PAPER

Temperature and Salinity Variability in the Mississippi Bight

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ABSTRACT

Conductivity-temperature-depth (CTD) profile data from five surveys performed by the R/V *Pelican* in the Mississippi Bight in February, May, and November 1999; and January-February and August-September 2000 have been analyzed. The data were collected within the framework of the Northern Gulf of Mexico Littoral Initiative (NGLI). The analysis of the T-S diagrams demonstrated substantial seasonal changes. Some estimates of the spatial variability at different scales were suggested. The analysis of the T-S data obtained at time-series stations revealed some interesting effects such as along-shelf intrusion of deep water into the coastal system and fine vertical T-S structures in shallow passes between the barrier islands.

INTRODUCTION

The Northern Gulf of Mexico Littoral Initiative (NGLI) is the most recent and comprehensive study of the littoral zone of the Mississippi/Alabama coast, focusing on the Mississippi Sound area. The goal of NGLI was to develop a sustained nowcasting/forecasting system for the coastal areas suitable for coastal resource management (Asper et al., 2001). Starting in 1999, NGLI has gathered a unique and significant database of hydrological observations that lends itself to various statistical and variability analyses.

The area of the Mississippi Sound is 2130 km^2 and the mean low water depth is only 3.0 m (Kjerfve, 1983). The series of sandy barrier islands (including Cat, Ship, Horn, Petit Bois, and Dauphin Islands) separate the shallow coastal waters from the Northern Gulf of Mexico. Fresh water inflow comes directly from major rivers such as the Pearl, Biloxi, and Pascagoula along with diffuse land drainage and small bayous, and indirectly from the Mississippi River and Mobile River. Saline waters from the Gulf are transported through the passes and straits between barrier islands.

Some estimates of temperature and salinity variability were performed by Eleuterius (1976a; 1976b) who suggested preliminary daily patterns of salinity distribution at various depths for the period from June1973 to February 1975 and determined monthly trends of salinity and temperature distribution at several stations for the same period of time. Three years later, Eleuterius and Beaugez (1979) presented a description of the climatic hydrographic conditions in the Mississippi Sound. It gave some estimates of the distributions of several hydrological parameters (temperature, salinity, oxygen, etc.) at various depths and at the bottom, but it was based on a small number of stations. Kjerfve (1983) collected and analyzed meteorological data, fresh water discharge, tides, currents, and temperature and salinity data from several mooring sites for the period of April-October 1980.

All these studies were based on rather scarce data available before NGLI and therefore they cannot be used for validating an operational numerical model of the area. NGLI surveys have provided a much larger number of sampling locations for the period of 2 years, higher vertical resolution, more repeatable stations, and better geographic positions of the stations than any previous hydrographic observations in the Mississippi Bight. Based on NGLI data an opportunity presents itself to perform some reasonable quantitative estimates of spatial and temporal variability of temperature and salinity in the area.

The purpose of this paper is to present an analysis of NGLI temperature and salinity data aimed at the comparison of observed and simulated data in the area. No attempts have been undertaken to determine the circulation in this area.

Oceanographic Observations

a. Data Acquisition, Processing and Editing

The measurement procedure for the CTD (conductivity-temperature-depth) profiler consists of lowering it to depth and raising it back to the surface. The seawater properties are measured during both lowering and raising, and the data sets obtained by the sensors are called downcasts and upcasts, correspondingly. Two sensors installed for both temperature and salinity result in two data sets—primary and secondary—so each CTD station consists of 4 data sets for both temperature and salinity.

Preliminary data processing was performed by the U. S. Naval Oceanographic Office. The editing of data that we have carried out was aimed at the creation of a *special* database useful for the assessment of a model performance, rather than at the generation of a universal database of all measured data. First, a set of primary data has been chosen for all stations. The analysis has shown a better quality of upcast data in the upper layers (0-5m), compared to downcast data, while both upcast and downcast data

looked reliable in deeper layers at most stations. A more homogeneous flow and less bubbles around the sensing elements, and a more stable upward motion of the CTD rosette may be the determining factors of a better quality of the upcasts. The data at the surface (0m) appeared very unreliable which is why they were not included in the database. Then the obvious outliers such as negative or very high values of temperature and salinity have been removed. No data filtering or smoothing has been performed.

A time-series group is a set of stations done at the same location for a period of up to 25 hours (diurnal cycle). Normally the sampling interval was 1 hour, with a few exceptions. There are 7 time-series stations in the February 1999 survey, 2 in May 1999, 6 in November 1999, 4 in January-February 2000, and 2 in the August-September 2000 survey, for total of 21 time-series stations (see Table 1).

A transect group is a sequence of stations done along some straight line. Most of the CTD stations were done within the Mississippi Sound, including short transects along ship channels off Pascagoula, Gulfport, and Biloxi. The transect along the ship channel in Mobile Bay was performed in all surveys (locations along the median of Mobile Bay, between the Mobile River delta and the Mobile Bay Pass; see maps on Figs 1.1a – 1.5a). Time-series groups were often done in or near the passes and straits of the Mississippi Sound or between Dauphin Island and Mobile Point. Offshore data consisted of long transects seaward of the barrier islands. The duration of the surveys ranged from 10 to 15 days.

b. General Analysis

To estimate the total range of salinity and temperature variations for the whole survey, T-S diagrams have been plotted. T-S diagrams reproduce not only the hydrological picture of the survey, but also allow a qualitative estimation of the data variability. Figs.1.1a – 1.5a show the location of CTD stations in 5 cruises of the R/V *Pelican*. T-S diagrams of these surveys are shown in Figs.1.1b – 1.5b. The T-S diagram for each survey includes both shallow and offshore stations, so it captures the variability on temporal and spatial scales of the whole survey (10-15 days, coverage of more than 30,000 km^2). It allows the analysis of large-scale features of the whole Mississippi Bight, with the separate consideration of the shallow and deep water contributions. At the same time, if needed, any particular water mass can be easily 'detached' from the total T-S diagram for examination on smaller scales.

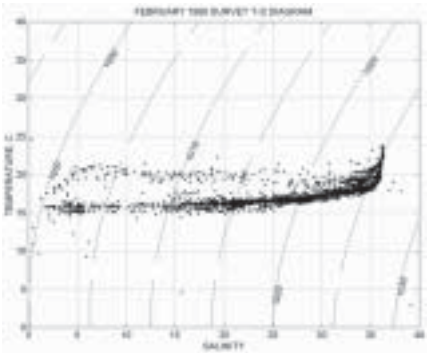
The February 1999 T-S diagram (Fig.1.1b) shows that, in wintertime, the seaward waters are warmer but still saltier

FIGURE 1

Location of CTD stations and T-S diagrams

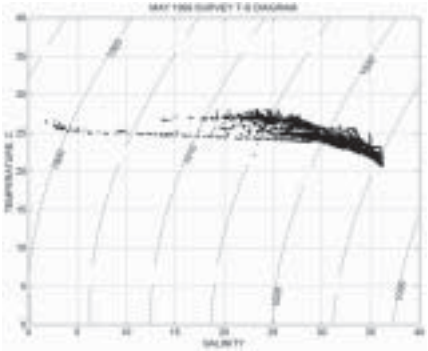
(1.1a) Location of February 1999 CTD stations

(1.1b) T-S diagrams for February 1999 survey



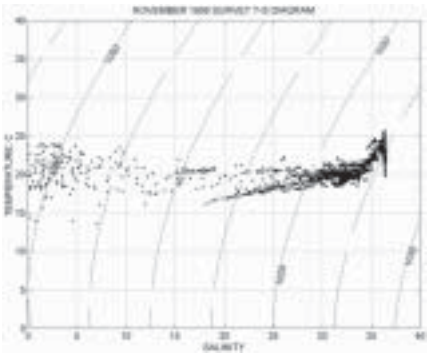
(1.2a) Location of May 1999 CTD stations

(1.2.b) T-S diagrams for May 1999 survey



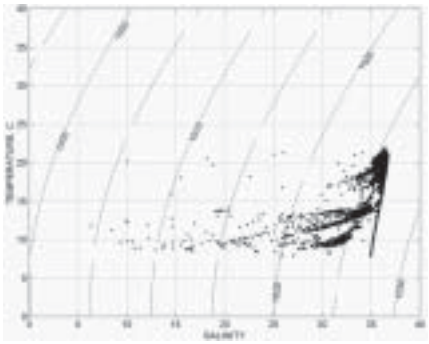
(1.3a) Location of November 1999 CTD stations

(1.3b) T-S diagrams for November 1999 survey



(1.4a) Location of January/February 2000 CTD stations

(1.4b) T-S diagrams for January/February 2000 survey



(1.5a) Location of August/September 2000 CTD stations

(1.5b) T-S diagrams for August/September 2000 survey

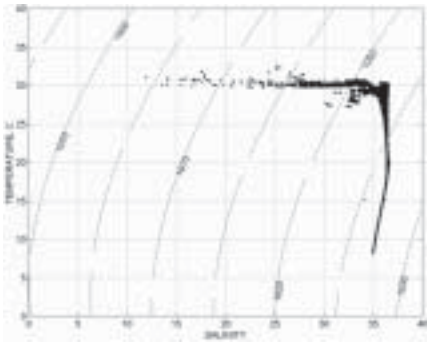


TABLE 1

Synopsis of analyzed oceanographic data.

CTD Surveys	Total number of stations	Duration of survey (days)	Number of time-series stations	Number of spatial groups	Number of transect groups
February 1999	245	13	7	4	5
May 1999	219	10	2	6	5
November 1999	312	14	6	6	4
January/February 2000	385	15	4	5	16
August/September 2000	178	15	2	3	7
Total:	1339	67	21	24	37

than coastal ones. The main curve on the T-S diagram bulging down from the right to the left side reflects this fact. A smaller group of data points builds up a secondary curve with almost constant temperatures (e.g., Pascagoula transect). A scattering of data points around the two distinct curves on the T-S diagram gives a clue about scales of temperature and salinity variability. Based on such an analysis we conclude that salinity gradients persist while the variation of temperature remains small. The T-S diagram for the May 1999 survey (Fig.1.2b) reveals a late spring vertical distribution when the surface waters become warmer by 6-7° C than deep layers. Again there are two T-S curves, but now they both are bulged down from the left corner to the right, which corresponds to the change in direction of the temperature gradient (towards land). Large changes in the heating regime in the springtime lead to higher variability of temperature values as compared to the February 1999 data.

For the November 1999 survey (Fig.1.3a), a single mean T-S curve (most concentrated data) was considered. This curve consists of two parts: a vertical group of points and a set of points bulged down from the right side to the left (see Fig.1.3b). The latter reveals subsurface gradients of both salinity and temperature while the former is caused by a sharp temperature gradient at depths from 60 m to 80-90 m. This sharp gradient is presumably the effect of upwelling along the shelf and shelf break.

The January-February 2000 survey (Fig.1.4a) has the largest number of stations (385). The T-S diagram (Fig.1.4b) represents a winter pattern where the seaward waters can be warmer than the waters in the near-coast zone. Here we have two distinct T-S zones: a vertical group of points, corresponding to a substantial temperature gradient in the 100–500 m layer, and two curves bulged down from the right side to the left. All T-S groups tend to 8° C temperature value—the surface value in the Mississippi Sound and the value in the deep continental slope. As compared to the February 1999 survey, the overall mean temperature of shallow coastal zones decreased by 4-5° C. The variability analysis shows that temperature variations at the surface layer 0.5–8 m are the highest among all processed surveys (at spatial scales more than 24 km). This is due to large differences in temperature (up to 10° C) between cold coastal surface waters and warmer Gulf waters.

The August-September 2000 survey (Fig.1.5a) includes 6 transects performed seaward of the barrier islands to depths as great as 480 m, the Mobile ship channel transect, and observations within the Mississippi Sound. It has been used for preliminary assessment of the performance of the Estuarine and Coastal Ocean Model (ECOM) (Vinogradova et.al., 2004). Small variations in temperature and salinity values from the mean vertical profiles have been observed in this survey. The average T-S

curve (Fig.1.5b) with a very small data scatter is readily seen on the T-S diagram. The horizontally aligned group of points corresponds to the river inflow (mostly Mobile Bay data) in shallow homogeneously warmed waters. The almost vertical group of points represents the 50–480 m portions of the Gulf transects where the temperature monotonically decreases with depth from 30°C to 7°C at the bottom while salinity has the mean value of about 36 (mean salinity of the Gulf of Mexico waters).

Spatial Variability within the Mississippi Bight

In this section, we estimate the variability of the T-S fields for different horizontal scales at various depth intervals and for different surveys. A rather simple approach is used to obtain a preliminary estimate. The amount of data available precludes the use of any sophisticated methods, like cluster method (see, e.g., Hur et al., 1998).

Towards the objective we select special groups of stations. A group is suitable for spatial variability analysis if (1) it is not a transect; (2) stations within a group are located in a region with similar bottom depths, current intensity, etc.; (3) the number of stations is not too small (otherwise the statistical methods would be inapplicable); and (4) the stations within a group should have been performed within a relatively short time period. All non-transect or non-anchored groups are considered as potential spatial groups, and, if they satisfy the requirements described above, they were used in the analysis. The total number of selected spatial groups is 24. The radius of the spatial group is defined as a half of the distance between the two most distant stations within the group. Fig.2a illustrates one example of spatial groups.

Estimation of spatial variability was performed by using the following procedure:

1. The spatial radius was calculated for each spatial group.
2. The average values of temperature and salinity were calculated within a group for each depth levels from 0.5 m to 8.0 m. This depth range is determined by the fact that most spatial groups are in shallow regions in the vicinity of barrier islands.
3. The standard deviations of temperature and salinity (within a group) were calculated for each depth level from 0.5 m to 8.0 m.

As a result, the plots shown in Figs. 2b and 2c have been constructed. These plots have three major axes: the depth in meters; spatial radius in kilometers; and standard deviation, in ppt, for salinity and in °C for temperature.

In general, the variability decreases with depth and increases with spatial scale. Note that there are pronounced sharp-gradient layers for some salinity and temperature vertical profiles in the upper subsurface zone of 2.5–6.0 m, which are caused by fresh water inflow, diurnal variations, and vertical mixing (see *Temporal Variability* section for further discussion). Due to these gradients, the deviation of salinity or temperature from their mean values increases with depth within some spatial groups.

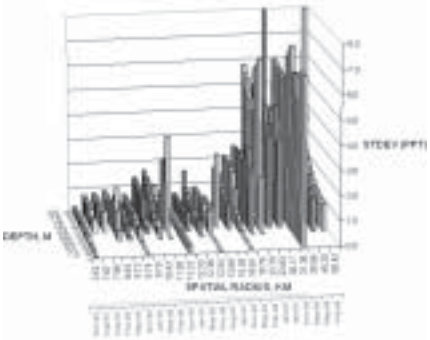
Thus the overall maximum salinity variability is 8.0 ppt (February 1999 survey, spatial scale of about 22.7 km, 5.0 m depth), and the maximum temperature variability is 3.0 °C (January-February 2000 survey, spatial scale of about 23.8 km, 1.0 m depth).

FIGURE 2

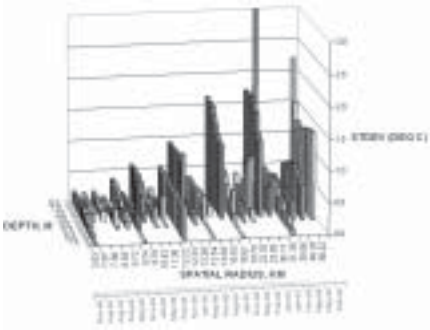
(2a) The illustration of spatial group definition. This is group 17, February 1999 survey, performed between Gulfport ship channel and Biloxi ship channel in the Mississippi Sound. Total duration (a time scale) of this group is 5 hours 24 minutes. Spatial scale is determined by the radius of a circle that barely covers all stations in the group. It is 8.83 km for this group, based on coordinates of stations 153 and 168, the most distant among all stations in this group. Standard deviations versus spatial scale for (2b) salinity and (2c) temperature. Vertical bars on these plots represent standard deviations computed for each spatial group. It gives an estimate of characteristic variability for a particular spatial scale, season, and depth associated with spatial groups.

(2a)

(2b)



(2c)



Seasonal trends are also seen on these two plots. The winter surveys (February 1999, November 1999, and January-February 2000) have similar high amplitudes of salinity deviations as compared to the May 1999 and August 2000 surveys on equivalent spatial scales. At all spatial scales, the smallest variations in temperature correspond to the August-September 2000 survey data whereas the highest temperature deviations correspond to the January 2000 survey.

Temporal Variability in the Mississippi Bight

A time-series group represents a set of observations performed at the same location for a period up to 25 hours with a sampling period from 30 min to 2.5 hours. The analysis based on these CTD stations gives information on the temporal variability of temperature and salinity fields for scales up to the diurnal cycle. The total number of processed time-series groups is 20.

We use two types of temporal variability representation. First, mean vertical temperature and salinity profiles are plotted with horizontal "error" bars equal to standard deviations at the corresponding depth levels. Second, graphs of temperature and salinity values versus time are constructed at different depths.

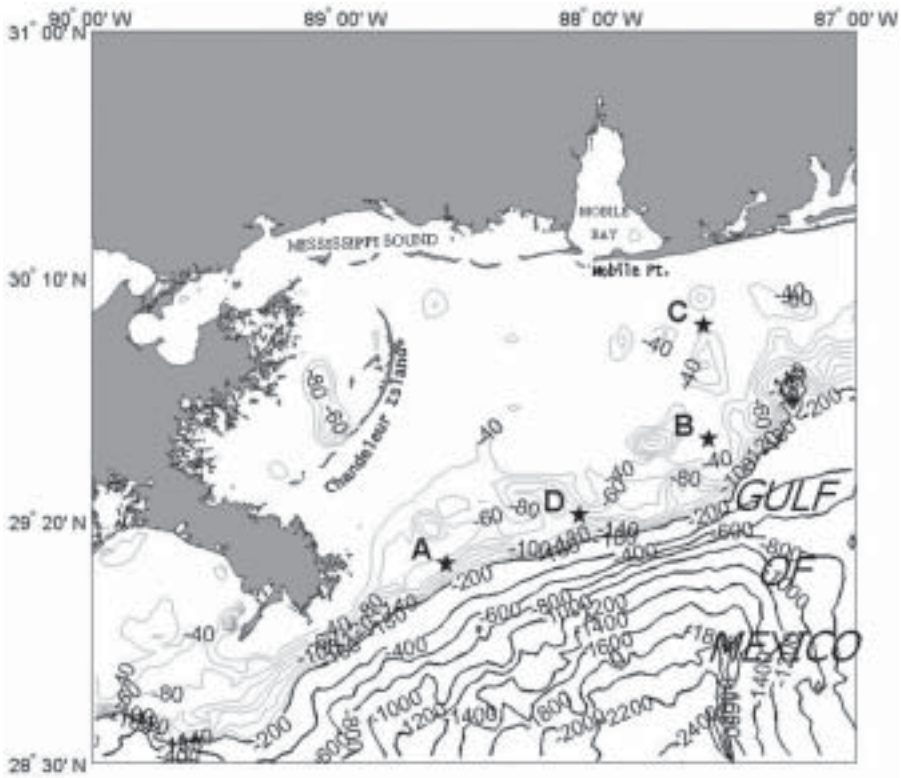
Time-series stations performed in November 1999 at 50–90 m depths in the vicinity of the shelf break reveal significant temperature drops in the near-bottom layer (Fig.3c). The upper layer (0–65 m) at station A with a total depth of 81 m is strongly homogeneous (25.5°C, 36.3 ppt, see Figs. 3b and 3c). At 65 m, the temperature drops dramatically while salinity increases slightly. Mean temperature and salinity at the bottom are 22.1° C and 36.4 ppt respectively. These gradients are stable on a diurnal time scale, with a slight change in the thickness of the near-bottom layer.

The presence of a stable, significant temperature gradient indicates the intrusion of another water mass into the homogeneous system. The intruding water mass is much colder and slightly saltier than the local well-mixed system. Temperature changes at 60,

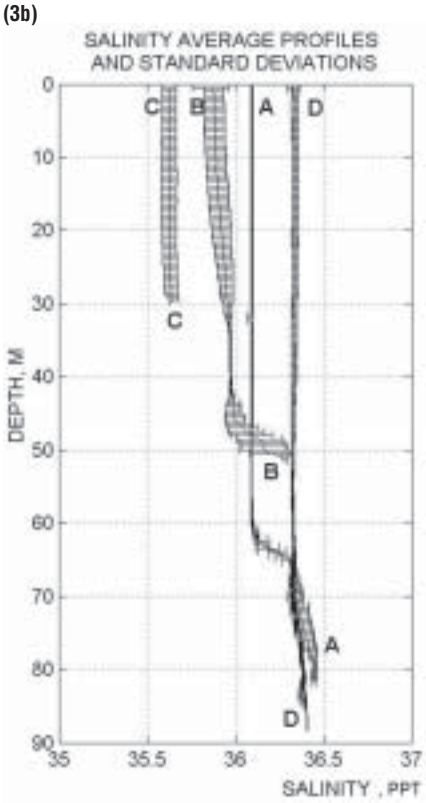
FIGURE 3

Along-shelf intrusion. (3a) Location of 4 selected time-series stations. Diurnal mean vertical profiles and standard deviations for salinity (3b) and temperature (3c) at 4 stations. Diurnal changes in temperature (3d) and salinity (3e) at 60, 75 and 80 m depths, station A.

(3a)



(3b)



(3c)

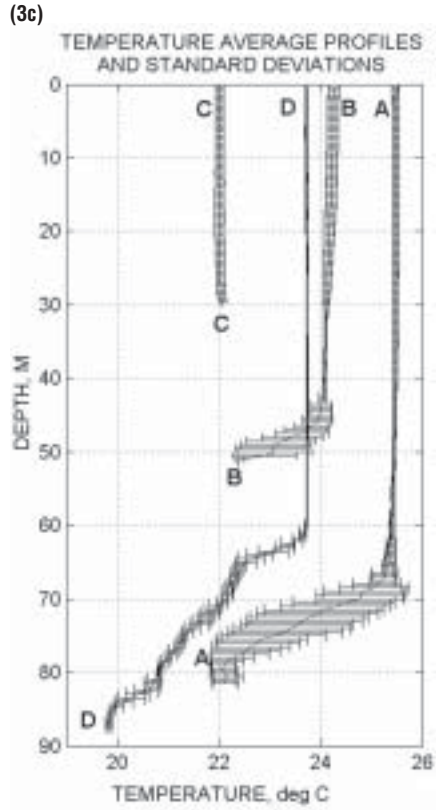
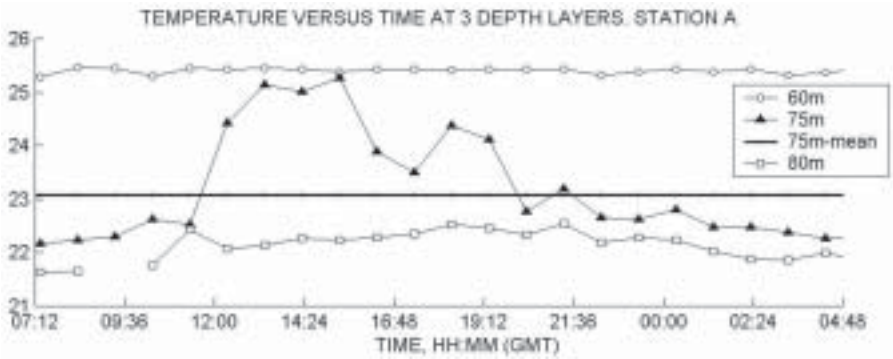


FIGURE 3

Along-shelf intrusion, continued.

(3d)



(3e)

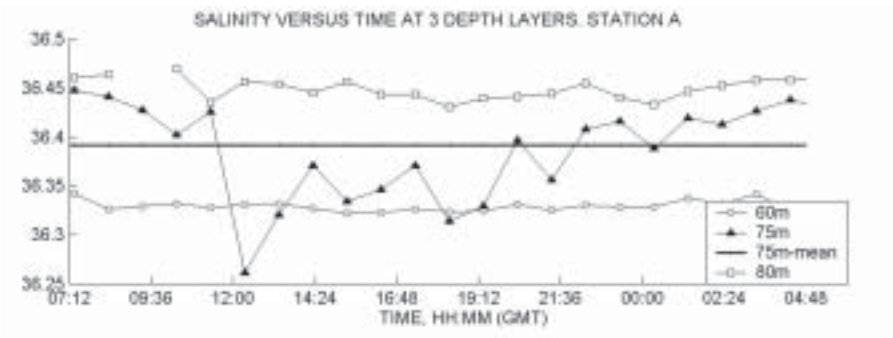


FIGURE 4

Time-series stations located near passes and straits. (4a) Location of 3 selected time-series stations. Vertical profiles of temperature and salinity observed at station 2 (4b), station 6 (4c) and station 14 (4d). Diurnal changes in temperature and salinity at 3 characteristic depth levels: station 2 (4e), station 6 (4f) and station 14 (4g).

(4a)

75, and 80 m depth levels at station A (Fig.3d) clearly show a large amplitude fluctuation at 75 m around the mean value that implies a strong and stable source of this intrusion. Similar bottom temperatures for different locations (as seen in vertical profiles of stations B, C, and D on Fig.3d) possibly identify the same water mass. An along-shelf upwelling is assumed to be a source of this water intrusion.

Station B (Fig.3a) was performed at 51m depth two days later than station A. It represents similar characteristics of the near-bottom layer, with a little less intensity. Shallow time-series station C (30 m depth) shows very homogeneous profiles from surface to bottom while the station D done at 88 m reveals a more sophisticated, stair-like structure for the temperature profile (Fig.3c).

The persistence of these gradients for more than two days, and the pronounced direction and intensity of intrusion prove the stable character of this phenomenon. The geographical location of described stations gives some indication of the horizontal scales of near-bottom intrusion. Data from this survey show the presence of a near-bottom water mass forming at about 40 m depth in the areas open to the shelf break.

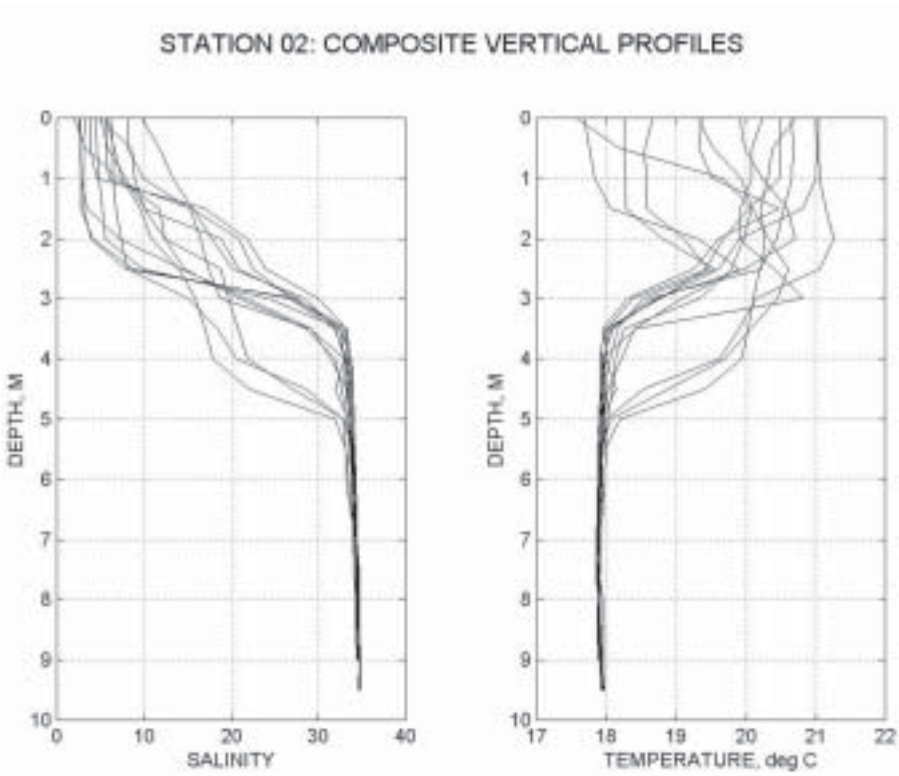
Time-series stations located in passes between the barrier islands provide some interesting material for studying the temperature and salinity vertical structure. The February 1999 survey reveals different types of diurnal variability in the vertical structure of both the salinity and temperature fields.

Station 02 (Fig. 4a) is located south of Mobile Bay, in the area of extensive fresh water outflow from Mobile Bay into the Gulf of Mexico. All temperature and salinity profiles at this station (Fig. 4b) show the existence of two distinct layers: lower (5–10 m) vertically homogeneous layer with no changes in time and upper layer (0-5m) highly variable both in time and in depth. Salinity changes from 2 to 10 ppt at the surface, and, starting from 5 m, gradually increases with depth up to 35 ppt. Low surface values of salinity may be caused by intense fresh water transport from Mobile Bay. Temperature changes from 21 to 17.5° C at the surface, while the subsurface vertical gra-

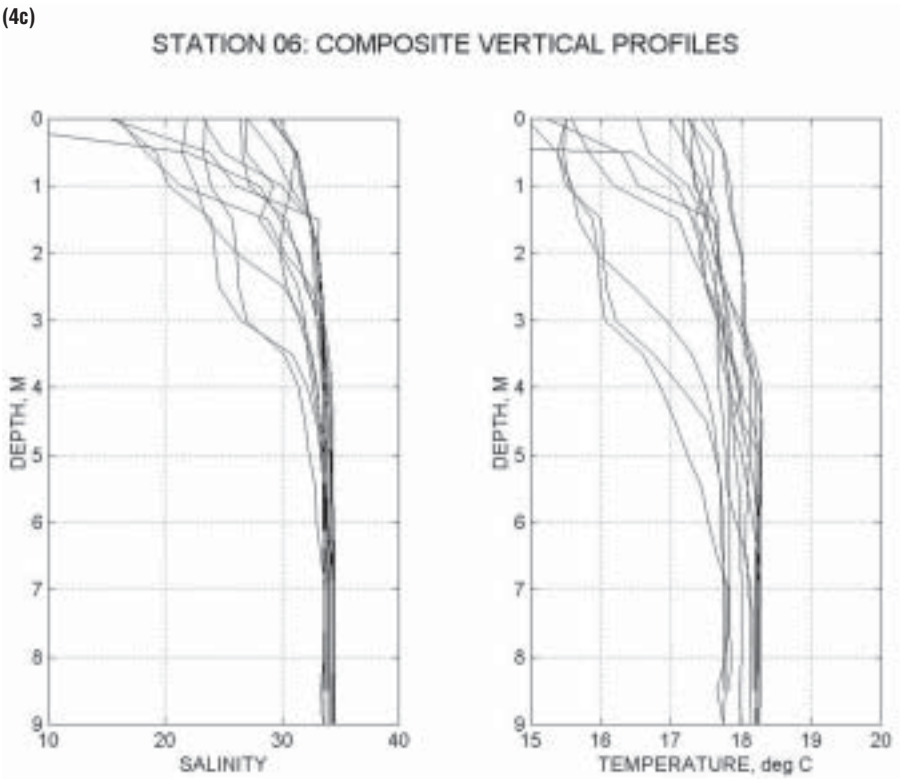
FIGURE 4

Time-series stations located near passes and straits, continued.

(4b)



(4c)



dient at 2–3 m remains almost unchanged. Subsurface temperature gradients are developed due to the tidal motion and diurnal warming/cooling of the upper layer. Fig.4e represents diurnal changes in temperature and salinity at 1.0m, 3.0m and 9.0m depths.

Station 06 south of Horn Island Pass represents another type of diurnal variability. There is no strong evidence of subsurface temperature gradients (Fig. 4c); and subsurface vertical salinity gradients are not as strong as at the previous location. This difference can be explained by smaller transport out from the Mississippi Sound through this pass. Fig.4f shows diurnal changes of temperature and salinity at 1.0 m, 3.0 m and 9.0 m depths.

Time-series station 14 located south of Cat Island Pass shows very small changes in both salinity and temperature within 25 hours (Fig. 4d) and it could be considered almost homogeneous in the vertical. Diurnal variations of temperature and salinity at 1.0 m, 3.0 m and 7.0 m depths are shown on Fig.4g.

Discussion

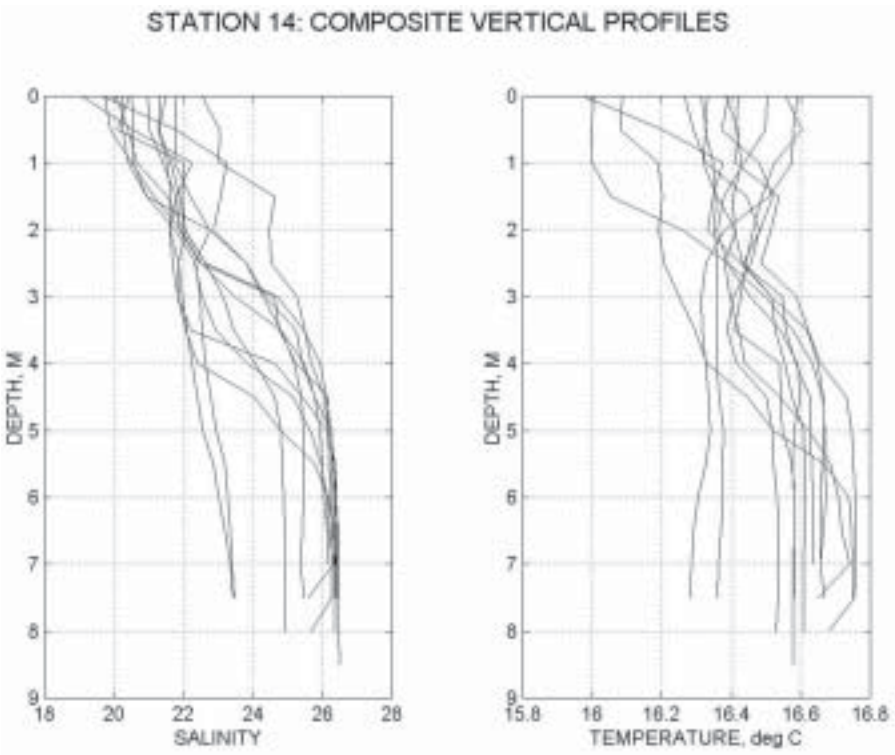
The NGLI CTD database appears to be useful for a preliminary study of the climatology of the Mississippi Sound. The comparison of surveys performed over one year from February of 1999 to January-February of 2000 provides some material for studying seasonal variability of temperature and salinity fields in the area. The comparison of February 1999 and January/February 2000 surveys have demonstrated a possibility of strong interannual variability. The results of the analysis are important for assessing the skill of hydrodynamic operational models of the region (Vinogradova et al., 2004).

High diurnal variability has been disclosed, based on the analysis of time-series stations. For the coastal waters, stratification can change dramatically within a day in some areas. In once vertically homogeneous waters, high subsurface vertical salinity gradients can develop within a few hours and can also vanish within a short time due to tidal advection through passes between the barrier islands.

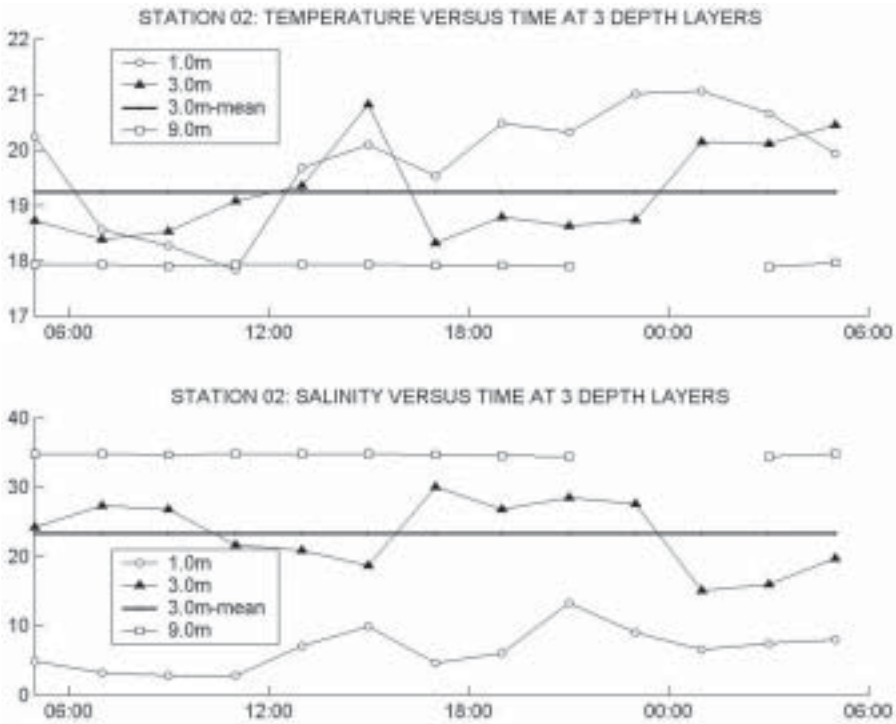
FIGURE 4

Time-series stations located near passes and straits, continued.

(4d)



(4e)



Special diagrams have been suggested helpful in estimating the spatial variability.

The late fall offshore stations located in the vicinity of the shelf edge reveal stable near-bottom vertical gradients in temperature caused by some intensive intrusion of a colder water mass. We hypothesize that along-shelf upwelling causes this intrusion although additional data and further analysis are needed to validate this assumption.

Acknowledgements

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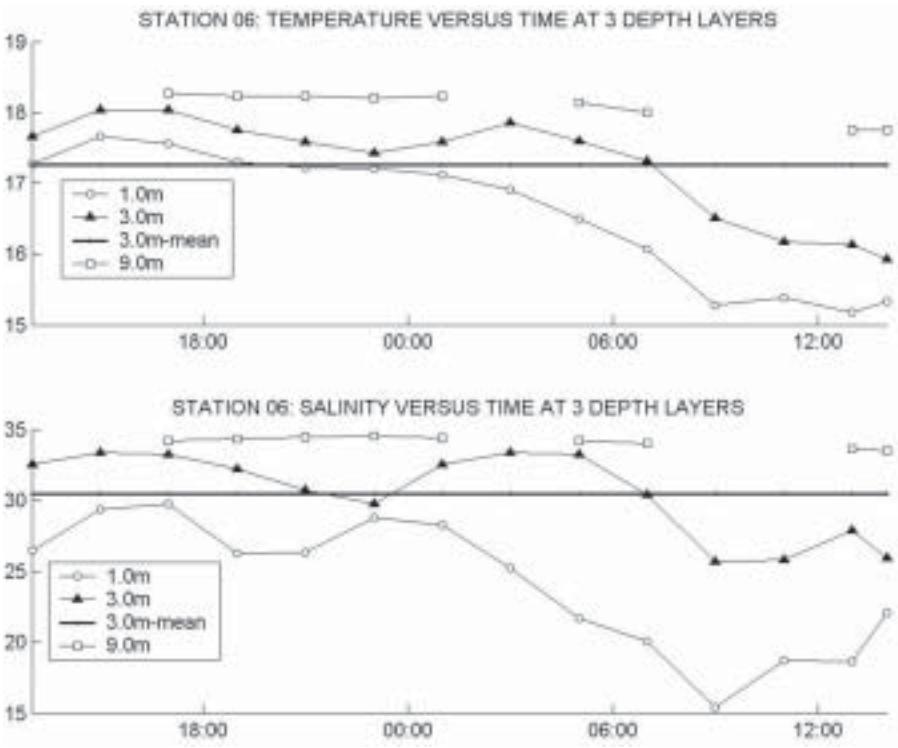
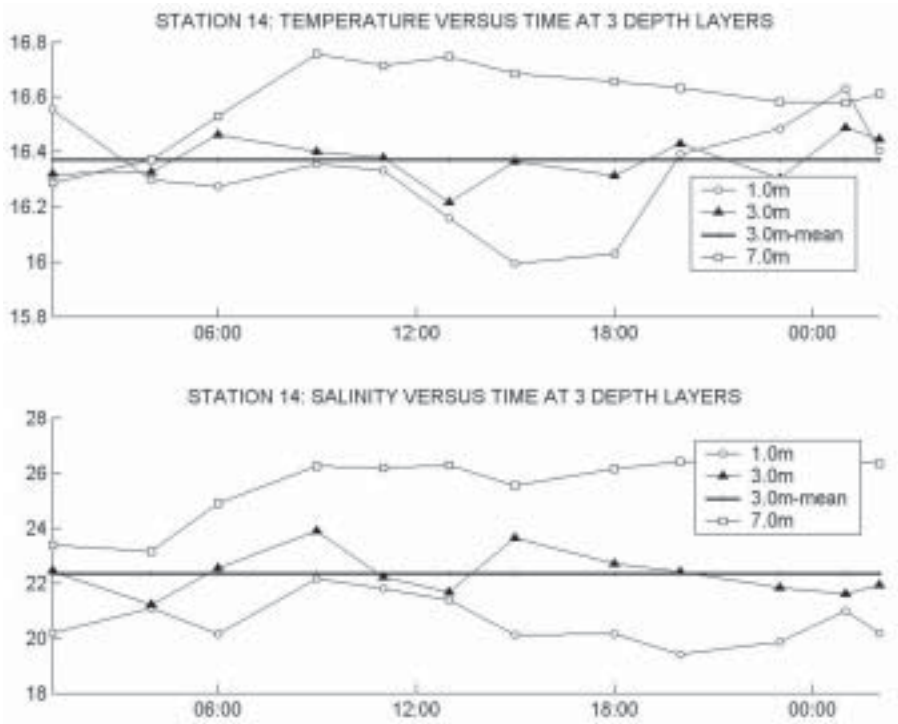
FIGURE 4

Time-series stations located near passes and straits, continued.

(4f)



(4g)



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