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Deploying a microstructure profiler in Corpus Christi Bay

by

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Abstract

The construction of a water desalination plant is being considered near Corpus Christi Bay TX, as a demonstration initiative funded by the State of Texas to determine whether desalination is a practical approach to obtaining a drought-proof water supply. Desalination plants discharge brine (hypersaline water) in the process of creating fresh water. Existing hypersaline water inflows to Corpus Christi Bay from adjacent waters are suspected to enhance density stratification in the water column. Stratification is often correlated with hypoxia. Therefore the desalination brine could possibly affect the development of hypoxia. There remains an open question as to whether disposal of desalination brine into Corpus Christi Bay would have negative ecological effects. Corpus Christi Bay hypoxia has been documented, but its physical causes have not been clearly identified. There is a need to understand the physical conditions leading to temporary stratification and hypoxia in a bay which is generally vertically mixed and has no long duration dissolved oxygen problems. To investigate stratification on short time scales, measurements were taken at two different areas in Corpus Christi Bay (near Oso Bay and Laguna Madre) using a variety of instruments (microprofiler, weather stations, water quality profiler, etc.) during four field trips that were conducted during the summer of 2005. The present thesis investigates the short-time scale physics of density currents entering Corpus Christi Bay from the adjacent upper Laguna Madre. There are two principal objectives to this work: 1) document the temporal and spatial behavior of salinity and temperature near the outlet of Laguna Madre where hypoxia has previously been recorded; and 2) develop new data processing, display and analysis methods for the SCAMP microstructure profiler. Note that this research project is not intended to provide conclusive demonstration that high-salinity density currents are directly linked to hypoxia, but is instead building the foundations for future analysis of this problem.

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Chapter 1. Introduction

1.1 Motivation

Corpus Christi Bay is located on the Texas coast, adjacent to the city of Corpus Christi. This water body has an area of 434 km^2 (Ward 1997), and an average depth of 3.2 meters (Orlando et al. 1991). The bay is microtidal (typical tidal amplitudes varying from 150 to 600 mm in the summer) and subject to strong meteorological forcing (Ward 1980) by winds, which may routinely peak at 7-10 m/s in summer (according to measurements herein).

The National Estuary Program (NEP, part of US Environmental Protection Agency) was established by Congress in 1987 to improve the quality of estuaries of national importance. Corpus Christi Bay was designated as a National Estuary in 1992, and the Coastal Bend Bays National Estuaries Program (CCBNEP, the NEP including Corpus Christi Bay) was created. The State of Texas has continued to support the Coastal Bend Bays Estuary Program (CBBEP), a non profit organization whose goal is to protect the health of the bays while supporting their economic growth.

The construction of a water desalination plant is being considered near Corpus Christi Bay, as a demonstration initiative funded by the State of Texas to determine whether desalination is a practical approach to obtaining a drought-proof water supply. Unfortunately, desalination plants discharge brine (*i.e.* hypersaline water) in the process of creating fresh water. Existing hypersaline water inflows to Corpus Christi Bay from adjacent waters are suspected to enhance density stratification in the water column (Applebaum et al. 2005). Stratification is often correlated with hypoxia (in Mobile Bay, Alabama (Turner et al. 1987), in Pamlico River Estuary, North Carolina (Stanley and Nixon 1992), in Corpus Christi Bay (Applebaum et al. 2005; Ritter and Montagna 1999; Ritter and Montagna 2001). Therefore the desalination brine could possibly affect the development of hypoxia. Episodic hypoxia was first documented in Corpus Christi Bay in 1988 (Montagna and Kalke 1992) and was reported most years since then (Ritter and Montagna 1999). Thus, there remains an open question as to whether disposal of desalination brine into Corpus Christi Bay would have negative ecological effects.

Corpus Christi Bay hypoxia has been documented, but its physical causes have not been clearly identified. Hypoxia in Corpus Christi Bay is usually an overnight or early morning phenomenon, and its duration is generally on the order of an hour (for more than 50% of the hypoxic events measured in 1999 and 2000, (Ritter and Montagna 2001). In Mobile Bay, Alabama (also shallow: 1-6 m depth), Turner found the order of magnitude for period of stratification and mixing to be as small as a day, if not hours (Turner et al. 1987). As a consequence, short-term study of hypoxic events can lead to an improved understanding of their development and disappearance.

There is a need to understand the physical conditions leading to temporary stratification and hypoxia in a bay which is generally vertically mixed and has no long-duration dissolved oxygen (DO) problems. The episodic hypoxia is associated with a stable layer of high-salinity water and is arguably controlled by hydrodynamics. While the stratification phenomenon studied herein has only been demonstrated within a specific area of Corpus Christi Bay, the results are likely applicable to understanding the fate of brine reject water from desalination plants sited on other Texas estuaries and embayments.

To investigate stratification on short time scales, measurements were taken at two different areas in Corpus Christi Bay (near Oso Bay and Laguna Madre) using a variety of instruments (microprofiler, weather stations, water quality profiler, etc.) during four field trips that were conducted during the summer of 2005.

1.2 Research Objectives

The present study investigates the short-time scale physics of density currents entering Corpus Christi Bay from the adjacent upper Laguna Madre and Oso Bay. There are two principal objectives to this work: 1) document the temporal and spatial behavior of salinity and temperature near the outlet of Laguna Madre where hypoxia has previously been recorded; and 2) develop new data processing, display and analysis methods for the SCAMP microstructure profiler. Note that this research project is not intended to provide a conclusive demonstration that high-salinity density currents are directly linked to hypoxia, but is instead building the foundations for future analysis of this problem.

1.3 Background and literature review

In the open waters of a shallow bay (*e.g.* Mobile Bay, Alabama: average depth of 3 m), vertical mixing due to wind, tidal shear and river inflows usually occurs frequently enough to control the spatial and temporal extent of low oxygen events (Turner et al. 1987). Since Texas bays are usually shallow, windy and well mixed, hypoxia should not be expected based on the Turner et al. 1987 definition; however, it has been reported in isolated locales as far back as 1942 in Galveston Bay (Gunter 1942), and has more recently been extensively documented in Corpus Christi Bay by Montagna and coworkers at the University of Texas Marine Science Institute (UTMSI) (Applebaum et al. 2005; Montagna and Kalke 1992; Morehead and Montagna 2003; Morehead and Montagna 2004; Ritter and Montagna 1999; Ritter and Montagna 2001).

Hypoxia creates physiological stress that is poorly tolerated by most animals (Ritter and Montagna 1999). Estuarine hypoxia is a commonly defined as dissolved oxygen (DO) concentrations below 2 mgL^{-1} (Dauer et al. 1992); however, Ritter and Montagna (1999) have shown that the appropriate definition of hypoxia for Corpus Christi Bay is DO < 3 mgL^{-1}, which is the threshold for measurable negative ecological effects in this bay. Hypoxia occurs in summer, predominantly in the southeast region of Corpus Christi Bay (Ritter and Montagna 2001) and typically only in the bottom waters, *i.e.* 1 to 2 m above the bottom (Ritter and Montagna 2001). Hypoxic events are predominantly intermittent, locally developing and persisting on the order of hours (Ritter and Montagna 2001) rather than days or weeks.

Stratification, defined as a persistent vertical density gradient, has been linked to hypoxia in Corpus Christi Bay (Applebaum et al. 2005; Ritter and Montagna 1999; Ritter and Montagna 2001). Stratification inhibits vertical mixing, which prevents DO introduced at the water surface from penetrating through the water column. Thus, stratification effectively isolates the sediments and the lower part of the water column, so that biogeochemical oxygen demand may deplete available DO. Stratification can be a particular problem during the summer because of high respiration (Stanley and Nixon 1992). It has been postulated that water column stratification impedes mixing processes and is a key factor in the onset of hypoxia in Corpus Christi Bay (Applebaum et al. 2005; Ritter and Montagna 1999; Ritter and Montagna 2001). Several related hypotheses about the physical processes have been raised to explain stratification in Corpus Christi Bay. First, there is minimal circulation of the water in the southeast region of the bay (Ritter and Montagna 1999) which limits the exchange of water. Second, episodic low wind speeds are considered a factor, as high speed winds help mix stratification and replenish oxygen, while low speed winds tend allow persistent stratification (Morehead et al. 2002). Third, it is known that stratification can be enhanced by high evaporation rates (Turner 1973), but whose relationship to Corpus Christi Bay hypoxia has not been studied. Finally, gravity currents of denser waters (presumably from hypersaline Laguna Madre) are suspected to play a role (Ritter and Montagna 1999).

Chapter 2. Experimental Methods

2.1 Introduction

Prior physical/hypoxia studies of Corpus Christi Bay have principally concentrated on the longer time-scale physics associated with hypoxia (Applebaum et al. 2005; Montagna and Kalke 1992; Ritter and Montagna 1999; Ritter and Montagna 2001). However, the development and destruction of stratification may be attributable to shorter time-scale phenomena, *e.g.* daily cycles of tides, evaporation and wind mixing. To address the gap in our knowledge, a program of field measurements was designed and conducted during the summer of 2005. In the following section of this thesis, geographical location, methods, equipment and data collection missions are described.

2.2 Geographical information

Corpus Christi Bay is located in the south part of the Texas Coastal Bend (see). The Texas Coastal Bend extends from Jackson County (north) to Kenedy County (south). Corpus Christi Bay is surrounded by the counties of Nueces and San Patricio (see Figure 2-1).

Freshwater inflows, ocean inlets and channels are the main water exchange sources for Corpus Christi Bay. The principal sources of freshwater inflow are the Nueces River and Oso Creek; the latter draining into Oso Bay along the southern boundary of the bay (Figure 2-3). According to USEPA (1999), Corpus Christi Bay has a 49700 km^2 drainage area, an average daily freshwater inflow of 34 m^3/s and an average salinity of 22 ppt. Although the bay is considered shallow — average depth of 3.2 meters (Orlando et al. 1991) — relative to estuaries along the eastern and western coasts of the USA, it is one of the

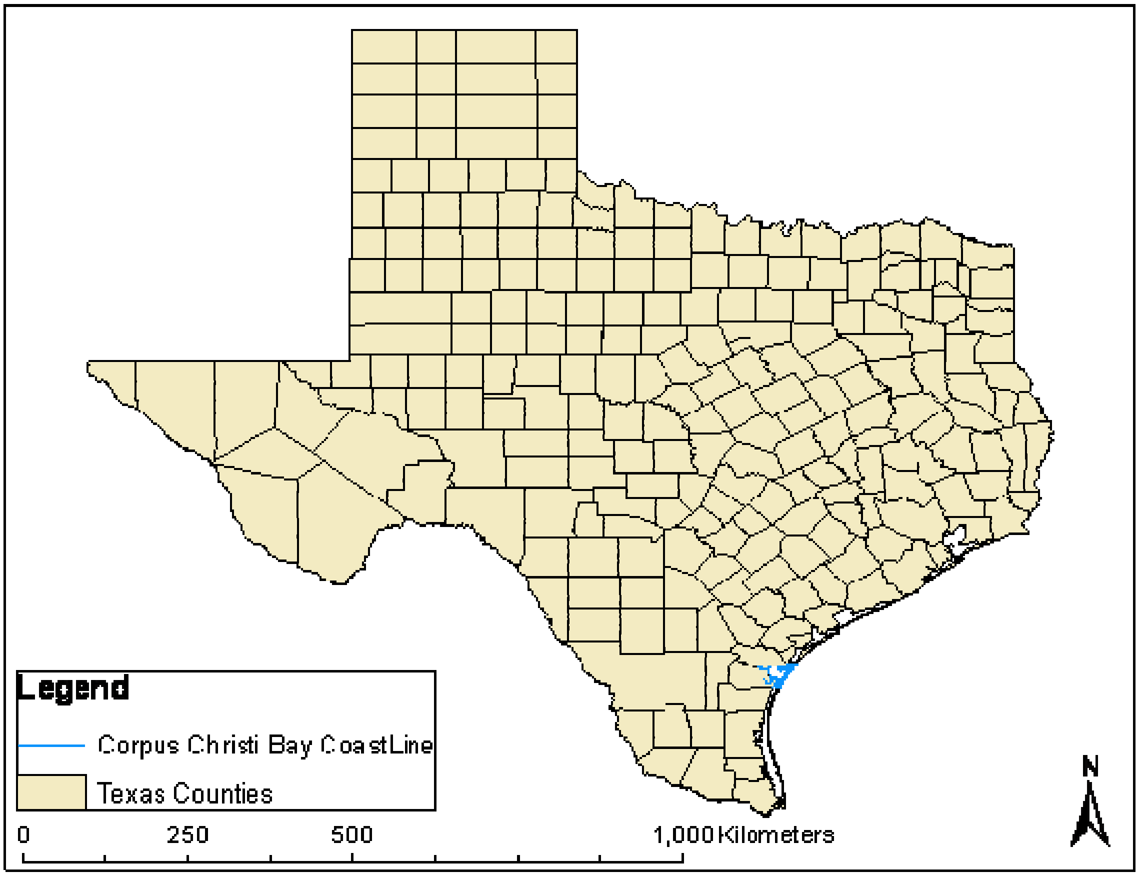


Figure 2-1 Location of Corpus Christi Bay in the State of Texas

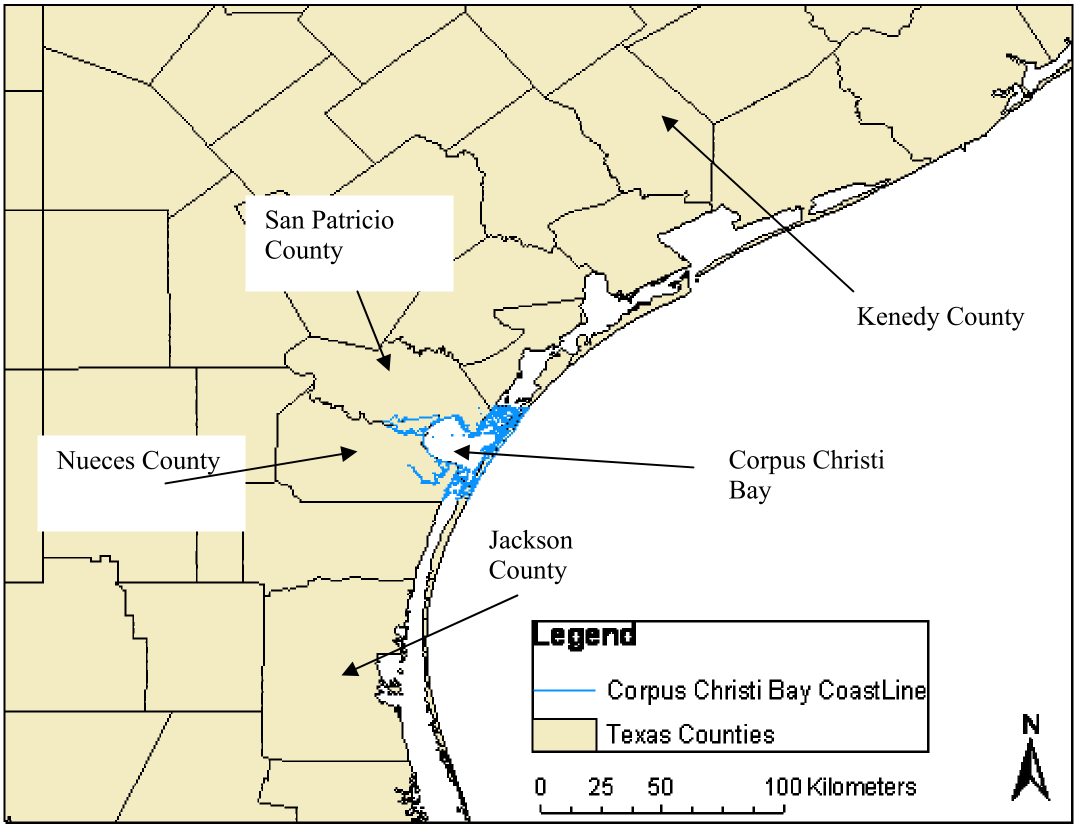


Figure 2-2 Corpus Christi Bay and surrounding counties

deepest bays on the Texas coast (Ward 1997). At its northern end, Corpus Christi Bay is connected to Aransas Bay via the Gulf Intracoastal Waterway (GIWW), which continues through the bay and into the Upper Laguna Madre at the southern end of Corpus Christi Bay. The bay is separated from the Gulf of Mexico by Mustang and North Padre Islands, which are low barrier islands typical to the North American Gulf coast. Aransas Pass (northeast end of the bay) is the main water inlet connecting Corpus Christi Bay and the Gulf of Mexico. Other inlets have been temporarily opened (Corpus Christi Pass, Corpus Christi fish pass, etc.) but are now closed by sand. Corpus Christi Bay is also connected to Aransas Bay (through Aransas Channel) and Baffin Bay (through Laguna Madre). The re-opening of Packery Channel, a tidal inlet into the Upper Laguna Madre (project directed by US Army Corps of Engineers, started in Oct. 2004, still in progress), is providing another source of water exchange with the Gulf of Mexico.

The demonstration water desalination plant that is being considered by the State of Texas would be co-located with the Barney Davis power plant for efficiency and economy. The power plant is located between Upper Laguna Madre and Oso Bay (see Figure 2-3). The Barney Davis power plant was built in 1975 (G. Ward, pers. comm.). The inlet water for the proposed desalination plant would be pumped from Laguna Madre using the existing power plant inlet piping and the brine would be discharged into Oso Bay through the existing power plant discharge piping.

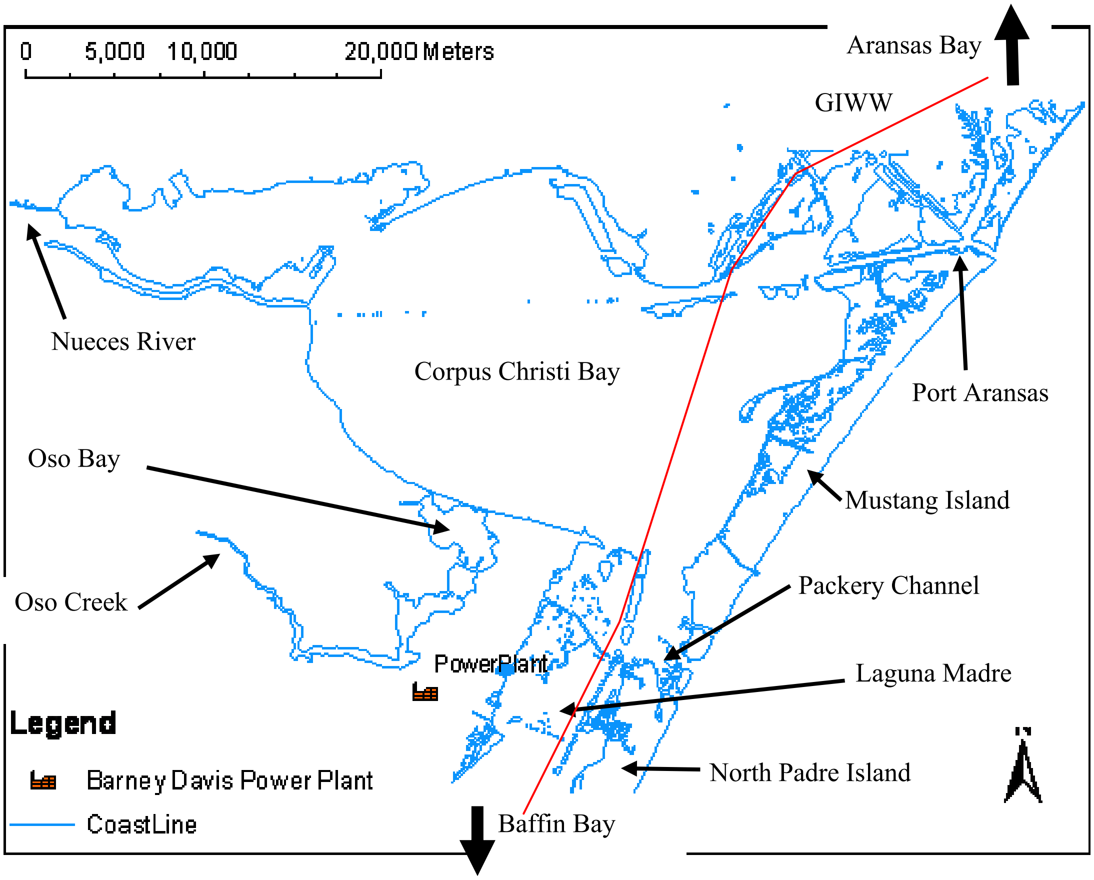


Figure 2-3 Principal features around Corpus Christi Bay

2.3 Overview of the experimental methods

Field experiments were conducted over short time scales (intensive sampling for one or two days) and limited spatial scales (< 5 km) to capture the development of dense gravity currents created through the daily salinity and heating/cooling cycles. The experiments were focused on two zones in Corpus Christi Bay near the connections to Upper Laguna Madre (Site A as shown in Figure 2-4) and Oso Bay (Site B as shown in Figure 2-5). The selection of the area near the Upper Laguna Madre was based upon the previous documentation of hypoxia in this region (Ritter and Montagna 1999). The selection of the area near Oso Bay was to determine if the outflow from this bay could create stratification that allows hypoxia development.

Four missions (each of two to three days) were conducted in the summer of 2005, with the help of 10 people. In order to gain a good understanding of the physical behaviors in both sites A and B, detailed vertical and horizontal resolution was obtained over small distances (less than 5 km), with short time scales (few hours to a day).

Vertical profiling was conducted at selected locations (between 5 and 10 locations per day) that were repeated several times during the day (3 to 6 times depending on the weather conditions, the duration of the mission and the number of locations). This profiling method enabled the documentation and analysis of both spatial and temporal changes in the water column at selected sites.

The principal measured variables were temperature, salinity and dissolved oxygen as a function of depth. Secondary variables (wind speed, tidal elevation) were also measured and/or obtained from other sources. Temperature and salinity were used to compute water density to examine the water column stratification that affects mixing and hypoxia. DO concentration measurements allow determination

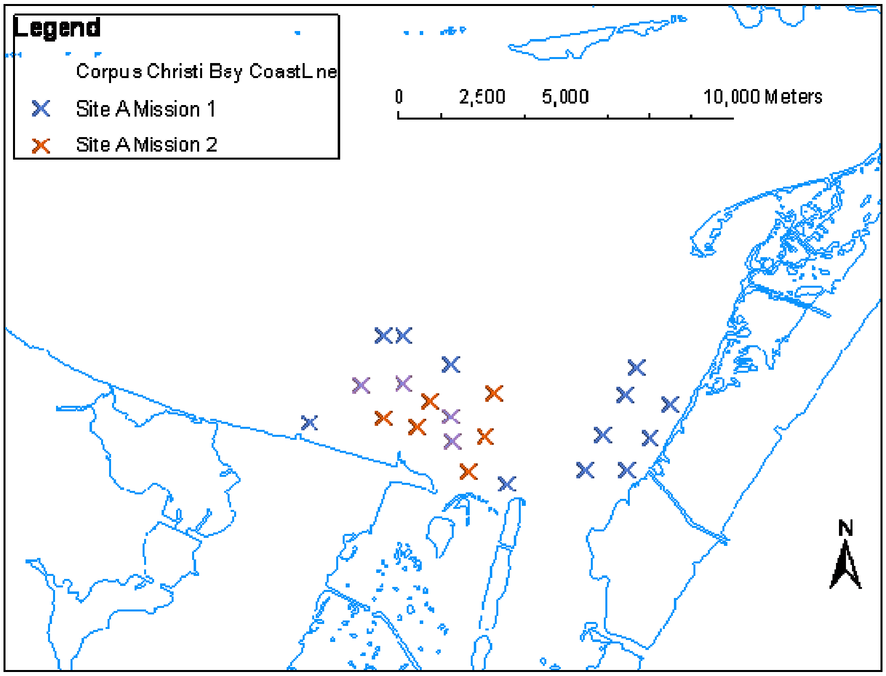


Figure 2-4 Site A Locations

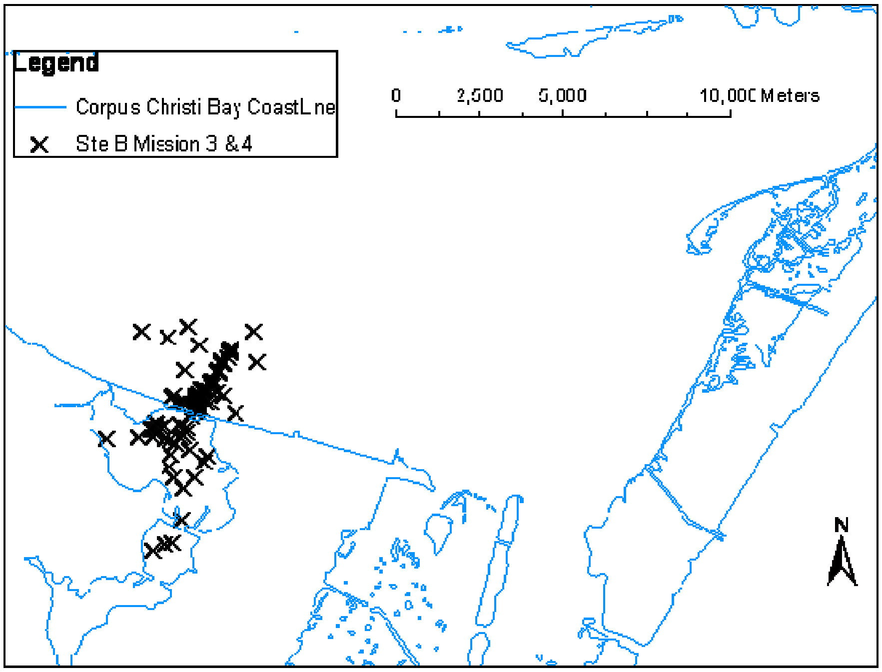


Figure 2-5 Site B Locations

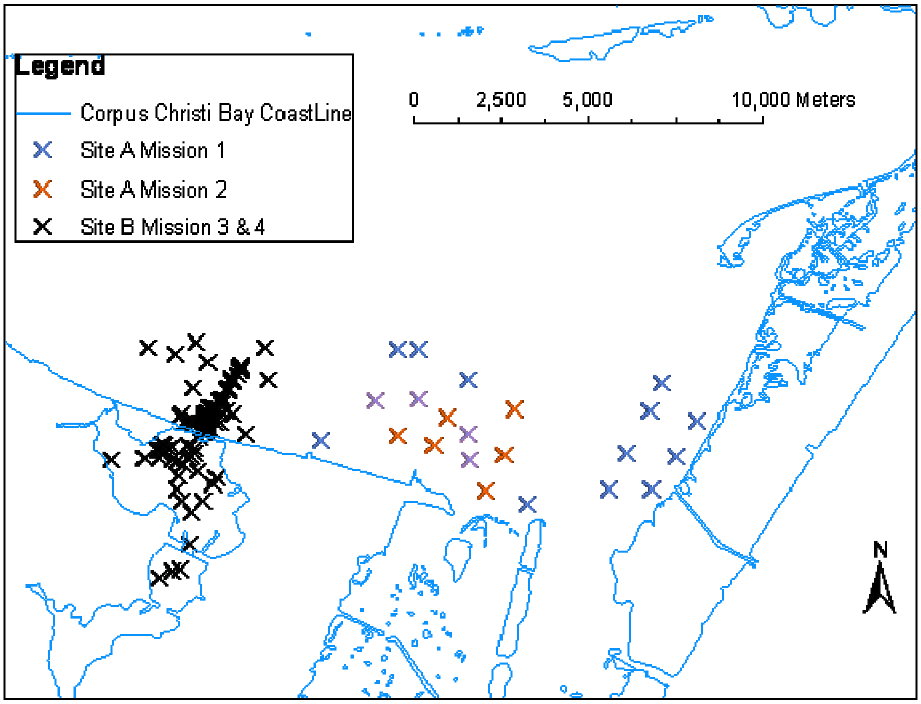


Figure 2-6 Map of all the sampled locations

of the oxygen conditions (anoxic = no oxygen; hypoxic = low oxygen concentration). Winds and tides were documented as they generally play a role as driving forces in the mixing process.

Sampling locations at Site A included positions previously sampled by UTMSI (33, 34, 37, 39 and 42 in Ritter and Montagna 1999, named here A033, A034, A037, A039 and A042) and new positions (A101, A102, A103, A104, A105) to provide finer spatial resolution (700 m to 1 km between neighbor locations). Sampling locations at Site B (with distance between neighbor locations ranging between 100 m and 500 m) were newly identified for the purpose of this study. Further details on the GPS locations can be found in Appendix B. At each sampling location, sampling time was typically 10 minutes. An interval of approximately 20 minutes was required between sampling sites (including travel time and boat positioning). The vertical profile resolution was approximately 1 mm for the microstructure profiler (SCAMP) and 30 cm for the water quality profiler (Manta). Both instruments are described in Section 2.4.

2.4 Equipment

For the purpose of our project, various pieces of equipment were used: two boats (detailed information on the boats can be found in Appendix C), two water profiling instruments (one water quality profiler and one microstructure profiler), two GPS receivers and two weather stations. The equipment is described in the following sections of this thesis.

2.4.1 SCAMP

Microstructure profiling was conducted using the Self Contained Autonomous MicroProfiler (SCAMP), which is manufactured by Precision Measurement Engineering Inc. (PME, based in California) in cooperation with the Centre for Water Research (CWR, part of the University of Western Australia).

The SCAMP is a portable, lightweight microstructure profiler designed to measure extremely small scale (order 1 mm) fluctuations of temperature and salinity. The fine-scale changes of temperature with depth (*i.e.* the temperature gradient), provide information on active mixing (see 4.2.6 Temperature and conductivity gradient). The fine-scale measurements provided by the SCAMP allow computation of temperature and salinity gradients that indicate turbulent overturns in the water column. The SCAMP was used to measure temperature (with two fast and one accurate sensors), electrical conductivity (with one fast and one accurate sensor), photo active radiation (one PAR sensor), fluorescence (one fluorometer) and turbidity (one turbidity sensor). The Matlab based software supplied with the SCAMP allows the user to upload, record, view, and analyze measurements (see Figure 2-8).

The SCAMP is free falling; the depth is continuously recorded and is computed based upon pressure sensor measurement. The instrument is quite tall (around 1 m) and cannot be practically deployed in depths shallower than 2.5 m. The SCAMP was deployed only at Site A because some areas in Site B were deemed generally too shallow to obtain effective measurements. The SCAMP is tethered by a string for retrieval after deployment, but is otherwise autonomous; it is battery-operated and executes a pre-programmed measurement sequence. Pre-programming sets the number of datapoints recorded in the water column, start time and/or start depth and end time and/or end depth. While the SCAMP can be deployed in either a downwards mode (sinking down with weights) or an upwards mode (floating up with buoyancy rings), the present work used only the downwards mode as the focus is on the turbulence near the bottom that affects stratification.

The ideal travel rate for the SCAMP is near 10 cm/s. This rate has to be checked every measurement day, and adjusted by adding floats or weights to the instrument body. Because the instrument takes several tenths of a second to reach a consistent falling speed after deployment, the initial second (corresponding to the first 10 cm at the 10 cm/s fall rate) of the SCAMP data deployment may be unreliable. In the present work, it was observed that the data recorded in the initial second of the deployment appeared to have some of the greatest differences between profiles. Therefore it is preferable not to use the data obtained at the surface (from 0 to 10 cm deep) in downwards mode and the data from the bottom (from the deepest measurement point to 10 cm above) of the water column in upwards mode. Thus, the initial 10 cm of data was filtered out in the present data analysis. This research is focused on the stratification near the sediment, therefore the data measured near the bottom needed to be reliable and the downwards mode was used. It should be noted that the SCAMP temperature and conductivity sensors are approximately 75 cm below the pressure sensor, so the good instrument data typically begin 85 cm below the water surface. Because the SCAMP drifts horizontally with the currents during deployment, the actual location of the SCAMP during data collection is not precisely at the boat location. Based on visual estimates of line deployed and visible surface drift, the SCAMP typically remained within about 10 to 20 m of the boat location.

Figure 2-7 SCAMP (from http://pme.com/scamp.htm)

The SCAMP is the support to multiple sensors. In this thesis, the focus is on temperature, conductivity and pressure measurements (see Section 4.2). Temperature sensors have a characteristic temporal response. The thermal time constants corresponding to the fast temperature sensors and the accurate temperature sensor on the SCAMP are respectively 0.007 s and 0.2 s. Usually, the shorter the thermal time is, the faster the sensor responds, but the less accurate it is. Conductivity sensors have a characteristic spatial response. The space constants are 2.5 mm and 15 mm for the fast and accurate conductivity sensors, respectively. Conductivity

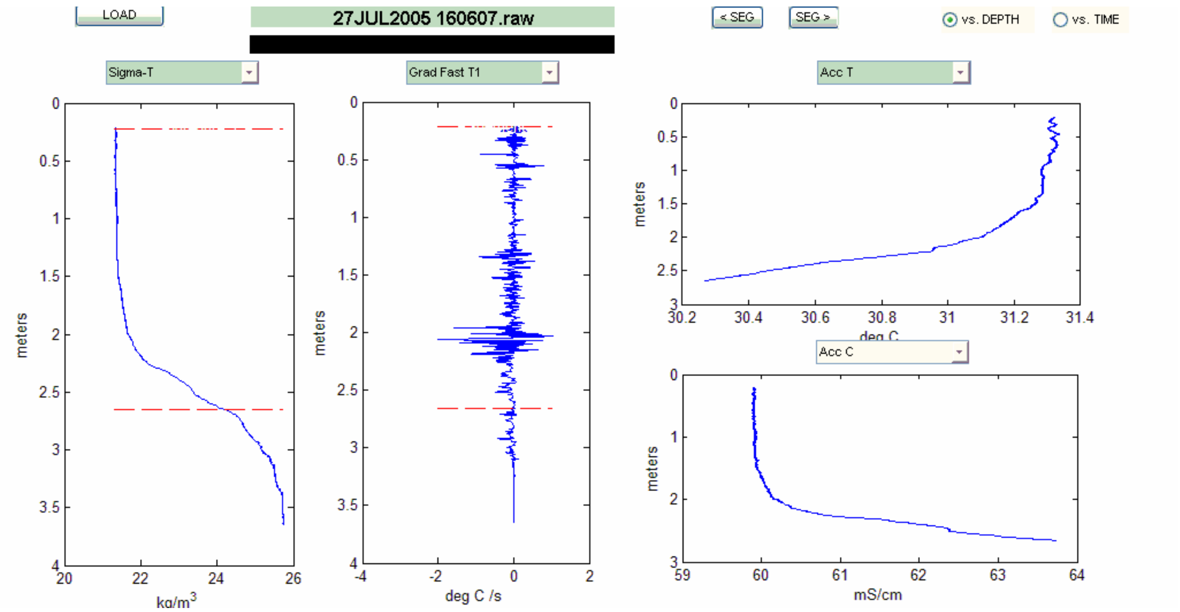


Figure 2-8 Example of SCAMP plot obtained with the software provided by PME. July 27 2005.

sensors with smaller space constants are faster but less accurate. The SCAMP takes a measurement every 10 ms (corresponding to 1 mm at the 10 cm/s fall rate). The pressure sensor used for depth computation gives an accuracy smaller than 1 mm. Fast sensors are designed to react quickly, so their output is suitable for computing small-scale gradients of a measured variable. Accurate sensors are used to obtain the profile of a measured variable, but cannot be used to compute gradients.

Figure 2-9 shows the location of each mounted sensor on the SCAMP and Figure 2-10 shows how the instrument is deployed.

Additional information and recommendations on the use of the SCAMP can be found in Appendix D.

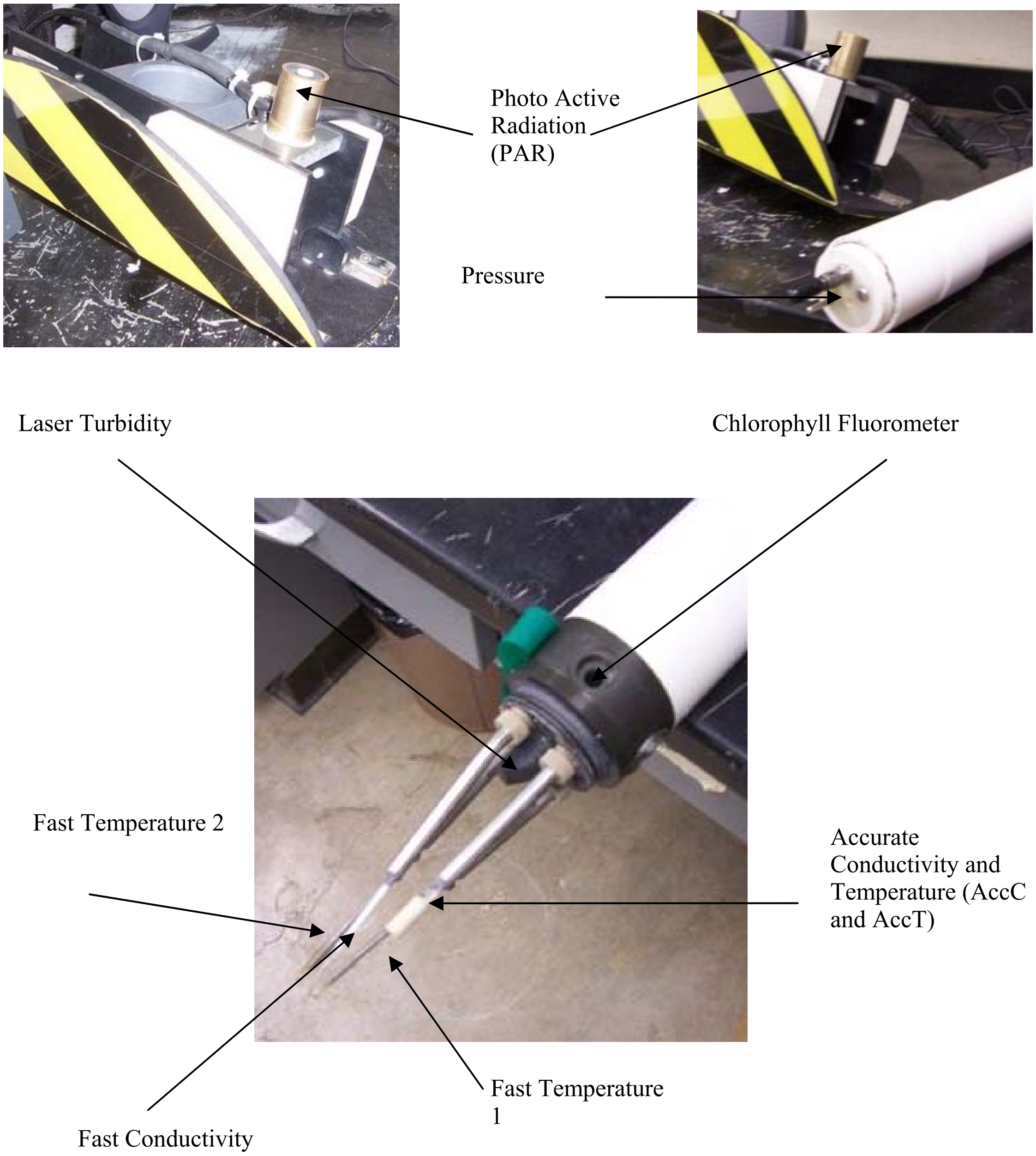


Figure 2-9 Positions of sensors on SCAMP

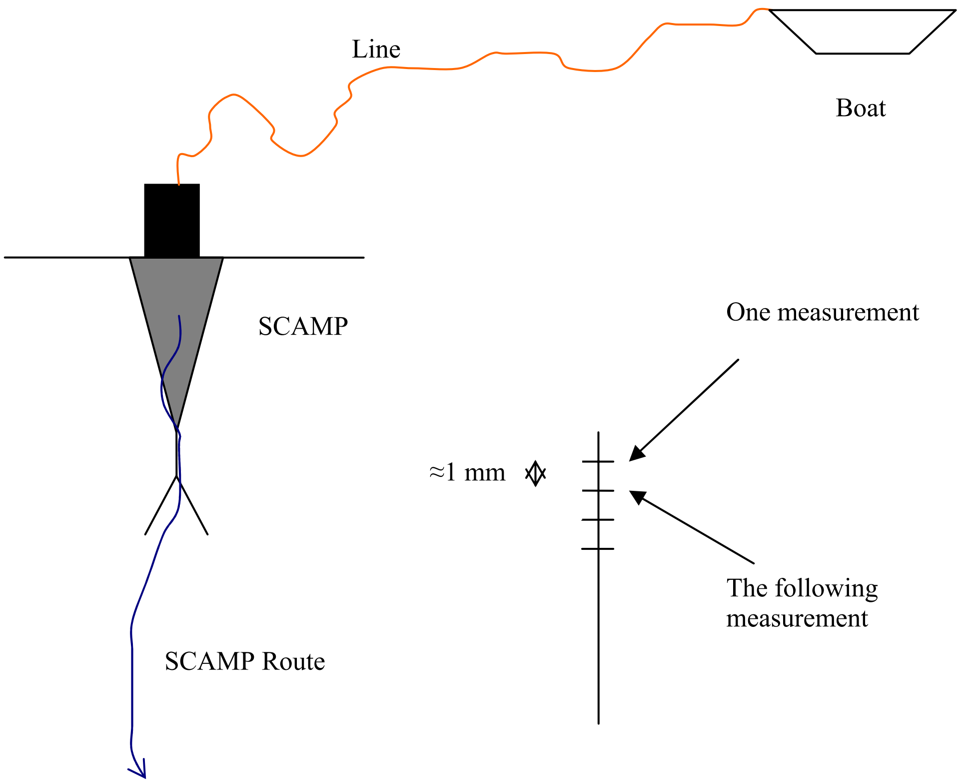


Figure 2-10 Deployment of SCAMP (not to scale)

2.4.2 Manta

Manta instruments are designed and manufactured by Eureka Environmental Engineering, and are used to measure parameters typically important in water quality investigations. In this investigation, two similar Manta instruments were used. One instrument was provided by the Texas Water Development Board (TWDB) and was deployed with the supervision of their personnel. A second instrument was provided on loan from Eureka for part of the experiments.

The Mantas that were used have five sensors, measuring temperature, conductivity, pH, pressure and Dissolved Oxygen (DO) concentration. A cable connects the Manta to a handheld computer that records the data. The same cable may be used to lower the instrument to the desired sampling depth, or (as in the case of the TWDB instrument) an additional line may be added to limit forces on the cable connections. The Manta (whose length is 50 cm) is smaller than the SCAMP and is deployed by hand. Unlike the SCAMP, only the bottom part (10 cm) of the Manta needs to be immersed in water to take measurements. Hence the Manta can take measurements in 10 cm of water. The size of the Manta and its deployment technique enable Manta profiling in shallow waters. The Manta was preferred for part of the experiment because it measures DO concentration (the SCAMP does not) and can be used in shallow waters. However, unlike the SCAMP, the Manta cannot be used to measure small-scale gradients and as a consequence cannot be used to infer turbulence characteristics. For effective use of manpower (not enough human resources were available to deploy both the SCAMP and the Manta during the 48 hour experiment) only the Manta was deployed at Site B because it can be used in shallow waters and can measure DO.

Figure 2-11 Manta (from http://www.eurekaenvironmental.com)

The Manta data collection is conducted by lowering the instrument to a desired depth, waiting for the instrument readings to stabilize (~10 s, sometimes longer), recording; then lowering to another depth. The stabilization time is necessary because the DO sensor does not respond quickly (which is why SCAMP DO sensors are still in the research stage). Thus, the Manta collects data at depths selected by the user. Measurements were taken at approximately 15 cm (6 in) intervals over most of the water column, with additional measurements at the bottom and approximately 5 cm off the bottom (Figure 2-12 shows how the instrument is deployed). The vertical resolution of the profiles obtained with the Manta is approximately 15 cm. Because the Manta depth is being controlled by a person in a boat, the instrument may move up and down slightly with the boat. In the presence of waves, it is difficult to hold the Manta at a steady depth. Vertical excursions of the instrument during deployment are estimated as between 2 cm (calm conditions) to about 10 cm (rougher conditions). Due to malfunction of the pressure sensor on the TWDB

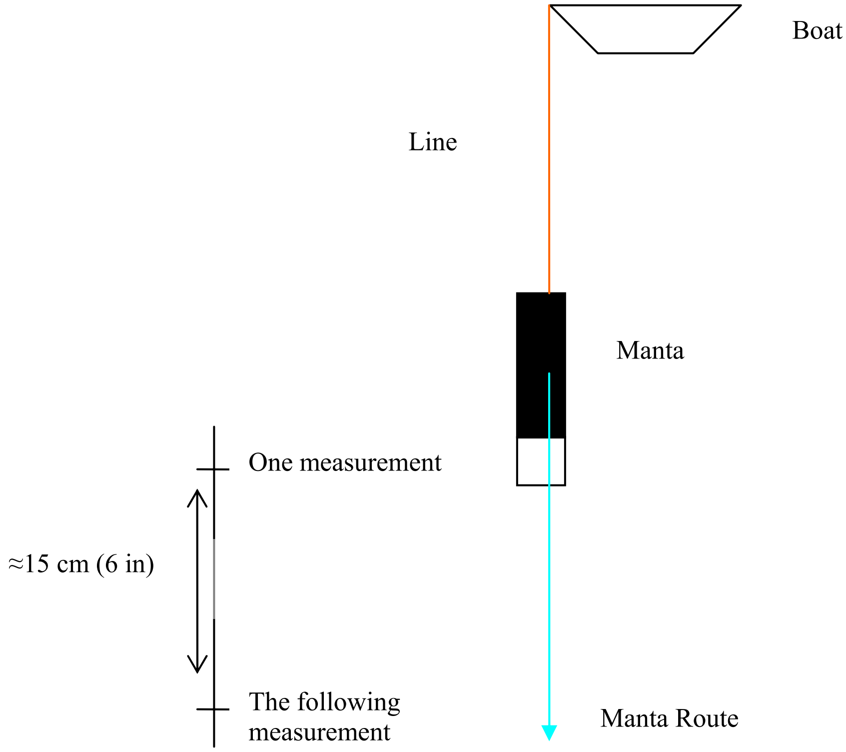


Figure 2-12 Deployment of Manta

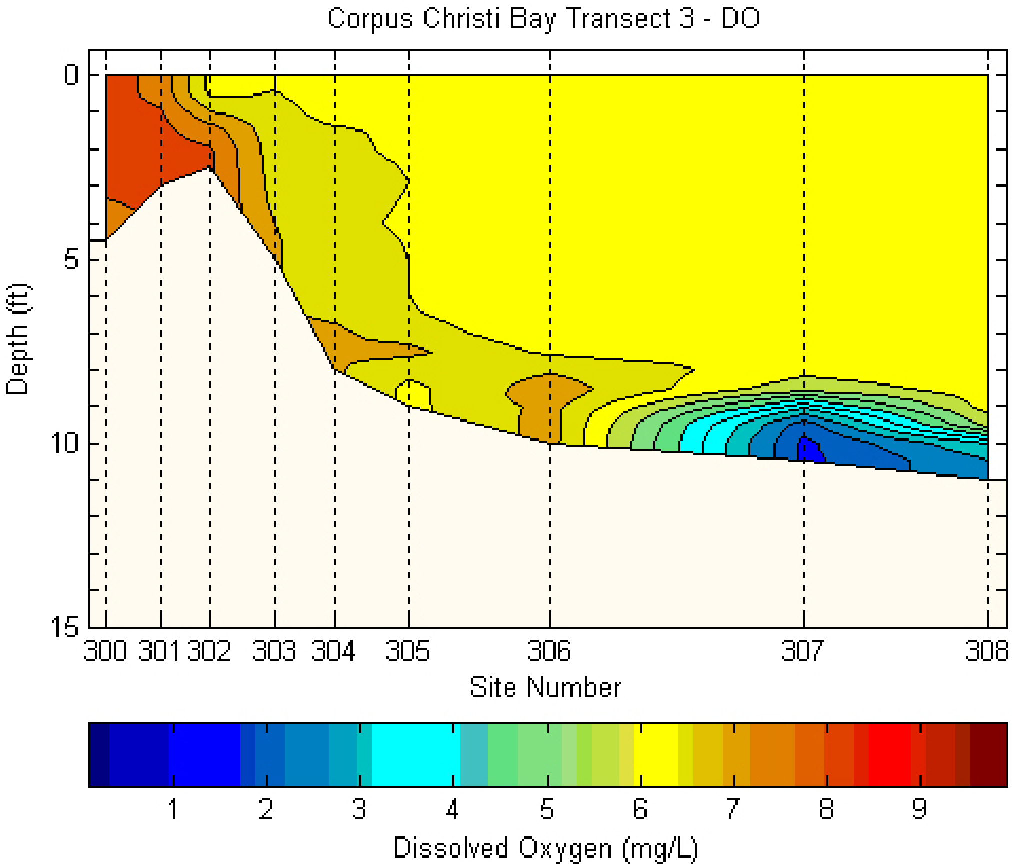


Figure 2-13 Sample graph of the data produced by the Manta (plot created by Jordan Furnans)

Manta during most of the deployments, the depth was estimated using marks on the deployment line. The formal depth measurement accuracy for the Manta pressure sensor is 1 mm; however, for the depth measurements based on the deployment line, an accuracy of ±5 cm is a more reasonable estimate. The accuracies of the other main Manta sensors are 0.08°C for temperature, 0.2 mg/L for DO, and 1 mS/cm for conductivity.

A single Manta deployment was performed at each location. A typical profile in 3 m of water (on August 22nd 2005 at location 307, starting at 1754 hours) with 20 measurement points took 4 min 31 s. Figure 2-13 shows an example plot created from data collected with the Manta. Nine Manta profiles at nine locations (B300 to B308) were used to draw this spatial contour plot of the dissolved oxygen concentration. All deployments were done on August 22nd 2005 between 1703 and 1806 hours.

2.4.3 GPS receivers

Two different GPS receivers were used during the missions. A Magellan Meridian Marine GPS unit was used for most of the SCAMP deployments. This unit has the standard GPS accuracy of within 3 meters or better (assisted by the U.S. Wide Area Augmentation System WAAS).

A more accurate GPS receiver was available on the TWDB boat used during some SCAMP deployments and the majority of the Manta deployments. The GPS Pathfinder Pro XRS receiver is designed for GIS data collection and data maintenance. This receiver has accuracy better than 1 m.

The GPS receivers were used to position the boat near the deployment site and record the actual position of the boat during the deployment. Because the boat position is affected by wind, current, anchor location and length of the anchor rope, the deployment position was typically within about 10 to 40 m of the target site. The average distance between the first deployment position and the target site was computed to be 43 m. Only four first deployment positions were more than 100 m away from the target site (on July 27th: A101 at 1720 hours; on July 28th A101 at 0424 hours, A042 at 1420 hours and A104 at 1520 hours). Another difficulty was caused by dragging anchor (due to current, wind and waves), but only a few times did this occur. Dragging anchor was reported on the log book for locations A042, A102, A103 and A104 on July 28th between 1420 and 1520 hours. Inglefield anchors were used in both boats.

Figure 2-14 Magellan Meridian Marine (from http://www.magellangps.com/)

2.4.4 *Weather Stations*

A hand-held weather station (Kestrel 4100) and a land-based weather station (CES weather station) were both used in this study. The Kestrel 4100 measures air speed, temperature and humidity; and stores these measurements in flash memory. Additional measurements of dew point, wind chill and heat stress index can be taken, but were not considered relevant to the present work. The Kestrel

Figure 2-15 Trimble GPS (from http://www.trimble.com/)

Figure 2-16 Kestrel 4100 hand-held weather station (from http://www.nkhome.com/)

does not provide wind direction. Data points were recorded manually at each deployment location. To use the instrument, the operator stood at the front of the boat, facing the wind and stored four consecutive measurements (approximate time of 10 s between each). The distance between the measurement point and the water surface water was visually estimated as on the order of 2.5 m. The instrument was oriented towards the strongest wind, requiring personal interpretation for alignment. Figure 2-16 shows a picture of the Kestrel 4100.

The land-based weather station was manufactured by Coastal Environmental Systems (CES) and uses their Zeno 3200 logger. For safety and security, the weather station was first deployed within sight of the ranger's office at Mustang Island State Park (see Figure 2-17). After analysis of Mission 1 (see discussion below), the weather station was moved to an isolated location along the bay side of Mustang island (see Figure 2-18). Locations Weather1 and Weather2 can be seen on Figure 2-19.

The land-based weather station measures wind speed, wind direction, wind gusts (the highest wind speed over the sampling time), standard deviation of wind speeds, air temperature, relative humidity, solar radiation, barometric pressure, and rainfall. The recordings are based on an average of the measurements taken during the sampling time (10 s). The time between the samples was programmed differently during missions and between missions to optimize the data storage between downloads. The elevation of the sensors placed on the land based weather station is approximately 2.5 m above the ground surface.

Table 1 shows the sampling times and the times between samples for the CES weather station.

The wind field over and near Corpus Christi Bay is subject to local effects as well as larger-scale

Figure 2-17 CES weather station at location Weather1

weather patterns. As a consequence, the wind speeds measured with the land-based station did not always correlate with those measured on the boat. Qualitative comparison of data from the handheld and fixed weather stations is provided in Section Chapter 3; further quantitative evaluation remains a subject for future investigation.

The weather data collected in these experiments was supplemented by data available from the TCOON (Texas Coastal Ocean Observation Network) observatory. The data used were downloaded from http://lighthouse.tamucc.edu/pq. In Corpus Christi Bay, the data from four TCOON stations are available at Texas State Aquarium, Ingleside, Port Aransas and Packery Channel. The station closest to the sampling locations with both wind and water elevation measurements is Ingleside. Therefore, Ingleside was chosen as the TCOON station to be used in this study. It is located at 27°49.3' N, 97°12.2' W (Figure 2-19). The vertical station datum for water elevation measurements is located 0.717 m above the North American Vertical Datum 1988 (NAVD88). Figure 2-19 shows the three locations of the two land based weather stations.

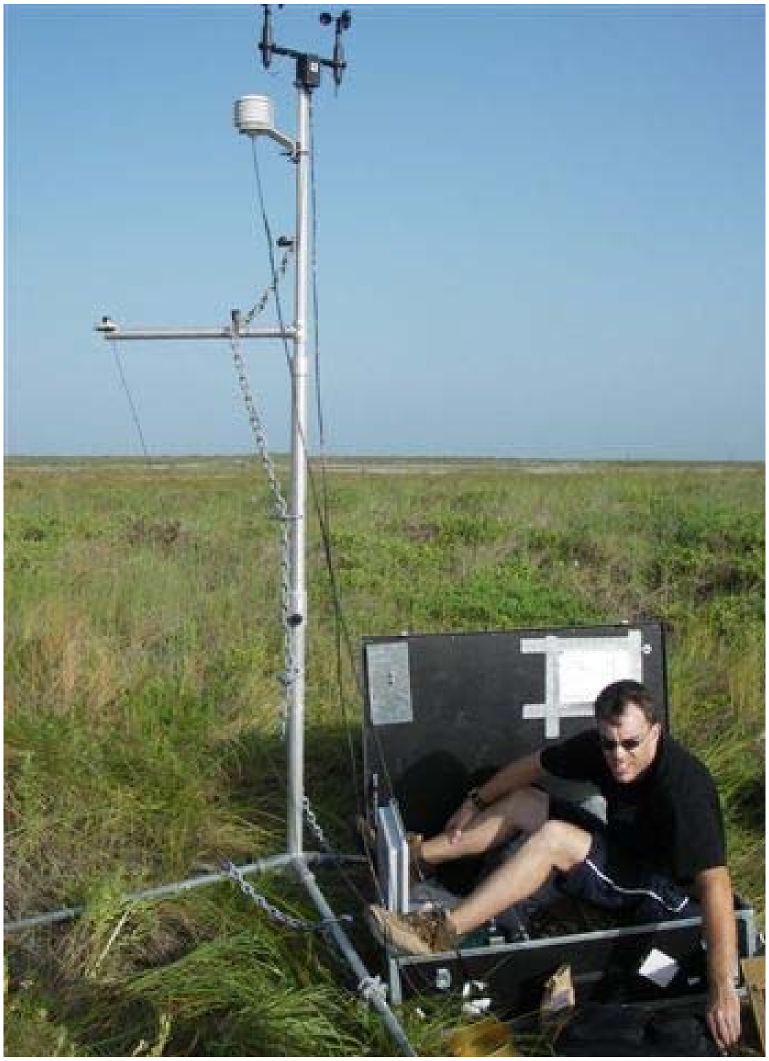


Figure 2-18 CES weather station at location Weather2

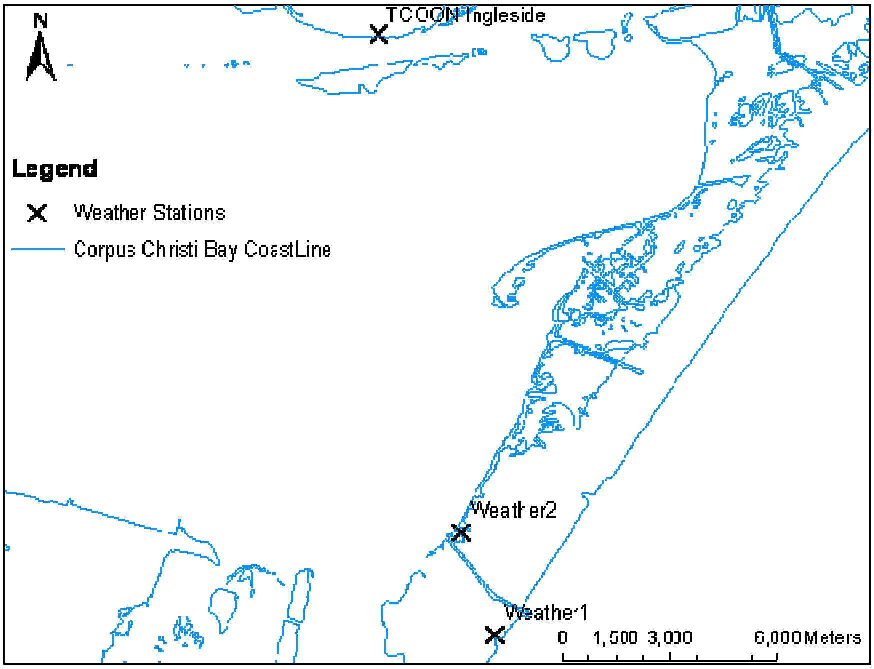


Figure 2-19 The three locations of the two land-based weather stations

Table 1 Sampling time and time between samples for the CES weather station

	Location	Sampling Time	Time between samples
Mission 1	Weather1	10 s	0.5 min
Between Missions 1 and 2	Weather1	10 s	10 min
Mission 2	Weather2	10 s	1 min
Between Missions 2 and 3	Weather2	10 s	15 min
Mission 3	Weather2	10 s	1 min
Between Missions 3 and 4	Weather2	10 s	10 min
Mission 4	Weather2	10 s	2 min

Chapter 3. Description of the data collection missions

A total of four missions were conducted during the summer 2005. The two first missions were located at Site A. The purpose of the last two missions was to investigate Site B. In this chapter we will describe all missions.

3.1 Mission 1: 07/05/2005 – 07/07/2005

Description and goals

The goals of this mission were: 1) familiarization with the equipment in general and with SCAMP deployments in particular, 2) emplacing the CES weather station, and 3) collection of SCAMP data at sites where UTMSI had previously sampled to provide guidance in developing future field experiments.

The people that participated in this field trip were Cédric David (UT), Jordan Furnans (TWDB) and Ben Hodges (UT). During this mission only the SCAMP was deployed. Both GPS receivers were used at different times during the experiment. The boat was deployed from the public boat ramp on the Laguna Madre side of Mustang Island at GIWW. The CES weather station was deployed on July 5th 2005 at 1300 hours at Mustang Island state park near the park office, location Weather1). shows the locations of the boat ramp and the weather stations.

The boat was deployed between 1600 and 1900 hours on the 5th, between 0800 and 1400 hours on the 6th and between 0700 and 1500 hours on the 7th. One crew (with the three members cited above) was deployed on the 5th and the 6th. On the 7th, another crew was deployed (Cédric David and Ben Hodges). The weather was mostly sunny, and the water calm, without wind on the 5th and the 6th. On the morning of the 7th the wind speeds ranged between 6 and 10 m/s (recorded by the CES weather station at location Weather1) and the water became choppy with whitecaps. By early afternoon the wind waves began to build. By 1500 hours, further boat operations were deemed dangerous, so the experiment was discontinued. The CES weather station was checked after sampling on July 6th. The frequency of measurements was changed from every 30 s to every 10 min to allow enough memory for recording the next month of weather data. Figure 3-2 shows the wind data recorded by the CES weather station at location Weather1 during Mission 1.

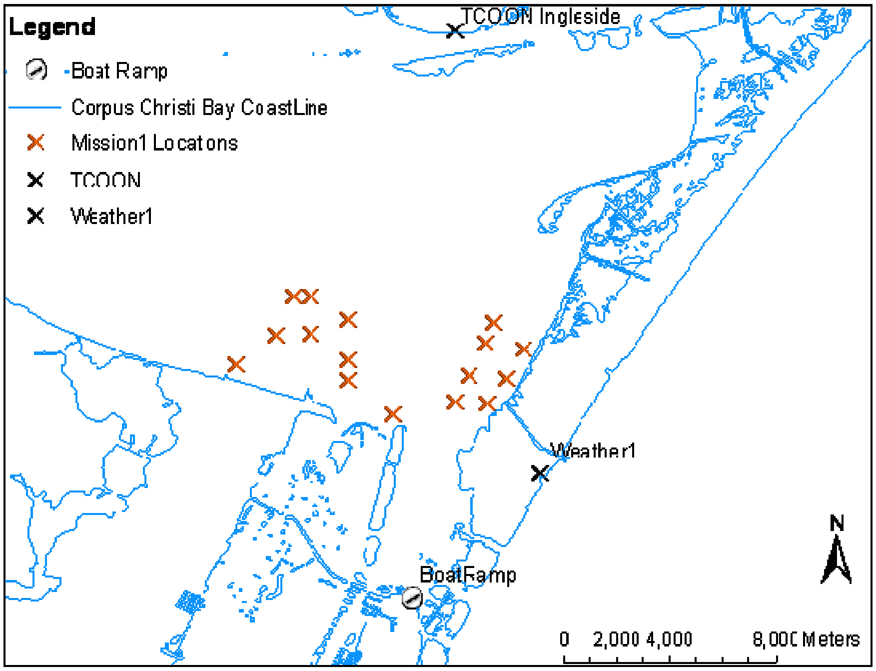


Figure 3-1 Locations of boat ramp and weather stations

Locations

Site A was investigated during this mission. Figure 3-4 shows the locations where samplings were conducted. Location A104 was created as a result of one of UTMSI locations being uploaded incorrectly in the GPS receiver. Figure 3-4 also shows Transect1 that was investigated for data analysis.

Key findings from Mission 1

Figure 3-3 to Figure 3-9 show typical temperature and salinity measurements taken during Mission 1. Four SCAMP deployments were executed at each location and time during Mission 1. In each figure three locations are shown: A039 (July 6th, 1047 hours), A042 (July 7th, 0720 hours) and A104 (July 7th, 0910 hours). The first four profiles of each plot correspond to four consecutive profiles taken at a given location. The fifth profile is a binned average of the four previous profiles. Section 5.2.1 further explains this type of plot. Analysis of the temperature and salinity profiles on consecutive profiles (Figure 3-3 to Figure 3-9) show that they are in good visual agreement. The scales of measured variables are therefore very similar over multiple deployments conducted within about 10 minutes (approximate time required for four deployments) over a 20 m space scale (horizontal drift of the SCAMP, see Section 2.4.1). As a consequence of this visual analysis, the water at Site A has spatial and temporal similarity over at least a 10 min time scale and a 20 m space scale, so three deployments were judged sufficient to provide description of the water column at a given time and location for future missions. Additional deployments were conducted when one (or more) of the three planned deployments was (were) aborted. Each SCAMP deployment recorded 50 s of measurements, suitable for a depth of approximately 5 meters at a fall rate of 10 cm/s. As this depth is greater than any of the study locations, the bottom was always reached by the SCAMP prior to the end of the sampling time.

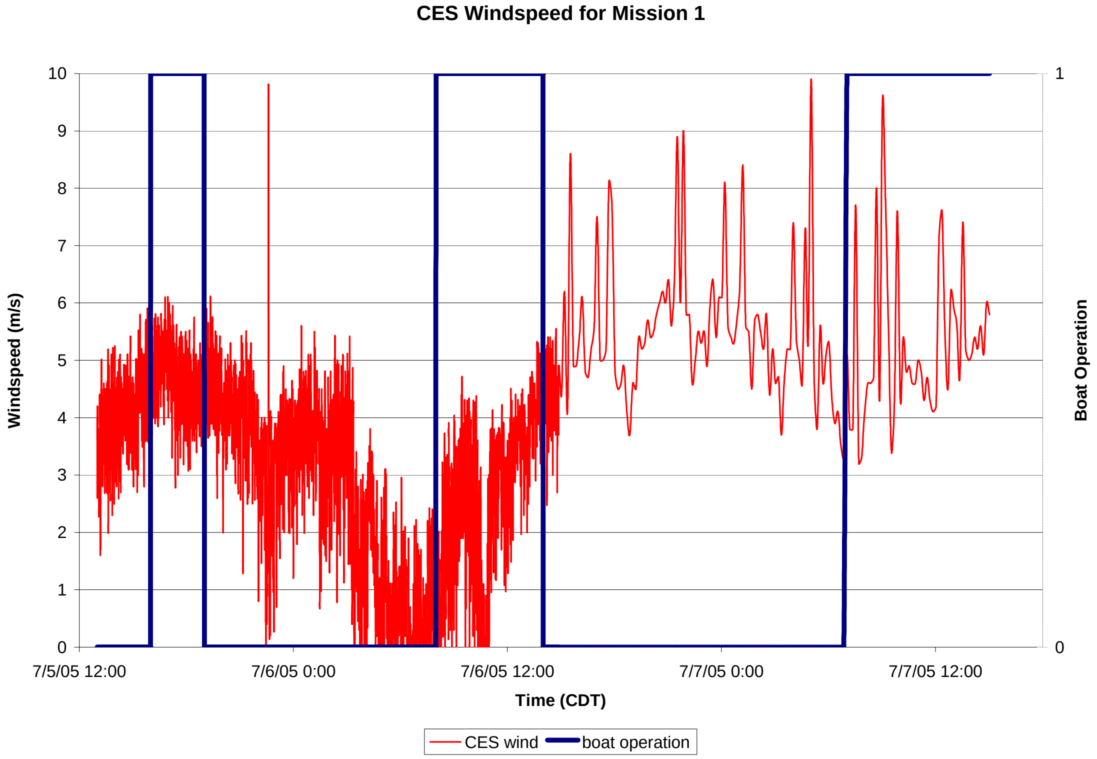


Figure 3-2 CES wind data for Mission 1 (Location Weather1), with boat operation times

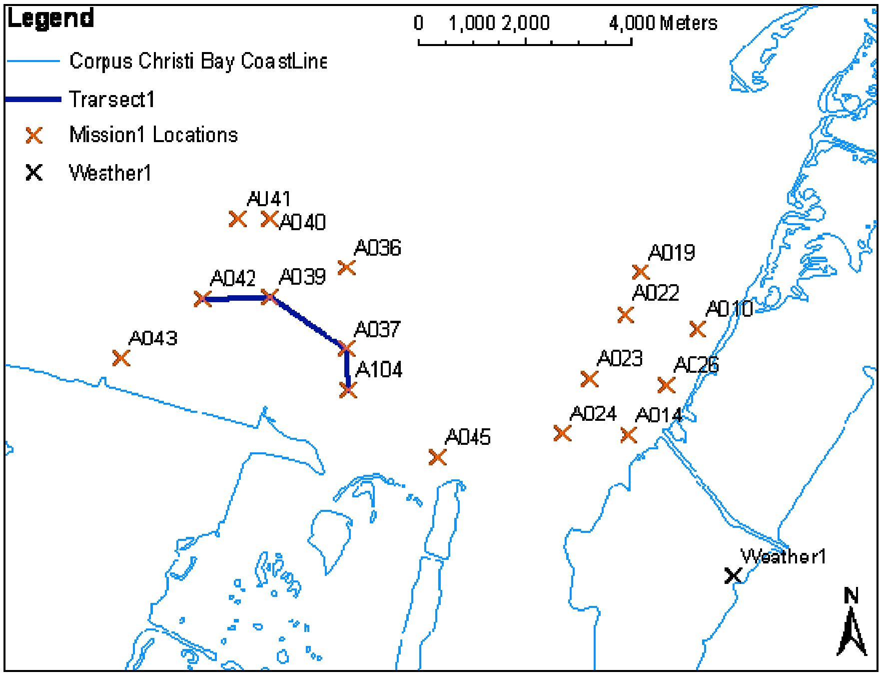


Figure 3-4 Locations for mission 1

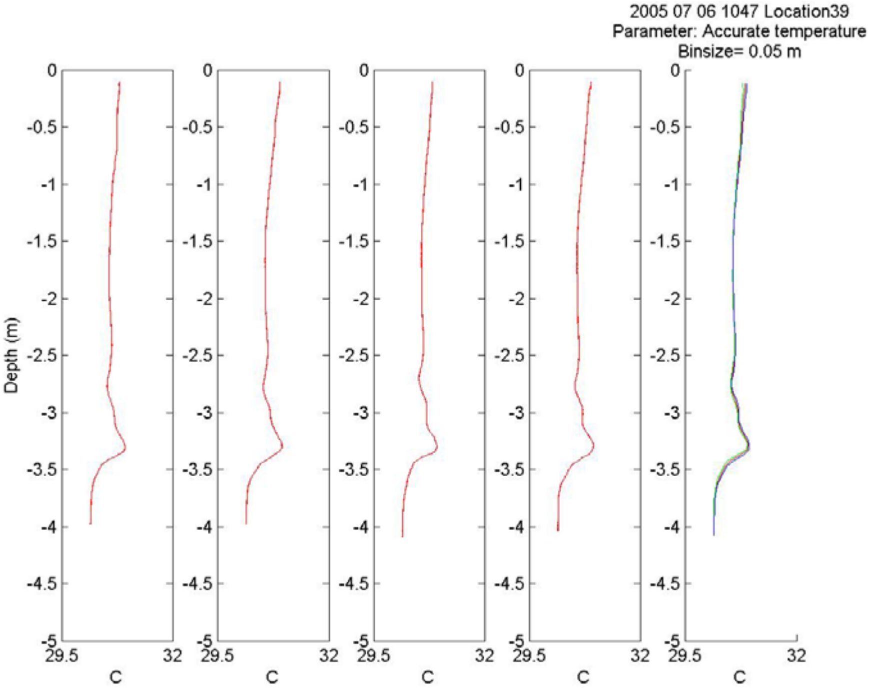


Figure 3-3 Accurate temperature profiles - location A039 - 1047 hours on July 6th

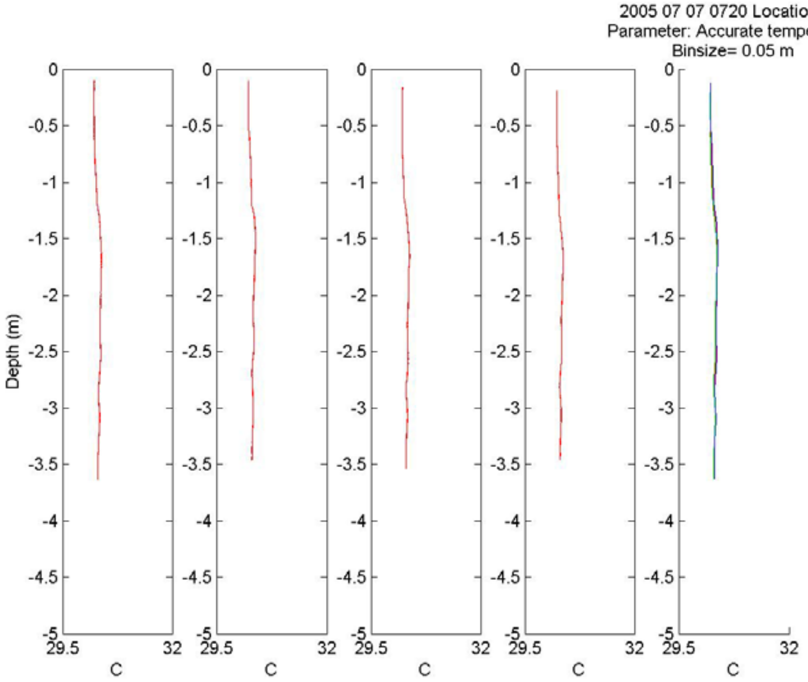


Figure 3-6 Accurate temperature profiles - location A104 - 0720 hours on July 7th

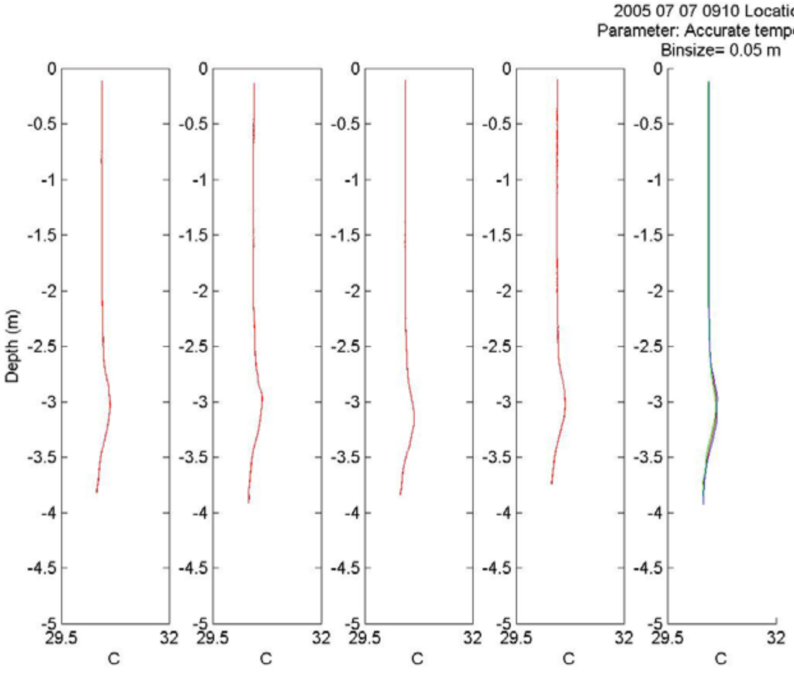


Figure 3-5 Accurate temperature profiles - location A042 - 0910 hours on July 7th

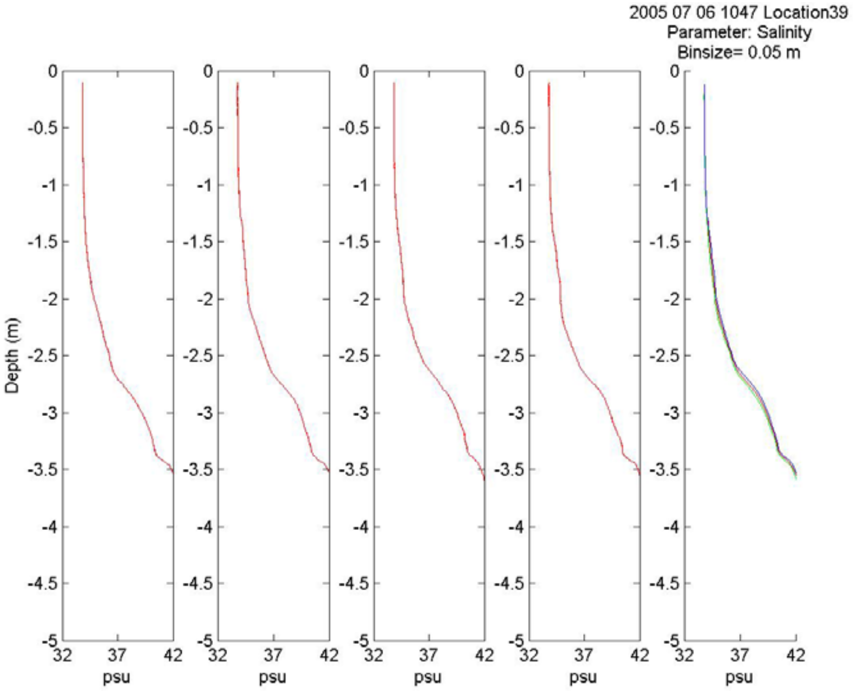


Figure 3-7 Salinity profiles - location A039 - 1047 hours on July 6th

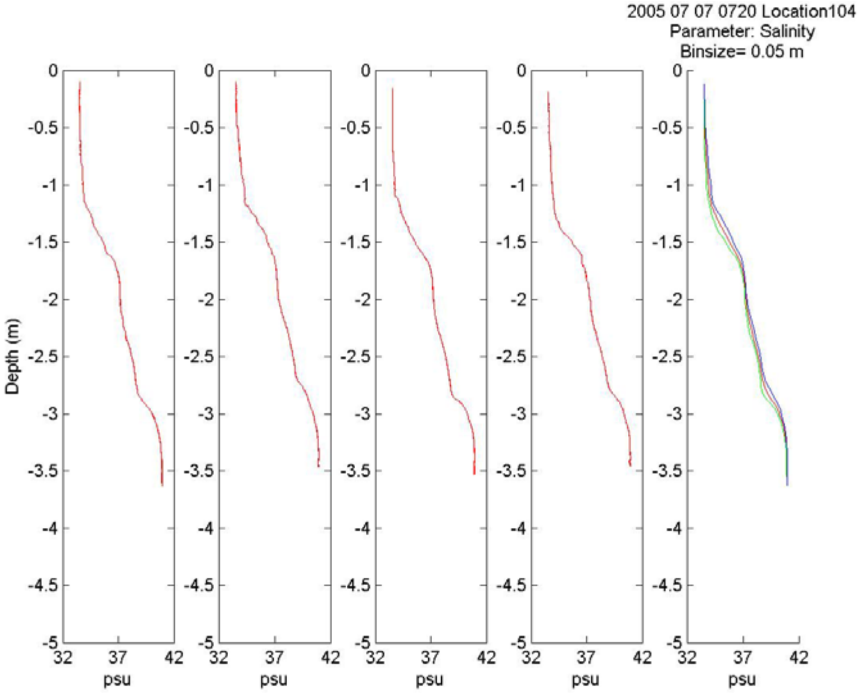


Figure 3-8 Salinity profiles - location A104 - 0720 hours on July 7th

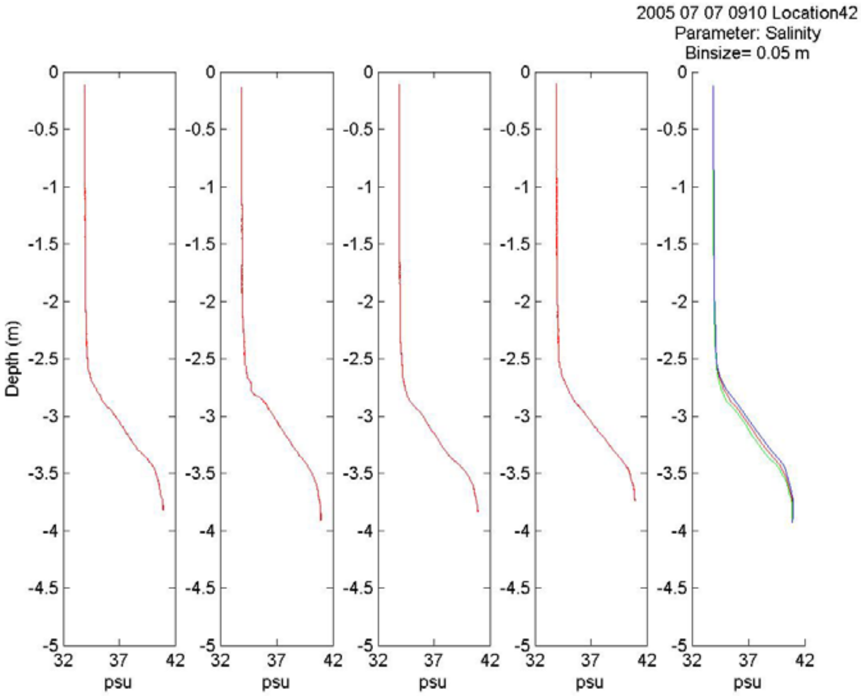


Figure 3-9 Salinity profiles - location A042 - 0910 hours on July 7th

Comparison of the CES weather station data (Figure 3-2) to weather notations in the log book (kept on the boat) indicated substantial disagreement during the first mission. Typical wind speeds during boat operations on July 5th and 6th were in the range of 2 to 4 m/s (from CES weather station, see Figure 3-2), whereas the log book included notations such as “no wind, no white caps, not choppy” as general comments for July 5th and 6th. Thus, it appears that even the low dunes of Mustang Island were sufficient to cause significant spatial gradients in the wind. As a result of these findings it was decided to move the CES weather station to location Weather2 (see Figure 2-18) during the following mission. To obtain a more quantitative understanding of the difference between the land-based measurements and the wind at the sampling locations, the Kestrel 4100 hand-held weather station (see section 2.4.4 above) was acquired for future missions. Figure 3-10 shows wind data from both the CES weather station at location Weather1 and the TCOON weather station at Ingleside. Visual inspection of this figure shows that the winds measured by the two stations are quite different.

A dense underflow was documented on transect 1 (see Section 5.2.2) and motivated the creation of new sampling locations (see Section 3.2).

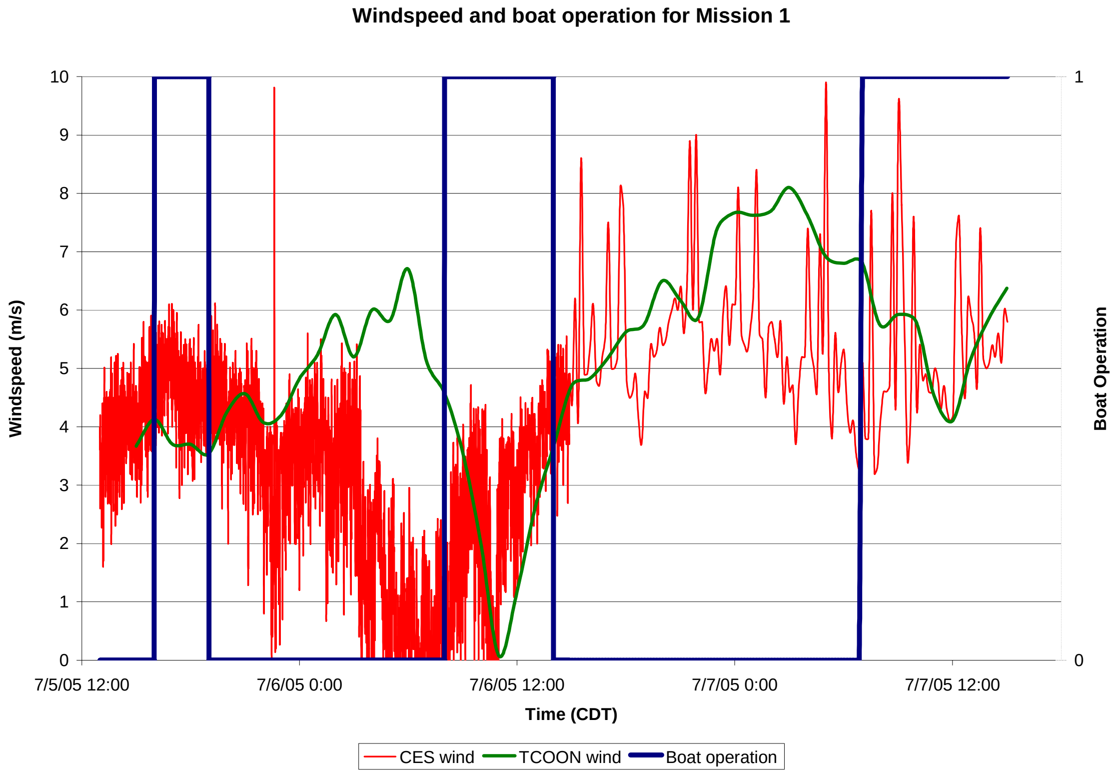


Figure 3-10 Wind data and boat operation for mission 1

3.2 Mission 2: 07/27/2005 – 07/28/2005

Description and goals

The goals of this mission were: 1) moving the CES weather station to location Weather2 on the bay side (see Figure 2-18), 2) conducting further investigation at Site A, including overnight sampling, with four new sampling locations.

The people that participated in this field trip were Cédric David (UT), Shipeng Fu (UT), Jordan Furnans (TWDB), Carla Guthrie (TWDB), Ben Hodges (UT), and Paula Kulis (UT). During this second mission both the SCAMP and the Manta were deployed, from a single boat. Both GPS receivers were used. Both the CES and the Kestrel handheld weather stations were used. The west side of Mustang Island, on the beach, was chosen as the new location for the CES weather station (location name: Weather2). Recordings at the new location started at 1230 hours on July 27th, and were taken every minute until 1830 hours on July 28th.

The boats were deployed between 1420 27th and 1520 hours on the 28th (overnight sampling was done in the night between the 27th and the 28th). Measurements were stopped between 1630 and 2030 hours on the 27th because of strong winds. Figure 3-11 summarizes the crew changes.

The weather was mostly sunny with winds varying from 1 to 8 m/s. The bay was weakly agitated (height of waves around 20 cm, from visual observations) the first 30 hours. In high wind conditions (6 m/s) on the 28th, the boat dragged anchor during deployments at locations A042 at 1420 hours and A104 at 1520 hours. Based on the GPS locations at the start and end of the sampling runs, the boat dragged up to 320 m during these deployments. As the waves built up (around 1 m high, estimated from visual observations), instrument deployment was discontinued.

Figure 3-12 shows winds recorded by the CES (land-based) and the Kestrel (handheld) weather stations. Wind data will be compared in the next paragraph.

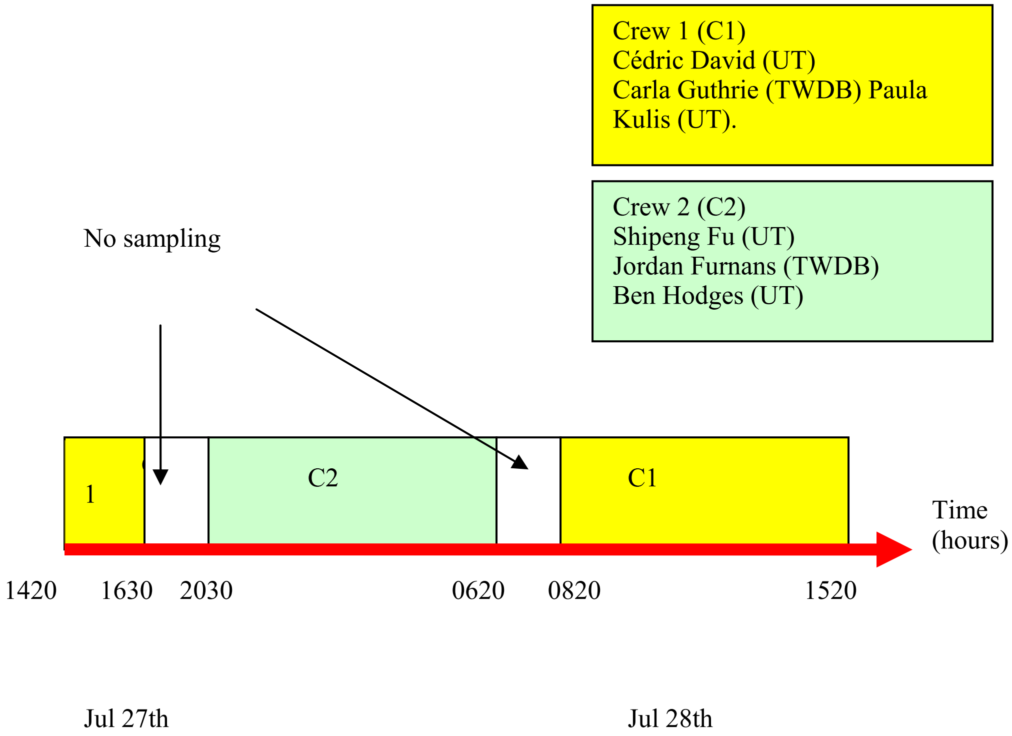


Figure 3-11 Crew changes for mission 2

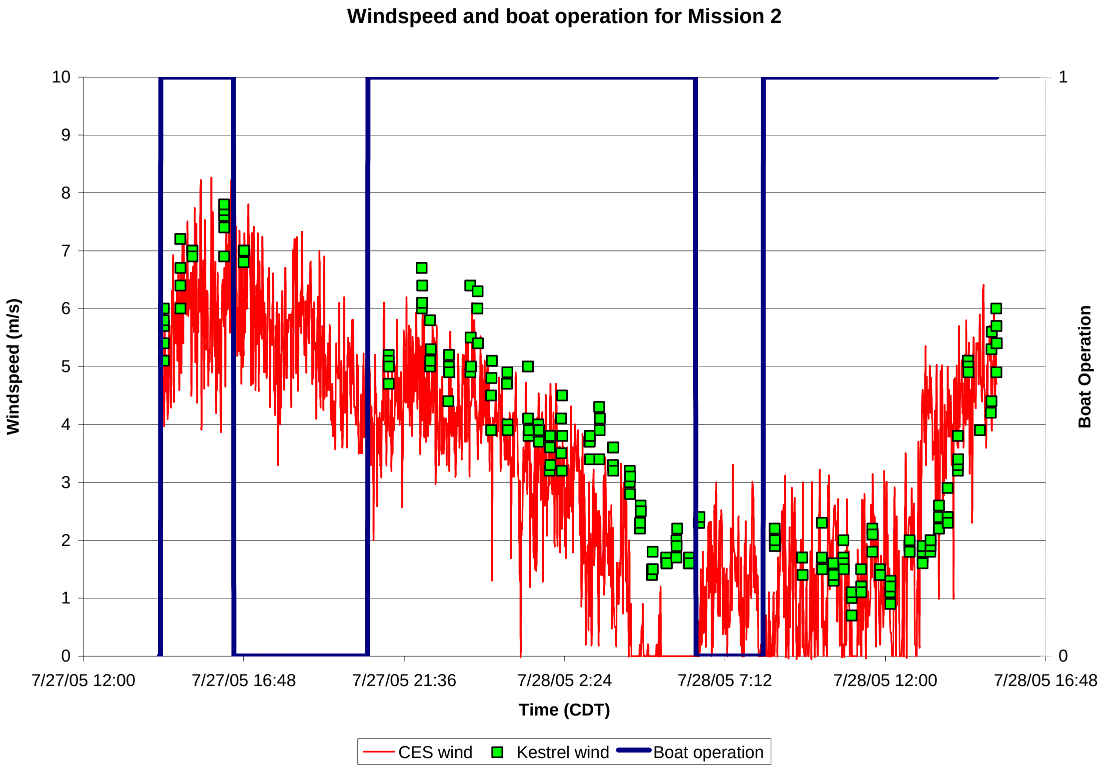


Figure 3-12 CES and Kestrel wind data for Mission 2 (Location Weather2), with boat operation times

Locations

The documentation of a dense underflow during Mission 1 motivated the creation of transects shown on Figure 3-14. The route that was followed for Mission 2 is plotted on Figure 3-13. The new sampling locations (A101, A102, A103 and A105) and the route were chosen in order to be able to study two transects perpendicular and one parallel to Laguna Madre.

Key findings from Mission 2

The decreased distance between sampling locations, associated with a decreased number of deployments at each location and time (3 deployments planned instead of 4) and with increased experience in the use of the equipment led to increased efficiency. Thirty-seven sites were sampled in 3 days during mission 1; forty-seven sites were sampled in two days during mission 2.

Figure 3-15 shows the wind data that was recorded by the three weather stations (CES, Kestrel and TCOON) during Mission 2. Visual analysis of the curves shows that the data are in good agreement. As a consequence it was decided to use TCOON data for analysis, as it is the only set of data that was consistently recorded during all missions.

The maximum wind speed that we found comfortable for launching the SCAMP in Corpus Christi Bay was approximately 7 m/s, based upon data recorded by the weather stations at on July 27th at 1600 hours. It was decided to use TCOON wind data in the SCAMP data processing because the visual agreement with two other wind datasets during Mission 2 and TCOON data is available for both first and second mission.

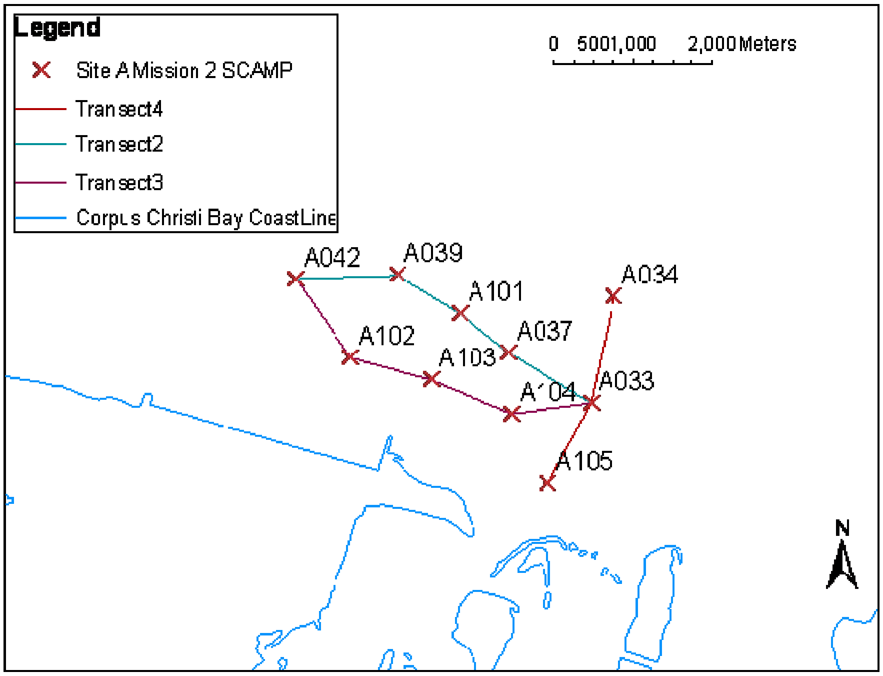


Figure 3-14 Transects studied during mission 2

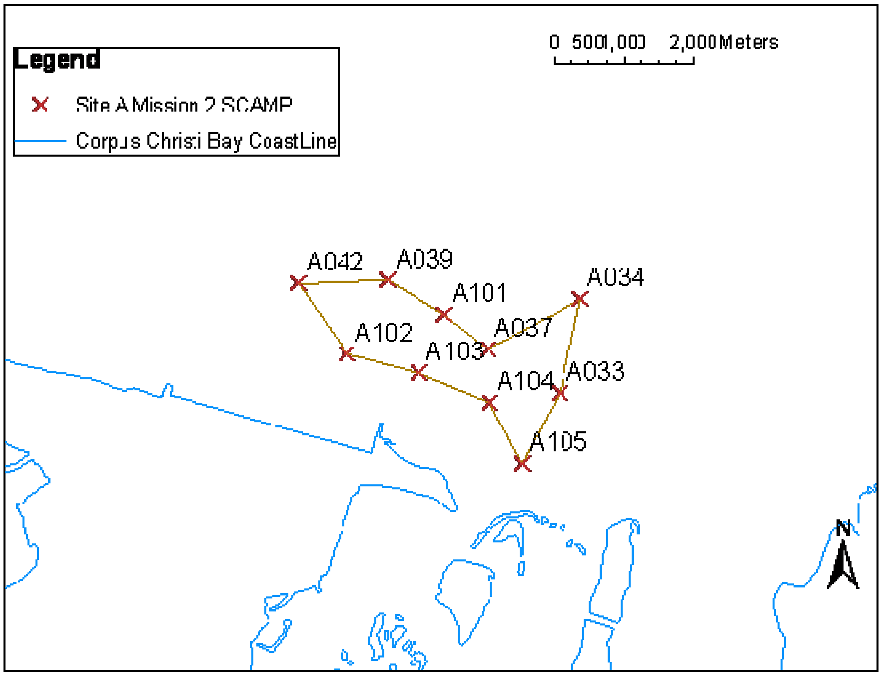


Figure 3-13 Route connecting sampled locations for Mission 2

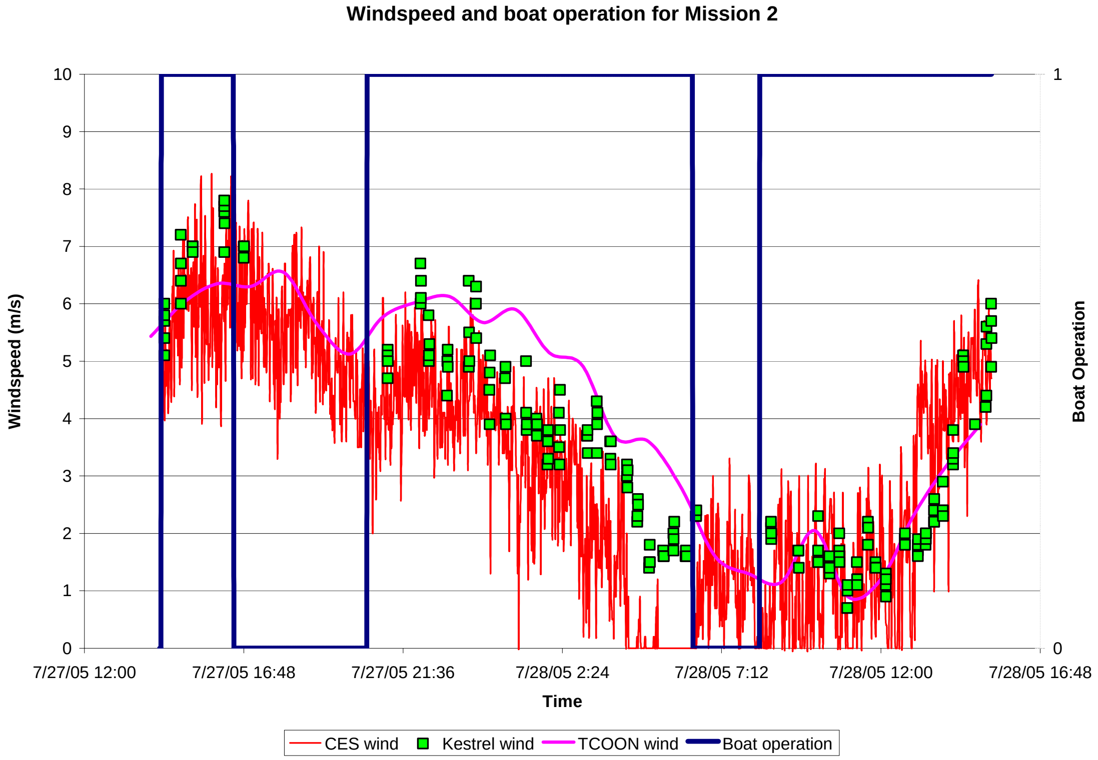


Figure 3-15 Wind data and boat operation for mission 2

3.3 Mission 3: 08/08/2005 – 08/10/2005 and Mission 4: 08/22/2005 – 08/24/2005

Only the Manta was deployed during mission 3 and 4. This thesis research is focused on SCAMP work and will only provide a basic description of the last two missions. The persons that participated in Mission 3 are Cédric David (UT), Jordan Furnans (TWDB), Ben Hodges (UT) and Keith Hodges (guest). During Mission 4, Shipeng Fu (UT), Jordan Furnans (TWDB), Ben Hodges (UT), Paula Kulis (UT), John Middleton (UT), Jessica Watts (UT), Holly Weynant (TWDB) and Terry Palmer (UTMSI) participated. The Manta, both GPS receivers and both weather stations were used. Figure 3-16 shows the area investigated during Missions 3 and 4.

3.4 Summary

This chapter described how and where measurements were taken in Corpus Christi Bay. The measurements provide with the basic material to reach research objectives: 1) document the temporal and spatial behavior of salinity and temperature near the outlet of Laguna Madre where hypoxia has previously been recorded, and 2) document the temporal and spatial behavior of salinity, temperature and oxygen near the outlet of Oso Bay. Oso Bay is where the proposed desalination plant outfall would be located.

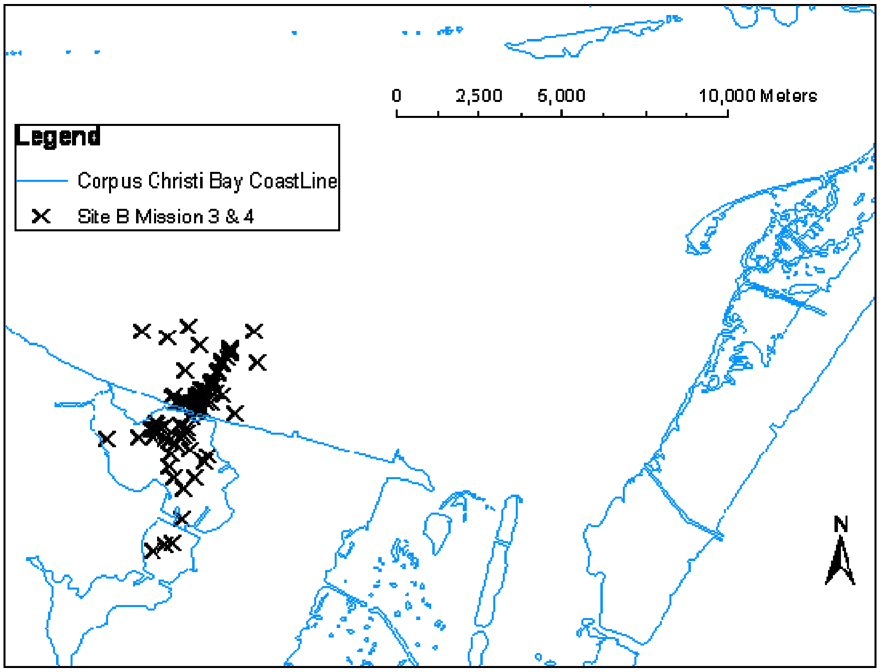


Figure 3-16 Area investigated during Missions 3 and 4

Chapter 4. Data processing

4.1 Introduction

The goal of this chapter is to portray the methods used for processing the data collected during the experiments. The emphasis is on how the experimental data was organized, scrubbed, filtered and plotted for analysis and interpretation. The data processing for data recorded with the Manta was created by Jordan Furnans at TWDB and will not be discussed in this thesis.

4.2 Parameters recorded or computed

4.2.1 Depth

"Depth" is used generically to denote the distance from the water surface to a measurement point that was sampled. "Water depth" is the distance from the water surface to the seafloor. All depths are expressed in meters (m).

4.2.2 Conductivity

Electrical conduction is an electrical phenomenon where a material (here water) contains movable particles with electric charge, which can carry electricity. When a difference of electrical potential is placed across a conductor, its movable charges flow, and an electric current appears. Conductivity is defined as the ratio of the current density to the electric field strength. It is the reciprocal of electrical resistivity. Electrical conductivity is a measure of how well a material allows the movement of electric charges. The SI derived unit is the Siemens (named after Werner von Siemens) per meter, Sm^{-1} (or A^{2}s^{3}m^{-3}kg^{-1}, where A is the SI base unit of electric current: ampere). According to measurements herein, a typical electrical conductivity for sea water in Corpus Christi Bay at the time of the study is 50 mS/cm (5 S/m). Discussion of the relationships linking conductivity and salinity in water will be given in Section 4.2.3.

4.2.3 Salinity

Salinity is the dissolved salt concentration of water (g salt/ kg water). In oceanography, it has been traditional to express salinity as concentration (mass of salt per unit mass of water) not as percent, but in parts per thousand (ppt or ‰), which is roughly equivalent to grams of salt per liter of water.

Salinity is now usually given in PSU or Practical Salinity Units. The Practical Salinity scale allows salinity to be measured by conductivity, and defines salinity in terms of the conductivity ratio of a sample to that of a solution of 32.4356 g of KCl at 15°C in a 1 kg solution. A sample of seawater at 15°C with conductivity equal to this KCl solution has a salinity of exactly 35 practical salinity units (PSU). SCAMP and Manta salinity measurements are given in PSU, whereas SCAMP measurements are in ppt.

4.2.4 Temperature

Temperature is a measure of the average kinetic energy of the particles in a sample of matter, in this study: water. In other words, temperature is a measure of activity and the frequency of collisions of molecules. Temperatures will be expressed here in Celsius °C.

4.2.5 Density

Density is a measure of mass per unit of volume. The SI unit of density is the kilogram per cubic meter (kg/m^3). In sea water, density is related to both salinity and temperature. Density increases with decreased temperature and/or increased salinity. Density differences due to higher salinities or lower temperatures are associated with gravity-driven underflows. During the course of this study the range of water temperatures recorded was 29.5 to 32 C and the range of salinity recorded was 32 to 42 PSU. Table 2 shows results of applying the UNESCO equation for density at constant pressure (UNESCO 1981) to the extremes of the parameter ranges. In the encountered climatic conditions, the influence of the salinity range on density (7.5 kg/m^3) is much higher than the effect of temperature on density (0.9 kg/m^3).

4.2.6 Temperature and conductivity gradients

Turbulent stirring increases the surface area between fluids with two different properties, which increases the mixing rate (*i.e.* diffusion depends on the gradient of the property and the area over which diffusion acts). Thus, the ability to measure the fine-scale gradients with fast-response sensors provides the ability to see the turbulent overturns that are stirring the fluid faster than it can diffuse. In this study, density stratification of the water column is due to temperature and conductivity (upon which salinity is computed) gradients. As a consequence, turbulent

Table 2 Change in water density with salinity and temperature according to the UNESCO equation

Temperature (°C)	Salinity (PSU)	Density (kg/m^3)	Δ (kg/m^3)
29.5	37	1023.4	0.9
32	37	1022.5	
30.75	32	1019.2	7.5
30.75	42	1026.7	

stirring can lead to small scale gradients of temperature and conductivity. At the microscale (order of 1 mm) high temperature and/or conductivity gradients are a sign for presence of active mixing in the stratified flow. However, all mixing occurs at the molecular level which occurs at very low diffusivities. T being the temperature, C the conductivity and z the depth, the mathematical definitions of the temperature gradients (°C/m) and conductivity gradients (S/m^2) are:

$$gradT = \frac{\partial T}{\partial z} \tag{1}$$

$$gradC = \frac{\partial C}{\partial z} \tag{2}$$

4.2.7 *Dissolved Oxygen concentration*

The dissolved oxygen (DO) concentration is the mass of gaseous oxygen dissolved in the water. DO is commonly expressed in mgL^{-1}. Oxygen gets into the water from mixing with the atmosphere and as a waste product of photosynthesis. Oxygen is also used by animals and plants. The combination of loading and use of oxygen influences its concentration. Hypoxia is defined based on DO concentrations. Ritter and Montagna (1999) have shown that the appropriate definition of hypoxia for Corpus Christi Bay is DO < 3 mgL^{-1}.

4.2.8 *Wind and tidal elevation*

Wind speed is the speed of movement of air relative to a fixed point on the Earth; it will be given in m/s in this study. Tidal elevation is the result of the regular rising and falling of water surface caused by changes in gravitational forces external to the Earth (mainly the Moon, but also the Sun and other celestial bodies). Tidal elevation will be given in meters (m) above the TCOON Ingleside station datum (see Section 2.4.4).

Both tidal elevation and wind are part of meteorological forcing, which is strong in Corpus Christi Bay (Ward 1980). Wind speed was measured by two weather stations (Kestrel 4100, CES weather station). Wind speed and tidal elevation were downloaded from TCOON.

4.3 SCAMP Data

A total of 314 SCAMP deployments were made during the two first field trips. With an average deployment to 3 m depth, an instrument resolution of 1 mm, and 21 data fields, this provides approximately 20 million data points. To ensure consistency of the data and facilitate their sharing, metadata (*i.e.* information on the data themselves) have been created. During the missions, log books were kept on the boats in order to record additional information on the measurements. Further information on the content of the log books and how they were translated into an electronic file can be found in Appendix E: Metadata.

Various types of files associated with SCAMP data were used for this thesis research. The "raw" data files (*.raw* filename extension) are the direct experimental data recorded by the instrument. The converted Matlab-format data files (*.mat* filename extension) are a copy of a reduced set of the original measurement files stored in a binary format that is easily loaded into Matlab. The converted files contain only the parameters that are the focus of this thesis (temperature, salinity, density, depth and temperature gradient). Picture files (*.jpg* filename extension) using the standard JPEG format are used for plots that have been created for data interpretation. Matlab scripts, functions and tools (*.m* filename extension) have been built to create the converted files and the figures.

All the file names are as self-explanatory as possible. Comments and summary of the programs are included in each file, and can be found in

Appendix J. The organization of the data processing can be sketched as shown in Figure 4-1.

The SCAMP provides 21 data fields. Nine fields are actual measurements and 12 are computed from the measurements. The nine measured fields are:

- Two fields for the fast temperature measurements,
- Two fields for the accurate temperature and conductivity,
- One field for the fast conductivity,
- One field for the photoactive radiation,
- One field for the fluorescence,
- One field for turbidity,
- One field for pressure.

For this thesis research, PAR, fluorescence and turbidity measurements were not analyzed. The measured parameters that are focused on (see Section 4.2) are temperature (two fast and one accurate temperature sensors) and conductivity (one fast and one accurate conductivity sensor) are directly measured. The purpose of the following is to shed light on how the other parameters (depth, density and salinity) were computed.

The water depth above the sensors is computed based upon the measurements of the pressure sensor itself (internal computation by the SCAMP). The instrument manufacturer calibrates the depth computation by using air pressure to press SCAMP's depth sensor. The calibration is based on depth for fresh water of constant density and is valid for up to 70 m. The relationship that is used is linear (*i.e.* the density is assumed to be constant), and given in the SCAMP manual.

$$D = k\,P \tag{3}$$

where D is the depth, P is the measured pressure and k is a coefficient. The SCAMP uses a combination of English and SI units, with pressure as psi and depth as m. For fresh water, $k = k_{fresh} = 0.7030696$ m/psi is the default SCAMP calibration. When depth is desired for different density, the coefficient k can be updated in the SCAMP through the user interface. For the present work the density correction was not made prior to taking measurements. A correction for the recorded freshwater depth to an equivalent saltwater can be computed as follows. The gage pressure at any depth is:

$$P = \int_D \rho g dz \tag{4}$$

where g is the gravitational constant. For a constant density, this is simply

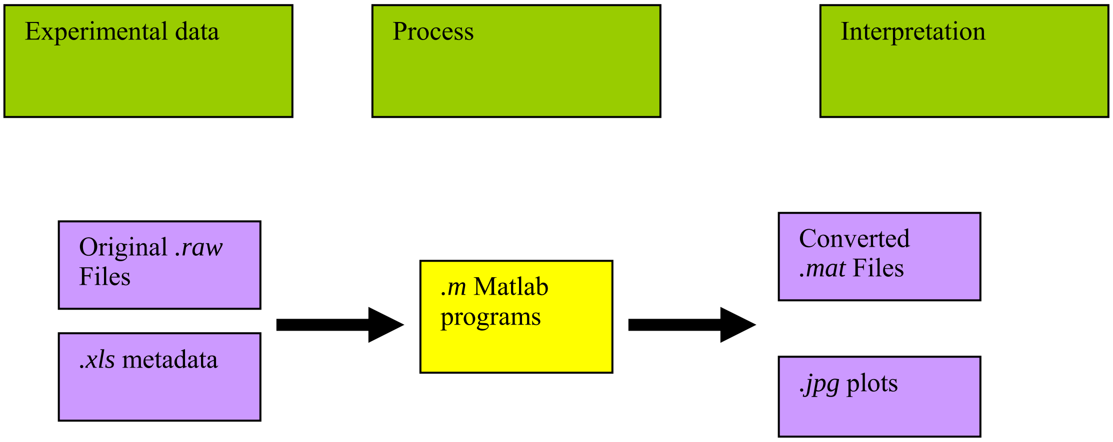


Figure 4-1 Organization of SCAMP data processing

$$P = \rho g D \qquad (5)$$

It follows that a consistently-dimensioned K can be defined as

$$K \equiv \frac{D}{P} = \frac{D}{\rho g D} = \frac{1}{\rho g} \qquad (6)$$

where K has the units m^2/Pa. The SCAMP coefficient 'k' is then

$$k = \frac{6894.757\,\mathrm{Pa}}{\mathrm{psi}} K \qquad (7)$$

Approximating the density of Corpus Christi Bay salt water as a constant value of 1023 kg/m^3 (which is correct within ±4 kg/m^3), the value for k_{salt} using eq. (7) is:

$$k_{salt} = 0.68729 m / psi \qquad (8)$$

The linear constant k_{salt} that is found is different from the constant k_{fresh} used in default SCAMP computation. It is possible to correct the depth measurements in the SCAMP processing. However, this was not done in the present work as the difference between k_{fresh} and k_{salt} generates the following error in the depth measurement:

$$\varepsilon_{\%} = 100 \times (1 - \frac{k_{salt}}{k_{fresh}}) = 2.30\% \qquad (9)$$

This error is equivalent to 6.9 cm at 3 m depth. The 2.30% error translates into approximately 2.30 % error in the gradients computation.

Matlab Executable (MEX, see Appendix F) modules were coded by PME. In the MEX files, salinity (ppt) and density are computed from temperature and conductivity (by *S_SAL.m* and *S_SIGT.m* functions respectively). The computations of both salinity and density use the equations for sea water neglecting pressure effects (UNESCO 1981).

The data format (*.raw*), data processing and display software provided with the SCAMP are not suitable for concurrent analysis of multiple profiles. As part of the present research, a method of saving the data in a custom Matlab file (*.mat*) and new display software were developed. The Matlab file uses a vector format. Each element of the vector is a Matlab structure containing the sampling data from one SCAMP deployment (depth, temperature, temperature gradient, salinity, density: each is a separate vector). There are usually three to five elements (structures) in the main vector, corresponding to sequential deployments made at one location around the same time. All data files were converted to Matlab format.

Figure 4-2 shows the organization inside a typical Matlab file developed in this project. The name of the file (*2005_07_28_0822_Location105.mat*) is created with the date (here, July 28th 2005 at 0822 hours) when sampling started at the sampling location (here, location A105). Each of the *.mat* files contains a vector generically named Rawdata. Rawdata(1) to Rawdata(*n*) are the elements of the vector Rawdata, each corresponding to a SCAMP deployment (*n* is the number of profiles that were taken at location A105). Components of the Rawdata structure provide the raw data produced by the SCAMP. For example, Rawdata(1).FastT0 gives one of the two fast temperature profiles taken during the first deployment. Chapter 7 gives the meaning of all abbreviations.

Visual identification of anomalies at the start of a profile is possible. However the size of the data set makes it impractical to visually examine every profile and identify the appropriate starting point for a good profile. As a consequence an automated approach to filtering the data was created. Two options were examined for automated identification and removal of questionable data created in the initial deployment of the SCAMP. The first option was filtering the entire profile to remove data points outside of some multiple (two to three) of the standard deviation for temperature and conductivity in the bin. This approach proved unsuccessful as some profiles with active turbulence had large standard deviations of temperature and/or conductivity. Thus, the first approach removed some data that was deemed reliable. The second option was simply removing all measurements recorded above 10 cm depth. This data visually appeared to have some of the strongest differences between profiles and therefore was considered the most unreliable due to the instrument deployment method (see Section 2.4.1).

Several consecutive vertical profiles were taken at the same location. Averaging was done to provide confidence in the data, limit the number of vertical

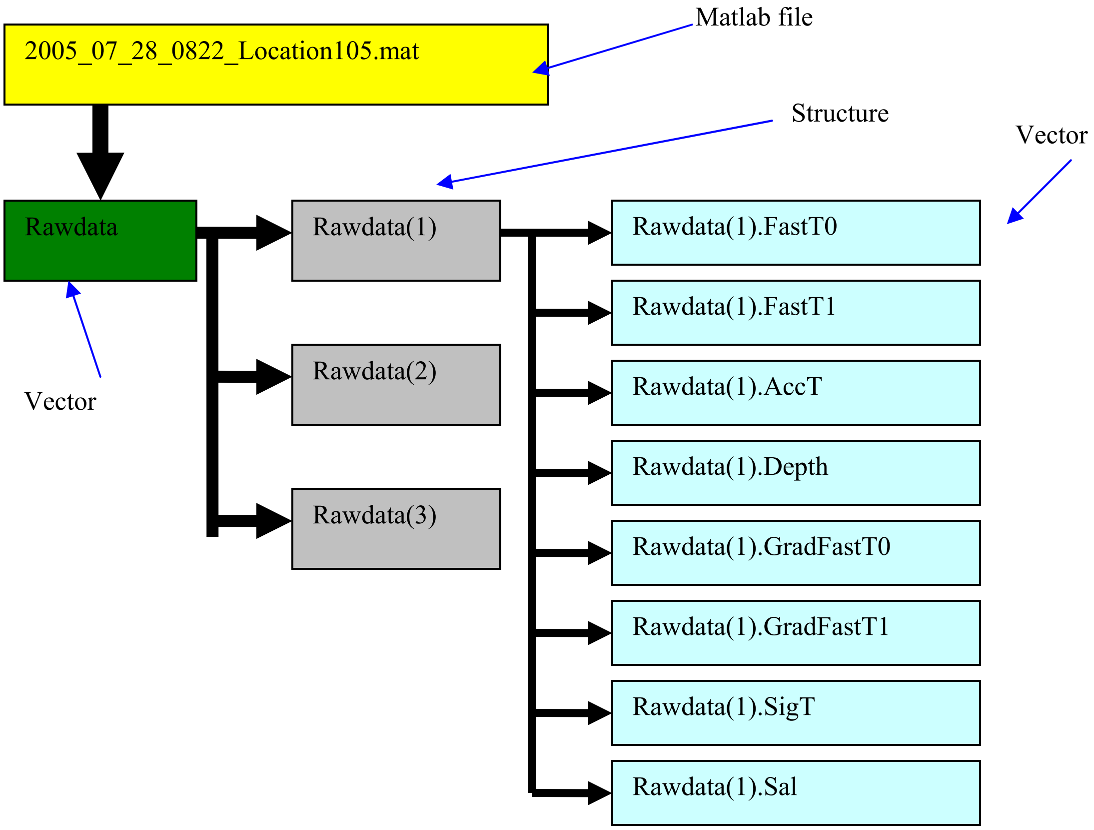


Figure 4-2 Organization of the Matlab files

profiles and facilitate the analysis. At each location and time, the average profile based on all available profiles was computed. The data were averaged in 5 cm bins starting at the water surface and proceeding down through the water column. The depth of the binned data is given at the center of the bin. For clarity, only two to three measurements per 5 cm bin are drawn in Figure 4-3, there are actually about 500 measurements per bin.

Plots were created to analyze the temporal and spatial changes in water column properties. Spatial transects and temporal variations are explained in Section Chapter 5.

Figure 4-4 summarizes the data processing procedure. Detailed explanations on the use of Matlab functions are given in Appendix J. Matlab functions are used to translate the SCAMP original files to figures suitable for analysis.

4.4 TCOON data

In 1989, the Conrad Blucher Institute for Surveying and Science (CBI) at Texas A&M University-Corpus Christi commenced the installation of a water-level measurement system in Corpus Christi Bay. The first systems installed provided real-time water level and meteorological data. This initial work motivated other state agencies (Texas General Land Office and the Texas Water Development Board) in contracting CBI to provide similar information for other areas along the Texas coast. Following a Texas Legislative mandate in 1991, this network of water level gauges became the Texas Coastal Ocean Observation Network (TCOON). As a result, TCOON expanded from an initial three stations in Corpus Christi in 1989 to over forty stations along the entire Texas coast by 1992. Matlab scripts were used in this thesis work to plot TCOON data with spatial transects and temporal evolutions created with SCAMP data.

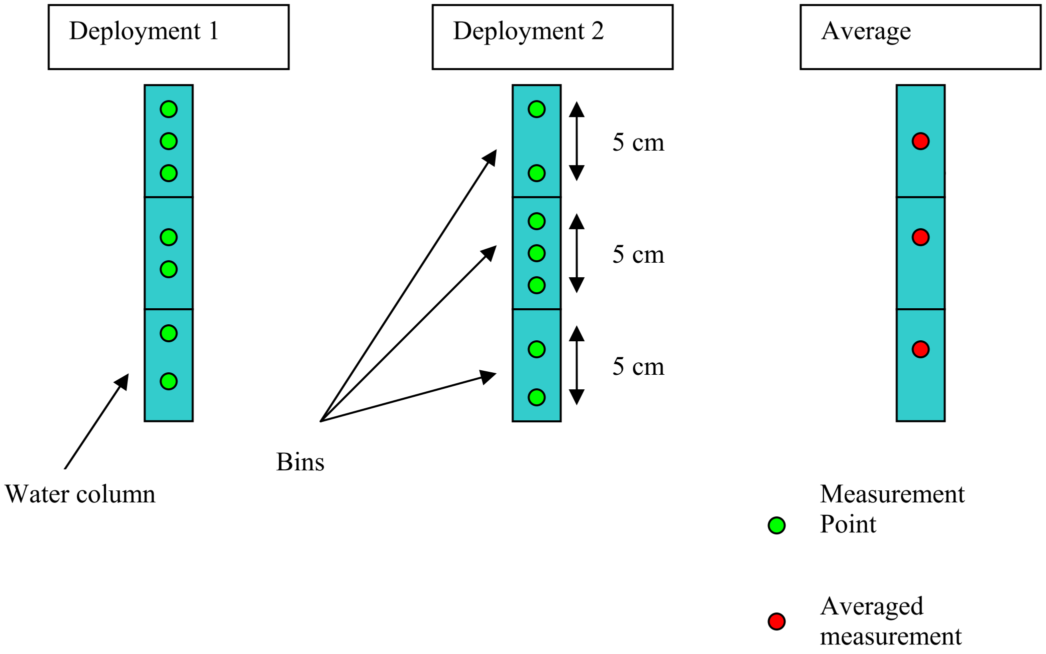


Figure 4-3 Binning and averaging

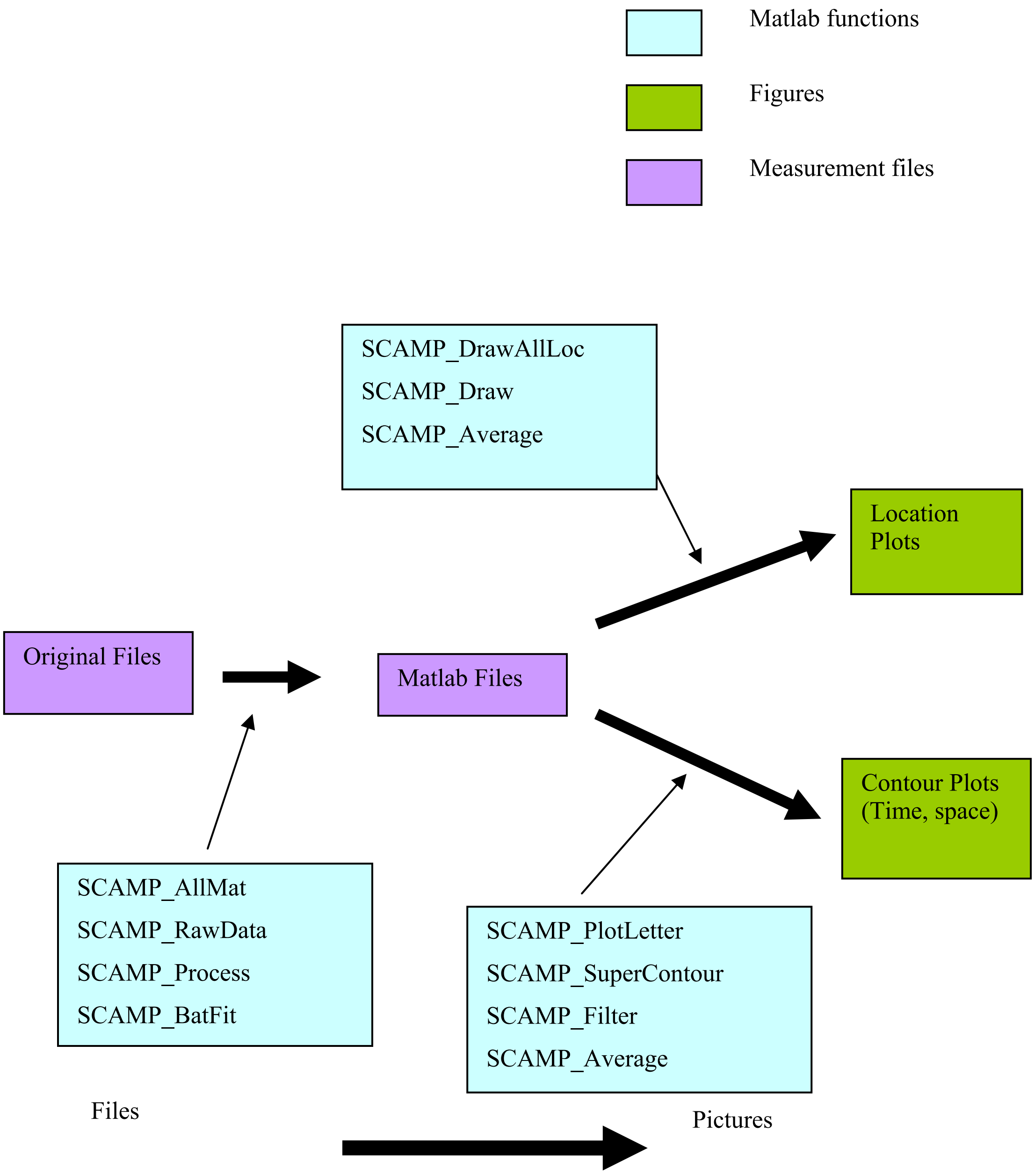


Figure 4-4 Summary of data processing

Chapter 5. Application of the data analysis methods

5.1 Introduction

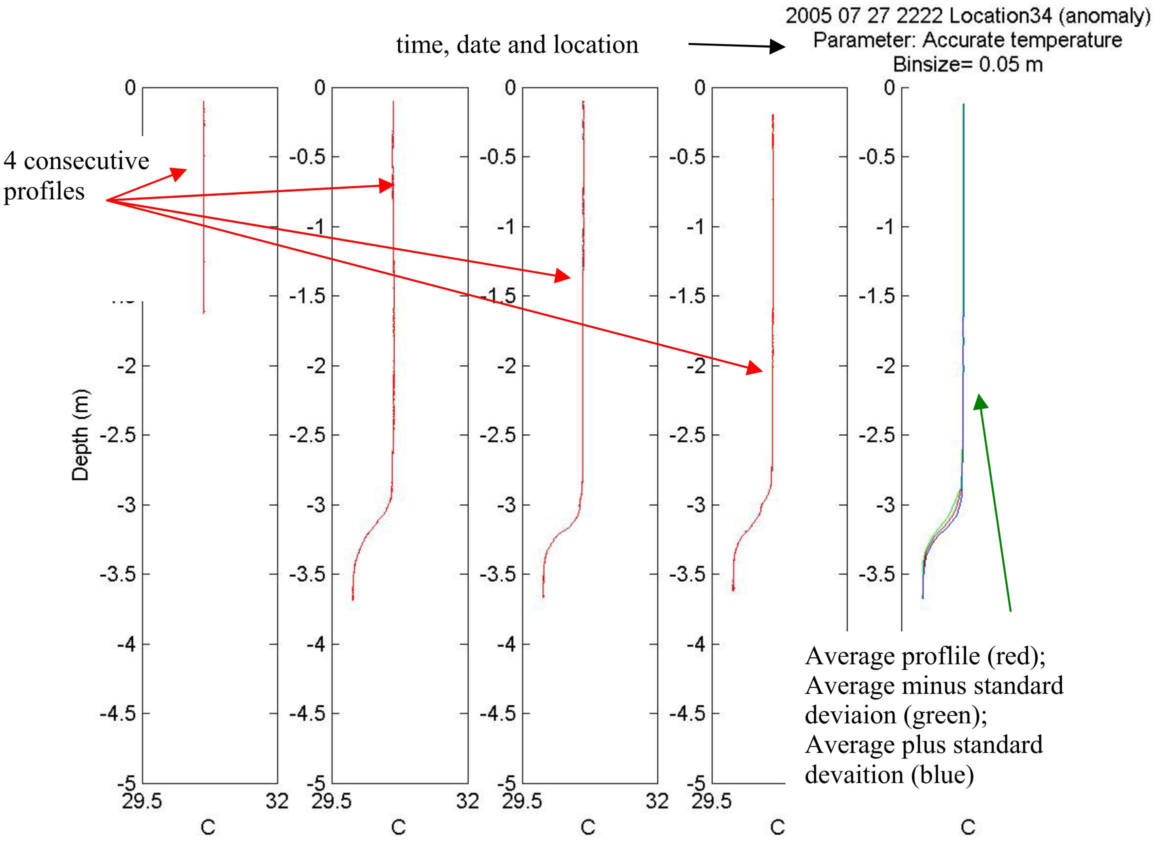
The purpose of this part is to provide and explain example figures that were created based upon the data analysis methods. The principal features, commonalities and differences that can be observed will be explained and associated with possible physical meanings. Additional profiles are provided in Appendix G, Appendix H and Appendix I.

5.2 Explanation of the figures

5.2.1 Figures at one location, with one parameter

Figure 5-1 shows data from four deployments executed between 2222 and 2231 hours on July 27th 2005 at location A034. The parameter plotted is accurate temperature (AccT). The size of the bins is 0.05 m.

The first profile is shorter than the others at this location, indicating the deployment was aborted prior to completion. Deployments were typically aborted when the drag plate retaining pin on the instrument was inadvertently pulled, the instrument's path was crossing under the boat, or the instrument recording was instigated prior to placement in the water. The filtering process has been by-passed in this figure, for explanation purposes. The low temperatures above 10 cm depth in the first profile are an indication of the instrument recording the air temperature when out of the water. It can be seen in the binned profile that the inclusion of these anomalous temperatures in the averages provides unreliable data. The sudden decrease of the temperature around 3 m deep is a sign of stratified water column. Other significant figures at one location can be found in Appendix G and Appendix H.



time, date and location

4 consecutive profiles

Average proflile (red); Average minus standard deviaion (green); Average plus standard devaition (blue)

Figure 5-1 One location and one parameter figure

5.2.2 Transects

Averaged profiles at nearby locations that were taken within several hours of each other can be combined to provide a transect that allows visualization of quasi-synoptic horizontal distributions of a property. As an example, Figure 5-2 shows data for the fifteen deployments starting at 0925 and ending at 1105 hours on July 28th 2005 at locations A033, A037, A101, A039 and A042 (transect 2). The deployments moving from left to right are increasing in time, so the warming of the near- surface water may be due to time as well as space. The salinity field appears to show an intrusion that is stronger to the left and weaker to the right. The temperature inversion at the bottom indicates that the high salinity water probably originated in a location and time where warm salty water is created by evaporation.

A set of formats for displaying the data was developed to allow analysis, comparison and graph for transects of SCAMP data. The driving forces (wind and tides) are placed at the top of the figure. The wind speed and tidal elevation data are TCOON data. The vertical bars on the wind speed and tides figure indicate the start and end time of the experiments. The binned average of the absolute value of temperature gradient profile, and its standard deviation for each location are plotted in the middle. Finally, contours of averaged accurate temperature and average salinity are plotted along the cross section. On the contours, the distance between each location is proportional to the actual distance *in situ*. The averaging is done over all deployments at each location.

5.2.3 Temporal evolution at one location

Averaged profiles at one location that were taken within several hours of each other can be combined to provide a contour of temporal evolution of a property over a short period of time (several hours to a day). As an example, Figure 5-3 shows data for the sixteen deployments taken at location A037 on July 7th 2005; at 0754, 1005, 1220 and 1420 hours. The deployments moving from left to right are increasing in time, the warming of surface water between morning (left hand side) and early afternoon (right hand) is clearly noticeable. The salinity field appears to be quite steady. The binned average of the absolute value of the temperature gradient shows peaks at the depth (approximately 2.5 m) where temperature stratification appears (at 1220 and 1420 hours). The same set of format for displaying the data was used for temporal evolution and spatial transects.

5.3 Availability of the data

The experimental data, the programs created for the purpose of this thesis as well as the three types of figures (location figures, space transects and temporal evolution) are saved on a CD and kept by Ben Hodges (hodges@mail.utexas.edu).

5.4 Efficiency of the software

The computer used for this thesis work is a Motion Computing M1200 with a Mobile Intel Pentium III 933 MHz processor and 1 GB of RAM. On this machine, plotting one single deployment profile using the PME software takes approximately 23 s. Using the software that were developed for this thesis work, it takes 52 s to plot multiple profiles for a transect with 17 deployments, averaged and filtered, with wind and tides plots. The data processing developed for this thesis is more suitable for concurrent analysis of multiple profiles, and around 7.5 times less time consuming.

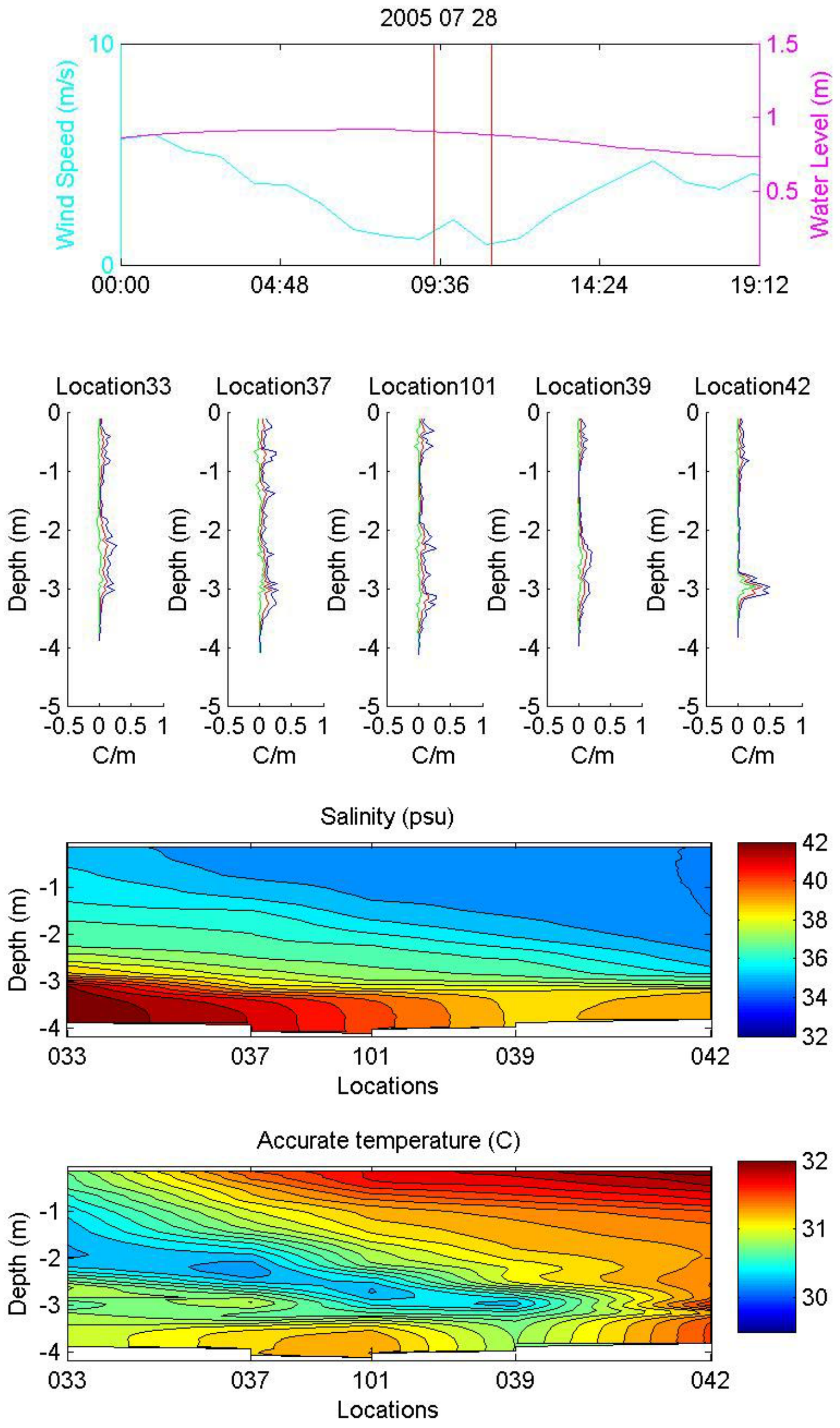


Figure 5-2 Spatial transect: Transect 2, on July 28th between 0925 and 1110 hours

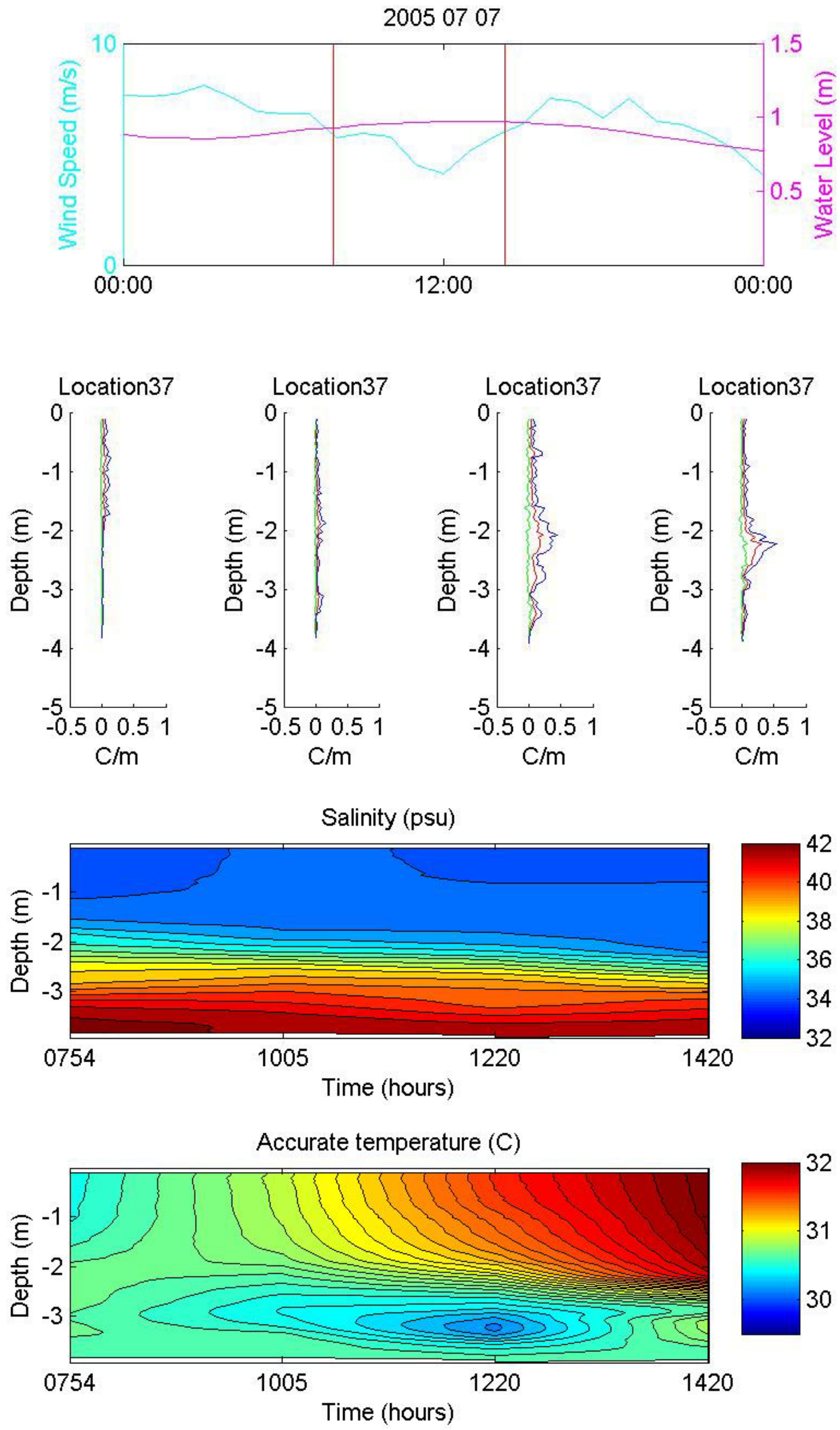


Figure 5-3 Temporal evolution at one location, Location A037 on July 07th between 0754 and 1420 hours

Chapter 6. Accomplishments

6.1 Summary

The first research objective was to document the temporal and spatial behavior of salinity and temperature near the outlet of Laguna Madre (Site A) where hypoxia has previously been recorded. Sampling was conducted during missions 1 and 2, with special emphasis on two transects parallel to the shoreline. Site A included positions previously sampled by UTMSI and newly identified positions. Short time scale data (few hours to a day) over small horizontal distances (less than 5 km) were gathered to enable the study of both spatial and temporal changes. Four spatial transects were studied with relatively close instrument deployments (700 m to 1 km between neighbor locations). Display methods for temperature, salinity, wind and tidal elevation data were developed to help future analysis of the physical processes. Metadata were created to ensure consistency and facilitate the sharing of the data.

The second research objective was to develop new data processing, and display methods for the SCAMP microstructure profiler. The data format (*.raw*), processing and display software provided with the SCAMP are not suitable for concurrent analysis of large numbers of multiple profiles. A methodology was developed for analyzing, comparing and graphing the datasets for transects of SCAMP data. SCAMP experimental data was converted and recorded in a Matlab file. Matlab programs were developed in order to average, filter and graph multiple SCAMP profiles and contours. The new software is about 7.5 times less time-consuming than the original software for displaying data.

6.2 Suggested future work

The research related to this thesis is ongoing at the Center for Research in Water Resources. The work described in this section could help improve the understanding of the phenomena studied:

- Visual analysis of the profiles at a given location and time led to the conclusion that three profiles were sufficient to provide description of the water column. An actual statistical analysis on binned profiles could help support this hypothesis.
- Further studies on the meaning of binned average temperature gradient could provide with a way to statistically quantify and relate stratification to mixing.
- Comparison of the DO data provided by the Manta and the SCAMP data from mission 2 could help connect hypoxia to stratification and/or dense underflows.

Acknowledgements

The work encompassed in this technical report was partially supported by Interagency Cooperation Contract 2005-001-059 between the University of Texas at Austin (Center for Research in Water Resources) and the Texas Water Development Board. Additional support on this project was provided by the Texas Higher Education Coordinating Board Advanced Technology Program Grant 003658-0162-2003. The contents of this technical report were originally submitted to the Department of Civil, Architectural and Environmental Engineering and the Graduate School at the University of Texas at Austin, as the M.S. Thesis for Cedric David, May 2006.

Chapter 7. Appendices

Appendix A. Abbreviations

AccC Accurate Conductivity

AccT Accurate Temperature

DO Dissolved Oxygen

FastC Fast Conductivity

FastT Fast Temperature

GradFastT Temperature gradient based upon the fast temperature sensors

GradFastC Conductivity gradient based upon the fast conductivity sensor

GIWW Gulf Intracoastal Waterway

Sal Salinity

SigT σ_T Density

TWDB Texas Water Development Board

UT University of Texas at Austin

UTMSI University of Texas Marine Science Institute

Appendix B. Table of GPS locations

Following are the GPS locations that were used for this study:

NAME	LAT	LONG
A001	27.813880	-97.140830
A002	27.797220	-97.150830
A003	27.783050	-97.146120
A004	27.781670	-97.176950
A005	27.767780	-97.194170
A006	27.750280	-97.195830
A007	27.732500	-97.200830
A008	27.715830	-97.203620
A009	27.693050	-97.211120
A010	27.713250	-97.180120
A011	27.728730	-97.173730
A012	27.743620	-97.166950
A013	27.764170	-97.157500
A014	27.695280	-97.191950
A015	27.773100	-97.165520
A016	27.762050	-97.180700
A017	27.742850	-97.184820
A018	27.747500	-97.181150
A019	27.722670	-97.189780
A020	27.734730	-97.186450
A021	27.737130	-97.207450
A022	27.715720	-97.192450
A023	27.704750	-97.198570
A024	27.695520	-97.202980
A025	27.722950	-97.177020
A026	27.703700	-97.185630
A027	27.738150	-97.170180
A028	27.754250	-97.161770

NAME	LAT	LONG
A029	27.723620	-97.212780
A030	27.705280	-97.220830
A031	27.698230	-97.220800
A032	27.693620	-97.229720
A033	27.704080	-97.230170
A034	27.716120	-97.227500
A035	27.731670	-97.226950
A036	27.723620	-97.239450
A037	27.709720	-97.239450
A038	27.702780	-97.252220
A039	27.718620	-97.252220
A040	27.731670	-97.252220
A041	27.731670	-97.257770
A042	27.718200	-97.263750
A043	27.708130	-97.277420
A044	27.722870	-97.277630
A045	27.691530	-97.224130
A046	27.824230	-97.139010
A101	27.714170	-97.245000
A102	27.709170	-97.257500
A103	27.706670	-97.248330
A104	27.702830	-97.239170
A105	27.695000	-97.235000
Weather1	27.671420	-97.174250
Weather2	27.697040	-97.182630
TCOON Ingleside	27.821667	-97.203333
PowerPlant	27.616667	-97.333333
BoatRamp	27.629320	-97.217980

Appendix C. Boats

Two boats were used for the field trips. The Texas Water Development Board owns a 17 feet long boat that has a 120 horse power engine.

The Center for Research in Water Resources (CRWR) owns a 14 feet long boat that has a 15 horse power engine.

Appendix D. Notes on SCAMP

The SCAMP is a very high definition measuring instrument. Learning how to use it has to be done through both reading of the very well written user's manual and trying it in actual experimental settings on a boat. The following few comments on its use associated to the user's manual might be valuable:

- **Cleaning of the sensors.** It has to be done after each day of measurements. De-ionized water should be used. Extra attention should be paid to the pressure sensor, which has to be rinsed softly (very fragile sensor) for at least 15 seconds.
- **Fluorometer and Turbidity sensor.** With the sensor set up that was used, the laser turbidity and chlorophyll fluorometer are linked. They cannot be used at the same time.
- **White plastic closure screw ring.** The closure ring can easily be wedged and impossible to unscrew without damaging it. Therefore, it should be greased with O-Ring grease whenever put back on. Also unscrew a quarter of a revolution when it has reached the maximum.
- **Conditions of use.** Due to the size of the instrument (approximately one meter), the SCAMP gives better results in at least 2 meters deep water.
- **Pens and trigger magnets.** These items are to be used very frequently during measurements; they are also the easiest to lose. The magnet is used on the SCAMP to trigger the start of a measuring sequence. Pens are used with the log book. It can be very convenient to have them attached with a piece of string to the toolbox or the SCAMP stand.
- **Log book.** Solid log books are to be chosen, because they will suffer "extreme" conditions on the boats!

Appendix E. Metadata

During the missions, log books were kept on the boats, providing additional information on the measurements, such as:

- The actual GPS location at the sampling point,
- The start and end time of the measurement,
- The operator,
- The weather conditions on the water,
- Comments on the actual deployment of the instrument.

This information has been typewritten in an Excel file, in table format, with the following fields:

- Name of the SCAMP file,
- Location,
- Start and end time at this particular location,
- Time of the actual measurement,
- Desired latitude and longitude,
- GPS device,
- Actual GPS location,
- Operator,
- Whether or not the profile was aborted,
- Comments

The file *SCAMP_Journal.xls* containing all the metadata is provided with the measurement files. A ReadMe.txt file was also created to give explanation on the different files that are provided.

Appendix F. MEX files

The computations for salinity and density in the SCAMP software were coded (by PME) in C programming language, as routines or subroutines. MEX-files are a way to call custom C or FORTRAN routines directly from MATLAB as if they were MATLAB built-in functions. MEX-Files were used here in the computations because they have the ability to call large existing C or FORTRAN routines directly from MATLAB without having to rewrite them as M-files.

MEX stands for MATLAB Executable. MEX-files are dynamically linked subroutines produced from C or Fortran source code that, when compiled, can be run from within MATLAB in the same way as MATLAB M-files or built-in functions.

Appendix G. SCAMP accurate temperature Graphs

In Figure 7-1, the temperature profile on the first deployment show features at the surface that don't match with the two other deployments. No particular comment has been made on the log book for this deployment. Figure 7-2 and Figure 7-3 show interesting features in temperature variations in the water column. At the approximate depths of 3.2 and 3.5 meters respectively, colder water can be found above warmer water.

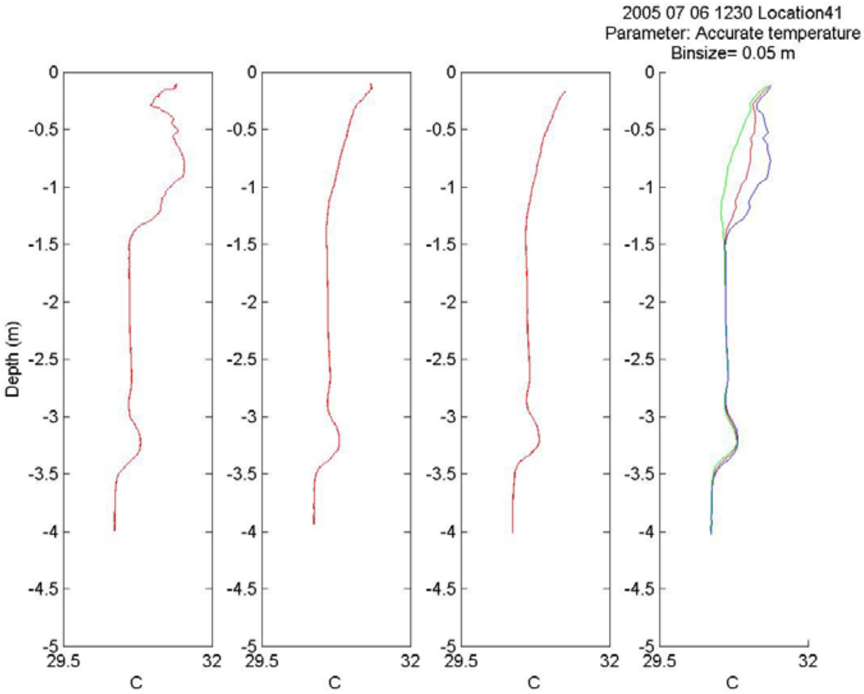


Figure 7-1 Anomaly in one of the deployments

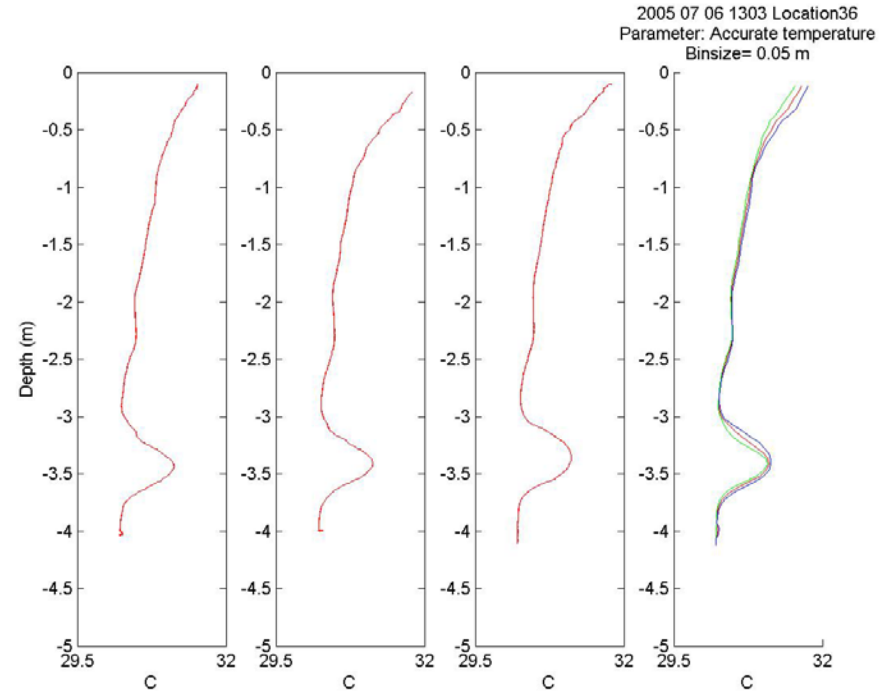


Figure 7-2 Interesting changes in temperature 1

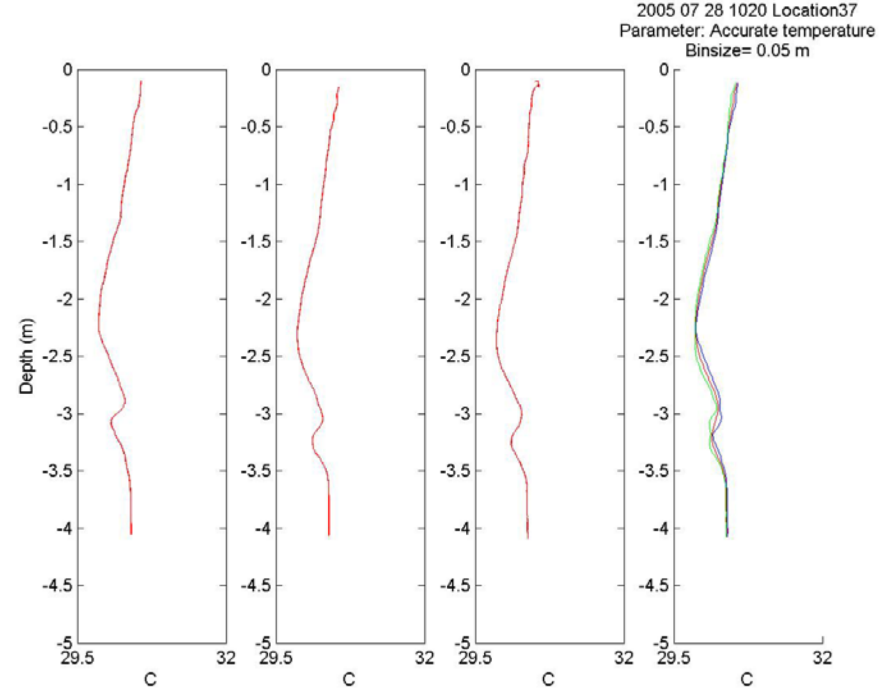


Figure 7-3 Interesting change in temperature 2

Appendix H. SCAMP salinity graphs

Figure 7-4 and Figure 7-5 show sudden changes in the salinity profiles, evidences of highly stratified water column.

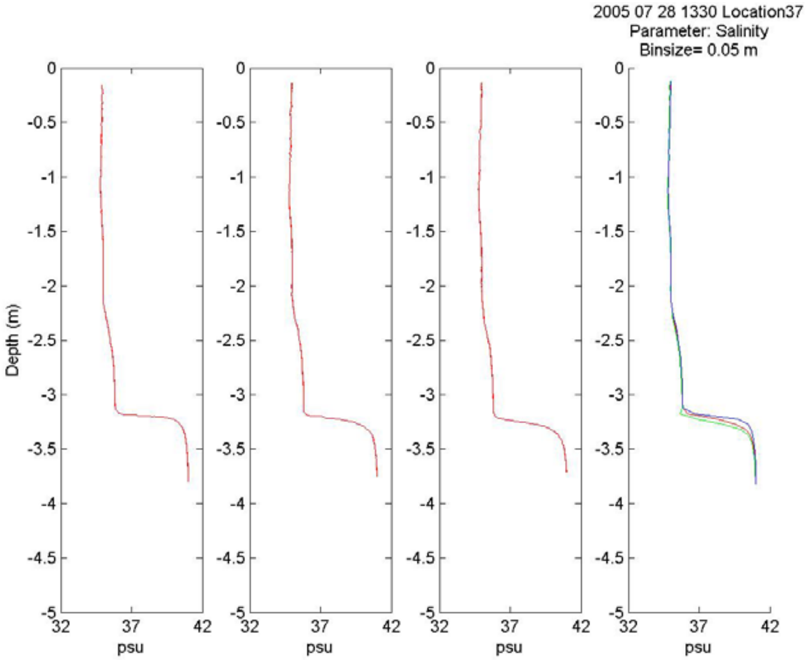


Figure 7-4 Sudden change in the salinity profile 1

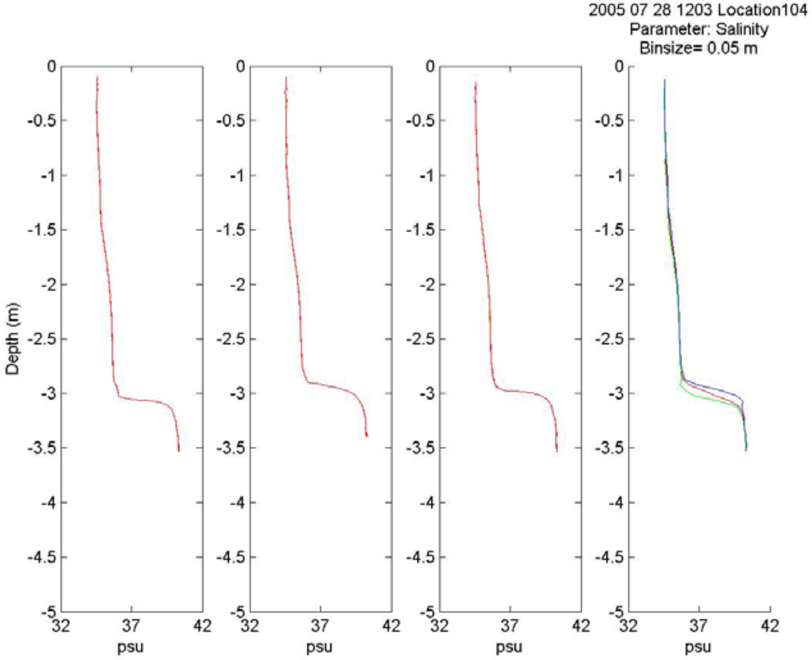


Figure 7-5 Sudden change in the salinity profile 2

Appendix I. SCAMP spatial transects

Figure 7-6, Figure 7-7 and Figure 7-8 show the temporal evolution of Transect 1 between 0720 and 1325 hours on July 7th 2005. An intrusion of cold salty water appears at 0945 and is bigger at 1145 hours. Figure 7-9 shows Transect 3 on July 28th between 0309 and 0606 hours. On this spatial transect, warmer water can be found underneath colder water.

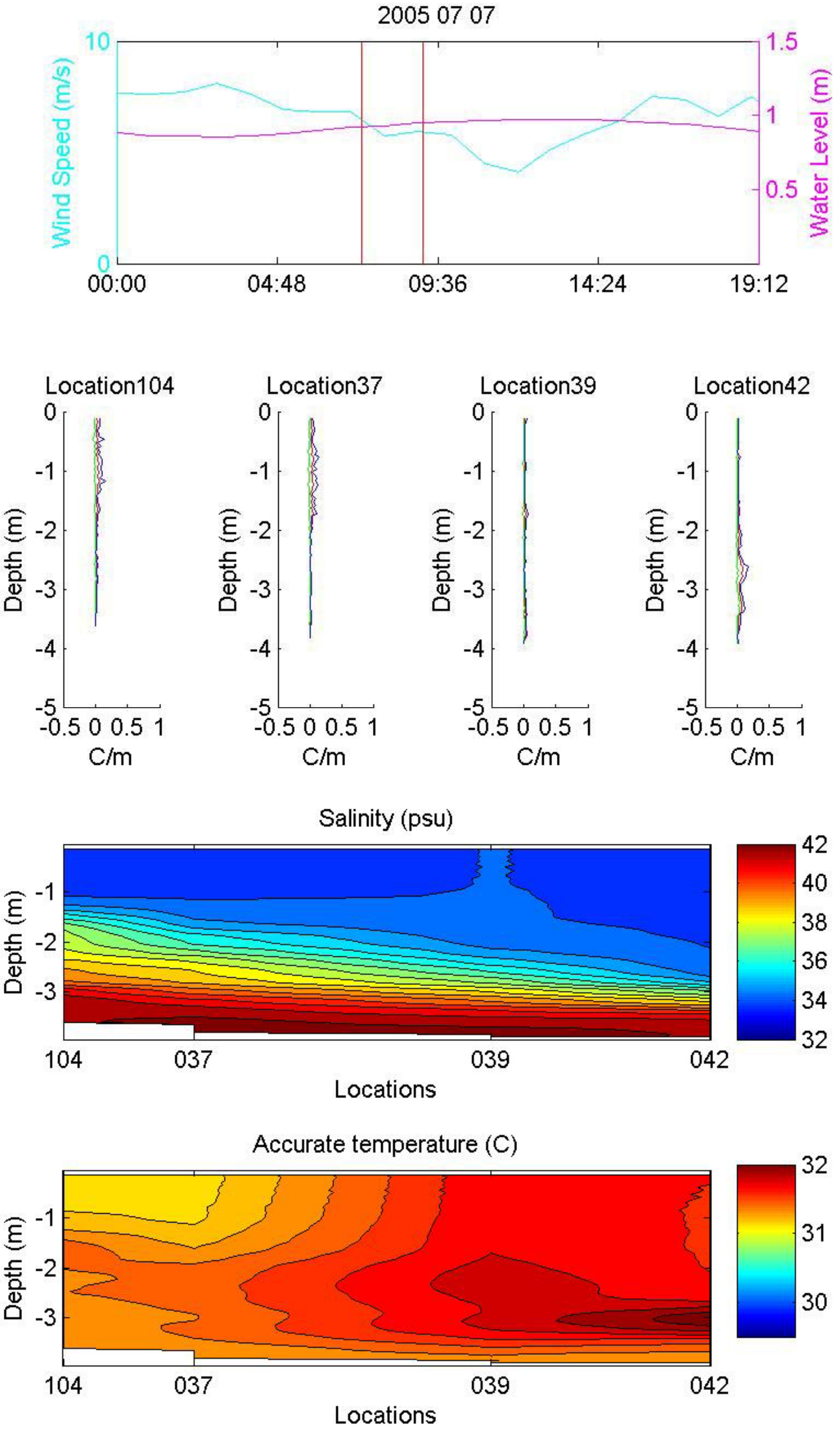


Figure 7-6 Transect 1; July 7th 2005, between 0720 and 0910 hours

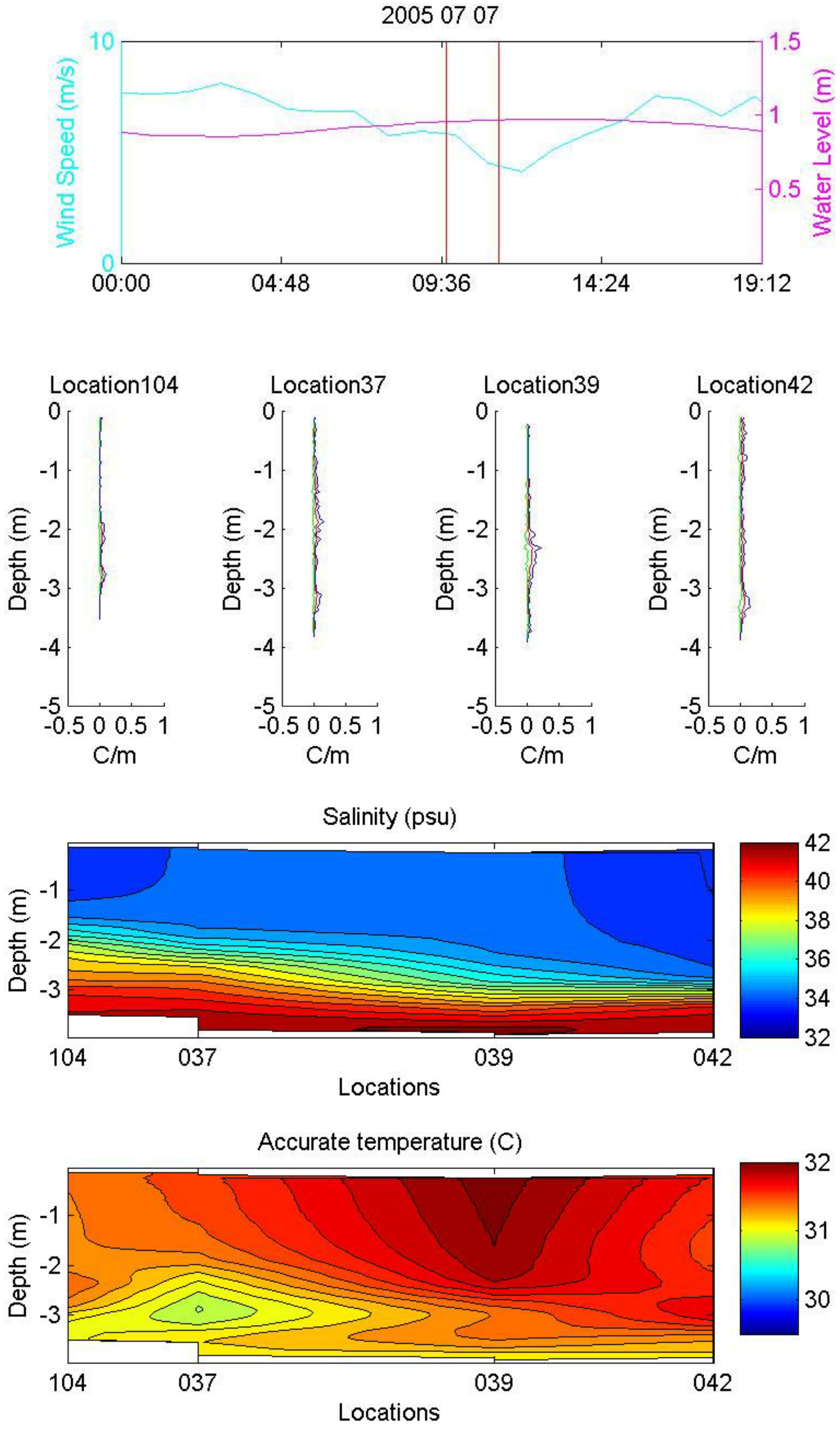


Figure 7-7 Transect 1; July 7th 2005, between 0945 and 1120 hours

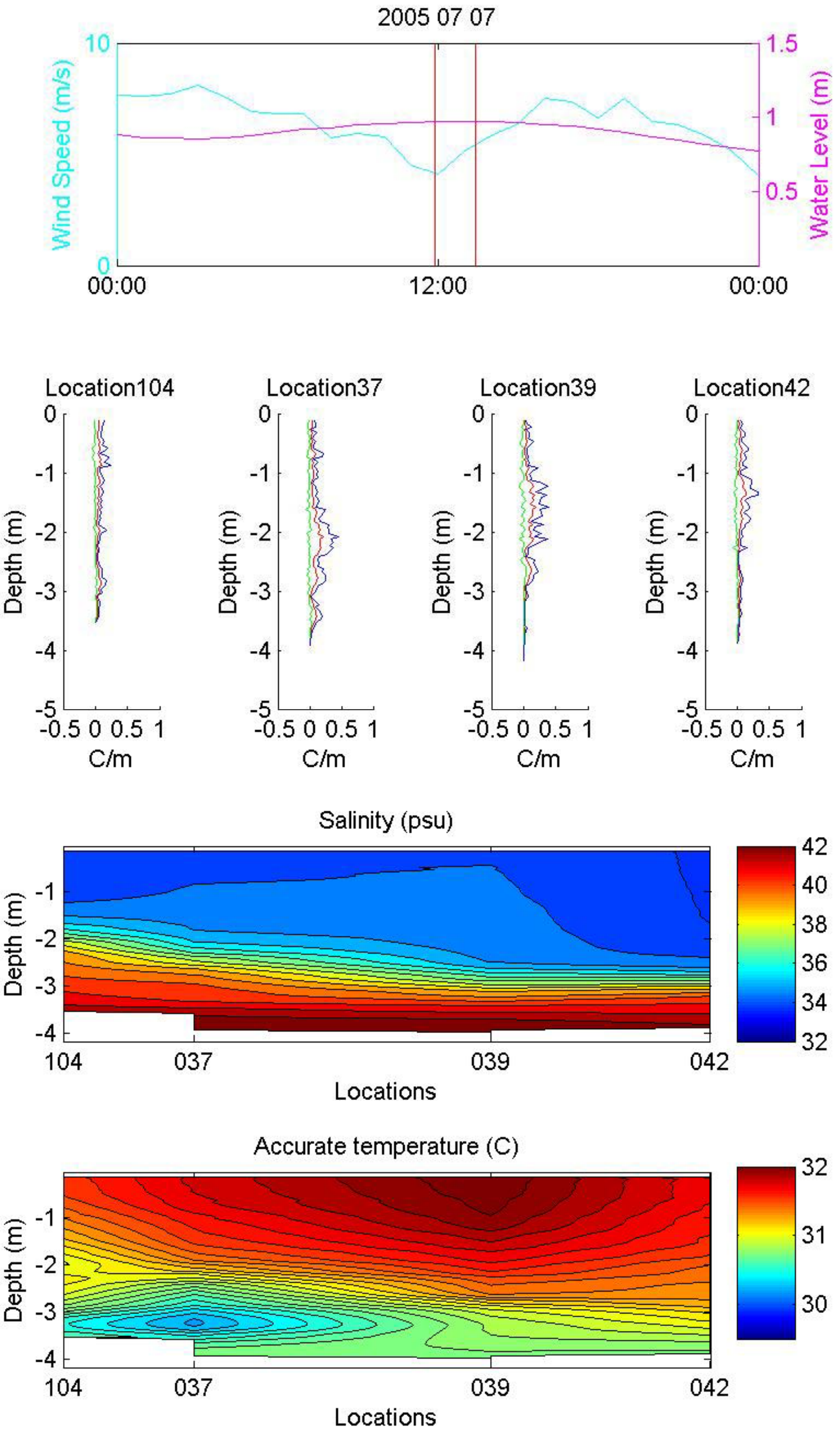


Figure 7-8 Transect 1; July 7th 2005, between 1155 and 1325 hours

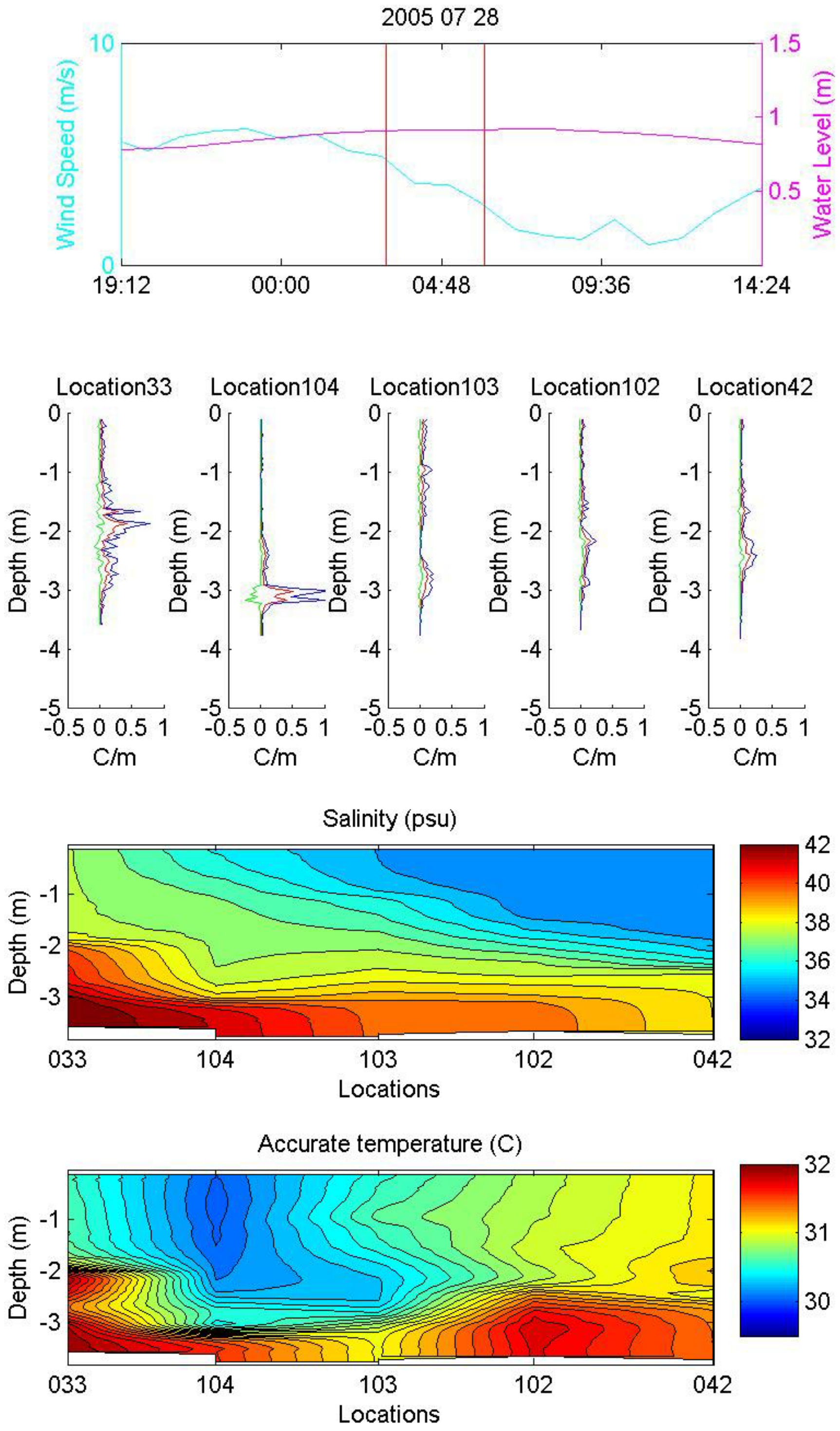


Figure 7-9 Transect 3; July 28th 2005, between 0309 and 0606 hours

Appendix J. Matlab Functions

Following are the Matlab functions and scripts that were used in order to process the data. The first lines of each program describe its use.

SCAMP_Rawdata

```
function rawdata = SCAMP_RawData(TextFile)
%%% SCAMP_RawData = SCAMP_RawData(TextFile)
%%% rawdata is a vector which elements are structures.
%%% Each structure corresponds to one deployment of the SCAMP.
%%% Example:
%%% rawdata(1) =  - Depth       --> Vector
%%%               - FastT0      --> Vector
%%%               - FastT1      --> Vector
%%% rawdata(2) = etc.
%%%
%%% This function prompts for a text file (textfile.txt) containing the name
%%% of the .raw files that are to be added to the vector rawdata.
%%% It returns the vector rawdata and saves it in a .mat file
%%% (textfile.mat)
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_Process
%%% called by: SCAMP_AllMat
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%If used as a function-----------------------------------------------------
FileName=importdata(TextFile);
iimax=length(FileName);
%-------------------------------------------------------------------------

%Choice of the text file summurizing the .raw files------------------------
% TextFile=uigetfile('*.txt','Select Text File');
% FileName=importdata(TextFile);
% iimax=length(FileName);
%-------------------------------------------------------------------------

%OR Choice of the .raw files separately------------------------------------
% FileName=uigetfile('*.raw','Select SCAMP Profiles','MultiSelect','on');
% iimax=length(FileName);
%-------------------------------------------------------------------------

%Creation of ChanEU_i and ChanName_i for each file-------------------------
for ii = 1:iimax
    myfile = char(FileName{ii});
    SCAMP_Process;
    thischan = ['ChanEU_',num2str(ii)];
    eval([thischan,' = ChanEU;']);
    %ChanEU_1 = ChanEU;
    thisname = ['ChanName_',num2str(ii)];
    eval([thisname,' = ChanName;']);
    %ChanName_1 = ChanName;
end
%-------------------------------------------------------------------------

%Creation of the rawdata structure-----------------------------------------
```

```
for ii=1:iimax
   thisprofile = eval(['ChanEU_',num2str(ii)]);
   rawdata(ii).FastT0=thisprofile{1};
   rawdata(ii).FastT1=thisprofile{2};
   rawdata(ii).FastC=thisprofile;
   rawdata(ii).AccT=thisprofile{6};
   rawdata(ii).Depth=thisprofile{15};
   rawdata(ii).GradFastT0=thisprofile{17};
   rawdata(ii).GradFastT1=thisprofile{18};
   rawdata(ii).SigT=thisprofile{35};
   rawdata(ii).Sal=thisprofile{36};
end
%----------------------------------------------------------------------

%Saving the rawdata structure in a .mat file------------------------------
Name=strrep(TextFile, '.txt', '');
save(char(['D:\+Research\Data\#.mat Files\',Name,'.mat']),'rawdata');
%----------------------------------------------------------------------
```

SCAMP_AllMat

```
function out=SCAMP_AllMat(TextTextFile)
%%% SCAMP_AllMat = SCAMP_AllMat(TextTextFile)
%%%
%%% This function prompts for a text file (texttextfile.txt) containing the
%%% name of the text files corresponding to the deployments at each
%%% location. It then calls the function SCAMP_RawData at every location
%%% and creates the corresponding .mat file in a specified folder.
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_RawData
%%% called by: N/A
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%Reads the text file containing the textfiles names-----------------------
TextFile=importdata(TextTextFile);
%----------------------------------------------------------------------

%Number of locations-----------------------------------------------------
jjmax=length(TextFile);
%jj is the index number for locations
%----------------------------------------------------------------------

%Creation of all the .mat files (for each location)-----------------------
for jj=1:jjmax
   SCAMP_RawData(TextFile{jj});
end
%----------------------------------------------------------------------
```

SCAMP_Average

```
function [outmean,outstd,outdepth]=SCAMP_Average(rawdata,datafield,binsize)
%%% [outmean,outstd,outdepth] = SCAMP_Average(rawdata,'datafield',binsize)
%%% rawdata is a vector of structures which one field (datafield) is to be
%%% averaged.
%%% rawdata(1) =  - Depth       --> Vector
%%%               - FastT0      --> Vector
%%%               - FastT1      --> Vector
%%% rawdata(2) = etc.
```

```
%%%
%%% binsize is the size, in meters of each bin
%%% outmean is the computed average
%%% outstd is the standard devation
%%% outdepth is a vector with depth points (1/2 interval), in meters
%%%
%%% designed for use with SCAMP output data
%%% calling: N/A
%%% called by: SCAMP_DrawAverage, SCAMP_SuperContour
%%% Cedric David
%%% University of Texas
%%% July 14, 2005

%ii variable for profiles to be average
%jj variable for bins

%To get the value of the parameter "absolute"----------------------------
[lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield)
%----------------------------------------------------------------------

%Number of profiles-----------------------------------------------------
nnp=length(rawdata);
%----------------------------------------------------------------------

%Number of bins, as the maximum number of bins over all the profiles-------
for ii=1:nnp
    nbin(ii) = round(max(rawdata(ii).Depth)/binsize)+1;
end
nnbin=max(nbin);
%----------------------------------------------------------------------

%Building the intervals-------------------------------------------------
for jj=1:nnbin+1
    border(jj)=(jj-1)*binsize;
end

for jj=1:nnbin
    outdepth(jj) = 0.5*(border(jj) + border(jj+1));
end
%----------------------------------------------------------------------

%Selecting the datapoints position in the interval------------------------
for jj=1:nnbin
    concat=[ ];
    for ii=1:nnp
        sel{ii}=find((rawdata(ii).Depth>=border(jj))&(rawdata(ii).Depth<border(jj+1)));
        concat=[concat;rawdata(ii).(datafield)(sel{ii})];
    end
    conc{jj}=concat;
end
%----------------------------------------------------------------------


%Averaging--------------------------------------------------------------
for jj=1:nnbin
    if absolute
        outmean(jj) = mean_with_NaN(abs(conc{jj}));
        outstd(jj) = std_with_NaN(abs(conc{jj}));
    else
        outmean(jj) = mean_with_NaN(conc{jj});
        outstd(jj) = std_with_NaN(conc{jj});
```

```
    end
end
%------------------------------------------------------------------------
```

SCAMP_Filter

```
function rawdataf = SCAMP_Filter(rawdata,top,bot)

%%% SCAMP_Filter(rawdata,top,bot)
%%%
%%% This function removes the top and the bottom part of the measurements
%%% according to the user's needs. It can also remove the points that have
%%% big standard deviation although this part in not activated here.
%%%
%%% Designed for use with SCAMP output data
%%% calling N/A
%%% called by: SCAMP_SuperContour, SCAMP_Draw, SCAMP_DrawAverage
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%Finding fieldnames and number of fields-----------------------------------
Names=fieldnames(rawdata);
kkmax=length(Names);
%------------------------------------------------------------------------

%FNumber of profiles------------------------------------------------------
jjmax=length(rawdata);
%------------------------------------------------------------------------

%Bottom and top cuttoff----------------------------------------------------
for jj=1:jjmax
    posb=find(rawdata(jj).Depth>bot);
    post=find(rawdata(jj).Depth<top);
    for kk=1:kkmax
        vec=rawdata(jj).(char(Names(kk)));
        vec(posb)=NaN;
        vec(post)=NaN;
        rawdata(jj).(char(Names(kk)))=vec;
    end
end
%------------------------------------------------------------------------

%Eliminating the points with big std---------------------------------------
% for jj=1:jjmax
%     for kk=1:kkmax
%         vec=rawdata(jj).(char(Names(kk)));
%         pos=find(abs((vec-mean_with_NaN(vec)))>2*std_with_NaN(vec));
%         vec(pos)=NaN;
%         rawdata(jj).(char(Names(kk)))=vec;
%     end
% end
%------------------------------------------------------------------------

rawdataf=rawdata;
```

SCAMP_Draw

```
function SCAMP_Draw(MatFile,datafield,binsize)
%%% SCAMP_Draw(MatFile,datafield,binsize)
%%%
```

```
%%% This function plots all the profiles corresponding to the datafield and
%%% adds the average profile with standard deviation for the same datafield
%%% at the end.
%%% This function also saves the plot as a .jpg file in an appropriate
%%% folder.
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_Average, SCAMP_Filter
%%% called by: SCAMP_DrawAllLoc
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%Loading of the data corresponding to the location-------------------------
load(MatFile);
%---------------------------------------------------------------------------

%Cleans the name for proper appearance on plot-----------------------------
Name=strrep(MatFile,'_',' ');
Name=strrep(Name,'.mat','');
%---------------------------------------------------------------------------

%Number of profiles in rawdata----------------------------------------------
iimax=length(rawdata);
%---------------------------------------------------------------------------

%Filter and average---------------------------------------------------------
rawdataf=SCAMP_Filter(rawdata,0.1,10);
[outmean,outstd,outdepth]=SCAMP_Average(rawdataf,datafield,binsize);
%---------------------------------------------------------------------------

%define parameters related to datafield-------------------------------------
[lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield);
%---------------------------------------------------------------------------

%Plotting procedure---------------------------------------------------------
for ii=1:iimax
    subplot(1,iimax+1,ii)
    plot (rawdataf(ii).(datafield),-rawdataf(ii).Depth,'r');
    ylim([-5 0]);
    if ii==1
        ylabel('Depth (m)')
    end
    xlim(inter1);
    xlabel(uni)
    set(gca,'XTick',dist)
end

subplot(1,iimax+1,iimax+1)
hold on
plot(outmean,-outdepth,'r')
plot(outmean-outstd,-outdepth,'g')
plot(outmean+outstd,-outdepth,'b')
ylim([-5 0]);
xlim(inter2);
xlabel(uni)
set(gca,'XTick',dist)
title({Name;['Parameter: ',lab];['Binsize= ',num2str(binsize),' m']});
hold off
%---------------------------------------------------------------------------
```

```
%Saving the .jpg file----------------------------------------------------
Name2=strrep(MatFile,'.mat','');
saveas(gcf,char(['D:\+Research\Data\#.jpg Files\SCAMP\Location\',num2str(datafield),'_',Name2,'.jpg']));
%gcf is the number of the current figure
%-------------------------------------------------------------------------
```

SCAMP_Draw_AllLoc

```
function SCAMP_DrawAllLoc(TextMatFile,datafield,binsize)
%%% SCAMP_DrawAllLoc(TextMatFile,datafield,binsize)
%%%
%%% This function plots (using SCAMP_Plot) all the profiles corresponding
%%% to the datafield and adds the average profile with standard deviation
%%% for the same datafield at the end.
%%% It also saves the plot as a .jpg file in an appropriate folder.
%%% This is done for all the Locations using the list in a text file
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_Draw
%%% called by: N/A
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%Cleans the name to appear correctly in the plotting window----------------
Name=strrep(TextMatFile, '_',' ');
Name=strrep(Name, '.txt','');
%-------------------------------------------------------------------------

%Reads the text file containing the textfiles names------------------------
MatFile=importdata(TextMatFile);
%-------------------------------------------------------------------------

%Number of locations-----------------------------------------------------
jjmax=length(MatFile);
%-------------------------------------------------------------------------

%-------------------------------------------------------------------------
%jj is the index number for locations (=nbr of average profiles)
%-------------------------------------------------------------------------

%Plotting and Saving Procedure--------------------------------------------
for jj=1:jjmax
   close all;
   SCAMP_Draw(MatFile{jj},datafield,binsize);
end
%-------------------------------------------------------------------------
```

SCAMP_DrawAverage

```
function outstd=SCAMP_DrawAverage(MatFile,datafield,binsize)
%%% SCAMP_DrawAverage(MatFile,datafield,binsize)
%%%
%%% This function plots the average only
%%% adds the average profile with standard deviation for the same datafield
%%% at the end.
%%% This function also saves the plot as a .jpg file in an appropriate
%%% folder.
%%%
%%% Designed for use with SCAMP output data
```

```
%%% calling SCAMP_Average, SCAMP_Filter
%%% called by: SCAMP_PlotLetter
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%To test as script---------------------------------------------------------
% MatFile='2005_07_06_1047_Location39.mat';
% datafield='GradFastT1';
% binsize=0.05;
%-------------------------------------------------------------------------

%Loading of the data corresponding to the location-------------------------
load(MatFile);
%-------------------------------------------------------------------------

%Cleans the name for proper appearance on plot-----------------------------
Name1=strrep(MatFile,'_',' ');
Name1=strrep(Name1,'.mat','');
Name2=Name1(17:size(Name1,2));
%-------------------------------------------------------------------------

%Number of profiles in rawdata---------------------------------------------
iimax=length(rawdata);
%-------------------------------------------------------------------------

rawdataf=SCAMP_Filter(rawdata,0.1,10);
[outmean,outstd,outdepth]=SCAMP_Average(rawdataf,datafield,binsize);

%define parameters related to datafield------------------------------------
[lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield)
%-------------------------------------------------------------------------

%Plotting procedure--------------------------------------------------------
hold on
plot(outmean,-outdepth,'r')
plot(outmean-outstd,-outdepth,'g')
plot(outmean+outstd,-outdepth,'b')
ylim([-5 0]);
xlim(inter2);
set(gca,'XTick',dist)
xlabel(uni)
ylabel('Depth (m)')
title(Name2)
hold off
%title({Name;['Parameter: ',datafield];['Binsize= ',num2str(binsize)]});
%-------------------------------------------------------------------------
```

SCAMP_SuperContourS

```
function Cont=SCAMP_SuperContourS(TextMatFile,datafield,binsize)
%%% SCAMP_SuperContourS(TextMatFile,datafield,binsize)
%%%
%%% This function plots a contour filled figure of the files
%%% It also saves the plot as a .jpg file in an appropriate folder.
%%%
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_Filter and SCAMP_Average
%%% called by: SCAMP_PlotLetterS
%%% Cedric David
```

```
%%% University of Texas
%%% March 8, 2006

%To be tested as a script------------------------------------------------
% TextMatFile='2005_07_28_1258_1410_033_037_101_039_042.txt';
% datafield='Sal';
% binsize=0.05;
%------------------------------------------------------------------------

%Creation of the vector giving the contour values--------------------------
if (strcmp(datafield,'Sal'))
   col=32:.5:42;
elseif strcmp(datafield,'AccT')
   col=29.5:.05:32;
else
   col=0:.5:100;
end
%------------------------------------------------------------------------

%Parameters corresponding to datafield------------------------------------
[lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield);
%------------------------------------------------------------------------

%Cleans the name to appear correctly in the plotting window----------------
Name=strrep(TextMatFile,'_',' ');
Name=strrep(Name,'.txt','');
%------------------------------------------------------------------------

%Reads the text file containing the textfiles names------------------------
MatFile=importdata(TextMatFile);
%------------------------------------------------------------------------

%Number of locations------------------------------------------------------
jjmax=length(MatFile);
%------------------------------------------------------------------------

%Creates a cell with the locations names to annotate the contour plots-----
for jj=1:jjmax
   annot{jj}=TextMatFile(22+(jj-1)*4:24+(jj-1)*4);
end
%------------------------------------------------------------------------

%computes the distance dist between the points----------------------------
load('GPS_Loc.csv')
dist=0;
lat=0;
long=0;
anglat=0;
anglong=0;

for jj=1:jjmax
   for kk=1:51
      if isequal(str2double(annot(jj)),GPS_Loc(kk,1))
         lat(jj)=GPS_Loc(kk,2);
         long(jj)=GPS_Loc(kk,3);
      end
   end
end

leng(1)=0;
dist(1)=0;
```

```
for jj=2:jjmax
    leng(jj)=6380*sqrt((tan((long(jj)-long(jj-1))*pi/180))^2+(tan((lat(jj)-lat(jj-1))*pi/180))^2);
    dist(jj)=dist(jj-1)+leng(jj);
end

%--------------------------------------------------------------------------
%jj is the index number for locations (=nbr of average profiles)
%ii is used as the scan number index
%kk is used as the GPS location index
%--------------------------------------------------------------------------

%Computation of the average profiles---------------------------------------
for jj=1:jjmax
    load(MatFile{jj});
    rawdataf=SCAMP_Filter(rawdata,0.1,10);
    [aa,bb,cc]=SCAMP_Average(rawdataf,datafield,binsize);
    meanstruct(jj).mean=aa;
    meanstruct(jj).std=bb;
    meanstruct(jj).depth=cc;
end
%--------------------------------------------------------------------------

%Max number of scans-------------------------------------------------------
for jj=1:jjmax
    nscan(jj)=length(meanstruct(jj).depth);
end
nnscan=max(nscan)
%--------------------------------------------------------------------------

%Finding the deeper depth--------------------------------------------------
depth=[];
for jj=1:jjmax
    if length(meanstruct(jj).depth)==nnscan
        depth=meanstruct(jj).depth;
    end
end
%--------------------------------------------------------------------------

%Normalization of the length of the average profiles-----------------------
for jj=1:jjmax
    for ii=1:nnscan
        if ii>length(meanstruct(jj).mean)
            meanstruct(jj).mean(ii)=NaN;
        end
    end
    meanstruct(jj).depth=depth;
end
%--------------------------------------------------------------------------

%Concatenating the profiles in a matrix------------------------------------
conc=zeros(nnscan,jjmax);
for jj=1:jjmax
    conc(:,jj)=meanstruct(jj).mean;
end
%--------------------------------------------------------------------------

%Plotting------------------------------------------------------------------
fig=contourf(dist,-depth,conc,col);
set(gca,'XTick',dist)
set(gca,'XTickLabel',annot)
xlabel('Locations')
```

```
% legend(datafield,'Location','NorthEast')
ylabel('Depth (m)')
colormap jet;
colorbar;
title([lab,' (',uni,')'])
% title({['Contour: ',Name];['Field: ',datafield];['Binsize (meters): ',num2str(binsize)]});
% saveas(gcf,char(['D:\SCAMP\Matlab\#SCAMP Files\#.jpg
Files\',num2str(datafield),'_',strrep(TextMatFile,'.txt',''),'.jpg']));    %gcf is the number of the current figure
%-----------------------------------------------------------------------
```

SCAMP_SuperContourT

```
function Cont=SCAMP_SuperContourT(TextMatFile,datafield,binsize)

%%% SCAMP_SuperContourT(TextMatFile,datafield,binsize)
%%%
%%% This function plots a contour filled figure of the files
%%% It also saves the plot as a .jpg file in an appropriate folder.
%%%
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_Filter and SCAMP_Average
%%% called by: SCAMP_PlotLetterT
%%% Cedric David
%%% University of Texas
%%% October 6, 2005

%To be tested as a script------------------------------------------------
% TextMatFile='2005_07_07_0720_1400_104_0720_0945_1155_1400.txt';
% datafield='AccT';
% binsize=0.05;
%-----------------------------------------------------------------------

%Creation of the vector giving the contour values-------------------------
if (strcmp(datafield,'Sal'))
   col=32:.5:42;
elseif strcmp(datafield,'AccT')
   col=29.5:.05:32;
else
   col=0:.5:100;
end
%-----------------------------------------------------------------------

%Parameters corresponding to datafield-----------------------------------
[lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield);
%-----------------------------------------------------------------------

%Cleans the name to appear correctly in the plotting window---------------
Name=strrep(TextMatFile,'_',' ');
Name=strrep(Name,'.txt','');
%-----------------------------------------------------------------------

%Reads the text file containing the textfiles names-----------------------
MatFile=importdata(TextMatFile);
%-----------------------------------------------------------------------

%Number of profiles at the same location---------------------------------
jjmax=length(MatFile);
%-----------------------------------------------------------------------

%Creates a cell with the locations names to annotate the contour plots-----
```

```
for jj=1:jjmax
    annot{jj}=TextMatFile(21+5*jj:24+5*jj);
end
%------------------------------------------------------------------------

%distance constont between each section of the plot-----------------------
dist=1:1:jjmax;
%------------------------------------------------------------------------

%------------------------------------------------------------------------
%jj is the index number for locations (=nbr of average profiles)
%ii is used as the scan number index
%------------------------------------------------------------------------

%Computation of the average profiles--------------------------------------
for jj=1:jjmax
    load(MatFile{jj});
    rawdataf=SCAMP_Filter(rawdata,0.1,10);
    [aa,bb,cc]=SCAMP_Average(rawdataf,datafield,binsize);
    meanstruct(jj).mean=aa;
    meanstruct(jj).std=bb;
    meanstruct(jj).depth=cc;
end
%------------------------------------------------------------------------

%Max number of scans-----------------------------------------------------
for jj=1:jjmax
    nscan(jj)=length(meanstruct(jj).depth);
end
nnscan=max(nscan)
%------------------------------------------------------------------------

%Finding the deeper depth------------------------------------------------
depth=[];
for jj=1:jjmax
    if length(meanstruct(jj).depth)==nnscan
        depth=meanstruct(jj).depth;
    end
end
%------------------------------------------------------------------------

%Normalization of the length of the average profiles----------------------
for jj=1:jjmax
    for ii=1:nnscan
        if ii>length(meanstruct(jj).mean)
            meanstruct(jj).mean(ii)=NaN;
        end
    end
    meanstruct(jj).depth=depth;
end
%------------------------------------------------------------------------

%Concatenating the profiles in a matrix-----------------------------------
conc=zeros(nnscan,jjmax);
for jj=1:jjmax
    conc(:,jj)=meanstruct(jj).mean;
end
%------------------------------------------------------------------------

%Plotting----------------------------------------------------------------
fig=contourf(dist,-depth,conc,col);
```

```
    set(gca,'XTick',dist)
    set(gca,'XTickLabel',annot)
    xlabel('Time (hours)')
    % legend(datafield,'Location','NorthEast')
    ylabel('Depth (m)')
    colormap jet;
    colorbar;
    title([lab,' (',uni,')'])
    % title({['Contour: ',Name];['Field: ',datafield];['Binsize (meters): ',num2str(binsize)]});
    % saveas(gcf,char(['D:\SCAMP\Matlab\#SCAMP Files\#.jpg
Files\',num2str(datafield),'_',strrep(TextMatFile,'.txt',''),'.jpg']));    %gcf is the number of the current figure
    %-------------------------------------------------------------------------
```

SCAMP_PlotLetterS

```
    function SCAMP_PlotLetterS(TextMatFile,TextWSD,binsize)
    %%% SCAMP_PlotLetterS(TextMatFile,binsize)
    %%%
    %%% This function plots tides and wind (from TCOON data), Contour plots at
    %%% the locations given in the matfile (salinity and temperature), and
    %%% average of Temperature gradient.
    %%% It also saves the plot as a .jpg file in an appropriate folder.
    %%%
    %%%
    %%% Designed for use with SCAMP output data
    %%% calling SCAMP_SuperContourS, SCAMP_DrawAverage, and PlotWeather
    %%% called by: N/A
    %%% Cedric David
    %%% University of Texas
    %%% March 8, 2006

    %To be tested as Script----------------------------------------------------
    % TextMatFile='2005_07_27_2157_0200_033_104_103_102_042.txt';
    % binsize=0.05;
    % TextWSD='WSD_CES.csv'
    %-------------------------------------------------------------------------

    %Cleans the name to appear correctly in the plotting window----------------
    Name=strrep(TextMatFile,'_',' ');
    Name=Name(1:10);
    %-------------------------------------------------------------------------

    %Graphical Definitions----------------------------------------------------
    set(gcf,'Position',[400 100 325 450])   %Position of the figure on the screen, pixels
                                            %[left bottom width height]
    set(gcf,'PaperPositionMode','manual')
    set(gcf,'PaperUnits','inches')
    set(gcf,'PaperSize',[8.5,11])           %[width, height] inches
    set(gcf,'PaperPosition',[1, 1, 6.5, 9]) %[left, bottom, width, height] inches

    bigaxes=axes;
    set(bigaxes,'Visible','off')
    %-------------------------------------------------------------------------

    %Reads the text file containing the .mat files names, gets their number----
    MatFile=importdata(TextMatFile);
    jjmax=length(MatFile);
    %-------------------------------------------------------------------------

    %Plotting------------------------------------------------------------------
```

```
clf reset

axes('Position',[0.2, 0.8, 0.6, 0.15])      %[left bottom width height] %
PlotWeather(TextMatFile,TextWSD)
title(Name)

for jj=1:jjmax
    axes('Position',[0.15+0.6*(jj-1)/(jjmax-1), 0.50, 0.09, 0.2])  %[left bottom width height] %
    SCAMP_DrawAverage(MatFile{jj},'GradFastT1',binsize);
end

axes('Position',[0.15, 0.27, 0.7, 0.15])      %[left bottom width height] %
SCAMP_SuperContourS(TextMatFile,'Sal',binsize)

axes('Position',[0.15, 0.05, 0.7, 0.15])      %[left bottom width height] %
SCAMP_SuperContourS(TextMatFile,'AccT',binsize)

%-----------------------------------------------------------------------

%Saving the picture file-----------------------------------------------
saveas(gcf,char(['D:\+Research\Data\#.jpg Files\SCAMP\Transect\','Trans_',strrep(TextMatFile,'.txt',''),'.jpg']));
%gcf is the number of the current figure
%-----------------------------------------------------------------------
```

SCAMP_PlotLetterT

```
function SCAMP_PlotLetterT(TextMatFile,TextWSD,binsize)
%%% SCAMP_PlotLetterT(TextMatFile,binsize)
%%%
%%% This function plots tides and wind (from TCOON data), Contour plots at
%%% the locations given in the matfile (salinity and temperature), and
%%% average of Temperature gradient.
%%% It also saves the plot as a .jpg file in an appropriate folder.
%%%
%%%
%%% Designed for use with SCAMP output data
%%% calling SCAMP_SuperContourT, SCAMP_DrawAverage, and PlotWeather
%%% called by: N/A
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%To be tested as Script-------------------------------------------------
% TextMatFile='2005_07_28_0200_1520_104.txt';
% binsize=0.05;
% TextWSD='WSD_CES.csv'
%-----------------------------------------------------------------------

%Cleans the name to appear correctly in the plotting window----------------
Name=strrep(TextMatFile,'_',' ');
Name=Name(1:10);
%-----------------------------------------------------------------------

%Graphical Definitions--------------------------------------------------
set(gcf,'Position',[400 100 325 450])   %Position of the figure on the screen, pixels
                                       %[left bottom width height]
set(gcf,'PaperPositionMode','manual')
set(gcf,'PaperUnits','inches')
set(gcf,'PaperSize',[8.5,11])          %[width, height] inches
set(gcf,'PaperPosition',[1, 1, 6.5, 9]) %[left, bottom, width, height] inches
```

```
bigaxes=axes;
set(bigaxes,'Visible','off')
%-------------------------------------------------------------------------

%Reads the text file containing the .mat files names, gets their number----
MatFile=importdata(TextMatFile);
jjmax=length(MatFile);
%-------------------------------------------------------------------------
%Plotting-----------------------------------------------------------------
clf reset

axes('Position',[0.2, 0.8, 0.6, 0.15])       %[left bottom width height] %
PlotWeather(TextMatFile,TextWSD)
title(Name)

for jj=1:jjmax
   axes('Position',[0.15+0.6*(jj-1)/(jjmax-1), 0.50, 0.09, 0.2])  %[left bottom width height] %
   SCAMP_DrawAverage(MatFile{jj},'GradFastT1',binsize);
end

axes('Position',[0.15, 0.27, 0.7, 0.15])       %[left bottom width height] %
SCAMP_SuperContourT(TextMatFile,'Sal',binsize)

axes('Position',[0.15, 0.05, 0.7, 0.15])       %[left bottom width height] %
SCAMP_SuperContourT(TextMatFile,'AccT',binsize)
%-------------------------------------------------------------------------

%Saving the picture file--------------------------------------------------
saveas(gcf,char(['D:\+Research\Data\#.jpg Files\SCAMP\Time\','Time_',strrep(TextMatFile,'.txt',''),'.jpg']));
%gcf is the number of the current figure
%-------------------------------------------------------------------------
```

PlotWeather

```
function PlotWeather(TextMatFile,TextWSD)
%%% PlotWeather(TextMatFile,TextWSD)
%%%
%%% This function plots winds and tides from normalized files.  It includes
%%% a time window of the experiments inside a 24 hours period.
%%%
%%% Designed for use with SCAMP output data
%%% calling N/A
%%% called by: SCAMP_PlotLetterS, SCAMP_PlotLetterT
%%% Cedric David
%%% University of Texas
%%% March 8, 2006

%To be tested as a script-------------------------------------------------
% TextMatFile='2005_07_28_0309_0500_033_037_101_039_042.txt';
% TextWSD='WSD_CES.csv';
%-------------------------------------------------------------------------

%Primary water level data-------------------------------------------------
TextPWL='PWL_TCOON.csv';
%-------------------------------------------------------------------------

%Loading the weather data in a matrix-------------------------------------
WSD=load(TextWSD);
PWL=load(TextPWL);
%-------------------------------------------------------------------------
```

```
    %Get the time stamps from the name of the TextMatFile, manage if next day--
    Time1=[TextMatFile(1:4),TextMatFile(6:7),TextMatFile(9:10),'T',TextMatFile(12:15),'00'];
    if str2num(TextMatFile(17:20))>str2num(TextMatFile(12:15))
      Time2=[TextMatFile(1:4),TextMatFile(6:7),TextMatFile(9:10),'T',TextMatFile(17:20),'00'];
    else
      d=str2num(TextMatFile(9:10));
      if d<10
        Time2=[TextMatFile(1:4),TextMatFile(6:7),['0',
num2str(str2num(TextMatFile(9:10))+1)],'T',TextMatFile(17:20),'00'];
      else
        Time2=[TextMatFile(1:4),TextMatFile(6:7),['',
num2str(str2num(TextMatFile(9:10))+1)],'T',TextMatFile(17:20),'00'];
      end
    end
    %----------------------------------------------------------------------

    %Number of weather data points-------------------------------------------
    iimax=size(WSD,1);
    jjmax=size(PWL,1);
    %----------------------------------------------------------------------

    %Creation of the date numbers--------------------------------------------
    julwsd=0;
    julpwl=0;
    for ii=1:iimax
      julwsd(ii)=datenum([WSD(ii,1) WSD(ii,2) WSD(ii,3) WSD(ii,4) WSD(ii,5) WSD(ii,6)]);
    end
    for jj=1:jjmax
      julpwl(jj)=datenum([PWL(jj,1) PWL(jj,2) PWL(jj,3) PWL(jj,4) PWL(jj,5) PWL(jj,6)]);
    end
    %----------------------------------------------------------------------

    %Limits on the plot-----------------------------------------------------
    T1=datenum(Time1,'yyyymmddTHHMMSS');
    T2=datenum(Time2,'yyyymmddTHHMMSS');
    L1=T1-0.5;
    L2=T2+0.5;
    for jj=1:jjmax
      B1(jj)=T1;
      B2(jj)=T2;
      V(jj)=jj/jjmax*10;
    end
    %----------------------------------------------------------------------

    %Plotting Procedure-----------------------------------------------------
    [AX,H1,H2]=plotyy(julwsd,WSD(:,8),julpwl,PWL(:,7));

    axes(AX(1));
    xlim([L1 L2]);
    ylim([0 10]);
    ylabel('Wind Speed (m/s)');
    hold on
    plot(B1,V,'r');
    plot(B2,V,'r');
    datetick(AX(1),'x',15,'keepticks')

    axes(AX(2));
    xlim([L1 L2]);
    ylim([0 1.5]);
    ylabel('Water Level (m)');
    datetick(AX(2),'x',15,'keepticks')
```

```
hold off
%--------------------------------------------------------------------------
```

SCAMP_Param

```
function [lab,uni,inter1,inter2,dist,absolute]=SCAMP_Param(datafield)
%%% SCAMP_Units(datafield)
%%%
%%% This function unifies the names, units, ranges for the different
%%% parameters
%%%
%%% Designed for use with SCAMP output data
%%% calling: N/A
%%% called by:
%%% Cedric David
%%% University of Texas
%%% April 12, 2006

%Taking the absolute value of the parameter--------------------------------
absolute=1 %Turn the absolute value on
% absolute=0 %Turn the absolute value off
%--------------------------------------------------------------------------

%Creating the parameters---------------------------------------------------
if (strcmp(datafield,'Sal'))
   lab='Salinity';
   uni='psu';
   inter1=[32 42];
   inter2=inter1;
   dist=[32 37 42];
elseif strcmp(datafield,'AccT')
   lab='Accurate temperature';
   uni='C';
   inter1=[29.5 32];
   inter2=inter1;
   dist=[29.5 32];
elseif strcmp(datafield,'GradFastT1')
   if absolute
      lab='|Temperature gradient|';
      uni='C/m';
      inter1=[-0.5 0.5];
      inter2=[-0.5 1];
      dist=[-0.5 0 0.5 1];
   else
      lab='Temperature gradient';
      uni='C/m';
      inter1=[-0.5 0.5];
      inter2=inter1;
      dist=[-0.5 0 0.5 1];
   end
else
   lab='unknown label';
   uni='unknown unit';
   inter1=[0 100];
   inter2=inter1;
   dist=[0 50 100];
end
%--------------------------------------------------------------------------
```

Chapter 8. References

8.1 Cited literature

Applebaum, S., Montagna, P. A., and Ritter, C. (2005). "Status and trends of dissolved oxygen in Corpus Christi Bay, Texas, USA." *Environmental Monitoring and Assessment*, 107, 297-311.

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8.2 Cited Internet links

http://pme.com/scamp.htm SCAMP home page

http://www.eurekaenvironmental.com/manta/overview.htm Manta home page

http://www.trimble.com/pathfinderproxrs.shtml Differential GPS receiver

http://www.magellangps.com/en/products/product.asp?PRODID=91 Handheld GPS receiver

http://lighthouse.tamucc.edu/TCOON/HomePage TCOON home page

http://www.coastalenvironmental.com CES weather station

http://www.nkhome.com/ww/wwindex.html Kestrel handheld weather station

http://www.epa.gov/owow/estuaries/

http://www.MathWorks.com Matlab home page

http://www.boat-ed.com/tx/handbook/pdf_index.htm The Handbook of Texas Boating Laws and Responsibilities