OCS Study
MMS 95-0027

Louisiana/Texas Shelf Physical Oceanography Program: Eddy Circulation Study

Annual Report: Year 2

MMS U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

OCS Study
MMS 95-0027

Louisiana/Texas Shelf Physical Oceanography Program: Eddy Circulation Study

Annual Report: Year 2

Author

Science Applications International Corporation

Prepared under MMS Contract
14-35-0001-30633
by
Science Applications International Corporation
615 Oberlin Road, Suite 300
Raleigh, North Carolina 27605

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

New Orleans
May 1995

DISCLAIMER

REPORT AVAILABILITY

Extra copies of the report may be obtained from the Public Information Unit (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Public Information Unit (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394

Telephone Number: 1-800-200-GULF
(504) 736-2519

CITATION

Suggested citation:

Science Applications International Corporation. 1995. Louisiana/ Texas Shelf Physical Oceanography Program: Eddy Circulation Study, Annual Report: Year 2. OCS Study MMS 95-0027. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 63 pp.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

LIST OF FIGURES (continued)

LIST OF TABLES

I. INTRODUCTION

This document describes progress of Science Applications International Corporation (SAIC) and its subcontractors in accomplishing the principal objectives of the Gulf of Mexico Eddy Circulation Study (Minerals Management Service (MMS) Contract 14-35-0001-30633) during the second field year, May 1, 1993 through April 30, 1994. The study is also known as the C component of the Louisiana/Texas Shelf Physical Oceanography Program (LATEX Program). Briefly stated, the study objectives are:

- monitoring and characterizing three classes of mesoscale circulation patterns important in the open sea and slope waters of the northwestern Gulf of Mexico (Tasks C-2, C-3, C-6, C-7);

- providing efficient, centralized logistics support, including Service ARGOS liaison for drifting buoys, air deployed expendable bathythermograph (AXBT) and current profiler (AXCP) probes, and expendable bathythermograph (XBT) probes for a ship-of-opportunity program (Tasks C-1 through C-6 and C-8);

- disseminating information collected during this study to other investigators on a regular basis (Tasks C-9 through C-11).

Monitoring mesoscale features has been accomplished by a series of seven aerial surveys with AXBTs and AXCPs to examine the instantaneous hydrographic and velocity structures of selected features. Continuous monitoring of features has been done using air-deployed, satellite-tracked drifting buoys (Clearwater Instrumentation, Inc., model LSD2). Satellite altimetry has been used to provide an historical perspective of conditions in the Gulf of Mexico from early 1985 through 1990.

Aerial surveys (including photography) and drifting buoy deployments were executed by an experienced subcontractor, Aero-Marine Surveys, Inc., under the direct supervision of an SAIC scientist. Eddy characterization will be accomplished by careful analysis of the data collected in this study along with selected data elements from the other two field components of the program and through synthesis of knowledge gained during this study with what is already known.

SAIC provided centralized storage and shipping of drifting buoys and air and ship launched expendable probes from a facility in Plano, Texas, operated by Specialty Devices, Inc. The operator of the facility is responsible for checkout of the satellite uplink

transmitter in each drifting buoy procured under this program. SAIC has made all necessary Service ARGOS arrangements and fee payments for drifting buoys, and provides ongoing liaison with Service ARGOS and the National Oceanic and Atmospheric Administration (NOAA) Office of Global Programs.

Dissemination of quality controlled data and analyzed results has taken place through regular posting on the GULF.MEX bulletin board service of OMNET® and through regular interaction among the investigators on this project. Drifter data have been provided periodically to Dr. Robert Leben, a LATEX C Principal Investigator at Colorado Center for Astrodynamics Research (CCAR) at the University of Colorado, for assimilation with ERS-1 and TOPEX altimeter data. Drifter data and AXBT/AXCP data have also been provided to Dr. Douglas Biggs at Texas A&M University (TAMU) and Dr. Giulietta Fargion (TAMU, Galveston) with whom joint papers have been presented at the 1994 Spring AGU Meeting in Baltimore, Maryland.

Chapter II presents an overview and chronology of events accomplished under each task of the contract. Chapter III documents progress during the second field year under Tasks C-2, C-3, C-6, C-7, C-8, and C-9 in data collection and archiving, results of quality control exercises, data shared with other investigators, analytical methods employed, and standard computer graphics.

II. OVERVIEW AND CHRONOLOGY OF INDIVIDUAL TASKS

2.1 Task C-1: Drifting Buoys Provided to Other Contractors

Seventeen drifters "drogued at the surface" were ordered for subsequent distribution: 16 to Texas A&M University (TAMU), prime contractor for the Louisiana/Texas Shelf Circulation and Transport Processes (LATEX A) Study; and one to Louisiana State University (LSU), prime contractor for the Mississippi River Plume Hydrography (LATEX B) Study. The chosen configuration was a Clearwater Instrumentation, Inc., World Ocean Circulation Experiment (WOCE) type drifter with a 6x1 m holey sock drogue and approximate 3 m tether such that the bottom of the drogue was at 9 m.

Under this task Specialty Devices, Inc. of Plano, Texas maintained a central logistics facility and performed a variety of logistics tasks involving shipping and receiving drifters for this Task and Tasks C-2 and C-3, aerial expendable stores for Task C-6, and expendable stores and equipment for Task C-8.

The original 17 surface configured drifters were received at the central logistics facility in two shipments on April 14, 1992, and May 29, 1992 during Year 1. By the end of Year 1 all but three of the drifters (two for LATEX A and one for LATEX B) had been shipped. Two of these drifters were shipped to LATEX A on July 28, 1993. The drifter allocated to LATEX B was shipped on March 17, 1994 and deployed on April 15, 1994. Four drifters provided to LATEX A during Year 1 were deployed on May 2, 1993.

The Specialty Devices, Inc. facility also accommodated the remaining eight (out of 20) air-deployed drifters delivered in Year 2. The air deployed drifters were received on May 5, 1993 and were shipped to various locations during the year as directed by the Program Manager. Table 2.1-1 shows the disposition of drifters during Year 2.

2.2 Task C-2: Drifting Buoys in Loop Current Eddies

The drifter configuration for this task was a Clearwater Instrumentation, Inc., WOCE type drifter with a 12x1 m holey sock drogue and approximate 88 m tether such that the bottom of the drogue was at 100 m. During Year 1 one drifter was air-deployed in October 1992 and failed immediately. A replacement drifter deployed two weeks later, from R/V GYRE during a transit of the Gulf of Mexico, operated for 169 days and stopped transmitting just before the end of Year 1.

Table 2.1-1. LATEX Drifter Inventory - Year 2

PTT ID	DEPTH	RCVD	SHIPPED TO	DEPLOY	YEAR END STATUS	TOTAL DAYS	REMARKS/PERFORMANCE
02448	100m	04/22/92	GYRE	06/02/93	off	0	Eddy W
02449	100m	04/22/92	GYRE	10/30/92	off	135	Eddy U
02450	200m	04/22/92	Galveston	12/12/93	on	138	GulfCet deploy in small cyclone
06935	6m	05/29/92	TAMU	05/02/93	off	53	
06937	6m	05/29/92	TAMU	05/02/93	off	43	
06938	6m	05/29/92	TAMU	05/02/93	off	171	
06939	6m	05/29/92	TAMU	05/02/93	off	0	
06941	6m	05/29/92	LSU	04/15/94	on	15	
07835	50m	05/29/92	Galveston	01/09/93	off	59	Exit GOM 6/93; OFF 6/29/93
07838	100m	05/05/93	Galveston	12/09/93	off	119	GulfCet deploy in Eddy X
07842	50m	05/05/93	Lafayette	12/22/93	off	245	Cyclone
07843	50m	05/05/93	Lafayette	12/22/93	on	128	Cyclone
07844	50m	05/05/93	Lafayette	12/22/93	off	152	Cyclone
07845	50m	05/05/93	Lafayette	12/22/93	on	128	Cyclone: no fixes,1-2 xmits/day
Drifters remaining for deployment in Year 3							
02445	200m	04/22/92	Biggs				Transferred to Dr. Doug Biggs/TAMU for
07841	200m	05/05/92	Biggs				ship deployment in Loop Current Eddies
Plus eight ordered from Horizon Marine for Delivery in Year 3.							
LATEX A:							
07833	50m	05/29/92	TAMU				
07834	50m	05/29/92	TAMU				Remaining air-deployable drifters
07839	100m	05/05/92	TAMU				transferred to TAMU for ship launch
07840	100m	05/05/92	TAMU				
03584	6m	09/21/92	TAMU				
06936	6m	05/29/92	TAMU				
06940	6m	05/29/92	TAMU				

Subsequently, during Year 1, it became apparent that the air-deployable version of this drifter was experiencing a large number of failures which were related to the parachute deployment system. Additionally there appeared to be other problems with the surface drifters where the drifters did not transmit as long as expected. All of the difficulties were outlined in the Year 1 Report (SAIC 1994). A decision was made during the later part of Year 1 not to deploy any drifters from aircraft until the problem was resolved.

Discussions were undertaken with Clearwater Instruments, Inc. to determine the source of the problem and effect a solution. During the discussions it was decided to repackage five drifters in our possession and these were returned to Clearwater for rework. Eight drifters intended for delivery in Year 2 were also to be packaged in this new configuration.

A decision was also made that the drifters would be deployed from ships if this could be done. Thus, drifters 2448 and 7838 were deployed in Eddy W (June 2, 1993) and Eddy X (December 9, 1993), respectively. The deployment of drifter 2448 was made from R/V GYRE during a transit of the Gulf of Mexico and deployment of drifter 7838 was made from R/V PELICAN during a "Distribution and Abundance of Marine Mammals in the North-Central and Western Gulf of Mexico" (GulfCet) Program cruise.

2.3 Task C-3: Drifting Buoys in Other Meso-Scale Features

Two different air-deployable configurations of the Clearwater Instrumentation, Inc., WOCE type drifter were chosen: one set of four with the bottom of the drogue at 200 m for deployment in slope eddies, and one set of 10 with the bottom of the drogue at 50 m for deployment in squirts. Except for drogue tether length, these drifters were identical to the Loop Current eddy drifters.

Following deployment of four repackaged drifters (see Section 2.2 above) in November 1993, when one drifter failed immediately and two others provided only intermittent fixes, a decision was made to provide the four remaining Clearwater drifters to LATEX A for conversion to the surface configuration. Two additional drifters were earmarked for deployment by ship in the Loop Current as opportunity arose. These six units were shipped on April 14, 1994 to TAMU.

After reprogramming funds originally budgeted for buoy refurbishment, eight drifters were ordered from Horizon Marine, Inc. These drifters were packaged in a configuration approximating

the dimensions of an A-size sonobuoy (0.9144 m (36 in) by 0.124 m (4.875 in) diameter) such that they could be launched from the same aircraft used for the aerial surveys, rather than from a leased air freighter. The drifters were configured with holey sock drogues and tethers to place the bottom of the drogue at 50 m (4), 100 m (2), or 200 m (2).

2.4 Task C-4: Returned Buoys

No buoys were recovered after deployment and returned to the manufacturer for refurbishment during Year 1 or Year 2. Funds from this task were reprogrammed to allow purchase of Horizon Marine air deployable drifters for use in Year 3.

2.5 Task C-5: Buoy Quality Control

Each of the drifters received by Specialty Devices, Inc., was turned ON, on receipt and again prior to shipment, and checked with a Telonics TSUR-B Satellite Uplink Receiver/Analyzer System to verify correct operation of the ARGOS platform terminal transmitter (PTT). Each unit's operation was also verified through receipt of the signal through Service ARGOS. No unit failed these predeployment tests.

2.6 Task C-6: Aerial Surveys

Five types of aerial survey were proposed to accomplish the objectives of the LATEX C program: Slope Surveys, Slope Eddy Surveys, Loop Current Eddy Surveys, Squirts and Jets Surveys, and Squirts and Jets Locator Surveys. These survey types are described below:

- Slope Survey - made over two days with 32 AXBTs on a regular hydrographic grid of five or six lines covering a portion of the upper slope between the 200 m and 2000 m isobaths. Three surveys were planned during each program year. The area covered in Year 2 was between 92°00'W and 94°36'W.

- Slope Eddy Location Survey - made with 16 AXBTs and five AXCPs on an as required basis if a slope eddy was discovered during a Slope Survey. Each survey was to be followed by aerial deployment of a drifter with a drogue at 200 m.

- Loop Current Eddy Survey - made with 16 AXBTs on an as required basis whenever the center of a Loop Current eddy was determined to have reached 90°W after separating from the Loop Current. Each survey was to be followed by aerial deployment of a drifter with a drogue at 100 m.

- Squirts and Jets Survey - made over two days with 32 AXBTs and nine AXCPs whenever a 'squirt' was detected in satellite imagery. This survey was to be followed by a Squirts and Jets Location Survey (16 AXBTs) and deployment of two drifters with drogues at 50 m. A sequence of two of these survey sets, separated by about one week, was planned in Year 2.

- Squirts and Jets Location Survey - made in one day with 16 AXBTs to determine the best locations in a 'squirt' for subsequent deployment of two drifters with drogues at 50 m.

Seven aerial surveys were actually conducted during Year 2: three Slope Surveys, one Slope Eddy Survey, two Loop Current Eddy Surveys, and a modified Squirts and Jets Survey/Squirts and Jets Location Survey. Additionally two days in May 1993 were devoted exclusively to aerial photography along selected ERS-1 ground tracks. Table 2.6-1 shows the surveys in sequence along with the types of probes used in each survey and the number of probes in each survey which returned valid data.

During Year 2 reduced size AXBTs ('A/3', 0.30 m (10.98 in) vice 0.9144 m (36 in) long and lighter in weight than standard 'A' size) were ordered from Hermes Electronics of Canada. The remaining full size ('A' size) Sparton AXBTs were used for Loop Current Eddy surveys. Use of the 'A/3' AXBTs allowed more probes to be carried and added to flexibility in flight scheduling. Reliability of 'A' size AXBTs was 100.0%, of 'A/3' size AXBTs was 93.5% and of AXCPs ('A' size) was 90.5%.

All surveys during Year 2 were conducted from the Paul Fournet Air Services facility at Lafayette Regional Airport in Lafayette, Louisiana. The support provided by this fixed base operator continued to be exceptional and included shipping and receiving activities before each survey and storage of materials, at no cost to the program.

2.7 Task C-7: Altimetry

The goal of this task, which is being carried out by Drs. George Born and Robert Leben at CCAR, is to use all publicly available U.S. Navy Geodetic Satellite (GEOSAT) data to provide an altimeter climatology consisting of the following elements:

Table 2.6-1. Aerial Survey Dates and Probe Usage

Survey	Type	Dates	AXBT		AXCP		Drifters	Remarks
			used	good	used	good		
F08	Slope	5/15-16/93	36	34	-	-		
F08	Slope	5/14,5/17/93	-	-	-	-		Photo runs (352 frames)
F09	Slope Eddy	5/18-19/92	15	14	5	4	3819	NRL/SSC Drifter, did not operate
F10	Slope	8/3-4/93	36	35	-	-		
F11	LCE	8/5/93	16	16	-	-	2448	Eddy W
F12	Slope	10/28-11/1/93	44	40				
F13	Squirt	12/16-21/93	62	57	16	15	7842, 7843 7844, 7845	7845 failed immediately 7842 & 7844 provided only sporadic positions
F14	LCE	12/23/93	16	16	-	-	7838	Eddy X from R/V PELICAN
		Total	225	212	21	19		
		Percent good	94.2		90.5			

- charts of the mean sea surface and mean slope;
- charts of sea surface topographic variability and slope variability for each year and season;
- charts of sea surface topography anomalies for each exact repeat cycle (ERC);
- charts of eddy paths, eddy size and shape, eddy decay and Loop Current penetration derived from the above; and
- wave height and wind speed analyses.

Work on the mean sea surface and mean slope was completed during Year 2 using 3½ years of GEOS 3, three months of Seasat and 22 cycles (approximately one year) of GEOSAT Exact Repeat Mission (ERM) altimeter data and bathymetric data. A method has been developed for correcting the selected reference mean surface for short wavelength geoid errors which allows accurate referencing of both historical and current repeat track altimeter data. The accuracy of this mean surface has been validated by comparisons of altimetry derived products with surveys and drifting buoys.

2.8 Task C-8: Ships-of-Opportunity

Support of the Ships-of-Opportunity (SOOP) program during Year 2 involved distribution of seven cases of T-7 XBT probes, in case lots, to investigators designated by the MMS Contracting Officer's Technical Representative (COTR). Four cases were provided to the GulfCet Program (Dr. Giulietta Fargion) and three cases to the TAMU Ship of Opportunity Program (Dr. Doug Biggs).

Data from these programs has been shared among the various Principal Investigators. In each instance where probes have been provided, they have been used to augment other sources of data and so do not represent a separate 'contiguous' data set. A side benefit from these programs was deployment of drifters in Loop Current eddies.

2.9 Task C-9: Data Quality Control

The goals of this task are to eliminate spurious or doubtful values in the data sets and to correct, where possible, values affected by identifiable and quantifiable sources of bias. Data collected or processed comprise three basic data types:

- Hydrographic Profile Data (XBTs/AXBTs/AXCPs),
- Lagrangian Data (Drifting Buoys), and
- Remotely Sensed Data (Altimetry).

Hydrographic profile data from AXBTs, AXCPs and drifter data are processed by SAIC, while quality control of altimetry data is performed by CCAR. Data from XBTs distributed under the SOOP Program are processed by the individual programs or investigators receiving the probes.

Initial quality control of AXBTs and AXCPs occurred in the field and involved aural evaluation when the probe was dropped, to ensure 'normal' operation, and substantial effort to provide duplicate copies of the raw data on nine-track analog tape and on digital audio cassette tape. Overall data return from AXBTs was 94.2%, as the result of 13 data losses in 225 drops. As noted in Section 2.6, two types of AXBT were used: 'A' size with reliability of 100.0% and 'A/3' size with reliability of 93.5%. Similarly, data return from AXCPs was 90.5%, based on two instrument failures in 21 drops. Final quality assurance/quality control (QA/QC) of these data is described in Section 3.9.

2.10 Task C-10: Analyses and Reports

The Annual Report: Year 1 (SAIC 1994) was prepared and submitted during Year 2. Work on updated drifter track analysis programs was initiated. Selected plots were generated with the *opcplot* plotting program (Brown 1994).

2.11 Task C-11: Information Transfer

This task has included posting to the GULF.MEX Electronic Bulletin Board on OMNET of the following types of messages:

- drifter tracks on a weekly basis, whenever a drifter was operational,
- cruise plans and reports before and after each set of surveys,
- inflection points from AXBTs after each aerial survey, and
- program schedule changes.

2.12 Task C-12: Government Furnished Equipment/Capital Equipment

There has been no activity under this task, which is designated for the refurbishment and return to MMS of government owned property at the end of the project.

III. DETAILS OF DATA COLLECTION AND ANALYSIS

3.1 Aerial Surveys and Drifting Buoy Deployments

Throughout the following discussion reference is made to scheduled activities even in the case of clearly event driven activities like Loop Current Eddy Surveys. The schedule was developed initially as a means of cost estimating and as a means of keeping the scientific community informed of forthcoming events in case cooperative ventures could be developed. The schedule was continually refined and updated based on occurrence of various events and on recommendations of the LATEX Science Advisory Panel or individual members of the panel.

Each survey event was identified in the schedule, and in the following discussions, by a designator which noted it as an aircraft based survey (F), a two digit sequence number, and a five character nickname. Thus the first survey conducted in Year 1 was identified as F01SLOPE. This same identification scheme was used for all data files.

The plan for each survey flight originally included aerial photography of the sea surface using a 70 mm format camera and black and white film, with emphasis on oceanic fronts. After the first series of 63 photographs, taken during the first Slope Survey in Year 1, were evaluated and found to be inadequate because they were taken at low altitude, discussions were initiated among MMS, SAIC, Aero-Marine Surveys and the Principal Investigator receiving the photographs to define more fully the exact requirements for the photographic component of the program. It was decided that the stated altitude requirement (~3,000 m) for useful photographs was incompatible with safety requirements imposed by dropping expendable probes from an aircraft and that photography would be limited to occasions when the altitude requirement could be met without compromising the main part of the program. An opportunity to provide a substantial number of photographs was developed during the last months of Year 1 and was carried out successfully during F08SLOPE in May 1993.

3.1.1 Slope Surveys

Three Slope Surveys were scheduled during Year 2 at times to coincide approximately with the quarterly hydrographic surveys made on the shelf by TAMU in the LATEX A study. The 'missing' Slope Survey was staggered over the three years of field work so that no one season would be consistently unsampled. The three planned

surveys were conducted as scheduled in early May, early August and early November 1993. The original grid planned for Year 2 and the grid actually used are shown in Figure 3.1-1. Modifications to the original grid were made based on flight experience during Year 1.

During Year 1 LATEX A deployed two inverted echo sounders along 92°W as shown in Figure 3.1-1 and AXBT drops were made at each station during Year 1. No further AXBT drops were made at LATEX A Mooring Station 43, the inverted echo sounder at 25°32.5'N 91°59.9'W, after the instrument was reported to be unrecoverable.

Slope Survey 4 (F08SLOPE and F09SEDDY)

The fourth Slope Survey (F08SLOPE) was conducted May 15-16, 1993 as shown in Figure 3.1-2. The survey was flown in two legs. It was preceded by a special photographic mission on May 14 along portions of an ERS-1 ground track (398), and followed on May 17 by an additional photographic mission along and parallel to ERS-1 ground track 441 as shown in Figure 3.1-3. A Slope Eddy Survey was undertaken on May 18 and consisted of two parallel north-south lines between the western edge of F08SLOPE and the Texas shelf break as shown in Figure 3.1-2.

Figures 3.1-4, 3.1-5 and 3.1-6 plot the depths of the 20°C, 15°C, and 8°C isotherms, respectively, from the combined data set and show a large anticyclone in the western half of the survey and possibly a smaller anticyclone in the northeastern corner. Figure 3.1-7 shows the thermal structure in the upper 800 m along an east-west section through the anticyclone. The original estimate was that the anticyclone observable in the western portion of this survey was Eddy V; however, later analysis indicated the feature observed was not Eddy V, which was believed to have dissipated in early spring (Year 1). The anticyclone was probably a remnant of an old Loop Current eddy.

A drifter provided by Naval Research Laboratory-Stennis Space Center was deployed following an AXCP pattern at 27°00'N 95°00'W in the anticyclone, but failed to operate.

Slope Survey 5 (F10SLOPE)

The fifth Slope Survey (F10SLOPE) was conducted August 3-4, 1993 as shown in Figure 3.1-8. A Loop Current Eddy survey (F11LEDDY), completed on August 5, 1993, is plotted also in Figure 3.1-8 to show its relation to F10SLOPE. F11LEDDY is discussed below. Figures 3.1-9, 3.1-10, and 3.1-11 show the depths of the 20°C, 15°C,

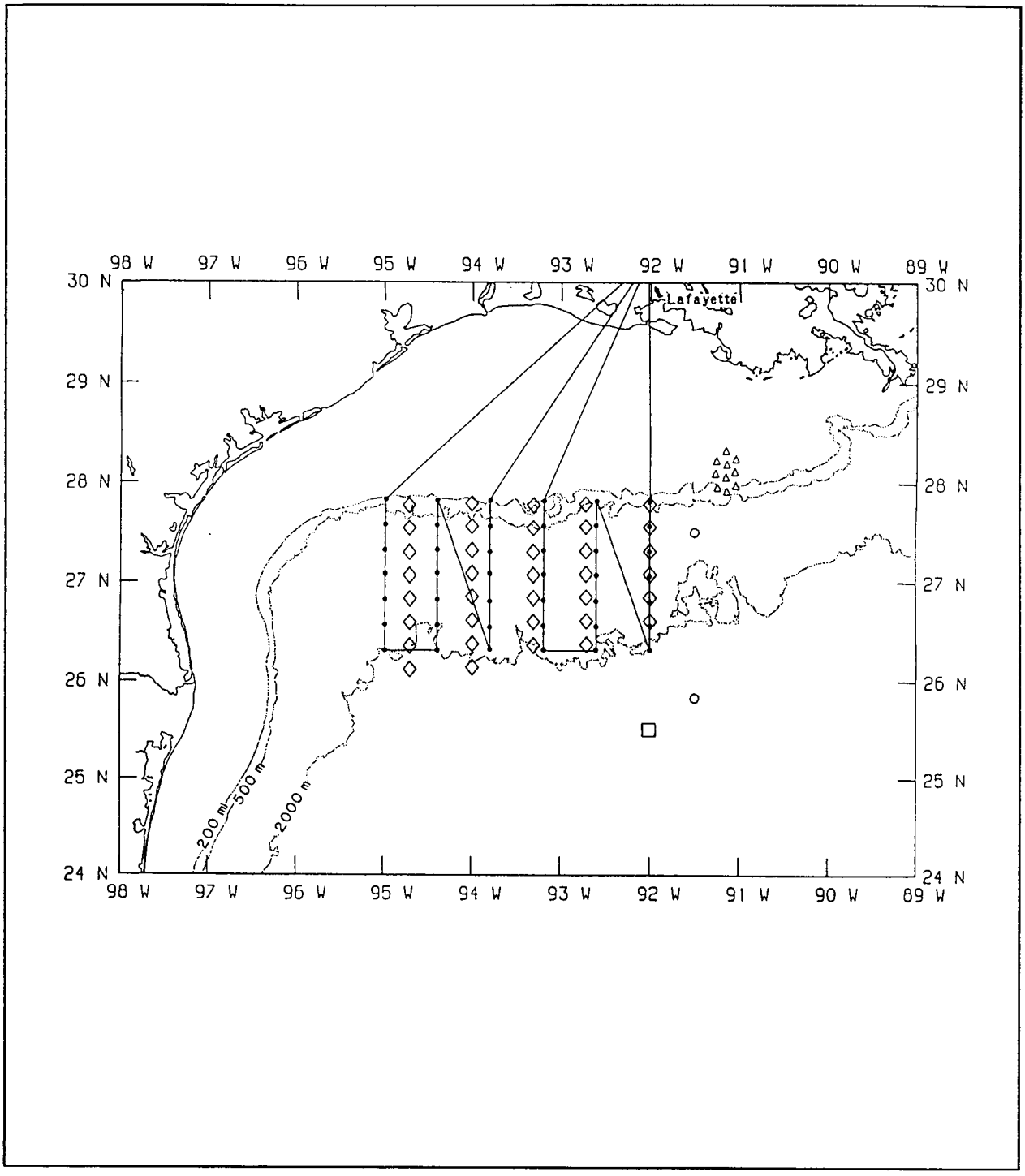

Figure 3.1-1. Plan for Year 2 Slope Surveys. Original AXBT stations are shown as small dots, actual AXBT stations as open diamonds, and IES 43 as an open square.

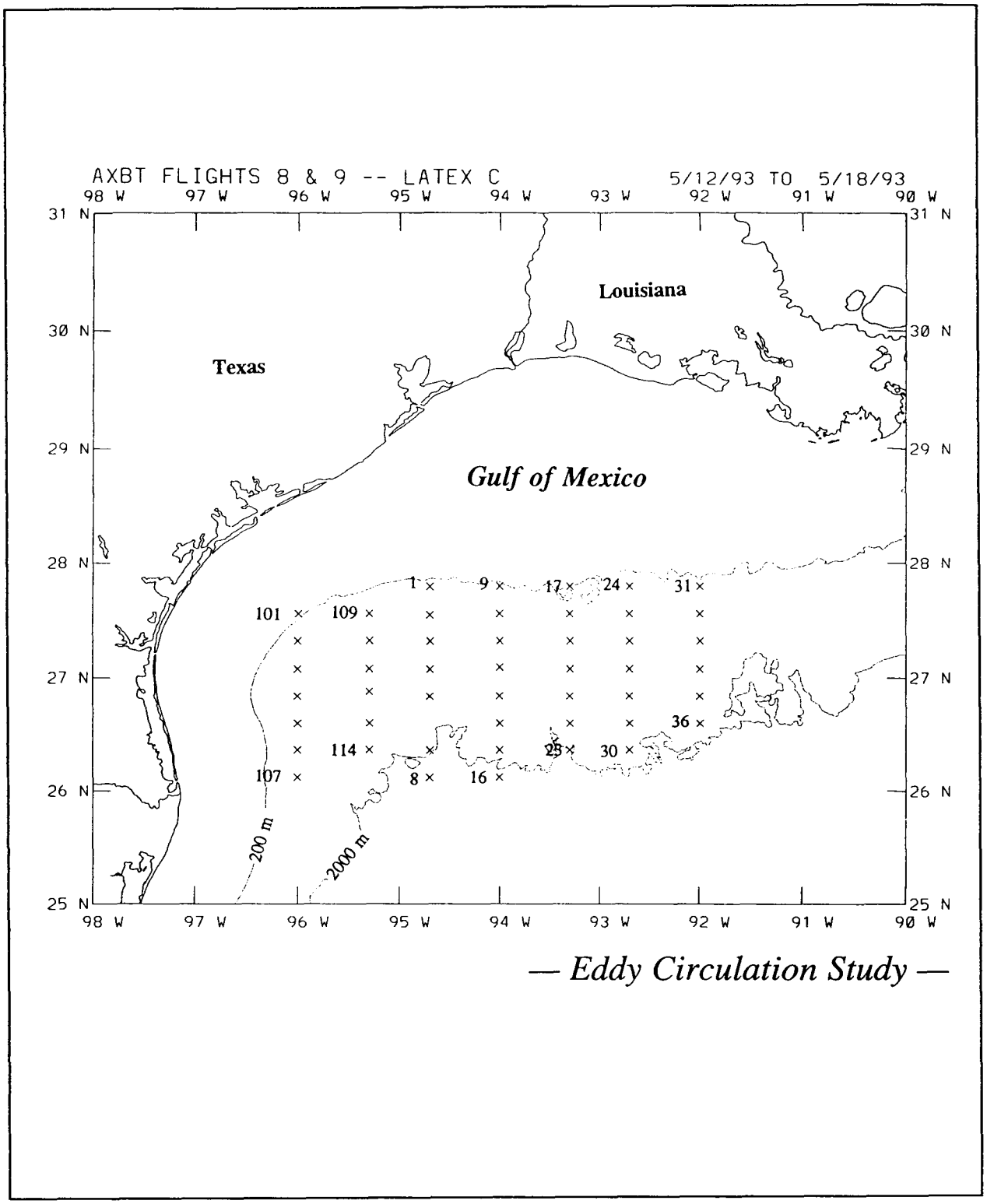

Figure 3.1-2. Station plot for surveys F08SLOPE and F09SEDDY.

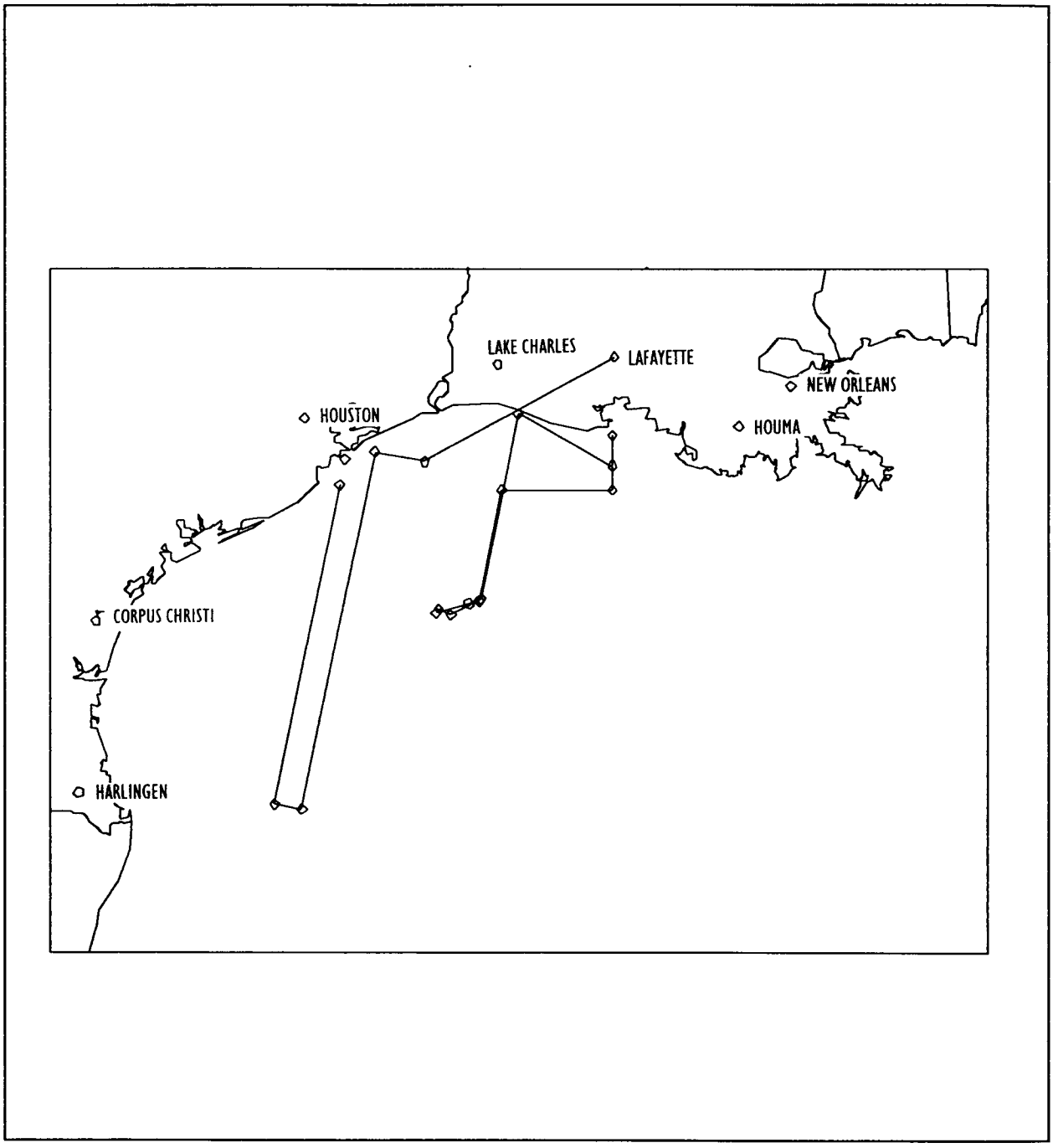

Figure 3.1-3. Flight tracks used during special photo mission along ERS-1 ground tracks. Eastern set shows track on May 14, 1994, including excursion over Flower Garden Banks. Western set shows track on May 17, 1994. Origin of flights was Lafayette, Louisiana.

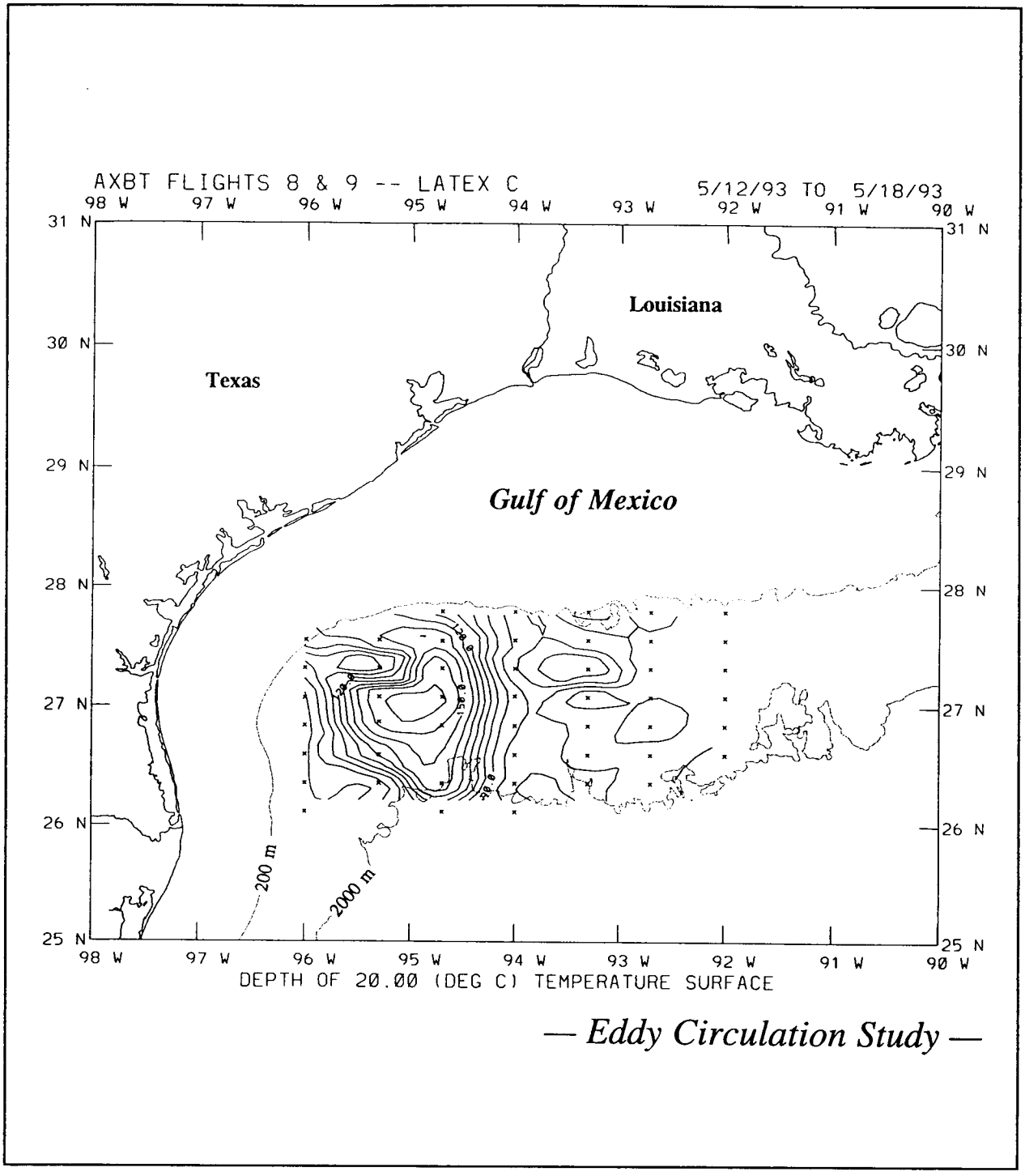

Figure 3.1-4. Depth of the 20°C isotherm from F08SLOPE and F09SEDDY AXBT data.

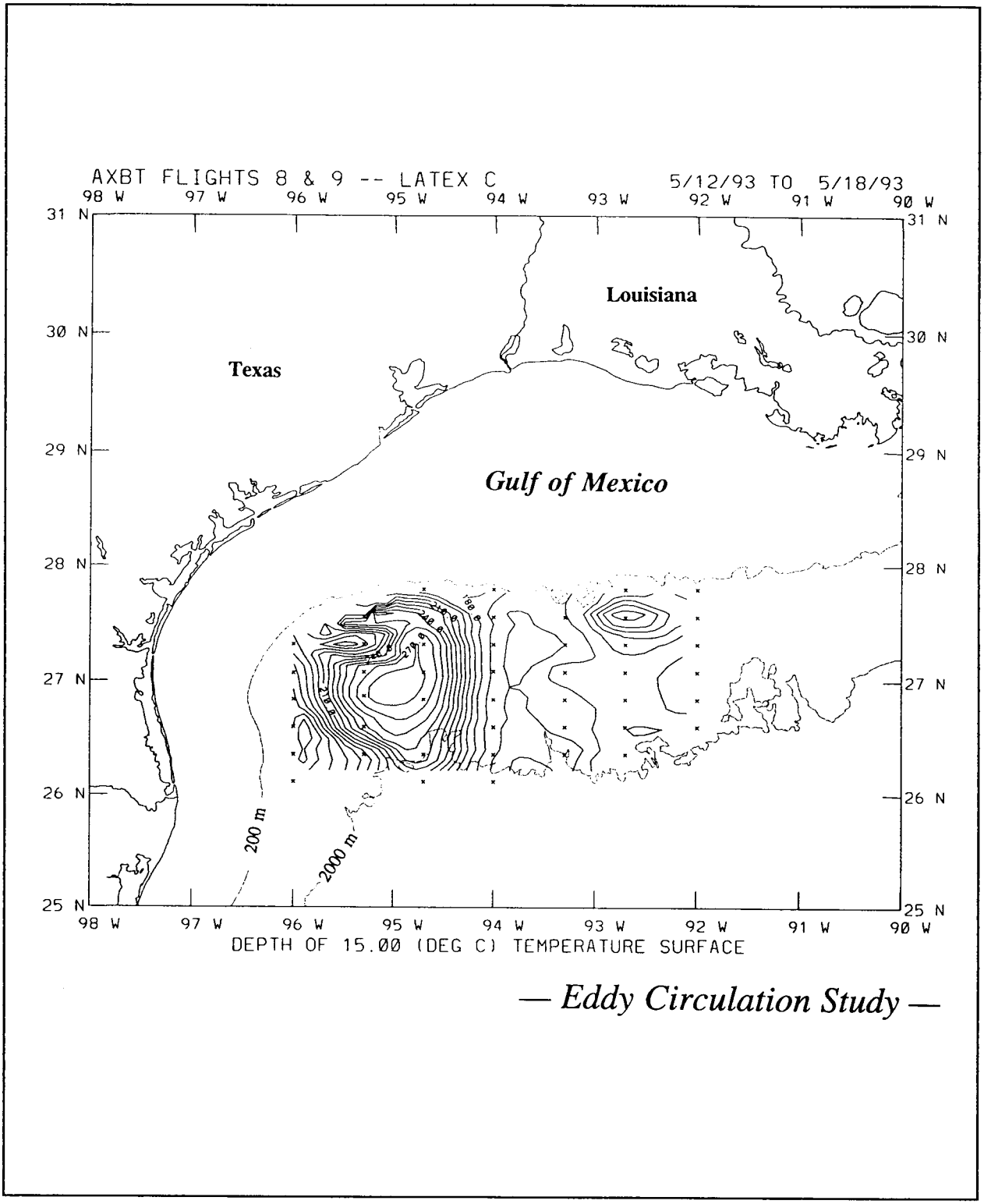

Figure 3.1-5. Depth of the 15°C isotherm from F08SLOPE and F09SEDDY AXBT data.

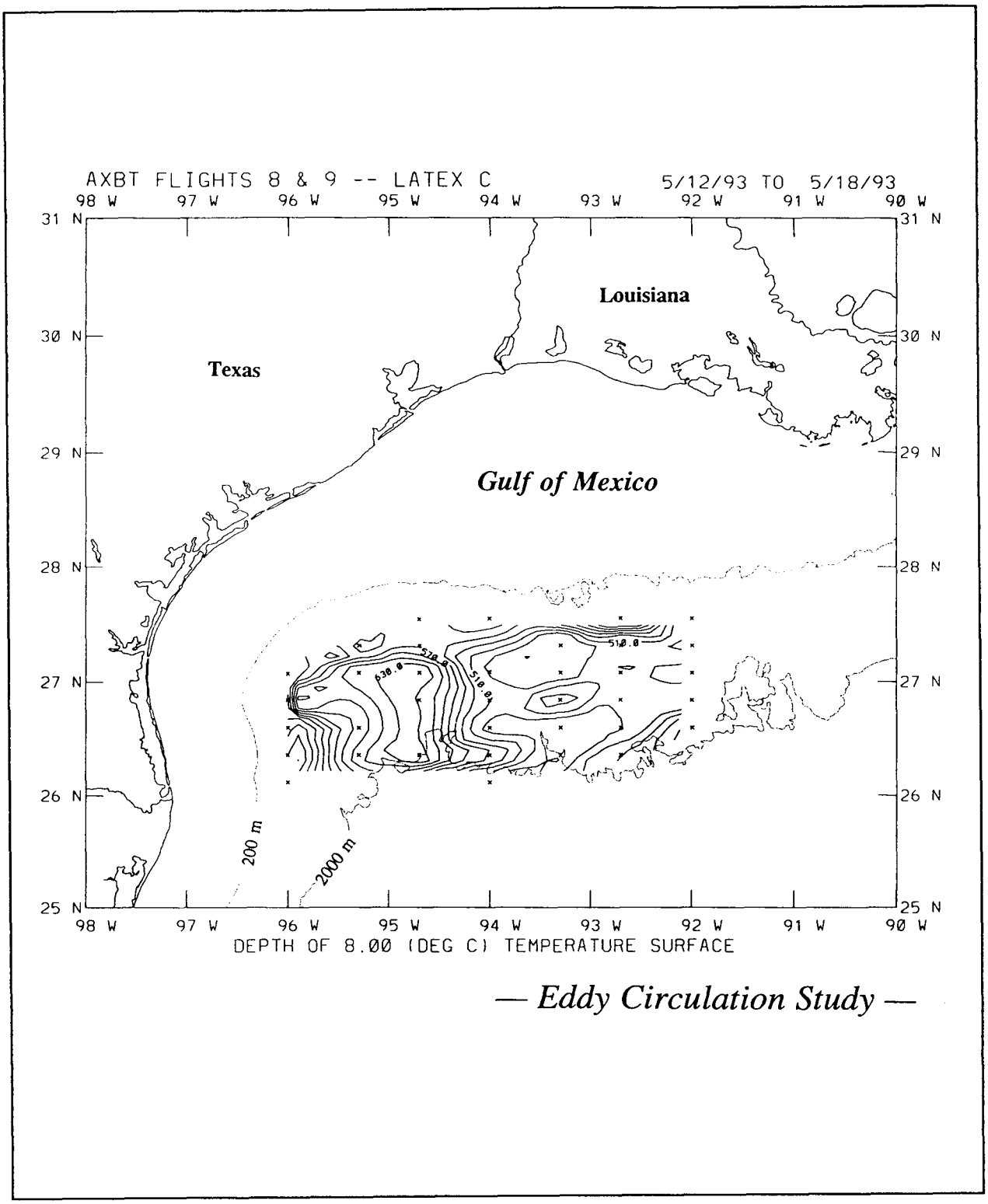

Figure 3.1-6. Depth of the 8°C isotherm from F08SLOPE and F09SEDDY AXBT data.

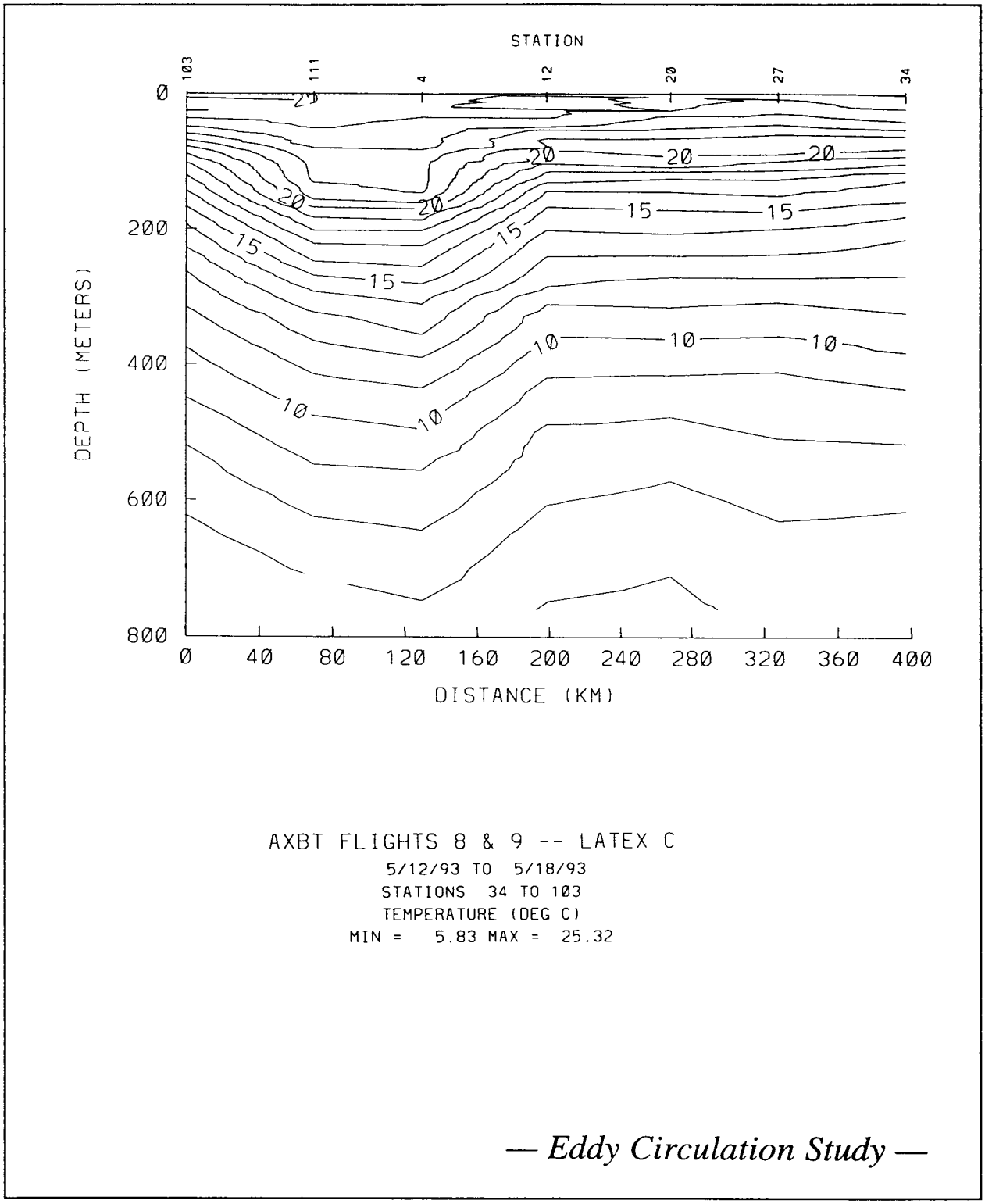

Figure 3.1-7. East-west 800 m section at approximately 27°05'N from F08SLOPE and F09SEDDY AXBT data.

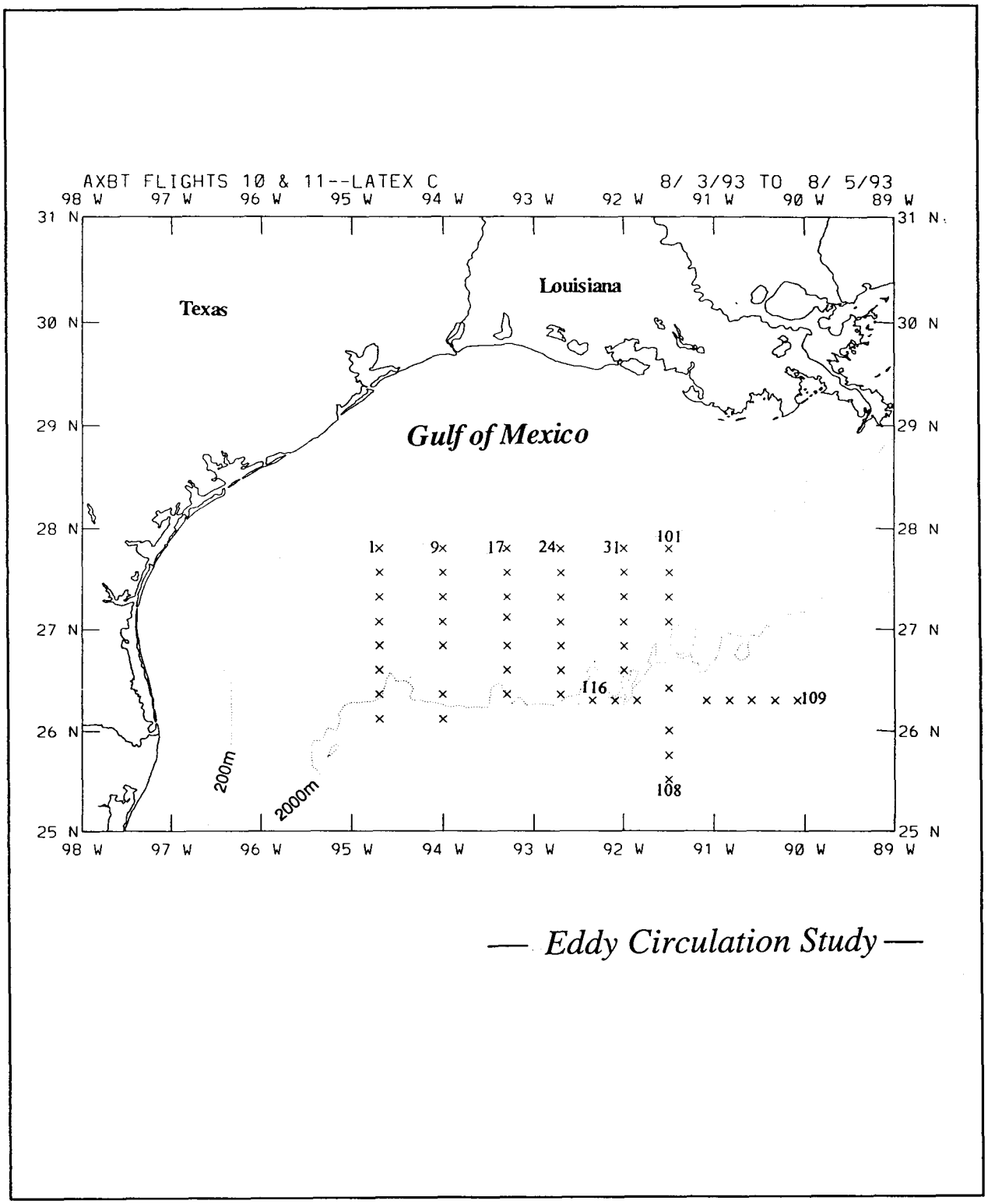

Figure 3.1-8. Station plot for surveys F10SLOPE and F11LEDDY.

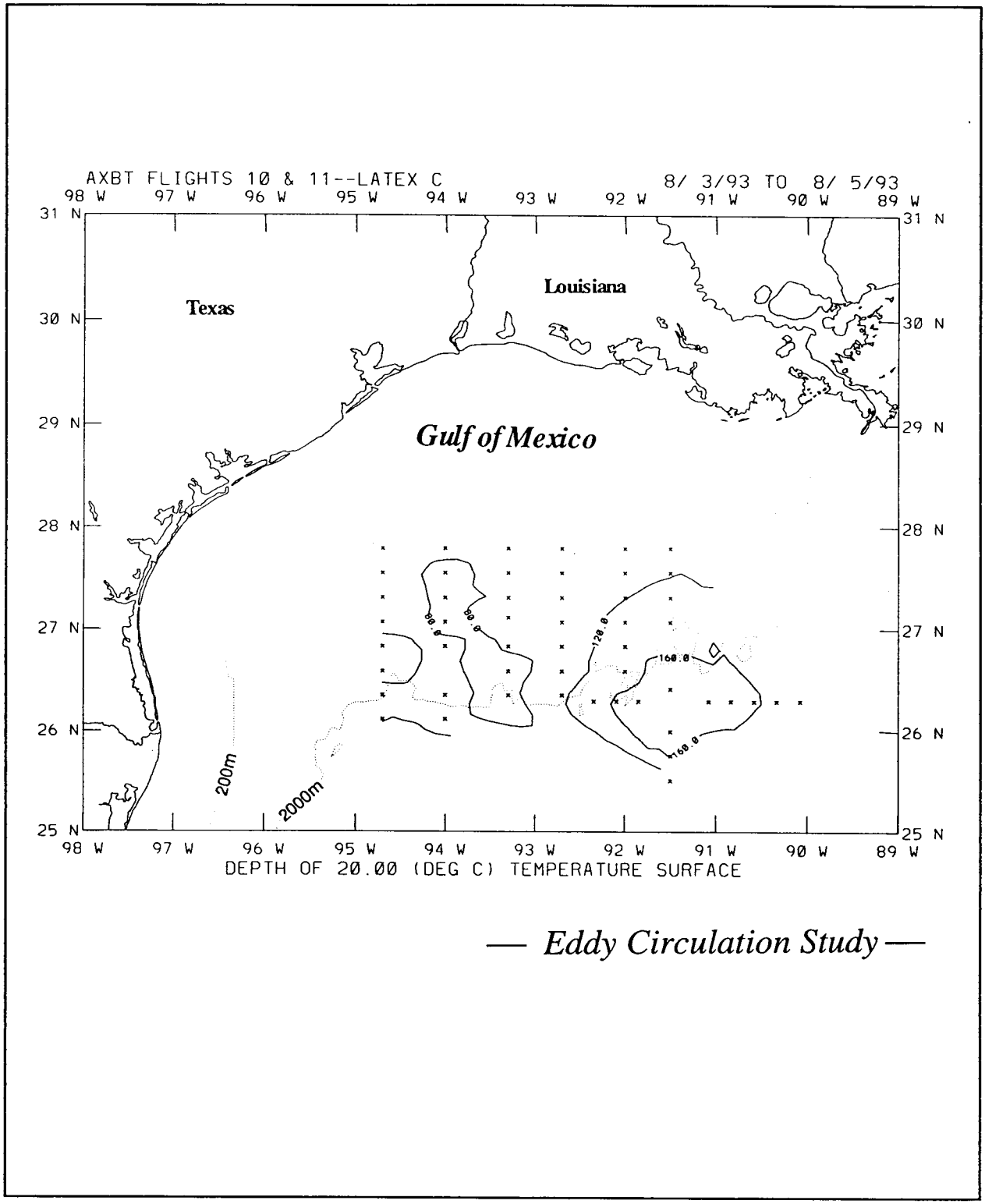

Figure 3.1-9. Depth of the 20°C isotherm from F10SLOPE and F11LEDDY AXBT data.

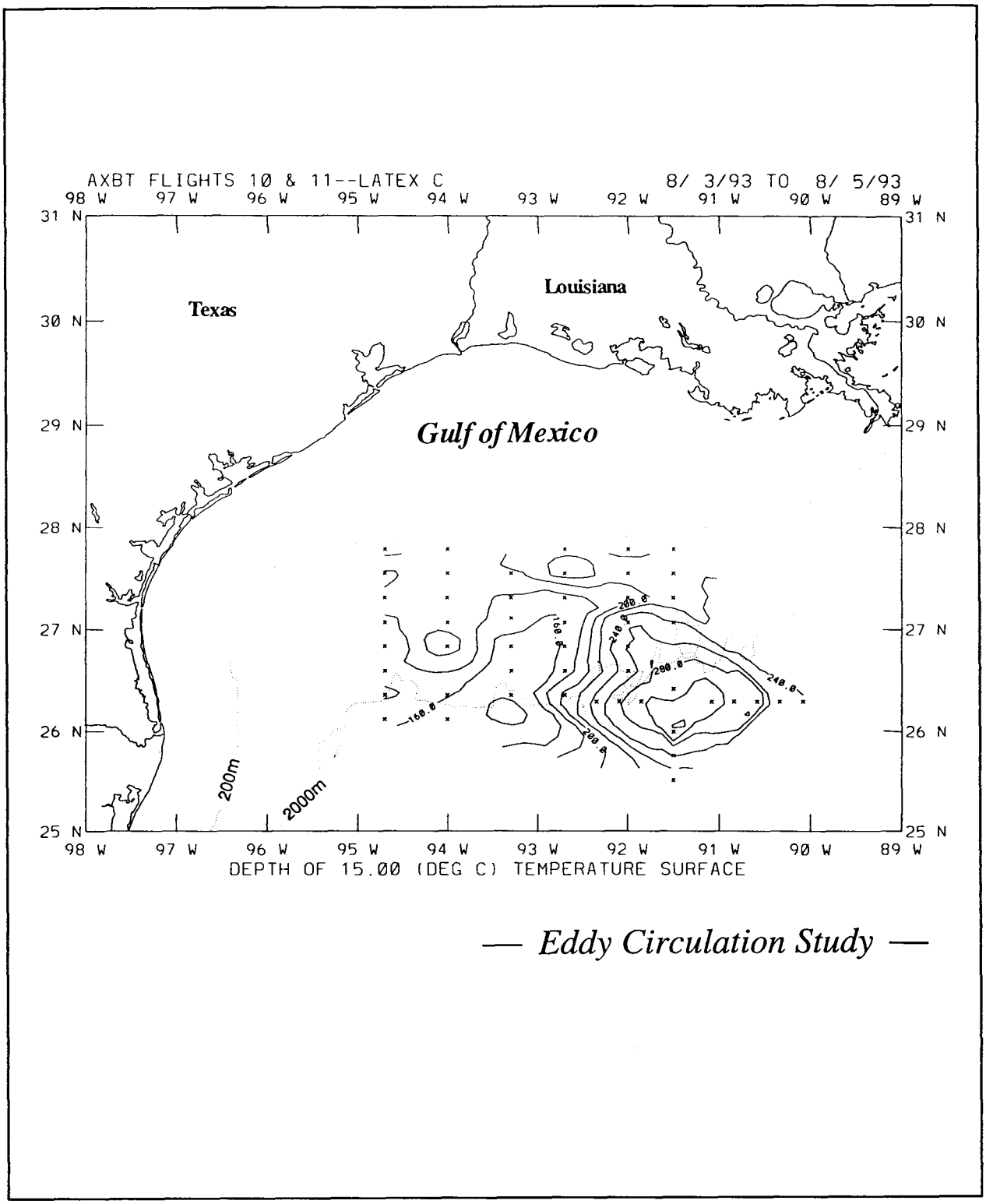

Figure 3.1-10. Depth of the 15°C isotherm from F10SLOPE and F11LEDDY AXBT data.

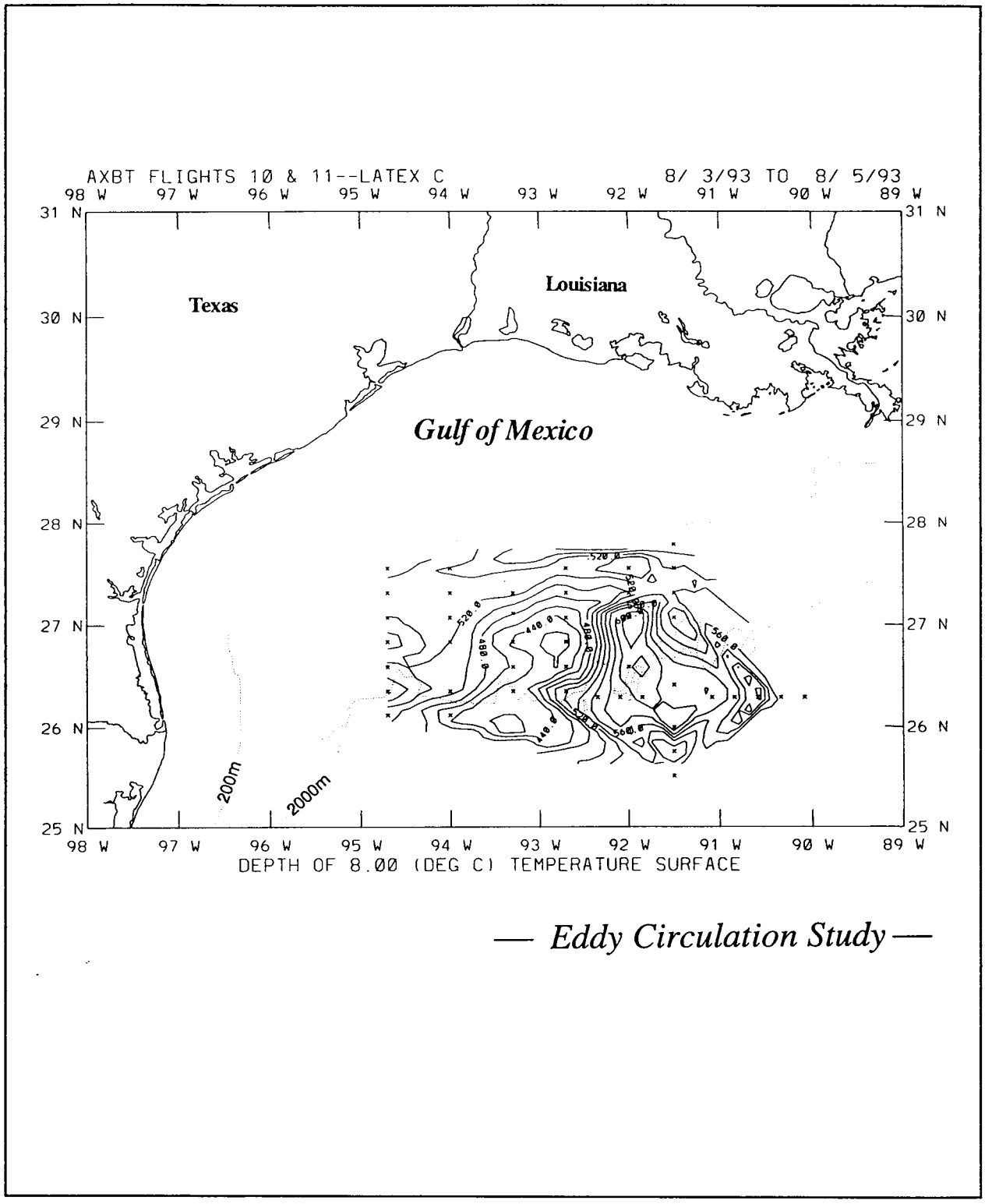

Figure 3.1-11. Depth of the 8°C isotherm from F10SLOPE and F11LEDDY AXBT data.

and 8°C isotherms, respectively, from the combined data sets. Figure 3.1-12 shows an east-west section through the survey area.

Slope Survey 6 (F12SLOPE)

The sixth Slope Survey (F12SLOPE) was completed in two legs between October 28 and November 1, 1993, as shown in Figure 3.1-13. Figure 3.1-14, 3.1-15, and 3.1-16 show the depths of the 20°C, 15°C, and 8°C isotherms, respectively. Two probable cyclones and an anticyclone are observable in the data. Figure 3.1-17 shows an east-west section through the survey area.

3.1.2 Loop Current Eddies

Two Loop Current Eddy Surveys were planned during Year 2, in April and October 1993, based on an estimated nine month eddy shedding period for Loop Current eddies and the expectation that an eddy would have been shed early in 1992 just prior to Year 1. The two surveys were actually conducted in August 1993 and December 1993.

Eddy W (F11LEDDY)

A survey of Eddy W (F11LEDDY) was completed on August 5, 1993 following a Slope Survey (F10SLOPE). The plan for the Loop Current Eddy survey was drawn to augment data collected during F10SLOPE and thus provide a fuller view of Eddy W. Figure 3.1-18 shows the station locations for both F10SLOPE and F11LEDDY. Figure 3.1-19 shows the depth of the 15°C isotherm determined solely from F11LEDDY data. Figure 3.1-20 shows the path of Drifter 2448, which was deployed in Eddy W on June 2, 1993 from R/V GYRE, combined with the station locations for F10SLOPE and F11LEDDY.

Eddy X (F14LEDDY)

A survey of Eddy X (F14LEDDY) was undertaken December 23, 1993 following F13SQURT as shown in Figure 3.1-21. No drifter was deployed following the survey since drifter 7838 had been deployed in the eddy on December 9, 1993 from R/V PELICAN. Figure 3.1-22 shows the depth of the 20°C isotherm determined from this survey.

3.1.3 Squirts and Jets Surveys

The first double Squirts and Jets survey was conducted in Year 1 and is documented in SAIC (1994). A second double survey (F13SQURT) was completed in Year 2 and is described below.

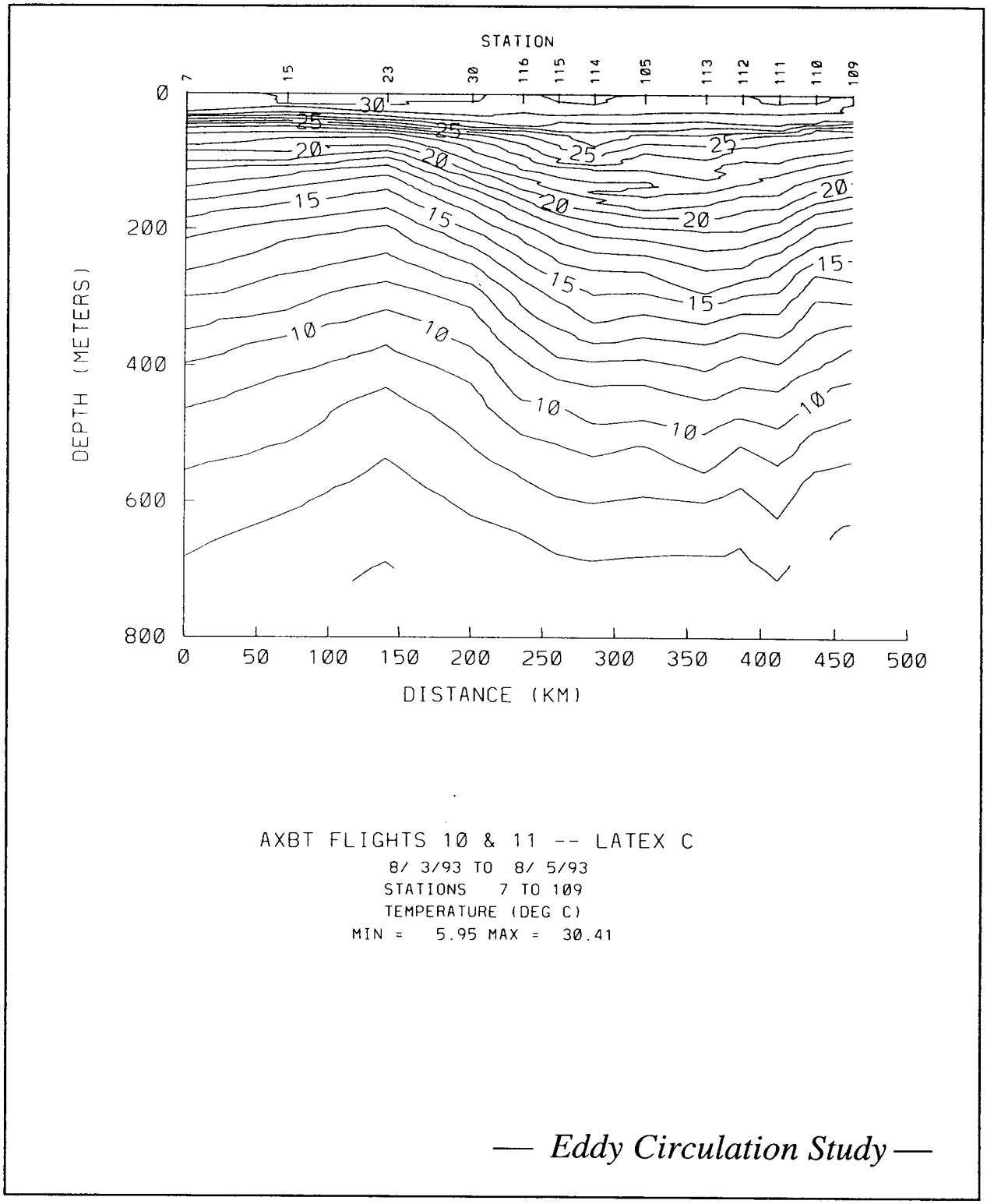

Figure 3.1-12. East-west 800 m section at approximately 26°05'N from F10SLOPE and F11LEDDY AXBT data.

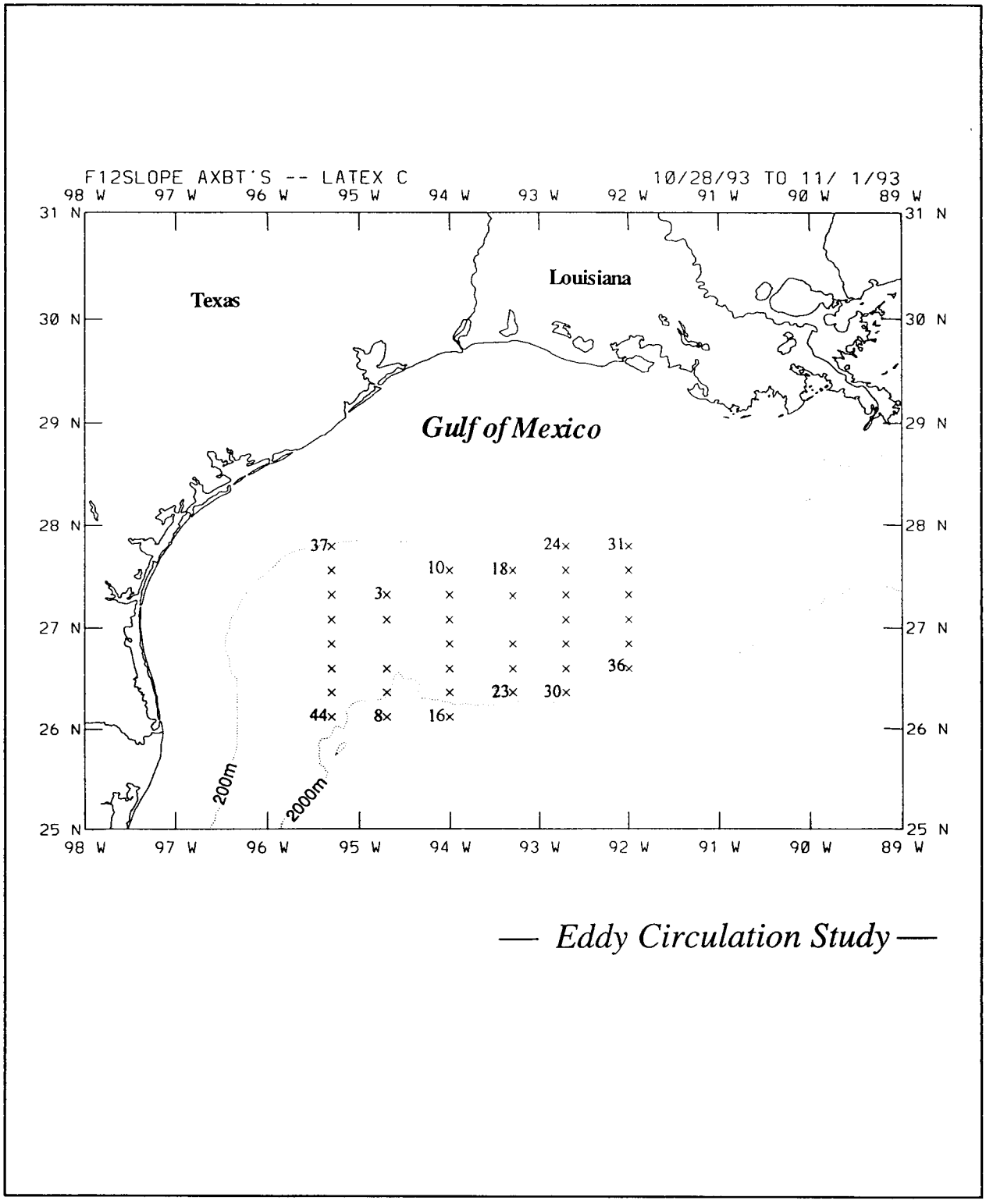

Figure 3.1-13. Station plot for survey F12SLOPE.

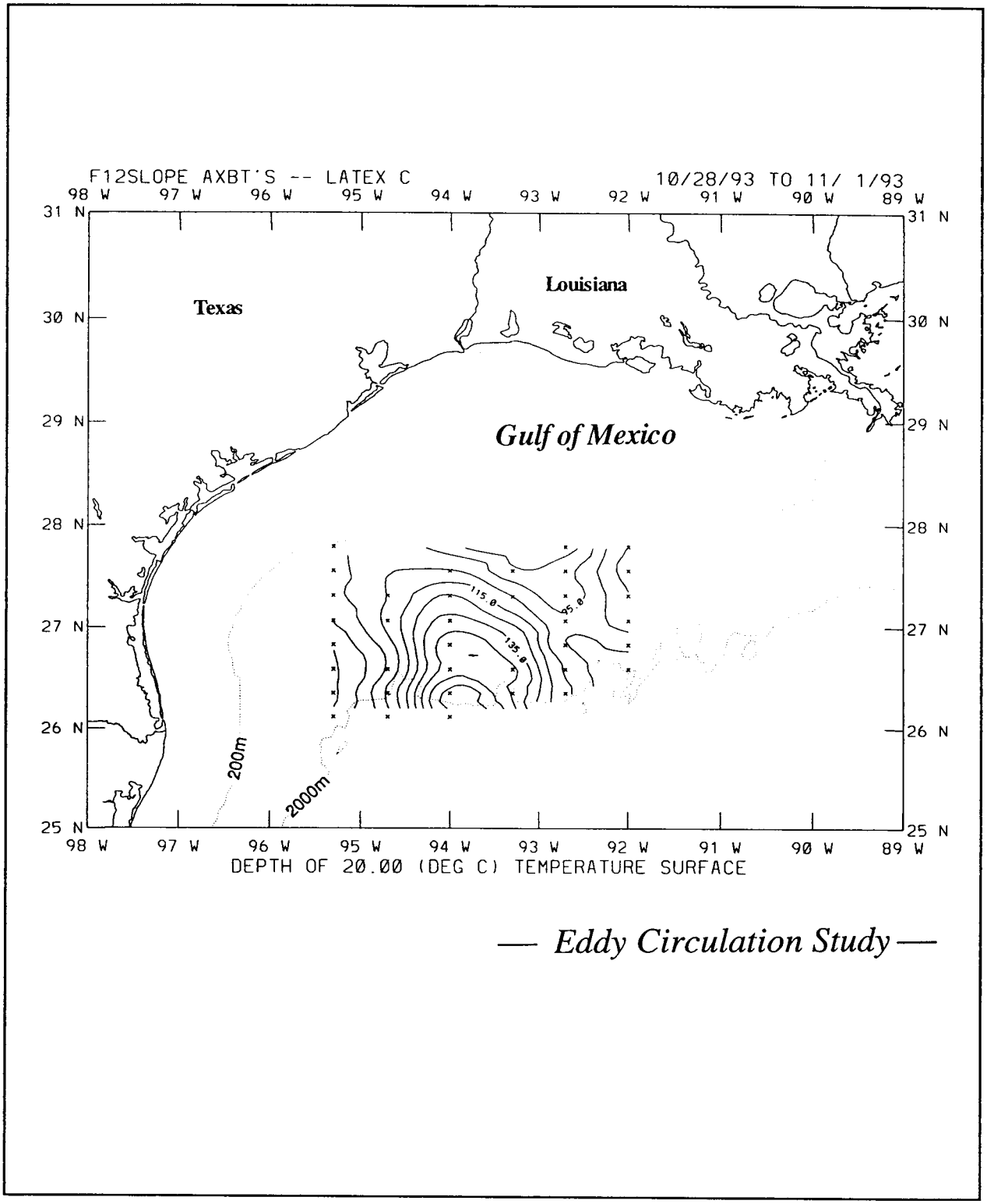

Figure 3.1-14. Depth of the 20°C isotherm from F12SLOPE AXBT data.

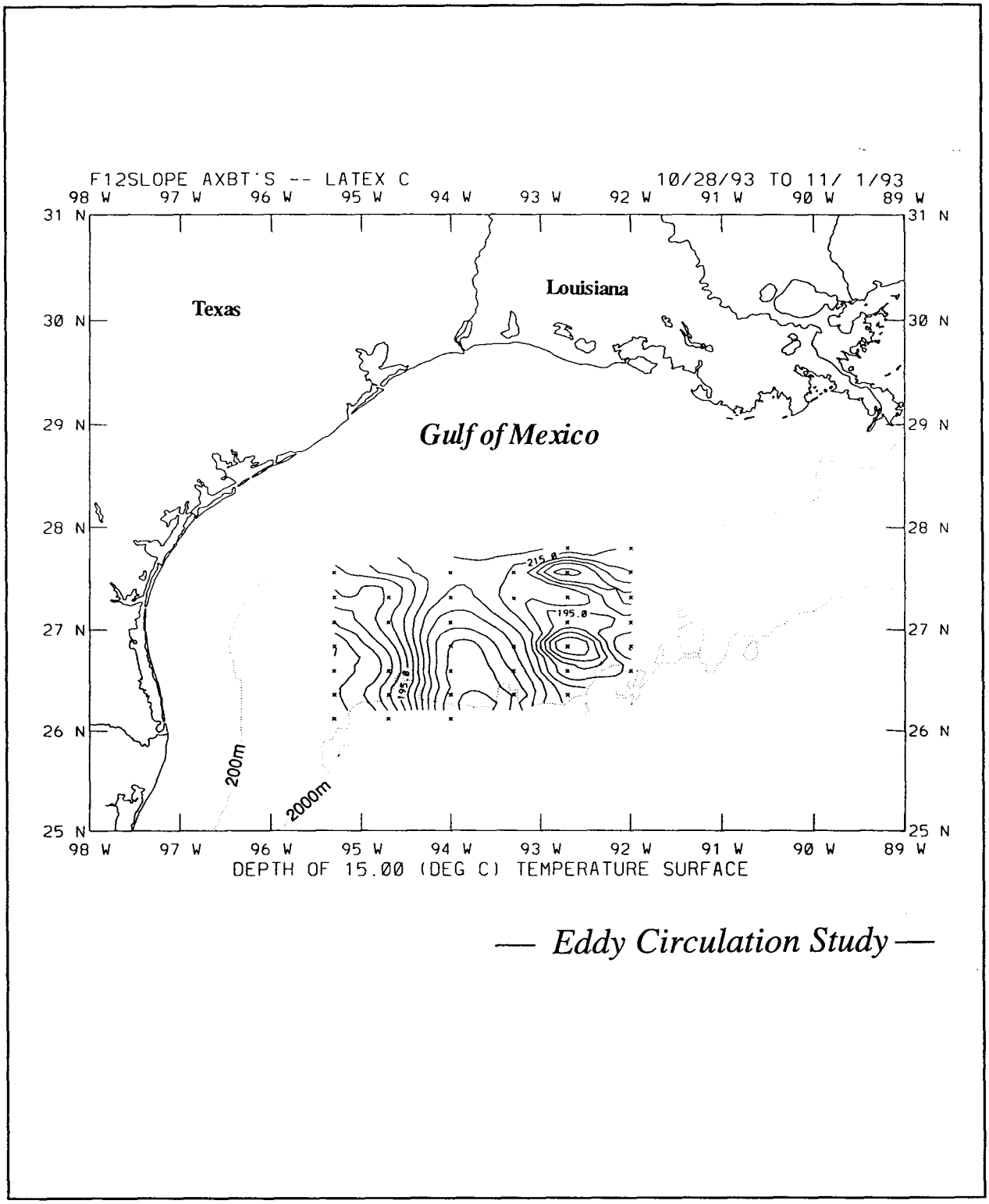

Figure 3.1-15. Depth of the 15°C isotherm from F12SLOPE AXBT data.

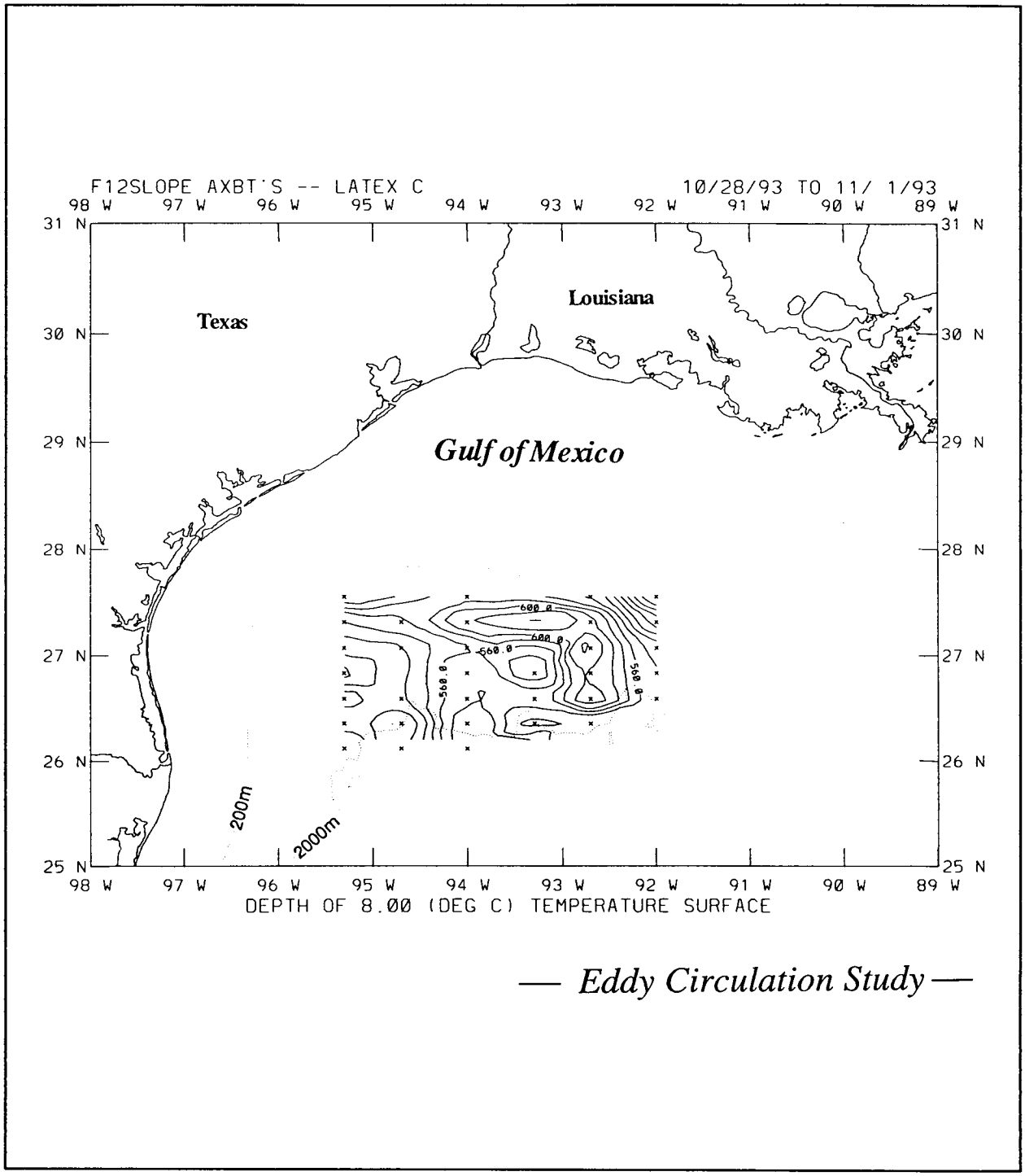

Figure 3.1-16. Depth of the 8°C isotherm from F12SLOPE AXBT data.

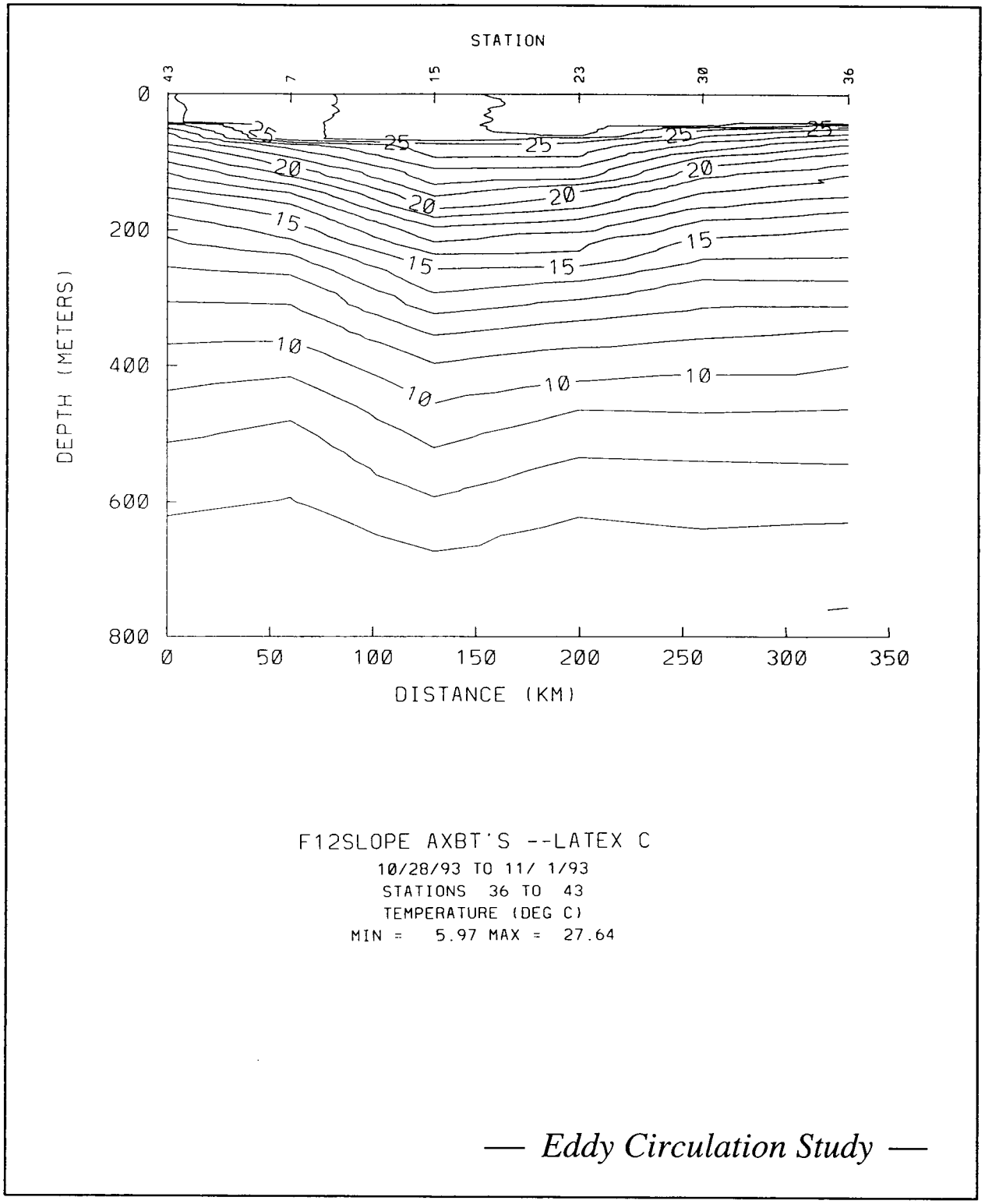

Figure 3.1-17. East-west 800 m section at approximately 26°22'N from F12SLOPE AXBT data.

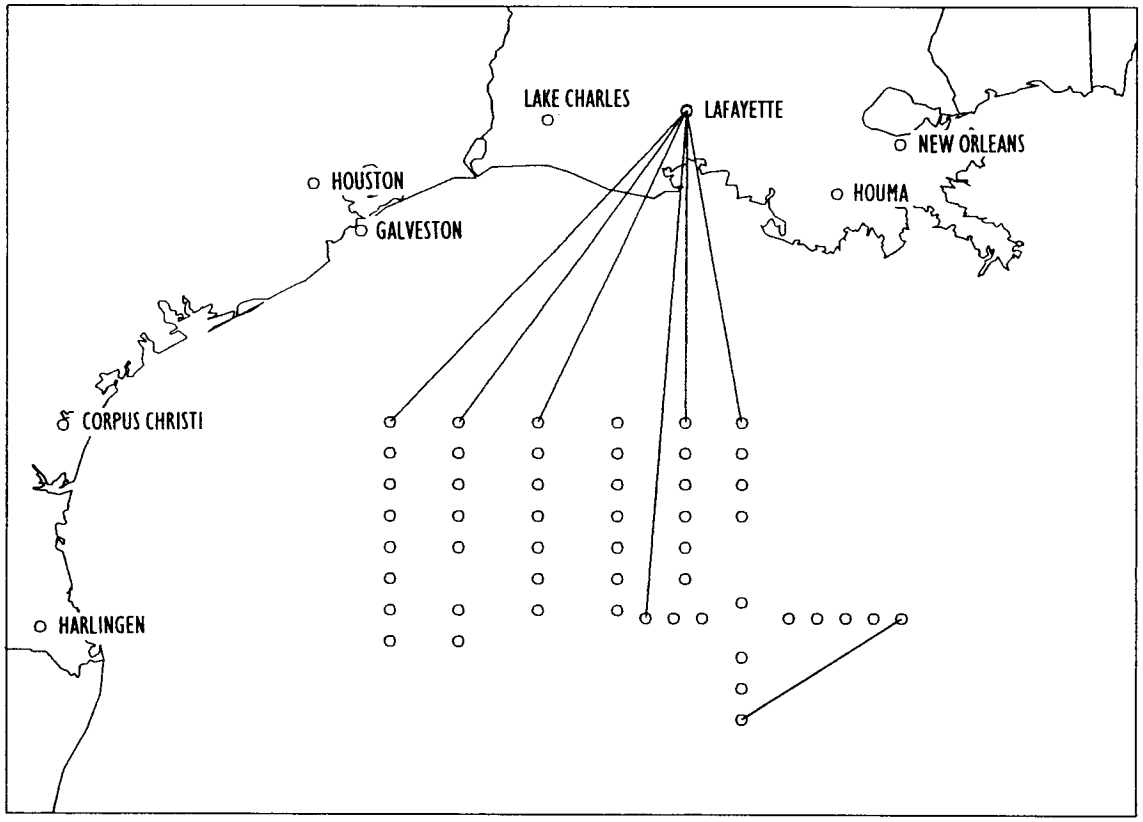

Figure 3.1-18. Station plot of F10SLOPE and F11LEDDY in *opcplot* format.

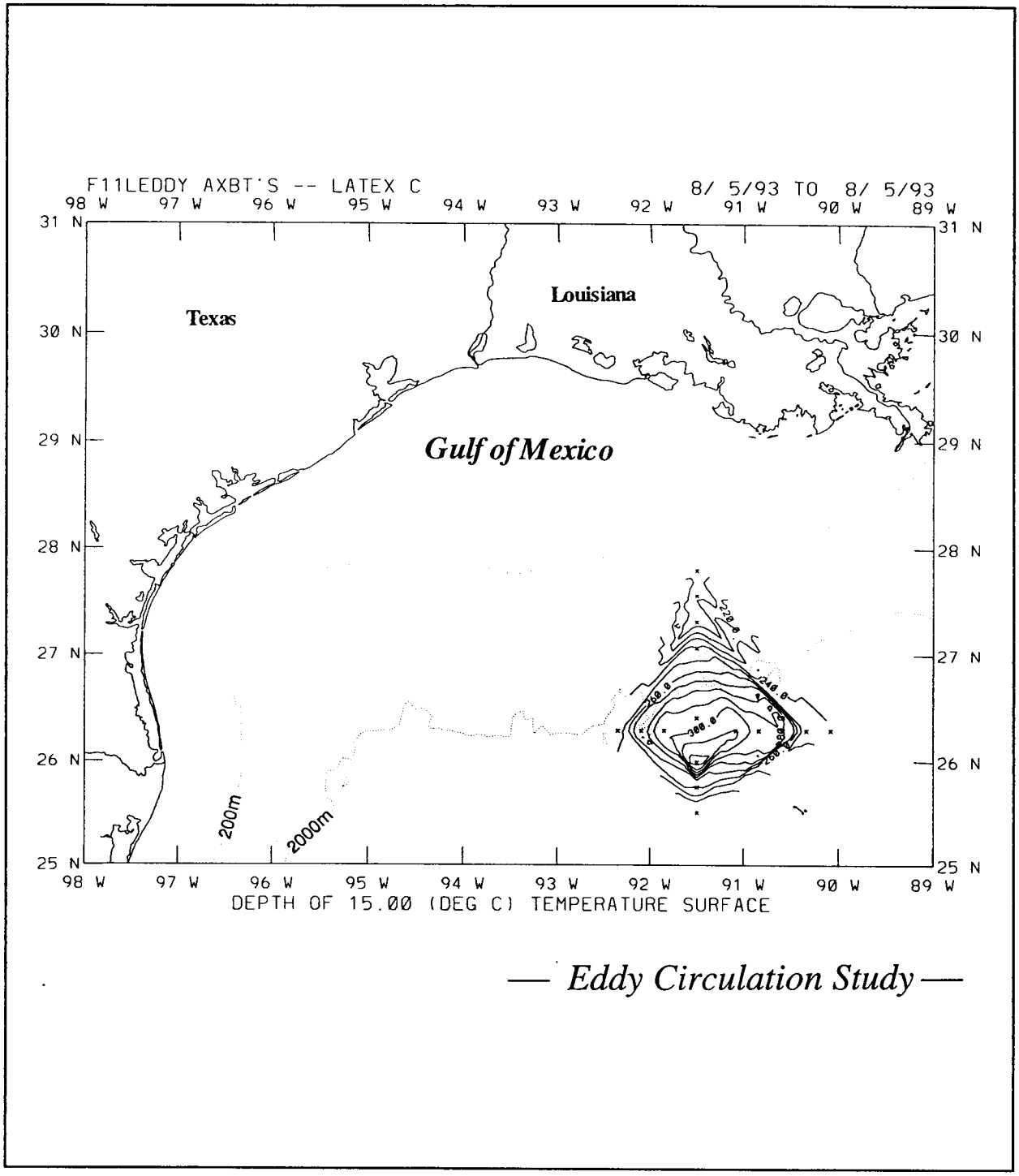

Figure 3.1-19. Depth of the 15°C isotherm only from survey F11LEDDY AXBT data.

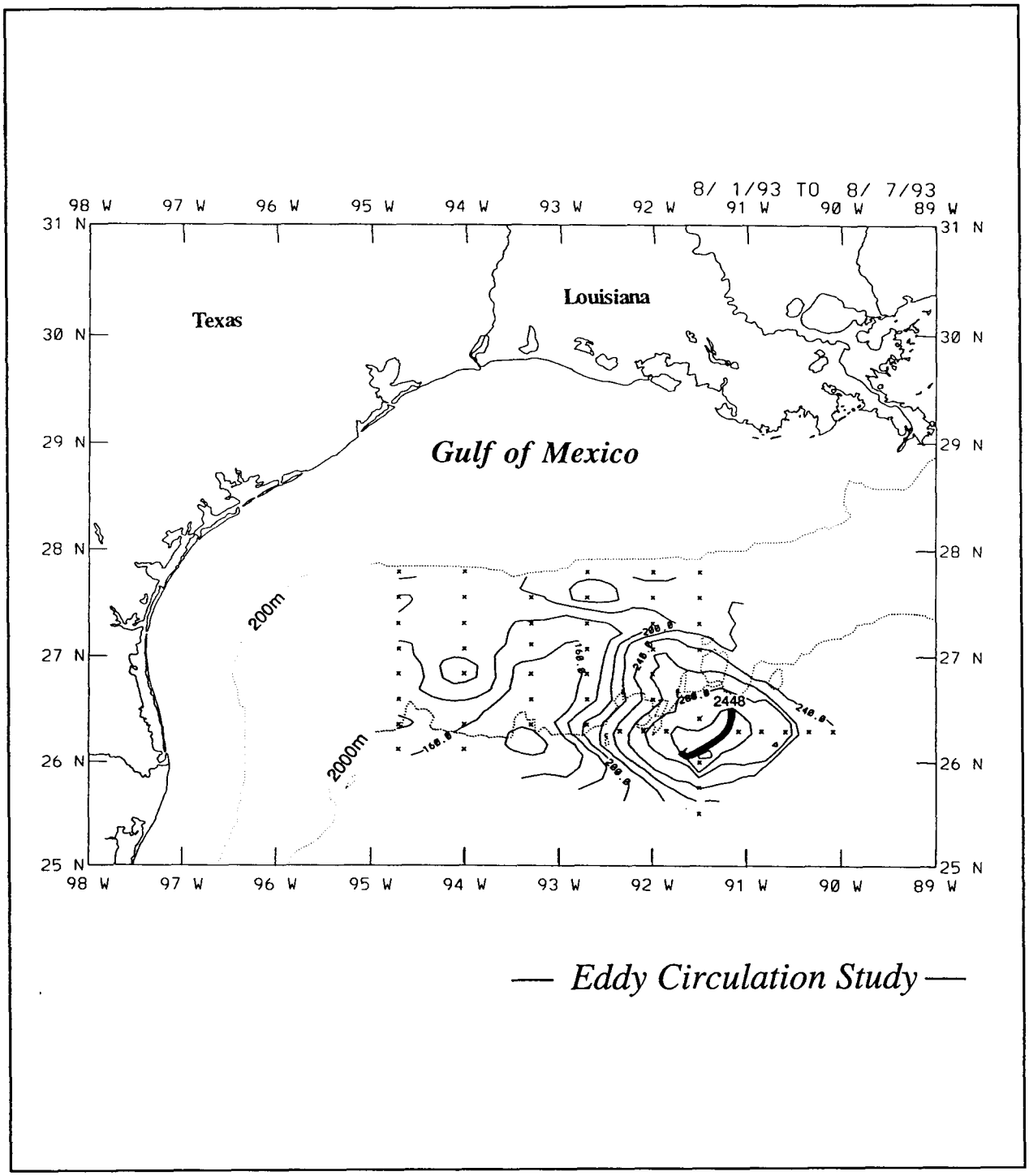

Figure 3.1-20. Plot of Drifter 2448 during period August 1-7, 1993 and the depth of the 15°C isotherm from F10SLOPE and F11LEDDY AXBT data.

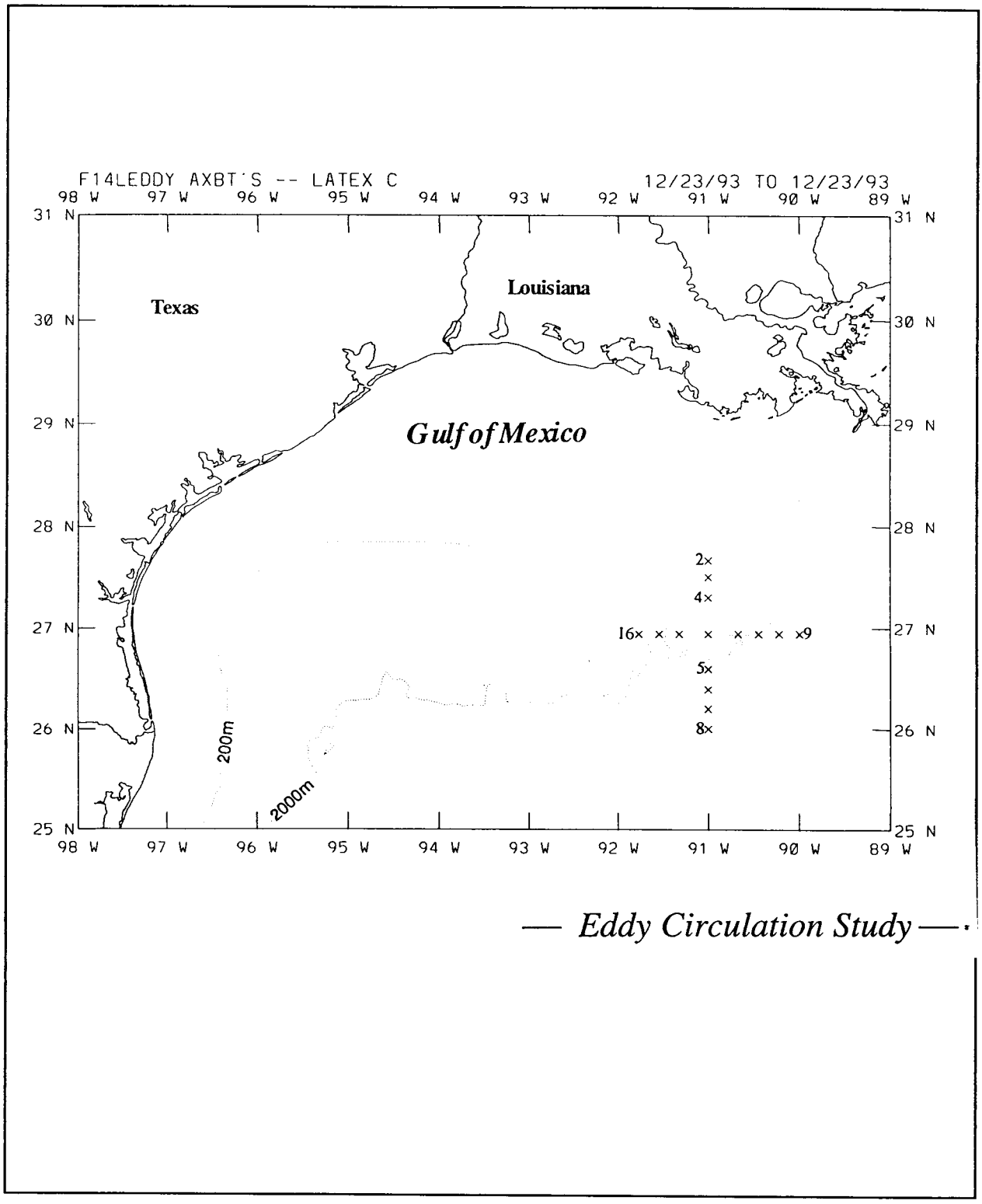

Figure 3.1-21. Station plot for survey F14LEDDY.

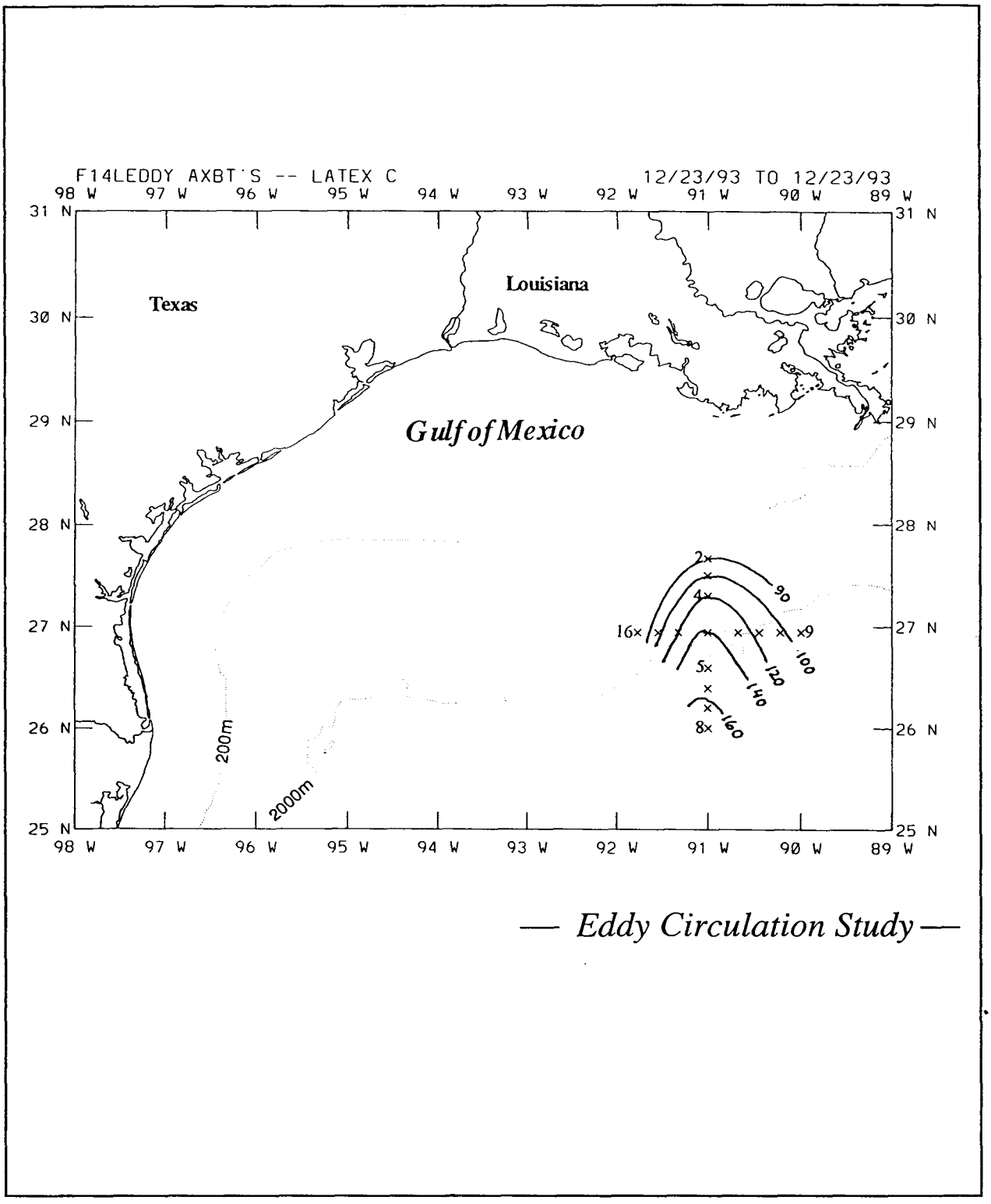

Figure 3.1-22. Depth of the 20°C isotherm from F14LEDDY AXBT data.

Modified Squirts and Jets Survey (F13SQURT)

F13SQURT was undertaken December 16-21, 1993 in possible cyclone between Eddy X and another possible large anticyclone at about 26°30'N 94°00'W. A 63-station AXBT survey was first completed December 16-18, 1993 as shown in Figure 3.1-23, along with survey F14LEDDY. Figures 3.1-24, 3.1-25, and 3.1-26 show the depths of the 20°C, 15°C, and 8°C isotherms determined from F13SQURT and F14LEDDY AXBT data. Figure 3.1-27 shows an 800 m deep, east-west section along 27°00'N from the combined surveys. Four drifters (7842, 7843, 7844, and 7845) were deployed on December 19, 1993 in the cyclone confirmed by the AXBT data. A 16-station AXCP survey was completed on December 21, 1993 through the drifter deployment area as shown in Figure 3.1-28. Figure 3.1-29 shows the first two days of two drifter tracks (7842 and 7843) and the currents above the 15°C isotherm as determined from the AXCP data.

3.2 Task C-7: Altimetry

The goal of this task is to produce an altimeter derived climatology from the GEOSAT Geodetic and ERM altimeter data sets. Over four years of altimeter data were collected from these combined missions, spanning the time period from April 1985 through December 1989, during which six major and at least two minor Loop Current eddies were directly observed.

To produce the final report climatology, CCAR has generated a gridded archive using the existing NOAA geophysical data record (GDR) GEM-T2 GEOSAT ERM data set available on compact disk read only memory (CD-ROM). This archive includes the 62 cycles of data that were obtained before the GEOSAT tape recorder failed in September 1989 and the line of sight data stream collected over the Gulf of Mexico by The Johns Hopkins University Applied Physics Laboratory until the ultimate failure of the satellite in January 1990.

A significantly improved version of the GEOSAT ERM data is in preparation for release in late spring or early summer 1995 by the National Oceanographic Data Center (NODC). This release will include new 10-cm orbits computed by the Goddard Space Flight Center, a more accurate ocean tide model derived from TOPEX/Poseidon altimeter data and a more reliable ionosphere correction from the IRI-90 model. If time permits, this data set can be used to compute the GEOSAT ERM topographic analyses for the program. Regridding of the altimeter data for collinear processing

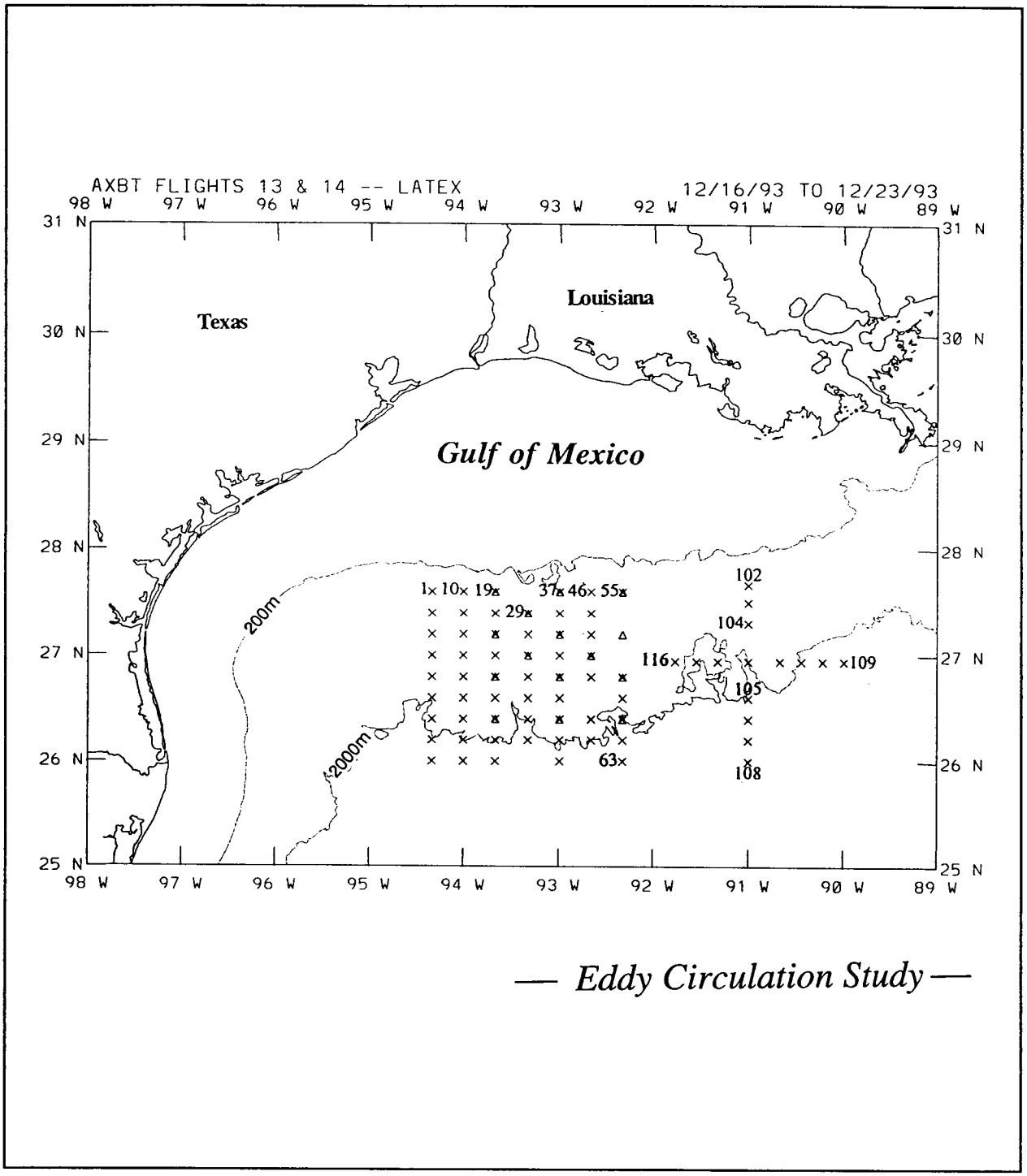

Figure 3.1-23 Station plot for surveys F13SQURT and F14LEDDY. AXBT stations are indicated by × and AXCP stations by ▵.

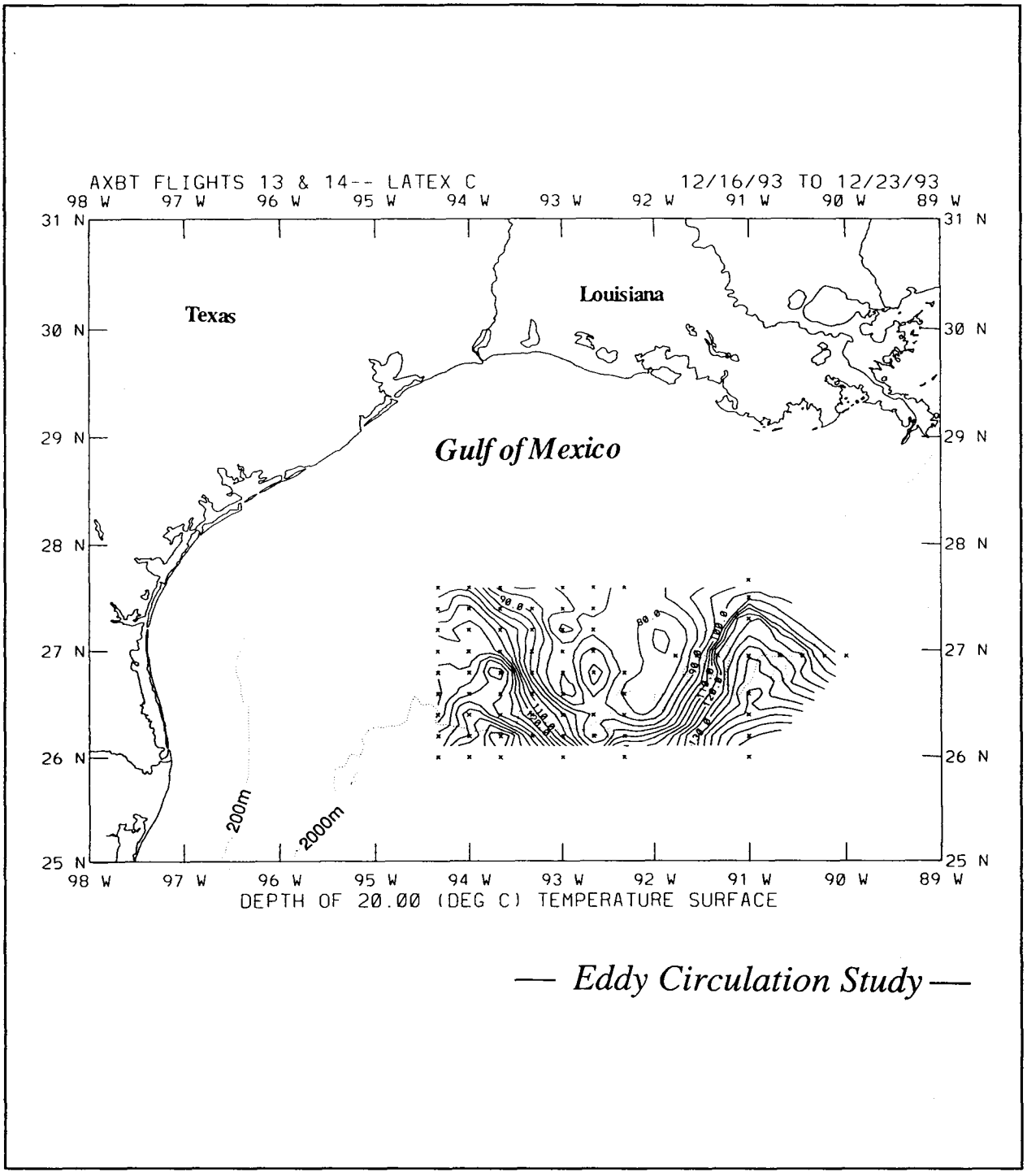

Figure 3.1-24. Depth of the 20°C isotherm from F13SQURT and F14LEDDY AXBT data.

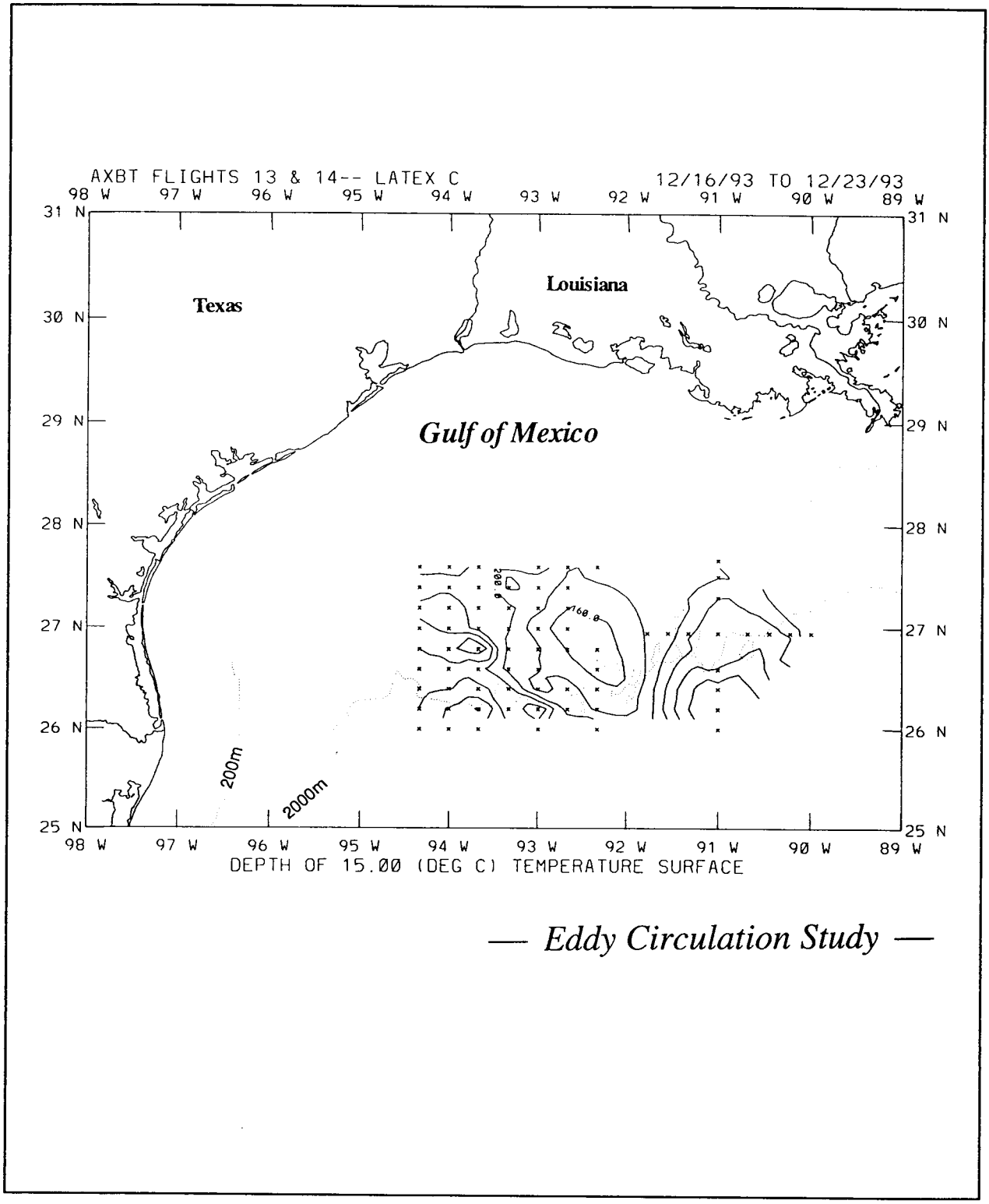

Figure 3.1-25. Depth of the 15°C isotherm from F13SQURT and F14LEDDY AXBT data.

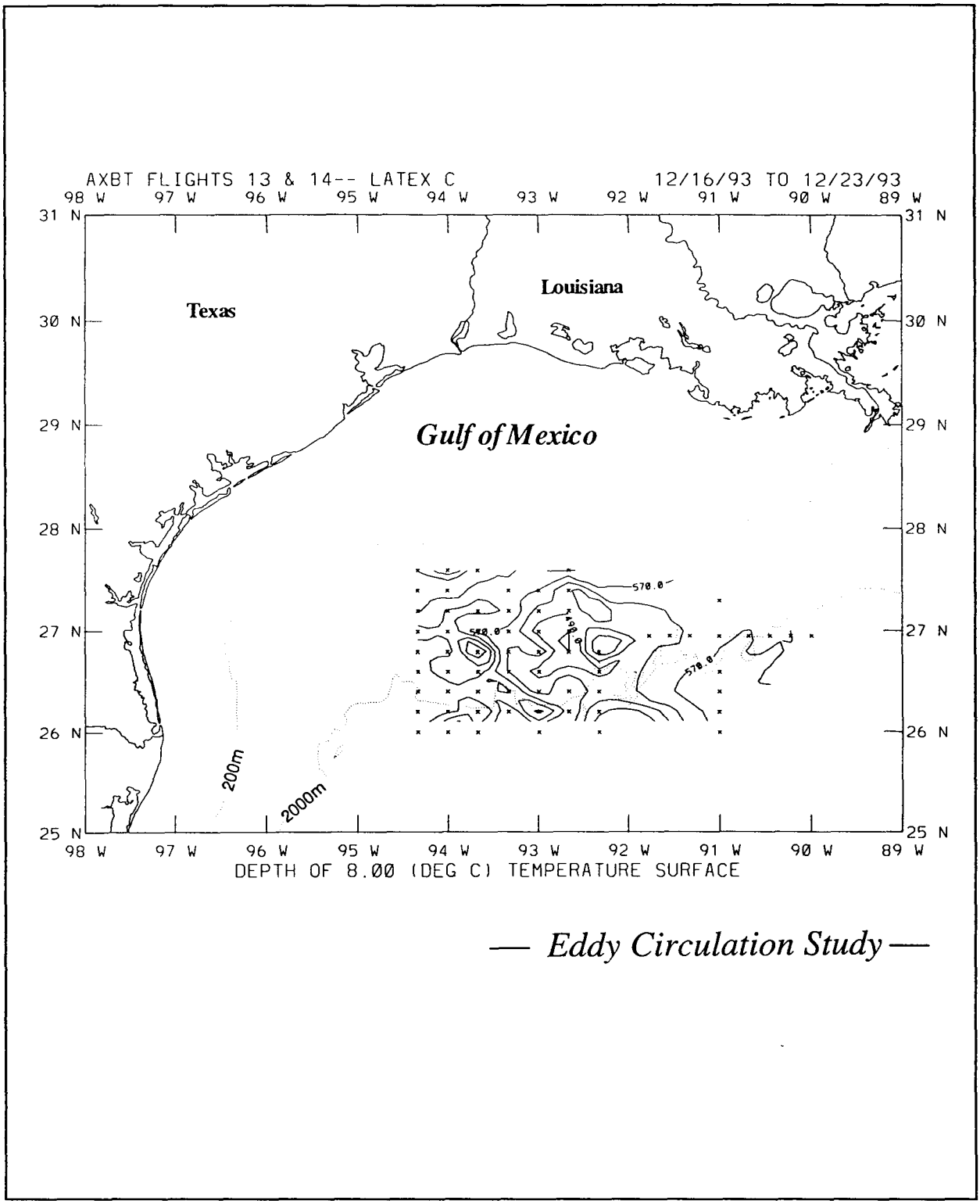

Figure 3.1-26. Depth of the 8°C isotherm from F13SQURT and F14LEDDY AXBT data.

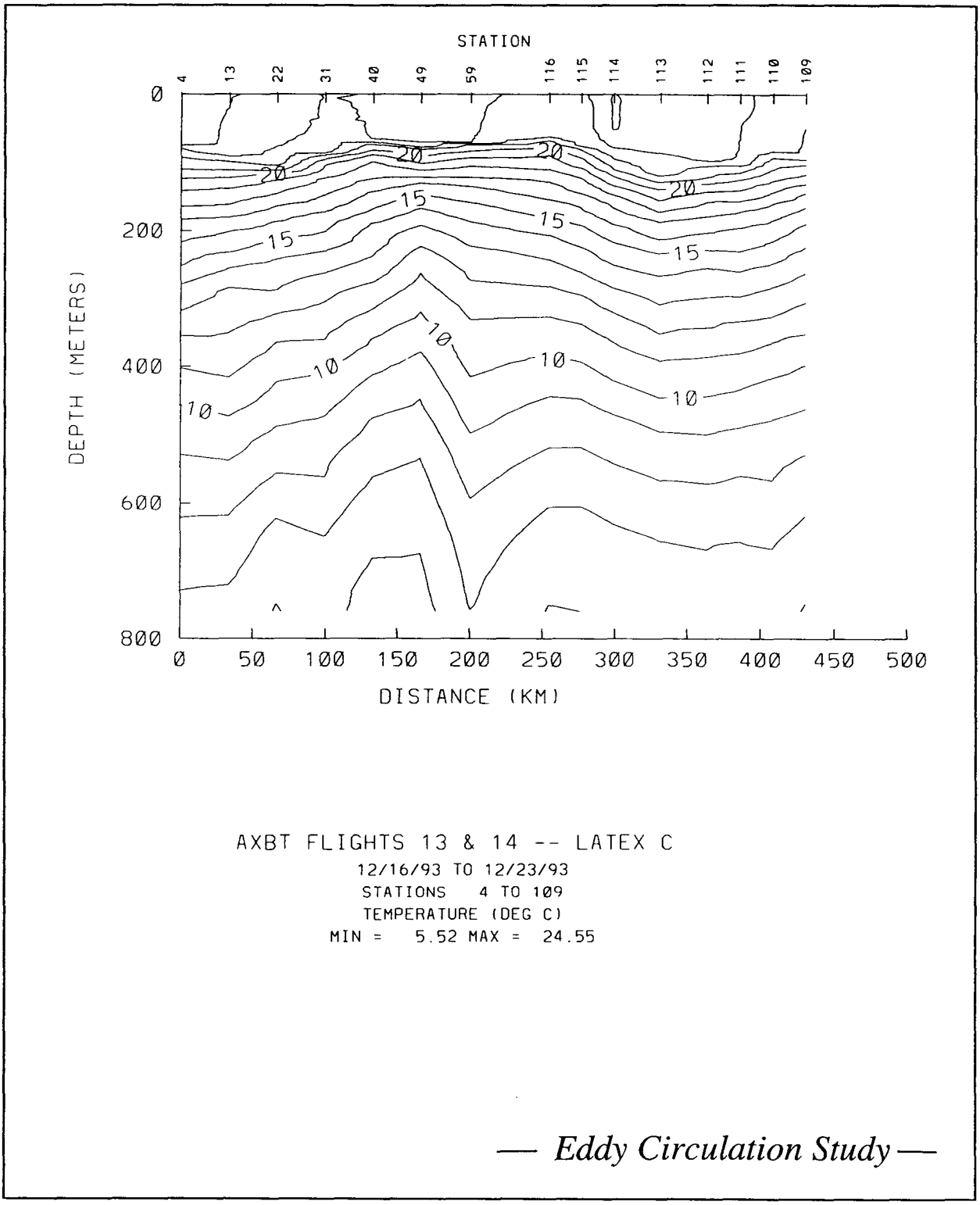

Figure 3.1-27. East-west 800 m section at approximately 27°00'N from F13SQURT and F14LEDDY AXBT data.

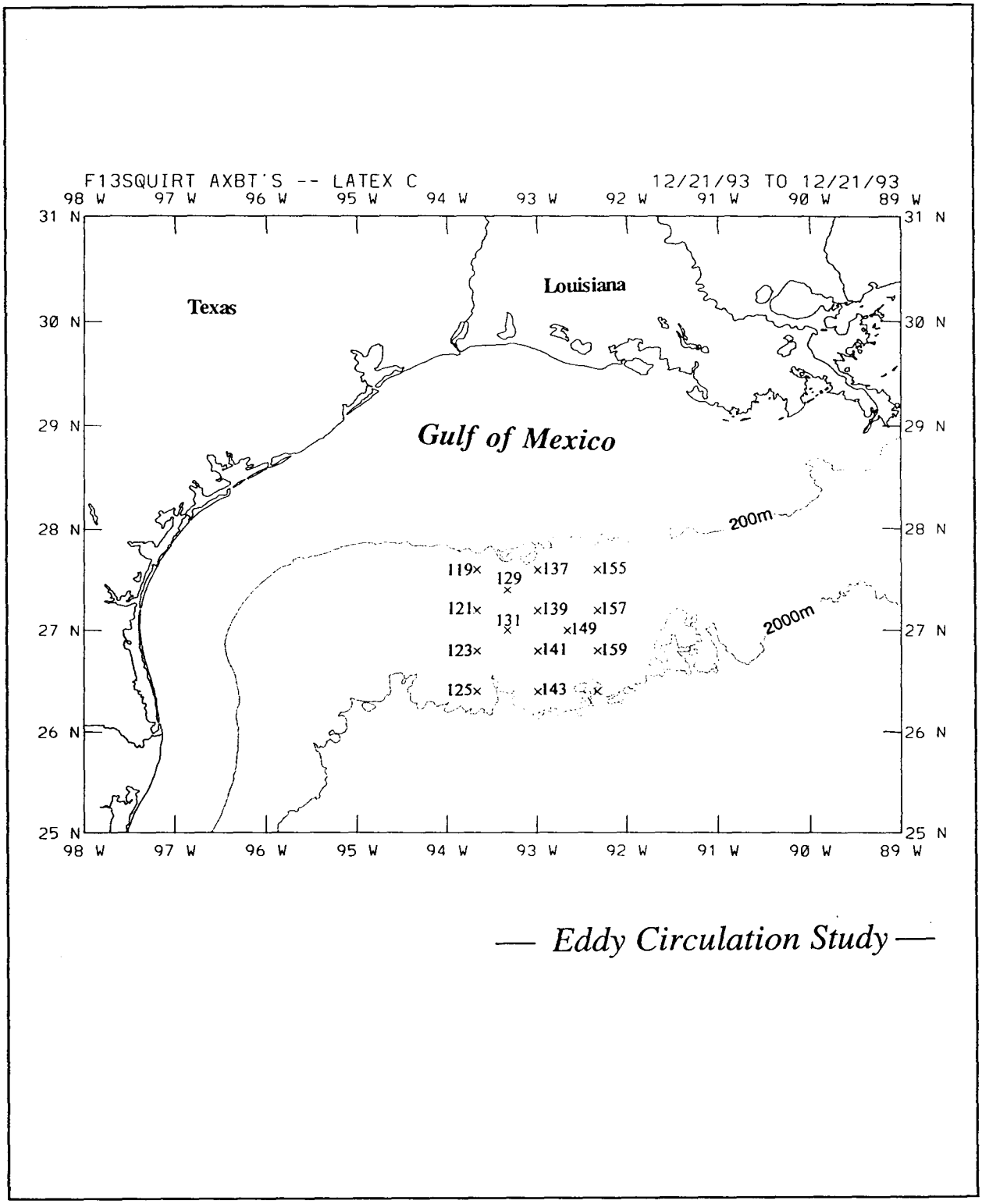

Figure 3.1-28. Station plot for F13SQURT AXCP survey.

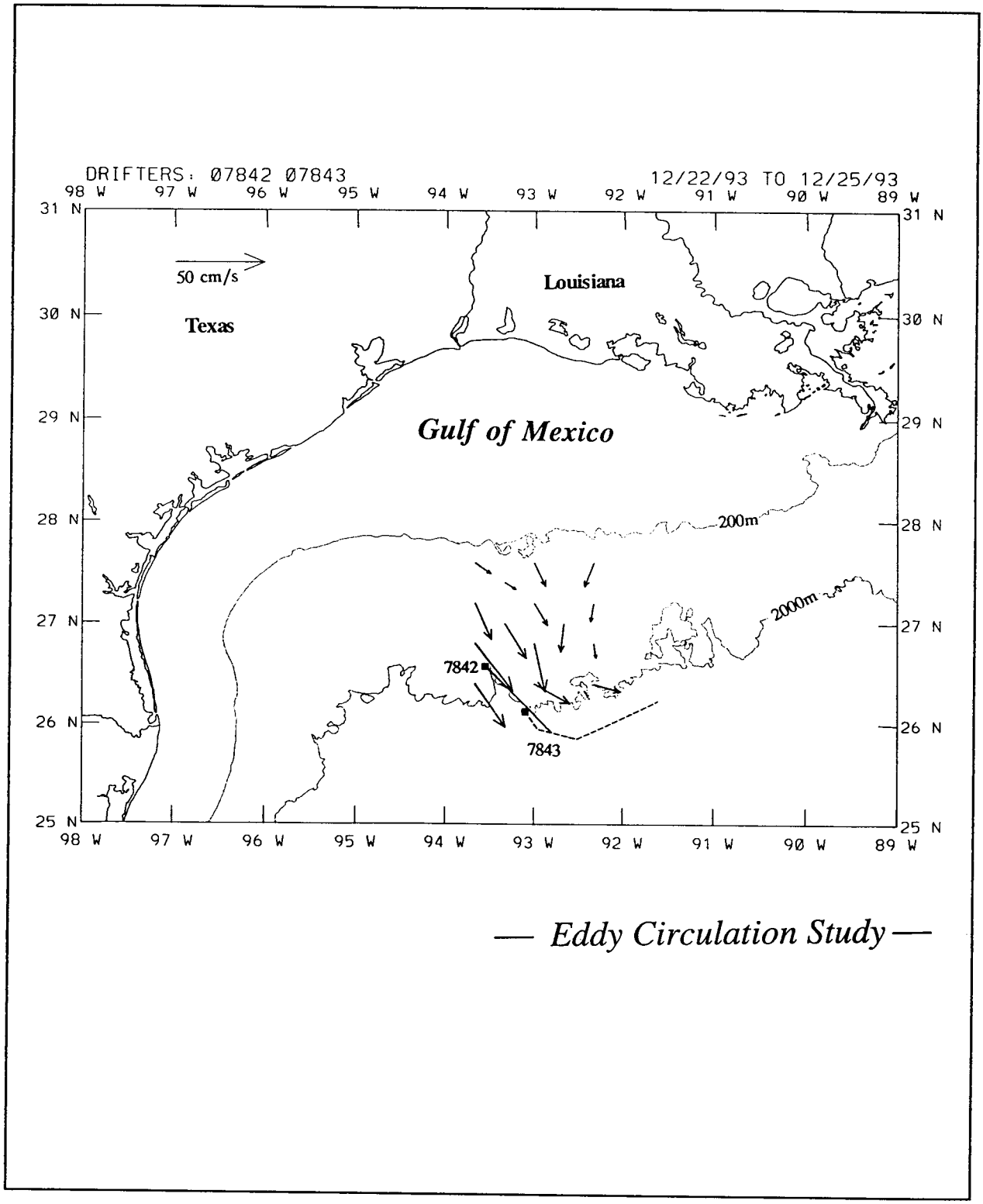

Figure 3.1-29. Currents above the 15°C isotherm from F13SQURT AXCP data and tracks of drifters 7842 and 7843.

can be performed quickly when the new CDs are available, using the software developed for the NOAA altimeter data format, which is not planned to be changed substantially in the new release (J. Lillibridge, NOAA/NODC, personal communication).

Research efforts at CCAR during Year 2 have focused on validating techniques which will be used to produce the GEOSAT derived altimetric data sets. Validation has been performed using TOPEX and ERS-1 data over the Gulf of Mexico by comparisons with LATEX hydrographic surveys and satellite-tracked drifting buoy observations. These comparisons have shown that it is now possible to accurately reference all past, present and future altimetric observations over the Gulf of Mexico to the same mean surface, allowing consistent comparisons and estimates of Loop Current eddy center paths, translation speeds and dynamic height anomalies. A byproduct of this validation effort has been production of a TOPEX and ERS-1 Gulf of Mexico climatology spanning the time period from April 1992 to December 1993, and near real-time altimetry products from TOPEX/Poseidon which are continually updated as those data become available. These products have been made available to LATEX Principal Investigators and can also be viewed on the World Wide Web (http://shaman.colorado.edu/gom.html).

Production of a "climatological" mean reference surface which can be used to accurately reference sea surface topography from the GEOSAT time period has been completed. A mean slope has also been computed from this reference surface. The altimetric mean reference surface selected is a gridded mean surface (Basic and Rapp 1992) which is referred to as the Rapp mean, and is based on a combination of 3½ years of GEOS 3, three months of Seasat and 22 cycles (approximately one year) of GEOSAT ERM altimeter data and bathymetric data. This mean surface estimate over the Gulf of Mexico is one of the most accurate available because of the high spatial resolution of the GEOS-3 data and the use of bathymetric data to improve accuracy at short length scales, and so was selected over a mean surface computed from only GEOSAT along-track data. A method has been developed for correcting the Rapp mean surface for short wavelength geoid errors, allowing accurate referencing of both historical and current repeat track altimeter data. The accuracy of this mean surface has been validated by comparisons of altimetry derived products with surveys and drifting buoys.

Optimally interpolated altimeter data coincident with the October 28-31, 1992 R/V GYRE Cruise 92G-13 are shown in Figure 3.2-1. Station locations are shown as filled circles along the cruise transect. Two warm-core rings, Eddies U and V, that were crossed by the survey line are clearly seen in the altimetry. The centers

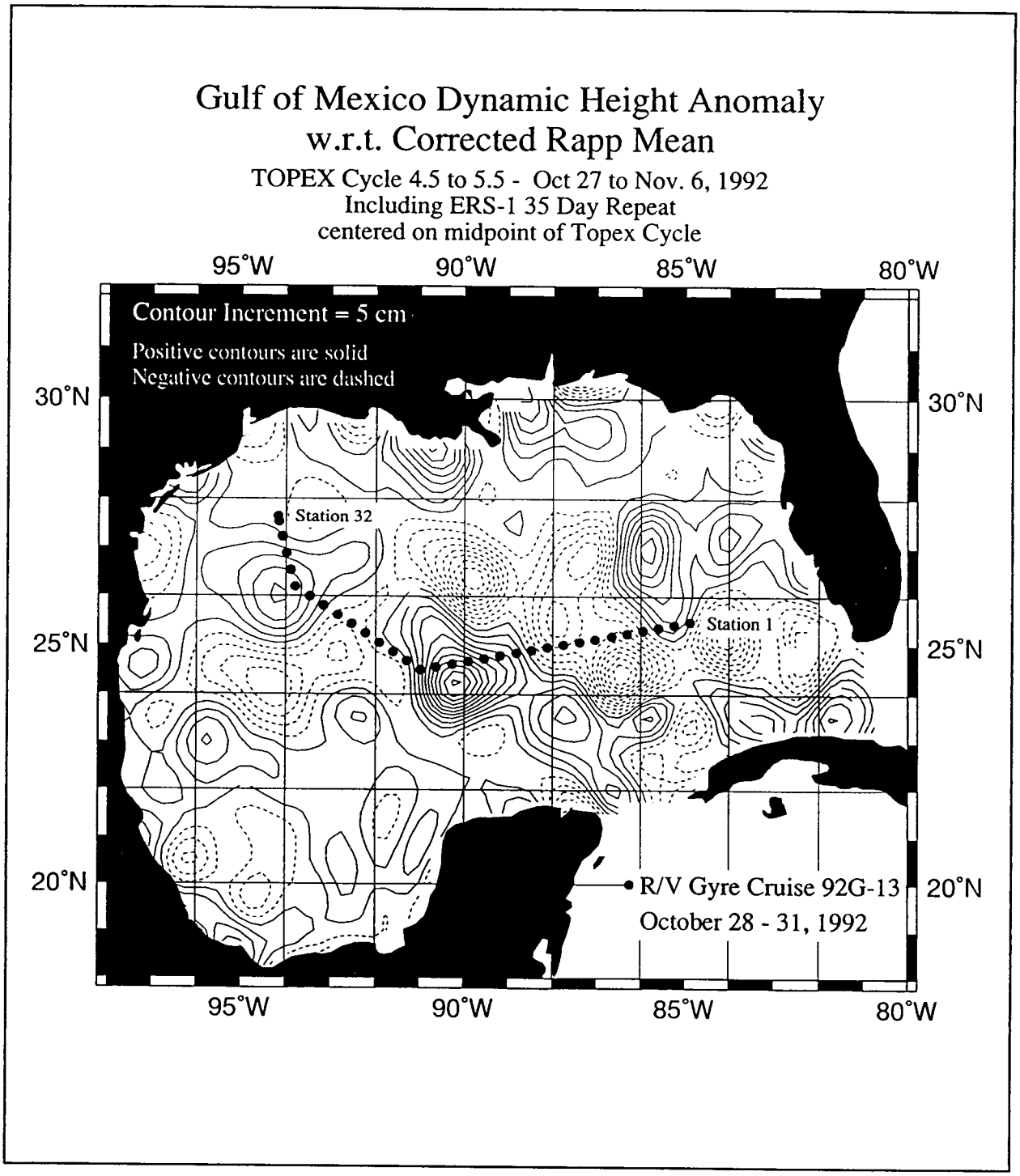

Figure 3.2-1. Dynamic height anomalies in the Gulf of Mexico from TOPEX and ERS-1 altimeter data relative to the corrected Rapp mean surface. Track of R/V GYRE Cruise 92G13 is indicated by dotted line.

of Eddies U and V are located near 90°W, 24°N and 94°W, 26°N, respectively, in Figure 3.2-1. Comparison with hydrography (Figure 3.2-2) shows agreement to 6.5 cm rms at all stations along the survey line. Differences at stations (16-32) west of 90°W, from near the center of Eddy U through Eddy V, had an rms value of only 3.1 cm. The excellent agreement west of 90°W supports the hypothesis that the mean circulation is quite weak in the deep western Gulf of Mexico and has been well approximated by the Rapp mean surface and correction.

Satellite-tracked drifting buoys have also been used to verify the accuracy of the altimetric mean reference surface. The trajectories of LATEX C Buoys 2447 and 2449, coincident with TOPEX cycle 7 (Figure 3.2-3), closely trace the sea surface height contours of Eddies U and V determined from combined TOPEX and ERS-1 analysis for this cycle. The qualitative agreement between the two data products is excellent. Quantitative validation is also possible by comparison of drifter velocities with altimetric derived geostrophic velocities at locations and times described by drifter trajectories. Geostrophic velocity anomalies are computed by differentiation of the altimeter derived sea surface height relative to the corrected mean reference surface. Simple linear interpolation is used to estimate the surface height field at times between successive analyses. Central finite differences are used to compute both the altimeter and buoy derived velocities. Comparison of these velocity estimates for the trajectories of buoys 2447 and 7835 (Figures 3.2-4 and 3.2-5, respectively) show that the altimetric analysis techniques and mean reference surface can be used to accurately describe the circulation in the western Gulf of Mexico. Analyses based on the tools validated with the TOPEX and ERS-1 data will be performed with the sea surface topography maps created from GEOSAT data (Figure 3.2-6).

3.3 Data Quality Control

This section addresses data quality control performed after the data have been collected and reviewed in the field. The procedures described are largely interactive steps undertaken on an ENCORE Series 91 Dual Processor machine running under UMAX V, a variant of AT&T UNIX V Release 4 optimized for parallel processing, in an X-Windows environment. The processing steps were largely developed over more than a decade using FORTRAN 77 and NCAR graphics and analysis routines. These routines are completely linked to a relational data base management system tailored in-house to support physical oceanographic work.

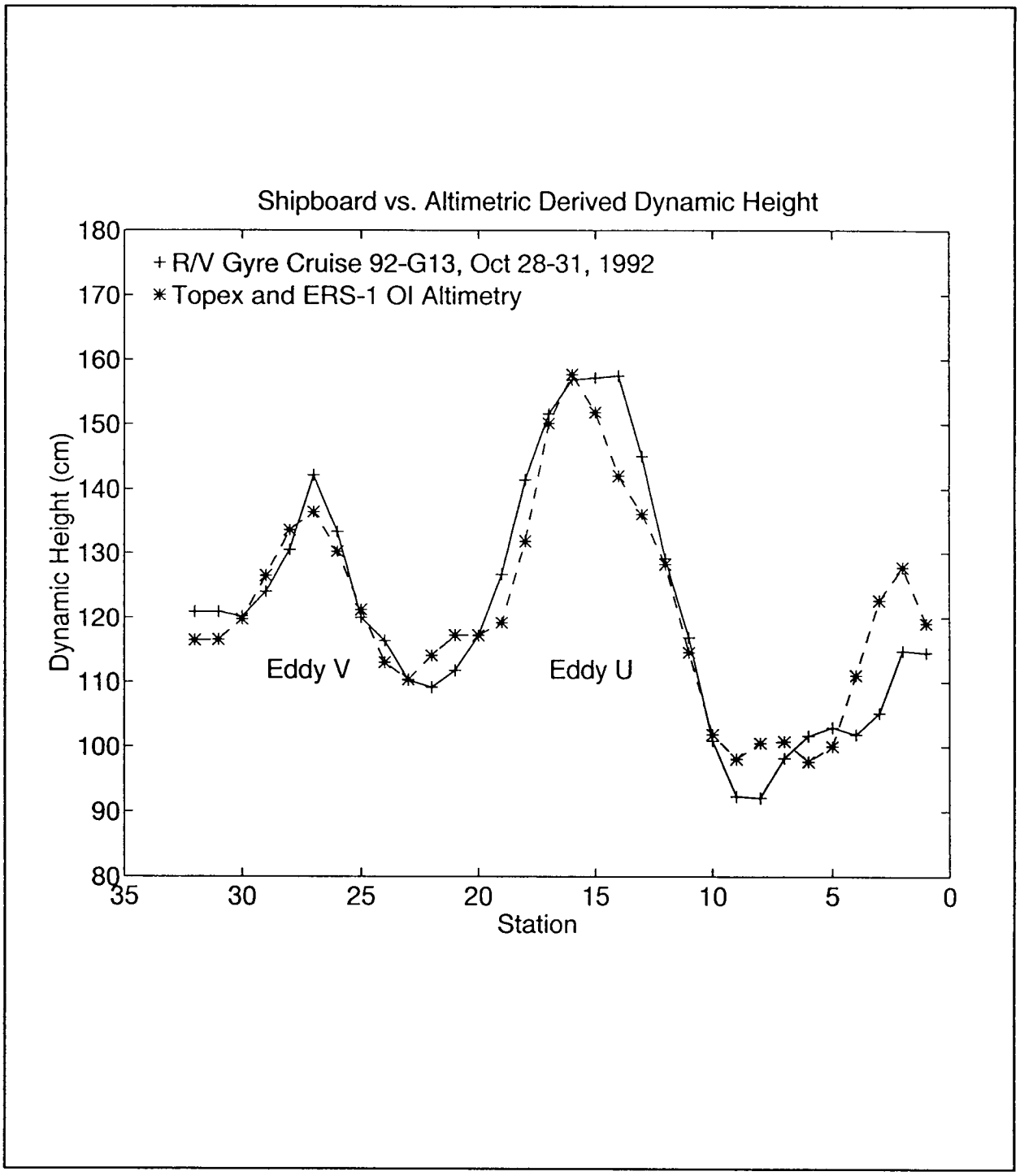

Figure 3.2-2. Dynamic heights across central Gulf of Mexico from TOPEX and ERS-1 altimeter data and hydrographic data along track of R/V GYRE cruise 92G13. Cruise track is shown in Figure 3.2-1.

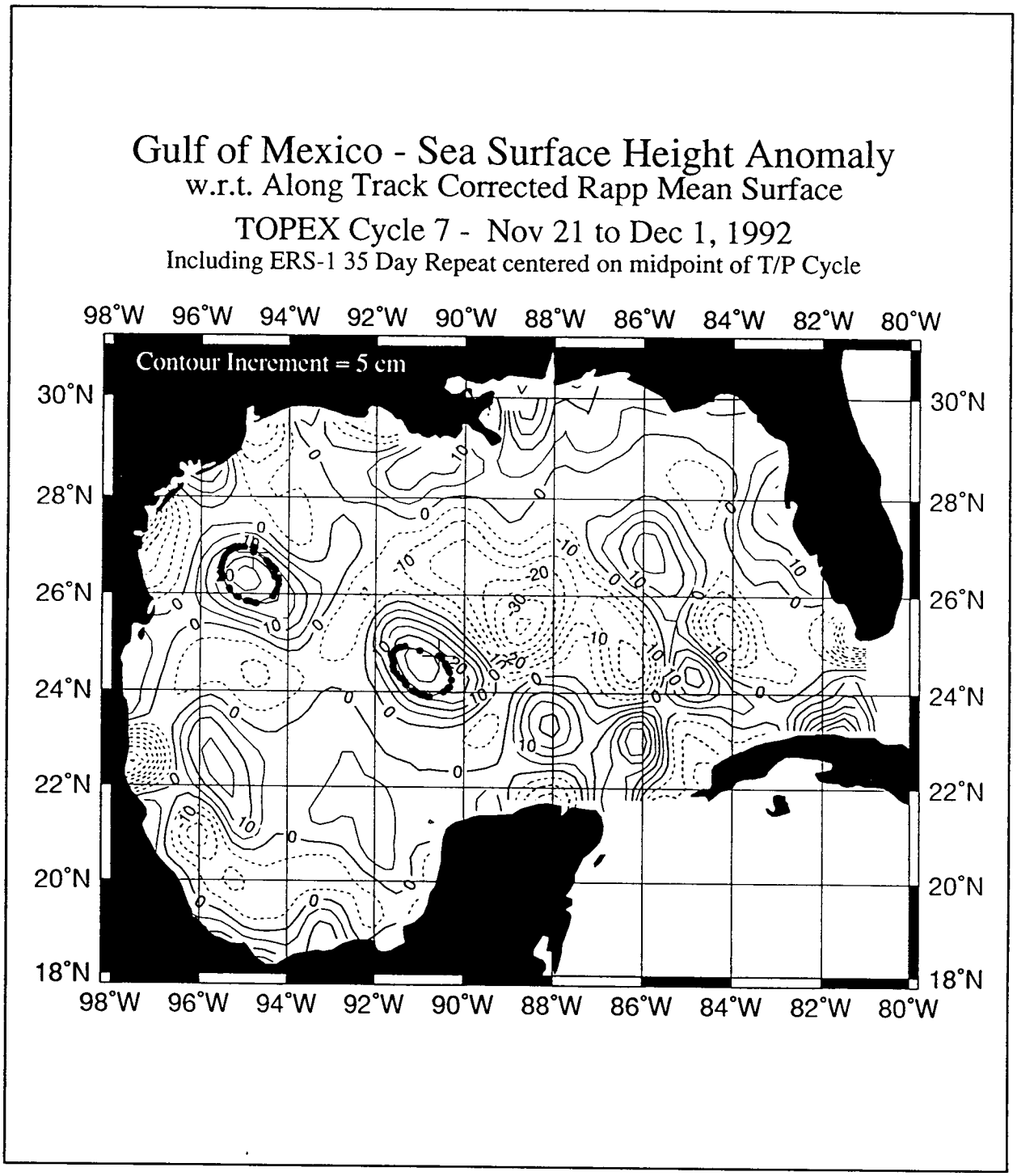

Figure 3.2-3. Sea surface height anomaly in the Gulf of Mexico from TOPEX Cycle 7 and ERS-1 data. Contemporaneous tracks of drifters 2447 (left, in Eddy V) and 2449 (right, in Eddy U) are shown by heavy lines.

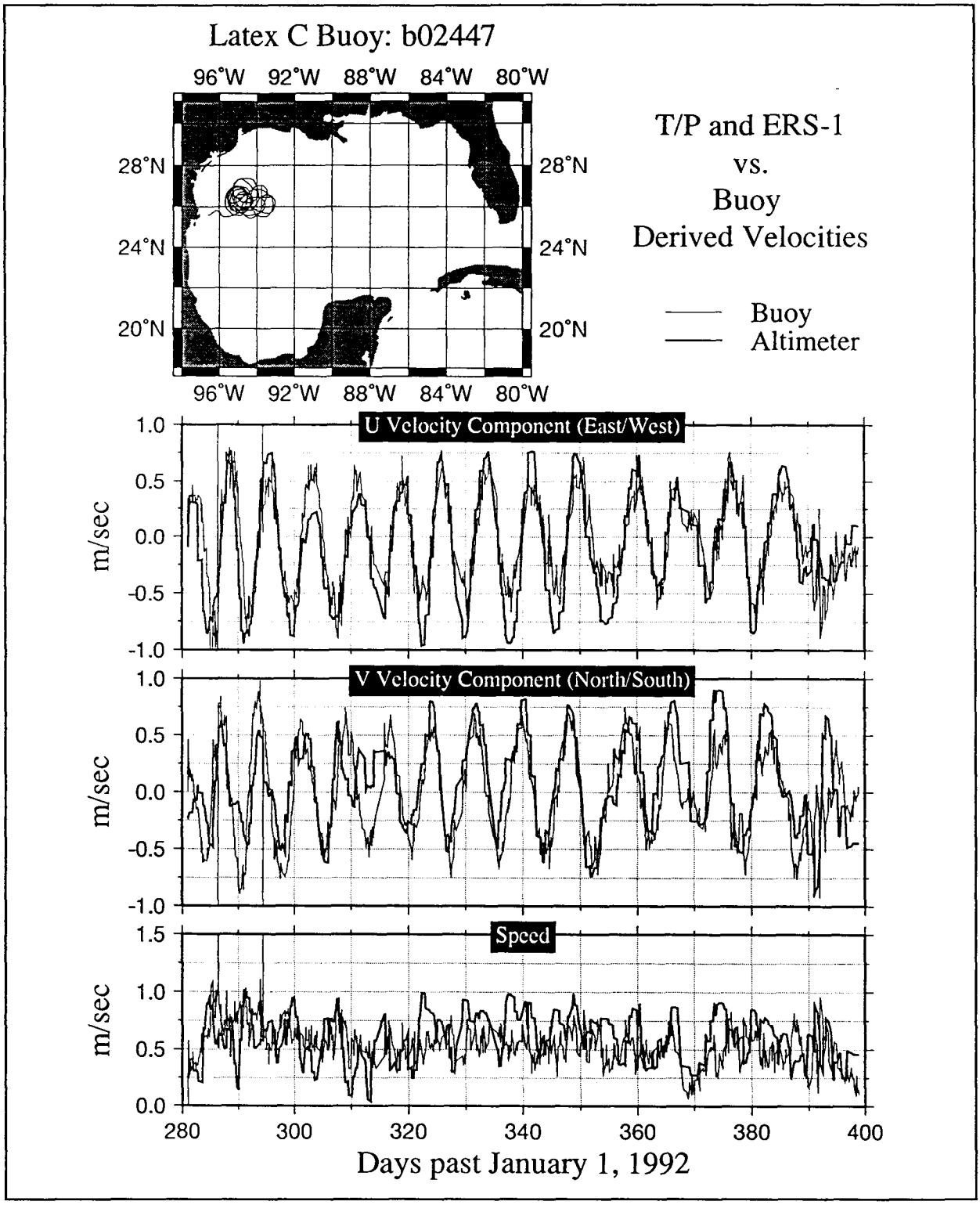

Figure 3.2-4. Current velocities derived from TOPEX and ERS-1 altimetry data and positions of drifter 2447.

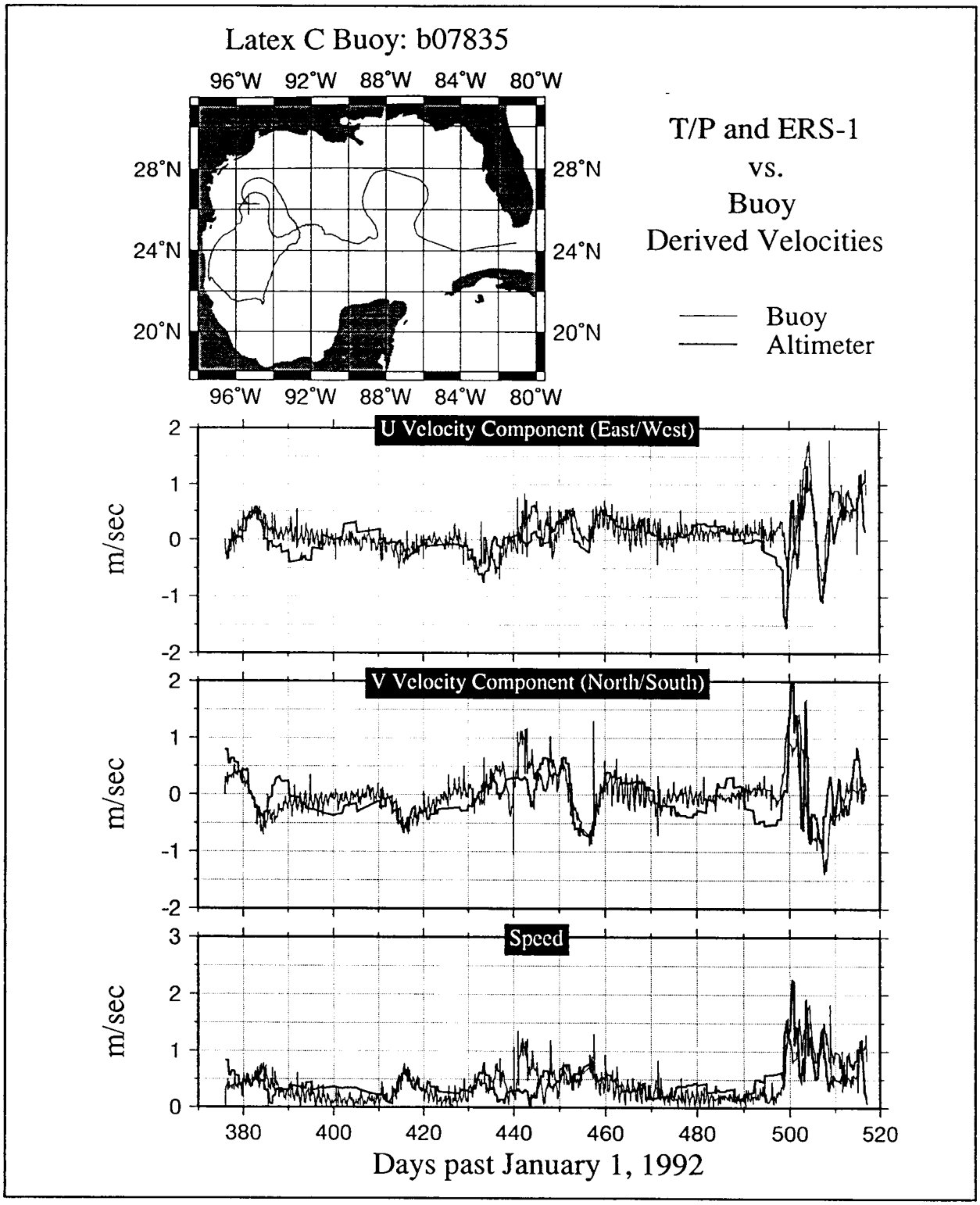

Figure 3.2-5. Current velocities derived from TOPEX and ERS-1 altimetry data and positions of drifter 7835.

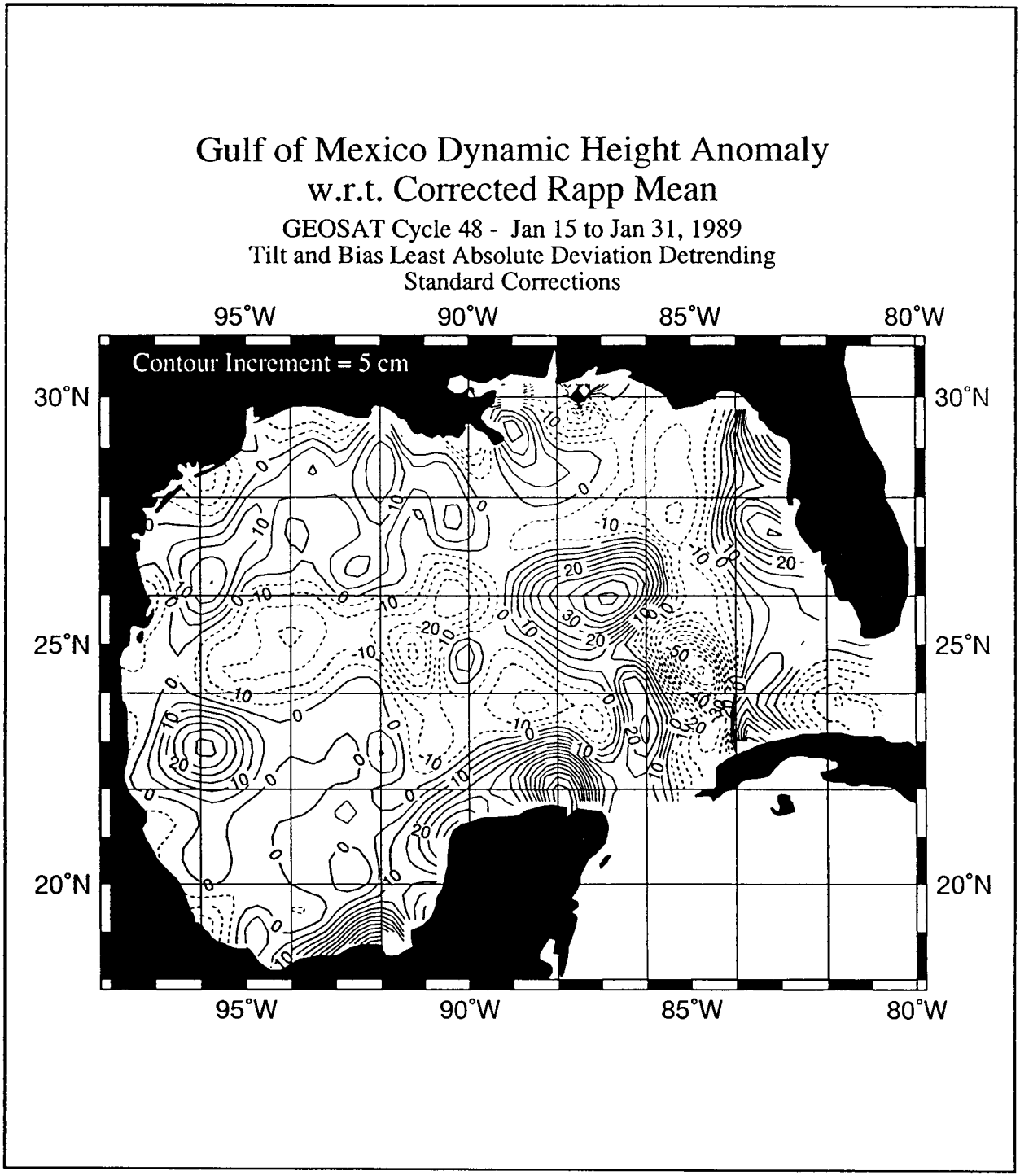

Figure 3.2-6. Dynamic height anomalies in the Gulf of Mexico from GEOSAT ERC 48 data relative to the corrected Rapp mean surface.

3.3.1 Hydrographic Profile Data

Detailed interactive computer procedures for QA/QC of profile data are online and are an integral part of entering data into the SAIC Physical Oceanographic Data Base Management System (PODBMS). These procedures provide specific checks at key junction points to insure a high-quality data product as diagrammed in Figure 3.3-1. The following summarizes the processing steps for XBT/AXBT and AXCP profile data:

XBT/AXBT Processing Procedures

Two hundred twenty five AXBTs were processed in Year 2. The data were recorded on both nine-track analog tape and on DAT cassettes from separate channels of the receiver in the aircraft. These data were then processed after the flight through a Sippican Mk12 Oceanographic Data Acquisition System which converts the data to an ASCII file containing a header with information about the drop and depth temperature pairs at approximately 0.15 m increments to a maximum depth of 760 m. The depth is computed from the fall time of the thermistor probe through the water column. The coefficients of the drop equation have been determined experimentally during the development of the probes. Calibration of the thermistor is accomplished during manufacture and is not duplicated in the field. The AXBT data are received from AeroMarine Surveys on 3½" IBM PC compatible diskettes.

- XBT/AXBT data are transferred into the PODBMS and a unique identifier (ID) is assigned to the data. The survey sequence number is part of the individual data file name, for example, file AB$01010.EDF is the AXBT deployed at station 10 in the first survey (F01SLOPE). Section 3.1 described the formation of the IDs used in this program. The data are then checked for spikes, large data gaps and total number of points through an interactive digital processing routine. The corrected data are archived to tape (nine-track, EXABYTE, or ¼" cassette) and stored in a climate controlled environment.

- Vertical temperature profiles are then checked individually, using an interactive graphics editor, for accuracy and smoothness. The routine allows the user to clip bad/noisy casts and to apply a spline to noisy or gappy data (a common problem of AXBT data, see Figure 3.3-2) in an attempt to smooth the data or supply missing data. The smoothing can be applied to an entire cast or to only a portion of the cast. Bad casts are deleted from the PODBMS.

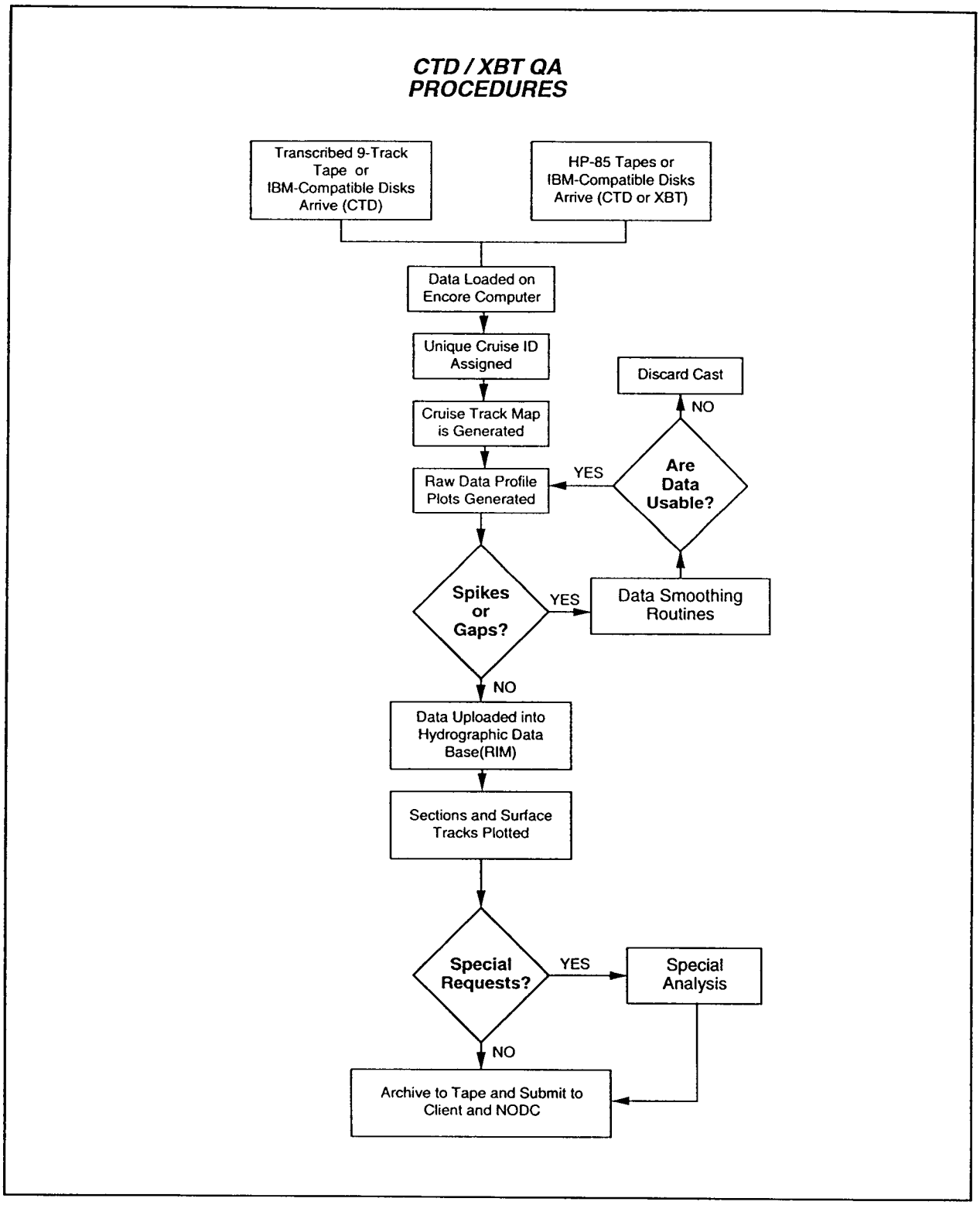

Figure 3.3-1. Schematic diagram of AXBT/XBT QA/QC procedures.

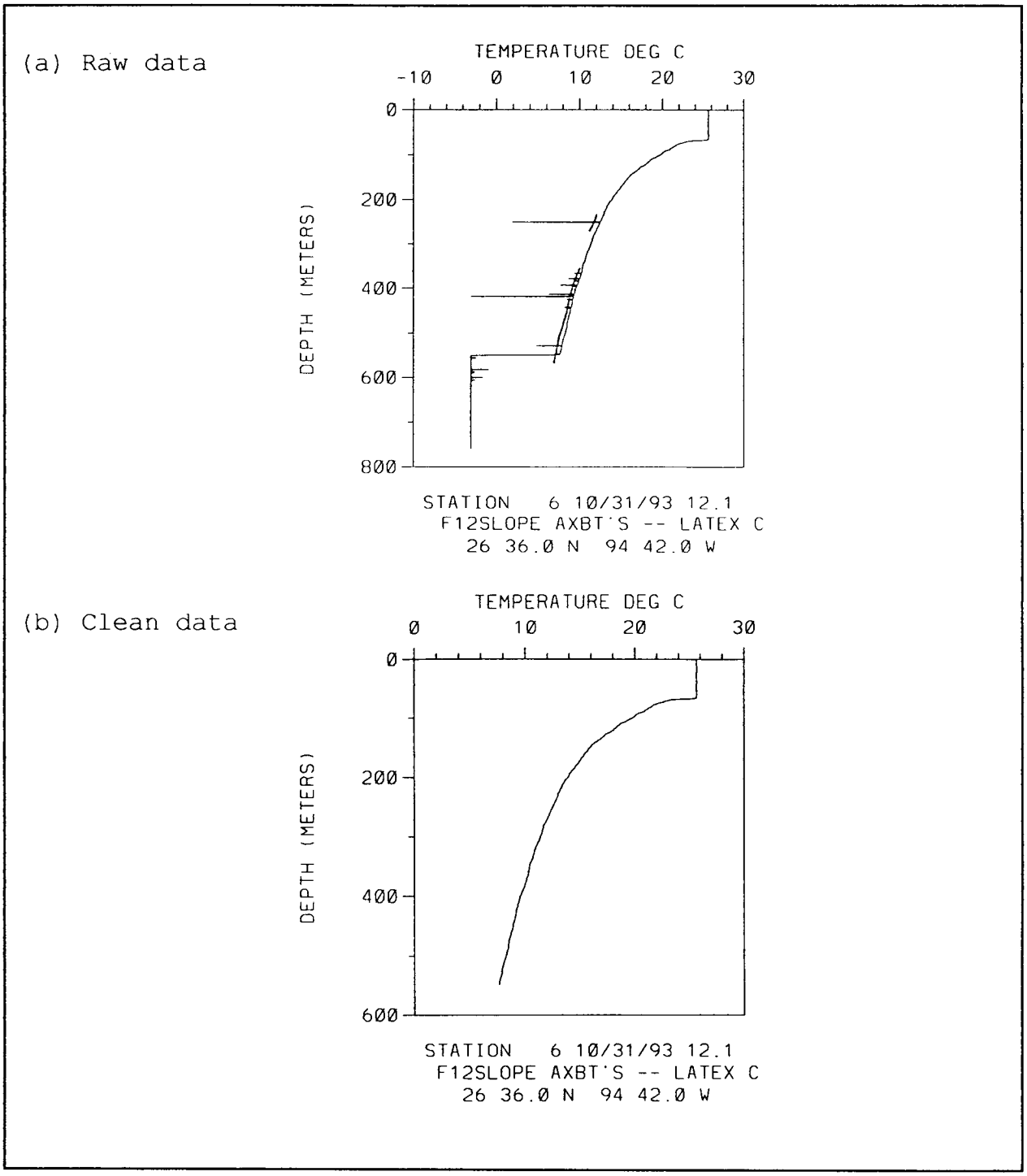

Figure 3.3-2. Plot of (a) raw AXBT data and (b) QA/QC'ed data from survey F12SLOPE station 6 showing data dropouts corrected by interpolation.

- One-meter increment data are used to produce vertical sections along and across isobaths (see Figure 3.1-7) or along major survey axes and horizontal contour maps of selected temperature surfaces (see Figure 3.1-4) or temperature at a selected depth. Surface tracks are also generated for each survey.

AXCP Processing Procedure

Twenty one AXCPs were processed during Year 2. Data acquisition for these probes was essentially similar to data acquisition for the AXBTs. Processing of these data was completed by AeroMarine Surveys, Inc., at their facility in Gales Ferry, Connecticut, using a Sippican Mk 10 XCP Digital Data Acquisition System which converts the data to an ASCII file containing a header with information about the drop, and depth, temperature, and velocity information at approximately 2.7 m increments to a maximum depth of 1500 m. Figure 3.3-3 shows the header and first five data lines generated by the Mk 10 system. Computations of depth and temperature are made in the same manner as for AXBTs.

Computation of velocity components from AXCP data uses a set of five 'standard' coefficients or five coefficients unique to each probe. Data processing procedures by SAIC after receipt of the AXCP data on 3½" diskettes are described below.

- Current Profiler data are transferred into the PODBMS from computer diskettes and the data set is assigned a unique ID as described above. The data are checked for spikes, large data gaps and the total number of points through an interactive digital processing routine. The corrected data are then archived to tape and stored in a climate controlled environment.

- Individual 'u' and 'v' components and temperature profiles are plotted and edited in a manner similar to XBT/AXBT data as shown in Figure 3.3-4. The three data components can be clipped or smoothed individually, depending on the quality of the data. Once again, the bad casts are deleted from the PODBMS.

- Ten-meter increment data are used to produce both vertical and horizontal contour sections. Cruise tracks and surface tracks are also generated for each flight. In addition, temperature data from adjacent AXBT stations can be merged with the AXCP data to provide a more detailed analysis of the vertical thermal structure of the water column.

(a)

MK10 Post Processing Application
Version V1.0 August, 1989
Sippican, Inc

Probe Header Information
Filename: C:\MK10\XCP$83.PRO

S/N	: 9999	Depth(m)	: 1500
Gcca	: 1846.02	Latitude	: 27,12.0,N
Gcora	: 915.66	Longitude	: 093,40.0,W
Gefa	: 24831.35	Cruise	: LATEX C 13
Gevfa	: 497.01	Ship	: N900AM
Gcvfa	: 493.07	Speed	: 140 knots
Fh	: .2674441	Heading	: 360 degrees
Fz	: -.405899	Memo	: sn. 93041012
FltrSz	: 22	Date	: 12-21-1993
StepSz	: 11	Time	: 15:20:01

Depth(m)	Temp(C)	U	V	Area	Rotf	Fefb	Fccb	Velerr
7.59	18.36	126.32	-31.88	369	15.32	1354	2203	174.53
10.42	22.92	11.88	-61.88	578	16.64	1544	2249	1.66
13.16	22.93	12.83	-57.04	576	17.14	1580	2250	1.22
15.87	22.95	14.47	-56.04	576	17.32	1537	2249	1.04
18.58	22.91	10.85	-58.70	579	17.37	1404	2248	1.24

(b)

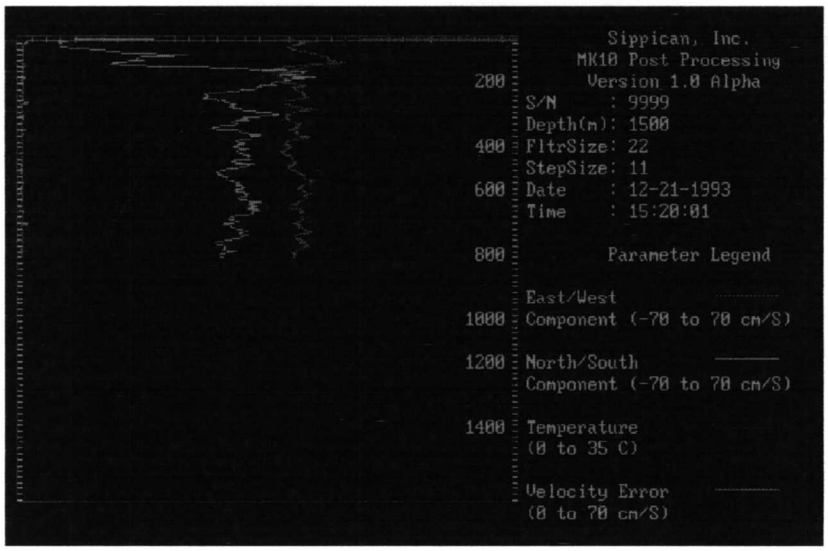

Figure 3.3-3. AXCP data file format from F13SQURT station 21. (a) Text from post-processing routine and (b) PC screen output.

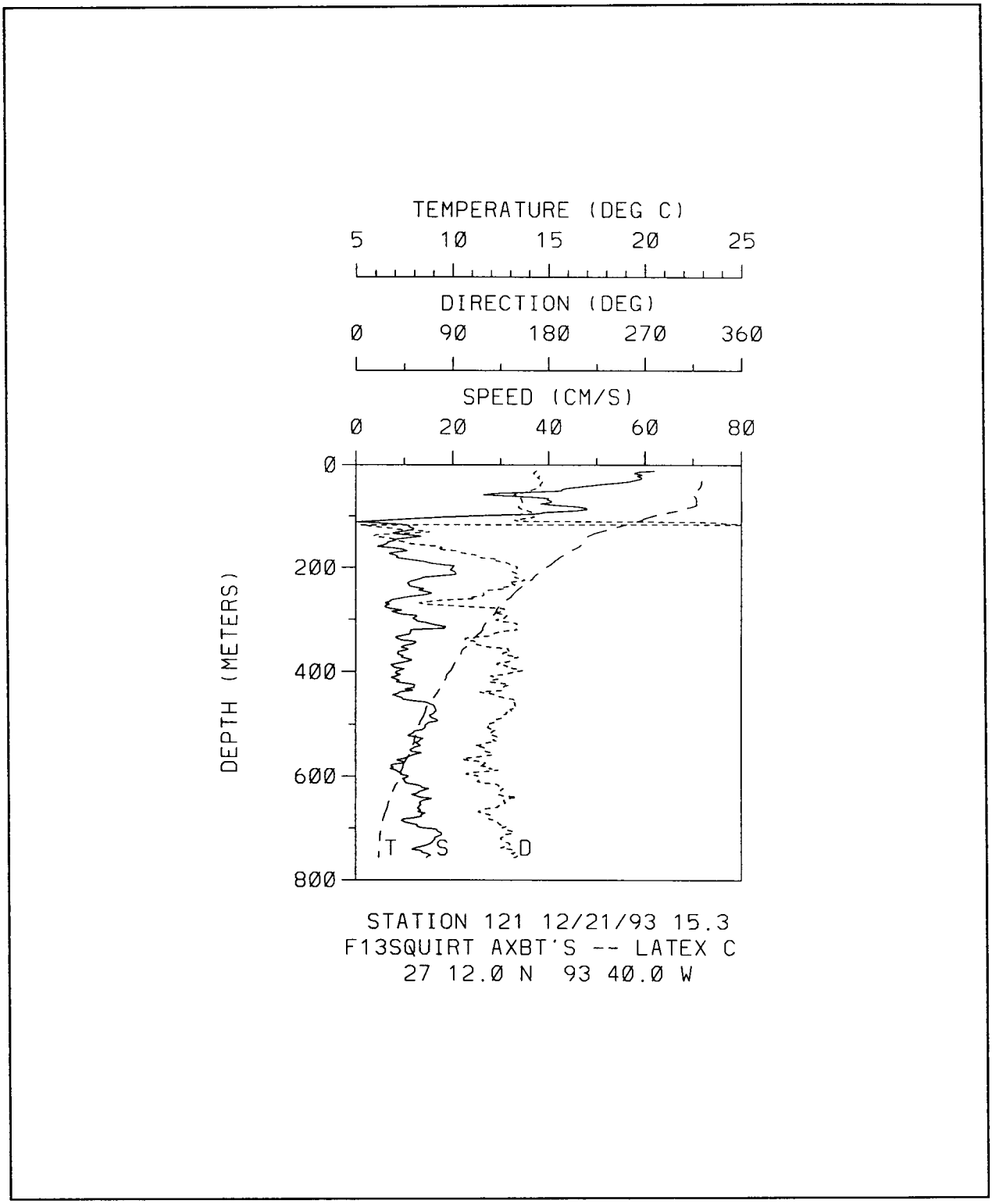

Figure 3.3-4. Plot of AXCP data from F13QURT station 21 after QA/QC.

- An NODC format tape is produced for data submission within three months of data receipt, and again at the end of the program.

3.3.2 Lagrangian Data

LATEX drifter data are received daily from the Service ARGOS U.S. Global Processing Center (USGPC) over the Internet. Drifter data for the shelf drifters deployed in LATEX A are also delivered daily to the LATEX A Data Office on Internet. The drifter data are also available through a dialup service (TYMNET) to the USGPC computer, and are thus available essentially in real time for use in the field to verify correct operation. These data include all transmissions received from each drifter and each position of the drifter determined by Service ARGOS. The files are edited to separate the position data for processing in the PODBMS, while the transmissions from the drifters are reviewed to evaluate qualitatively battery condition, drogue presence, and sea water temperature.

Interactive procedures remove all duplicate positions, verify the validity of each position fix, sort the data into a time-ordered sequence and archive the data into the PODBMS. Once loaded into the system, a final visual check is made on the data by plotting the individual buoy trajectories on a high-resolution map of the study area, which contains detailed bathymetry and coastline, and looking for spurious changes in the buoy's movement (see Figure 3.1-20, for example). The data are also written in *opcplot* (Brown 1994) format for placement on the GULF.MEX electronic bulletin board as shown in Figure 3.3-5.

(a) Data file

```
07838,9312092225,-90.6370,27.4010,D
  344,9312102219,-90.3670,27.2940,B
  346,9312121420,-89.9810,26.8950,B
  347,9312131358,-89.8680,26.6280,B
  348,9312142129,-89.8560,26.2670,B
  349,9312151458,-89.9030,26.0290,B
```

(b) Graphic

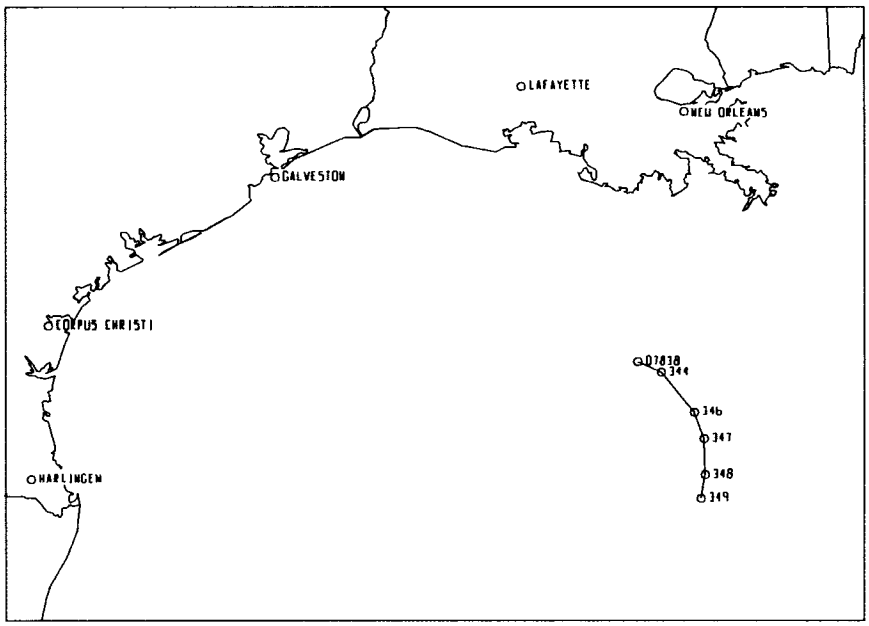

Figure 3.3-5. Track of Drifter 7838 during December 9-15, 1993 in *opcplot* format. (a) Portion of data file. (b) Graphic from *opcplot*.

IV. REFERENCES

Basic, T. and R.H. Rapp. 1992. Oceanwide Prediction of Gravity Anomalies and Sea Surface Heights Using Geos-3, Seasat and Geosat Altimeter Data, and ETOPO5U Bathymetric Data. Report No. 416, Dep. of Geodetic Science and Surveying, The Ohio State University, Columbus.

Brown, M.L. 1994. OPCPLOT: Oceanographic charting software for the world's seas, May 1994. OCS Report MMS 93-0020. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 61 pp.

Science Applications International Corporation. 1994. Louisiana/ Texas Shelf Physical Oceanography Program: Eddy Circulation Study, Annual Report: Year 1. OCS Study MMS 94-0027. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, La. 53 pp.

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Royalty Management Program** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.