Gulf of Mexico OCS Region

MMS

# Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico: Draft Interim Report

Gulf of Mexico Region

OCS Study
MMS

# Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico: Draft Interim Report

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## ABOUT THE COVER

Cover artwork shows the study area along the continental slope in the Gulf of Mexico from the Texas-Mexico border to the Alabama-Florida state line and between the 100 m and 2000 m isobaths.

## ABSTRACT

The purpose of this study is to determine the seasonal and geographic distribution and movements of cetaceans in areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. The study is restricted to the area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 m and 2,000 m isobaths. In addition to conducting aerial and shipboard visual surveys, this program (hereafter referred to as the GulfCet Program) has collected hydrographic data in situ and by remote sensing to characterize the preferred habitats of cetaceans in the study area. When the analysis is complete, we will identify environmental variables which correlate with the seasonal distribution of cetaceans. Finally, we have attempted to tag and track a limited number of sperm whales using satellite telemetry.

The GulfCet Program is a 3.25 year project which commenced on October 1, 1991 and will finish on December 31, 1994. This interim report summarizes project accomplishments and results for the first four aerial and six shipboard surveys (TAMUG), two of the regularly scheduled Ichthyoplankton/Marine Mammal survey cruises conducted by the National Marine Fisheries Service, and three sperm whale tagging cruises. When completed, this study will help the MMS to assess the potential effects of deepwater exploration and production on marine mammals in the Gulf of Mexico.

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We gratefully thank the Texas Institute of Oceanography and the National Marine Fisheries Service for cost-sharing the use of all research vessels used for the surveys and sperm whale tagging on this project.

# I. Executive Summary

## 1.1 Overview

The MMS has the responsibility to assure that oil and gas operations on the Outer Continental Shelf (OCS) Leases in the Gulf of Mexico are conducted in a manner that reduces risks to the marine environment. To meet their responsibilities under the Marine Mammal Protection Act (MMPA) of 1972 and the Endangered Species Act (ESA) of 1973, the MMS must understand the effects of oil and gas operations on marine mammals.

The purpose of this study is to determine the seasonal and geographic distribution and movements of cetaceans in areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. The study is restricted to the area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 m and 2,000 m isobaths. In addition to conducting aerial and shipboard visual surveys, the GulfCet Program has collected hydrographic data in situ and by remote sensing to characterize the preferred habitats of cetaceans in the study area. When the analysis is complete, we will identify environmental variables which correlate with the seasonal distribution of cetaceans. Finally, we have attempted to tag and track a limited number of sperm whales using satellite telemetry.

The GulfCet Program is a 3.25 year project which commenced on October 1, 1991 and will finish on December 31, 1994. Because the final surveys will not be completed until April 1994, this report does not include models of cetacean abundance or extensive correlations of cetacean distribution with environmental variables. Instead, this interim report summarizes project accomplishments and results for the first four aerial and six shipboard surveys, two of the regularly scheduled Ichthyoplankton/Marine Mammal survey cruises conducted by the National Marine Fisheries Service, and three sperm whale tagging cruises.

The GulfCet Program is being conducted by the Texas Institute of Oceanography, National Marine Fisheries Service at the Southeast Fisheries Science Center, and Oregon State University.

## 1.2 Cetacean Surveys

### 1.2.1 Survey Organization and Objectives

A major part of the GulfCet Program's field research consists of seasonal, line transect surveys to determine the distribution and to estimate the abundance of cetaceans in the study area. Three types of surveys are being conducted: 1) visual surveys from an aircraft, 2) visual surveys from a ship, and 3) acoustic surveys using a linear hydrophone array towed behind the visual survey ship.

### 1.2.2 Aerial Surveys

Four seasonal aerial surveys were completed for the summer (10 August-19 September 1992), fall (3 November-16 December 1992), winter (1 February-22

March 1993), and spring (25 April-1 June 1993) seasons. The objective of the surveys was to collect seasonal line transect and distributional data on cetaceans.

The study was designed to survey about 6,500 transect km per season. Transects were oriented perpendicular to the bathymetry. Surveys were conducted using standard cetacean aerial survey methods. Transect lines were surveyed from 750 feet at a speed of 110 knots.

A total of 164 cetacean groups was sighted on-effort during the four surveys. Twenty-five sightings were off-effort including a group of ten killer whales. At least 18 species of cetaceans have been sighted to date. Bottlenose dolphins, pantropical spotted dolphins, dwarf/pygmy sperm whales, Risso's dolphin were the most commonly sighted species.On-effort group sighting rates were highest in summer and spring, and lowest in fall. The summer, winter and spring average group sizes of all cetacean groups sighted were over twice the fall average. Of species sighted more than once, pantropical spotted dolphins had the largest average group size of all the species sighted, whereas dwarf/pygmy sperm whales had the smallest. Only three groups of pantropical spotted dolphins were sighted in winter. However, a group of 150 striped dolphins and a group of 200 spinner dolphins were seen in winter. These two groups accounted for 38% of the cetaceans sighted in winter. During the spring, groups of 175 and 400 melon-headed whales were sighted. These groups accounted for 50% of the animals sighted in spring.

With sightings from all four seasons combined,cetacean groups were sighted throughout the length of study area and at all water depths. However, distinct species were found at different water depths. Bottlenose dolphins and Atlantic spotted dolphins were sighted primarily near the shelf edge (200-300 m). Pantropical spotted dolphins and dwarf/pygmy sperm whales were found in much deeper water (greater than 300 m). Pilot whales and Risso's dolphins inhabited the greatest range of water depths (greater than 1500 m).

#### 1.2.3 Shipboard Visual Surveys (TAMUG)

The study area was surveyed along 14 north-south transect lines. Survey procedures followed closely those developed for dolphin surveys in the eastern tropical Pacific. Two members of each survey teams searched for marine mammals through pedestal-mounted 25X150 *Fujinon* binoculars, while the third observer acted as data recorder and assisted in searching with 7X binoculars. Sighting effort was conducted during daylight hours in which sighting conditions were acceptable (Beaufort sea states of less than 6 with good visibility).

A total of 340.81 hours of sighting effort was conducted on the first six cruises. This represents 4587.49 kilometers of transect line surveyed. A total of 258 marine mammal sightings were made within the study area on the first six cruises. Of these, 182 were "on effort" and are usable in the density and abundance estimates. The 76 "off-effort" sightings can be used only in estimating mean herd size, and will not be used to estimate density and abundance.

Based only on the sightings from these six cruises, the only species with an adequate sample size for abundance estimates is the bottlenose dolphin (32 on effort sightings). It is likely that the number of sperm whale sightings will equal at least 30 by the end of the project. All other species will have to be pooled based on the number of sightings, taxonomic relationships, and general habitat types.

Sperm whales and pantropical spotted dolphins were the most common cetaceans seen in oceanic waters. An unexpected finding was the paucity of short-finned pilot whales. Several poorly-known species have turned out to be moderately common (beaked whales, pygmy and dwarf sperm whales, melon-headed whale, and Fraser's and clymene dolphins). Both melon-headed whales and Fraser's dolphins were almost completely unknown in the Gulf of Mexico before this study began, each represented by one or two standings. The first live sightings of these species in the Gulf (and for Fraser's dolphin, the first for the entire Atlantic Ocean) were recorded during this project. The clymene dolphin was well-known in the Gulf from strandings previous to this project, but also was poorly-represented by live sightings.

1.2.4 Shipboard Visual Surveys (NMFS)

The Southeast Fisheries Science Center (SEFSC) has conducted two of four planned vessel surveys aboard the NOAA *RV Oregon II* as part of the SEFSC contributed effort to the Gulfcet Program. The first survey was conducted from April 21-June 8, 1992 (spring-summer), and the second survey took place during January 4-February 14, 1993 (winter). Both surveys were designed to collect: 1) marine mammal sighting data to estimate abundance, distribution and diversity, and 2) environmental data to evaluate factors which may affect the distribution, abundance and diversity of marine mammals.

Visual sighting data were collected by two teams of three observers during daylight hours, weather permitting (i.e, no rain, Beaufort sea state less than 6). Two observers searched for marine mammals using high-power (25 power) binoculars mounted on the ship's flying bridge. The third observer maintained a search of the area near the trackline unaided and with handheld binoculars, and recorded data.

A total of 6,154 transect kilometers were visually sampled for marine mammals during the spring-summer survey resulting in 273 sightings of at least 20 species of cetaceans. The bottlenose dolphin and the pan-tropical spotted dolphin were the most frequently sighted species and accounted for 21% and 19%, respectively, of identified sightings. Risso's dolphins, sperm whales, and dwarf sperm whales were the next most frequently sighted, and accounted for 11%, 8%, and 8%, respectively, of identified sightings.

The winter survey resulted in the visual sampling of 4,017 transect kilometers. At least 10 cetacean species were observed in a total of 46 sightings. Sperm whales were the most commonly sighted cetaceans, with 9 sightings (25% of identified sightings).Atlantic spotted dolphins and pan-tropical spotted dolphins were the next most common with six herd sightings each (17% each of identified sightings).

The *Stenella* dolphins, with the exception of the Atlantic spotted dolphin, were sighted most frequently in the deeper, off-shelf waters of the survey area. Sightings of bottlenose dolphins, Risso's dolphins, and Atlantic spotted dolphins all appeared to occur quite frequently along the edge of the continental shelf. However, whereas Atlantic spotted dolphins were sighted only along the shelf edge, bottlenose dolphins were also seen frequently on the continental shelf while Risso's dolphins were also seen in the deeper Gulf waters.

Members of the sperm whale family were sighted both along the shelf edge and in the deeper waters of the survey area. Kogia sp. sightings were located throughout the deeper waters, with no apparent pattern. Sightings of sperm whales, however, showed an apparent disjunct distribution with sightings in Mississippi and DeSoto canyons and a band along the southern edge of the survey area.

Four species not seen on the previous SEFSC marine mammal vessel surveys were observed on the present surveys. Blainville's beaked whale,the melon-headed whale, and Fraser's dolphin were all sighted on the spring-summer survey, and melon-headed whales were seen on the winter survey. These observations represented some the first documented sightings of these species in the Gulf of Mexico (Fraser's dolphins were observed earlier in 1992 during a Texas A&M shipboard visual and acoustic survey). Melon-headed whales were also observed during the winter survey, and the first SEFSC vessel sightings of killer whales occurred during the spring-summer survey.

### 1.2.5 Shipboard Acoustic Surveys

A linear hydrophone array was towed behind the Texas A&M University visual survey ship to record the distinctive underwater vocalizations of cetaceans. This passive acoustic survey technique enabled us to identify cetaceans in the vicinity of the ship in order to determine their distribution and to estimate their abundance. The towed array has 195 hydrophones and an overall frequency sensitivity from 10 Hz to 30 kHz, with maximum sensitivities at 30 Hz, 480 Hz, 3.84 kHz, 5 kHz, 10 kHz, and 15 kHz. The array has maximum sensitivity in a ringed pattern perpendicular to the long axis of the array and very little sensitivity either fore or aft. It therefore detects little ship-generated noise, particularly the higher frequencies.

The towed array was deployed whenever the ship was on a transect line.It was towed at a uniform speed of 5 knots for the first four cruises and 6.5 knots for cruises five and six. The speed of the vessel determines the depth of the array, with an approximate depth of 18 m at a speed of 5 knots and 12 m at 6.5 knots.

A complete list of contacts which includes the species, date and location of each acoustic contact is included in the Appendix. It is important to note that the locations shown for marine mammals are for "first contact", which may not be the final, computed location for these contacts. This is a problem primarily for sperm whales which can be heard over 20 miles from the vessel.

A total of 4,496 miles (96% of the planned distance) was acoustically surveyed during Cruises 1-4. The 4% which was not survey resulted from equipment failure or poor weather. We had a total of 246 acoustic contacts on 910 recorded tapes. This is equivalent to 0.0547 acoustic contacts/survey mile. Many of these contacts represent more than one animal.

The most common marine mammal acoustic contacts (149) have been unidentified dolphins. These contacts were generally whistles recorded primarily at night or during poor weather conditions when visual identification was impossible. Of the 64 identified marine mammal acoustic contacts, 33 (51%) have been from sperm whales.

The majority of the sperm whale contacts have been off the mouth of the Mississippi River or on the western side of the study area. Contacts with bottlenose dolphins have occurred along the shallower, northern edge of the study area, whereas contacts with pan-tropical spotted dolphins have been in the deeper water along the eastern continental slope.

These distribution patterns are reflected in the average water depths for acoustic contacts. Pan-tropical spotted dolphins and sperm whales were found in the deepest water (mean depths = 1667 m and 1272 m, respectively) while bottlenose dolphins occurred in more shallower water (mean depth = 315 m). Several of the deeper bottlenose dolphin contacts occurred off the mouth of the Mississippi River, where the continental shelf is narrow (i.e. 10 miles).

### 1.2.6 Satellite Tagging of Sperm Whales

Oregon State University was responsible for placing Satellite-linked Time-Depth Recorders (SLTDRs) on sperm whales to determine their movements, diving behavior and preferred habitat. To accomplish this goal, three cruises were undertaken: two in the Gulf of Mexico (October 1992 and June 1993) and one in the Galapagos (March 1993). The Galapagos cruise was intended as a test for tag deployment and attachment.

The SLTDRs used for this project were designed and built by Oregon State University using Wildlife Computers*TM* controller boards and Telonics*TM* ST-6 Platform Transmitter Terminals (PTTs) and housed in a stainless steel cylinder (0.05 m diameter, 0.19 m long, 0.8 kg in weight). The exterior of the housing had attachments which consisted of two stainless steel rods (0.127 m long, 0.006 m diameter) with one pair of folding toggles mounted behind double-edged blades at the end of each rod.

The transmitters were attached to whales with compound crossbow capable of generating 150 lbs.of force. The SLTDR was attached to an aluminum shaft with a "C"-shaped cup at one end. The shaft with the SLTDR was then fired from the crossbow. A line (20 lbs. test) attached to the aluminum shaft enabled the SLTDR to be recovered should it miss the whale. Once the SLTDR was attached to the whale, the shaft was designed to fall off.

The SLTDRs collected data over eight, three-hour summary periods daily. These data included three histograms: maximum depth of all dives, duration of dive, and time spent at various depth ranges. Other data for each three hour period included the longest dive, deepest dive, duration of deepest dive, temperature at deepest depth, longest surface duration uninterrupted by a submergence of greater than 6 seconds, and total surface duration.

The first tagging cruise was conducted from September 30 to October 14, 1992 in the Gulf of Mexico. The cruise covered an area where previous GULFCET cruises and aerial surveys had observed sperm whales, but had to remain within the ship's operational limits (offshore to 100 miles from Venice, LA). Visual contact with 8-10 sperm whales was made only once for about four hours on October 9. Unfortunately, we did not get close enough to tag any animals.

The second cruise was conducted in the eastern Pacific off the Galapagos Islands from 20-31 March, 1993. The purpose of this cruise was to test techniques to approach and attach SLTDRs to sperm whales.The waters around the Galapagos were an ideal test ground because, unlike the Gulf of Mexico, the seasonality and distribution of large numbers of sperm whales had been well documented for this area.On March 26, we succeeded in attaching a SLTDR to a sperm whale, but the telemeter failed to transmit data. Two other tagging attempts were unsuccessful.

The third tagging cruise was conducted 6-29 if June 1993 in the Gulf of Mexico. The vessel covered 2331.4 km searching for sperm whales. A maximum of 87 individuals were seen during the cruise.The sperm whales we found were quite small. Most were less than 8 m in length and were considered too small to tag; a few were up to 8 m. Two animals were tagged; the first (about 8 m in length) on 7 June and the second (about 7 m in length) on 11 June. None of the telemeters transmitted data.

While searching for sperm whales in the Gulf of Mexico, we obtained some circumstantial evidence that active seismic vessels may affect the distribution of sperm whales. Although our observations represent circumstantial evidence, the change in whale sightings after the onset of seismic activity is sufficient to warrant concern and additional studies.

### 1.3 Environmental Data Surveys

The circulation of the Gulf of Mexico is remarkable because of its variability and intensity. The most prominent circulation features in the Gulf are (1) the intense Loop Current System in the eastern Gulf and (2) an anticyclonic cell of circulation in the western Gulf.Nearly two-thirds of the U.S. mainland and half the area of Mexico drains into the Gulf of Mexico. The Mississippi and other rivers with their associated nutrient and sediment loads have a great influence on the Gulf. The prominent Gulf of Mexico circulation features and the high fresh water input interact to make the Gulf of Mexico a very complex environment. The goal of the GulfCet program is to develop an understanding of environmental features and their effect on the spatial and temporal distribution of cetacean species in the northwestern Gulf of Mexico.

Environmental data collection for the GulfCet Program consists of, eight TAMUG hydrographic surveys, summer and winter National Marine Fisheries Service (NMFS) surveys, and a synoptic overview by remote sensing. Satellite images are from NOAA's Advanced Very High Resolution Radiometer (AVHRR) polar orbiting satellites.

1.3.1 Hydrographic Surveys (TAMUG)

The GulfCet program conducts four cruises each year, one cruise per season, for two of the three years of the program. Each cruise has three purposes: a visual survey of marine mammals, an acoustic survey using a towed hydrophone array, and a hydrographic survey. A transect consisting of 14 North-South track lines is followed during the cruises. The hydrographic survey was designed to sample the mesoscale-to- large scale features in the Gulf.CTD stations are located at the 100 and 2000 m isobaths (except at the Mexican border), and at 40 nautical mile intervals on each track line. The location and spacing of the 84 XBT hydrographic stations was based on the 200, 350, 500, 800, 1000, and 1500 m isobath locations for each of the 14 North-South track lines.

Data collected on each GulfCet cruise were obtained by lowering a CTD with a rosette, XBT deployments, and LUMCON's continuously recording Multiple Interface Data Acquisition System (MIDAS). For the first six cruises, a total of 503 XBT and 222 CTD stations were completed for a total of 723 stations. Vertical profiles of salinity, temperature, oxygen, and beam attenuation coefficient (transmissometry) were measured at every CTD station. In addition, 1753 chlorophyll and 583 salinity samples were obtained.

The temperature-salinity (T-S) plots show a remarkable uniformity below 17°C, indicating that the waters in the study area constitute essentially a single system. Data from all the hydrographic stations reveal a distinct maximum salinity greater than 36.60 psu and a minimum salinity less than 34.9 psu; this excludes the surface fresh water near the Mississippi plume (which was as low as 12.76 psu). These salinity signatures are characteristic of Subtropical Underwater and Antarctic Intermediate Water, respectively. During the GulfCet cruises, we have detected several ediies (Triton, "V", "W" and "X") with a salinity greater than 36.60 psu, which is the hallmark of the Loop Current eddies.

The observed depth of the 8°C and 15°C isotherms indicates the presence of features such as the eddies. Regions where the temperature surface is deep corresponds to anticyclonic (clockwise) circulation, and those regions where the temperature surface is shallow corresponds to cyclonic (counterclockwise) circulation. A prominent anticyclonic eddy is almost always present in the western Gulf of Mexico. Small cyclonic eddies (cold water) are often associated with the periphery of this dominant feature, and the 8°C isotherm topography is the preferred detection tool for these eddies.

During the 1993 flood, the Mississippi plume was streaming to the east, which is a rare occurrence. This event was visible on satellite images and was confirmed by our hydrographic data (GulfCet, Cruise 6).
Our sampling grid has proven to be useful in sampling the meso-to-large scale features of the Gulf of Mexico. We were able to detect all the major eddies (Triton, "V", "W" and "X") and events present in the northwestern Gulf from 1992 to 1993. These anticyclonic eddies shed vorticity as regions of cyclonic circulation when they feel bottom, and the companion cold-core (upwelling) features probably are areas of greater production and may be preferred areas for marine mammals. Further analyses on the hydrographic features and environmental habitat of marine mammals continues.

### 1.3.2 Remote Sensing and Geographic Information System

Stennis Space Center (NMFS) is providing remote sensing and geographic information system (GIS) support for the GulfCet project. The GIS will be used to integrate and analyze the various data types to explore possible relationships between the distribution and abundance of marine mammals and satellite and shipboard measurements of environmental variables in the Gulf of Mexico.

Data are collected by the Advanced Very High Resolution Radiometer (AVHRR) carried onboard the NOAA polar orbiting satellites and provide partial or full coverage of the study area twice per day (one daytime and one nighttime overflight) depending on the orbital path and cloud coverage. The data are currently being obtained from the NOAA-11 satellite and are expected to be available from NOAA-12 in the near future. With both satellites operating, up to four images per day will be available.

The Naval Research Laboratory at Stennis Space Center maintains a satellite receiving station and archive facility for AVHRR images and is the primary source of data for the project. The satellite data are being processed into sea surface temperature (SST) images. Each SST image is also being processed into an absolute magnitude of the SST gradient image using 3 x 3 template masks configured as Sobel operators and an arithmetic overlay operation. The visible channels of the AVHRR from daytime overflights are also being processed into turbidity images, primarily to examine the areal extent and location of edges of the Mississippi River plume. A total of 199 AVHRR images have been acquired (as of October 6th)for the study. The satellite data products, shipboard and aircraft observations of marine mammals, and environmental data collected aboard the vessels will be included as map layers in the GIS data base.

The GIS hardware consists of a Silicon Graphics UNIX workstation and peripherals; software is the Advanced Geographic Information System (AGIS), developed by Delta Data system, and the Science and Technology Laboratory Applications Software (ELAS), developed by the National Aeronautics and Space Administration. All of the digital map layers used in the GIS data base will be registered to a portion of the Gulf of Mexico master image (GMMI) that includes the GulfCet study area and thus encompasses the area from 26°to 31° N Latitude and 81°to 98° W Longitude. Some of the map layers tentatively identified for use in the GIS data base can be stored as raster or vector data files.

The GIS will be used for qualitative analysis of data structure by using such functions as retrieval and classification and logical operations to create interactive map displays, tabular summaries, and data plots in an effort to visualize relationships between the distribution and abundance of cetaceans and satellite and shipboard measurements of environmental variables. The dimensionality of the data, i.e., the potential number of input variables for multivariate statistical analysis, is expected to be large since GIS analysis tools such as proximity measures will enable analysts to explore the data in ways that would be virtually impossible using a conventional analysis methods.

The initial exploratory analysis will be followed by a more formal, quantitative analysis of the data using multivariate statistical techniques. Variables to be used in the analysis will be exported from the GIS to one or more statistical software packages: (1) the Statistical Analysis System (SAS) offering a wide range of univariate and multivariate statistical procedures; (2) the Cornell Ecology Programs provide cluster, detrended correspondence analysis, and ordination techniques for ecological research; and (3) SpaceStat spatial analysis software.

# II. INTRODUCTION

## 2.1 Background and Objectives

The Mineral Management Service (MMS) has the responsibility to assure that oil and gas operations on the Outer Continental Shelf (OCS) Leases in the Gulf of Mexico are conducted in a manner that reduces risks to the marine environment. To meet their responsibilities under the Marine Mammal Protection Act (MMPA) of 1972 and the Endangered Species Act (ESA) of 1973, the MMS must understand the effects of oil and gas operations on marine mammals. As the oil and gas industry moves into deeper water along the continental slope in their continuing search for extractable reserves, information is needed on the at-sea distribution, movements, behavior, and preferred habitats of cetaceans, especially large and deep water species in the Gulf of Mexico (Table 2.1). This study will help the MMS to assess the potential effects of deepwater exploration and production on marine mammals in the Gulf of Mexico.

The purpose of this study is to determine the seasonal and geographic distribution and movements of cetaceans in areas potentially affected by future oil and gas activities along the continental slope in the north-central and western Gulf of Mexico. The study is restricted to the area bounded by the Florida-Alabama border, the Texas-Mexico border, and the 100 m and 2,000 m isobaths (Figure 2.1). In addition to conducting aerial and shipboard visual surveys, the GulfCet Program has collected hydrographic data in situ and remote sensing data to characterize the preferred habitats of cetaceans in the study area. When the analysis is complete, we will identify environmental variables which correlate with the seasonal distribution of cetaceans. Finally, we have attempted to tag and track a limited number of sperm whales using satellite telemetry.

The GulfCet Program is a 3.25 year project which commenced on October 1, 1991 and will finish on December 31, 1994. Because the final surveys will not be completed until April 1994, this report does not include models of cetacean abundance or extensive correlations of cetacean distribution with environmental variables. Instead, this interim report summarizes project accomplishments and results for the first four aerial and six shipboard surveys, two of the regularly scheduled Ichthyoplankton/Marine Mammal survey cruises conducted by the National Marine Fisheries Service (NMFS), and three sperm whale tagging cruises.

## 2.2 Program Participants

The GulfCet Program is administered by the Texas Institute of Oceanography (TIO), which has scientific expertise in marine mammal biology, bioacoustics, and oceanography through its Marine Mammal Research Program, the Department of Marine Biology, the Department of Engineering Technology, and the Department of Oceanography at Texas A&M University. Additional expertise is provided by the NMFS at the Southeast Fisheries Science Center which has extensive experience in aerial and shipboard surveys of marine mammals in the Gulf of Mexico. This part of the project is contracted under a separate Interagency Agreement between the MMS and NMFS. Finally, the

| | |
|---|---|
| **Balaenidae** | |
| Right Whale | *Eubalaena glacialis** |
| **Balaenopteridae** | |
| Blue Whale | *Balaenoptera musculus** |
| Fin Whale | *B. physalus** |
| Sei Whale | *B. borealis** |
| Bryde's Whale | *B. edeni* |
| Minke Whale | *B. acutorostrata* |
| Humpback Whale | *Megaptera novaeangliae** |
| **Physeteridae** | |
| Sperm Whale | *Physeter macrocephalus** |
| Pygmy Sperm Whale | *Kogia breviceps* |
| Dwarf Sperm Whale | *K. simus* |
| **Ziphiidae** | |
| Cuvier's beaked whale | *Ziphius cavirostris* |
| Blainville's beaked whale | *Mesoplodon densirostris* |
| Sowerby's beaked whale | *M. bidens* |
| Gervais' beaked whale | *M. europaeus* |
| **Delphinidae** | |
| Melon-headed whale | *Peponocephala electra* |
| Pygmy killer whale | *Feresa attenuata* |
| False killer whale | *Pseudorca crassidens* |
| Killer whale | *Orcinus orca* |
| Short-finned pilot whale | *Globicephala macrorhynchus* |
| Rough-toothed dolphin | *Steno bredanensis* |
| Fraser's dolphin | *Lagenodelphis hosei* |
| Common dolphin | *Delphinus delphis* |
| Bottlenose dolphin | *Tursiops truncatus* |
| Risso's dolphin | *Grampus griseus* |
| Atlantic spotted dolphin | *Stenella frontalis* |
| Pantropical spotted dolphin | *S. attenuata* |
| Striped dolphin | *S. coeruleoalba* |
| Spinner dolphin | *S. longirostris* |
| Clymene dolphin | *S. clymene* |

Table 2.1. Cetaceans of the Gulf of Mexico.

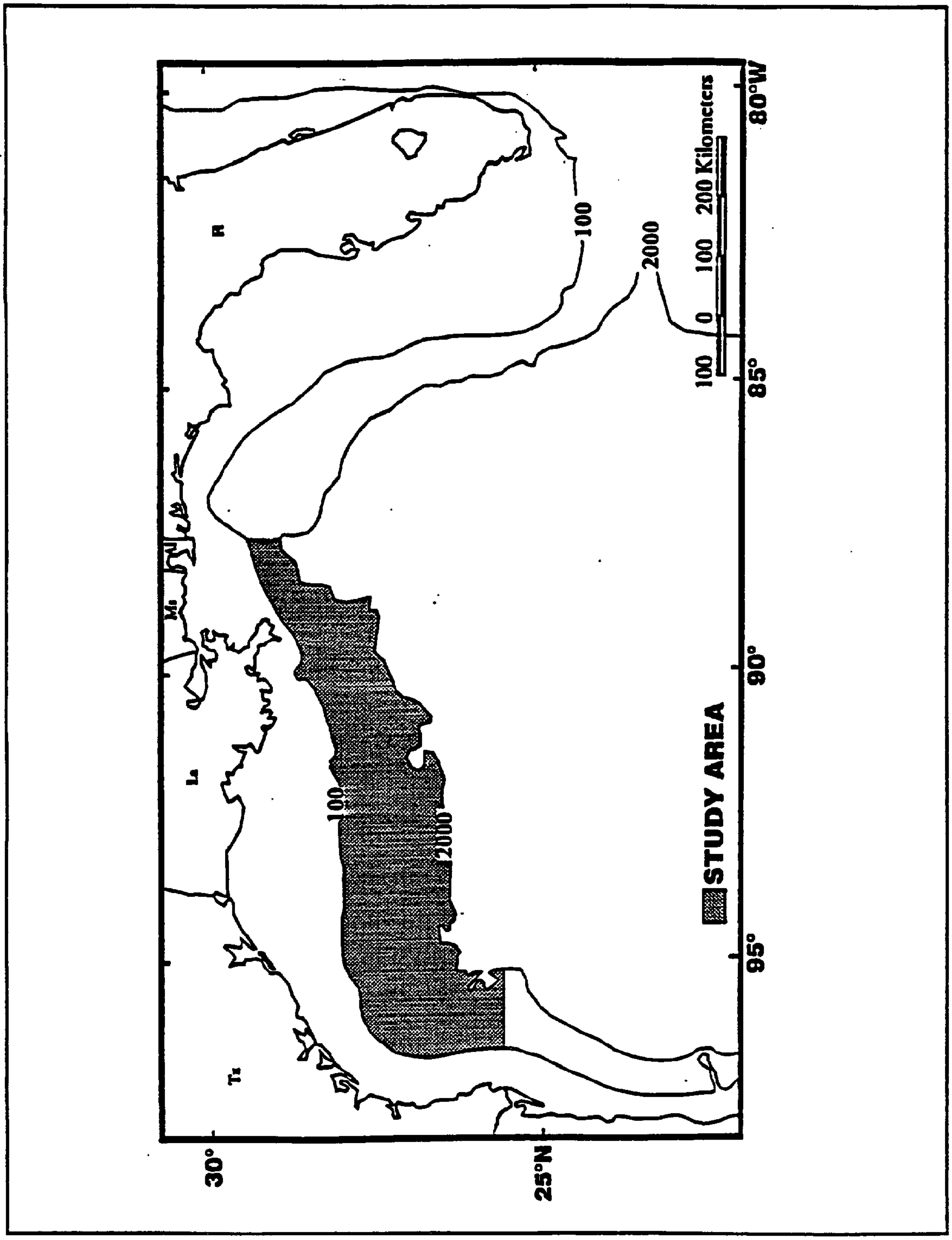


Figure 2.1. Study area between the 100 and 2000 m isobaths,extending as far east as the Florida-Alabama border, and as far southwest as Texas-Mexico border.

project includes scientists from the Hatfield Marine Science Center (HMSC) at Oregon State University who have developed techniques to tag and track whales using satellite telemetry. A list of the program's participants is shown in Table 2.2 .

The GulfCet Program has a Scientific Review Board (SRB) composed of five experts who review and comment on the project's goals, methodologies, results, analyses and conclusions. The current SRB members include:

J. Thomas, Ph.D.
Office of Aquatic Studies
Western Illinois University
Macomb, IL 61455.

H. Whitehead, Ph.D.
Department of Biology
Dalhousie University
Halifax, Nova Scotia, Canada B3H 4J1.

S. Reilly, Ph.D.
NMFS - Southwest Fisheries Center
8604 La Jolla Shores Dr.
La Jolla, CA 92038.

J. Cochrane, Ph.D.
Dept. of Oceanography
Texas A&M University
College Station, TX 77843.

K. Norris, Ph.D.
1985 Smith Grade
Santa Cruz, CA 95060.

Dr. N. Bray of the Scripps Institution of Oceanography, La Jolla, California, was a previous SRB member who was replaced by Dr. J. Cochrane in September 1993.

## 2.3 Report Organization

The main text of this report is divided into two sections: Cetacean Surveys and Environmental Data Surveys. Under the section on Cetacean Surveys, Mullin and Hansen begin with a description of the aerial survey methods, results and a discussion of the data acquired so far (Section 3.2). Jefferson and Wursig continue with a discussion of the Texas A&M University shipboard visual surveys of marine mammals (Section 3.3.1). Hansen and Mullin describe the NMFS shipboard marine mammal surveys in Section 3.3.2., and Benson, Evans and Norris present data acquired during the shipboard acoustic surveys using a towed hydrophone array (Section 3.3.3). Finally, Mate describes the techniques and difficulties of attaching satellite telemeters to sperm whales (Section 3.4).

In the section on Environmental Data Surveys, Fargion begins with a description of the hydrographic survey techniques, data analysis and a discussion of the results from the first six shipboard surveys (Section 4.2). May and Leming continue with a discussion of remote sensing data acquisition and the Geographic Information System (GIS) that will be used in the final data analysis for this project (Section 4.3).

| | | |
|---|---|---|
| Randall W. Davis | Program Manager | TIO, TAMUG |
| Bernd Würsig | Deputy Prgm. Manager | TIO, TAMUG |
| Gerald P. Scott | Prgm. Mgr. for NMFS | NMFS, SFSC |
| Giulietta Fargion | Data Manager | TIO, TAMUG |
| Robert Benson | Principal Investigator | TAMU, DET |
| William Evans | Principal Investigator | TIO, TAMUG |
| Larry Hansen | Principal Investigator | NMFS, SFSC |
| Thomas Lemming | Principal Investigator | NMFS, SFSC |
| Bruce Mate | Principal Investigator | HMSC, OSU |
| Nelson May | Principal Investigator | NMFS, SFSC |
| Keith Mullin | Principal Investigator | NMFS, SFSC |

Abbreviations:

| | |
|---|---|
| TIO,TAMUG | Texas Institute of Oceanography, Texas A&M University at Galveston |
| TAMU, DET | Texas A&M University, Department of Engineering Technology |
| NMFS, SFSC | National Marine Fisheries Service, Southeast Fisheries Science Center |
| HMSC,OSU | Hatfield Marine Science Center, Oregon State University |

Table 2.2. Management structure, principal investigators and their affiliations.

# III. CETACEAN SURVEYS

## 3.1 Introduction

A major part of the GulfCet Program's field research consists of seasonal, line transect surveys to determine the distribution and to estimate the abundance of cetaceans in the study area. Three types of surveys are being conducted: 1) visual surveys from an aircraft, 2) visual surveys from a ship, and 3) acoustic surveys using a linear hydrophone array towed behind the visual survey ship. Each of the three survey methods has its advantages and disadvantages in terms of sighting marine mammals at sea. For example, visual surveys from ships are very limited by available daylight and good weather (Beaufort 4 or better), whereas the towed hydrophone array can operate day and night in all but the most severe weather conditions. However, the hydrophone array does not always enable us to identify a particular species by its vocalizations and cannot be used to determine pod size. The visual surveys from an aircraft can cover larger areas in a short period of time, but also are limited to good weather conditions. In addition, the limited fuel capacity of the aircraft prevents it from reaching the 2000 m isobath (located 210 miles from shore) along portions of the Texas coast. As a result, the aircraft cannot survey the entire study area. Each method of estimating abundance has inherent limitations and assumptions. By using three different survey methods, we will arrive at the best estimates of seasonal distribution and abundance.

## 3.2 Aerial Surveys

### 3.2.1 Methods

Four seasonal, aerial surveys were completed for the summer (10 August - 19 September 1992), fall (3 November - 16 December 1992), winter (1 February - 22 March 1993), and spring (25 April - 1 June 1993) seasons. Eight seasonal surveys are scheduled. The surveys were conducted on the continental slope in the U.S. Gulf of Mexico in an area bounded by Florida-Alabama state border, the U.S. - Mexico border, the 100 m isobath and the 2,000 m isobath (east of 90°W) or the 1,000 m isobath (west of 90°W). The objective of the surveys was to collect seasonal line transect and distributional data on cetaceans.

The survey platform of choice was a DeHavilland (DHC-6) Twin Otter, turbine engine aircraft modified for marine mammal surveys. This aircraft was used in MMS supported aerial surveys in the Gulf of Mexico during 1989 and 1990 (Mullin et al. 1990). A Twin Otter was not available for the first (summer) aerial survey. Therefore, a Partenavia twin-turbine aircraft was contracted from Aspen Helicopters (Oxnard, California). This aircraft was modified with bubble windows, had transect line visibility, and was suitable for collecting line transect data. However, the aircraft had a flight time of only 4.5 hours. Because the transit time to the study area is long (about 1 hour), this limited the amount of survey time per flight. A Twin Otter was available from the NOAA Aircraft Operations Center for the fall, winter and spring surveys and will be used for all subsequent GufCet surveys. The Twin Otter is also modified with large bubble windows and has transect line visibility. The Twin Otter has a flight time of 6.5 hours.

Based on several considerations, including projected availability of acceptable survey conditions and available funding, the study was designed to survey about 6,500 transect km per season. Each season the study area was covered uniformly. Transects from a random start were placed equidistance apart across the study area. Transects were oriented perpendicular to the bathymetry. Therefore, transects were placed north-south off Alabama, Mississippi and Louisiana and east-west off Texas. Bases of operation were Harlingen, Texas; Galveston, Texas; Lafayette, Louisiana; and Pascagoula, Mississippi. A window of 45-days was allocated to each season, and surveys were only conducted on days when flying conditions were safe and there were none to few whitecaps.

Surveys were conducted using standard cetacean aerial survey methods. A typical survey flight began at around 0800 in the morning and lasted about 6.5 hours. Three observers participated in each flight and rotated through two observer positions and the computer station. Transect lines were surveyed from 750 feet at a speed of 110 knots. When cetaceans were sighted, the distance to the group from the transect line was measured with an inclinometer. A dye marker was usually dropped to mark the position and the aircraft was diverted to circle the group. The species was identified to the lowest taxonomic level possible. The number of adults and calves were counted and the location recorded. In compliance with our survey permit, the behavior of the group at the time of the sighting and after the sighting were noted. Data on survey conditions were collected (i.e., weather, water color, glare, water clarity and sea state). Data were also collected on sea turtles and other marine life sighted.

The survey team included Wayne Hoggard, Carolyn Rogers, Jon Peterson, Gina Childress, Kevin Rademacher, Lesley Higgins, Carol Roden, Sean O'Sullivan and Keith Mullin, all from the Southeast Fisheries Science Center. Steve Viada, of the Minerals Management Service, participated in survey flights on 9 September 1992 and 15 March 1993. Behavioral observations of cetacean groups from the aircraft were made on 12 February 1993 by Bernd Würsig, Kathleen Dudzinski, and Dagmar Fertl from Texas A&M at Galveston.

3.2.2 Results and Discussion

During the summer season, all of the proposed 77 transect lines, totaling 6,571 km, were surveyed (Table 3.1). Weather caused major interruptions in the survey on two occasions. The survey team disbanded in Galveston on 24 August and the aircraft was moved inland while Hurricane Andrew was in the Gulf Mexico. Because of the destruction in coastal Louisiana, the survey was resumed from Pascagoula, and the Louisiana portion of the study area was surveyed last. Because the survey was well ahead of schedule, both in terms of flight hours and window-days used, the aircraft and survey team returned to Pascagoula. This was done in order to resurvey several transect lines previously surveyed under marginal weather conditions and to provide the locations of sperm whales for the GulfCet sperm whale tagging effort scheduled to begin in early October. Fifty-seven cetacean groups were sighted during this survey (Table 3.1). Six sightings were off-effort. At least 13 species of cetaceans were sighted during the entire survey. Pantropical spotted dolphins, bottlenose dolphins and dwarf/pygmy sperm whales were the most commonly sighted species. Two mixed species groups were sighted:

| | Sum. 92 | Fall 92 | Win. 93 | Spr. 93 |
|---|---|---|---|---|
| Days in window | 40 | 44 | 50 | 38 |
| Survey days | 15 | 10 | 12 | 16 |
| Weather days | 17 | 31 | 28 | 17 |
| Travel days | 6 | 3 | 4 | 1 |
| Other days | 2 | 0 | 4 | 4 |
| Flight hours | 97 | 80 | 90 | 100 |
| Transects completed | 77 | 66 | 74 | 74 |
| Transects proposed | 77 | 74 | 74 | 74 |
| Transect kilometers | 6571 | 5506 | 6246 | 6370 |
| Number of sightings | 51 | 24 | 37 | 51 |
| Number of animals | 946 | 226 | 912 | 1159 |
| Off-effort sightings | 7 | 2 | 4 | 6 |
| Number of species | 13 | 9 | 10 | 12 |
| Group sightings rate (groups/100 km) | .78 | .44 | .59 | .80 |
| Animal sighting rate (animals/100 km) | 14.4 | 4.1 | 14.6 | 18.2 |
| Average group size | 18.1 | 9.4 | 24.6 | 22.7 |

Table 3.1. Summary of Summer 1992, Fall 1992, Winter 1993, and Spring 1993 GulfCet Aerial Surveys.

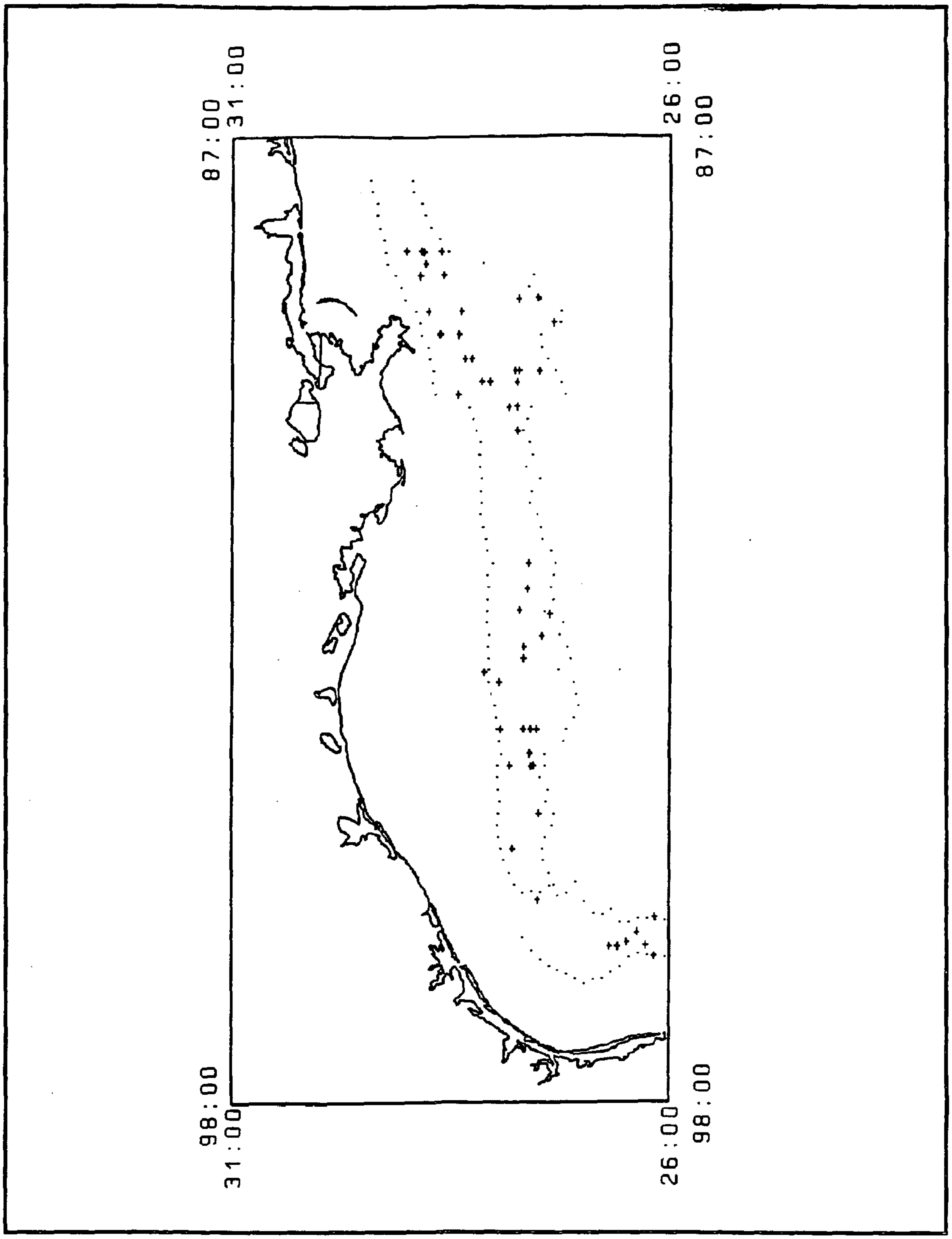


Figure 3.1. Location of each marine mammal group sighted (+)during Summer 1992 GulfCet Aerial Survey.

bottlenose dolphins and Risso's dolphins, and bottlenose dolphins and Atlantic spotted dolphins. Cetacean groups did not appear to be uniformly distributed in the study area (Figure 3.1). In addition to cetaceans, 27 sea turtles were sighted including 23 leatherback sea turtles, an endangered species.

In the fall season, of the proposed 74 transect lines, only 66 were completed because of poor weather (Table 3.1). A total of 3,395 transect km was surveyed (88% of the proposed effort). High winds and rain were persistent throughout the survey and caused major interruptions. Twenty-six cetacean groups were sighted. Two sightings were off-effort. At least nine species of cetaceans were sighted during this survey. Cetacean groups did not appear to be uniformly distributed in the area surveyed (Figure 3.2). Four leatherback sea turtles and one loggerhead sea turtle were sighted.

The winter survey window was extended from 45 to 50 days because of mechanical problems with the aircraft on four days. The costs associated with these days were absorbed by the NOAA Aircraft Operations Center. High winds and rain were persistent throughout the survey window and caused major interruptions in the survey. Twenty-eight days of the window had unacceptable survey conditions. Surveys were conducted on 12 days and all of the proposed 74 transect lines were completed (Table 3.1). A total of 6,246 transect km was surveyed. Forty-one cetacean groups were sighted including four off-effort sightings. At least ten species of cetaceans were sighted including the first sightings of Bryde's/sei whale, striped dolphins, clymene dolphins and spinner dolphins during the GulfCet aerial surveys. Other species sighted included pantropical spotted dolphins, bottlenose dolphins, dwarf/pygmy sperm whales, Risso's dolphins, Atlantic spotted dolphin, pilot whales. Cetacean groups were found throughout the area surveyed (Figure 3.3). Four leatherback sea turtles and four chelonid sea turtles were sighted.

The spring survey was completed in 38 days. Weather was generally good throughout the survey window, and there were no major interruptions. All of the proposed 74 transect lines were surveyed (Table 3.1). Fifty-one cetacean groups were sighted on-effort during the line transect surveys (Figure 3.4). Six sightings were made off-effort. At least 12 species of cetaceans were sighted during the entire window including the first sighting of Fraser's dolphin during the GulfCet aerial surveys. Seventeen Fraser's dolphins were observed in a tight group along with 400 melon-headed/pygmy killer whales that were in many sub-groups spread out over a large area. There was also a group of rough-toothed dolphins among these whales. This group of 400 cetaceans is the largest we have observed in the Gulf of Mexico. In addition to cetaceans, three leatherback sea turtles and one chelonid sea turtle were sighted. Except for three turtles, all of the leatherback sea turtles sighted during the four seasonal surveys were aggregated near the Mississippi River delta (Figure 3.5).

A total of 164 cetacean groups was sighted on-effort during the four surveys. Twenty-five sightings were off-effort including a group of ten killer whales. At least 18 species of cetaceans have been sighted to date. Bottlenose dolphins, pantropical spotted dolphins,dwarf/pygmy sperm whales, also Risso's dolphins were the most commonly sighted species. On-effort group sighting rates were highest in summer and spring, and lowest in fall (Table 3.2). The summer, winter and spring average group sizes of all cetacean groups sighted were over twice the fall average. This resulted in a large difference in the sighting

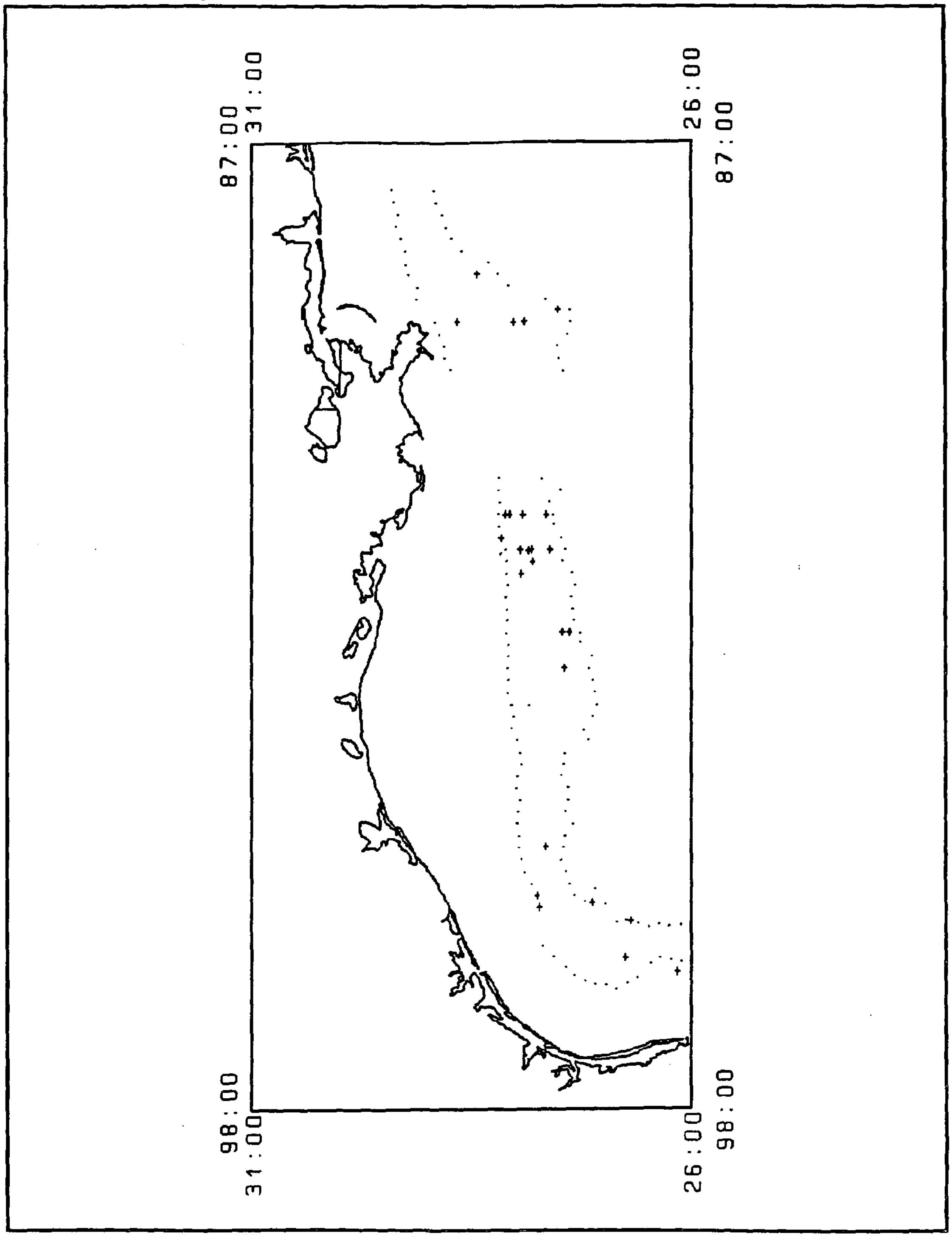


Figure 3.2. Location of each marine mammal group sighted (+) during Fall 1992 GulfCet Aerial Survey.

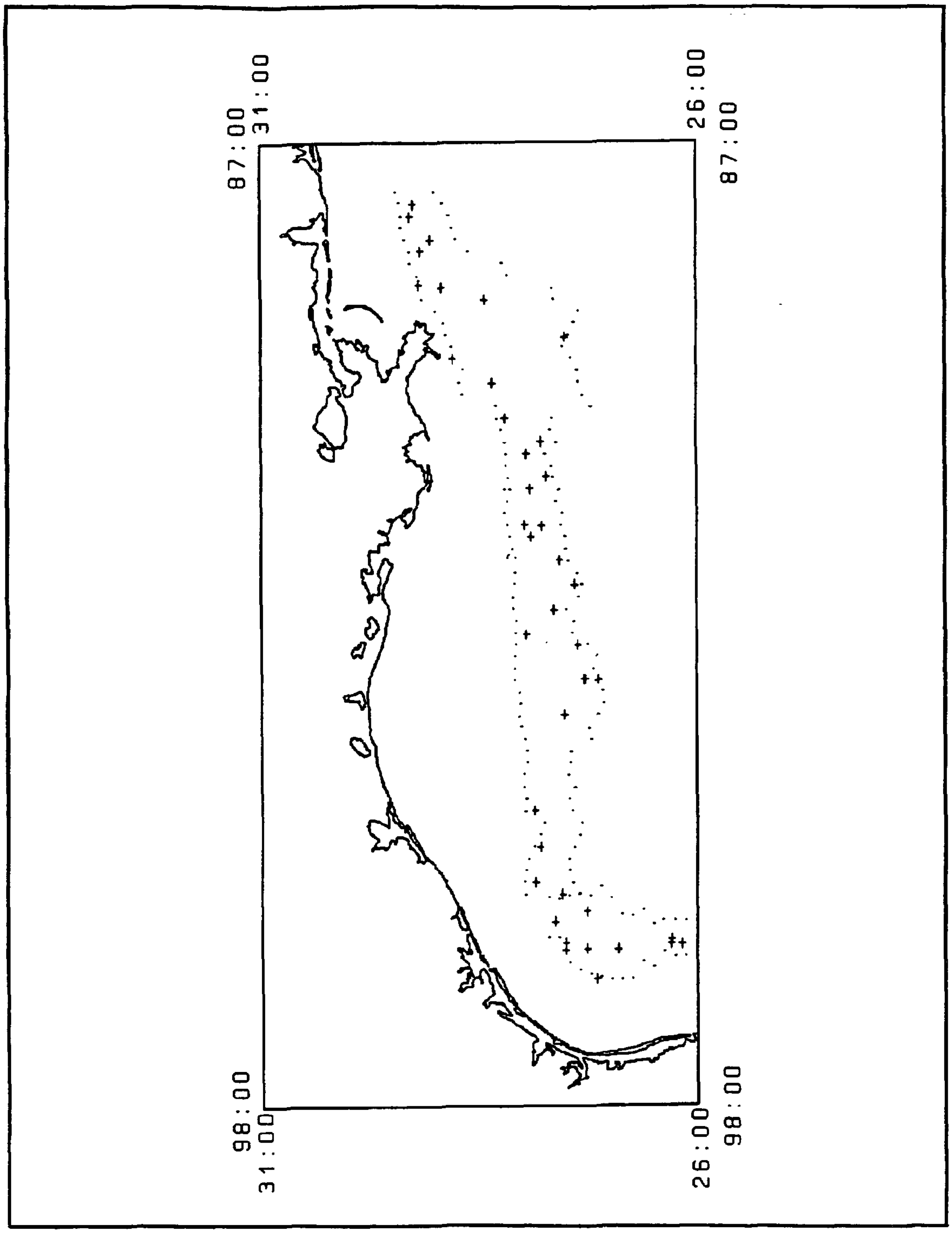


Figure 3.3. Location of each marine mammal group sighted (+) during Winter 1993 GulfCet Aerial Survey.

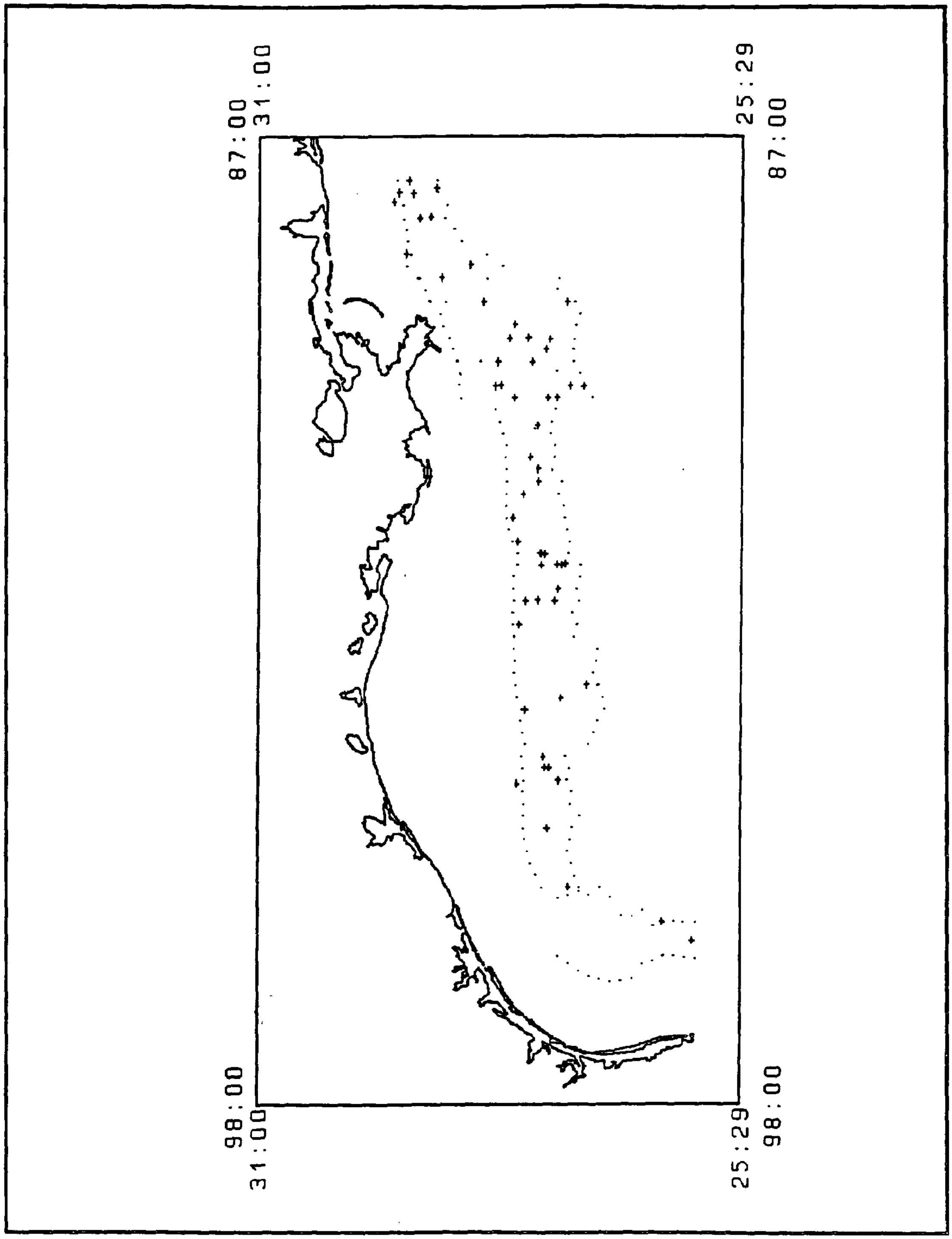


Figure 3.4. Location of each marine mammal group sighted (+) during Spring 1993 GulfCet Aerial Survey.

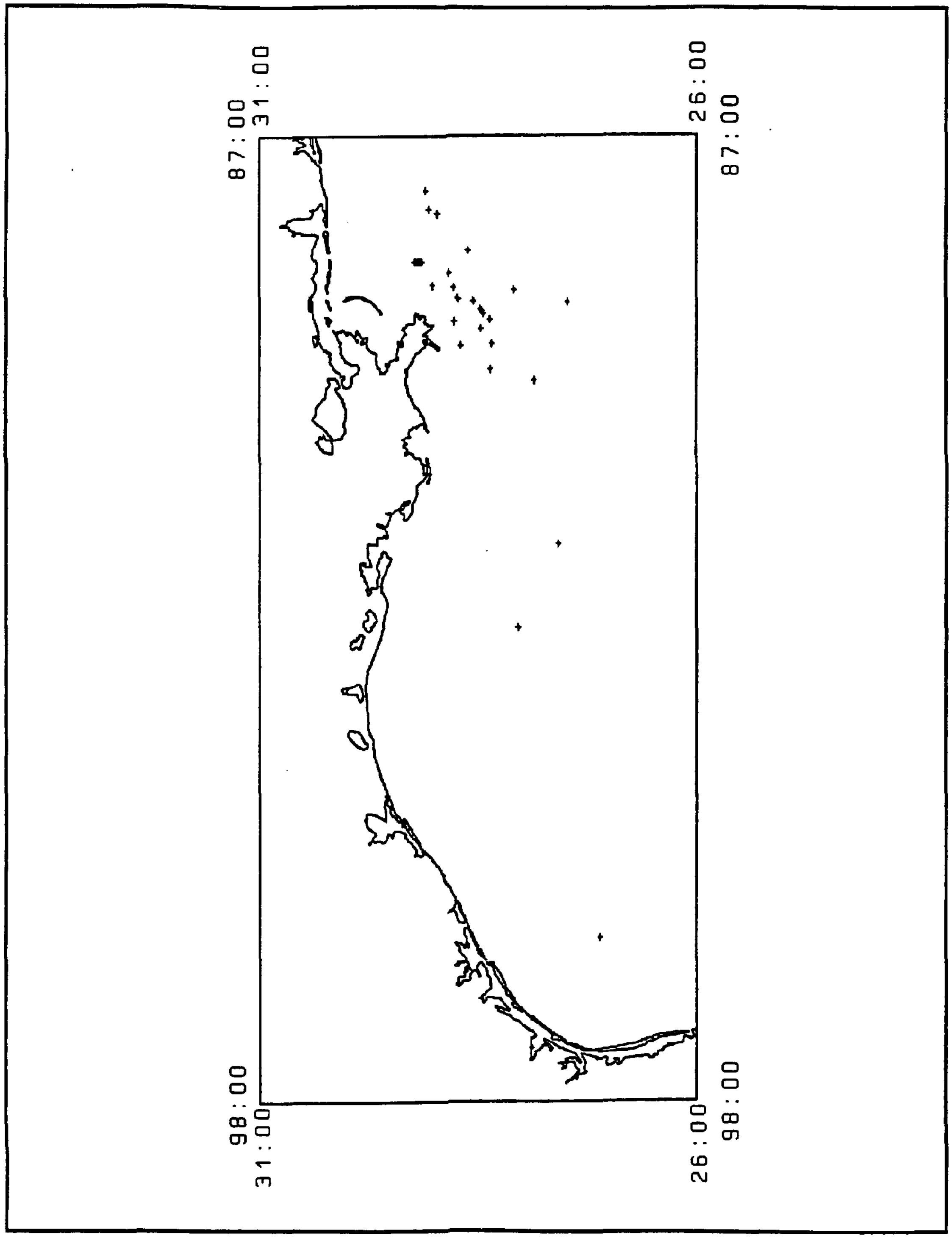


Figure 3.5. Location (+) of leatherback sea turtles sightings during Summer and Fall 1992, Winter and Spring 1993 GulfCet Aerial Surveys.

| Species | $n^1$ | Group size | range | Depth (m) | range | $n^2$ S | $n^2$ F | $n^2$ W | $n^2$ S |
|---|---|---|---|---|---|---|---|---|---|
| Brdye's/sei whale | 1 | 1.0 | - | 213 | - | 0 | 0 | 1 | 0 |
| sperm whale | 10 | 2.1 | 1- 4 | 934 | 499-1934 | 3 | 2 | 0 | 7 |
| dwarf/pygmy sperm whale | 18 | 1.3 | 1- 3 | 743 | 151-1316 | 7 | 1 | 4 | 7 |
| *Mesoplodon* sp. | 1 | 4.0 | - | 630 | - | 1 | 0 | 0 | 0 |
| beaked whale | 5 | 2.6 | 1- 4 | 1041 | 894-1316 | 1 | 2 | 0 | 2 |
| melon-headed/pygmy killer whale | 3 | 195.7 | 12-400 | 663 | 513- 835 | 1 | 0 | 0 | 2 |
| false killer whale | 1 | 35.0 | - | 974 | - | 1 | 0 | 0 | 0 |
| killer whale | 0 | 10.0 | - | 874 | - | 1 | 0 | 0 | 0 |
| pilot whale | 6 | 15.1 | 5- 35 | 904 | 241-1876 | 3 | 2 | 0 | 2 |
| rough-toothed dolphin | 5 | 20.0 | 3- 48 | 829 | 85-1316 | 2 | 1 | 0 | 2 |
| bottlenose dolphin | 32 | 14.0 | 1- 60 | 337 | 65-1316 | 8 | 4 | 12 | 12 |
| Risso's dolphin | 16 | 12.5 | 4- 33 | 704 | 234-2088 | 2 | 2 | 5 | 8 |
| Atlantic spotted dolphin | 10 | 18.1 | 6- 42 | 252 | 126- 546 | 2 | 1 | 4 | 3 |
| pantropical spotted dolphin | 19 | 40.0 | 5-100 | 1024 | 435-1815 | 13 | 1 | 3 | 6 |
| striped dolphin | 1 | 150.0 | - | 1035 | - | 0 | 0 | 1 | 0 |
| spinner dolphin | 1 | 200.0 | - | 1055 | - | 0 | 0 | 1 | 0 |
| clymene dolphin | 3 | 29.0 | 9- 40 | 885 | 601-1298 | 0 | 0 | 1 | 2 |
| Fraser's dolphin | 1 | 17.0 | - | 835 | - | 0 | 0 | 0 | 1 |
| bottlenose/Atlantic spotted | 3 | 12.3 | 2- 25 | 259 | 64- 329 | 1 | 0 | 1 | 3 |
| striped/spinner/clymene dolphin | 5 | 19.6 | 2- 60 | 504 | 98- 795 | 2 | 1 | 2 | 0 |
| unidentified dolphin | 12 | 4.5 | 1- 20 | 546 | 95-1613 | 11 | 4 | 4 | 2 |
| unidentified small whale | 9 | 1.8 | 1- 3 | 1084 | 693-1748 | 6 | 1 | 0 | 2 |
| unidentified large whale | 2 | 1.0 | 1- 1 | 1556 | - | 2 | 0 | 0 | 0 |
| unidentified odontocete | 4 | 1.0 | 1- 1 | 544 | 93-1356 | 0 | 4 | 0 | 0 |

1 - total number of groups sighted on-effort.
2 - includes groups sighted off-effort.

Table 3.2. Species of cetaceans sighted, mean group sizes, and mean water depths from the Summer 1992, Fall 1992, Winter 1993, and Spring 1993 GulfCet Aerial Surveys.

rate of animals in summer, winter and spring compared to fall. Much of the decline in sightings in fall can be attributed to a decline in sightings of dwarf/pygmy sperm whale and pantropical spotted dolphins. Of species sighted more than once, pantropical spotted dolphins had the largest average group size of all the species sighted, whereas dwarf/pygmy sperm whales had the smallest. Because of their large average group size, the decline in pantropical sightings accounted for much of the difference in the total number of animals sighted in the fall compared to the summer. Only three groups of pantropicals were sighted in winter. However, a group of 150 striped dolphins and a group of 200 spinner dolphins were seen in winter. These two groups accounted for 38% of the cetaceans sighted in winter. During the spring, groups of 175 and 400 melon-headed whales were sighted. These groups accounted for 50% of the animals sighted in spring.

With sightings from all four seasons combined, cetacean groups were sighted throughout the length of study area and at all water depths (Figures 3.1 to 3.4). However, distinct species were found at different water depths (Table 3.2). Bottlenose dolphins and Atlantic spotted dolphins were sighted primarily near the shelf edge (200-300 m). Pantropical spotted dolphins and dwarf/pygmy sperm whales were found in much deeper water (greater than 300 m). Pilot whales and Risso's dolphins inhabited the greatest range of water depths (greater than 1500 m).

The results of the four surveys are similar in several respects to those found by Mullin et al. (1991) in the north-central Gulf during 1989 and 1990. The only species identified in the earlier surveys that were not identified during these surveys were the fin whale and Cuvier's beaked whale. Also, in both studies, species were found at similar water depths. However, compared to Mullin et al. (1991), there has been a paucity of sperm whale and Risso's dolphin sightings during the GulfCet surveys. In future surveys, based on data from strandings and opportunistic sightings, it is reasonable to expect that humpback whales or minke whales could be sighted.

## 3.3 Shipboard Visual Surveys

### 3.3.1 Visual Surveys: TAMUG

#### 3.3.1.1 Methods

Two survey vessels, the R/V *Longhorn* and R/V *Pelican*, were used for the Texas A&M University shipboard marine mammal visual surveys. On the first cruise, we used the *Longhorn*, a 32-m, 210-ton research vessel operated by the University of Texas. For the next five cruises, we used the *Pelican* which is also 32 m long and has a displacement weight of 244 tons. The *Pelican* is owned by the Louisiana Universities Marine Consortium (LUMCON).

The research vessel traversed the study area from either east to west or west to east on each cruise at a speed of six knots when on transect and nine knots when running between transect lines. The survey was conducted from the top of the pilothouse on both vessels (observer eye height was approximately 7.7 m on the *Longhorn* and 8.9 m on the *Pelican*).

Survey procedures followed closely those developed for dolphin surveys in the eastern tropical Pacific. There were two, 3-person survey teams, one of which was on duty during all daylight hours while in the study area. The teams rotated every 2 hours. Two primary observers searched for marine mammals through pedestal-mounted 25X150 *Fujinon* binoculars,while the third observer acted as data recorder and assisted in searching with 7X binoculars. Each primary observer searched a $100^{o}$ swathe, from $90^{o}$ on their side to $10^{o}$ past the bow on the opposite side; the data recorder focused his/her effort near the ship and around the trackline. Thus the total primary search path was $180^{o}$, with a $20^{o}$ overlap centered at the bow. Observers rotated positions every 30 minutes to avoid fatigue.

Sighting angle was recorded with the aid of a graduated scale at the base of the binoculars, and radial distance to the sightings was either estimated by eye (generally for sightings within a few hundred meters of the ship) or calculated using reticles etched into the right eyepiece of the binoculars. Radial distance was estimated from reticle readings by the equation:

$$R = x \tan(\arctan(89.173/\sqrt{x}) - 0.001088\ r),$$

where R = radial distance (km), r = reticle reading, and x = eye height (in nautical miles). Perpendicular distance was calculated from radial distance and sighting by:

$$y = R \sin \varnothing,$$

where y = perpendicular distance and $\varnothing$ = sighting angle.

Sighting effort was conducted during daylight hours in which sighting conditions were acceptable. Acceptable conditions were defined as Beaufort sea states of less than 4 with good visibility. Sometimes rain, fog, glare, or excessive ship roll interrupted the survey in sea states less than Beaufort 4. During daylight hours when survey effort was suspended due to poor weather, at least one observer was stationed on the bridge to record "off effort" sightings which could be used for determining species distribution and estimating herd size. Sighting and effort data were collected on standardized forms developed by the NMFS.

In the final report, density will be calculated using line transect methods with the computer program DISTANCE (Laake et al., 1993) Because sightings of individuals for most species of cetaceans are not independent events, herds will be considered the basic targets of the survey. We will use the 'rule of thumb' suggested by Burham et al. (1980) and Buckland et al. (1993) for the absolute minimum sample size for abundance estimation. This rule stipulates that estimates should be based on no fewer than 30 sightings or detections. Thus, any species with less than 30 "on effort" sightings will be pooled with others to obtain adequate sample sizes. The basic line transect density formula (Burnham et al., 1980) is:

$$D = \frac{n\ f(O)}{2L},$$

where D = density estimate of objects (herds), n = number or objects sighted, f(0) = probability density function of the perpendicular distance data, and L = total length of transect.

Multiplying the density estimate by the species or species group mean herd size yields an estimate of individual density. Multiplying this value by the total study area gives an estimate of the numerical abundance for individuals of that species or species group:

$$N = \frac{n\, f(0)\, E(s)\, A}{2\, L\, g(0)}$$

where N = abundance estimate, E(s) = mean herd size, A = total study area and g(0) - the probability that an object on the trackline is detected (Buckland et al., 1993). In most cases, g(0) is assumed to be 1; however this is probably not true for long-diving species, and thus g(0) must be calculated and factored into the equation for these species.

The effective strip width (ESW), an index of the sightability of the species (or groups), will also be computed for each species group with a density estimate as:

$$ESW = \frac{2}{f(0)}.$$

Because extremely large coefficients of variation could result from the survey effort being stratified by season to produce separate line transect estimates, seasonal differences will be examined instead by computing sighting rates for different seasons (i.e, number of herds or individuals per 1000 km of trackline surveyed), and comparing these between seasons.

3.3.1.2 Results and Discussion

A total of 340.81 hours of sighting effort was conducted on the first six cruises (Table 3.3). This represents 4587.49 kilometers of transect line surveyed. In addition, 17.08 hours of independent observer (IO) effort were conducted. The independent observer effort will be used to test the assumption that g(0) = 1 (i.e. that all animals on the trackline are detected). For long diving species, such as sperm whales and beaked whales, such an assumption is probably invalid, and a correction for submerged animals will be included in the final abundance estimates for these species (see Barlow, 1993).

A total of 258 marine mammal sightings were made within the study area on the first six cruises (Table 3.4). Of these, 182 were "on effort" and are usable in the density and abundance estimates. The 76 "off-effort" sightings can be used only in estimating mean herd size, and will not be used to estimate density and abundance.

Based only on the sightings from these six cruises, the only species with an adequate sample size for abundance estimates is the bottlenose dolphin (32 on effort sightings). It is likely that the number of sperm whale sightings will equal to at least 30 by the end of the project. All other species will have to be

| Cruise # | 1 | 2 | 3 | 4 | 5 | 6 | Total |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Hours of Effort | 39.65 | 79.28 | 37.13 | 41.32 | 68.13 | 75.30 | 340.81 |
| Hours of IO Effort | - | - | - | - | 6.66 | 10.42 | 17.08 |
| Km of Effort | 487.40 | 1036.56 | 535.86 | 529.39 | 956.62 | 1041.66 | 4587.49 |

Table 3.3. Summary of hours and kilometers of survey effort conducted (IO refers to independent observers effort).

| Species | On Effort | Off Effort | Total |
|---|---|---|---|
| Sperm Whale | 25 | 11 | 36 |
| Cuvier's beaked whale | 2 | 0 | 2 |
| Pygmy sperm whale | 1 | 0 | 1 |
| Dwarf sperm whale | 1 | 0 | 1 |
| Short-finned pilot whale | 0 | 1 | 1 |
| False killer whale | 2 | 1 | 3 |
| Melon-headed whale | 2 | 0 | 2 |
| Risso's dolphin | 5 | 0 | 5 |
| Fraser's dolphin | 2 | 0 | 2 |
| Rough-toothed dolphin | 1 | 1 | 2 |
| Bottlenose dolphin | 32 | 13 | 45 |
| Atlantic spotted dolphin | 5 | 2 | 7 |
| Pantropical spotted dolphin | 17 | 9 | 26 |
| Spinner dolphin | 1 | 0 | 1 |
| Clymene dolphin | 5 | 1 | 6 |
| Striped dolphin | 3 | 0 | 3 |
| Unid. cetacean | 11 | 3 | 14 |
| Unid. large whale | 2 | 0 | 2 |
| Unid. *Kogia* | 2 | 1 | 3 |
| Unid. beaked whale | 5 | 3 | 8 |
| Unid. *Mesoplodon* | 3 | 3 | 6 |
| Unid. small whale | 22 | 3 | 25 |
| Unid. dolphin | 33 | 24 | 57 |
| **Total** | **182** | **76** | **258** |

Table 3.4. Summary of marine mammal sightings: TAMUG.

pooled based on the number of sightings, taxonomic relationships, and general habitat types (Wade and Gerrodette, in press). For example, oceanic species of *Stenella* (pantropical spotted, striped, spinner, and clymene dolphins) all occur in large herds and may be pooled, but the fifth species (Atlantic spotted dolphin) is a continental shelf species that is found in small herds and would not be included in the above grouping.

There have been several unexpected results from these shipboard,visual surveys. First, the most common species observed along the outer edge of the continental shelf in this region of the Gulf of Mexico is the bottlenose dolphin, not the Atlantic spotted dolphin as indicated by Schmidly (1981). Sperm whales and pantropical spotted dolphins were, by far, the most common cetaceans seen in oceanic waters. The only exception to this occurred on the sixth cruise in which very few pantropical spotted dolphins were sighted. The prevalence of sperm whales as the most abundant large cetacean was expected. However, previous research had not indicated that the pantropical spotted dolphin was the most common oceanic species. Mullin et al. (1991) found Risso's dolphin to be more common in parts of the Gulf. However, their study was not directly comparable to ours, since it occurred in shallower water (mostly along the upper continental slope) and in a very limited geographic area.

Another unexpected finding is the paucity of short-finned pilot whales. Strandings and past sighting records would have led us to believe that this is one of the most common, medium-sized cetaceans offshore (Schmidly, 1981).

Several poorly-known species have turned out to be moderately common (beaked whales, pygmy and dwarf sperm whales, melon-headed whale, and Fraser's and clymene dolphins). Both melon-headed whales and Fraser's dolphins were almost completely unknown in the Gulf of Mexico before this study began, each represented by one or two standings. The first live sightings of these species in the Gulf (and for Fraser's dolphin, the first for the entire Atlantic Ocean) were recorded during this project (Leatherwood et al., in press; Mullin et al., submitted). The clymene dolphin was well-known in the Gulf from strandings previous to this project, but also was poorly-represented by live sightings (Jefferson and Odell, in prep.)

### 3.3.3 Visual Surveys: NMFS *RV Oregon II*

#### 3.3.3.1 Methods

The Southeast Fisheries Science Center (SEFSC) has conducted two of four planned vessel surveys aboard the NOAA *R/V Oregon II* as part of the SEFSC contribution effort to the GulfCet Program. The first survey was conducted from April 21 to June 8, 1992 (spring-summer), and the second survey took place from January 4 to February 14, 1993 (winter). Both surveys were designed to collect: 1) marine mammal sighting data to estimate abundance, distribution and diversity, and 2) environmental data to evaluate factors which may affect the distribution, abundance and diversity of marine mammals. These surveys are also part of the SEFSC's overall marine mammal research program. Similar vessel surveys have been conducted annually during the spring-summer in the northern Gulf of Mexico since 1990.

The spring-summer survey was conducted in three separate legs, with the first two legs covering the off-shelf waters of the northern Gulf between 83°- 96°W longitude. The third leg concentrated on the GulfCet study area between 87°-96°W longitude. The winter survey consisted of three legs, all essentially within the GulfCet study area between 87°-96° W longitude. The major difference in sampling between the two surveys was in the visual sampling strategy. During legs I and II of the spring-summer survey, visual sampling occurred during daylight hours along a cruise track that was sampled 24 hours a day for ichthyoplankton; daylight transects could be latitudinal or longitudinal, or a combination of both (Figure 3.6 and 3.7). Ichthyoplankton sampling did not occur on leg III of the spring-summer survey or during daylight hours on all legs of the winter survey. This resulted in visual sampling on only longitudinal transects (Figures 3.6 to 3.11).

Visual sighting data were collected by two teams of three observers during daylight hours, weather permitting (i.e, no rain, Beaufort sea state less than 6). Each team had at least two members experienced in shipboard marine mammal observation and identification techniques. Two observers searched for marine mammals using high-power (25 X), large format "Bigeye" binoculars mounted on the ship's flying bridge. The third observer maintained a search of the area near the trackline with handheld binoculars and recorded data. Sighting data were recorded with a computer in the format required for line-transect analysis. Information collected included species, herd-size, perpendicular sighting distance, and data on environmental conditions (i.e, Beaufort sea state, sun position, etc.) which could affect the observers' ability to sight animals. Ancillary data included behavior and associated animals.

In general, environmental stations were located every 30 minutes of latitude or longitude along the cruise track. The stations included CTD/STD hydrocasts to a maximum depth of 500 m. An XBT was dropped halfway between the environmental stations. A thermo-salinograph operated throughout the entire cruise; surface water salinity and temperature were recorded every minute of time. Data from the hydrographic survey are in the SEAMAP (NOAA) data base.

3.3.2.2 Results and Discussion

A total of 6,154 transect kilometers were visually sampled for marine mammals during the spring-summer survey despite weather and mechanical problems which caused the loss of about 15 effort-days. The visual sampling resulted in 273 sightings of at least 20 species of cetaceans (Table 3.5). The bottlenose dolphin and the pantropical spotted dolphin were the most frequently sighted species and accounted for 21% and 19%, respectively, of identified sightings. Risso's dolphins , sperm whales , and dwarf sperm whales were the next most frequently sighted, and accounted for 11%, 8%, and 8%, respectively, of identified sightings.

The winter survey resulted in the visual sampling of 4,017 transect kilometers, although weather conditions significantly hampered the sampling effort. The survey was suspended on two days due to severe weather (sea state greater than Beaufort 6), and reduced on eleven additional survey days when average daily sea state was greater than Beaufort 4. At least 10 cetacean species were observed in a total of 46 sightings (Table 3.5). Sperm whales were the

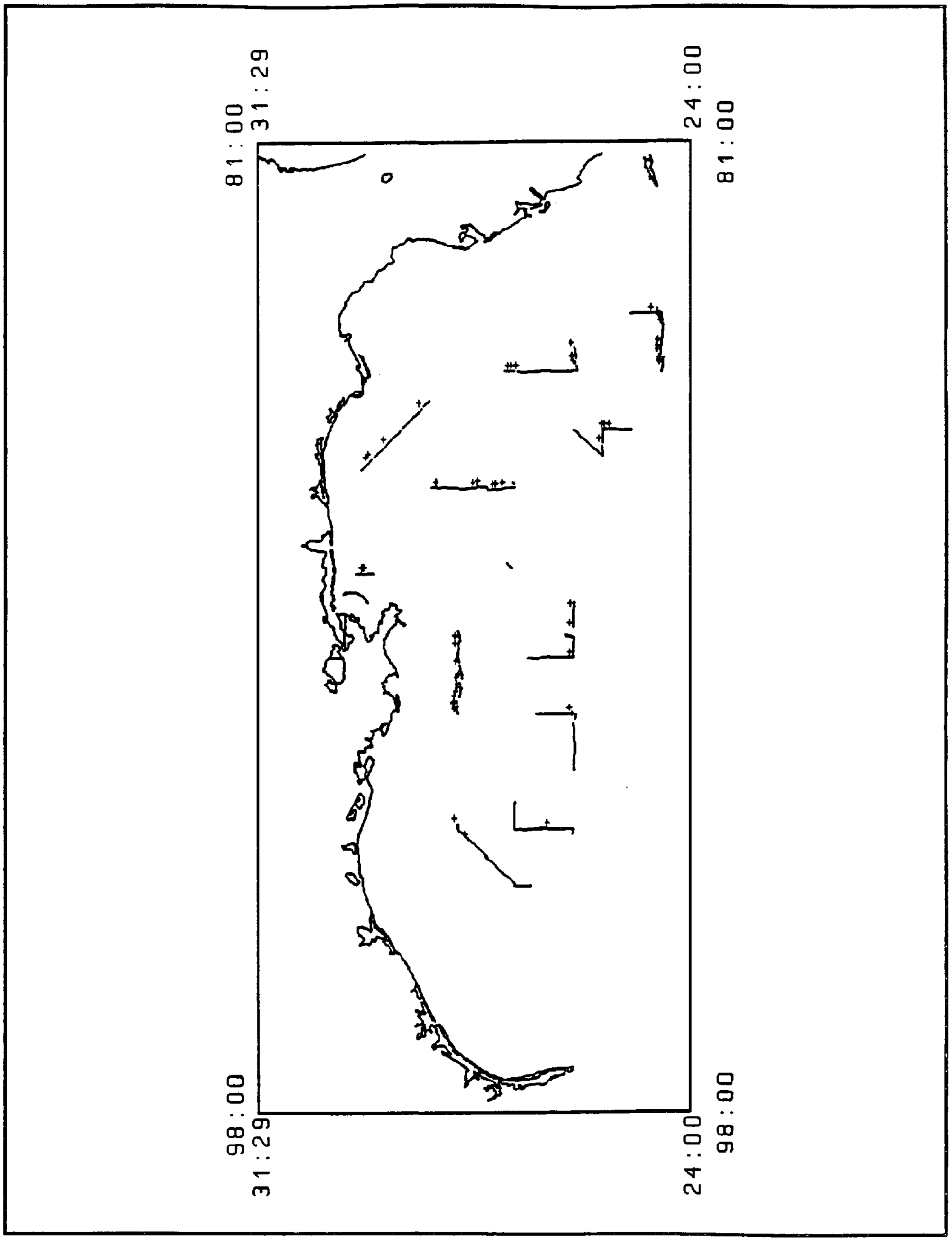


Figure 3.6. On-effort daylight cruise track and location (+) ofcetacean sightings during Leg 1 of spring-summer survey, NOAA ship.

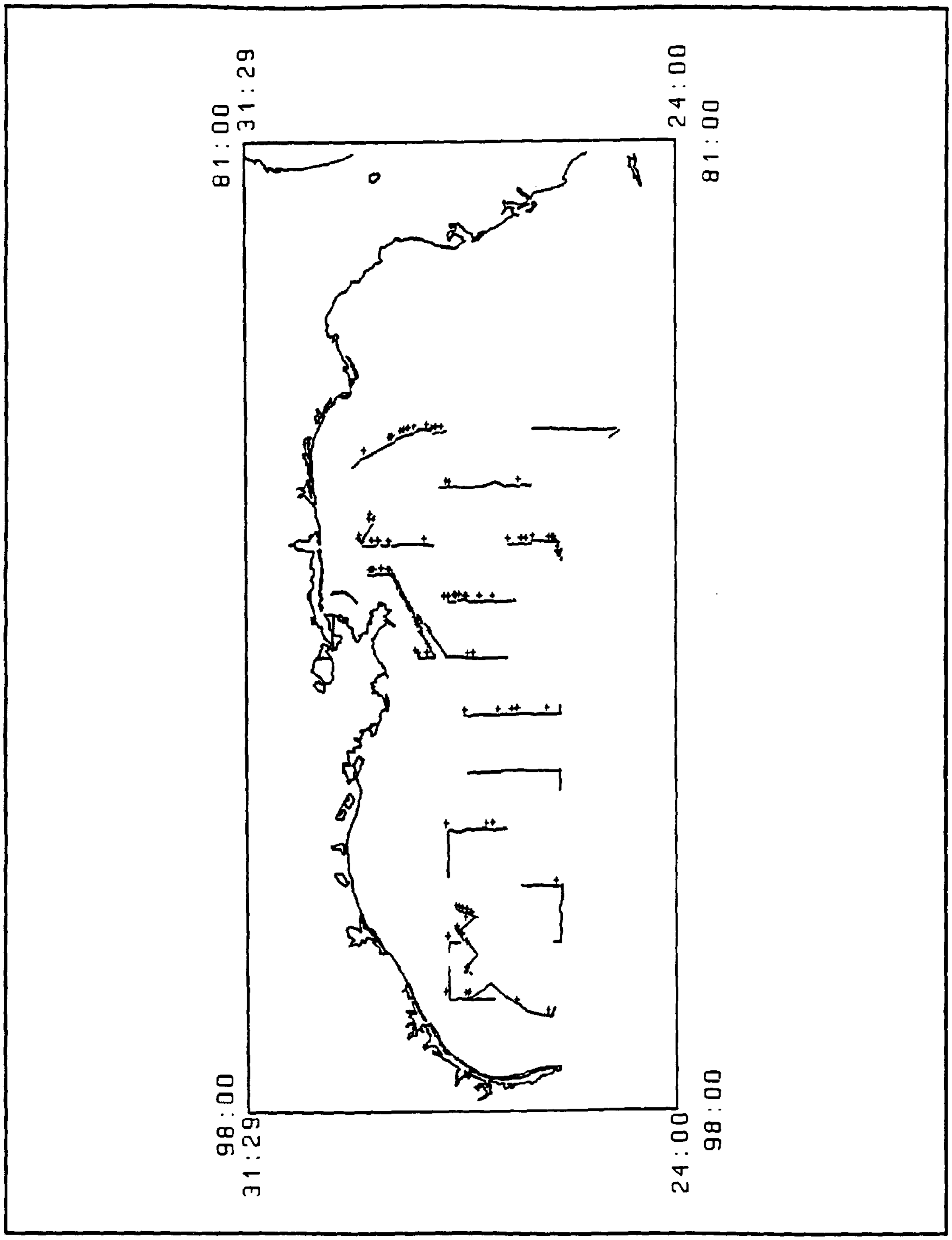


Figure 3.7. On-effort daylight cruise track and location (+) of cetacean sightings during Leg 2 of spring-summer survey, NOAA ship.

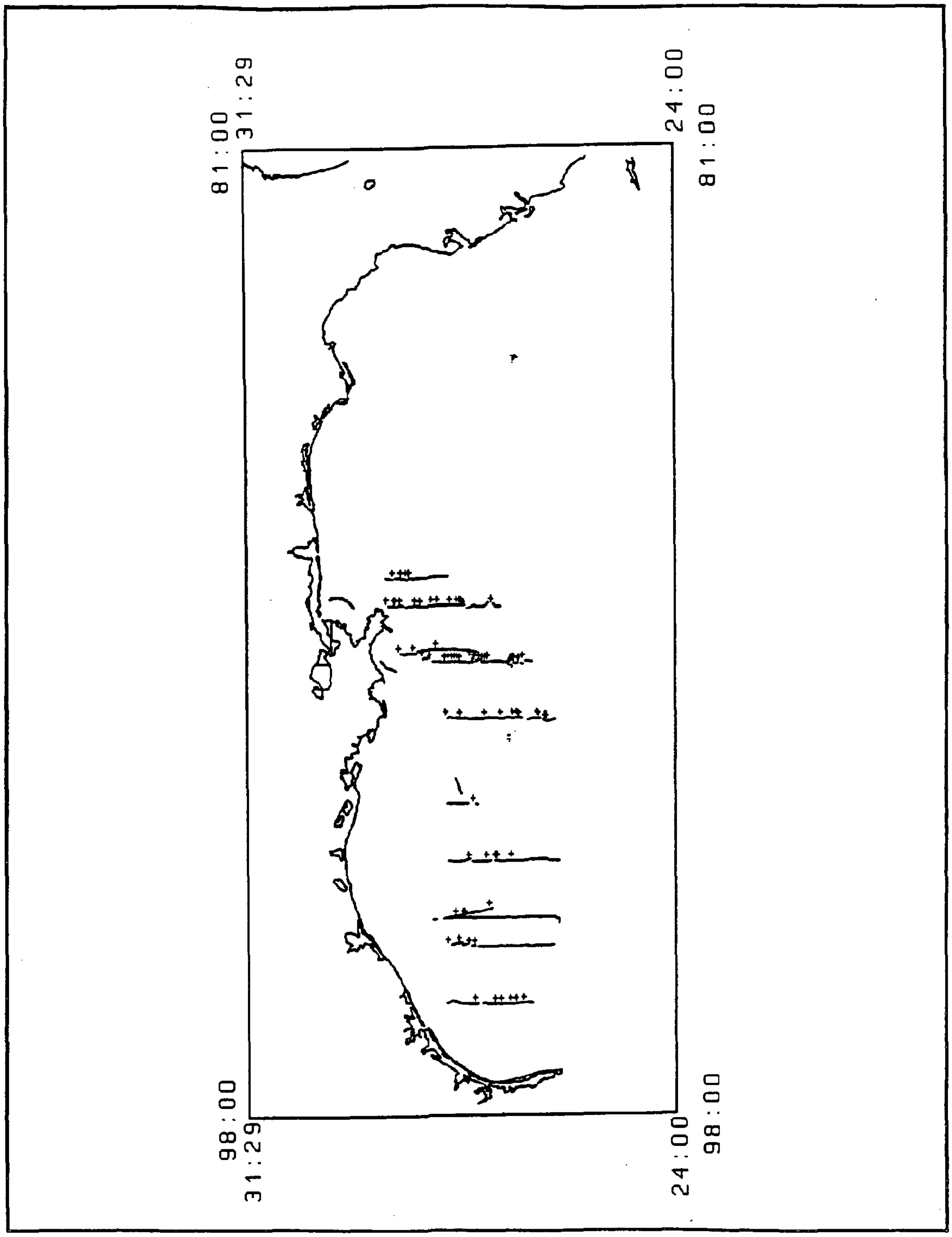


Figure 3.8. On-effort daylight cruise track and location (+) of cetacean sightings during Leg 3 of spring-summer survey, NOAA ship.

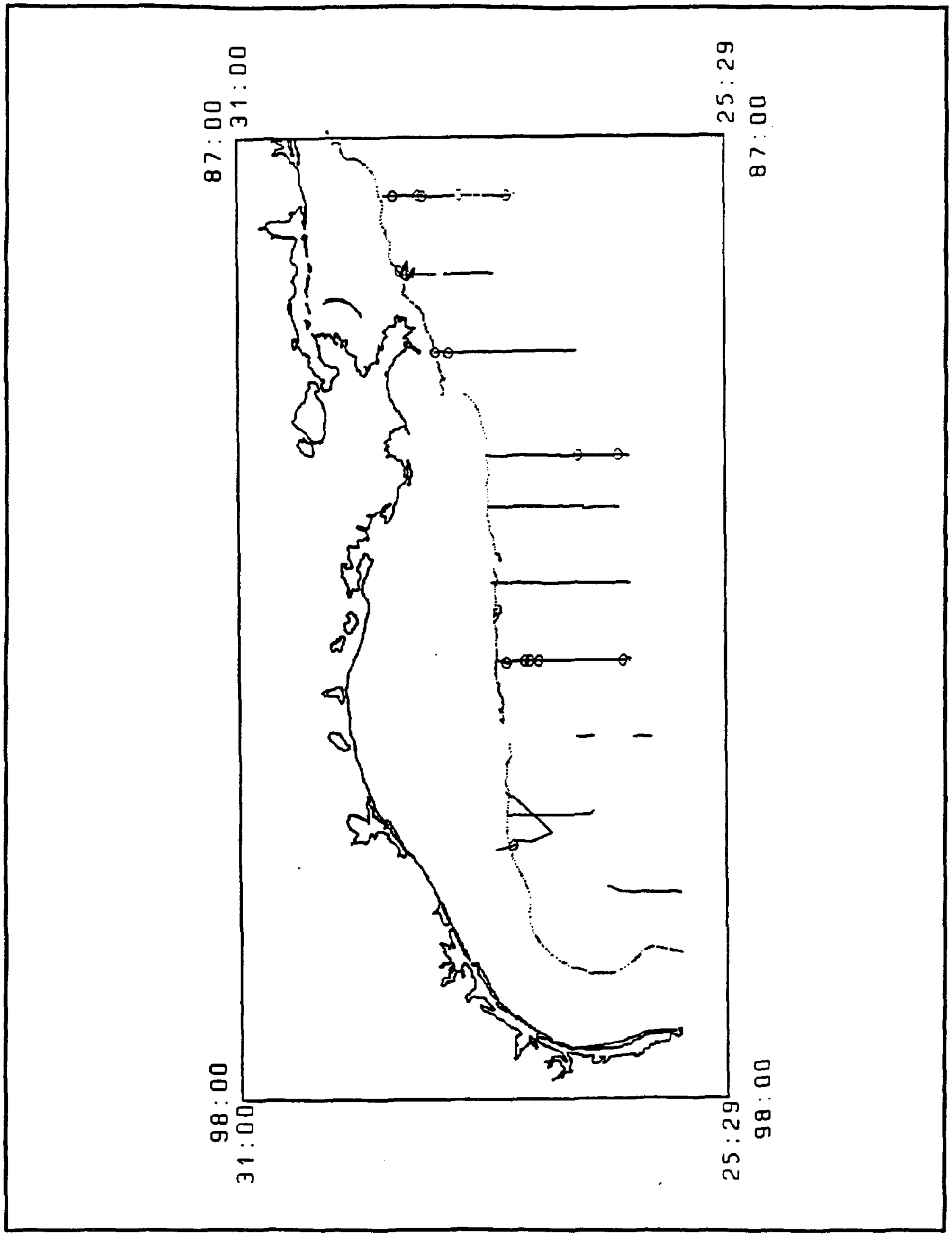


Figure 3.9. On-effort daylight cruise track and location (+) of cetacean sightings during Leg 1 of winter surveysummer survey, NOAA ship.

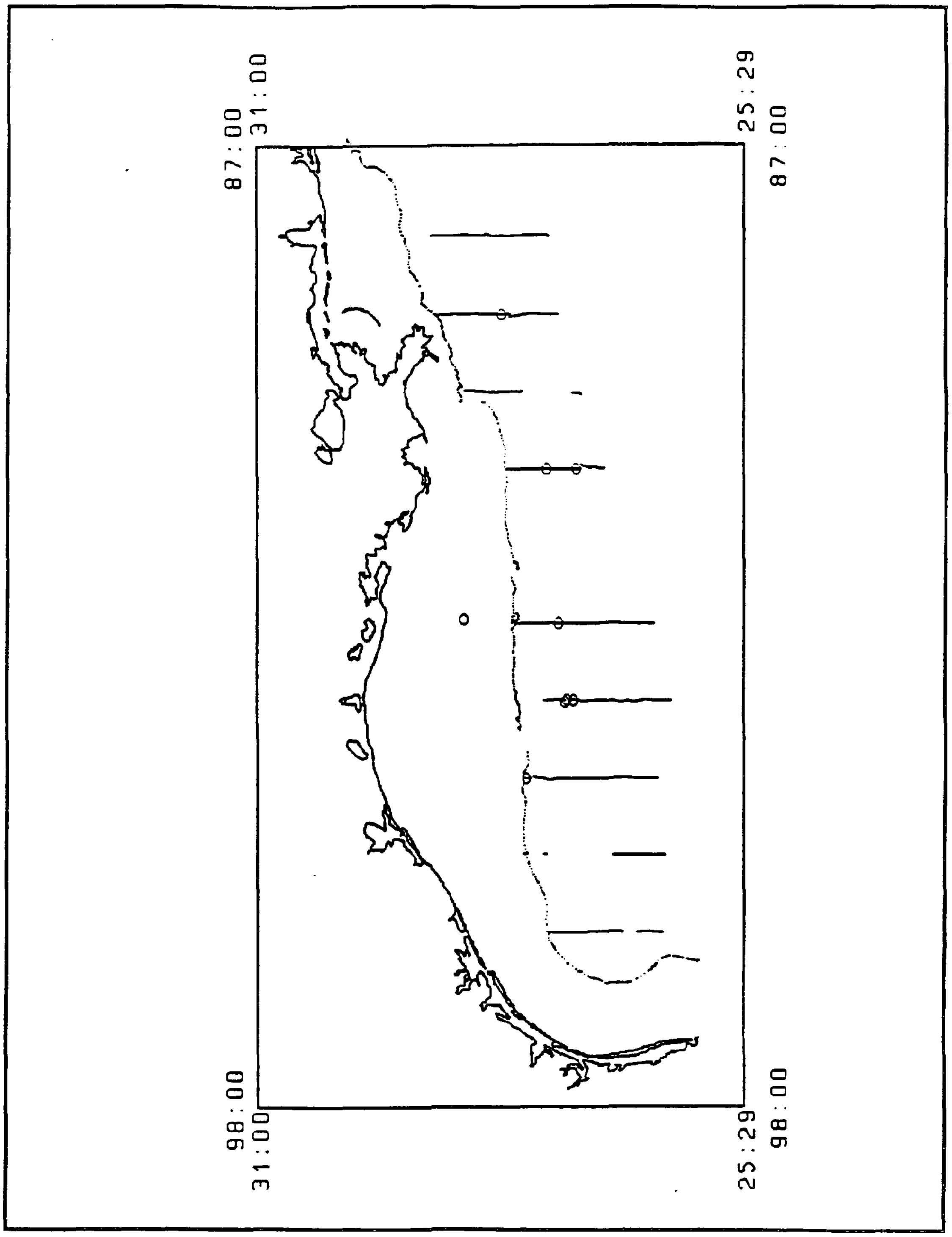


Figure 3.10. On-effort daylight cruise track and location (+) ofcetacean sightings during Leg 2 of winter surveysummer survey, NOAA ship.

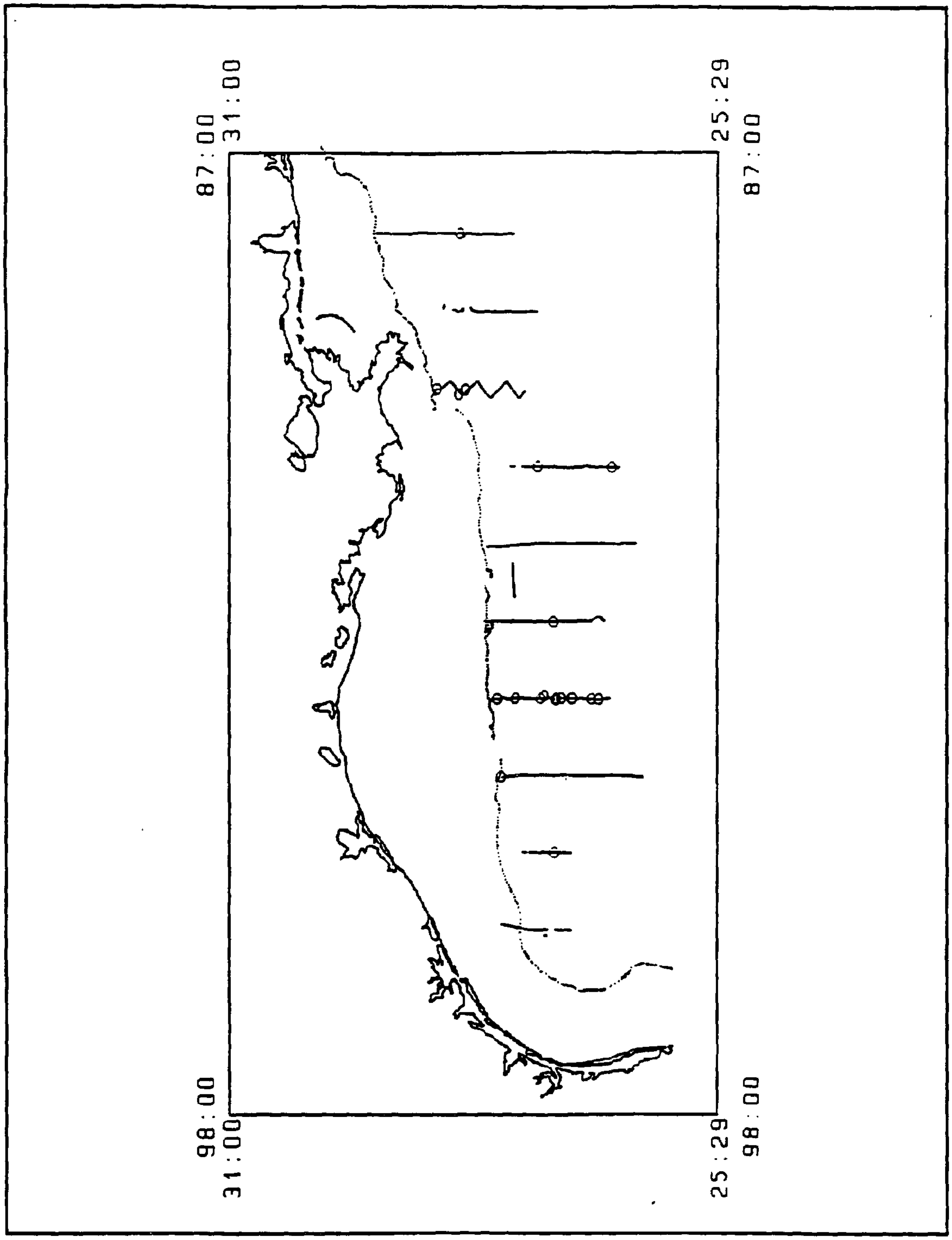


Figure 3.11. On-effort daylight cruise track and location (+) ofcetacean sightings during Leg 3 of winter surveysummer survey, NOAA ship.

| SPECIES | SUMMER-SPRING | WINTER |
|---|---|---|
| *Balaenoptera edeni* | 1 | - |
| *Balaenoptera edeni/borealis* | 3 | - |
| *Physeter macrocephalus* | 19 | 9 |
| *Kogia breviceps* | 5 | 1 |
| *Kogia simus* | 18 | - |
| *Kogia* sp. | 12 | - |
| *Mesoplodon* sp. | 6 | - |
| *Mesoplodon densirostris* | 1 | - |
| Unidentified Ziphiid | 2 | 1 |
| *Peponocephala electra* | 2 | 1 |
| *Feresa attenuata* | 2 | - |
| *Feresa/Peponocephala* | 1 | - |
| *Pseudorca crassidens* | 1 | - |
| *Orcinus orca* | 1 | - |
| *Globicephala macrorhynchus* | 3 | 2 |
| *Steno bredanensis* | 5 | - |
| *Lagenodelphis hosei* | 1 | - |
| *Tursiops truncatus* | 48 | 5 |
| *Grampus griseus* | 24 | - |
| *Stenella frontalis* | 7 | 6 |
| *Tursiops/Stenella frontalis* | 1 | - |
| *Stenella attenuata* | 43 | 6 |
| *Stenella coeruleoalba* | 7 | 2 |
| *Stenella longirostris* | 6 | - |
| *Stenella clymene* | 6 | 2 |
| *Stenella sp.* | 1 | 1 |
| Unidentified dolphin | 27 | 8 |
| Unidentified small whales | 4 | - |
| Unidentified odontocete | 16 | 2 |
| TOTALS | 273 | 46 |

Table 3.5. Summary of cetacean sightings from the spring-summer and winter vessel survey (NMFS).

most commonly sighted cetaceans, with 9 sightings (25% of identified sightings). Atlantic spotted dolphins and pantropical spotted dolphins were the next most common with six herd sightings each (17% each of identified sightings).

The sighting distribution data from the spring-summer survey were combined with that from the spring-summer surveys from 1990-92 for a preliminary evaluation of distribution patterns. This evaluation does not correct for effort. Sighting data from the winter survey were not included because of possible seasonal differences. Figure 3.12 illustrates the sightings of all cetaceans during the spring-summer surveys. In general, it appears that sightings were more common in the central portion of the northern Gulf. Sightings also appear to be more common in the eastern side of the survey area than in the western side. However, more survey effort has been expended in the central and eastern portions of the area, and the apparent differences in sighting distribution may reflect effort.

The *Stenella* sp., with the exception of the Atlantic spotted dolphin, were sighted most frequently in the deeper, off-shelf waters of the survey area. Figure 3.13 illustrates the sightings of the pantropical spotted dolphins; other *Stenella* (with the previously noted exception) display the same pattern. The sighting distribution of the Atlantic spotted dolphin was quite different with all sightings located on the edge of the continental shelf (Figure 3.14).

Sightings of bottlenose dolphins, Risso's dolphins,and Atlantic spotted dolphins all appeared to occur quite frequently along the edge of the continental shelf. However, whereas Atlantic spotted dolphins were sighted only along the shelf edge, bottlenose dolphins were also seen frequently on the continental shelf while Risso's dolphins were also seen in the deeper Gulf waters (Figures 3.14 to 3.16).

Members of the sperm whale family were sighted both along the shelf edge and in the deeper waters of the survey area. Kogia sp. sightings were located throughout the deeper waters, with no apparent pattern. Sightings of sperm whales, however, showed an apparent disjunct distribution with sightings in Mississippi and DeSoto canyons and a band along the southern edge of the survey area (Figure 3.17). This apparent distribution should be interpreted with caution, since what appears to be a band along the southern edge may only represent the tip of a distribution that was not fully observed. The distribution could quite possibly extend beyond the limits of the survey area.

Other species, such as pilot whales, rough-toothed dolphins, false killer whales, beaked whales, Bryde's whale, and others were seen too infrequently to justify evaluation of sighting distributions on a species basis. Overall, however, nearly all of these species appear to occur most frequently in the deeper waters and not on the continental shelf or shelf edge. The exception to this pattern was Bryde's whale, with nearly all sightings occurring in or along the edge of DeSoto canyon.

Four species not seen on the previous SEFSC marine mammal vessel surveys were observed on the present surveys. Blainville's beaked whale, the melon-headed whale and Fraser's dolphin were all sighted on the spring-summer survey, and melon-headed whales were seen on the winter survey. These observations represented some the first documented sightings of these species

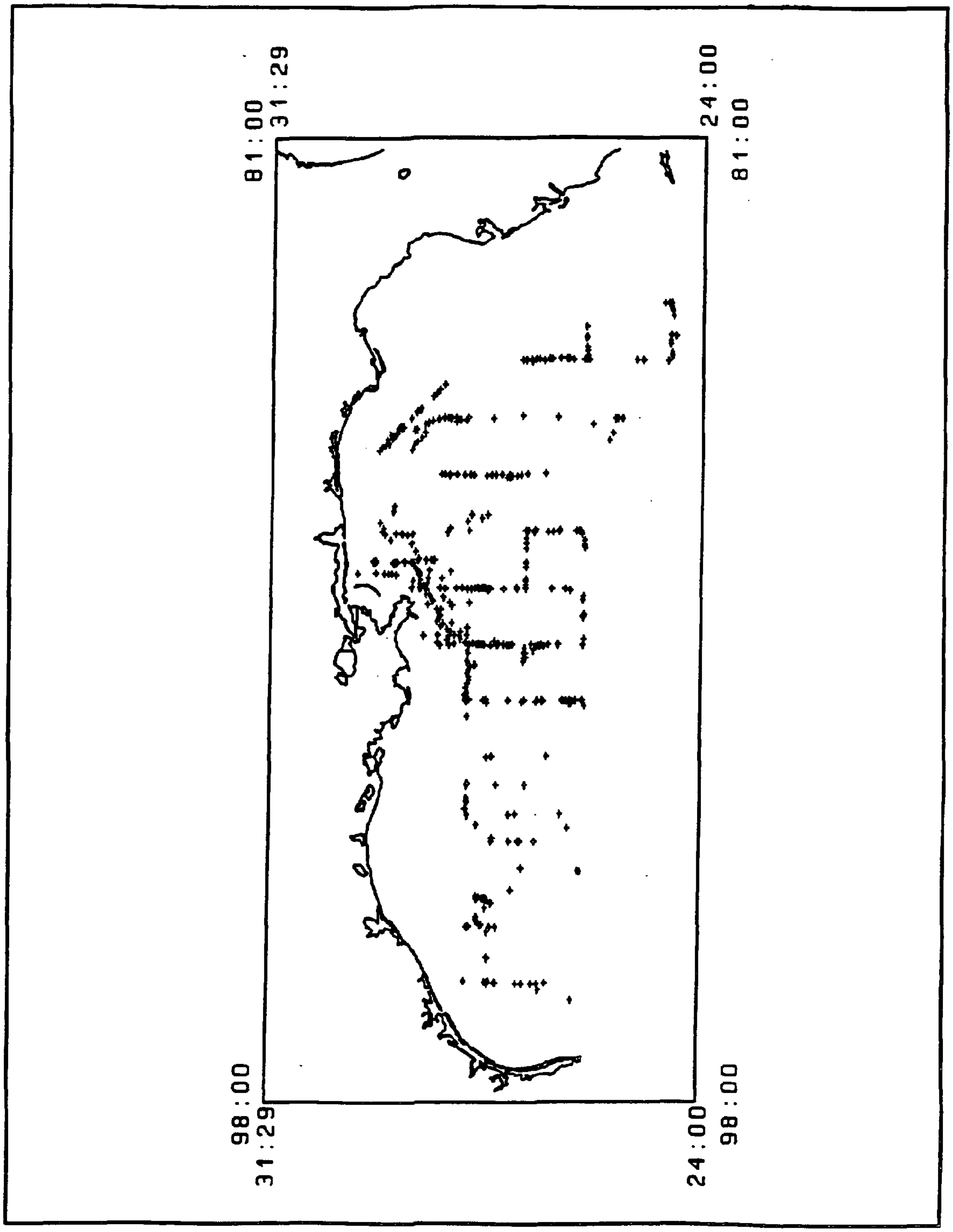


Figure 3.12. Locations (+) of all cetacean groups sighted during SEFC marine mammal cruises in the northern Gulf of Mexico: 1990-1992.

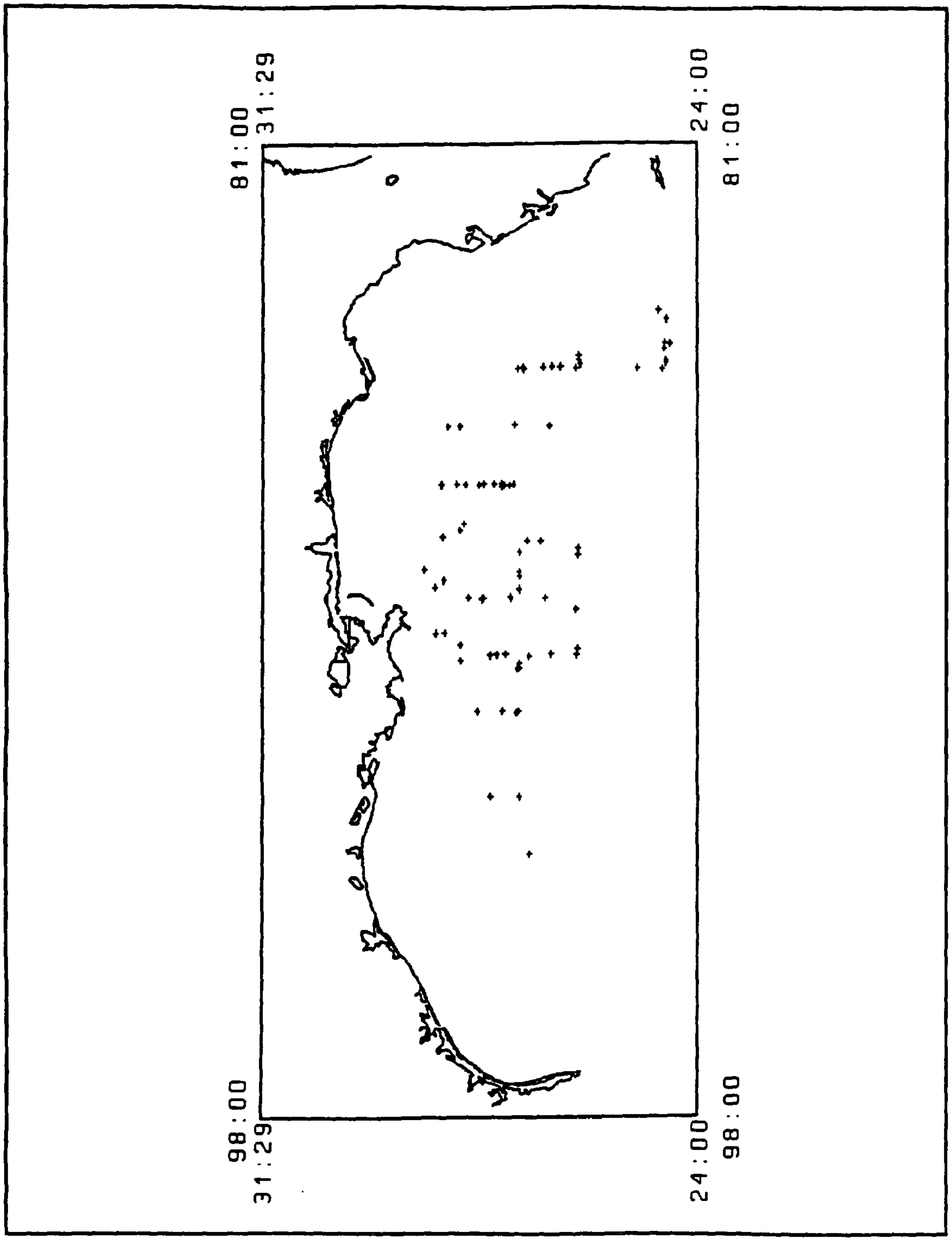


Figure 3.13. Locations (+) of *S. attenuata* groups sighted during SEFC marine mammal cruises in the northern Gulf of Mexico: 1990-1992.

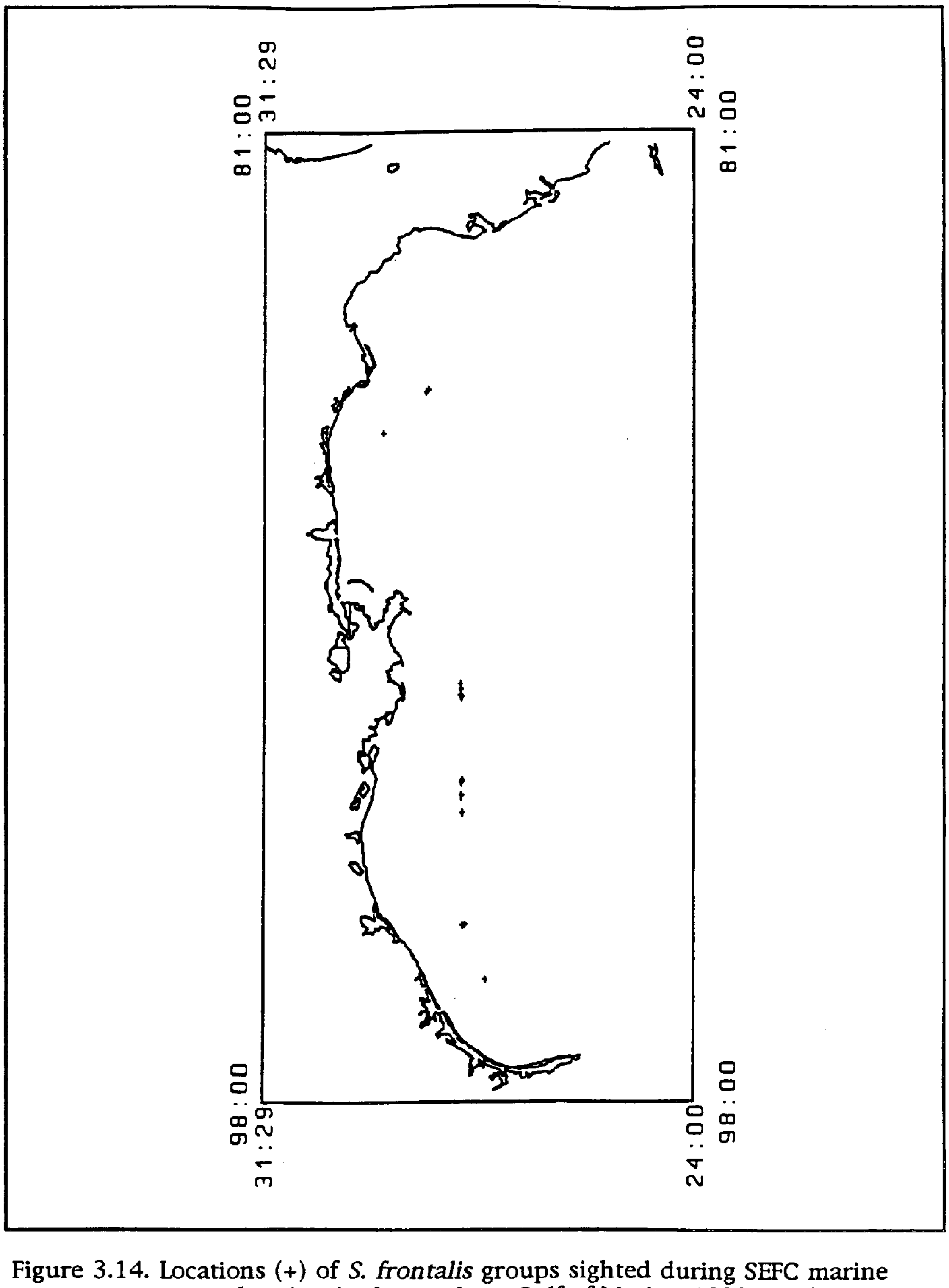


Figure 3.14. Locations (+) of *S. frontalis* groups sighted during SEFC marine mammal cruises in the northern Gulf of Mexico: 1990- 1992.

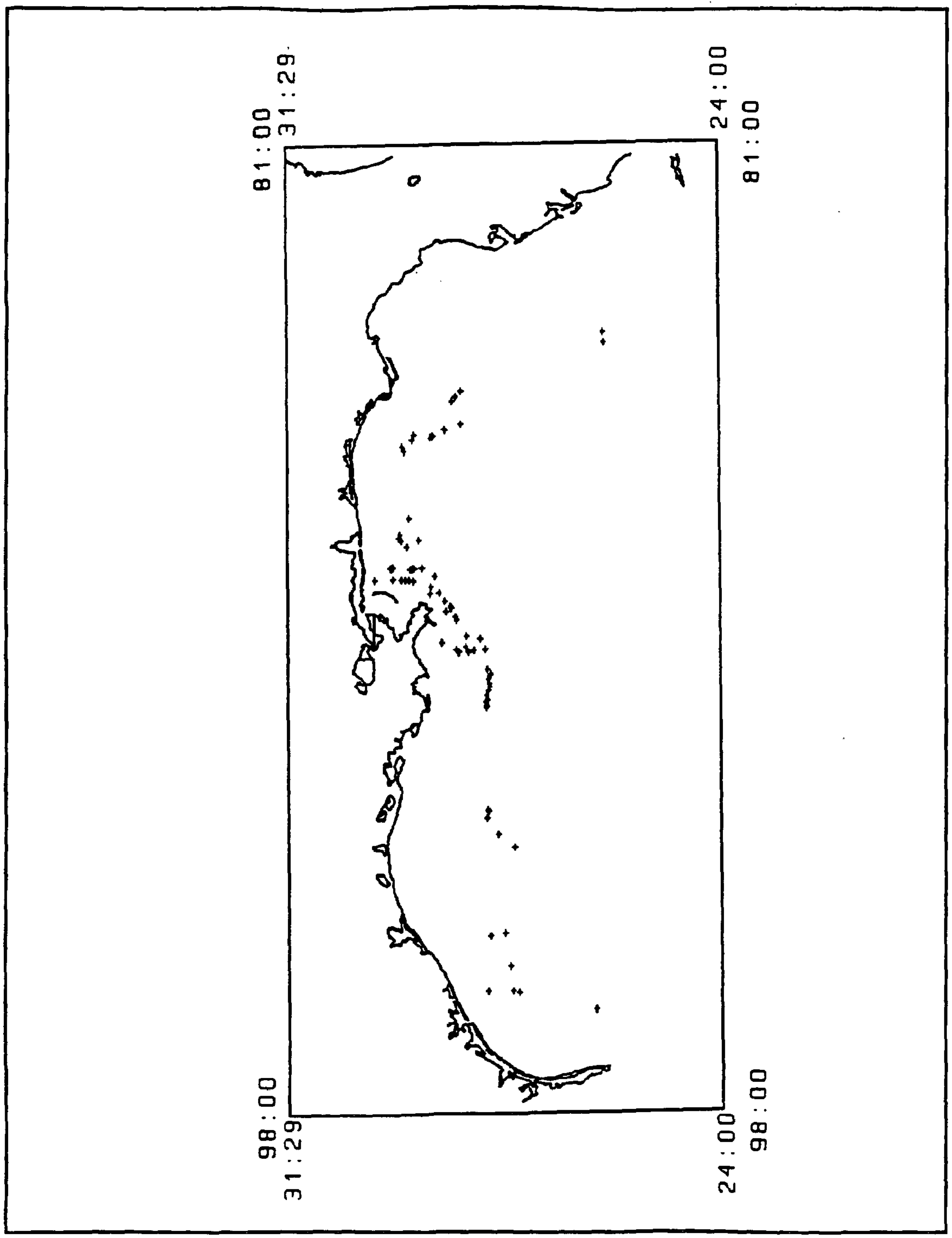


Figure 3.15. Locations (+) of *Tursiops truncatus* groups sighted during SEFC marine mammal cruises in the northern Gulf of Mexico: 1990-1992.

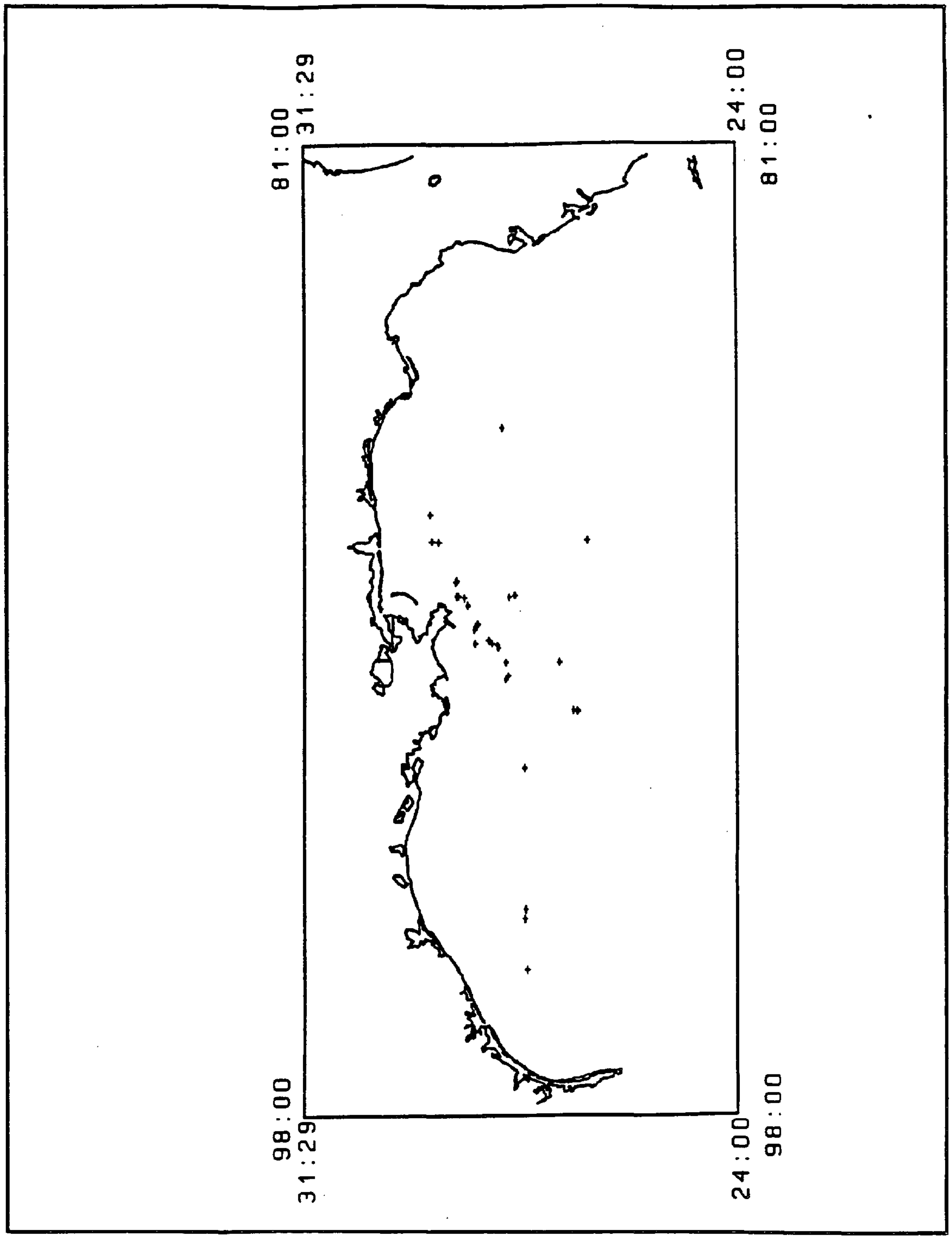


Figure 3.16. Locations (+) of *Grampus griseus* groups sighted during SEFC marine mammal cruises in thenorthern Gulf of Mexico: 1990-1992.

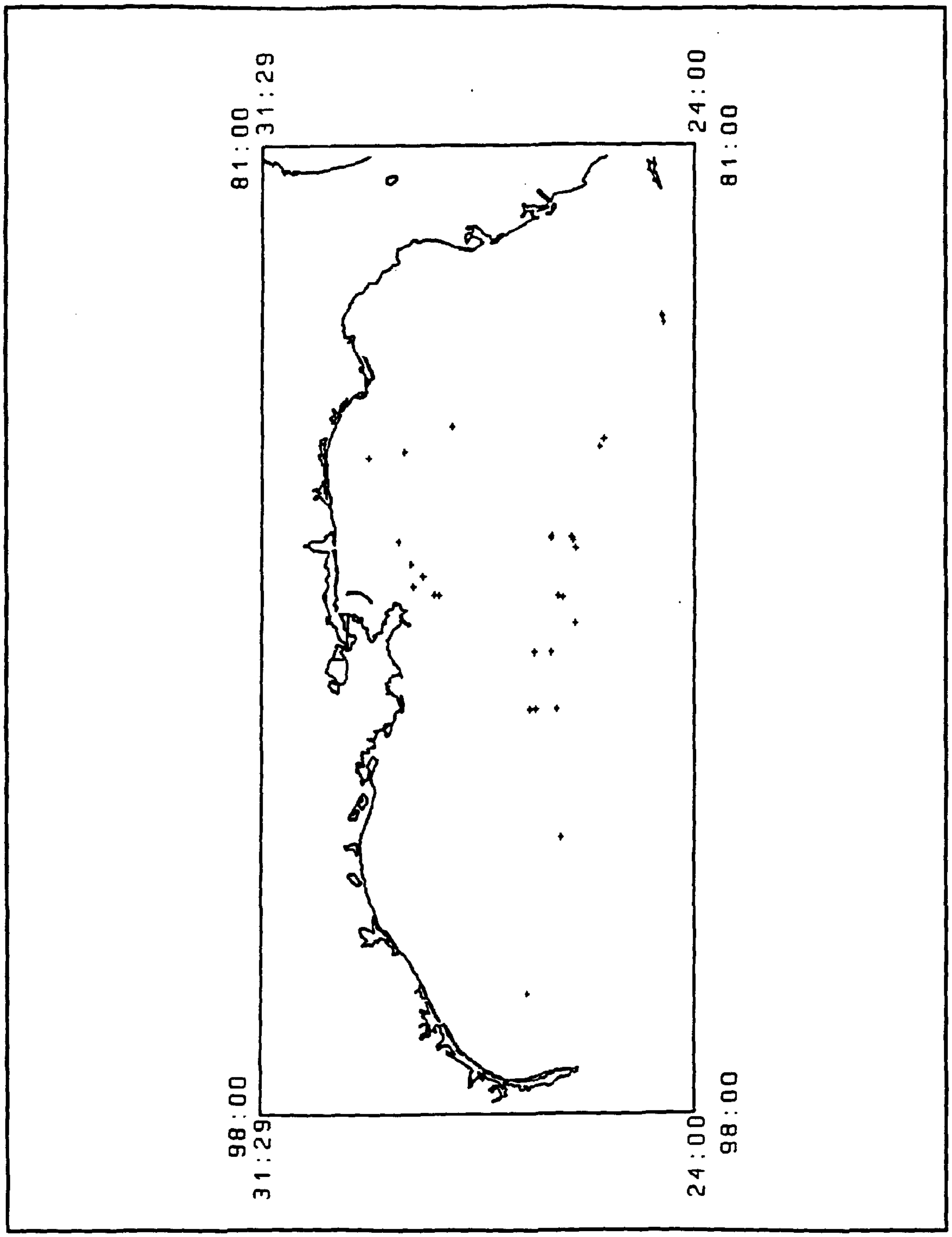


Figure 3.17. Locations (+) of *Physeter macrocephalus* groups sighted during SEFC marine mammal cruises in the northern Gulf of Mexico: 1990- 1992.

in the Gulf of Mexico (Fraser's dolphins were observed earlier in 1992 during a Texas A&M shipboard visual and acoustic survey). Melon-headed whales were also observed during the winter survey, and the first SEFSC vessel sightings of killer whales occurred during the spring-summer survey.

3.3.3 Acoustic Surveys: TAMUG

3.3.3.1 Methods

A linear hydrophone array was towed behind the Texas A&M University visual survey ship (i.e. the *Longhorn* or the *Pelican*) to record the distinctive underwater vocalizations of cetaceans. This passive acoustic survey technique enabled us to identify cetaceans in the vicinity of the ship in order to determine their distribution and to estimate their abundance. This hydrophone array has been used in previous studies to determine the distribution of cetaceans in the Eastern Tropical Pacific (Thomas et al., 1986).

The hydrophone array is made of three sections; a deck cable, a tow cable, and a "wet section" which contains the active elements (hydrophones) of the array (Figure 3.18). The 30 m deck cable connects the shipboard electronics to the active array via the tow cable at the winch. The 184 m tow cable (1.04 inch outer diameter) has 32 pairs of electical wires and is negatively buoyant. The 235 m "wet section" of the array is composed of four sections: a forward "dead section", fore and aft vibration isolating mechanisms (VIMs), fore and aft high frequency sections with depth and temperature sensors, and a middle-low frequency section. The VIMs are elastic sections designed to reduce low frequency, self-induced noise.

The towed array has 195 hydrophones organized into 18 groups. These groups are tuned to six different frequency bands. In the low frequency section (Figure 3.19), eight groups of hydrophones are tuned to 30 Hz, one group at 480 Hz, and a third group at 3.84 kHz. In each fore and aft high frequency section, there are hydrophone groups tuned to 5, 10, and 15 kHz. The hydrophones of each tuned section are separated along the array by a distance equal to the wavelength of the tuned frequency in order to increase sensitivity (as indicated by its directivity index). For example, the 20 AQ 10 hydrophones of the 5 kHz tuned segment are each separated by 33 cm to maximize the directivity index at that frequency.

The towed array has an overall frequency sensitivity from 10 Hz to 30 kHz, with maximum sensitivities at 30 Hz, 480 Hz, 3.84 kHz, 5 kHz, 10 kHz, and 15 kHz. Because of the speed (3.75 inches per second) used to record the signals, the actual bandwidth varies from 10 Hz to 12.5 kHz. The array has maximum sensitivity in a ringed pattern perpendicular to the long axis of the array and very little sensitivity either fore or aft. It therefore detects little ship-generated noise, particularly the higher frequencies (Figure 3.20).

The towed array is connected to a model RA-44A Portable Geophysical Amplifier (SIE, Inc.) (Figure 3.21). The amplifier has 18 channels, each with its own gain control, and, for the high frequency channels, variable cut-off filters. The amplified signals are recorded on an eight channel Racal Store V analog tape recorder. The recorder has seven tape speeds ranging from 0.47 to 30 inches per second (ips) and three bandwidth settings for each channel. We

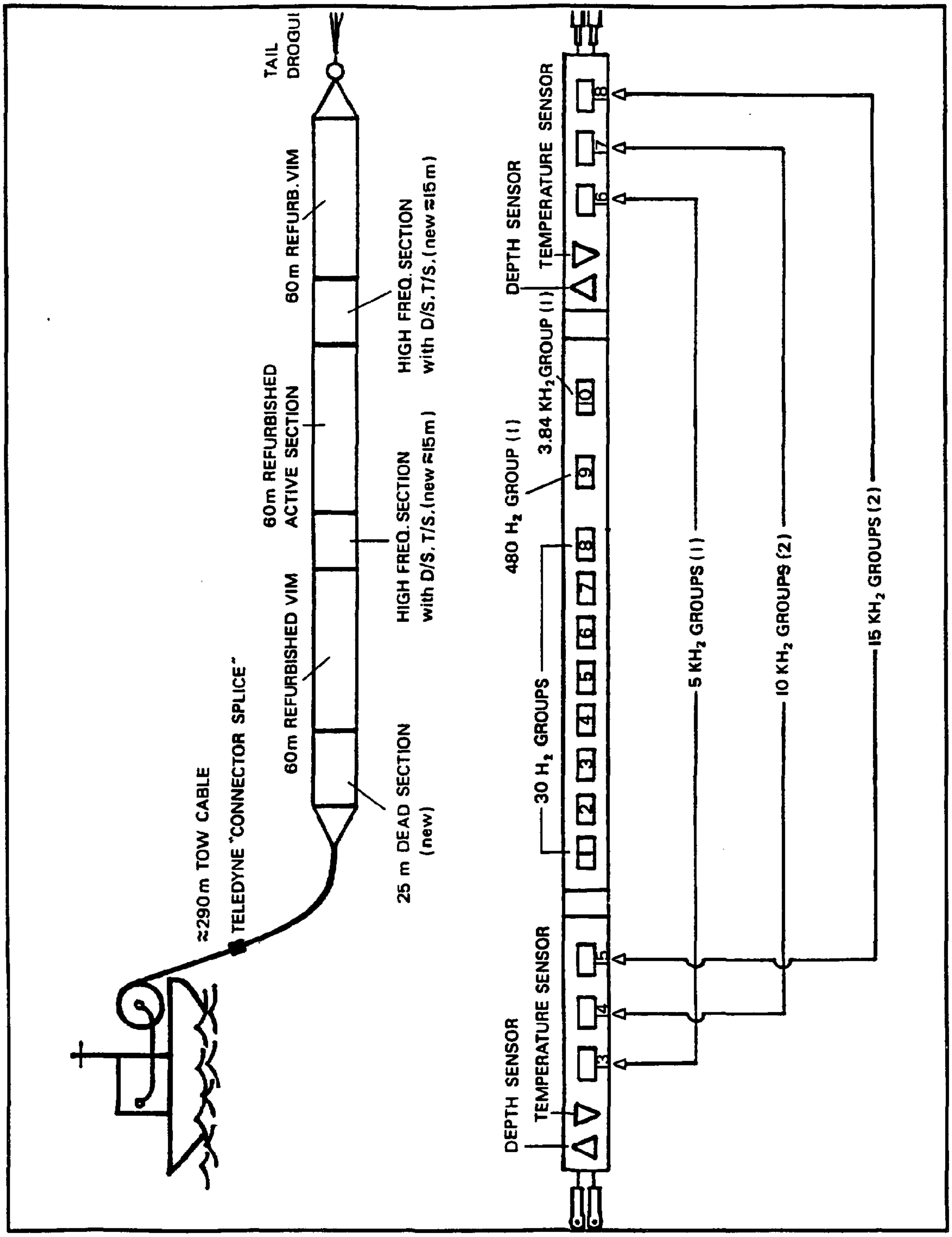


Figure 3.18. Schematic diagram of the hydrophone array.

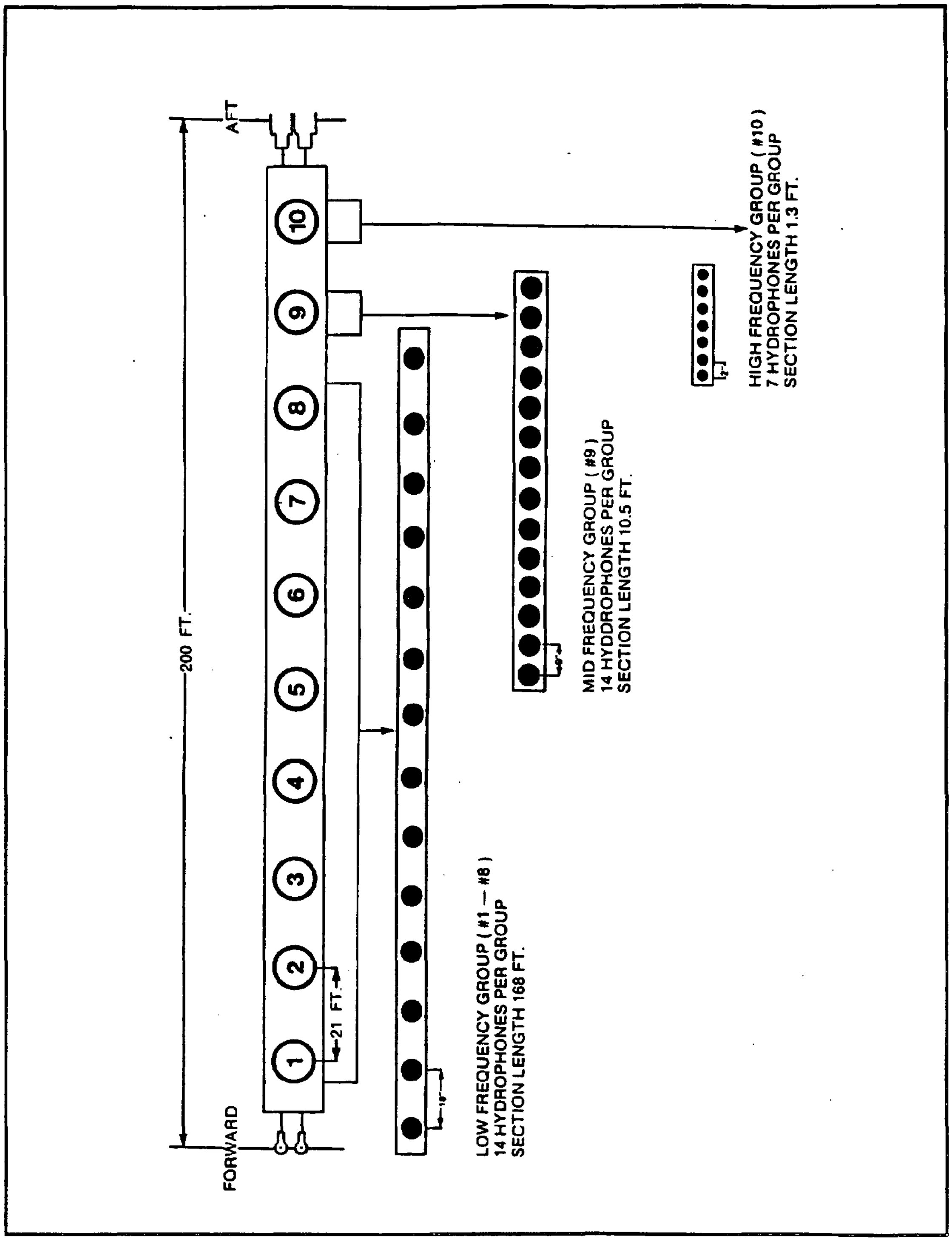


Figure 3.19. Blowup schematic diagram of the low frequency section of the hydrophone array.

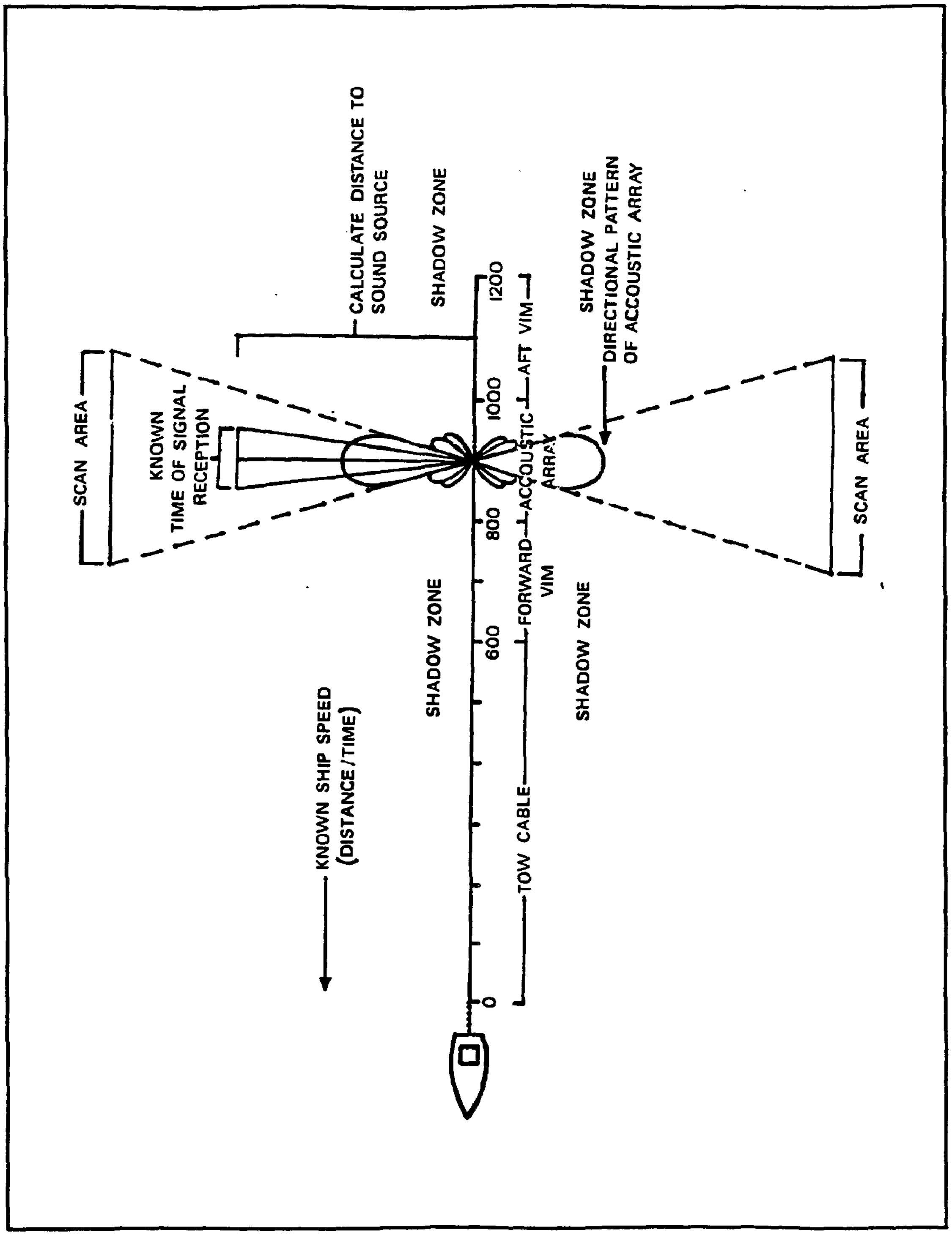


Figure 3.20. The directivity pattern of the hydrophone array.

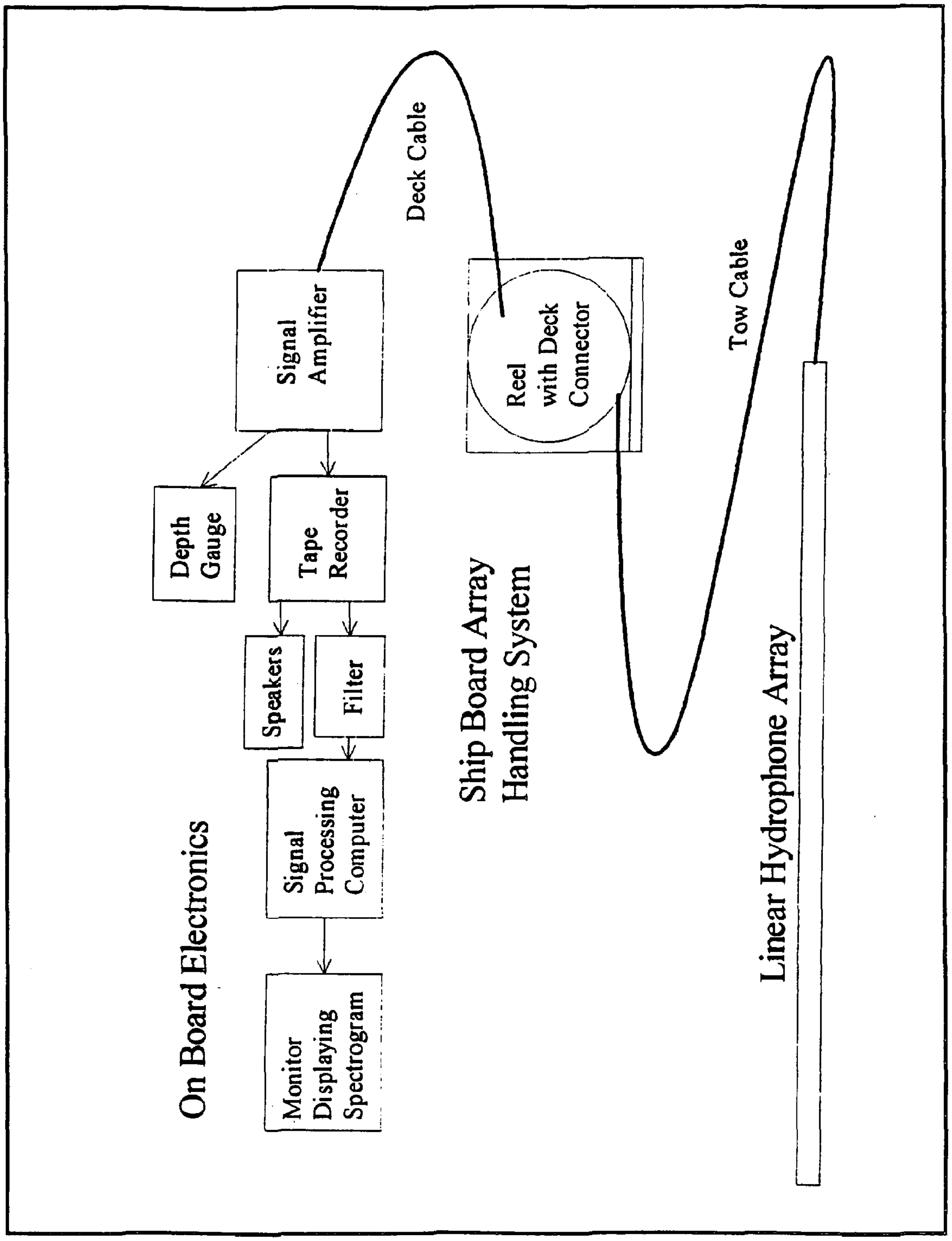


Figure 3.21. The configuration of the on-board electronics..

recorded at 3.75 ips, which resulted in a 2.5 kHz bandwidth for the low frequency channels and a 12.5 kHz bandwidth for the high frequency channels. At this tape recorder speed, we recorded approximately 200, 40-minute tapes on each cruise.

Eight channels of the tape recorder were used in recording the output from the array. The operator kept a logbook of the frequency range for each recorded channel, the amplifier gain, and the tape recorder attenuation. These tape recorder settings were noted at the beginning of each 40-minute tape along with the date, time, track number, tape speed, and ship's speed. Once this information was written on a data form, the operator monitored the array's acoustic signal both visually with the real-time spectrograph and acoustically with either headphones or speakers. Whenever a signal was received, the tape speed, time, and geographic location were recorded in a logbook.

While at sea, electronic signals were processed on an AST 386 microcomputer using SIGNAL™ software which had a subroutine (RTS) that provided real time spectrograms on a color monitor. Signal analysis at the Center for Bioacoustics (Texas A&M Universtiy) was performed using a Kay Elemetrics model 5500 dual channel, real-time spectrograph. This instrument can simultaneously produce spectrograms (frequency vs time displays with relative amplitude signified by shades of gray), oscillograms (time vs amplitude), and spectra (frequency vs amplitude). Frequency and time domain analyses can be analyzed further for species identification.

The towed array was deployed whenever the ship was on a transect line. It was towed at a uniform speed of 5 knots for the first four cruises and 6.5 knots for cruises five and six. The speed of the vessel determines the depth of the array, with an approximate depth of 18 m at a speed of 5 knots and 12 m at 6.5 knots. The array was brought onboard whenever the vessel stopped (i.e. for CTD casts).

The first step in our analysis of acoustic contacts was to verify that the recorded signal was from a marine mammal and, when possible, to identify the species. At this time, we can identify certain species based on our library of known vocalizations. We assume that when an animal is seen, vocalizations heard concurrently are produced by it. However, if more than one species is seen simultaneously, then the source of the signal is listed as unknown. All tapes are reviewed in the laboratory by one of the acoustic technicians, who checks the written record made at sea for the location of the acoustic contact on the tape. The technician then enters the revolution number, time, geographic location, presumed species identity (including unknown), and any comments into a computer database.

Three steps will be used to identify unknown vocalizations. First, a series of acoustic parameters will be defined that characterize aspects of the vocalizations of known species. These parameters will include direct measurements of the signal (such as duration) and derived values (such as mean bandwidth assymetry). Algorithms have been written that automatically implement these parameters on the computer. Secondly, signals from identified animals will be analyzed using these algorithms to train multivariate statistical programs using jack-knife procedures. The level of accuracy will depend on the size of the training set. For some species (i.e.

Fraser's dolphin), there are very few recordings. In fact, for this species we made the first recordings. In other cases (i.e., pantropical spotted dolphin), we have a large collection of recorded vocalizations. Identification algorithms for all species for which we have recorded vocalizations will be completed by February 1994.

3.3.3.2 Results and Discussion

The acoustic contacts for the first four cruises are summarized in Table 3.6. A complete list which includes the species, date and location of each acoustic contact is included in Volume 2 (Appendix). It is important to note that the locations shown for marine mammals are for "first contact", which may not be the final, computed location for these contacts. This is a problem primarily for sperm whales, which can be heard over 20 miles from the vessel.

Cruise 1: All 14 transect lines were surveyed, with only line 3 left unfinished due to poor weather. We recorded 257 tapes and made 49 acoustic contacts with biological sources. Of these, seven were identified as sperm whales, six as dolphins, three as *Stenella sp.*, and 22 were unidentified dolphins. Acoustic contacts occurred throughout the study area, although there were fewer at the southern ends of transect lines 1-4 (Figure 3.22). Recordings were made in the presence of bottlenose dolphins, pantropical spotted dolphins, clymene dolphins, and sperm whales. Measurements were also made of sound pressure levels on each channel of the Racal tape recorder using a B & K meter. Ocean depth and the presence of the deep scattering layer were recorded from the ship's depth gauge when animals were encountered. Seven species (bottlenose dolphins, pantropical spotted dolphins, clymene dolphins, Altantic spotted dolphins, Risso's dolphins, sperm whales, and Cuvier's beaked whales) were visually identified.

Cruise 2: Over the course of 13 transect lines, we recorded 226 tapes and made 70 contacts with biological sources (Figure 3.23). We made recordings from five species, all of which had been recorded on the previous cruise. Recordings were made from four sperm whales including one visual sighting of six animals. Eight of the 70 acoustic contacts were sperm whales, two were bottlenose dolphins, three were *Stenella sp.*, and 48 were unidentified dolphins or other cetaceans. Among the recordings of unidentified cetaceans, some may have been pulses from an unidentified Mesoplodon and from whistles killer whales. As with the first cruise, there were few acoustic contacts at the southern ends of transect lines 1-5; most of these were sperm whales. Likewise the central northern region of the study area also contained few contacts, with the highest number of encounters in the eastern half of the study area. Sperm whales were heard in the same location on transect lines 2 and 12 (ocean depth 700-1200 m) as occurred on Cruise 1 four months earlier.

Cruise 3: Continuous recordings were made on 13 transect lines resulting in 47 acoustic contacts (Figure 3.24). This represented more acoustic contacts per unit distance than on previous cruises. Because the visual survey effort was greatly reduced due to bad weather, we had only two contacts (sperm whales and pantropical spotted dolphins) when the animals were both seen and their vocalizations recorded. Because of the unique character of sperm whale pulses, we were able to identify them immediately. Ten sperm whale contacts were made on this cruise compared to seven on Cruise 1 and eight on Cruise 2. The

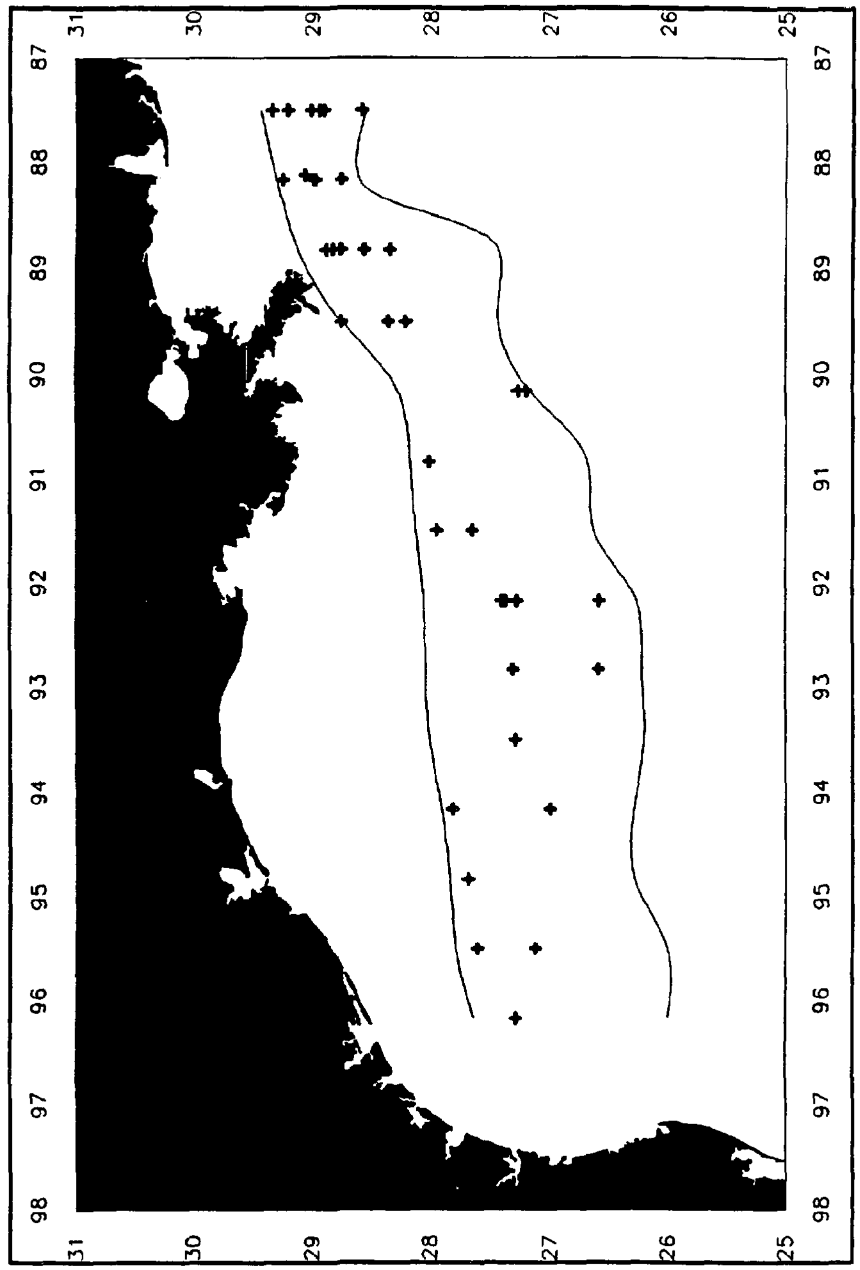


Figure 3.22. Distribution of acoustic contacts on Cruise 1.

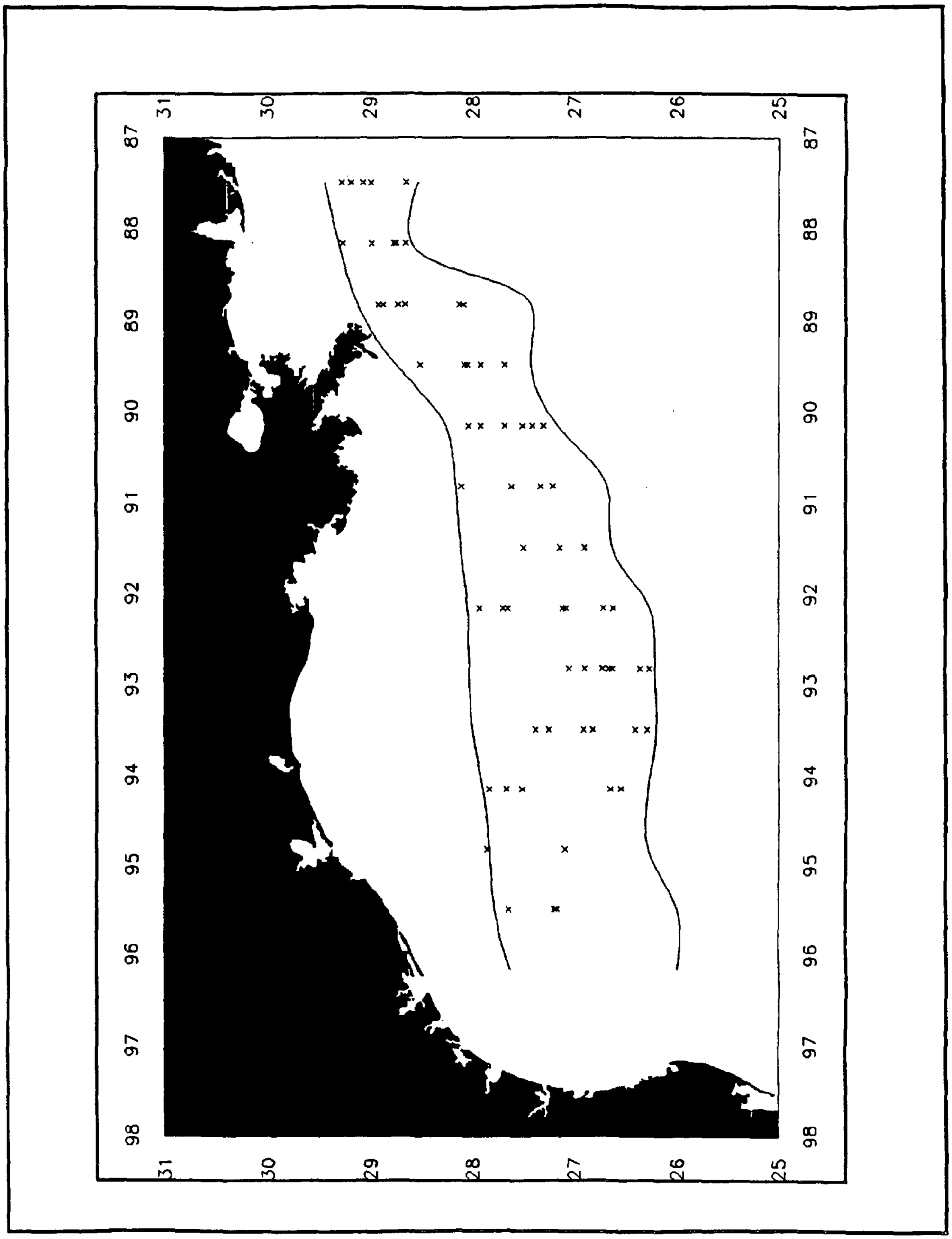


Figure 3.23. Distribution of acoustic contacts on Cruise 2.

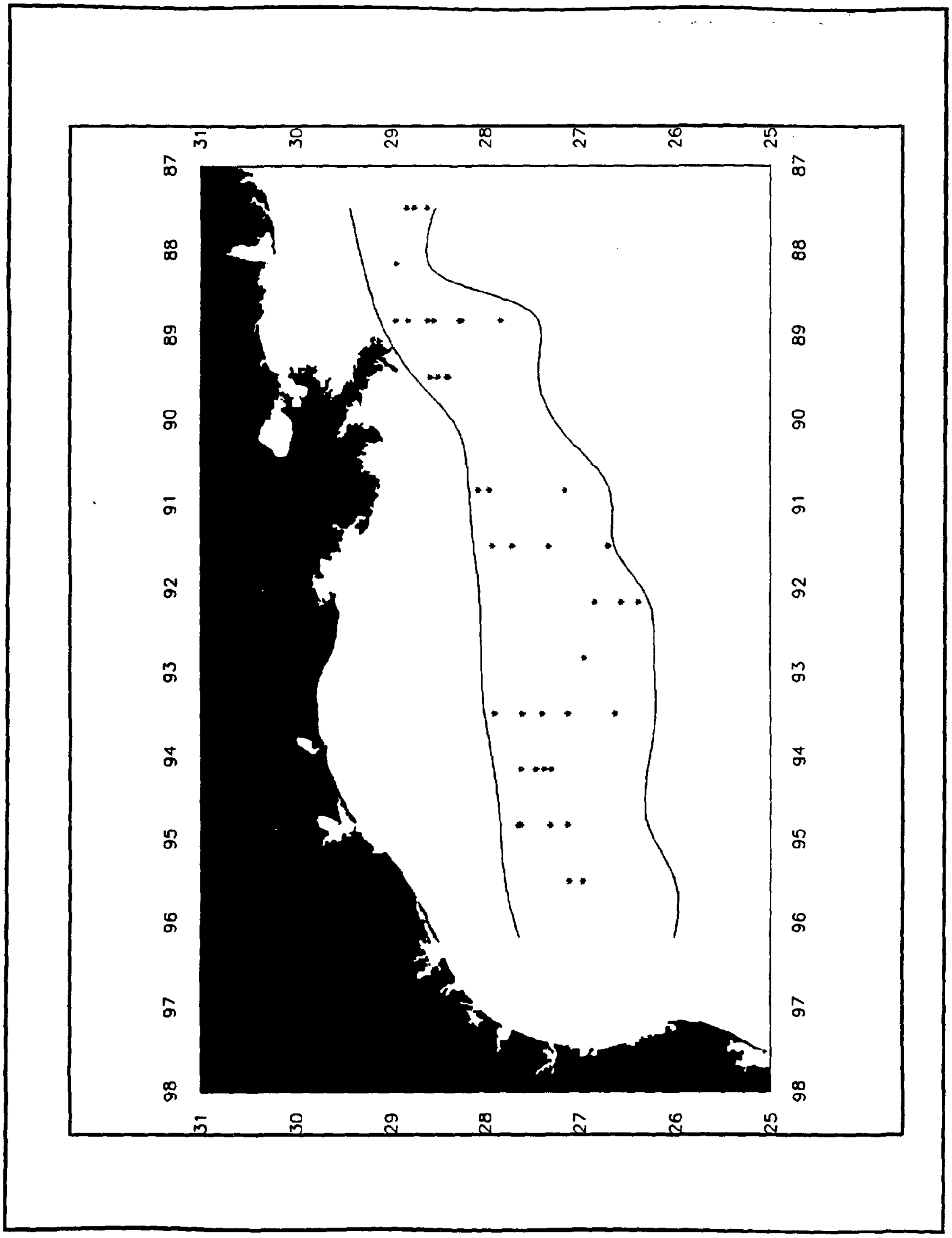


Figure 3.24. Distribution of acoustic contacts on Cruise 3.

sperm whale pulses were often heard for over an hour. Sperm whales have been encountered in the same area (27°11 N latitude, 95°30 W longitude) on transect line 2 on the first two cruises. At the south end of line 2, we also recorded and observed what appeared to be a large, solitary sperm whale, perhaps a bull. Sperm whales also have been observed repeatedly along transect line 12 near the mouth of the Mississippi River. However, on this cruise we did not hear sperm whales on transect lines 11 or 12, but we did hear them on line 14 as well as the area in between transect lines 12 and 13 in deep water.

Cruise 4: Recordings were made on along all 13 transect lines resulting in 76 acoustic contacts. Simultaneous observations and recordings were made for sperm whales (2) and pantropical spotted dolphins (5). Overall, we had 8 acoustic contacts with sperm whales, including contacts along transect line 12 where we've heard whales on previous cruises. The acoustic contact with sperm whales on line 2, where we saw many animals, was 35 miles to the south of contacts on previous cruises. We also had two acoustic contacts with presumed pilot whales. One of these contacts was concurrent with a sperm whale contact. As with previous cruises, we had many contacts with unidentified dolphins, typically whistles at night. The unidentified dolphins may be pantropical spotted dolphins, but confirmation must await further analysis.

3.3.3.3 Summary

A total of 4,496 miles (96% of the planned distance) was acoustically surveyed during Cruises 1-4. The 4% which was not surveyed resulted from equipment failure or poor weather. We had a total of 246 acoustic contacts on 910 recorded tapes (see Table 3.6). This is equivalent to 0.0547 acoustic contacts/survey mile. Many of these contacts represent more than one animal.

The most common marine mammal acoustic contacts (149) have been unidentified dolphins.These contacts were generally whistles recorded primarily at night or during poor weather conditions when visual identification was impossible. Of the 64 identified marine mammal acoustic contacts, 33 (51%) have been from sperm whales.

A preliminary analysis of the distribution of sperm whale acoustic contacts for Cruises 2, 3 and 4 was conducted by a graduate student (T. Sparks). He defined a contact as any sperm whale signal received after more than 30 minutes of silence. He identified a total of 25 contacts during 472.3 hours of acoustic sampling or 0.053 sperm whale contacts/hour of effort. There were no visual sperm whale contacts during 157.7 hours of concurrent visual effort, although there were five, off-effort visual contacts. These five visual contacts occurred, on average, 64.4 minutes (range 7-206 minutes) after the acoustic contact. The frequency of acoustic contacts did not correlate with time of day or transect line number.

The locations of identified marine mammal acoustic contacts show some preliminary patterns. Sperm whales (Figure 3.25) have been encountered on transect line 2 on all four cruises. We have also heard sperm whales in the same area on line 12. Overall, the majority of the sperm whale contacts have been off the mouth of the Mississippi River or on the western side of the study

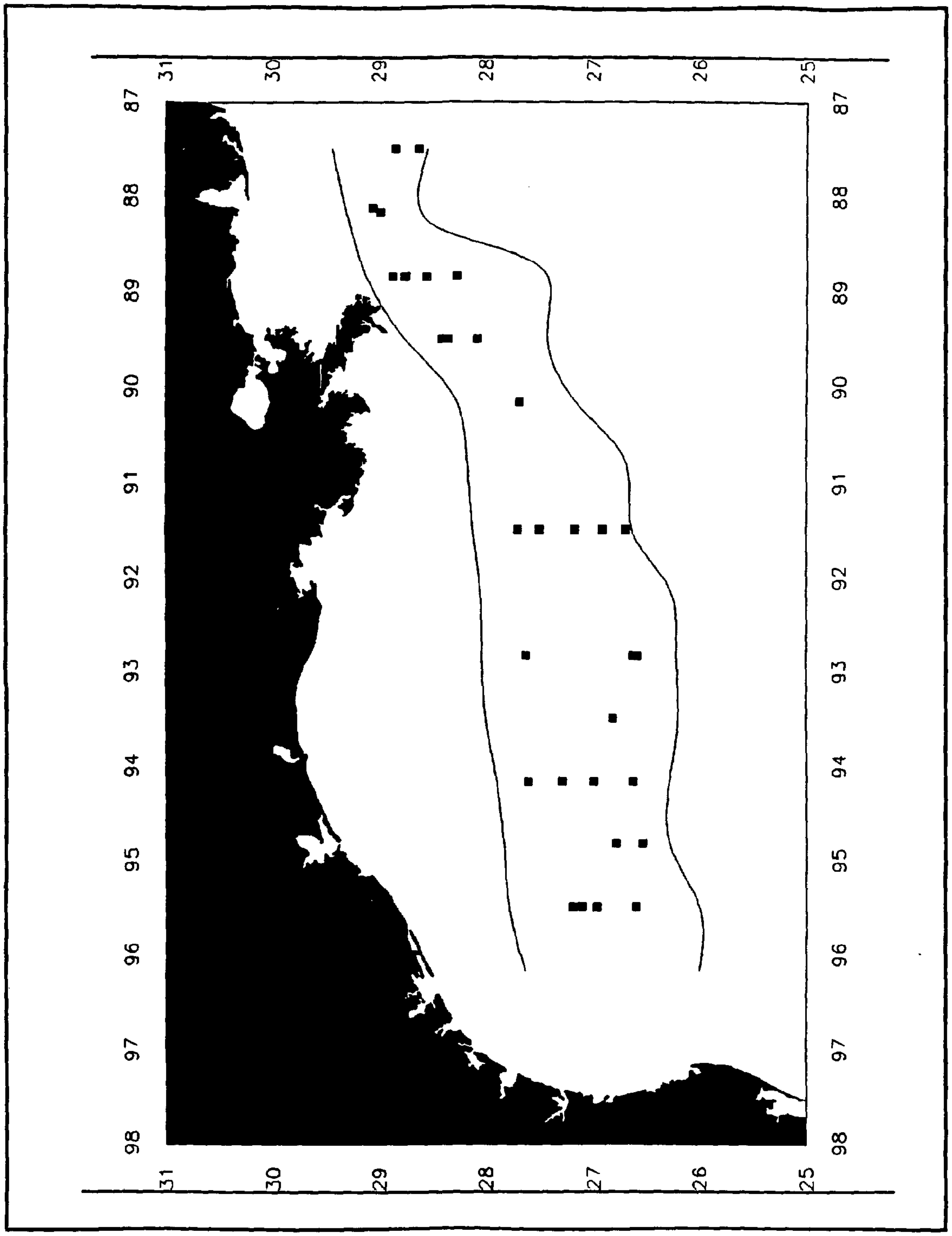


Figure 3.25. Distribution of Sperm whales on Cruises 1- 3.

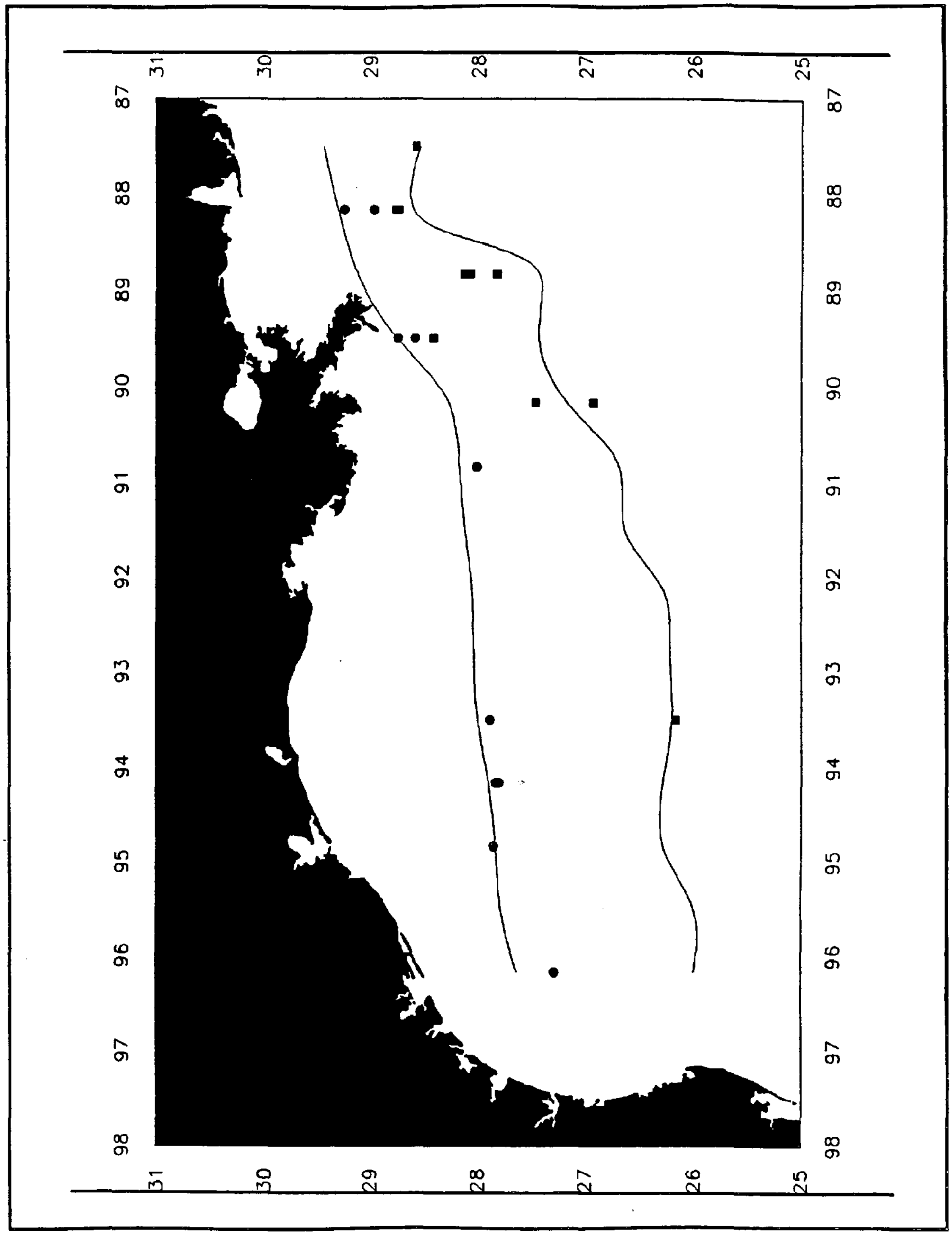


Figure 3.26. Distribution of *Tursiops truncatus* (circles) and *Stenella attenuata* (squares) during Cruises 1-3.

| Cruise # | Species | | | | | | | Other Biological | Unid. | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| | *P. macrocephalus* | *T. truncatus* | *Stenella* | | Dolphins | | Unid. Cetacean | | | |
| | | | *attenuata* | sp. | Other | Unid. | | | | |
| 1 | 7 | 6 | 2 | 1 | | 22 | 3 | 3 | 5 | 49 |
| 2 | 8 | 2 | 4 | 3 | | 47 | 1 | 2 | 3 | 70 |
| 3 | 10 | 2 | 1 | | 1 | 22 | 8 | 2 | 1 | 47 |
| 4 | 8 | | 5 | | | 58 | 3 | 2 | | 76 |
| Total | 33 | 10 | 16 | 4 | 1 | 149 | 15 | 9 | 9 | 246 |

Table 3.6. Acoustic contacts by cruise (TAMUG).

area. There have been no contacts on transect lines 7 and 9 and only one on lines 5 and 10.

Contacts with bottlenose dolphins have occurred along the shallower, northern edge of the study area, whereas contacts with pantropical spotted dolphins have been in the deeper water along the eastern continental slope (Figure 3.26). There has been only one pantropical spotted dolphin contact west of transect line 10, that being at the extreme southern end of transect line 5.

These distribution patterns are reflected in the average water depths for acoustic contacts. Pantropical spotted dolphins and sperm whales were found in the deepest water (mean depths = 1667 m and 1272 m, respectively) while bottlenose dolphins occurred in more shallow waters (mean depth = 315 m). Several of the deeper bottlenose dolphin contacts occurred off the mouth of the Mississippi River, where the continental shelf is narrow (i.e. 10 miles).

### 3.4 Satellite Tagging of Sperm Whales

#### 3.4.1 Introduction

Oregon State University was responsible for placing Satellite-linked Time-Depth Recorders (SLTDRs) and location only by satellite telemeters on sperm whales to determine their movements, diving behavior and preferred habitat. To accomplish this goal, three cruises were undertaken:two in the Gulf of Mexico (October 1992 and June 1993) and one in the Galapagos (March 1993). The Galapagos cruise was intended as a test for tag deployment and attachment.

#### 3.4.1 Methods

The satellite telemeters used for this project were designed and built by Oregon State University using Wildlife Computers™ controller boards and Telonics™ ST-6 Platform Transmitter Terminals (PTTs) and housed in a stainless steel cylinder (5 cm diameter, 19 cm long, 0.8 kg in weight). The exterior of the housing had attachments which consisted of two stainless steel rods (12.7 cm long, 0.6 cm diameter) with one pair of folding toggles mounted behind double-edged blades at the end of each rod.

The transmitters were attached to whales with compound crossbow capable of generating 150 lbs. of force. The satellite telemeter was attached to a "C"-shaped cup at one end of an aluminum shaft. The shaft with the satellite telemeter was then fired from the crossbow. A line (20 lbs. test) attached to the aluminum shaft enabled the satellite telemeter to be recovered if it missed the whale. Once the satellite telemeter was attached to the whale, the shaft was designed to fall off.

The Telonics PTTs transmitted a 400 milliwatt (mW) signal every 40 seconds when in the programed "on" mode. To conserve battery power, the tag was equipped with a saltwater switch so that it transmitted only at the surface. A small, VHF radio transmitter was attached to the housing to enable real-time tracking at sea. The VHF transmitters were tuned to specific frequencies, had different repetition rates, and transmitted continuously.

All satellite telemeters were identifiable by a code transmitted to the satellite as part of a 256 bit data stream. The SLTDRs collected data over eight, three-hour summary periods daily. These data included three histograms: depth of dives, duration of dives, and time spent at various depth ranges. Other data for each three hour period included the longest dive, deepest dive, duration of deepest dive, temperature at deepest depth, longest surface duration uninterrupted by a submergence of greater than six seconds, and total surface duration.

Transmission was scheduled for four, two-hour periods (eight hours) daily. A status message was relayed in lieu of the collected data after every 15 transmissions. This message provided information on battery voltage, sea surface temperature, number of transmissions, current zero depth offset, and a current assessment of saltwater resistance. All messages included a cyclic, redundancy code checksum for error detection purposes.

The Wildlife Computers pressure transducer and software were tested extensively using a relay box to simulate dives to different depths and durations. The satellite telemeter housing was tested to 2000 m in a pressure bomb. Based on these tests, we decided to pot the transmitter, batteries and controller board in epoxy to provide greater structural strength.

3.4.3 Results

Cruise 1: The first tagging cruise was conducted from 30 September to 14 October, 1992. We used was the *R/V McGrail*, an 82 foot long converted Coast Guard Cutter operated by Texas A&M University. The *McGrail* arrived in Venice, LA on September 31 and left for Galveston Sept 14, 1992. We were able to work for only 4.5 of the 13 days due to poor weather and equipment failures on the vessel.

Our cruise covered an area where previous GulfCet cruises and aerial surveys had observed sperm whales, but had to remain within the ship's operational limits (offshore to 100 miles from Venice). Visual contact with sperm whales was made only once for about four hours. On October 9, 8 - 10 sperm whales were sighted. We approached the whales and observed little reaction to the boat. Unfortunately, we did not get close enough to tag any animals. The animals showed very little reaction to our approaches, and there were no instances of "alarm" responses. The whales changed their course only slightly when the ship approached to within 8 m.

Cruise 2: This cruise was conducted in the eastern Pacific off the Galapagos Islands from 20-31 March, 1993. We used the *R/V Odyssey*, a 92 foot long sailboat owned and operated by the Whale Conservation Institute. Three SLTDRs were supplied by the GulfCet Program. The other operating costs for this cruise were provided by Oregon State University's Marine Mammal Foundation.

The purpose of this cruise was to test techniques to approach and attach SLTDRs to sperm whales. The waters around the Galapagos were an ideal test ground because, unlike the Gulf of Mexico, the seasonality and distribution of large numbers of sperm whales had been well documented for this area.

We located and followed several hundred sperm whales over a five day period using visual and acoustic contacts. We were able to make close approaches to sperm whales without overt changes in their behavior. Whales occasionally changed direction during very close vessel approaches but did not show a "flight" response to the boat.

On March 26, we succeeded in attaching a SLTDR to a sperm whale.The telemeter was placed about 0.5 m from the whale's dorsal ridge and appeared to be flush against the animal's skin. The animal not appear to startle or take flight after attaching the telemeter but continued its initial submergence pattern and surfaced only a few minutes later 100 m from the boat.

Two other tagging attempts were unsuccessful: in the first instance, the telemeter hit the dorsal ridge of the animal and glanced off. In the second instance, the animal arched suddenly so the tag missed its target completely. The animal then fluked and broke the retrieval line which would otherwise have allowed us to recover the tag.

This was an excellent learning cruise in which we developed approach techniques which were used later in the Gulf of Mexico. We learned that our method of attachment works for sperm whales but that care needs to be taken to avoid tagging in the area near the dorsal ridge.

Cruise 3: The second GulfCet tagging cruise. used the *R/V Acadiana*, a twin diesel, 58 foot long vessel chartered from LUMCON (Louisiana Universities Marine Consortium). The Oregon State University team arrived in Cocodrie, on June 1, 1993. Construction of a tagging platform and some remaining LUMCON charter activities were completed by June 5. The ship left Cocodrie on June 6 and returned on June 29. We were able to work for 14 of the 24 days; 4 days were used for transit between Cocodrie, and Port Eads, LA (June 6,14,16 and 29); 1 day the ship fulfilled a previous charter obligation (June 15); 5 days were spent in port during tropical storm Arlene (June 17-21).

The tagging platform was constructed from a 2-piece, 9 m long, fiberglass extension ladder with a pulpit at the end made of wood. The platform was stabilized with tension wires and extended 3.5 m off the starboard side of the ship. The platform was extremely stable, and it was possible to pull it in while underway and during docking.

Visual observations, the towed hydrophone array and sonabuoys were used to locate whales. The areas surveyed were based on previous GulfCet aerial and shipboard sightings. During 24-hour operation, scientific watches were held from 0600-2000 daily with two OSU persons on watch at all times. All cetacean sightings were recorded. At night, the scientific crew stood 2-hour watches which included acoustic stations (monitoring a suspended hydrophone) and maintaining vessel safety.

When whales were spotted, one observer remained in visual contact with the animals while the other scientists prepared the tagging equipment, 35 mm cameras, video recording equipment and data sheets. VHF radio headsets were worn by the captain and scientific crew to communicate on the whale's location and to coordinate the ship's movements for tagging.

The vessel covered 2331.4 km searching for sperm whales (Figure 3.27). Sperm whales were seen on seven days and heard on 11 days. The number of whales ranged from 4-22 per day with up to 8 animals seen at one time (Tables 3.7 and 3.8). A maximum of 87 individuals were seen during the cruise. Animals were sighted most often in the afternoon.

Animals were approached to within 75 m at which time the vessel was slowed and one engine shut down to reduce noise for the final approach. The sperm whales we found were quite small. Most were less than 8 m in length and were considered too small to tag; a few were up to 8 m. Even these presented a small target and needed to be within 5 m of the ship and perpendicular to the tagging platform (approximately parallel to the vessel's starboard side) before a shot could be attempted. Positioning was critical for successful tagging. Because there are subdermal anchors at each end of the cylindrical tag, the tag's trajectory must be perpendicular to the whale or the tag will not attach properly. Tagging attempts were made only when the animal's back was well out of the water and not arched.

Two animals were tagged. The first whale (about 8 m in length) was tagged on 7 June with an SLDR. Only one message was heard from this tag. Photos revealed that the tag was located on the dorsal ridge with the forward tyne of the housing implanted 5-8 cm in the blubber and the rear tyne only 2.5 cm. We believe that this tag fell off the animal shortly after attachment due to incomplete penetration of the tynes into the blubber. The second animal (about 7 m in lenght) was tagged on 11 June with a location-only telemeter. The telemeter placement was good. Although penetration was not complete, it was judged to be adequate. We have conducted further shock tests but at present do not know why this telemeter failed.

All other opportunities (12-13 and 23-24 June) for tagging were with animals judged to be too small.We saw no whales on four of the last five days despite excellent weather and sighting conditions (25-29 June).

A seismic vessel, the *Acadian Commander*, began seismic surveys on 23 June in an area where whales had been routinely seen (Figures 3.28 and 3.29). The seismic surveys were expected to continue for 30 days. Whales were seen on the periphery of the seismic survey area on the 23 and 24 June, but not in the middle of the area where we had seen many whales regularly before the seismic work began. No whales were seen in or near this area after 24 June (9 survey days). While the change we observed in whale distribution may have been due to normal movements or a change in prey concentration, it did coincide with the onset of seismic activity. Therefore, there may be a cause-and-effect relationship, and the possibility can only be resolved with further investigation. Very few other cetaceans or sea birds were seen during this cruise.

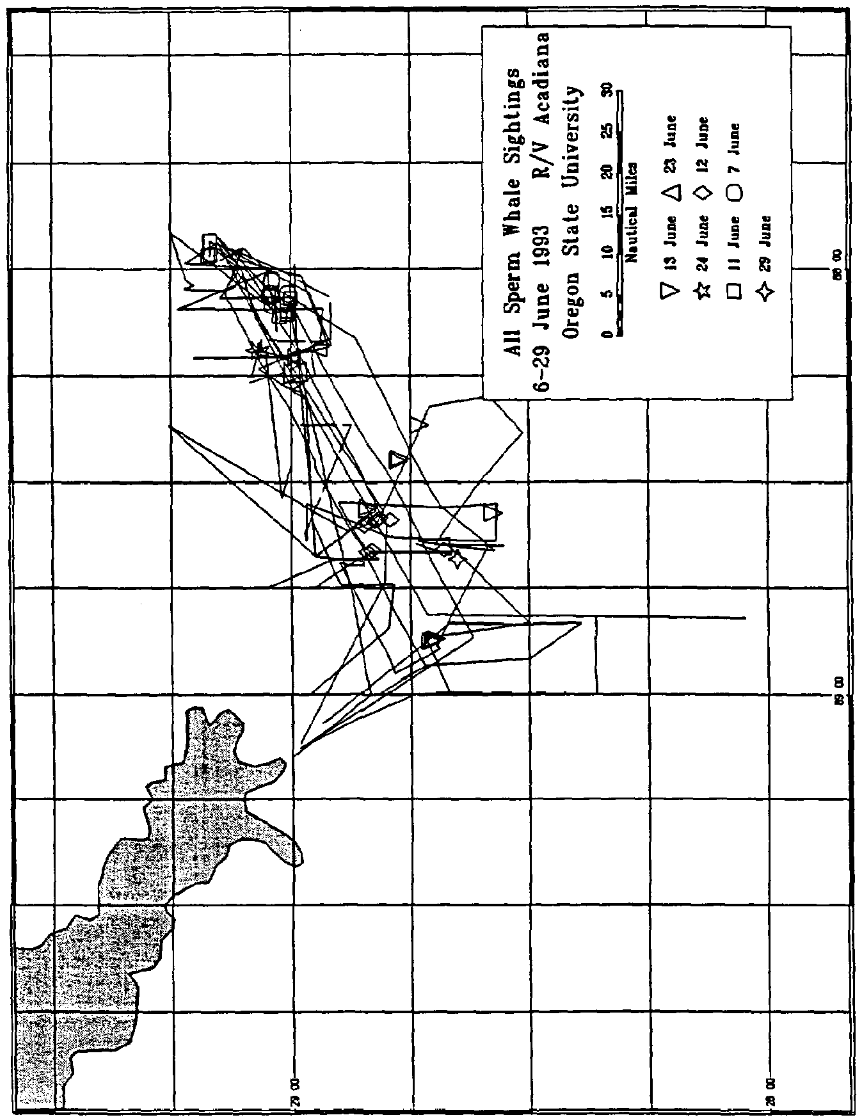


Figure 3.27. Sperm whale sightings, June 6-29, 1993 aboard R/V *Acadiana*..

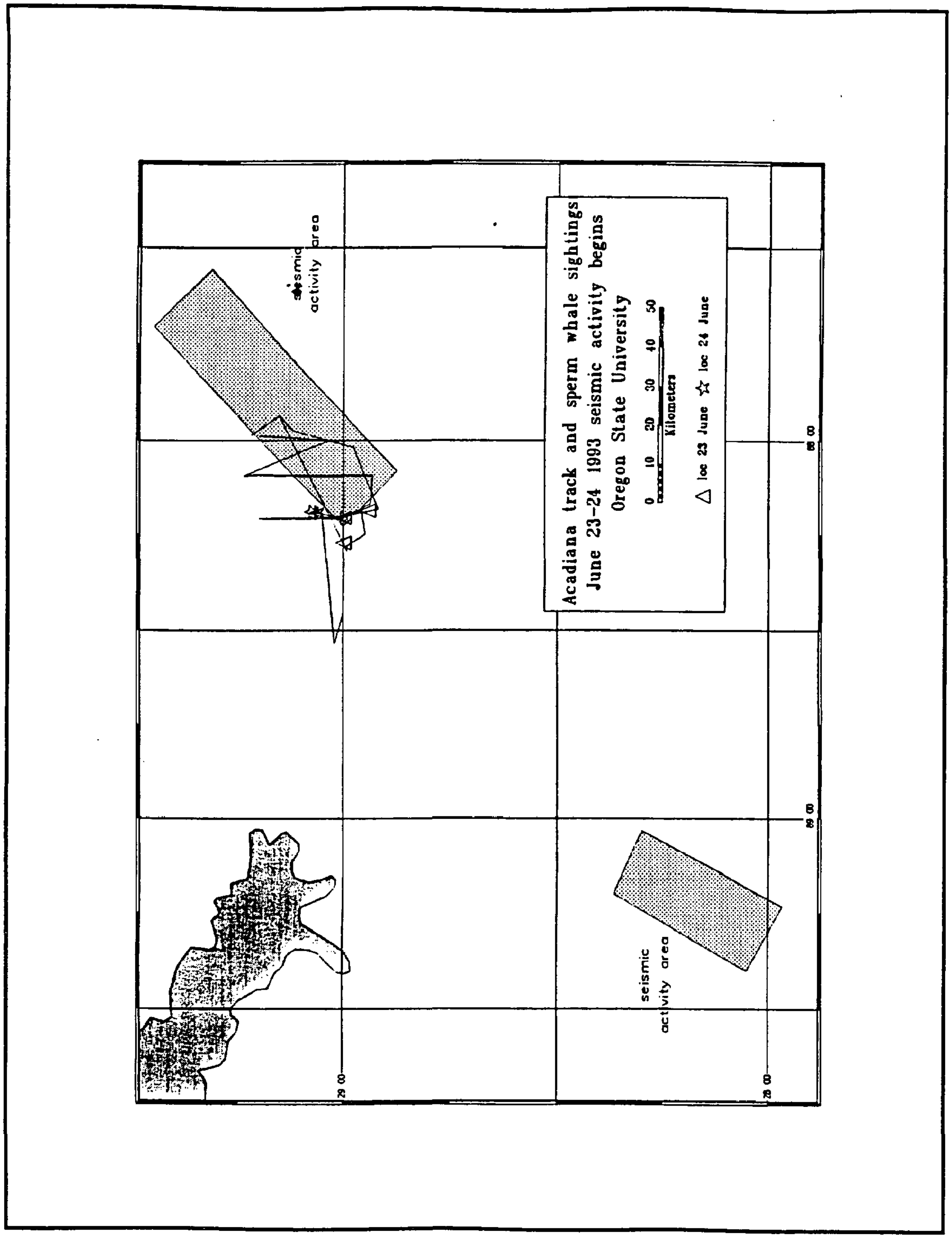


Figure 3.28. R/V *Acadiana* cruise track and sperm whale sightings June 23-24, 1993 with seismic activity begininng.

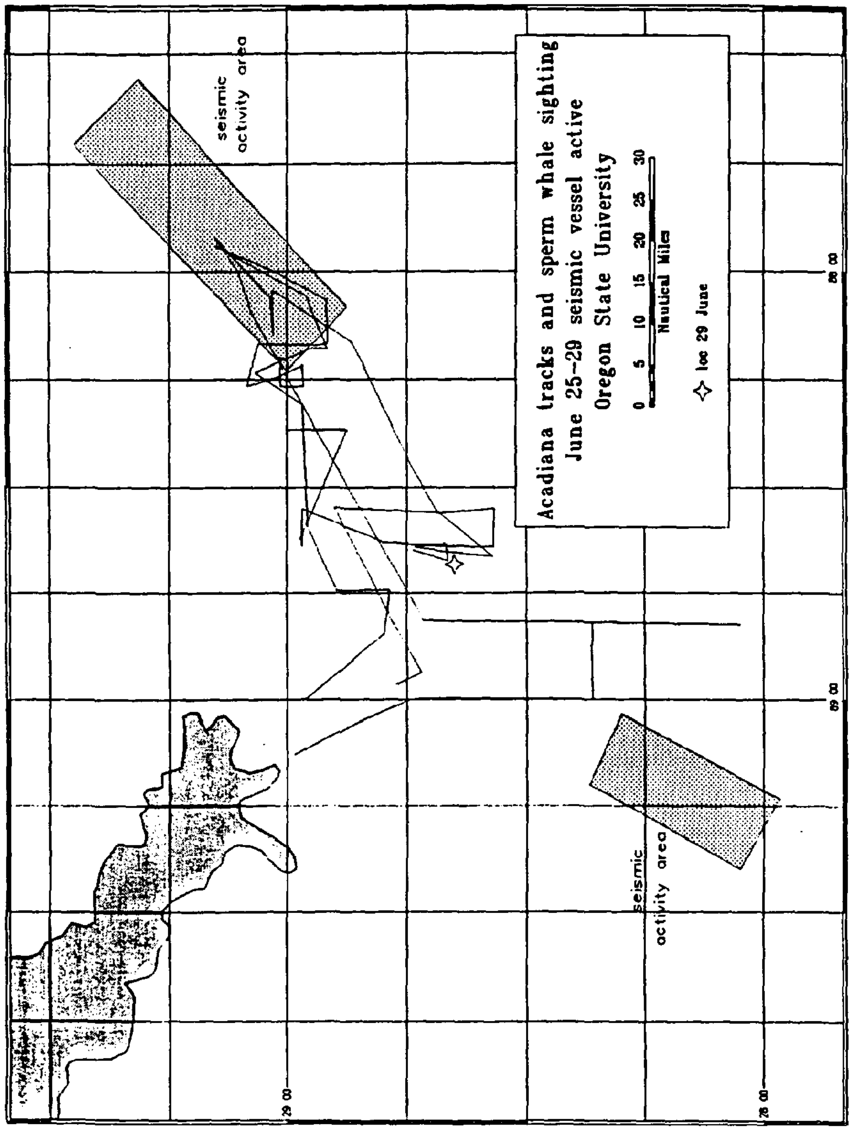


Figure 3.29. R/V *Acadiana* cruise trackand sperm whale =sightings June 25-29, 1993 with activity seismic vessel.

Sperm Whale Sightings - Oregon State University - R/V Acadiana

| Date | Time | Lat/Long | Number |
|---|---|---|---|
| 6/7/93 | 1608 | 29°02.35/88°01.54 | 7 |
| 6/7/93 | 1710 | 29°02.23/88°03.50 | 3 |
| 6/7/93 | 1900 | 29°02.26/88°05.15 | 4 |
| 6/12/93 | 1520 | 28°49.32/88°35.48 | 3 |
| 6/12/93 | 1750 | 28°50.40/88°35.71 | 3 |
| 6/12/93 | 1810 | 28°40.68/88°39.67 | 1 |
| 6/12/93 | 1945 | 28°50.36/88°40.09 | 4 |
| 6/13/93 | 0815 | 28°42.47/88°52.71 | 2 |
| 6/13/93 | 0828 | 28°42.01/88°52.24 | 2 |
| 6/13/93 | 0845 | 28°41.68/88°52.14 | 1 |
| 6/13/93 | 1637 | 28°43.85/88°22.01 | 3 |
| 6/13/93 | 1740 | 28°46.40/88°26.66 | 1 |
| 6/13/93 | 1900 | 28°50.47/88°34.07 | 5 |
| 6/13/93 | 1915 | 28°50.29/88°34.40 | 4 |
| 6/23/93 | 1240 | 28°56.25/88°11.17 | 2 |
| 6/23/93 | 1345 | 28°57.70/88°12.43 | 2 |
| 6/23/93 | 1426 | 29°00.12/88°12.91 | 3 |
| 6/23/93 | 1430 | 29°00.39/88°12.81 | 3 |
| 6/23/93 | 1508 | 29°00.13/88°12.33 | 1 |
| 6/23/93 | 1725 | 28°56.56/88°11.26 | 3 |
| 6/23/93 | 1740 | 28°56.70/88°11.57 | 1 |
| 6/23/93 | 1835 | 28°59.58/88°16.94 | 4 |
| 6/23/93 | 1908 | 28°58.59/88°17.53 | 3 |
| 6/24/93 | 1145 | 29°00.37/88°12.41 | 2 |
| 6/24/93 | 1308 | 29°02.34/88°12.09 | 2 |
| 6/24/93 | 1347 | 29°04.42/88°11.47 | 3 |
| 6/24/93 | 1450 | 29°03.63/88°11.62 | 4 |
| 6/29/93 | 1805 | 28°39.70/88°41.00 | 2 |
| 6/29/93 | 1830 | 28°38.80/88°41.55 | 2 |

Table 3.7. Sperm whale sightings, June 7-29, 1993.

<u>Other species seen</u> (100% confidence)

| Date | Time(CDT) | Lat/Long | What | Number |
|---|---|---|---|---|
| 6/7/93 | 1420 | 28°40.64/89°05.69 | Tursiops truncatus | 2 |
| 6/7/93 | 1940 | 28°36.70/88°43.03 | Stenella attenuata | 15-20 |
| 6/12/93 | 1350 | 28°54.29/88°23.85 | Stenella clymene | 25-30 |
| 6/23/93 | 1930 | 28°59.40/88°17.64 | Lagenodelphis hosei | 3 |
| 6/24/93 | 0745 | 29°07.13/87°58.52 | Stenella attenuata | 25 |
| 6/24/93 | 1010 | 28°58.11/88°02.64 | Stenella attenuata | 35-40 |
| 6/24/93 | 1345 | 29°04.80/88°10.94 | Steno bredanensis | 8 |
| 6/27/93 | 1920 | 28°46.40/88°57.81 | Grampus griseus | 5 |

Table 3.8. Other marine mammal species sighted June 7-29, 1993.

### 3.4.4 Discussion

Previous information about sperm whales in the Gulf has indicated that they are sparsely distributed and have very small pod sizes. The sperm whales sighted during the tagging cruises were in a patchy distribution over a large geographic region and were usually in loose groups of 2-8 animals.

Of particular interest was the small size of the sperm whales sighted. We do not believe that any of the animals were over 8 m. Four whales appeared small enough to be calves which may have been weaned recently. At one point, we were in an area with about eight small animals at the surface. We stayed in this area for two hours and saw no evidence of any larger animals. Large animals would be expected if these small ones were part of a mixed group of females, calves and juveniles. This juvenile group social structure may be unique to this area. It has never been reported in the scientific literature and certainly deserves more attention. We have examined the stranding records and concluded that sperm whales of normal size do exist in the Gulf, and we were not merely looking at a population of small individuals.

While searching for sperm whales in the Gulf of Mexico, we obtained some circumstantial evidence that active seismic vessels may affect the distribution of sperm whales. During five of our first nine survey days, we consistently sighted sperm whales, generally in a localized geographic area. During this time, the *Acadian Commander* was preparing to begin seismic testing. During the first two days of seismic activity (34 guns shooting every 10 seconds at 1800 psi, 24 hours a day), we located only a few sperm whales on the margins of the seismic survey area. We found no whales for the next five days in that region. Although our observations represent circumstantial evidence, the change in whale sightings after the onset of seismic activity is sufficient to warrant concern and additional studies.

We attached satellite telemeters to two small animals on this cruise: an SLTDR and a location-only telemeter. The lack of penetration of the tynes appeared to be due to the tough skin and blubber on the animal's dorsal ridge. The small size of the animals that we tagged may have exacerbated this problem. Our attachment methods have worked very well on right whales and bowhead whales but may have to be modified for sperm whales.

### 3.4.5 Recommendations

1. To determine when and where adult sperm whales occur, it would be helpful if aerial and shipboard observers could obtain length estimates of all sperm whales sighted.

2. The possible connection between active seismic vessels and sperm whale movements deserves further study. If successful, satellite tracking would be a valuable tool to examine animal movements in areas of seismic surveys.

3. If possible, satellite telemeter attachments should be tested on sperm whale carcasses.

4. Alternative satellite telemeters and attachments need to be considered for tagging small individuals.

5. Because of the difficulty in finding sperm whales, future tagging cruises should dedicate at least six weeks of sea time to tag animals. The vessel should be certified to operate beyond 100 miles from shore.

6. Aerial surveys should be coordinated with tagging cruises to initially locate sperm whales most efficiently.

7. Photo and video-documentation of the tagging process is important to verify the quality of tag attachment, document potential tagging reactions, and identify individuals which are tagged.

8. Aerial and shipboard surveys and tagging efforts should obtain information on the schedules and operational areas of seismic surveys. If MMS does not have a program to monitor seismic surveys, it should consider one so that marine mammal surveys can use this important variable to interpret results.

3.6 References for Section III

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# IV. ENVIRONMENTAL DATA

## 4.1 Introduction

The circulation of the Gulf of Mexico is remarkable because of its variability and intensity. The most prominent circulation features in the Gulf are the intense Loop Current System in the eastern Gulf and an anticyclonic cell of circulation in the western Gulf (Nowlin and McLellan, 1967; Behringer, et al., 1977; Merrell and Vazquez, 1983). The Loop Current's path and extent of intrusion into the Gulf varies with season, but reaches a maximum in the summer, at which time an anticyclonic eddy separates from the loop and drifts westward (Hofmann and Wortley 1986; Merrel and Vazquez 1983). High fluctuations in frequency of eddies (from 8 to 17 months) have been reported by Behringer et al. (1977). Different types of eddies have also been described, including anticyclonic eddies and cyclonic-anticyclonic eddy pairs (Merrell and Morrison, 1981; Brooks and Legeckis, 1982). Less is known about the circulation in the western Gulf relative to the eastern Gulf (Merrell and Morrison, 1981). Two main mechanisms of the observed anticyclonic gyre in the western Gulf have been suggested. The first is that the gyre is maintained by loop eddies which have drifted to the west (Ichiye, 1967; Schroeder, et al., 1974), and the second is that the gyre is driven by a curl of wind stress (Nowlin 1972). An equal contribution of both mechanisms has been suggested by Merrell and Morrison (1981).

Nearly two-thirds of the U.S. mainland and half the area of Mexico drains into the Gulf of Mexico (Weber, et al., 1990). The Mississippi and other rivers with their associated nutrient and sediment loads have a great influence on the Gulf. The seasonality cycle of the Mississippi River is shown in Figure 4.1 (mean flow plus or minus one standard deviation). The mean river flow is computed at Vicksburg, Ms. using daily data from 1932 to 1986. Figures 4.2 and 4.3 show the flow of the river from November 1978 to June 1986, with a time series of chlorophyll pigments from the Coastal Zone Color Scanner (CZCS). It is clear that the Mississippi River plays an important role in the interannual variations of chlorophyll and in developing areas of high productivity in the Gulf. The 1992-1993 Mississippi River flow was anomalous in its seasonality and flow (United States Department of the Interior, United States Geological Survey, 1992 and 1993). Therefore, the Mississippi could affect the spatial and temporal distribution of cetaceans in the Gulf of Mexico.

The prominent Gulf of Mexico circulation features (such as the Loop Current, the 1992-1993 eddies Triton, "U", Velasquez (V), and Whopper (W), and the high fresh water input of May and August -September, 1993) interact to make the Gulf of Mexico a very complex environment. The goal of the GulfCet Program is to develop an understanding of environmental features and their effect on the spatial and temporal distribution of cetacean species in the northwestern Gulf of Mexico. Environmental data collection for the GulfCet Program consists of, eight (TAMUG) hydrographic surveys, summer and winter National Marine Fisheries Service (NMFS) surveys, and a synoptic overview by remote sensing. Satellite images are from NOAA's Advanced Very High Resolution Radiometer (AVHRR) polar orbiting satellites. Stennis Space Center (NMFS) is providing the remote sensing as well as the Geographical Information System (GIS) support for the GulfCet Project.

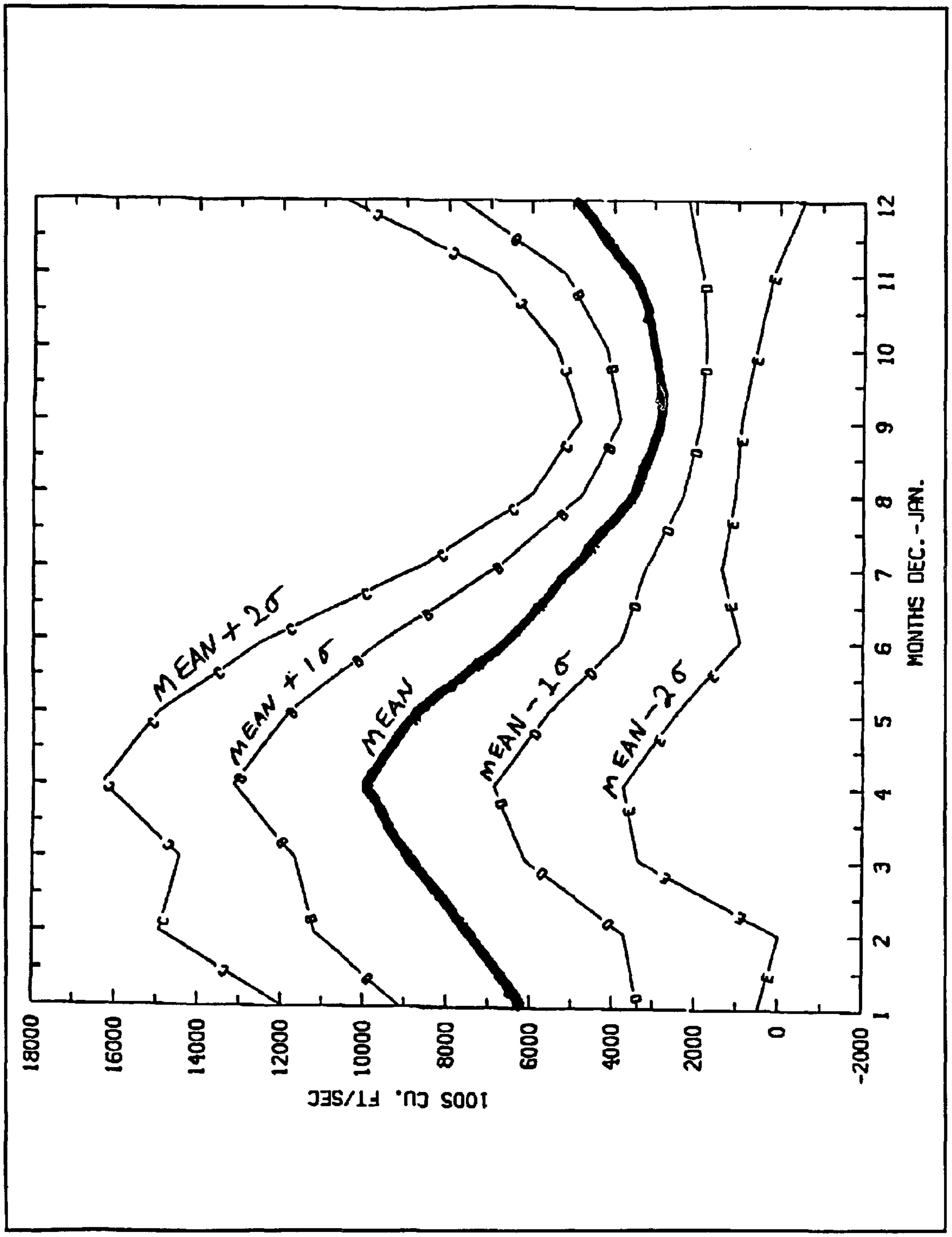


Figure 4.1. Mississippi River flow from 1932 -1986.

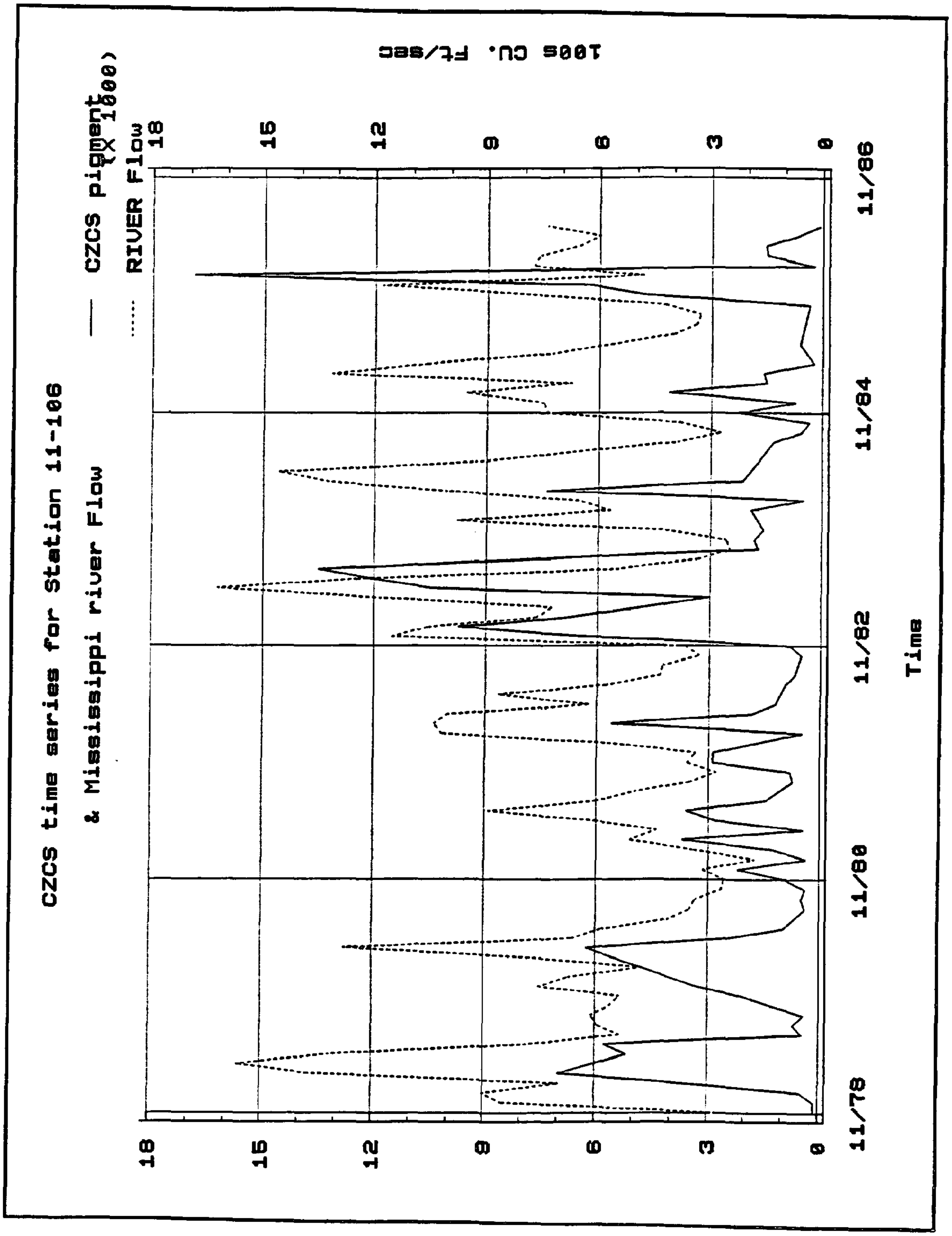


Figure 4.2. Time series 1979 -1986 of Mississippi River flow & chlorophyll pigment data from CZCS (data in close proximity to GulfCet station 11-106).

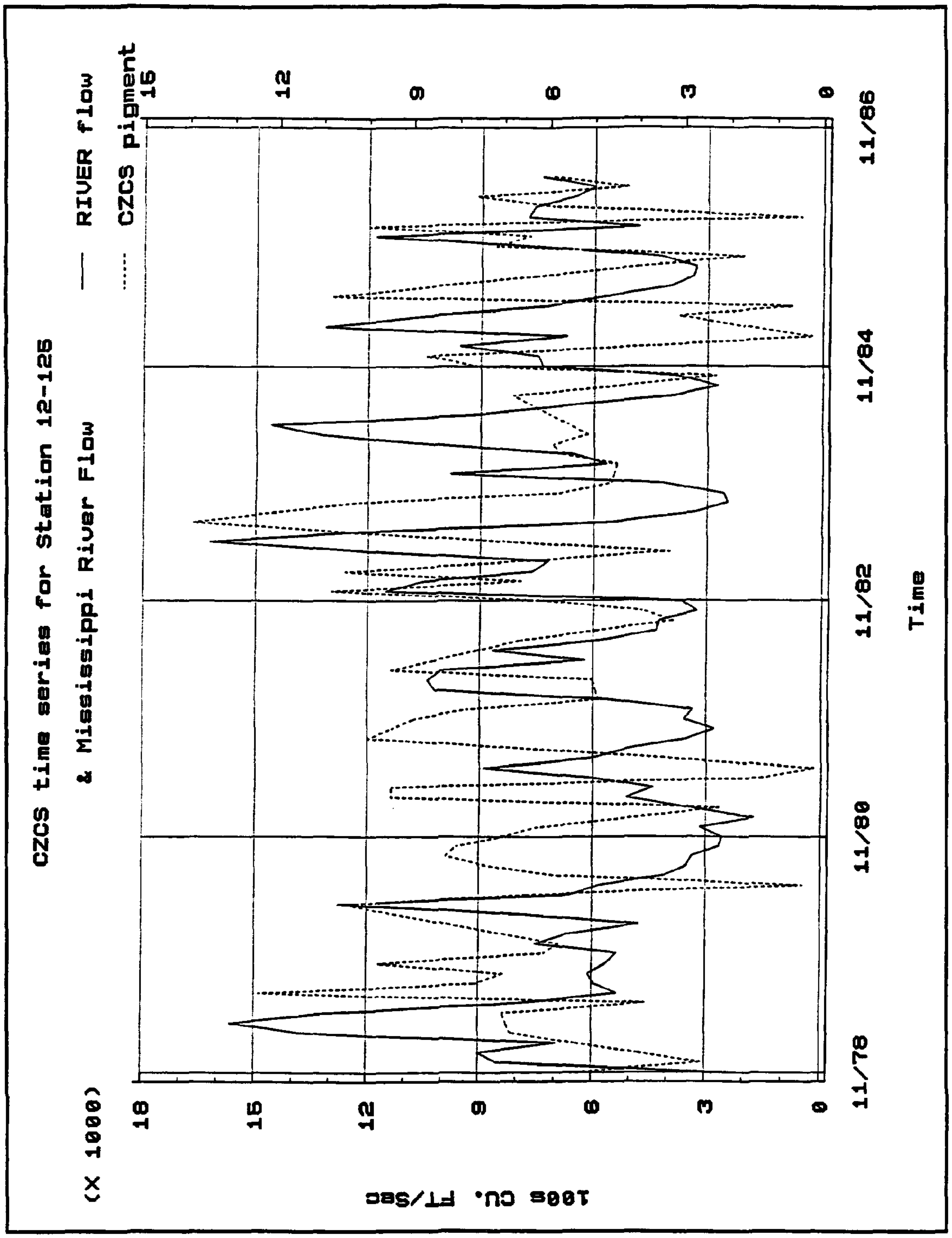


Figure 4.3. Time series 1979 -1986 of Mississippi River flow & chlorophyll pigment data from CZCS (data in close proximity to GulfCet station 12-125).

## 4.2 Hydrographic Survey: TAMUG

### 4.2.1 Introduction

This section presents an overview of the extensive, multivariate hydrographic data set collected during the GulfCet Program. Its objective is to provide a foundation on which the reader can understand the methods of data acquisition and steps taken to process the data. Pre-analysis corrections or adjustments are identified and discussed.

Data collected during the program will be submitted to the National Oceanographic Data Center (NODC) and will be available to the public from that source. The integrated analyses of the data discussed below form the basis for the process syntheses presented in section 4.2.6.

### 4.2.2 Transect and Cruise Design

The GulfCet Program conducts four TAMUG sponsored cruises each year, one cruise per season, for two of the three years of the program. Each cruise has three purposes: a visual survey of marine mammals, an acoustic survey using a towed hydrophone array, and a hydrographic survey. A transect consisting of 14 North-South track lines (Figure 4.4) is followed during the cruises. The hydrographic survey was designed to sample the mesoscale to large scale features in the Gulf. The choice of location and spacing of the 50 CTD hydrographic stations for this study is based on the following:

a) estimates of spatial scales in the study region (eg., slope eddy radii of 50-100 km) from bibliographic references;
b) acoustic and visual survey constraints;
c) ship time constraints;
d) similar survey patterns in MMS other Programs : LATEX A, LATEX B, and LATEX C;
e) CTD time estimates;
f) previous historical data.

As a result, CTD stations are located at the 100 and 2000 m isobaths (except at the Mexican border), and at 40 nautical mile intervals on each track line. The location and spacing of the 84 XBT hydrographic stations was based on the 200, 350, 500, 800, 1000, and 1500 m isobath locations for each of the 14 North-South track lines.

### 4.2.3 Summaries of Cruises 1-6

The first TAMUG GulfCet cruise (Cruise 1), was a sixteen day spring cruise (April 15-May 1, 1992), aboard the University of Texas at Austin's ship, *R/V Longhorn*. This cruise was divided into three legs as the result of personnel transfers and inclement weather delays. The following are the dates for each leg of the cruise: leg 1: April 15 -17; leg 2: April 20 -21; and leg 3: April 23 -May 1, 1992. No underway navigation or meteorlogical system was available for this cruise. Technical difficulties in the initial CTD casts resulted in fewer CTD stations being sampled than had been planned. The nature of these problems was found to be flooding in the main CTD housing, and partial failure of the

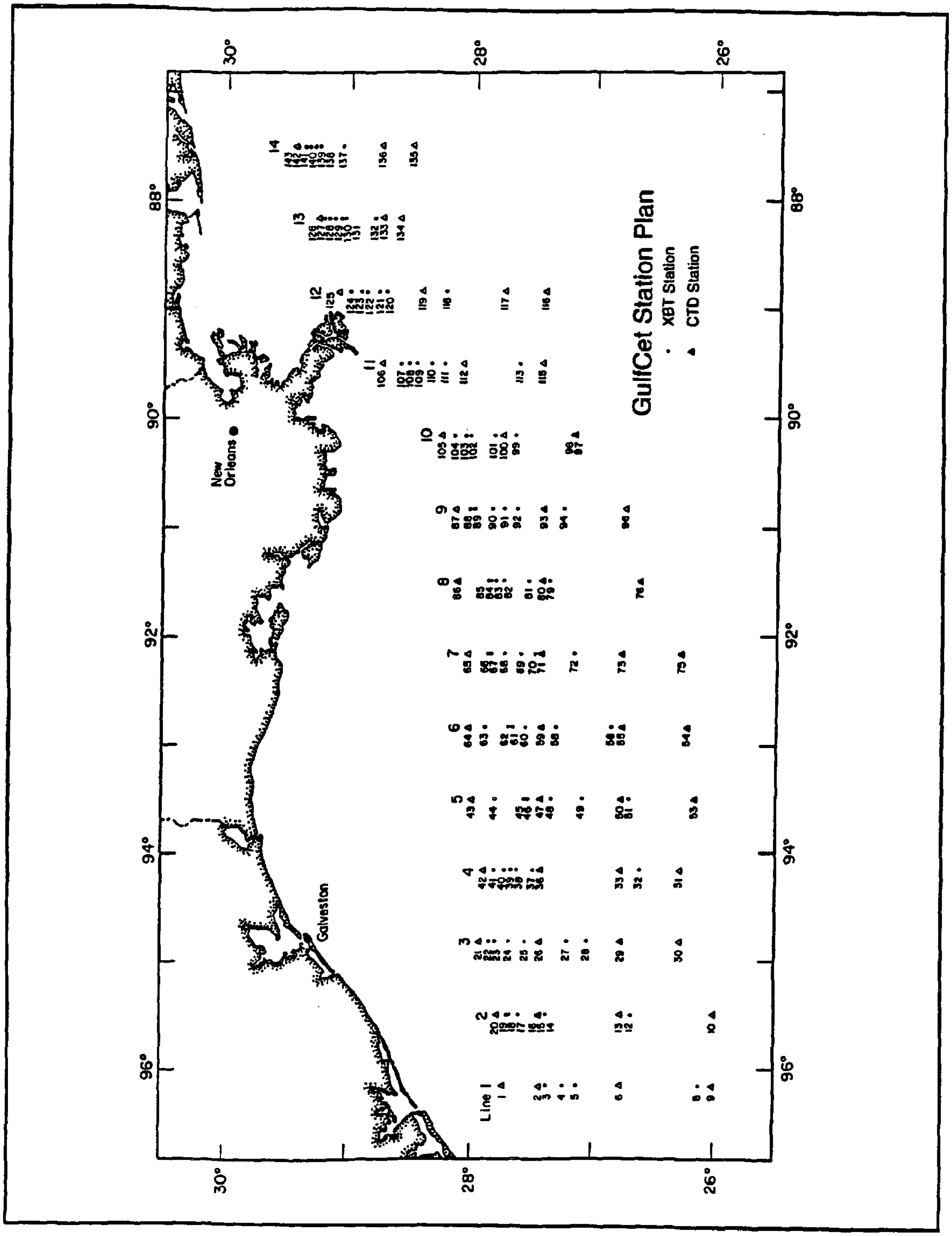


Figure 4.4. GulfCet station plan.

pumping system. A total of 15 CTD casts, 96 XBT stations, 115 salinity samples, and 127 chlorophyll samples were completed. CTD casts were to a maximum depth of 1000 m for this cruise and all cruises following. Further details have been published in a report entitled "GulfCet Cruise 01 Hydrographic Data", Technical Report 93-01-T (Fargion and Davis, 1993).

Following Cruise 1, all GulfCet cruises were conducted aboard the *R/V Pelican* of the Louisiana University Marine Consortium (LUMCON). This vessel presented several advantages, such as increased stability for the visual survey of marine mammals, increased laboratory space, and a continuously recording navigation and meteorlogical system.

GulfCet Cruise 2, a fourteen day summer cruise, took place between August 10-24, 1992. Track (transect) line 1 was dropped from the station plan for this cruise and in all succeeding cruises due to vessel schedule constraints. A total of 44 CTD casts and 78 XBT stations were completed, and 85 salinity samples and 273 chlorophyll samples were taken. Further details are available in "GulfCet Cruise 02 Hydrographic Data", Technical Report 93-02-T (Fargion and Davis, 1993).

GulfCet Cruise 3, a fifteen day fall cruise, took place November 8-22, 1992. Track line 10 and a portion of line 11 were not sampled due to inclement weather. A total of 39 CTD casts and 75 XBT stations were completed, resulting in 75 salinity samples and 425 chlorophyll samples. Technical Report 93-03-T (Fargion and Davis, 1993), "GulfCet Cruise 3 Hydrographic Data", gives complete details regarding the data for this cruise.

The fourth GulfCet Cruise, a fifteen day winter cruise, occurred between February 12-27, 1993. 80 salinity and 476 chlorophyll samples were collected from 44 CTD casts. 84 XBT stations were completed as well. Details of this cruise have been published in "GulfCet Cruise 4 Hydrographic Data", Technical Report 93-04-T (Fargion and Davis, 1993).

GulfCet 5, a ten day spring cruise, took place May 24-June 5, 1993. Track 2 as well as track 1 were dropped from the station plan for this cruise due to vessel scheduling constraints. To maximize the workable time, CTD's were cast only to a maximum of 500 m. 75 XBT stations and 42 CTD casts were completed, providing 84 salinity and 111 chlorophyll samples.

The second summer cruise, the eleven day GulfCet cruise 6, occurred August 27-September 5, 1993. Track lines 2 and 3, in addition to line 1, were dropped from the station plan for this cruise as a result of ship schedule restrictions. A depth of 800 m was the maximum depth to which the CTD was lowered to maximize available time. A total of 38 CTD casts and 94 XBT stations were completed, resulting in 144 salinity and 341 chlorophyll samples.

Figure 4.5 summarizes the total number of CTD and XBT stations completed for each line for cruises 1-6. A total of 503 XBT and 222 CTD stations were completed for a total of 723 stations. In total, 1753 chlorophyll and 583 salinity samples were obtained. Data for cruises 1-4 are included in the accompanying Volume II (Appendix) to this report as well.

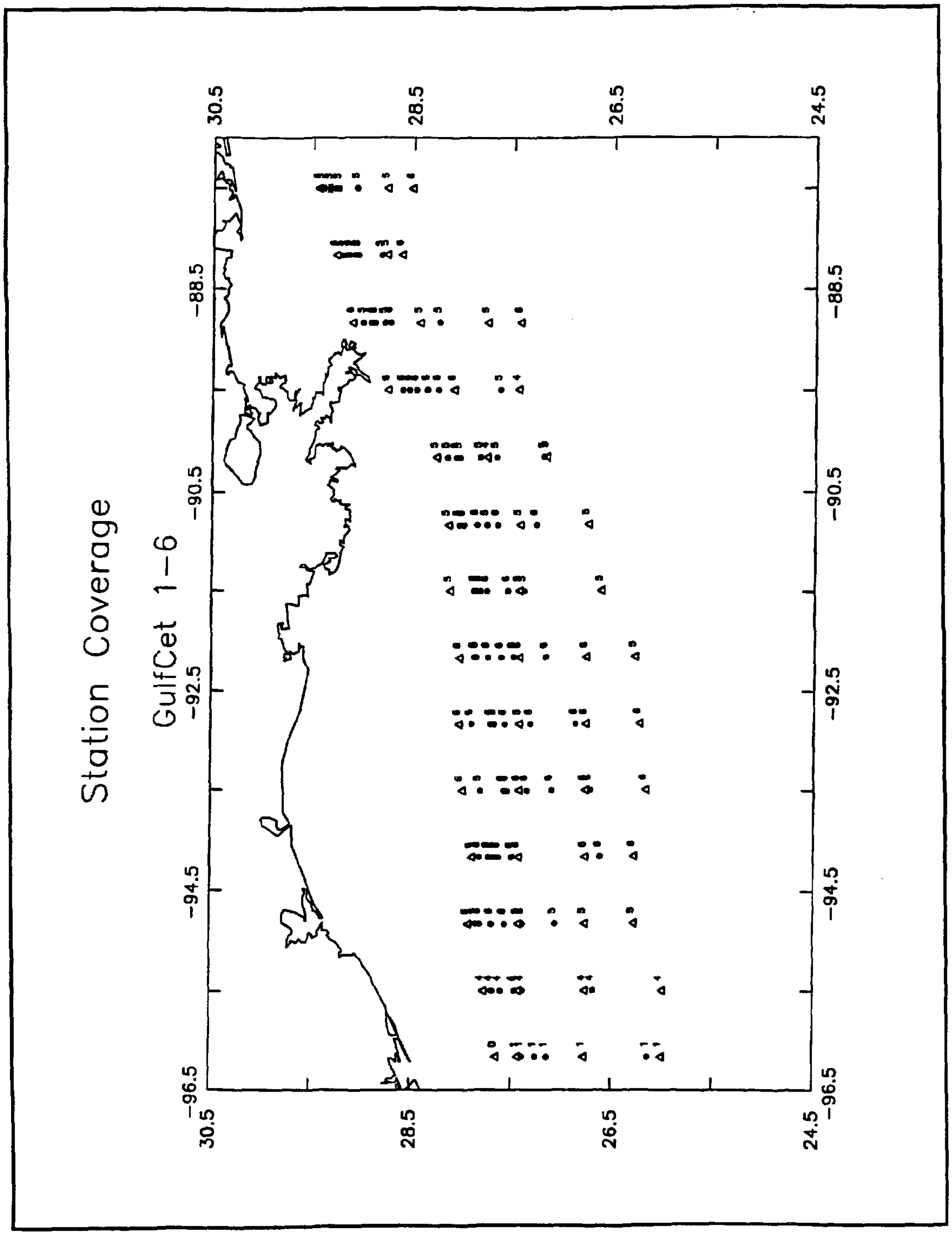


Figure 4.5. Total number of CTD & XBT stations Cruises 1-6.

4.2.4 Shipboard Measurements and Procedures

Data collected on each GulfCet cruise were obtained by lowering a CTD with a rosette, XBT deployments, and LUMCON's continuously recording Multiple Interface Data Acquisition System (MIDAS) (Walser, et al., 1992).

4.2.4.1 CTD/Rosette Casts

Vertical profiles of salinity, temperature, oxygen, and beam attenuation coefficient (transmissometry) were measured at every CTD station. Once on station and after the vessel had come to a complete stop, the CTD/Rosette was lowered to just below the surface. Bottom depth was checked, and time and location were recorded. During the downcast, temperature, salinity and beam attenuation coefficient were graphically dispayed in real-time as a function of depth. CTD data were acquired at 24 Hz. Once near the bottom, the CTD/Rosette was stopped and held for 5 minutes at that depth before starting the upcast. During this time, the sampling depths for the upcast were selected. The upcast was identical to the downcast except the instrument was stopped at the selected sampling depths, and the Niskin bottles were tripped. The CTD/Rosette was lowered to the sea floor, or to a maximum depth of 1000 m. At stations less than 500 m, in situ fluorescence was also measured. Secchi disk and environmental data were gathered using World Meteorlogical Organization (WMO) codes.

The water sample depth selection was based on chlorophyll sample criteria and followed these general guidelines:

-100 m stations: water samples were taken at depths of 0, 5, 15, 20, 30, 40, 50, 60,70, 80, 90, and 100 m.

-All other stations: sampling depths were 0, 10, 20, 30, 40, 55, 70, 85, 100, 125, 150, and 1000 m.

Occasionally, due to special circumstances (on cruise 06 nutrient samples were collected) or to the presense of unusual hydrographic features, sample depths were added or deleted. A salinity sample was always taken from the shallowest and deepest bottle.

Water samples for chlorophyll analysis were filtered at sea using GF/F filters (4.7 cm. diameter, and 0.7 micron retention size). The filters were stored in liquid nitrogen and a -80°F freezer until analyzed at TAMUG. GulfCet chlorophyll samples were analyzed for chlorophyll a and phaeopigments using a Turner Designs Fluorometer and following a modified Strickland and Parsons (1972) procedure. Precision of chlorophyll and phaeopigment analysis was +/- 0.01 $\mu g\ L^{-1}$. Replicates of chlorophyll samples for line 4 were given to the MMS LATEX-A Program for HPLC pigment analysis.

4.2.4.2 XBT

XBT's were launched at depths of 200, 350, 500, 800, 1000, and 1500 meters along each track line. At an XBT station, either a Sparton of Canada or Sippican T-7, T-10, or T-20 XBT probe (depending on the depth) was deployed while the ship was underway. Ship speed during deployment did not exceed 7-8 knots. Extra XBT deployments (one or two) per cruise coincided with CTD casts. Additional

XBT's were launched during some marine mammal sightings, for acoustic array calibration, and when unusual hydrographic features were detected (i.e., GulfCet cruise 6).

4.2.4.3 Multiple Interface Data Acquisition System (MIDAS)

A continuous recording of navigation data, surface hydrographic data (salinity, temperature, fluorescence, light transmission, and sea water flow rate), meteorological data (wind speed, wind direction, air temperature, barometric pressure, and solar irradiance) was collected with the MIDAS system. The MIDAS system sampling rate is an average of every fifteen seconds. This system uses a Sea-Bird Electronics' temperature sensor, and a Sea Tech, Inc. fluorometer and transmissometer. The conductivity-temperature meter on the MIDAS is calibrated annually at Sea-Bird Electronics.

4.2.5. Data Analysis

This section describes the various analyses used to present and identify physically meaningful processes or conditions. These analyses that are accepted as routine within the physical oceanographic community are not described in detail.

4.2.5.1 XBT and CTD Data Processing

Raw XBT frequency data were processed with an in-house conversion program using Sparton's drop rates (Sparton of Canada, 1992). The processed XBT data are interpolated at 1 m steps using a program developed at Scripps Institute of Oceanography (La Jolla, CA). The XBT data are calibrated against CTD casts. Scatter plots were made of the CTD depth and XBT depth difference (for the compared isotherm) versus XBT isotherm depth (Singer, 1990). The first order empirical fit was $y = 0.047x - 2.9$. A depth adjustment was made in the data to compensate for the fact that XBT isotherms were shallower than CTD isotherms.

The CTD data was processed using Sea-Bird's Seasoft software. The following CTD data processing steps were used:

1. DATCNV: Converts raw data to binary engineering units and stores data in CNV files.
2. SPLIT: Splits the CNV files into upcast and downcast files.
3. WILDEDIT: Checks for and marks 'wild' data points.
4. FILTER: Filters data columns to produce zero phase time shifts.
5. ALIGNCTD: Aligns specific temperature, conductivity, and oxygen measurements with their corresponding pressure measurements.
6. In-house program: Converts temp. to ITS-90 scale (UNESCO, 1991).
7. CELLTM: Removes conductivity cell thermal mass effects from conductivity data.
8. LOOPEDIT: Marks the scan where CTD is moving less than the minimum velocity or traveling backwards due to ship roll.
9. DERIVE: Computes dissolved oxygen and depth.
10. BINAVG: Averages the data into 1 m. depth bins.
11. DERIVE: Computes salinity (PSS-78), density (EOS80), potential temperature (Pot.Temp), specific volume anomaly (SVA), & sound velocity (Chen-

Millero) using Fofonoff and Millard's (1983) formulas. Also computes dynamic height anomaly (Dyn Ht).

The CTD salinity calibration data were obtained from upcast salinity water samples and from temperature and salinity sensor calibration. These sensors were sent to Sea-Bird Electronics, Inc. for calibration after 100 casts. Salinity samples were analyzed in the Dept. of Oceanography of Texas A&M University, using a Guildline Connectively Coupled Salinometer (model number 8400A). The Salinometer was standardized with Wormley Standard Seawater. Salinity bottle data were plotted against CTD salinity casts. Differences were found to be within the range of the accuracy of the instruments.

4.2.5.2 MIDAS

The MIDAS continuously recorded data was processed with an in-house program which cuts cruise track lines from the continuously recorded file, and plots raw data with no corrections.

4.2.5.3 Dynamic Height

XBT data were combined with CTD data to compute local geostrophic circulation fields. A micro VAX 3600 computer was used for the calculations of dynamic height and mass transport/geostrophic velocity between station pairs, as described by Biggs, et al. (1990). All of our geopotential computations for cruises 1-4, and 6 are referenced to the 800 dbar surface (GulfCet cruise 5, is referenced to the 500 dbar). Hofmannn and Worley (1986) have shown empirically that choice of an 800 to 850 dbar reference level should allow baroclinic transport calculations to be in the mass balance throughout the western Gulf of Mexico. Their model is supported by transport calculations for anticyclone eddies (Biggs, 1992).

4.2.6 Technical Discussion

4.2.6.1 Characteristic Temperature-Salinity Relationship

Figure 4.6 shows temperature versus salinity for all observations on cruises 2-6. In addition, temperature-salinity (T-S) plots have been done for each of the four seasons as follows: winter refers to December-January-February, and incorporates Cruise 4 (Figure 4.7); spring refers to March-April-May, and incorporates Cruises 1 and 5 (Figure 4.8); summer refers to June-July-August, and incorporates Cruises 2 and 6 (Figure 4.9); and fall refers to September-October-November, and incorporates Cruise 3 (Figure 4.10). These plots show a remarkable uniformity below 17°C, indicating that the waters in the study area constitute essentially a single system. Data from all the hydrographic stations reveals a distinct maximum salinity greater than 36.60 psu and a minimum salinity less than 34.9 psu; this excludes the surface fresh water near the Mississippi plume (which was as low as 12.76 psu).

These salinity signatures are characteristic of Subtropical Underwater and Antarctic Intermediate Water, respectively. Usually the Subtropical Underwater salinity maximum is centered at about 200 m. The Antarctic Intermediate Water salinity minimum in the eastern Gulf occurs between depth of 800 to 1000 m (shallower in the western Gulf). The intense salinity

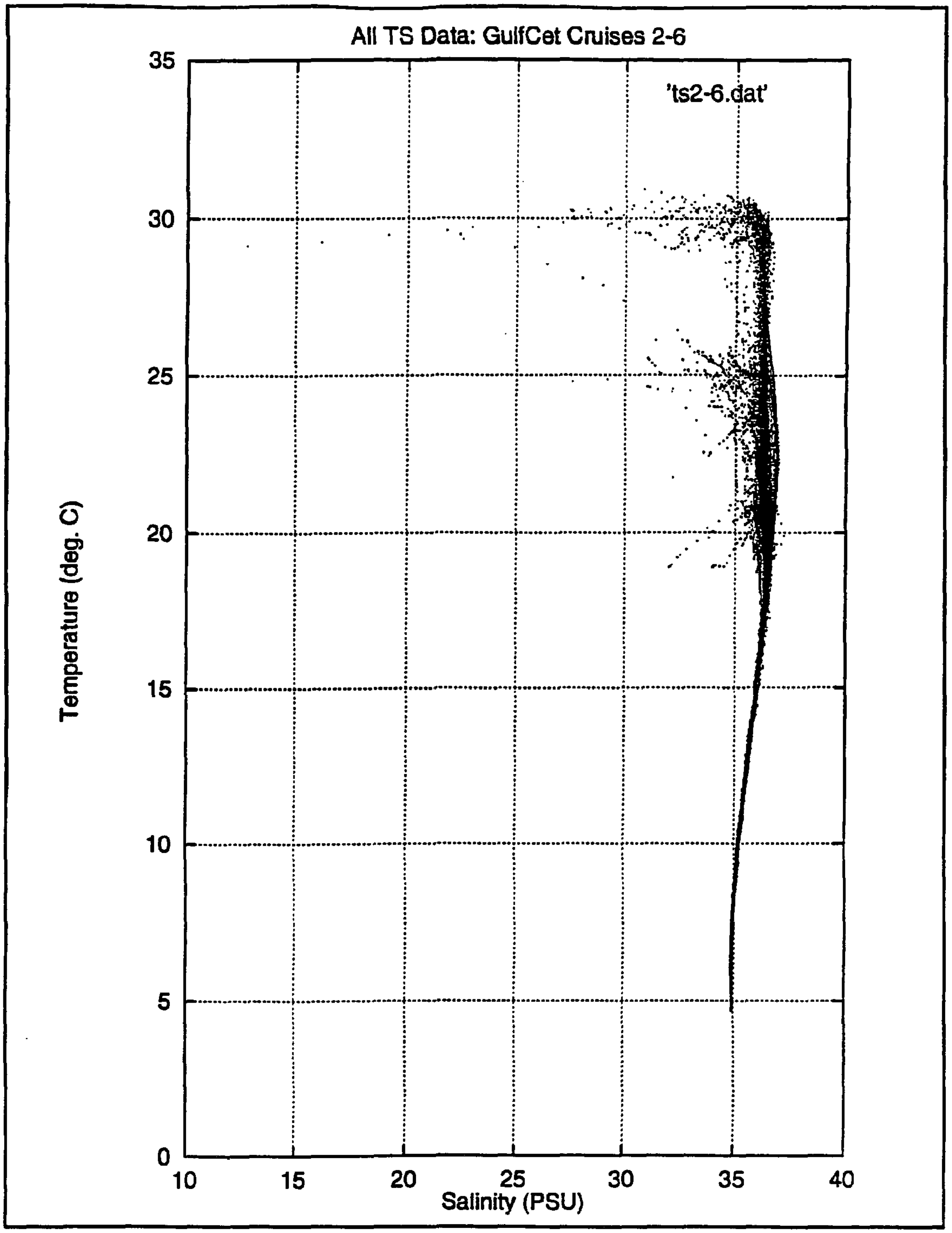


Figure 4.6. T-S Plot: all CTD data Cruises 2-6.

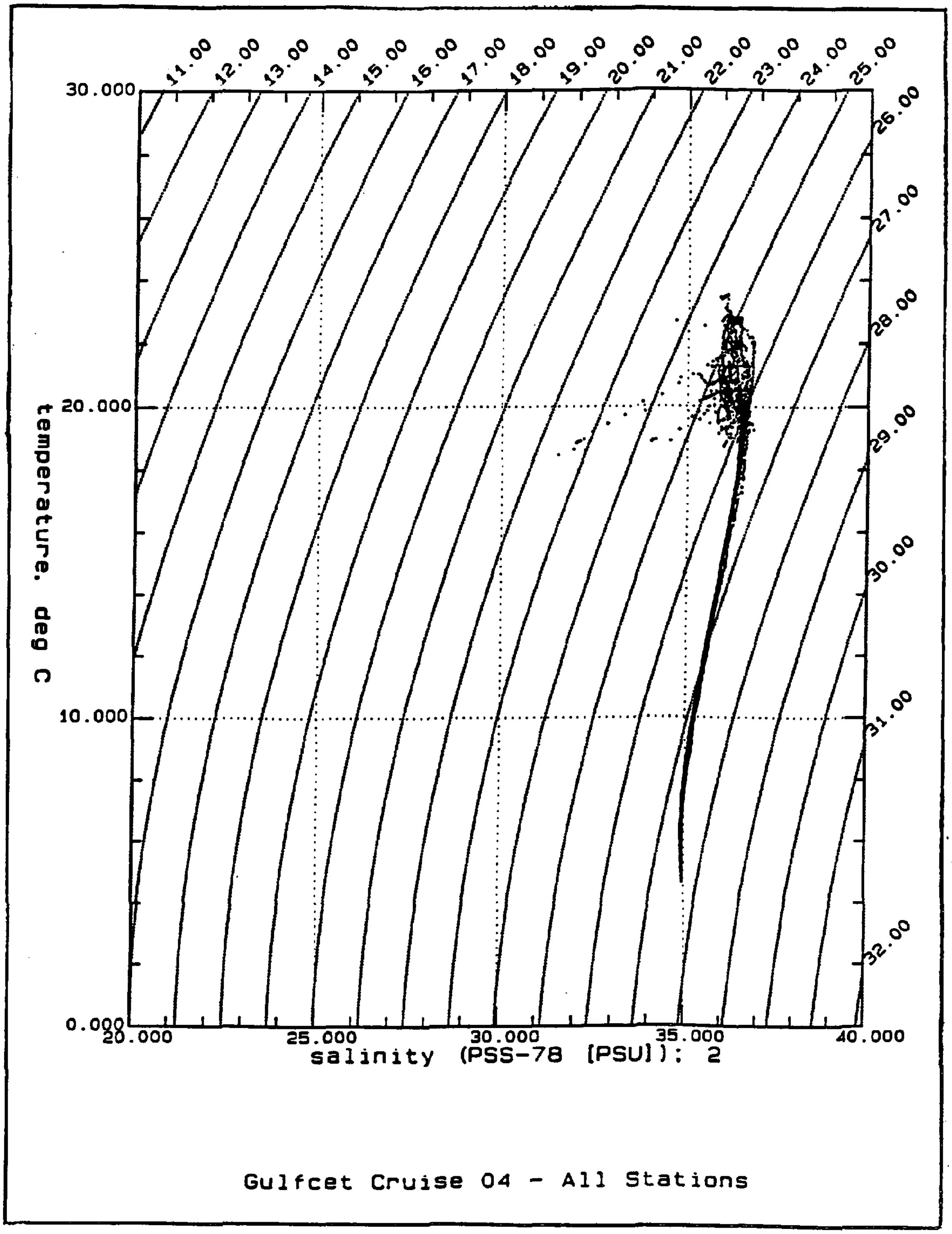


Figure 4.7. Winter T-S Plot: CTD data Cruise 4.

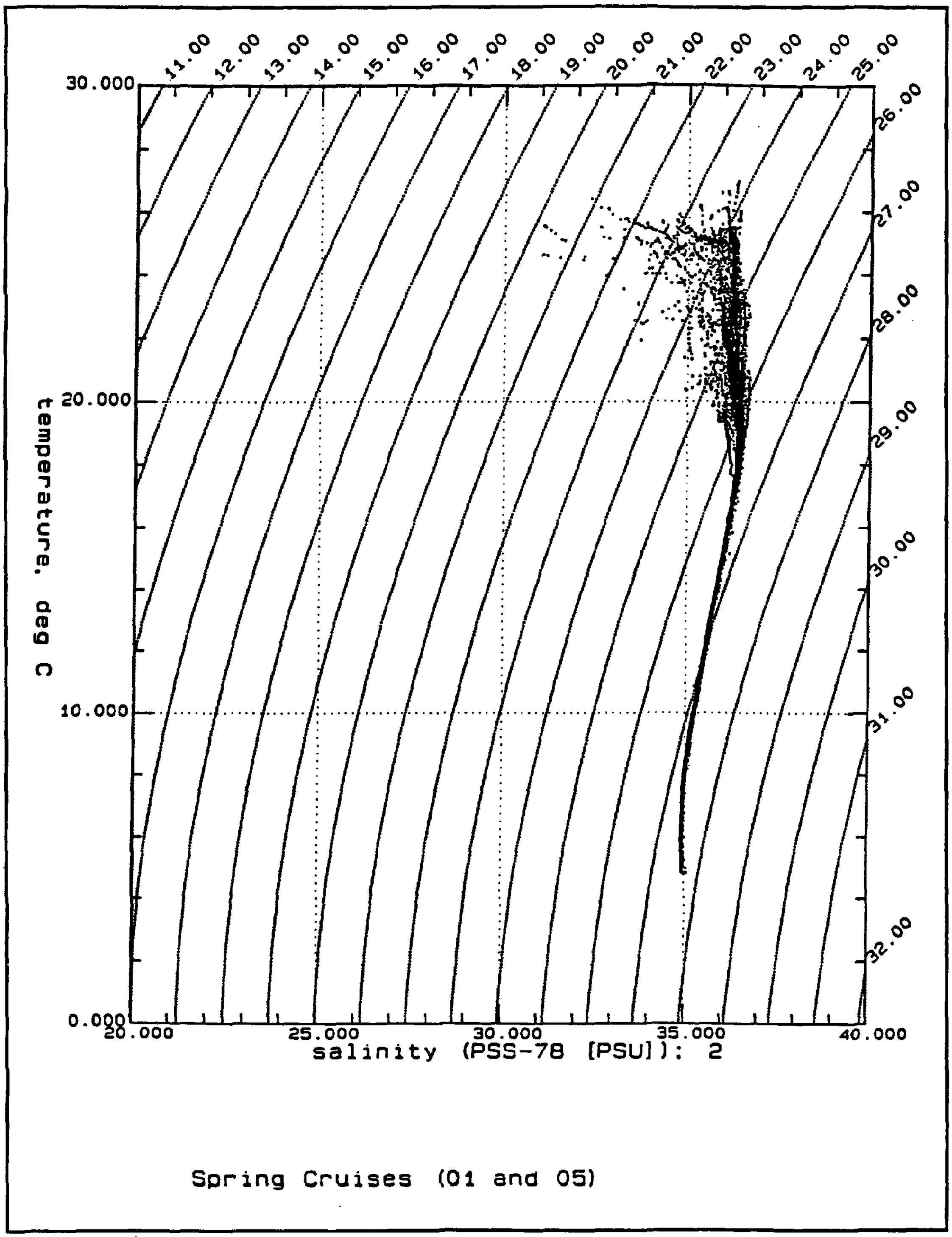


Figure 4.8. Spring T-S Plot: CTD data Cruises 1 & 5.

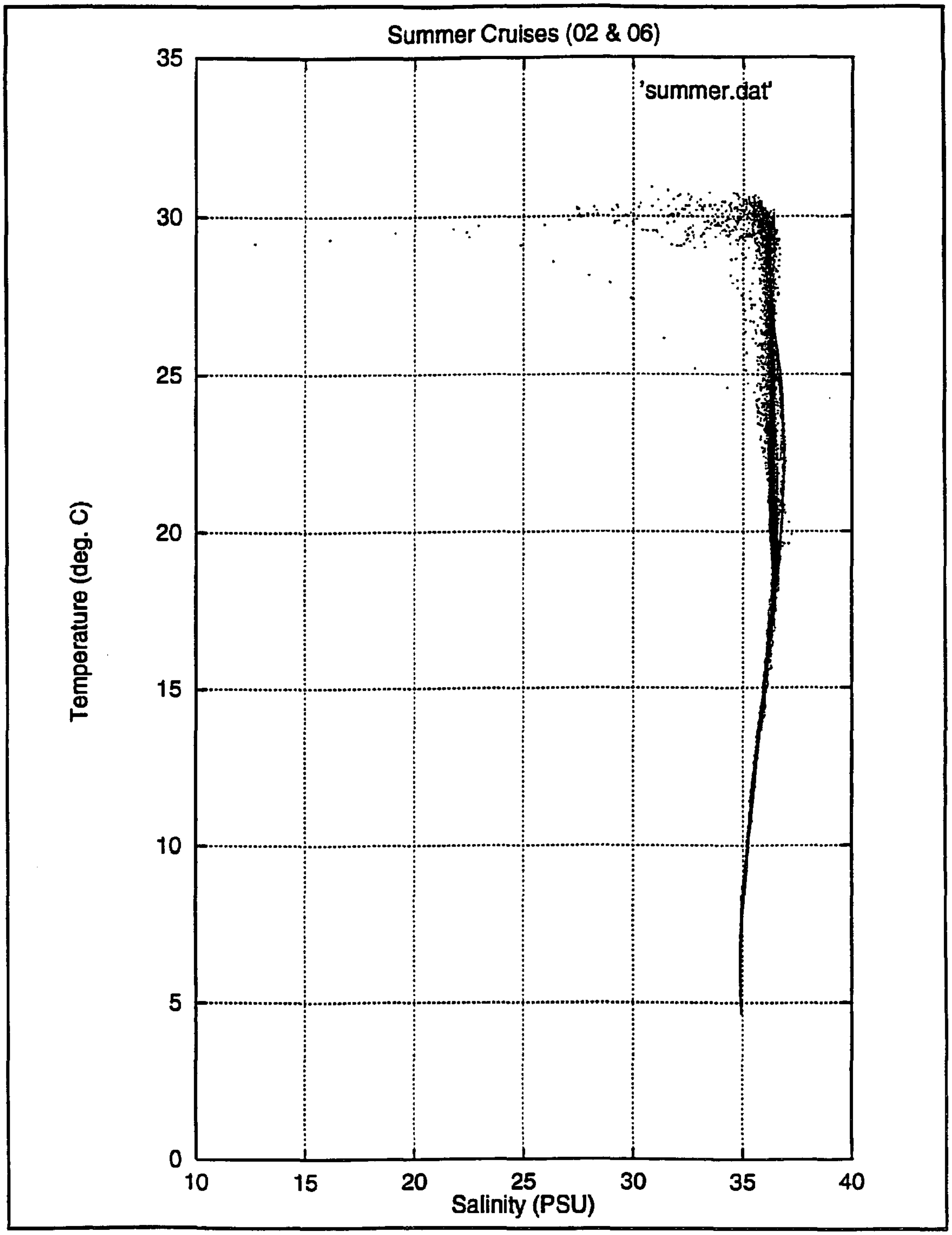


Figure 4.9. Summer T-S Plot: CTD data Cruises 2 & 6.

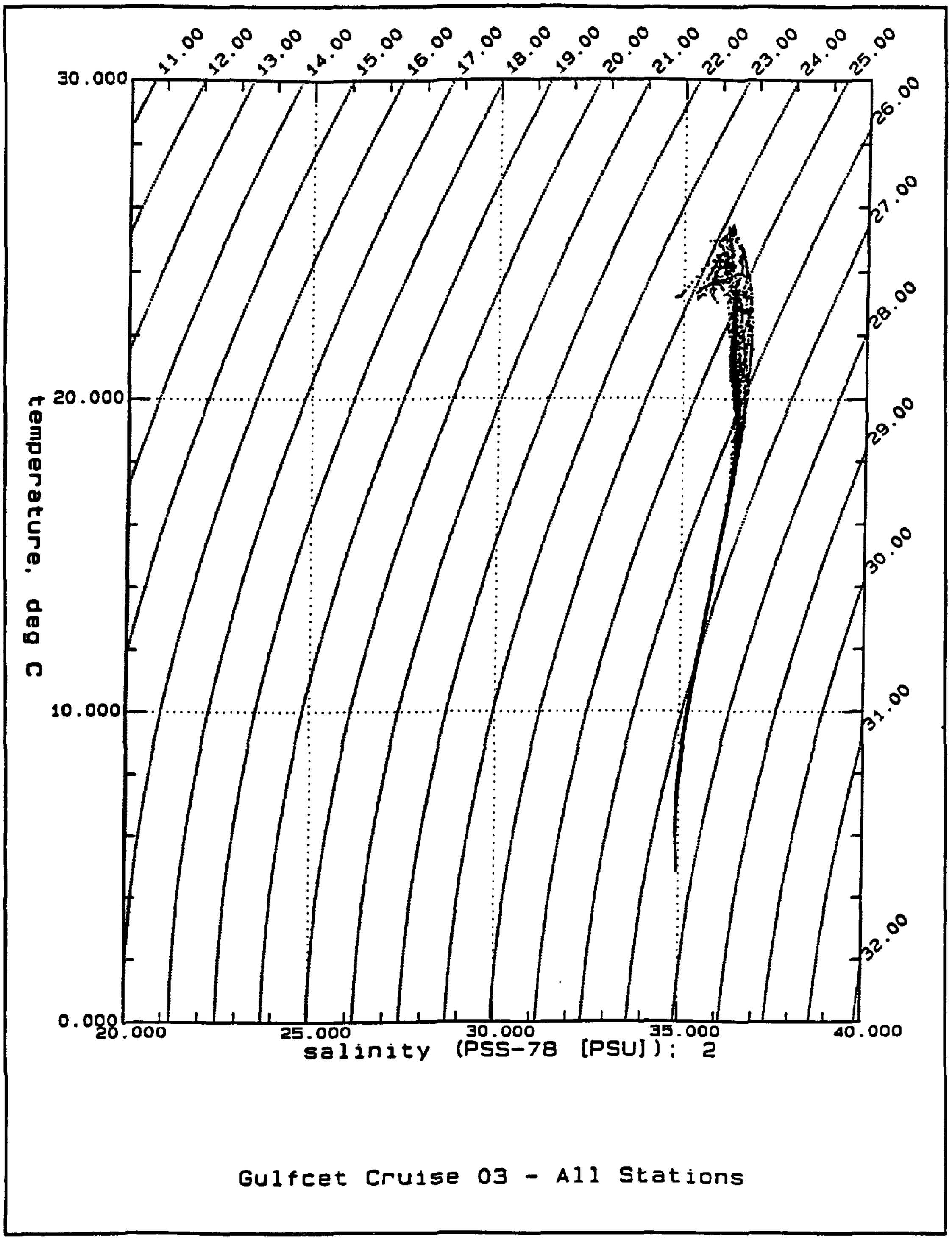


Figure 4.10. Fall T-S Plot: CTD data Cruise 3.

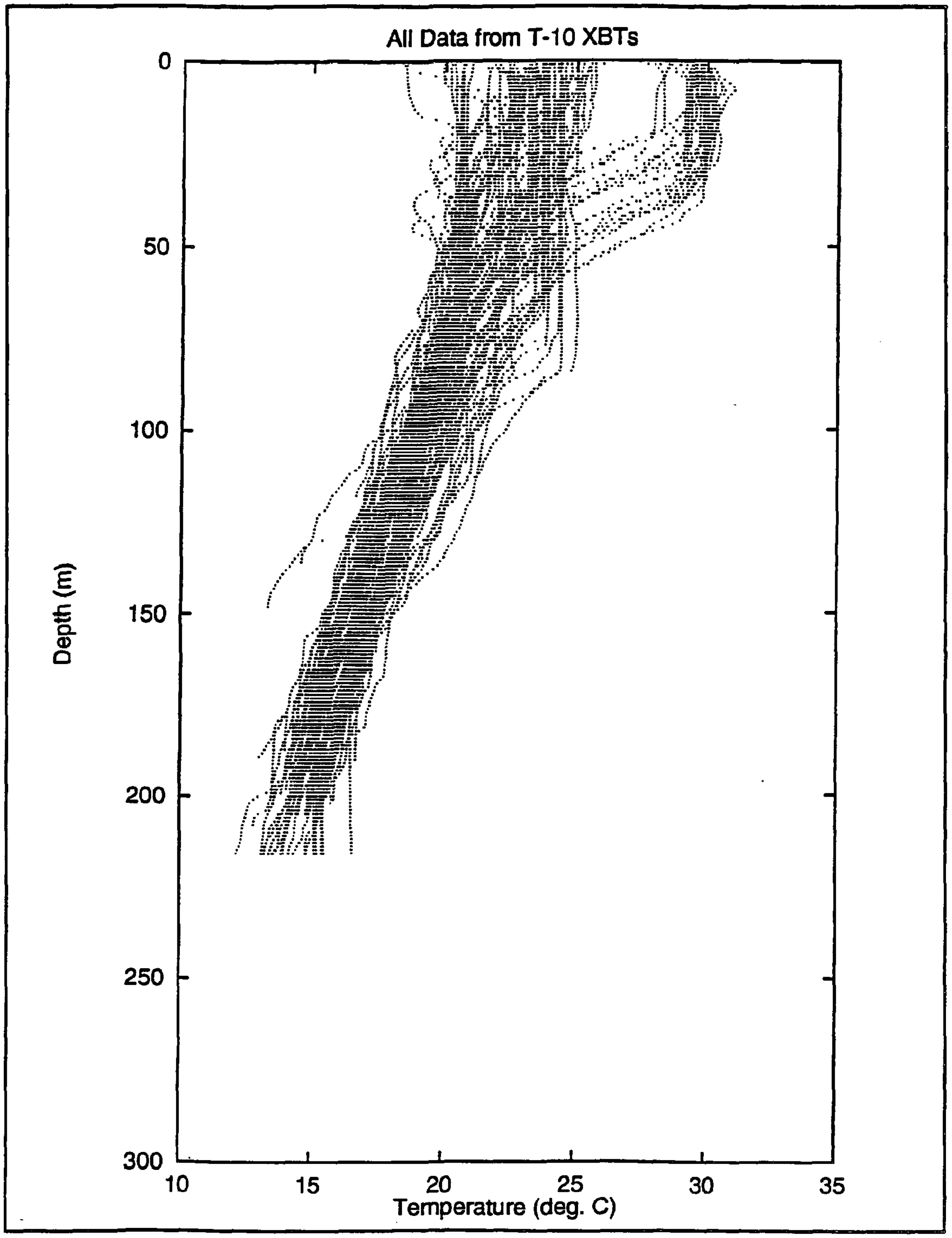


Figure 4.11. T-10 XBT Temperature Plot: Cruises 1- 6.

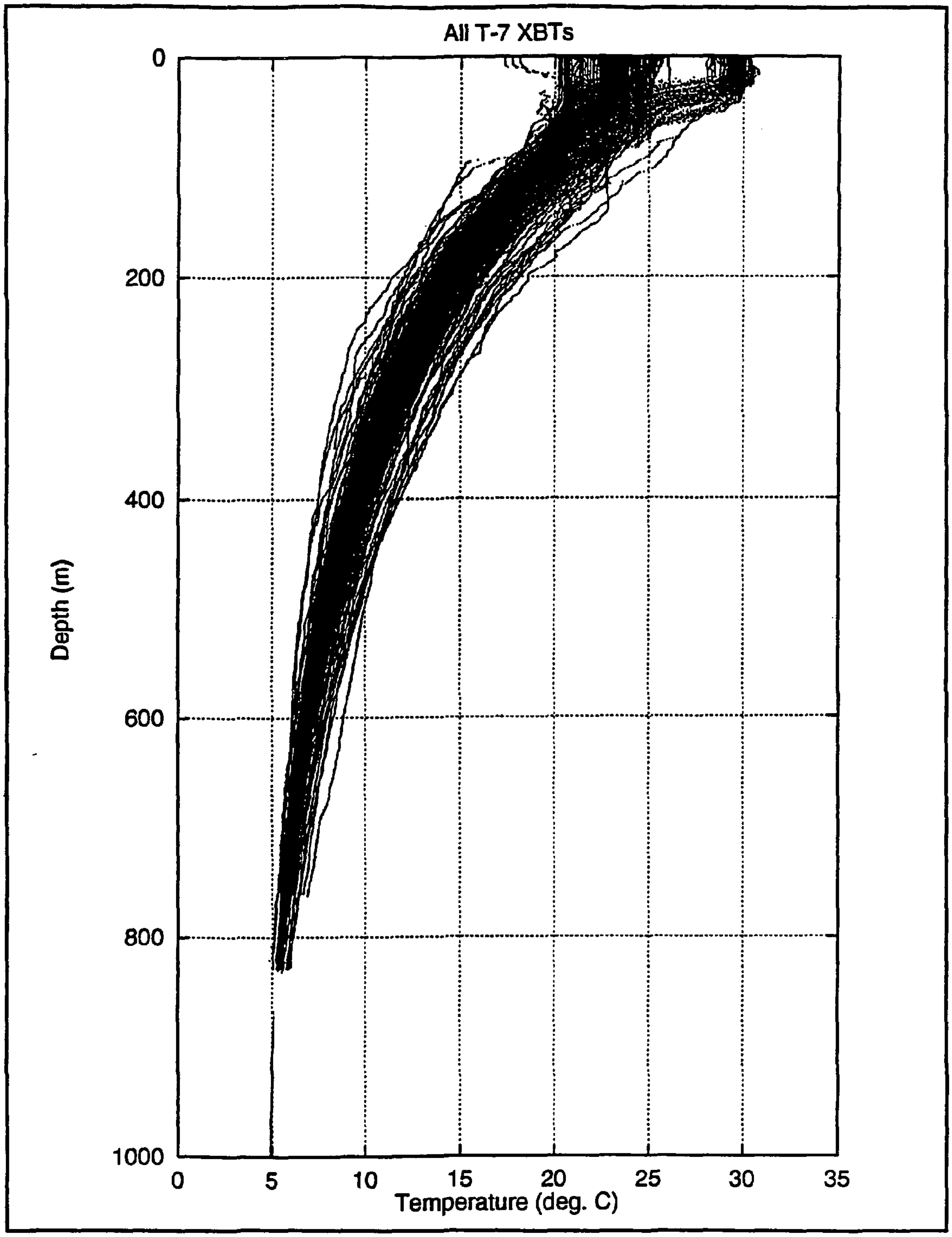


Figure 4.12. T-7 XBT Temperature Plot: Cruises 1- 6.

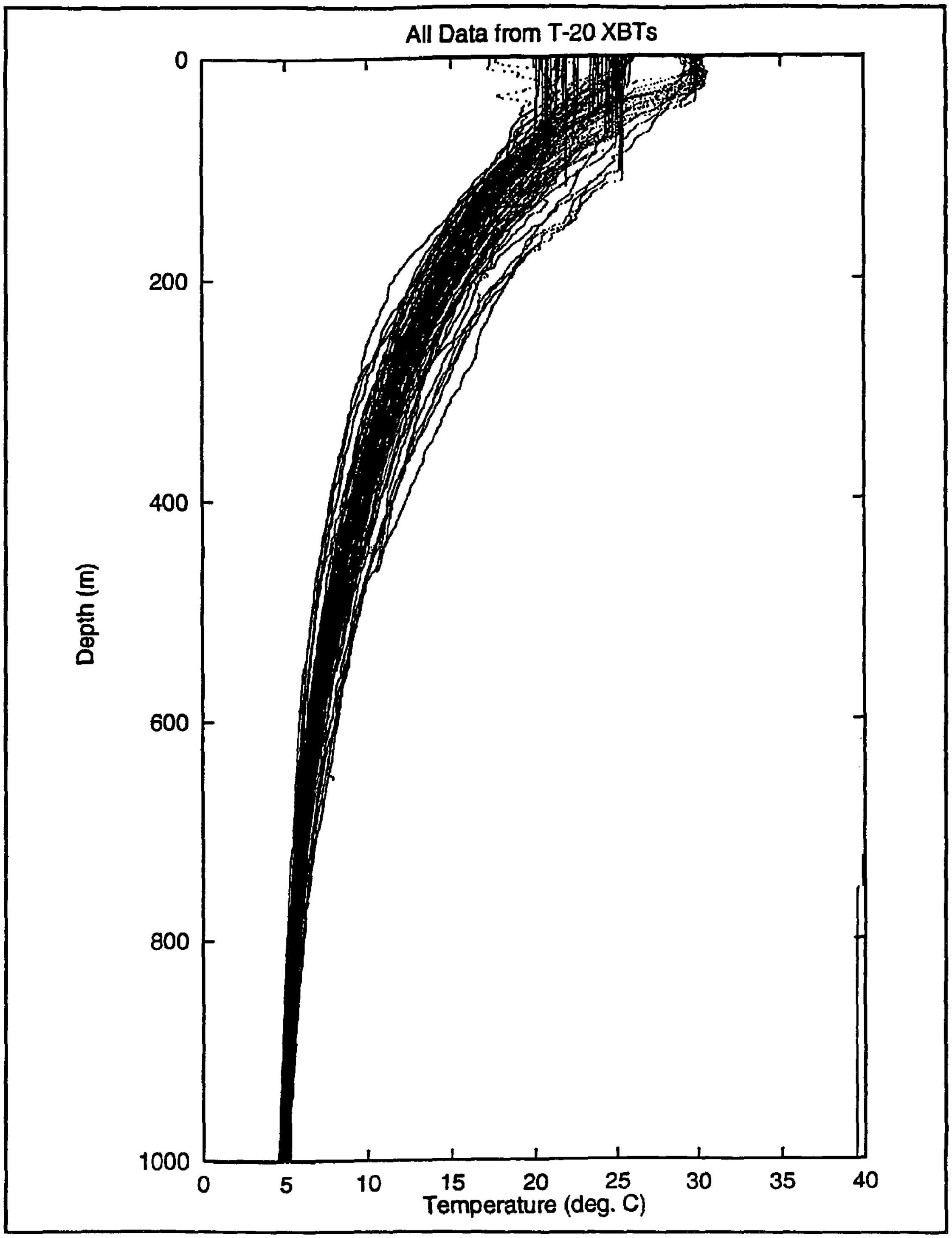


Figure 4.13. T-20 XBT Temperature Plot: Cruises 1- 6.

maximum of the Subtropical Underwater is found in the region of the Loop Current and in rings derived from this current. During the GulfCet cruises, we have detected several eddies with a salinity greater than 36.60 psu, which is the hallmark of Loop Current eddies.

XBT temperature data has been plotted by probe type: T-10 probe data are represented in Figure 4.11, Figure 4.12 shows T-7 probe data, and T-20 probe data are shown in Figure 4.13. These XBT data have not been corrected with the depth adjustment which would have compensated for the XBT isotherms being shallower than the CTD isotherms. These temperature versus depth plots show the ranges of the variability in the XBT temperature profiles during cruises 1 to 6 cruises (1992-93). The presence of "bad" probes was also identified in this fashion.

4.2.6.2 20°C, 15°C, and 8°C Isotherms

All XBT temperature data (XBT stations and extra XBT's) have been corrected and plotted with CTD temperature data. Figures 4.14 through 4.32 show the 20°, 15°, and 8° C isotherm depths over the entire study area for cruises 1- 6.

The observed depth of the 15°C and 20°C isotherms, as well as the flat nature of the 20°C isotherm, indicates the presence of features such as the eddy Triton in Cruise 2, eddy "U" in Cruise 2, eddy "V" in Cruises 3 and 4, and Eddy Whopper in Cruise 6. Regions where the temperature surface is deep corresponds to anticyclonic (clockwise) circulation, and those regions where the temperature surface is shallow corresponds to cyclonic (counterclockwise) circulation. Surface waters warmer than 14°C in the western Gulf are frequently relatively flat in cyclonic eddies and do not always depict these features well.

A prominent anticyclonic eddy is almost always present in the western Gulf of Mexico. Small cyclonic eddies (cold water) are often associated with the periphery of this dominant feature, and the 8°C isotherm topography is the preferred detection tool for these eddies. In particular, doming isotherms may represent the initial stages of development of a cyclonic feature which is linked to the primary eddy and evolves in strength during subsequent stages of eddy-slope interaction. This intensification of the anticyclonic-cyclonic pair (oppositely rotating vortices) has been observed in the past in the western Gulf (Merrell and Morrison, 1981; Brooks and Legeckis, 1982; Merrell and Vazquez, 1983; Broks, 1984). A comparison between the 15° and 8°C isotherms can reveal different sizes and areas of eddy location that can indicate whether the vertical axis of the core is tilted.

The following summary identifies the major hydrographic features found in cruises 1 through 6 located by survey track (transect) lines (see Figure 4.4 for track-line designations):

Cruise 1: Cyclonic eddy on track-line 7, (Figure 4.14, 4.15, and 4.16)

Cruise 2: Anticyclonic eddy, Triton, on track-lines 2 & 3 with associated strong cyclonic eddy on track-line 5 (seen in the 15° and 8°C isotherm); anticyclonic eddy "U", track-line 8 with associated cyclonic eddy on track-line 11 (Figures 4.17 to 4.19).

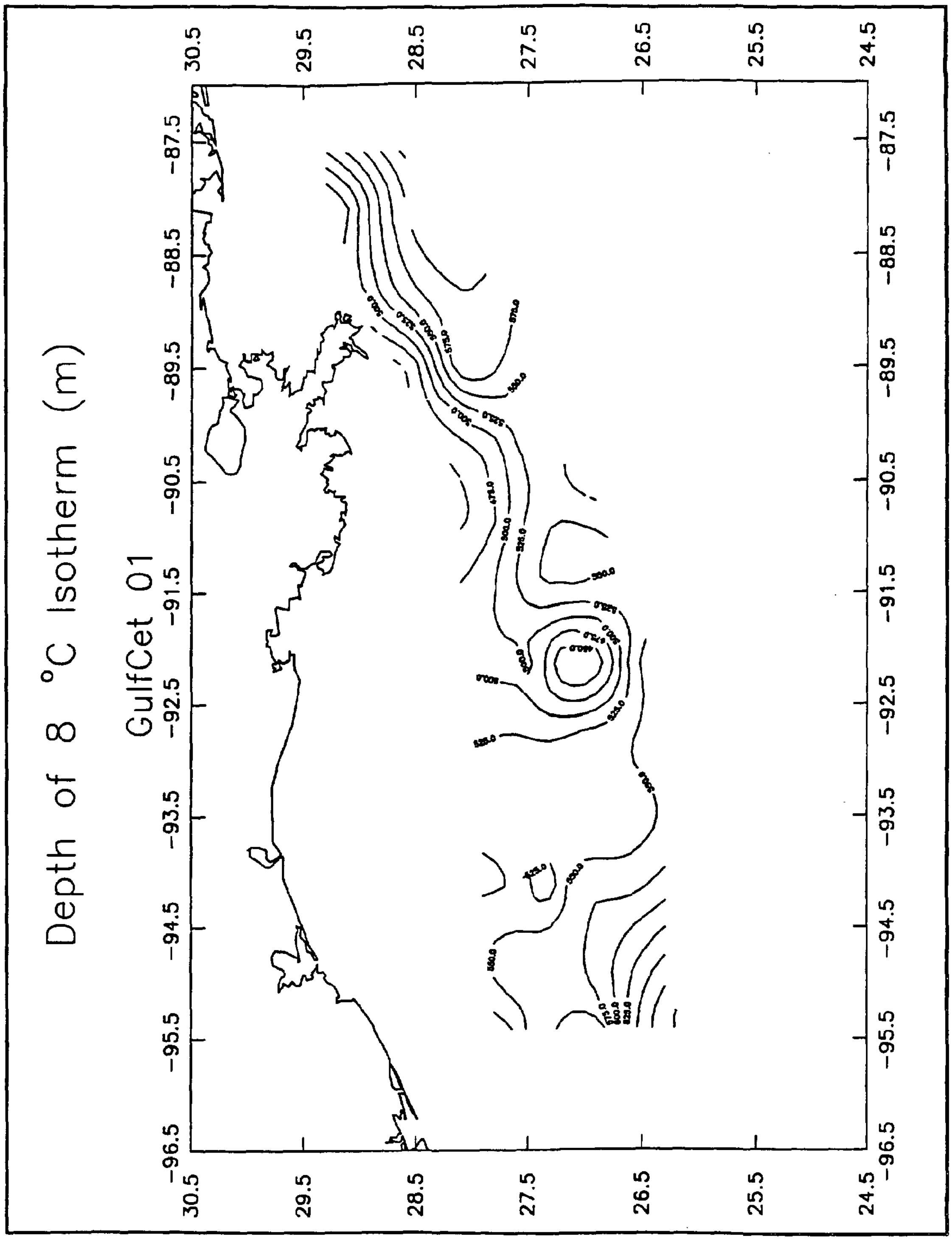


Figure 4.14. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 1.

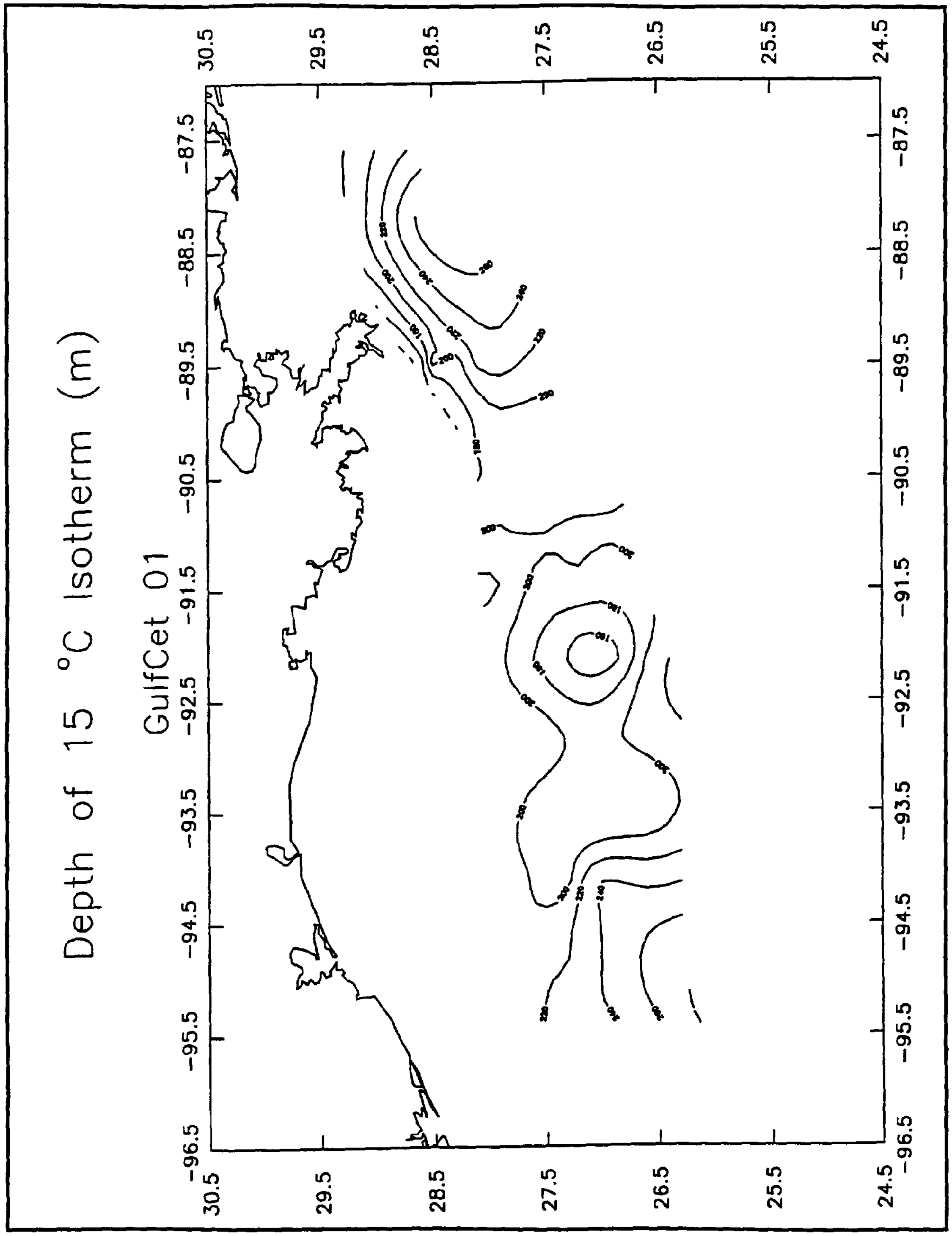


Figure 4.15. Topography of the 15°C temperature surfacebased on all XBT and CTD data Cruise 1.

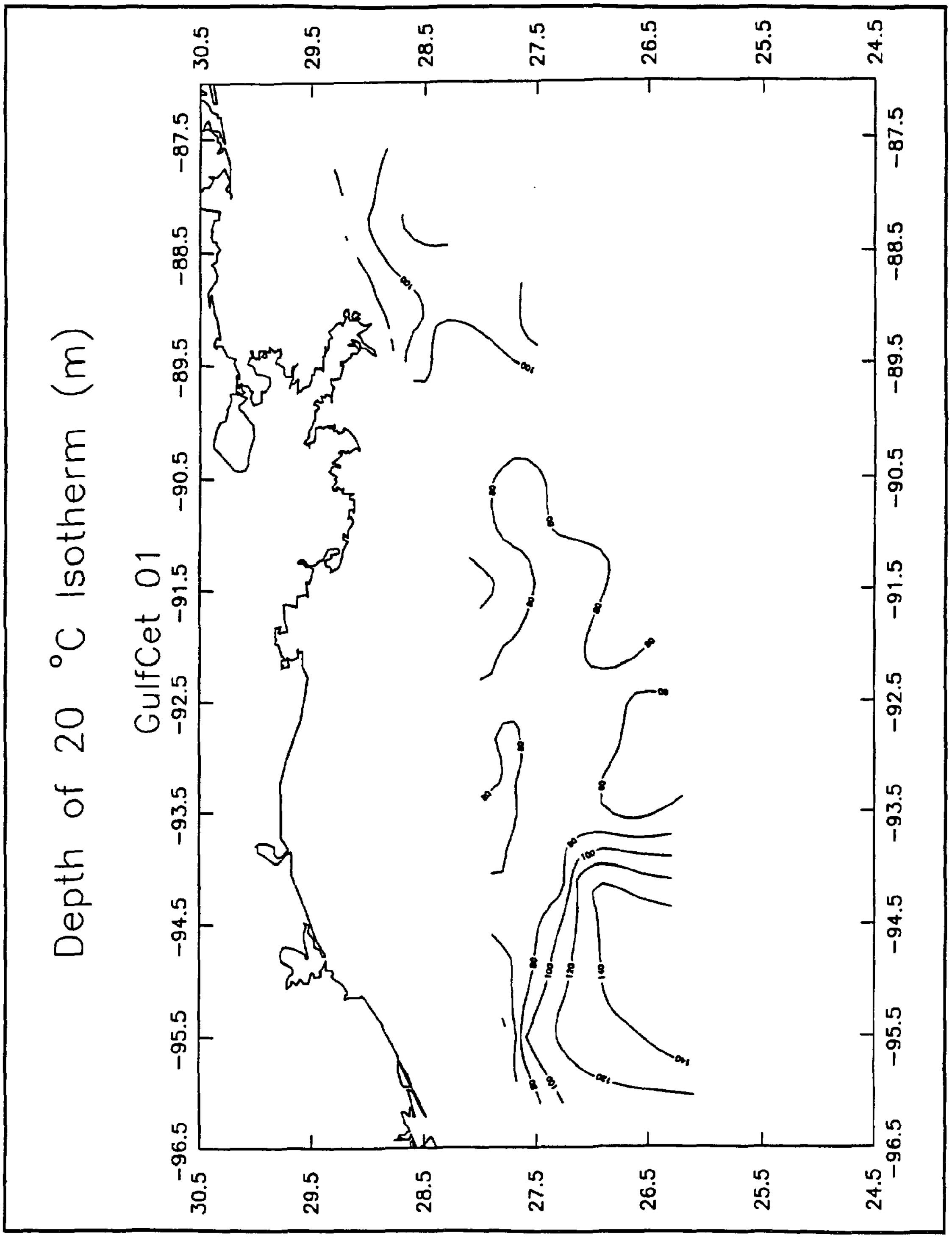


Figure 4.16. Topography of the 20°C temperature surfacebased on all XBT and CTD data Cruise 1.

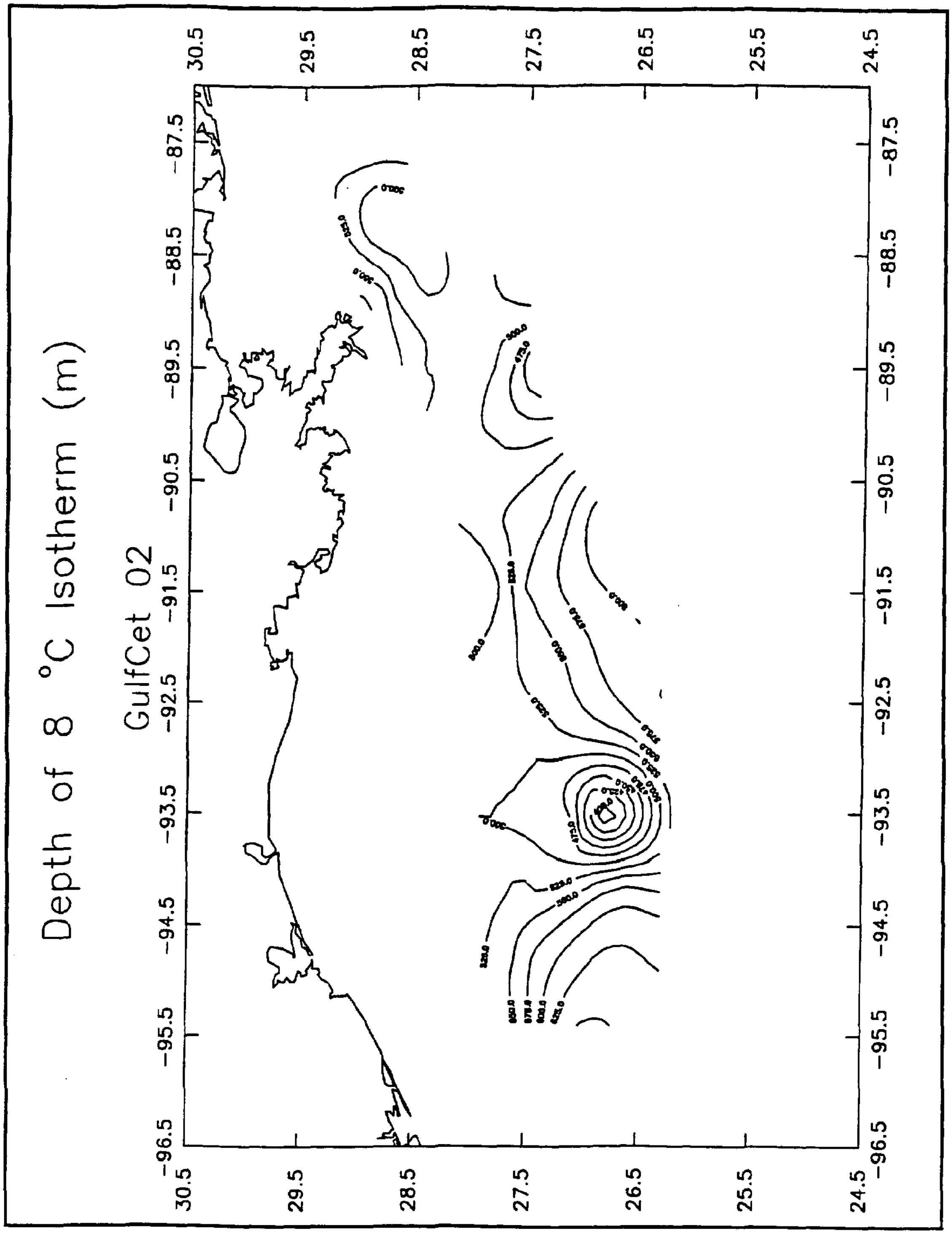


Figure 4.17. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 2.

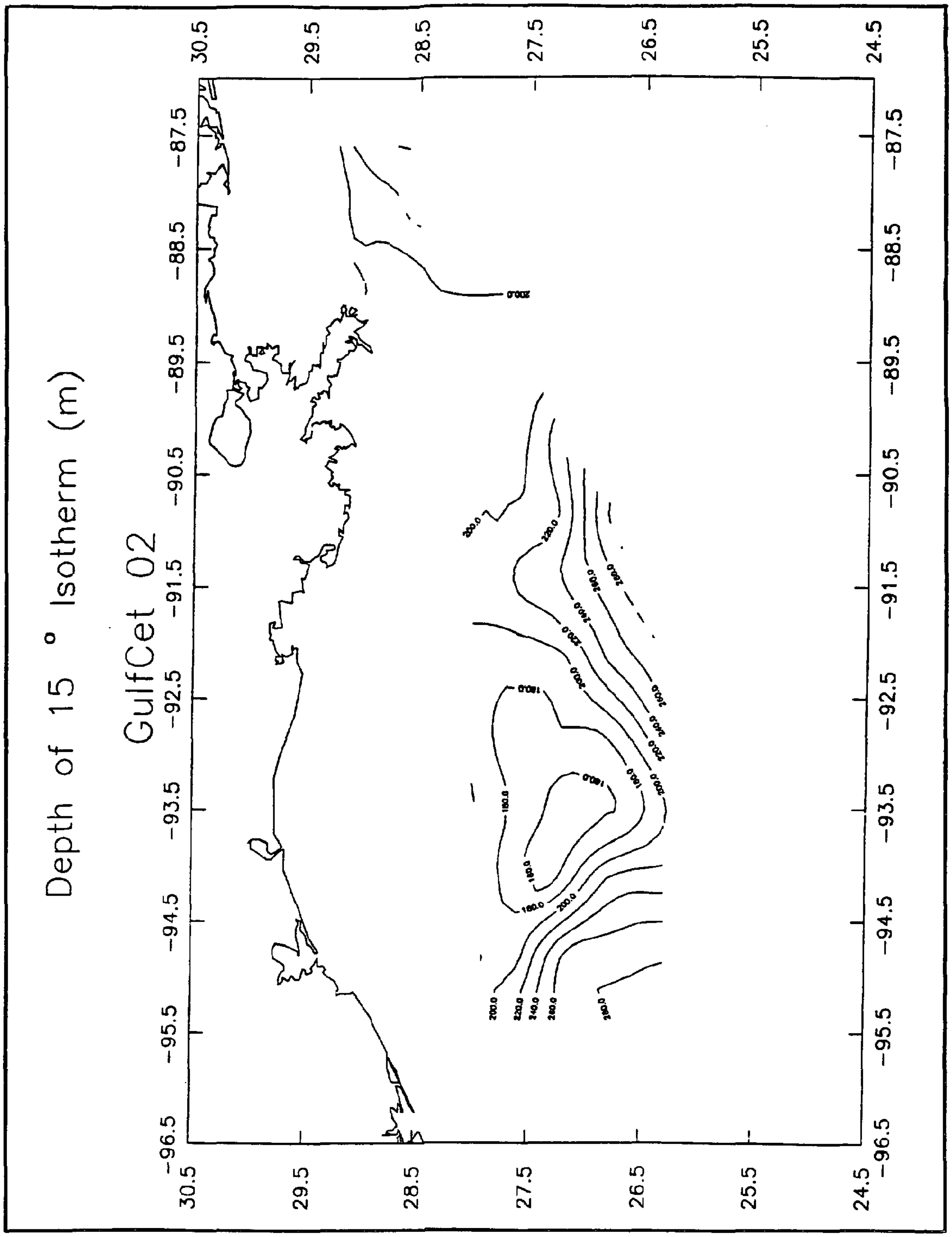


Figure 4.18. Topography of the 15°C temperature surface based on all XBT and CTD data Cruise 2.

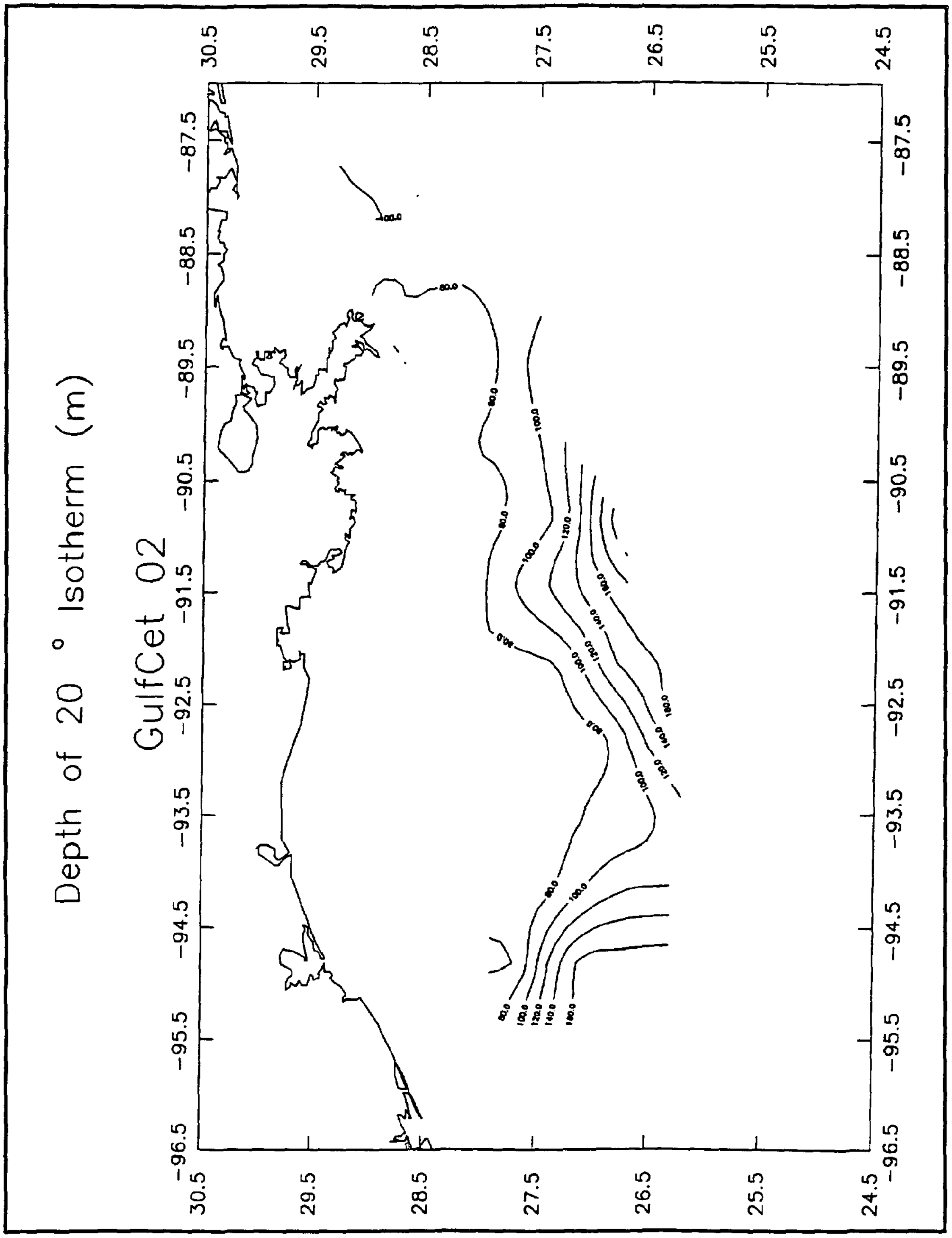


Figure 4.19. Topography of the 20°C temperature surface based on all XBT and CTD data Cruise 2.

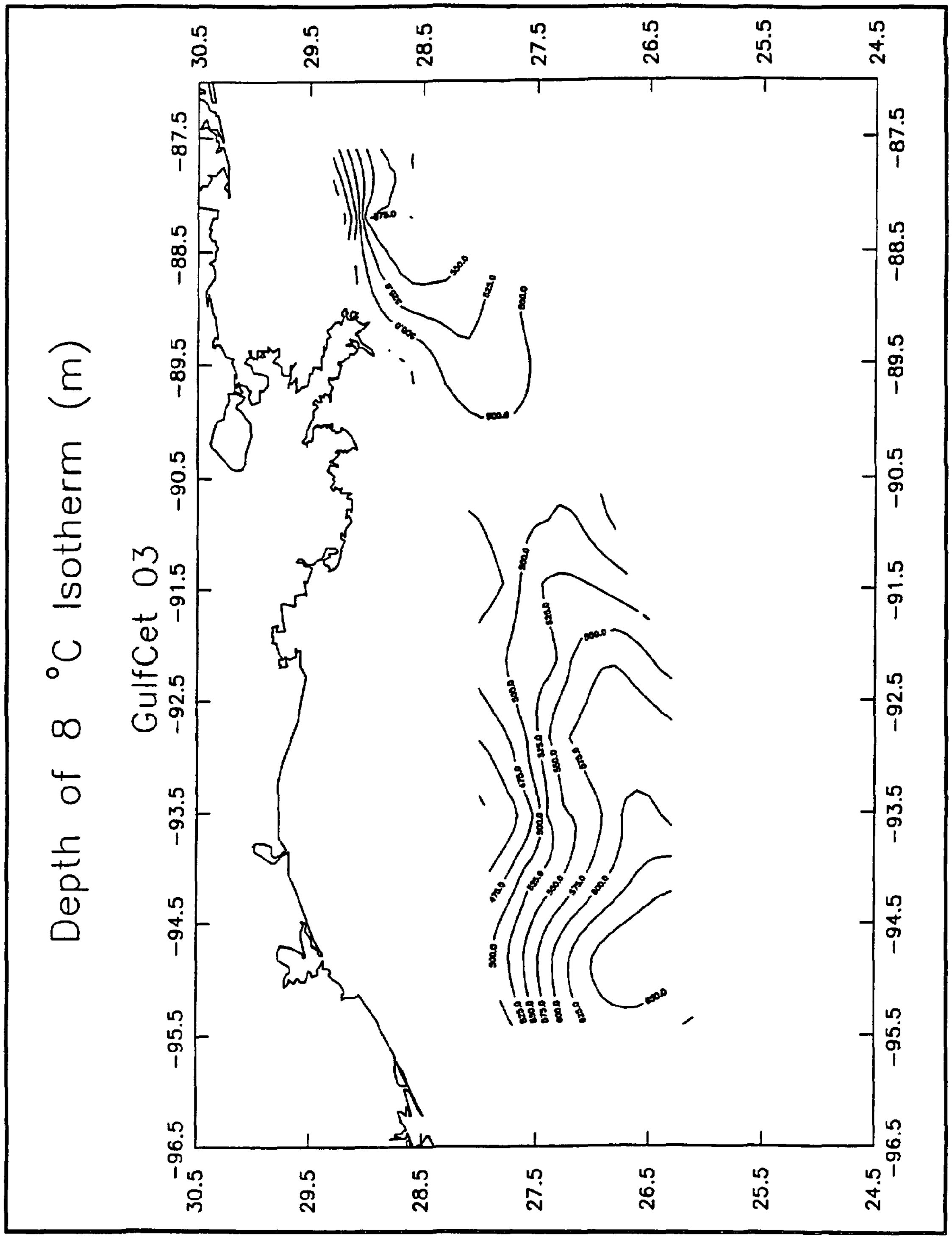


Figure 4.20. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 3.

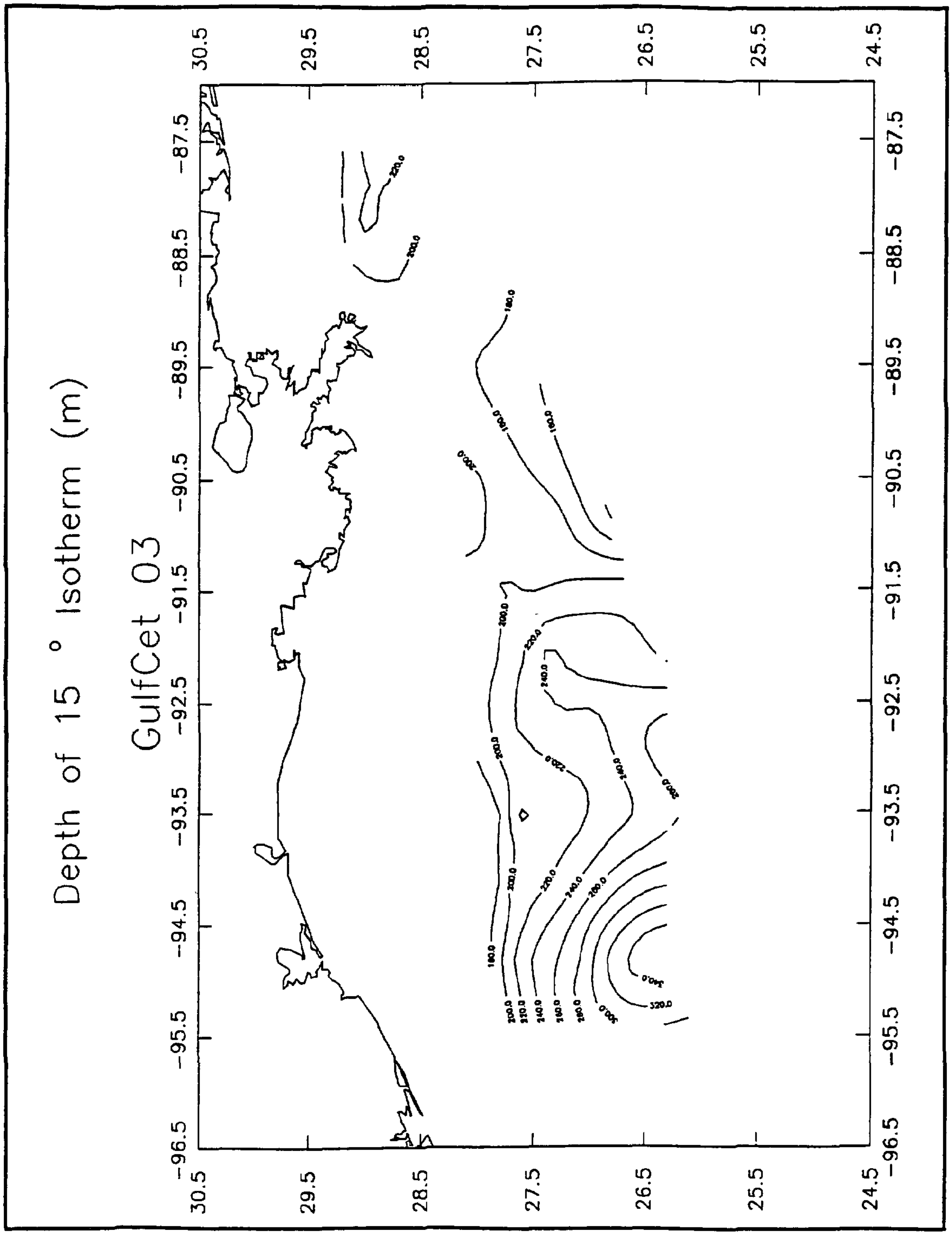


Figure 4.21. Topography of the 15°C temperature surface based on all XBT and CTD data Cruise 3.

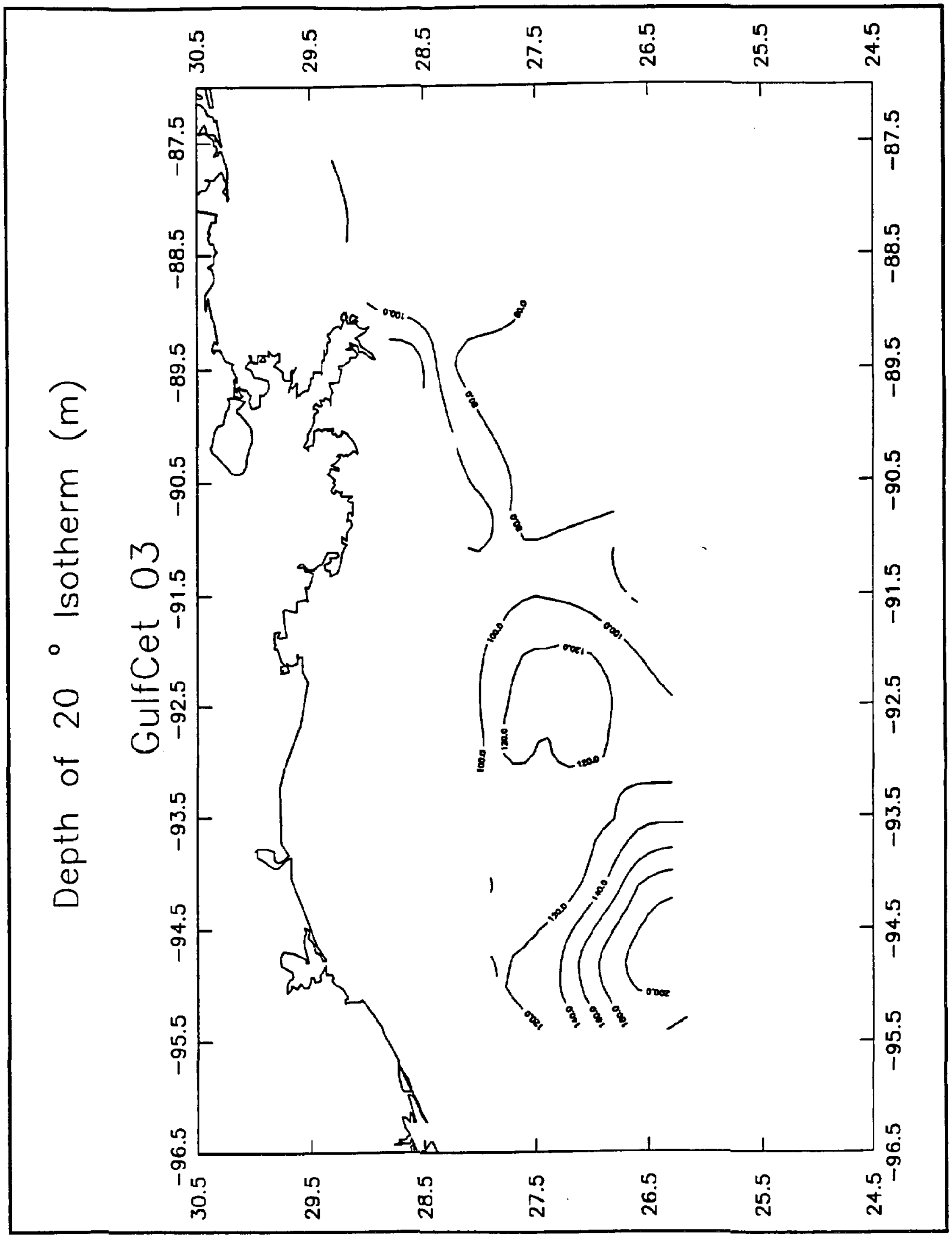


Figure 4.22. Topography of the 20°C temperature surface based on all XBT and CTD data Cruise 3.

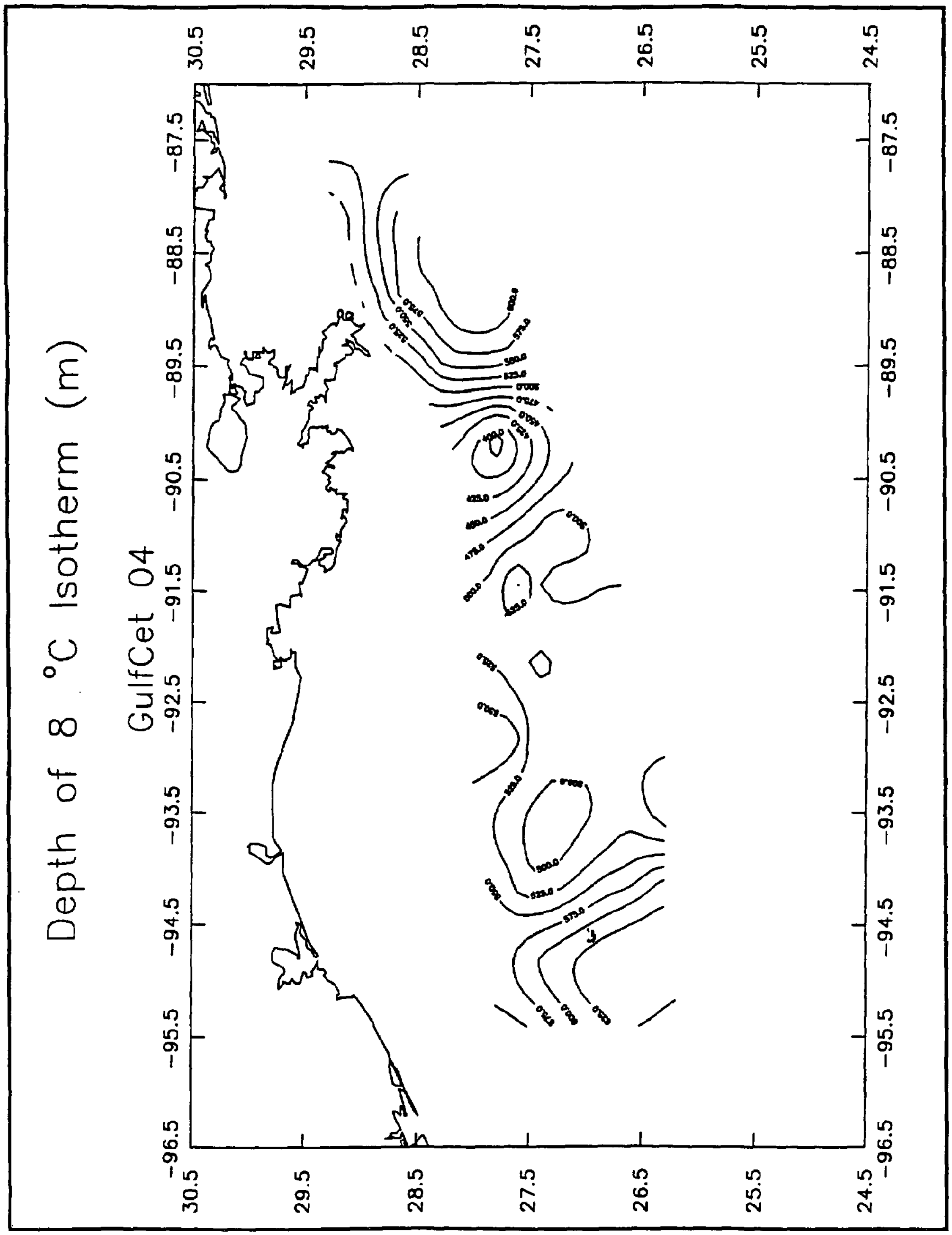


Figure 4.23. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 4.

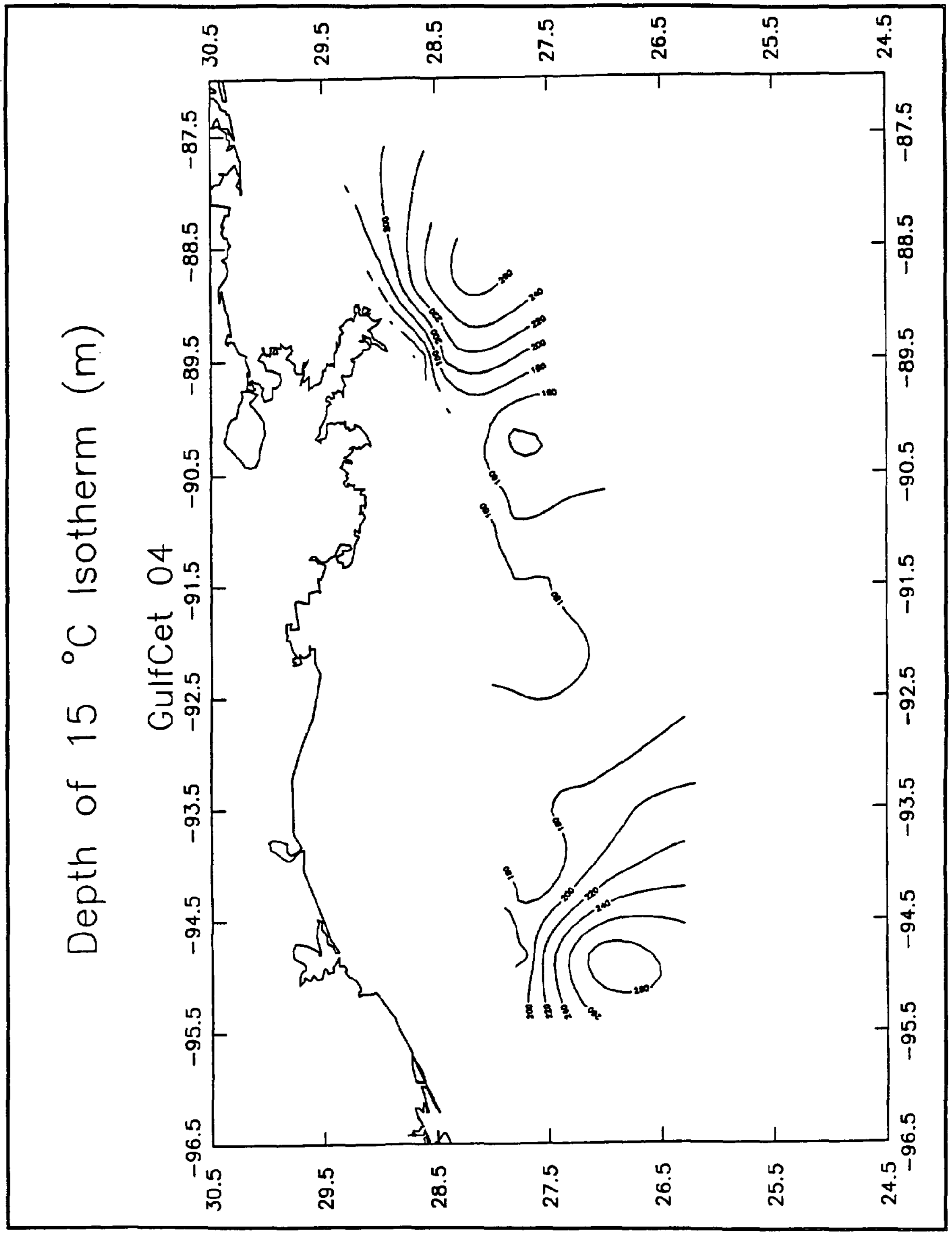


Figure 4.24. Topography of the 15°C temperature surface based on all XBT and CTD data Cruise 4.

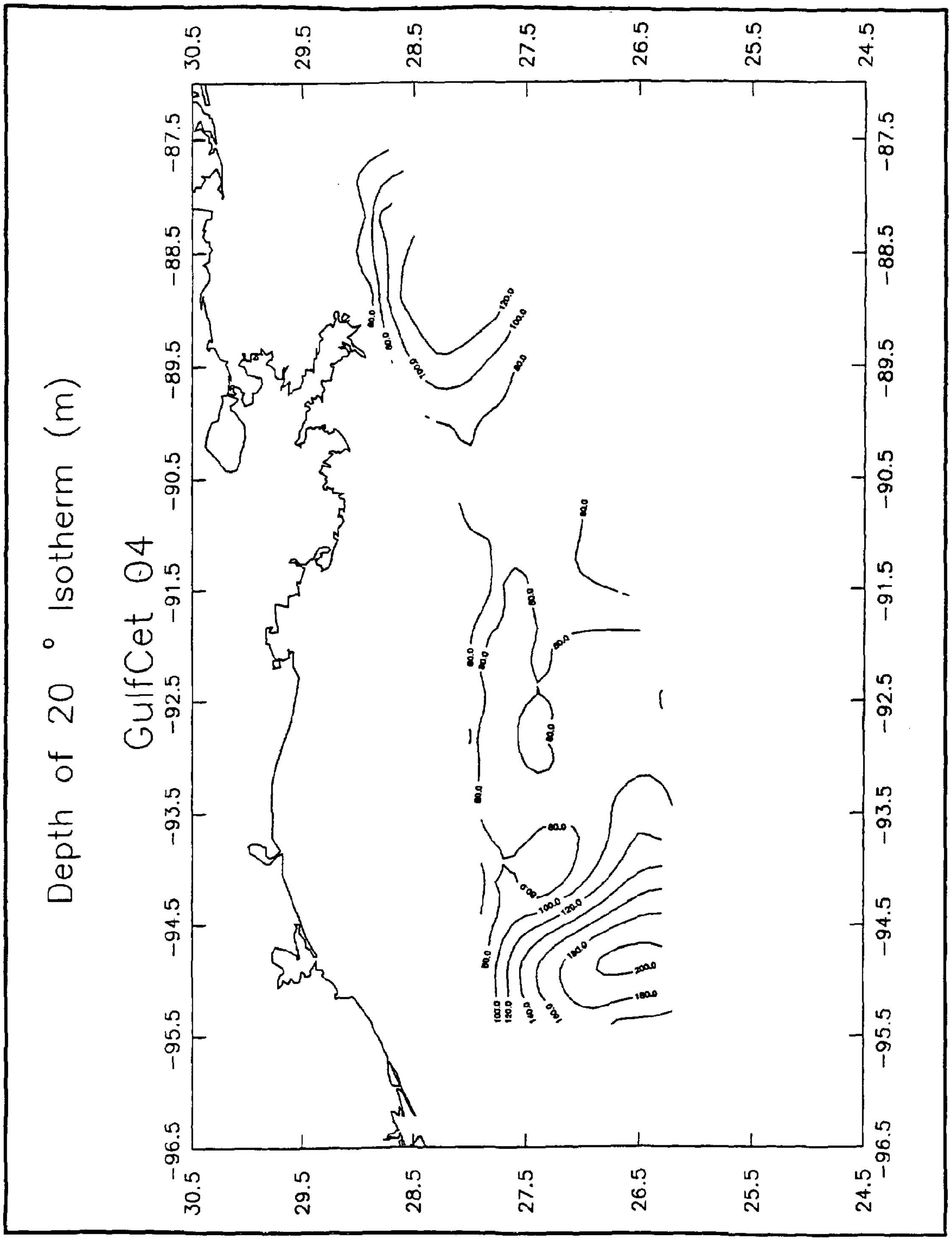


Figure 4.25. Topography of the 20°C temperature surface based on all XBT and CTD data Cruise 4.

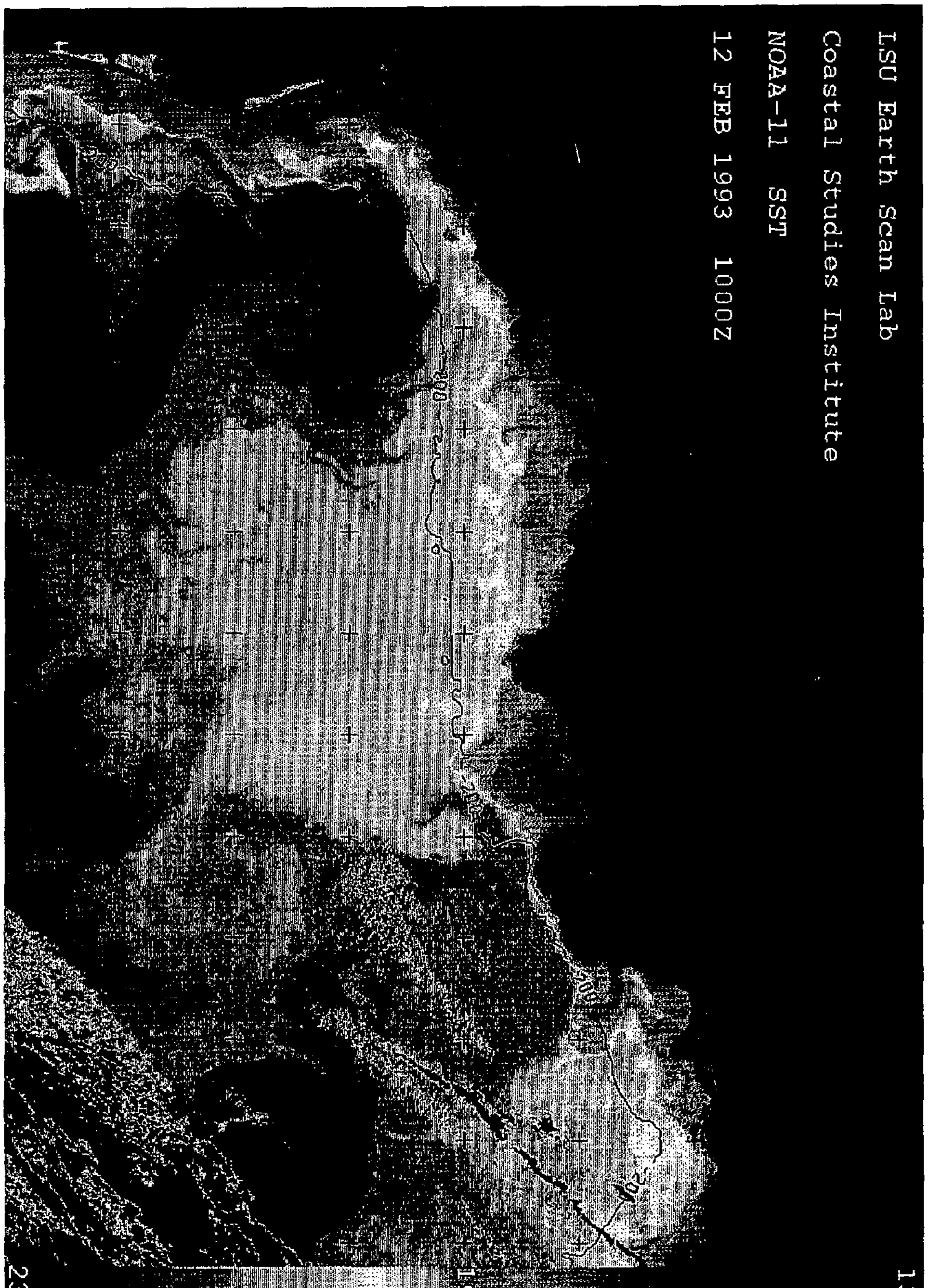


Figure 4.26. NOAA-AVHRR SST (°C) analysis in the western Gulf of Mexico for February 12, 1993 (Coastal Studies Institute).

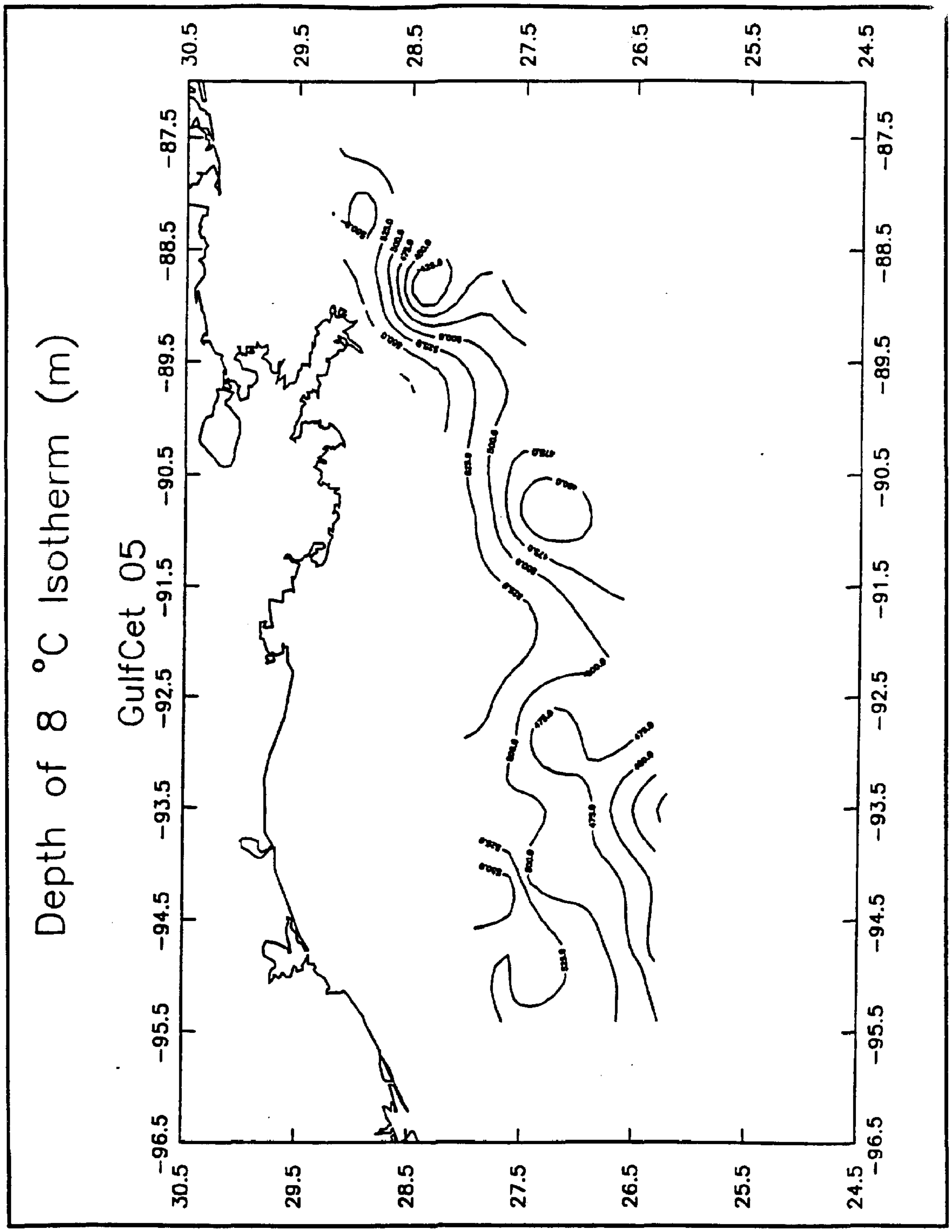


Figure 4.27. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 5.

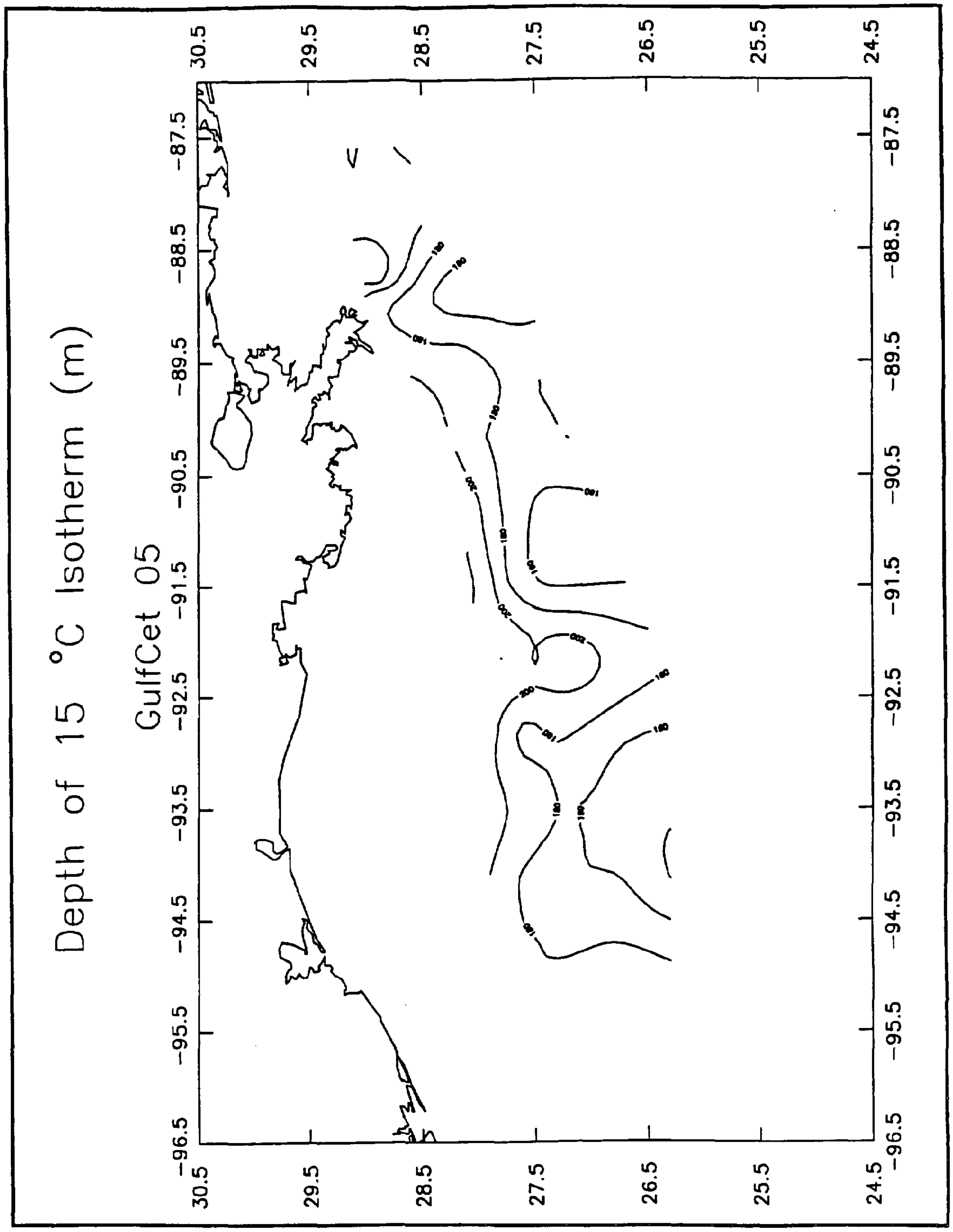


Figure 4.28. Topography of the 15°C temperature surface based on all XBT and CTD data Cruise 5.

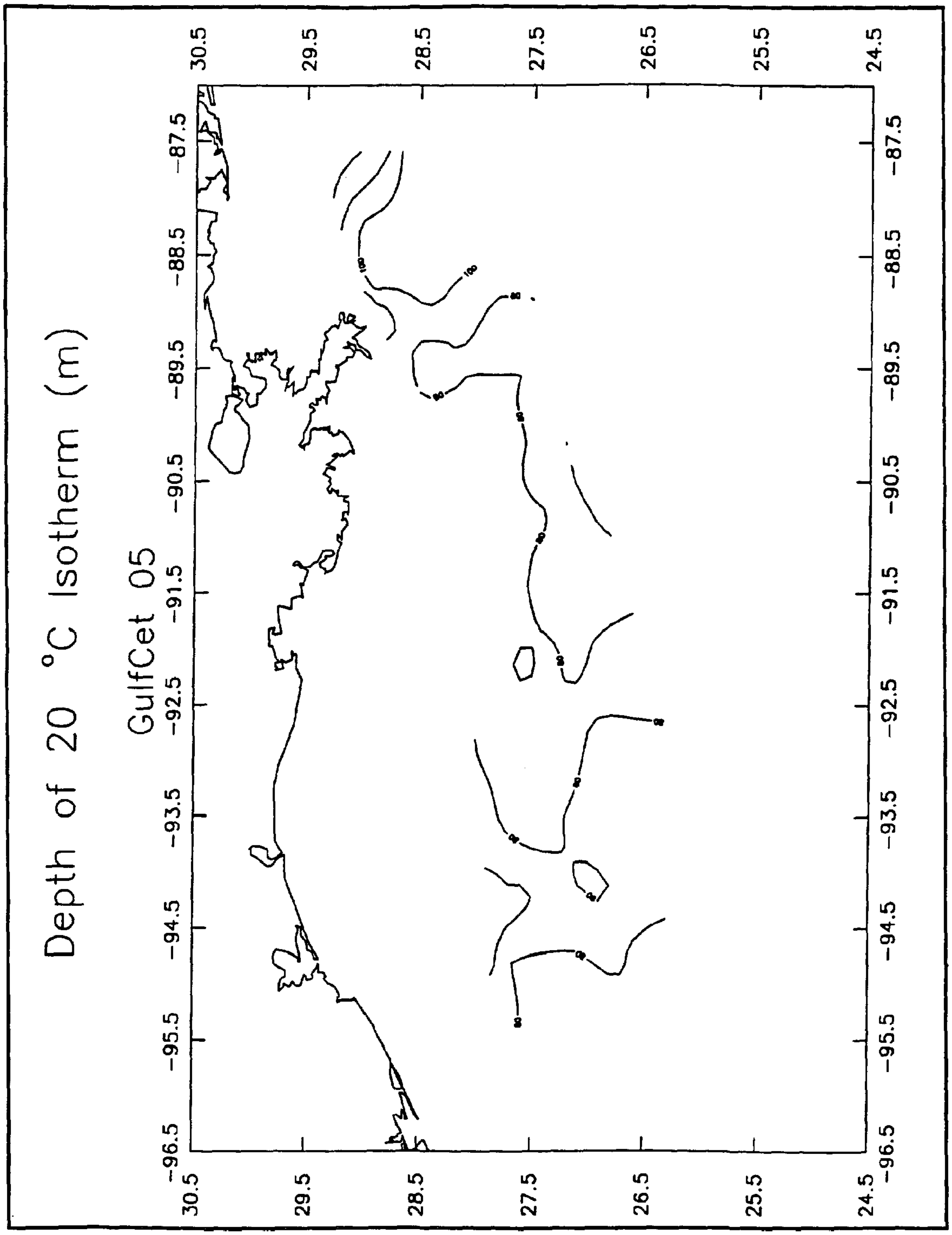


Figure 4.29. Topography of the 20°C temperature surface based on all XBT and CTD data Cruise 5.

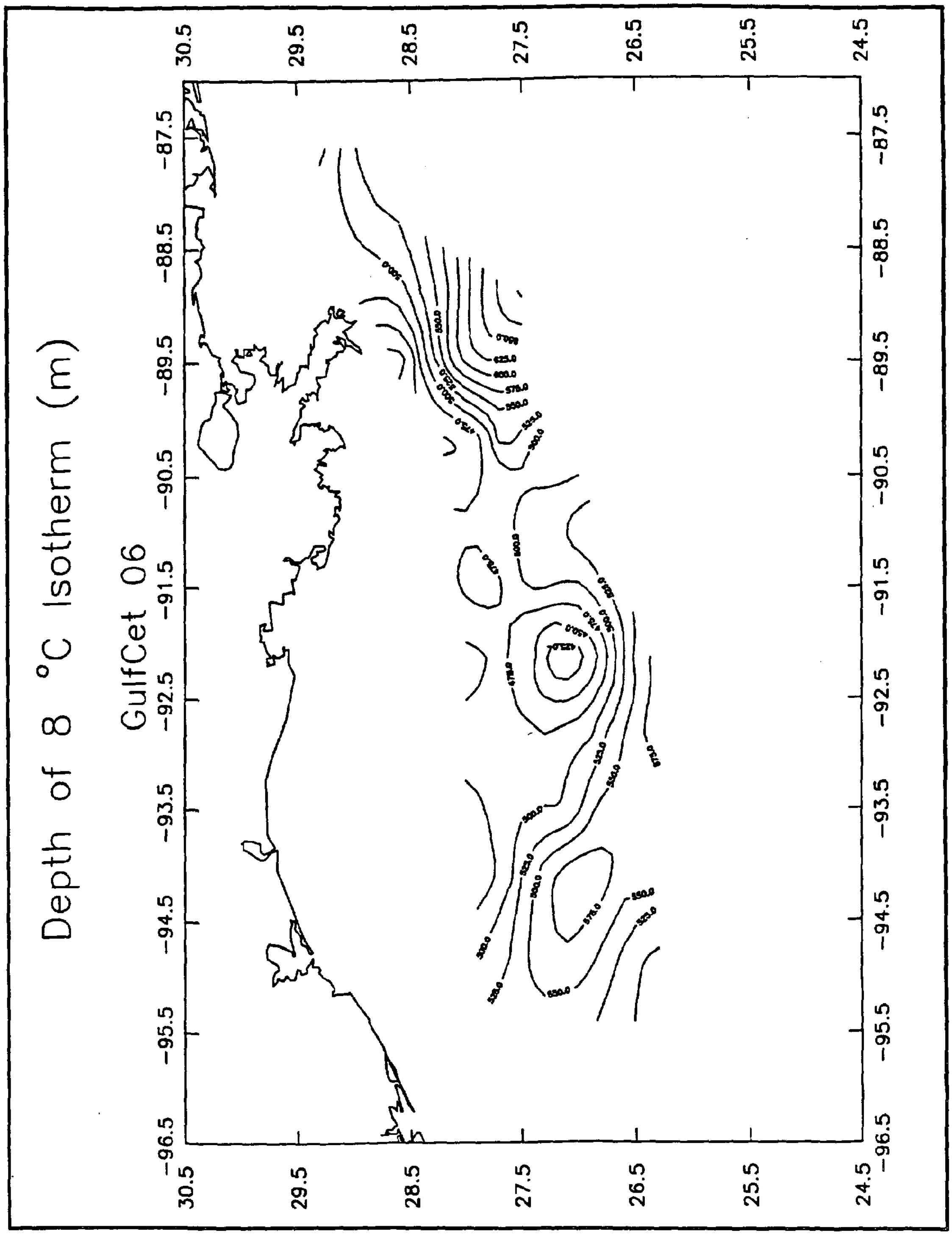


Figure 4.30. Topography of the 8°C temperature surface based on all XBT and CTD data Cruise 6.

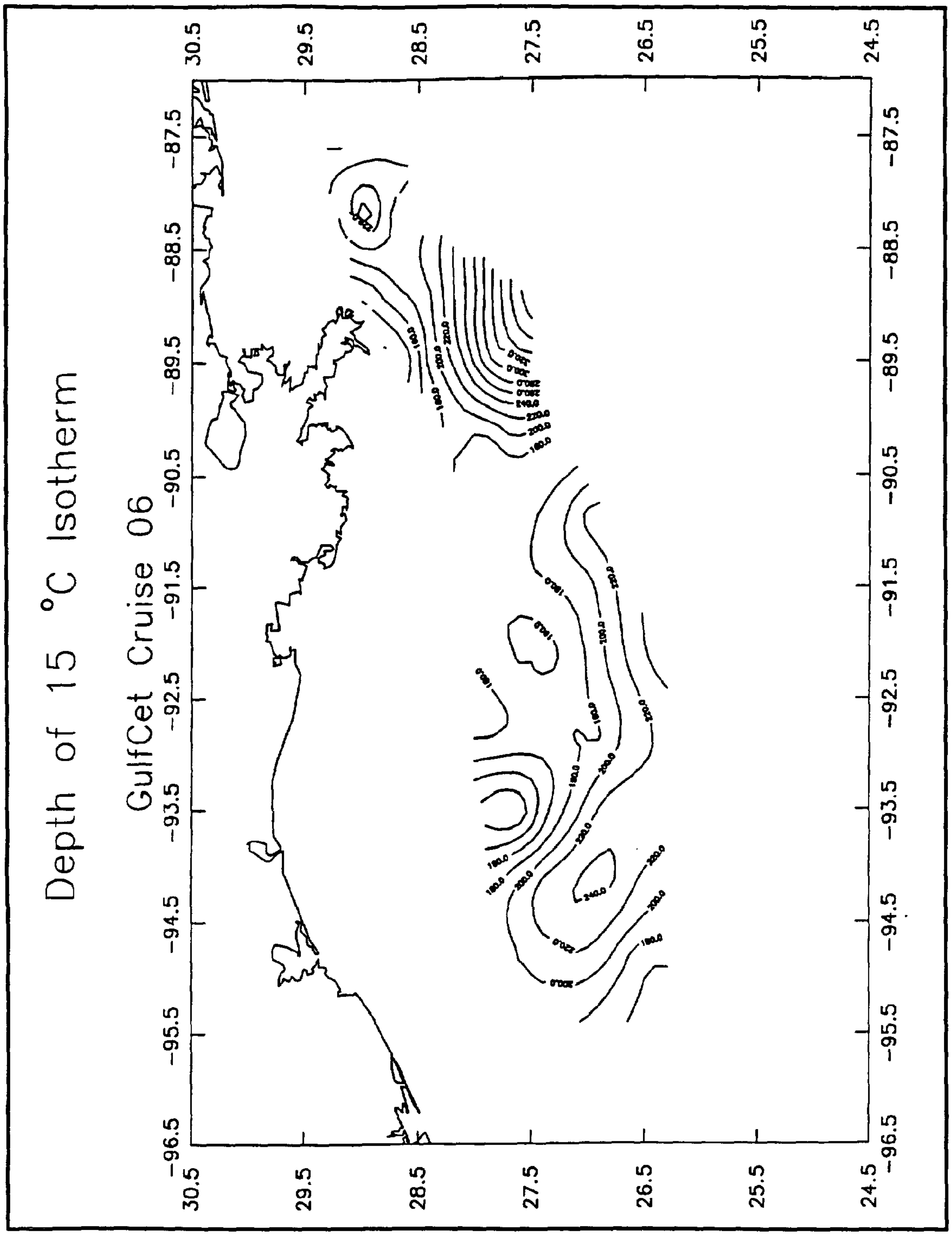


Figure 4.31. Topograpy of the 15°C temperature surfacebased on all XBT and CTD data Cruise 6.

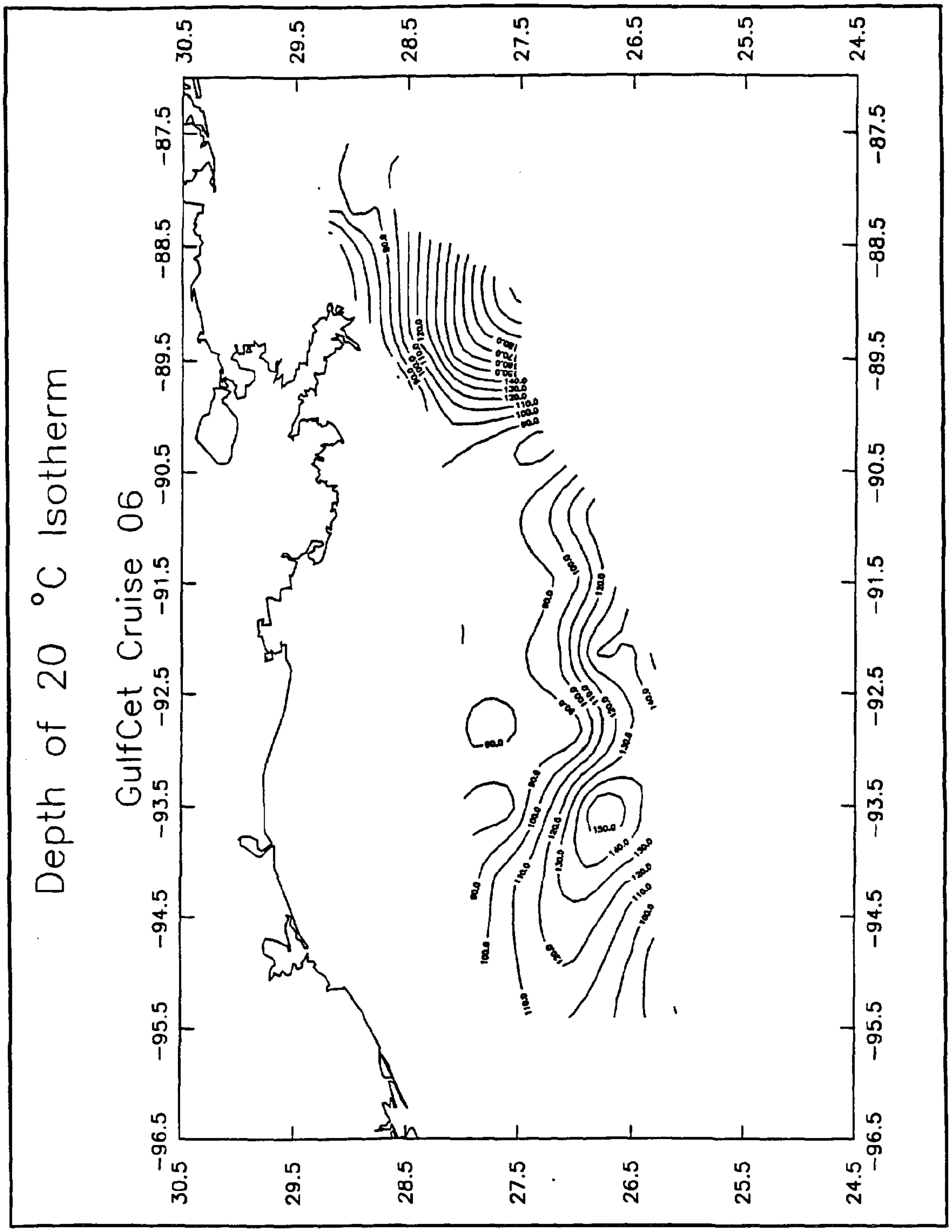


Figure 4.32. Topography of the 20°C temperature surface based on all XBT and CTD data Cruise 6.

Cruise 3: Anticyclonic eddy on track-lines 2 & 3, eddy "V", detected at all three isotherm depths (Figures 4.20 through 4.22).

Cruise 4: Anticyclonic eddy on track-lines 2 & 3, eddy "V"; cyclonic eddy on track-lines 9 & 10 (evident on Figure 4.23) associated with anticyclonic eddy found on track-line 12, not named, but confirmed by satellite image (Figures 4.24 through 4.26).

Cruise 5: Very complex topography, presence of small weak cyclonic eddies at the southern border (Figure 4.27) and small anticyclonic eddies inside our study area (Figures 4.28-4.29).

Cruise 6: The anticyclonic eddy "W" on track-lines 4, 5, and 6; eddy "W" is elongated and squashed with an associated cyclonic eddy on track-line 7. Anticyclonic eddy " X" or the Loop Current, on track-line 12 (Figures 4.30 through 4.32).

4.2.6.3 Dynamic Height

Eddy Triton was not present in the western Gulf during Cruise 1, April, 1992 (Figure 4.33). It was seen on Cruise 2, August, 1992, with a dynamic height greater than 125 dyn cm and salinity greater than 36.6 psu (Figure 4.34). During the same summer cruise, eddy "U", in the central area of our study, presented a dynamic height greater than 140 dyn cm. Figure 4.35 is a composite figure of dynamic heights and LATEX A drifter track number 2447 for the month of August, 1992. Eddy "V" was detected on our fall (November 1992) with a dynamic height greater than 140 dyn cm (Figure 4.36), and in the winter cruise (February 1993) with a dynamic height around 125 dyn cm (Figure 4.37). Figure 4.38 is a composite figure of dynamic heights and LATEX A drifter track number 2447 for the month of November 1992. The complex topography seen in the spring Cruise 5 did not present any dynamic features (Figure 4.39). Cruise 6, on August 1993, detected the north side of eddy "W" with a dynamic height around 120 dyn cm, and eddy "X" (or the Loop Current) with a dynamic height higher than 145 dyn cm (Figure 4.40).

4.2.6.4 Clorophyll Data

Chlorophyll analyses are still underway, with only preliminary results presented here. Figures 4.41 through 4.44 show the surface chlorophyll a values determined for cruises 3 to 6. Surface values range from 0.01 to 0.18 $mg/m^3$, with higher values found in the area near the Mississippi River plume. "Hotspots" of chlorophyll are seen offshore in Cruises 3 and 5. Further analyses will attempt to correlate these hotspots with the cold cyclonic eddy seen in the 8°C isotherm depth maps.

4.2.6.5 Mississippi River: 1992 versus 1993

Figures 4.45 through 4.50 show salinity versus 0, 3, and 5 m depths for cruises 2 and 6. During the 1993 flood, the Mississippi plume was streaming to the east, which is a rare occurrence. This event is shown in satellite images (Figure 4.51) and confirmed by our hydrographic data.

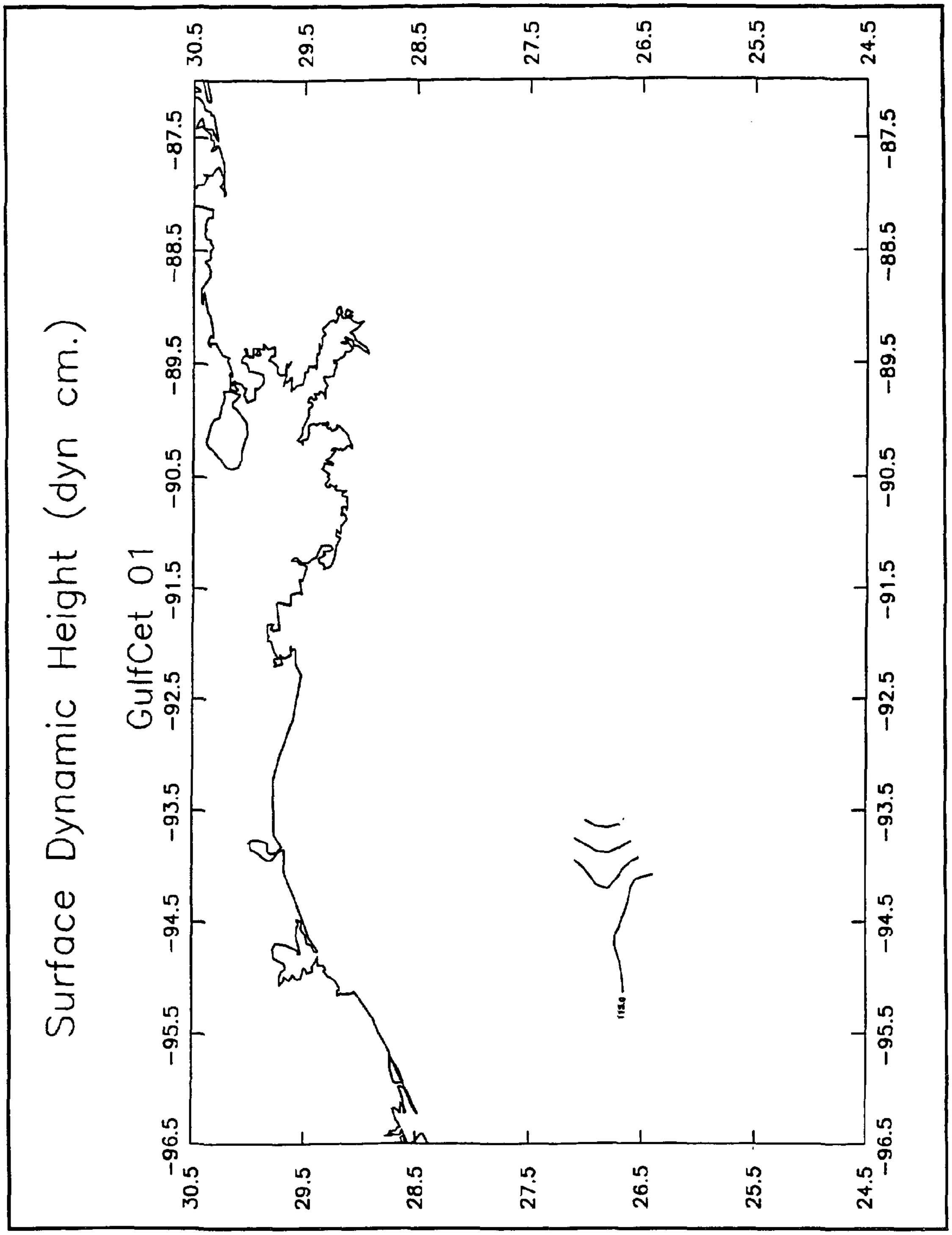


Figure 4.33. Surface dynamic topography (cm) with respect to 800 m from GulfCet 1 survey.

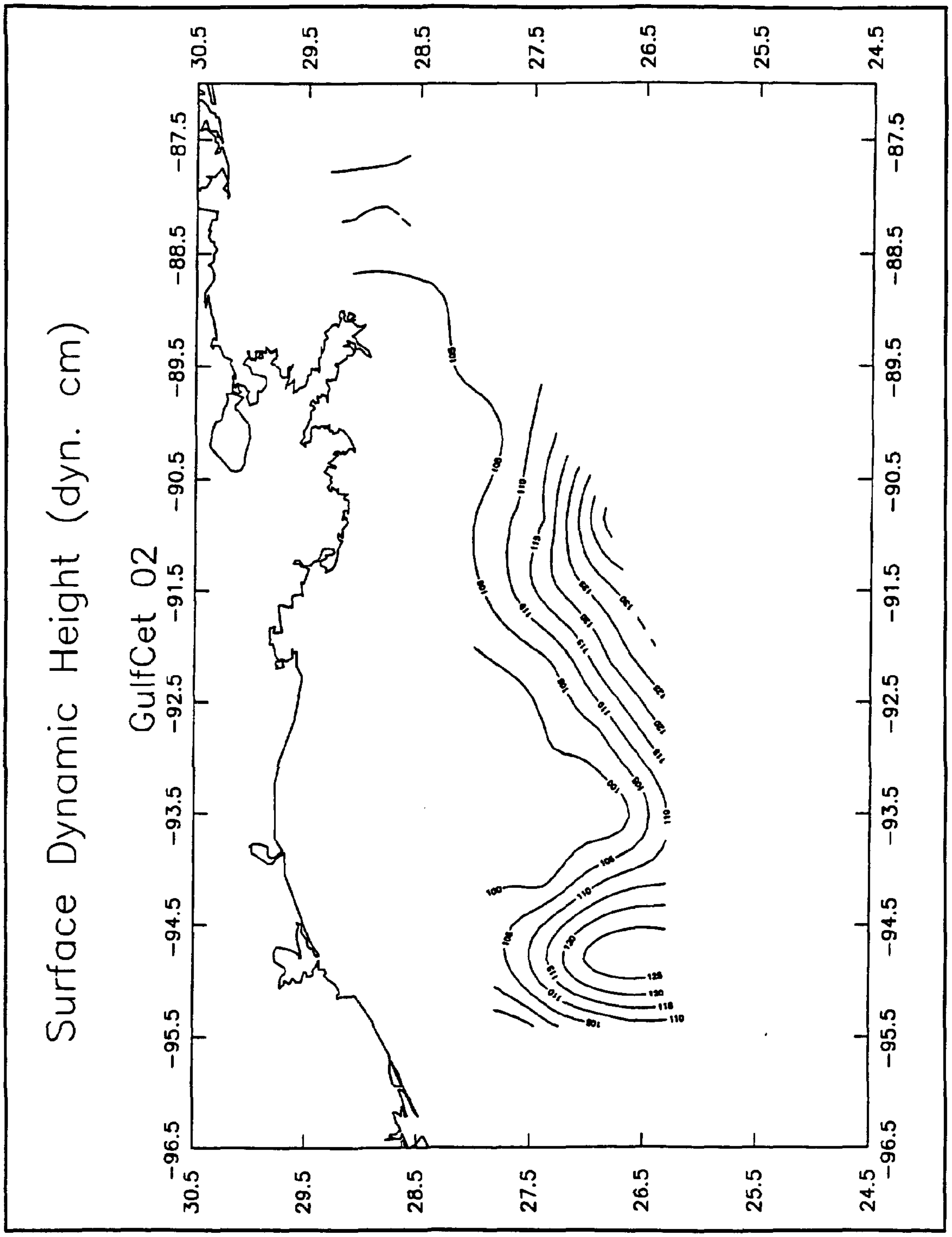


Figure 4.34. Surface dynamic topography (cm) with respect to 800 m from GulfCet 2 survey.

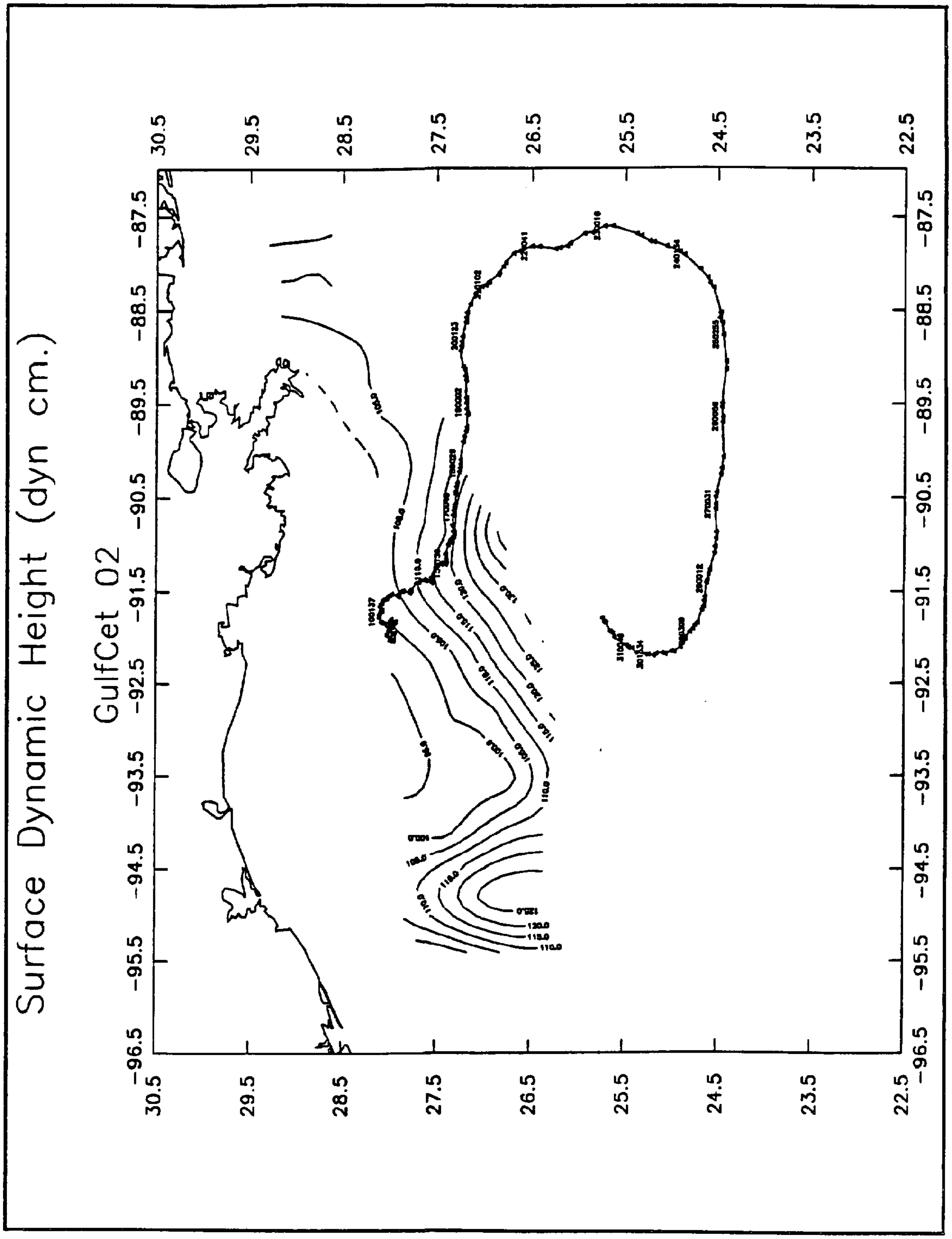


Figure 4.35. Cruise 2 surface dynamic topography (cm) and LATEX-A drifter # 2447, August 1992.

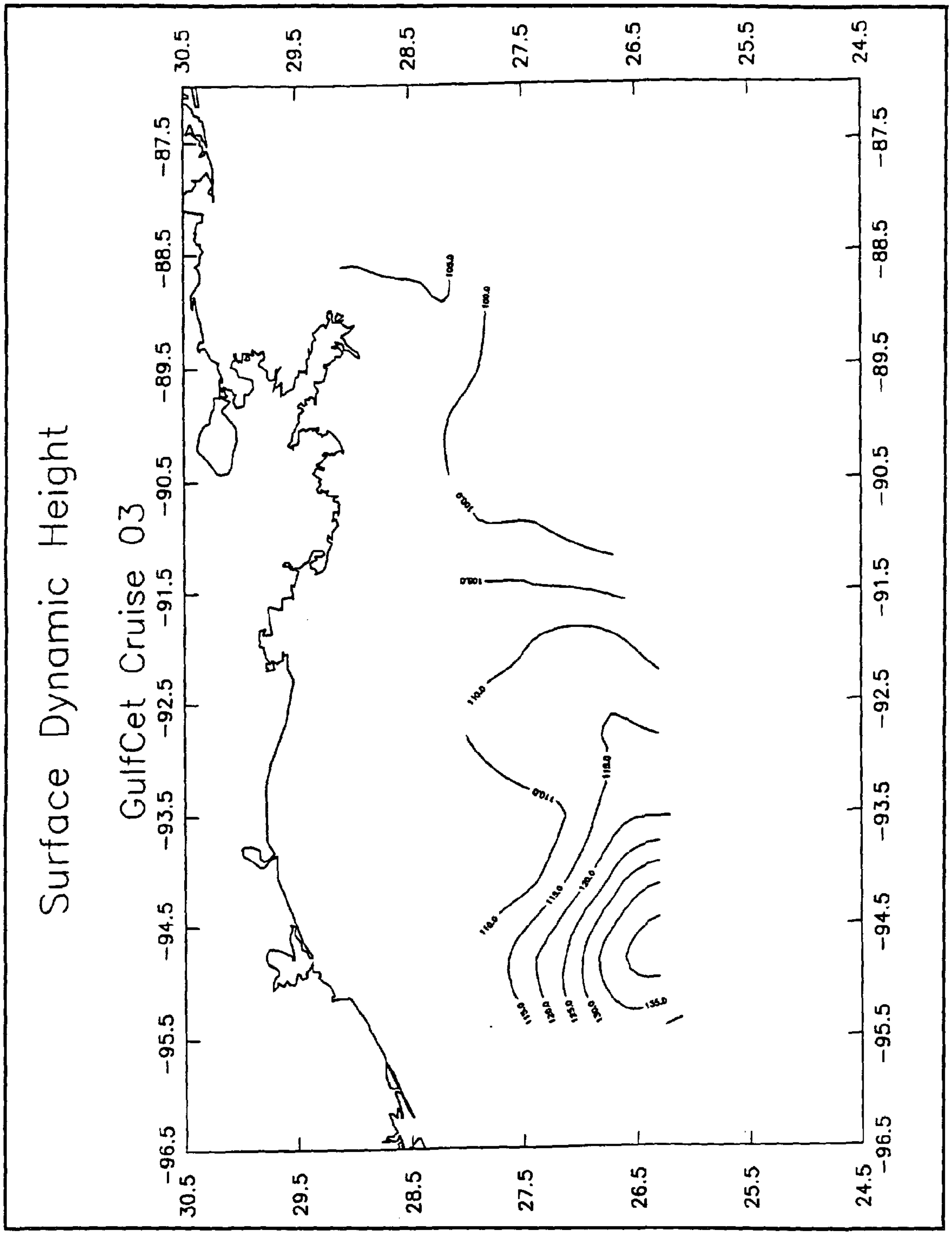


Figure 4.36. Surface dynamic topography (cm) with respect to 800 m from GulfCet 3 survey.

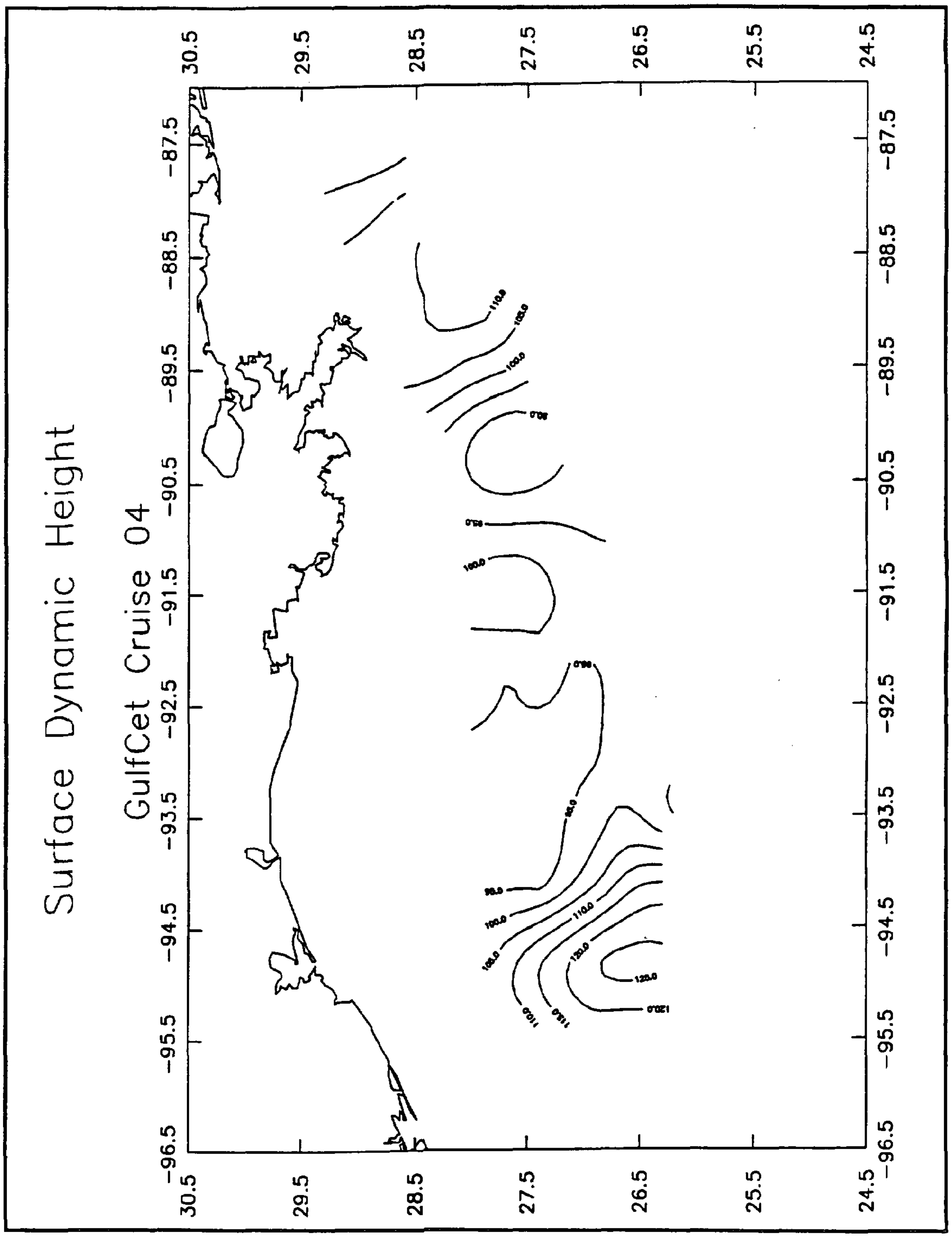


Figure 4.37. Surface dynamic topography (cm) with respect to 800 m from GulfCet 4 survey.

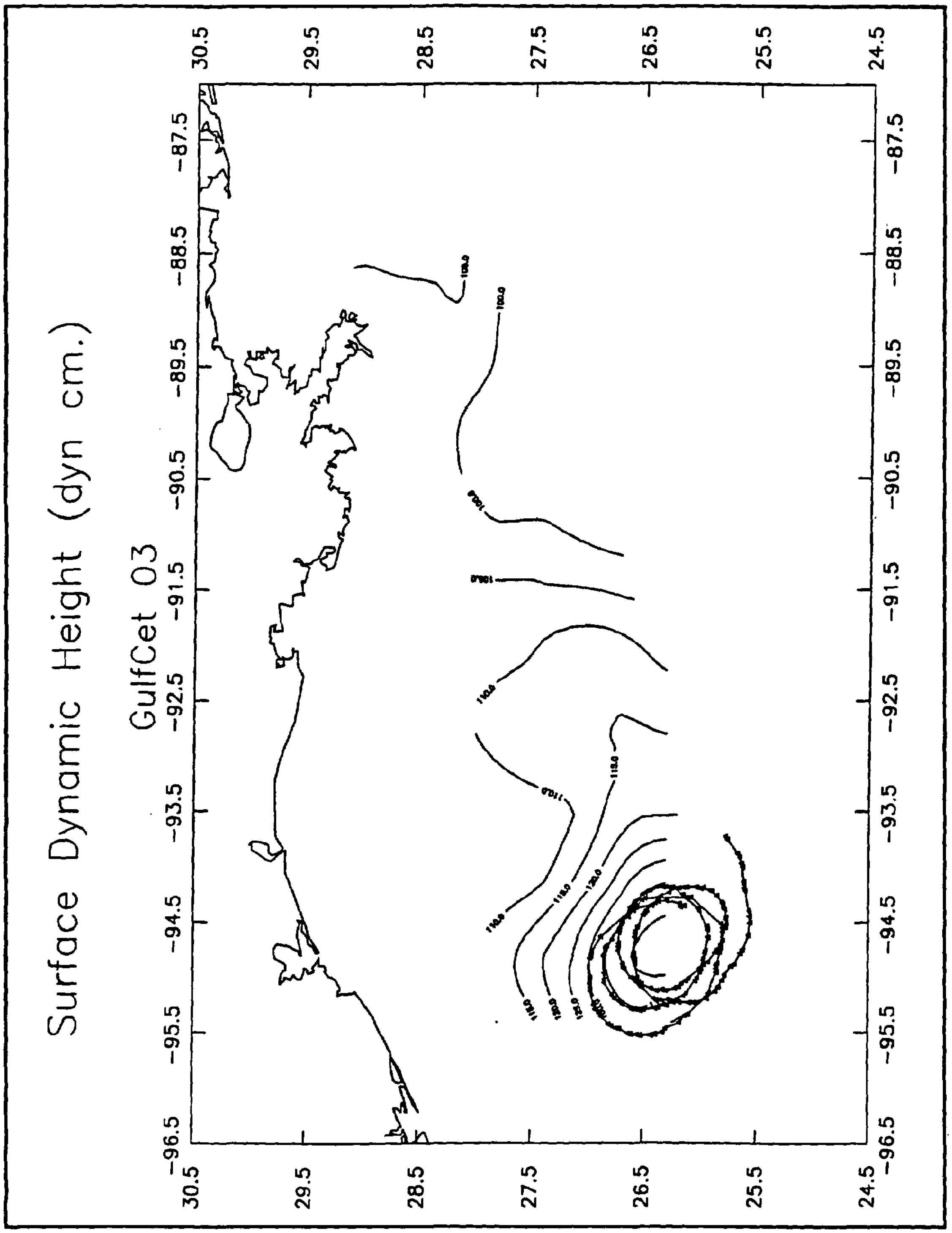


Figure 4.38. Cruise 3 surface dynamic topography (cm) and LATEX-A drifter # 2447, November 1992.

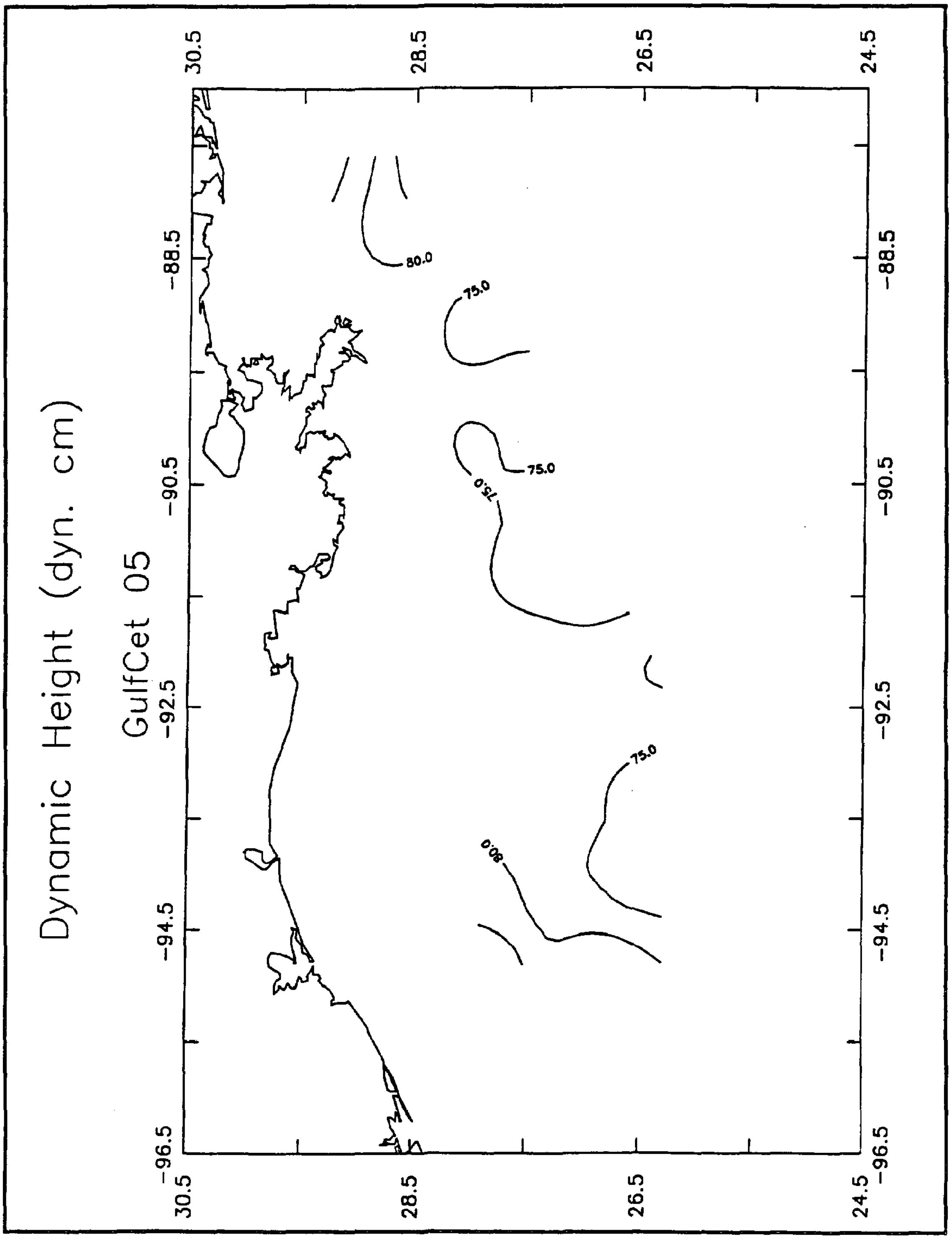


Figure 4.39. Surface dynamic topography (cm) with respect to 800 m from GulfCet 5 survey.

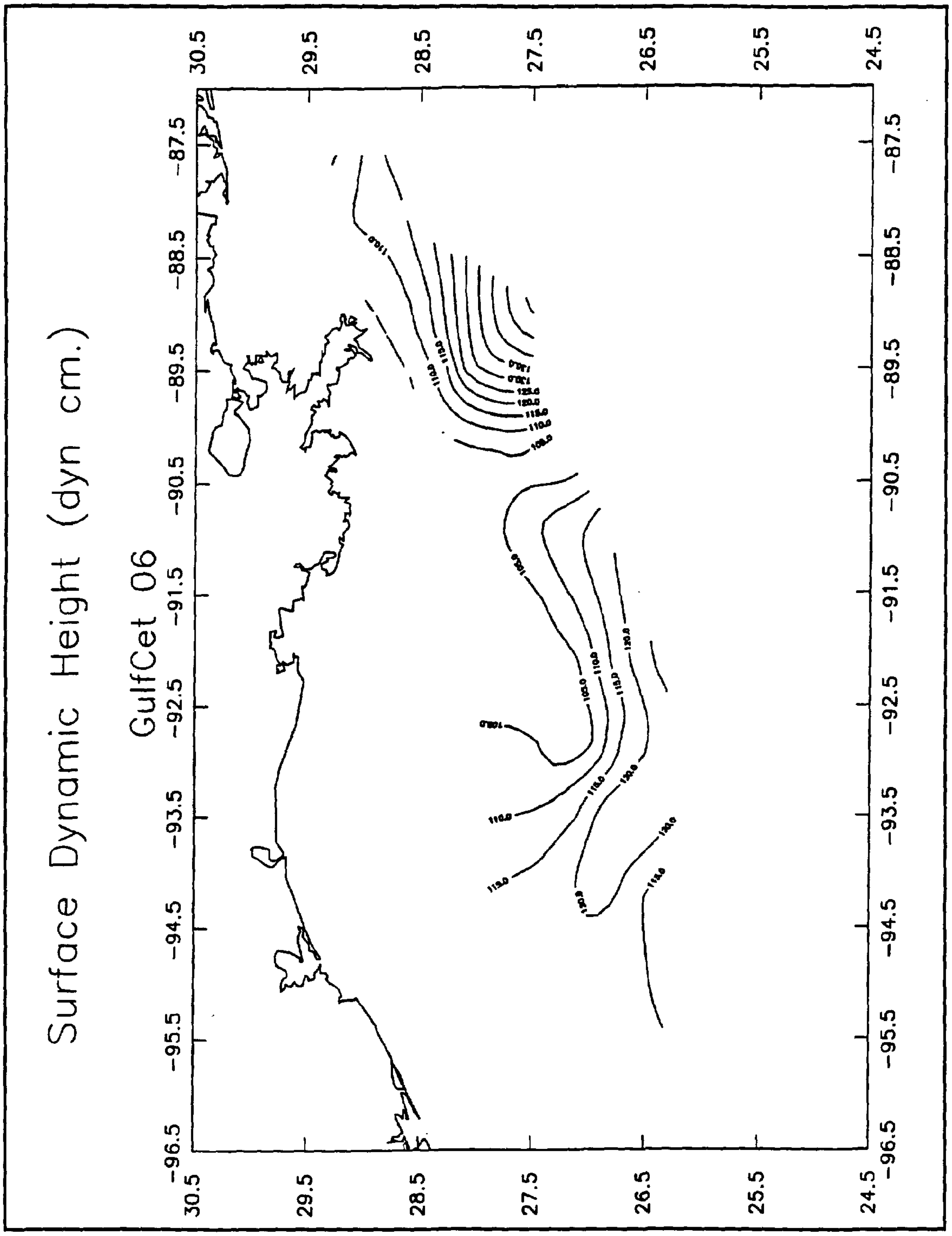


Figure 4.40. Surface dynamic topography (cm) with respect to 800 m from GulfCet 6 survey.

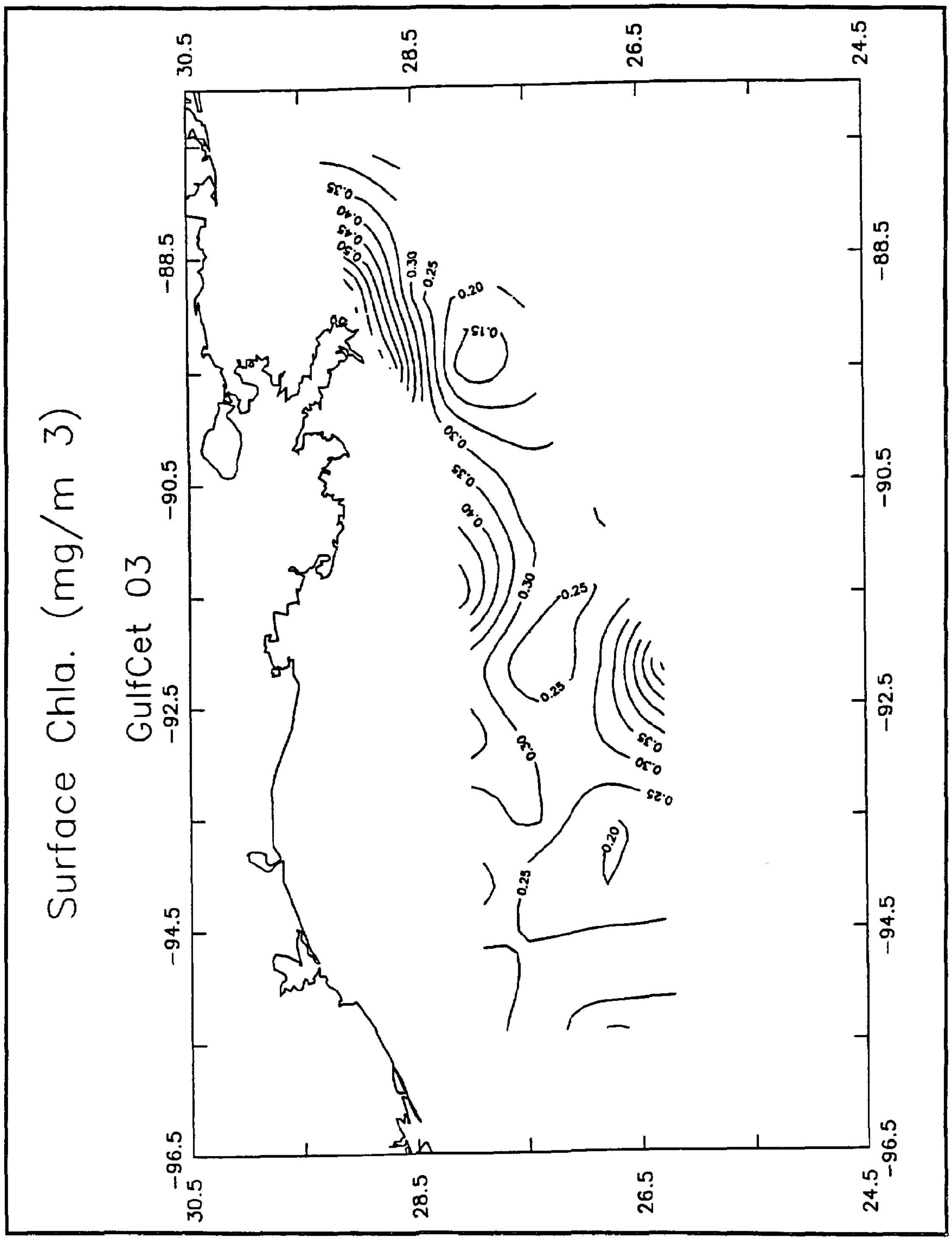


Figure 4.41. Chlorophyll a surface distribution in mg/m$^3$during the November 1992 survey (Cruise 3).

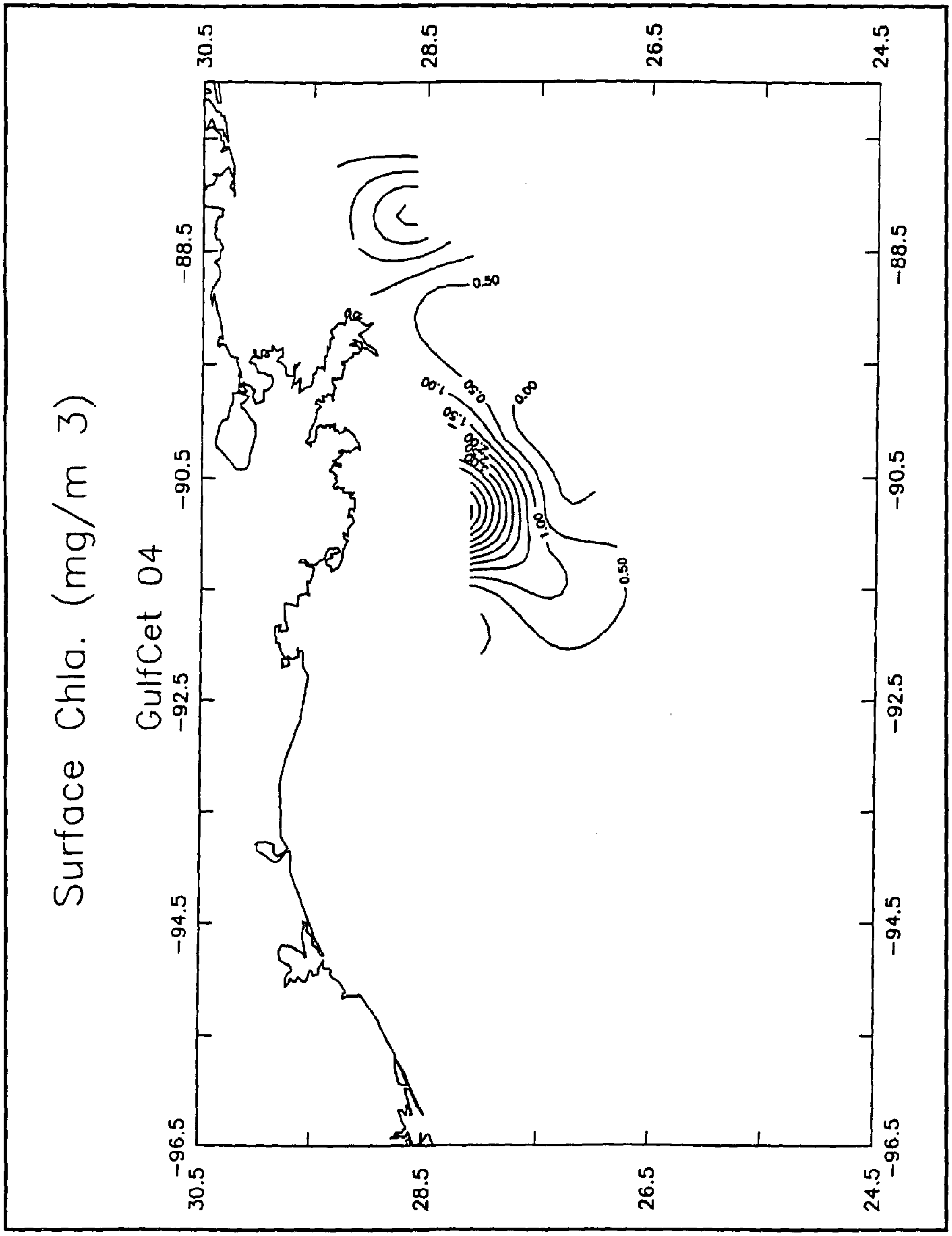


Figure 4.42. Chlorophyll a surface distribution in mg/m$^3$ during the February 1992 survey (Cruise 4).

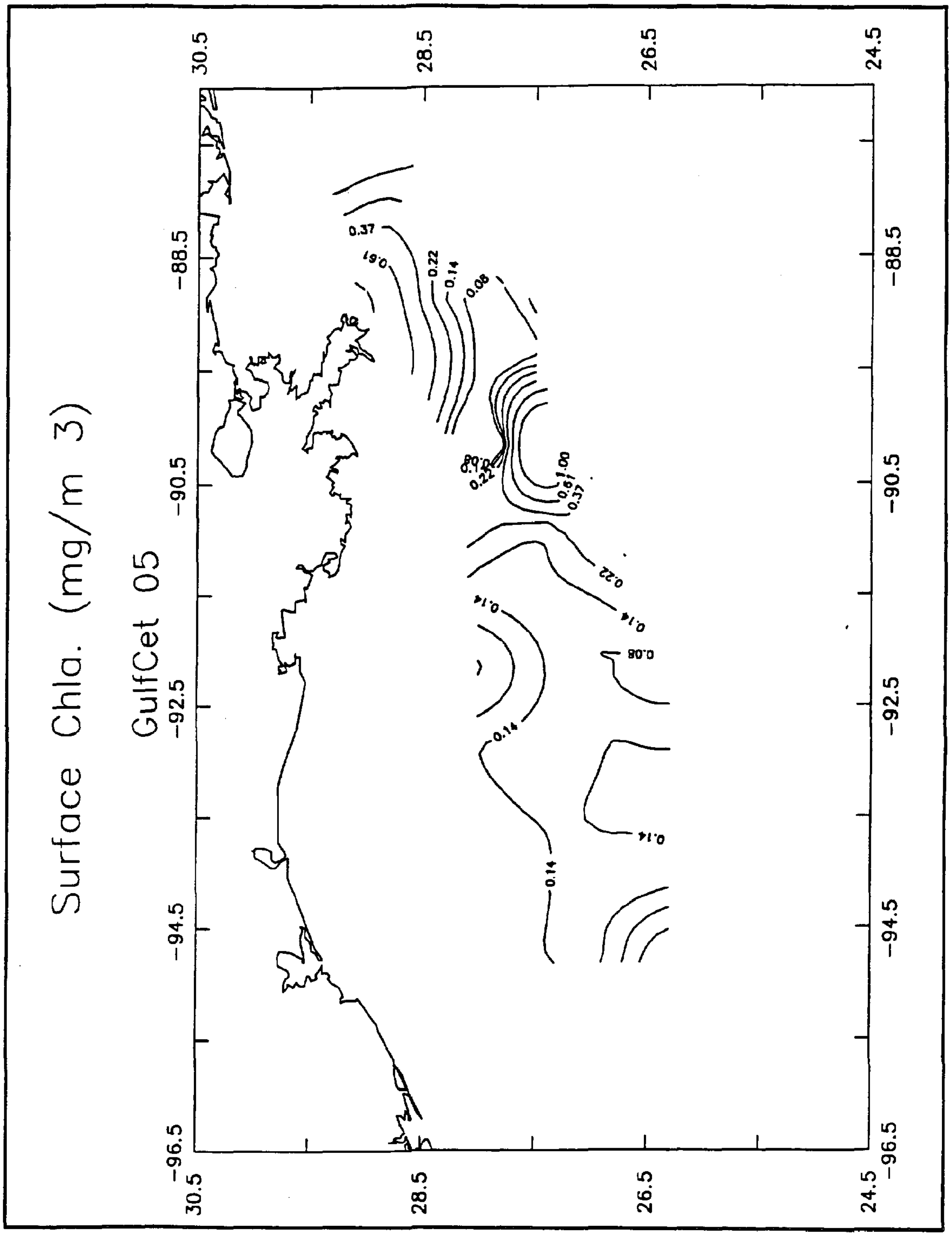


Figure 4.43. Chlorophyll a surface distribution in mg/m$^3$ during the May 1993 survey (Cruise 5).

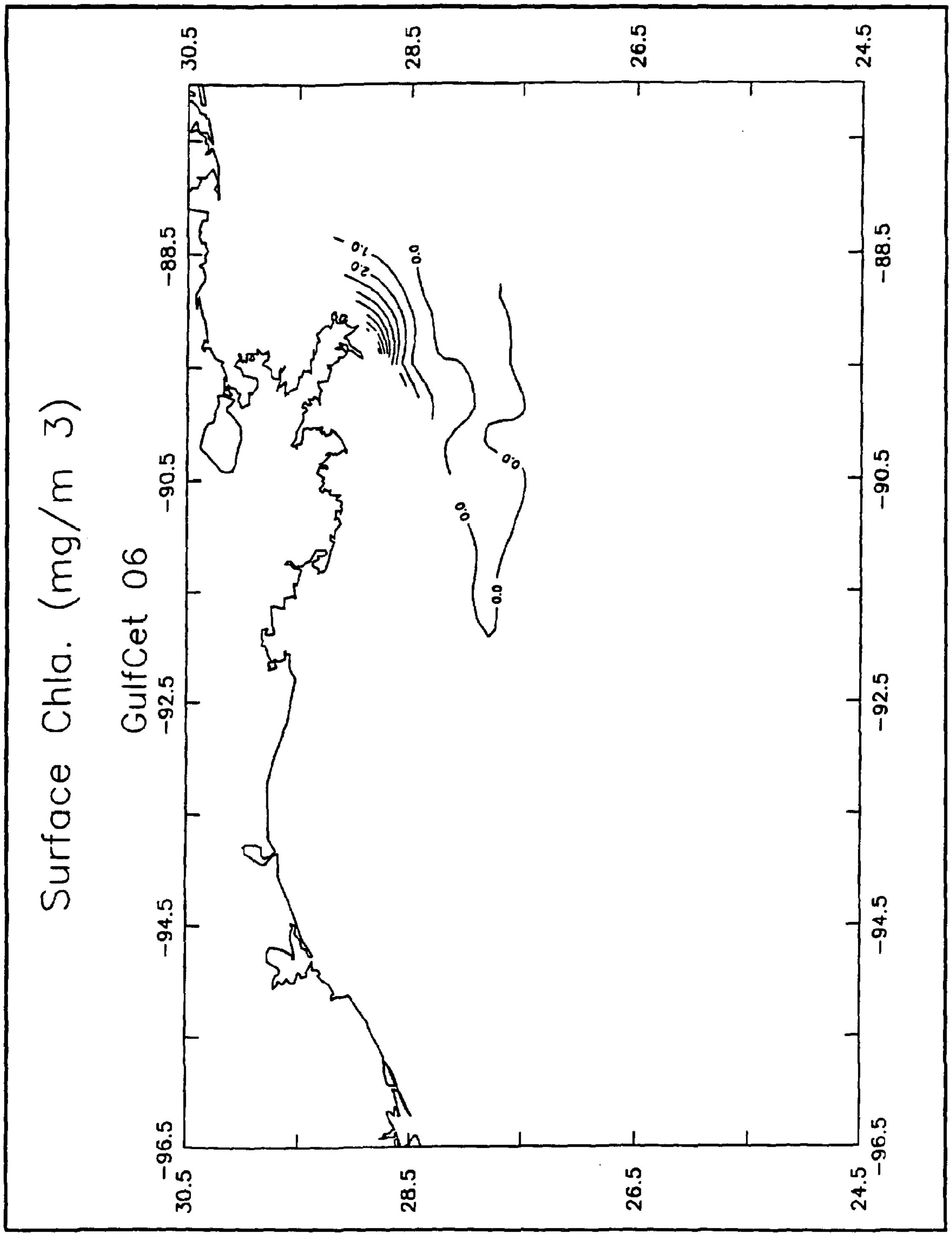


Figure 4.44. Chlorophyll a surface distribution in mg/m$^3$ during the August 1993 survey (Cruise 6).

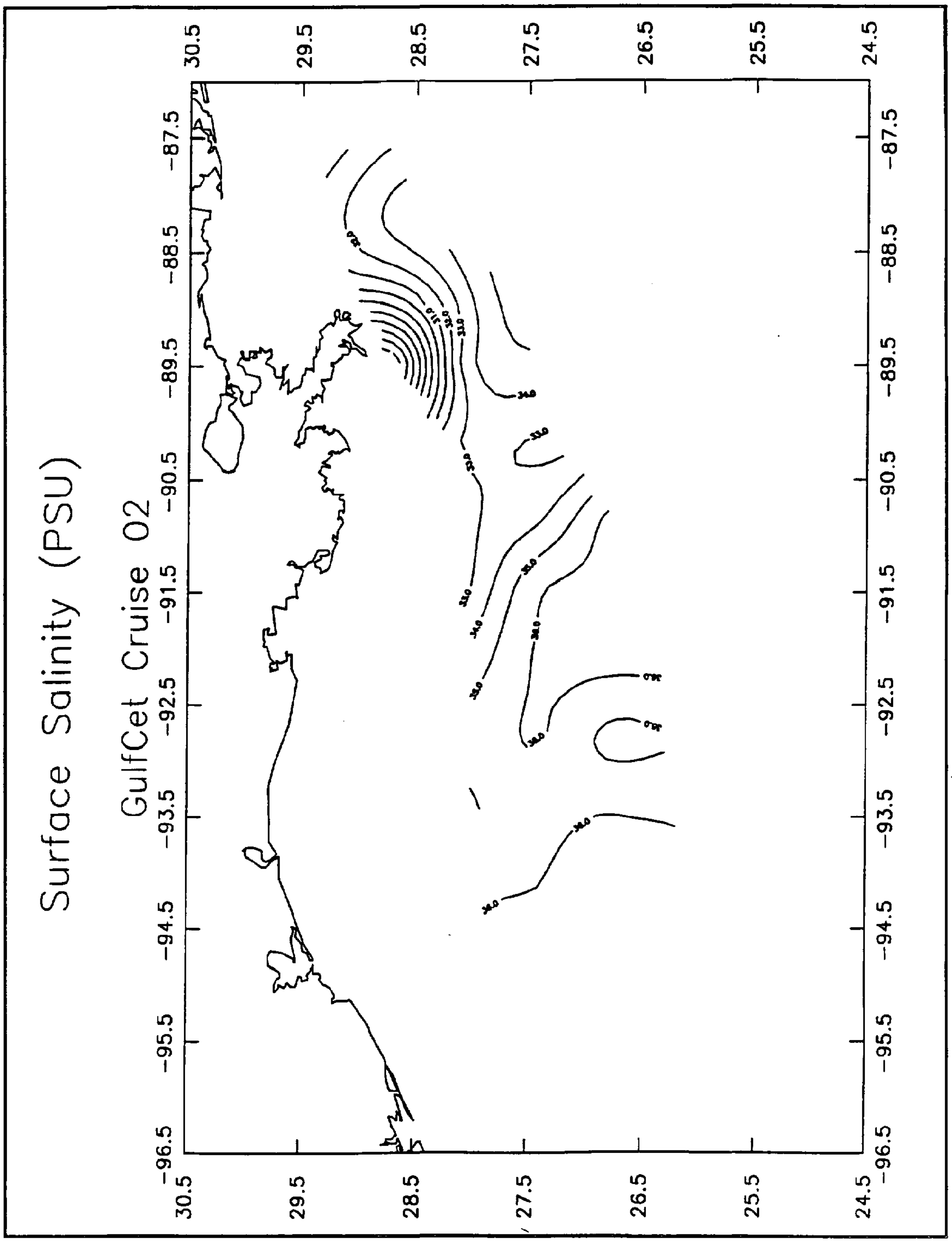


Figure 4.45. Salinity distribution at 0 m during the August 1992 survey (Cruise 2).

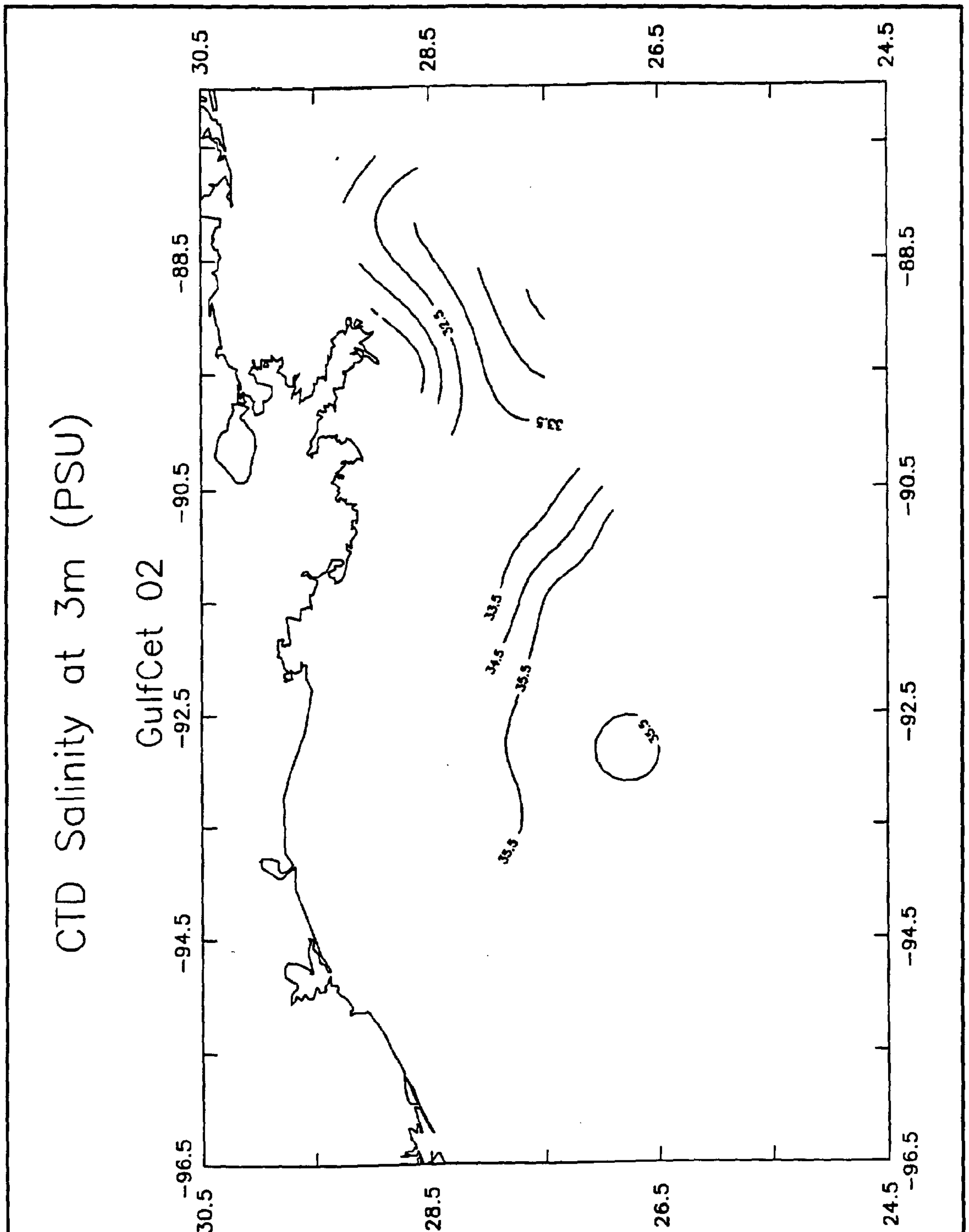


Figure 4.46. Salinity distribution at 3 m during the August 1992 survey (Cruise 2).

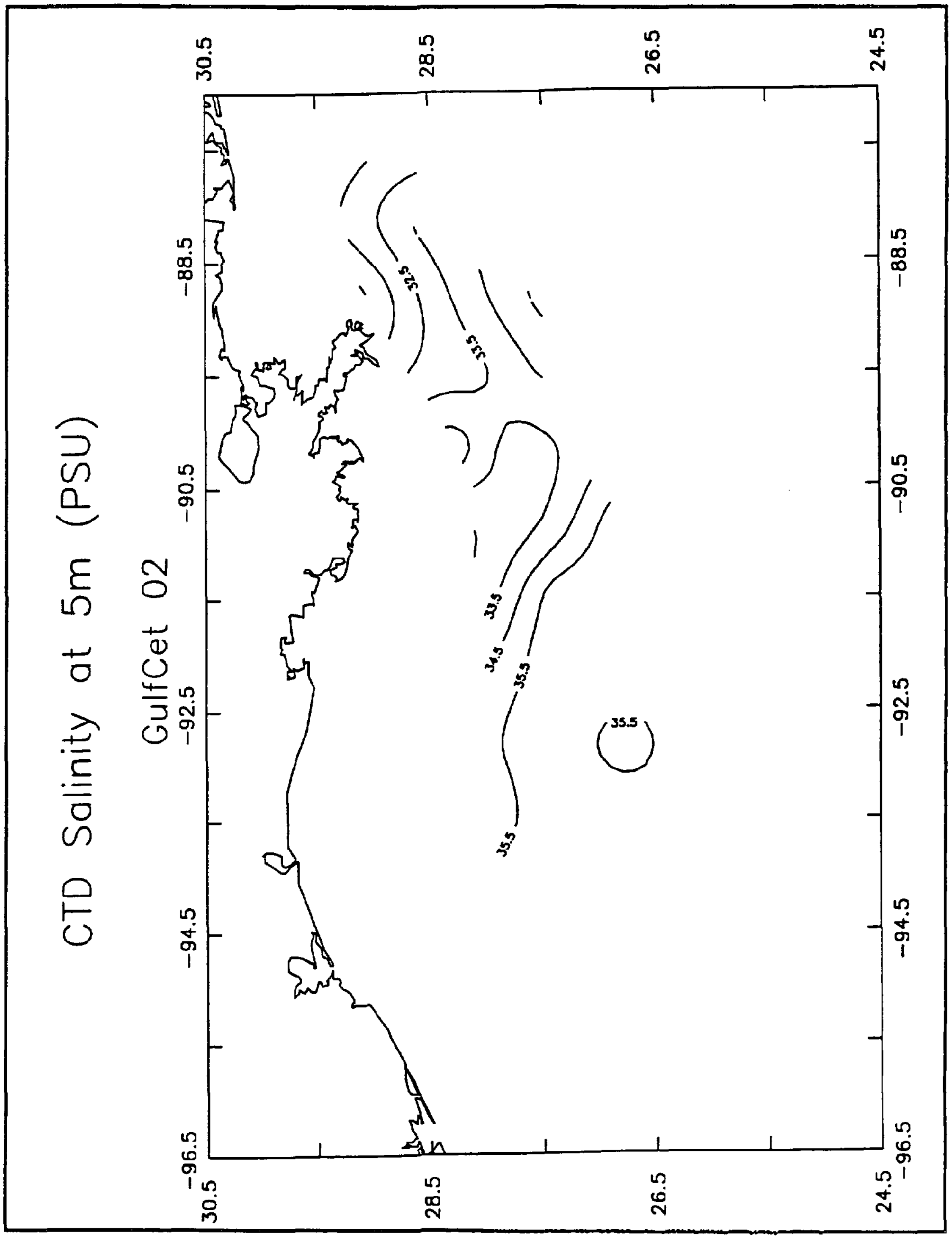


Figure 4.47. Salinity distribution at 5 m during the August 1992 survey (Cruise 2).

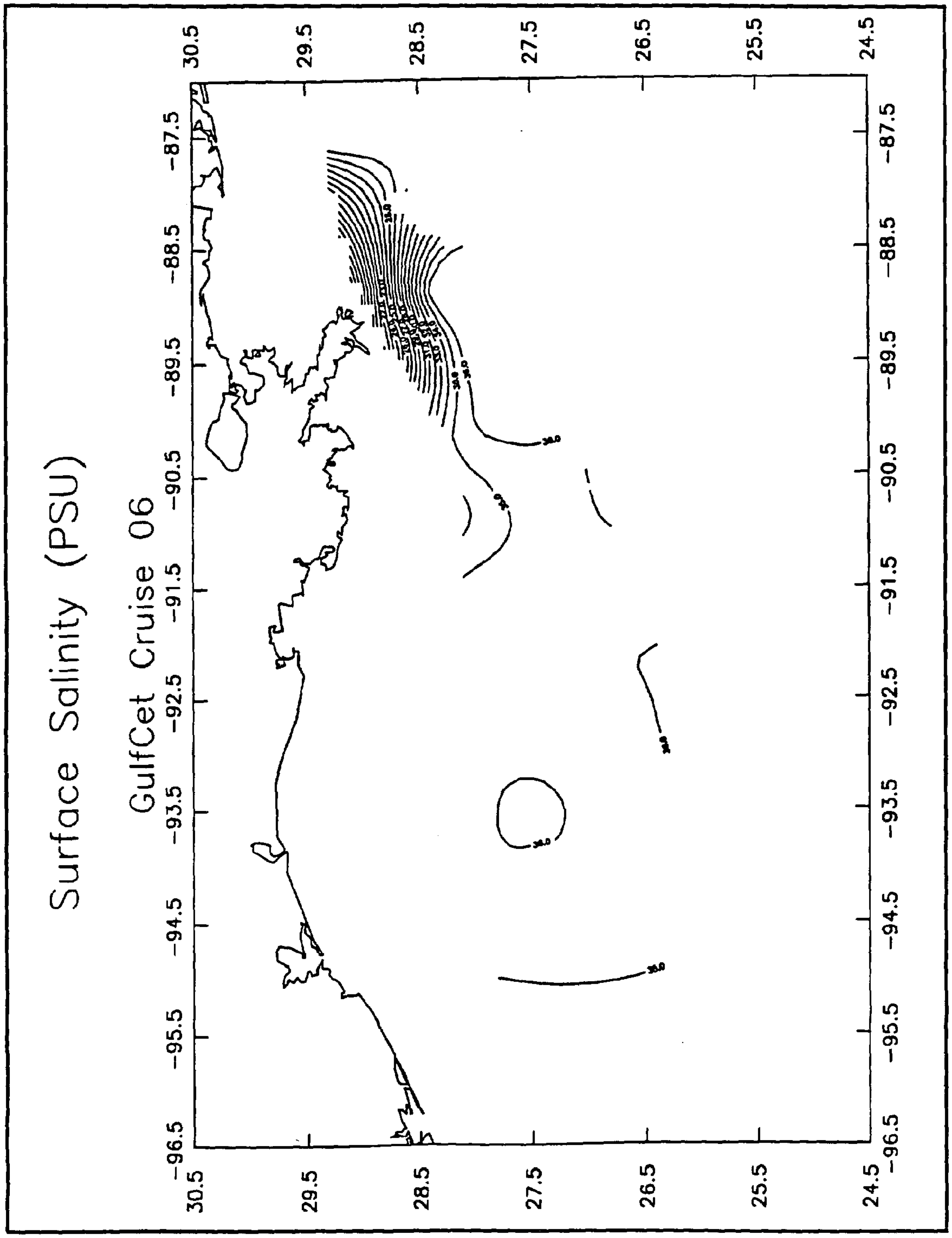


Figure 4.48. Salinity distribution at 0 m during the August 1993survey (Cruise 6).

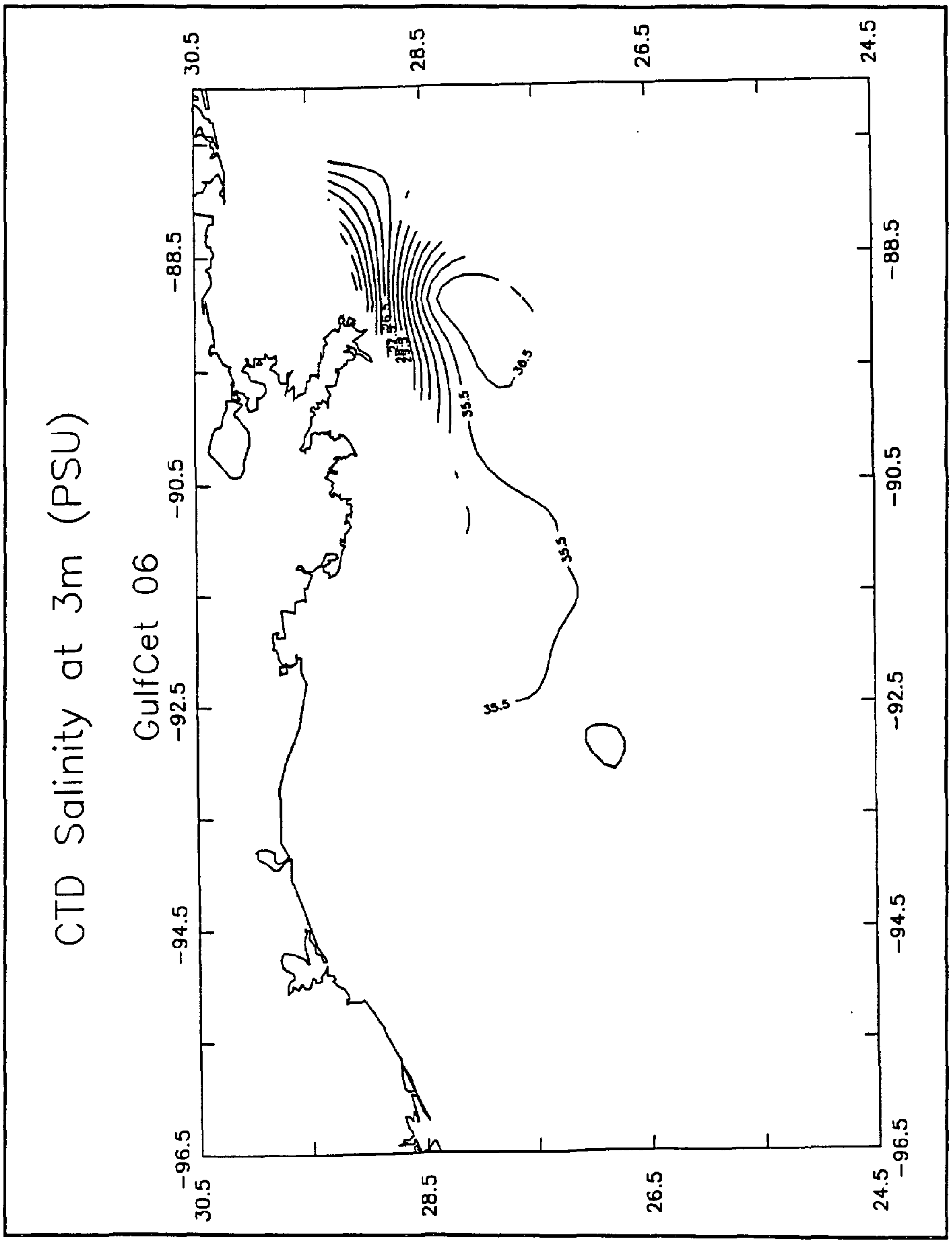


Figure 4.49. Salinity distribution at 3 m during the August 1993 survey (Cruise 6).

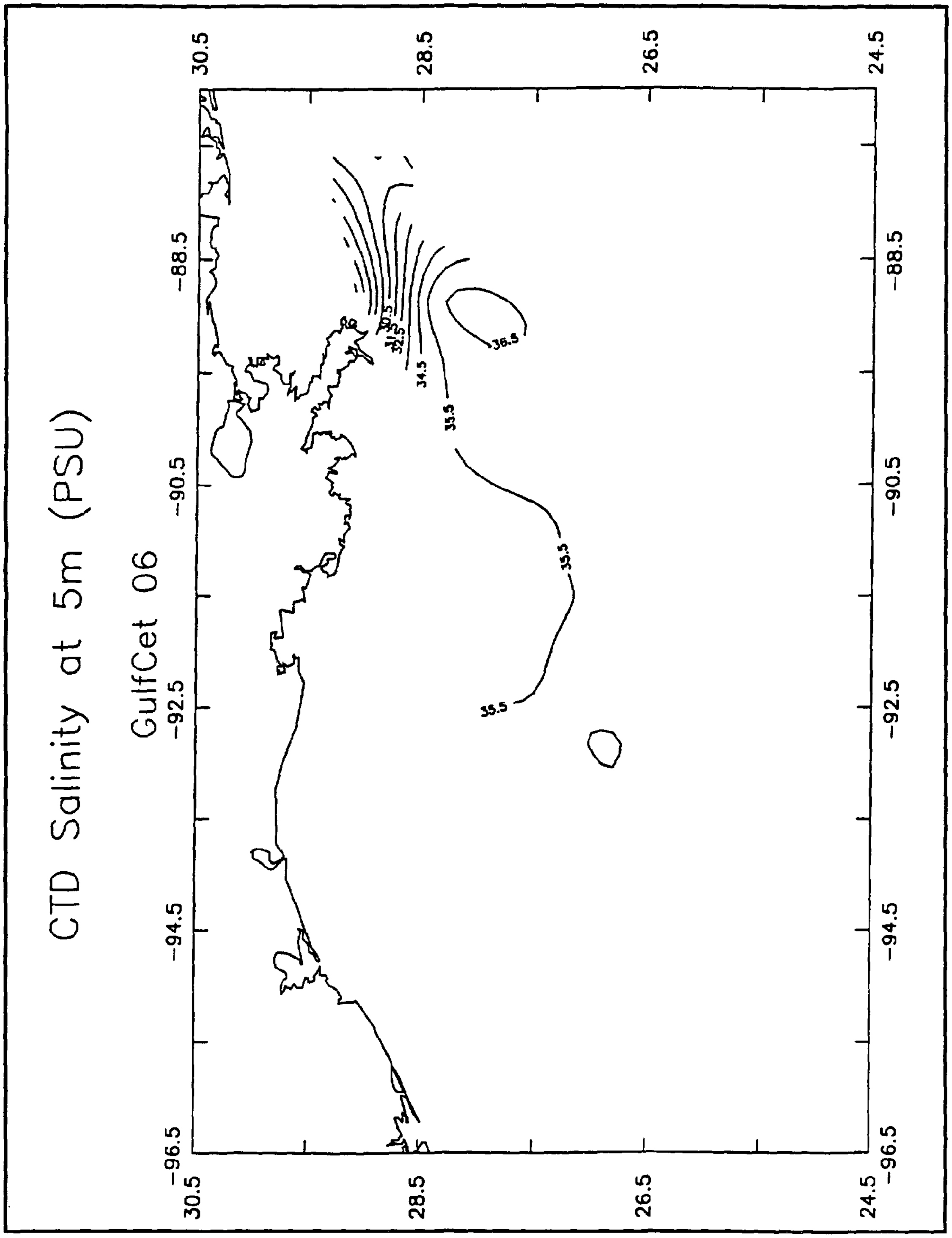


Figure 4.50. Salinity distribution at 5 m during the August 1993 survey (Cruise 6).


Figure 4.51. NOAA-AVHRR reflectance analysis in the western Gulf of Mexico for August 10, 1993 (Coastal Studies Institute).

#### 4.3.7 Conclusion

Our sampling grid has proven to be useful in sampling the meso-to-large scale features of the Gulf of Mexico. We were able to detect all the major eddies and events present in the northwestern Gulf from 1992 to 1993. These anticyclonic eddies shed vorticity as regions of cyclonic circulation when they feel bottom, and the companion cold-core (upwelling) features probably are areas of greater production and may be preferred areas for marine mammals. Futher analyses on the hydrographic features and environmental habitat of marine mammals continues.

## 4.3 Remote Sensing and Geographic Information System

### 4.3.1 Introduction

Oceanographic observations obtained from satellites have some important advantages (but also limitations) over observations obtained from ship. The first advantage is synopticity, or the ability to have an overall view of a large part of the ocean in a short time. The capacity of satellite sensors to sample large areas of the ocean densely and rapidly has improved greatly our ability to observe spatial patterns and patchiness. The assessment of heterogeneity and the identification of spatial structure provide important information regarding physical and biological oceanography, especially as marine organisms are known to have a nonuniform distribution (Steele, 1978).

Stennis Space Center (NMFS) is providing remote sensing and geographic information system (GIS) support for the GulfCet project. The GIS will be used to integrate and analyze the various data types to explore possible relationships between the distribution and abundance of marine mammals and satellite and shipboard measurements of environmental variables in the Gulf of Mexico.

### 4.3.2 Tasks Completed

#### 4.3.2.1 Support for Ship and Aircraft Surveys

The acquisition of satellite images continued in an effort to support the ship and aircraft surveys during the two year field effort. The data are collected by the Advanced Very High Resolution Radiometer (AVHRR) carried onboard the NOAA polar orbiting satellites and provide partial or full coverage of the study area twice per day (one daytime and one nighttime overflight) depending on the orbital path and cloud coverage. The data are currently being obtained from the NOAA-11 satellite and are expected to be available from NOAA-12 in the near future. With both satellites operating, up to four images per day will be available. The Naval Research Laboratory at Stennis Space Center maintains a satellite receiving station and archive facility for AVHRR images and is the primary source of data for the project. The satellite data are being processed into sea surface temperature (SST) images. Figure 4.52 is an example of the product, using the multichannel SST algorithms described by McClain, et al. (1985), and rectified to fit a simple cylindrical (linear longitude/latitude) map projection (Snyder, 1987). Each SST image is also being processed into an

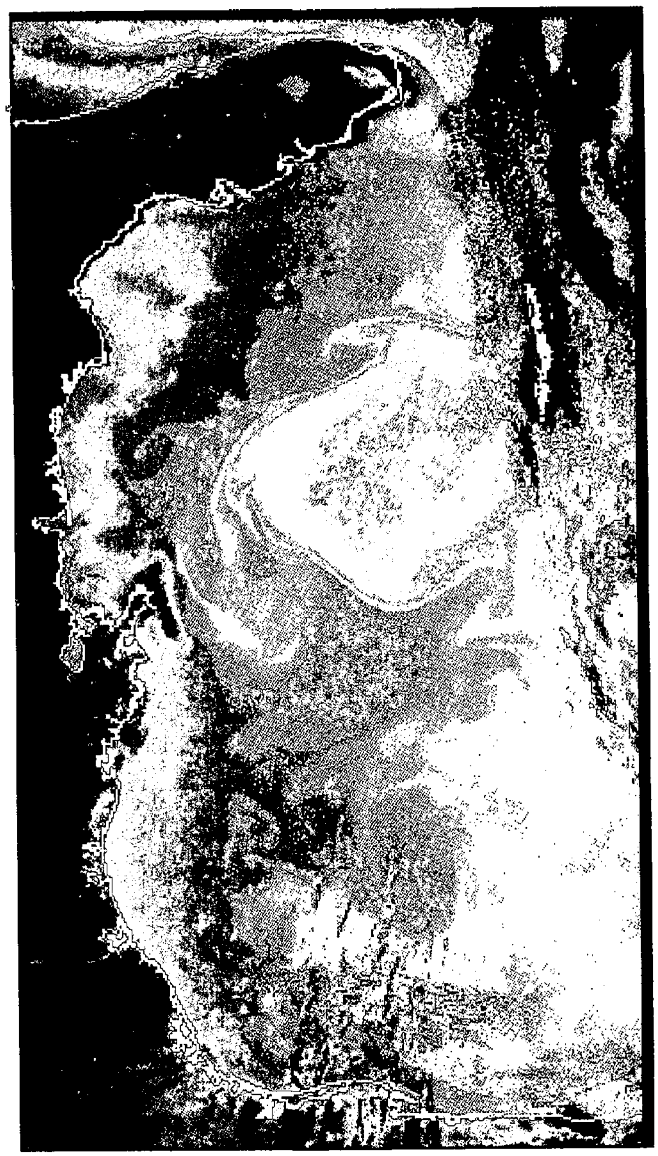

Figure 4.52. NOAA-AVHRR SST analysis in the Gulf of Mexico, April 11, 1993.

| Date | Time | Satellite | Orbit |
|---|---|---|---|
| 12-APR-92 | 09:17 | NOAA-11 | 18,284 |
| 13-APR-92 | 09:04 | NOAA-11 | 18,298 |
| 13-APR-92 | 20:26 | NOAA-11 | 18,305 |
| 14-APR-92 | 08:51 | NOAA-11 | 18,312 |
| 15-APR-92 | 08:39 | NOAA-11 | 18,326 |
| 15-APR-92 | 20:02 | NOAA-11 | 18,333 |
| 17-APR-92 | 21:19 | NOAA-11 | 18,362 |
| 20-APR-92 | 09:23 | NOAA-11 | 18,397 |
| 20-APR-92 | 20:43 | NOAA-11 | 18,404 |
| 21-APR-92 | 09:08 | NOAA-11 | 18,411 |
| 21-APR-92 | 20:30 | NOAA-11 | 18,418 |
| 22-APR-92 | 08:56 | NOAA-11 | 18,425 |
| 22-APR-92 | 20:19 | NOAA-11 | 18,432 |
| 23-APR-92 | 08:44 | NOAA-11 | 18,439 |
| 27-APR-92 | 09:40 | NOAA-11 | 18,496 |
| 27-APR-92 | 21:00 | NOAA-11 | 18,503 |
| 28-APR-92 | 20:48 | NOAA-11 | 18,517 |
| 01-MAY-92 | 08:49 | NOAA-11 | 18,552 |
| 01-MAY-92 | 20:12 | NOAA-11 | 18,559 |
| 02-MAY-92 | 08:37 | NOAA-11 | 18,566 |
| 02-MAY-92 | 20:00 | NOAA-11 | 18,573 |
| 06-MAY-92 | 09:33 | NOAA-11 | 18,623 |
| 06-MAY-92 | 20:53 | NOAA-11 | 18,630 |
| 07-MAY-92 | 09:19 | NOAA-11 | 18,637 |
| 08-MAY-92 | 20:28 | NOAA-11 | 18,658 |
| 09-MAY-92 | 20:17 | NOAA-11 | 18,672 |
| 10-MAY-92 | 20:05 | NOAA-11 | 18,686 |
| 15-MAY-92 | 20:45 | NOAA-11 | 18,757 |
| 16-MAY-92 | 09:14 | NOAA-11 | 18,764 |
| 18-MAY-92 | 08:46 | NOAA-11 | 18,792 |
| 19-MAY-92 | 19:58 | NOAA-11 | 18,813 |
| 21-MAY-92 | 09:54 | NOAA-11 | 18,835 |
| 21-MAY-92 | 21:14 | NOAA-11 | 18,842 |
| 25-MAY-92 | 09:07 | NOAA-11 | 18,891 |
| 08-AUG-92 | 08:56 | NOAA-11 | 19,964 |
| 30-AUG-92 | 09:45 | NOAA-11 | 20,261 |
| 30-AUG-92 | 21:05 | NOAA-11 | 20,268 |
| 31-AUG-92 | 09:33 | NOAA-11 | 20,275 |
| 02-SEP-92 | 09:09 | NOAA-11 | 20,303 |
| 02-SEP-92 | 20:29 | NOAA-11 | 20,310 |
| 03-SEP-92 | 08:57 | NOAA-11 | 20,317 |
| 11-SEP-92 | 09:01 | NOAA-11 | 20,430 |
| 11-SEP-92 | 20:22 | NOAA-11 | 20,437 |
| 19-SEP-92 | 09:05 | NOAA-11 | 20,543 |
| 19-SEP-92 | 20:26 | NOAA-11 | 20,550 |
| 04-OCT-92 | 20:51 | NOAA-11 | 20,762 |
| 05-OCT-92 | 09:16 | NOAA-11 | 20,769 |
| 05-OCT-92 | 20:39 | NOAA-11 | 20,776 |
| 12-OCT-92 | 09:31 | NOAA-11 | 20,868 |
| 12-OCT-92 | 20:51 | NOAA-11 | 20,875 |
| 13-OCT-92 | 09:19 | NOAA-11 | 20,882 |
| 13-OCT-92 | 20:39 | NOAA-11 | 20,889 |
| 14-OCT-92 | 09:07 | NOAA-11 | 20,896 |
| 14-OCT-92 | 20:27 | NOAA-11 | 20,903 |

| Date | Time | Satellite | Orbit |
|---|---|---|---|
| 12-NOV-92 | 09:59 | NOAA-11 | 21,306 |
| 28-NOV-92 | 21:32 | NOAA-11 | 21,539 |
| 29-NOV-92 | 09:55 | NOAA-11 | 21,546 |
| 29-NOV-92 | 21:19 | NOAA-11 | 21,553 |
| 30-NOV-92 | 09:43 | NOAA-11 | 21,560 |
| 30-NOV-92 | 21:06 | NOAA-11 | 21,567 |
| 10-DEC-92 | 09:23 | NOAA-11 | 21,701 |
| 11-DEC-92 | 09:11 | NOAA-11 | 21,715 |
| 11-DEC-92 | 20:32 | NOAA-11 | 21,722 |
| 04-JAN-93 | 09:23 | NOAA-11 | 22,054 |
| 04-JAN-93 | 20:43 | NOAA-11 | 22,061 |
| 27-JAN-93 | 09:46 | NOAA-11 | 22,379 |
| 31-JAN-93 | 08:58 | NOAA-11 | 22,435 |
| 31-JAN-93 | 20:19 | NOAA-11 | 22,442 |
| 02-FEB-93 | 09:02 | NOAA-11 | 22,548 |
| 08-FEB-93 | 20:23 | NOAA-11 | 22,555 |
| 11-FEB-93 | 21:26 | NOAA-11 | 22,598 |
| 12-FEB-93 | 09:54 | NOAA-11 | 22,605 |
| 12-FEB-93 | 21:14 | NOAA-11 | 22,612 |
| 13-FEB-93 | 09:42 | NOAA-11 | 22,619 |
| 13-FEB-93 | 21:02 | NOAA-11 | 22,626 |
| 17-FEB-93 | 20:14 | NOAA-11 | 22,682 |
| 04-MAR-93 | 09:13 | NOAA-11 | 22,887 |
| 04-MAR-93 | 20:33 | NOAA-11 | 22,894 |
| 05-MAR-93 | 09:01 | NOAA-11 | 22,901 |
| 08-MAR-93 | 10:05 | NOAA-11 | 22,944 |
| 09-MAR-93 | 09:53 | NOAA-11 | 22,958 |
| 09-MAR-93 | 21:13 | NOAA-11 | 22,965 |
| 10-MAR-93 | 09:41 | NOAA-11 | 22,972 |
| 10-MAR-93 | 21:01 | NOAA-11 | 22,979 |
| 25-MAR-93 | 10:00 | NOAA-11 | 23,184 |
| 26-MAR-93 | 09:48 | NOAA-11 | 23,198 |
| 27-MAR-93 | 09:38 | NOAA-11 | 23,212 |
| 28-MAR-93 | 09:25 | NOAA-11 | 23,226 |
| 31-MAR-93 | 21:48 | NOAA-11 | 23,276 |
| 01-APR-93 | 10:15 | NOAA-11 | 23,283 |
| 01-APR-93 | 21:36 | NOAA-11 | 23,290 |
| 02-APR-93 | 10:03 | NOAA-11 | 23,297 |
| 10-APR-93 | 10:07 | NOAA-11 | 23,410 |
| 10-APR-93 | 21:27 | NOAA-11 | 23,417 |
| 11-APR-93 | 09:54 | NOAA-11 | 23,424 |
| 11-APR-93 | 21:15 | NOAA-11 | 23,431 |
| 12-APR-93 | 09:44 | NOAA-11 | 23,438 |
| 12-APR-93 | 21:03 | NOAA-11 | 23,445 |
| 15-APR-93 | 20:30 | NOAA-11 | 23,487 |
| 16-APR-93 | 10:35 | NOAA-11 | 23,495 |
| 18-APR-93 | 21:33 | NOAA-11 | 23,530 |
| 22-APR-93 | 09:23 | NOAA-11 | 23,579 |
| 22-APR-93 | 20:45 | NOAA-11 | 23,586 |
| 23-APR-93 | 09:11 | NOAA-11 | 23,593 |
| 26-APR-93 | 21:34 | NOAA-11 | 23,643 |
| 27-APR-93 | 10:01 | NOAA-11 | 23,650 |

Table 4.1. Date and time (GMT) of acquisition, satellite and orbit numbers of the 106 AVHRR images acquired through October 1986.

| | | | |
|---|---|---|---|
| 04-MAY-93 | 10:16 | NOAA-11 | 23,749 |
| 04-MAY-93 | 21:40 | NOAA-11 | 23,756 |
| 05-MAY-93 | 10:04 | NOAA-11 | 23,763 |
| 06-MAY-93 | 09:52 | NOAA-11 | 23,777 |
| 06-MAY-93 | 21:14 | NOAA-11 | 23,784 |
| 07-MAY-93 | 09:39 | NOAA-11 | 23,791 |
| 07-MAY-93 | 21:04 | NOAA-11 | 23,798 |
| 08-MAY-93 | 09:25 | NOAA-11 | 23,805 |
| 11-MAY-93 | 10:31 | NOAA-11 | 23,848 |
| 12-MAY-93 | 10:19 | NOAA-11 | 23,862 |
| 13-MAY-93 | 21:31 | NOAA-11 | 23,883 |
| 14-MAY-93 | 09:55 | NOAA-11 | 23,890 |
| 14-MAY-93 | 21:19 | NOAA-11 | 23,897 |
| 15-MAY-93 | 21:07 | NOAA-11 | 23,911 |
| 16-MAY-93 | 09:28 | NOAA-11 | 23,918 |
| 16-MAY-93 | 20:53 | NOAA-11 | 23,925 |
| 17-MAY-93 | 09:16 | NOAA-11 | 23,932 |
| 17-MAY-93 | 20:43 | NOAA-11 | 23,939 |
| 18-MAY-93 | 09:04 | NOAA-11 | 23,946 |
| 21-MAY-93 | 10:11 | NOAA-11 | 23,989 |
| 21-MAY-93 | 21:34 | NOAA-11 | 23,996 |
| 22-MAY-93 | 09:59 | NOAA-11 | 24,003 |
| 23-MAY-93 | 09:46 | NOAA-11 | 24,017 |
| 23-MAY-93 | 21:10 | NOAA-11 | 24,024 |
| 24-MAY-93 | 09:33 | NOAA-11 | 24,031 |
| 29-MAY-93 | 10:14 | NOAA-11 | 24,102 |
| 29-MAY-93 | 21:38 | NOAA-11 | 24,109 |
| 30-MAY-93 | 10:02 | NOAA-11 | 24,116 |
| 30-MAY-93 | 21:25 | NOAA-11 | 24,123 |
| 31-MAY-93 | 09:50 | NOAA-11 | 24,130 |
| 31-MAY-93 | 21:13 | NOAA-11 | 24,137 |
| | | | |
| 01-JUN-93 | 21:01 | NOAA-11 | 24,151 |
| 01-JUN-93 | 09:37 | NOAA-11 | 24,144 |
| 02-JUN-93 | 09:23 | NOAA-11 | 24,158 |
| 04-JUN-93 | 10:41 | NOAA-11 | 24,187 |
| 05-JUN-93 | 10:29 | NOAA-11 | 24,201 |
| 05-JUN-93 | 21:55 | NOAA-11 | 24,208 |
| 06-JUN-93 | 10:17 | NOAA-11 | 24,215 |
| 06-JUN-93 | 21:41 | NOAA-11 | 24,222 |
| 07-JUN-93 | 21:28 | NOAA-11 | 24,236 |
| 08-JUN-93 | 09:53 | NOAA-11 | 24,243 |
| 09-JUN-93 | 09:39 | NOAA-11 | 24,257 |
| 10-JUN-93 | 09:33 | NOAA-11 | 24,271 |
| 15-JUN-93 | 21:31 | NOAA-11 | 24,349 |
| 16-JUN-93 | 09:56 | NOAA-11 | 24,356 |
| 23-JUN-93 | 21:34 | NOAA-11 | 24,462 |
| 24-JUN-93 | 21:22 | NOAA-11 | 24,476 |
| 25-JUN-93 | 09:47 | NOAA-11 | 24,483 |
| 25-JUN-93 | 21:10 | NOAA-11 | 24,490 |
| 29-JUN-93 | 01:25 | NOAA-12 | 11,034 |
| | | | |
| 01-JUL-93 | 10:15 | NOAA-11 | 24,568 |
| 01-JUL-93 | 21:39 | NOAA-11 | 24,575 |
| 02-JUL-93 | 10:02 | NOAA-11 | 24,582 |
| 02-JUL-93 | 21:25 | NOAA-11 | 24,589 |
| 04-JUL-93 | 21:02 | NOAA-11 | 24,617 |
| 05-JUL-93 | 09:24 | NOAA-11 | 24,624 |
| 07-JUL-93 | 10:41 | NOAA-11 | 24,653 |
| 08-JUL-93 | 10:30 | NOAA-11 | 24,667 |
| 16-JUL-93 | 21:58 | NOAA-11 | 24,787 |
| 17-JUL-93 | 21:44 | NOAA-11 | 24,801 |
| 19-JUL-93 | 21:19 | NOAA-11 | 24,829 |
| 25-JUL-93 | 21:47 | NOAA-11 | 24,914 |
| 26-JUL-93 | 10:12 | NOAA-11 | 24,921 |
| | | | |
| 01-AUG-93 | 01:16 | NOAA-12 | 11,503 |
| 05-AUG-93 | 01:32 | NOAA-12 | 11,560 |
| 07-AUG-93 | 00:47 | NOAA-12 | 11,588 |
| 10-AUG-93 | 10:29 | NOAA-11 | 25,133 |
| 18-AUG-93 | 21:57 | NOAA-11 | 25,253 |
| 19-AUG-93 | 10:21 | NOAA-11 | 25,260 |
| 19-AUG-93 | 13:49 | NOAA-12 | 11,766 |
| 22-AUG-93 | 09:44 | NOAA-11 | 25,302 |
| 22-AUG-93 | 21:08 | NOAA-11 | 25,309 |
| 23-AUG-93 | 14:02 | NOAA-12 | 11,823 |
| 24-AUG-93 | 01:22 | NOAA-12 | 11,830 |
| 24-AUG-93 | 13:41 | NOAA-12 | 11,837 |
| | | | |
| 11-SEP-93 | 10:41 | NOAA-11 | 25,585 |
| 21-SEP-93 | 10:21 | NOAA-11 | 25,726 |
| 22-SEP-93 | 00:57 | NOAA-12 | 12,242 |
| 23-SEP-93 | 09:54 | NOAA-11 | 25,754 |
| 23-SEP-93 | 21:19 | NOAA-11 | 25,761 |
| 24-SEP-93 | 09:43 | NOAA-11 | 25,768 |
| 24-SEP-93 | 21:08 | NOAA-11 | 25,775 |
| 28-SEP-93 | 22:00 | NOAA-11 | 25,832 |
| 29-SEP-93 | 10:24 | NOAA-11 | 25,839 |
| 29-SEP-93 | 21:47 | NOAA-11 | 25,846 |
| 30-SEP-93 | 10:11 | NOAA-11 | 25,853 |
| 30-SEP-93 | 21:34 | NOAA-11 | 25,860 |
| | | | |
| 01-OCT-93 | 09:59 | NOAA-11 | 25,867 |
| 04-OCT-93 | 11:02 | NOAA-11 | 25,910 |
| 04-OCT-93 | 13:59 | NOAA-12 | 12,420 |
| 05-OCT-93 | 01:19 | NOAA-12 | 12,427 |
| 05-OCT-93 | 10:50 | NOAA-11 | 25,924 |
| 06-OCT-93 | 22:02 | NOAA-11 | 25,945 |

Table 4.1a. Date and time (GMT) of acquisition, satellite and orbit numbers of the 106 AVHRR images acquired through October 1986.

| Map layer(s) | Platform | Method of data capture | Data source | Measurement unit | Depth range (m) | Estimated no. of map layers per survey | GIS data model |
|---|---|---|---|---|---|---|---|
| Cetacean surveys | ship | observers | GulfCet | numbers/species | 0 | 1 | vector or raster |
| | aircraft | observers | GulfCet | numbers/species | 0 | 1 | vector or raster |
| Water temperature (WT) | ship | CTD/XBT | GulfCet | °C | 0-500 | 14[1] | vector or raster |
| | ship | flow-thru | GulfCet | °C | 0 | 1 | vector or raster |
| | satellite | AVHRR[2] | NOAA | °C | 0 | 0-17+[3] | raster |
| WT gradients[4] | satellite | AVHRR | NOAA | °C/km | 0 | 0-17+ | raster |
| Water turbidity | satellite | AVHRR | NOAA | plume/non-plume[5] | 0 | 0-9+ | raster |
| Salinity | ship | CTD | GulfCet | PSU | 0-500 | 14 | vector or raster |
| | ship | flow-thru | GulfCet | PSU | 0 | 1 | vector or raster |
| Chlorophyll | ship | CTD | GulfCet | mg/l | 0 | 1 | vector or raster |
| | ship | flow-thru | GulfCet | mg/l | 0 | 1 | vector or raster |
| Sea floor maps | ship | GLORIA[6] | USGS | 0-255[7] | - | 1 | raster |
| Bathymetry | ship | note[8] | NMFS | m | 100-2,000 | 1 | raster |
| | ship | note[9] | USGS/NOAA | m | 100-2,000 | 1 | vector |
| Coastline | - | note[10] | DMA | longitude/latitude | - | 1 | vector |
| Oil field structures | - | - | MMS | longitude/latitude | - | 1 | vector |
| Survey transects | ship | LORAN-C | GulfCet | longitude/latitude | - | 1 | vector |
| | aircraft | LORAN-C | GulfCet | longitude/latitude | - | 1 | vector |

[1] Each map layer will correspond to a National Oceanographic Data Center (NODC) standard depth level, i.e., 0, 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, or 500 m.

[2] Advanced Very High Resolution Radiometer carried onboard the NOAA-11 and NOAA-12 polar orbiting satellites.

[3] Zero, partial, or full coverage of the GulfCet study area up to twice each day per satellite depending upon the orbital path and cloud cover.

[4] Absolute magnitude of the sea surface temperature (SST) gradients derived from horizontal (east-west) and vertical (north-south) SST gradients extracted from each satellite-observed SST image using Sobel operators (Gonzales and Wintz 1977).

[5] Mississippi River plume derived from the visible channels of the AVHRR using the algorithm described by Stumpf (1992) that aggregates water into two classes: plume and non-plume.

[6] Long-range side scan sonar referred to as the Geological Long-Range Inclined Asdic (GLORIA); the raw data were radiometrically and geometrically corrected and processed into sea floor maps by the U.S. Geological Survey (USGS).

[7] The sea floor maps are 8-bit raster images with intensities ranging from 0 (no return) to 255 (strong return). The intensities are directly related to the backscattered sonar return which is a function of the sea floor gradient, bottom roughness, and sediment characteristics.

[8] 16-bit raster surface interpolated to a 0.01° x 0.01° longitude/latitude pixel size using National Ocean Survey point depth measurements (1-min longitude/latitude spacing) and bilinear cubic spline functions; approximate area of coverage is 81-98° W longitude and 25-31° N latitude.

[9] Bathymetry lines manually digitized (in 10 m increments) from NOAA charts and included with the USGS GLORIA sea floor maps.

[10] Gulf of Mexico coastline manually digitized from 1:1,000,000 scale jet navigation charts and included as part of the Digital Chart of the World, a public domain dataset produced by the Defense Mapping Agency (DMA).

Table 4.2. GIS data base characteristic for the map layers identified for the GulfCet project.

absolute magnitude of the SST gradient image using 3 x 3 template masks configured as Sobel operators (Gonzales and Wintz 1976) and an arithmetic overlay operation (Aronoff, 1989 and Appendix, Volume II). The visible channels of the AVHRR from daytime overflights are also being processed into turbidity images, primarily to examine the areal extent and location of edges of the Mississippi River plume, using the algorithm described by Stumpf (1992). A total of 199 AVHRR images have been acquired (as of October 6th) for the study and are listed in Table 4.1. The satellite data products, shipboard and aircraft observations of marine mammals, and environmental data collected aboard the vessels will be included as map layers in the GIS data base (Table 4.2).

4.3.2.2 Support for the Whale Tagging Effort

Satellite images acquired during September-October were selectively processed into SST images and provided to colleagues at Oregon State University (OSU) attempting to place satellite tracking tags on sperm whales in the Northern Gulf of Mexico. A total of three SST images were processed during the two week field effort and transferred to OSU using FTP/IP (INTERNET). A public domain image processing package described by Leming (1989) that operates on a minimally-equipped personal computer was also provided to enable the OSU investigators to display the images in color and perform simple image manipulation tasks.

Prior to the second tagging effort in June, OSU investigators were provided with C-Coast software and set up to access satellite-derived SST and visible channel images through the Coast Watch Gulf of Mexico Regional Node at SSC. The PC-based C-coast software was developed with Coast Watch funding to enable users to import, manipulate, enhance, and export Coast Watch image products as well as overlay non-image data (e.g., sperm whale sightings).

4.3.2.3 GIS Procurement

The GIS hardware consists of a Silicon Graphics UNIX workstation and peripherals; software is the Advanced Geographic Information System (AGIS), developed by Delta Data sytem, and the Science and Technology Laboratory Applications Software (ELAS), developed by the National Aeronautics and Space Administration (Beverly and Penton 1989). A more detailed description of the hardware and software is given in Volume II (Appendix).

4.3.2.4 Acquisition of Collateral Data Sets

In addition to the satellite, survey, and environmental data being collected for the project, other digital maps were tentatively identified for use in the GIS data base and are listed in Table 4.2.

4.3.2.5 Infrastructural Improvements

There were a number of infrastructural improvements within the last year at NMFS-SSC that will directly benefit the GulfCet effort, but completed at no cost to the project. The FTP/IP (INTERNET) communications link became fully operational and will be essential for the efficient transfer of data (particularly digital maps) among investigators at NMFS, TAMUG, and OSU. The personal computers that will be used to support the project have been linked through a local area network and have been upgraded from an MS-DOS operating environment to an OS2/Windows environment. The CoastWatch Program became fully operational in December 1992 and is available as a secondary source of satellite observed SST images for the project. Major software improvements were completed for the satellite receiving station last year to streamline day-to-day operations of the unit. In addition to CoastWatch, the station will serve as a backup source for satellite data.

### 4.3.3 GIS Data Management and Analysis

#### 4.3.3.1 Base Map Coordinate System

All of the digital map layers used in the GIS data base will be registered to a portion of the Gulf of Mexico master image (GMMI) that includes the GulfCet study area and thus encompasses the area from 26° to 31° N Latitude and 81° to 98° W Longitude. The GMMI is a raster image consisting of three land cover classes: land, water, and land pixels adjacent to water (coastline). The file was generated from vector coastline data reformatted from the Digital Chart of the World data base (U.S. Defense Mapping Agency, 1992). The master image is earth located with longitude/latitude coordinates using a simple cylindrical projection (linear longitude/latitude) system (Snyder 1987). The dimensions of each pixel in the GMMI are 0.01° longitude by 0.01° latitude. Longitude and latitude coordinates are being collected concurrently with the cetacean survey observations from aircraft and vessels and with shipboard measurements of environmental variables using global positioning system or LORAN-C receivers. These earth-located data will later be converted to AGIS map layers and stored as either raster or vector files (Table 4.2).

#### 4.3.3.2 Raster versus Vector Data Models

Some of the map layers tentatively identified for use in the GIS data base can be stored as raster or vector data files (Table 4.2). The GIS software currently available, with the exception of AGIS, will store and analyze raster or vector maps, but will not handle both data types simultaneously. Thus, depending on the software, mapping projects initiated with both types of data files require conversion from one form to the other, i.e., raster to vector or vector to raster prior to data basing and analysis. If a large number of layers have to be converted for a particular project, the process can require a significant amount of machine and staff time. Although the AGIS data base supporting GulfCet could contain a mixture of both map types (Table 4.2), there are two important operational concerns that have to be considered. First, the vector model is a more compact data structure than the equivalent map stored in a raster form (Aronoff 1989). Since most of the data volume in the GulfCet data base will consist of raster maps (primarily satellite-observed data), there may be slight advantage in storing other data layers (e.g., shipboard measurements of salinity) as vector maps. However, online mass storage requirements for the project were carefully considered when drafting the specifications for the UNIX workstation. The 1.5 gigabytes of online storage (one hard drive and two optical drives) descibed in Volume II (Appendix), should provide ample room to store and analyze either a mixture of raster and vector maps or all of the data as raster maps. The second and primary operational concern may be processing speed; certain GIS analysis functions, e.g. overlay operations

(Volume II, Appendix,), are more efficiently implemented with raster maps than with vector maps (Aronoff 1989). Some benchmarking will be conducted to compare processing speeds of identical GIS tasks operating on (1) a mix of raster and vector maps and (2) the same maps converted to raster files. Based on the outcome of the evaluation, it may be more advantageous to convert all of the maps to the raster domain given the anticipated volume of data that will have to be processed for the project.

### 4.3.3 Processing Protocol

The GIS will be used for qualitative analysis of data structure by using such functions as retrieval and classification and logical operations (Volume II, Appendix) to create interactive map displays, tabular summaries, and data plots in an effort to visualize relationships between the distribution and abundance of cetaceans and satellite and shipboard measurements of environmental variables. The dimensionality of the data, i.e., the potential number of input variables for multivariate statistical analysis, is expected to be large since GIS analysis tools such as proximity measures (Volume II, Appendix) will enable analysts to explore the data in ways that would be virtually impossible using a conventional analysis methods. The initial exploratory analysis will be followed by a more formal, quantitative analysis of the data using multivariate statistical techniques. Variables to be used in the analysis will be exported from the GIS to one or more statistical software packages: (1) the Statistical Analysis System (SAS) offering a wide range of univariate and multivariate statistical procedures; (2) the Cornell Ecology Programs provide cluster, detrended correspondence analysis, and ordination techniques for ecological research (Gauch, 1982); and (3) SpaceStat spatial analysis software (Anselin, 1992).

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