°00'W. This polygon included the following geographic regions of the GOM: Massachusetts Bay, Wilkinson Basin, the central Gulf ledges, southern Jordan Basin, Crowell Basin, and the western Scotian Shelf.

DATA COLLECTION

The sampling regimen at every station included deployment of an expendable bathythermograph (XBT) probe and concurrent collection of a sea-surface bucket sample for temperature calibration and salinity determination. In both polygons, XBT's were used to measure water-column temperatures down to a maximum depth of 500 m. Stations were positioned on the basis of time intervals rather than actual geographical locations. Sampling was at least hourly in the MAB, and varied from every 1-2 hr in the GOM. Prior to 1981, all data were collected utilizing Sippican analog recorders, and traces were digitized. Thereafter, data were recorded digitally.

Ship position, time of XBT deployment, and water-column depth (taken from a depth chart or fathometer) were recorded in the computer and on a MARMAP log sheet. Full details on SOOP operational procedures and theory are available in Benway and Jossi (in review).

TEMPORAL SCALES OF SAMPLING

Monitoring of water temperature and salinity in the MAB and GOM began in mid-year 1970. However, data collected before 1978 were too incomplete for atlas portrayal. In the MAB, one or two (occasionally three to four) sampling cruises were conducted per month. By comparison, there was one sampling cruise per month carried out across the GOM. Although it was desirable to sample during the first 2 wk of a month for logistical reasons (*i.e.*, being able to repeat sampling in case of failure), sampling often occurred later in the month. However, annual means of the variables measured on both routes reveal no pattern or step change related to the variation of sampling times. During 1986, no XBT's were deployed in the GOM, so no bottom temperature data were collected. Gulf of Maine surface salinity sampling ceased after 1993.

SPATIAL SCALES OF SAMPLING

In the MAB, a typical transect began with the first station at Ambrose Tower (40°27.5'N, 73°49.6'W; distance from reference point = 17 km) (Figure 1a). Generally, subsequent stations occurred about every hour (*i.e.*, every 25-35 km depending on vessel speed) across the continental shelf. Stations were spaced at 15-min (*i.e.*, 7-km) intervals near the continental shelf break. Thereafter stations occurred each hour until the North Wall of the Gulf Stream was reached. The first station when traveling from Bermuda to New Jersey was at the Gulf Stream North Wall, with sampling at the outbound intervals until reaching Ambrose Tower. Surface water samples and water-column temperature data were collected at each station.

In the GOM, sampling was initiated from either end of the Route MC polygon until 1993. Thereafter, sampling took place from Nova Scotia to Massachusetts (Figure 1b). Surface water samples were collected every 1 or 2 hr (*i.e.*, every 18 or 36 km), and water-column temperature profiles were obtained no less than every 2 hr.

DATA PROCESSING

The depth of each XBT voltage reading was derived as a function of time alone, using XBT descent equations shown in Table 1.

The XBT voltage readings were converted to temperatures in several steps. First, a Sippican system MK-9 XBT Controller transmitted hexadecimal voltage values (representing XBT thermistor measurements) to a shipboard personal computer. Second, the XBT program converted those hexadecimal voltage equivalents to resistance, and then to temperature (°C), in the following manner:

1. Convert hexadecimal value to decimal value.
2. Convert decimal value to (V) voltage (*i.e.*, $V = 10.0 \times$ decimal value / 4096).
3. Convert (V) voltage to (R) resistance as measured in ohms (*i.e.*, $R = (18094 - 1490.1) \times V$).
4. Convert (R) resistance to (T) temperature as measured in°C (*i.e.*, $T = -273.15 + \{1 / [A + (B \times \ln R) + C \times (\ln R)^3)]\}$, where: $A = 1.29502 \times 10^{-3}$, $B = 2.34546 \times 10^{-4}$, and $C = 9.9434 \times 10^{-8}$).

This logarithmic equation was first presented by Steinhart and Hart (1968). The constants were determined empirically from laboratory tests of XBT thermistors (Georgi *et al.* 1980).

Quality control (QC) software was designed specifically for the digital data format established in 1981. For each sampling station, QC plots of temperature versus depth were produced, and all depth-temperature pairs were listed. QC plots were used to determine water-column depth, surface temperature, and bottom temperature, as well as to delete inaccurate XBT drops. Water-column depth was determined by comparing the log sheet depth with any bottom impact marks on the QC plot. Surface bucket temperatures were used to calibrate probe values. Bottom temperatures were chosen from corresponding probe bottom impact marks located on the analog graph output.

Conductivity measurements of sea surface samples were generated by use of a Guildline Model 8400a Autosal. Conductivities were converted to salinity values using the UNESCO standard equations of state (UNESCO 1981).

Time-distance checks were performed on all recorded time and position data to eliminate erroneous log entries. Analyses of the data revealed considerable temporal and spatial variability for surface temperature, surface salinity, and bottom temperature along both of the routes. As a result, a time-space mapping technique was developed to portray the data in a form that retained most of the original detail, to show long-term means and variances, and to determine departures from the means for individual years. Further, the technique permitted the extraction of spatially coherent time series and the analysis of relationships among measured values.

GRIDDING

To overcome problems associated with irregular sampling in both space and time, the data were subjected to a gridding procedure. The design of the gridding method was developed in part with other research at NOAA Fisheries' Narragansett Laboratory (Jossi *et al.* 1991; Thomas 1992). From each irregularly spaced raw data matrix, the gridding technique calculated a curved planar surface using interpolated data values at regular, spatial-temporal grid points. Time-space grids of single-year values, base-period (1978-90) mean values, standard deviation values, and single-year data algebraic anomaly and standardized anomaly values were produced. The 1978-90 period was selected as the base period to compare the post-1990s' results with those published for the 1970s and 1980s (Benway, Jossi, Thomas *et al.* 1993).

Each grid was defined by route polygon reference distance (range: 0-452 km) along the x-axis, time (range: 0-365.25 days) along the y-axis, and sample scalar values along the z-axis. For MAB bottom temperature data, the grid values at greater than the 210-km reference distance were converted to blanks due to the limits of the XBT probe. All grids were constructed such that grid points occurred at intervals of 17.38 km and 15.22 days, *i.e.*, there were 27 grid columns (26 divisions in x) along each polygon, and 25 grid rows (24 divisions in y) for every year or base period (Table 2).

Grid dimensions and techniques were chosen by considering, in descending order of importance: 1) the closeness of fit between the actual data values and the interpolated grid values as measured by the characteristics of the residuals; 2) the average data coverage in time and space; 3) the portrayed rates of change of the scalar values; and 4) the intended use of final products. The statistical characteristics of the residuals are reported in Table 3. Distributions of the residuals from the base-period grids, and of a composite of the residuals from the single-year grids, are fairly symmetrical (Figures 2 and 3). One exception is the residuals for route MB base-period bottom temperatures, which although having a centered mean, exhibited extreme skewness and kurtosis. This likely is due to the very rapid depth change at the offshore limit of sampling, and the resulting significant difference in depth sampled (*i.e.*, water temperatures measured) with small changes of reference distance. None of the residual sets satisfied the Kolomogorov D statistic for normality. An inherent bias in this gridding technique is the de-emphasis of extreme amplitudes in the raw data values. However, the tails of the residual distributions (Figures 2 and 3) do not show that this is a severe problem.

The remainder of this section will detail the sequence of gridding steps applied to all data types. First, a base-period weighted mean grid, including all data collected during 1978-90, was generated (Figures 4-9, panel A). Second, the base-period grid surface, at the actual spatial-temporal location of each observation, was subtracted from observed values to produce a data set of base-period residuals (Figure 2). Calculation of these values assumed a flat, rather than curved surface in each neighborhood. Third, a weighted variance was found by squaring all residual values, and then gridding these squared residuals. Finally, a standard deviation grid (Figures 4-9, panel B) was created by taking the square root of the variance grid (the calculation did not include the number of observations, which exceeded 70 at all grid points). It should be noted that all base-period mean and standard deviation grid values were localized in time and space, because each grid value was the weighted mean of all observations within the search ellipse surrounding that grid point. The time-space distributions of the observations used in these base-period calculations are shown in Figures 4-9, panel c.

Maps of single-year conditions, anomalies, and standardized anomalies were derived for each route and data type (Figures 10-53 and 55-66). First, each single-year conditions map was created by gridding all observed data from that year (panel A). Second, the base-period grid surface, at the actual spatial-temporal location of each observation, was subtracted from observed values, producing a set of algebraic anomalies (*i.e.*, residuals) for each year, which, in turn, were used to produce annual anomaly maps (panel B). Finally, by dividing the anomaly at each observation point by the corresponding interpolated standard deviation (taken from the base-period standard deviation grid surface), standardized anomalies were calculated for every observation in a given year. Each annual standardized anomaly map was generated by gridding these standardized anomaly values (panel C). For portrayal of statistically significant events, standardized anomaly map contour intervals were chosen by picking the 15.2% and 84.8% percentile levels, as an approximation of one standard deviation, and the 2.3% and 97.7% percentile levels, as an approximation of two standard deviations, from the 13-yr data set of standardized anomalies.

The grid files calculated above also were used to produce base-period means and annual means and anomalies for the transects as a whole. Base-period means were calculated using all grid values from 1978 through 1990. Single-year means were obtained using the same process, but for a single data year. Single-year anomaly means were calculated by subtracting the base-period mean grid values from the single-year mean grid values.

TIME PLOTS

Portrayals of the grid files indicate that neither transect exhibits spatial coherence over its full extent. Further, these portrayals are inconvenient for examining interannual variations.

To deal with these two issues in the GOM, cluster analyses (Thomas 1992) were used. Four clusters were established to represent spatially distinct points along the transects for the variables involved. The clusters selected (and the reference distances to the centers of those clusters) were Massachusetts Bay (48 km), western GOM (165 km), eastern GOM (277 km), and Scotian Shelf (396 km). Slices at these points were taken through all standardized anomaly grids for the period of record to produce data for time plots. Grid surface values were derived (again assuming a flat surface in the neighborhood) each time the slice crossed a grid line (each 15.22 days except where grids were blanked due to insufficient data), and are in the same units (standard deviations) as the grids of origin.

For the MAB, one point was selected at a reference distance of 101 km to represent continental shelf conditions usually not influenced by either land mass or slope water conditions. This reference distance also marks that point along the transect representing the mean center of the Cold Pool (Cook 1985). A running-average fit was generated by taking the average of all data collected within 15 mo before and after a given time-plot point.

RESULTS

In the MAB, 294 cruises were conducted during the base period (1978-90). An additional 183 cruises were conducted during 1991-2001, for a total of 477. In the GOM, 209 cruises were conducted during the base period. An additional 144 cruises were conducted during 1991-2001, for a total of 353.

Contoured, 13-yr mean portrayals of surface temperature, bottom temperature, and surface salinity values are shown for the MAB (Figures 4-6) and GOM (Figures 7-9). Each figure contains three panels: (A) weighted means of the smoothed observations for the 13-yr time frame; (B) estimated standard deviations of the weighted mean values; and (C) data location within the 13-yr, 452-km base area.

Also presented are surface temperature, bottom temperature, and surface salinity variations in time and space for each year, 1991-2001, for the MAB and GOM (Figures 10-53 and 55-66), with the exception of 2000 for the GOM where sampling coverage was insufficient to produce standard portrayals. Each single-year figure contains three panels: (A) annual conditions; (B) departures of the annual conditions from the 13-yr mean values expressed as algebraic anomalies; and (C) departures of the annual conditions from the 13-yr mean values expressed as standardized anomalies.

Figure 67 shows the average relation between bottom depth and reference distance along the two transects.

Figure 68 shows the spatially coherent clusters from which GOM time plots were extracted. Figure 69 shows time plots of surface temperature, surface salinity, and bottom temperature at mid-shelf of the MAB. Figures 70-73 show time plots of these variables for Massachusetts Bay, western GOM, eastern GOM, and Scotian Shelf.

In the summary of the first 13 yr of monitoring, Benway, Jossi, Thomas *et al.* (1993) discussed 1978-90 baseline conditions of surface and bottom temperature and surface salinity along the MAB and GOM transects. This discussion is repeated below because it and the base-period portrayals are central to understanding the annual and inter annual variations of these features. Also, the variance about these mean conditions is important when interpreting the significance of single-year departures.

Annual conditions for 1991-98 have been presented as *NAFO SCR Documents*, as cited in the "Introduction." Although one purpose of this report was to present recalculated departures for these years using consistent baselines, the recalculation showed no significant differences from those resulting from the varying base periods utilized in these former reports. Therefore, the 1991-98 recalculated annual portrayals are presented, but only data collected for 1998-2001 are discussed in this report.

BASELINE CONDITIONS DURING 1978-90

Middle Atlantic Bight

Surface Temperature

Baseline conditions of surface temperature across the MAB (Figure 4A) show annual minimum values of less than 4°C in late February very nearshore, of 4-8°C during mid-March on the shelf, and of 8-20°C during mid-March progressing southeastward through the Slope and Gulf Stream water masses. The highest rate of vernal warming takes place along the entire transect during late June, with peak annual temperatures greater than 22°C over the shelf and greater than 26°C offshore achieved by late August. From August to the end of the year temperatures decline fairly uniformly over the entire transect.

On the shelf, the periods of highest variability in these baseline conditions (Figure 4B) occur in early June when standard deviations about the 1978-90 means are in excess of 2°C. These variations are largely due to interannual differences in the timing of the vernal warming of the surface waters of the MAB. Variations in excess of 1°C occur over the inner shelf during the November and December period. The November variations can be partly attributed to the interannual differences of timing of the fall overturn. The December variations include record-breaking, cold winter temperature values in 1978.

Offshore, the standard deviations about the baseline values generally range from 2°C to more than 3°C, with the highest values along the boundary between the Slope and Gulf Stream water masses. The baseline values for this region are the most variable along the transect due to the extensive migrations of both the Shelf/Slope Front and the Gulf Stream North Wall.

Mean surface temperature for the entire transect is 16.3°C (Table 4).

Surface Salinity

The dominant features of the time-space surface salinity field across the shelf portion of the MAB transect (Figure 5A) are the meltwater runoff from mid-March to late April, and the shorter duration river discharge in mid-August, both concentrated within 30 km of Ambrose Tower.

The Shelf-Slope Front, defined by 34.5 practical salinity units (PSU), shows considerable spatial variation through the year, being just seaward of the shelf break from January through April, then migrating over 100 km further offshore by mid-June, and returning to the area seaward of the shelf break by October. Even greater seasonal excursion can be seen in the 35-PSU isohaline from about 240 km in the winter to about 430 km in July and August.

Variations about these baseline conditions (Figure 5B) are highest nearshore where standard deviations from February through April exceed 3 PSU, and values in excess of 1 PSU occur throughout the year, resulting from variations in the timing and magnitude of runoff. Variations in excess of 1 PSU occur across the shelf in June and offshore in August and September. The influence of upstream conditions on these values (particularly outflow from the GOM) is not easily determined from this one transect, but is expected to be a contributing factor.

Mean surface salinity for the entire transect is 33.81 PSU (Table 4).

Bottom Temperature

Baseline conditions of bottom temperatures across the MAB shelf (Figure 6A) show annual minimum values from less than 2°C nearshore in mid-February to less than 5°C at the shelf break in late May. The Cold Pool is a major feature of the bottom temperature regime along this transect. It occurs during the period between the onset of stratification (approximately from late March inshore to late April offshore) and the fall overturn (approximately from early September nearshore to early December offshore) (Cook 1985). Fall overturn produces maximum bottom temperatures across the shelf, exceeding 16°C nearshore and 13°C offshore to the shelf-slope frontal boundary.

Variations about baseline values (Figure 6B) show standard deviations in excess of 4°C nearshore in late July and early August associated with wind mixing of these shallow waters, and upwelling and downwelling events common to that area. A large portion of the inner shelf during September and October, and the outer shelf during October and November, have standard deviations more than 2°C coinciding with the seaward progression of the fall overturn. Beyond the 200-km reference distance, the standard deviations exceed 2°C during most of the year, reflecting the influence of the migrating Shelf-Slope Front on the bottom, as well as the passage of warm-core rings. Midshelf deviations more than 1°C occur during all but the winter months, and can be largely attributed to interannual variability in Cold Pool temperature and boundaries.

Mean bottom temperature for the entire transect is 8.8°C (Table 4).

Gulf of Maine

Surface Temperature

Baseline conditions of surface temperature across the GOM transect (Figure 7A) range from a minimum of less than 3°C over the Scotian Shelf in mid-March, and less than 4°C over Massachusetts Bay in late-February, to a maximum of 19°C for Massachusetts Bay and Wilkinson Basin, and over 14°C through Crowell Basin just onto the Scotian Shelf in August. The highest rate of change due to vernal warming occurs during late May through early July across the entire transect. After August, surface temperatures, with the exception of the mixed portions of the Scotian Shelf, decline rapidly.

Periods of highest variability occur during June to mid-October over much of the transect (Figure 7B). Fall overturn generally occurs during late October through early December, leading to further variability. The high variations over the eastern end of the transect can be attributed to variation in the Scotian Shelf Current.

Mean surface temperature for the entire transect is 9.1°C (Table 5).

Surface Salinity

The GOM surface salinity conditions vary less than those in the MAB, but still show a wide range of values over the region (Figure 8A). Salinities range from a minimum of less than 30.5 PSU during the peak runoff into Massachusetts Bay in early June, to a maximum of near 33.5 PSU over the Scotian Shelf in early November. Unlike the nearshore waters of the New York Bight during late summer - early fall, there is no secondary pulse of river runoff

The standard deviation about the baseline conditions is less than 0.5 PSU for much of the time-space area (Figure 8B). However, deviations reaching 1 PSU occur from April to June over portions of Massachusetts Bay. Deviations between 0.5 and 0.7 PSU occur over portions of Crowell Basin during January and February, and over scattered areas at the eastern end of the transect during February through April. In addition, standard deviations from 0.5 to 0.7 PSU occur from August through December beginning over the Scotian Shelf and progressing westward to include Crowell Basin.

Mean surface salinity for the entire transect is 32.43 PSU (Table 5).

Bottom Temperature

Conditions within the GOM range from a minimum of less than 3°C over the Scotian Shelf from February through late April, and less than 4°C over Massachusetts Bay during the same time period (Figure 9A). Central ledges bottom temperatures have average minima generally between 6° and 7°C. Maximum temperatures greater than 10°C occurred over the eastern end of the transect from late September through early November. Maximum temperatures on the western end of the transect occurred during the same time period but only reached slightly over 9°C. These times of maximum bottom temperature coincide with fall overturn for these shelf areas. These maxima are absent for the basin areas which are commonly isolated from the overturn event by the Maine Intermediate water, and where standard deviations are generally less than 1°C.

The largest time-space standard deviations about the baseline conditions appear over the Scotian Shelf during late fall and winter (Figure 9B).

Mean bottom temperature for the entire transect is 6.7°C (Table 5).

ANNUAL CONDITIONS DURING 1998-2001

Middle Atlantic Bight -- 1998

Surface Temperature

There were above-average temperatures in the nearshore area from January through April, while there were below-average temperatures from the 175-km reference distance to near the end of the transect during mid-February through mid-May (Figure 48). The above-average nearshore temperatures may have been a consequence of the mild 1997/98 winter air temperatures as measured at Newark and JFK airports (National Climatic Data Center 1998).

Annual minimum surface temperatures between 5° and 6°C occurred inshore in February. From the outer shelf to about the 350-km reference distance, the minimum of less than 6°C occurred in March. This latter condition was from 4° to more than 8°C below baseline values, and represents continuation of a negative trend beginning in 1996. It also is the greatest negative departure of surface temperature in the MAB since monitoring began, and exceeds the previous record set in 1996 by over 2°C. These record low offshore temperatures may be the result of increased transport of water from the Labrador Shelf to the Slope Sea (Rossby and Benway 2000).

Annual maximum values occurred in August along the entire transect, reaching over 24°C on the shelf, and over 26°C near the outer end of the transect.

In September and early October, significantly positive anomalies occurred at about the 40-km reference distance due, in part, to the later-than-average occurrence of the fall overturn. A negative anomaly in excess of 4°C was centered at the outer end of the transect in November, and a significantly positive anomaly over 3°C occurred at the 280-km reference distance in December.

Despite the record-breaking conditions in late winter and early spring, the transect only averaged 0.6°C below normal in 1998 (Table 4).

Surface Salinity

Values ranged from less than 26.5 PSU in March and again in October off Ambrose Light, to greater than 36 PSU at the outer end of the transect in February and March (Figure 49).

The below-baseline salinities which have dominated this transect since 1996 continued through 1998. One explanation for the early-in-the-year, low inshore salinities was a combination of above-average precipitation with mild 1997/98 winter conditions as measured at Newark and JFK airports, both of which are compatible with heavy, early river discharge in the apex of the MAB (National Climatic Data Center 1998). Low offshore salinities may be the result of increased transport of water from the Labrador Shelf region. A low North Atlantic Oscillation (NAO) Index for the mid-to-late 1990s has been suggested by Rossby and Benway (2000) as a possible indicator of increased transport from the Labrador Shelf which, in turn, may cause a southerly shift of the Gulf Stream and lead to lower offshore salinity values.

Most notable were: 1) the period from January into March when significantly negative anomalies exceeded 2 PSU inshore near Ambrose Light, and the period in April when significantly negative anomalies exceeded 3 PSU offshore from beyond the shelf break out to about the 425-km reference distance; and 2) negative salinity conditions continuing through most of the remainder of the year, with only minor exceptions offshore in August and September. Salinities more than 1.5 PSU below baselines occurred variously over the inner 250 km of the transect after July. At Ambrose Light in October, salinities measured more than 4 PSU below baselines. Another unusual pattern in the surface salinity in 1998 was the shifting offshore of isohalines. For example, the 30-PSU isopleth extended to the 140-km reference distance in late July, some 100 km seaward of average, and occupied a good deal more time-space area than average (Figure 5).

Salinity for the entire transect averaged 1.11 PSU below average for 1998, the third consecutive year of lower-than-average salinities, and the lowest mean annual salinity of the 1991-99 period (Table 4).

Bottom Temperature

Minimum bottom temperatures during 1998 were less than 6°C, occurring during February nearshore, and during March and April over the outer shelf (Figure 50). Maximum bottom temperatures on the inner shelf greater than 12°C coincided with fall overturn in October. Annual bottom temperature maxima greater than 13°C occurred over the outer shelf in January and December.

Positive departures from baselines occurred generally over the inner two thirds of the shelf from January to August, with departures exceeding 3°C at Ambrose Tower in early May, and exceeding 2°C on the mid-shelf in June. From mid-August through November, lower-than-average conditions prevailed, with negative anomalies exceeding 4°C on the mid-shelf in October. By December, conditions along most of the transect were near baseline values.

The general pattern of anomalies during 1998 was somewhat similar to those during the previous year, but for the transect as a whole, bottom temperature values averaged 0.2°C below the baseline, compared to 0.9°C above the baseline in 1997 (Table 4).

Gulf of Maine -- 1998

Monthly coverage along the GOM transect has been difficult since late 1993, and this difficulty has impacted the value of results for all three data types in this report. Surface salinity sampling became impossible at that time. Therefore, the following discussion will be limited to those time-space areas where sufficient data exist. Table 5 lists the annual means and anomalies for the transect as a whole since 1991 only where sufficient data exist.

Surface Temperature

Adequate coverage began in April 1998 (Figure 51). By then temperatures measured between 0° and more than

1°C warmer than average from western Crowell Basin well onto the Scotian Shelf. Above-average conditions spread westward to the central ledges in May and June, and still further westward during July to August, when anomalies of +2° to +3°C existed from Wilkinson Basin onto the western Scotian Shelf, respectively. Higher-than-average air temperatures, as measured at Boston and Providence airports during 7 out of the first 8 mo of the year, may have contributed to these anomalous temperatures (National Climatic Data Center 1999).

From October to the end of the year, the Crowell Basin and Scotian Shelf portions of the transect were colder than average, with temperatures more than 2°C below baseline. Offshore autumn winds led to destratification of the water column, bringing below-average-temperature bottom water to the surface as disclosed by SOOP water-column temperature data. During this same time period, the western GOM was close to baseline values.

Annual minimum temperatures occur during the period of no coverage, so they cannot be commented on. The annual maximum temperature exceeded 21°C, and occurred during July in the Wilkinson Basin and central ledges portion of the transect.

Bottom Temperature

Adequate coverage began in April (Figure 52). West of the central ledges, the transect was slightly warmer than average from April through December. The most interesting feature is the significantly-below-average bottom temperatures in Crowell Basin in April, and the shifting of that condition eastward across the Scotian Shelf by November, and westward back onto the central ledges in December. These low bottom temperatures may be a consequence of an increase in water transport from the Labrador Shelf, as indicated by the NAO Index which decreased during the mid-1990s (Rossby and Benway 2000).

Annual minimum bottom temperatures occur during the period of no coverage, so they cannot be commented on. The annual maximum bottom temperature exceeded 10°C, and was observed in Massachusetts Bay in November.

Middle Atlantic Bight -- 1999

Surface Temperature

Annual minimum surface temperatures between 4.2° and 6°C occurred inshore from February through March. Annual maximum values occurred in August along the entire transect, with temperatures reaching 24°-25°C on the shelf, and 28°-29.4°C offshore at the outer end of the transect (Figure 53).

From January through April, above-average temperatures prevailed in the nearshore area, much like the conditions in 1998. In January and February, positive anomalies existed from the outer shelf to the 320-km reference distance. A brief period of significantly higher-than-average temperatures occurred at the very end of the transect in January, exceeding the mean by more than 4°C. Higher-than-normal air temperatures at Newark and JFK airports during the 1998/99 winter months may have contributed to the continental shelf portion of this pattern (National Climatic Data Center 1999), while the above-average temperatures at the outer end of the transect were the consequence of the transect encountering Gulf Stream water during January.

From late August through September, a significantly positive anomaly with temperatures more than 2°C above average occurred at the 50-km reference distance. This inshore anomaly was most likely a consequence of higher-than-average air temperatures (as measured at the Newark and JFK airports) during the spring and summer months (National Climatic Data Center 1999). With the exception of August and October, above-average air temperatures prevailed through December (National Climatic Data Center 2000) and possibly contributed to water temperatures 2°C higher than average from mid-November through December from mid-shelf to the shelf break.

Water temperatures 2°-4°C above average beyond the shelf break during November and December coincided with a large meander of the Gulf Stream bringing the North Wall over 100 km shoreward of its usual position (Figure 54). In November, this feature coincided with an anomaly from 2° to more than 4°C below average as slope water was displaced/entrained along the feature's eastern edge.

For 1999, the entire transect averaged 1.0°C above the baseline surface temperature of 16.3°C, and appears to mark the end of a 1996-98 cool period (Table 4).

Surface Salinity

From January into June, lower-than-average salinities were generally observed along the shelf, with values of 2.4 PSU below baseline at the 50-km reference distance in February, and 1.5 PSU below baseline near the shelf break in May (Figure 55). A notable exception to this pattern was above-average salinity occurring inshore of the 25-km reference distance in March. This anomaly may have been a consequence of lower-than-normal winter and spring precipitation (as measured at the Newark and JFK airports) leading to reduced river runoff in the spring (National Climatic Data Center 2000).

Beyond the shelf break, at the 300- to 450-km reference distance, a low salinity anomaly was observed during February and March, with values of 0.5-1.3 PSU below baseline. This anomaly coincided with the passage of a warm-core ring which entrained a long streamer of cooler, fresher shelf water through the outer part of the transect.

Salinity values for the transect were near average for the remainder of the year, with the notable exceptions of a positive salinity anomaly at the shelf break coinciding with downwelling observed in the SOOP water-column temperature data during July and August, and a negative salinity anomaly at the outer end of the transect in November. This negative anomaly coincided with the offshore movement by the North Wall of the Gulf Stream and the passage of a warm-core ring as mentioned above.

Salinity values for the transect as a whole ranged from 27.5 PSU in April near Ambrose Light to above 36.0 PSU at the outer end of the transect in January, August, September, and December. For 1999, the transect averaged 0.20 PSU below the baseline, continuing a 4-yr period of below-average salinities (Table 4).

Bottom Temperature

From January through March 1999, bottom temperatures across the shelf were up to 4°C above average, possibly due to unusually mild winter air temperatures (as measured at Newark and JFK airports) experienced during the 1998/99 winter months (National Climatic Data Center 2000) (Figure 56). For the transect as a whole, temperatures were generally above the baseline throughout the year, with significantly positive anomalies of water up to 8°C above average inshore during June and July, and 3°C above average at the 140- to 175-km reference distance during May and June.

Annual minimum bottom temperatures of less than 5°C were observed in March nearshore. Annual maximum bottom temperatures greater than 19°C were observed during June to early August nearshore, and bottom temperatures between 18° and 19°C occurred in October on the inner shelf, coinciding with fall overturn.

Water temperatures between 2° and 3°C below normal were observed beyond the shelf break during May-June and during October-December. This latter period coincided with the passage of a large warm-core ring with entrained streamers of cooler shelf water and a seaward movement of the Gulf Stream North Wall mentioned above.

The transect as a whole averaged 10.6°C, the highest mean annual temperature and departure from the baseline during the 1991-99 period (Table 4).

Gulf of Maine -- 1999

Surface Temperature

Temperatures across the transect were near average from January through April (Figure 57). There was no coverage from May through the first half of July. When sampling resumed, surface temperatures generally 1°-2°C above average were observed in Massachusetts Bay and the Wilkinson Basin from July through September. Surface temperatures 2°-3°C above average were observed from eastern Wilkinson Basin to the eastern terminus of the transect in August. By early October, the Crowell Basin had surface temperatures more than 4°C above the baseline. Temperatures across the Scotian Shelf were 2°-3°C higher than average in September. With the exception of the Wilkinson Basin, temperatures generally remained more than 1°C higher than average after late October.

Annual minimum surface temperature for the transect was 1.4°C, and occurred on the Scotian Shelf in March. Annual maximum values for the transect reached 22°C, and occurred near the boundary of Wilkinson Basin and the central ledges during July and August.

Bottom Temperature

The year began with average temperatures across the Massachusetts Bay and Wilkinson Basin portions of the transect. Colder-than-average bottom water was observed on the central ledges and Crowell Basin in January (Figure 58). This cold water was a continuation of conditions in late 1998 (Figure 52). The cold water remained in Crowell Basin through March when temperatures reached more than 2°C below average.

Starting on the western Scotian Shelf in February, and spreading across Crowell Basin in April, water more than 1°C warmer than average occupied the time-space area. Adequate coverage was interrupted from May through the first half of July. However, warmer water continued to dominate the eastern GOM when sampling resumed. By late August, this positive anomaly had spread westward onto the central ledges, and by late September and early October, it had spread eastward across the Scotian Shelf where temperatures more than 2°C above normal were observed. These warmer-than-average bottom temperatures may be a consequence of reduced coldwater transport from the Labrador Shelf region, as suggested by a rising NAO Index during the late 1990s (Rossby and Benway 2000). Temperatures for the remainder of the year were near average for Massachusetts Bay and western Wilkinson Basin, and more than 1°C above average from the eastern Wilkinson Basin to the Scotian Shelf.

Annual maximum transect bottom temperatures between 12° and 13°C occurred on the Scotian Shelf in late September and early October. Annual minimum bottom temperatures between 1° and 2°C were observed on the Scotian Shelf in March.

Middle Atlantic Bight -- 2000

Surface Temperature

Annual minimum surface temperatures less than 4°C occurred nearshore in late February (Figure 59). Minimum temperatures offshore were between 8°C and 10°C during the latter half of December. Annual maxima occurred in mid-August, reaching greater than 22°C over the shelf, and greater than 28°C near the end of the transect.

Anomalously warm water was found over the entire transect during January and February where temperatures generally exceeded means by 2°-4°C on the shelf, and by 6°-8°C offshore. This anomalous feature was a continuation of the event of late 1999 resulting from a large Gulf Stream meander (Figure 54). For the inner 300 km of the transect, conditions were near normal from March through October. From the shelf break to the 300-km reference distance in November and December, temperatures were generally more than 2°C below average. Offshore of the 320-km reference distance, temperatures remained above average throughout the year, exceeding means by more than 4°C in April, May, October, and December.

For 2000, the entire transect averaged 1.1°C above average (Table 4).

Surface Salinity

Annual minimum surface salinity values occurred from May through August at the inshore end of the transect (Figure 60). Annual maxima in excess of 36.5 PSU occurred beyond the 380-km reference distance from late October to the end of the year.

Significantly high salinities were centered at the 90- and 180-km reference distances in February, and at the 440-km reference distance in January. The inner 350 km of the transect were generally near average from late March through August. From mid-September to late October, salinities dropped to more than 1 PSU below average over the inner 75 km of the transect. From the shelf break to the 300-km reference distance, salinities more than 1.5 PSU below average occurred during November and December.

The outer end of the transect was generally saltier than average from May to the end of the year, with values exceeding means by as much as 1-1.5 PSU.

The entire transect averaged 0.29 PSU above average during 2000 (Table 4).

Bottom Temperature

Annual minimum bottom temperatures less than 5°C occurred over the inner 50 km of the transect in early March (Figure 61). Annual maxima greater than 22°C occurred at about the 20-km reference distance in early August.

Like 1999, bottom temperatures over much of the shelf were above average; the only exception being at the 150-km reference distance in April and again in November. Values exceeded means by 1°C over much of the outer shelf from January through October, and inshore by more than 8°C in early August.

Ordinarily, maximum bottom temperature is reached in late September, and coincides with the fall overturn (Figure 6). In 2000, the maximum was reached in early August due to recurring downwelling in the New York Bight apex region (Pacific Fisheries Environmental Laboratory 2000), and a maximum 65-km shoreward excursion of the Gulf Stream North Wall from early June through August (Johns Hopkins University Applied Physics Laboratory 2000).

Gulf of Maine -- 2000

As noted earlier, sampling coverage of surface and bottom temperatures and surface salinity in the GOM during 2000 was insufficient to produce the standard portrayals.

Middle Atlantic Bight -- 2001

Surface Temperature

Annual minimum temperatures of less than 4°C occurred over the inner shelf in mid-February (Figure 62). Minimum temperatures at the 450-km reference distance were just over 20°C, and occurred in early April. An annual maximum greater than 22°C was reached over the entire shelf by mid-July, with a progressive persistence from inshore to offshore. The end of the transect reached maximum temperatures greater than 28°C in September.

The warmer-than-average water beyond the shelf break in 2000 generally continued to be present through March 2001, exceeding means by more than 4°C. Brief and spatially isolated anomalous events occurred through the middle third of the year (*e.g.*, cold water between the 200- and 275-km reference distances in May, and hot water beyond the 400-km reference distance in August and September). This latter feature resulted from the passage of a warm-core ring across the transect (NOAA CoastWatch Northeast Regional Node 2002). Other significantly positive anomalies began to appear over the outer shelf in October, resulting from a belated fall overturn in that region. Significantly high surface temperatures extended over the first 340 km of the transect by December, coinciding with the second-warmest November-January air temperatures in several bordering states since weather records began in 1895 (National Oceanic and Atmospheric Administration 2002).

For 2001, the entire transect averaged 0.8°C above average (Table 4).

Surface Salinity

Annual minimum salinities of less than 27.5 PSU were centered very nearshore in early April (Figure 63). Highest values occurred from January through mid-March at the outer end of the transect.

Salinities more than 1.5 PSU below average briefly occurred between the 230- and 310-km references distances in January, a remnant of a feature with an inshore-undulating time-space margin during 2000. Salinities more than 2.0 PSU below average also occurred seaward of the spring runoff plume during April and May. An area centered on the shelf break in between April and June reached significantly low values (by more than 2.0 PSU) during the middle of this time period. Moderately-higher-than-average salinities occurred offshore during the first 3 mo of the year, and again at isolated locations inshore and offshore in August and September, and offshore in December. These offshore anomalies correspond well with positive anomalies of surface temperature.

For 2001, the entire transect averaged 0.09 PSU above average (Table 4).

Bottom Temperature

Typical annual minimum bottom temperatures of less than 4°C occurred in February at about the 50-km reference distance (Figure 64). Annual maximum temperatures in excess of 18°C occurred nearshore in July.

In terms of departures from the 1978-90 baselines, the first half of the year generally remained within normal variability. By early July, significantly-warmer-than-average water was present over more than 50 km of the outer shelf, and anomalously cooler water occupied the slope area beyond 200 km. The 10-11°C water of the upper 100 m of a warm-core ring was found about 65 km shoreward of the average location of water with these temperatures, leading to the positive anomalies. Likewise, the ordinarily deeper and colder water of the ring was present at shallower depths in August and September due to the ring's shoreward position.

Gulf of Maine -- 2001

Surface Temperature

Continued poor coverage occurred for the transect in 2001 (Figure 65). Near-normal annual minimum temperatures less than 4°C occurred in Massachusetts Bay during February and early March. Annual minimum values of 2°C were recorded on the eastern end of the transect from February to late March.

Temperatures over the western margins of the Scotian Shelf were more than 1°C below average during the same February-to-late-March period. Measurements taken in June over the western 300 km of the transect indicate that that portion of the GOM was headed for an anomalously warm summer, perhaps exceeding means by nearly 3°C; lack of coverage prevents verification. However, from June through September, the western Scotian Shelf had significantly low temperatures, falling below the baselines by more than 3°C. From late November to the end of the year, temperatures were near average over the entire transect.

No annual means for the entire transect were calculated.

Bottom Temperature

Annual minimum bottom temperatures on the ends of the transects were similar to those for surface temperatures in magnitude (*i.e.*, less than 4°C in the west; less than 2°C in the east), although the minima persisted longer at the bottom than they did at the surface (Figure 66). No sampling occurred during the usual annual maxima on the bottom.

Significantly warm water appeared from the 150- to 230-km reference distances in January. By June, this feature had reached westward to about the 90-km reference distance. This westward movement of warm water is consistent with intrusions of slope water from the Northeast Channel that follows the deeper channels of the GOM in areas of the sampling transect. Figure 66, Panel B, shows continuity of the features during the first 6 mo of the year, while panel C does not. This difference is due to the temperature departures in April not reaching significant levels.

The significantly cold water between the 240- and 320-km reference distances during mid-March to mid-April is a westward extension of the anomalously cold water which occurred over the Scotian Shelf during at least the first 9 mo of the year. Here, and in the vicinity of Cape Sable in June, bottom temperatures were more than 2°C below average.

Coverage was not sufficient to allow calculation of a transect-wide average of bottom temperature for the year.

TIME PLOTS OF ANOMALIES FOR THE 1978-2001 TIME SERIES

The five time plots are the result of taking a multiyear slice through the standardized anomaly grids at one reference distance in the MAB, and four in the GOM. An adequate analysis of these time plots is beyond the scope of this paper. However, the overlay of a 15-mo running average reveals features of the signal that are felt to be significant enough to warrant comment.

Middle Atlantic Bight

The location chosen to represent the MAB was the 101-km reference distance, or approximately 40°N, 73°W, along the transect (Figure 1a).

Surface Temperature

Isolated months during 1978-2001 departed significantly from the 1978-90 means (Figure 69). Departures in excess of two standard deviations were more numerous in the 1990s than in the previous years, even after adjustments to account for the 1990s not being included in the base period. Sequential, monthly positive or negative departures were more numerous in the 1990s than in previous years. The December 2001 and January 2002 anomalies both exceeded the previous series record of September 1990.

Finally, anomalies averaged higher after 1990 (+0.39) than through 1990 (-0.07).

Surface Salinity

Isolated months during 1978-2001 departed significantly from the 1978-90 means, and are especially more prevalent in the late 1990s than in earlier years (Figure 69). There is more month-to-month consistency in the surface salinity departures than in the surface temperature departures. Uninterrupted positive departures of 2 yr (*i.e.*, 1980-81 and 1985-86), and uninterrupted negative departures of 2-3 yr (*i.e.*, 1996-98 and 1998-99), occurred.

No trend during the time period was apparent, although anomalies averaged lower after 1990 (-0.34) than through 1990 (+0.17).

Bottom Temperature

Greater departures in the 1990s also occurred in the bottom temperature data (Figure 69). The phase changes of the smoothed values are quite similar through the time period for the bottom temperature and the surface temperature. Departures from 1994 through 2000 were considerably larger than during the earlier part of the series.

Anomalies averaged slightly higher after 1990 (+0.10) than through 1990 (-0.07).

Massachusetts Bay

The location chosen to represent Massachusetts Bay was the 48-km reference distance, or approximately 70°20'W, along the transect (Figure 1b).

Surface Temperature

With the exception of isolated monthly departures near, or in excess of, two standard deviations, the 1978-88 period exhibited no enduring anomalous surface temperatures (Figure 70). During 1989 to early 1990 and during 1992 to mid-1994, mostly colder-than-average conditions prevailed. Positive anomalies were briefly present from mid-1990 through 1991. After 2000, most departures were positive.

The smoothed values depart from the mean considerably less than those for surface temperature in the MAB.

No trend during the time period was apparent.

Surface Salinity

Salinity anomalies generally shifted from negative values at the beginning of 1978 to a positive peak by mid-1980, declined generally through early 1984 to a period minimum, rose sharply to a positive peak in mid-1985, declined generally to a negative point in late 1987, and after generally climbing to a positive peak in 1990, again declined generally to a negative point at the end of the sampling period in 1993 (Figure 70). The longest sustained period was that of negative anomalies in 1983 and 1984.

Bottom Temperature

From 1978 to 1981, bottom temperatures were near normal (Figure 70). Positive departures occurred during 1982 and 1983, followed by near-average values in the mid-1980s. From 1987 through early 1990, and from early 1992 to mid-1994, values were generally negative, after which departures became inconsistent, with several significantly warm months. Departures in the late 1990s were less excessive than in the earlier period, and might result in a warming trend for these data -- anomalies averaged slightly higher after 1990 (+0.10) than through 1990 (-0.11).

Western Gulf of Maine

The location chosen to represent the western GOM was the 165-km reference distance, or approximately 68°55'W, along the transect (Figure 1b).

Surface Temperature

Variations from 1978 through 1990 followed a similar pattern to those for surface temperature anomalies in Massachusetts Bay, except that they were of slightly larger magnitude (Figure 71). Positive anomalies generally occurred from 1983 to early 1985; negative anomalies occurred in 1982, generally for a fairly prolonged period from mid-1986 to 1991, and generally again from mid-1991 to 1994. This pattern was followed in 1996 by the lowest annual average temperature anomaly of the period, from which values began increasing to reach their highest of the period by 2000. This latter pattern was not seen in Massachusetts Bay.

No trend was apparent, although the last 5 yr of the period exhibited consistent and numerous significant positive departures.

Surface Salinity

The western GOM surface salinity pattern follows that of Massachusetts Bay very closely (Figure 71). The only major exception was that in the western GOM, the 1985 positive anomalies persisted to the beginning of 1987. The maximum positive anomaly of the time series occurred in mid-1985, and the maximum negative anomaly occurred in mid-1984.

No trend was apparent during the time period.

Bottom Temperature

Patterns here were also very similar to those for bottom temperature in Massachusetts Bay, although the departures were of less magnitude (Figure71). The maximum negative anomaly of the time series occurred in late 1996. Positive anomalies generally dominated from 1991 to near the end of 2001, with the maximum positive anomaly of the time series occurring in mid-1991. Variations were larger in the late 1990s than earlier in the period.

Anomalies averaged higher after 1990 (+0.43) than they did through 1990 (-0.29).

Eastern Gulf of Maine

The location chosen to represent the eastern GOM was the 277-km reference distance, or approximately 67°37'W, along the transect (Figure 1b).

Surface Temperature

Patterns in the eastern GOM followed those to the west very closely (Figure 72). The maximum negative anomaly of the time series occurred in early 1988, and the maximum positive anomaly of the time series occurred in late 1999. The only major difference from the pattern to the west occurred in 1998 when a brief but major shift to cold water interrupted a general 4-yr uptrend. The larger anomalies of the late 1990s -- compared to the earlier years -- are again present.

Anomalies averaged higher after 1990 (+0.22) than they did through 1990 (-0.07), largely as a result of values from 1998 through 2000.

Surface Salinity

Variations in this portion of the GOM are quite similar in pattern and magnitude to those to the west (Figure 72). The maximum positive anomaly of the time series occurred in early 1990, and the maximum negative anomalies of the time series occurred in 1984 and 1987.

Negative anomalies dominated after 1986.

Bottom Temperature

Patterns and magnitudes of bottom temperature departures in the eastern GOM are quite similar to those in the western GOM from 1978 to 1990 (Figure 72). Thereafter, the patterns begin to go out of phase, and the magnitudes, especially in the late 1990s, were much more negative in the eastern GOM, exhibiting significantly-lower-than-average temperatures in 1998 and early 1999. The maximum positive and negative anomalies of the time series occurred in 1998 and 1997, respectively, and were part of the usual late 1990s relatively extreme anomalies.

Anomalies averaged higher after 1990 (+0.08) than through 1990 (+0.32).

Scotian Shelf

The location chosen to represent the Scotian Shelf was the 396-km reference distance, or approximately 66°15'W, along the transect (Figure 1b).

Surface Temperature

From 1978 through mid-1993, surface temperature anomaly patterns on the Scotian Shelf generally followed those in the eastern GOM (Figure 73). However, the magnitudes of departure in the former were considerably less than those in the latter. From 1993 to 1998, temperatures varied in opposite phase to those to the west. By 1999, both areas exhibited warmer-than-average temperatures, with the departures on the Scotian Shelf of lesser magnitude. Values returned to near average at the end of 2000, became negative during much of 2001, and returned to a positive phase at the end of the time series.

Larger anomalies were apparent during the 1990s than during earlier years, and no trend was seen over the entire time period.

Surface Salinity

Patterns of variation in surface salinity deviations were generally in phase with those in the eastern and western GOM, and to a lesser extent with those in Massachusetts Bay, during the entire period of sampling. However, like surface temperature, the salinity departures from means were less than those in the western sections.

No trend was apparent during the time period.

Bottom Temperature

Patterns of variation in bottom temperature deviations as determined by the smoothed data seemed to be in synchrony -- except for 1988-92 -- with the patterns in the eastern GOM (Figure 73). However, these shifts often resulted in Scotian Shelf temperatures being in a positive phase while those to the west were in a negative phase, and vice versa.

Bottom temperature measurements from the eastern GOM are obtained from considerably greater depths (Figure 72) than the measurements from the Scotian Shelf, and would be expected to represent different water masses. Unfortunately, an investigation of a connection between these patterns is beyond the scope of this paper.

DISCUSSION

This paper presents time-space portrayals of surface temperature and salinity and bottom temperature data from the MAB and the GOM during 1991-2001. The style of the portrayals was chosen to aid in comparison of these data with those published earlier (Benway, Jossi, Thomas *et al.* 1993). Also presented are time plots of anomalous conditions of these data for the 1978-2001 period.

Record high and low values for all three data types, and for both geographical regions, all occurred during the 1990s. Surface temperatures along both transects during 1996 averaged the lowest during the entire 1978-2001 period, departing from baselines by 1.1°C in both regions. The highest annual average surface temperatures in the MAB occurred during 1994 and 1995, and in the GOM during 1991. Three years of consistently low surface temperatures in the MAB ended in 1999.

Surface salinities in the MAB had their lowest annual averages in 1998, departing from baselines by 1.1 PSU. Four years of consistently low surface salinities in the MAB ended in 2000.

Bottom temperatures in the MAB were lowest in 1994, averaging 1.4°C below the base period. Lowest bottom temperatures in the GOM occurred in 1997, averaging 0.5°C below the baseline. In the MAB, 1999 had the highest average bottom temperatures for the period of record (+1.8). In the GOM, 1994 had the highest average bottom temperatures for the period of record (+0.5).

As the monitoring program continues, special attention will be paid to the relatively extreme behavior of the ecosystem that occurred in the 1990s.

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Table 1. Equations for calculating depth during an expendable bathythermograph deployment (Sippican Corporation 1970)

Probe Type	Depth Range (m)	Equation[a]
T-4	0-460	$D = [(6.472) \times (T - 0.00216) \times (T^2)]$
T-6	0-460	$D = [(6.472) \times (T - 0.00216) \times (T^2)]$
T-7	0-760	$D = [(6.472) \times (T - 0.00216) \times (T^2)]$
T-10	0-200	$D = [(6.301) \times (T - 0.00216) \times (T^2)]$

[a] D = depth of voltage reading in meters; T = time of descent in seconds.

Table 2. Gridding methods and elliptical search radii for both sampling routes and grid types

Route	Grid Type	Grid Size	Grid Limits	No. of Grids	Gridding Method	Search Radii	Anisotropy
MB and MC	Single year	x = 17.38 km; y = 15.22 days	x = 0-452 km; y = 0-365.25 days	x = 27; y = 25	Kriging: *linear variogram *no nugget effect *nearest 50 neighbors *data outside grid used *no smoothing *blank grid if less than four values in search	x = 60 km; y = 70 days	1:1 circular search of scaled data
MB and MC	Base period	x = 17.38 km; y = 15.22 days	x = 0-452 km; y = 0-365.25 days	x = 27; y = 25	Inverse distance weighting: *weighting factor = 2 *nearest 200 neighbors *data outside grid used *duplicates averaged *no smoothing	x = 30 km; y = 35 days	1:1 circular search of scaled data

Table 3. Summary statistics for gridding residuals for the Middle Atlantic Bight (Route MB) and Gulf of Maine (Route MC). (Route MB single-year residuals resulted from gridding of all surface and bottom temperature and surface salinity data from 1978 through 2001. Route MC single-year surface salinity residuals resulted from gridding only data from 1978 though 1993. Base-period residuals resulted from gridding of all data from 1978 through 1990. Normality was based on the Kolomogorov *D* statistic.)

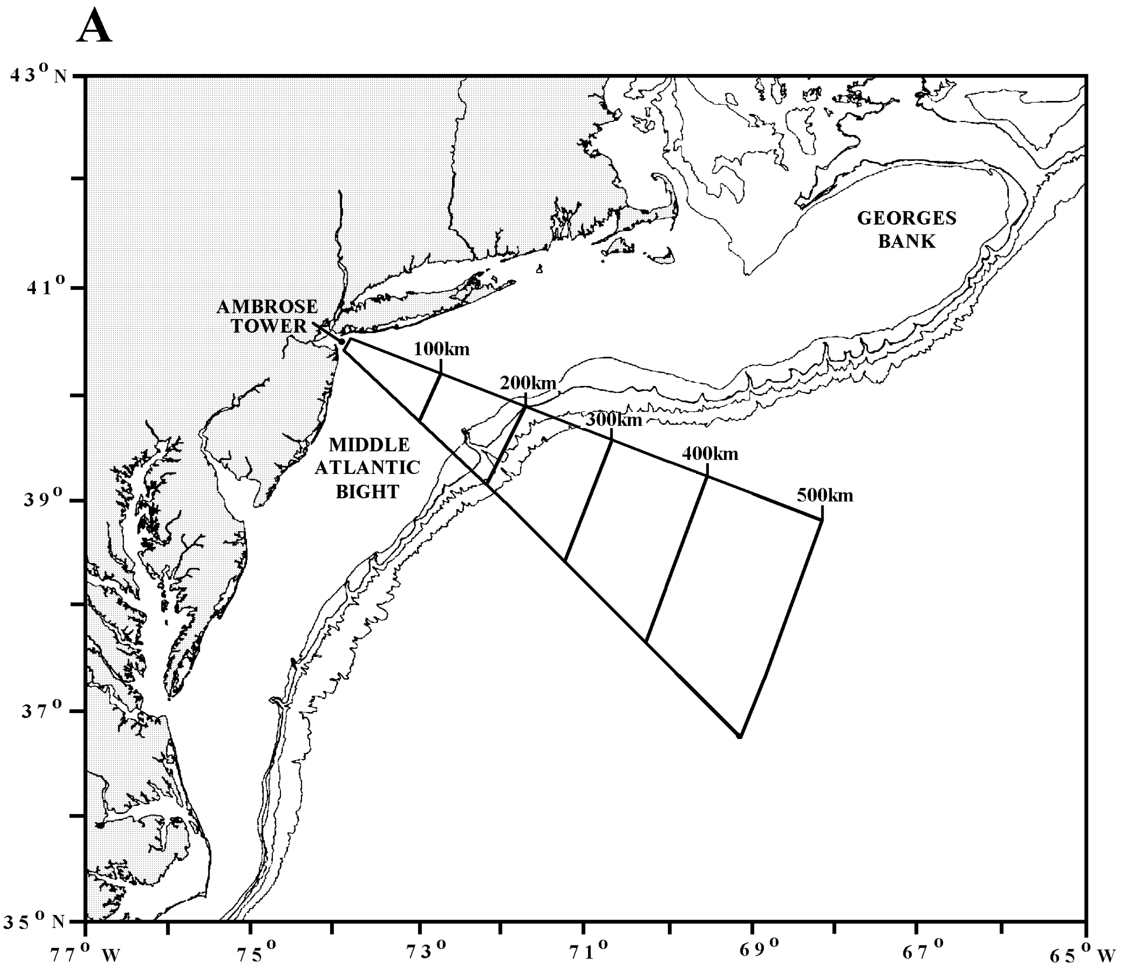
Data Type	Grid Type	N	Min.	Max.	Mean	*s*	Skewness	Kurtosis	Normality
Route MB									
Surface temperature	Single year	7607	-5.110	+6.486	-0.008	0.733	+0.234	7.627	$D = 0.083$; $P > D < 0.010$
	Base period	5056	-8.676	+10.479	-0.040	1.851	-0.009	1.310	$D = 0.035$; $P > D < 0.010$
Surface salinity	Single year	7538	-5.003	+3.233	+0.003	0.370	-0.819	15.045	$D = 0.111$; $P > D < 0.010$
	Base period	5091	-10.090	+5.977	+0.024	0.906	-0.355	7.683	$D = 0.054$; $P > D < 0.010$
Bottom temperature	Single year	3545	-5.132	+10.700	+0.036	0.798	+1.278	16.521	$D = 0.107$; $P > D < 0.010$
	Base period	2380	-6.165	+10.188	-0.0350	2.067	+12.164	368.937	$D = 0.103$; $P > D < 0.010$
Route MC									
Surface temperature	Single year	4668	-2.914	+2.870	-0.004	0.408	+0.349	5.176	$D = 0.081$; $P > D < 0.010$
	Base period	3317	-4.164	+6.186	+0.024	1.135	+0.333	1.937	$D = 0.041$; $P > D < 0.010$
Surface salinity	Single year	4129	-1.973	+1.171	-0.000	0.157	-1.299	23.3431	$D = 0.139$; $P > D < 0.010$
	Base period	3340	-4.256	+1.963	-0.018	0.473	-0.961	5.338	$D = 0.062$; $P > D < 0.010$
Bottom temperature	Single year	2654	-2.359	+1.891	-0.003	0.283	-0.125	6.125	$D = 0.073$; $P > D < 0.010$
	Base period	1797	-3.789	+4.833	-0.030	0.798	+0.039	1.870	$D = 0.035$; $P > D < 0.010$

Table 4. Annual mean values and anomalies of surface temperatures and salinities and bottom temperatures for the entire Middle Atlantic Bight transect from 1991 through 2001

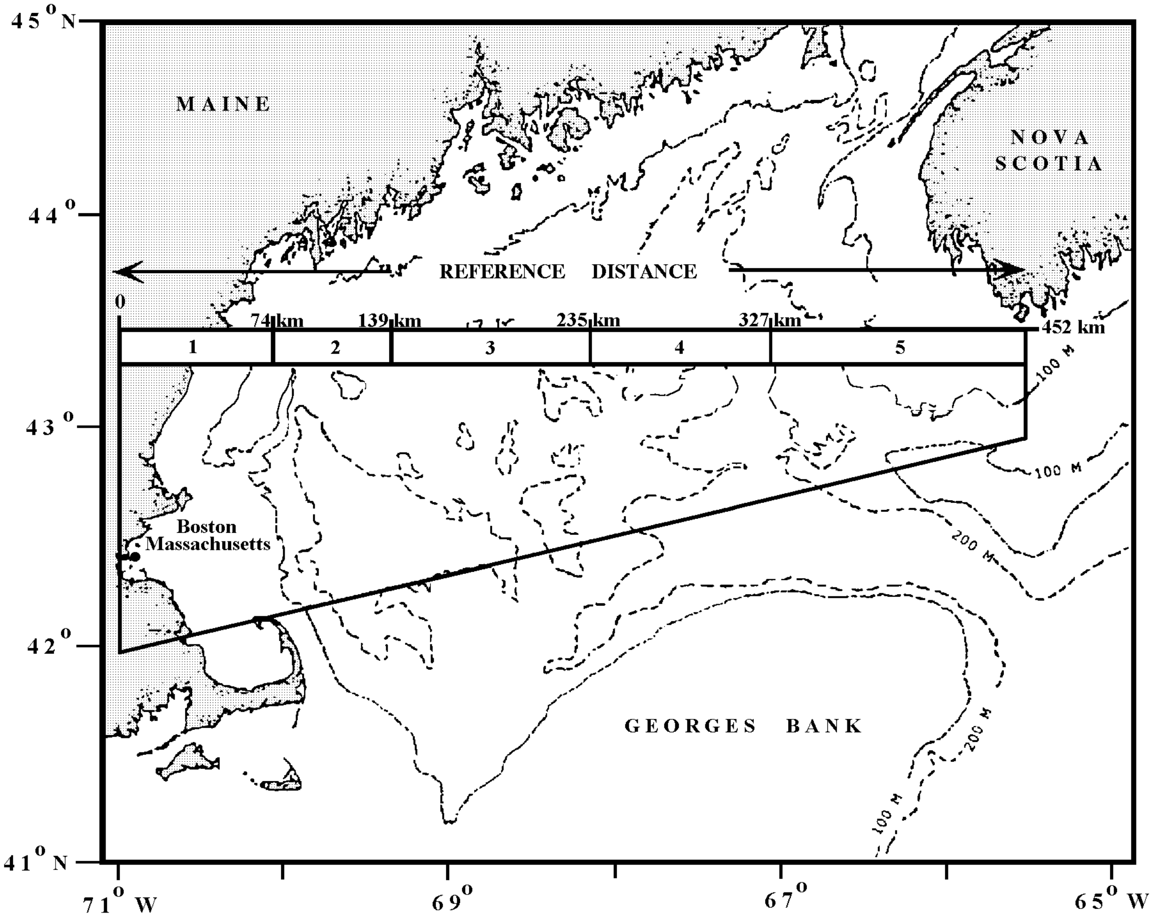
Year(s)	Measure	Surface Temperature (°C)	Surface Salinity (PSU)	Bottom Temperature (°C)
1978-90	Baseline value	16.3	33.81	8.8
1991	Mean value	17.5	33.82	8.8
	Mean anomaly	+1.2	+0.01	0.0
1992	Mean value	16.0	34.53	9.0
	Mean anomaly	-0.3	+0.72	0.2
1993	Mean value	15.7	33.57	8.9
	Mean anomaly	-0.6	-0.24	0.1
1994	Mean value	17.6	34.06	7.4
	Mean anomaly	+1.3	+0.25	-1.4
1995	Mean value	17.6	34.32	9.9
	Mean anomaly	+1.3	+0.51	1.1
1996	Mean value	15.2	32.86	8.5
	Mean anomaly	-1.1	-0.95	-0.3
1997	Mean value	15.5	33.27	9.7
	Mean anomaly	-0.8	-0.54	0.9
1998	Mean value	15.7	32.70	8.6
	Mean anomaly	-0.6	-1.11	-0.2
1999	Mean value	17.3	33.61	10.6
	Mean anomaly	+1.0	-0.20	1.8
2000	Mean value	17.4	34.10	10.4
	Mean anomaly	+1.1	+0.29	1.6
2001	Mean value	17.1	33.90	9.8
	Mean anomaly	+0.8	+0.09	1.0

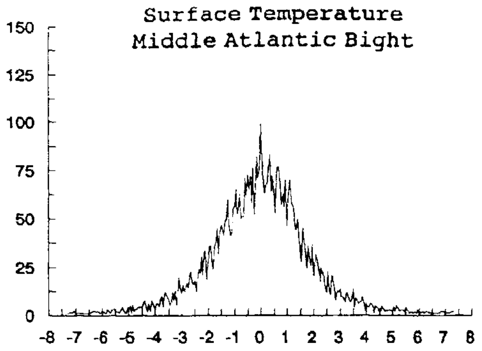
Table 5. Annual mean values and anomalies of surface temperatures and salinities and bottom temperatures for the entire Gulf of Maine transect from 1991 through 1997. (Insufficient coverage from 1998 through 2001 prevented calculation of annual means.)

Year(s)	**Measure**	**Surface Temperature (°C)**	**Surface Salinity (PSU)**	**Bottom Temperature (°C)**
1978-90	Baseline value	9.1	32.43	6.7
1991	Mean value	9.5	32.24	7.0
	Mean anomaly	+0.4	-0.19	+0.3
1992	Mean value	8.4	32.00	6.6
	Mean anomaly	-0.7	-0.43	-0.1
1993	Mean value	8.9	31.93	6.5
	Mean anomaly	-0.2	-0.50	-0.2
1994	Mean value	9.1		7.2
	Mean anomaly	0.0		+0.5
1995	Mean value	9.4		7.1
	Mean anomaly	+0.3		+0.4
1996	Mean value	8.0		6.9
	Mean anomaly	-1.1		+0.2
1997	Mean value	9.0		6.2
	Mean anomaly	-0.1		-0.5

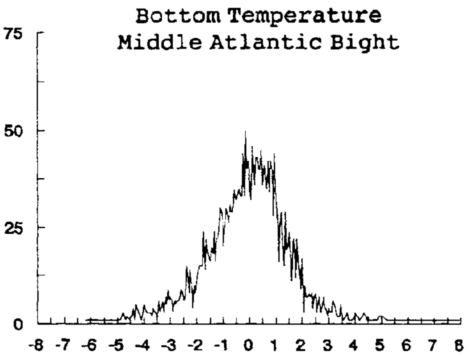

A
43° N
41°
39°
37°
35° N
77° W
75°
73°
71°
69°
67°
65° W
AMBROSE
TOWER
MIDDLE
ATLANTIC
BIGHT
GEORGES
BANK
100km
200km
300km
400km
500km

B

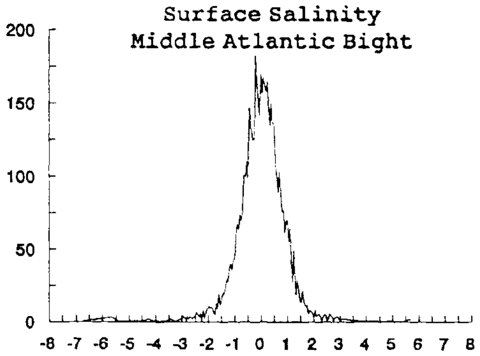

45° N
44°
43°
42°
41° N
71° W
69°
67°
65° W
MAINE
NOVA SCOTIA
REFERENCE DISTANCE
0
74 km
139 km
235 km
327 km
452 km
1
2
3
4
5
Boston
Massachusetts
GEORGES BANK
100 M
200 M


Surface Temperature
Middle Atlantic Bight

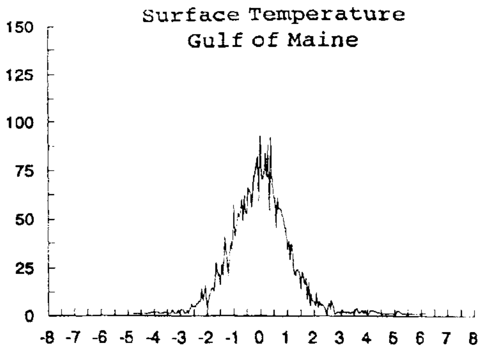
A


Bottom Temperature
Middle Atlantic Bight

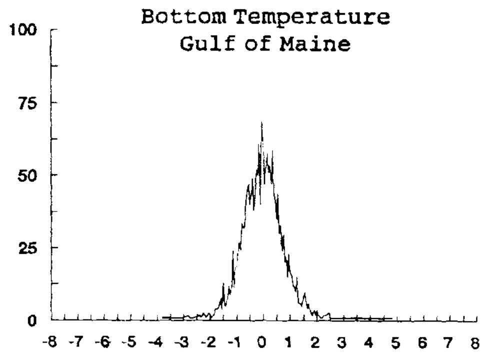
B


Surface Salinity
Middle Atlantic Bight

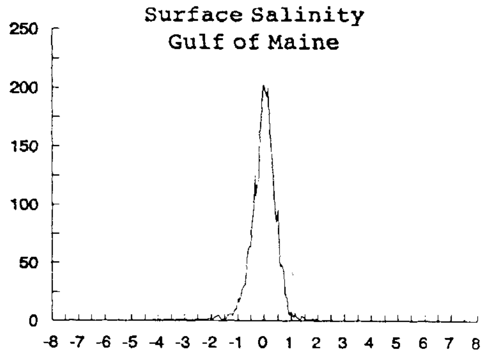
C


Surface Temperature
Gulf of Maine

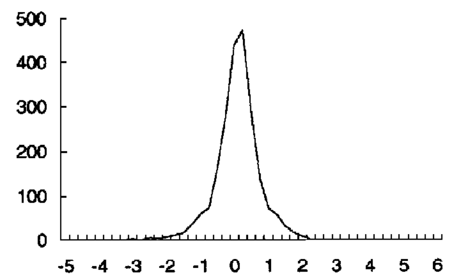
D


Bottom Temperature
Gulf of Maine

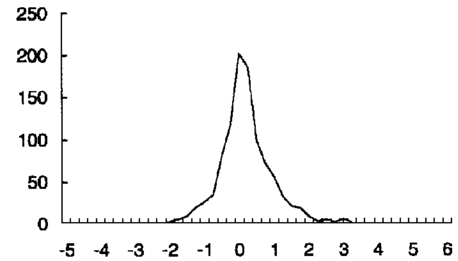
E


Surface Salinity
Gulf of Maine

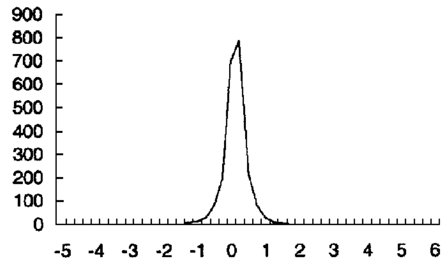
F


Surface Temperature
Middle Atlantic Bight

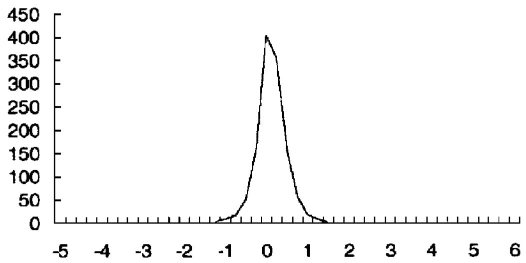
A


Bottom Temperature
Middle Atlantic Bight

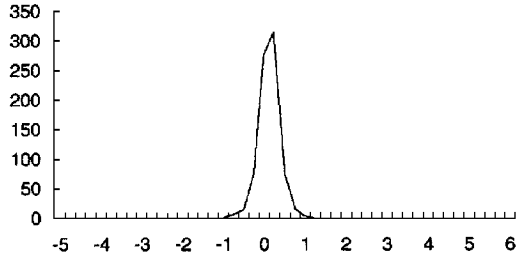
B


Surface Salinity
Middle Atlantic Bight

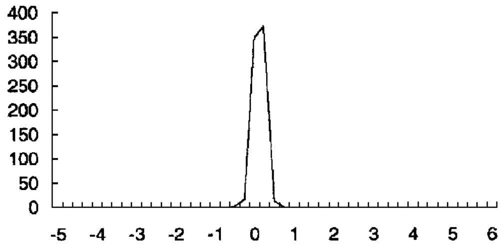
C


Surface Temperature
Gulf of Maine

D


Bottom Temperature
Gulf of Maine

E


Surface Salinity
Gulf of Maine

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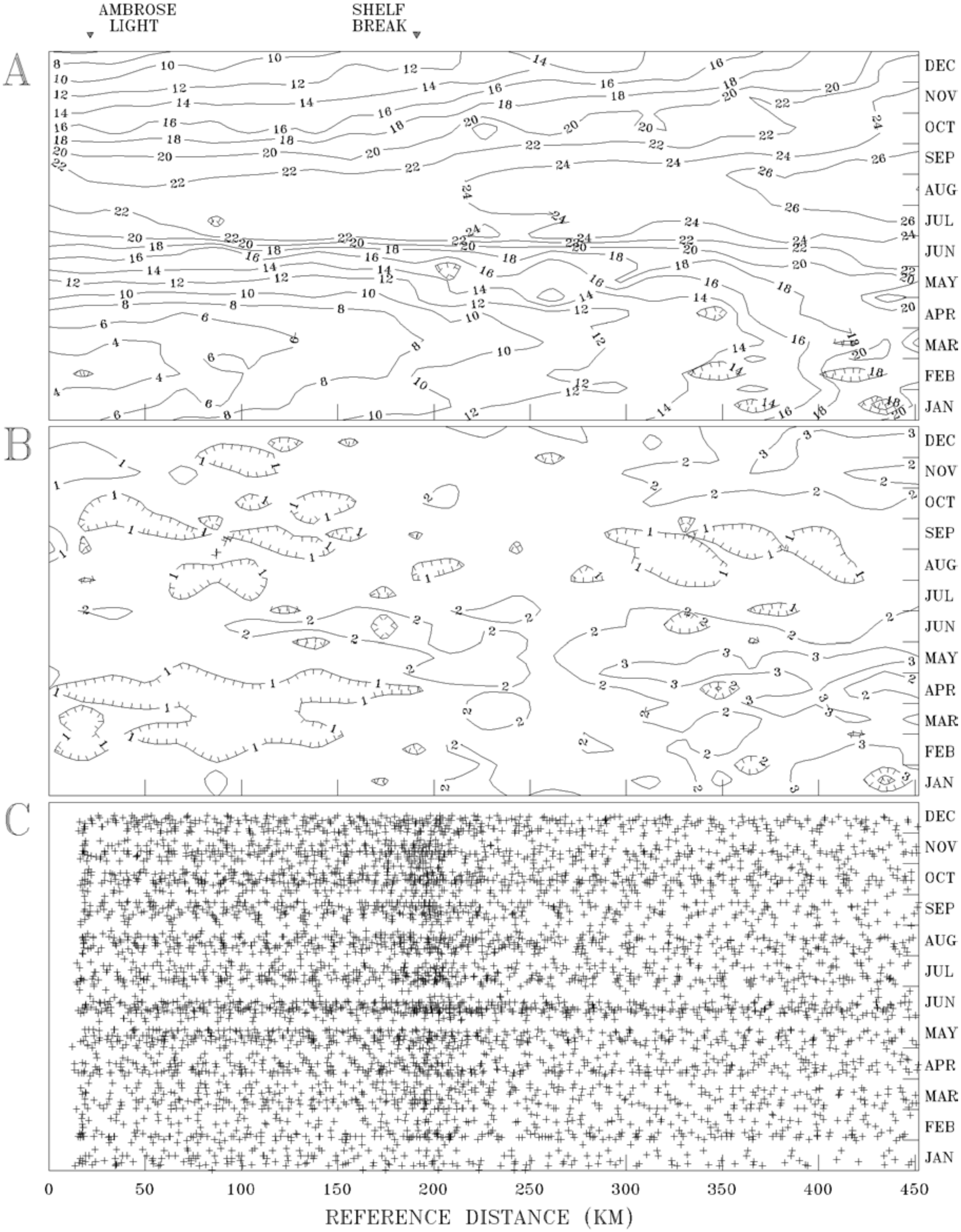
AMBROSE LIGHT
SHELF BREAK
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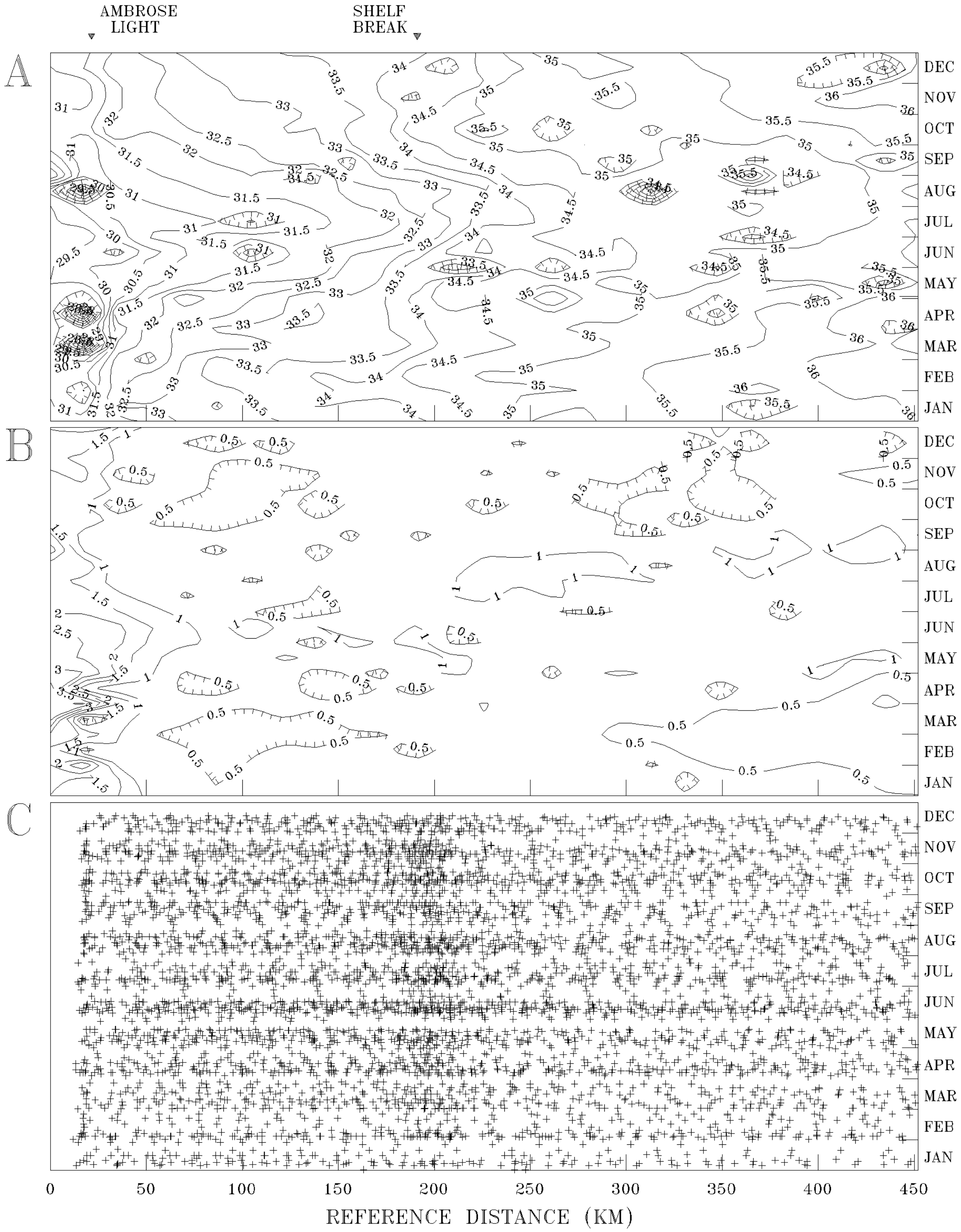
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450
REFERENCE DISTANCE (KM)

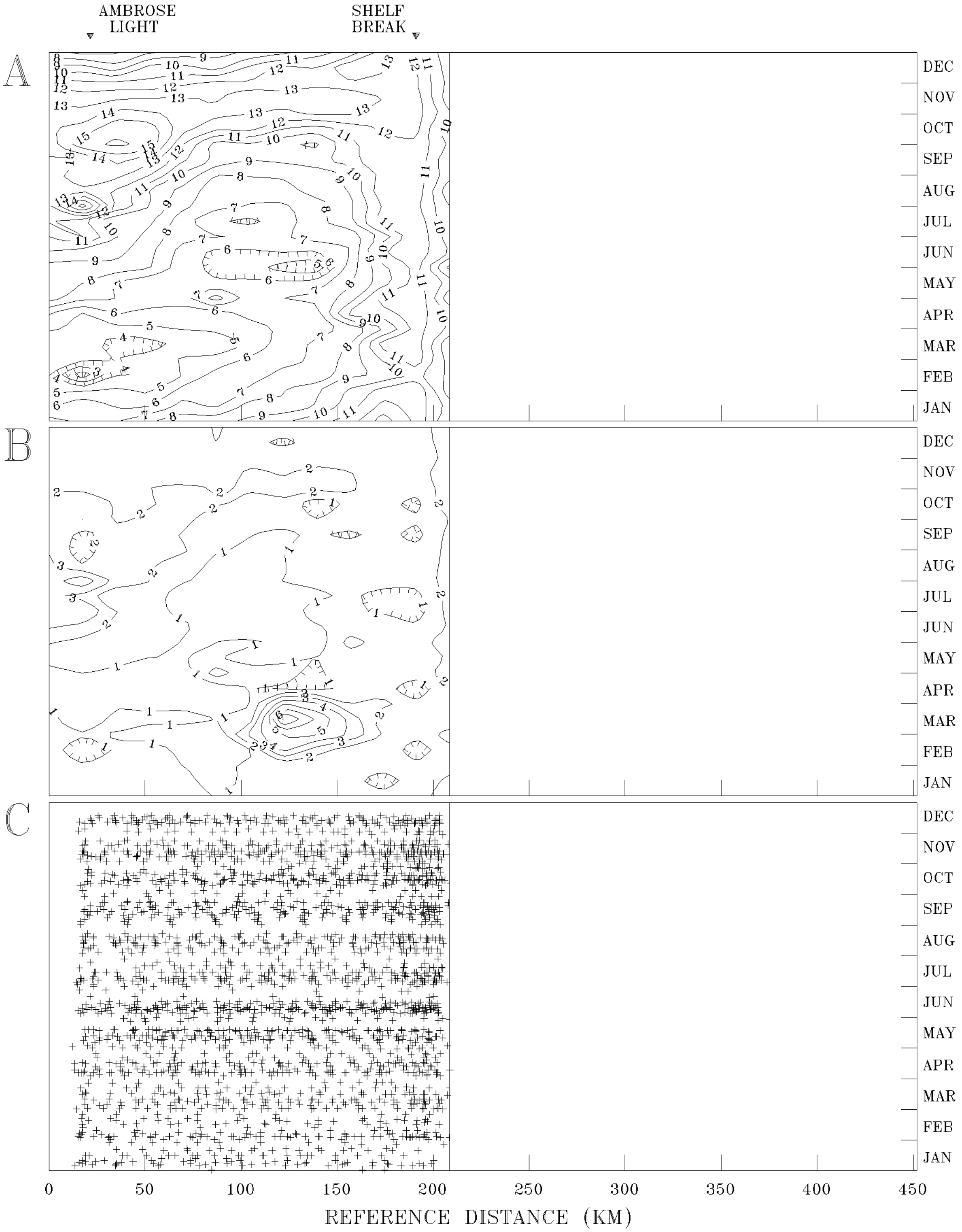
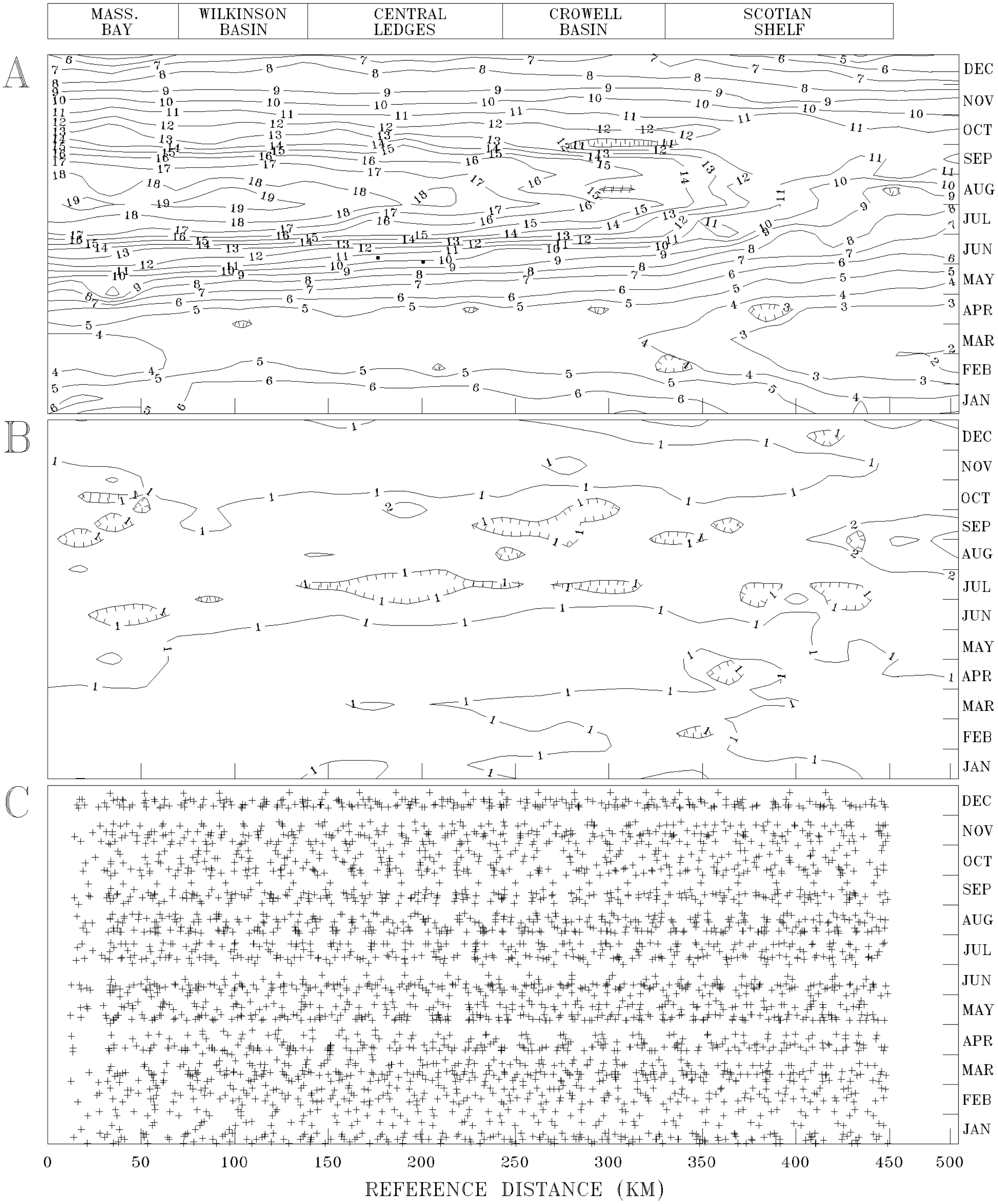


Figure 6. Mean bottom temperature conditions along the Middle Atlantic Bight route during 1978-90. A. Means of measured values (°C). B. Standard deviations of measured values (°C). C. Station locations in time and space. (In panels A and B, values decline on those sides of contour lines with hachures.)


MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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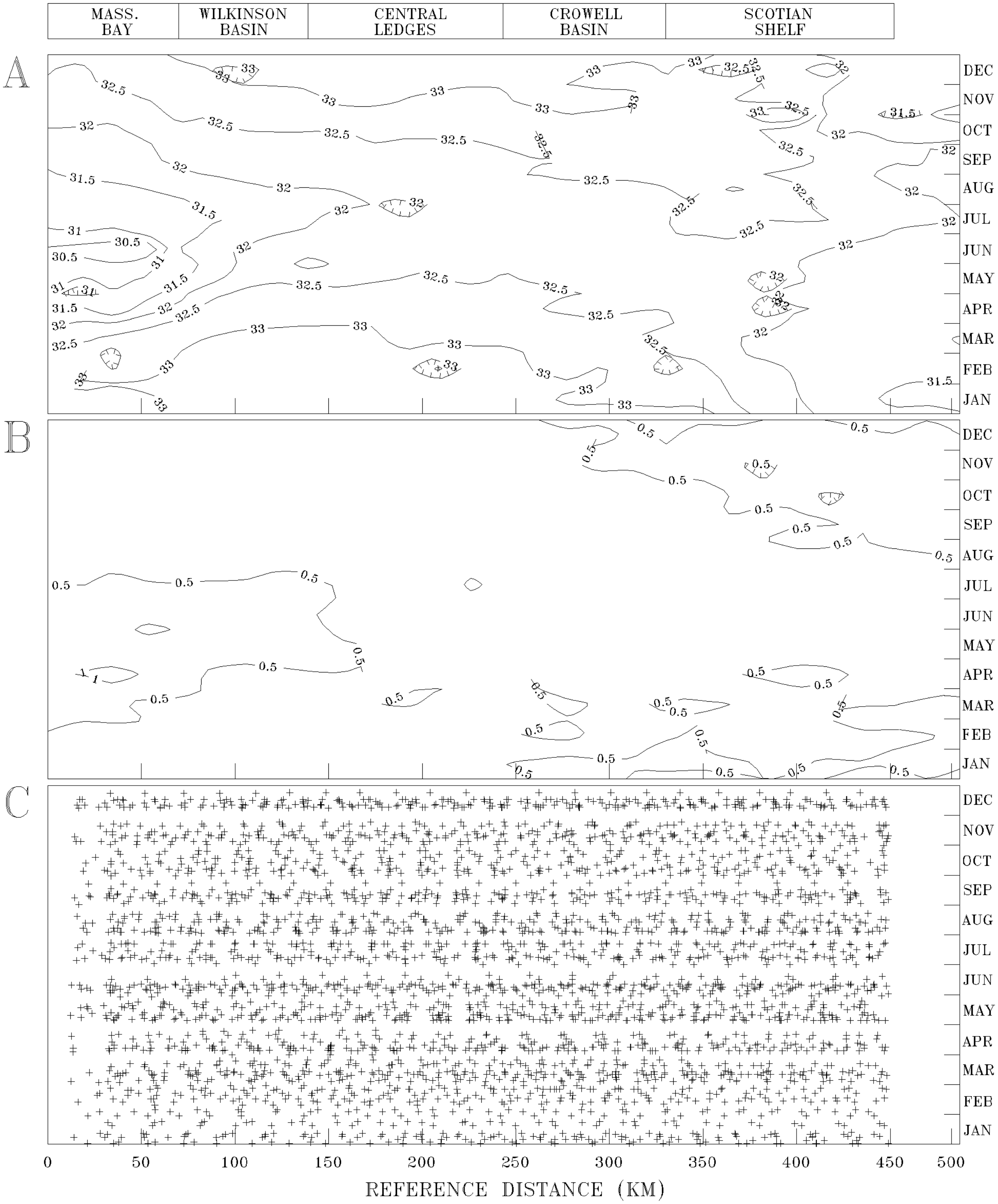
REFERENCE DISTANCE (KM)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WILKINSON BASIN
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CROWELL BASIN
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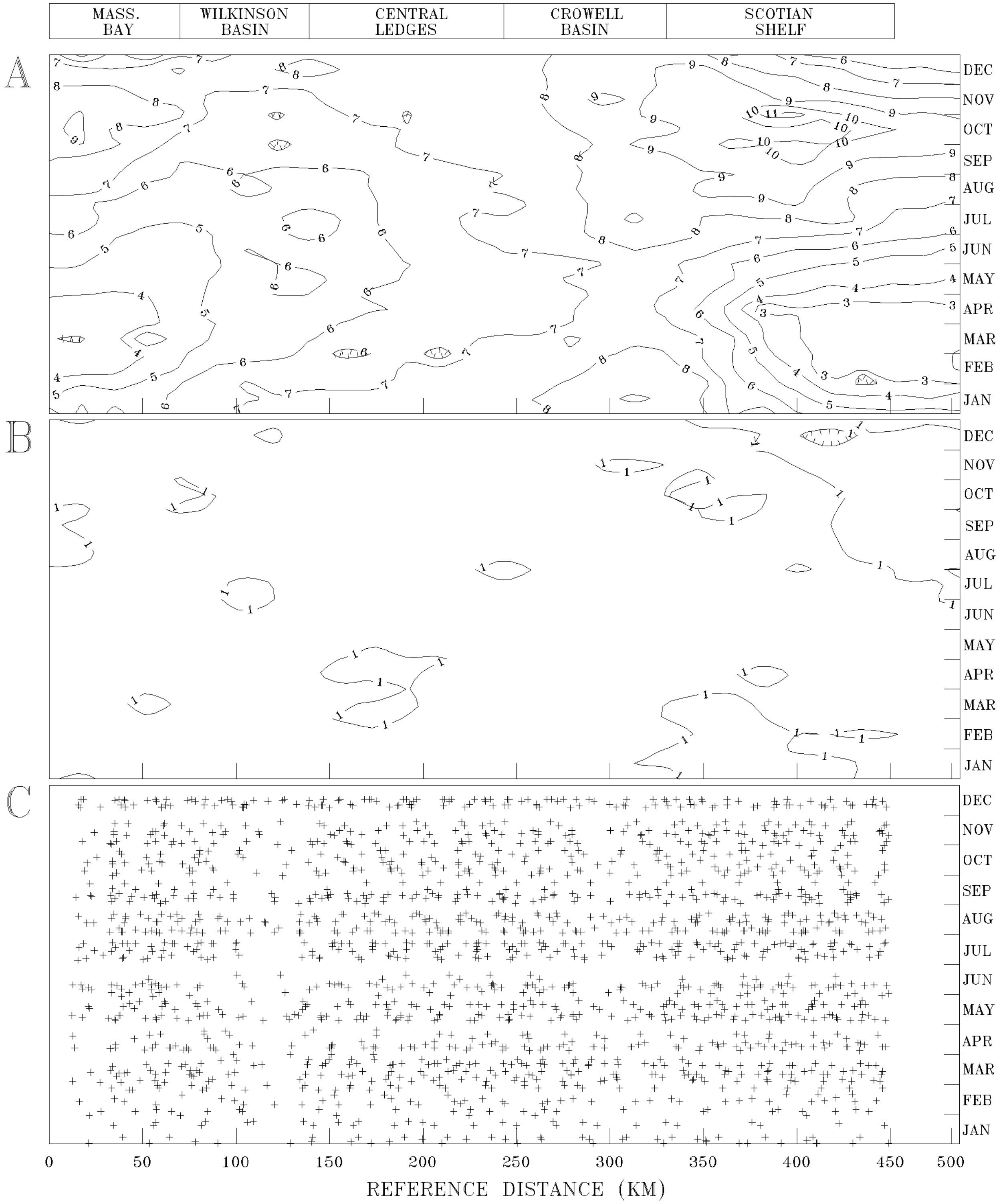
REFERENCE DISTANCE (KM)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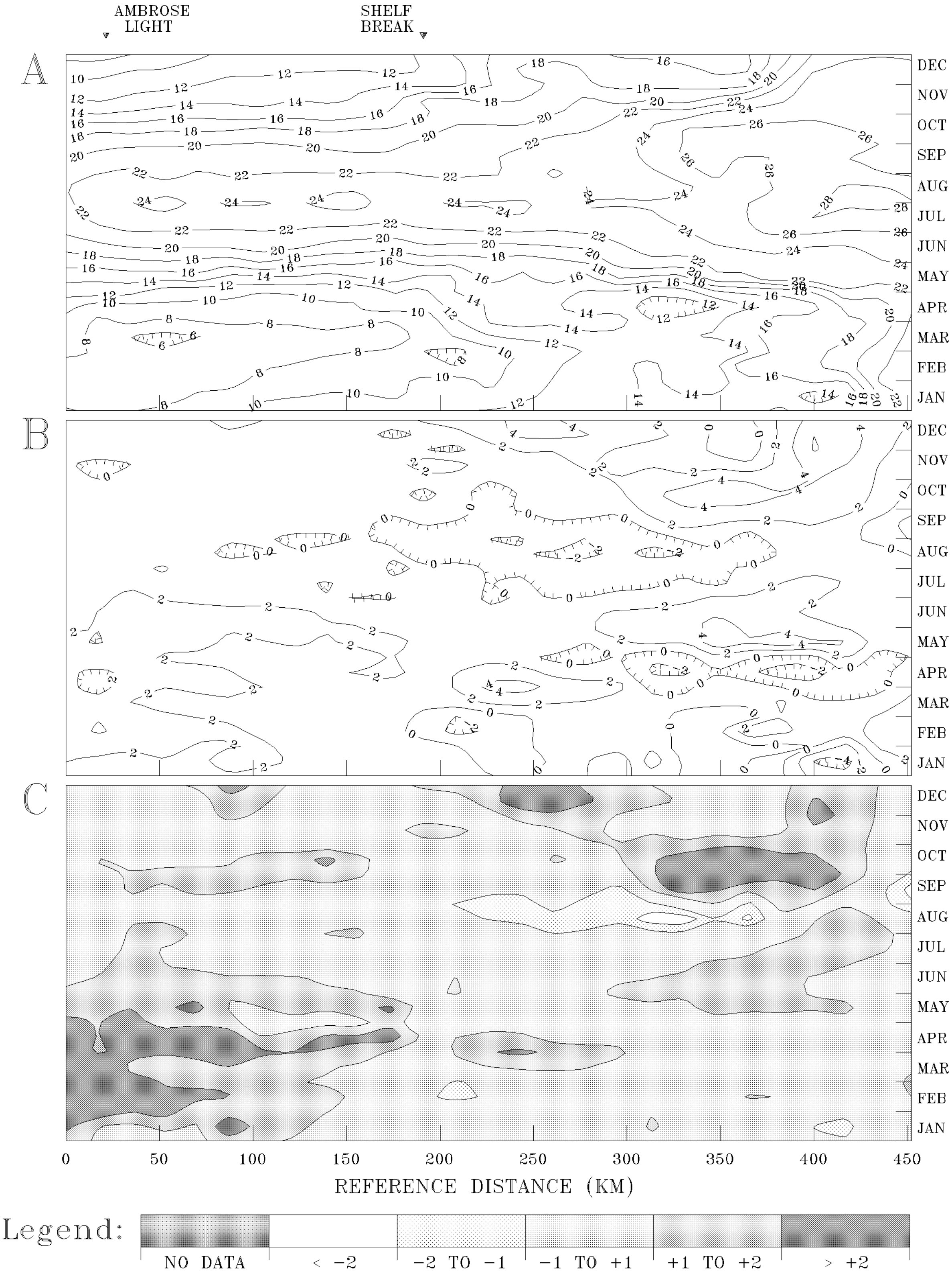
AMBROSE LIGHT
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Legend:
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-1 TO +1
+1 TO +2
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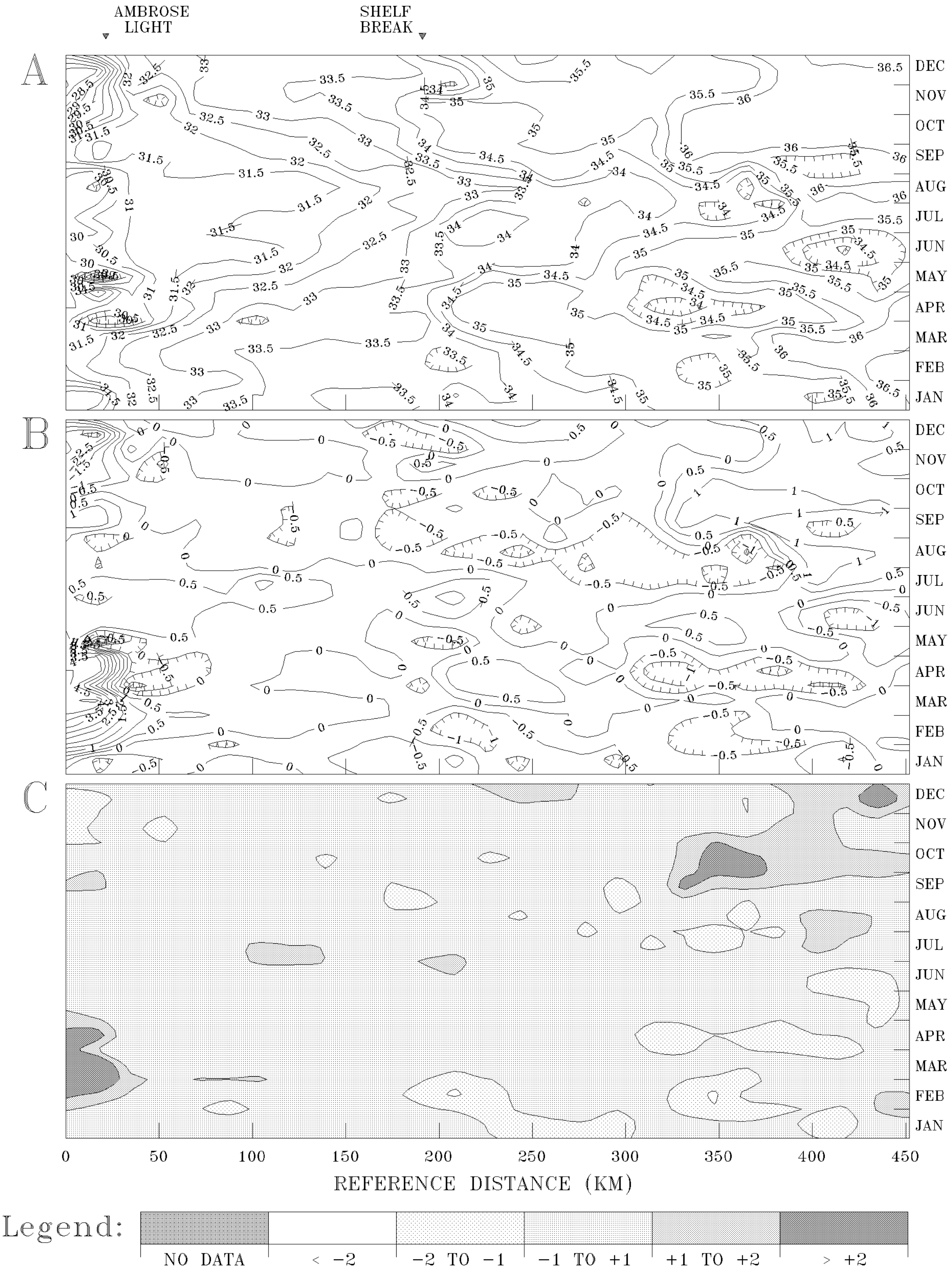
i.e.


AMBROSE LIGHT
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Legend:
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+1 TO +2
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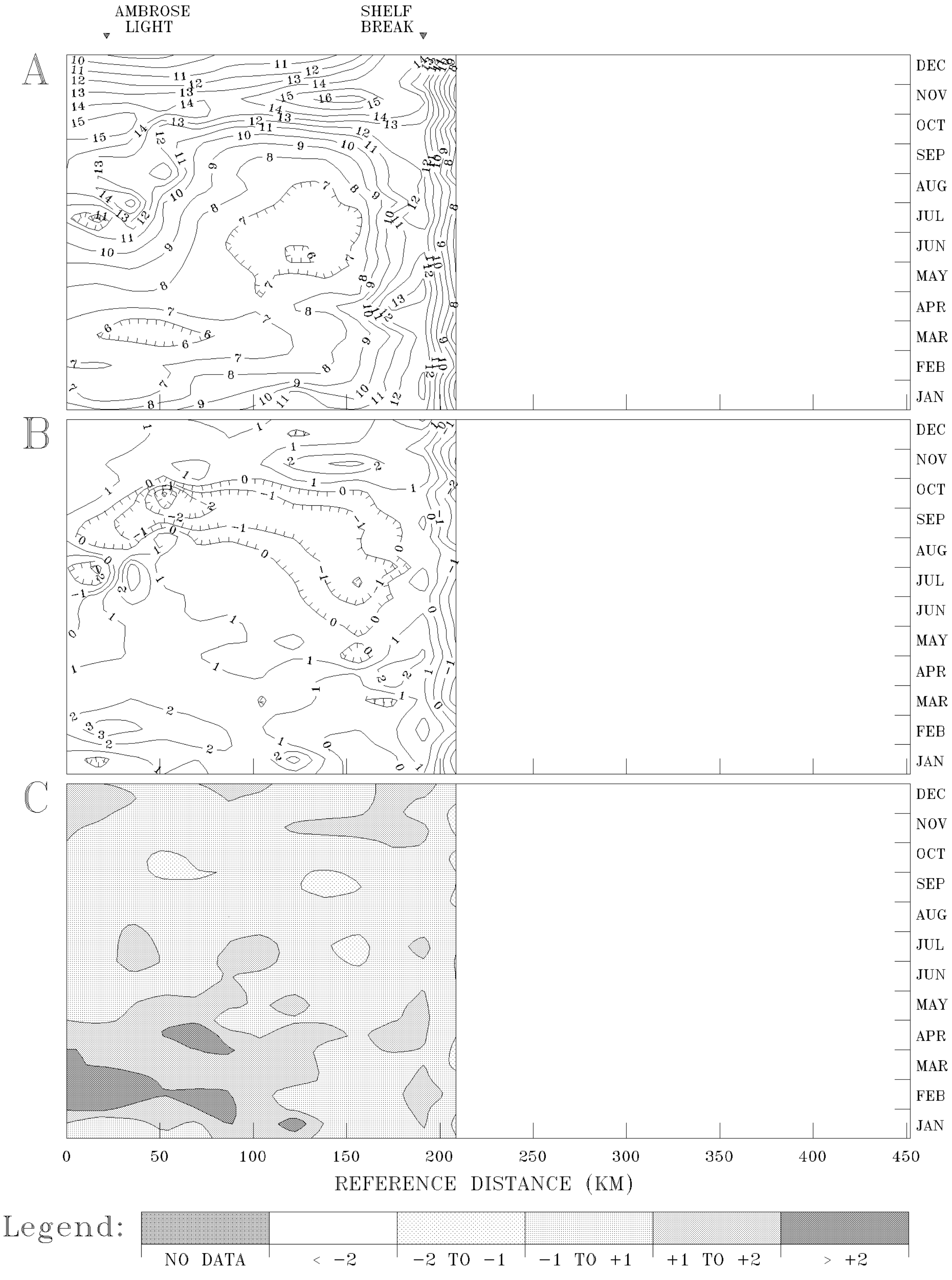
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> +2

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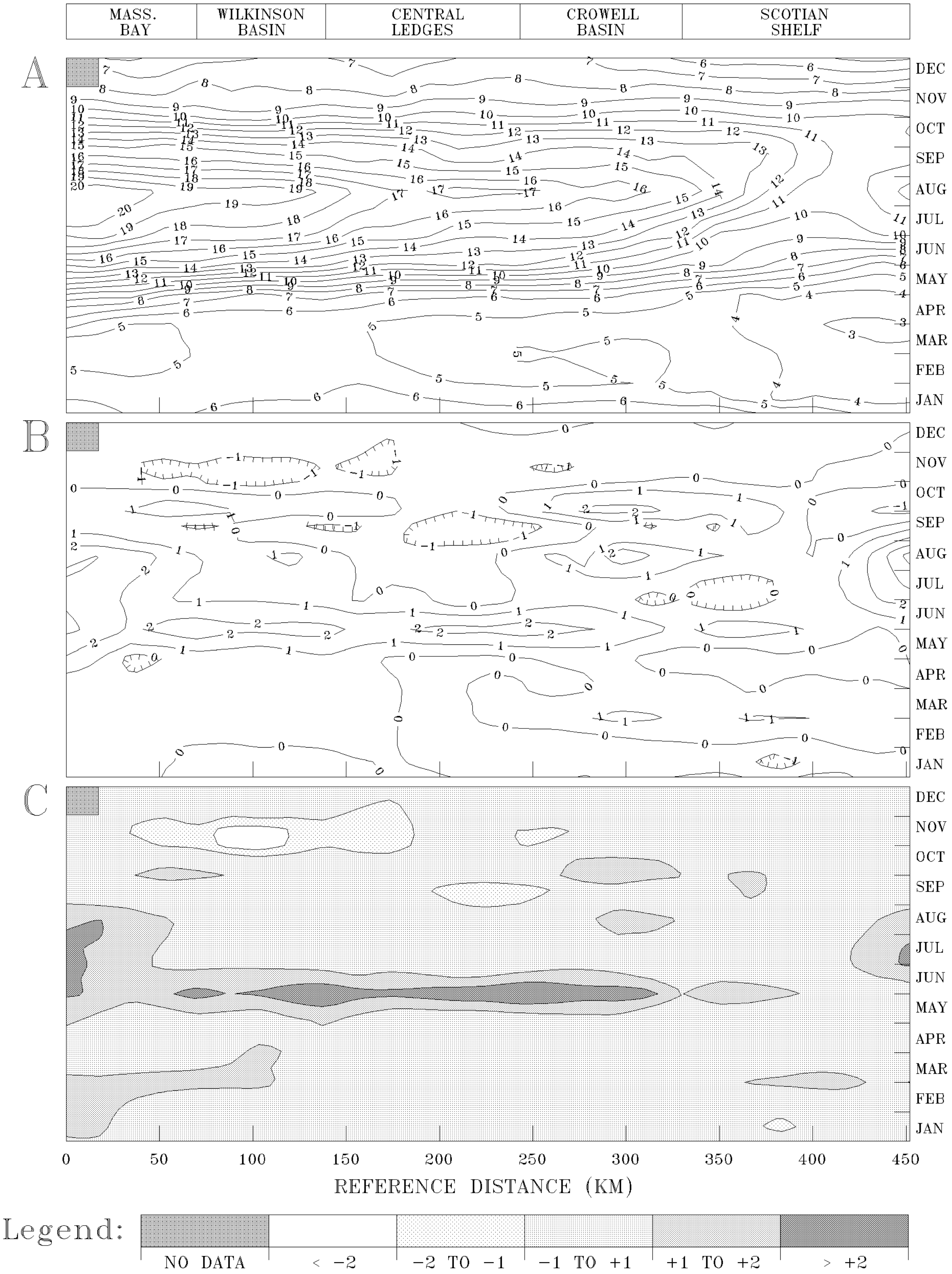
MASS. BAY
WILKINSON BASIN
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CROWELL BASIN
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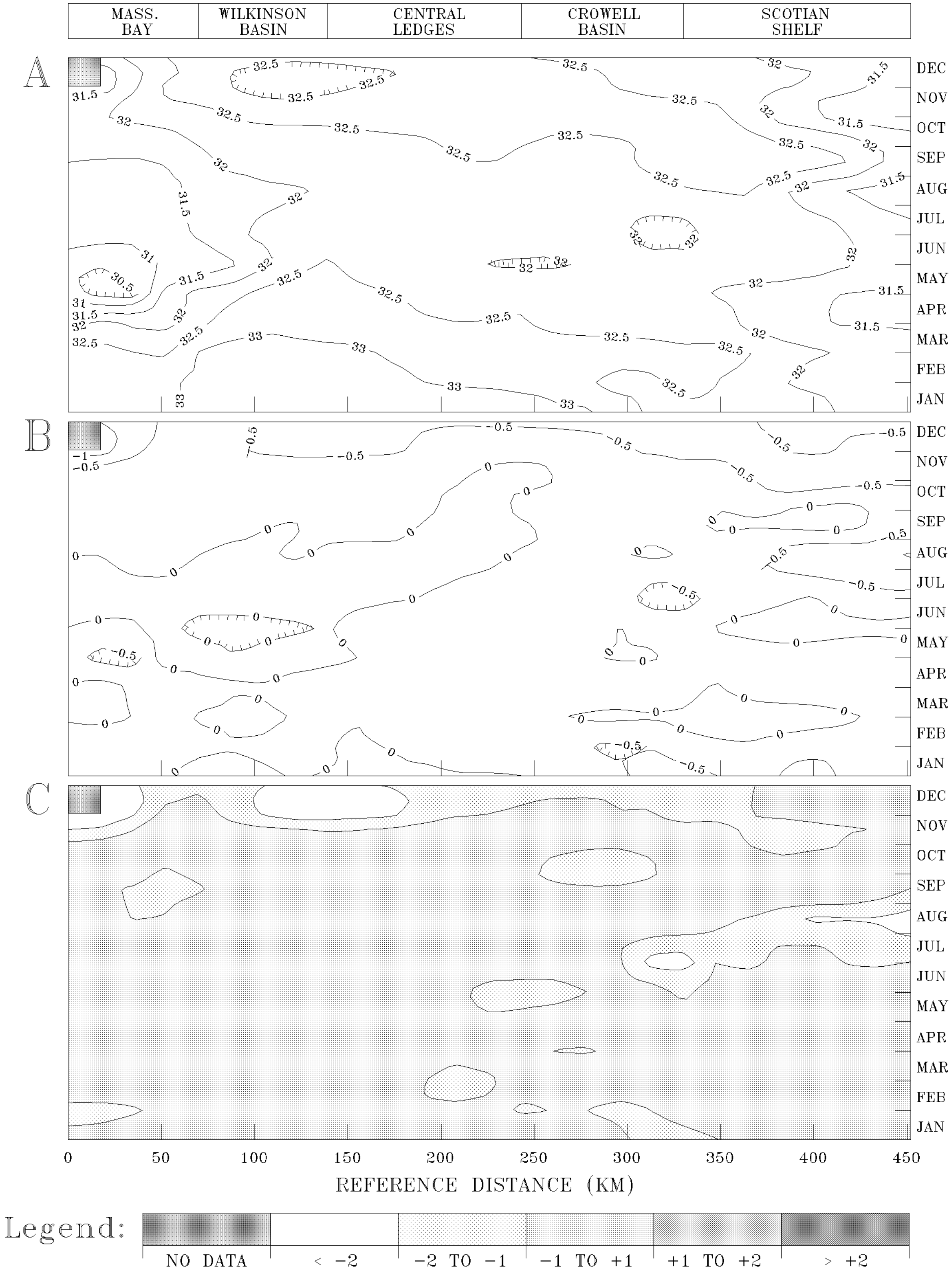
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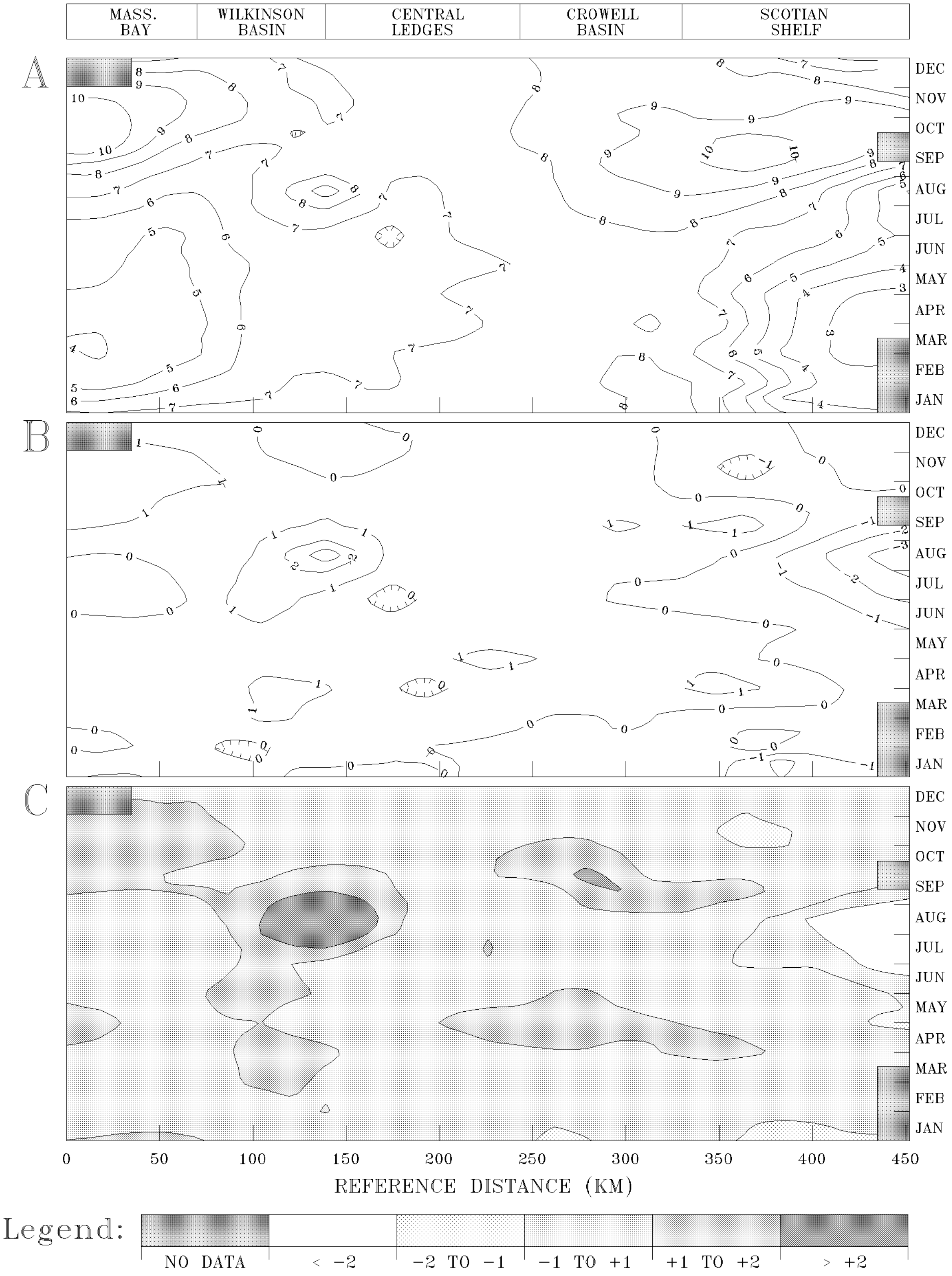
MASS. BAY
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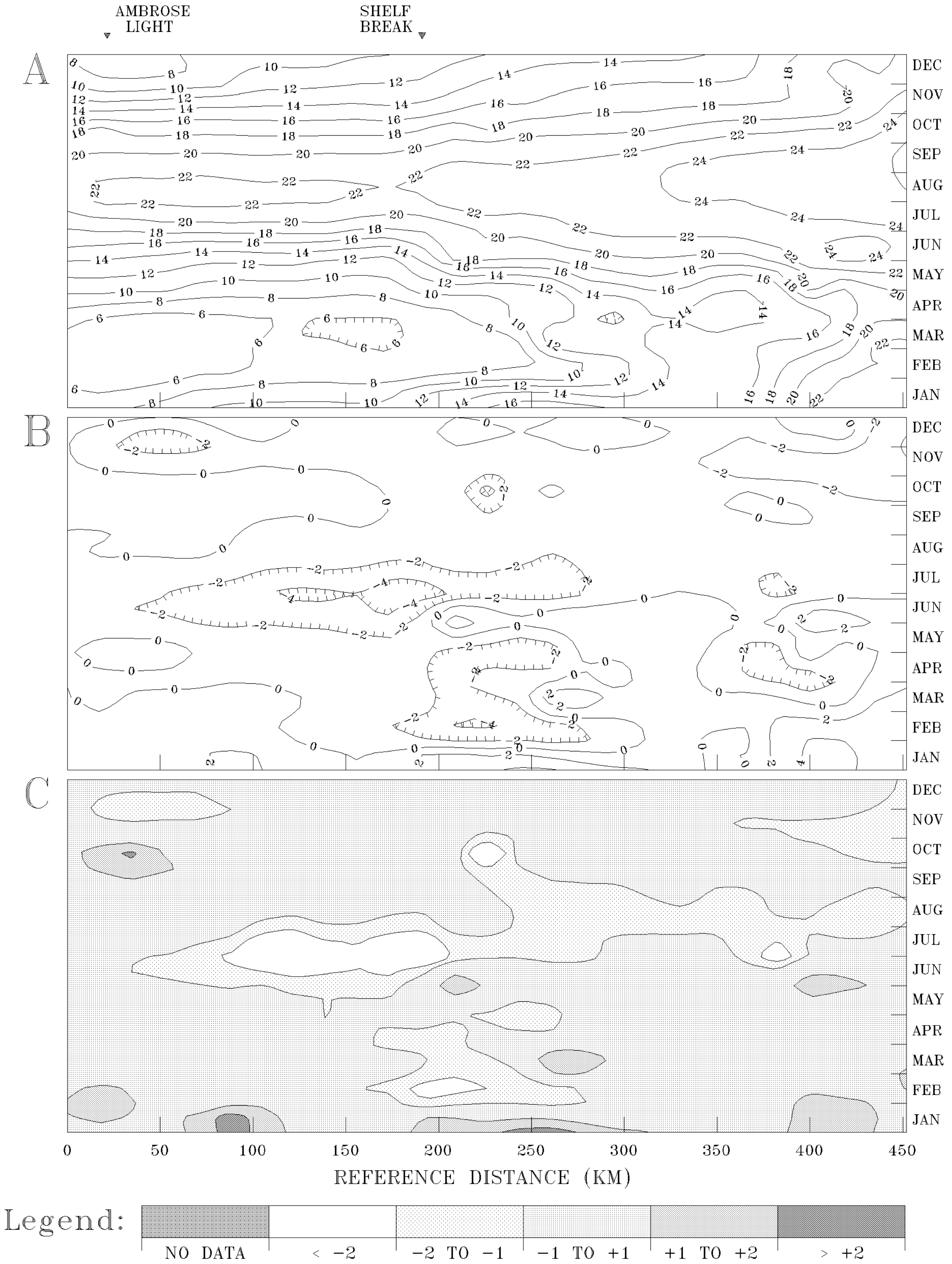
AMBROSE LIGHT
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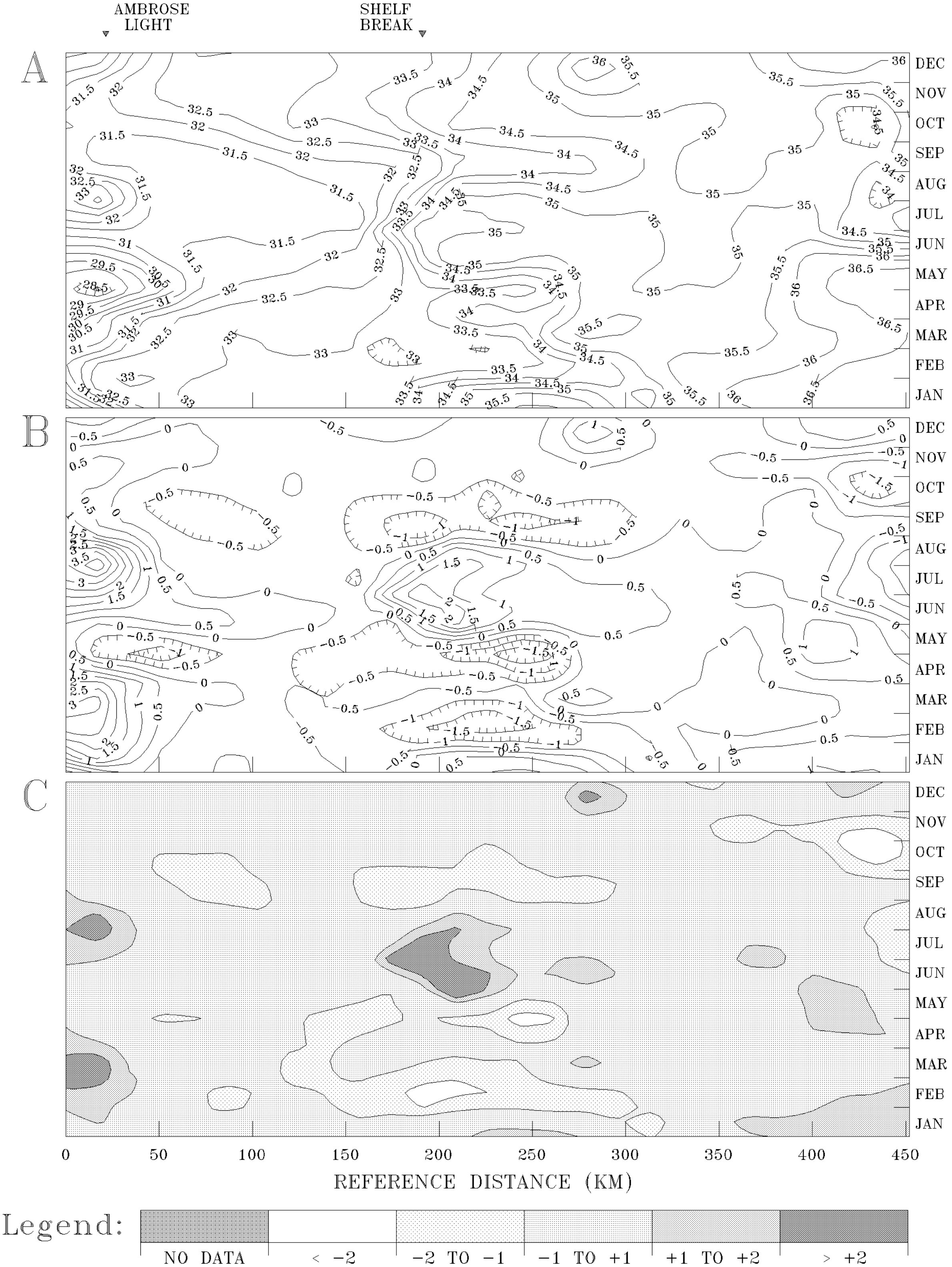
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Legend:
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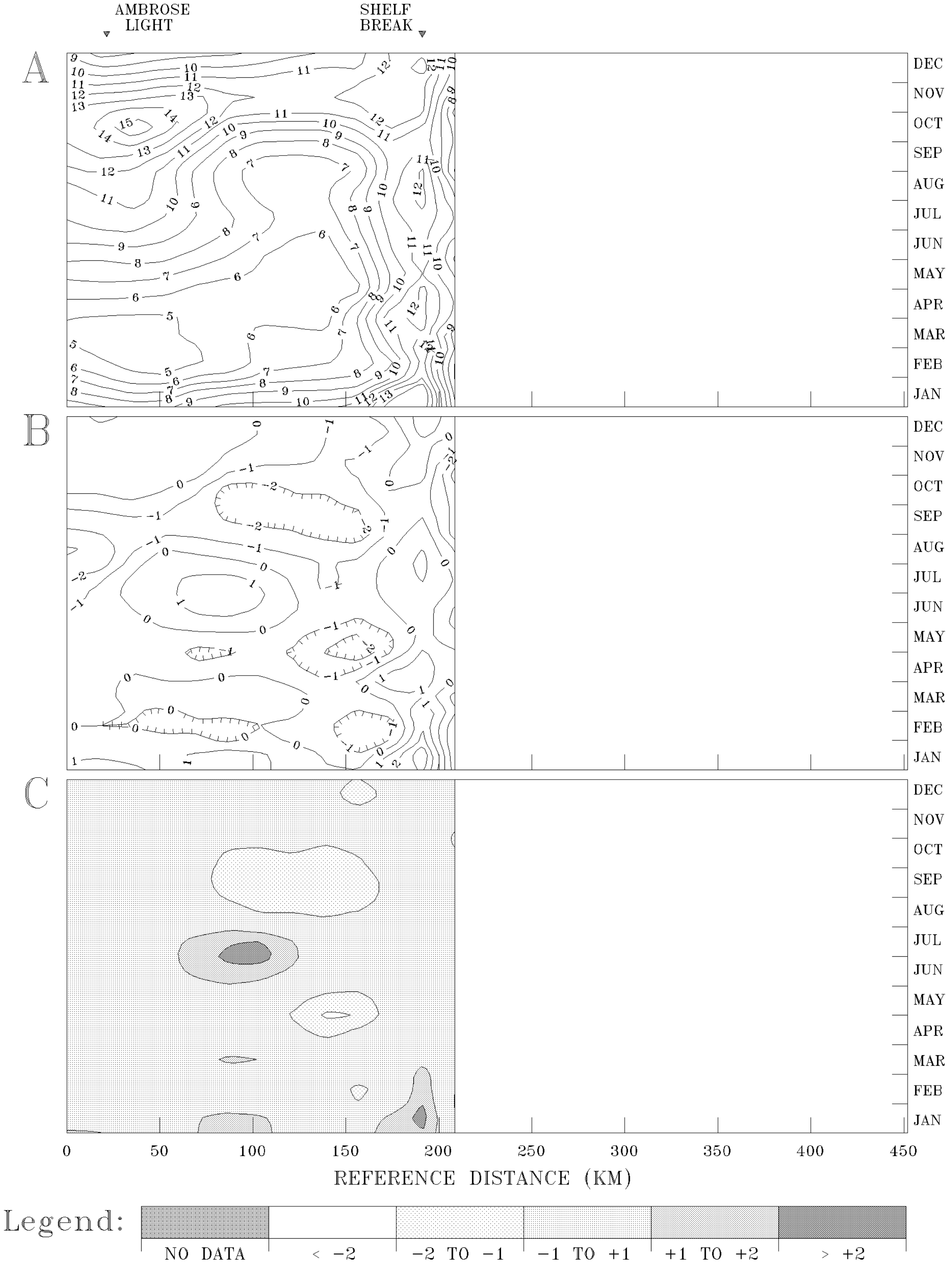
AMBROSE LIGHT
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Legend:
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-1 TO +1
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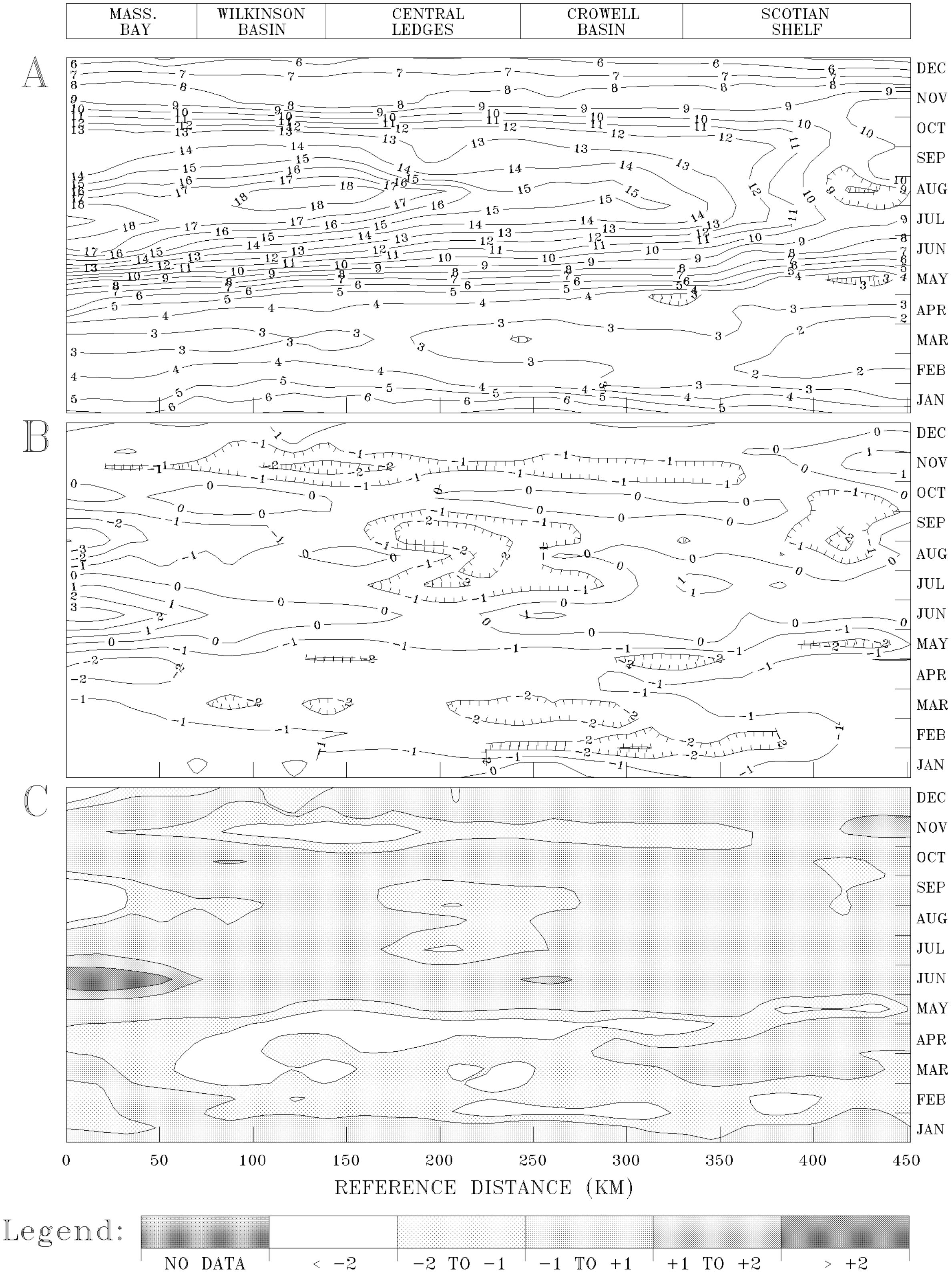
MASS. BAY
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CENTRAL LEDGES
CROWELL BASIN
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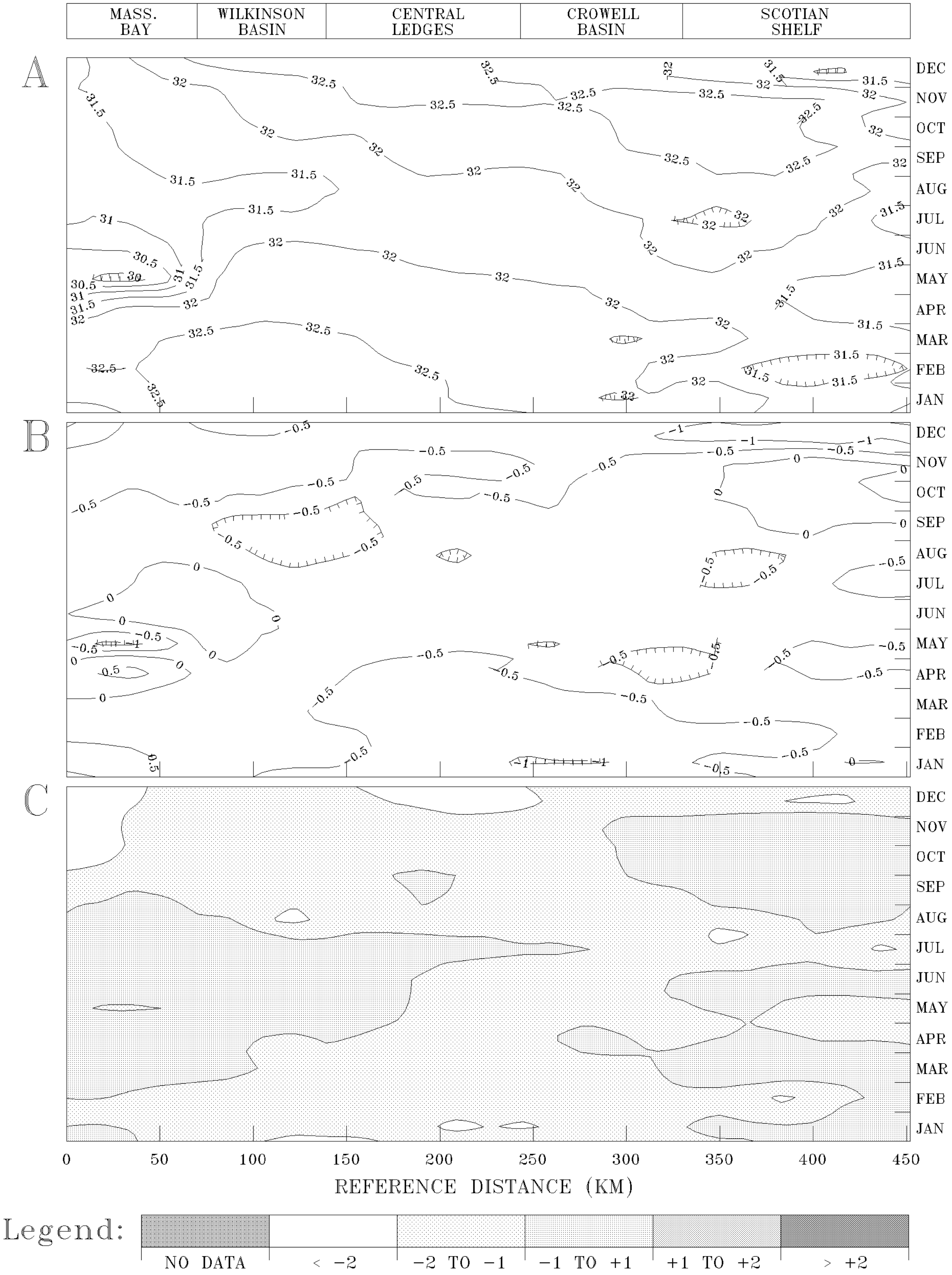
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CROWELL BASIN
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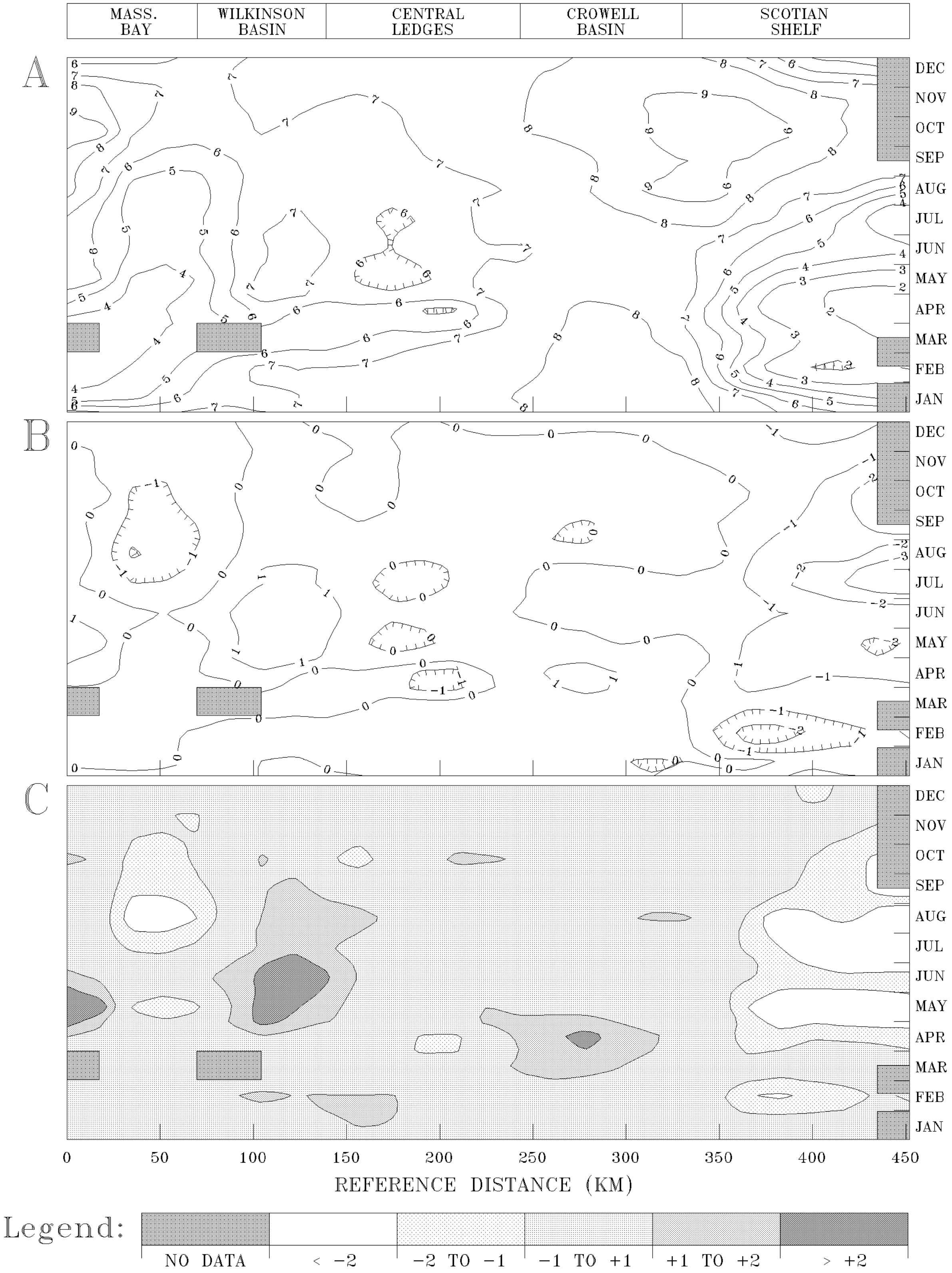
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CENTRAL LEDGES
CROWELL BASIN
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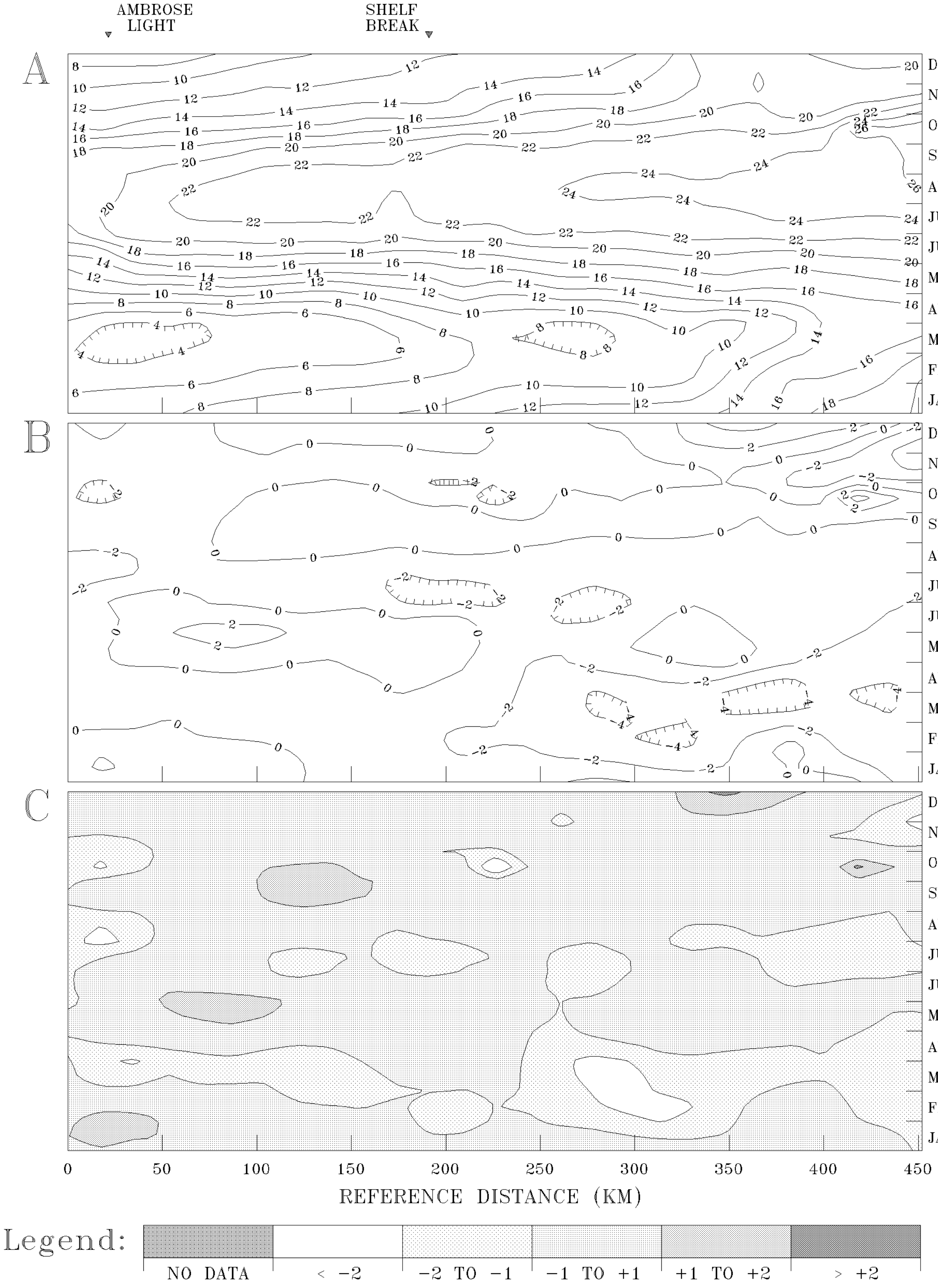
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Legend:
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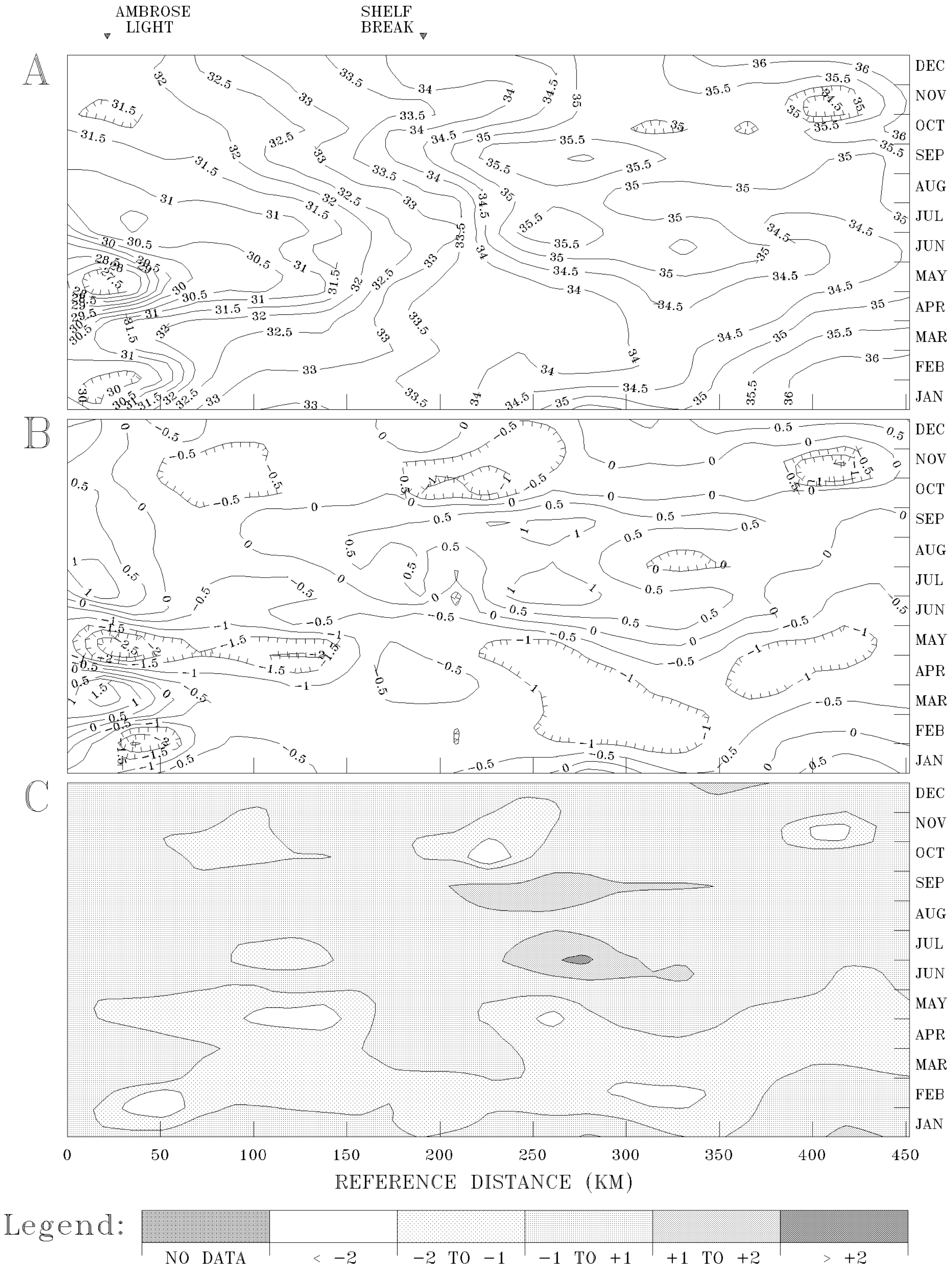
AMBROSE LIGHT
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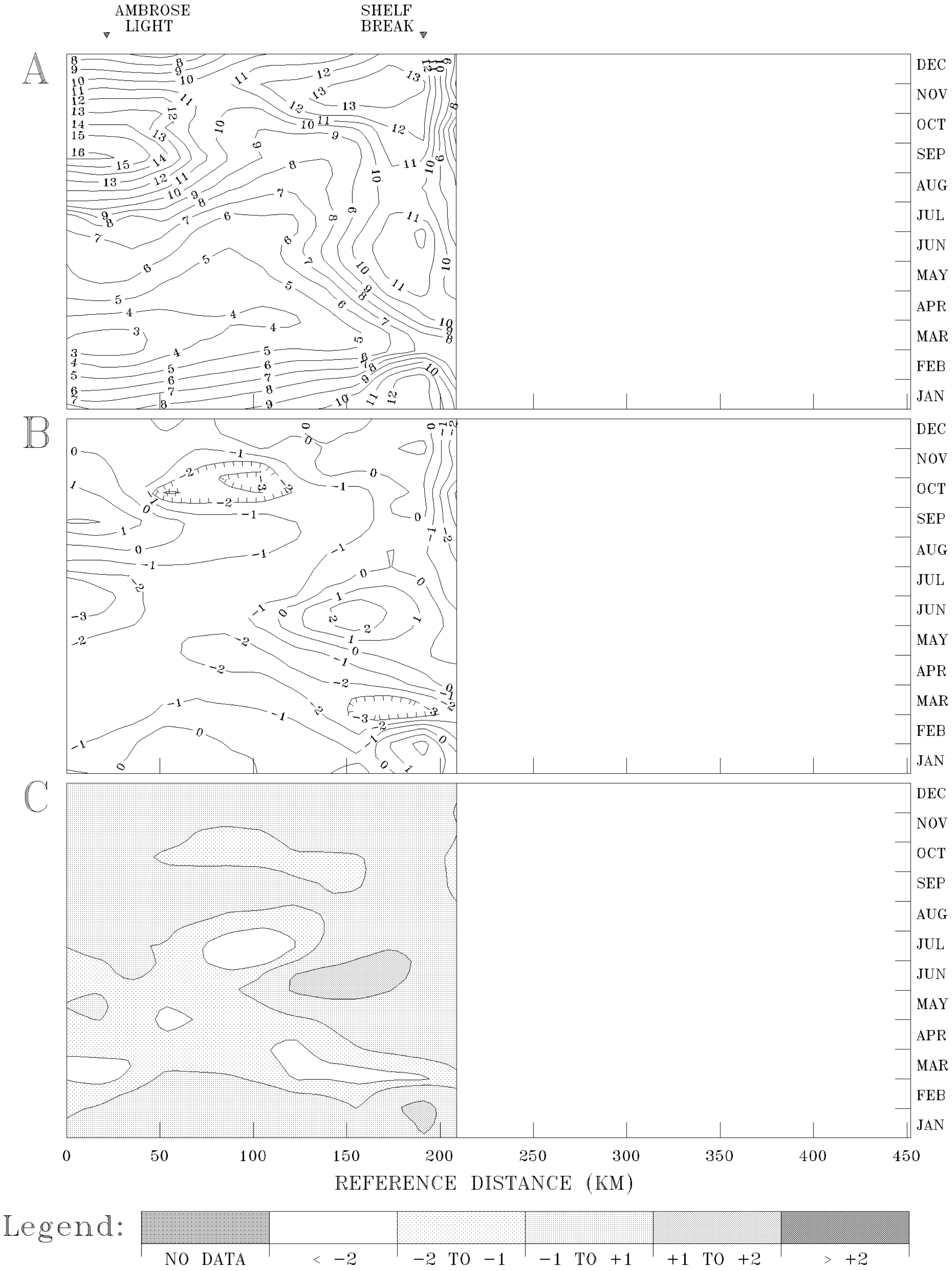
AMBROSE LIGHT
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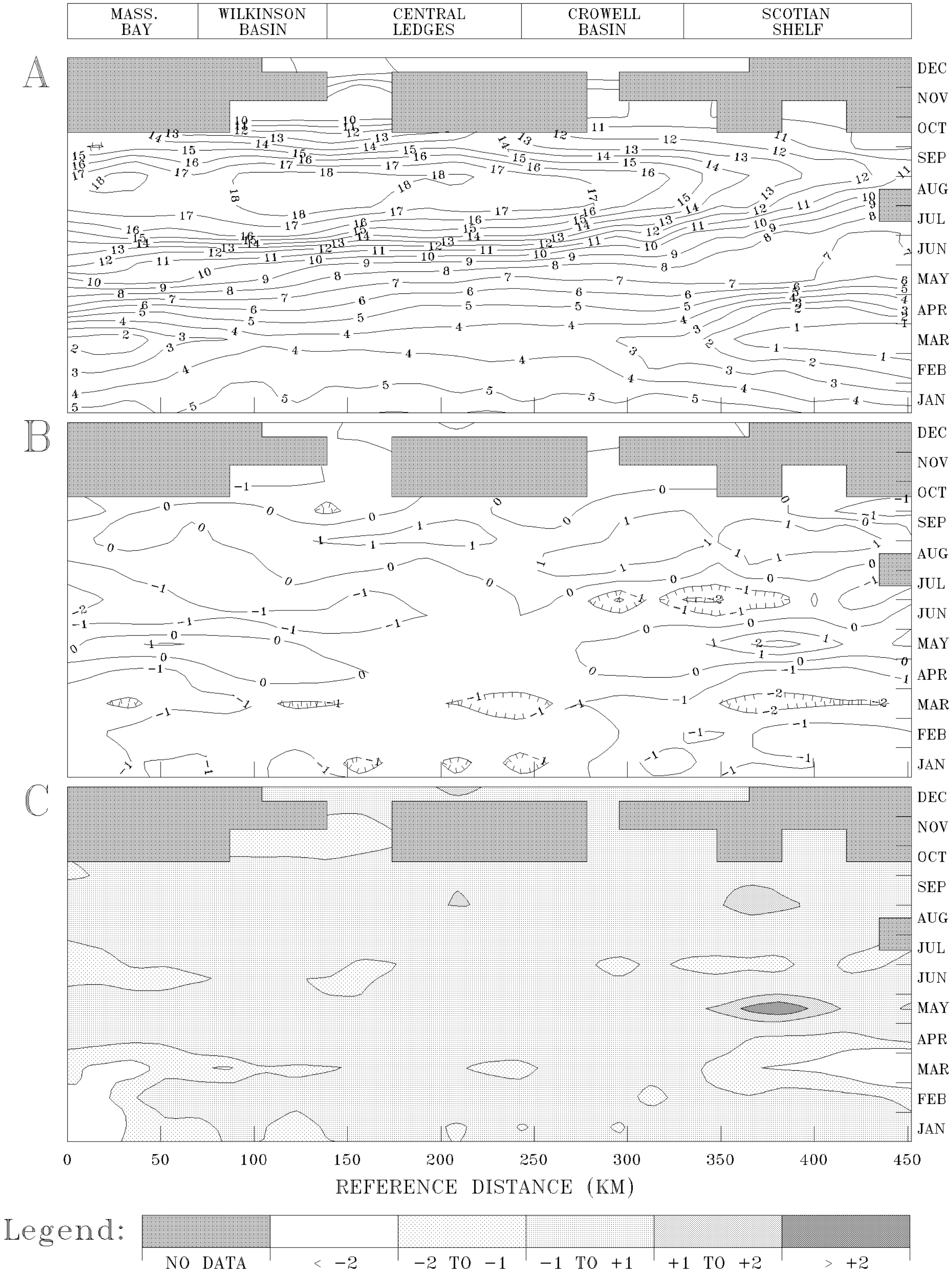
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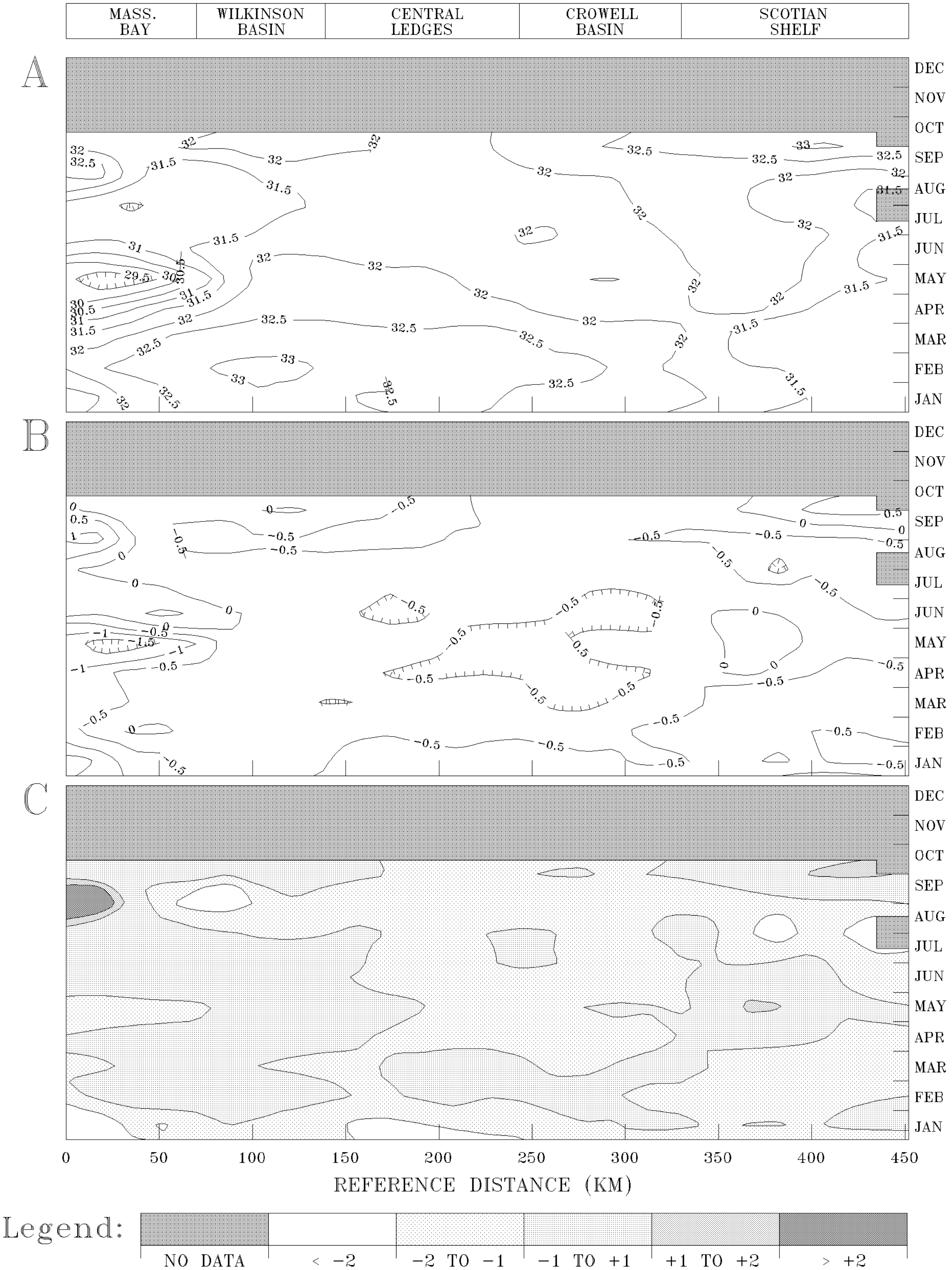
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CENTRAL LEDGES
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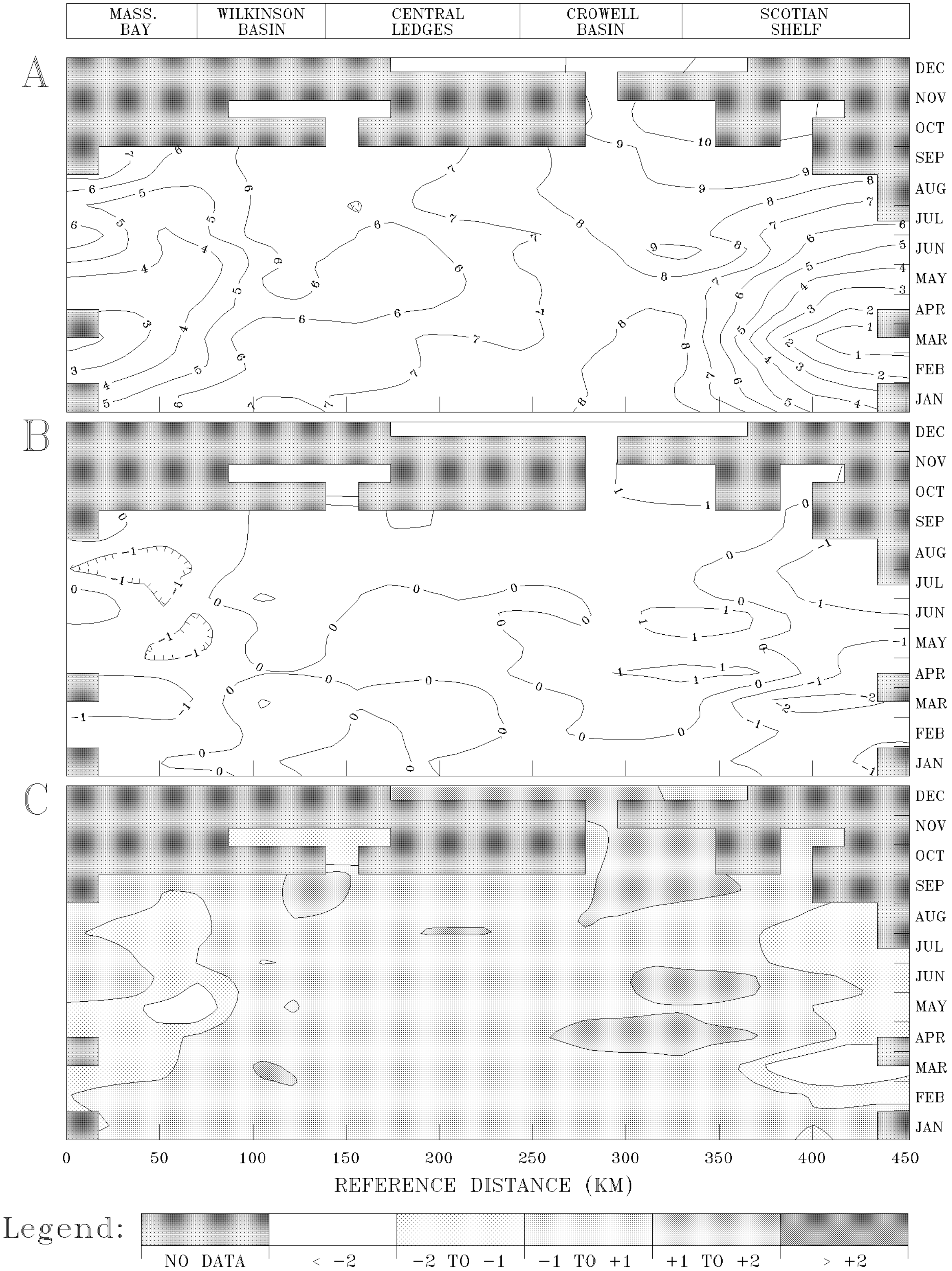
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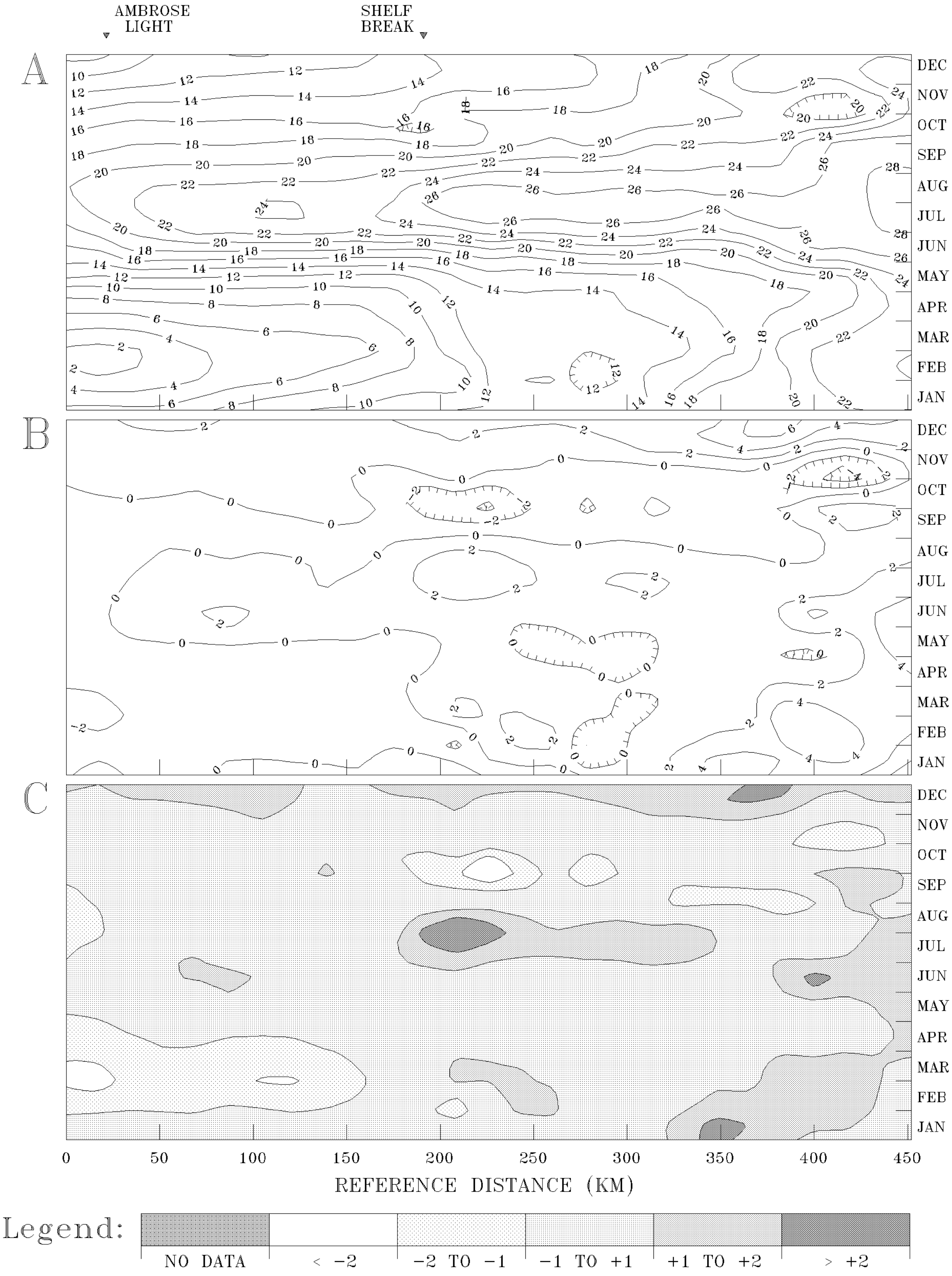
AMBROSE LIGHT
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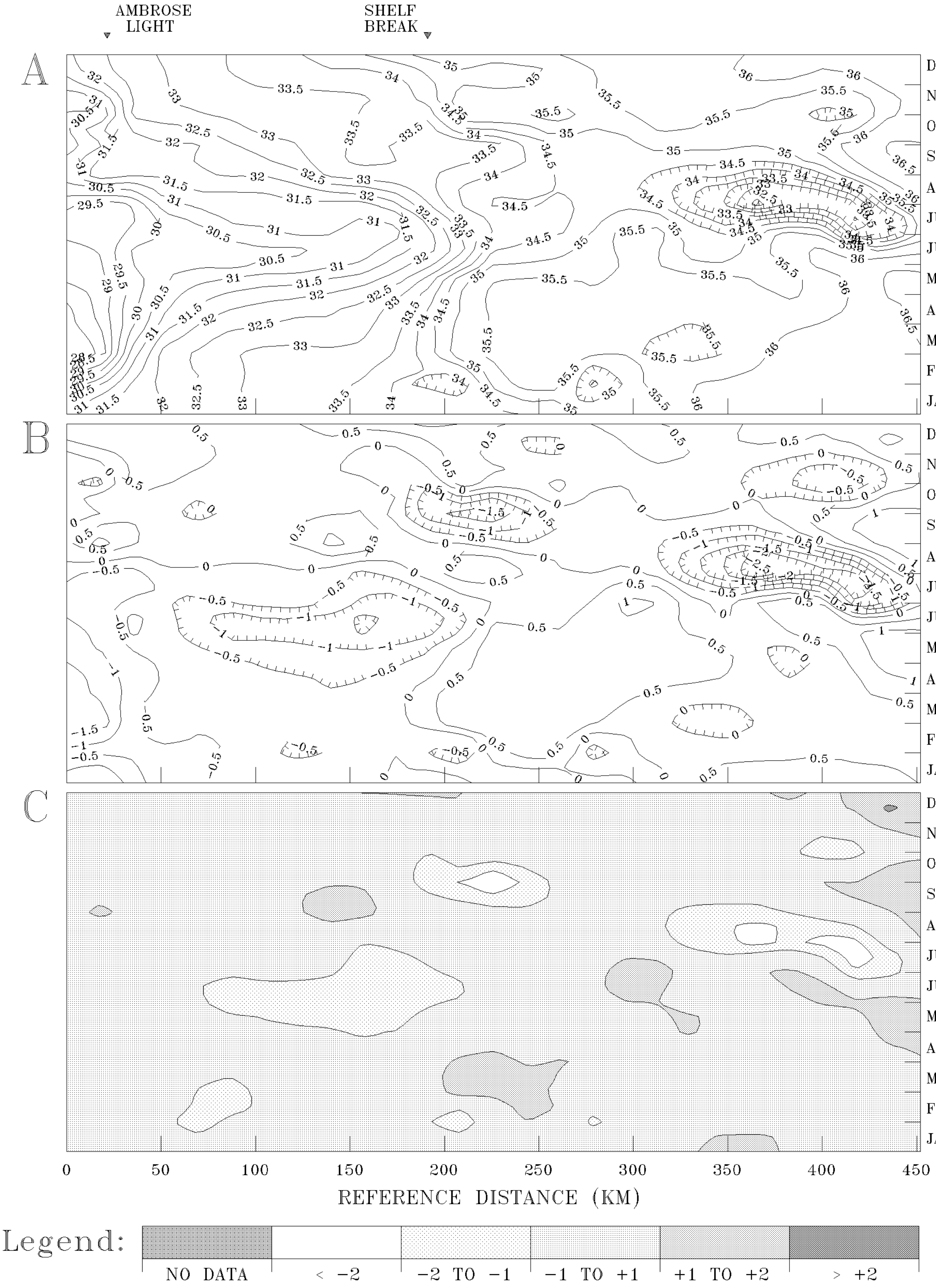
AMBROSE
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Legend:
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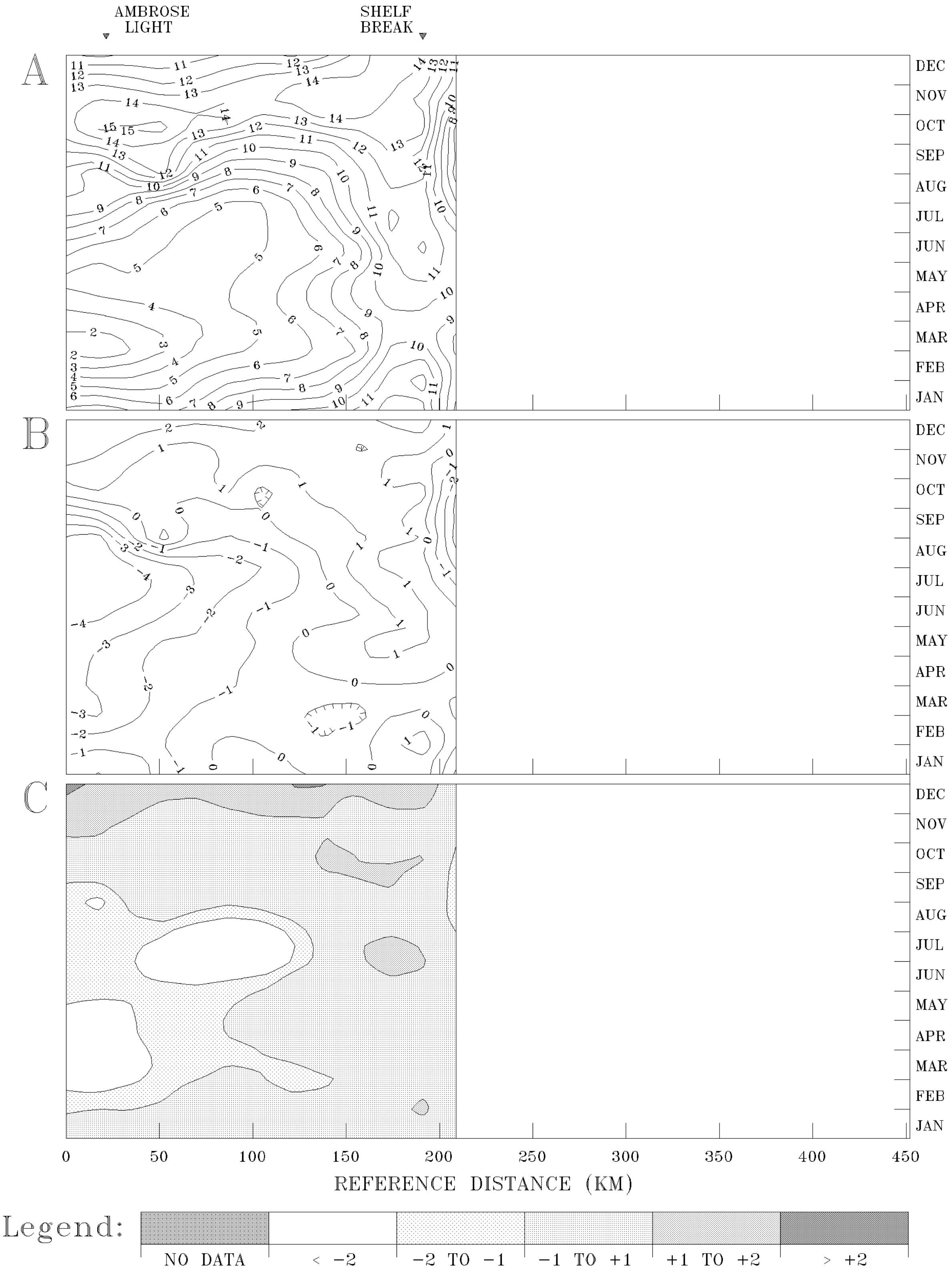
AMBROSE LIGHT
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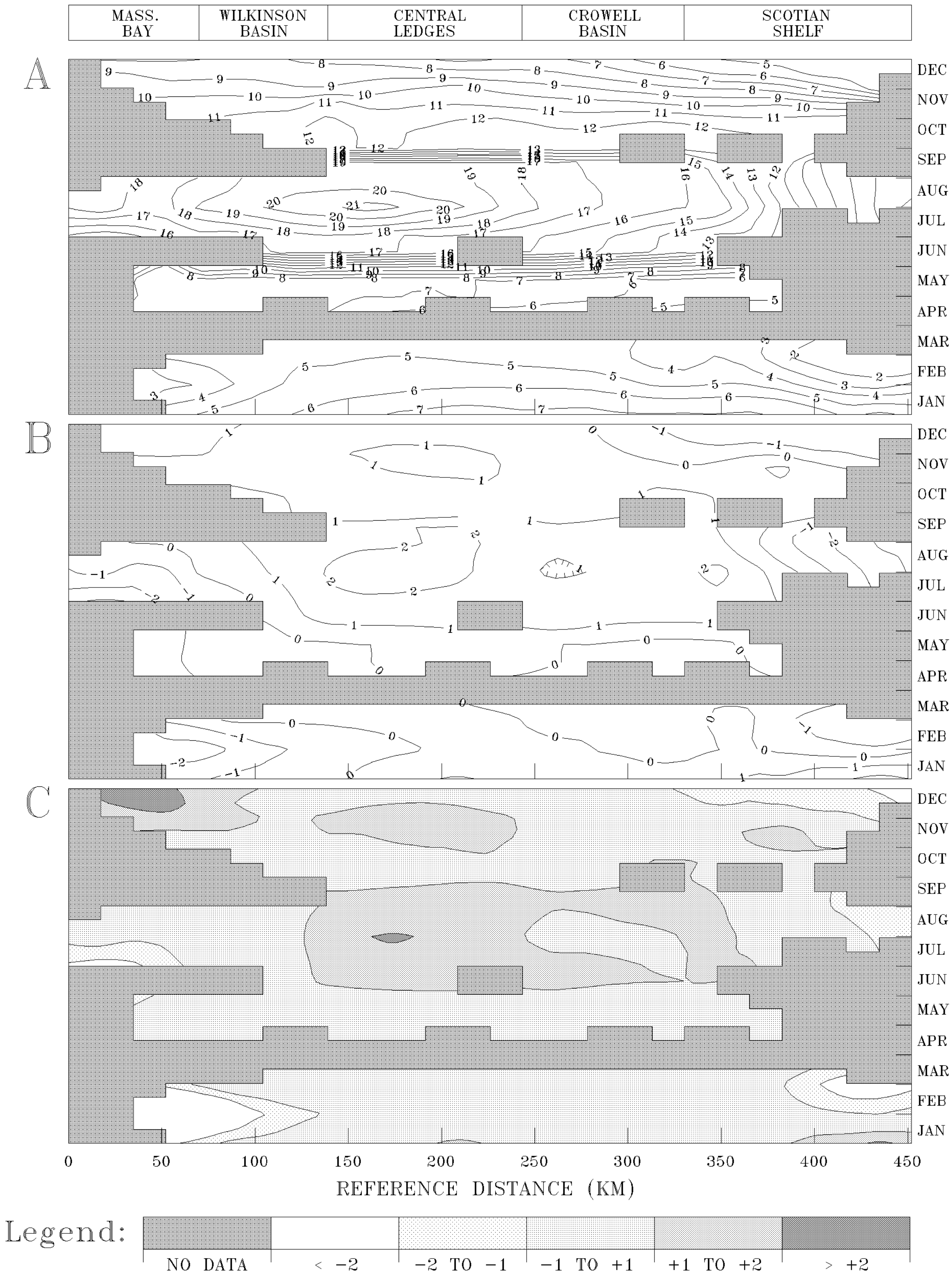
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
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Legend:
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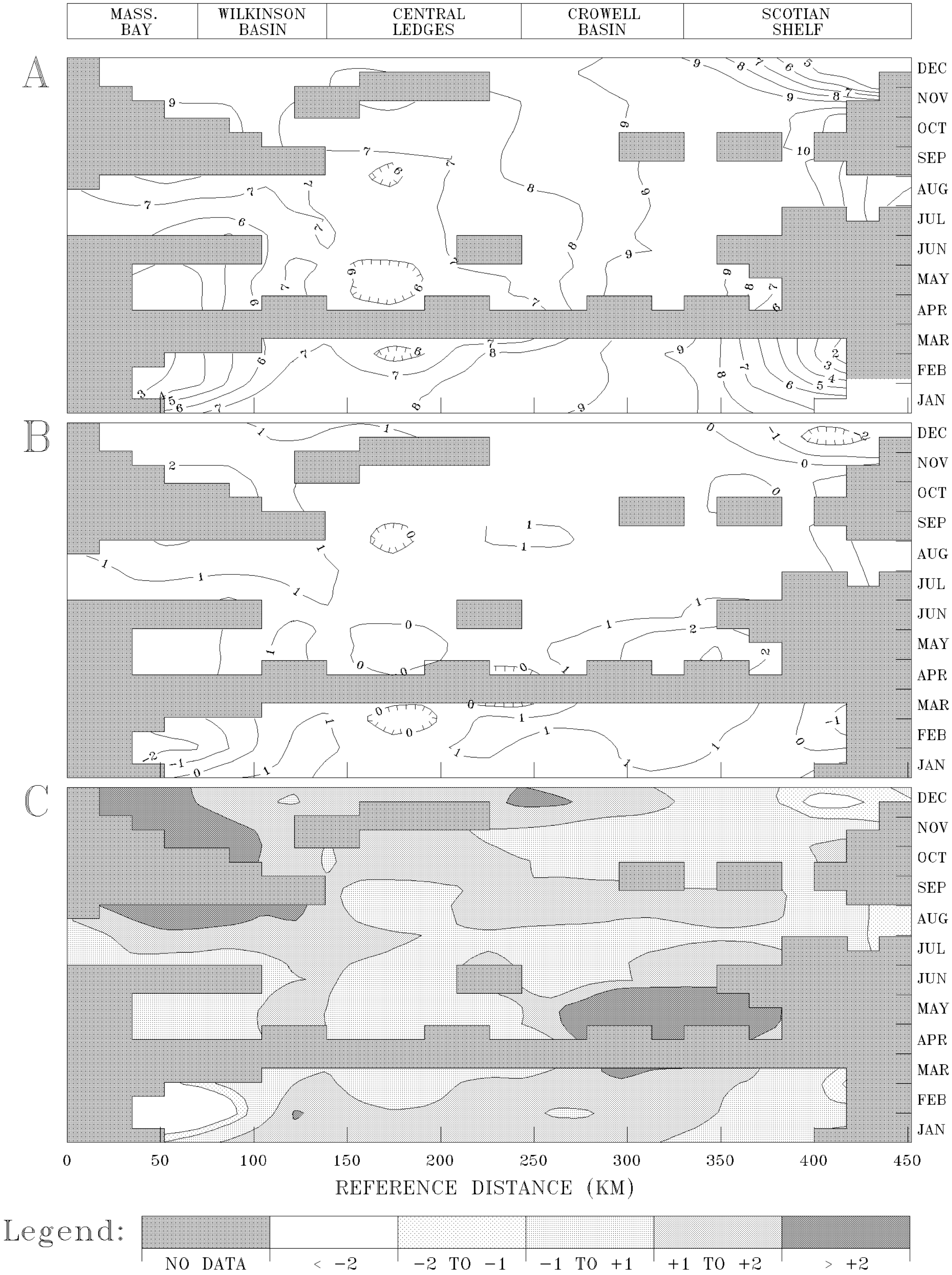
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
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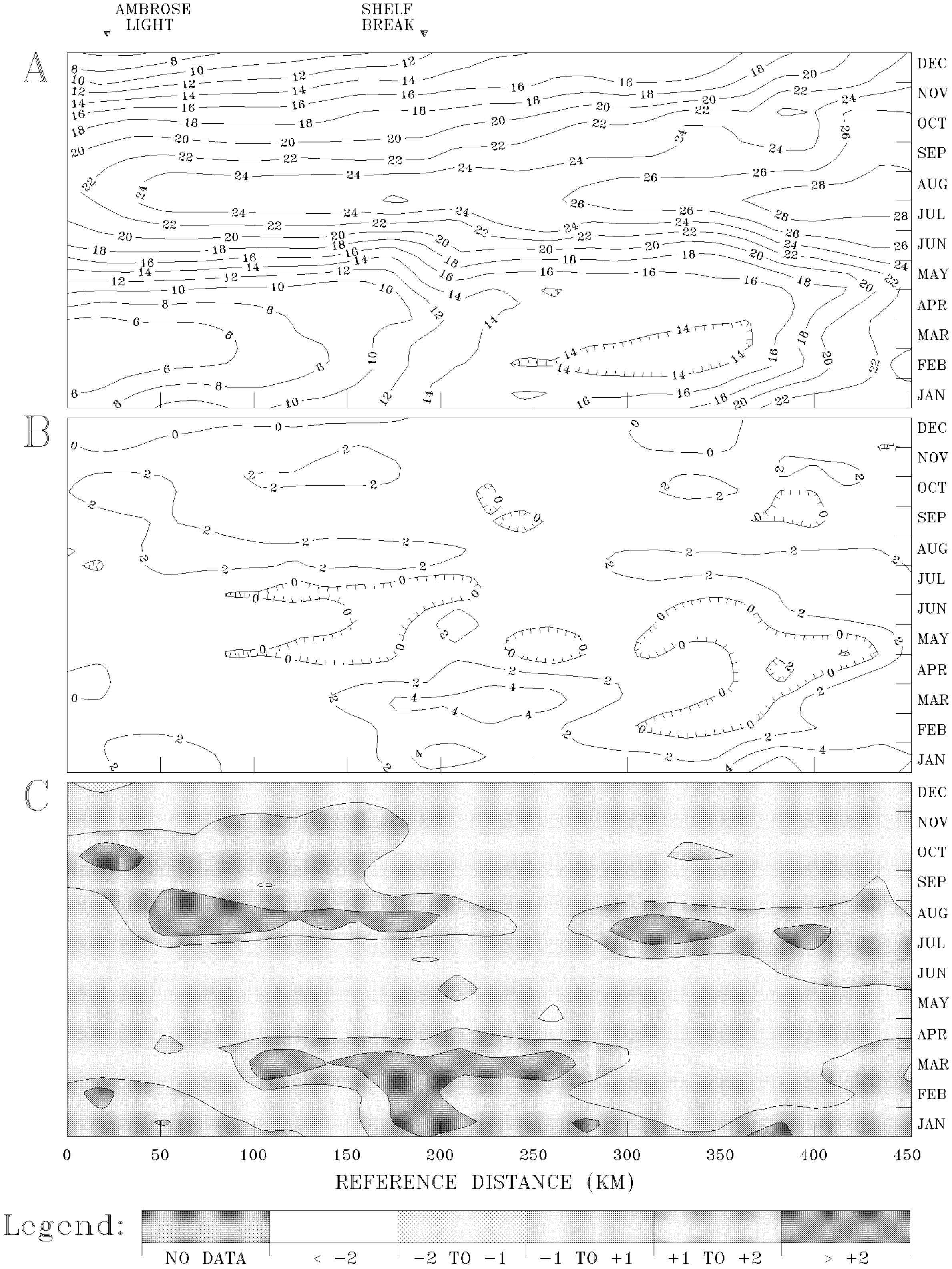
AMBROSE LIGHT
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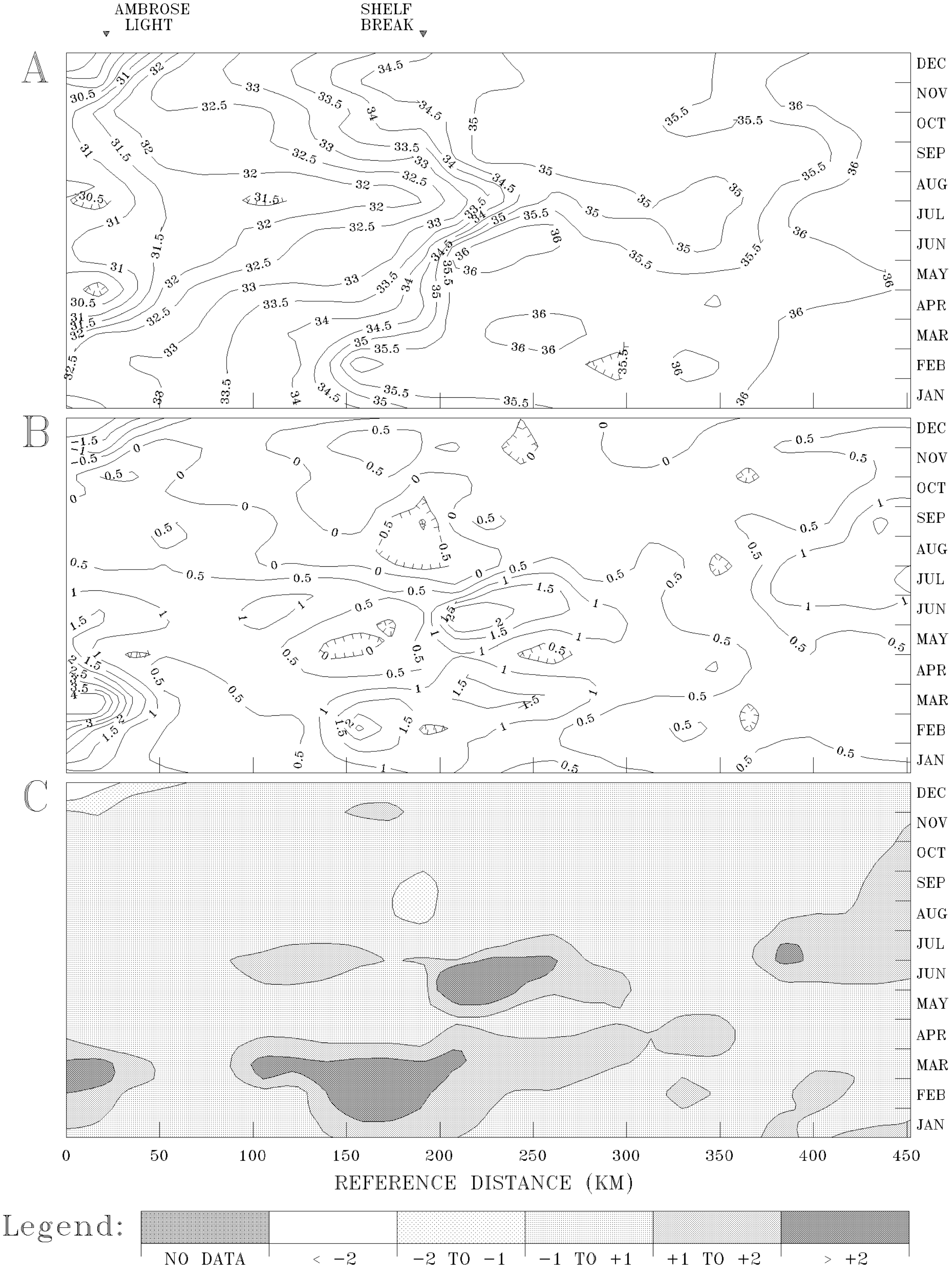
AMBROSE LIGHT
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Legend:
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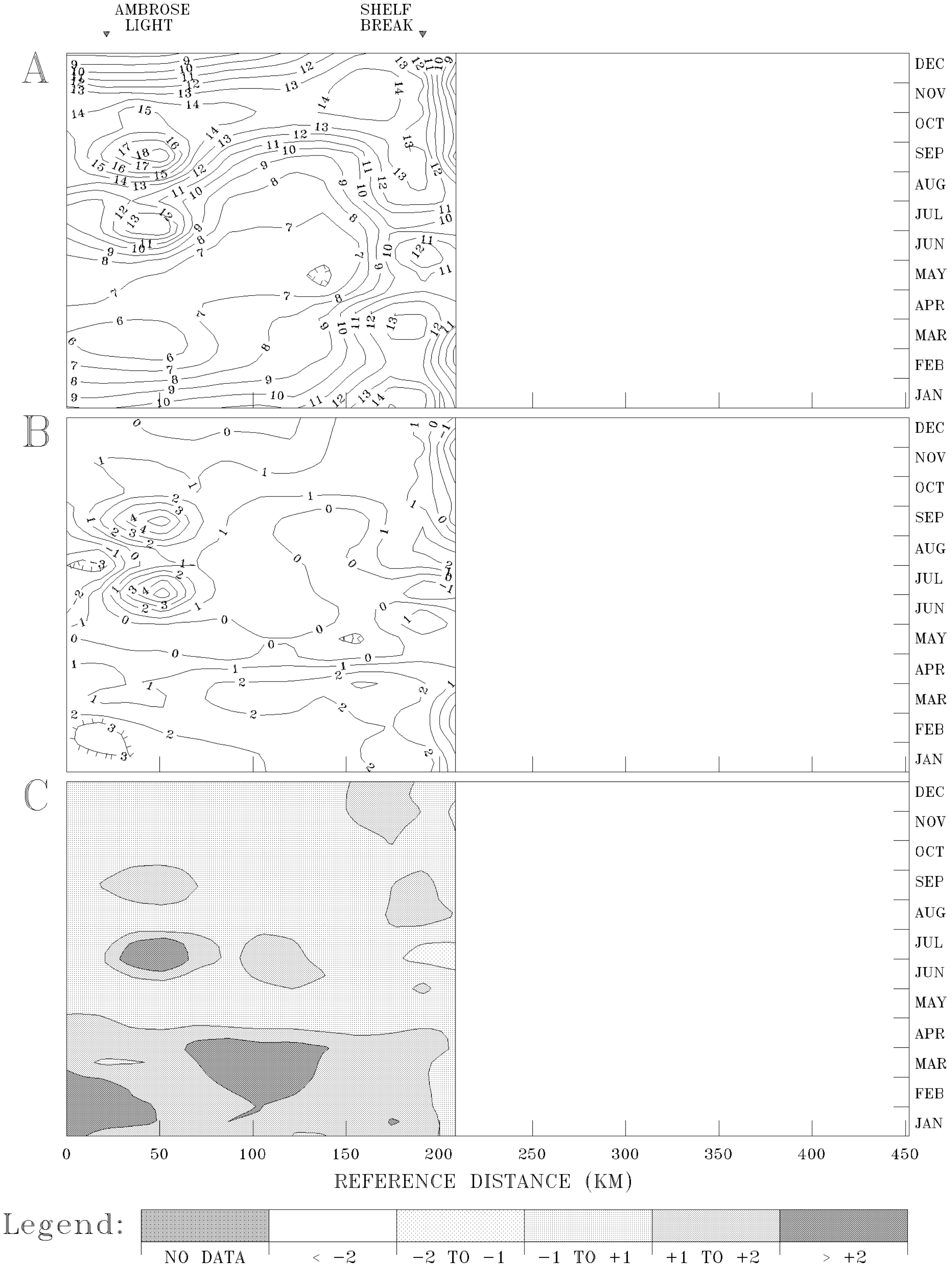
AMBROSE LIGHT
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Legend:
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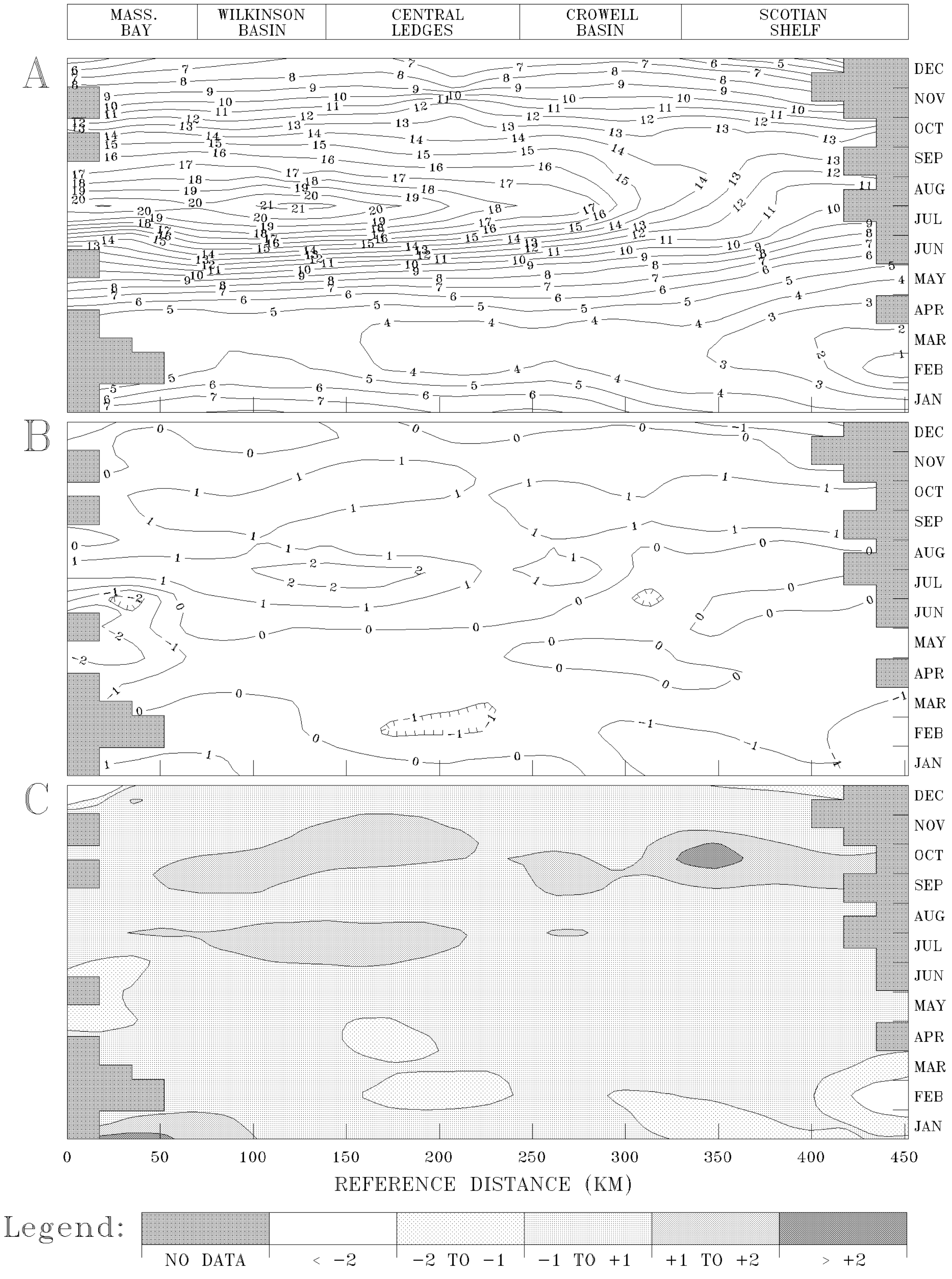
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
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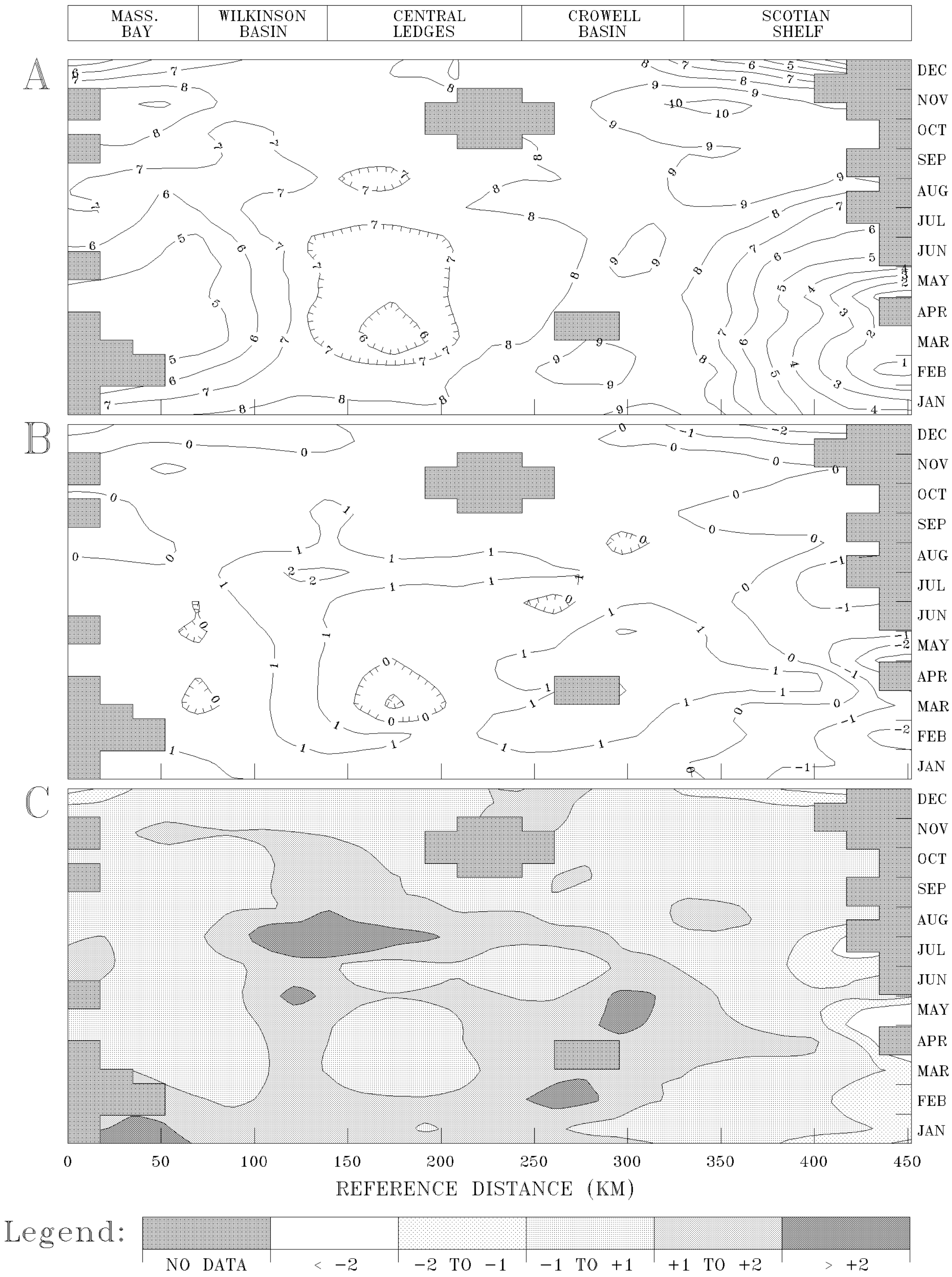
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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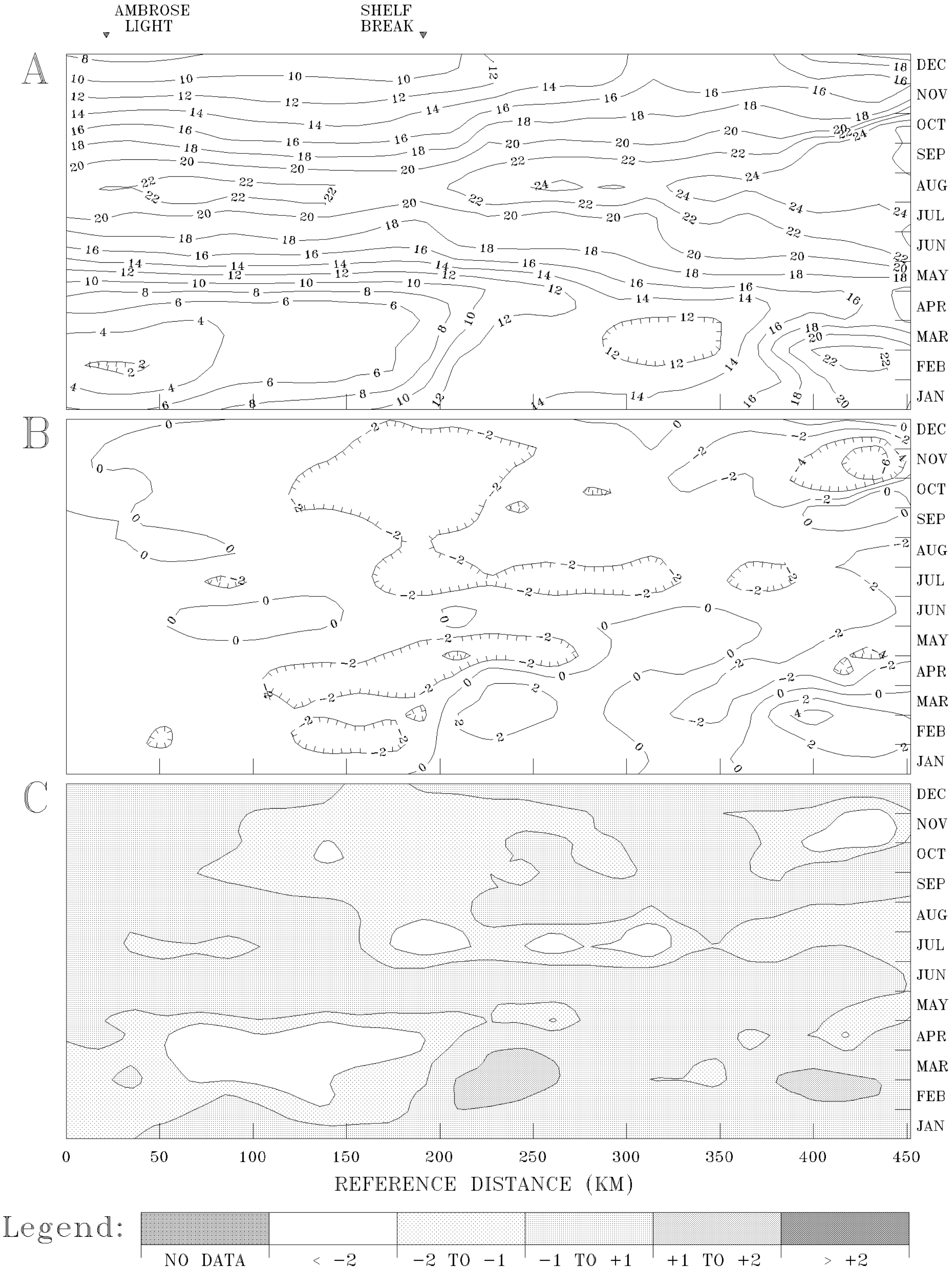
AMBROSE LIGHT
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Legend:
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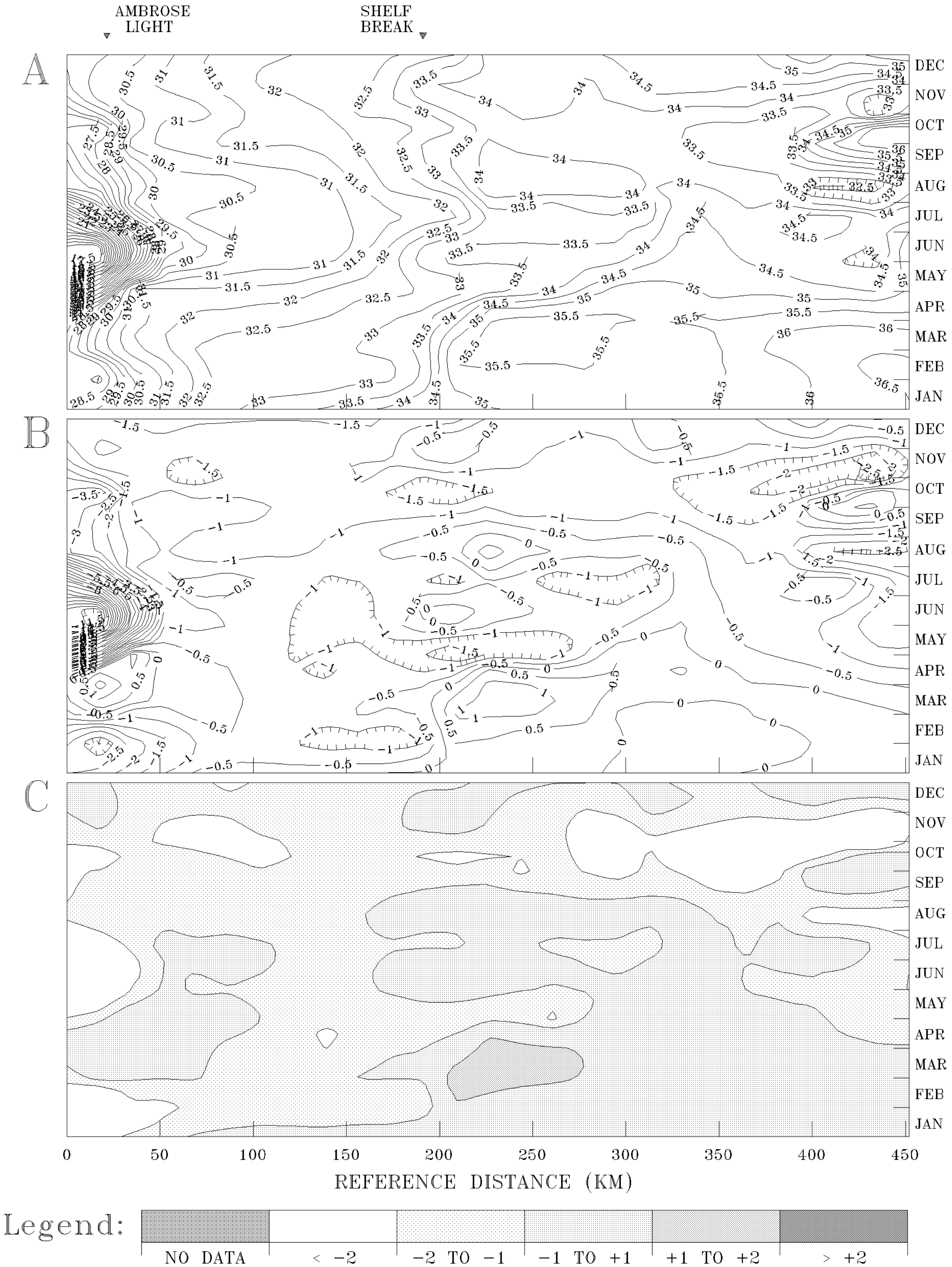
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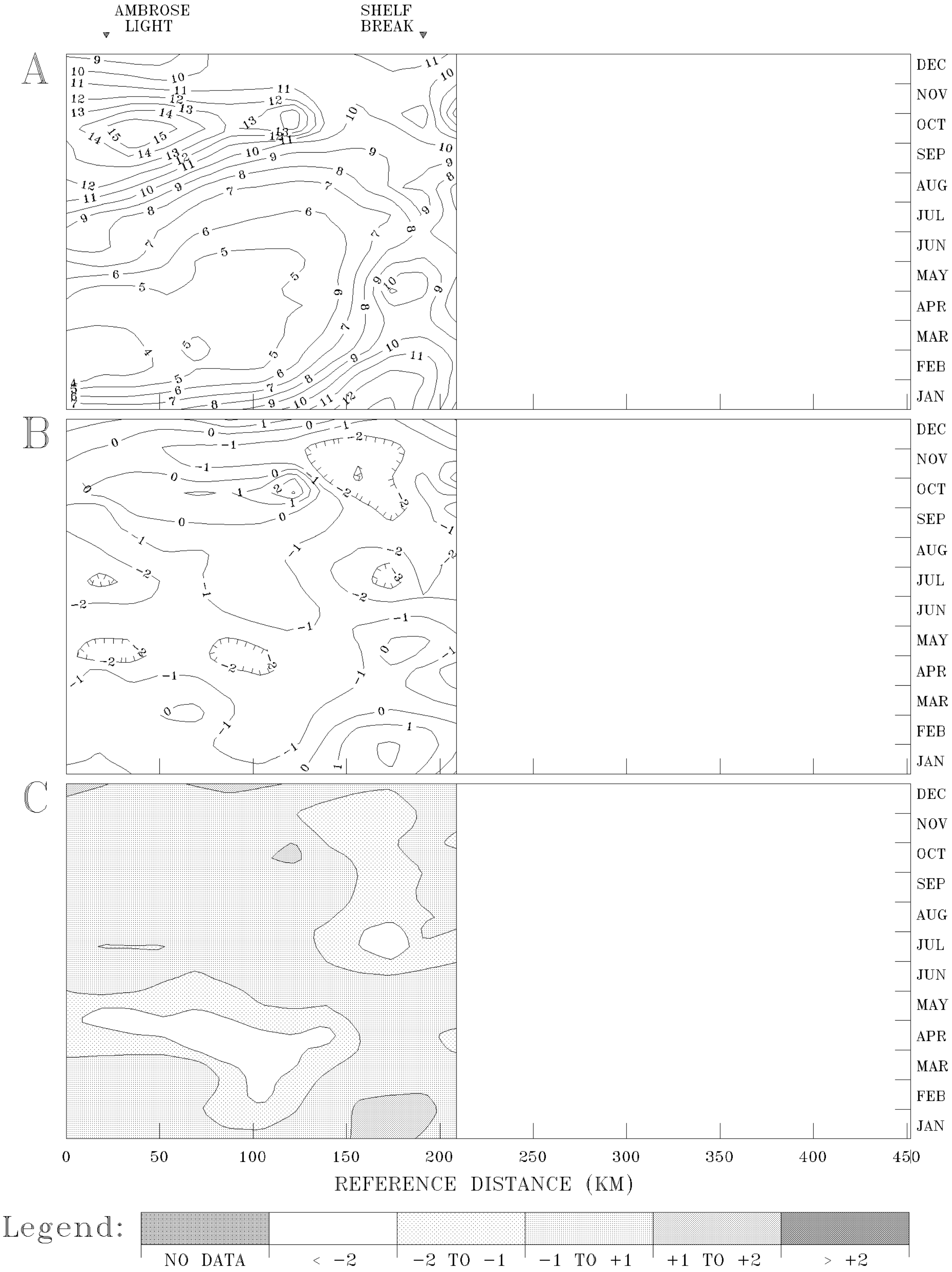
AMBROSE LIGHT
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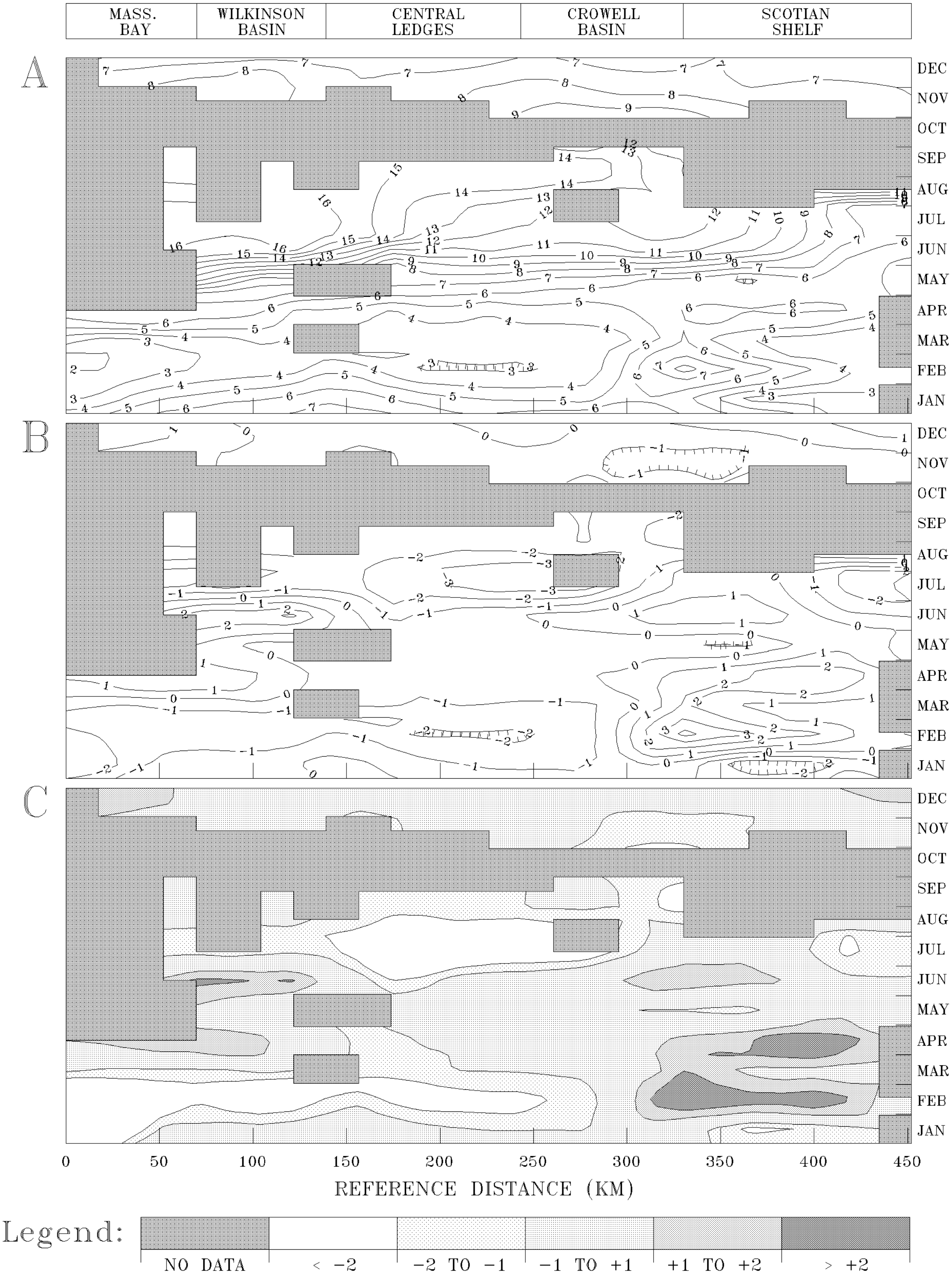
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
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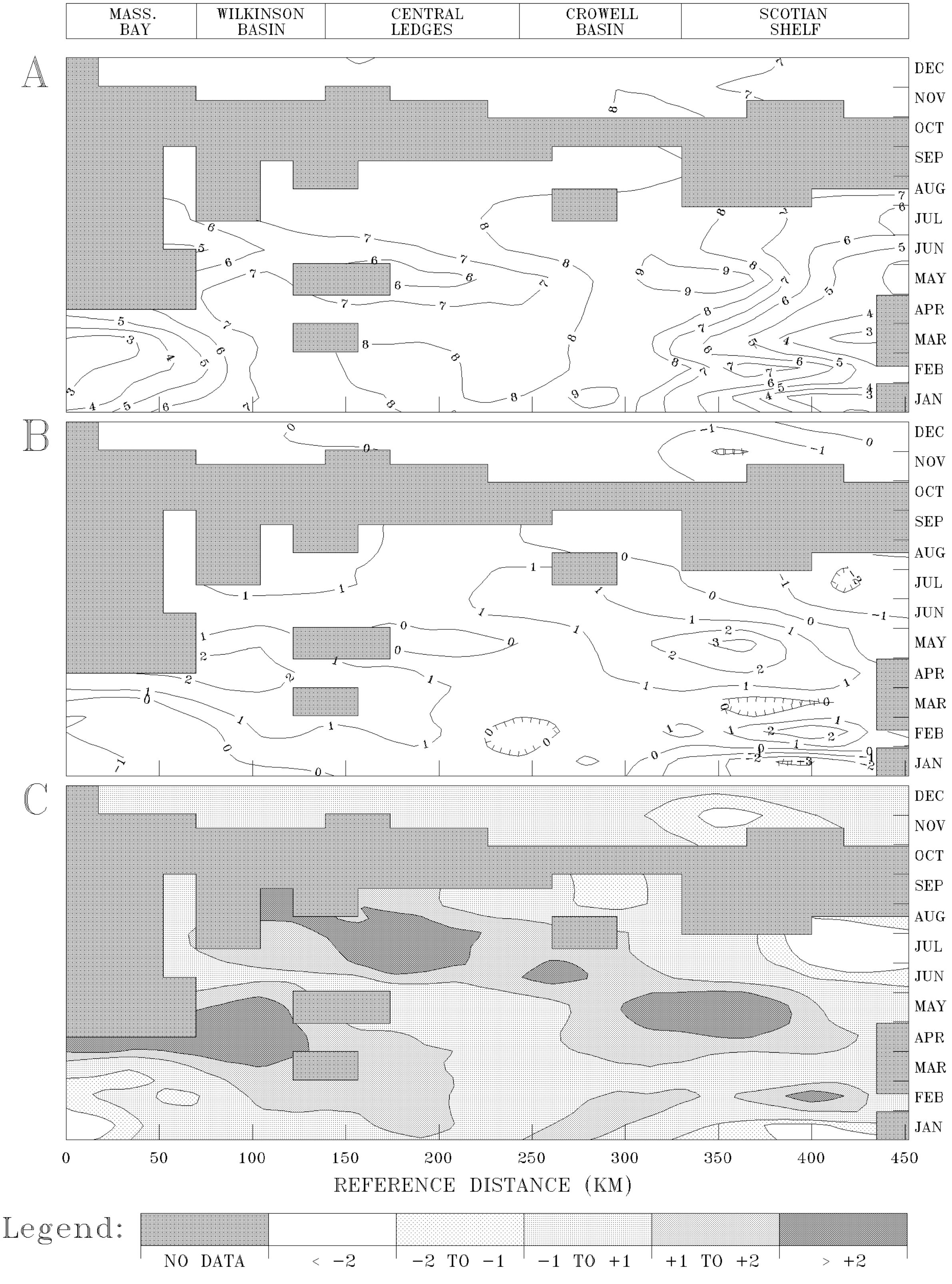
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
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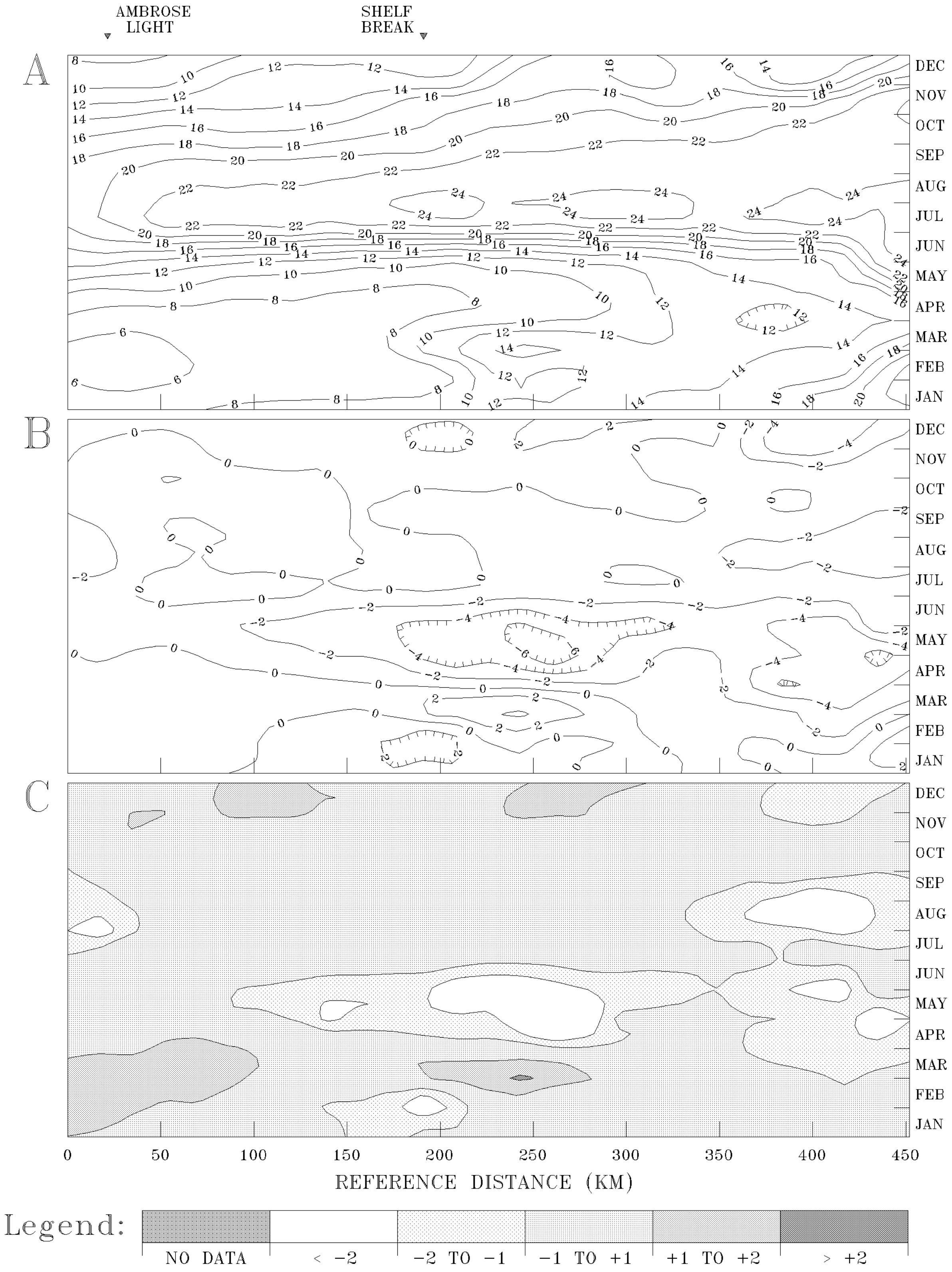
AMBROSE LIGHT
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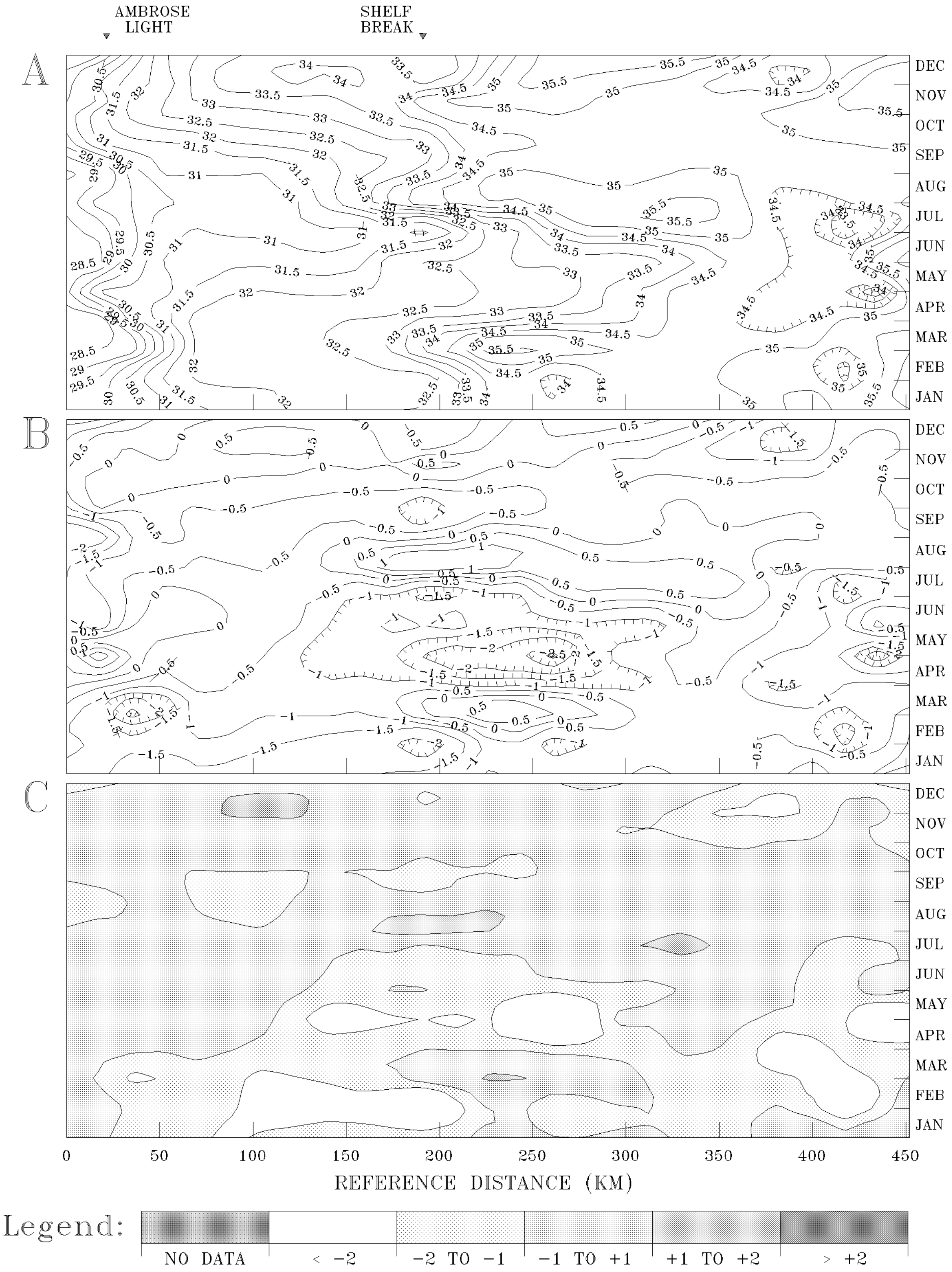
AMBROSE LIGHT
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Legend:
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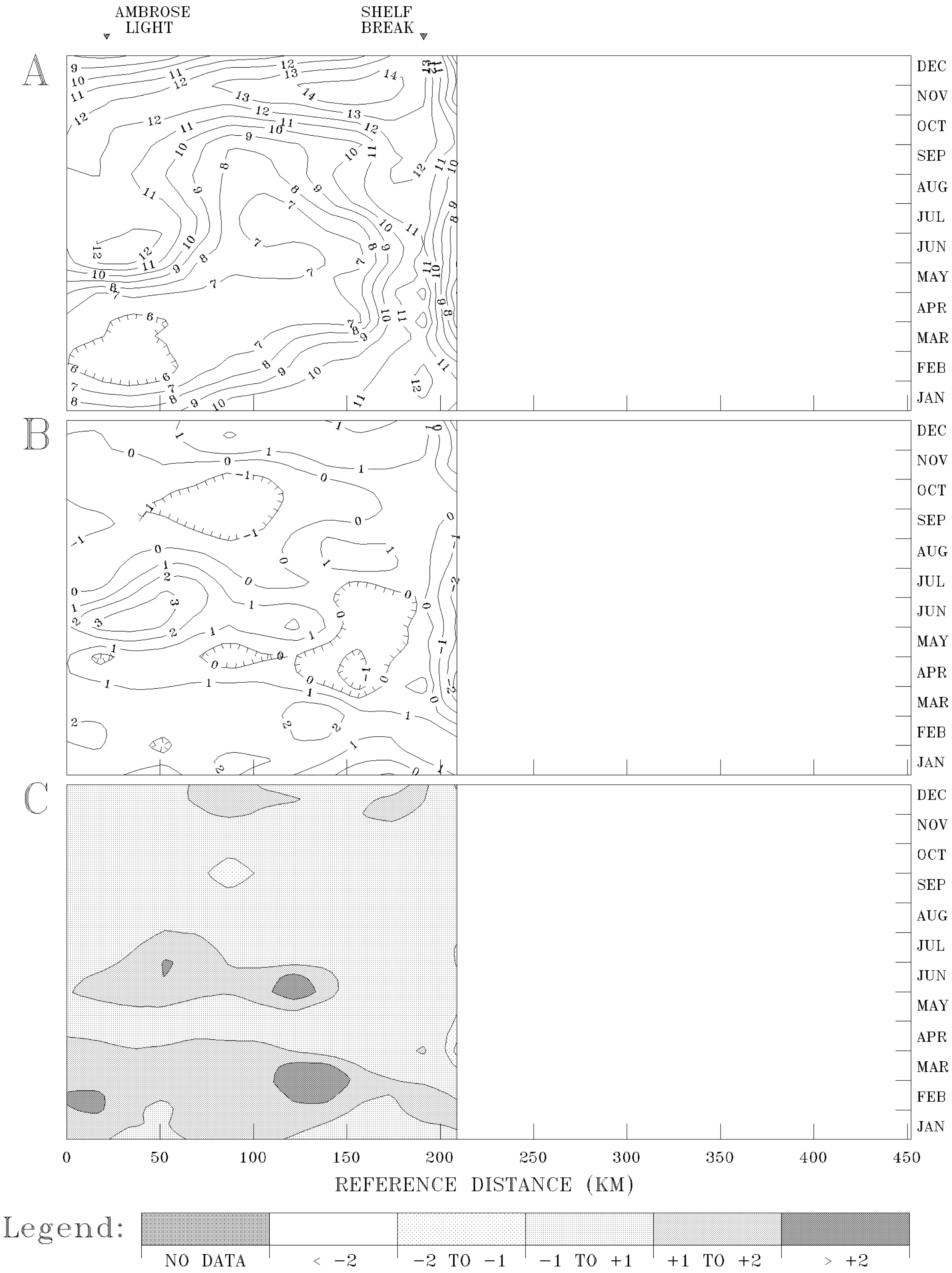
AMBROSE LIGHT
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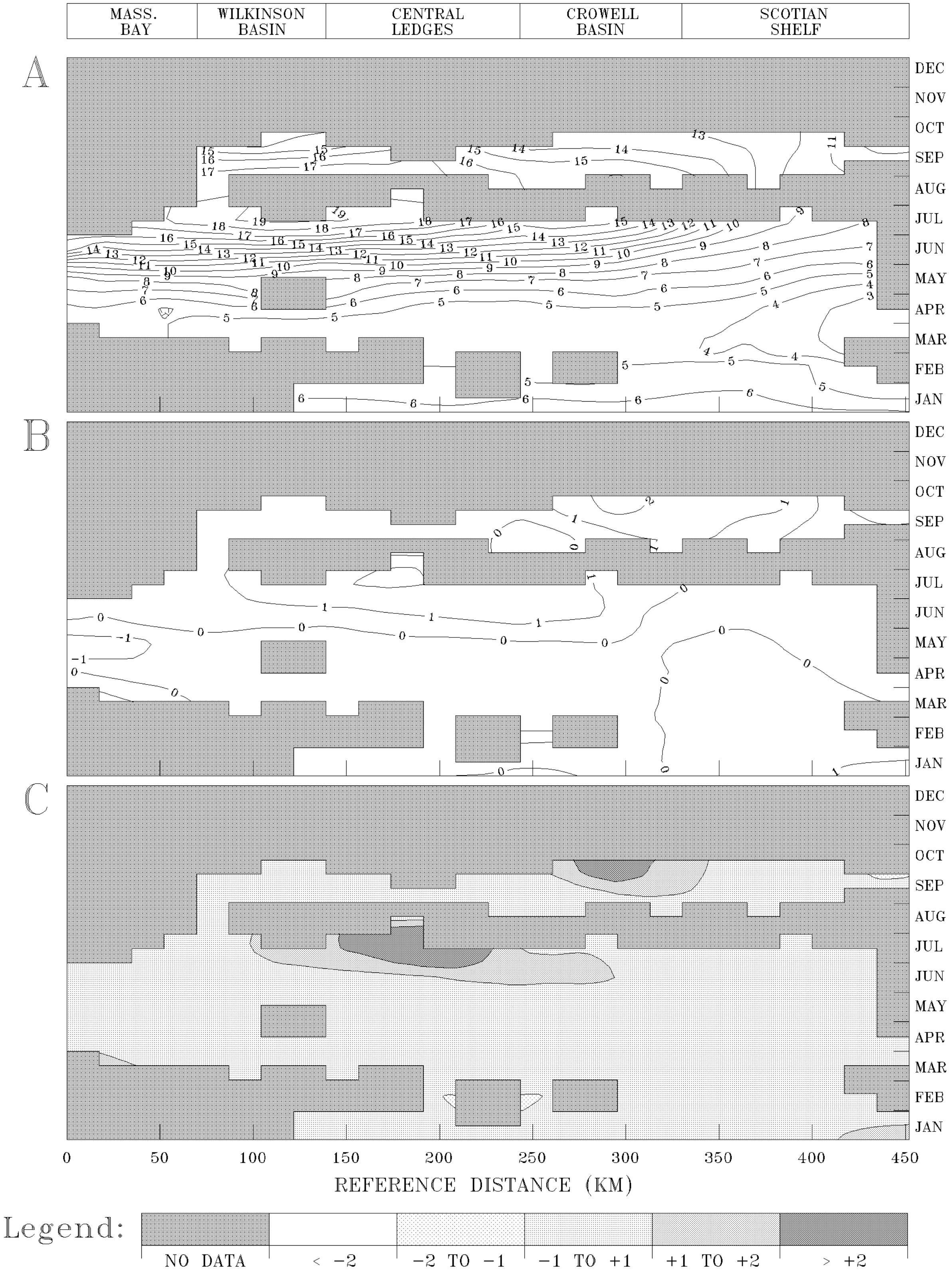
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
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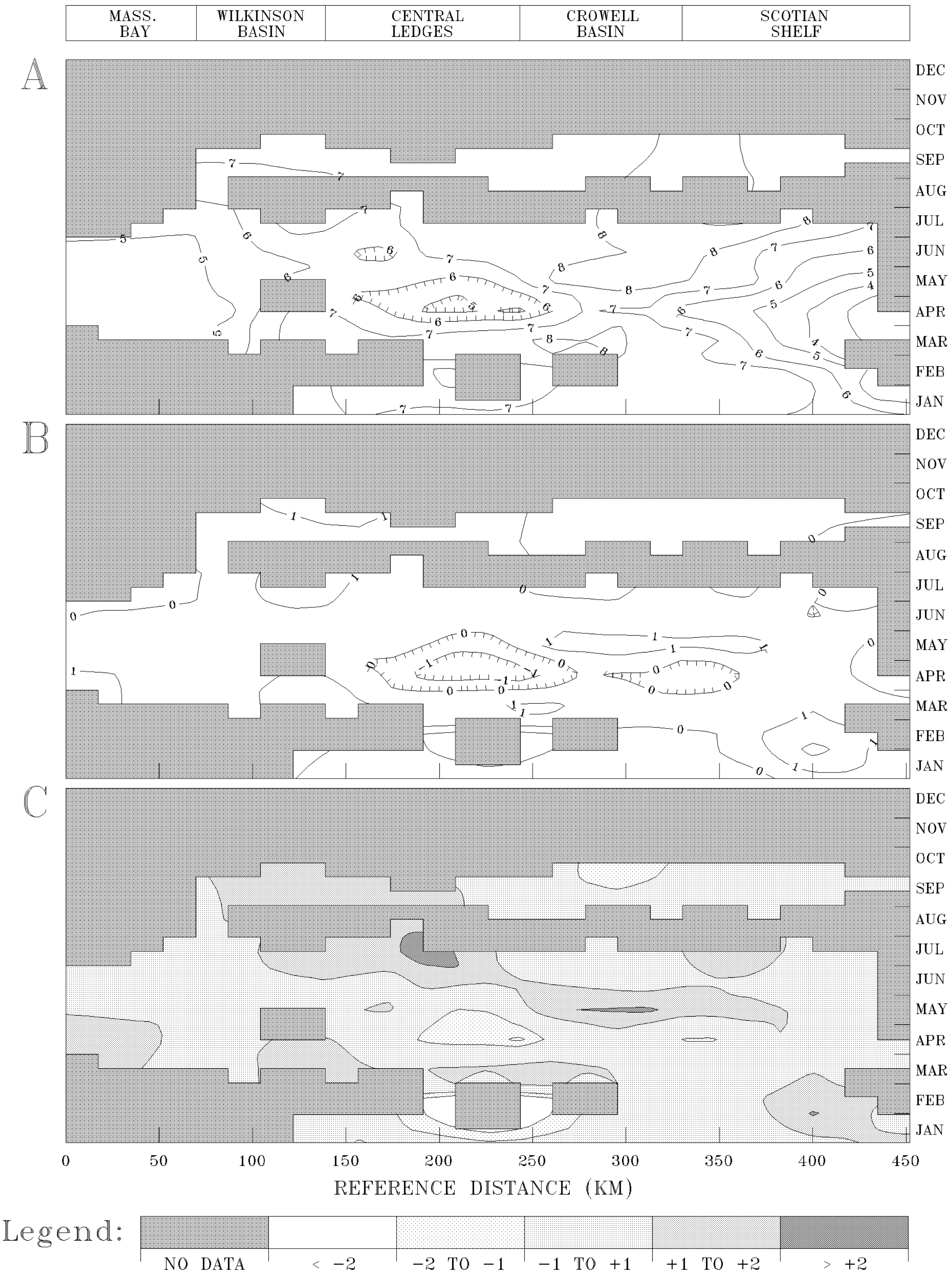
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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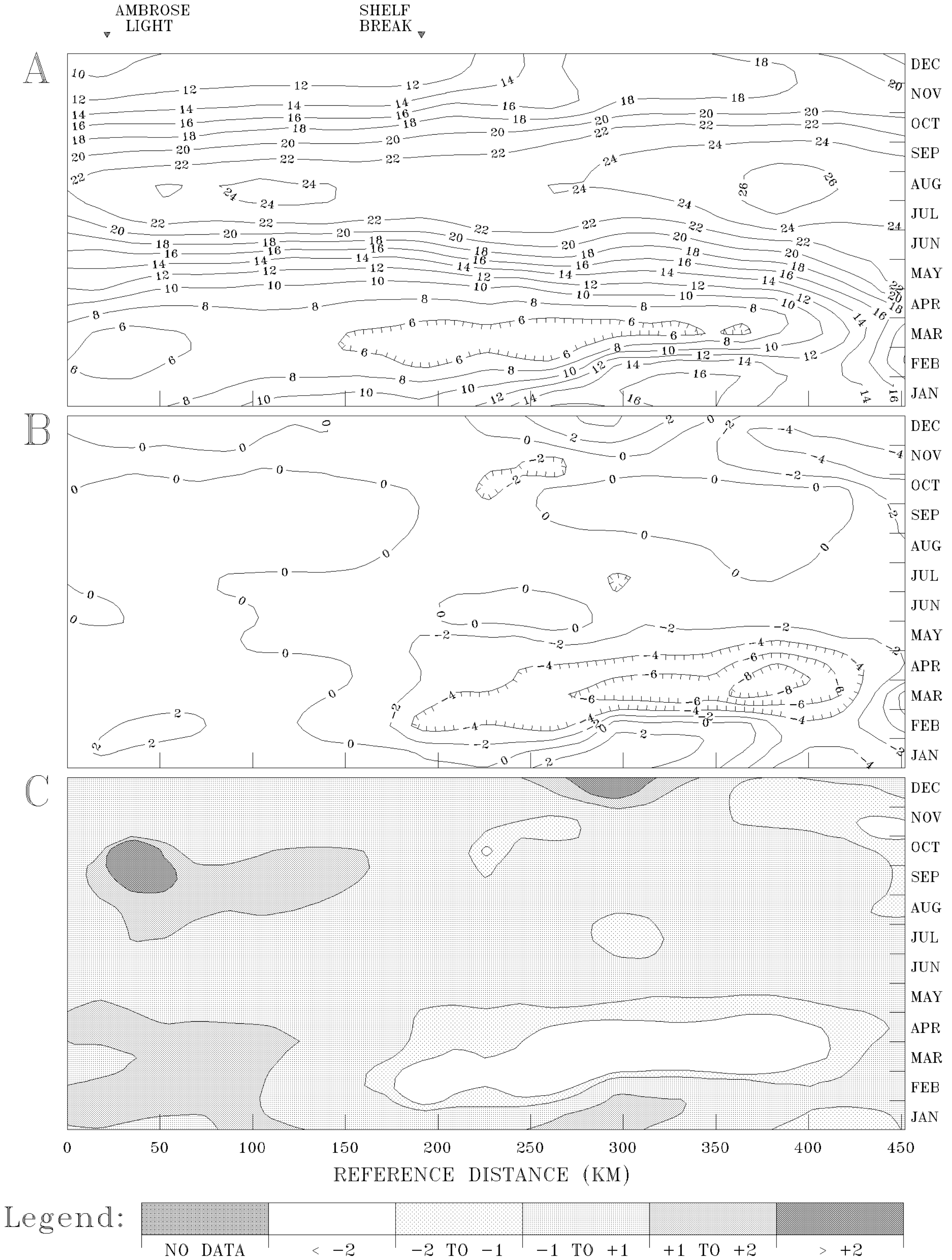
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
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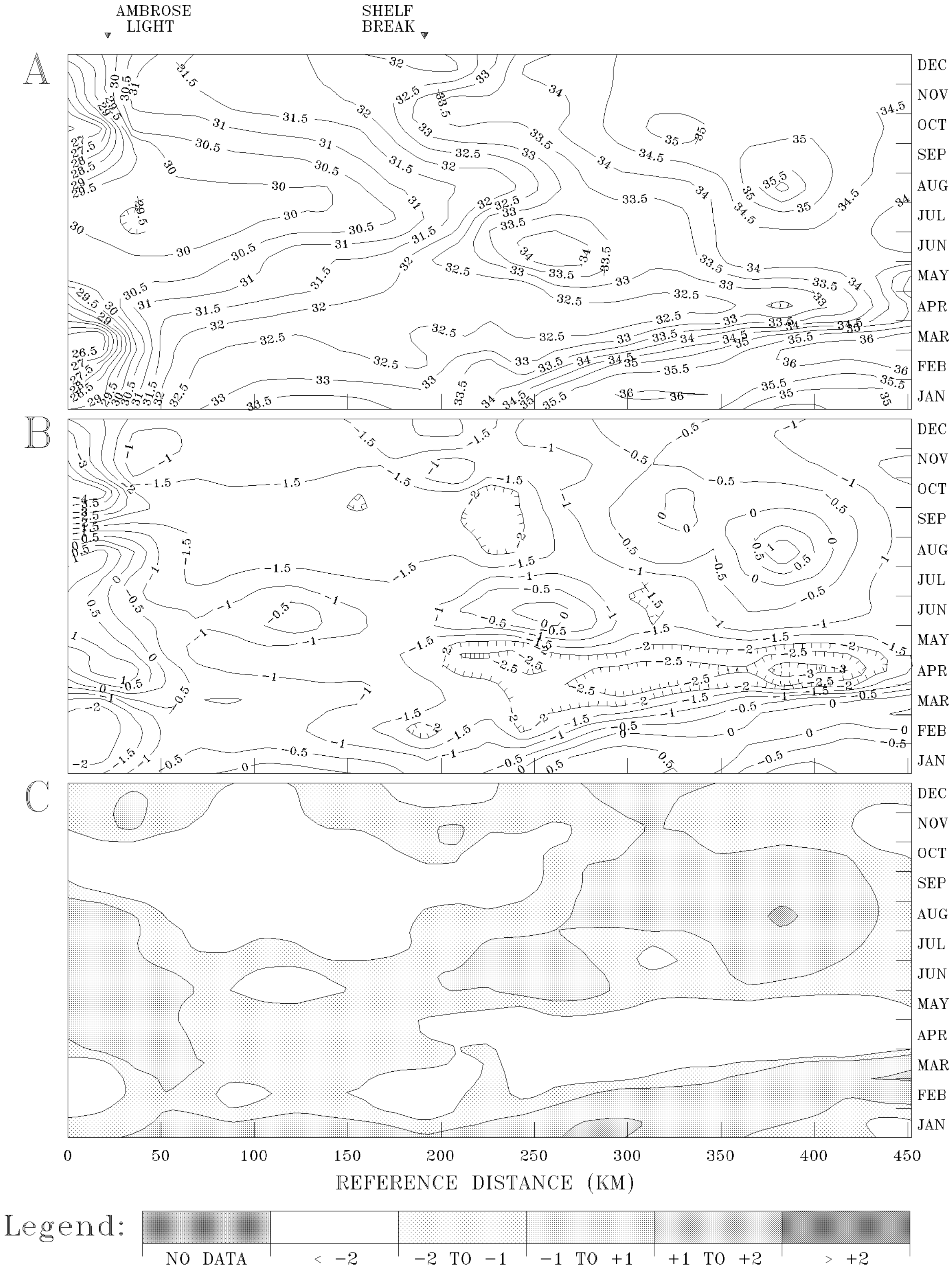
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
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-1 TO +1
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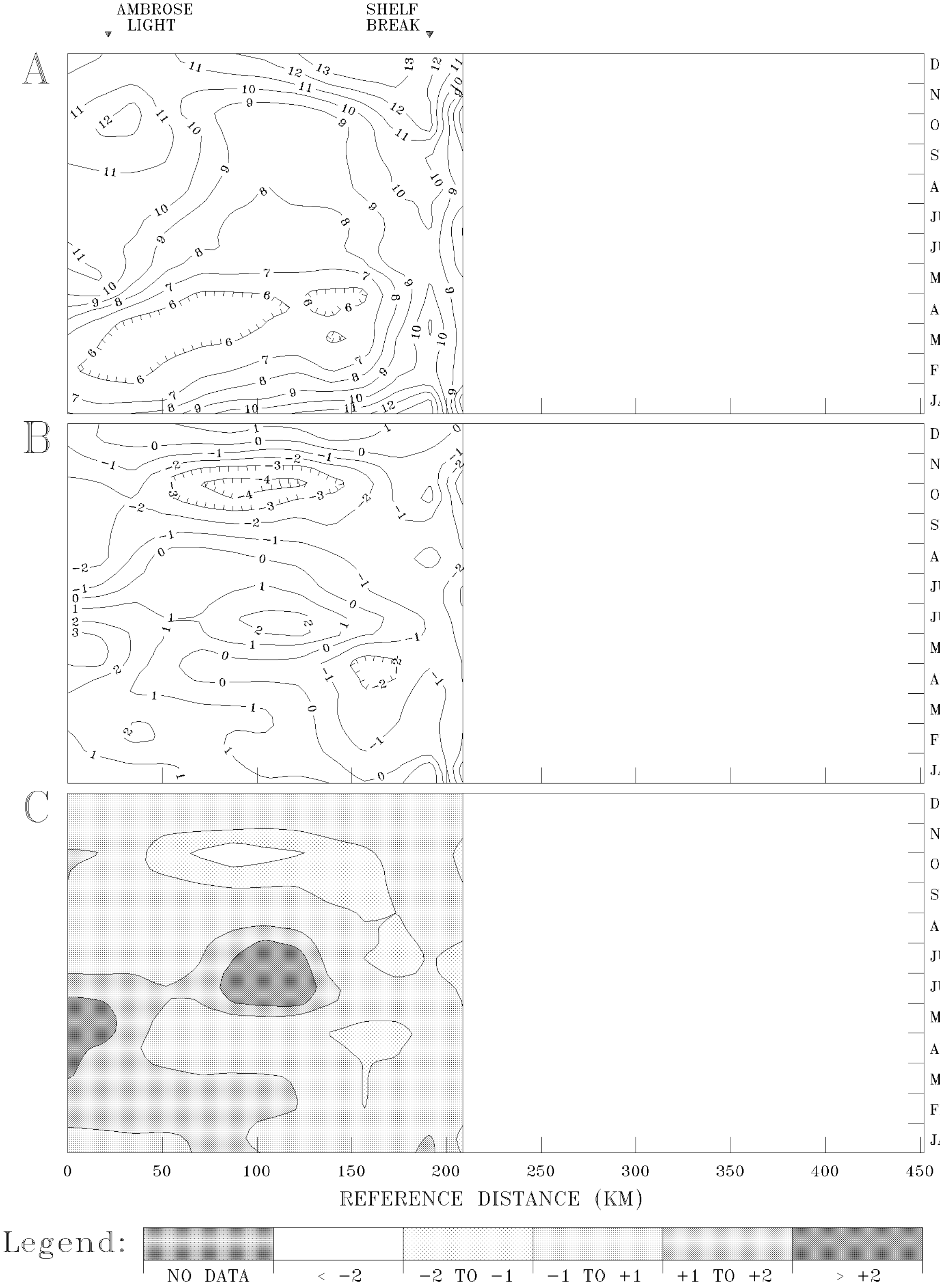
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
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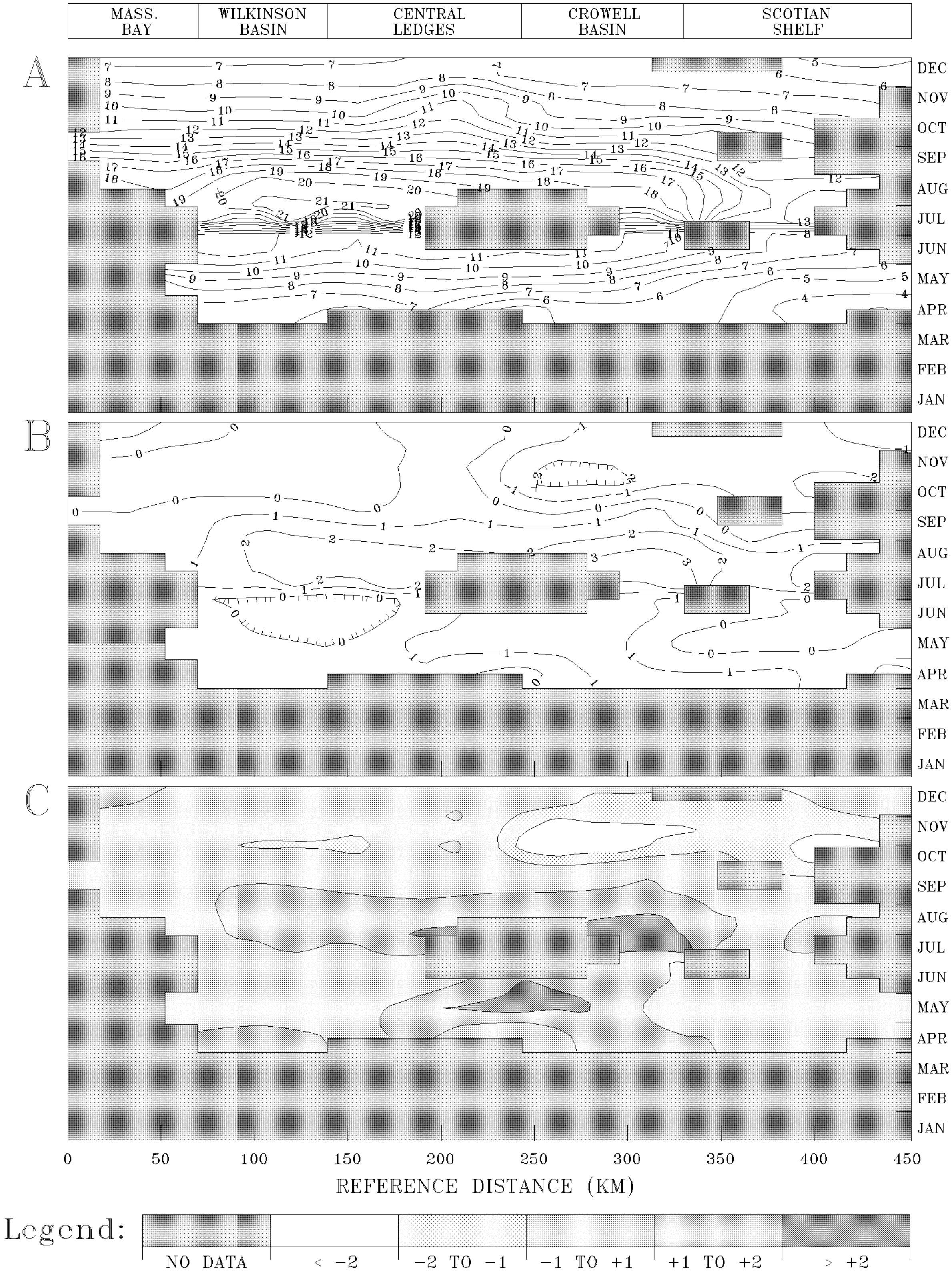
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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REFERENCE DISTANCE (KM)
Legend:
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MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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REFERENCE DISTANCE (KM)
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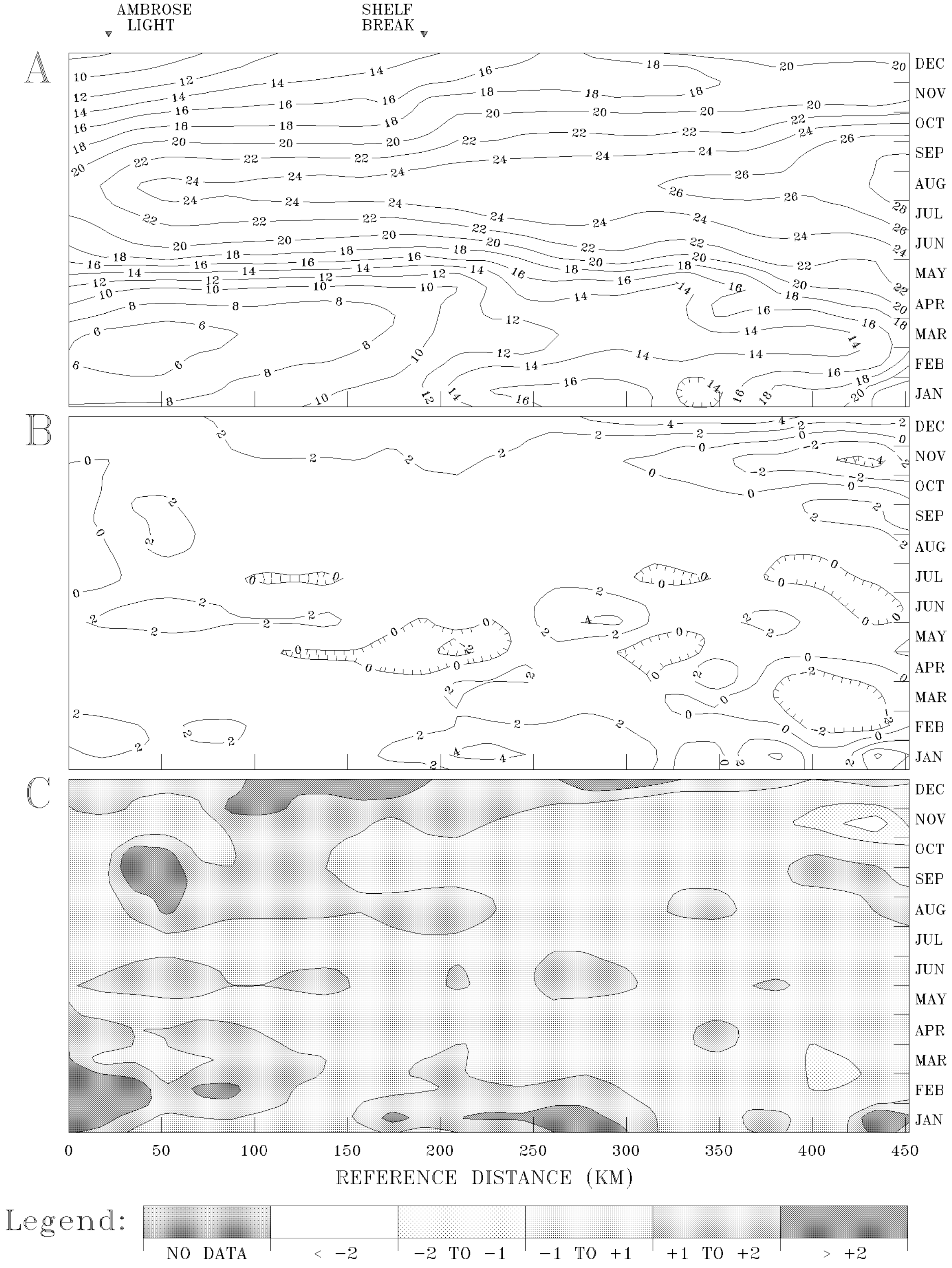
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
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i.e.

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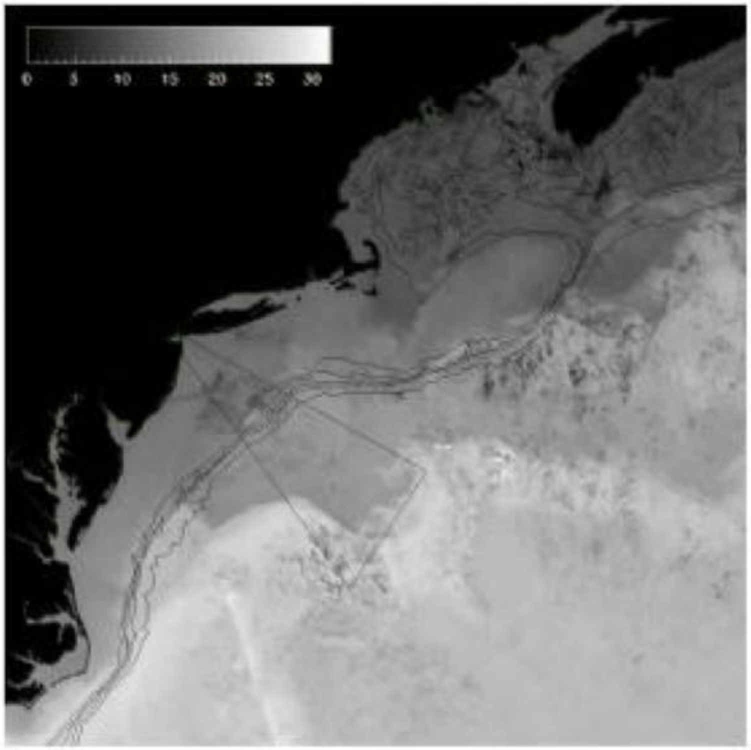
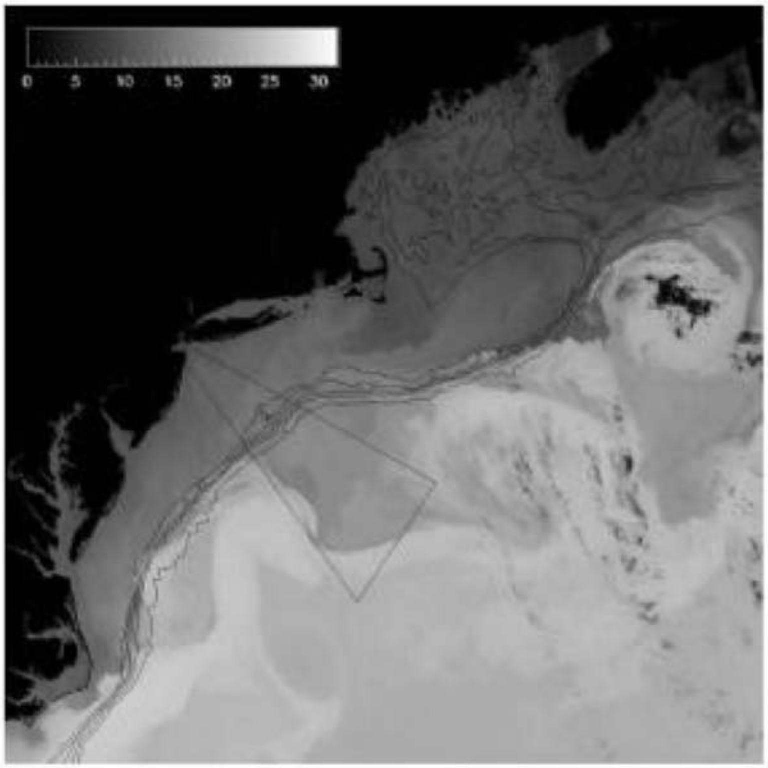
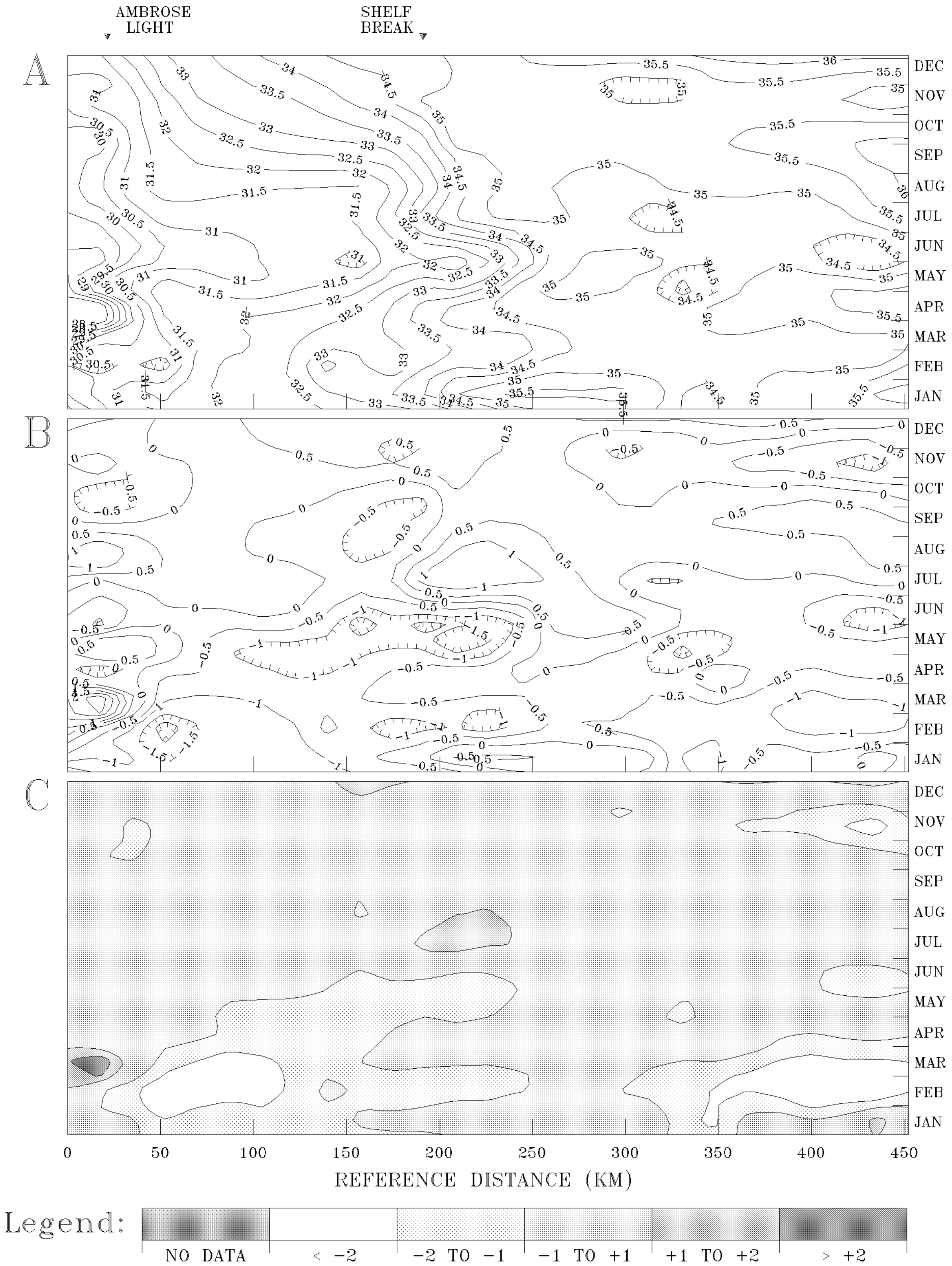


B




AMBROSE LIGHT
SHELF BREAK
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REFERENCE DISTANCE (KM)
Legend:
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−1 TO +1
+1 TO +2
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i.e.

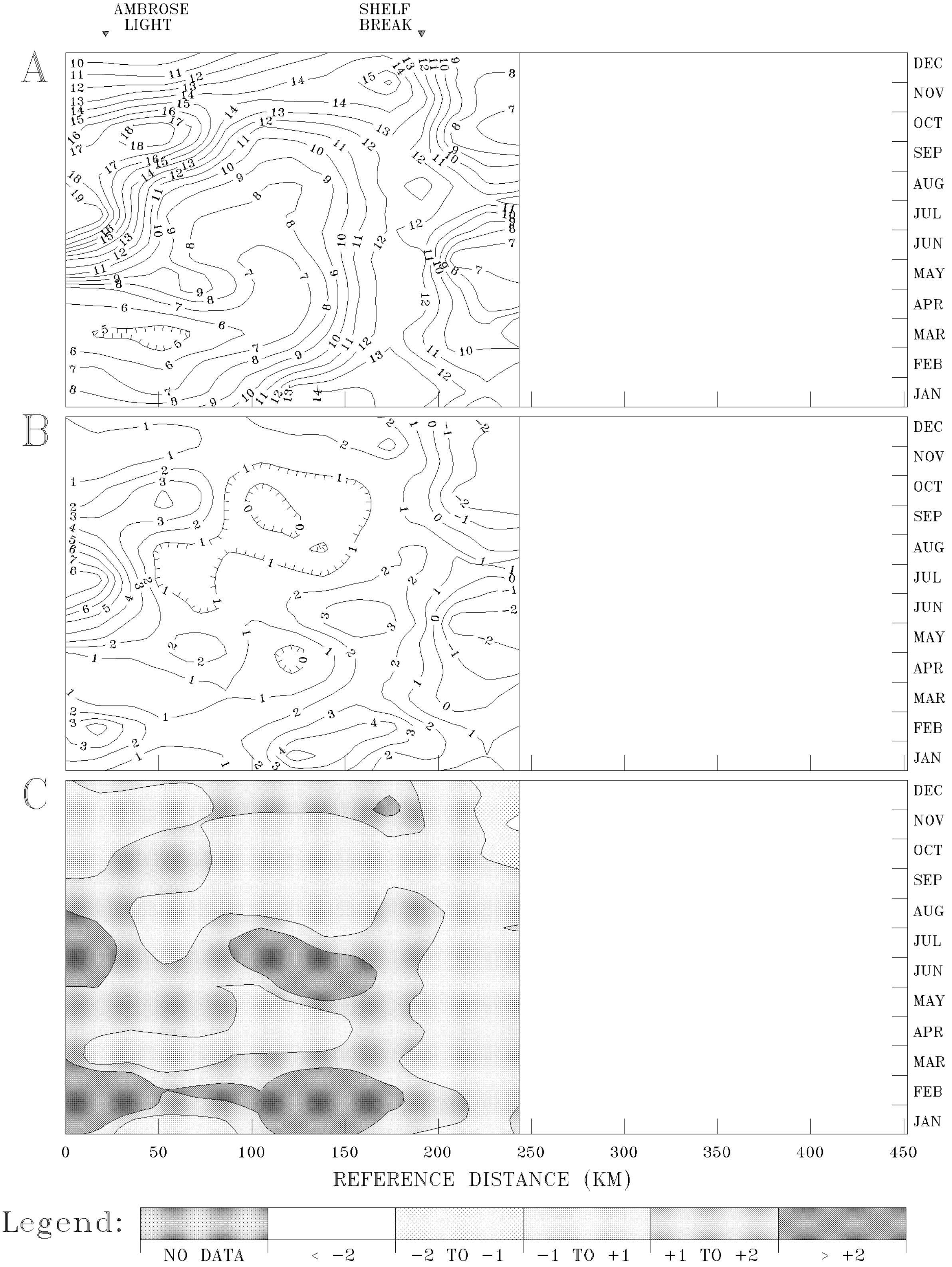
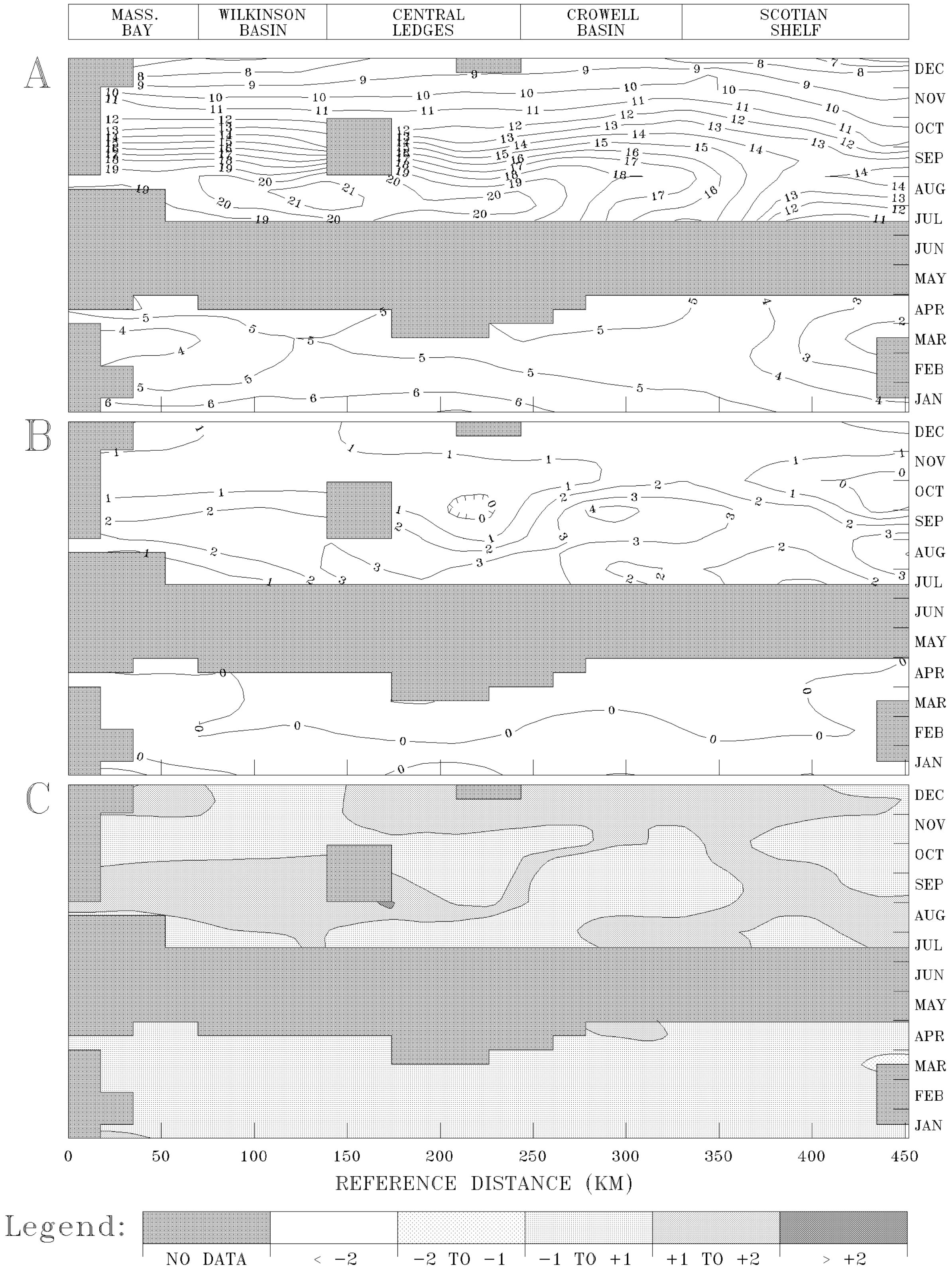


Figure 56. Bottom temperature conditions along the Middle Atlantic Bight transect during 1999. A. Measured values (°C) in time and space. B. Anomalies in time and space based on 1978-90 means. C. Standardized anomalies (*i.e.*, standard deviations) in time and space based on 1978-90 means and variances (scale given in legend). (In panels A and B, values decline on those sides of contour lines with hachures.)


MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
< −2
−2 TO −1
−1 TO +1
+1 TO +2
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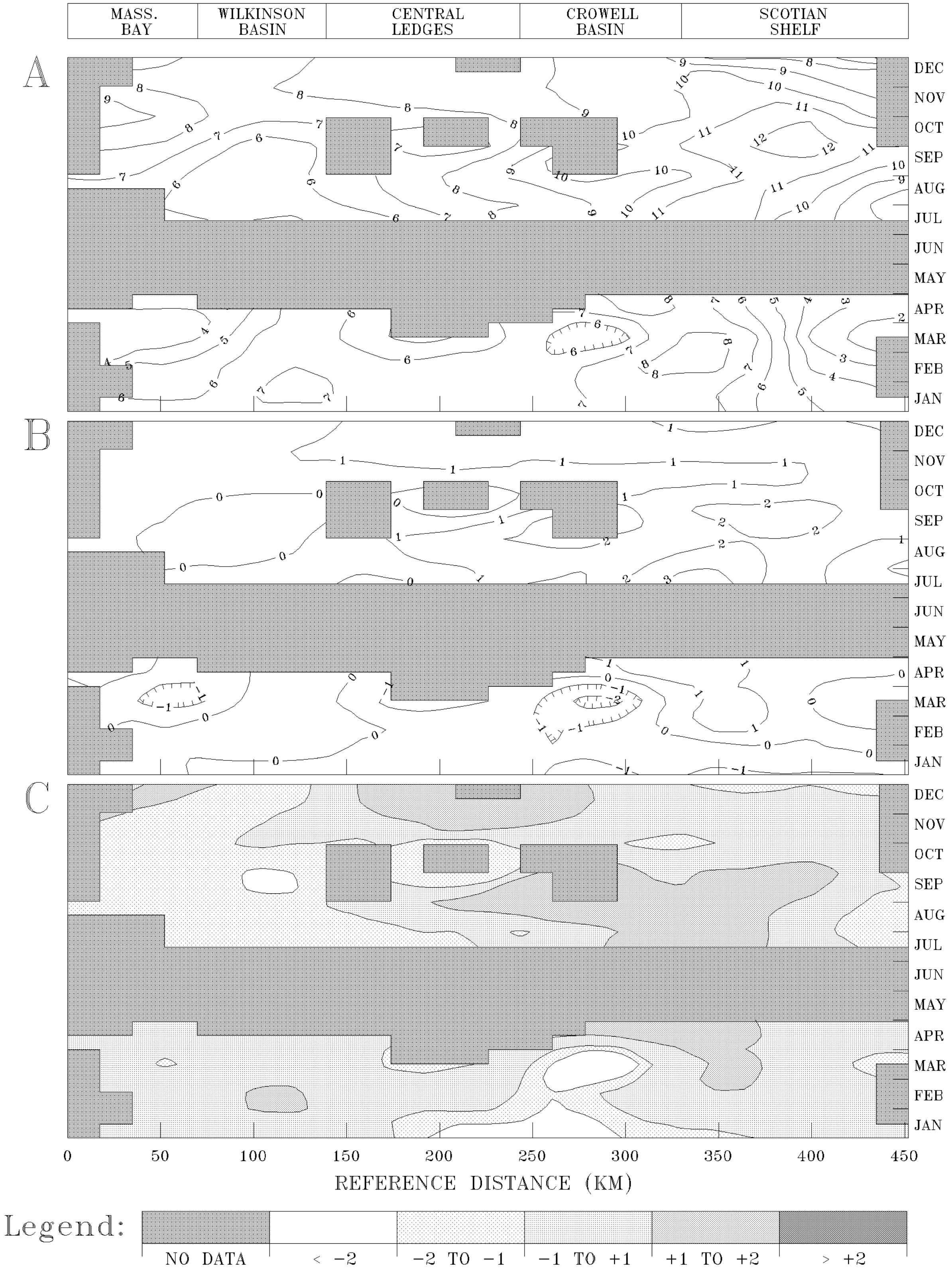
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
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+1 TO +2
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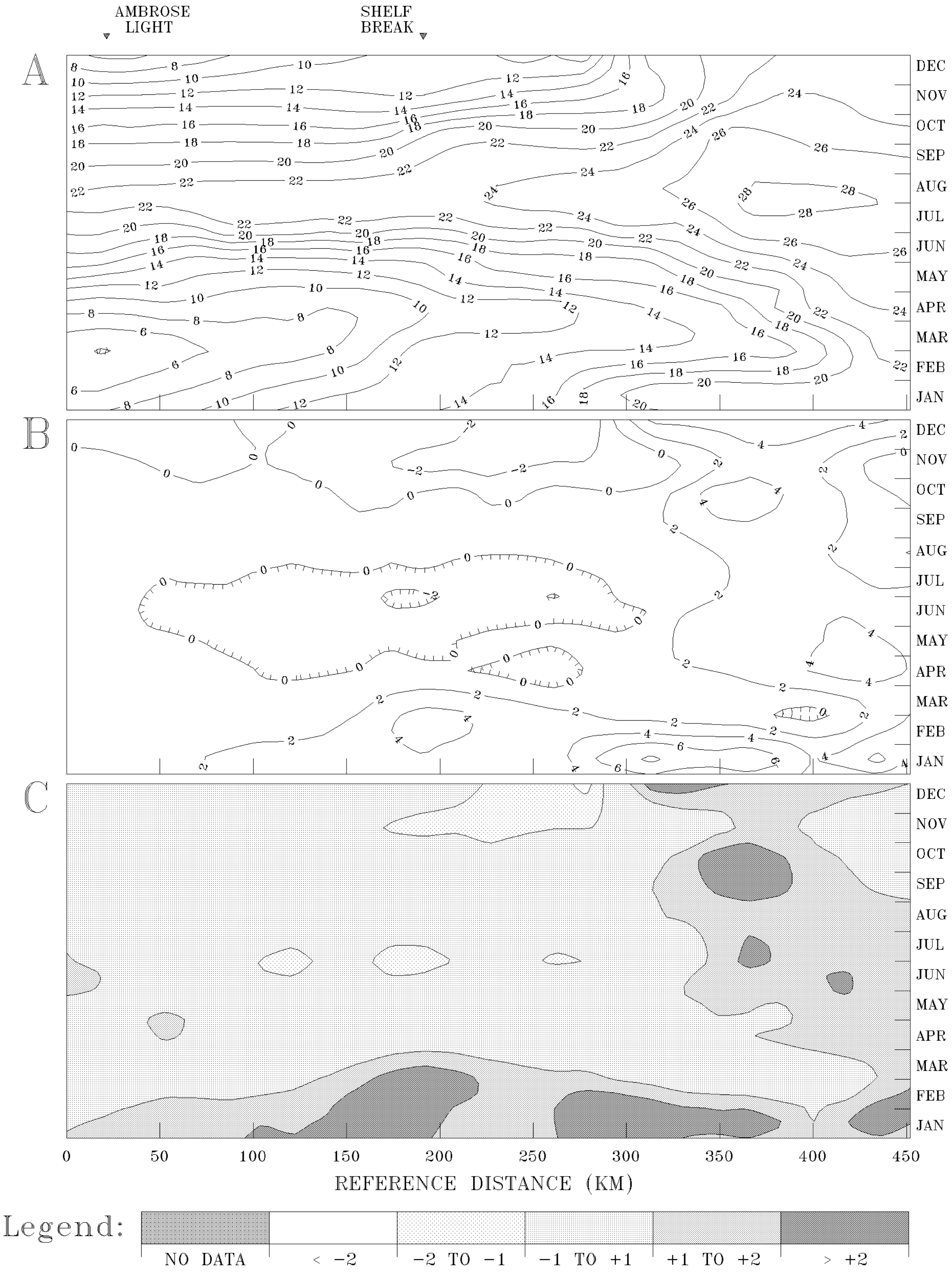
i.e.


AMBROSE LIGHT
SHELF BREAK
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
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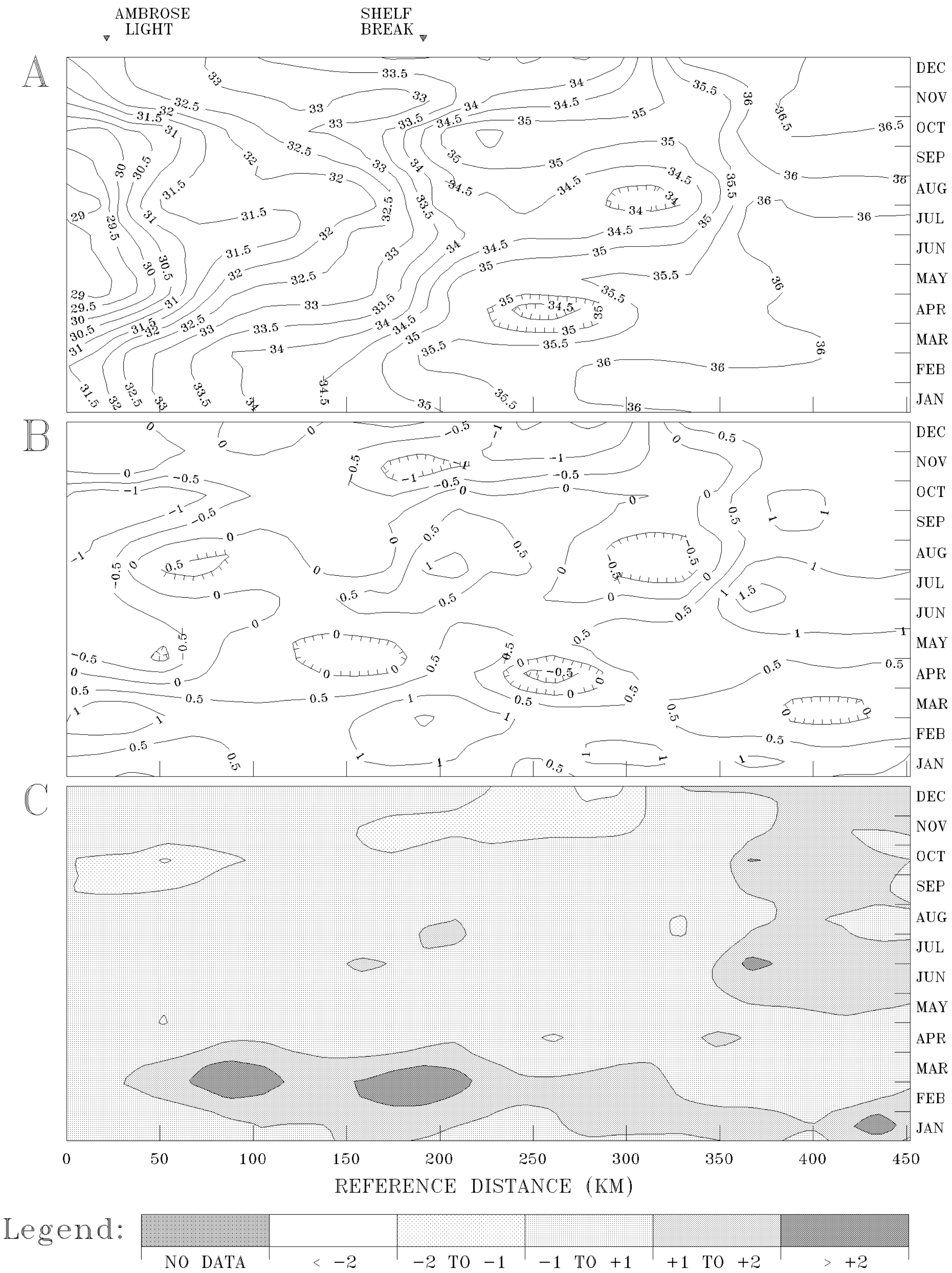
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
< −2
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−1 TO +1
+1 TO +2
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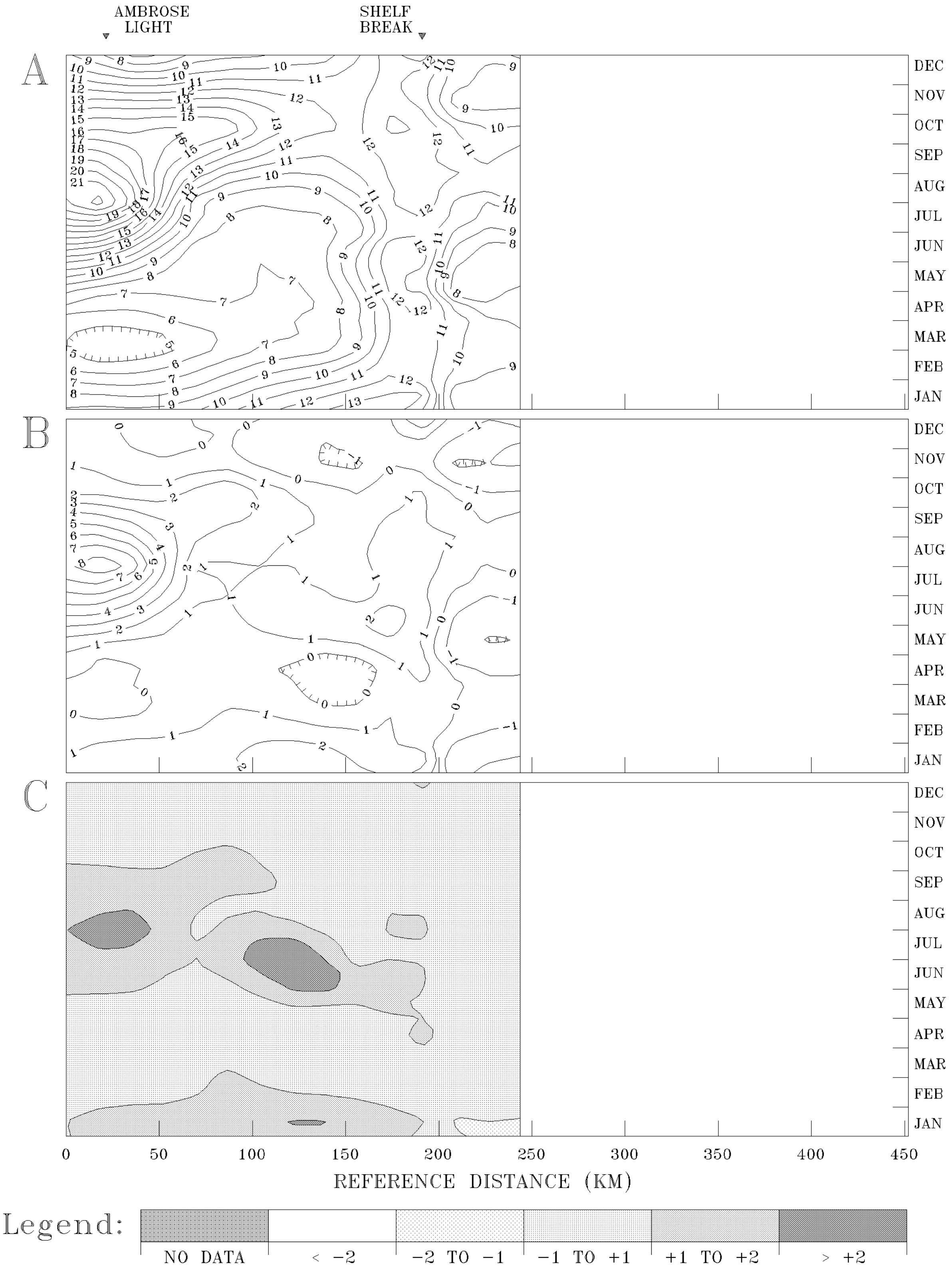
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
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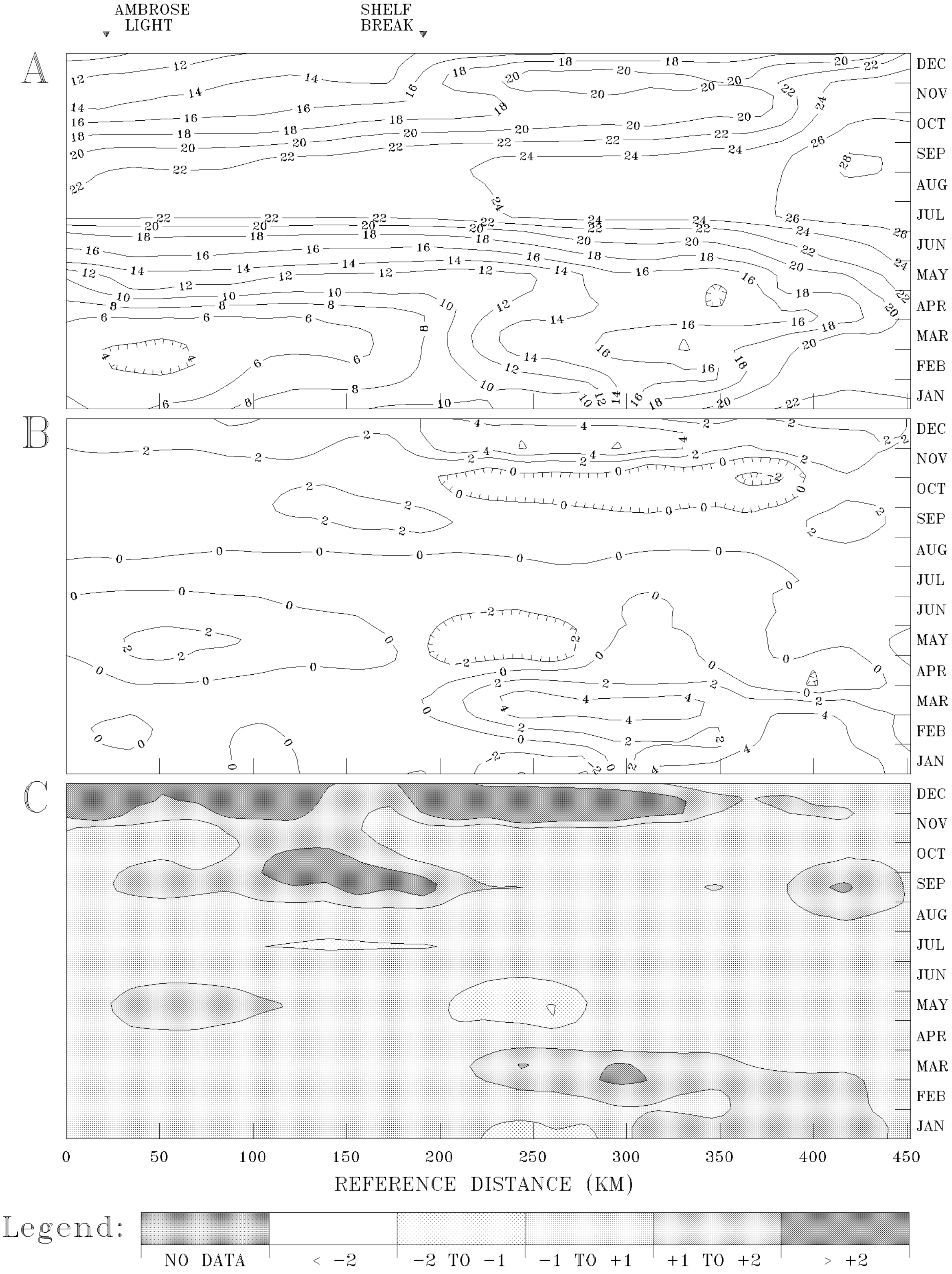
AMBROSE LIGHT
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
< -2
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+1 TO +2
> +2

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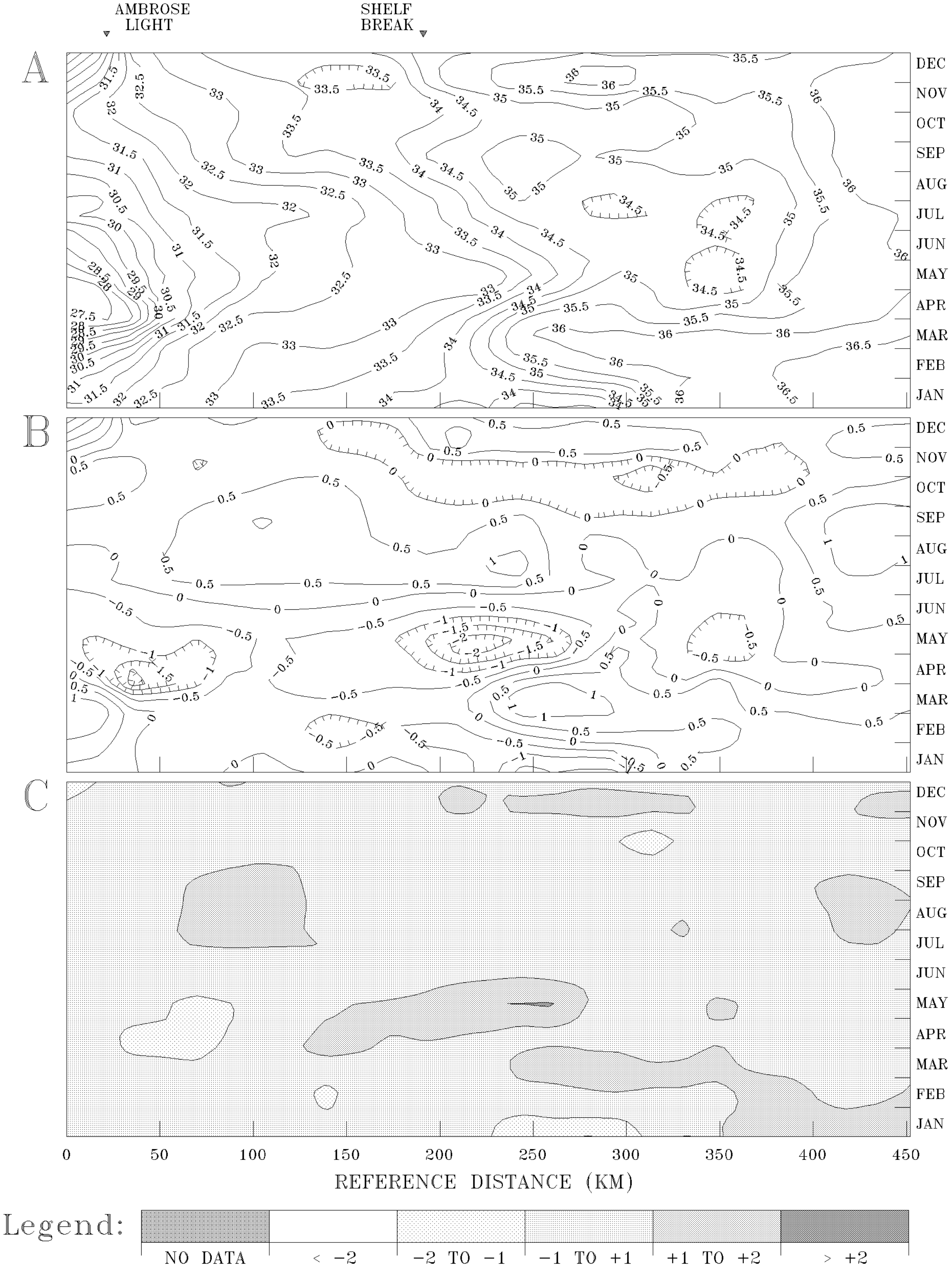
i.e.


AMBROSE LIGHT
SHELF BREAK
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REFERENCE DISTANCE (KM)
Legend:
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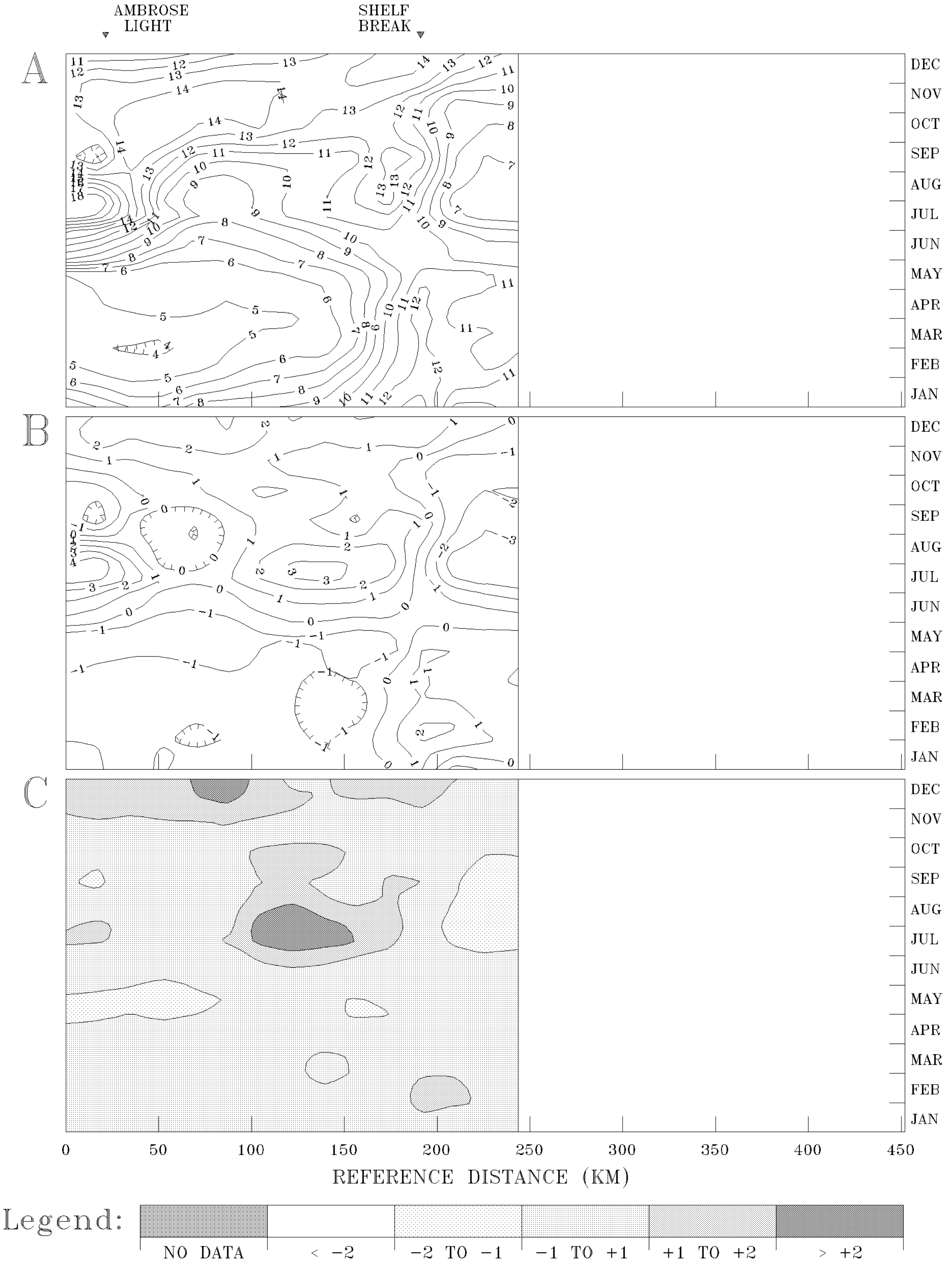
-2 TO -1
-1 TO +1
+1 TO +2
> +2

i.e.


AMBROSE LIGHT
SHELF BREAK
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
< -2
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MASS. BAY
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CROWELL BASIN
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REFERENCE DISTANCE (KM)
Legend:
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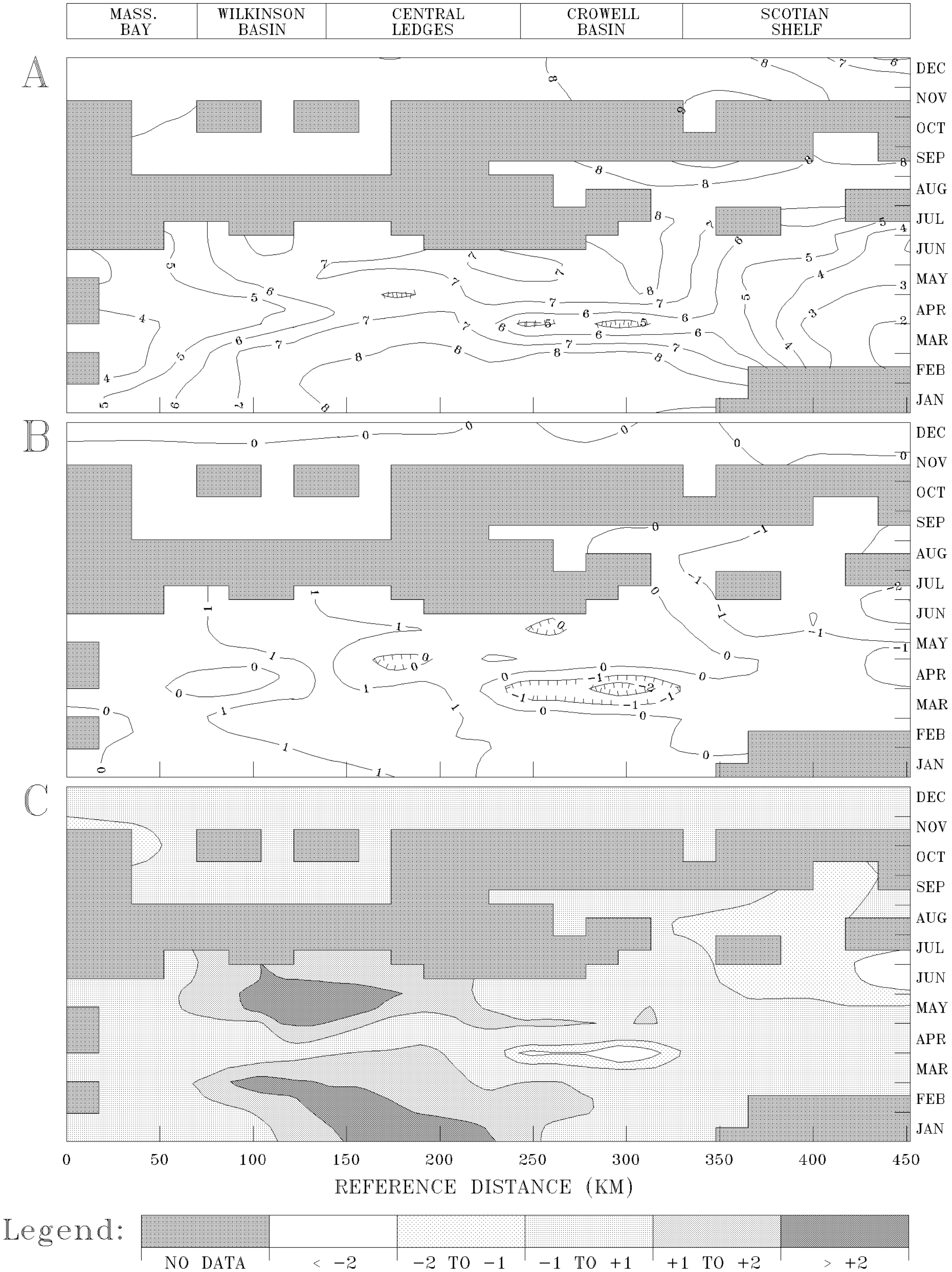
MASS. BAY
WILKINSON BASIN
CENTRAL LEDGES
CROWELL BASIN
SCOTIAN SHELF
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REFERENCE DISTANCE (KM)
Legend:
NO DATA
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−2 TO −1
−1 TO +1
+1 TO +2
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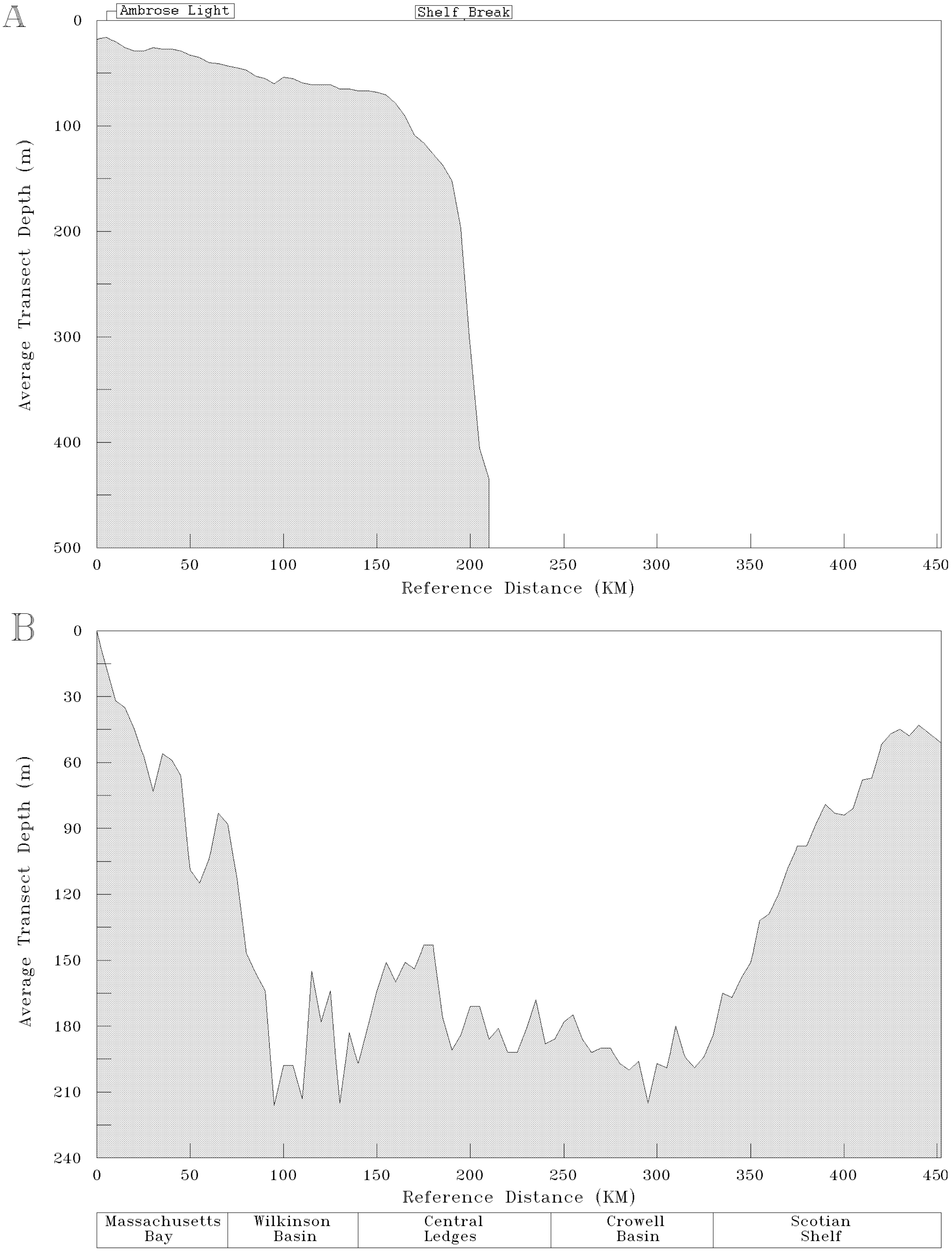
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Ambrose Light
Shelf Break
Average Transect Depth (m)
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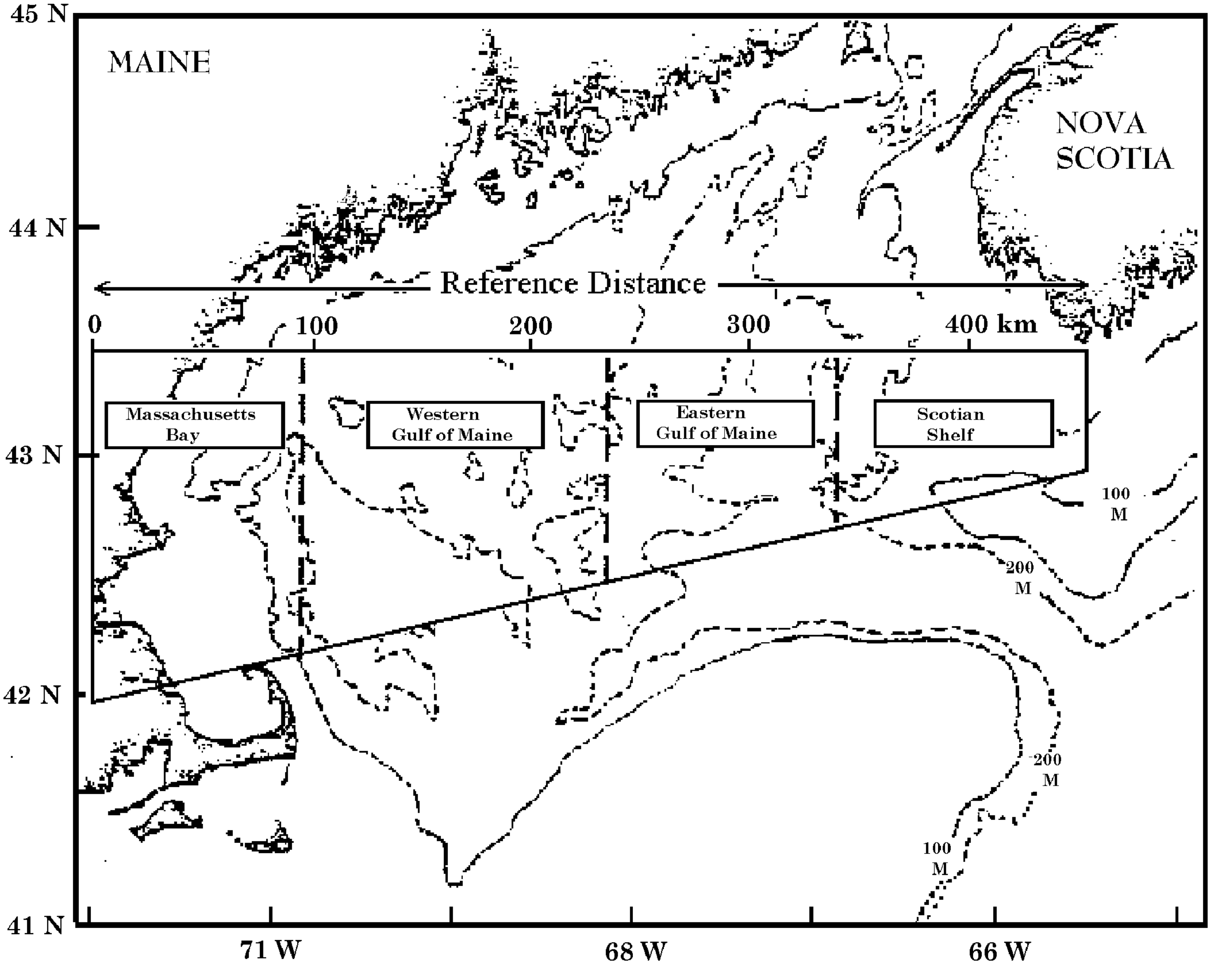
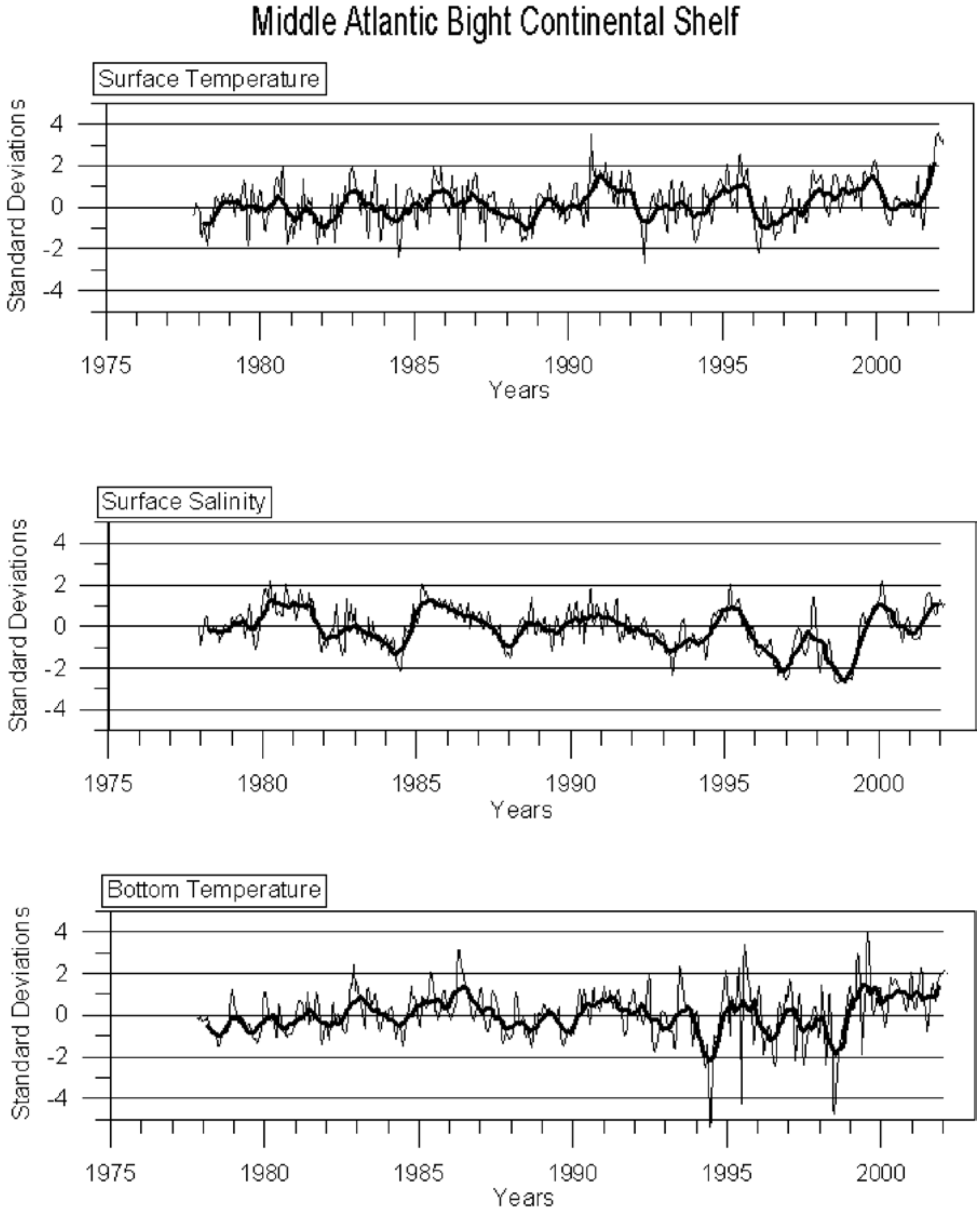
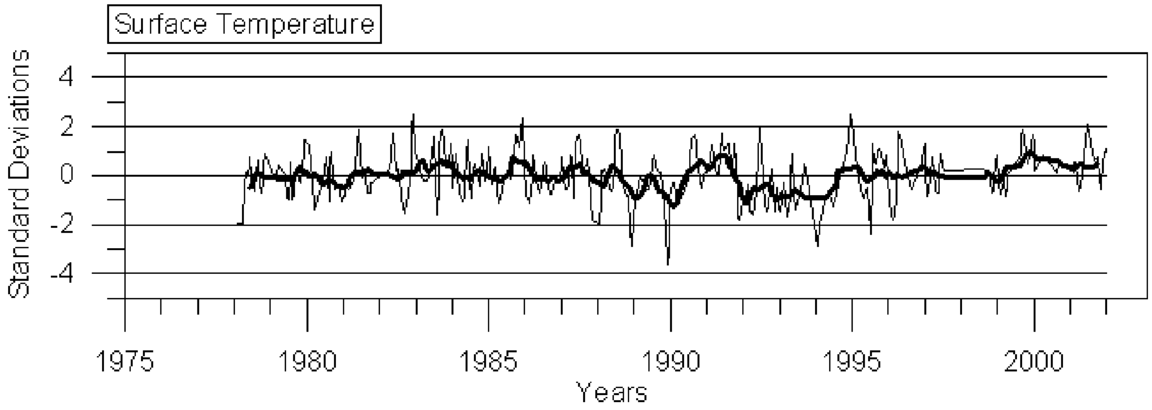
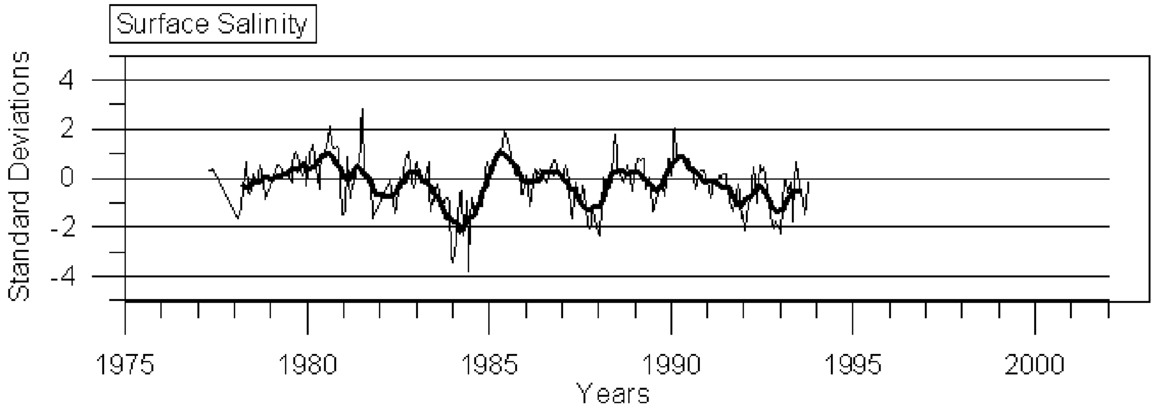
350
400
450
Reference Distance (KM)
B
Average Transect Depth (m)
0
30
60
90
120
150
180
210
240
0
50
100
150
200
250
300
350
400
450
Reference Distance (KM)
Massachusetts Bay
Wilkinson Basin
Central Ledges
Crowell Basin
Scotian Shelf

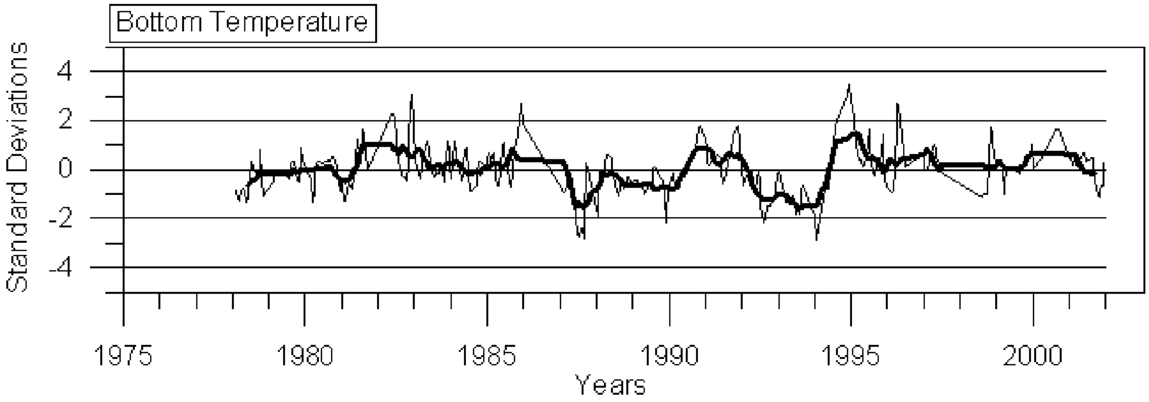

45 N
44 N
43 N
42 N
41 N
MAINE
NOVA SCOTIA
Reference Distance
0
100
200
300
400 km
Massachusetts Bay
Western Gulf of Maine
Eastern Gulf of Maine
Scotian Shelf
100 M
200 M
200 M
100 M
71 W
68 W
66 W


Middle Atlantic Bight Continental Shelf
Surface Temperature
Standard Deviations
4
2
0
-2
-4
1975
1980
1985
1990
1995
2000
Years
Surface Salinity
Standard Deviations
4
2
0
-2
-4
1975
1980
1985
1990
1995
2000
Years
Bottom Temperature
Standard Deviations
4
2
0
-2
-4
1975
1980
1985
1990
1995
2000
Years

Massachusetts Bay

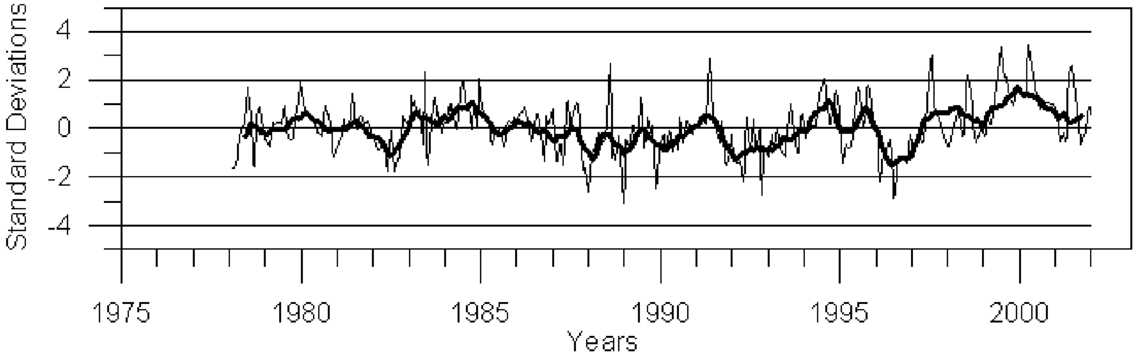




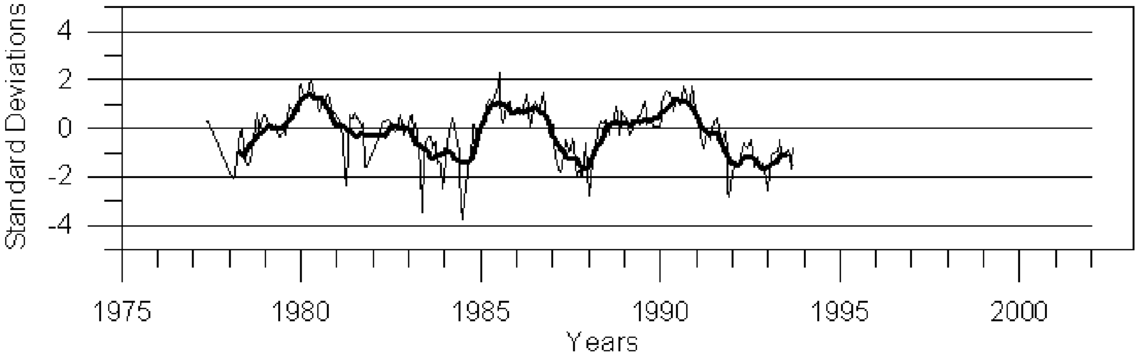


Western Gulf of Maine

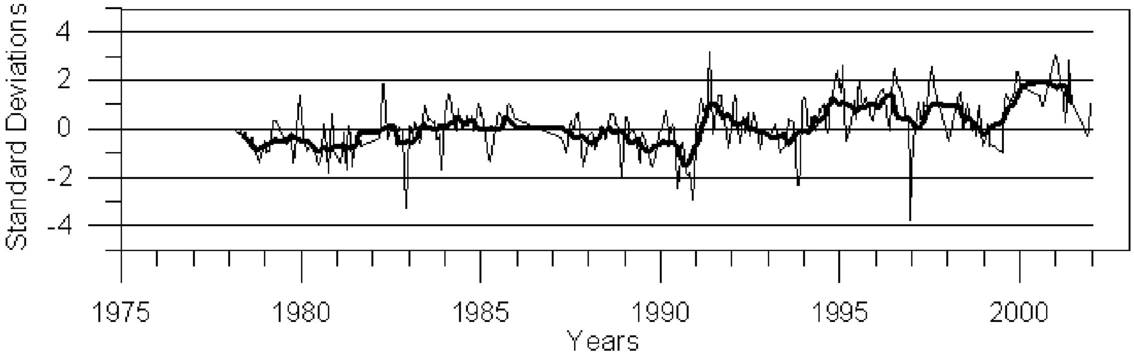
Surface Temperature



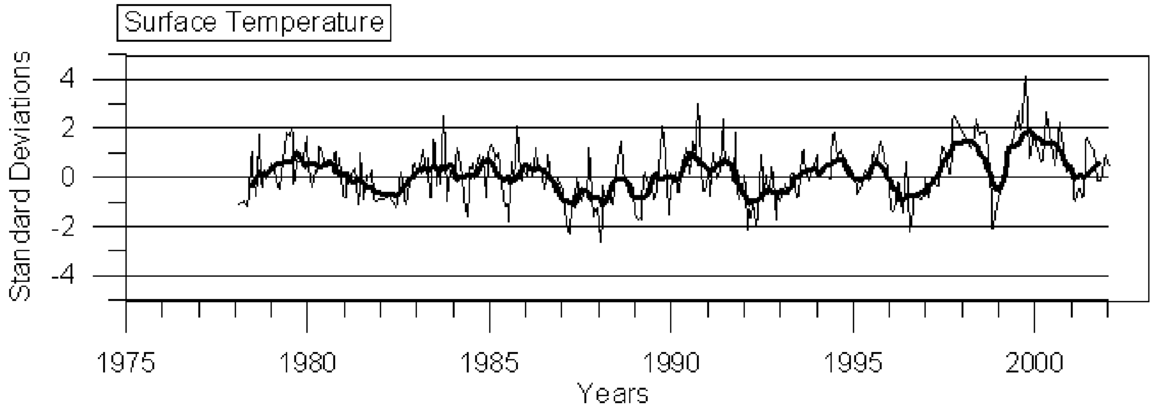
Surface Salinity

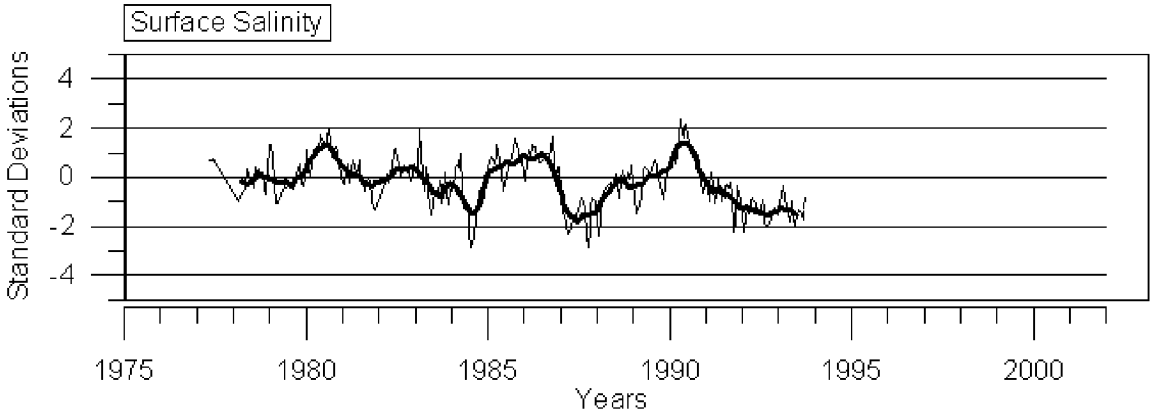


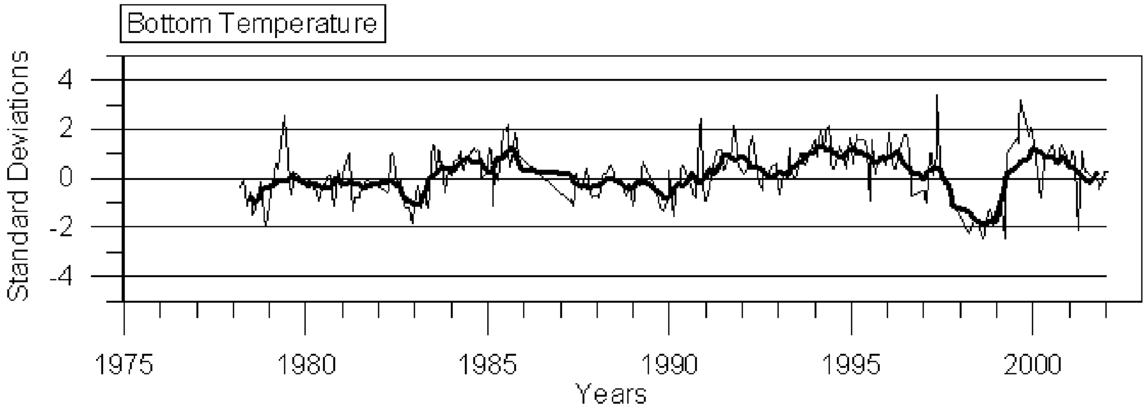
Bottom Temperature



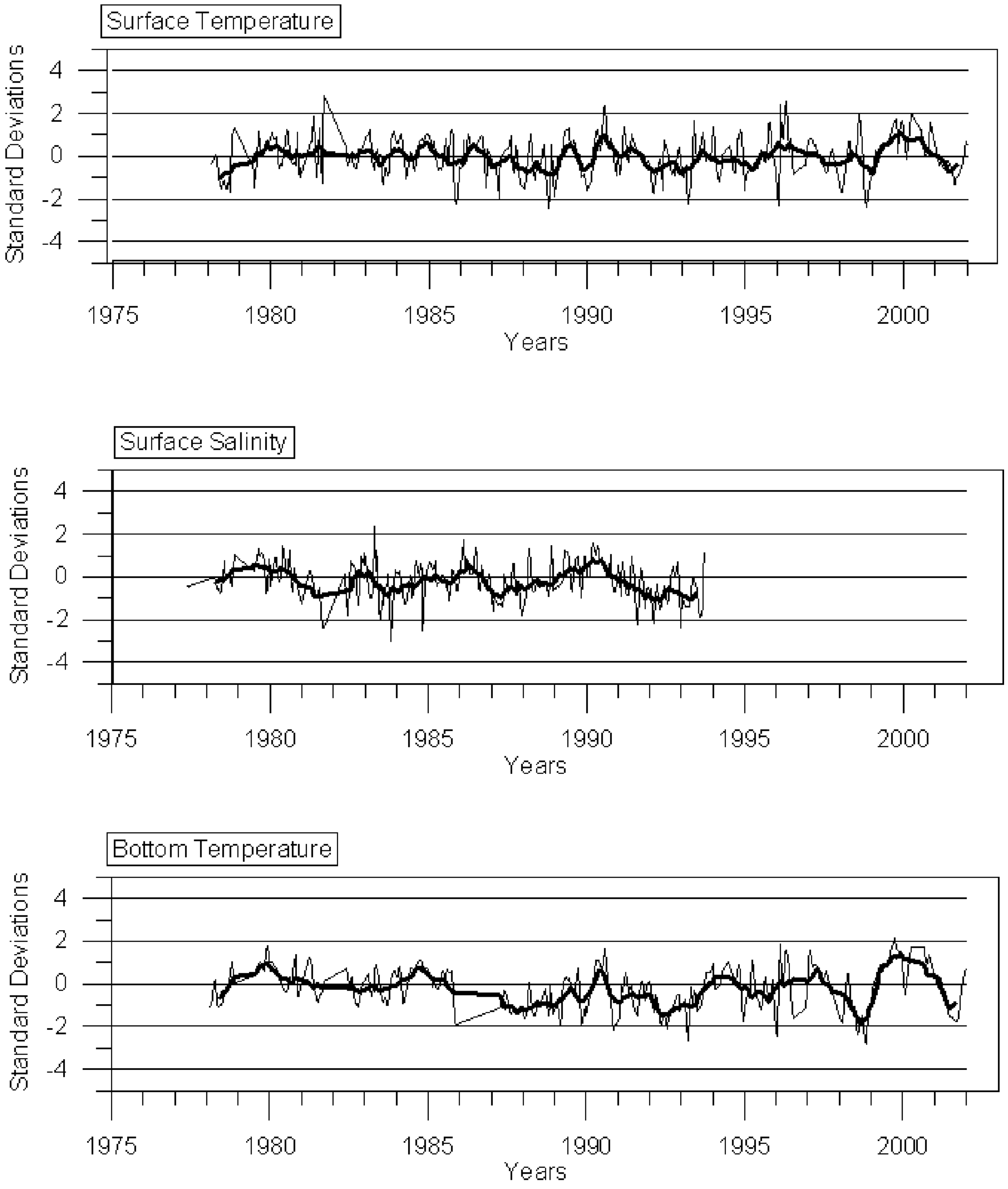
Eastern Gulf of Maine







Scotian Shelf



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This series represents a secondary level of scientific publishing in the National Marine Fisheries Service (NMFS). For all issues, the series employs thorough internal scientific review, but not necessarily external scientific review. For most issues, the series employs rigorous technical and copy editing. Manuscripts that may warrant a primary level of scientific publishing should be initially submitted to one of NMFS's primary series (*i.e., Fishery Bulletin, NOAA Technical Report NMFS,* or *Marine Fisheries Review*).

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Jon A. Gibson (Biological Sciences Editor)
NMFS Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543-1026 USA.

NORTHEAST FISHERIES SCIENCE CENTER
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Northeast Fisheries Science Center
National Marine Fisheries Service, NOAA
166 Water St.
Woods Hole, MA 02543-1026

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Publications and Reports of the Northeast Fisheries Science Center

The mission of NOAA's National Marine Fisheries Service (NMFS) is "stewardship of living marine resources for the benefit of the nation through their science-based conservation and management and promotion of the health of their environment." As the research arm of the NMFS's Northeast Region, the Northeast Fisheries Science Center (NEFSC) supports the NMFS mission by "planning, developing, and managing multidisciplinary programs of basic and applied research to: 1) better understand the living marine resources (including marine mammals) of the Northwest Atlantic, and the environmental quality essential for their existence and continued productivity; and 2) describe and provide to management, industry, and the public, options for the utilization and conservation of living marine resources and maintenance of environmental quality which are consistent with national and regional goals and needs, and with international commitments." Results of NEFSC research are largely reported in primary scientific media (*e.g.*, anonymously-peer-reviewed scientific journals). However, to assist itself in providing data, information, and advice to its constituents, the NEFSC occasionally releases its results in its own media. Those media are in four categories:

NOAA Technical Memorandum NMFS-NE -- This series is issued irregularly. The series typically includes: data reports of long-term or large-area studies; synthesis reports for major resources or habitats; analytical reports of environmental conditions or phenomena; annual reports of assessment or monitoring programs; manuals describing unprecedented field and lab techniques; literature surveys of major resource or habitat topics; proceedings and collected papers of scientific meetings; and indexed and/or annotated bibliographies. All issues receive internal scientific review and most issues receive technical and copy editing.

Northeast Fisheries Science Center Reference Document -- This series is issued irregularly. The series typically includes: data reports on field and lab observations or experiments; progress reports on continuing experiments, monitoring, and assessments; manuals describing routine surveying and sampling programs; background papers for, and summary reports of, scientific meetings; and simple bibliographies. Issues receive internal scientific review, but no technical or copy editing.

Resource Survey Report (formerly *Fishermen's Report)* -- This information report is a quick-turnaround report on the distribution and relative abundance of selected living marine resources as derived from each of the NEFSC's periodic research vessel surveys of the Northeast's continental shelf. There is no scientific review, nor any technical or copy editing, of this report.

The Shark Tagger -- This newsletter is an annual summary of tagging and recapture data on large pelagic sharks as derived from the NMFS's Cooperative Shark Tagging Program; it also presents information on the biology (movement, growth, reproduction, etc.) of these sharks as subsequently derived from the tagging and recapture data. There is internal scientific review, but no technical or copy editing, of this newsletter.

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