

- Final Report -

**Analysis of physical mixing process between estuaries
and the Gulf of Mexico at the Aransas Pass tidal inlet,
TX**

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Abstract: To quantify the mixing processes between South Texas bays and the Gulf of Mexico at the Aransas Pass tidal inlet at Port Aransas, TX, a mixing model for two end-members based on water temperature and salinity is developed. The mixing ratios of individual end-members at the Aransas Pass inlet are analyzed for the period between September 2007 and December 2008. The two mixing end-members are represented as low salinity waters (LS; i.e. San Antonio Bay waters) and high salinity waters (HS; i.e. combination of offshore Gulf of Mexico and Laguna Madre waters). The observed temperature and salinity can be represented by the sum of individual mixing end-member characteristics and the estimated mixing ratios. The observation data at the University of Texas Marine Science Institute (UTMSI) pier at the Aransas Pass inlet and data from nearby coastal ocean observation platforms and historic observations are utilized in the data analysis. In both 2007 and 2008, the HS contribution is more dominant at the Aransas Pass inlet (mixing ratio of 60-80 %). It indicates that influences of the higher salinity components from the Gulf of Mexico and/or Laguna Madre are more significant in water exchange than that of the lower salinity component from San Antonio Bay at this location. The high frequency variability of mixing ratios suggests that the LS contribution may increase by as much as 20% during certain periods of the year. During cold events associated with northerly winds occurred in 23-31 October and 22-27 November of 2007, water properties changed rapidly at the Aransas Pass inlet, and the LS contribution increased up to 50-60 %. This change pattern appears to be related to the strength of northerly winds. The present analysis cannot distinguish contribution from the Gulf of Mexico from that of the Laguna Madre, unfortunately, due to lack of temperature difference between the two end-members. Thus, it is not clear with the present data which of two high-salinity end-members, is more responsible to the water composition at the study area.

Key words: Aransas Pass tidal inlet, mixing ratio, end-member

1. Introduction

Estuarine systems act as a transition zone between rivers and wetlands and coastal oceans, and they are important nursery and feeding grounds for a number of marine species. The chemical and biological processes in the estuarine system largely depend on the degree of physical mixing processes of exchanging seawater and freshwater (Dyer, 1991). Therefore, the study on physical mixing process is the first step to understand complex interactions in the estuarine environment. The Aransas Pass tidal inlet, a dredged navigational channel (400-500 m wide), plays a major role in exchanging waters and materials between the Gulf of Mexico (seawater) and the bays and estuaries of the coastal South Texas (freshwater) (Ward et al., 1982; Min, 2008). High salinity waters mainly come from offshore Gulf of Mexico and Laguna Madre, and they frequently form hyper-saline condition (> 36 psu) in the bays during summer. On the other hand, there are several rivers providing freshwater into the study area: San Antonio, Mission, Aransas, Nueces, and Guadalupe Rivers. The freshwater river discharges vary substantially with time at all rivers in daily to annual time scales resulting in large variability of salinity in the bays (U.S. Geological Survey). The study region is one of highly dynamic regions with an environmental extremes due to large salinity variation in various time scales (see Fig. 1 for multi-year salinity variability observed at Ingleside in Corpus Christi Bay, Orlando et al., 1993). The Aransas Pass inlet is also an important pathway to nursery regions and feeding grounds for larval fishes (Brown et al., 2004; Brown et al., 2005).

Solis and Powell (1999) report that bulk mixing efficiency $\left(e = \frac{V_{fr}}{V_t} \cdot \frac{s/\sigma}{1 - s/\sigma} \right)$ in the study area (see Fig. 2 for the larger study area), which is defined as the ratio between freshwater inflow volume (V_{fr}) and tidal prism volume (V_t) that is available for mixing

with estuarine water, normalized by the salinity ratio between mixed estuarine outflow water (S) and incoming seawater of tidal prism (σ). The e value is less than ca. 0.15 in Aransas, Corpus Christi, and Baffin Bays, indicating relatively small contribution of inflowing freshwater. They also estimate long residence times (> 350 days) for Corpus Christi and Aransas Bays. However, their study focuses on comparison of the general physical mixing conditions among the Gulf of Mexico estuaries. Considering time-scales of variation in physical and biogeochemical properties in estuarine system, time-series analysis including quantitative mixing ratios among different water masses would be greatly beneficial to understand complex mixing process. Although the Aransas Pass tidal inlet presents at a physically and ecologically important location connecting the inner bays and the offshore Gulf of Mexico ([EPA, 1999](#)), such an extensive analysis has not been conducted at this area yet. Thus, I apply a two end-member (freshwater vs. seawater) mixing model at the Aransas Pass tidal inlet to analyze the mixing processes and quantify the mixing ratios among the individual water mass end members between South Texas bays and the Gulf of Mexico. The end-member characteristics for mixing processes are defined by their temperature and salinity on T-S diagram. Number of existing time-series data in the study region are used for the analysis. I hypothesize that the physical compositions of waters observed at the Aransas Pass tidal inlet can be quantitatively explained by the sum of several end-member characteristics at any given time, namely LS and HS. The main goals of this study are i) to investigate the variability of physical properties such as water temperature, salinity, winds, and currents at the Aransas Pass tidal inlet observation site (i.e. UTMSI pier or Aransas Pass ship channel) from September 2007 to December 2008, ii) to quantify the high-resolution variability of

end-member mixing ratios at the Aransas Pass site, and iii) to get more insights on the effects of the cold events on water mixing processes. The report consists of the following sections: 1. Introduction, 2. Data and Method, 3. Results, 4. Discussions, and 5. Summary.

2. Data and Method

2.1 The data used

I have collected data from a variety of sources for the study area: Centralized Data Management Office (CDMO; <http://cdmo.baruch.sc.edu>), Texas Coastal Ocean Observation Network (TCOON; <http://lighthouse.tamucc.edu/TCOON/>), the University of Texas Marine Science Institute (UTMSI; <http://nearshore.utmsi.utexas.edu/>), and the Texas Water Development Board (TWDB, <http://midgewater.twdb.state.tx.us/datasondes/datasondes.html>). The water temperature and salinity data measured at the Mission-Aransas National Estuarine Research Reserve (MANERR) System-wide Monitoring Platforms are extracted from CDMO database for April 2007–December 2008 period. The platforms are at Mesquite Bay (MB: MANERR#1), Copano Bay East (CBE: MANERR#2), Copano Bay West (CBW: MANERR#3), Aransas Bay (AB: MANERR#4), and Aransas Pass ship channel (SC: MANERR#5). Water temperature and salinity data measured from San Antonio Bay (127: GBRA #1) and Upper Laguna Madre (LM 170: NPSBB, and LM 171: NPSBI, Jun - Dec 2008) are extracted from TCOON database for January–December 2008 period. Water temperature and salinity data for San Antonio Bay (SAB), Corpus Christi Bay (CCB), and Laguna Madre (LM 171, Sep 2007 - May 2008) waters are extracted from TWDB database for June 2007–December 2008 period. The UTMSI pier observation

data for air/water temperatures, current, and wind data for January 2007–December 2008 are also utilized. Although the Aransas Pass inlet salinity data is available from the UTMSI data, it is not used in the present study because the salinity data are offset to lower than actual values during the study period, based on separate data sonde comparison measurements (D.-H. Min, personal communication). The LONGSECS hydrographic data observed by R/V Longhorn (January 1994–March 1996) and several nearshore hydrographic data observed by Min (unpublished data; May, July, August, and October 2008) are used to characterize the offshore Gulf of Mexico water end-member (Off). The detailed information on the utilized data is summarized in [Table 1](#). Here, I apply the mixing model for two end-members to the Aransas Pass inlet (i.e. UTMSI pier or Aransas Pass Ship Channel; SC), where different water flows converge, to estimate the individual end-member mixing ratios. Other stations data (MB, CBE, CBW, AB, 127, 170, 171, CCB, Off, and LONGSECS) are used to determine the temperature and salinity characteristics of mixing end-members on T-S diagram. The period available for the SC data from CDMO is from Sep. 2007 to Dec. 2008, so I analyze the data for that period ([Table 1](#)). I use the UTMSI pier data to analyze current and wind patterns in comparison with the analyzed mixing ratios.

2.2 The mixing model for two end-members

Water temperature and salinity are usually known as conservative tracers that are not affected by biological process ([Tomczak, 1981](#)), so these two parameters are widely used to calculate mixing ratios among different water parcels. Based on number of available end-members with temperature and salinity information, we can set up an appropriate mixing model among linear, triangle, or quadrangle type. The triangle mixing model uses

the ratios of the relative distances among three apexes (end-members) in T-S diagram and observed data (Fig. 3a, Mamayev, 1975). A more complex mixing model for four end-members is introduced by Chen et al. (1995), but not shown here. It is a combination of two and three end-member mixing models. Here, I primarily use the two end-member mixing model. For example, if seawater (with temperature and salinity of T_1 & S_1) and freshwater (with T_2 & S_2) are involved in physical mixing within the Aransas Pass tidal inlet, observed temperature and salinity (T_{obs} & S_{obs}) can be expressed as the combination of end-member characteristics (i.e. T_i & S_i) and mixing ratios (f) with mass conservation as follows:

$$T_{obs} = \sum_{i=1}^2 f_i \cdot T_i \text{ ---- (1)}$$

$$S_{obs} = \sum_{i=1}^2 f_i \cdot S_i \text{ ---- (2)}$$

$$\sum_{i=1}^2 f_i = 1 \text{ ---- (3)}$$

where, f_1 and f_2 are the mixing ratio of end-member 1 and end-member 2, respectively. Based on T-S diagram, individual mixing ratios among different end members at particular location can be estimated as mathematical expressions of various distance components shown in the Fig. 3b (Proudman, 1953). Thus, the mixing ratios for two end-members are given as:

$$dist1 = \sqrt{(S_1 - S_{obs})^2 + (T_1 - T_{obs})^2} \text{ ---- (4)}$$

$$dist2 = \sqrt{(S_2 - S_{obs})^2 + (T_2 - T_{obs})^2} \text{ ---- (5)}$$

$$f_1 = \frac{dist2}{dist1 + dist2} \text{ and } f_2 = \frac{dist1}{dist1 + dist2} \text{ ---- (6)}$$

where, dist1 (or 2) is the distance from observation to end-member 1 (or 2).

2.3 Determination of the temperature and salinity characteristics of end-members

T-S diagram can not only be used to represent the mixing process among water masses, but also to determine the characteristics of end-members ([Mamayev, 1975](#); [Tomczak, 1981](#)). I plot SC temperature and salinity data of CDMO on T-S diagram for the study period of Sep. 2007 - Dec. 2008 ([Fig. 4](#)). The salinity and temperature vary widely from 13 to 43 psu and 10 to 30 °C, respectively, during this period. The variability of temperature can be explained by the seasonal change (also see [Figs. 9a and 10a](#)), but that of salinity appears to be controlled mainly by tidal mixing between the low and high salinity waters ([Solis and Powell, 1999](#)). To find the source waters to represent low and high salinity waters, all the available data obtained from adjacent regions connecting with the Aransas Pass inlet are plotted together in the T-S diagram for 2007 and 2008 ([Fig. 5](#)). Low salinity waters originate in the San Antonio Bay (SA), and high salinity waters originate in Laguna Madre (LM) and/or offshore Gulf of Mexico waters (Off). This T-S pattern is well accordant with that of [Min \(2008\)](#), who reports that the physical mixing at the Aransas Pass inlet is composed by three end-members in summer 2008 – fresher San Antonio and Copano Bays waters, saline Laguna Madre and Corpus Christi Bay waters, and offshore Gulf of Mexico waters. In general, the triangle model is applied to the case of mixing by three end-members to quantify their mixing ratios ([Mamayev, 1975](#)). However, temperature is not distinguishable among the source waters over different seasons in this study area, so we cannot use the triangle model in this case. Although the Laguna Madre waters and the offshore Gulf of Mexico waters are both likely responsible for the high salinity component at the Aransas Pass inlet, I cannot distinguish the offshore

vs. the Laguna Madre water with the presently available data because temperature distributions between the two sources are indistinguishable in general. Therefore, I use the two end-member mixing model instead, to estimate their mixing ratios at the Aransas Pass inlet with some assumptions; i) the San Antonio Bay waters represent the low salinity waters (LS), ii) combination of the offshore Gulf and Laguna Madre waters represent the high salinity waters (HS), and iii) the salinity characteristics of end-members are valid for a month of time scale because the salinity is conservative (Fig. 6a). Because temperature is not conservative in the study region, its daily characteristics are determined by a least square curve fitting (Fig. 6b and Appendix A1). The offshore data are available only during May, July, August, and October 2008 for the study period (Table 1). Thus, I add the past LONGSECS hydrographic data observed between Jan. 1994 and Mar. 1996 off Port Aransas in the Gulf of Mexico to estimate the general salinity characteristic of offshore Gulf of Mexico waters (Fig. 7). It appears that most of the offshore salinity data below the shallow surface layer converge to $S \sim 36$ psu regardless of seasonal variation. Thus, 36 psu is regarded as the general salinity characteristic of the offshore Gulf waters for the months the offshore observations were not performed during the study period. The salinity characteristics of the two end-members for each month during the study period are summarized in Table 2 and shown in Fig. 8. The detailed methods to define the characteristics of end-members and to calculate their mixing ratios are described in Appendix A1-A2 written in MATLAB™ program.

3. Results

3.1 Variation in physical properties at the Aransas Pass inlet

3.1.1 Sep.-Dec. 2007 period

As shown in [Fig. 9a](#), water temperature is relatively constant at 30°C during September at the Aransas Pass inlet. Since October, temperature gradually decreases with time and temperature reaches about 15-20°C in December. The salinity fluctuates centered at about 30 psu during September to December, with the short-term daily salinity fluctuation with magnitude of 0.3-20 psu due to tidal cycle ([see \$\Delta S\$ in Fig. 9a](#)). The raw current and wind data at time 2-min interval are used in the figure (red). The 6-hour interval data are overlaid with blue sticks in the same figure. As shown in [Fig. 9b](#), the northerly and southerly winds repeatedly alternate during September and October, and the northerly winds are stronger and more dominant during November and December. The average wind speed is 5.3 m/sec with the instant maximum speed of 19.6 m/sec. The currents alternate the northwest and southeast directions during this period mainly due to the Northwest-Southeast alignment of the Aransas Pass inlet. The speed of currents increase as wind speed increases during November-December period. The average current speed is 0.36 m/sec with the maximum speed of 3.3 m/sec. It appears that wind forcing plays a significant role in current speed changes and therefore mixing at the Aransas Pass tidal inlet ([Ward et al., 1982; Brown et al., 2004](#)).

3.1.2 Jan.-Dec. 2008 period

The changes of water temperature with time show a typical feature of seasonal change ([Fig. 10a](#)). Water temperature gradually increases during the spring, it reaches to the maximum during the summer, and then it decreases with the beginning of the fall toward

the minimum in the winter. Due to the shallow depths, water temperature is largely influenced by the seasonal change. Between January and March, the salinity fluctuates at around 30 psu, and it rapidly decreases to 20 psu in April. Since mid-April, salinity continuously increases toward the summer (June–August), when the Aransas Pass inlet maintains the hyper-saline condition with salinity of ca. 35–40 psu with maximum salinity at 43.5 psu. Daily tidal variation of salinity is less than 10 psu, and even lower during the fall period in 2008. The southerly winds are dominant throughout the year in 2008 except for fall and winter times (see blue lines of [Figs. 10b and 11b](#)). The northerly and southerly winds alternate during winter (January to March) and fall (September to December) with stronger speed of the northerly winds. Following the tidal cycle, the currents during 2008 maintains the average speed of 0.42 m/sec with the max speed of 3.4 m/sec ([Fig. 10c](#)). I compare the 2007 and 2008 results during the same months from September to December. The high-salinity condition (>35 psu) exists till mid-September in 2008 ([Fig. 11a](#)), whereas the salinity in 2007 does not show such condition during a same month period ([Fig. 9a](#)). This is likely due to the impacts of extended drought in 2008 and aftermath of severe flood in 2007 summer. The temperature patterns in 2007 and 2008 are quite similar in the range of 15 to 30 °C ([Figs. 9a and 11a](#)). The daily salinity variability is more dramatically decreasing in the 2007 period, whereas the daily salinity variability is insignificant during the same month period in 2008, indicating more enhanced LS water contribution in 2007. As seen in [Figs. 9b and 11b](#), the northerly winds are generally dominant during November and December in both 2007 and 2008. The currents alternate between two major directions along the tidal inlet axes following the tidal cycle. However, the feature of current speeds in 2008 is different from the 2007

result (Figs. 9c and 11c). High speeds are maintained during November and December in 2007, corresponding to high wind speeds. On the other hand, low current speeds appear during November and December in 2008, despite high wind speeds. Thus, the current system at the Aransas Pass inlet is not simple. Overall, temperature and wind patterns are similar in both years. Salinity is much higher in 2008 than in 2007.

3.2 Variation of mixing ratios of end-members at the Aransas Pass inlet

3.2.1 Sep.-Dec. 2007 period

The mixing ratio of low salinity waters (LS) fluctuates between 20 and 40% with large short-term variance during September to October, and the high salinity waters (HS) cover mixing ratio of approximately 60-80% at the Aransas Pass inlet (Fig. 12). After late October when the LS mixing ratio (~50%) reaches its peak briefly, the LS mixing ratios decrease during first half of November. The LS mixing ratios then increase during late November with three peaks of high mixing ratio (~50%) in 27 November, 4 December, and 17 December. The HS maintains high mixing ratio greater than 80% in general during November and December. In summary, the HS is dominant at the Aransas Pass inlet and its contribution is estimated at 60-80%. On the other hand, the contribution of LS is with 20-40% of the mixing ratio. The HS predominantly occupies water composition in the Aransas Pass inlet in fall/winter 2007 with quite dynamic short-term variation.

3.2.2 Jan.-Dec. 2008 period

The mixing ratios of LS vary between 20 and 40% during January through March in 2008 (Fig. 13a), and HS mixing ratio stays high at ~80% with significant daily variability similar to that of 2007. During April, the mixing ratio of LS dramatically increases to ~

50%. At the same time, the HS mixing ratio rapidly decreases. After this peak, the LS mixing ratio gradually decreases by the end of June, whereas the HS mixing ratio steadily increases. During the summer (July and August), water properties at the Aransas Pass inlet are predominantly governed by HS, and its contribution is greater than 80%, sometimes reaching nearly 100% although briefly. On the other hand, the contribution of LS stays below 20% (Fig. 13b). The mixing ratio of LS begins to increase rapidly in September and stays at the peak of mixing ratio of ~50% during October. Since then, the contribution of LS gradually decreases to ~20% by the end of the year. Overall, the HS is dominant at the Aransas Pass inlet during 2008, and its contribution is estimated to 70-80%. On the other hand, contribution of LS is 20-30% at the same time, except for April and October (~50%). This seems to be related to the changes in wind patterns, i.e. from northerly to southerly during April-May and from southerly to northerly during September-October (Figs. 10b and 11b). The results indicate that the waters being exchanged at the Aransas Pass inlet are largely determined by the HS (Off+LM) component.

3.3 Validation of mixing ratios with the estimated temperature and salinity

To examine the validity of the estimated mixing ratios, I use the approach which calculates the correlation coefficient between the observed temperature (or salinity) and the estimated temperature (or salinity) based on the end-member characteristics and their mixing ratios. Mathematically, the estimated temperature (T_{est}) and salinity (S_{est}) are expressed as:

$$T_{est} = \sum_{i=1}^2 f_i \cdot T_i^{EM} \text{ ---- (7)}$$

$$S_{est} = \sum_{i=1}^2 f_i \cdot S_i^{EM} \text{ ----- (8)}$$

where, T_i^{EM} and S_i^{EM} stand for temperature and salinity characteristics of end-member, respectively ([Appendix A1 and Table 2](#)), and f is its mixing ratio. If the estimated mixing ratio accurately reflects the real mixing processes in the study area, the estimated temperature and salinity would be highly correlated with the observed temperature and salinity with high correlation coefficient values. The correlation coefficients between the observed and estimated parameters during the study period are greater than 0.97 ([Fig. 14](#)). It supports that the mixing ratios estimated by the two end-member mixing model are reliable, although the current mixing model is not perfect due to the lack of temperature difference among end-members. The detailed procedure how to validate the estimated mixing ratios with the MATLAB program is described in [Appendix A3](#).

4. Discussions

4.1 The cold events in October and November 2007

[Min and Amos \(2008\)](#) report an influence of a cold event on water characteristics change at the Aransas Pass inlet during October 2007, based on vertical sonde profiling observation at the UTMSI pier. They found that freshwater transport increased during the cold norther event, and so salinity decreased during this event due to enhanced transport of freshwater in the bays to the north of Aransas Pass inlet. Although the salinity gradient along the Gulf-wide estuarine system has been studied ([Orlando et al., 1993](#)), impact of fall/winter wind events accompanied by abrupt temperature drop are not well studied despite its potentially important impact on local ecosystem. I use a T-S diagram and time-series analysis of the physical properties observed at the Aransas Pass inlet to better

understand the influence of the cold event (Fig. 15). As shown in the T-S diagram (Fig. 15a), the distribution of temperature is bimodal with two patches at each month during this period: colder vs. warmer groups. The air temperature drops suddenly by as much as 6-9°C in 23-25 October and 22-27 November periods, water temperature follows the same pattern with lesser magnitude, and salinity decreases by as much as 10-15 psu within the same day (Fig. 15b). During these cold periods, northerly winds are dominant (Fig. 15c; note solid bars for the cold events). The currents alternate between the northwest and southeast directions during the cold periods, but the current speeds are much higher in 22-27 November than in 23-25 October (Fig. 15d) The HS contribution decreases to 40-50%, and LS contribution increases to 50-60% during the cold events (Fig. 15e). The cold events with the comparable magnitude did not happen during 2008, and the San Antonio Bay was saltier in 2008 (Fig. 8) It appears that the strong northerly winds can facilitate the transport of LS from the San Antonio Bay to the Aransas Pass inlet particularly during the ebb tidal cycle, otherwise its influence is checked at minimum in the area. Such abrupt change of physical properties, even for a short period of time, might cause big stress to the ecosystem of Mission-Aransas estuaries. We need to study more of the impact of the cold event on ecosystem.

4.2 Mixing ratio changes during the study period

As Solis and Powell (1999) indicate small relative contribution of inflowing freshwater in the local bays of the study area, this analysis also shows that the HS contribution is much higher than that of LS. This might be influenced by geographical location. The Aransas Pass inlet observation site is very close to the mouth of the Gulf of

Mexico, so it would likely be more exposed to the tidal prism of incoming Gulf of Mexico waters. However, as discussed in 4.1, local weather system can drive some episodic events suddenly that increase LS contribution greatly in the study area. In addition, I use a combination of offshore Gulf of Mexico (Off) and Laguna Madre (LM) waters as an end-member to represent the high salinity waters (HS). At this time, I cannot estimate individually quantitative contribution due to the lack of independent parameter (see discussion in 4.3). However, I speculate that the relative contribution between Off and LM is dependant of local weather condition. As shown in [Fig. 8](#), LM is much saltier in 2008 than 2007 during the same period. The 2008 is an extreme drought year, so the salinity characteristic is more influenced by LM than Off.

4.3 The limits of the analysis

The actual physical mixing in the Aransas Pass tidal inlet is likely driven mostly by three different end-members: the San Antonio Bay waters (SA), the Laguna Madre waters (LM), and the offshore Gulf of Mexico waters (Off). However, I use the two end-member mixing model to estimate the mixing ratio, i.e., LS (SA) and HS (Off+LM), at the Aransas Pass inlet because I cannot separate the LM and Off contributions independently on T-S diagram with the current dataset. The temperatures over different seasons are not distinguishable among the end-members as an independent parameter, which means that the temperature is similar throughout the study area at the same time period due to shallow water depths. Total alkalinity (TA) or oxygen isotope ($\delta^{18}\text{O}$) data can probably be a useful additional conservative parameter to supplement temperature ([Khim and Krantz, 1996](#), [Millero et al., 1998](#); [Zeebe and Wolf-Gladrow, 2001](#); [Kim and](#)

Lee, 2004). However, these parameters require discrete water sample collection and elaborate chemical analysis, so it is not practical to measure them continuously. Hydrographic surveys in the study area with observation of these two parameters can distinguish the LM vs. Off and provide a snapshot to figure out the actual mixing process at a particular time. Other potentially useful parameters for mixing analysis are dissolved oxygen and pH. They can be easily measured continuously along with temperature and salinity. However, these two parameters are largely dependent on temperature effect and biological activity, so they are not conservative to be able to separate the influence of LM vs. Off. The surface water data are mostly used in this analysis due to data availability, although the depth at the Aransas Pass inlet is greater than 15m (Table 1). The present analysis assumes the results represent the water column process of the Aransas Pass inlet. If we measured physical and biogeochemical properties at the bottom of the channel as well, we might have been able to represent more general mixing process at the Aransas Pass inlet. A big challenge still remains on how to distinguish the influence of Off vs. LM. Additional conservative parameters besides temperature and salinity should be routinely measured in the study area, so we can more accurately estimate the physical mixing processes among different end members at the Aransas Pass inlet in the future.

5. Summary

The Aransas Pass tidal inlet plays a major role in exchanging waters and materials between the Gulf of Mexico and the bays and estuaries of the coastal South Texas. Considering time-scales of physical or biogeochemical property variability in estuarine system, time-series analysis is useful to understand complex mixing process. Through this study, I i) investigate the variability of physical properties such as temperature,

salinity, currents, and winds at the Aransas Pass tidal inlet observation site (i.e. UTMSI pier or Aransas Pass Ship Channel) from September 2007 to December 2008, ii) quantify end-member mixing ratios of waters at the Aransas Pass site in high-frequency temporal resolution, and iii) get more insights on the effects of the cold events on water mixing processes. Overall, temperature and wind patterns are similar in 2007 and 2008, except for the cold events. Salinity is higher in 2008 than in 2007 due likely to the extended drought. A two end-member (i.e. freshwater vs. seawater) mixing model is developed and applied at the Aransas Pass tidal inlet. The end-members are represented by low salinity waters (LS; i.e. San Antonio Bay waters) and high salinity waters (HS; i.e. combination of offshore Gulf of Mexico and Laguna Madre waters). During 2007 and 2008, the HS influence is dominant, and its contribution is estimated at 60-80%. The LS contribution is low at 20-40% at the same period. The HS predominantly occupies water composition in the Aransas Pass tidal inlet, implying that the local ecosystem is more exposed to the physical and biogeochemical properties of HS near the Aransas Pass inlet area. The estimated mixing ratios are validated with the calculated correlation coefficient between the observed and estimated parameters. The correlation coefficients are greater than 0.97, supporting reliability of the estimated mixing ratios through the mixing model. The cold events associated with northerly winds occurred during fall of 2007 increased the LS contribution up to 50-60 %, which originates in the San Antonio Bay north of the Aransas Pass inlet. It suggests the importance of winds on water and property transport and mixing in the local bays and estuaries. In the present study, mixing processes between the low-salinity and high-salinity components are explained with the two end-member mixing model at the Aransas Pass tidal inlet. It is still a big challenge to develop a

method to distinguish the influence of offshore Gulf of Mexico waters vs. Laguna Madre waters. Additional conservative, and hopefully continuously measured, property data that can differentiate the influences of the Gulf of Mexico and Laguna Madre would greatly help in better quantifying the mixing processes in the study region.

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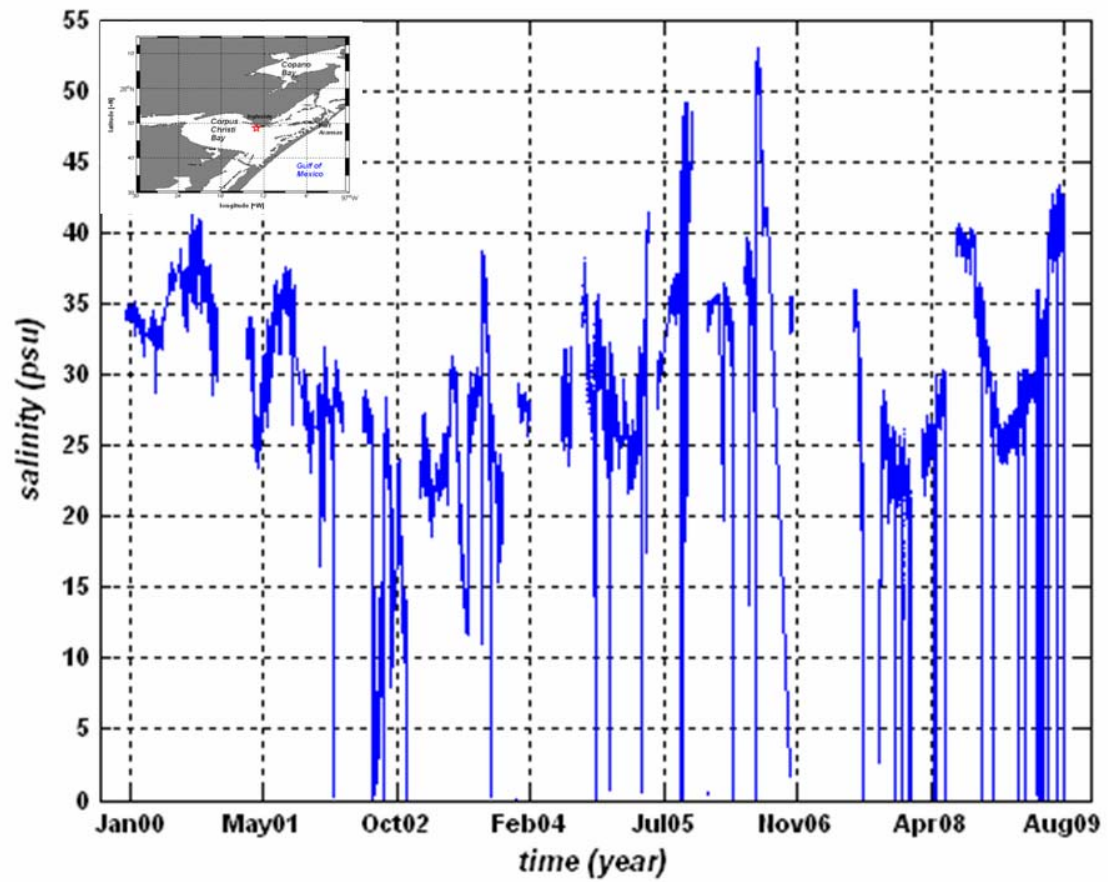


Fig. 1 Variation of salinity with time at Ingleside station (red pentagram) in Corpus Christi Bay (Jan. 2000 - Aug. 2009). Data source is from Texas Water Development Board (<http://midgewater.twdb.state.tx.us/>).

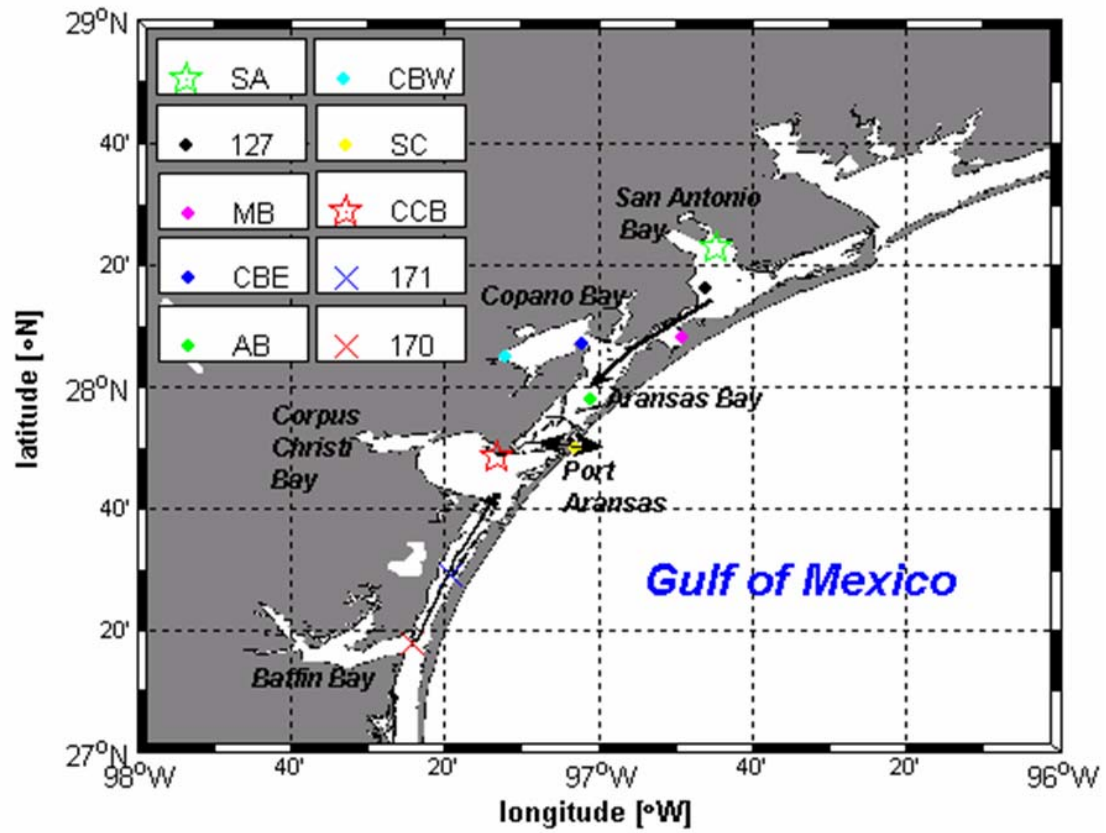


Fig. 2 The study area map (SA: San Antonio, CCB: Corpus Christi Bay, AB: Aransas Bay, CBW: Copano Bay West, SC: Ship Channel, CBE: Copano Bay East, MB: Mesquite Bay). The black arrows indicate schematic water flows, and the double arrow represents schematic water exchange through the Aransas Pass tidal inlet between the bays and the Gulf of Mexico.

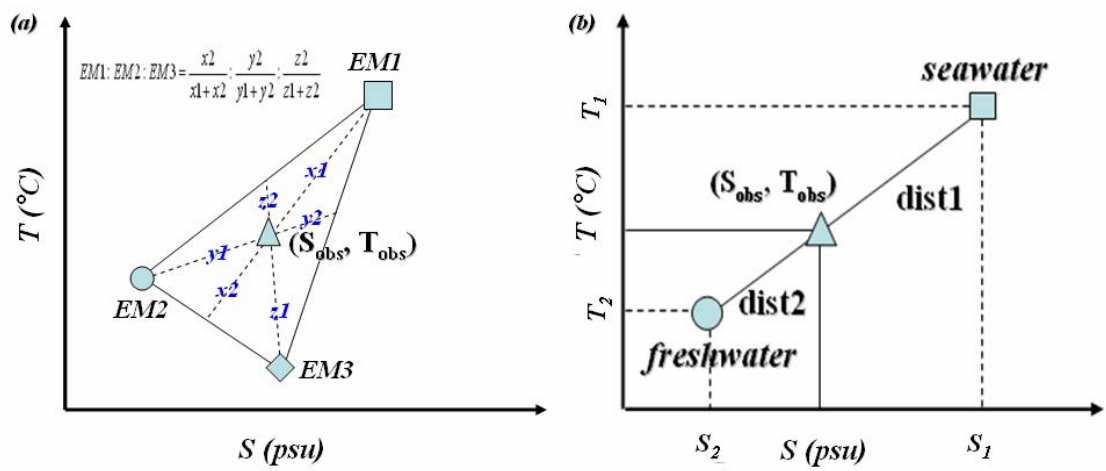


Fig. 3 Illustrations of the mixing process for (a) three and (b) two end-members (EM) on T-S diagram. The mixing ratios for the observed water parcel $(S_{\text{obs}}, T_{\text{obs}})$ are determined by the ratios of relative distances between end-members and observed data.

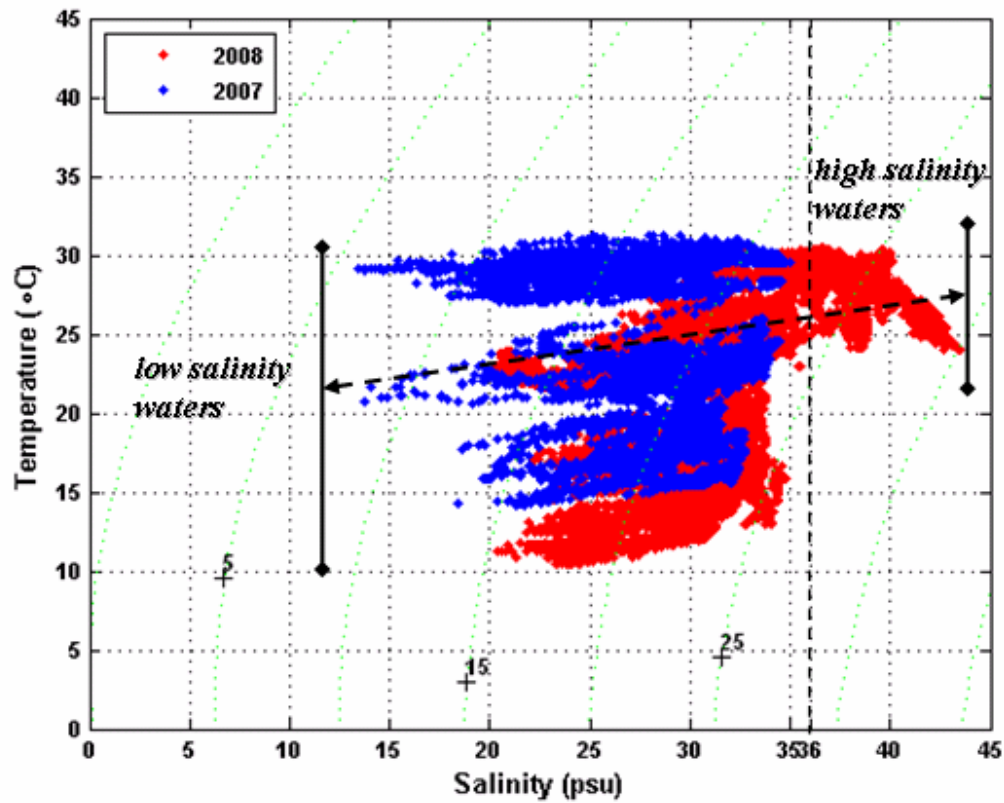


Fig. 4 T-S diagram at the Aransas Pass Ship Channel site (SC: MANERR#5) in 2007 (blue) and in 2008 (red). The two solid lines approximately represent low salinity and high salinity end-member waters, and a dashed arrow between the two solid lines is hypothetical mixing line. The salinity of 36 psu (dashed line) corresponds to the general salinity of Gulf of Mexico waters.

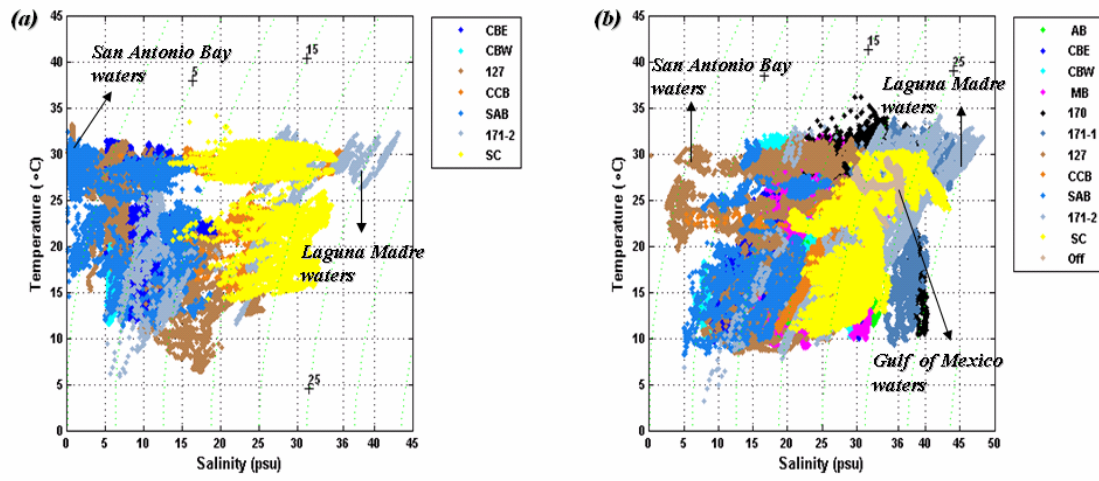


Fig. 5 T-S diagrams showing all data used in the current study (a) September-December 2007 and (b) January-December 2008 periods. Note that SC data represent temperature and salinity at the Aransas Pass inlet.

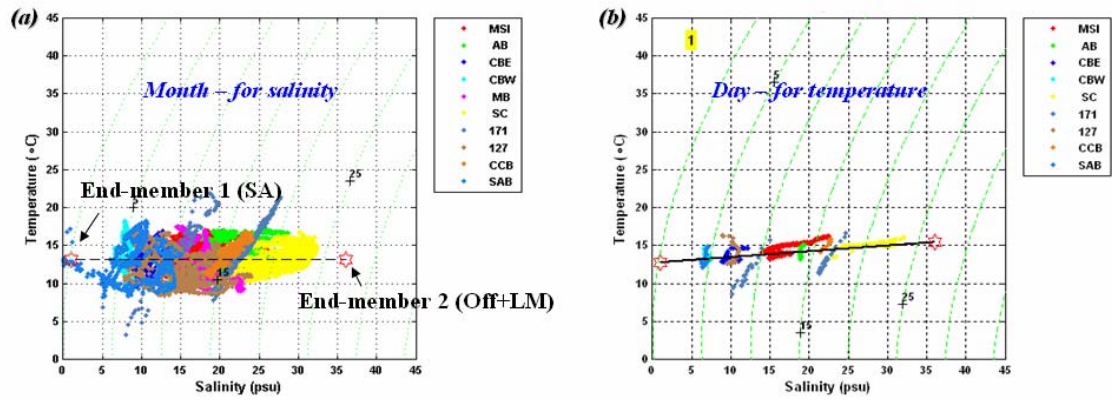


Fig. 6 An example of determination of the temperature and salinity characteristics of end-members with January 2008 data; (a) the monthly salinity characteristic of end-members, (b) the daily temperature characteristic determined by least square curve fitting.

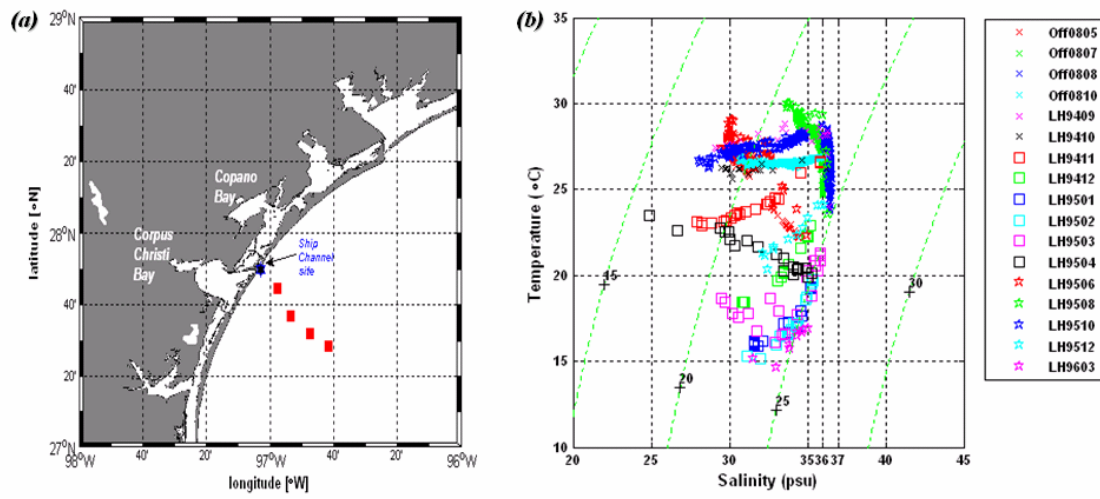


Fig. 7 The offshore data observed by R/V Longhorn between January 1994 and March 1996 (LH9409-LH9603) and by Min between May and October 2008 (Off0805-Off0810, unpublished data); (a) selected station map, (b) T-S diagram of the offshore data extracted from the nearshore stations.

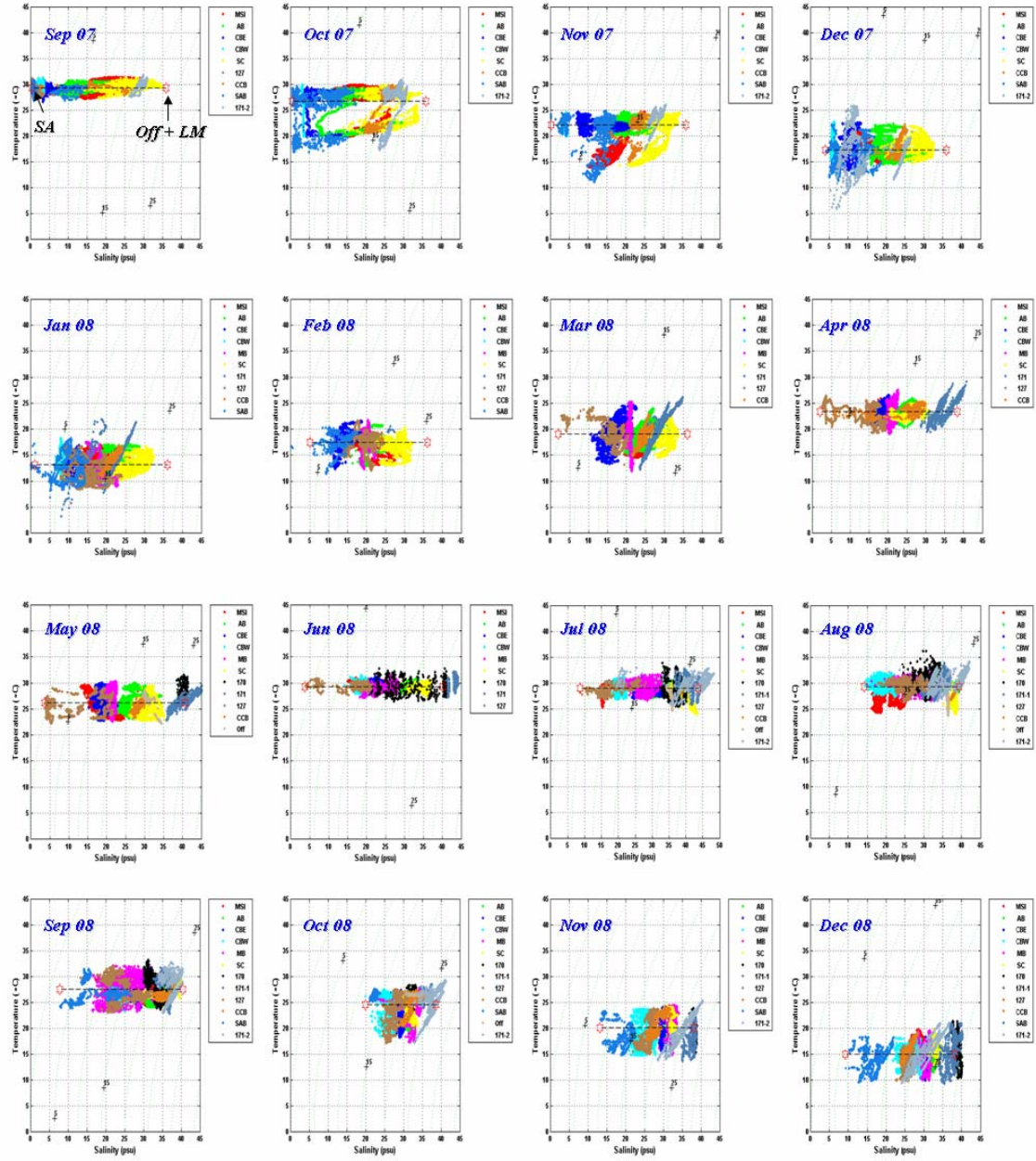


Fig. 8 The salinity characteristics of two end-members based on monthly temperature and salinity data from all available observations in the study area (Sep. 2007 - Dec. 2008). The dashed line with red hexagram indicates the monthly salinity characteristic.

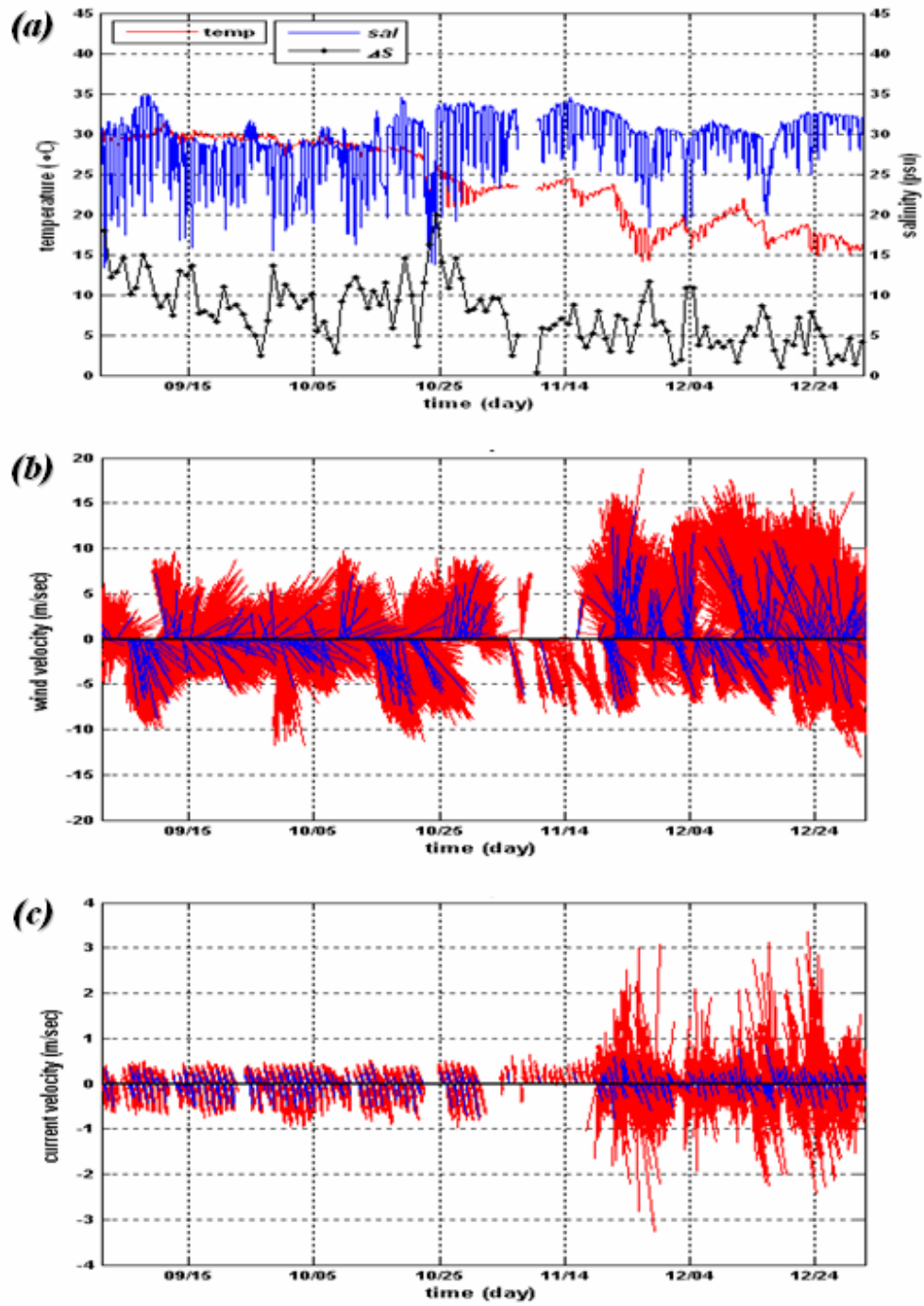


Fig. 9 The variations in physical properties at the Aransas Pass inlet during September through December 2007; (a) water temperature, salinity, and ΔS (daily max salinity – daily min salinity), (b) wind, and (c) current. The blue solid lines for winds and currents are at 6-hour intervals.

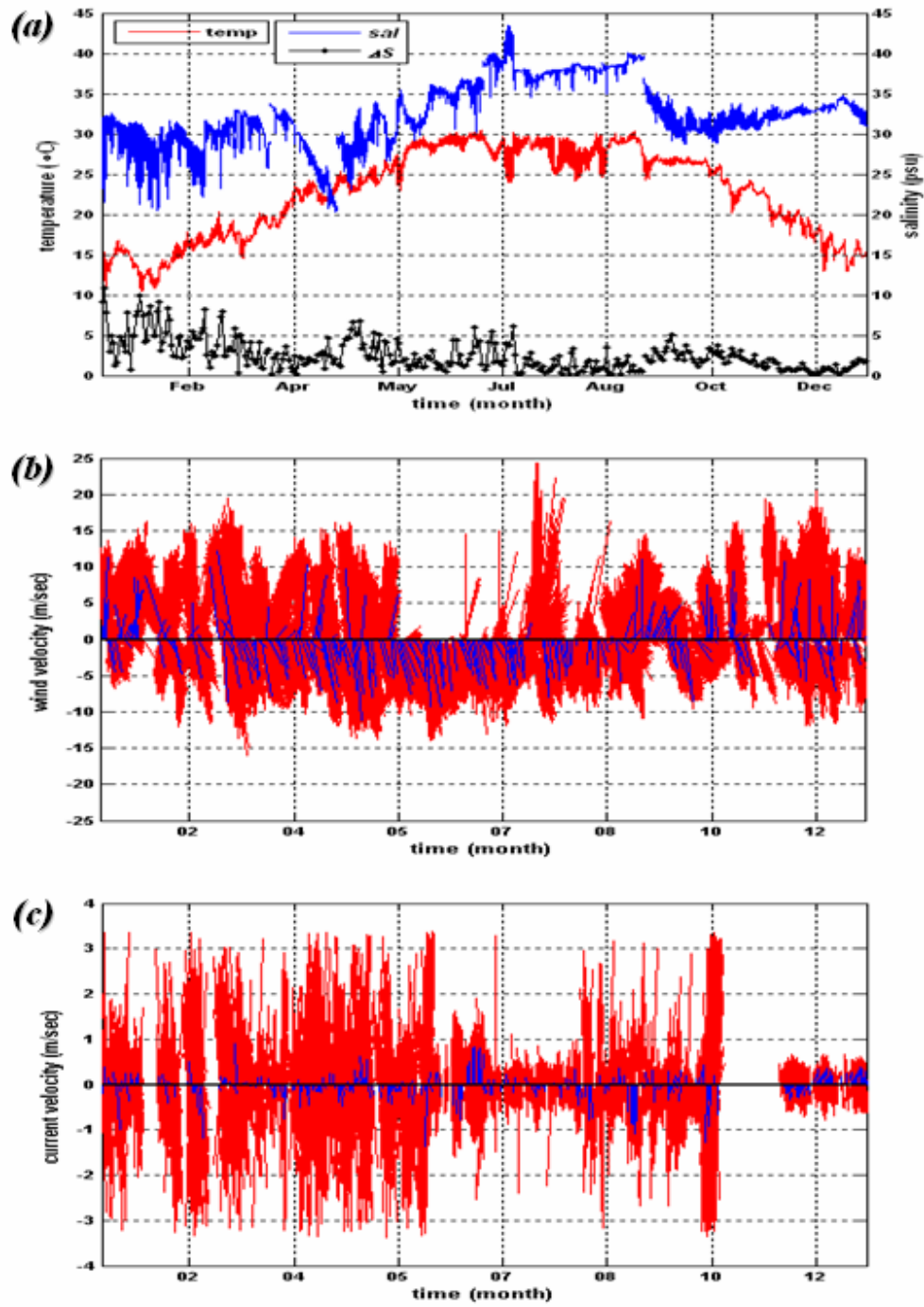


Fig. 10 The variations in physical properties at the Aransas Pass inlet during 2008; (a) water temperature, salinity, and ΔS (daily max salinity – daily min salinity), (b) wind, (c) current. The blue solid lines for winds and currents are at 24-hour intervals.

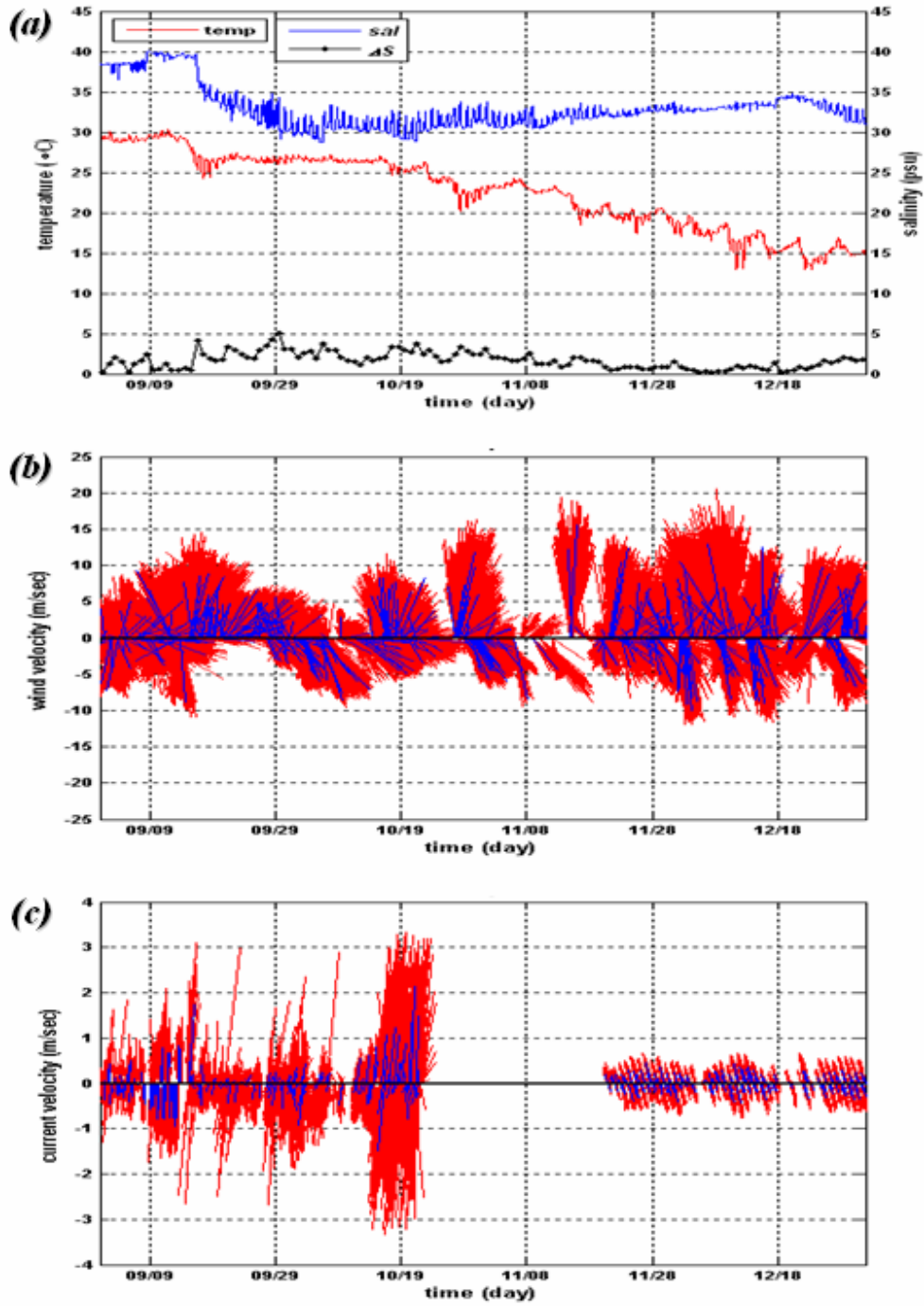


Fig. 11 The variations in physical properties at the Aransas Pass inlet September through December 2008; (a) water temperature, salinity, and ΔS (daily max salinity – daily min salinity), (b) wind, (c) current. The blue solid lines for winds and currents are at 6-hour intervals.

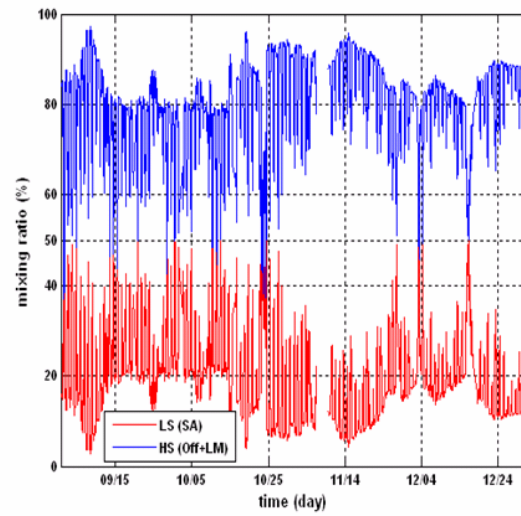


Fig. 12 The result of mixing ratios at the Aransas Pass inlet during September – December 2007.

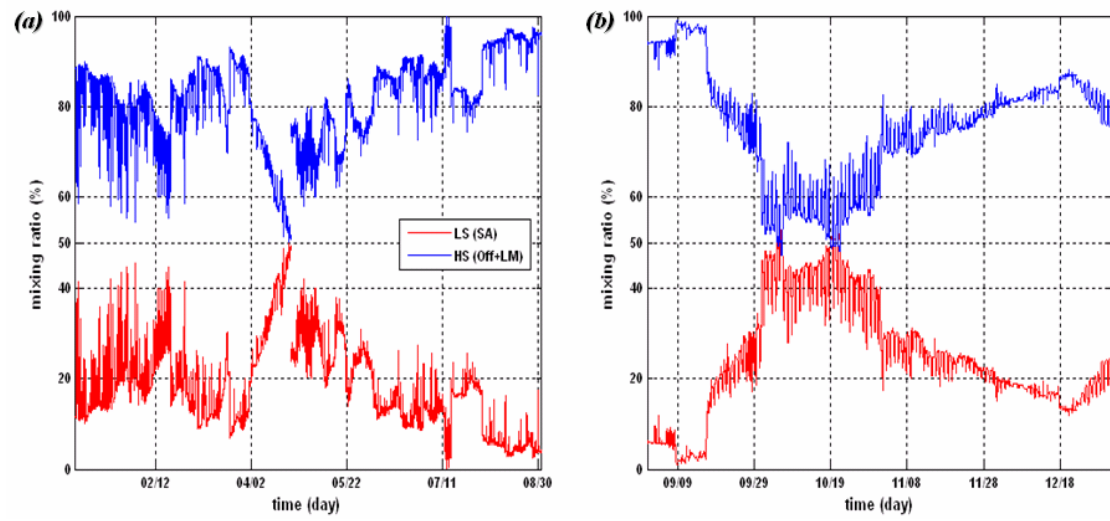


Fig. 13 The result of mixing ratios at the Arkansas Pass inlet during 2008; (a) January – August 2008, and (b) September – December 2008.

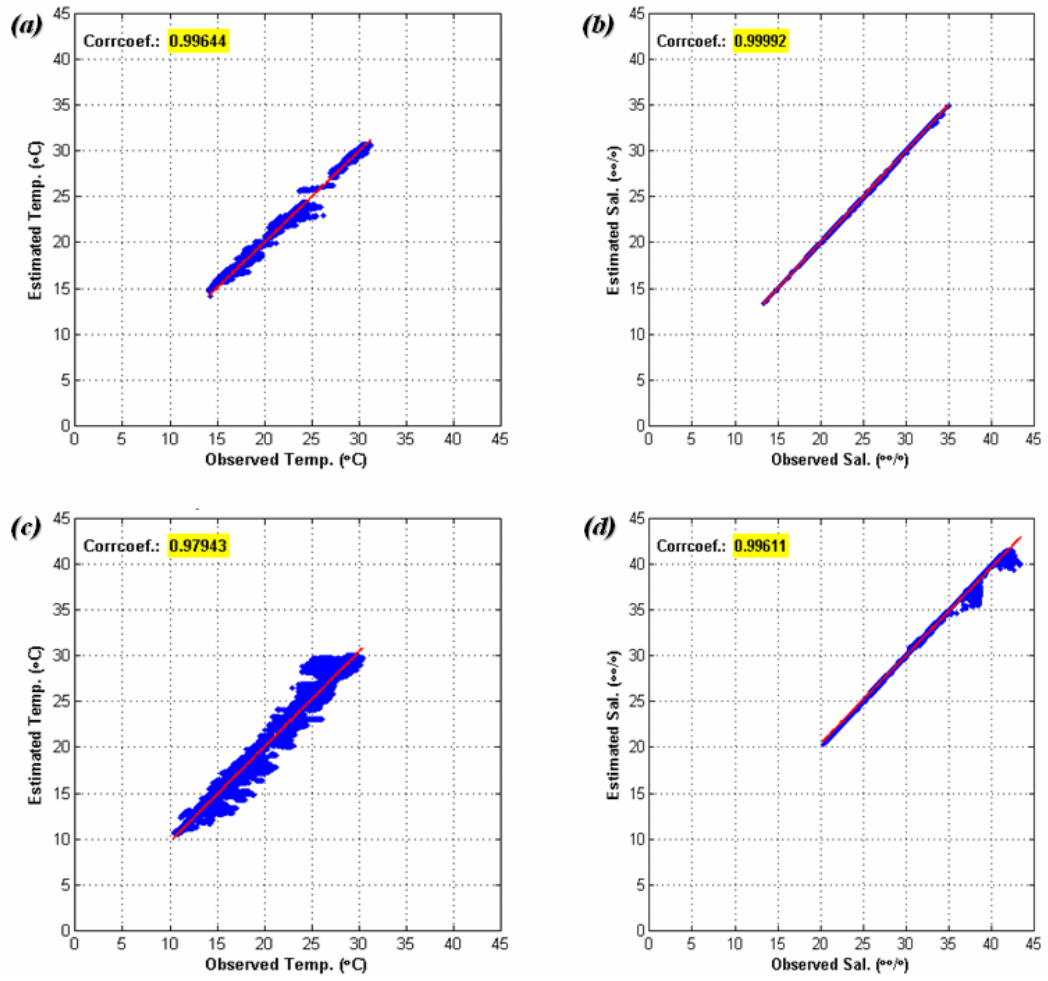


Fig. 14 The correlations between the observed and estimated temperature and salinity based on combination of the end-member characteristics and their mixing ratios; (a) observed T vs. estimated T during September through December 2007, (b) observed S vs. estimated S during September through December 2007, (c) observed T vs. estimated T during 2008, (d) observed S vs. estimated S during 2008.

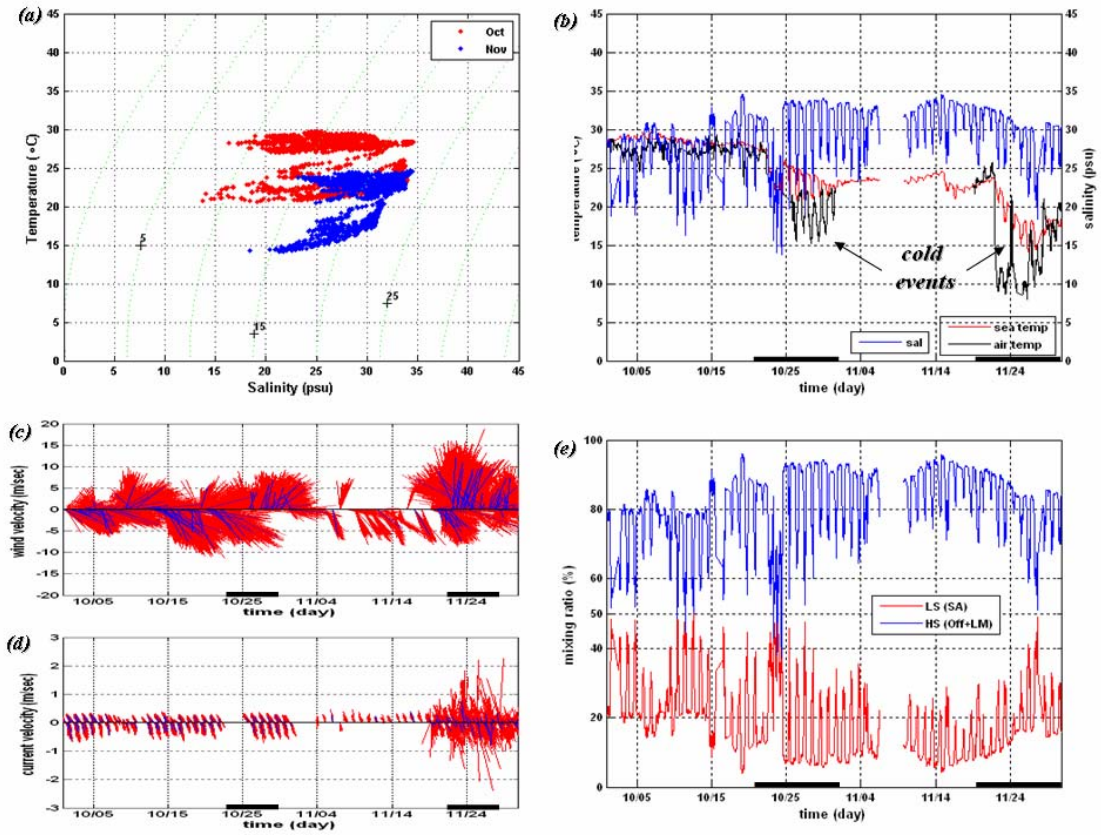


Fig. 15 Variability of the physical properties during the cold events in October and November 2007; (a) T-S diagram, (b) variation in air/sea temperatures and salinity, (c) in wind, (d) in current, (e) in mixing ratio. The black solid bars on x-axis indicate the cold events.

Table 1. Data used for this study for the 2007 and 2008 periods. The months with available data used in analysis are marked with symbols.

2007														Source	Used Properties	Measured depth (m)	Quality Control
St	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
LM 171														TCOON			
LM 170														TCOON			
SA 127	o	o	o	o	o	o	o	o	o					TCOON	wT, S	0 - 1.31	x
AB				o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 2.95	o
CBE				o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 2.55	o
CBW							o	o	o	o	o	o	o	CDMO	wT, S	0 - 1.84	o
MB														CDMO			
SC									o	o	o	o	o	CDMO	wT, S	0 - 6.06	o
Off														Dr. Min		full depth	
LM 171							*	*		*	*	*	*	TWDB	wT, S	0 - 0.6	x
CC							*	*		*	*	*	*	TWDB	wT, S	0 - 1.5	x
SAB							*	*		*	*	*	*	TWDB	wT, S	0 - 11.4	x
MSI pier	o	o	o	o	o	o	o	o	o	o	o	o	o	UTMSI	aT, wT, C, W	1.2 - 2.85	x
2008														Source	Used Properties	Measured depth (m)	Quality Control
St	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
LM 171						o	o	o	o	o	o	o	o	TCOON	wT, S	0 - 0.8	x
LM 170					o	o	o	o	o	o	o	o	o	TCOON	wT, S	0 - 0.83	x
SA 127	o	o	o	o	o	o	o	o	o	o	o	o	o	TCOON	wT, S	0 - 1.69	x
AB	o	o	o	o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 3.14	o
CBE	o	o	o	o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 2.71	o
CBW	o	o	o	o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 2.11	o
MB	o	o	o	o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 1.64	o
SC	o	o	o	o	o	o	o	o	o	o	o	o	o	CDMO	wT, S	0 - 6.47	o
Off					Δ		Δ	Δ		Δ				Dr. Min	wT, S	full depth	o
LM 171	*	*	*	*	*		*	*	*	*	*	*	*	TWDB	wT, S	0 - 1.03	x
CC	*	*	*	*	*		*	*	*	*	*	*	*	TWDB	wT, S	0 - 1.48	x
SAB	*	*								*	*	*	*	TWDB	wT, S	0 - 1.1	x
MSI pier	o	o	o	o	o	o	o	o	o	o	o	o	o	UTMSI			
R/V Longhorn														Source	Used Properties	Measured depth (m)	Quality Control
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec					
1994										v	v	v		LONGSECS	wT, S	full depth	x
1995	v	v	v	v		v		v		v		v		LONGSECS	wT, S	full depth	x
1996	v		v											LONGSECS	wT, S	full depth	x

wT: water temperature, S: salinity, aT: air temperature, C: current speed/direction, W: wind speed/direction

TCOON: Texas Coastal Ocean Observation Network (<http://lighthouse.tamucc.edu/TCOON/HomePage/>),

CDMO: Centralized Data Management Office of NERR (<http://cdmo.baruch.sc.edu/>),

UTMSI: The University of Texas at Austin Marine Science Institute (<http://nearshore.utmsi.utexas.edu/>),

TWDB: Texas Water Development Board (<http://midgewater.twdb.state.tx.us/>).

The LONGSECS and offshore data measured by R/V Longhorn and Min (unpublished data), respectively, are used for the offshore Gulf of Mexico waters.

Table 2. The salinity (psu) characteristics of end-members for each month during September 2007 – December 2008; LS denotes low salinity waters from San Antonio Bay, and HS stands for high salinity waters as combination of offshore Gulf of Mexico and Laguna Madre waters (Off+LM). Note that the temperature characteristics of end-members are not shown because they are determined by least square curve fitting (Appendix A1).

year	month	LS(SA)	HS(Off + LM)
2007	Sep	0.2	36
	Oct	0.4	36
	Nov	0.1	36
	Dec	3.9	36
2008	Jan	1	36
	Feb	5	36
	Mar	2	36
	Apr	2	38.4
	May	3.5	40.7
	Jun	3.7	40.1
	Jul	8.6	43.6
	Aug	14.2	39.4
	Sep	7.7	40.4
	Oct	19.8	38.7
	Nov	13.1	38.2
	Dec	9.2	38.2

- Appendix -

A1. Determination of the characteristics of end-members with Matlab™ program

```
EM_Aug = zeros(31,4);

for i = 1:31;

figure;

n = 8; % input of the number of Month

a = i-1; b = i+1;

load C:\MATLAB\NERR_08\CDMO\Aransas_Bay_08.txt; % Aransas Bay
Mon_AB = Aransas_Bay_08(:,1);
T_AB = Aransas_Bay_08(:,6);
S_AB = Aransas_Bay_08(:,7);
Day_AB = Aransas_Bay_08(:,2);
index_1 = find(Mon_AB == n & T_AB >= 0 & S_AB >= 0 & Day_AB > a & Day_AB < b);
T_AB = T_AB(index_1);
S_AB = S_AB(index_1);

load C:\MATLAB\NERR_08\CDMO\Copano_Bay_East_08.txt; % Copano Bay East Bay
Mon_CBE = Copano_Bay_East_08(:,1);
T_CBE = Copano_Bay_East_08(:,6);
S_CBE = Copano_Bay_East_08(:,7);
Day_CBE = Copano_Bay_East_08(:,2);
index_2 = find(Mon_CBE == n & T_CBE >= 0 & S_CBE >= 0 & Day_CBE > a & Day_CBE < b);
T_CBE = T_CBE(index_2);
S_CBE = S_CBE(index_2);

load C:\MATLAB\NERR_08\CDMO\Copano_Bay_West_08.txt; % Copano Bay West Bay
Mon_CBW = Copano_Bay_West_08(:,1);
T_CBW = Copano_Bay_West_08(:,6);
S_CBW = Copano_Bay_West_08(:,7);
Day_CBW = Copano_Bay_West_08(:,2);
index_3 = find(Mon_CBW == n & T_CBW >= 0 & S_CBW >= 0 & Day_CBW > a & Day_CBW < b);
T_CBW = T_CBW(index_3);
S_CBW = S_CBW(index_3);

load C:\MATLAB\NERR_08\CDMO\Mesquite_Bay_08.txt; % Mesquite Bay
Mon_MB = Mesquite_Bay_08(:,1);
T_MB = Mesquite_Bay_08(:,6);
S_MB = Mesquite_Bay_08(:,7);
Day_MB = Mesquite_Bay_08(:,2);
index_4 = find(Mon_MB == n & T_MB >= 0 & S_MB >= 0 & Day_MB > a & Day_MB < b);
T_MB = T_MB(index_4);
S_MB = S_MB(index_4);

load C:\MATLAB\NERR_08\CDMO\Ship_Channel_08.txt; % Ship Channel
Mon_SC = Ship_Channel_08(:,1);
T_SC = Ship_Channel_08(:,6);
```

```

S_SC = Ship_Channel_08(:,7);
Day_SC = Ship_Channel_08(:,2);
index_5 = find(Mon_SC == n & T_SC >= 0 & S_SC >= 0 & Day_SC > a & Day_SC < b);
T_SC = T_SC(index_5);
S_SC = S_SC(index_5);

load C:\MATLAB\NERR_08\TCOON\Baffin_Bay170_08.txt; % Baffin Bay 170
Mon_170 = Baffin_Bay170_08(:,1);
T_170 = Baffin_Bay170_08(:,6);
S_170 = Baffin_Bay170_08(:,7);
Day_170 = Baffin_Bay170_08(:,2);
index_6 = find(Mon_170 == n & T_170 >= 0 & S_170 >= 0 & Day_170 > a & Day_170 < b);
T_170 = T_170(index_6);
S_170 = S_170(index_6);

load C:\MATLAB\NERR_08\TCOON\Bird_Island171_08.txt; % Bird Island 171_1
Mon_171_1 = Bird_Island171_08(:,1);
T_171_1 = Bird_Island171_08(:,6);
S_171_1 = Bird_Island171_08(:,7);
Day_171_1 = Bird_Island171_08(:,2);
index_7 = find(Mon_171_1 == n & T_171_1 >= 0 & S_171_1 > 0 & Day_171_1 > a & Day_171_1 < b);
T_171_1 = T_171_1(index_7);
S_171_1 = S_171_1(index_7);

load C:\MATLAB\NERR_08\TCOON\GBRA_127_08.txt; % GBRA 127
Mon_127 = GBRA_127_08(:,1);
T_127 = GBRA_127_08(:,6);
S_127 = GBRA_127_08(:,7);
Day_127 = GBRA_127_08(:,2);
index_8 = find(Mon_127 == n & T_127 >= 0 & S_127 >= 5 & Day_127 > a & Day_127 < b);
T_127 = T_127(index_8);
S_127 = S_127(index_8);

load C:\MATLAB\NERR_08\TWDB\CCB_08.txt; % Corpus Chrisity Bay
Mon_CCB = CCB_08(:,2);
T_CCB = CCB_08(:,6);
S_CCB = CCB_08(:,7);
Day_CCB = CCB_08(:,3);
index_9 = find(Mon_CCB == n & T_CCB >= 0 & S_CCB >= 0 & Day_CCB > a & Day_CCB < b);
T_CCB = T_CCB(index_9);
S_CCB = S_CCB(index_9);

load C:\MATLAB\NERR_08\TWDB\SAB_08.txt; % San Antonio Bay
Mon_SAB = SAB_08(:,2);
T_SAB = SAB_08(:,6);
S_SAB = SAB_08(:,7);
Day_SAB = SAB_08(:,3);
index_10 = find(Mon_SAB == n & T_SAB >= 0 & S_SAB >= 0 & Day_SAB > a & Day_SAB < b);
T_SAB = T_SAB(index_10);
S_SAB = S_SAB(index_10);

load C:\MATLAB\NERR_08\Offshore\Offshore_Aug_08.mat; % Offshore
index_11 = find(Off_T >= 0 & Off_S >= 0);
T_Off = Off_T(index_11);
S_Off = Off_S(index_11);

```



```

load C:\MATLAB\NERR_08\TWDB\Bird_Island171_08.txt; % Bird Island 171_2
Mon_171_2 = Bird_Island171_08(:,2);
T_171_2 = Bird_Island171_08(:,6);
S_171_2 = Bird_Island171_08(:,7);
Day_171_2 = Bird_Island171_08(:,3);
index_12 = find(Mon_171_2==n&T_171_2>=0&S_171_2>1&Day_171_2>a&Day_171_2<b);
T_171_2 = T_171_2(index_12);
S_171_2 = S_171_2(index_12);

H1 = plot(S_AB, T_AB, 'g','markersize',8); hold on;
H2 = plot(S_CBE, T_CBE, 'b','markersize',8); hold on;
H3 = plot(S_CBW, T_CBW, 'c','markersize',8); hold on;
H4 = plot(S_MB, T_MB, 'm','markersize',8); hold on;
H5 = plot(S_SC, T_SC, 'y','markersize',8); hold on;
H6 = plot(S_170, T_170, 'k','markersize',8); hold on;
H7 = plot(S_171_1, T_171_1, 'l','markersize',8,'color',[.3 .5 .7]); hold on;
H8 = plot(S_127, T_127, 'l','markersize',8,'color',[.7 .5 .3]); hold on;
H9 = plot(S_CCB, T_CCB, 'l','markersize',8,'color',[.9 .5 .1]); hold on;
H10 = plot(S_SAB, T_SAB, 'l','markersize',8,'color',[.1 .5 .9]); hold on;
H11 = plot(S_Off, T_Off, 'l','markersize',8,'color',[.8 .7 .6]); hold on;
H12 = plot(S_171_2, T_171_2, 'l','markersize',8,'color',[.6 .7 .8]); hold on;

HH = zeros(12,1);
HH(1,1) = isempty(H1); HH(2,1) = isempty(H2); HH(3,1) = isempty(H3);
HH(4,1) = isempty(H4); HH(5,1) = isempty(H5); HH(6,1) = isempty(H6);
HH(7,1) = isempty(H7); HH(8,1) = isempty(H8); HH(9,1) = isempty(H9);
HH(10,1) = isempty(H10); HH(11,1) = isempty(H11); HH(12,1) = isempty(H12);

ind = find(HH==0);
leg = str2mat(' AB','CBE','CBW',' MB',' SC','170','171-1','127','CCB','SAB','Off','171-2');
legend(leg(ind,:),-1); hold on;

% Data Matrix for least-square curve fitting
% Those of stations (127, 170, 171, SAB) are only used to determine the characteristics of enm-members.
SS = [S_AB;S_CBE;S_CBW;S_MB;S_SC;S_CCB;S_127;S_171_1;S_171_2]; % sensitivity 5 -
two_Aug5.mat
TT = [T_AB;T_CBE;T_CBW;T_MB;T_SC;T_CCB;T_127;T_171_1;T_171_2];

% least-square curve fitting
poly = polyfit(SS,TT,1);
xi = linspace(14.2,39.4,100);
z = polyval(poly,xi);
plot(xi,z,'k','linewidth',1.5); hold on;

xii = [14.2;39.4]; yii = [z(1,1);z(1,100)];
plot(xii,yii,'rh','markersize',12); hold on;

% regression slope and y-interceptor
zz8(i,:) = [poly];

% Daily End-Members for January
EM_Aug(i,:) = [z(1,1) 14.2 z(1,100) 39.4]; % [EM1-T EM1-S EM2-T EM2-S]

```

```

% axis
axis([0 45 0 45]);
axis square;
set(gca,'xtick',[0:5:45],'fontsize',8,'fontweight','bold');
set(gca,'ytick',[0:5:45],'fontsize',8,'fontweight','bold');
grid on;

% T-S diagram
t = 0:1:45;
s = 0:1:45;
[S,T] = meshgrid(s,t);
[sig] = sw_dens0(S,T) - 1000;
v = 0:5:35; % density interval

[C,h] = contour(s,t,sig,v,'g');
hold on;
clabel(C,(5:10:25),'fontsize',8,'fontweight','bold');
hold on;

hh = i;
gg = num2str(hh);

xlabel('Salinity (psu)','fontsize',10,'fontweight','bold');
ylabel('Temperature (°C)','fontsize',10,'fontweight','bold');
title('NERR T&S diagram - Aug. 2008','fontsize',10,'fontweight','bold');
text(5,42,gg,'fontsize',10,'fontweight','bold','HorizontalAlignment','center','BackgroundColor','y');

set(gca,'box','on');
set(gcf,'color','w');
hold off
end

save('C:\MATLAB\NERR_08\Two_endmember_mixing\Two_Aug.mat','EM_Aug','zz8');

```

A2. Calculation of the mixing ratios of end-members

```

month = 8;

% Data loading
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_Aug.mat %EM_Aug,zz8
T_e1 = EM_Aug(:,1); S_e1 = EM_Aug(:,2);
T_e2 = EM_Aug(:,3); S_e2 = EM_Aug(:,4);

% Data loading - CDMO Ship Channel 2008 data
load C:\MATLAB\NERR_08\CDMO\Ship_Channel_08.txt; % Ship Channel
mon = Ship_Channel_08(:,1); day = Ship_Channel_08(:,2);
year = Ship_Channel_08(:,3); hour = Ship_Channel_08(:,4);
minu = Ship_Channel_08(:,5); sec = zeros(length(mon),1);
T_SC = Ship_Channel_08(:,6); S_SC = Ship_Channel_08(:,7);

% Redefine variables for a specific month
ind0 = find(mon==month&T_SC>=0&S_SC>=0&day>=0&year>=0&hour>=0&minu>=0&sec>=0);
mon = mon(ind0); day = day(ind0); year = year(ind0);

```

```

hour = hour(ind0); minu = minu(ind0); sec = sec(ind0);
T_obs = T_SC(ind0); S_obs = S_SC(ind0);

n = length(mon);
dd = (1:1:length(T_e1))';

% Calculating projected T & S
for i = 1:n;
    for j = 1:length(dd);
        if day(i) == dd(j);
            S_E1 = S_e1(j); T_E1 = T_e1(j); S_E2 = S_e2(j); T_E2 = T_e2(j);
            Tp_SC(i,1) = polyval(zz8(j,:),S_obs(i));
        end
    end
    % Calculate distance between end member 1 & 2 and observations
    dist1 = sqrt((S_E1 - S_obs(i)).^2 + (T_E1 - Tp_SC(i)).^2);
    dist2 = sqrt((S_E2 - S_obs(i)).^2 + (T_E2 - Tp_SC(i)).^2);
    % Calculate the mixing ratios of end member 1 & 2
    f1 = (dist2./(dist1 + dist2)); F1 = f1.*100;
    f2 = (dist1./(dist1 + dist2)); F2 = f2.*100;
    sum1 = F1 + F2;
    S1_est(i,1) = f1.*S_E1 + f2.*S_E2;
    T1_est(i,1) = f1.*T_E1 + f2.*T_E2;
    dT1 = T_obs(i) - T1_est(i,1);
    Aug_mixing1(i,:) = [F1 F2 sum1 dT1];
end

% Calculating observed T & S
for i = 1:n;
    for j = 1:length(dd);
        if day(i) == dd(j);
            S_E1 = S_e1(j); T_E1 = T_e1(j); S_E2 = S_e2(j); T_E2 = T_e2(j);
        end
    end
    % Calculate distance between end member 1 & 2 and observations
    dist11 = sqrt((S_E1 - S_obs(i)).^2 + (T_E1 - T_obs(i)).^2);
    dist22 = sqrt((S_E2 - S_obs(i)).^2 + (T_E2 - T_obs(i)).^2);
    % Calculate the mixing ratios of end member 1 & 2
    f11 = (dist22./(dist11 + dist22)); F11 = f11.*100;
    f22 = (dist11./(dist11 + dist22)); F22 = f22.*100;
    sum2 = F11 + F22;
    S2_est(i,1) = f11.*S_E1 + f22.*S_E2;
    T2_est(i,1) = f11.*T_E1 + f22.*T_E2;
    dT2 = T_obs(i) - T2_est(i,1);
    Aug_mixing2(i,:) = [F11 F22 sum2 dT2];
end

Aug_mixing = [Aug_mixing1 Aug_mixing2 T_obs S_obs T1_est S1_est T2_est S2_est];
n_date8 = datenum(year,mon,day,hour,minu,sec);

save
('C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Aug.mat','Aug_mixing','n_date8');

```

A3. Validation of mixing ratios (correlation coefficient between estimated T(S) and observed T(S))

```

figure;
% Data loading
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Jan.mat; %
Jan_mixing,n_date1;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Feb.mat; %
Feb_mixing,n_date2;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Mar.mat; %
Mar_mixing,n_date3;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Apr.mat; %
Apr_mixing,n_date4;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_May.mat; %
May_mixing,n_date5;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Jun.mat; %
Jun_mixing,n_date6;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Jul.mat; %
Jul_mixing,n_date7;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Aug.mat; %
Aug_mixing,n_date8;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Sep.mat; %
Sep_mixing,n_date9;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Oct.mat; %
Oct_mixing,n_date10;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Nov.mat; %
Nov_mixing,n_date11;
load C:\MATLAB\NERR_08\Two_endmember_mixing\Two_mixing_ratios_Dec.mat; %
Dec_mixing,n_date12;

%Sep08_mixing = [F1 F2 sum1 dT1 F11 F22 sum2 dT2 T_obs S_obs T1_est S1_est T2_est S2_est];
%           1 2 3 4 5 6 7 8 9 10 11 12 13 14

T_obs =
[Jan_mixing(:,9);Feb_mixing(:,9);Mar_mixing(:,9);Apr_mixing(:,9);May_mixing(:,9);Jun_mixing(:,9);Jul_
mixing(:,9);Aug_mixing(:,9);Sep_mixing(:,9);Oct_mixing(:,9);Nov_mixing(:,9);Dec_mixing(:,9)];
S_obs =
[Jan_mixing(:,10);Feb_mixing(:,10);Mar_mixing(:,10);Apr_mixing(:,10);May_mixing(:,10);Jun_mixing(:,
10);Jul_mixing(:,10);Aug_mixing(:,10);Sep_mixing(:,10);Oct_mixing(:,10);Nov_mixing(:,10);Dec_mixing
(:,10)];

T_est =
[Jan_mixing(:,13);Feb_mixing(:,13);Mar_mixing(:,13);Apr_mixing(:,13);May_mixing(:,13);Jun_mixing(:,
13);Jul_mixing(:,13);Aug_mixing(:,13);Sep_mixing(:,13);Oct_mixing(:,13);Nov_mixing(:,13);Dec_mixing
(:,13)];
S_est =
[Jan_mixing(:,14);Feb_mixing(:,14);Mar_mixing(:,14);Apr_mixing(:,14);May_mixing(:,14);Jun_mixing(:,
14);Jul_mixing(:,14);Aug_mixing(:,14);Sep_mixing(:,14);Oct_mixing(:,14);Nov_mixing(:,14);Dec_mixing
(:,14)];
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
1 = corrcoef(T_obs, T_est);

RT1 = num2str(rt1(1,2));

```

```

n = 1;
poly = polyfit(T_obs,T_est,n);
xi = linspace(min(T_obs),max(T_obs),100);
z = polyval(poly,xi);
plot(T_obs, T_est, 'b.','markersize',12); hold on;
plot(xi,z,'r-','linewidth',1.5); hold on;

axis([0 45 0 45]);
axis square;
grid on;
ylabel('Estimated Temp. ({\circ}C)','fontsize',10,'fontweight','bold');
xlabel('Observed Temp. ({\circ}C)','fontsize',10,'fontweight','bold');
title('Ship Channel Jan. ~ Dec. 2008','fontsize',10,'fontweight','bold');
text(5,42,'Corrcoef.:','fontsize',10,'fontweight','bold','HorizontalAlignment','center');
text(10,42,RT1,'fontsize',10,'fontweight','bold','HorizontalAlignment','left','BackgroundColor','y');
set(gca,'box','on');
set(gcf,'color','w');
hold on;
hold off

```