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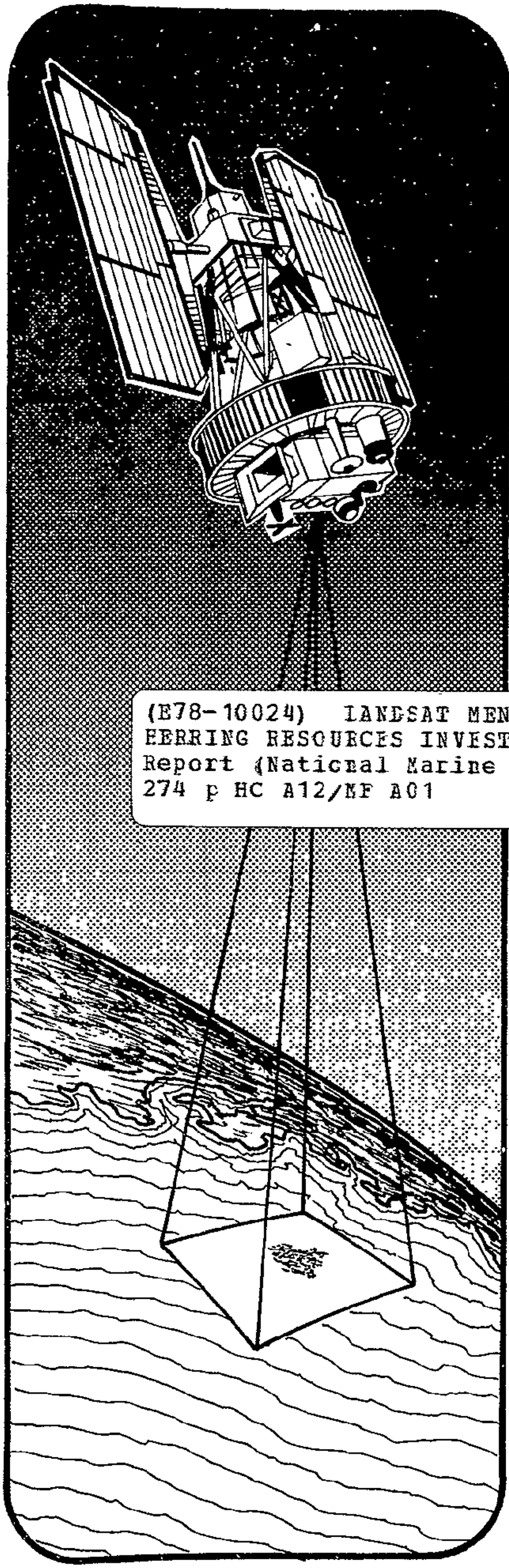

LANDSAT Menhaden and Thread Herring Resources Investigation

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FINAL REPORT

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southeast Fisheries Center
National Fisheries Engineering Laboratory
National Space Technology Laboratories
NSTL Station, Mississippi 39529

DEDICATION

This report is dedicated to the memory of Mr. J. Steele Culbertson, past Director of the National Fish Meal and Oil Association. Without his visionary perspective, enthusiastic support, and active participation and encouragement, this investigation would not have been possible.

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National Oceanic and Atmospheric Administration
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and

National Aeronautics and Space Administration
National Space Technology Laboratories
Earth Resources Laboratory
NSTL Station, Mississippi 39529

in consultation with

National Fish Meal and Oil Association
1100 Seventeenth Street, N. W.
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FINAL REPORT

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Sioux Falls, SD

Principal Investigator: Andrew J. Kemmerer

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16. Abstract

This 30-month investigation involving Federal agencies, private industry, and state institutions demonstrated the feasibility of using satellite data for enhancing the management and utilization of coastal fishery resources. The investigation involved extensive sampling of selected oceanographic measurements remotely and from surface vessels for correlation with distribution measurements of menhaden and thread herring in two dissimilar study areas in the northern Gulf of Mexico. The best correlations were found between menhaden distribution and MSS radiance values. These correlations led to the development of algorithms which divided the study areas into high and low probability menhaden fishing areas based solely on MSS data. Classification accuracies approached 90 percent.

A demonstration experiment was conducted in which LANDSAT MSS data were converted into a chart of high and low probability menhaden fishing areas for dissemination to the fishing fleet less than 21 hours after satellite coverage. The fleet reported the high probability areas produced some of the best catches of the season.

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PREFACE

The primary objective of this 30-month investigation was to establish the feasibility of enhancing the management and utilization of coastal fisheries through satellite remote sensing technology. This objective was achieved through a program divided into two phases and involving extensive field operations and analyses. The first phase (follow-on) was designed to develop the rationale and methodology for applying remote sensing to coastal fisheries, and the second phase (extension) was designed to utilize the methodology in a simulated operational application.

The investigation was conducted in two study areas in the northern Gulf of Mexico. Menhaden were the principal target species; thread herring were secondary. Correlations were sought between distribution patterns of the target species and oceanographic parameters which could be remotely sensed. These correlations led to the development of classification algorithms for dividing the study areas into high and low probability menhaden fishing areas based on LANDSAT MSS data. Classification accuracies approaching 90% were realized (i.e. most menhaden catch locations reported by the fishing fleet on the day of LANDSAT coverage fell within or adjacent to inferred high probability fishing areas).

A simulation of an operational satellite system for providing tactical resource assessment and fishery information was completed successfully. LANDSAT MSS data were processed and classified into high and low probability fishing areas for dissemination to the fishing fleet 21 hours after satellite reception. The fishing fleet reported commercial quantities of menhaden were concentrated in the inferred high probability areas. Subsequent interviews and discussions with fishing industry representatives indicated that satellite remote sensing had proven its potential value as a tactical fishing tool.

ACKNOWLEDGEMENTS

The Principal Investigator gratefully acknowledges the cooperation and assistance of the many people who participated in this investigation. It is not possible to recognize each individual, but those who made major contributions and deserve special recognition are: the co-investigators, Mr. Kenneth J. Savastano and Mr. E. Glade Woods of NMFS/NFEL and Mr. Kenneth H. Faller of NASA/ERL; Mr. Thomas E. Reynolds, Director, NFMOA; and the NFMOA Cooperators Mr. Benjamin R. Humphreys and Mr. Thomas G. Christopher of Standard Products, Inc., Mr. Dalton R. Berry of Petrou Fisheries, Inc., Mr. Patrick J. Doody of Zapata Haynie Corporation, Mr. Joseph Schollenberger of Seacoast Products, Co., and Mr. Edward W. Swindell, Jr. and Mr. W. Borden Wallace of Wallace Menhaden Products. Special appreciation also is extended to all menhaden plant managers, fleet managers, vessel captains and crews, chief pilots, and spotter pilots who helped make the investigation successful. Special thanks are due Mobil, Continental, Shell, and Exxon oil companies for allowing observers aboard their offshore oil platforms; the NASA/NSTL contractor personnel from General Electric Company and Computer Sciences Corporation; the NASA/ERL contractor personnel from Lockheed Electronics, Inc., the NASA/Slidell Computer Center and their contractor Integrated Systems Service, Inc.; the NASA/Goddard Space Flight Center; the NASA/Johnson Space Center aircraft crews and sensor operators; the helicopter pilots and crews of the United States Geological Survey; and the many other groups and agencies who contributed time and effort to this investigation. And finally, a special note of appreciation is extended to two people who worked diligently behind the scenes to enable others to complete their assigned tasks, Mrs. Sue Ellis and Mrs. Nona Lewis of NMFS/NFEL.

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ABBREVIATIONS AND SYMBOLS

CCT	Computer Compatible Tape
CZCS	Coastal Zone Color Scanner
DOI	Department of Interior
DOT	Department of Transportation
EDS	Environmental Data Service
ERL	Earth Resources Laboratory (NASA)
EROS	Earth Resources Observation Systems
ERTS	Earth Resources Technology Satellite
GSFC	Goddard Space Flight Center
ICES	International Council for the Exploration of the Sea
IPS	Image Processing Systems
JSC	Johnson Space Center
LANDSAT	Earth Resources Technology Satellite (formerly ERTS)
LLLTV	Low Light Level Television
MARMAP	Marine Resources Monitoring, Assessment and Prediction Program
MSS	Multispectral Scanner
M^2S	Modular Multispectral Scanner
NASA	National Aeronautics and Space Administration
NESS	National Environmental Satellite Service
NFEL	National Fisheries Engineering Laboratory
NFMOA	National Fish Meal and Oil Association
NIMBUS	NASA Experimental Research Satellite
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NSTL	National Space Technology Laboratories
NWS	National Weather Service
OCSO	Outer Continental Shelf Operations
PIDS	Portable Image Display System
PRT-5	Precision Radiation Thermometer-5
RS	Remote Sensing
SEFC	Southeast Fisheries Center
USCG	United States Coast Guard
USGS	United States Geological Survey

SECTION 1

INTRODUCTION

1.1 BACKGROUND AND OVERVIEW

This report is the eighth and final document covering the LANDSAT Menhaden and Thread Herring Resources Investigation, Proposal Number 20770, which was initiated on April 29, 1975. Originally scheduled as a 22-month study, the investigation was extended six months in 1976 for added field operations and data analyses, and two months in 1977 for report preparation.

The investigation was designed as a logical progression from an earlier experiment initiated in 1972, the ERTS-1 Menhaden Experiment, NASA/ERTS-1 Project Number 240, GSFC ID CO 321, Contract No. S-70246-AG (Stevenson and Pastula, 1973). This earlier experiment was conducted jointly by the National Marine Fisheries Service (NMFS), the National Aeronautics and Space Administration (NASA), and Earth Satellite Corporation, representing the National Fish Meal and Oil Association (NFMOA). Its purpose was to demonstrate the feasibility of using ERTS-1 data to determine the availability and distribution of Gulf menhaden, Brevoortia patronus, in the Mississippi Sound and adjacent waters. Results from the ERTS-1 Experiment suggested that correlations exist between certain oceanographic parameters and the distribution of menhaden. The LANDSAT Investigation subsequently evolved to verify these correlations and, if appropriate, expand them to include the entire Gulf menhaden fishery.

The investigation occurred in two phases. The first phase, referred to as the "follow-on", initially constituted the entire investigation, but the results dictated a second phase, referred to as the "extension". In retrospect, the two phases would have been more appropriately identified as technique development and technique demonstration. However, to maintain consistency with previously published work, the original nomenclature is retained in this document.

A significant departure in this investigation, compared to the ERTS-1 Experiment, was almost total reliance on the menhaden fishing industry for fishery data, and on remote sensing for oceanographic information. Two study areas were used during the follow-on phase: one in the Mississippi Sound and one south of Morgan City, Louisiana. The Mississippi Sound was selected to enable a direct comparison of results with the ERTS-1 Experiment; the Louisiana test site was selected for verification and comparison of the results. The study area used for the extension was the Louisiana study area expanded westward to include three adjacent LANDSAT ground tracks.

As in the ERTS-1 Experiment, Gulf menhaden were selected as the target species. This selection was based on the surface schooling nature of menhaden which should facilitate remote sensing applications, the existence of a well-developed and cooperative fishing industry, and the overall value and productive nature of the fishery. Thread herring (Opisthonema oglinum) were included as a secondary target species because of their surface schooling nature and potential value as a source of high protein fish meal and oil.

A basic assumption of the experimental rationale used in the investigation was fish distribution and behavior are predictable functions of the environment. This assumption was verified through an experimental design that provided for conversion of remotely sensed data into synoptic measurements of selected oceanographic parameters, conversion of the measurements into inferred fish distribution patterns, and verification of the patterns by the fishing fleet.

The first phase consisted of a series of major field operations in each study area to develop models and algorithms necessary for converting remotely sensed oceanographic data into inferred fish distribution patterns. The second phase consisted of a controlled demonstration performed under simulated operational conditions to demonstrate the value of remotely sensed data for resource assessment and fishing operations. An added feature of the second phase was an examination of the persistence, or stability, of the oceanographic parameters used to develop inferences about fish distribution.

1.2 GOAL AND OBJECTIVES

The goal of this investigation was to demonstrate potentials of aerospace remote sensing for enhancing the management and utilization of living marine resources. The world fisheries catch has increased dramatically over the past several decades, growing from about 27.6 million metric tons in 1954 to a peak of 70.2 million metric tons in 1971, and averaging about 55 million metric tons since the late 1960's. Estimates of potential production range as high as 2,000 million metric tons (reviewed by Schaefer and Alverson, 1968) but more conservatively the practical potential may be closer to 90 million metric tons (Moiseev, 1973). This potential, however, may not be obtainable due to overfishing of preferred stocks and the energy required to harvest underutilized resources (Kemmerer, Savastano, and Faller, 1977). Increased attention must be given to the development and application of improved management techniques to minimize dangers of overfishing, and to more efficient and energy-reducing methods of harvesting resources, especially those currently underutilized. Aerospace remote sensing may provide some of the information required to improve existing fishery management and utilization practices.

The primary objective of the first phase was to verify or establish the relationship of certain environmental parameters, observable from aerospace platforms, to the distribution of Gulf menhaden, and then to demonstrate how these relationships could be used to enhance menhaden management and utilization. A secondary objective was to establish similar relationships for a potentially important fishery resource--thread herring. Sub-objectives of the first phase included:

- Confirm the value of satellite derived data as inputs for a distribution prediction model for adult menhaden in the Mississippi Sound.

- Test the utilization of satellite derived data as inputs for a distribution prediction model for adult menhaden over the entire season of menhaden availability in the Mississippi Sound and off Louisiana.

- Test the utilization of satellite derived data as inputs for a distribution prediction model for adult thread herring off the coast of Louisiana.

- Continue the development of techniques for the application of remotely sensed data to living marine resource assessment and utilization.

The objective of the second phase was to demonstrate an application of the methodology developed in the first phase. Specific sub-objectives included:

- Simulate the use of an operational satellite system to provide tactical resource assessment and fishing information.

- Define the persistence of menhaden distribution patterns as predicted from LANDSAT multispectral scanner data, over a 24-hour period.

Each principle participating group contributed to the achievement of these objectives and sub-objectives while working toward specific group objectives. These objectives were:

National Marine Fisheries Service/National Fisheries Engineering Laboratory (NMFS/NFEL)

- Continue development of techniques for management of multidisciplinary fisheries research programs which rely on remotely sensed information.

- Continue development of a data management system to facilitate production of fisheries significant environmental information from remotely sensed data.

- Determine relationships between the distribution and abundance of menhaden and thread herring and selected oceanographic parameters (e.g. water temperature, salinity, color, and transparency).

- Test the hypothesis that satellite data contains fishery-significant information.

National Aeronautics and Space Administration/Earth Resources Laboratory (NASA/ERL)

- Provide oceanographic information collected by remote sensing for correlation with in situ and remote biological measurements.

- Evaluate and demonstrate use of aircraft and LANDSAT remote sensing instruments to measure or infer a set of basic oceanographic parameters.

- Develop necessary techniques for inferring water salinity, turbidity, and chlorophyll patterns from remote measurements.

National Fish Meal and Oil Association (NFMOA)

- Evaluate the potential application of satellite data to commercial fishing operations and management.
- Develop, among interested Association members, the technical capability to utilize remotely sensed data in commercial fishing operations and management.
- Identify technical development requirements to meet anticipated commercial fishing and management problems.

1.3 ORGANIZATION AND PARTICIPANTS

The investigation was a cooperative venture; principal participants from the Federal Government and private industry were:

National Oceanic and Atmospheric Administration (NOAA)
- National Marine Fisheries Service (NMFS)
  - Southeast Fisheries Center (SEFC)
    - National Fisheries Engineering Laboratory (NFEL)

National Aeronautics and Space Administration (NASA)
- National Space Technology Laboratories (NSTL)
  - Earth Resources Laboratory (ERL)

National Fish Meal and Oil Association (NFMOA)

Other Federal and state agencies, academic institutions, and private organizations and industries contributed significantly to the investigation. They were:

National Oceanic and Atmospheric Administration (NOAA)

- National Environmental Satellite Service (NESS)
- Environmental Data Service (EDS)
- National Weather Service (NWS)
- Environmental Research Laboratories (NOAA/ERL)
- National Marine Fisheries Service (NMFS)
  - Southeast Fisheries Center (SEFC)
    - Miami Laboratory
    - Beaufort Laboratory
    - Pascagoula Laboratory

National Aeronautics and Space Administration (NASA)

Johnson Space Center (JSC)

Goddard Space Flight Center (GSFC)

National Space Technology Laboratories (NSTL)

Department of the Interior (DOI)

United States Geological Survey (USCG)

Earth Resources Observation Systems (EROS)

Outer Continental Shelf Operations (OCSO)

Department of Transportation (DOT)

United States Coast Guard (USCG)

Nichols State University

Mississippi State University

Shell Oil Company

Continental Oil Company

Exxon Oil Company

Mobil Oil Company

The organization structure was composed of principal and co-investigative participants. Principal participants and their functional responsibilities are presented in Figure 1-1. The principal investigator from NFEL was responsible for all technical and administrative matters affecting the investigation. He was assisted by an advisory group composed of representatives from each primary participating agency or group. The NFMOA provided advice on the fishery utilization aspects of the investigation, while NASA advisors insured maximum use of appropriate remote sensing technology. The NMFS advisors provided guidance on experimental design and analyses related to resource assessment and management.

A unique feature of the investigation was significant involvement by the fishing industry in all phases. Each of the five NFMOA member companies engaged in the Gulf fishery appointed one or more representatives to assist in the planning, data acquisition, data analysis, and report preparation phases. These representatives, referred to as NFMOA cooperators, also served as principal interfaces between their respective companies and the other participants. Periodic meetings were held with the cooperators to review progress, results, and problem areas. Policy matters were referred to the Director, NFMOA, after discussion with the cooperators.

PRINCIPAL INVESTIGATOR

Advisory Group

NFMOA (Utilization)

NASA (RS Technology)

NMFS (Assessment)

NASA/ERL

Principal Responsibilities Include:

- Acquisition of RS environmental data
- Acquisition of oceanographic sea truth data
- Conversion of RS data into synoptic measurements of selected oceanographic parameters
- Technical assistance to other organizational elements
- Acquire and analyze U-2 spectral data

NFMOA

Principal Responsibilities Include:

- Review and evaluation of all experimental procedures, analyses, results, and conclusions
- Provide fishing data from vessels and aircraft
- Evaluation of RS data for commercial fish harvest

NMFS/NFEL

Principal Responsibilities Include:

- Acquisition of RS fisheries data
- Acquisition of sea truth fisheries data
- Development of fishery models
- Evaluation of RS fisheries information for resource assessment and management
- Project coordination and data management

Figure 1-1. Organizational Structure and Principal Responsibilities for Management of the LANDSAT Investigation

1.4 BENEFITS

The most significant benefit realized from this investigation was an increased awareness by industry and resource managers of the potential of satellite remote sensing for enhancing the management and utilization of living marine resources. This interest has been manifested in several areas including numerous information requests from domestic and foreign government agencies, domestic and foreign fishing companies and firms, and domestic and foreign scientists. Several countries including the Republic of South Africa, Brazil, and Mexico have or are considering sending scientists to the United States for training in applications of space technology to fisheries. Partly because of this investigation, the International Council for the Exploration of the Sea (ICES) has formed a special working group to address aerospace remote sensing potentials for fishery and oceanographic investigations.

Results from the investigation demonstrated operational ocean color remote sensing could be used to significantly reduce search time for concentrations of menhaden. Through the use of satellite data, it appears that 80 percent or more of the coastal waters could be excluded from searching activities. For fishermen, this could mean a significant reduction in fuel costs and fishing effort to achieve a profitable harvest; and for resource managers, it would mean a significant increase in the efficiency of resource assessment surveys. This efficiency would be attained through an ability to tactically stratify survey designs, resulting in an increase in accuracy and precision of stock assessment estimates.

The success of the investigation will stimulate applications of satellite remote sensing in other fisheries. The rationale, approach and techniques developed for and evolved from this investigation represent a significant achievement that can be adopted for use in other areas and fisheries. Adoption should enable other investigators to achieve worthwhile results for significantly less money and time. For example, several fishery investigations have been proposed for the NIMBUS-G Coastal Zone Color Scanner (CZCS) program. The proposed cost of these investigations, on a fishery by fishery basis, is roughly 40 percent of the cost of this LANDSAT program. This reduction in cost is possible because of the operations, data management, and analytical techniques and procedures developed for or during this investigation.

The investigation provided a meaningful transfer of technology to the menhaden industry. This transfer represented a working knowledge of the potential application of satellite data to commercial fishing operations and management, and was facilitated by the unique organizational structure of the investigation. Industry representatives were involved in all investigative phases including planning, operations, analysis, and report preparation. The success is attributed to this uniqueness, and the willingness and cooperative nature of the industry.

Success of the near-real-time demonstration of the potential tactical benefits of satellite assisted fishing operations was especially beneficial. While the demonstration should not be credited with one of the best fishing days of the season, it can be considered one of the most effective demonstrations of the potential value of remote sensing for enhancing fishing and resource assessment operations ever achieved. This demonstration impacted all levels of management within the fishing industry including vessel captains, spotter pilots fleet managers, and company managers.

Quantitative relationships were established between menhaden distribution and oceanographic variables. These relationships should enhance future studies of fish behavior and responses to environmental parameters ultimately leading to improved management practices. This is especially important for coastal species that live and reproduce in a highly dynamic and complex environment. A change in the environment could result in concomitant changes in the productivity and resultant yield of these fishes. Existing management attitudes tend to relate all changes in stock size to fishing pressures. Poor years in terms of fish yields generally are blamed on overfishing when they may be due to changes in environmental conditions. Reductions in fishing pressure normally are required in either case to insure continuance of a productive fishery; however, if stock reductions are due to an environmental change, fishing pressure should be allowed to return to normal levels as environmental conditions improve.

A significant benefit is a further refinement in remote sensing requirements for fisheries. For example, it does not appear that spatial resolutions of more than about 500 meters are required for application to coastal fisheries, and resolutions of 1 kilometer or more probably are adequate for oceanic species. Frequency of repeat coverage is the most critical consideration for a useful tactical fishing or resource assessment satellite sensor. Coverage should be at least daily. Spectral resolution requirements are still uncertain although it does appear the spectral bands and dynamic ranges of the multispectral scanners aboard LANDSAT spacecraft are acceptable for one important coastal pelagic--menhaden.

The investigation defined and tested requirements for an operational satellite-based system dedicated to fishery applications. This definition was achieved during the follow-on phase and verified in the extension phase through a practical demonstration experiment.

Extensive oceanographic and fishery data obtained during the investigation will have many applications in studies related to coastal processes and fisheries. These data will assist in definition of minimum levels of effort required to obtain usable ecological, environmental, and fishery information. Considerable insight has been provided into areas of investigation applicable to remote sensing, and techniques and methods have been defined for effective conversion of remotely sensed data into measurements of oceanographic parameters.

1.5 REPORT FORMAT AND CONTENT

The report is divided into sections with emphasis on data analyses as prior details have been reported elsewhere; e.g., planning (NMFS, 1975 and 1976), field operations (Brucks, 1977) and data (Savastano and Holley, 1977). These reports were in addition to the Type II quarterly progress reports provided during the investigation.

Follow-on and extension phases are discussed separately in most sections because the phases were distinct. The first dealt with the development of techniques while the second was concerned with a practical demonstration of results from the first.

Section 2 covers experimental design and provides a summary of the rationale and approaches used in the investigation. The menhaden and thread herring fisheries are reviewed in Section 3 and the study areas for both phases are described in Section 4. The extensive planning and coordination requirements of the investigation prompted Section 5, a review of how these requirements were satisfied, and Section 6 provides a summary of the field operations used in both phases. These operations are reviewed in greater detail in a special operations report (Brucks, 1977). Section 7 addresses the schedules for both phases, and a data summary addressing quantity and quality aspects of data is given in Section 8. A special report on data was prepared for separate distribution (Savastano and Holley, 1977). A description of the data management system is contained in Section 9. Sections 10 and 11 deal with data analysis for the follow-on and extension phases of the investigation, respectively. Section 12 summarizes investigative results as a function of objectives, and Section 13 provides recommendations for future studies. A series of appendices are provided for additional detail on selected portions of the investigation.

SECTION 2

EXPERIMENTAL DESIGN

2.1 OVERVIEW

The experimental rationale used for the follow-on and extension phases was similar to that used for the ERTS-1 Menhaden Experiment (Kemmerer, et al., 1974) and an applications study conducted in 1973, the Skylab-3 Oceanic Gamefish Investigation (Savastano, 1975). It consisted of inferring the distribution of menhaden and thread herring from remote measurements of selected oceanographic parameters. Four discrete units of data were used:

- Aerospace remotely sensed data
- Oceanographic data
- Fish distribution data
- Fishery utilization data

The data units were related as shown in Figure 2-1. Aerospace remotely sensed data were used to infer oceanographic data which were then used to derive the distribution of the target species. This latter information was then used to identify likely areas for harvest of the resources.

2.2 FOLLOW-ON PHASE

The follow-on phase was designed to establish relationships between menhaden and thread herring distribution and oceanographic parameters which could, or potentially could, be measured remotely. It relied heavily on remote measurements of oceanographic parameters, as opposed to the ERTS-1 Experiment which emphasized traditional approaches to oceanographic sampling. The fishing industry was depended on to provide fishery information, representing a significant departure from the previous experiment. Finally, the experiment emphasized data acquisition to verify or reject conclusions derived during the ERTS-1 experiment.

2.2.1 DESIGN MODEL

Two study areas were used in the follow-on phase so that two experiments could be conducted simultaneously. This enabled a direct comparison of results geographically and temporally (i.e. within a fishing season, between fishing seasons, and between study areas). A minimum of three major field operations were scheduled for each study area to provide information for comparisons within the fishing season. These were augmented with several supplementary missions for added temporal comparisons. Integral to the experimental design was an assumption that if consistent results could be achieved temporally and spatially, the results could be extrapolated to the entire Gulf menhaden fishery.

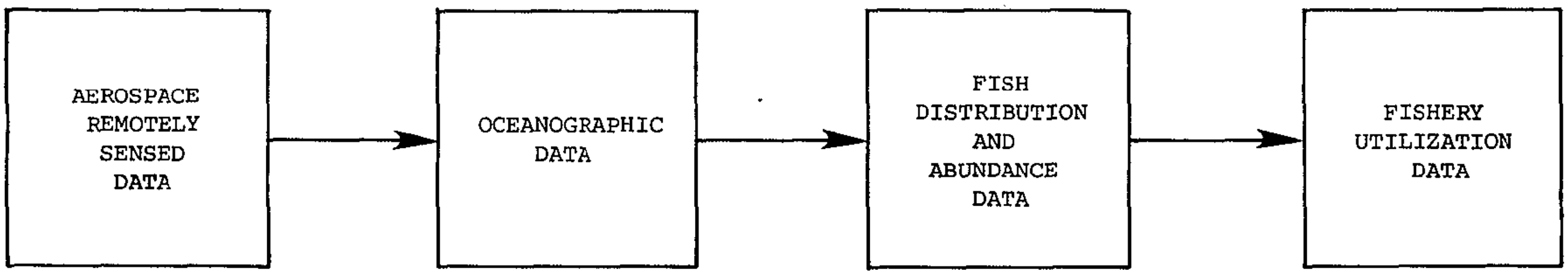

Figure 2-1. Overview of the Experimental Rationale Used in the LANDSAT Menhaden and Thread Herring Investigation

The experimental design, evolved from the ERTS-1 Experiment, is presented conceptually in Figure 2-2. The most critical components of the model are the links between experimental units. Aerospace remotely sensed data were converted into oceanographic information by oceanographic models. In some cases, such as surface water temperature and salinity, models existed which served the needs of the investigation; in others, such as chlorophyll concentrations and water turbidity, suitable models had to be developed.

The link between the oceanographic and fish distribution experimental units was partially satisfied by the ERTS-1 Experiment. Eight regression models were developed which linked menhaden distribution to selected oceanographic parameters. Thus, an initial thrust was to verify the links so they could be used to focus subsequent efforts on the most important parameters affecting fish distribution. This was done through an extensive surface truth sampling effort at sites of menhaden and thread herring capture by the fishing fleet.

The final link between fish distribution and fishery utilization was satisfied by direct comparison of inferred fish distribution patterns to locations of commercial catches or observations in the two study areas. This link established fish availability to the commercial fleet and overall validity of the experimental design.

Within the experimental design shown in Figure 2-2, there are two feedback loops to the aerospace remote sensing unit. These feedback loops were an essential part of the experimental design and served the similar purpose of establishing how remotely sensed data should be processed and analyzed to maximize usefulness. Initially, it was assumed classical oceanographic parameters such as temperature, salinity, chlorophyll concentration, and water turbidity could be used to infer fish distribution. However, it was found later that fish distribution patterns could be directly derived from remotely sensed data with more accuracy and precision than with the classical parameters.

2.2.2 DATA ACQUISITION

Data acquisition activities for the follow-on phase were divided into main and supplementary missions. Main missions were designed to satisfy data requirements of the experimental design; supplementary missions were designed to provide limited data for test and verification of results from the main missions. An essential requirement of both types of missions was concurrence with LANDSAT coverage.

Principal sources of aerospace remotely sensed data included the LANDSAT 1 and 2 multispectral scanners, and the color scanners and passive microwave and infrared sensing radiometers aboard two NASA aircraft. Surface truth oceanographic data were collected from research vessels and oil platforms for calibration and verification of the models used to infer oceanographic measurements from the remotely sensed data. The fishing industry (fishing vessels and spotter aircraft) provided most of the fish distribution data and all utilization data. Initial plans were to use aerial photography as the primary source of fish distribution data, but for still unexplained

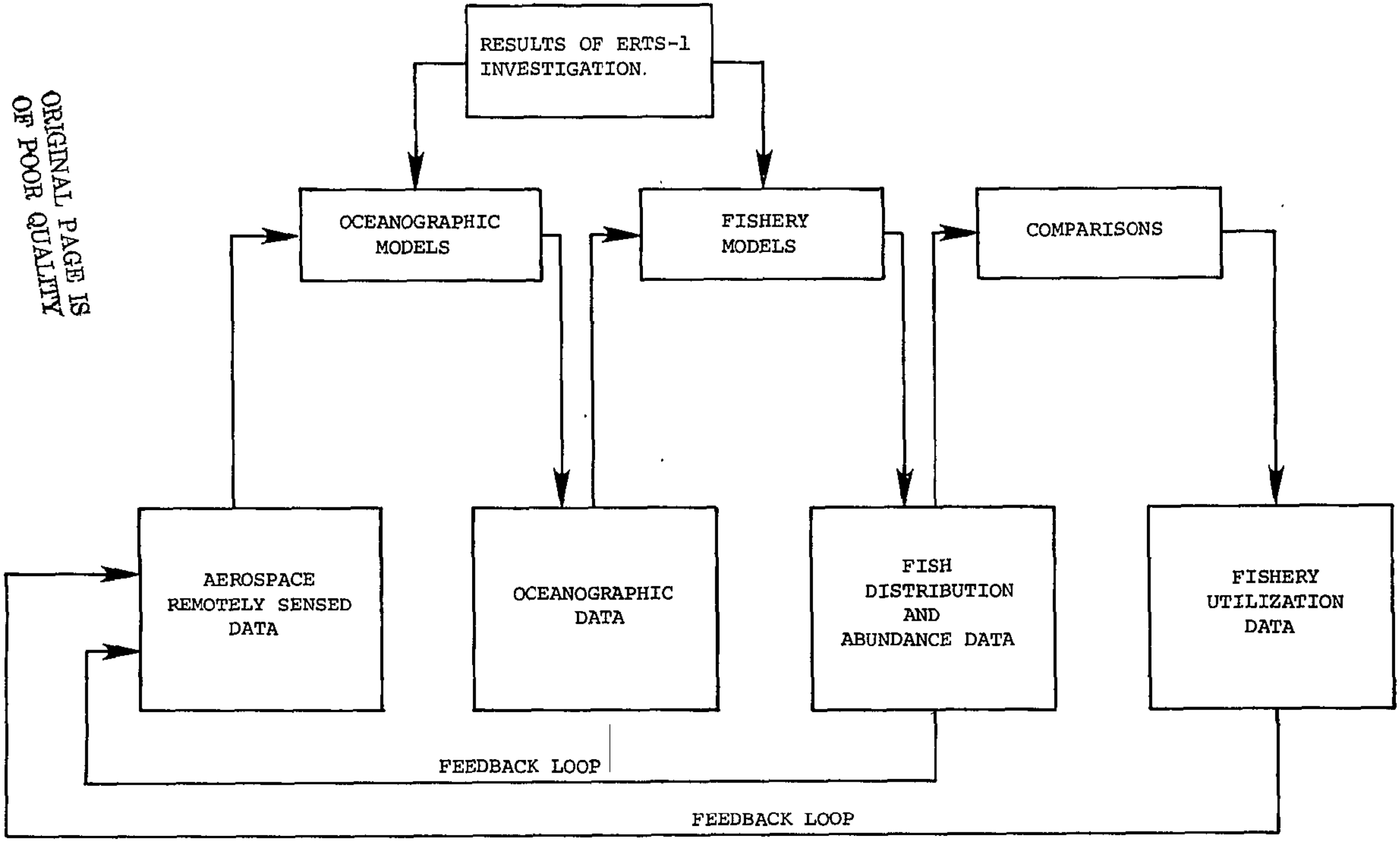

Figure 2-2. Model of the Experimental Design Used in the LANDSAT Menhaden and Thread Herring Investigation

reasons, photography proved to be unacceptable for this purpose. As an added experimental control, a series of samples were collected from selected fishing vessels at locations of fish capture, to enable precise determinations of oceanographic conditions in areas of fish concentrations.

2.3 EXTENSION PHASE

The extension phase was conducted to demonstrate the value of satellite remote sensing as a tactical aid to fishing operations and resource assessment surveys. A secondary purpose was to investigate the persistence of fishery significant parameters measured from space, for qualification of the demonstration.

2.3.1 DESIGN MODEL

The experimental design used in this phase essentially was a modified version of the one used in the first phase. It capitalized on results achieved during the follow-on phase, especially resultant data analysis techniques and procedures.

Models developed during the follow-on phase for converting LANDSAT MSS data into fishery significant information, calibrated with fishing data acquired at or near the time of satellite coverage, were used to process and analyze LANDSAT MSS data to produce a fish distribution probability chart. This chart was disseminated to the fishing fleet for a near-real-time evaluation. The fishing fleet's reports plus limited surface truth oceanographic data collected from selected fishing vessels were used to test and evaluate the accuracy of the probability chart. Data from the overlap region in two consecutive LANDSAT images were used to determine persistence which, in turn, was used to qualify the test and evaluate results. The study area used for the extension was the original Louisiana study area extended westward to include three adjacent LANDSAT coverages. Gulf menhaden were the target species.

2.3.2 DATA ACQUISITON

Primary sources of data were LANDSAT and the fishing industry. LANDSAT MSS data were the only aerospace remotely sensed data acquired. Selected fishing vessels and spotter aircraft equipped with special navigation systems were used to provide fish location information on the day of satellite coverage for calibrating the models. Special logs were used by vessel captains and spotter pilots to test and evaluate the LANDSAT derived fishing probability chart. These logs were placed on all cooperating fishing vessels and aircraft. Scientific observers aboard vessels equipped with navigation systems acquired accurate fish distribution and surface oceanographic data to aid in evaluating the probability charts.

Data for the persistence portion of this phase were acquired from the same platforms. Fish distribution data from the fishing fleet and spotter aircraft were used to calibrate the models for conversion of LANDSAT MSS data into probability charts to determine changes of inferred fish distribution patterns over a 24-hour period.

2.3.3 EVALUATION

Ideally, an evaluation of the value of satellite data for enhancing fishing operations should be done by supplying a portion of the fleet with satellite derived probability fishing charts and requesting the remaining portion of the fleet to fish without this information. The evaluation would be simply a comparison of fishing success. However, this was not practical for several reasons. First, it was not logical to assume the fleet would depend on a relatively untested technique to help them find commercial concentrations of fish. Second, spotter aircraft could direct portions of the fleet without probability charts into high probability areas through direct observations of fishing success. And third, it was not the intent to give one vessel or company a competitive edge over another.

A practical alternative to acquire information for the evaluation was to ask cooperating vessel captains and spotter pilots for opinions. These opinions were obtained in an unstructured format by scientific observers aboard selected vessels, and by personnel stationed at several company ports and airports used by the spotter pilots. Additionally, many chief spotter pilots, fleet managers, and management level personnel within the participating companies were polled for their opinions.

The final form of evaluation was to use fishing logs from cooperating vessels and spotter aircraft to establish areas of fish concentration for comparison to the distribution patterns inferred from LANDSAT MSS data.

SECTION 3

DESCRIPTION OF FISHERIES

3.1 MENHADEN

The menhaden fishery is one of the oldest and most valuable fisheries in the United States, and the largest in terms of landing volume. Menhaden landings were first recorded in the Gulf of Mexico in 1880 when less than 454 kg were landed in West Florida (Lyles, 1965). With annual fluctuations, landings in the Gulf increased to a 1971 record of 728,868 metric tons. This amounted to more than 74 percent of the total Atlantic and Gulf menhaden landings and over 32 percent of the total U.S. commercial harvest of all fishery resources. Landings in the Gulf have exceeded 486,000 metric tons every year since 1971.

Menhaden are not consumed directly by humans, but are processed into fish meal, oil and solubles which are high in proteins, amino acids, minerals and other nutrients (Figure 3-1). Meal and solubles are used as animal feed supplements providing nutrition and growth factors, particularly for poultry and swine. Fish oil is used for a large variety of products, including margarine, paints, resins, lubricants, caulking compounds, soaps, cosmetics, pharmaceuticals, steel hardening, and leather tanning.

Considerable information exists on the biology of menhaden with most of the material conveniently referenced in bibliographies by Gunter and Christmas (1960), Reintjes, Christmas and Collins (1960), Reintjes (1964), and Reintjes and Keney (1975). An excellent summary of the fishery has been compiled by Christmas and Etzold (1977) as background material for a regional menhaden management plan.

Menhaden are members of the family Clupeidae. Adults are relatively small, usually weighing about 100 gms and measuring about 17 cm in fork length. They inhabit coastal waters, occurring in large dense schools from April to October. During the rest of the year, they apparently move offshore and disperse. Spawning occurs offshore from October to April and eggs and larvae are transported into estuaries by currents. As the juveniles develop, movement is back into coastal waters, usually after about 1 year.

The life span of Gulf menhaden is relatively short, with 1 and 2 year old fish constituting more than 90 percent of the commercial catch. Three and 4 year old fish are not common. All are sexually mature by age 3, although age 1, and in some instances late 0 year classes, contribute to the high productivity of the fishery.

Twin-boat purse seining is the principle method used to harvest menhaden. Minor catches are made with gillnets and traps, primarily for sale as bait. The purse seining technique in use today is similar to early techniques; however, many improvements have been made over the years. All vessels built since the mid-1950's have steel hulls. The average hold capacity is about 318 metric tons although some vessels have capacities of 725 metric tons.

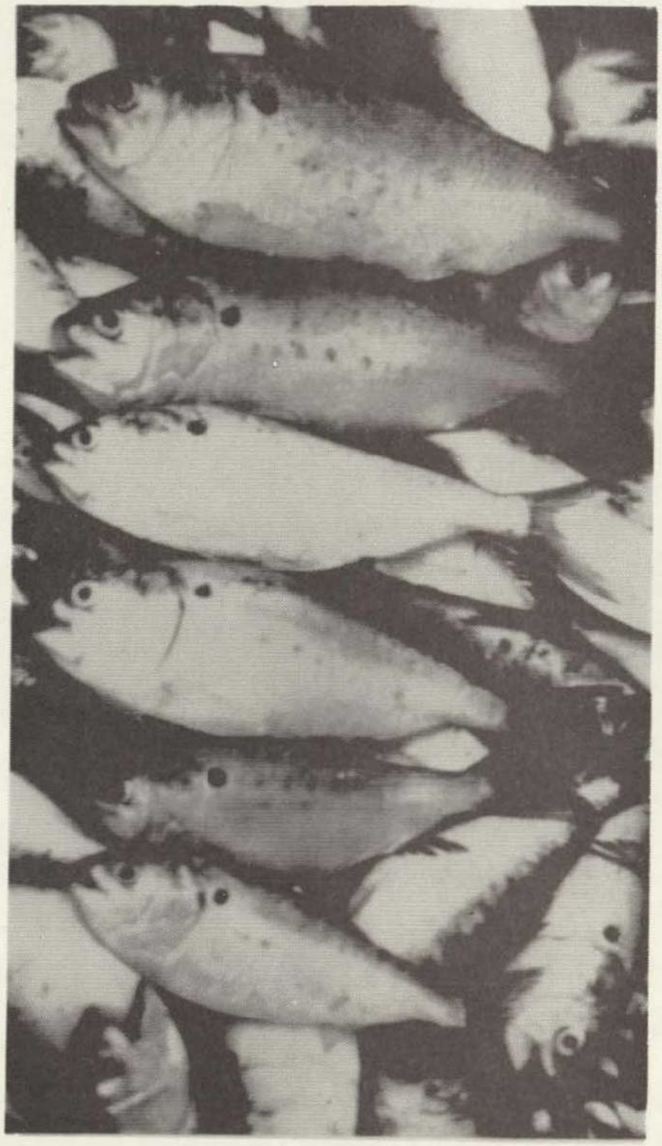

Figure 3-1. Target Species - Menhaden (Brevoortia patronus)

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Recent additions to the fleet carry about 454 metric tons, are about 50 meters in length and can travel about 26 km/hr. The speed and hold capacity permits an extensive operational range.

Menhaden along the Gulf Coast are fished from about mid-April to October. Fishing takes place during the daylight hours, usually within 16 kilometers of shore and as close to a processing plant as possible. The fishing operation requires close coordination between vessel captains and spotter pilots (Figure 3-2). The spotter pilot locates fish schools and assists during capture by keeping the vessel captain informed of the school's movements. Aboard the fishing vessels (Figure 3-3) are two "purse boats" usually 11 to 12 meters in length, diesel powered, and carried in davits (curved uprights which extend over the side of the larger vessel). When the vessel captain feels a school is large enough and in an area amenable to capture (information supplied by the spotter pilots), he orders the purse boats lowered. These boats carry a purse seine which is equally divided between them. They are lashed together when they are launched and operate as one.

The lashed purse boats move toward the school of fish, separate - playing the net out behind them - and move in a large circle, surrounding the fish with the net. Normally, the seine is about 365 m long by 37 m deep and is constructed from 3.8 or 4.4 cm stretch mesh synthetic twine. The top of the net is equipped with floats to keep fish from escaping over it, and the bottom is equipped with brass rings. When the purse boats meet at the far side of the school, the ends of the seine are made fast, and the bottom is closed by means of a line passed through the brass rings (Figure 3-4). Fish are concentrated in the net by hauling the wings of the net into the purse boats. At a predetermined time, the vessel captain signals the larger vessel to the purse boats. The seine is secured to the larger vessel forming a triangle with the vessels. The fish are pumped from the net into the hold of the fishing vessel.

Each complete fishing operation, sending out purse boats to loading fish aboard the fishing vessel, is referred to as a "set". In an average day, a menhaden vessel may make from three to six sets.

Menhaden vessels generally return to a processing plant when loaded, at the end of the fishing week (Monday through Friday), when mechanical problems develop, or for other reasons. The holds are partially flooded with sea water to unload a vessel and the fish and water are pumped into the plant. The fish are steam-cooked and pressed to produce a solid cake and liquids. The solids are dried and ground to form fish meal, and the liquids are centrifuged to yield oils. The remaining water ("stickwater") contains proteins which are concentrated to produce fish solubles, a substance resembling molasses. Solubles are rich in proteins and are used in animal feeds.

3.2 THREAD HERRING

The thread herring, *Opisthonema oglinum*, is a member of the family Clupeidae occurring in tropical and subtropical waters of the western Atlantic Ocean

Figure 3-2. NFMOA Spotter Aircraft

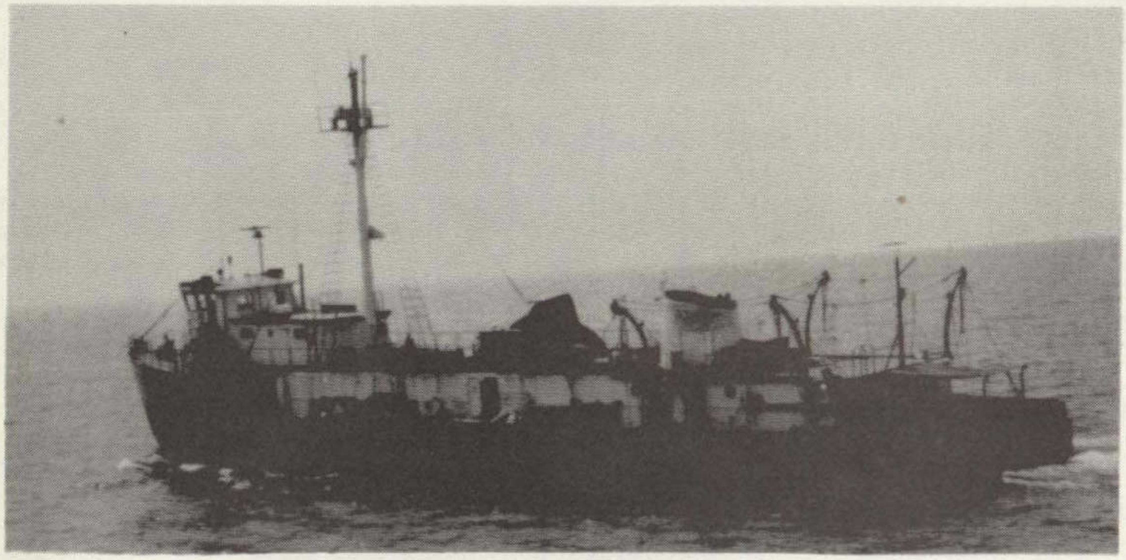

Figure 3-3. Menhaden Fishing Vessel

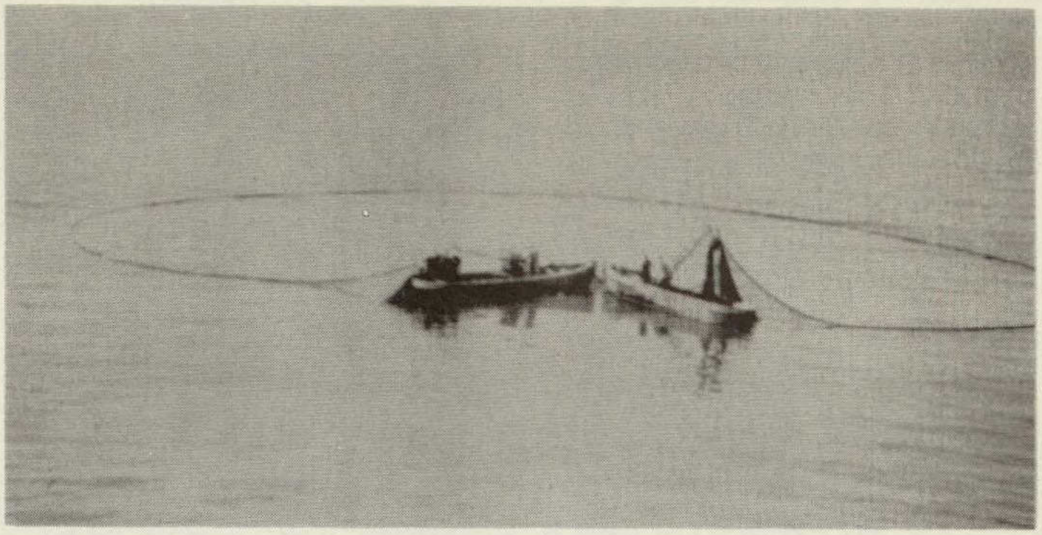

Figure 3-4. Purse Boats on a "Set"

and throughout the Gulf of Mexico. The full extent of the thread herring population in the Gulf is unknown, although NMFS investigators have estimated its size to be about 907,000 metric tons (Bullis and Carpenter, 1969).

In general appearance, thread herring resemble menhaden. The most identifiable characteristic is a thread-like elongation of the last ray of the dorsal fin. This characteristic is sufficient to differentiate thread herring from most other fish and has led to the name "hairy back" frequently used by fishermen. The gizzard shad (Dorosoma cepedianum) also has a similar long last ray on its dorsal fin; but thread herring have scales crossing over a ridge in their backs, anterior to the origin of the dorsal fin. The gizzard shad is naked of scales along this ridge, and the pectoral fin of the thread herring folds into a groove not found in the gizzard shad.

Very little is known about thread herring--its biology, responses to environmental parameters, and population dynamics. A research program to gain information on these fish, initiated in 1967 by NMFS along the Gulf coast of Florida (Fuss, Kelly, and Prest, 1969), was short lived due to political pressures which virtually eliminated a developing fishery off the Gulf coast of Florida. Very little work has been done on thread herring in the north central part of the Gulf of Mexico.

Thread herring apparently undergo rather significant migrations which are not well understood or documented. The Florida schools appear to move south in the winter, presumably in response to low temperatures, and north again when waters have warmed above $17^{o}C$.

Thread herring do not live very long, which seems characteristic of many coastal pelagic species in the Gulf of Mexico. Scales taken from these fish in commercial catches indicated that 70 percent of them were 2 years old with only about 3 percent of them attaining the third year of life.

Adult thread herring appear to spawn from March through August, with spawning activity peaking in June. Most of the spawning appears to occur in offshore waters. Young thread herring have not been found in large numbers in near-shore shallow areas suggesting a preference for offshore waters, which is in direct contrast to menhaden. This could be due to a preference for high salinity waters (e.g., 30 ppt), although a few juveniles have been found in waters with salinities down to 17 ppt.

Thread herring are filter feeders, straining small organisms from the water with numerous, closely spaced gill rakers. Copepods appear to be their chief food item, although pelecypods, gastropods, and "cypris" stage barnacles are frequently taken. The frequency of finely graded sediments in stomach samples reported by NMFS investigators suggests some bottom feeding, and a reported presence of minute fish scales indicates some carnivorous feeding.

The only NMFS recorded landings of thread herring over the last four years were in Louisiana: 1971--1,690 metric tons; 1972--1,490 metric tons; 1973--1,710 metric tons; and 1974--2,000 metric tons. The four-year average was 1,730 metric tons, which is roughly 0.3 percent of the average menhaden landings for the entire Gulf of Mexico.

Several reasons are given as to why menhaden fishermen do not seek thread herring more as a primary species. These fish are difficult to catch, inhabit clear water, and frighten easily when approached by purse boats. Thread herring also are slightly smaller than menhaden and at times are so small that gilling occurs in the webbing of the seines.

3.3 CATCH STATISTICS

Figure 3-5 shows how menhaden landings have steadily increased from 1947 to 1976. Similar figures are unavailable for thread herring. The figures show little difference in menhaden landings between 1975 and 1976, the two years encompassed by this investigation. Menhaden landings in 1972, during the ERTS-1 Menhaden Experiment, however, were significantly different from those in 1975 and 1976.

Peak landings generally occur during the summer months (Figure 3-6), even though the fishery is active throughout the fishing season (i.e., April through October). In 1975 and 1976 the peaks occurred in July and August, respectively. In 1972, however, there were two peaks, May and July. In the best year reported to date (1971), the peak catch occurred in June. The significance of these differences is unknown.

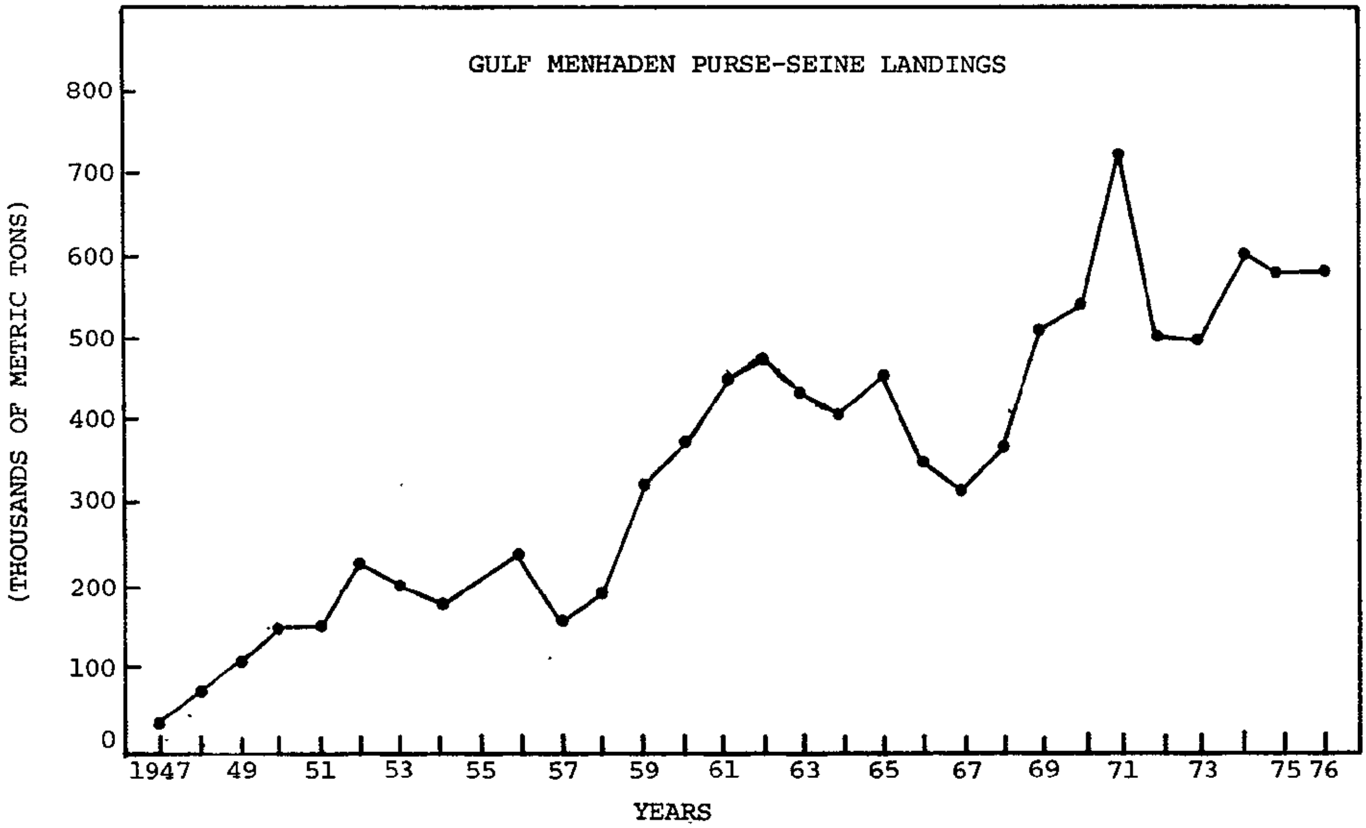

Figure 3-5. Actual Landings of Gulf Menhaden in Thousands of Metric Tons, 1947 - 1976 (from Christmas and Etzold, 1977)

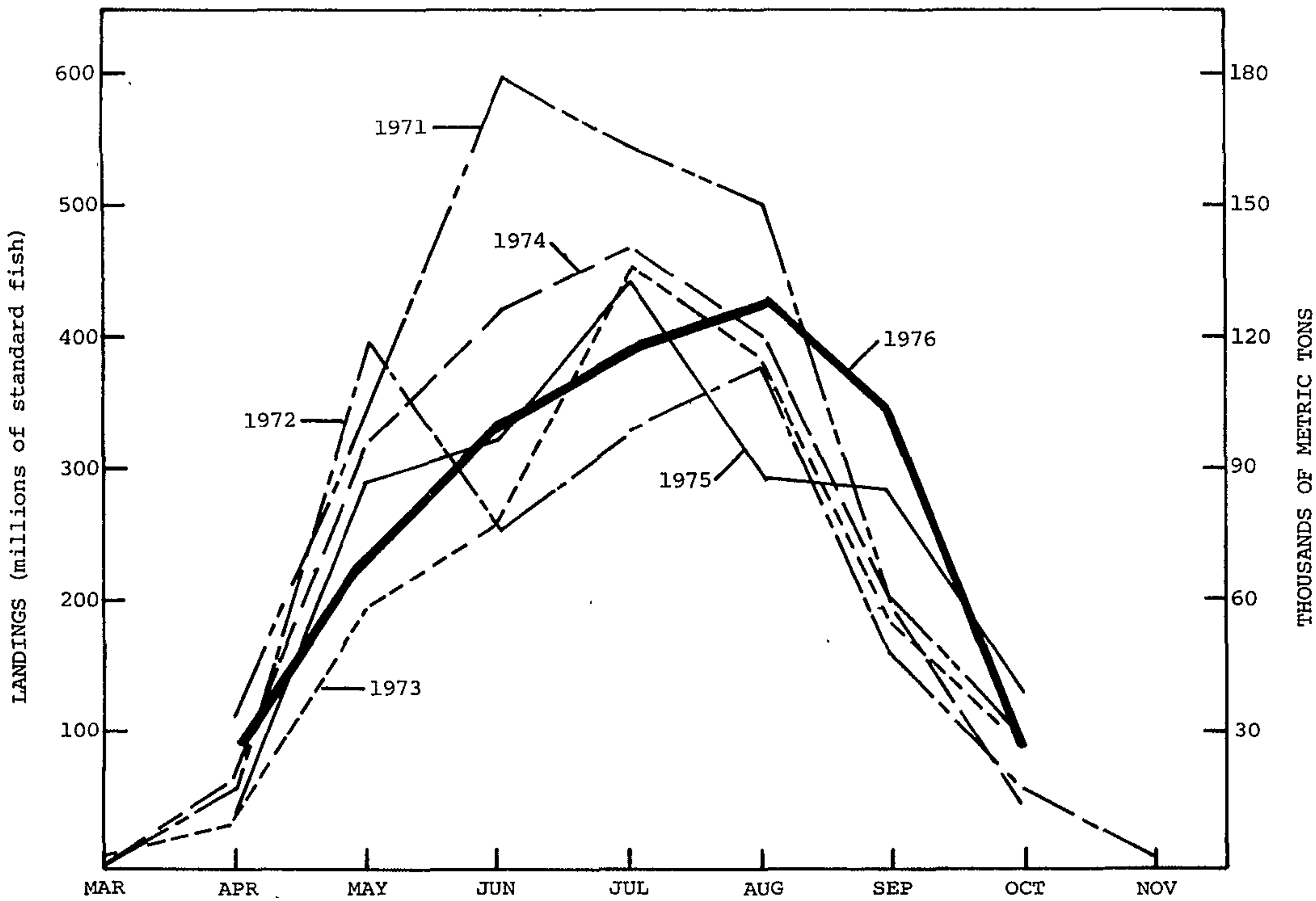

Figure 3-6. Gulf Menhaden Landings by Month, 1971-1976 (from Chapoton, 1977)

SECTION 4

DESCRIPTION OF STUDY AREAS

Study areas used for the follow-on and extension phases are shown in Figures 4-1, 4-2, and 4-3. During the follow-on phase, two study areas were used: the eastern portion of the Mississippi Sound and south of Morgan City, Louisiana. The study area used for the extension was the Louisiana study area extended westward to encompass three adjacent LANDSAT coverages.

4.1 FOLLOW-ON

4.1.1 MISSISSIPPI SOUND STUDY AREA

The Mississippi Sound is an estuarine complex located in the northeastern part of the Gulf of Mexico (Figure 4-1) interfacing with the oceanic water of the Gulf proper, through a chain of barrier islands situated almost parallel to the coast. The shore boundary of the Sound includes coastal areas of Louisiana, Mississippi, and Alabama.

The Sound itself is approximately 17 km wide by about 110 km in length, with an average depth of about 4 meters. Maximum depth is about 6 meters. Major brackish water embayments influencing the Sound are Mobile Bay to the east, and Biloxi Bay and St. Louis Bay to the west. The Pearl and Pascagoula River systems provide an influx of fresh water to the Sound. The western part of the Sound is further influenced by mixing of water from Lake Pontchartrain located to the northwest and interconnected by a body of shallow water known as Lake Borgne. The area immediately south of the barrier islands is characterized by near-oceanic water which provides a contrast to the Sound proper.

The Mississippi Sound was used during the ERTS-1 Menhaden Experiment to capitalize on an apparent existence of a bio-environmental relationship that manifested itself in the production and support of a viable menhaden fishery. Since the completion of the ERTS-1 Experiment, additional information has been reported on environmental conditions within the Sound. It has been shown the range of temperature is $13^{\circ}C$ to $32^{\circ}C$, the salinity range is 2 ppt to 32 ppt, and the maximum Secchi depth recordings are generally between 0.6 and 1.2 meters (Atwell, 1973).

4.1.2 LOUISIANA STUDY AREA

Caillou Bay, Atchafalaya Bay, and Marsh Island form the inshore boundary of the Louisiana Study area (Figure 4-2). The seaward limit, approximately at the 24 m curve and 50 km offshore, contains many oil platforms.

Effluent from the Atchafalaya River System (volume discharge in Louisiana second only to the Mississippi River) supports large estuarine areas and creates a hydrological zone of offshore transition from estuarine to coastal oceanic environments. Inshore, the estuarine environment is characterized by a temperature range of about 12 to $29^{\circ}C$ and a salinity range of 12 ppt to 23 ppt. In the summer, the average temperature and salinity are $27^{\circ}C$ and 18 ppt, respectively (Perret, et al., 1971).

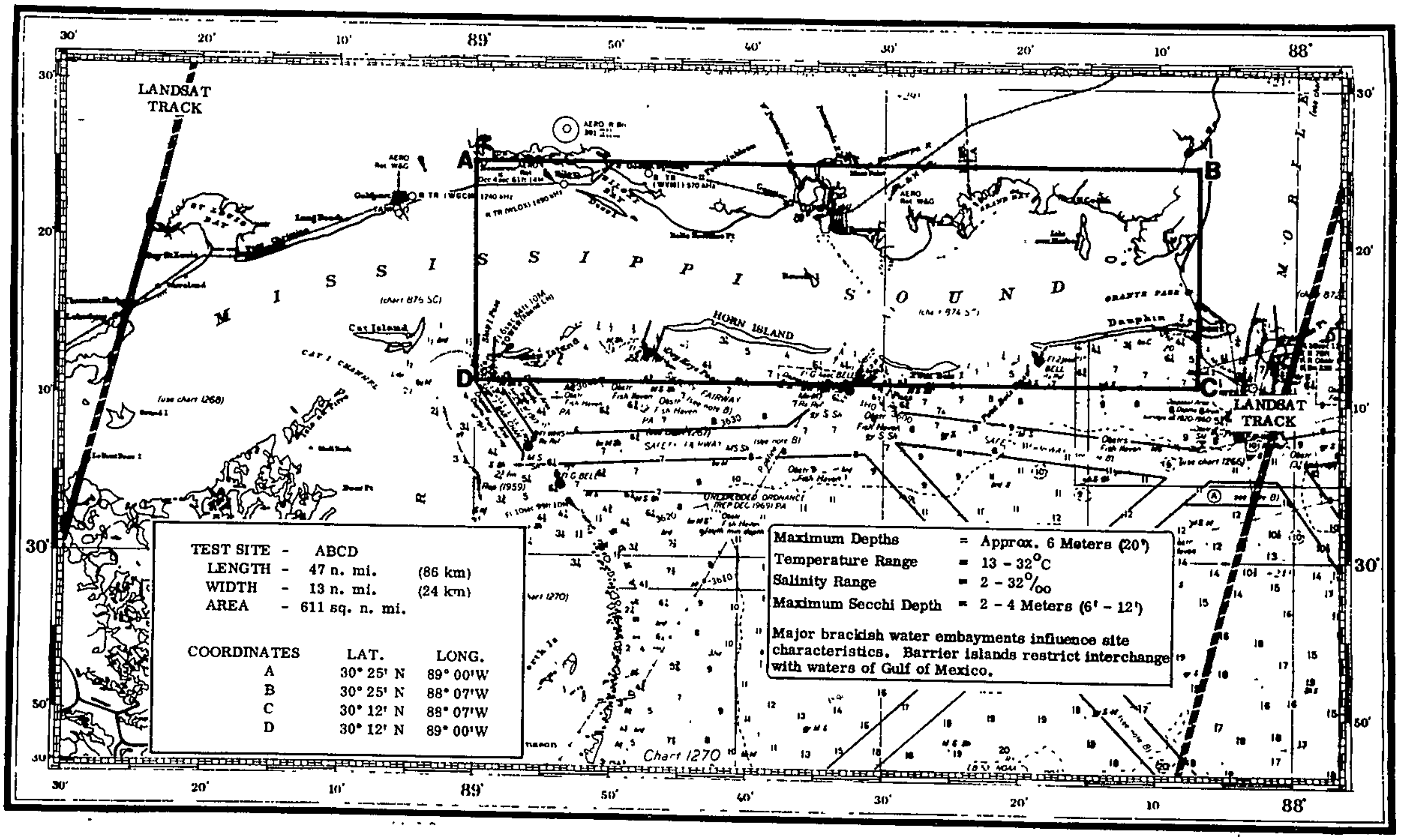

Figure 4-1. Mississippi Sound Study Area

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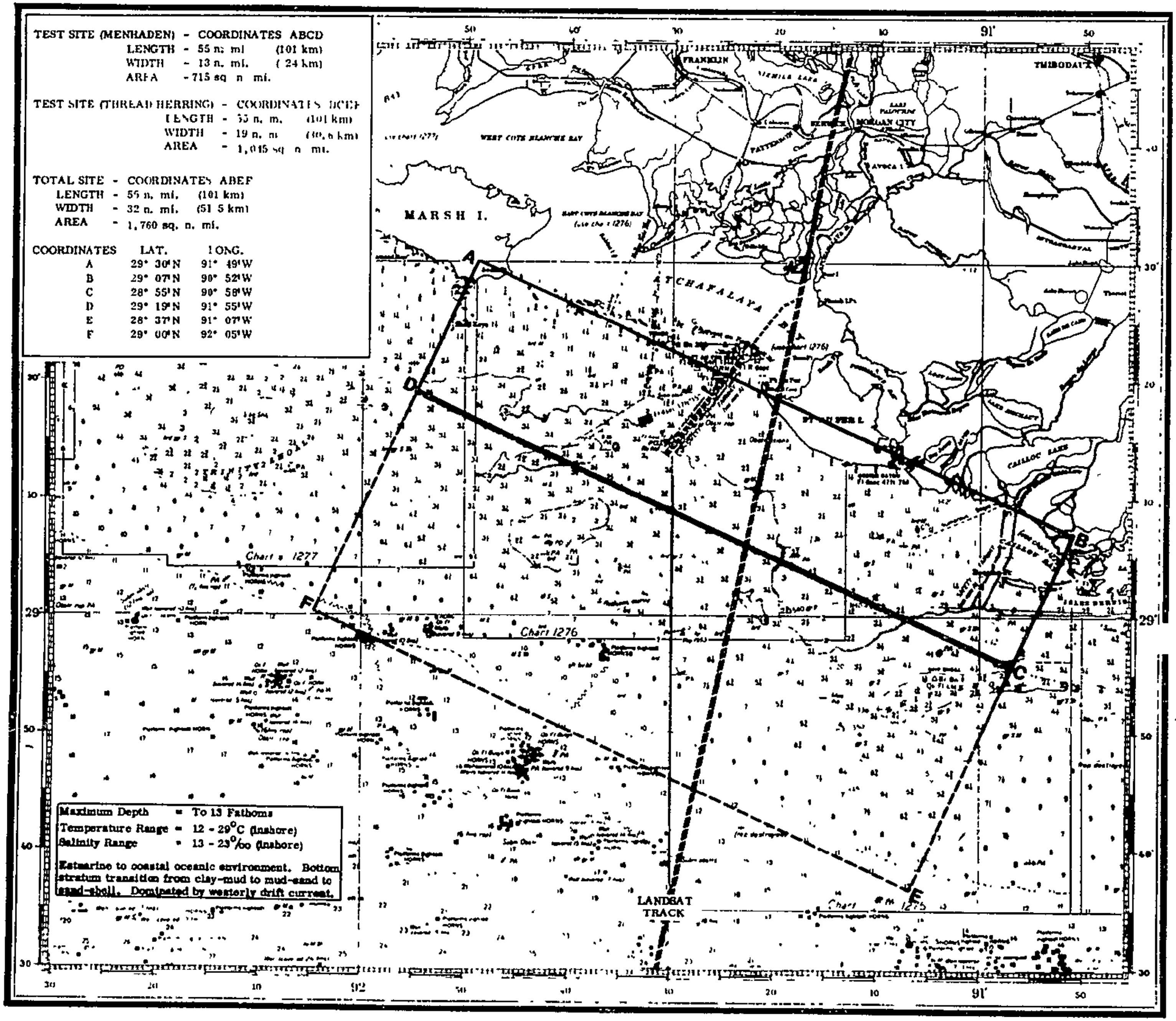

Figure 4-2. Louisiana Study Area

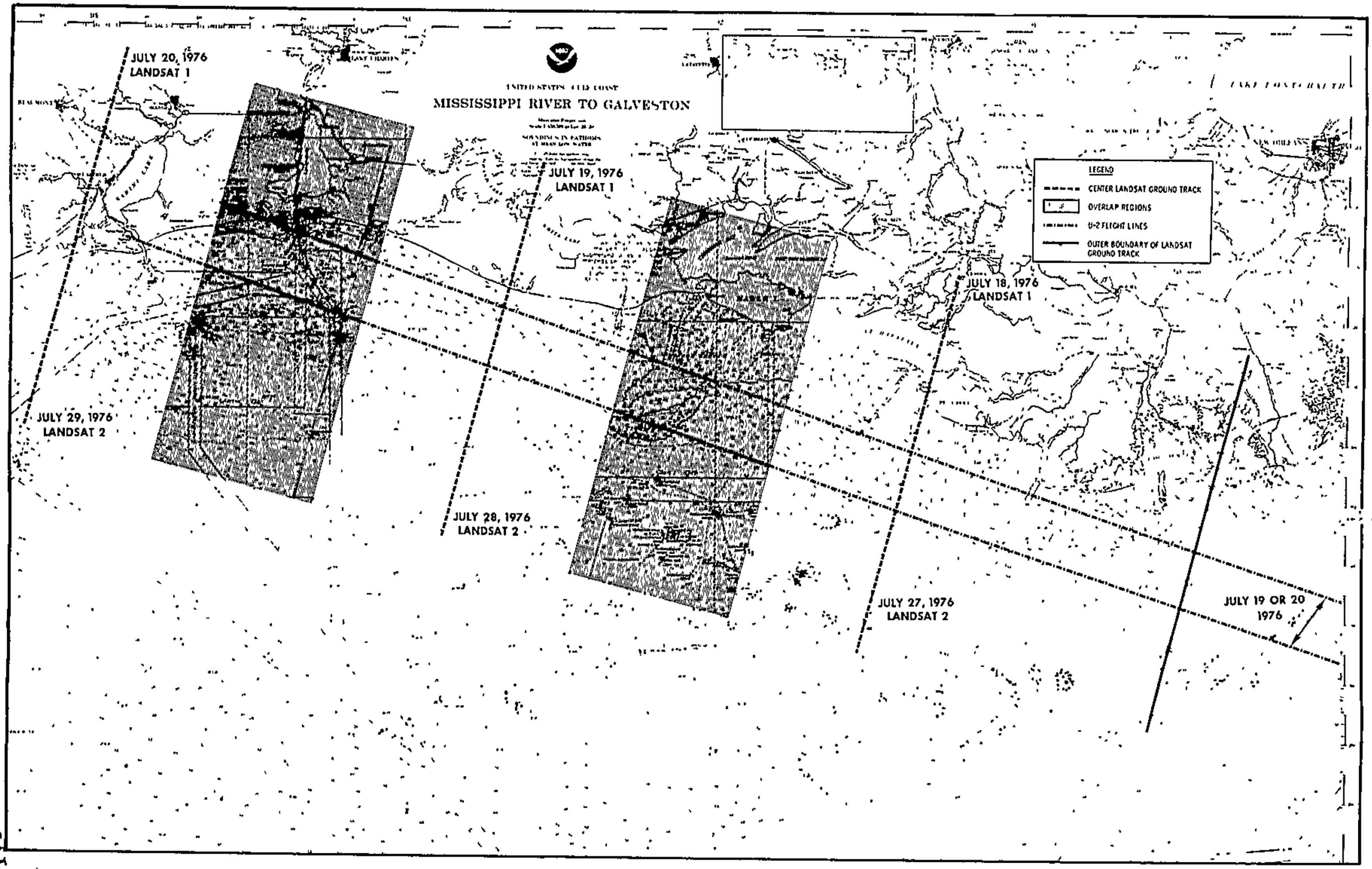

Figure 4-3. Louisiana Study Area Used During the Extension Phase of the Investigation

The type material deposited on the bottom depicts a seaward transition from an estuarine to a coastal oceanic environment. The study area is dominated by a westerly drift current and the bottom stratum is characterized by an offshore transition from clay-mud to mud-sand to sand-shell.

4.2 EXTENSION

The study area used for the extension phase of the investigation was the Louisiana coastal area bounded on the west by the Sabine River and on the east by Timbalier Bay (Figure 4-3). The eastern portion of this area is characterized by a wandering, broken shoreline of estuaries which are influenced by discharges of fresh waters from the Atchafalaya River. Shelf topography is typified by shoal areas 2 to 5 m in depth. The western portion is characterized by older and more established estuaries, and the shoreline is even and well defined. Fine grained mud and sand particles are carried westward by along shore currents and the bottom topography is generally uniform ranging in depth from 4 to 18 m. The inshore environment is characterized by a temperature range of $8^{o}C$ to $34^{o}C$ and a salinity range of 11 ppt to 24 ppt. In the summer the average temperature and salinity are about $28^{o}C$ and 14 ppt, respectively (Perret, et al., 1971).

SECTION 5

PLANNING AND COORDINATION

5.1 RATIONALE

An overall intent of the investigation was to ensure that each primary participant became and remained an effective and productive contributor throughout all investigative phases. This was considered essential because of the multidisciplinary and multi-interest nature of the investigation. A number of approaches were considered and used. Some worked well while others only partially satisfied program objectives. These approaches were applied to the planning, operational, analytical, and reporting phases of the investigation. Emphasis was on industry participation and coordination because if satellite remote sensing is to become an effective resource assessment and fishery utilization tool, the endorsement of the fishing industry is necessary.

5.2 FEDERAL INVESTIGATORS

Planning and coordination between the principal Federal agencies participating in this investigation, NFEL and ERL, were straightforward. Initially, a number of overview and planning documents were prepared cooperatively for review, modification, and acceptance. Most of this work was done months before the investigation was formally initiated in April 1975. These documents outlined the experimental rationale, analytical procedures, and type of field operations required to satisfy the analytical demands. Schedules were prepared and jointly reviewed for acceptance or rejection. Often an initial procedure was found to be impractical for operational reasons and was modified or rejected and replaced. Meetings were held weekly prior to initiation of the investigation and frequently several times a week after the investigation began. Data from the 1972 menhaden experiment often were used to test and verify proposed or planned aspects of the investigation. When a procedure was agreed upon by the Federal participants, it was presented to the industry cooperators and other industry representatives (e.g., chief spotter pilots and vessel captains) for review and comment.

An overview planning document summarizing the experimental design and operational procedures for the investigation was prepared (NMFS, 1975). This document covered background, objectives, experimental rationale and design, operational overview, schedules, analytical procedures, and management plan. The document, however, did not address the extension phase of the investigation as this latter phase was not conceived until after a significant portion of the follow-on phase had been completed.

Planning and coordination efforts were intense just prior to a field operation. Each participating agency prepared an operations plan to satisfy their particular requirements. Then, at least a week before the operation, meetings were held daily to review and update the overall plan. These updates were integrated immediately after each meeting and distributed to all participants.

Any significant departure from the original plan was reviewed with industry for concurrence. Immediately after a field operation, a formal debriefing was held to identify status, problems, and evaluate the success probability of the field operation. These debriefings generally included representatives from each element of the operation.

After the 1975 field operations, coordination and planning efforts were de-emphasized to concentrate on analyses. However, formal meetings were held monthly to establish status, identify problem areas, and review findings. In addition, each participant was asked to summarize his activities in quarterly report drafts for incorporation into Type II reports. These reports were distributed to all participants for review and comment.

The extension phase generally adhered to coordination and planning procedures followed during the first phase (NMFS, 1976). However, the real-time processing of the LANDSAT MSS data into a fishing probability chart mandated a series of dry-runs and other coordination efforts to ensure success. These efforts encompassed all aspects of the demonstration portion and involved the investigators who would be participating in the operation. LANDSAT MSS data from previous coverages of the study area were used in the dry-runs and timed records of activity were maintained. These records were reviewed following each dry-run and plans were modified to eliminate problem areas.

5.3 INDUSTRY COOPERATORS

Each Gulf company within the NFMOA appointed one or more people to represent them, referred to as NFMOA cooperators. The cooperators served as the official interface between their companies and the other investigators, and participated in all planning, operations, analysis, and report preparation phases of the investigation. They worked directly with the principal investigator and an industry liaison investigator from NMFS appointed specifically to schedule and coordinate investigative matters of interest to the cooperators.

Generally, meetings were held every other month with the cooperators in the early stages of the investigation to review status, plans, experimental procedures, and findings (Appendix E). Problem areas were identified so the cooperators could help solve them. A basic tenet was that the investigation would be conducted on a non-interference basis which made coordination essential. All requirements impacting the fishing industry were presented to the cooperators first. For example, if six vessels were required to carry scientific observers, the companies and vessels which would be involved were identified by the cooperators before any other action was taken. Matters of policy were discussed with the cooperators and forwarded to the Director of NFMOA with recommendations for resolution.

The cooperators reviewed all official documents resulting from the investigation prior to formal release. Press releases and other forms of information dissemination to the general public were also reviewed. These reviews served two primary purposes: information transfer and accuracy in reporting on matters resulting from or involving commercial fishing operations. They were not of a censorship nature.

Based on advice from the cooperators, a series of meetings also were held with vessel captains, spotter pilots, fleet managers, and other industry members to explain the investigation and review status (Appendix E). Often these meetings were used to elicit cooperation and explain requirements.

Reviews of the investigation were presented at official meetings of the NFMOA. These reviews served to inform executive management levels in the companies of progress and findings. They are summarized in Appendix E.

5.4 TRAINING AND STANDARDIZATION

Establishment of routine and standard data collection and analysis techniques for use by all participants in the investigation was essential to minimize errors and maximize compatibility of results. Experience in previous investigations, where standardization had been assumed and not mandated resulting in critical data being discarded because of poor quality, provided impetus to these efforts.

Training sessions were held periodically during the course of the investigation to familiarize the scientific observers and data collectors scheduled to board fishing vessels and oil platforms with procedures required to collect and process oceanographic and fishery data. These procedures were detailed in instruction booklets carried by the observers and collectors to their respective platforms. Standardized sampling kits and data forms also were provided to minimize chances of error. Training sessions began with the instructors carefully explaining the investigation followed by instructions on sampling procedures. Observers and data collectors were required to operate all the sampling equipment to gain experience and to be evaluated by the instructors. A training session was held prior to the field operation portion of the extension phase to train the observers in the operation of LORAN-C navigation equipment.

Sampling equipment and procedures used on the fishing vessels, research vessels, and oil platforms were identical. Samples requiring laboratory analysis, regardless of source, were analyzed with the same equipment and by the same analysts. Analytical priority was given to surface truth oceanographic and fishery data immediately following a field operation so data could be compared and quality verified.

Standard fishing logs were provided to the vessel captains and spotter pilots prior to each mission. The logs were designed and finalized after extensive review and discussions with the captains and pilots. Special briefing sessions were held with industry participants where experimental design was explained (i.e., the essential nature of the data) and instructions were given for filling out the fishing logs. The logs were reviewed and evaluated after each mission to identify misunderstandings and other sources of error, and the affected vessel captain or spotter pilot contacted.

SECTION 6

FIELD OPERATIONS

6.1 FOLLOW-ON

6.1.1 APPROACH

Field operations during the follow-on phase were conducted to satisfy data requirements of the experimental design defined in Section 2. An overview of a typical main day mission is shown in Figure 6-1; nominal research vessel sampling stations, aircraft flight lines, oil platform locations, and LANDSAT surface tracks for the Mississippi Sound and Louisiana study areas are shown in Figures 6-2 and 6-3, respectively. Responsibility for specific portions of each field operation was assigned to a primary participant based on capability, interest, and agreement (Table 6-1).

Table 6-1. Field Activities of Primary Participants

PARTICIPANT	ACTIVITY
NFEL	Mission management and coordination; fishing vessel and oil platform observers; fishing vessel and spotter pilot data; aerial photography and LLLTV.
ERL	Remotely sensed salinity, temperature, and color data (ERL Beechcraft and NASA NP3A); research vessels and crews; communications; aerial photography.
NFMOA	Coordination with member companies; observer accommodations aboard vessels; fishery data from vessels and spotter aircraft; pre-mission fishery data.

6.1.2 DATA ACQUISITION PLATFORMS AND SYSTEMS

Various data acquisition platforms (Table 6-2) were used to supply information for each analytical element of the experimental design. The platforms included satellites, aircraft, surface vessels, offshore oil platforms and land base stations. Instrumentation and equipment used on the platforms are summarized in Tables 6-3 and 6-4. Table 6-5 summarizes the parameters measured from each platform.

6.1.2.1 Satellites

The investigation was designed around LANDSAT-1 and -2 and their multispectral scanner systems (Figure 6-4). The satellites are alike; LANDSAT-1 was launched in 1972 and LANDSAT-2 in 1975. They are in sun-synchronous orbits at altitudes of 915 kilometers. Each spacecraft provides repeat coverage

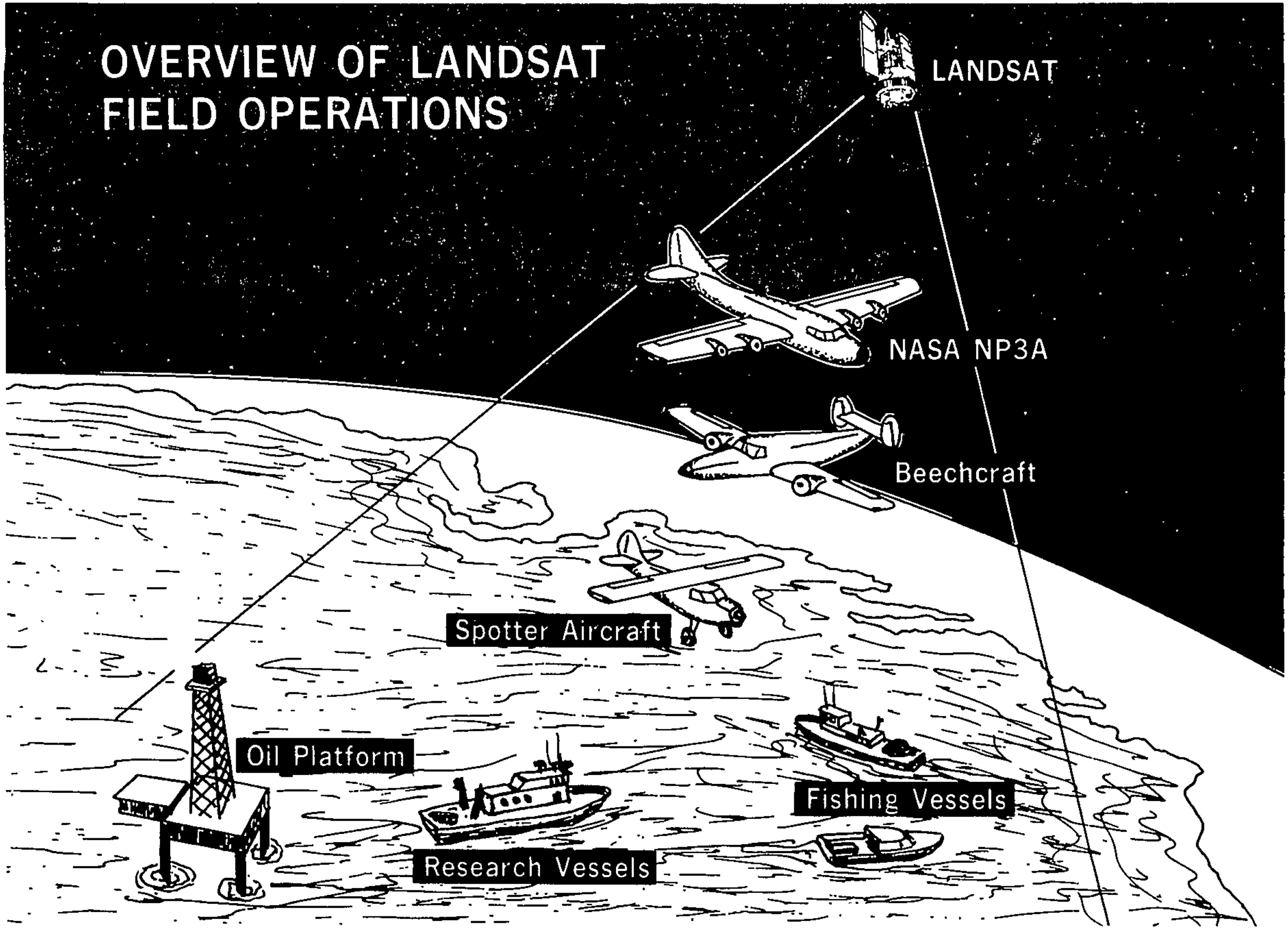

Figure 6-1. Overview of a Main Day Mission in the Louisiana Study Area (1975)

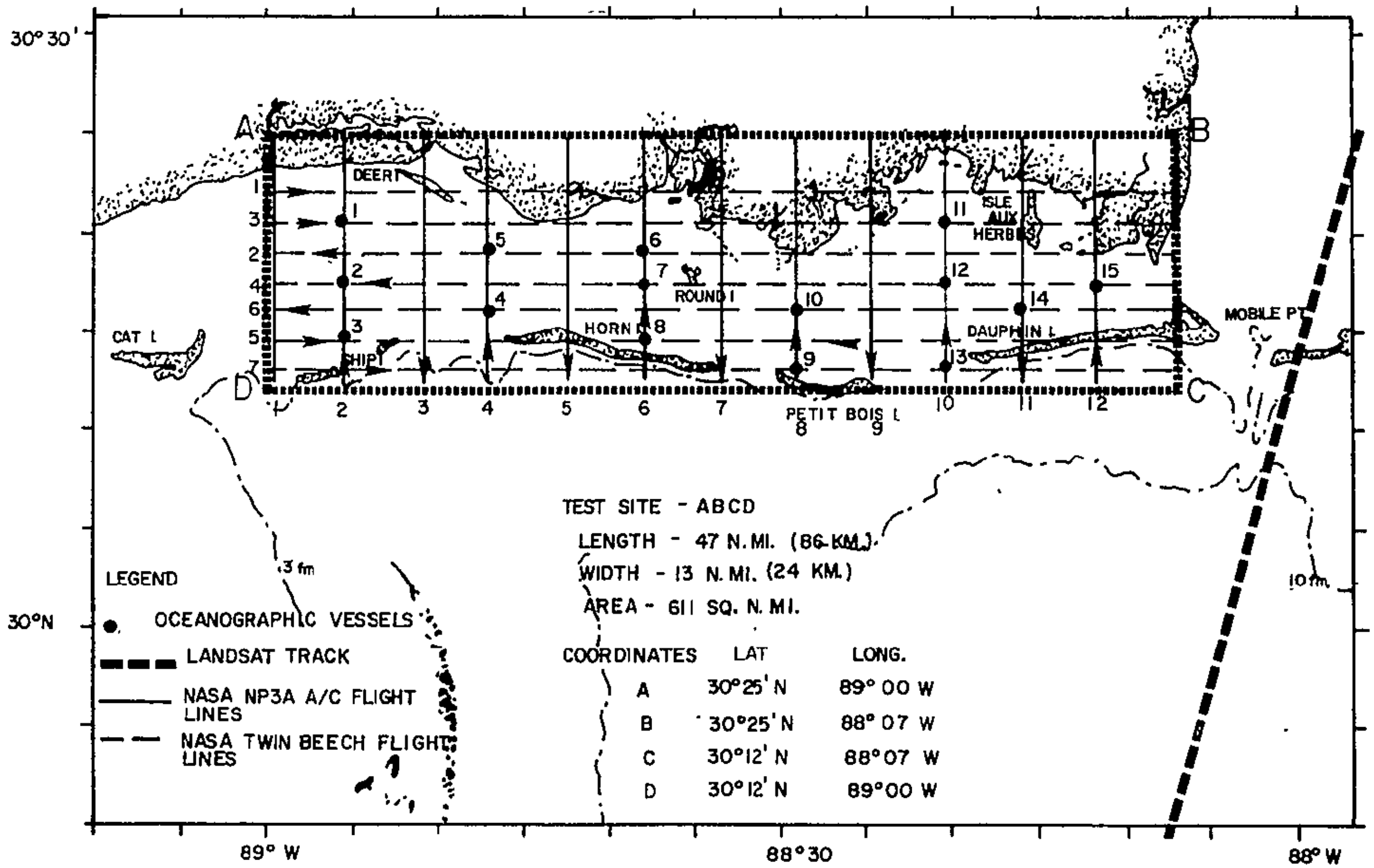

Figure 6-2. Mississippi Sound Study Area Showing the LANDSAT Surface Track, Aircraft Flight Lines, and Oceanographic Sampling Stations

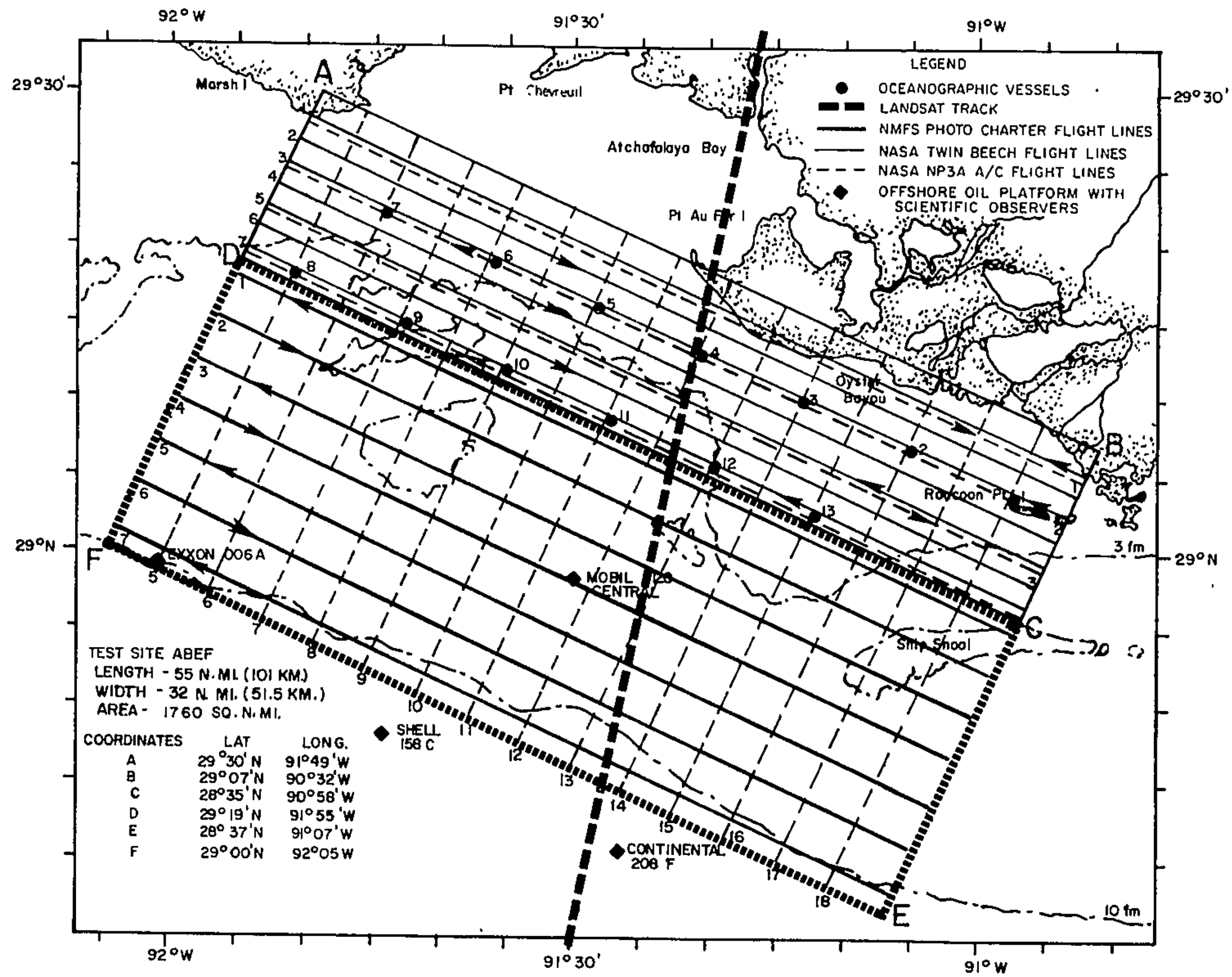

Figure 6-3. Louisiana Study Area Showing the LANDSAT Surface Track, Aircraft Flight Lines, Oceanographic Sampling Stations, and Oil Platform Locations

Table 6-2. Data Acquisition Platforms

Satellites	Aircraft	Research Vessels
LANDSAT-1	NASA/NP3A (1)	NASA/The ERL
LANDSAT-2	NASA/Twin Beech (1)	En Vie (charter)
SMS/GOES	Cessna 172 Spotter Aircraft (15)	Miss Iris (charter)
	Piper Apache (1)	Riptide (charter)
	Helicopters (2)	Bally Hoo (charter)

Oil Platforms

Continental Block 208 "F"
Exxon Block South Marsh 006 "A"
Mobil Block 120 Central Facility
Shell Block 158 "C"

National Fish Meal and Oil Association Menhaden Vessels

Galveston Bay	Allen W. Haynie
Carl Burton	Q. O. Dunn
Willard P. LeBeouf	Gulf Coast
Tiger Point	Acadia
Rachel Burton	Captain Gibby
Terrebonne Bay	Mary Virginia
Marsh Island	Lois C.
W. L. Burton	Tiger Shark
Timbalier Bay	Raccoon Point
Fat Chance	Sea Raider II
Trinity Shoals	Sea Ranger
Maverick	Fighter
Berwick Bay	Green Run
Sabine Pass	Texas
Beach Comber	Roamer Shoals
R. L. Haynie, Jr.	Sea Raider
A. G. Dunton	Sea Bee
Gussie J. Flynn	Mississippi Sound

Table 6-3. Support Aircraft and Instrumentation

AIRCRAFT	NASA/NP3A	NASA/Twin Beech	Piper Apache	Cessna 172
NAVIGATION SYS.	LTN-51 Inertial Sys.	R-Nav	LORAN-C	LORAN-C; Omni; dead reckoning
MAXIMUM RANGE	3700 kilometers	1485 kilometers	1335 kilometers	930 kilometers
MAX DURATION	8.0 hours	6.0 hours	4.0 hours	4.0 hours
FLIGHT ALT.	300 and 1525 meters	3050 meters	915 and 3050 meters	---
FLIGHT SPEED	610 kilometers/hr	260 kilometers/hr	340 kilometers/hr	210 kilometers/hr
SENSORS	Modular Multi-spectral Scanner; Multi-frequency Microwave Radio-meter; Bore Site Camera; PRT-5	RS-18 Multispectral Scanner; KC-1B Aerial Mapping Camera; IR Film 2443; PRT-5; Wratten 15 Filter	RC-10 Aerial Map-ping Camera; Kodak Aerochrome Infrared Film; 2443 Wratten 12 Kodak Filter; Low-light-level Image Intensifier	Visual Observation fish schools

Table 6-4. Surface Platforms and Instrumentation

SURFACE PLATFORM	OCEANOGRAPHIC VESSELS	FISHING VESSELS	OIL PLATFORMS
NAVIGATION EQUIPMENT	LORAN-C	LORAN-C; Dead Reckoning	Fixed Positions
SENSORS/ EQUIPMENT	Turner Model 111 Fluorometer	<u>Portable Sampling Kits Included</u>	
	Marine Sky Vane	Surface Water Sampler	Vacuum Pump
	KS-5-3 Salinometer	Chlorophyll Filter Apparatus	Secchi Disc
	Martek Transmissometer	Forel-Ule Indicator	
	Interocean Relative Irradiance Meter	Plastic Buckets with Hand Line	
	Fathometer	Dry Ice Containers	
	Barometer	Dividers	
	Psychrometer	Sample Bottles	
		Office Supplies	
		Mercury Thermometers	

Portable Sampling Kits were used as back-up to electronic systems on oceanographic vessels

Table 6-5. Summary of Principal Parameters Measured During Main Missions Supplementary Mission Included only Fishing Vessels without Observers, Spotter Aircraft, and LANDSAT

	SURFACE				AIRCRAFT					SATELLITES	
Parameter	Fish Ves without Observer	Fish Ves with Observer	Oceano-graphic Vessel	Oil Platform	NP3A	NASA ERL Aircraft	NFMOA Spotters	NMFS Photo	LLLTV*	LANDSAT	SMS/GOES
Salinity		X	X	X	X						
Chlorophyll		X	X	X	(X*)	(X)				(X)	
Color		X	X	X	X*	X				X	
Transparency		X	X	X	(X*)	(X)				(X)	
Temperature		X	X	X	X	X					
Water Depth		X	X	X							
Fish School Locations			X			X	X	X	X		
Location of Fish Catches	X	X				X		X			
Meteorology			X				X				X

* Louisiana study area only

( ) Uncertain Accuracy

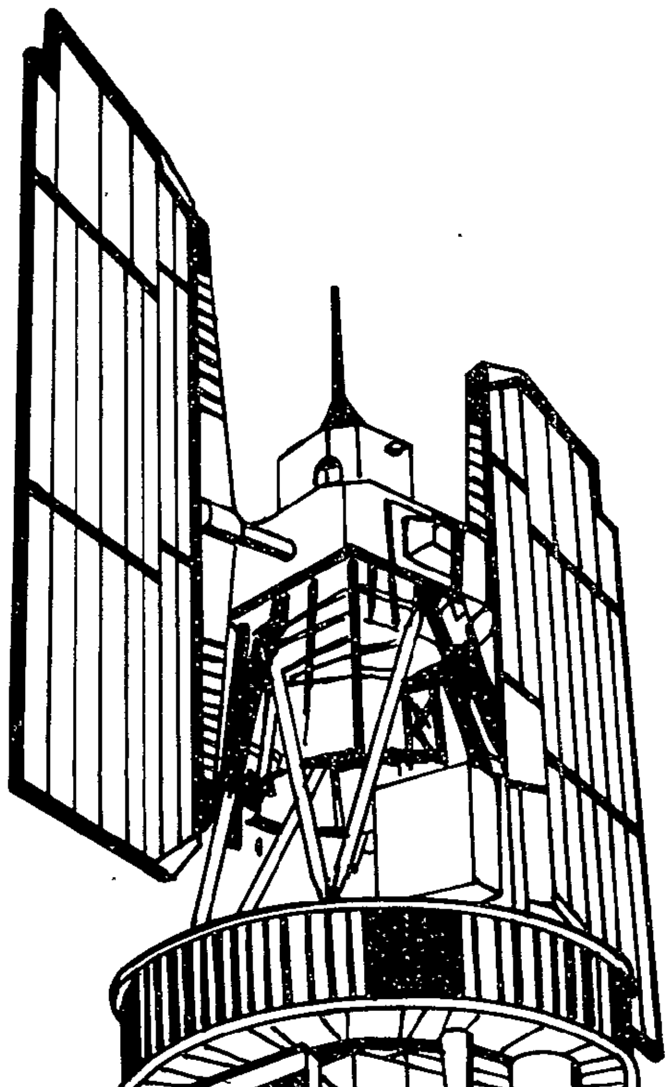

Figure 6-4. LANDSAT

every 18 days; the orbits are synchronized such that one or the other provides coverage of an area every nine days. The multispectral scanner (MSS) is a line scanning device which uses an oscillating mirror to scan a 185 kilometer swath of the terrain passing beneath. The scanner produces four synchronous images, each covering a different portion of the electromagnetic spectrum. Wavelength ranges of each band are:

Band 4 (green)	500-600 nm
Band 5 (lower red)	600-700 nm
Band 6 (upper red - lower infrared)	700-800 nm
Band 7 (infrared)	800-1100 nm

A detailed description of LANDSAT and its sensor systems is given in the LANDSAT Data Users Handbook, 2 September 1976, Goddard Space Flight Center, Document Number 76SDS4258. Main and supplementary mission operations were scheduled to coincide with LANDSAT-1 or -2 coverage of the study areas.

6.1.2.2 Aircraft

Airborne sensor systems were utilized to augment satellite acquired data and provide pertinent information not obtainable by LANDSAT. The most heavily instrumented aircraft was the NASA NP3A. It provided remotely sensed data for water color, salinity, and temperature data. The NASA ERL Beechcraft provided additional remotely sensed water color and temperature data as well as aerial photography for fish distribution and abundance information. A chartered Piper Apache was used to collect fisheries data using aerial photography during daylight hours and a low-light-level television camera at night. NFMOA spotter aircraft (Cessna 172) also were utilized to obtain fish distribution and abundance data on a non-interference basis during routine fishing operations.

6.1.2.3 Vessels

During main missions, three research vessels were used to acquire surface truth data for calibration and verification of the oceanographic models used to convert aerospace remotely sensed data into measurements of selected oceanographic parameters. Two vessels were chartered while the third, The ERL, was supplied by NASA/ERL.

Participating companies of the NFMOA provided fishing vessels for supplementary and main missions. These vessels were used to acquire catch data on a non-interference basis. In addition, during main missions, up to six fishing vessels were used to collect a series of oceanographic measurements made by scientific observers on each fishing vessel at locations of fish capture.

6.1.2.4 Offshore Platforms

Surface truth oceanographic data were obtained in the Louisiana study area during the 1975 operations by placing scientific observers aboard manned oil platforms. Four platforms were occupied by the observers during the first two main missions and two platforms were occupied on the third main mission.

6.1.3 COORDINATION OF ACTIVITIES AND PERSONNEL

Coordination of field activities was essential to meet the data acquisition requirements. Operation managers and coordinators were identified to assure proper implementation of activities, coordination, and communication among all field participants.

An industry liaison investigator was assigned responsibility for activities involving coordination between the fishing industry and Federal participants. Principal contacts included NFMOA fleet managers, fishing vessel captains, and spotter pilots. A NASA field operations manager was identified to manage activities pertaining to NASA remote sensing systems, oceanographic surface truth, and operate a communications command post. An NMFS field operations manager and oceanographic coordinator were responsible for field activities involving scientific observers on fishing vessels and oil platforms, the charter photographic aircraft, and fishery data collectors. Personnel participating in field operations for the investigation were divided into nine groups.

- Remote Sensing Aircraft Crews - pilots, navigators, and flight engineers of the aircraft operating over the two study areas. The crew for the NP3A was provided by NASA/JSC, for the ERL Beechcraft by ERL, and for the NFEL charter aircraft by NFEL as part of the charter.

- Remote Sensing System Operators - all personnel directly involved with operating aircraft-supported remote sensing systems over the study areas. Operators for the systems aboard the NP3A were provided by NASA/JSC, who were assisted by ERL personnel. ERL provided operators for all sensors aboard the ERL Beechcraft except for the LLLTV system which was operated by NFEL. NFEL provided operators for the sensors on the NFEL charter aircraft.

- Surface Truth Vessel Crew - captains, mates, and deck hands required to operate the surface truth vessels. The crew for The ERL was provided by ERL and the crews for the charter vessels were provided as part of the charter agreements.

- Surface Truth Vessel Samplers - a minimum of two samplers on each of the three research vessels. The samplers were trained and provided by ERL for each vessel.

- Fishing Vessel Crews - captains, mates and fishermen on each NFMOA cooperating vessel. Each participating company was responsible for crews.

- Spotter Aircraft Pilots - responsible for obtaining fishery information during the main and supplementary mission periods and for collection of fish distribution information prior to a main mission. Each participating company was responsible for its respective pilots.

- Fishing Vessel Observers - up to six observers were aboard fishing vessels to obtain oceanographic measurements at locations of fish captures. The observers were trained and provided by NFEL for placement aboard vessels identified by the participating NFMOA companies.

- Fishing Data Collectors - at least two data collectors were used to interview and collect completed data forms from fishing vessel captains and spotter pilots. These collectors were trained and provided by NFEL.

- Oil Platform Samplers - samplers on two or more oil platforms in the Louisiana study area during each main mission. These samplers were trained and provided by NFEL to obtain oceanographic measurements for evaluating temporal variations in data collected from other platforms.

6.1.4 SAMPLING PROCEDURES, INSTRUMENTATION, AND METHODS

Surface water temperature was determined by bucket thermometers with accuracies of $\pm 0.1^{\circ}C$ or Beckman RS5-3 salinometers with accuracies of $\pm 0.5^{\circ}C$. Water depth was determined with a fathometer, when available, to an accuracy of ± 0.3m, or with a calibrated lead line with an estimated accuracy of ± 0.2m. Secchi depth was determined to 0.2m (measurements were recorded in feet) with a standard white 30-cm diameter Secchi disc (Harvey, 1963). Forel-Ule color was determined with a Forel-Ule color comparator off the shady side of the vessel over a Secchi disc at a depth of one meter. Accuracy was estimated to be ± 1 unit (Secchi, ca 1866). Salinity was determined either *in situ* with Beckman RS5-3 salinometers, accuracy of about ± 0.3 ppt, or in the laboratory with a Beckman RS-7B salinometer, with accuracy of ± 0.03 ppt.

Surface chlorophyll samples were collected in polyethylene buckets. Either 250 or 500 ml samples were then filtered through 0.45 micron millipore acetate filters. All filters were immediately frozen and returned to the laboratory for analysis. The analytical procedure used was described by SCOR-UNESCO Working Group #17 (Determination of photosynthetic pigments in Sea-Water, UNESCO, Paris, 1969).

Surface station locations were determined by dead reckoning during the follow-on phase in 1975 and by InterNav LORAN-C navigation systems during the 1976 extension phase. The LORAN-C units were accurate to ± 1 km.

Other data such as humidity, barometric pressure, sea state, visibility, cloud cover, fluorescence, and relative radiance were acquired by ERL from research vessels. Measurement and analytical procedures are described in ERL report number 154, LANDSAT Menhaden - Thread Herring Resource Investigation Surface Measurement Report (December, 1975).

Locations of fish capture were determined by fishing vessel captains using dead reckoning during the 1975 follow-on. Estimated accuracy was ± 2 km. For the 1976 extension phase, locations were determined by scientific observers using an InterNav LORAN-C navigation system with an accuracy of ±1 km. Number of fish caught was estimated by vessel captains and was generally ±10 percent of the actual number when the fish were counted at off-loading.

Spotter pilot reports of fish locations during the 1975 follow-on phase were based on dead reckoning, with an estimated accuracy of +2 km. During the 1976 extension phase, one spotter pilot was equipped with a LORAN-C navigation system; the other spotter pilots provided locations based on omni bearings. Positions based on the omni readings, however, proved unreliable. Number of fish schools and school size were estimated usually by the spotter pilots.

6.1.5 MISSION MANAGEMENT AND CONTROL

6.1.5.1 Main Missions

The Principal Investigator retained final decision authority regarding all aspects of mission control. He was assisted in mission management by managers from ERL and NFEL who were responsible for organizing, planning, scheduling, and implementing the respective roles of each laboratory. An example of activities, decision parameters, and criteria involved in mission implementation and control is given in Table 6-6.

6.1.5.2 Supplementary Missions

A single mission control plan was prepared for the supplementary missions which was periodically updated during the course of the investigation. This plan identified vessels, spotter aircraft, points of contact, and personnel involved in these missions. It also specified where to distribute and collect data forms from pilots and vessel captains of participating NFMOA companies. The industry liaison investigator managed these activities, and at least two people were assigned to collect the data forms.

6.1.6 OPERATIONAL ACTIVITIES

6.1.6.1 Typical Main Missions

Fishing vessel observers boarded the vessels on Sunday night regardless of mission day. A Sunday boarding was required because the vessels normally departed their ports on Sunday and often did not return until the following Friday or Saturday night.

Oil platform observers were flown to the platforms on the day prior to the main day mission and returned on the evening of the mission day. Helicopter transportation service was provided by the Outer Continental Shelf Operations Office of the United States Geological Survey. The observers collected data hourly on main mission days.

Table 6-6. Typical Main Mission Control Activities

Day	Decision/Activity	Parameters/Criteria
-7	Mission Plan Completed	N/A
-6	Review Mission Status	N/A
-5	Review Mission Status	N/A
-4	Identify Fishing Vessels for Observers Notify Observers Notify Charter Vessels	Major Weather Forecast Aircraft Operational Fishing Vessel Avail. LANDSAT Operational
-3	Decisions to Terminate, Hold, or Continue	Same as above with update
-2	Final Fishing Vessel Identification for Observers Decision to Terminate, Hold, or Continue	Same as above with update plus final fishing vessel availability information
-1	Board Fishing Vessels Deploy Samplers Test Site Selection (Western) Decision to Terminate, Hold, or Continue	NP3A Operational LLLTV Reports Fishing Reports Local Weather Forecasts
0	Board and Deploy Oceanographic Sea-truth Vessels Launch Aircraft Decision to Terminate or Continue	Local Weather Update 2 out of 3 Oceanographic Vessels Operational Normal Whitecaps

Logistics for the Louisiana study area missions were more complex than those for the Mississippi Sound due to the distances involved. The ERL vessel (The ERL) generally departed from Gulfport, Mississippi, three days prior to the main mission day to ensure ample time for arriving on station. The oceanographic vessels (The ERL and two chartered vessels) were boarded at Grand Isle, Louisiana, by the sampling crews the day before the mission and the night was spent on station. Mississippi Sound missions were operated out of Gulfport.

A communications command post was established at Grand Isle initially and later at Houma, Louisiana, for the Louisiana study area missions. A command post for the Mississippi Sound missions was maintained at NSTL. The command posts were manned on the day prior to the main day mission. Normally, personnel at the command post included the NFEL and ERL operations managers, the Principal Investigator, the industry liaison investigator, and a radio operator. The command post functioned primarily to coordinate activities, monitor schedules, make necessary last minute adjustments to the schedule, and to abort or continue field activities depending on weather conditions and/or platform failures.

On the day prior to a main day mission, the industry liaison investigator contacted selected NFMOA spotter pilots to ascertain where menhaden and thread herring were being observed or caught. This information was critical for the Louisiana study area as the offshore flightlines were selected to maximize the probability of flying over areas with fish. Normally, several NFMOA pilots flew the entire Louisiana study area to acquire this information. At sunrise on the mission day, selected NFMOA spotter pilots contacted The ERL to relay information on weather and cloud cover conditions to the command post. Information was relayed through The ERL concerning mission status and especially any schedule changes in The ERL and NP3A aircraft operations.

Aircraft operational activities were coordinated to ensure flight safety. Prior to the field operations, a meeting was held with representatives of Federal Aviation Administration, NASA aircraft personnel, chief spotter pilots of NFMOA, and charter aircraft operators to thoroughly discuss all aspects of aircraft operations, and to establish a common communication frequency between aircraft.

The NP3A operated out of Houston, Texas, or Nashville, Tennessee, and the ERL Beechcraft out of Stennis Field, Mississippi, for all main day missions. The NMFS chartered aircraft flew out of Houma, Louisiana. Constant communications with the aircraft were maintained via telephones prior to takeoff and by radio through The ERL during flight operations.

A mission debriefing was held the week following each main day mission. All principal mission participants attended the meeting and a complete review was made of the operation. This debriefing was held primarily to uncover problems and correct them prior to the next mission.

Except for data collection from the fishing vessels and spotter aircraft, all main day mission data acquisition activities were limited to the day of LANDSAT coverage. Since the scientific observers had to remain aboard the fishing vessels throughout the fishing week, sampling functions were performed throughout the week. Fishing vessel captains and spotter pilots acquired data the day before, the day of, and the day after satellite coverage so information on general fish movement patterns could be developed.

6.1.6.2 Typical Supplementary Day Missions

The normal supplementary day mission involved only vessel captains and spotter pilots. These missions were designed to coincide with LANDSAT-1 and -2 coverages. Captains and pilots were requested to provide fish catch and location information the day before, the day of, and the day after each supplementary day mission.

6.2 EXTENSION PHASE

6.2.1 APPROACH

Data acquisition activities during the extension phase were similar to those described for the follow-on. A major difference was data were utilized in near real-time. Specifically, LANDSAT-1 data from one overpass were processed and classified into a high and low probability fishing area chart for dissemination to the commercial fishing fleet within 21 hours. The persistence objective of the extension phase was pursued through a comparison of waters classified as high and low probability fish areas within the overlap regions between two successive LANDSAT data frames. An overview of the field operations is presented in Figure 6-5.

Another significant difference between the field operations for this and the follow-on phase is that no remote sensing aircraft were specifically used. A U-2 overflight of the study area was made, but this overflight had no impact on either objective of the extension. Additionally, only a small number of chlorophyll samples were collected from the fishing vessels. All other parameters measured from the fishing and research vessels remained the same as during the follow-on phase.

6.2.2 PLATFORMS AND SYSTEMS

Platforms and systems used for the extension phase included LANDSAT 1 and 2, a research vessel, fishing vessels, and spotter aircraft. No instrumented remote sensing aircraft were used. Eight fishing vessels and a chief spotter pilot were supplied with LORAN-C navigational equipment for precise fish school location information.

6.2.3 PERSONNEL

Personnel aboard the research vessel, fishing vessels, and spotter aircraft were essentially the same as for the follow-on phase. Scientific observers were on eight fishing vessels equipped with LORAN-C navigational systems to operate the systems and collect oceanographic measurements. Other personnel unique to this operation are identified as follows:

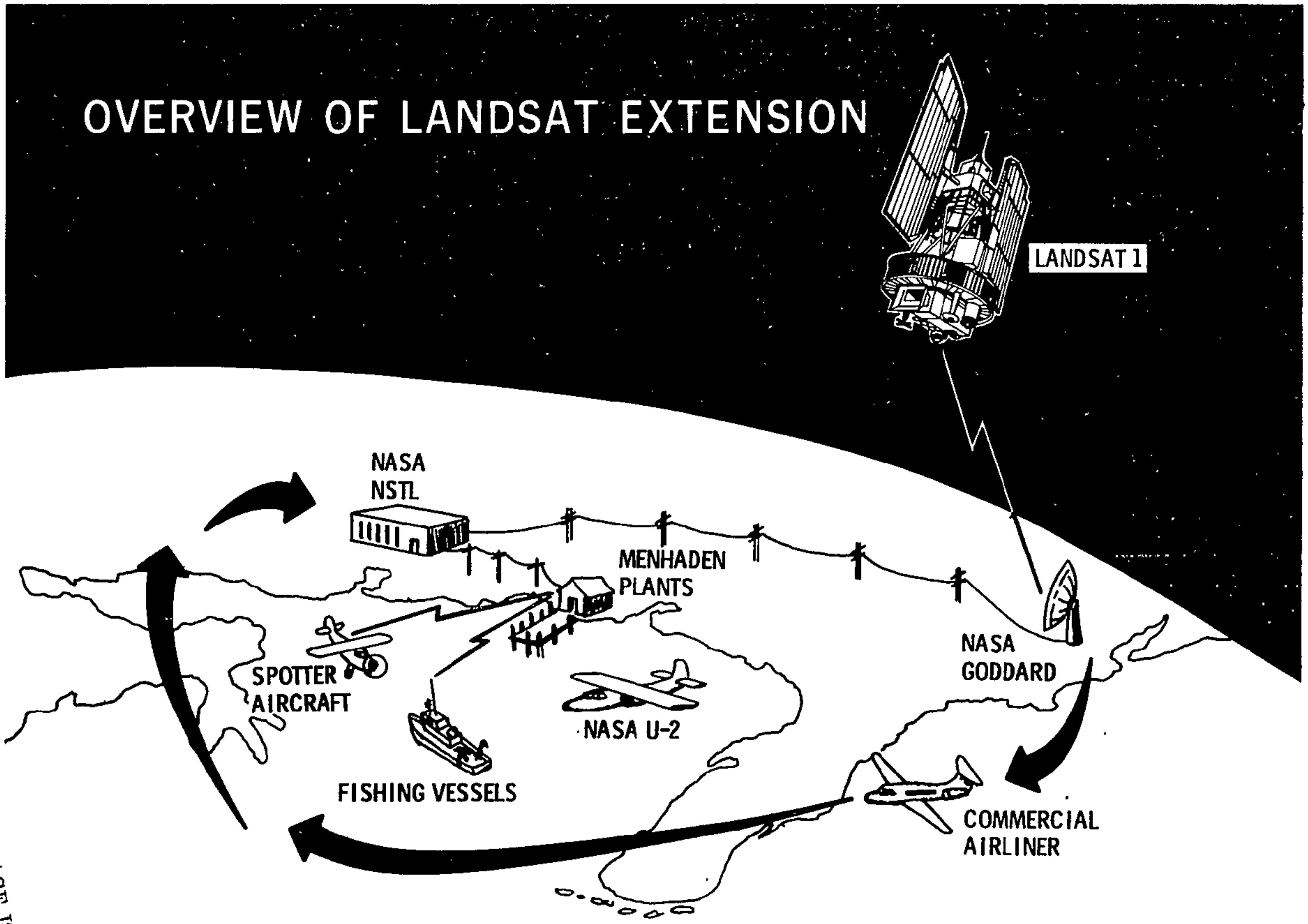

Figure 6-5. Conceptual Overview of the Field Operations Performed During the Extension Phase of the Investigation

- Plant Coordinators - stationed at each fishing plant to make periodic radio contact with the scientific observers aboard the fishing vessels to obtain fish location information, and to telephone the information to the mission manager at the Slidell Computer Center.

- Airport Coordinators - stationed at selected airports to meet spotter pilots, obtain fish location information, and telephone the information to the mission manager at the Slidell Computer Center.

- Satellite Data Acquisition and Evaluation - an investigator was at the Goddard Space Flight Center to evaluate the quality of LANDSAT-1 imagery (cloud cover, haze, etc.) immediately after reception. He was assisted in this evaluation by the Director of the NFMOA. The evaluation was performed only once for the demonstration portion of this phase.

- Data Integration and Control - personnel were at the Slidell Computer Center to receive all information telephoned to them by field coordinators, and to exercise data formatting and control procedures.

6.2.4 MANAGEMENT

The Principal Investigator was responsible for overall management of the extension phase. Assistance was provided by a mission manager and operations managers responsible for the activity of their respective laboratories.

6.2.5 OPERATIONAL ACTIVITIES

Trained scientific observers were placed aboard eight fishing vessels with appropriate oceanographic sampling gear and LORAN-C navigational equipment. During the first period (July 18-23, 1976) the observers were aboard five vessels out of Cameron, and three vessels out of Intracoastal City, Louisiana. During the second period (July 25-30, 1976) the observers were aboard two vessels each from Cameron, Intracoastal City, Morgan City and Dulac, Louisiana.

On the first LANDSAT-1 data acquisition day (July 19, 1976) fish school locations identified by the fishing vessel observers were relayed through the plant coordinators to the NASA Slidell Computer Center to be transferred to the LANDSAT coordinate system. At the same time, the Goddard Space Flight Center processed LANDSAT data immediately upon receipt and sent computer compatible tapes via a commercial airliner to Slidell where training data were extracted (i.e., locations of menhaden capture). The MSS data were then classified into high and low probability fishing zones, fishing charts were prepared, and the information was distributed to NFMOA fleet and plant managers, chief spotter pilots, and vessel captains.

6.3 ANCILLARY INFORMATION

Appendices are provided to document information pertinent to the field operations supporting the LANDSAT investigation. Appendix A contains examples of forms used for data acquisition. Appendix B shows aircraft flightlines and Appendix C identifies the station locations occupied by surface vessels and spotter aircraft. Appendix D presents contours of oceanographic data collected during the investigation. Appendix E lists meetings, reports, and publications resulting from the LANDSAT investigation.

SECTION 7

SCHEDULES

7.1 OVERVIEW

The follow-on phase was scheduled for 18 months with an additional four months for final report preparation and review. This schedule was extended six months in 1976 to include the extension phase and two months were added in 1977 at the request of the Principal Investigator. Thus, the official period of the investigation was 30 months.

Although the investigation did not begin officially until April 1975, planning efforts began in January 1975 (Figure 7-1). These early planning efforts were essential to enable field operations to begin early in the 1975 menhaden fishing season. Field operations for the follow-on phase terminated in late September 1975, coinciding roughly with the end of the fishing season. Analytical efforts began as data became available and continued throughout the investigation, although at a reduced level during the planning and field operations portion of the extension phase.

Planning and coordination for the extension phase began in late March 1976 and continued until the field operations began in July 1976 (Figure 7-1). Field operations lasted two weeks and were immediately followed by analyses. These analyses involved data from both 1975 and 1976 field operations. Seven quarterly reports were prepared during the investigative period (Figure 7-1). A field operations report covering both phases of the investigation was published in April 1977, and a special data report in May 1977. Other reports published as a direct result of the investigation included an experimental plan for the follow-on phase in June 1975, and a combined experimental and field operations plan for the extension phase in July 1976.

7.2 FOLLOW-ON

Figure 7-2 summarizes the main and supplementary missions conducted in the Mississippi Sound during 1975. The first two main missions were conducted as planned with all platforms operational. The third main mission (July 31, 1975) was rescheduled to September 5, 1975, due to inclement weather and unavailability of the NP3A aircraft.

Figure 7-3 summarizes the main and supplementary missions conducted in the Louisiana study area during 1975. The first two main missions were conducted as planned with all platforms operational. The third scheduled main mission (July 24, 1975) was aborted due to a reported LANDSAT-1 malfunction and was rescheduled to coincide with a LANDSAT-2 overpass on August 20, 1975. Later, it was learned that LANDSAT-1 had successfully acquired data on July 24, 1975.

7.3 EXTENSION

Field operations of the extension phase were scheduled for July 1976. Figure 7-4 summarizes the missions conducted and platforms used during this period. The LANDSAT-1 overpass on July 19, 1976, was used to satisfy the operational simulation objective, and LANDSAT-2 overpasses of July 27 and 28, 1976 were used to satisfy the persistence objective.

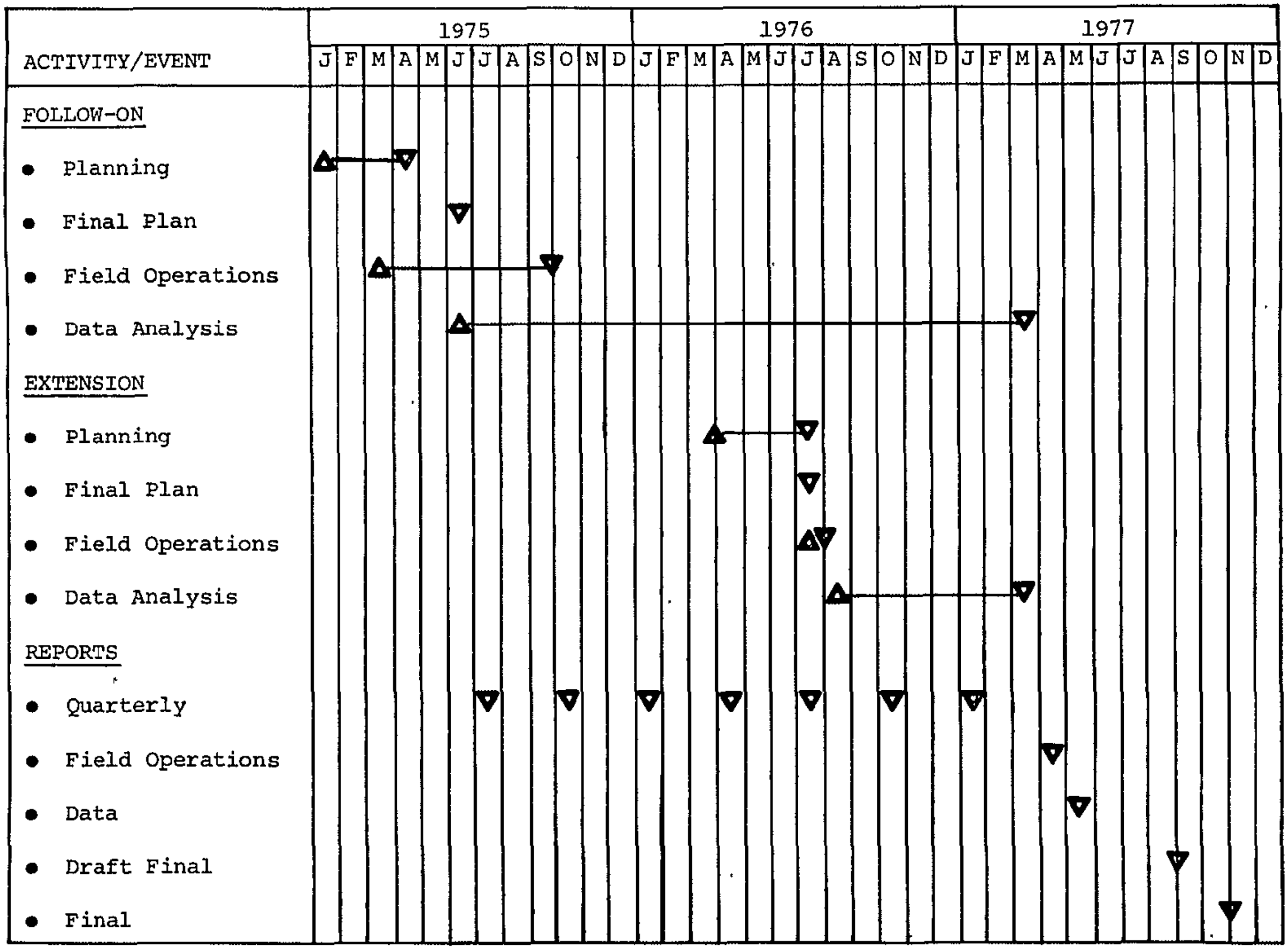

Figure 7-1. Overview Schedule for the LANDSAT Menhaden and Thread Herring Investigation

PLATFORM / MISSION	MAIN	MAIN	SUPPLE-MENTARY	ABORTED MAIN 1	SUPPLE-MENTARY	MAIN 2	SUPPLE-MENTARY
DATE	MAY 2	MAY 20	JUN 25	JUL 31	AUG 18	SEP 5	SEP 23
FISHING VESSELS	X	X	X	X	X	X	X
SPOTTER AIRCRAFT	X	X	X	X	X	X	X
FISHING VESSEL OBSERVERS	X	X		X		X	
RESEARCH VESSELS	X	X				X	
ERL AIRCRAFT	X	X					
NP3A AIRCRAFT	X	X				X	
LANDSAT II	X	X	X	X	X	X	X

1 Mission aborted due to inclement weather and unavailability of NP3A.

2 ERL Aircraft unable to complete mission due to inclement weather and mechanical failure.

Figure 7-2. Summary of Mississippi Sound Missions (1975)

PLATFORM / MISSION	MAIN	MAIN	SUPPLE-MENTARY	ABORTED MAIN [1]	SUPPLE-MENTARY	RESCHED-ULED MAIN	SUPPLE-MENTARY	SUPPLE-MENTARY
DATE	APR 25	MAY 13	JUN 18.	JUL 24	AUG 11	AUG 20	AUG 29	SEP 16
FISHING VESSELS	X	X	X	X	X	X	X	X
SPOTTER AIRCRAFT	X	X	X	X	X	X	X	X
FISHING VESSEL OBSERVERS	X	X		X		X		
RESEARCH VESSELS	X	X				X		
OIL PLATFORMS	X	X				X		
ERL AIRCRAFT	X	X				X		
NP3A AIRCRAFT	X	X				X		
PHOTO-GRAPHIC AIRCRAFT	X	X				X		
LANDSAT I	X	X	X	X	X	X [2]	X	X

1 Mission aborted due to mechanical failure reported aboard LANDSAT I

2 LANDSAT II

Figure 7-3. Summary of Louisiana Study Area Missions (1975)

		MAIN	DATE (JULY 1976)										
	18 SUN	19 MON	20 TUE	21 WED	22 THU	23 FRI	24 SAT	25 SUN	26 MON	27 TUE	28 WED	29 THU	30 FRI
FISHING VESSELS		X	X	X	X	X							
FISHING VESSELS WITH OBSERVERS (8)		X	X	X	X	X			X	X	X	X	X
SPOTTER AIRCRAFT	X	X	X	X						X			
SPOTTER AIRCRAFT WITH LORAN-C		X									X		
RESEARCH VESSELS (2)			X										
U-2 AIRCRAFT			X										
LANDSAT I	X	X	X										
LANDSAT II										X	X	X	

Figure 7-4. Summary of the Louisiana Study Area Mission for the Extension Phase of the Investigation (1976)

SECTION 8

DATA SUMMARY

8.1 FOLLOW-ON PHASE

Data collected during the follow-on phase included aerospace remotely sensed data, oceanographic data, fish distribution and abundance data, and fisheries utilization data. Fisheries utilization data included parameters such as fish school size, number of schools, time of day, water depth, location, fishing activity, and meteorological conditions. Generally, these data were collected for every set made by vessels with scientific observers on board. Partial data sets, however, were available from spotter aircraft and fishing vessels without observers.

8.1.1 MISSISSIPPI SOUND

8.1.1.1 LANDSAT

Table 8-1 provides a summary of LANDSAT-2 data collected in 1975 for the Mississippi Sound study area. A visual inspection of LANDSAT imagery was made before computer compatible tapes (CCT) were ordered. This inspection showed the study area to be obscured by clouds during the May 2, September 5, and September 23, 1975, missions. Thus, CCT's were ordered and digitally analyzed only for the May 20 and June 25, 1975, missions. Although LANDSAT data acquired on August 18, 1975, were cloud free, insufficient fishing data were collected for analysis.

Table 8-1. LANDSAT-2 Data Summary for Mississippi Sound Study Area (1975)

MISSION DATE	I.D. CODE	PERCENT CLOUD COVER	DATA QUALITY	CCT RECEIVED	CCT ANALYZED
May 2 (Main)	2100-15445	100	Poor	No	No
May 20 (Main)	2118-15448	10	Good	Yes	Yes
June 25 (Supplementary)	2154-15450	0	Excellent	Yes	Yes
July 31 (Main Aborted)	2190-15442	100	Poor	No	No
August 18 (Supplementary)	2208-15435	0	Excellent	No	No
September 5 (Main	2226-15432	100	Poor	No	No
September 23 (Supplementary)	2244-15433	100	Poor	No	No

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8.1.1.2 Research Aircraft

A summary of data collected by remote sensing aircraft over the Mississippi Sound is presented in Table 8-2. The quality of the remotely-sensed salinity measurements for the May 2 mission was poor. The NP3A aircraft flew a total of 24 flight lines during the other two missions (May 20 and September 5, 1975) for a total distance of about 479 km. The number of digitized temperature and salinities were 582 and 580, respectively. The ERL Beechcraft was grounded by mechanical problems during the September 5, 1975, mission. For the other two missions, a total of 13 flight lines and over 1028 km were flown by the Beechcraft providing 678 PRT-5 temperature measurements. Additionally, RS-18 and aerial photography data were acquired during both missions.

8.1.1.3 Research Vessels, Fishing Vessels, and Spotter Aircraft

Tables 8-3 through 8-6 provide summaries of fishing and oceanographic data collected during main missions in the Mississippi Sound. A "test" in the context of these tables is the measurement of all or nearly all the parameters identified in Table 6-5 at each sampling station by research and fishing vessels with observers. The fishing data are separated into two categories: fish school locations and number of schools observed. The reason for separation is many individual schools often were observed in one general location, particularly by spotter pilots.

Overall, data quality was good. The best mission week for fishing activity was September 5, 1975. Unfortunately, inclement weather and ERL Beechcraft mechanical problems prevented a full operational array of observations. For these missions, a total of 455 oceanographic tests, 156 fish school locations, and 812 separate fish schools were reported.

8.1.2 LOUISIANA STUDY AREA

8.1.2.1 LANDSAT

LANDSAT data collected during 1975 for the Louisiana study area are summarized in Table 8-7. Cloud cover precluded analysis of data for the April 25, May 13, and August 20, 1975, missions. Insufficient fishing data were available for analysis of the August 25, 1975, supplementary mission. No LANDSAT data were acquired for the June 18, August 11, and September 16, 1975 missions. The Louisiana study area is on the fringe of the GSFC receiving station reception zone and it is possible atmospheric conditions may not have been suitable for reception of MSS data on those days. Of the eight possibilities, only the July 24, 1975 data were suitable for complete analysis.

8.1.2.2 Research Aircraft

Table 8-8 summarizes data collected by research aircraft for the Louisiana study area during 1975. Overall data quality was good. The NP3A flew a total of 32 flight lines covering a distance of about 2081 km. For three

Table 8-2. Research Aircraft Data Summary for Mississippi Sound Study Area

MISSION DATE (1975)	NP3A					ERL BEECHCRAFT					
	FLIGHT LINES	DISTANCE (km)	DIGITIZED TEMP/SAL	DATA QUAL	M^2S ACQ	FLIGHT LINES	DISTANCE (km)	DIGITIZED TEMP	DATA QUAL	RS18	PHOTO
May 2	12	207	Not used	Poor	No	7	597	678	Good	Yes	Yes
May 20	12	207	269/269	Good	No	6	431	Not used	Good	Yes	Yes
Sep. 5	12	272	313/311	Good	No	0	0	0	N/A	No	No
TOTAL	36	686	582/580			13	1028	678			

Table 8-3. Research Vessel, Fishery Vessel and Spotter Aircraft Data Summary for Mississippi Sound - May 2, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	NUMBER OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Research Vessel	2	15	0	Good	15
Menhaden Fishing Vessel	6	25	91	Good	116
TOTALS	8	40	91		131

FISH DATA						
DATA SOURCE	FISH SCHOOL LOCATIONS			NUMBER OF SCHOOLS SPOTTED		
	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	7	7	14	51	40	91
Vessel Captains	1	2	3	1	2	3
TOTALS	8	9	17	52	42	94

Table 8-4. Research, Fishing Vessel and Spotter Aircraft Data Summary for Mississippi Sound - May 20, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	NUMBER OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Research Vessel	2	15	0	Good	15
Menhaden Fishing Vessel	6	50	166	Good	216
TOTALS	8	65	166		231

FISH DATA

DATA SOURCE	FISH SCHOOL LOCATIONS			NUMBER OF SCHOOLS SPOTTED		
	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	7	7	14	51	40	91
Vessel Captains	1	2	3	1	2	3
TOTALS	8	9	17	52	42	94

Table 8-5. Research, Fishing Vessel and Spotter Aircraft Data Summary for Mississippi Sound - July 31, 1975*

OCEANOGRAPHIC DATA					
DATA SOURCE	NUMBER OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Research Vessel	0	0	0	N/A	0
Menhaden Fishing Vessel	4	1	35	Good	36
TOTALS	4	1	35		36

FISH DATA

DATA SOURCE	FISH SCHOOL LOCATIONS			NUMBER OF SCHOOLS SPOTTED		
	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	0	11	11	0	29	29
Vessel Captains	0	0	0	0	0	0
TOTALS	0	11	11	0	29	29

*Rescheduled as a supplementary day due to inclement weather and unavailability of NP3A aircraft.

Table 8-6. Research Vessel, Fishing Vessel and Spotter Aircraft Data Summary for Mississippi Sound - September 5, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	NUMBER OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Research Vessel	2	15	0	Good	15
Menhaden Fishing Vessel	2	4	38	Good	42
TOTALS	4	19	38		57

FISH DATA						
	FISH SCHOOL LOCATIONS			NUMBER OF SCHOOLS SPOTTED		
DATA SOURCE	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	16	29	45	102	237	339
Vessel Captains	4	35	39	4	35	39
TOTALS	20	64	84	106	272	378

Table 8-7. LANDSAT-1 Data Summary for Louisiana Study Area (1975)

MISSION DATE	ID CODE	PERCENT CLOUD COVER	DATA QUALITY	CCT RECEIVED	CCT ANALYZED
April 25	5006-15485	70	Poor	Yes	No
May 13	5024-15480	80	Poor	No	No
June 18	No data	-	-	-	-
July 24	5096-15435	10	Good	Yes	Yes
August 11	No data	-	-	-	-
August 20*	2210-15554	90	Poor	Yes	No
August 29	5132-15414	20	Good	No	No
September 16	No data	-	-	-	-

*LANDSAT-2

Table 8-8. Research Aircraft Data Summary for Louisiana Study Area (1975)

MISSION DATE	NP3A FLIGHT LINES	FLIGHT DIS. (km)	DIGITIZED TEMP/SAL	DATA QUAL	M^2S ACQ	ERL BEECHCRAFT FLIGHT LINES	FLIGHT DIS. (km)	DIGITIZED TEMP	DATA QUAL	RS18	PHOTO
Apr 25	11	687	745/649	Good	Yes			Not taken		Yes	Yes
May 13	11	724	835/835	Good	Yes	7	352	278	Good	Yes	Yes
Aug 20	10	670	756/756	Good	Yes	7	474	421	Good	Yes	Yes
TOTALS	32	2081	2336/2240			14	826	699			

missions, 2336 temperature and 2240 salinity measurements were digitized. No temperature data were acquired by the ERL Beechcraft for the April 25, 1975 mission. For the other two missions, 14 flight lines covering 826 km were flown by the Beechcraft. A total of 699 PRT-5 temperature measurements were digitized. Additionally, the NP3A acquired M^2S data and the ERL Beechcraft acquired RS-18 and photographic data on all three missions.

8.1.2.3 Research Vessels, Fishing Vessels, Spotter Aircraft, Oil Platforms

Tables 8-9 through 8-12 summarize fishing and oceanographic data collected for each main mission in the Louisiana study area. Due to a reported failure aboard LANDSAT-1, the July 24, 1975, mission was rescheduled as a supplementary day mission. Scientific observers were aboard fishing vessels, however, so oceanographic and fishing data were collected as planned. The most fishing information collected was from the May 13, 1975, mission. Overall data quality was excellent. For these missions a total of 927 oceanographic tests, 178 fish school locations and 1008 separate fish schools were reported.

Table 8-9. Research Vessel, Fishing Vessel, Spotter Aircraft and Oil Platform Data Summary for Louisiana - April 25, 1975

OCEANOGRAPHIC DATA

DATA SOURCE	OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Oil Platforms	4	36	0	Good	36
Oceanographic Vessels	2	35	0	Good	35
Menhaden Fish. Vessels	5	38	160	Good	198
TOTALS	11	109	160		269

FISH DATA

DATA SOURCE	FISH SCHOOL LOCATIONS MAIN DAY	REMAINDER WEEK	TOTAL	NUMBER SCHOOLS SPOTTED MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	10	2	12	85	99	184
Vessel Captains	12	1	13	12	1	13
TOTALS	22	3	25	97	100	197

Table 8-10. Research Vessel, Fishing Vessel, Spotter Aircraft and Oil Platform Data Summary for Louisiana - May 13, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Oil Platforms	4	36	0	Good	36
Oceanographic Vessels	2	35	0	Good	35
Menhaden Fish. Vessels	6	43	194	Good	237
TOTALS	12	114	194		308

FISH DATA						
	FISH SCHOOL LOCATIONS			NUMBER SCHOOLS SPOTTED		
DATA SOURCE	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	19	23	42	102	200	302
Vessel Captains	6	24	30	6	24	30
TOTALS	25	47	72	108	224	332

Table 8-11. Research Vessel, Fishing Vessel, Spotter Aircraft and Oil Platform Data Summary for Louisiana - July 25, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Oil Platforms	Not Deployed	-	-	-	-
Oceanographic Vessels	0	0	0	0	0
Menhaden Fish. Vessels	6	34	156	Good	156
TOTALS	6	34	156		156

FISH DATA						
	FISH SCHOOL LOCATIONS			NUMBER SCHOOLS SPOTTED		
DATA SOURCE	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	11	26	37	138	244	382
Vessel Captains	9	10	19	9	10	19
TOTALS	20	36	56	147	254	401

Table 8-12. Research Vessel, Fishing Vessel, Spotter Aircraft and Oil Platform Data Summary for Louisiana - August 20, 1975

OCEANOGRAPHIC DATA					
DATA SOURCE	OBSERVERS	NUMBER TESTS MAIN DAY	NUMBER TESTS REMAINDER WEEK	DATA QUALITY	TOTAL TESTS
Oil Platforms	2	18	0	Good	18
Oceanographic Vessels	2	35	0	Good	35
Menhaden Fish. Vessels	5	25	116	Good	141
TOTALS	9	78	116		194

FISH DATA						
	FISH SCHOOL LOCATIONS			NUMBER SCHOOLS SPOTTED		
DATA SOURCE	MAIN DAY	REMAINDER WEEK	TOTAL	MAIN DAY	REMAINDER WEEK	TOTAL
Spotter Pilots	3	3	6	28	31	59
Vessel Captains	1	18	19	1	18	19
TOTALS	4	21	25	29	49	78

8.2 EXTENSION

Data collected during the extension phase were essentially the same as those collected during the follow-on phase, except that research aircraft and oil platform data were not collected. A problem encountered during the follow-on phase was uncertainty about locations of fish school observations from fishing vessels and spotter aircraft. To alleviate this problem, one spotter aircraft and all fishing vessels with observers were equipped with LORAN-C navigational systems. Position accuracy with LORAN-C was estimated to be ± 1 km. Spotter aircraft without LORAN-C were asked to record school locations by omni signal fixes; however, these positions later proved unreliable.

8.2.1 LANDSAT

Table 8-13 summarizes data acquired during the extension phase. Four data sets were relatively cloud free. The July 19, 1976, overpass was selected for the operational simulation objective and the July 27 and 28, 1976, overpasses were chosen for the persistence objective. Only a small amount of fishing data were available for the July 29, 1976, overpass because most fishing activity was east of the coverage area.

Table 8-13. LANDSAT Data Summary for Extension Phase (1976)

MISSION DATE	LANDSAT	ID CODE	PERCENT CLOUD COVER	DATA QUALITY	CCT RECEIVED	CCT ANALYZED
July 19	1	5457-15255	10	Excellent	Yes	Yes
July 27	2	2552-15485	10	Excellent	Yes	Yes
July 28	2	2553-15543	10	Excellent	Yes	Yes
July 29	2	2554-16001	10	Excellent	Yes	No

8.2.2 FISHING VESSELS AND SPOTTER AIRCRAFT

Table 8-14 summarizes fishing and oceanographic data collected off Louisiana during the extension phase. Only spotter pilot data for which LORAN-C locations were available are presented. A total of 273 oceanographic tests and 290 fish school locations were reported for both weeks. The general quality of the data was excellent.

Table 8-14. Fishing Vessel and Spotter Pilot Data Summary for Extension Phase (1976)

MISSION DATE	NUMBER OBSERVERS	NUMBER TESTS	SPOTTER PILOTS	FISHING VESSELS	TOTAL FISH OBSERVATIONS
July 19	8	43	21	42	63
Remainder of Week	8	103	0	95	95
July 27	8	27	0	25	25
July 28	8	36	13	34	47
Remainder of Week	8	64	0	60	60
Totals		273	34	256	290

SECTION 9

DATA MANAGEMENT

9.1 OVERVIEW

A data management system was established to handle data from definition of requirements through production of desired end products. This system was designed to accept, process, store, and analyze data according to the experimental rationale described in Section 2. Initially, data required to satisfy the experimental units were identified in terms of specific parameters, temporal and spatial needs, accuracies, measurement and reporting units, and user products (e.g., contours, listings, statistical analyses, etc.). Data acquisition and computer loading forms were subsequently designed and used throughout the investigation. Data from these forms were converted to digital form, reformatted, and inputted to the data management system. Satellite imagery and other photographic products were stored in a supporting imagery library. Figure 9-1 presents a conceptualization of this system.

9.2 FIELD ACQUISITION AND COMPUTER LOADING FORMS

Special field data acquisition and computer loading forms were developed for the fishing vessel captains, spotter pilots, and scientific observers aboard fishing vessels and oil platforms (Appendix A). Comprehensive instructions and sample completed forms were included with the field forms. Separate forms were prepared for the industry participants for the Mississippi Sound and Louisiana study areas. The spotter pilot data acquisition form was sized for easy handling in the cramped cockpit of the aircraft. Forms used on the research vessels differed in design from those used on the other platforms in that additional parameters (e.g., meteorological) and measurement procedures (e.g., constant flow fluorometers, transmissometers, etc.) were included. Additional information on these latter forms and sampling procedures is found in a special ERL report entitled, "LANDSAT Menhaden and Thread Herring Resources Investigation Surface Measurement Report," Number 154.

9.3 DATA PREPARATION, EDITING, CORRECTION, AND PROCESSING

General preparation, editing, correction, and processing functions performed on the data are shown in Figure 9-2. Quality control was maximized to ensure accurate data for analysis and archival. Chlorophyll-a measurements were corrected for changes caused by sample degradation over time. This correction was incorporated into an algorithm developed from a group of samples collected simultaneously and allowed to degrade predetermined periods of time under simulated field and laboratory conditions (ERL Report Number 154).

9.4 SOFTWARE AND COMPUTER HARDWARE

Software developed for two computer systems were used. The primary system was a UNIVAC 1108 multiprocessor located at the NASA Slidell Computer Center, Slidell, Louisiana (Figure 9-3). The software used on this system consisted

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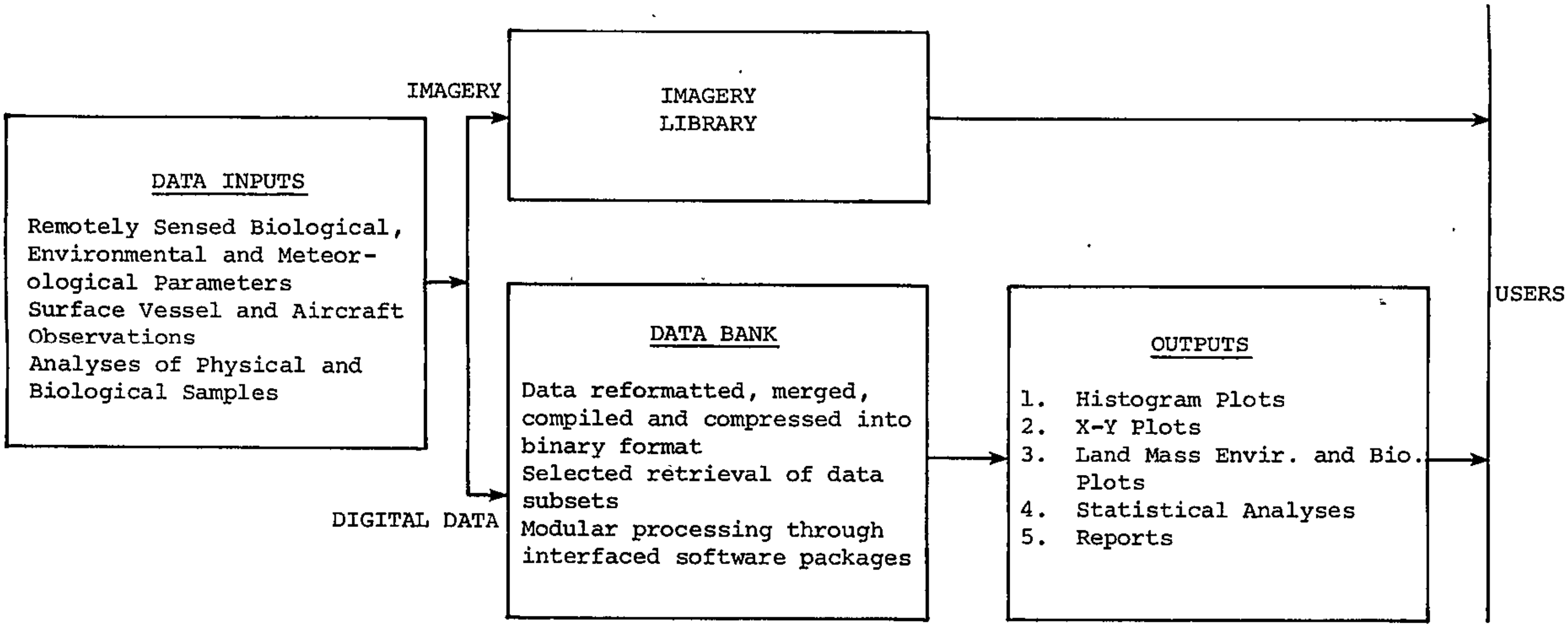

Figure 9-1. Establishment and Use of the LANDSAT Data Management System

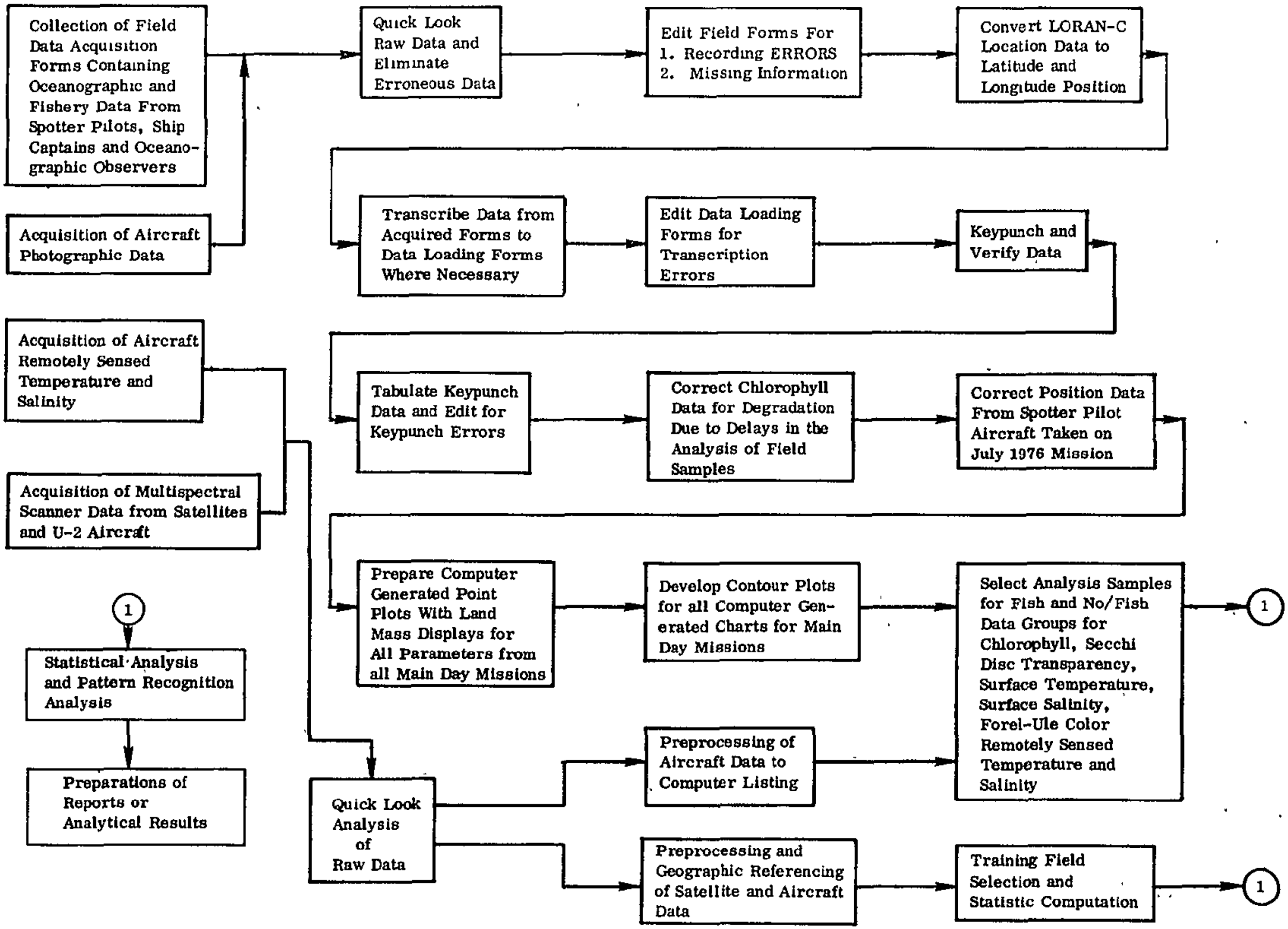

Figure 9-2. Data Processing and Analysis Flow Diagram

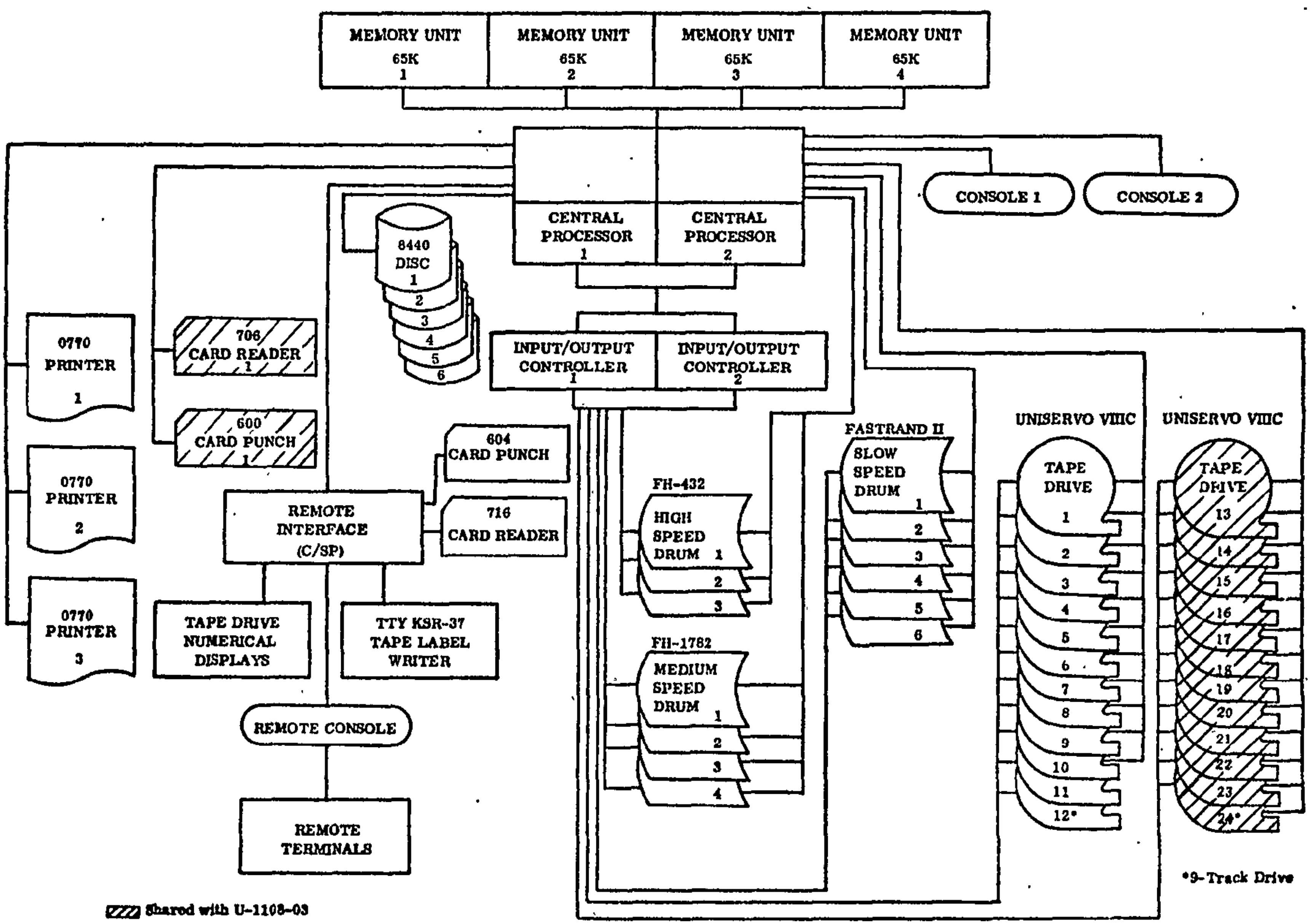

Figure 9-3. UNIVAC 1108 Multiprocessor (1108-01)

of three main segments (Figure 9-4). The first segment reformatted digital data for input to the second segment, the Information Storage and Retrieval System (ISRS), which developed a compressed data bank. The ISRS enabled selective retrievals of pertinent information subsets from the compressed file, listings of information, and information storage on magnetic tapes for input to specific analytical routines. The last segment of the data management system was a collection of computer programs for analyzing and displaying selectively retrieved information subsets; e.g., statistical analyses, mathematical computations, and graphical displays (land mass plots, contour and symbol plots, histogram plots, and x-y plots).

The second computer system used was developed by ERL specifically for analyzing LANDSAT MSS data. The system (Whitley, 1976) was used to reformat LANDSAT MSS data tapes, select and edit training field data, perform selective classifications, display classified data, and film record classification results.

9.5 DATA ARCHIVAL

A temporary archive of raw and processed data, and a library of satellite imagery, aircraft data and other photographic products is being maintained by NFEL. All useful data which are not generally available through special data centers such as EROS will be provided to NOAA/EDS along with appropriate background information and format instructions for permanent archival.

9.6 DATA REPORTS

Two special data reports were prepared to document methodology and data availability. The first report was prepared by ERL to document research vessel surface measurements during both phases (ERL Report Number 154, "LANDSAT Menhaden and Thread Herring Resources Investigation Surface Measurement Report"), and the second by NFEL to include all other digital data (Gulf of Mexico, Menhaden and Thread Herring Resources Investigation Data Report, April 29, 1975 - February 28, 1977).

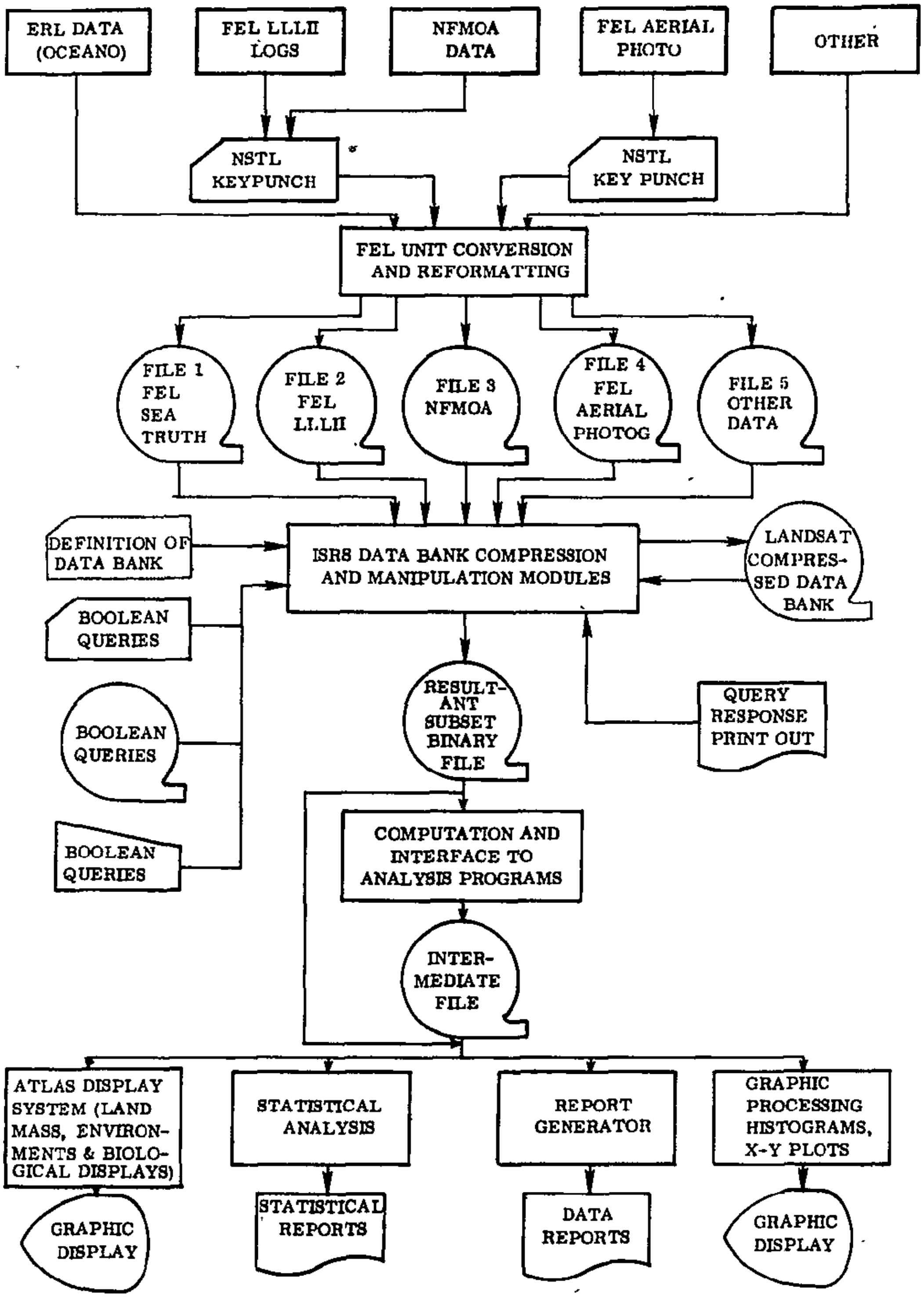

Figure 9-4. LANDSAT Data Management Software System

SECTION 10

FOLLOW-ON ANALYSIS AND RESULTS

10.1 APPROACH

The experimental rationale discussed in Section 2 defined the approach taken to analyze data from the follow-on phase. Initial emphasis was on data from fishing vessels to focus subsequent efforts. Fishery data from the 1975 portion of the investigation were compared to similar data from the ERTS-1 Menhaden Experiment to establish if factors other than those specifically being observed might be affecting the results. Environmental data from surface-truth sampling efforts were contrasted similarly. Significant analytical efforts were then focused on remote measurements of selected oceanographic parameters so that these measurements could be used to infer fish distribution patterns.

10.2 FISHERY DATA

A number of factors were examined to determine if they might be significantly confounding results from the investigation. These factors included environmental parameters such as precipitation, cloud cover, river discharge, wind speed and direction, tidal stage, time of day and day of week, and fishery parameters such as total landings and year class of captured fish.

Environmental conditions were similar in 1975 and 1976. Significantly less precipitation occurred in 1972 during the ERTS-1 Menhaden Experiment which might explain why menhaden landings in 1972 were considerably less than in 1975 and 1976 (Section 3). More fish were caught in the morning and evening hours than mid-day, and more were caught on the first day of the fishing week (Monday) than on other days. A slight increase appeared on Fridays, however, compared to the period from Tuesday through Thursday. None of the parameters examined appeared to be significantly different between study years and, therefore, probably were not significantly affecting the fishery data. These parameters and relationships are being studied under a separate contract between NFEL and Mississippi State University.

10.3 ENVIRONMENTAL DATA

10.3.1 SURFACE TRUTH

During the investigation the waters of the Mississippi Sound changed from an estuarine environment to an environment composed of shelf water. The temperature and salinity fields (Appendix D) show that on May 2, 1975, the Sound was relatively uniform in temperature and the range of salinity (5.6 to 11.6 ppt) progressed from an inshore low to an offshore high centered around the eastern island passes. On May 20, 1975, a tongue of medium salinity water was centrally located in the Sound separating low salinity water to the west and high salinity water to the east. A large cyclonic eddy dominated circulation between Pascagoula and Biloxi, Mississippi. Data collected on September 5, 1975, revealed the temperature field to be nearly homogeneous (29.1° to 30.1°C), and that the Mississippi Sound had been flushed of its low salinity, estuarine water. Salinity ranged from 17.3 to 25.1 ppt with an apparent increase offshore. The change from estuarine to shelf water also was evidenced by a gradual trend from high (brown) to low (blue-green) Forel-Ule measurements and increasing

Secchi disc visibility depths. Both parameters indicated a transition to the clearer shelf water compared with the more frequently experienced turbid estuarine water.

The standing stock of phytoplankton, as evidenced by chlorophyll measurements remained relatively constant. Chlorophyll concentrations remained high in the western and central Mississippi Sound throughout the investigation.

The Louisiana study area was dominated inshore by effluent water from the Atchafalaya River system (Appendix D). Although large volumes of water enter the Gulf of Mexico through Atchafalaya Bay, the distribution of the discharge water was restricted to near shore due to coastal circulation patterns and impingement of the offshore water mass. Comparisons of temperature and salinity fields show a system of cyclonic and anticyclonic meanders prevailed within a generally westward circulation pattern. The concentration of chlorophyll changed dramatically during this investigation from low values with some patches of high concentrations in April and May to uniformly high concentrations in August. As evidenced by gradients of chlorophyll, Forel-Ule and Secchi depths, the seaward progress of the Atchafalaya River water mass was restricted by offshore circulation and entrained into the westward coastal current.

10.3.2 REMOTE MEASUREMENTS

10.3.2.1 Salinity

The remote measurement of salinity is possible because microwave radiation emitted from the sea contains information on salinity and temperature. Microwave radiation is measured as apparent temperature, or brightness temperature T_B, which is related to the thermodynamic temperature T by the expression $T_B = eT$, where e is the emissivity of the solution. The emissivity of an aqueous saline solution, such as sea water, is a function of the complex dielectric constant; i.e., the dielectric constant at microwave frequencies varies with temperature and conductivity. Emissivity manifested as brightness temperature can be measured in the microwave region of the electromagnetic spectrum, and thermodynamic temperature can be measured in the infrared region where the dielectric constant does not vary with salinity. Because the relationship between conductivity (and hence salinity) and the dielectric constant is known, salinity may be derived from the computed emissivity.

A technique for performing these computations has been developed (Thomann, 1973) and used extensively at ERL. This technique consists of the preparation of a table of emissivity values for the expected range of salinities and temperatures. Each entry in the table corresponds to an emissivity for a specific temperature and salinity, with the entire table prepared for the particular microwave frequency and the microwave antenna angle. Emissivity is computed as the ratio of brightness temperature to thermodynamic temperature. The table is entered at the measured thermodynamic temperature, and the salinity producing the closest emissivity to the calculated value is reported as the salinity for the particular data point.

Routine analyses of data from five successful missions over the Mississippi Sound and off Louisiana proceeded as follows:

- Approximate flight lines were plotted on study area charts based on information recorded in flight logs and corrected with photography acquired over the flight lines.

- Data tapes containing corrected microwave temperatures of the sea surface, as measured in the L-band region of the microwave spectrum, and infrared radiometric data, were obtained. Corrections made to the data during preprocessing were for antenna, temperature, wave-guide temperature, and radome effects. Tabulations and plots of the data were developed.

- Tabulation and plots of the microwave data were examined to determine data quality, and to determine the exact time that the antenna pattern crossed the coastline. This permitted a further refinement in locating the aircraft.

- Times the aircraft flew over the surface sampling stations were determined from the position of the aircraft in space, time and photographic coast line crossings, and log data.

- Brightness and thermodynamic temperatures were averaged over 10-second intervals, which corresponded to approximately 0.8 km along the flight lines. Ten second averages also were obtained for the intervals centered at each surface sampling station.

- Microwave brightness temperatures and infrared radiometric temperatures were compared to surface measurements from the sampling stations. Corrections for gain and offset perturbations in both sets of data were made. Normally PRT-5 data requires only an additive correction from atmospheric effects manifested as a reduction in infrared radiometric temperature. However, an additional correction had to be made due to a change in sensor gain caused by the filter material required to restrict sensible radiation to the nominal 8-12 μm band of the sensor flaking off. Gain corrections to PRT-5 data were minor, but were considered for these data sets as well as the normal additive atmospheric correction. Also, a gain correction was applied to the microwave data.

  Additive correction to the microwave data was required to compensate for the reflection of galactic microwave radiation by the sea surface, and uncertainty in the zero calibration of the sensor. Data from surface sampling stations were used for this calibration for flight lines flown east to west, north to south, west to east, and south to north.

- Emissivities were computed for each of the 0.8 km samples and surface sampling stations with all corrections supplied to the data. Corresponding salinities were determined.

- Salinities were plotted on navigation charts of the study areas based on plots and tabulations of salinity as a function of time and aircraft positioning data.

Analysis of five of the six data sets produced excellent results. Surface measurements were compared to remote measurements and to remote measurements obtained at different times over the same location.

Results of these comparisons are shown in Table 10-1. The average accuracy of measurements was $\pm$1.69 ppt, based on comparisons between surface truth and remote measurements. Precision of measurements ranged from 0.48 to 2.58 based on RMS errors computed for relative values at intersections of flight lines. These results were considered excellent if one considers positioning errors (aircraft and surface vessel), changes in salinity over time, errors in remote measurements caused by electronic drift and changes in radome and antenna temperatures, and other subtle system problems.

Table 10-1. Absolute and Relative Salinity Error Analyses for differences between remote and surface truth measurements and remote measurements at flight line intersections, respectively

STUDY AREA	DATE (1975)	SURFACE TRUTH (PPT)*	INTERSECTING FLIGHT LINES (PPT)**
Louisiana	April 25	1.58	1.95
Mississippi	May 2		
Louisiana	May 13	2.45 1.76	1.71
Mississippi	May 20	1.46	1.53
Louisiana	August 20	2.56	2.58
Mississippi	September 5	1.09	0.48

* $\left[\left(\frac{1}{n-1}\right)(x_{st} - x_{remote})^2\right]^{1/2}$

**RMS deviation between remote measurements at intersections of flight lines.

Figures 10-1 and 10-2 are sample plots of salinity along flight lines off the Louisiana coast. Figure 10-1 shows a decrease in salinity from left to right as the aircraft flew toward the coast from the open Gulf. Square symbols on the plot denote the surface truth measurements. Figure 10-2 shows salinity measurements along a flight line flown parallel to the coast. There is a sharp decrease in salinity as the line crosses from the saline coastal waters (15-20 ppt) to the mixing zone along the edge of the water mass emptying from the Atchafalaya River. Rapidly changing salinity patterns within this zone can be seen clearly in the remotely sensed data, while point samples acquired from the surface vessels do not indicate such a complex structure.

Salinity measurements inferred from microwave data were used to develop salinity contour maps for the five successful missions (Appendix D). Hand contouring was performed on charts showing the 10 second (0.8 km) average salinity values. These charts show the salinity gradient from the shore to open waters in both study areas. Effects of fresh water outflow from rivers and marsh areas also are evident in both areas, with the outflow from the Atchafalaya River being the dominant feature in the contours for the Louisiana study area. A consistent phenomenon was observed; an area of low salinity values was noted south of Point Au Fer Island suggesting the existence of a fresh water spring.

Data from one mission flown shortly after midday were not processed. The high elevation of the sun apparently caused the center of the specular reflection pattern to fall within the field of view of the antenna thereby greatly increasing apparent temperatures. This reflection pattern moved in and out of the field of view as the automatic guidance system of the aircraft pursued the flight lines, making it impossible to interpret the data.

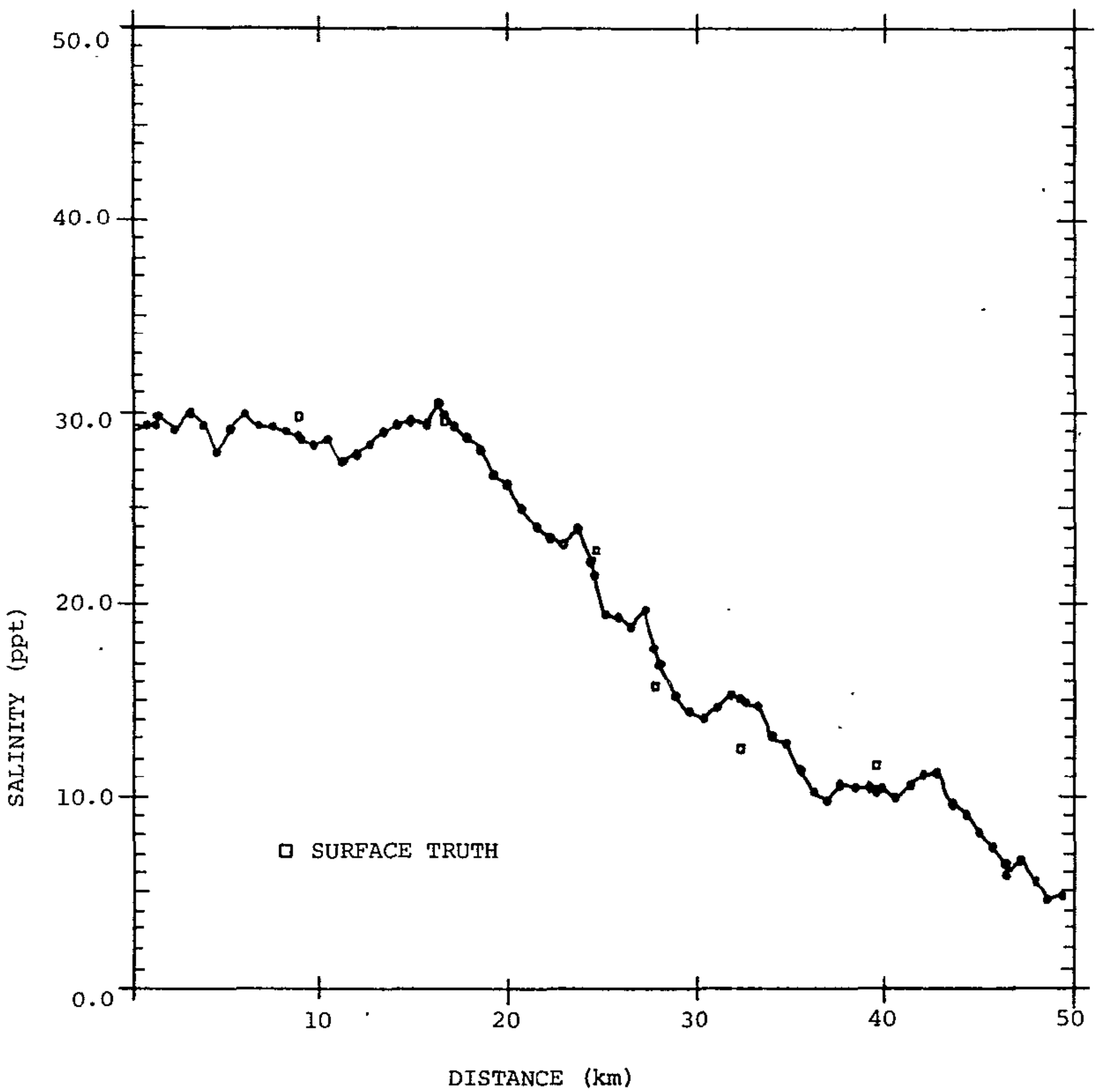

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Figure 10-1. Remotely Sensed Salinity for one Flight Line Off Louisiana (August 20, 1975)

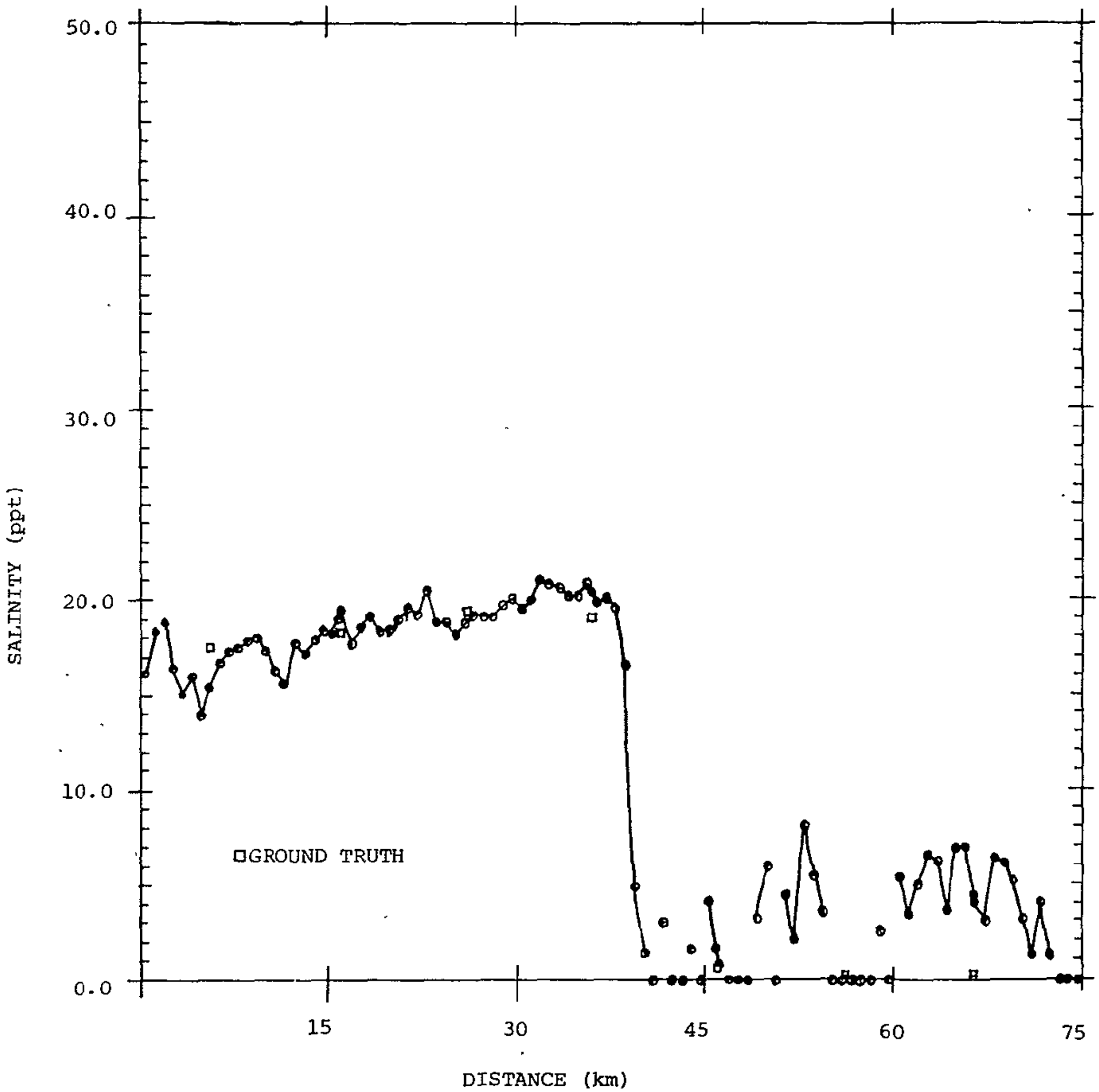

Figure 10-2. Remotely Sensed Salinity Along one Flight Line off Louisiana (April 25, 1975)

10.3.2.2 Temperature

Radiation emitted from the sea in the 8-12 μm region of electromagnetic spectrum is a direct function of the thermodynamic temperature of the surface waters. Because emissivity in this region does not vary significantly with factors such as salinity, it is possible to use a radiometer sensitive to this radiation for surface water temperature measurements. Because the atmosphere normally reduces the amount of radiation received by the sensor and the amount of radiation removed is primarily a function of the moisture content of the atmosphere, it is theoretically possible to derive sea surface temperature from remote measurements of the emitted infrared radiation and knowledge of the moisture content of the atmosphere. In practice, however, it is more practical to measure the sea surface temperature in situ for calibration of the sensor.

Thermal infrared data were processed for all six main missions (Appendix D). Data sets were provided for four missions by the PRT-5 flown on the ERL light aircraft and by the same type instrument on the NP3A for the remaining two missions. Data were of excellent quality, although special consideration was given to the NP3A data due to the filter degradation problem discussed under salinity measurements. Routine processing of thermal data proceeded as follows:

- Approximate flight lines were plotted on study area charts based on information recorded in flight logs, then corrected based on aerial photography.
- Data were recorded in analog format during the missions and converted to a digital format. Radiometric temperature at the surface truth stations was determined.
- Differences between remote and surface measurements were determined at several stations and averaged to develop an atmospheric correction term. In the case of the data sets acquired by the sensor on the NP3A, a gain correction term was computed in addition to the atmospheric correction term to account for gain changes due to filter degradation. Different correction terms were computed for the low and high altitude flight lines flown by the NP3A over the Louisiana study area. Two calibration terms were used on the May 25 Mississippi Sound mission because of different atmospheric conditions prevailing near the barrier islands and near shore.
- A correction term was applied to the entire data set (or appropriate portion) to develop plots and tabulations of sea surface temperature.

Analysis of infrared radiometer data for the six main missions provided sea surface temperature measurements of very good quality (Table 10-2). Comparison of remote measurements with in situ measurements taken near the flight lines indicated an accuracy of about $\pm$ 0.2°C to 0.3°C. Errors in the remote measurements were probably due to variations in the moisture content of the atmosphere over the study area, changes in the surface temperature between the time of the in situ measurement and the aircraft overflight, and spatial variations due to a surface sampling station not being directly beneath a flight line.

A typical plot of temperature along a flight line is shown in Figure 10-3. This plot shows a general warming trend of surface water from west to east in the Mississippi Sound. The flight line crossed a small island which can be seen in the thermal data as a hot point due to differences between emissivities of water and land.

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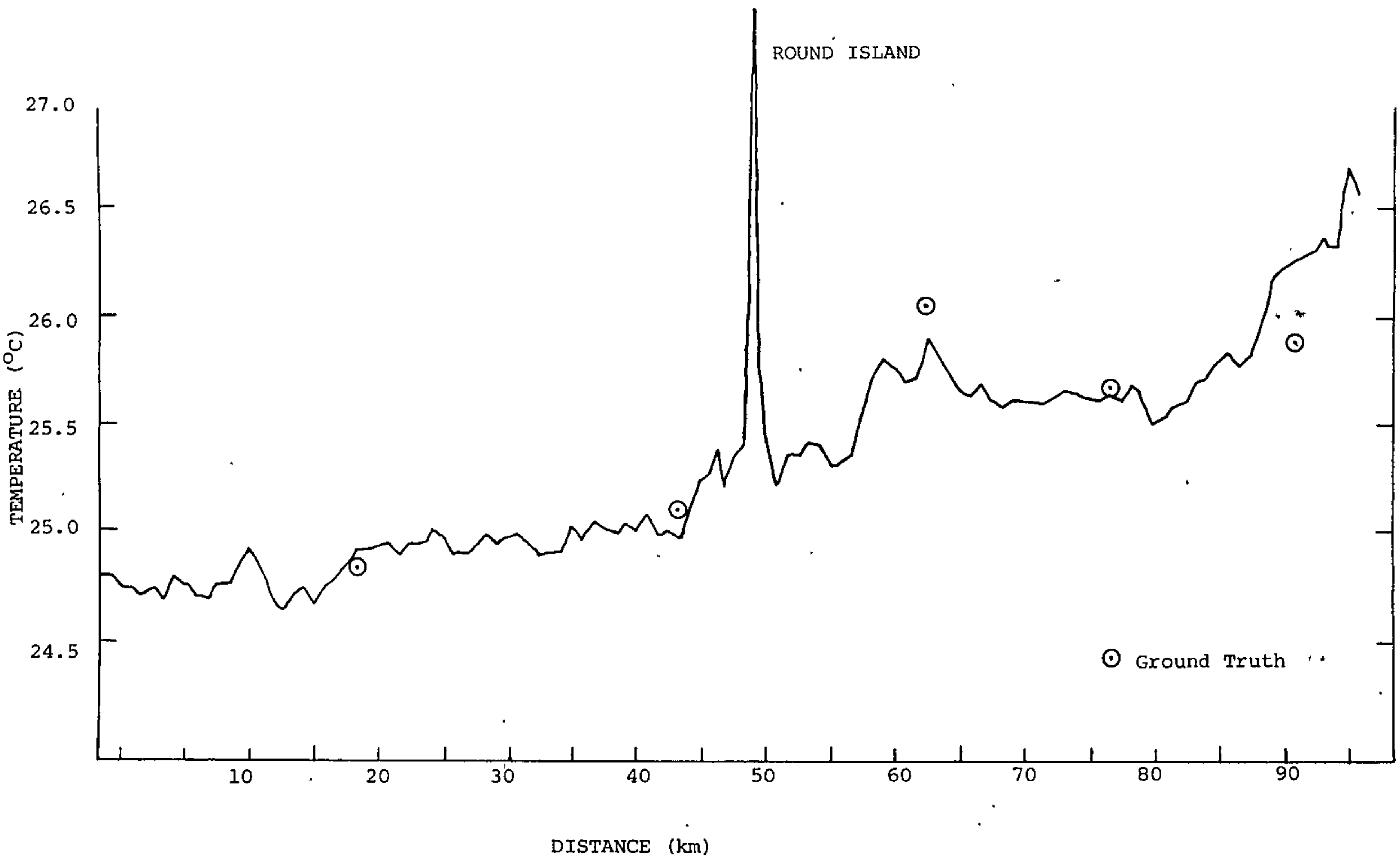

Figure 10-3. Radiometric Temperature Measurements from the Mississippi Sound Along Flight Line 4 (May 20, 1975)

Table 10-2. Thermal Measurement Error Analysis

Study Area	Date (1975)	RMS Deviation From Surface Truth (^{o}C)	Number of Data Points for Comparison
Louisiana	April 25	0.46	18
Mississippi	May 2	0.20	24
Mississippi	May 20	0.19	4
Louisiana	May 25	0.18	13
Louisiana	August 20	0.24	19
Mississippi	September 5	0.29	17

10.3.2.3 Forel-Ule Ocean Color

Standard Forel-Ule ocean color measurements were obtained during each main mission. These measurements indicated the color of the sea as it appeared to an observer by comparison with standard colored solutions. It was subjective, but did enable a comparison of water colors in different areas and at different times when sophisticated equipment required for the precise determination of upwelled light was not available.

The Forel-Ule scale assigns a number to each color, with the low numbers corresponding to the deep blues of open ocean waters, the intermediate numbers to green colors, and the highest numbers to the yellow-browns. LANDSAT color data on the other hand, are represented by a set of four numbers, each corresponding to the radiance of the scene in a different spectral band. The values increase monotonically with radiance; therefore, one would expect low values in the green and red spectral bands associated with green water (intermediate Forel-Ule) and high values in the green and red bands associated with brown water (high Forel-Ule). Based on this rationale a linear model in the form $F = \sum_{i=1}^{4} a_i R_i + a_o$ was developed to permit estimation of Forel-Ule color (F) from remotely sensed upwelling radiance (R) in MSS band i.

The model was applied to data acquired by the LANDSAT MSS on July 24, 1975, and to aircraft data acquired August 20, 1975. Satellite data were preprocessed to increase radiometric resolution at the expense of spatial resolution by averaging 42 adjacent picture elements (six scan lines and seven elements), multiplying the average radiance by four, and rounding to the nearest integer. Integer processing of the scanner data was performed routinely because of the large volume of data.

The model yielded results which agreed well with surface observations. The linear model applied to aircraft data showed a root mean square error of 1.54, with the range of the measurements being from 8 to 16. This should be considered excellent agreement, as subjective uncertainty in the measurement is probably about one unit. However, when applied to the extensive area included in the LANDSAT frame, the model performed poorly. Classification of Forel-Ule color was good in areas from which data were acquired to develop the model, but outside these areas, e.g., in extremely turbid river water and extremely clear, deep blue ocean water, the model gave unreasonable results. This was not unexpected, however, as empirical results often cannot be extrapolated beyond the range of data used to develop the statistics.

A second approach was used to infer Forel-Ule color measurements from LANDSAT data. This approach was based on a discriminant function routine used to regress five discrete categories of Forel-Ule color measurements against radiance measurements in the four MSS bands. The color categories and radiance values used in the analysis are presented in Table 10-3 and the discriminant functions are presented in Table 10-4. The routine classified 12 out of the 14 samples correctly for an accuracy of 86 percent. The July 24, 1975, MSS data were classified with the routine and results are presented in Figure 10-4.

10.3.2.4 Secchi Extinction Depth

The physical phenomena which interact to govern the depth to which a white Secchi disc is visible from the surface are complex. Essentially, scattering of light from suspended particulate matter and absorption of light by pigments dissolved in the water cause light penetrating the sea to be attenuated, and cause the image of the disc being lowered into the water to be attenuated and diffused. The disc disappears at the point where light backscattered from the water column is equal in intensity to the light reflected from the Secchi disc through the water column.

Previous work has shown it is possible to estimate the Secchi extinction depth from remote measurements of water color. Holyer (1973) found a linear combination of airborne spectral radiometer measurements made at a series of different wavelengths correlated significantly with the fourth root of the Secchi extinction depth, and Faller (1974) found a simple ratio of radiance at two wavelengths modelled the turbidity measurement well. The same data set used by Holyer was analyzed under this investigation to simulate LANDSAT MSS data. The results were obtained with a model of the form

$$S = \left[(a_1 R_1 + a_2 R_2 + a_3 R_3 + a_4 R_4) / (R_1 + R_2 + R_3 + R_4)\right]^4$$

Where S is Secchi disc visibility depth, R_i is the radiance measurement for band i of the MSS, and a_i is a fitting parameter. The root mean square of the fractional error was 0.18 which was well within the precision of the surface measurement. As a further test of the technique, LANDSAT data from August 7, 1972, were analyzed with the model. The results were a root mean square fractional error of 0.31, corresponding to an uncertainty of 0.5 meters.

The fourth power relationship could not be applied successfully to the LANDSAT data sets of May 20 and July 24, 1975. Errors were on the order of 50 percent and the model did not function well outside the area where surface measurements were made despite the fact that turbidities were of the same order of magnitude. A plausible explanation of the problem lies in the optically active constituents of sea water. Turbidity is caused by suspended inorganic particles, plant fragments and phytoplankton. Different combinations of these constituents may result in very different water colors, although the resulting Secchi extinction depth may be constant. Since the model essentially uses a measure of chromaticity, some error can be expected.

The same model also was applied to aircraft multispectral scanner data required on August 20, 1975. The results were better, with the root mean square fractional error being 0.2, corresponding to an uncertainty of 0.3 meters. The LANDSAT data

Table 10-3. Training Samples for Forel-Ule Classification of July 24, 1975, MSS Data

CLASS	SAMPLE NO.	MSS RADIANCE VALUES			
		B4	B5	B6	B7
Offshore Water	1	23.900	12.700	6.000	.600
	2	23.600	12.400	5.900	.600
	3	24.400	13.700	7.100	.700
	4	23.700	12.100	6.400	.600
Forel-Ule #14	5	27.200	15.100	7.400	.900
Forel-Ule #15	6	32.500	24.800	11.400	1.300
Forel-Ule #16	7	34.600	27.700	12.300	1.600
	8	38.100	34.600	17.500	2.500
Forel-Ule #17	9	25.500	14.900	7.700	1.000
	10	35.600	29.300	13.300	1.900
	11	38.000	35.700	18.000	2.700
	12	38.300	36.700	19.300	3.000
	13	38.500	37.300	21.000	3.500
	14	38.400	37.000	20.800	3.400

Table 10-4. Discriminant Function Forel-Ule Classifiers for July 24, 1975, MSS Data

CLASS	CONSTANT	MSS BAND COEFFICIENTS			
		B4	B5	B6	B7
Offshore	-156.617	18.267	-4.218	-14.238	27.456
Forel-Ule #14	-202.958	20.997	-4.830	-17.576	38.018
Forel-Ule #15	-216.291	20.914	-4.220	-15.514	23.704
Forel-Ule #16	-234.559	21.820	-4.322	-17.108	30.201
Forel-Ule #17	-205.478	20.559	-4.325	-16.814	35.304

COLOR PHOTOGRAPH

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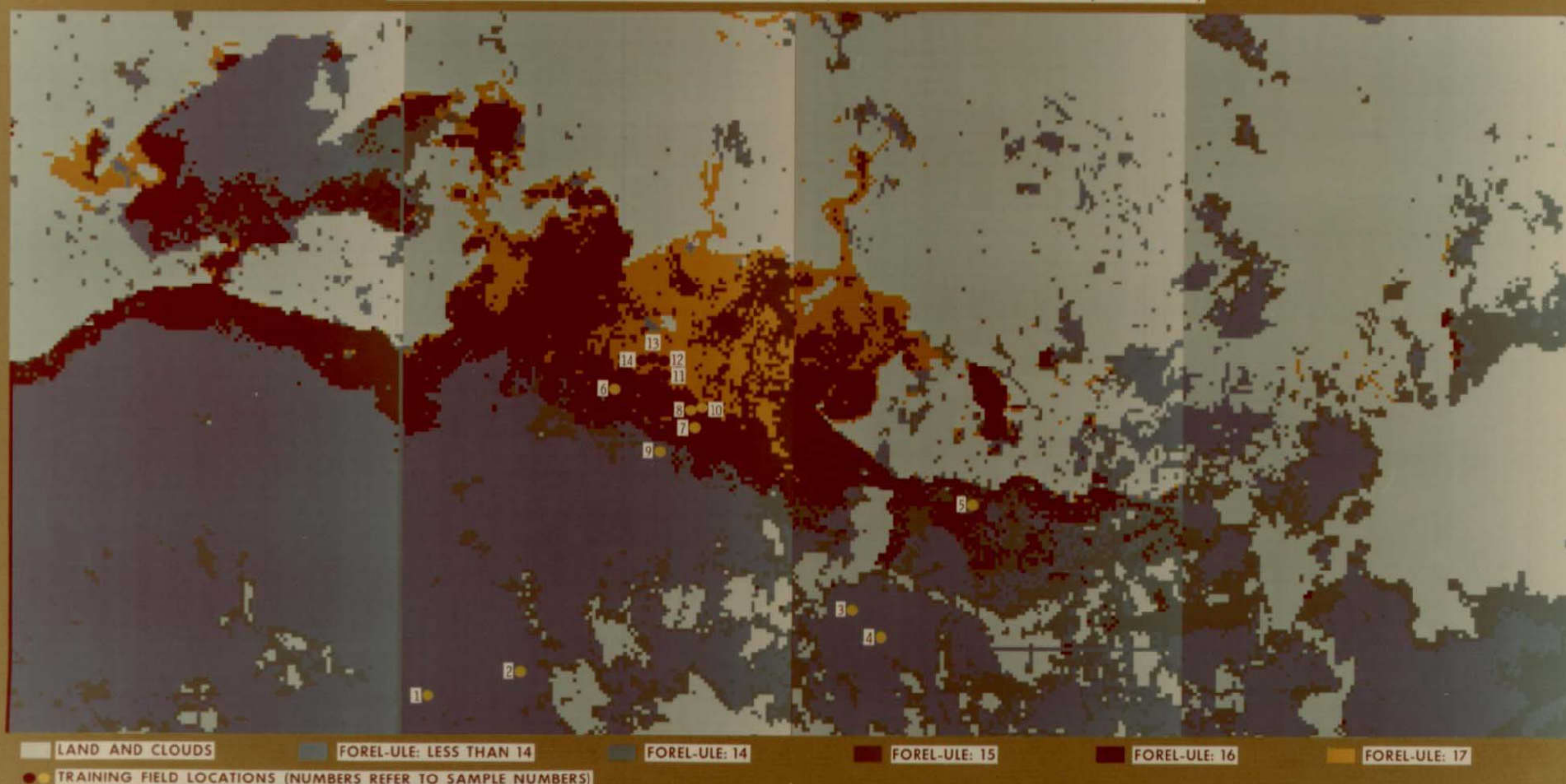
Figure 10-4. Forel-Ule Color Classification of July 24, 1975, LANDSAT MSS Data (Louisiana)

FORELL-ULE COLOR CLASSIFICATION OF JULY 24, 1975 LANDSAT MSS DATA (LOUISIANA)



acquired on this date could not be used because of cloud cover over the study area. The success of the model with this data set, and with the two data sets analyzed previously, indicates it is possible to infer Secchi extinction depth remotely; however, the two failures indicate the measurements may not always be reliable.

A second analytical approach to turbidity remotely was taken. This approach made use of a discriminant function analysis technique to classify MSS data into four Secchi disc categories. Surface samples used in this analysis are shown in Table 10-5.

Four linear functions of the radiance values which best separated the classes are shown in Table 10-6.

The classification function classified 13 of the 14 samples correctly for an accuracy of 93 percent. Results from the July 24, 1975, MSS data are shown in Figure 10-5.

10.3.2.5 Chlorophyll-a

Chlorophyll-a is a pigment found in all phytoplankton. It is not dissolved in sea water, so the pigment's effect on light propagation in the sea cannot be totally explained by Beer's law. Some light is scattered directly from the surface of the phytoplankton cell, while some is transmitted through the cell. The transmitted light is attenuated in a wavelength dependent manner by the pigment.

A statistical approach to developing a relationship between chlorophyll-a concentrations and water color was used by Holyer (1973) and Faller (1974) with airborne spectral radiometer data. Holyer found a fourth power relationship existed between chlorophyll concentrations and remotely sensed water color data, giving a root mean square fractional error of 0.15 over a concentration range of 1.2 to 39.6 mg/m^3. Faller found a linear combination of radiance at several wavelengths, normalized by the radiance at 520 nm, permitted calculation of the chlorophyll-a content of surface waters with a root mean square fractional error of 0.26 over a range of 0.0 to 5.0 mg/m^3. Because oceanographic conditions were expected to be comparable to those considered by Holyer, a similar model was used with aircraft data from August 20, 1975, and LANDSAT data from July 24, 1975. A discriminant function analysis approach also was utilized which categorized the surface measurements into three different chlorophyll-a concentration ranges.

Chlorophyll-a measurements inferred from aircraft data with the Holyer model yielded a fractional error of 0.32. The range of values was 1.7 to 38.6 mg/m^3, and the uncertainty of the remote measurement was 3.9 mg/m^3. Application of the model to LANDSAT MSS data, however, was not successful. This lack of success may have been due to atmospheric interference and significant time differences between many of the surface samples and satellite coverage.

The lack of success with the fourth power model prompted an analysis of MSS data through a discriminant function approach. This approach utilized broad chlorophyll concentration ranges: less than 6 mg/m^3, 6 to 10 mg/m^3, and 10 to 30 mg/m^3. Samples selected for analysis are shown in Table 10-7 and the linear functions which were used to separate the data are given in Table 10-8. All of the samples used to develop the classifier classified correctly.

Results of a discriminant function classification of LANDSAT MSS data from July 24, 1975, are shown in Figure 10-6. The significance of the results is questionable, however, due to the very broad ranges of the chlorophyll concentration categories.

Table 10-5. Training Samples for a Secchi Disc Classification of July 24, 1975, MSS Data

CLASS	SAMPLE NO.	MSS RADIANCE VALUES B4	B5	B6	B7
Offshore (>1.5 m)	1	23.900	12.700	6.000	.600
	2	23.600	12.400	5.900	.600
	3	24.400	13.700	7.100	.700
	4	23.700	12.100	6.400	.600
Secchi 5 (0.9-1.5 m)	5	27.200	15.100	7.400	.900
Secchi 3 (0.6-0.9 m)	6	25.500	14.900	7.700	1.000
	7	38.000	35.700	18.000	2.700
	8	38.300	36.700	19.300	3.000
	9	38.500	37.300	21.000	3.500
	10	38.400	37.000	20.800	3.400
Secchi 2 (<0.6 m)	11	32.500	24.800	11.400	1.300
	12	34.600	27.700	12.300	1.600
	13	38.100	34.600	17.500	2.500
	14	35.600	29.300	13.300	1.900

Table 10-6. Discriminant Function Secchi Disc Classifier for July 24, 1975, MSS Data (Resulting values must be multiplied by 0.3048 to yield Secchi disc extinction depths in meters)

CLASS	CONSTANT	MSS COEFFICIENTS B4	B5	B6	B7
Offshore	-328.688	38.335	-5.933	-32.503	31.749
Secchi 5	-421.972	43.627	-6.755	-38.113	42.332
Secchi 3	-381.417	40.807	-6.020	-34.891	37.301
Secchi 2	-483.892	46.019	-6.353	-39.246	35.225

Table 10-7. Training Samples for a Chlorophyll Classification of July 24, 1975, MSS Data

CLASS (CHLOROPHYLL mg/m^3)	SAMPLE NO.	MSS RADIANCE VALUES			
		B4	B5	B6	B7
0-6	1	23.900	12.700	6.000	.600
	2	23.600	12.400	5.900	.600
	3	24.400	13.700	7.100	.700
	4	23.700	12.100	6.400	.600
6-10	5	27.200	15.100	7.400	.900
10-30	6	38.300	36.700	19.300	3.000
	7	34.600	27.700	12.300	1.600
	8	38.500	37.300	21.000	3.500
	9	35.600	29.300	13.300	1.900
	10	38.100	34.600	17.500	2.500
	11	38.400	37.000	20.800	3.400
	12	38.000	35.700	18.000	2.700
	13	31.200	23.000	10.800	1.400

Table 10-8. Discriminant Function Chlorophyll Classifier for July 24, 1975, MSS Data

CLASS (CHLOROPHYLL mg/m^3)	CONSTANT	MSS COEFFICIENTS			
		B4	B5	B6	B7
0-6	-360.968	38.242	-3.251	-28.616	45.207
6-10	-469.409	43.824	-3.735	-34.056	58.289
10-30	-610.187	48.765	-2.889	-36.640	54.772

COLOR PHOTOGRAPH

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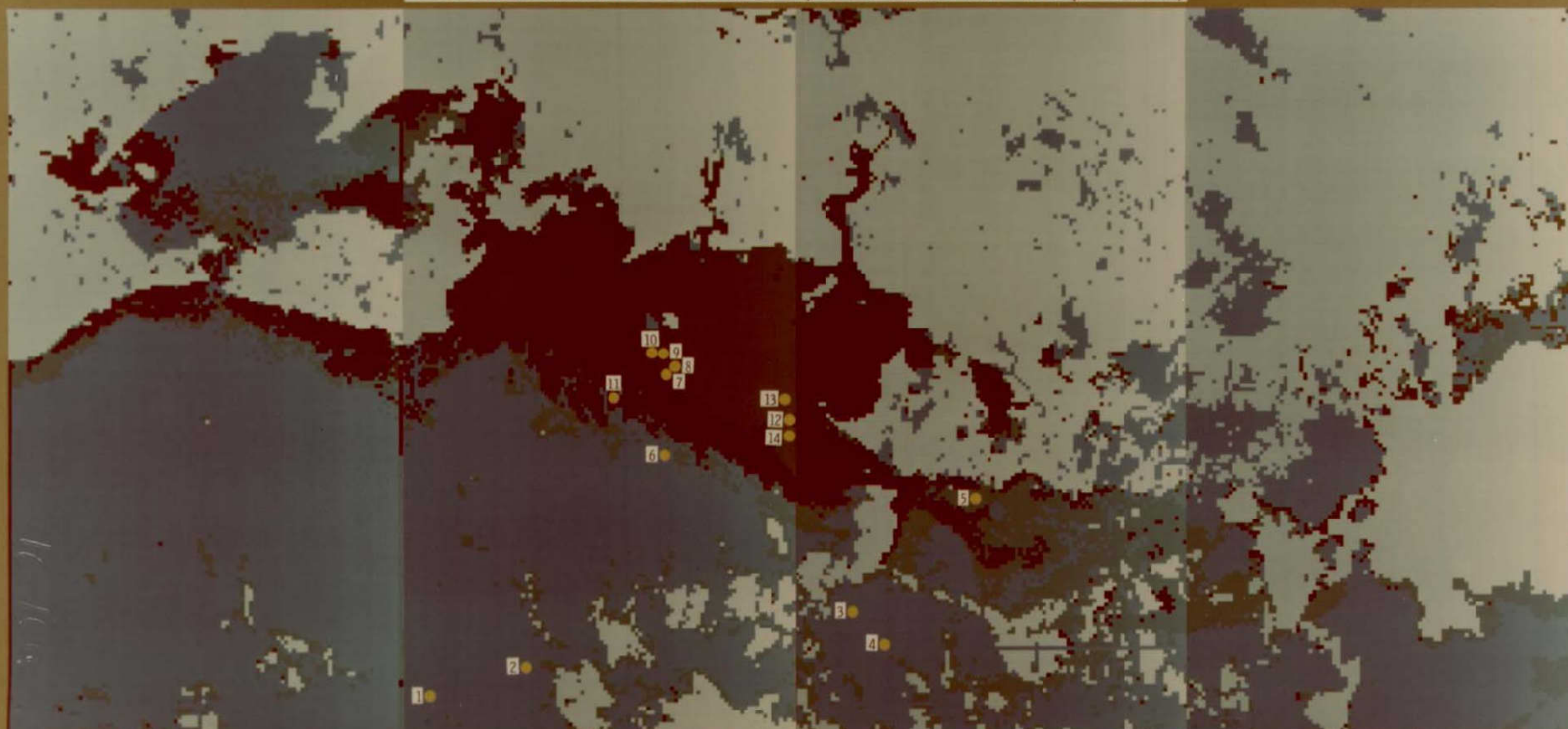
Figure 10-5. Secci Depth Classification of July 24, 1975 LANDSAT MSS Data (Louisiana)

SECCHI DEPTH CLASSIFICATION OF JULY 24, 1975 LANDSAT MSS DATA (LOUISIANA)



LAND AND CLOUDS
SECCHI DEPTH - 1.5 m
SECCHI DEPTH - 0.9 m
SECCHI DEPTH - 0.6 m
UNCLASSIFIED: GREATER THAN 1.5 m
TRAINING FIELD LOCATIONS (NUMBERS REFER TO SAMPLE NUMBERS)

COLOR PHOTOGRAPH

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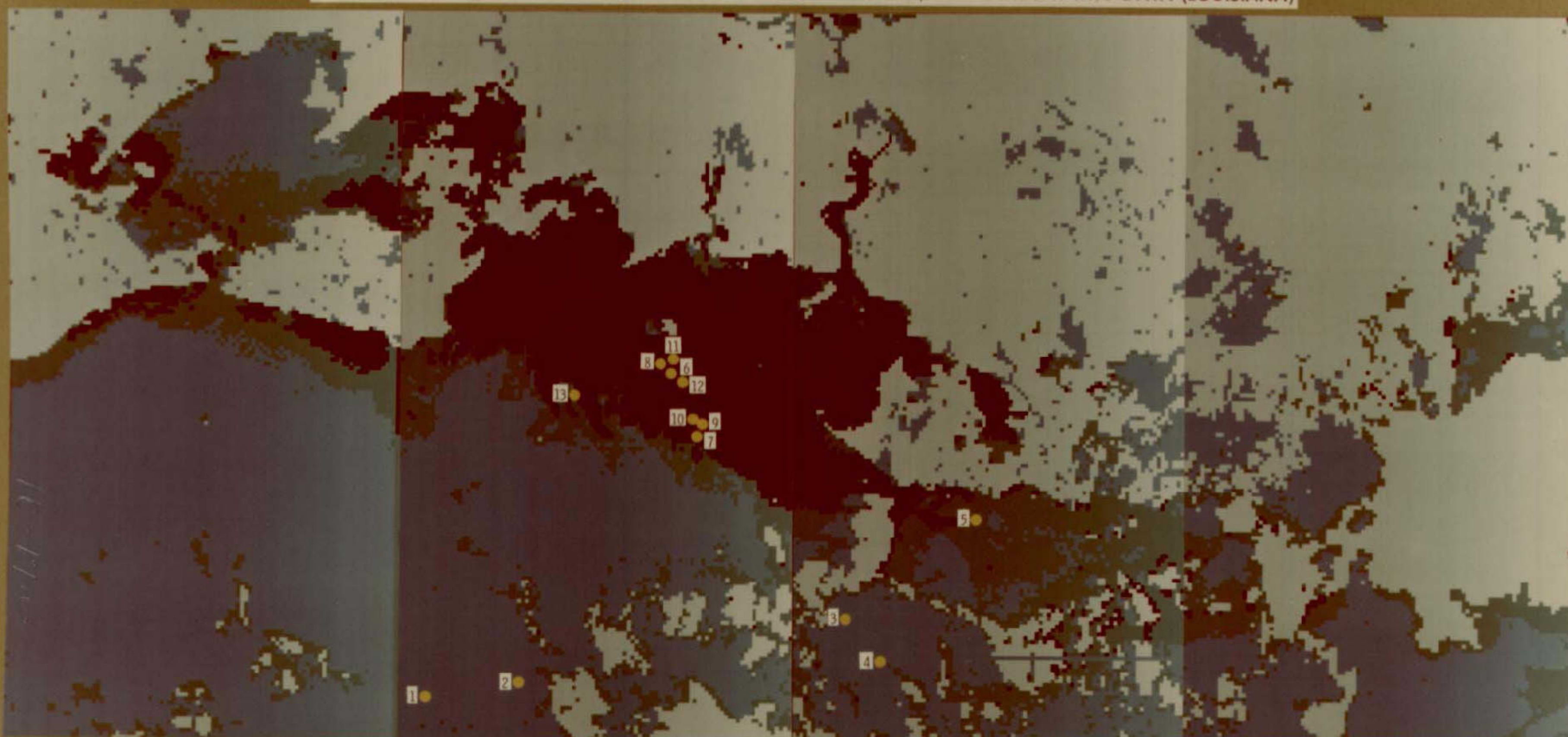
Figure 10-6. Cholorophyll-a Concentration Classification of July 24, 1975 LANDSAT MSS Data (Louisiana)

CHLOROPHYLL - a CONCENTRATION CLASSIFICATION OF JULY 24, 1975 LANDSAT MSS DATA (LOUISIANA)



LAND AND CLOUDS

CHLOROPHYLL CONCENTRATION : LESS THAN 6 mg/m^3

CHLOROPHYLL CONCENTRATION: 6 - 10 mg/m^3

CHLOROPHYLL CONCENTRATION: 10 - 30 mg/m^3

TRAINING FIELD LOCATIONS (NUMBERS REFER TO SAMPLE NUMBERS)

10.4 RELATIONSHIPS BETWEEN FISH DISTRIBUTION AND OCEANOGRAPHIC PARAMETERS

10.4.1 CLASSICAL OCEANOGRAPHIC PARAMETERS

10.4.1.1 Histogram Analysis

As the experimental rationale employed in this investigation depended on predictable relationships between fish distribution and oceanographic parameters, initial analytical emphasis was given to them to guide subsequent analyses. The most available source of information to establish these relationships were the samples taken by scientific observers aboard fishing vessels. Ideally, this analysis should have been done by comparing oceanographic conditions at locations with and without fish. However, this was not practical because the fishing vessels generally remained in areas where fish were being or had been caught, i.e., the samples were heavily biased in favor of areas with fish. The only other alternative was to examine temporal and spatial variability in the parameter values. An inherent assumption in this approach was that those parameters showing consistency with respect to areas with fish influenced fish distribution. For example, if all fish were caught in waters with a temperature of X°C, regardless of season and location, then temperature would be assumed to affect fish distribution. An added test, however, was made to ensure consistency was a function of fish preference, and not a result of a homogenous environment. This test was performed by examining the difference between samples from fishing and research vessels.

Surface water temperature, salinity, turbidity, color, and chlorophyll concentrations at locations of menhaden capture were examined in a histogram format as a function of time (Figures 10-7 through 10-11). Included in this analysis are histograms constructed from surface truth measurements acquired from the research vessels. These latter measurements, however, probably are not truly representative of general oceanographic conditions in the study areas as they were not taken randomly, but were collected from sampling stations biased to ensure coverage of areas suspected of having fish.

Surface water temperature, salinity, and chlorophyll concentrations appeared to have little or no effect on menhaden distribution in the two study areas (Figures 10-7, 10-8, and 10-11). Menhaden generally were caught throughout the range of temperatures measured during any given mission period. As the waters warmed through the summer, fish were caught in progressively warmer waters. The range of salinity values associated with menhaden capture was so broad that any direct effect on distribution seems unlikely, except possibly at concentrations exceeding about 25 ppt. The lack of a consistent relationship between menhaden catch and chlorophyll concentrations was perplexing. Menhaden are filter feeders; therefore, a reasonably good relationship between their food supply; i.e., phytoplankton or the planktonic organisms that feed on phytoplankton; and distribution should be expected. The poor relationship, however, may be due to inadequate samples as phytoplankton are known to exhibit extremely patchy distribution patterns.

Relationships between menhaden capture, Secchi disc visibility, and water color were consistent over time in both study areas (Figures 10-9 and 10-10). Furthermore, there appeared to be differences between most of the menhaden and research vessel measurements. Both factors suggest these parameters were affecting menhaden distribution.

A comparison between measurements at sites of menhaden capture in the two study areas support conclusions derived from temporal comparisons (Figure 10-12). Salinity and temperature measurements lacked consistency. Secchi disc, water color, and

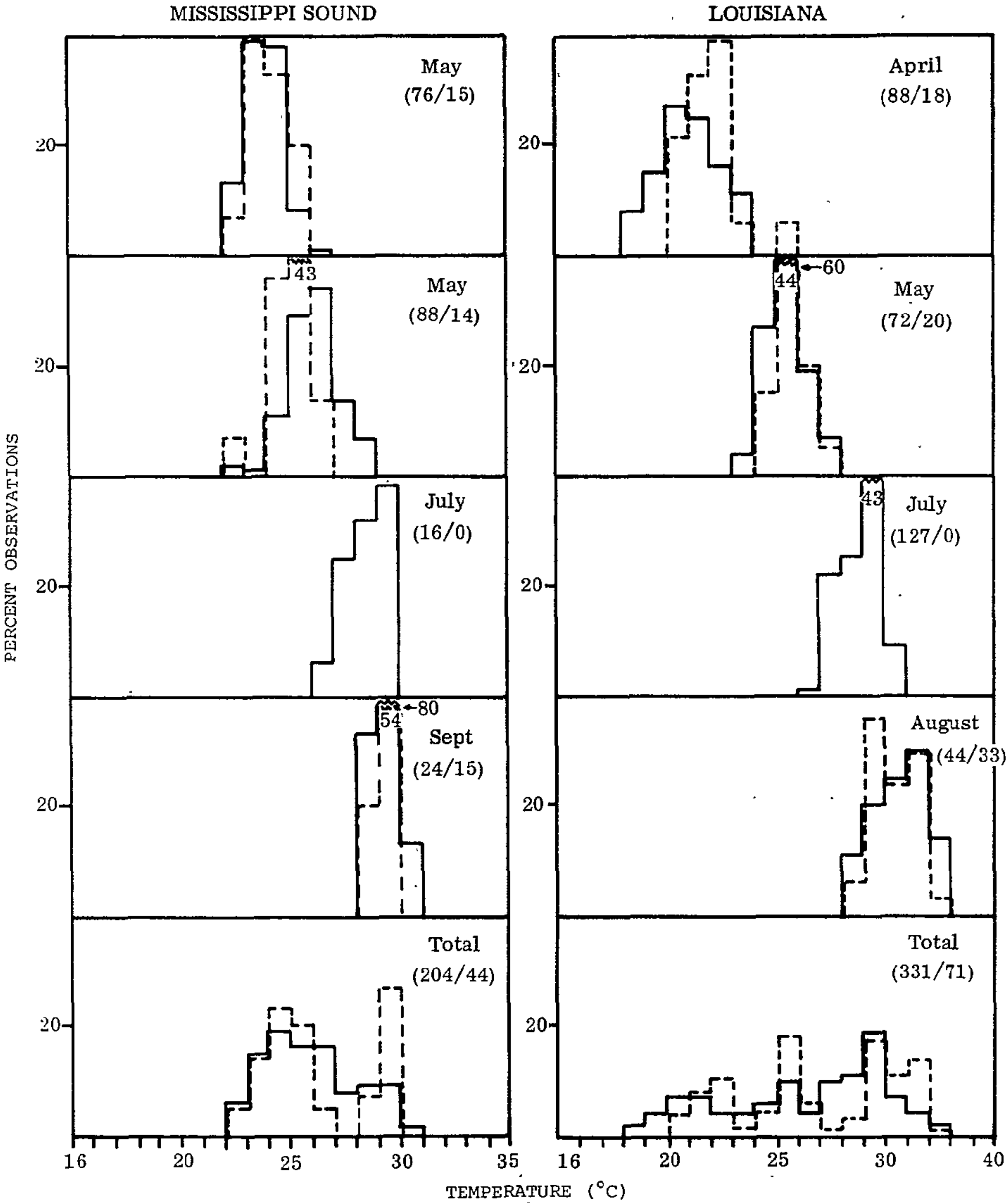


Figure 10-7. Comparison of Temperature (°C) Measurements from Locations of Menhaden Capture (solid lines) and Oceanographic Stations (broken lines) in the Mississippi Sound and Louisiana Study Areas Numbers in Parentheses Represent Sample Sizes for the Menhaden and Oceanographic Samples Respectively

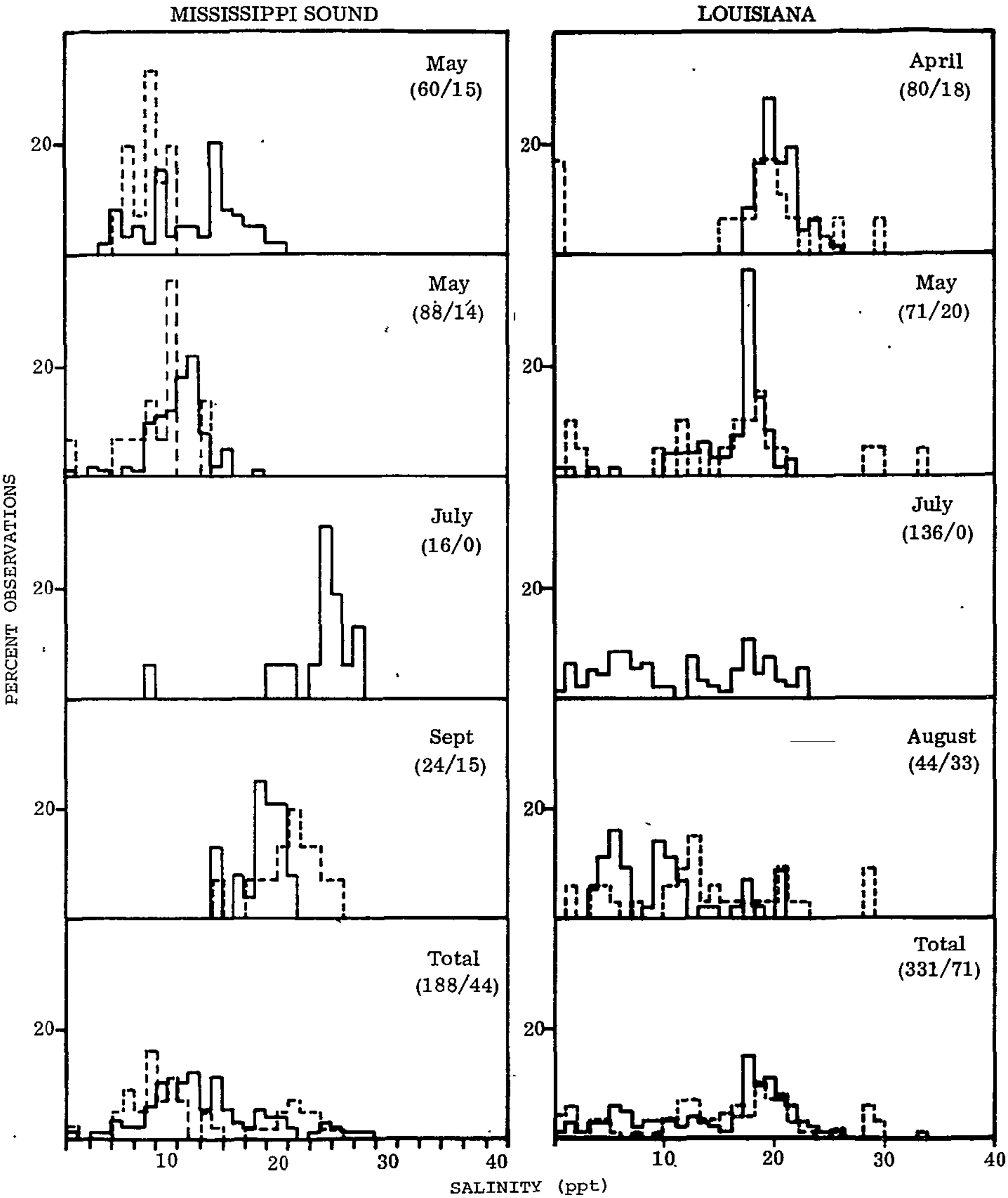


Figure 10-8. Comparison of Salinity Measurements from Locations of Menhaden Capture (solid lines) and Oceanographic Stations (broken lines) in the Mississippi Sound and Louisiana Study Areas Numbers in Parentheses Represent Sample Sizes for the Menhaden and Oceanographic Samples Respectively

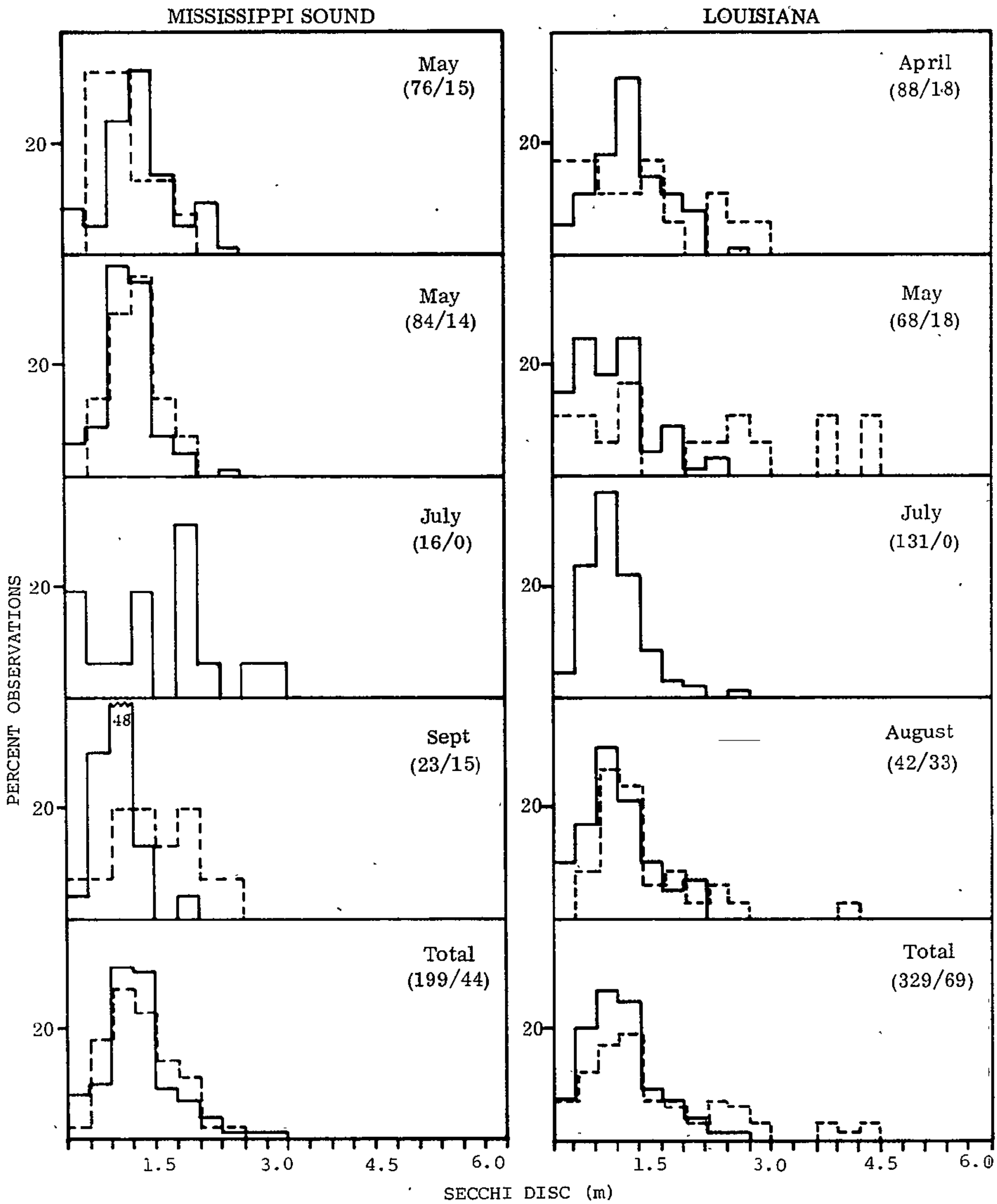


Figure 10-9. Comparison of Secchi Disc Measurements from Locations of Menhaden Capture (solid lines) and Oceanographic Stations (broken lines) in the Mississippi Sound and Louisiana Study Areas Numbers in Parentheses Represent Sample Sizes for the Menhaden and Oceanographic Samples Respectively

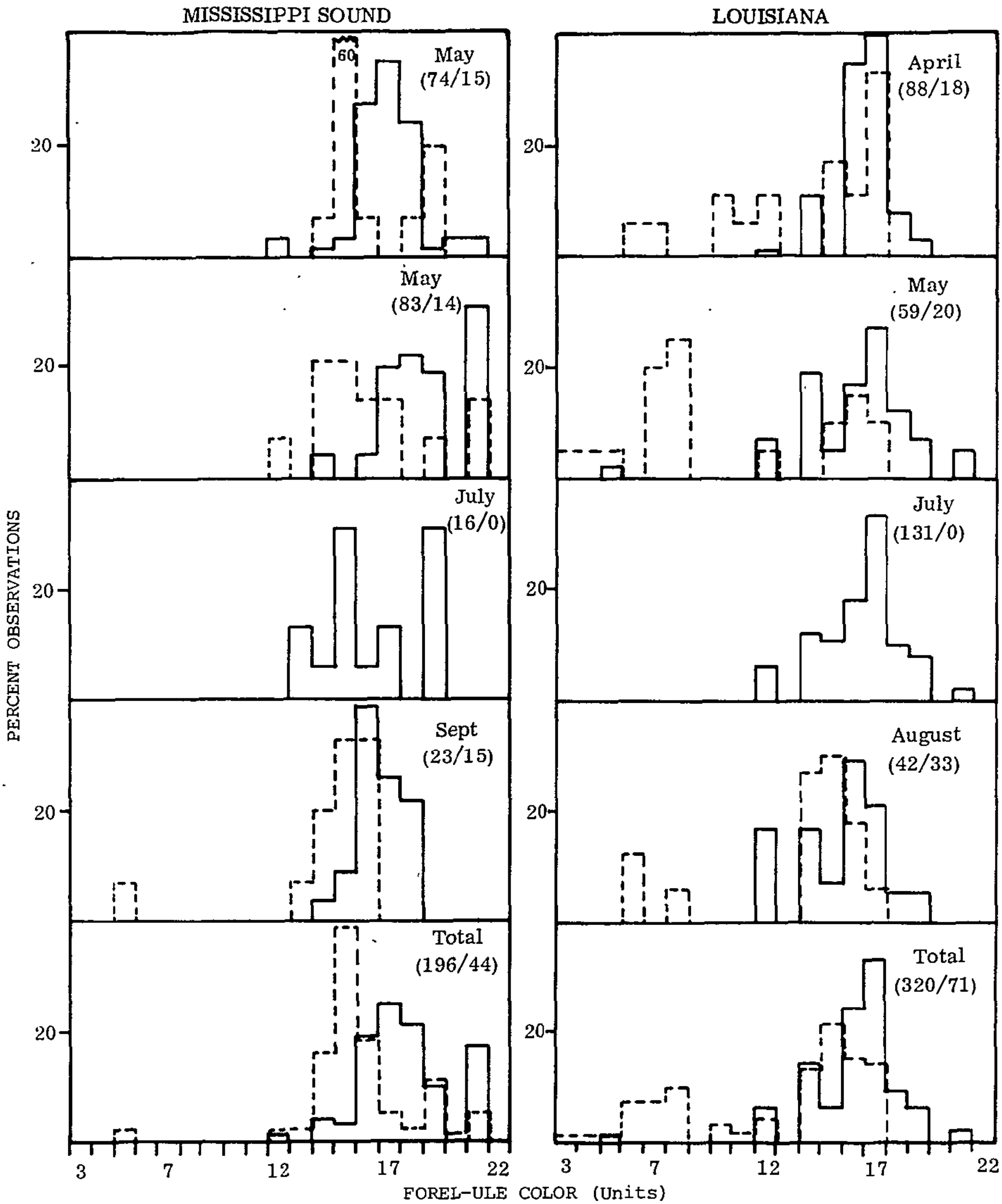


Figure 10-10. Comparison of Forel-Ule Measurements from Locations of Menhaden Capture (solid lines) and Oceanographic Stations (broken lines) in the Mississippi Sound and Louisiana Study Areas. Numbers in Parentheses Represent Sample Sizes for the Menhaden and Oceanographic Samples Respectively

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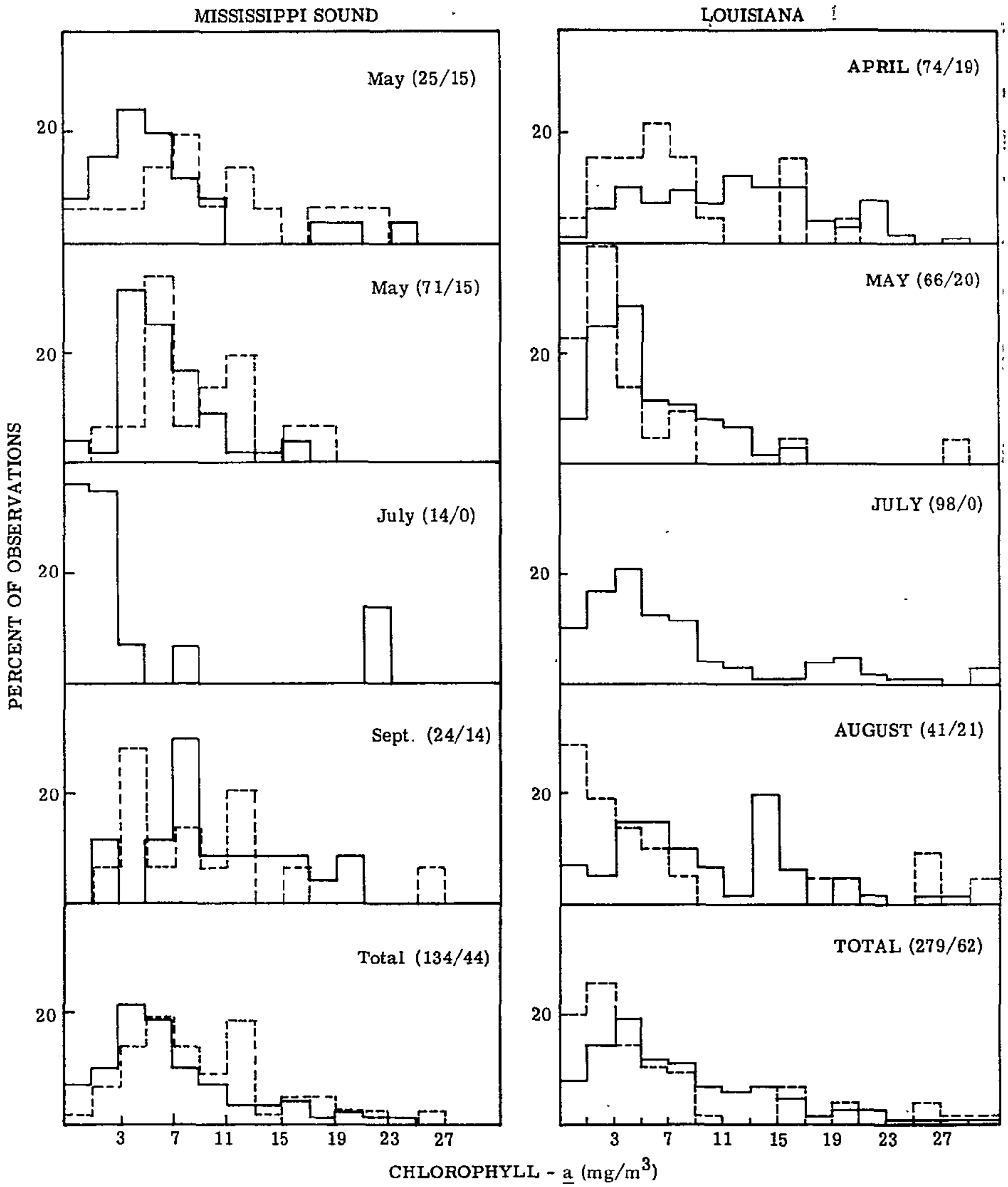

Figure 10-11. Comparison of Chlorophyll Measurements from Locations of Menhaden Capture (solid lines) and Oceanographic Stations (broken lines) in the Mississippi Sound and Louisiana Study Areas Numbers in Parentheses Represent Sample Sizes for the Menhaden and Oceanographic Samples Respectively

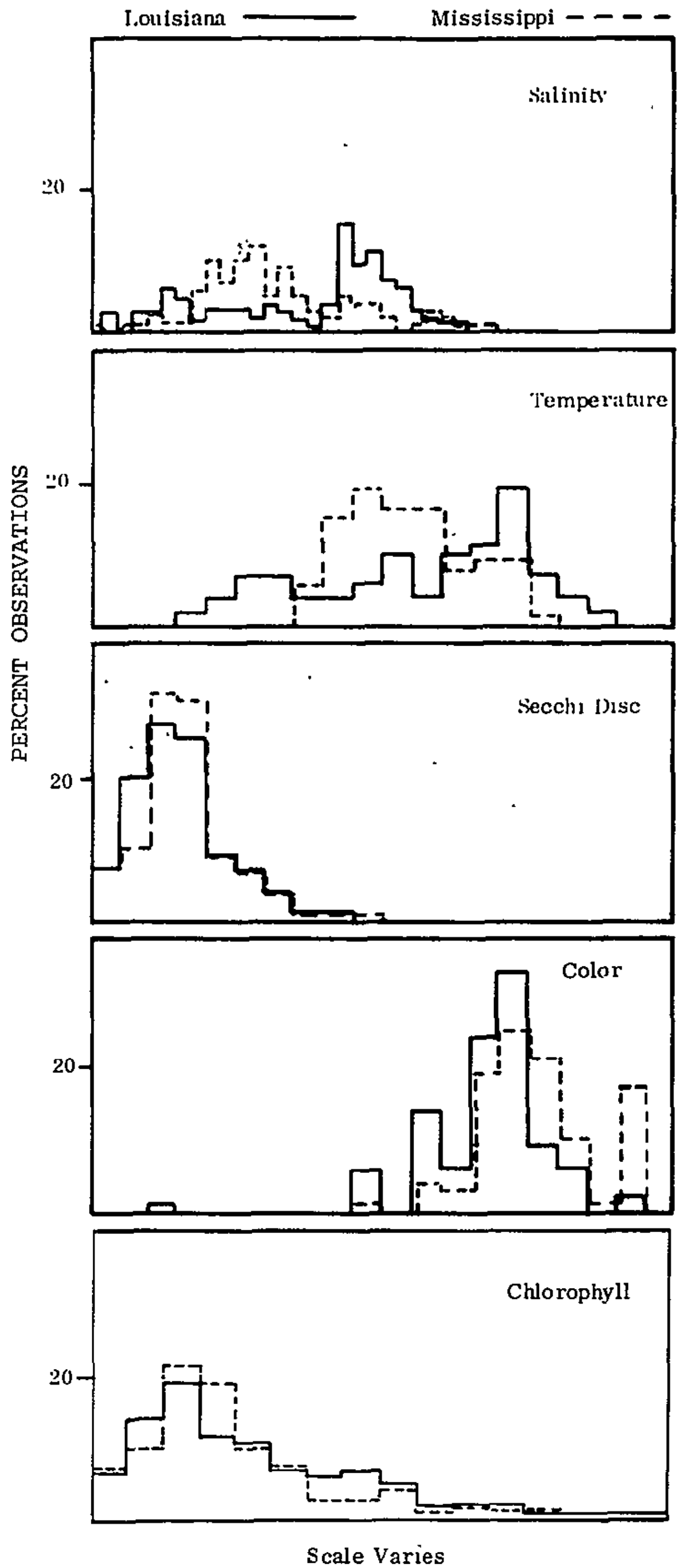

Figure 10-12. Summary of Measurements Taken at Sites of Menhaden Capture for the Two Study Areas

chlorophyll measurements were almost identical. Chlorophyll, however, probably should not be considered a controlling parameter based on the temporal comparisons.

An additional test of the temporal and spatial comparisons was performed by comparing oceanographic conditions at locations of menhaden capture in 1975 with similar measurements taken during the ERTS-1 Menhaden Experiment, and off Louisiana during the 1976 extension phase (Figure 10-13). Similar conclusions resulted; temperature and salinity measurements demonstrated little or no consistency and Secchi disc and water color measurements remained relatively constant over time, between years, and between study areas.

Tables 10-9 through 10-11 summarize the oceanographic parameter statistics for each study area by mission date for locations with and without menhaden. As demonstrated in the histograms, temperature, salinity and chlorophyll measurements associated with menhaden had no consistency from mission to mission or from study to study area. Furthermore, the overall means for temperature and salinity for areas both with fish and without fish were virtually identical in both areas.

A similar analysis was attempted, but later abandoned, for thread herring. Too few surface truth measurements from locations of thread herring capture were available (Table 10-12). A significant number of these fish were caught during the course of the investigation, but few catches were made by vessels with scientific observers aboard, and almost none of the spotter pilot sightings were during a period or in an area where oceanographic measurements were being made.

While the limited number of samples from sites of thread herring capture or observation makes it difficult to develop meaningful conclusions, certain observations are warranted. For example, thread herring appeared to prefer slightly warmer water than menhaden (29.8°C versus 28.5°C), waters with greater visibilities (Secchi disc visibility of 3.81 m versus 1.06 m), bluer waters (Forel-Ule 11.2 versus 16.3) and waters more saline (19.99 ppt versus 15.93 ppt). In the foregoing comparisons, the figure given for menhaden is the mean of means given in Tables 10-9, 10-10, and 10-11.

10.4.1.2 Correlation Analysis and Modeling

Correlation analysis and modeling efforts concentrated on two groups of classical oceanographic and fish distribution data. The first group consisted of oceanographic and fish distribution data collected by scientific observers aboard commercial fishing vessels and included areas with and without fish capture. The second group consisted of oceanographic data from fishing vessels at locations of fish capture only, research vessels, research aircraft, and oil platforms. The fish distribution data were from scientific observers aboard fishing vessels and from fishing vessel captain and spotter pilot reports.

10.4.1.2.1 Fishing Vessel Data

Surface truth temperature, Secchi disc transparency, Forel-Ule color, salinity, and chlorophyll-a measurements were separated into two groups for each day of the six main and two aborted main mission periods. The two data groups represented areas with and without fish capture. The number of samples collected at menhaden, thread herring, and without fish areas are listed in Table 10-13.

Several days of menhaden data and all thread herring data were excluded from analysis due to the small number of samples collected. Individual days, days grouped by mission, days grouped by study area (Louisiana or Mississippi) and all data collected

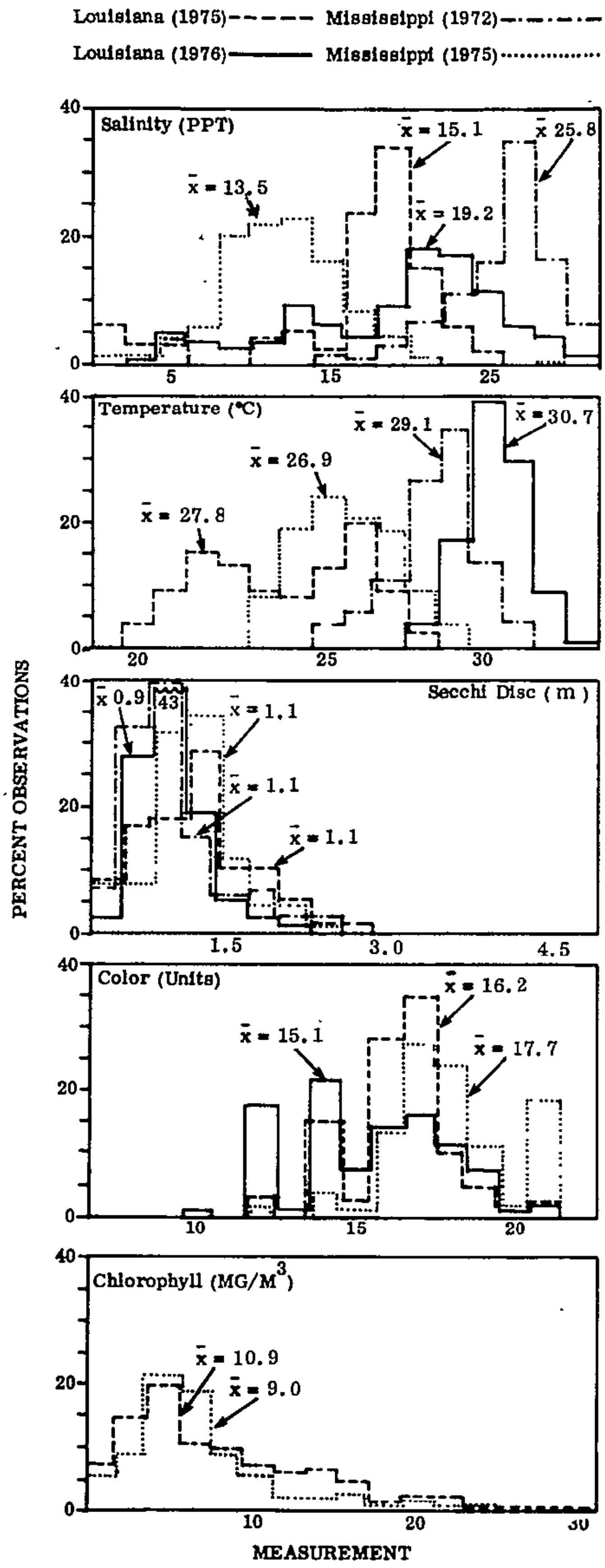

Figure 10-13. Comparison of Oceanic Conditions at Sites of Menhaden Capture ($\overline{x}$ = mean)

Table 10-9. Statistics* for Selected Oceanographic Parameter Measurements from Locations of Menhaden Capture and No-Fish Observations in the Louisiana Study Area

MISSION DATE (1975)	WATER TEMP (°C)			F-U COLOR (units)			SALINITY (ppt)			Secchi Depth (m)			Chlorophyll (mg/m^3)		
	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s	n	$\bar{x}$	s
With Fish 4/21-4/25	82	22.0	1.3	82	16.5	1.3	74	20.4	1.9	82	1.28	0.49	73	14.3	7.4
Without Fish 4/25	19	23.1	1.1	19	13.6	3.6	19	18.0	8.4	19	1.34	0.85	19	8.6	5.7
With Fish 5/12-5/17	70	26.5	0.9	57	16.3	2.1	69	15.9	4.2	65	0.98	0.49	60	7.4	4.3
Without Fish 5/13	23	26.6	0.7	23	10.6	4.8	23	17.0	8.1	21	2.59	2.77	21	5.6	6.7
With Fish 7/21-7/25	114	31/2	3.7	109	16.3	2.0	114	12.6	6.6	109	1.01	0.43	98	9.8	9.0
Without Fish 7/24	NO DATA														
With Fish 8/18-8/22	42	31.7	1.1	40	15.5	1.9	42	11.0	5.3	40	1.07	0.49	40	12.9	7.9
Without Fish 8/20	21	31.3	1.0	33	13.5	3.4	33	14.7	7.6	31	2.56	3.69	21	8.9	10.8
With Fish All Missions	308	27.8	4.7	288	16.2	1.9	299	15.1	6.1	296	1.10	0.49	271	10.9	8.0
Without Fish All Missions	63	27.1	3.4	75	12.6	4.1	75	16.3	8.0	71	2.26	2.97	61	7.7	8.1

*n = sample size
$\bar{x}$ = mean
s = standard deviation

Table 10-10. Statistics*for Selected Oceanographic Parameter Measurements from Locations of Menhaden Capture and No-Fish Observations in the Mississippi Sound

MISSION DATE (1975)	WATER TEMP (°C)			F-U COLOR (units)			Salinity (ppt)			Secchi Depth (m)			Chlorophyll mg/m^3		
	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s
With Fish 4/28-5/2	75	24.9	0.8	73	17.0	1.5	60	12.5	4.1	75	1.22	0.49	43	9.2	5.3
Without Fish 5/2	15	25.2	0.8	15	16.0	1.8	15	8.5	1.9	11	0.91	0.30	14	11.8	5.9
With Fish 5/19-5/23	74	27.3	1.2	69	19.0	1.7	74	10.7	3.2	70	1.01	0.34	71	8.4	3.9
Without Fish 5/20	15	26.1	1.0	15	16.0	2.6	15	9.4	3.5	15	1.04	0.37	15	9.7	4.6
With Fish 7/28-7/31	14	29.6	0.8	14	17.3	2.5	14	24.1	2.3	14	1.58	0.79	14	6.2	7.9
Without Fish	NO DATA														
With Fish 9/3-9/5	23	30.6	0.7	22	16.5	1.1	23	18.6	2.2	22	0.85	0.30	23	12.2	5.8
Without Fish 9/5	14	29.8	0.3	14	14.2	2.9	14	21.7	2.2	14	1.37	0.58	13	9.7	6.4
With Fish All Missions	186	26.9	2.2	178	17.7	1.9	171	13.5	5.3	181	1.13	0.49	151	9.0	5.3
Without Fish All Missions	44	27.0	2.1	44	15.4	2.5	44	13.0	6.5	40	1.13	0.49	42	10.4	5.6

*n=sample size
$\overline{x}$=mean
s=standard deviation

Table 10-11. Statistics* for Selected Oceanographic Parameter Measurements for Locations of Menhaden Capture off Louisiana (1976)

MISSION DATE (1976)	WATER TEMP (°C)			F-U COLOR (units)			SALINITY (ppt)			SECCHI DISC (m)			CHLOROPHYLL (mg/m^3)		
	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s	n	$\overline{x}$	s
With Fish 7/19-7/24	135	30.4	0.9	122	14.8	3.0	128	16.0	6.5	136	0.98	0.34	10	9.6	4.8
With Fish 7/26-7/30	115	31.0	0.9	114	15.5	2.6	118	22.7	4.8	114	0.91	0.27	NO DATA		
With Fish All Missions	250	30.7	0.9	236	15.1	2.8	246	19.2	6.6	250	0.94	0.30	10	9.6	4.8

*n = sample size
$\overline{x}$ = mean
s = standard deviation

Table 10-12. Oceanographic Conditions at Locations of Thread Herring Capture and Observation

DATE (1975)	TEMPERATURE (^{o}C)	SECCHI DISC (m)	FOREL-ULE (units)	SALINITY (ppt)	CHLOROPHYLL-a (mg/m^3)
5/12	25.4	2.44	5	21.24	9.5
5/13	26.6	1.22	12	16.40	5.8
5/19	23.8	2.44	14	28.44	2.3
7/25	29.5	1.52	14	12.38	4.5
8/19	30.2	1.83	12	16.69	3.9
8/19	30.9	2.44	12	16.44	2.7
8/19	30.1	1.83	16	16.55	1.6
8/19	30.0	1.83	12	17.28	3.9
8/20	30.7	12.19	3	29.21	1.0
8/20	30.3	11.89	4	29.19	0.0
8/20	31.4	12.19	4	29.23	0.0
8/20	29.7	2.44	10	16.66	3.4
8/20	31.3	0.91	17	12.01	8.3
8/20	31.2	2.13	14	19.58	2.7
8/21	33.2	1.52	16	19.48	2.4
8/21	33.1	2.13	14	19.14	4.1
$\bar{x}$ =	29.8	3.81	11.2	19.99	3.50
s =	2.54	4.13	4.65	5.87	2.63
n =	16	16	16	16	16

$\bar{x}$ = mean
s = standard deviation
n = sample size

Table 10-13. Fishing Vessel Data Sets

SEQUENCE NO.	DATE (1975)	MENHADEN SAMPLES	THREAD HERRING SAMPLES	NO-FISH SAMPLES	TOTAL SAMPLES
1	4/21	0	0	0	0
2	4/22	15	0	5	20
3	4/23	19	0	22	41
4	4/24	18	0	14	32
5	4/25	24	0	30	54
6	4/28	0	0	0	0
7	4/29	1	0	0	1
8	4/30	6	0	2	8
9	5/01	23	0	2	25
10	5/02	12	0	7	19
11	5/12	26	1	5	32
12	5/13	2	0	50	52
13	5/14	8	0	9	17
14	5/15	10	0	12	22
15	5/16	9	0	5	14
16	5/17	1	0	0	1
17	5/19	14	1	12	27
18	5/20	36	0	5	41
19	5/21	38	0	0	38
20	5/22	18	0	1	19
21	5/23	11	0	2	13
22	7/21	29	0	0	29
23	7/22	14	0	5	19
24	7/23	18	0	3	21
25	7/24	16	0	10	26
26	7/25	15	1	6	22
27	7/28	11	0	5	16
28	7/29	1	0	7	8
29	7/30	4	0	2	6
30	7/31	0	0	0	0
31	8/18	18	0	7	25
32	8/19	12	4	11	27
33	8/20	2	2	25	29
34	8/21	6	2	8	16
35	8/22	1	0	3	4
36	9/03	10	0	2	12
37	9/04	11	0	2	13
38	9/05	1	0	2	3
39	4/21 - 4/25	76	0	71	147
40	4/28 - 5/02	42	0	11	53
41	5/12 - 5/17	56	1	81	138
42	5/19 - 5/23	117	1	20	138
43	7/21 - 7/25	92	1	24	117
44	7/28 - 7/31	16	0	14	30
45	8/18 - 8/22	39	8	54	101
46	8/03 - 9/05	22	0	6	28
47	La. (39,41,43,45)	263	10	230	503
48	Miss. (40,42,44,46)	197	1	51	249
49	All	460	11	281	752

were analyzed using correlation and multiple regression techniques. Correlation coefficients for each parameter by day and group are given in Table 10-14. The dependent variable in each case was presence or absence of menhaden (i.e., 0 = no fish and 1 = fish). Analysis of correlation coefficients for each parameter shows inconsistency in magnitude and sign. The frequency of these inconsistencies by day and parameter is given in Table 10-15.

A summary of a step-wise multiple regression analysis performed on the data is given in Table 10-16. Menhaden distribution was the dependent variable and was established by assigning areas with and without menhaden values of 1 and 0, respectively.

The number and percentage of areas classified incorrectly were computed from data used to develop the models (Table 10-16). The models inaccurately classified most of the no-fish areas. This was anticipated, however, as the no-fish samples were collected from fishing vessels which presumably try to remain in, or close to, areas containing fish.

The selection order of the parameters (Secchi disc, salinity, temperature chlorophyll-a and Forel-Ule color) used to develop the regression models also is shown in Table 10-16. This selection was done automatically by the computer routine based on which parameter reduced the remaining sum of squares the most (i.e., explained most of the remaining error). Inaccurately defined no-fish samples probably were responsible for lack of consistency in the selection order (Table 10-17).

It is evident that collection of accurate no-fish oceanographic data is impractical from commercial menhaden fishing vessels under normal fishing conditions. This conclusion was used to streamline sampling procedures during the extension phase of the investigation.

10.4.1.2.2 Fishing Vessel, Research Vessel, Oil Platform, Research Aircraft, and Spotter Pilots

Correlation and multiple regression analytical techniques were applied to fish distribution data, and measurements of temperature, Forel-Ule color, salinity, Secchi disc transparency, chlorophyll-a and remotely sensed temperature and salinity data collected during two mission periods each in the two study areas. Areas with and without menhaden were identified from fishing vessel captains and spotter pilot reports. Correlation coefficients for each parameter considered are presented in Table 10-18.

A summary of the step-wise multiple regression analysis is shown in Table 10-19. Menhaden distribution was the dependent variable and was established by assigning areas with and without menhaden values of 1 and 0, respectively.

Regression model correlation coefficients averaged about 0.62 for the four missions indicating a fairly low level of statistical precision. Nonlinear combinations of the parameters failed to increase precision. However, the regression models were about 75 percent accurate in classifying the study areas into with and without menhaden areas. Accuracy was computed from the samples used to develop the models.

Forel-Ule color measurements generally correlated well with menhaden distribution (Table 10-18) and dominated the regression models (Table 10-19). Surface water temperature also correlated significantly with menhaden distribution which is contrary to earlier conclusions developed from an analysis of samples from fishing vessels.

Table 10-14. Correlation Coefficients for the Relationship of Menhaden Distribution to Selected Oceanographic Parameters.

DATE (1975)	SAMPLE SIZE	TEMP.	SECCHI DISC	FOREL-ULE COLOR	SALINITY	CHLOROPHYLL-a
4/22	20	.209	-.053	-.023	.213	.109
4/23	41	.122	-.133	-.218	-.119	-.131
4/24	32	.204	.060	-.216	-.085	-.055
4/25	54	.442	-.462	.330	-.522	.176
4/21 - 4/25	147	.108	-.303	.196	-.271	.096
4/30	8	.345	-.556	.421	-.280	.405
5/02	19	.248	-.400	.102	-.107	-.467
4/28 - 5/02	53	.139	-.217	-.021	.025	-.197
5/12	31	-.154	-.105	.356	-.221	.142
5/14	17	.275	.051	-.017	-.506	.420
5/15	22	.002	.427	-.557	.425	-.141
5/16	14	-.054	.375	-.109	.553	-.129
5/12 - 5/17	137	.214	-.340	.279	-.251	.084
5/19	26	.603	.151	.067	.203	-.208
5/20	41	.193	.142	-.220	.323	-.058
5/19 - 5/23	137	.360	.206	-.152	.297	-.016
7/22	19	-.377	-.507	-.086	-.576	-.247
7/23	21	.158	-.269	.078	-.269	.008
7/24	26	.350	.405	-.306	.657	-.378
7/25	21	.287	.333	-.139	.241	-.498
7/21 - 7/25	116	.063	.126	-.063	.159	-.307
7/28	16	-.031	.269	-.316	.221	-.289
7/30	6	-.202	-.757	.948	-.600	.481
7/28 - 7/31	30	-.084	-.251	.237	-.145	-.042
8/18	25	.090	-.171	-.130	-.081	.215
8/19	23	-.229	-.239	-.180	-.233	.166
8/21	14	-.500	.053	.147	.303	.132
8/18 - 8/22	93	.005	-.305	.220	-.283	.271
9/03 - 9/05	28	.283	-.497	.083	-.143	-.091
La.	493	.131	-.205	.240	-.214	.061
Miss.	248	.012	-.088	-.052	.066	-.082
All	741	.103	-.285	.229	-.143	-.008

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Table 10-15. Correlation Coefficient Frequency in Percent

RANGE	TEMPERATURE	SECCHI DISC	FOREL-ULE	SALINITY	CHLOROPHYLL-a
-.7 to -.8	0	3	0	0	0
-.6 to -.7	0	0	0	3	0
-.5 to -.6	3	6	3	10	0
-.4 to -.5	0	6	0	0	6
-.3 to -.4	3	13	6	0	6
-.2 to -.3	6	19	9	25	6
-.1 to -.2	3	10	16	16	13
.0 to -.1	10	6	16	6	22
TOTAL	25	63	50	60	53
.0 to .1	16	10	13	6	13
.1 to .2	22	9	9	3	16
.2 to .3	22	6	16	16	9
.3 to .4	9	6	6	6	0
.4 to .5	3	6	3	3	9
.5 to .6	0	0	0	3	0
.6 to .7	3	0	0	3	0
.7 to .8	0	0	0	0	0
.8 to .9	0	0	0	0	0
.9 to 1.0	0	0	3	0	0
TOTAL	75	37	50	40	47

Table 10-16. Summary of Step-Wise Multiple Regression (n=number and %=percent)

DATE (1975)	TOTAL NUMBER OF SAMPLES	NUMBER OF FISH SAMPLES	NUMBER OF NO-FISH SAMPLES	INCORRECTLY CLASSIFIED				ORDER OF SELECTION	DEGREES OF FREEDOM	CORRELATION COEFFICIENT
				FISH		NO-FISH				
				n	%	n	%			
4/22	20	15	5	1	7	4	80	Sa,Se,C,T,F	5/14	.432
4/23	41	19	22	11	58	6	27	F,Se,C,Sa,T	5/35	.345
4/24	32	18	14	4	22	8	57	F,Sa,T,C,Se	5/26	.373
4/25	54	24	30	6	25	7	23	Sa,F,T,Se,C	5/48	.618*
4/21-4/25	147	76	71	20	26	30	42	Se,T,F,C,Sa	5/141	.361*
4/30	8	6	2	0	0	0	0	Se,C,T,Sa,F	5/2	.915
5/02	19	12	7	1	8	1	14	C,Se,F,T,Sa	5/13	.746*
4/28-5/02	53	42	11	0	0	8	87	Se,C,F,T,Sa	5/47	.463
5/12	31	26	5	1	4	4	80	F,T,C,Se,Sa	5/25	.437
5/14	17	8	9	1	13	2	22	Sa,T,C,Se,F	5/11	.780*
5/15	22	10	12	4	40	2	17	F,Sa,T,C,Se	5/16	.641
5/16	14	9	5	1	11	2	40	Sa,Se,F,T,C	5/8	.599
5/12-5/17	137	56	81	34	61	17	21	Se,F,T,Sa,C	5/131	.362*
5/19	26	14	12	4	29	3	25	T,Sa,F,C,Se	5/20	.677*
5/20	41	36	5	0	0	5	100	Sa,T,F,Se,C	5/35	.443
5/19-5/23	137	117	20	0	0	11	55	T,Sa,F,Se,C	5/131	.573**
7/22	19	14	5	0	0	2	40	Sa,T,Se,F,C	5/13	.735
7/23	21	18	3	0	0	3	100	Sa,F,T,C,Se	5/15	.346
7/24	26	16	10	2	13	2	20	Sa,F,C,T,Se	5/20	.715*
7/25	21	15	6	2	13	2	33	C,Sa,Se,T,F	5/15	.612
7/21-7/25	116	92	24	3	3	22	92	C,Sa,T,F,Se	5/110	.315
7/28	16	11	5	0	0	2	40	F,C,Sa,Se,T	5/10	.643
7/28-7/31	30	16	14	6	37	6	43	Se,C,F,Sa,T	5/24	.326
8/18	25	18	7	0	0	5	71	C,T,Sa,Se,F	5/19	.393
8/19	23	12	11	4	33	3	27	Se,T,S,Sa,C	5/17	.376
8/21	14	6	8	3	50	1	13	T,Se,F,Sa,C	5/8	.557
8/18-8/22	93	39	54	21	54	10	19	Se,C,F,T,Sa	5/87	.379
9/03-9/05	28	22	6	1	5	3	50	Se,T,F,C,Sa	5/22	.592
La.	493	263	230	22	8	153	67	Se,T,F,Sa,C	5/487	.314**
Miss.	248	197	51	0	0	51	100	Se,Sa,C,F,T	5/242	.197
All	741	460	281	0	0	245	87	Se,T,C,Sa,F	5/735	.302**

Se = Secchi Disc, Sa = Salinity, T = Temperature, C = Chlorophyll,a, F = Forel-Ule color,
*Significant at 90 percent, **Significant at 99 percent.

Table 10-17. Parameter Selection Frequency

ORDER	Number of Times Parameter Selected at Indicated Order. TEMPERATURE	SECCHI DISC	FOREL-ULE	SALINITY	CHLOROPHYLL-a
1st	3	11	6	8	4
2nd	10	6	4	7	5
3rd	8	2	13	2	7
4th	7	7	3	9	6
5th	4	6	6	6	9

Table 10-18. Correlation Coefficients for the Relationship of Menhaden Distribution to Selected Oceanographic Parameters (1975)

Parameter	Louisiana Test Site		Mississippi Sound	
	April 25	May 13	May 2	May 20
Temperature	0.289**	0.234*	0.332*	0.184*
Forel-Ule Color	0.286**	0.477**	0.442*	0.434**
Salinity	0.211*	-0.050	-0.069	0.048
Secchi Disc	-0.068	-0.329*	0.086	-0.202*
Chlorophyll-a	0.027	0.544**	-0.259	0.184*
Sample Size	70	40	22	78
Remote Salinity	0.184*	0.195	Not Available	0.253*
Remote Temperature	0.387**	0.066	0.192	-0.046
Sample Size	57	30	21	65

*Significant at 90 percent confidence level

**Significant at 99 percent confidence level

Table 10-19. Coefficient Summary of Step-Wise Multiple Regression Analyses

PARAMETERS AND REGRESSION STATISTICS	LOUISIANA		MISSISSIPPI SOUND	
	APRIL 25	MAY 13	MAY 2	MAY 20
Temperature	0.0565	-0.0569	0.1321	0.2400
Forel-Ule Color	0.0762	0.0337	0.0780	0.0950
Salinity	0.0467	0.0230	-0.3070	0.0455
Secchi Disc	-0.0566	-0.0219	0.1676	-0.1340
Chlorophyll-a	-0.0319	0.0471	-0.0669	0.0045
Intercept	-2.2793	1.1051	-1.4458	-7.5722
Correlation Coefficient	0.516	0.589	0.695	0.628
F-Value	4.633	3.609	2.988	9.394
Degrees of Freedom	5/64	5/34	5/16	5/72
Significance Level	99.5	97.5	95.0	99.9
Order of Selection	T,F,Sa, C,Se	C,F,Sa, Se,T	F,T,Sa, C,Se	F,T,Sa, Se,C

The relatively low level of precision associated with the secchi disc measurements was disappointing especially since the same measurements at locations of menhaden capture did suggest a good relationship between water clarity and menhaden distribution. The relatively low level of precision associated with salinity measurements was not unexpected based on earlier analysis (Section 10.4.1.1). Remotely sensed measurements of temperature and salinity also did not correlate well with menhaden distribution.

10.4.2 REMOTELY SENSED OCEAN COLOR

Because of the significant relationship found between menhaden distribution and water color several analytical procedures were tested to investigate direct relationships between menhaden distribution and LANDSAT ocean color data. The following sections describe the analyses and results obtained.

10.4.2.1 Correlation Analysis and Modeling

Preprocessed LANDSAT data for each spectral band were regressed against sample areas with and without menhaden (Table 10-20). Band 5 generally correlated more precisely than did the other bands (exception July 24, 1975). Interestingly, however, band 4 produced the best correlation coefficients for the Louisiana study area. Whether significance should be given to this is unclear; however, a precise correlation with band 4 seems reasonable due to the relatively clear waters in the study area. Power transformations of the spectral data failed to significantly increase precision.

Multiple regression models were developed from MSS spectral data for three missions (Table 10-21 through Table 10-23). The regression models were used to classify LANDSAT data into low and high probability fishing areas for each mission. They were about 85 percent accurate in classifying the study areas into the two categories based on the samples used to develop the models.

Menhaden distribution appeared to be more predictable from LANDSAT MSS data than from classical oceanographic parameters (e.g., temperature, salinity, Secchi disc visibility, etc.). This could be due to a number of factors. Most obvious is the inherent averaging effect of LANDSAT measurements over individual pixels. Surface truth measurements, on the other hand, are point values subject to considerable variability, especially in areas as dynamic as the Mississippi Sound and Louisiana study areas. Another factor may have been sampling accuracy. Surface measurements generally have a certain amount of error because of sampling procedures. In particular, Forel-Ule water color is a highly subjective measurement. This error would be reduced with LANDSAT color data.

10.4.2.2 Classification Techniques and Image Classifications

Procedures for processing LANDSAT MSS data are shown in Figure 10-14. Menhaden locations were determined primarily from spotter aircraft and fishing vessel reports, along with selected locations where no fish schools were observed during the entire main day of the mission. These locations were translated into the LANDSAT coordinate reference system and radiance data were extracted from the computer compatible tapes (CCT). For some classifications, a time restriction was imposed on the selection of the training areas, i.e., only fish school locations identified ± 2 hours of LANDSAT coverage were used in the classification. The time edit eliminated possible errors resulting from rapidly changing oceanographic conditions and presumably concurrent changes in fish distribution. Statistics (means and standard deviations) for each training area were computed for radiance values from individual pixels. The nominal

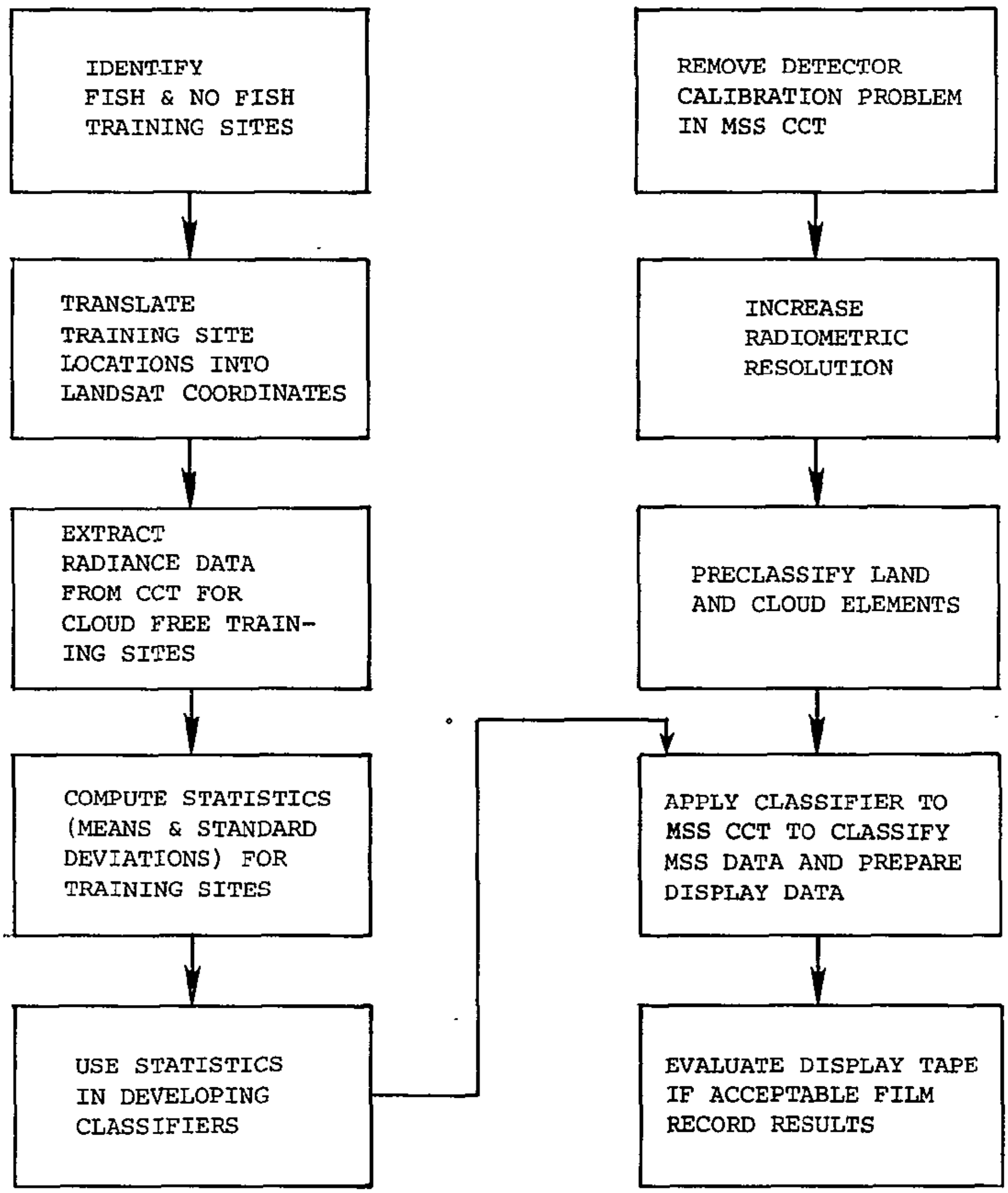

Figure 10-14. MSS Data Processing

Table 10-20. Correlation Coefficients for the Relationship of Menhaden Distribution to LANDSAT Spectral Data (1975)

MSS BAND	LOUISIANA	MISSISSIPPI SOUND	
	July 24	May 20	June 25
B4	0.416**	0.647**	0.461*
B5	0.356*	0.741**	0.822**
B6	0.282*	0.666**	0.685**
B7	0.200	0.607**	0.300*
Sample Size	33	36	18

*Significant at 90 percent confidence level
**Significant at 99 percent confidence level

Table 10-21. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for July 24, 1975, (Louisiana)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS
B4	0.0384
B5	0.1398
B6	-0.3059
B7	0.2422
Intercept	-0.7134
Correlation Coefficient	0.5941
F-Value	3.8835
Degrees of Freedom	4/28
Significance Level	90
Order of Selection	B4, B6, B5, B7
Percent Classified Correctly	73%

Table 10-22. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for May 20, 1975, (Louisiana)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS
B4	-0.0287
B5	0.3116
B6	0.2888
B7	0.5545
Intercept	-2.7863
Correlation Coefficient	0.762
F-Value	10.719
Degrees of Freedom	4/31
Significance Level	97.5
Order of Selection	B5, B6, B7, B4
Percent Classified Correctly	86%

Table 10-23. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for June 25, 1975, (Mississippi Sound)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS
B4	-0.2082
B5	0.3729
B6	-0.1382
B7	0.1902
Intercept	-0.3123
Correlation Coefficient	0.8939
F-Value	12.921
Degrees of Freedom	4/13
Significance Level	97.5
Order of Selection	B5, B4, B6, B7
Percent Classified Correctly	100%

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size of a training sample was 144 pixels (12 x 12). The statistics were used to aid in the development of MSS data classifiers.

In parallel with development of training area data, errors in the CCT's caused by an inconsistent calibration of the six detectors in each band were removed and radiometric resolution of the data was improved. Radiometric improvement resulted from averaging each band over a 6 scan line by 8 element wide matrix and multiplying the averages by 4. This process increased the radiometric range from 0 to 63 to 0 to 252. The sacrifice in spatial resolution probably was not critical as water features tend to be relatively consistent over large areas. During the preprocessing, land and cloud pixels were identified by higher reflectance in the infrared band, and were assigned a value of 255. The resulting MSS data were classified and stored on disc or tape. The file was color film recorded when found to be acceptable.

Basic MSS data processing procedures, except development and application of classifiers, remained consistent for all classification efforts. Major differences were in development, application, and evaluation of the different classifiers. These classifiers included multiple regression, discriminant function, and pattern recognition (Parallelepiped, ELLTAB and a maximum likelihood classifier). Each technique and corresponding results are discussed in the following sections.

10.4.2.2.1 Parallelepiped Classifiers

The first classifier used to process LANDSAT MSS data was a parallelepiped classifier depicted in three dimensions in Figure 10-15. The upper and lower limits for each MSS band for the May 20 data were established for menhaden training areas as the mean value for each MSS band, plus or minus one standard deviation (Table 10-24). LANDSAT MSS digital data from May 20, 1975, were classified into high and low probability fishing areas with the classifier (Figure 10-16). Twenty-five menhaden school locations fell within or immediately adjacent to areas classified as high probability fishing areas, four did not. Nineteen additional schools had been located on the day of the mission, but outside the $\pm$ 2 hour time window from LANDSAT overpass. Of these, 16 fell within or immediately adjacent to the high probability fishing areas, with three falling into the low probability area. In general, the classifier worked well except for several school locations in the right-center portion of the figure. These exceptions probably were due to cloud contamination of pixels.

Data acquired during the 1972 ERTS-1 menhaden experiment were analyzed similarly. Menhaden school positions, however, were not precise because they had been recorded on a 0.8 km reference grid. Analysis of these data resulted in classification of almost the entire western portion of the Mississippi Sound as a high probability fishing area. The approach was modified slightly when a statistical analysis indicated the standard deviation of all individual pixels comprising the training set included a high spatial frequency noise resulting from miscalibration of the six MSS detectors. This noise subsequently was eliminated by additional processing. Limits of the classification range were established as the mean of all points within the training set, plus or minus the standard deviation of the means of the individual training sites. Table 10-24 shows both sets of limits for comparison purposes. The new classification was more acceptable, with about 15 percent of the Sound classified into high probability fishing areas. The resulting classification was not film recorded.

The parallelepiped method also was used for the June 25, 1975, supplementary mission in the Mississippi Sound (Figure 10-17). This mission was selected because of relatively little cloud coverage and good fishing data. Twelve fish school locations

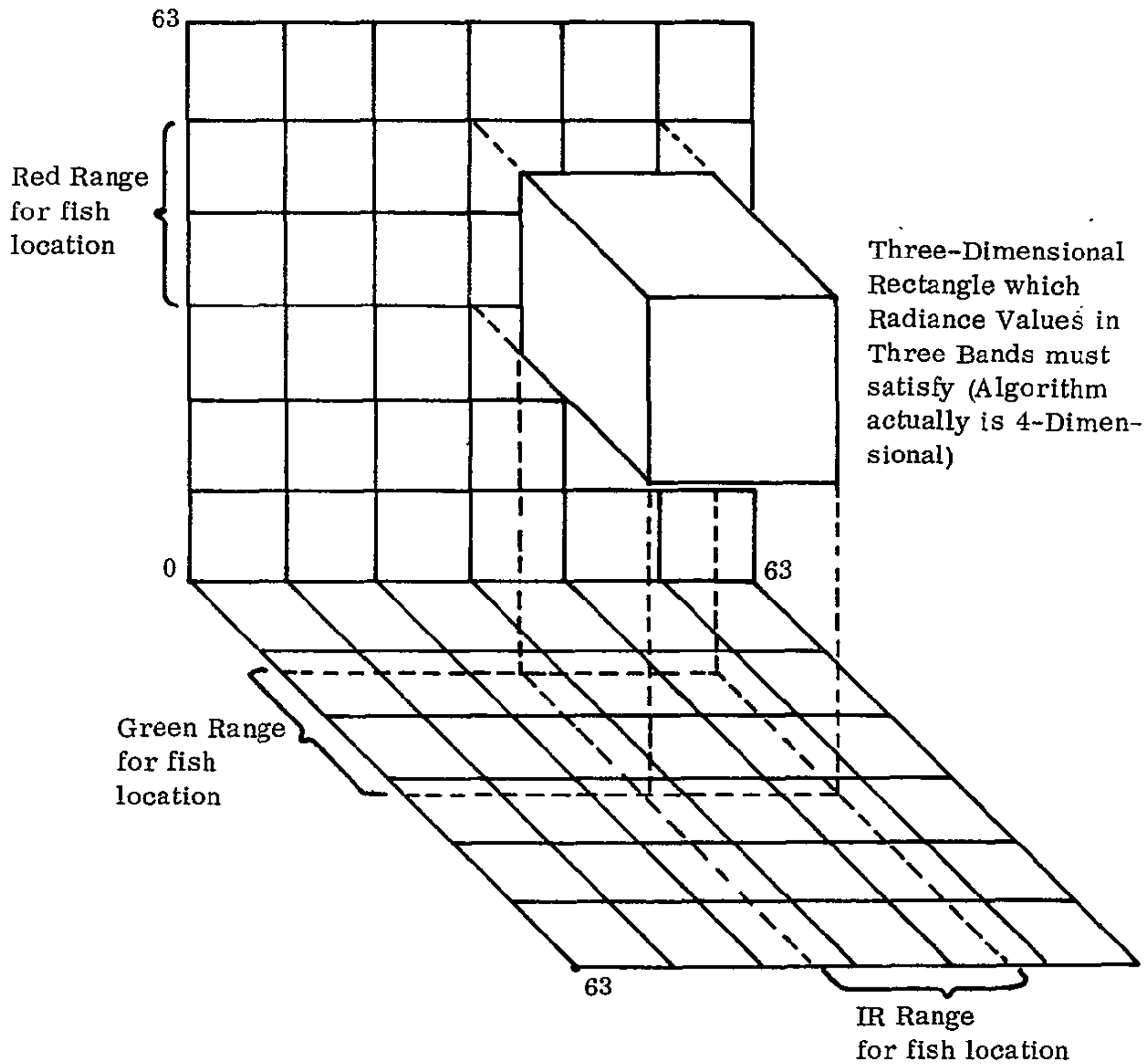

Figure 10-15. Conceptualization of Computer Parallelepiped Classification Algorithm

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OF POOR QUALITY

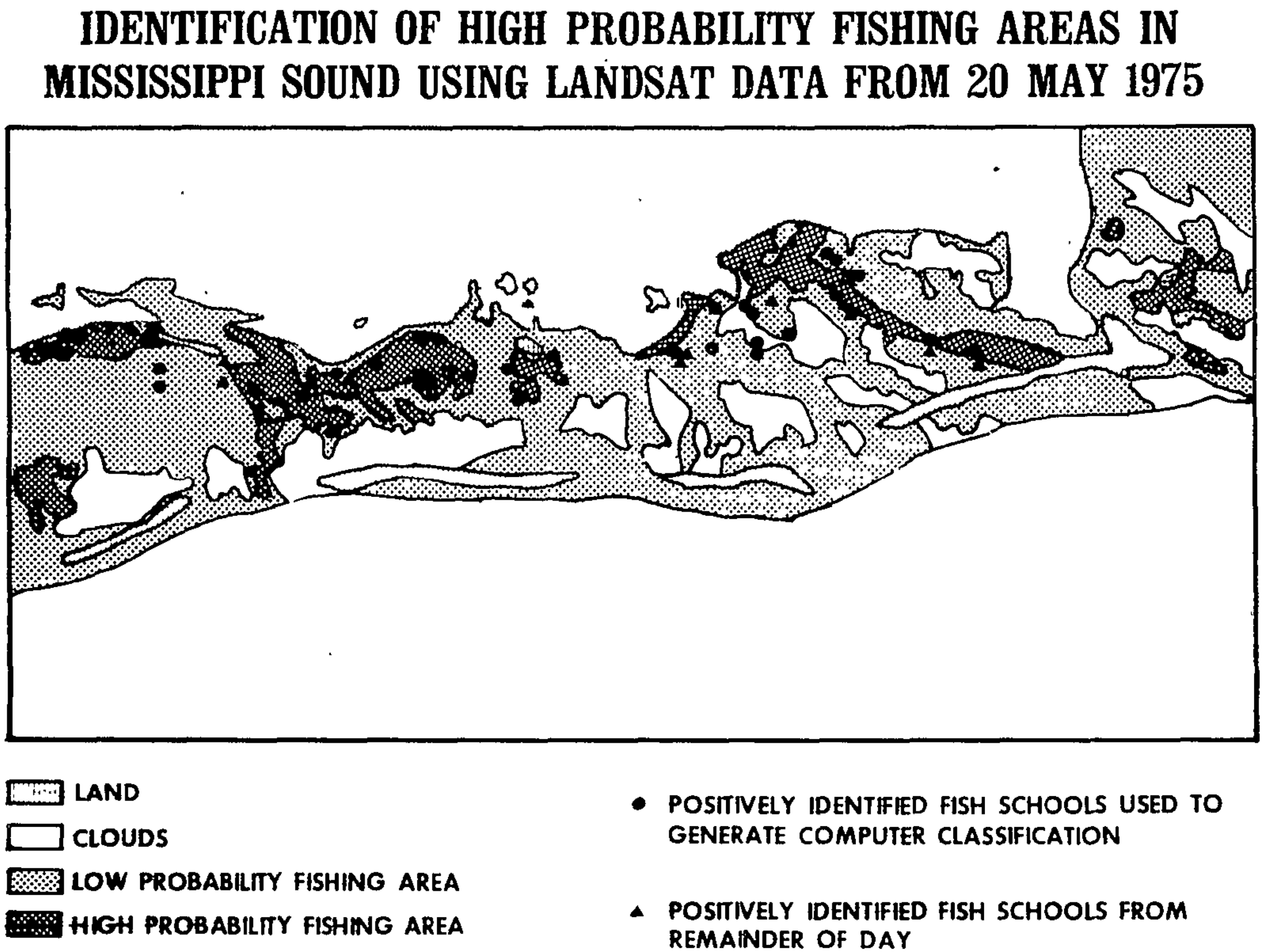

Figure 10-16. A Parallelepiped Classification of LANDSAT MSS Data from May 20, 1975

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Figure 10-17. A Parallelepiped Classification of LANDSAT MSS Data from June 25, 1975, (Mississippi Sound)

25 JUNE 1975

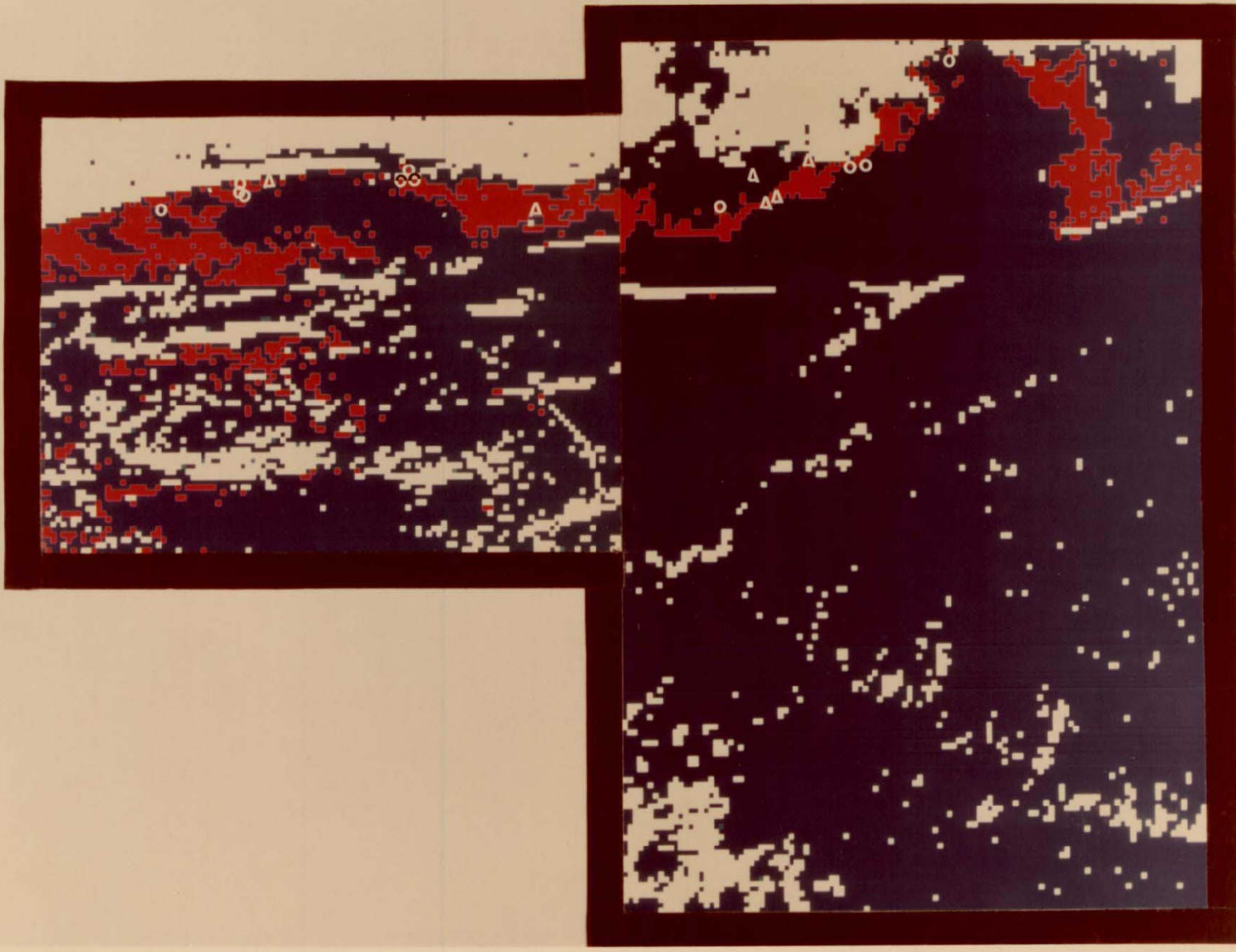

Table 10-24. Parallelepiped Classification Limits

May 20, 1975								
	Band 4		Band 5		Band 6		Band 7	
	Low	High	Low	High	Low	High	Low	High
A	95	108	84	97	45	58	4	10
B	95	108	84	97	46	57	6	9
August 7, 1972								
	Band 4		Band 5		Band 6		Band 7	
	Low	High	Low	High	Low	High	Low	High
A	120	128	81	90	48	55	11	16
B	122	126	83	88	59	53	13	14

A: mean plus or minus standard deviation of entire class grouping

B: mean plus or minus standard deviation of means of individual sets within each class grouping

were used to develop the classifier algorithm and 18 for testing. Twenty-six of the total menhaden locations (30) classified correctly for an accuracy of 87 percent.

An initial attempt to apply the single class parallelepiped classifier technique to July 24, 1975, data from the Louisiana study area was relatively unsuccessful (Figure 10-18). Most menhaden school locations failed to fall into high probability fishing areas. Additional analyses revealed there were three or four unique spectral signatures associated with the fish school areas which would have to be considered in classification algorithms.

10.4.2.2.2 Multiple Regression Classifiers and Results

Multiple regression models derived from MSS data for the Mississippi Sound were developed and used to classify May 20, 1975, MSS data. The first model was developed based on linear combinations of the four MSS bands:

$$Z = 2.7863 - 0.0287\ B4 + 0.3116\ B5 + 0.2888\ B6 + 0.5545\ B7$$

If Z exceeded 0.5, the pixel was classified as a high probability fish area; if Z was less than 0.5 the pixel was classified as a low probability fish area. Results from the classification are shown in Figure 10-19. Approximately 85 percent of the 36 training locations for fish and no-fish areas classified correctly. However, most of the water classified as high probability fishing areas.

A non-linear model was used unsuccessfully to significantly reduce the number of pixels classified as high probability fishing areas. All combinations of the independent variables and powers up to the fourth power were computed for the 36 fishing areas. Results are shown in Table 10-25 and a classified image in Figure 10-20.

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Figure 10-18. A Parallelepiped Classification of LANDSAT MSS Data from July 24, 1975, (Louisiana)

24 JULY 1975

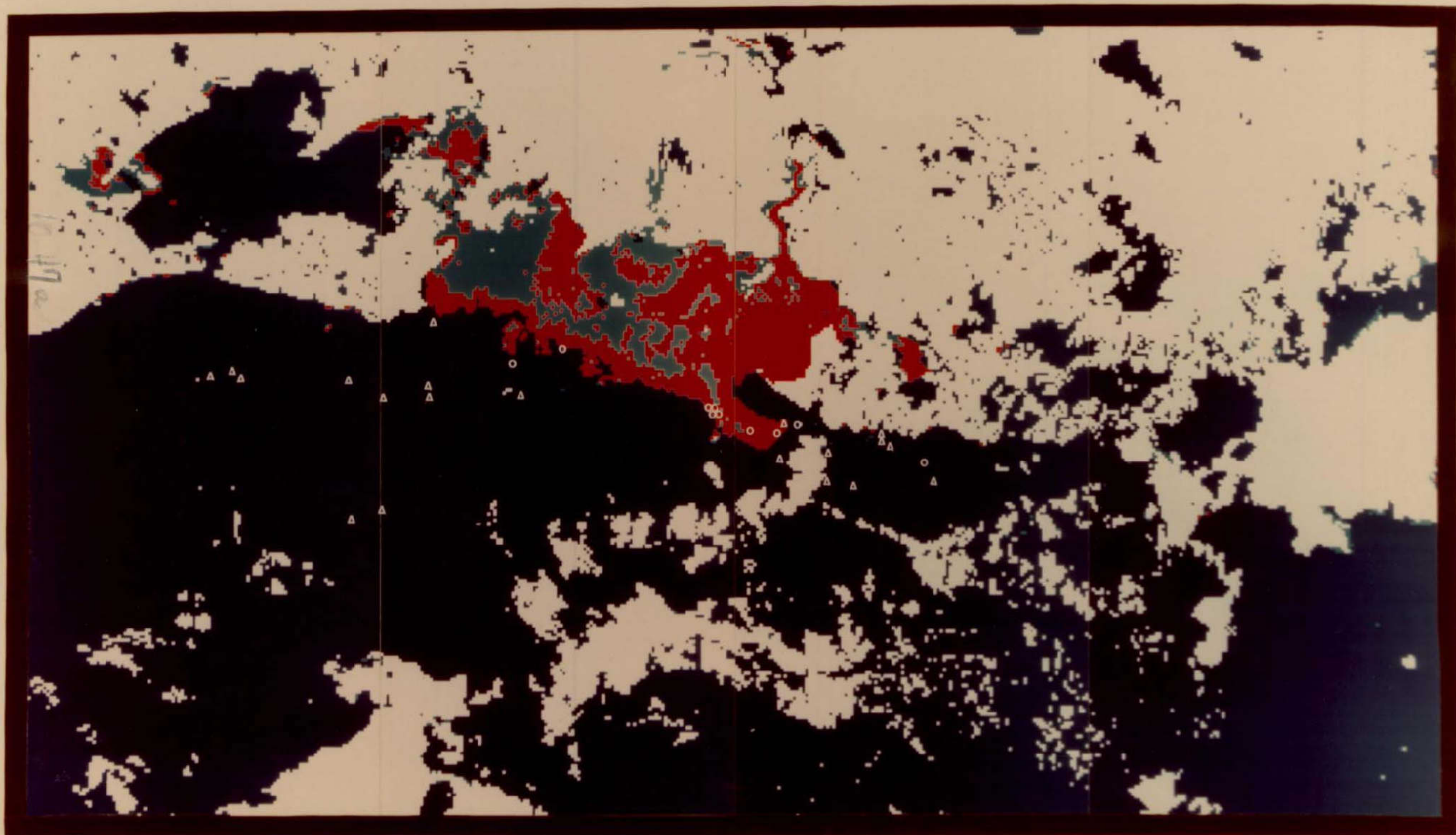

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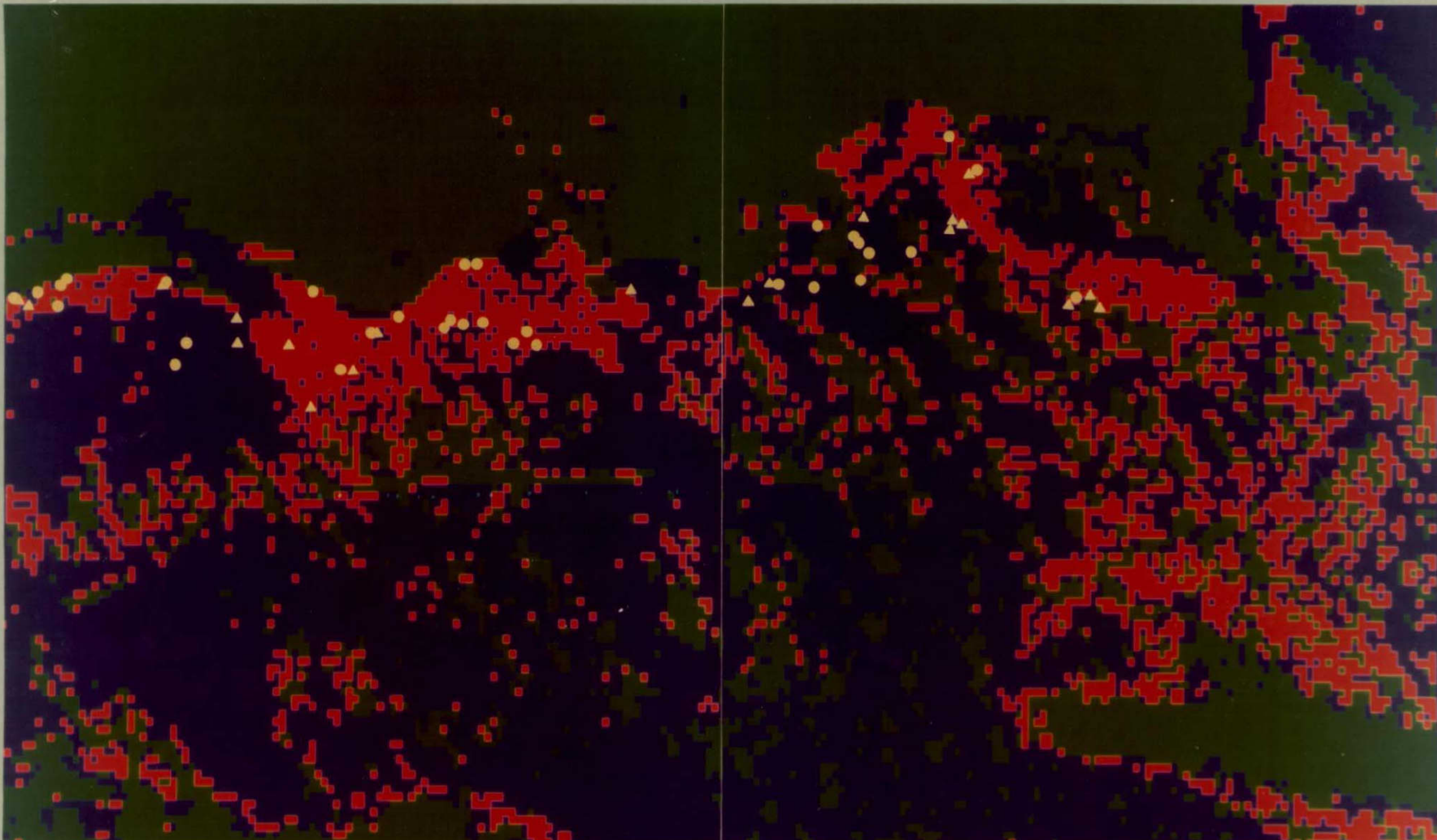
Figure 10-19. Classification of May 20, 1975, MSS Data Using Linear Multiple Regression Model (Mississippi Sound)

PREDICTED HIGH PROBABILITY FISHING LOCATIONS USING LANDSAT DATA FROM 20 MAY 1975
LINEAR MULTIPLE REGRESSION CLASSIFIER



LAND AND CLOUDS

WATER

PREDICTED HIGH PROBABILITY FISHING AREAS

FISH SCHOOL LOCATIONS USED FOR TRAINING

FISH SCHOOL LOCATIONS FOR REMAINDER OF DAY

COLOR PHOTOGRAPH

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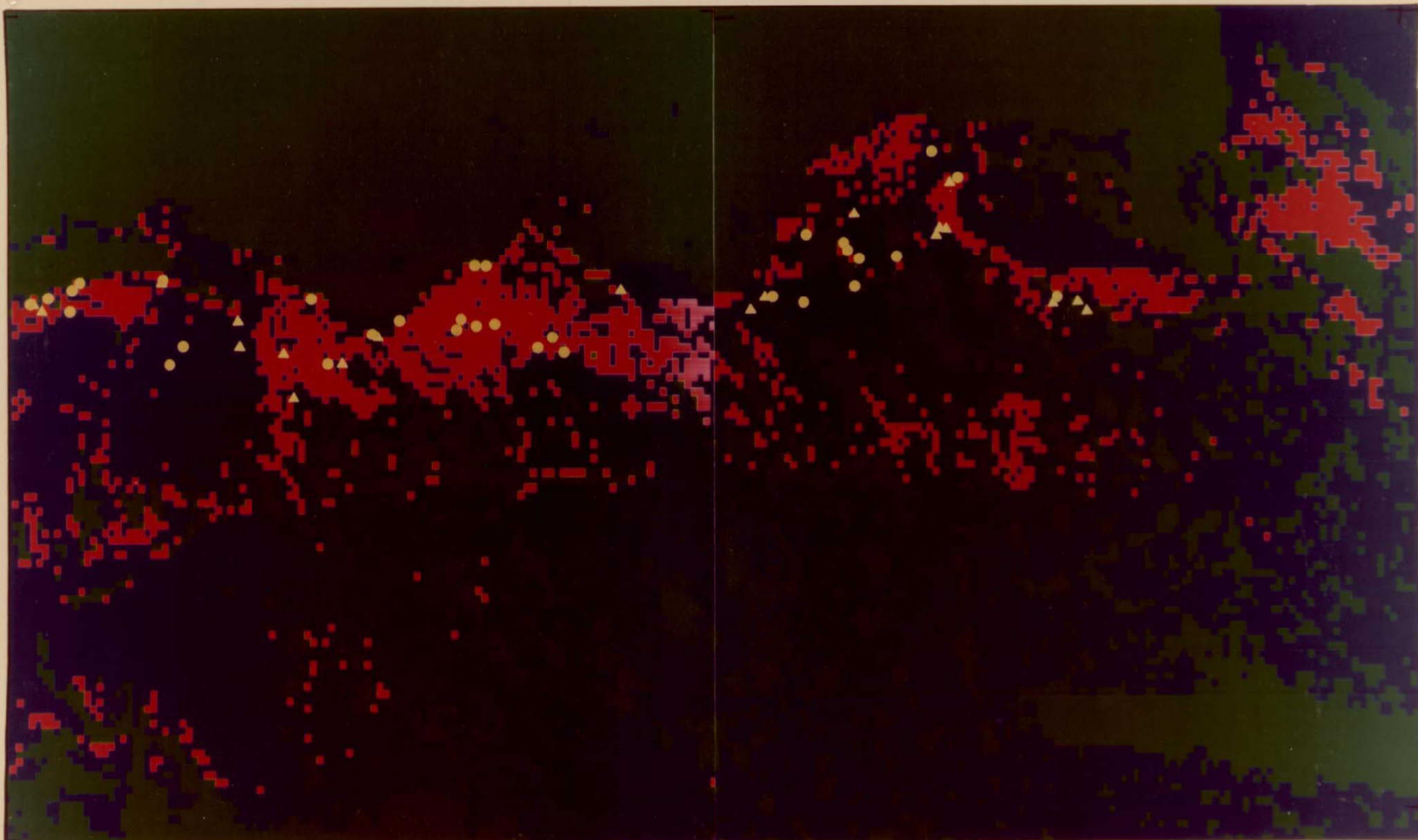
Figure 10-20. Classification of May 20, 1975, MSS Data With a Non-Linear Multiple Regression Model (Mississippi Sound)

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 20 MAY 1975
NON-LINEAR REGRESSION CLASSIFIER



LAND AND CLOUDS

WATER

PREDICTED HIGH PROBABILITY FISHING AREAS

● FISH SCHOOL LOCATIONS USED FOR TRAINING

▲ FISH SCHOOL LOCATIONS FOR REMAINDER OF DAY

Table 10-25. Summary of Step-Wise Multiple Regression Analysis of LANDSAT MSS Spectral Data for May 20, 1975, Using Linear and Non-linear Terms (Mississippi Sound)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENT
B5	0.3041
B7	8.1047
$(B6)^2$	-0.0620
$(B7)^2$	-2.2694
$(B6)^3$	0.0002
Intercept	-7.6555
Correlation Coefficient	0.808
F-Value	11.281
Degrees of Freedom	5/30
Significance Level	99%
Order of Selection	B5, B7, $(B6)^2$, $(B7)^2$, $(B6)^3$
Percent Classified Correctly	95%

10.4.2.2.3 Pattern Recognition Classifiers and Results

The standard pattern recognition technique used at ERL is a table look-up implementation of a maximum likelihood classifier known as ELLTAB (Jones 1974). LANDSAT data from July 24, 1975, (Louisiana study area) were processed with this classifier and results compared to those obtained with a discriminant function classification (discussed in the next section). More of the scene classified as high probability fishing areas with the ELLTAB classification, but manipulation of *a priori* probabilities and thresholds permitted reduction of these areas to approximately 15 percent of the total water scene. The resulting classification was not film recorded.

Because the ELLTAB computer routine has very rigid input requirements and requires several iterations to converge on an acceptable classification, a simpler likelihood classifier was investigated. This classifier was a modification of Purdue's maximum likelihood classifier which is used by ERL. Results were almost identical to those provided by ELLTAB. The resulting classification was not film recorded.

Results show that pattern recognition classifiers such as ELLTAB and the modified Purdue Maximum Likelihood Classifier can be used to classify LANDSAT MSS data for fishery applications even with multiple fish signature training areas. Iterations of the classifications, however, are required to converge on an acceptable product.

10.4.2.2.4 Discriminant Function Classifiers and Results

In parallel with pattern recognition software testing, a discriminant function technique was investigated to determine if multiple fish signature data from July 24, 1975, could be classified better than with the other techniques. A group of discriminant function classifiers were developed for menhaden. Training sample data are shown in Table 10-26.

The classifiers were developed using a discriminant function routine from the Beechcraft (BMD) Programs (Dixon, 1964). Classification functions for the July 24, 1975, MSS data are shown in Table 10-27.

MSS data from the four spectral bands were evaluated by each of the six functions for all pixels which had not been preclassified as land or clouds. Pixels initially were assigned to the with or without-fish classes depending upon which function maximized the absolute values, and then classified into high or low probability fishing pixels depending upon whether or not they fell within plus or minus two standard deviations of the mean radiance values computed from all training areas. Limits for the with-fish classes are given in Table 10-28. The discriminant function classified 27 of 33 training samples correctly for an accuracy of 82 percent. The resulting classification for the July 24, 1975, MSS data is shown in Figure 10-21.

A second set of discriminant function classifiers was developed for the June 25, 1975, MSS data from the Mississippi study area. Training sample data sets consisted of one fish class and one no-fish class (Table 10-29). Classification functions are shown in Table 10-30.

The MSS data for June 25, 1975, were processed following the same procedures described previously. Means and two standard deviation limits for MSS data are shown in Table 10-31.

The discriminant function classified 18 out of 18 training samples correctly. The resulting classification for the June 25, 1975, MSS data is shown in Figure 10-22.

A third set of discriminant function classifiers were developed for the May 20, 1975, MSS data taken over the Mississippi study area. Training sample data sets consisted of three classes of fish data and two classes of no-fish data (Table 10-32). Classification functions derived with the five training data sets are shown in Table 10-33 and the means and standard deviations are presented in Table 10-34.

The discriminant function classified 33 out of 42 training samples correctly for an accuracy of 79 percent (Figure 10-23). The discriminant function technique produced satisfactory results for classification of water masses into high and low probability menhaden areas.

10.4.2.3 Comparisons

Because the discriminant function classifier proved to be an effective way to infer high probability fishing areas on the day of satellite coverage, an attempt was made to determine if the same classification could be used to predict fish school locations for the day following satellite coverage. Fish school locations were determined for the day following each of the classified main days (i.e., July 24, June 25, and May 20, 1975). These locations were converted to LANDSAT coordinates and plotted as overlays on the classified images.

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Figure 10-21. Discriminant Function Classification of July 24, 1975, LANDSAT MSS Data (Louisiana)

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 24 JULY 1975
DISCRIMINANT FUNCTION CLASSIFIER

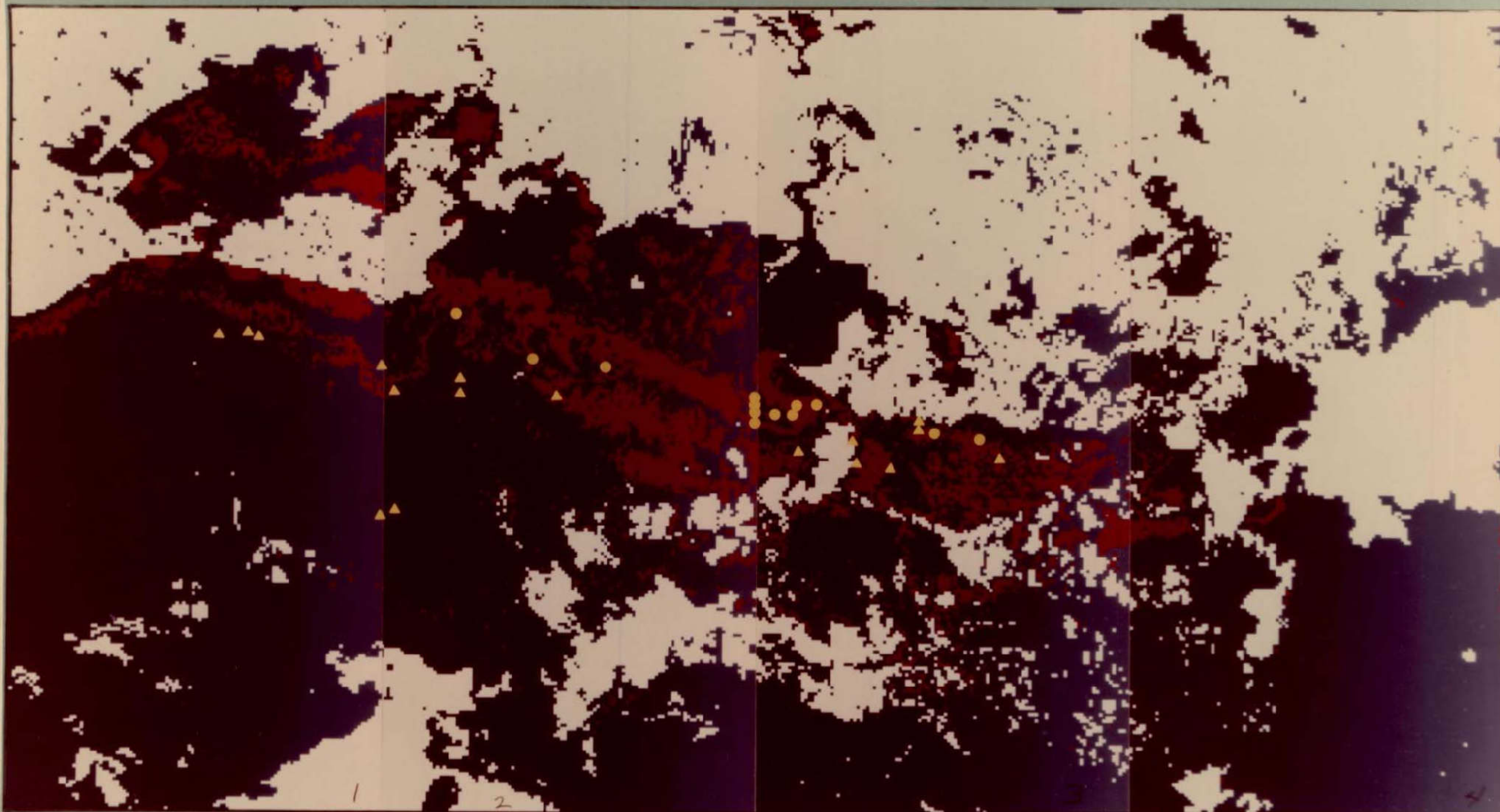

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Figure 10-22. Discriminant Function Classification for June 25, 1975, MSS Data (Mississippi Sound)

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 25 JUNE 1975

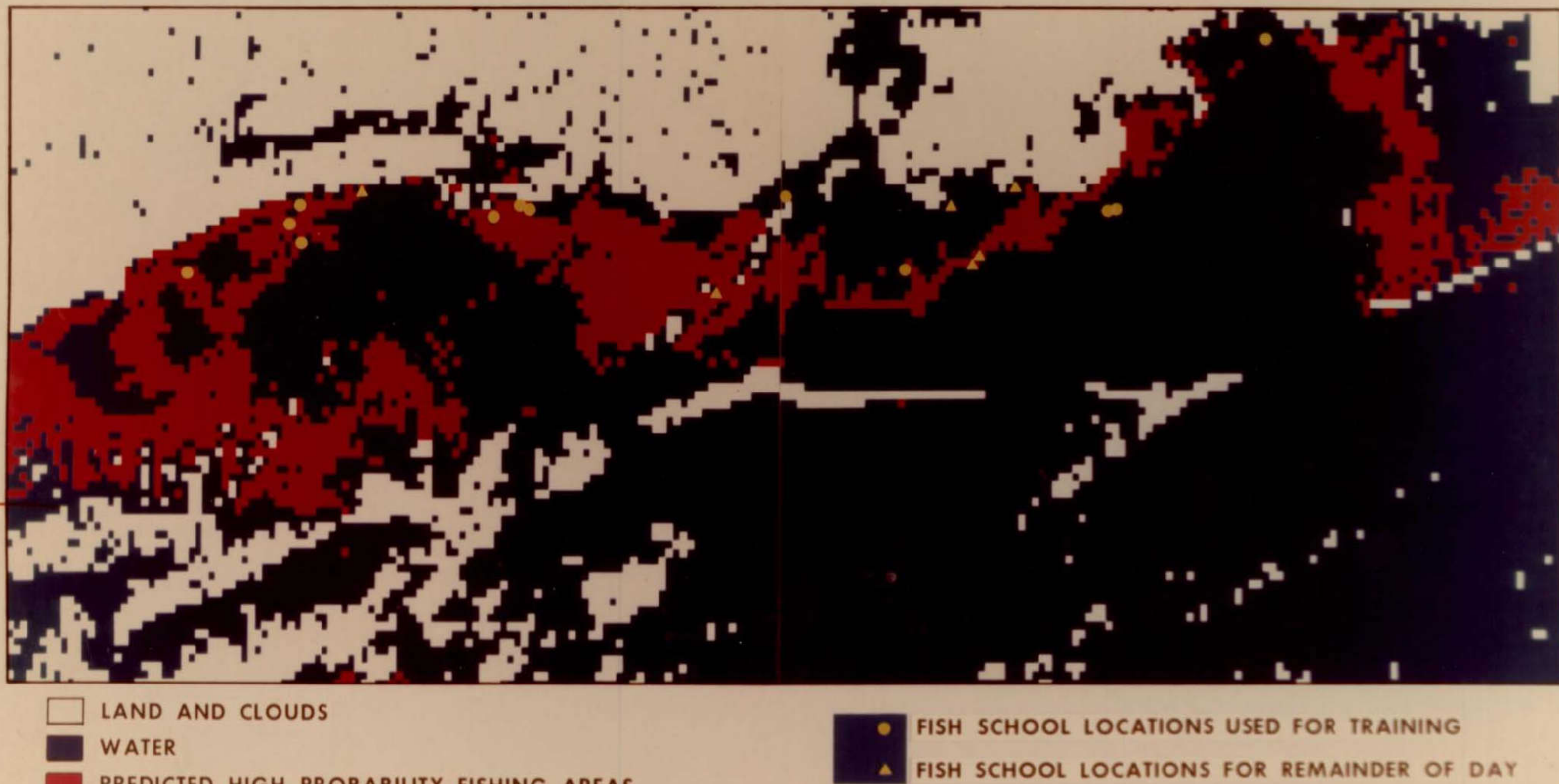

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Figure 10-23. Discriminant Function Classification for May 20, 1975, MSS Data (Mississippi Sound)

IDENTIFICATION OF HIGH PROBABILITY FISHING AREAS IN MISSISSIPPI SOUND USING LANDSAT DATA FROM 20 MAY 1975

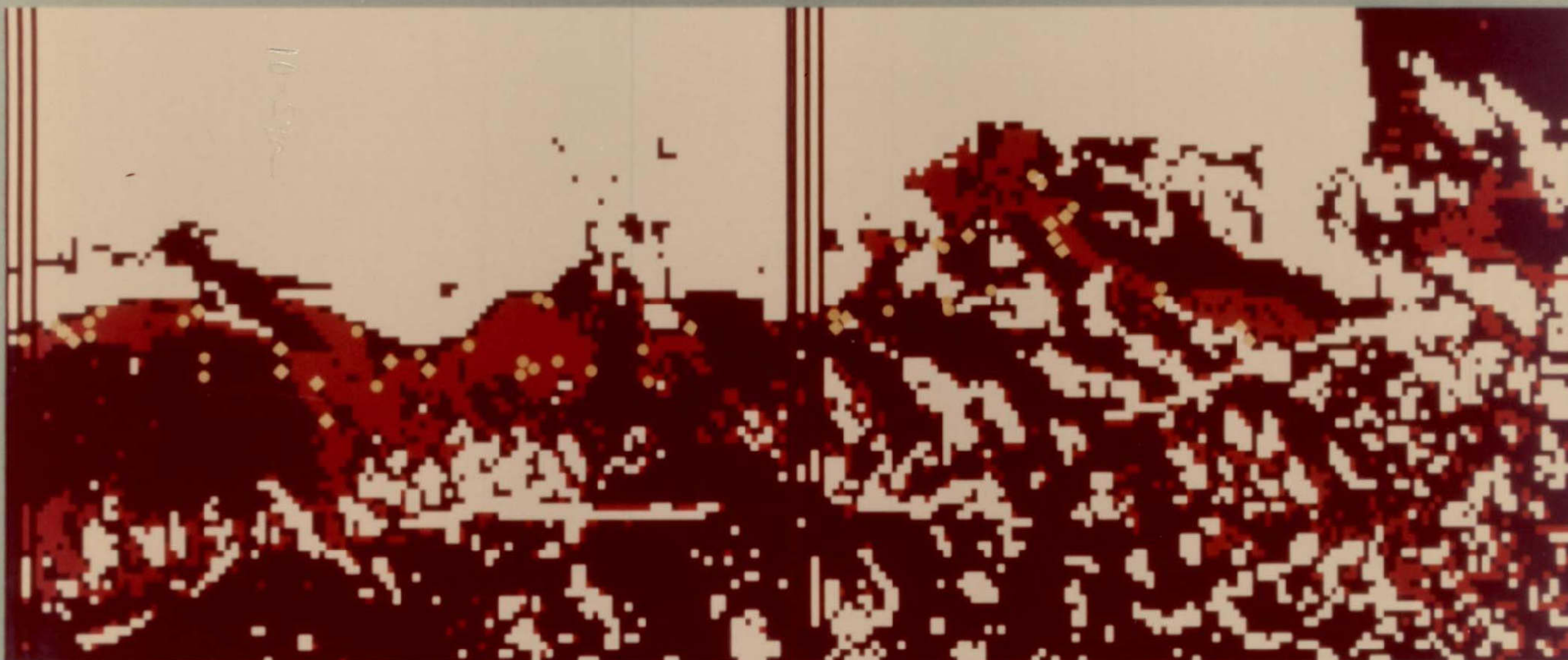

Table 10-26. MSS Training Field Radiance Data for July 24, 1975, (Louisiana) (Mean Value in Counts)

CLASS	TRAINING SITE NUMBER	MSS BAND B4	B5	B6	B7
FISH 1	1	36.400	29.800	14.100	1.500
	2	33.400	23.400	11.200	1.400
	3	37.500	32.500	15.700	1.900
	4	36.400	31.000	14.800	2.100
	5	32.700	25.000	11.500	1.300
FISH 2	6	38.200	35.900	19.200	2.400
	7	37.700	36.400	19.900	3.000
	8	37.800	36.400	20.000	3.200
	9	37.700	36.100	19.500	3.100
FISH 3	10	25.900	15.500	8.500	1.200
	11	28.000	16.600	8.200	.900
	12	28.600	19.200	9.200	1.100
	13	27.300	15.000	7.300	.900
NO-FISH 1	14	38.000	35.400	19.000	2.500
	15	37.800	35.900	20.000	3.100
	16	38.400	37.100	21.200	3.500
	17	39.100	37.200	21.800	3.700
	18	40.600	39.000	21.000	3.100
NO-FISH 2	19	28.900	18.500	8.900	1.000
	20	32.400	23.500	12.200	1.600
	21	25.500	15.000	8.100	.900
	22	29.700	19.500	9.000	1.000
	23	27.100	16.700	7.000	.900
NO-FISH 3	24	20.600	10.100	5.900	.800
	25	21.300	10.700	6.200	.900
	26	23.700	12.700	6.600	.600
	27	21.900	11.300	6.700	1.000
	28	24.400	13.000	6.600	.900
	29	24.300	12.800	6.400	.800
	30	21.500	12.500	6.400	.800
	31	21.500	10.100	4.800	.500
	32	20.500	9.700	4.700	.600
	33	21.100	10.200	5.100	.700

Table 10-27. Discriminant Function Classifiers for July 24, 1975, MSS Data (Louisiana)

CLASS	INTERCEPT	MSS COEFFICIENTS			
		B4	B5	B6	B7
Fish 1	-364.910	35.184	-21.734	6.028	12.039
Fish 2	-357.700	31.023	-21.964	16.392	3.605
Fish 3	-321.207	35.732	-25.870	8.995	11.826
No-Fish 1	-388.437	32.467	-24.176	19.185	3.653
No-Fish 2	-322.447	35.338	-25.144	9.218	9.515
No-Fish 3	-247.410	31.887	-24.275	9.033	10.605

Table 10-28. Mean ($\bar{x}$) and Two Standard Deviations (2s) for July 24, 1975, MSS Data (Louisiana)

CLASS	MSS BAND ($\bar{x} \pm 2s$)			
	B4	B5	B6	B7
Fish 1	35.280±4.198	28.340±7.878	13.460±4.020	1.640±0.688
Fish 2	37.850±0.476	36.200±0.490	19.650±0.738	2.925±0.718
Fish 3	27.450±2.324	16.575±3.746	8.300±1.574	1.025±0.300
No-Fish 1	38.780±2.264	36.920±2.790	20.600±2.210	3.180±0.920
No-Fish 2	28.720±5.246	18.640±6.434	9.200±3.508	1.080±0.590
No-Fish 3	22.080±2.974	11.310±2.628	5.940±1.562	0.760±0.316

Table 10-29. MSS Training Field Radiance Data for June 25, 1975, (Mississippi Sound) (Mean Value in Counts)

CLASS	TRAINING SITE NUMBER	MSS BAND			
		B4	B5	B6	B7
Fish	1	22.8	18.6	10.0	0.8
	2	22.4	19.4	10.0	0.9
	3	21.5	18.5	9.8	0.5
	4	22.3	18.3	9.3	0.5
	5	22.7	19.0	9.2	0.7
	6	23.2	19.6	10.1	0.9
	7	23.1	19.4	9.8	0.8
	8	25.1	22.0	12.1	1.4
	9	25.9	20.9	11.1	1.4
No-Fish	1	19.7	15.1	8.0	0.4
	2	21.8	17.1	8.4	0.5
	3	22.9	17.3	8.7	0.6
	4	24.0	17.4	10.1	1.1
	5	21.6	15.4	8.4	0.9
	6	21.2	14.8	7.9	0.7
	7	21.5	15.1	7.9	0.5
	8	21.5	15.3	8.2	0.9
	9	23.1	18.0	9.9	0.9

Table 10-30. Discriminant Function Classifiers for June 25, 1975, MSS Data (Mississippi Sound)

FUNCTION	INTERCEPT	MSS BAND COEFFICIENTS			
		B4	B5	B6	B7
Fish	-361.284	36.024	-8.139	17.353	-149.284
No-Fish	-346.914	39.707	-14.737	19.798	-152.649

Table 10-31. Mean ($\overline{x}$) and Two Standard Deviation (2s) Limits for June 25, 1975, MSS Data (Mississippi Sound)

CLASS	MSS BAND ($\overline{x} \pm 2s$)			
	B4	B5	B6	B7
Fish	23.222±2.798	19.522±2.422	10.156±1.818	0.889±0.636
No-Fish	21.922±2.510	16.167±2.502	8.611±1.662	0.722±0.478

Table 10-32. May 20, 1975, MSS Training Radiance Data (Mississippi Sound) (Mean Value in Counts)

CLASS	TRAINING SITE NUMBER	MSS BAND			
		B4	B5	B6	B7
Fish 1	1	26.700	22.800	13.500	2.100
	2	27.500	23.900	14.100	2.200
	3	28.200	25.500	16.800	2.900
	4	26.400	22.100	11.800	1.400
	5	26.600	23.800	14.100	2.300
	6	26.200	21.800	12.400	2.000
	7	25.800	23.500	13.400	2.200
	8	26.800	24.500	14.600	2.300
	9	23.900	22.700	14.000	2.000
	10	24.100	22.000	12.400	1.600
	11	24.800	22.500	12.700	1.900
	12	26.900	23.100	12.400	1.600
	13	27.200	23.000	12.200	1.400
Fish 2	14	25.100	21.000	11.500	1.500
	15	23.400	21.300	11.700	1.500
	16	23.200	20.400	11.200	1.600
	17	24.400	20.800	12.000	1.500
	18	22.600	19.000	11.400	1.700
	19	23.500	19.900	11.700	1.700
Fish 3	20	22.300	17.800	10.100	1.300
	21	22.600	17.900	10.200	1.400
	22	22.000	18.000	10.400	1.500
No-Fish 1	23	22.600	18.300	10.500	1.400
	24	22.800	18.400	10.400	1.400
	25	22.500	18.000	9.900	1.200
	26	23.400	18.800	10.200	1.200
	27	21.200	18.900	11.100	1.400
	28	22.000	19.600	11.400	1.300
	29	22.900	18.100	9.700	1.200
	30	22.300	18.700	10.600	1.500
	31	22.600	19.000	10.500	1.200
	32	22.300	17.900	9.900	1.200
	33	22.200	17.700	10.300	1.400
	34	22.600	18.600	10.500	1.300
No-Fish 2	35	25.800	21.400	12.200	2.000
	36	23.300	21.800	12.200	1.400
	37	23.000	21.700	12.200	1.500
	38	25.900	20.900	11.600	1.300
	39	25.500	21.000	11.500	1.300
	40	26.400	22.000	12.200	1.800
	41	24.400	20.200	11.600	1.800
	42	26.300	21.900	12.000	1.500

Table 10-33. Discriminant Function Classifiers for May 20, 1975, MSS Data (Mississippi Sound)

FUNCTION	INTERCEPT	MSS BAND COEFFICIENTS			
		B4	B5	B6	B7
Fish 1	-574.236	14.035	40.896	-10.496	-14.917
Fish 2	-457.847	13.254	35.096	-7.564	-18.936
Fish 3	-371.369	13.704	28.025	-3.668	-21.548
No Fish 1	-392.164	13.495	29.729	-3.805	-24.589
No Fish 2	-508.748	14.144	39.968	-8.143	-20.886

Table 10-34. Mean ($\bar{x}$) and Two Standard Deviation (2s) Limits for May 20, 1975, MSS Data (Mississippi Sound)

CLASS	MSS BAND ($\bar{x} \pm 2s$)			
	B4	B5	B6	B7
Fish 1	26.238±2.568	23.169±2.118	13.415±2.698	1.992±0.842
Fish 2	23.700±1.798	20.400±1.682	11.583±0.558	1.583±0.196
Fish 3	22.300±0.600	17.900±0.200	10.233±0.306	1.400±0.200
No Fish 1	22.450±1.074	18.500±1.082	10.417±0.972	1.308±0.216
No Fish 2	25.075±2.778	21.363±1.242	11.938±0.632	1.575±0.520

Figure 10-24 shows the locations of fish schools reported for July 25, 1975, superimposed on the July 24, 1975, discriminant function classification. Of the 30 school locations, 26 (84 percent) fell within the predicted high probability areas.

Figure 10-25 shows reported fish school locations on June 26, 1975, superimposed on the June 25, 1975, discriminant function classification. In this instance 17 of the 23 school locations (74 percent) were within the high probability areas. Similarly, an overlay of fish school locations on May 21, 1975, was made for the May 20, 1975, classification. A total of 13 of 19 schools (68 percent) were located in the inferred high probability fishing areas (Figure 10-26).

Results provided encouragement that classifications of high probability fishing areas could be used to predict areas of menhaden concentration 24 hours after satellite coverage. It was not known, however, how persistent classification patterns would be over the time period which led to the pursual of the answer to the question during the extension phase of the investigation.

10.4.2.4 GOES Simulation

The rationale behind the GOES simulation was to determine if this system might be considered operational for providing tactical fishing information. GOES provides

COLOR PHOTOGRAPH

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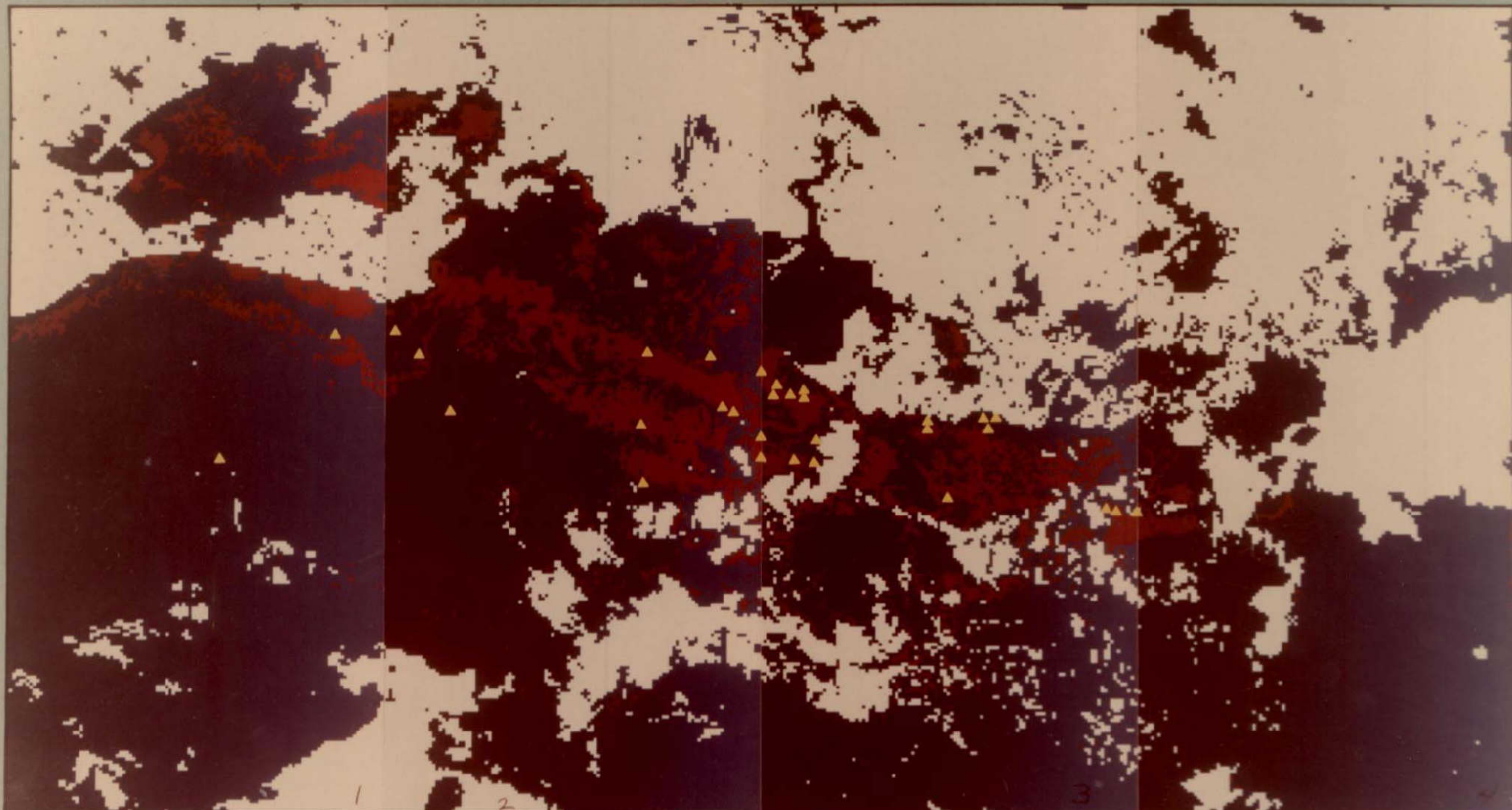
Figure 10-24. Menhaden School Locations Reported on July 25 Superimposed on July 24, 1975, Classified LANDSAT MSS Data (Louisiana)

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 24 JULY 1975
DISCRIMINANT FUNCTION CLASSIFIER



Land and clouds

Water

Predicted high probability fishing areas

▲ Fish school locations on 25 July 1975

COLOR PHOTOGRAPH

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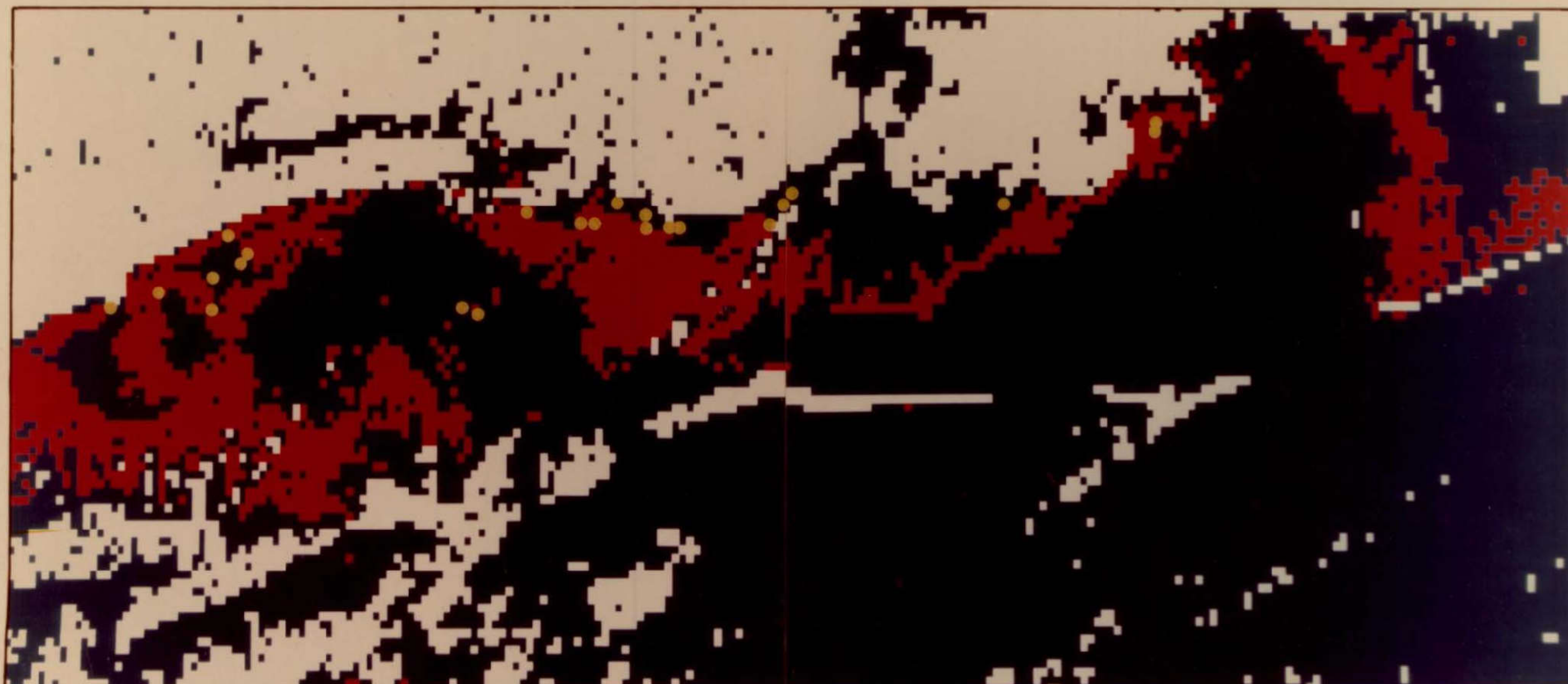
Figure 10-25. Menhaden School Locations Reported on June 26 Superimposed on June 25, 1975, Classified LANDSAT MSS Data (Mississippi Sound)

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 25 JUNE 1975



LAND AND CLOUDS

WATER

PREDICTED HIGH PROBABILITY FISHING AREAS

FISH SCHOOL LOCATIONS ON 26 JUNE

COLOR PHOTOGRAPH

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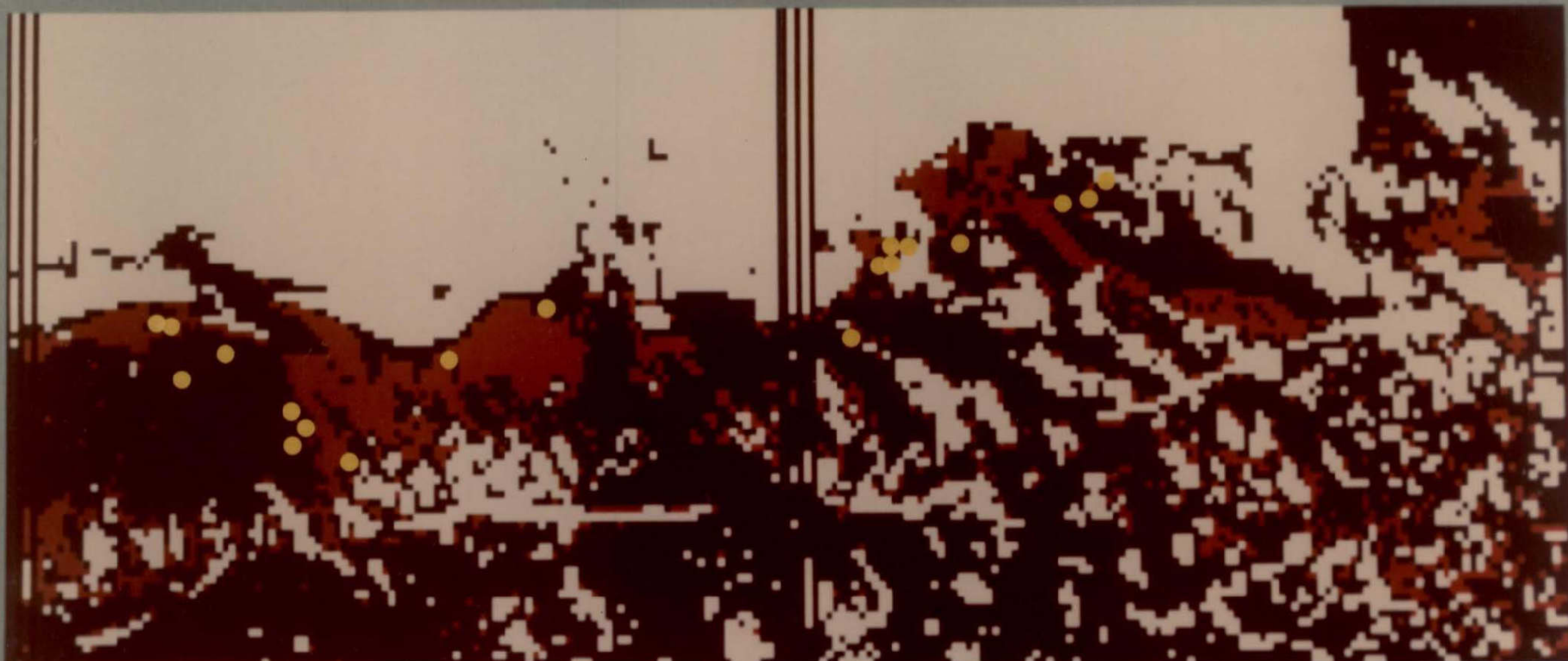
Figure 10-26. Menhaden School Locations on May 21 Superimposed on May 20, 1975, Classified LANDSAT MSS Data (Mississippi Sound)

10-630

IDENTIFICATION OF HIGH PROBABILITY FISHING AREAS IN MISSISSIPPI SOUND USING LANDSAT DATA FROM 20 MAY 1975



Land and Clouds

Water

High Probability Fishing Areas

Fish School Locations on 21 May

repeat coverage every 30 minutes compared to the 18-day LANDSAT coverage cycle.

LANDSAT data for each spectral band and the sum of band 4 and 5 were compared to with- and without-menhaden sample areas through correlation analysis (Table 10-35). The sum of the two bands was used to approximate the spectral response of the GOES system. The summation, however, does not accurately simulate GOES data. It provides a rough approximation because (1) LANDSAT bands 4 and 5 do not cover the exact spectral range of GOES, (2) spectral response curves were not used to adjust the radiance values before summation, and (3) spatial resolution of LANDSAT data was degraded only to about 1/3 of that provided by GOES.

As seen in Table 10-35, the sum of bands 4 and 5 correlated well with menhaden distribution. This area of analysis clearly warrants additional investigation.

Multiple regression models were developed from MSS spectral data for three missions, with all four bands and the sum of bands 4 and 5 (Tables 10-36 to 10-38). Regressior models constructed from the sum of bands 4 and 5 compared favorably with the four band models.

10.4.3 COMBINED CLASSICAL OCEANOGRAPHIC PARAMETER AND REMOTELY SENSED OCEAN COLOR

Correlation with multiple regression analyses were performed on May 20, 1975, on data from the Mississippi Sound to determine if an improved classifier could be developed with combined classical oceanographic and LANDSAT MSS data. Table 10-39 provides a comparison of correlation coefficients for the two data sets and demonstrates that MSS data correlates more precisely with menhaden distribution than the classical oceanographic parameters.

A multiple regression model also was developed from the two data sets (Table 10-40). A slight improvement in model precision was noted over an earlier model developed solely for MSS data, but not enough to warrant the additional parameters.

Table 10-35. Correlation Coefficients for the Relationship of Menhaden Distribution to LANDSAT Spectral Data

MSS BAND	LOUISIANA	MISSISSIPPI SOUND	
	JULY 24	MAY 20	JUNE 25
B4	0.416**	0.647**	0.461*
B5	0.356*	0.741**	0.822**
B6	0.282*	0.666**	0.685**
B7	0.200	0.607**	0.300*
B4 and B5	0.382*	0.703**	0.708**
Sample Size	33	36	18

*Significant at the 90 percent confidence level
**Significant at the 99 percent confidence level

Table 10-36. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for July 24, 1975, (Louisiana)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS	
	4 BAND MODEL	BAND 4 AND 5 MODEL
B4	0.0384	
B5	0.1398	
B6	-0.3059	
B7	0.2422	
B4 and B5		0.1090
Intercept	-0.7134	-0.1813
Correlation Coefficient	0.5941	0.3815
F-Value	3.8835	5.28123
Degrees of Freedom	4/28	1/31
Significance Level	90	60
Order of Selection	B4, B6, B5, B7	B4 and 5
Percent Classified Correctly	73%	70%

Table 10-37. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for May 20, 1975, (Mississippi Sound)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS	
	4 BAND MODEL	BAND 4 AND 5 MODEL
B4	-0.0287	
B5	0.3116	
B6	0.2888	
B7	0.5545	
B4 and B5		0.9147
Intercept	-2.7863	-3.6410
Correlation Coefficient	0.762	0.703
F-Value	10.719	33.184
Degrees of Freedom	4/31	1/34
Significance Level	97.5	80
Order of Selection	B5, B6, B7, B4	B4 and 5
Percent Classified Correctly	86%	81%

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Table 10-38. Summary of Step-Wise Multiple Regression Analyses of LANDSAT MSS Spectral Data for June 25, 1975, (Mississippi Sound)

MSS BAND AND REGRESSION PARAMETER	REGRESSION COEFFICIENTS	
	4 BAND MODEL	BAND 4 AND 5 MODEL
B4	-0.2082	
B5	0.3729	
B6	-0.1382	
B7	0.1902	
B4 and 5		0.10781
Intercept	-0.3123	-3.8573
Correlation Coefficient	0.8939	0.7085
F-Value	12.921	16.123
Degrees of Freedom	4/13	1/16
Significance Level	97.5	75
Order of Selection	B5,B4,B6,B7	B4 and 5
Percent Classified Correctly	100%	83%

Table 10-39. Comparison of Correlation Coefficients for the Relationship of Menhaden Distribution to LANDSAT MSS and Surface Truth Data, May 20, 1975, (Mississippi Sound)

PARAMETERS	CORRELATION COEFFICIENT
MSS Band 4	0.643**
MSS Band 5	0.746**
MSS Band 6	0.676**
MSS Band 7	0.638**
Temperature	-0.101
Forel-Ule Color	0.353*
Salinity	0.097
Secchi Disc	-0.289*
Sample Size	34

*Significant at the 90 percent confidence level
**Significant at the 99 percent confidence level

Table 10-40. Summary of the Step-Wise Multiple Regression Analysis of LANDSAT MSS and Surface Truth Data from May 20, 1975, (Mississippi Sound)

PARAMETER	REGRESSION COEFFICIENT
MSS Band 4	0.0060
MSS Band 5	0.2642
MSS Band 6	-0.3335
MSS Band 7	0.7481
Temperature	-0.0133
Forel-Ule Color	0.0475
Salinity	0.0361
Secchi Disc	-0.0287
Intercept	-3.2169
Correlation Coefficient	0.812
F-Value	6.056
Degrees of Freedom	8/25
Significance Level	99.95
Order of Selection	B5,C5,F,Sa,B7,C6,Se,T,C4

SECTION 11

EXTENSION ANALYSIS AND RESULTS

The analysis and results of the 1976 extension are divided into sections consistent with the two principal objectives: (1) simulation of an operational satellite system to provide tactical information for assessment surveys and commercial harvest of menhaden; and (2) definition of the persistence of LANDSAT inferred high probability fishing areas over a 24-hour period.

11.1 OPERATIONAL SIMULATION

11.1.1 APPROACH

Analysis of water color data acquired by the LANDSAT MSS during the follow-on phase indicated the particular water in which menhaden were most often found could be identified and discriminated from waters which typically did not contain significant numbers of fish. LANDSAT, however, is not designed for real-time applications, and it would be impossible to demonstrate the significance of resource assessment and commercial fishing applications without near real-time dissemination of inferred menhaden distribution patterns. Consequently, special arrangements were made with GSFC to preprocess LANDSAT MSS data immediately upon receipt from the satellite and supply the data to investigators for near real-time processing and analysis. Calibration data for the models used to convert MSS data into a probability chart were provided on the same basis from NFMOA spotter pilots working in the study area and scientific observers aboard selected commercial menhaden vessels.

The first data processing plan (Figure 11-1) identified events, data flow, and schedules for the operational system simulation. Fishing data collected from vessels and aircraft would be used at GSFC to determine if the simulation should be aborted. Fishing data also would be used to identify training samples for LANDSAT MSS data classification into high and low probability fishing areas.

In preparation for the simulation experiment, "dry runs" were made to determine if initial timing schedules for GSFC and Slidell data processing could be attained. The first dry run at GSFC on a test data set took about 5 hours to complete which was within the alloted 6-hour period (Figure 11-1). A second dry run reduced processing time to 3 hours; however, the lack of earlier commercial airline flights to New Orleans prevented improvement in the overall schedule.

On July 10, 1976, the first dry-run of the Slidell portion of the operation was attempted. After 16 hours of processing, about 65 percent of the work was completed. The remaining portion had to be delayed for 3 days due to other hardware commitments. The dry-run took a total of 25 hours to complete which was greatly in excess of the allotted 8-hour period (Figure 11-1). The

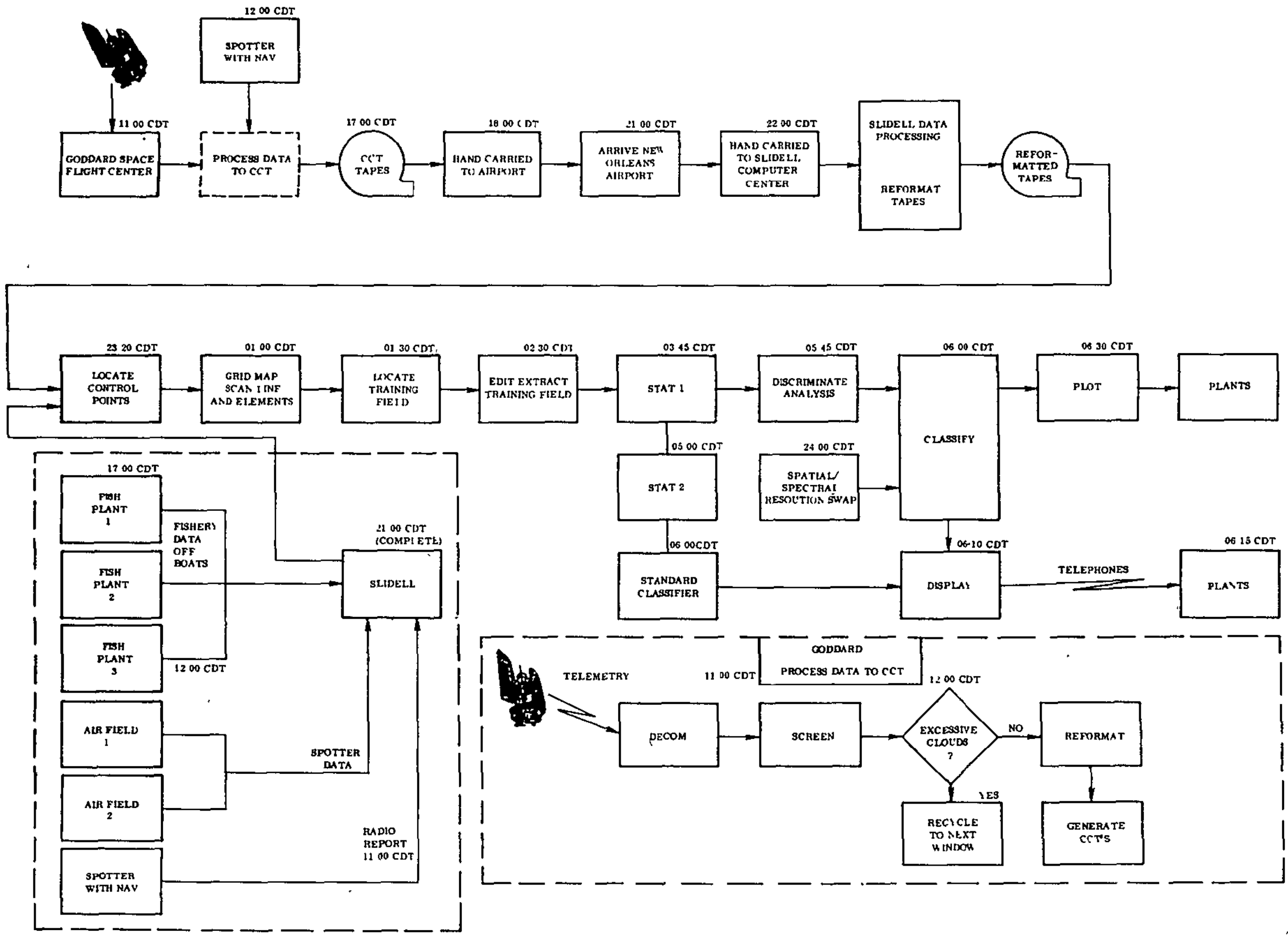

Figure 11-1. Events and Data Flow for Operational System Simulation

most significant problem encountered was image registration (i.e. geographically referencing the pixels). Based on this information, a second processing sequence was developed which, even though more complex, was expected to reduce processing time (Figure 11-2).

A second attempt was initiated to process a set of test data within the allotted time period at Slidell on July 16, 1976. This dry-run required 14 hours to complete. Thus, the new procedure reduced processing time by 11 hours and highlighted problems which, if eliminated, should bring the processing operation to within the allotted time period.

11.1.2 DATA PROCESSING AND ANALYSIS

The day prior to the principal satellite pass (July 19, 1976) scientific observers boarded eight menhaden vessels at ports across western and central Louisiana. The satellite was due to pass over west central Louisiana, covering the area from Sabine Pass to Marsh Island, so vessels expected to be fishing in that area were selected. Two menhaden spotters were made available to the investigation the day before the orbit to determine prime areas for the study and to provide precise fish school location data for the zone of overlap between that day's LANDSAT coverage and coverage the next day. An abundance of fish was reported in the study area.

The satellite passed over the area at 1026 hrs. (CDT) on July 19, 1976. The entire western portion of the study area was free of clouds and the eastern part was approximately 50 percent cloud covered. Data transmission from the satellite to GSFC was completed successfully.

Representatives from NFEL and NFMOA were situated at GSFC to review LANDSAT data shortly after reception. Fish school locations were telephoned to GSFC at about 1100 CDT so the extent of cloud cover over menhaden school locations could be evaluated.

LANDSAT data were received at GSFC at 1027 CDT. The first quick-look at the imagery was at 1115 CDT. At that stage, the recording process introduced severe scan line dropout. Input data were re-recorded three times until the scan line problem was eliminated. The image was then framed such that it contained approximately 50 percent land and water, respectively.

Early fishing reports placed most of the menhaden school locations in the easternmost portion of the image, which was extensively cloud covered. A decision to continue or terminate the mission was postponed until additional fishing reports could be received. Personnel at GSFC, however, continued to process data to a CCT format. A decision to continue the mission was made at 1330 CDT.

Two sets of CCT's were delivered to the NFEL representative at 1500 CDT. The tapes were hand-carried via commercial airliner to Slidell, arriving at 2045 CDT. By the time the tapes arrived, menhaden school locations, identified by the fleet or by spotter pilots, had been plotted on navigation charts. Locations were established by LORAN-C or VHF omnidirectional VOR navigation.

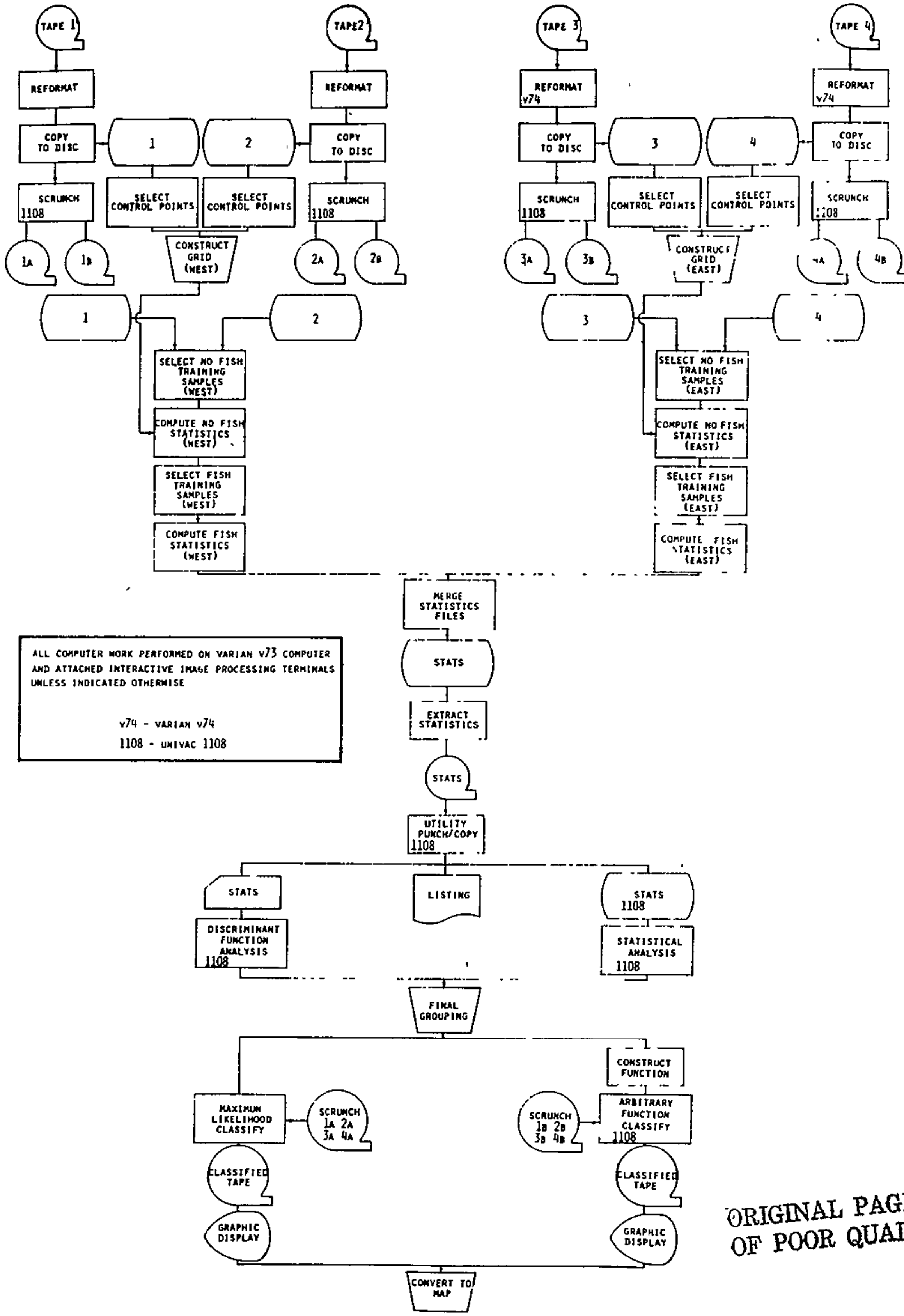

Figure 11-2. Slidell Data Processing Flow Diagram

The first step in processing LANDSAT data at ERL was to reformat the four image tapes into a format compatible with ERL software. This was performed simultaneously on Tapes 1 and 3 and then on 2 and 4 with ERL's Varian V-73 and V-75 computers (Figure 11-2). When a tape was reformatted, it was read into disc storage to facilitate access by the two Comtal 8100 Image Processing Systems (IPS). Two reformatted tapes (1 and 3) were ready for analysis by 2130 CDT.

One phase of the processing was correlating LANDSAT pixels to the existing base map. Control points were identified in the image and on 1:250,000 scale USGS maps. A grid of scan lines and elements was constructed on the map from the control points. These points had been identified with earlier LANDSAT data so the points could be plotted quickly (10 to 15 minutes per tape). The grid was transferred to navigation charts on which menhaden school locations were plotted. The first tape was gridded on the map by 2345 CDT and the last tape by 0145 CDT, July 20, 1976. While the maps were being gridded, training samples for no-fish areas were selected. These areas were regions where no fish were caught either the day before or the day of the principal satellite pass. Training samples were selected by 0040 CDT. Statistics for no-fish samples were computed with the Comtal systems at 2340 CDT (July 19, 1976) for Tapes 3 and 4, but were not computed for Tapes 1 and 2 until later. Training data for the fish school locations were taken from 2345 to 0045 CDT on the IPS, after which the statistics were computed. All statistics for the individual fish and no-fish training samples were computed by 0230 CDT. Data files containing statistics for the two IPS's were merged, extracted onto magnetic tape in card image format, and taken to the Univac 1108 computer system for simultaneous card punch for each training sample to create a FASTRAN file for further analysis. The cards and new file were available at 0315 CDT.

A graphic display of individual training samples was prepared which showed each sample as a function of mean radiance in the green and red channels. A preliminary grouping was performed with this display. No-fish data were divided into five groups, and fish data into two groups. NFEL analyzed the grouped data using a discriminant function analysis technique while ERL conducted a detailed analysis of the separability of the groups. Two similar groupings of training samples resulted which were ready for classification by 0455 CDT.

While other analyses were underway, special tapes were prepared on the 1108 system which reduced spatial resolution of LANDSAT data to improve radiometric resolution. The final data had a distribution of 0 to 254 counts to represent the range of light intensities detected by the sensor, as opposed to 0 to 63 in the original data. Land and clouds were preclassified and set to a value of 255 in each spectral channel. These tapes were ready at 0200 CDT. A maximum likelihood classifier was applied to the tapes generated for use on the Varian system, but the tapes could not be read. After considerable difficulty, new tapes were generated. The tape problem delayed completion of the final product approximately 1 hour. Meanwhile, another computer program was written to generate similar tapes on the V-73 system as it appeared the problem was caused by the 1108's 9-track tape units as opposed to the standard

7-track units. The V-73 has a 9-track capability. The newly generated tapes were classified with a maximum likelihood classifier by 0800 CDT July 20, 1976. Later analyses determined the problem was a programming error rather than a system malfunction.

Results of the discriminant function analysis were in the form of a function for each of the water classes (two fish and five no-fish). These water classes were programmed into the ERL software and implemented on the 1108 for Arbitrary Function Classification. The classifier was iterated four times on the radiometric resolution expanded tapes with a limitation that a point must fall within 1, 1-1/2, 2, and 3 standard deviations of the mean of a particular class for it to be placed in that class. The classifications were complete by 0715 CDT, July 20, 1976.

11.1.3 DISSEMINATION OF RESULTS

The classified tapes were placed on the Portable Image Display System (PIDS) and locations of high probability areas were sketched onto navigation charts (Figure 11-3). Results were transmitted by telephone to the commercial fleet at 0730 CDT through fleet managers and chief spotter pilots. A further refinement of the classification was attempted and at 0830 CDT an improved prediction was relayed to the fishing fleet and a copy of the probability chart was given to the spotter pilot with LORAN-C.

11.1.4 VERIFICATION OF RESULTS

A later analysis of the position reports from the LORAN-C equipped spotter aircraft indicated a constant bias of 10 microseconds on the LORAN line. The corrections were applied and affected training samples reselected. The resultant reclassification, however, was not significantly different from the original. Figure 11-4 is the corrected discriminant function classification of the July 19, 1976 LANDSAT data. It includes a further restriction that a pixel was required to be within ± 2 standard deviations of the mean in each channel to be classified as high probability. Superimposed on the chart are fish school locations for July 20, 1976, reported by the fishing fleet and spotter pilots. If menhaden school location areas which could not be classified due to cloud cover are ignored, the majority of the observations fall in or immediately adjacent to the inferred high probability areas.

11.2 PERSISTENCE ANALYSIS

The second objective of the extension was to determine the persistence of LANDSAT predicted high probability fishing areas over a 24-hour period. Comparisons of fish school locations on the day following the satellite overpass demonstrated the classifications were reasonably successful predictors over 24 hours (see 10.4.2.3). The relative persistence of the predicted high probability areas from one day to the next, however, was not known.

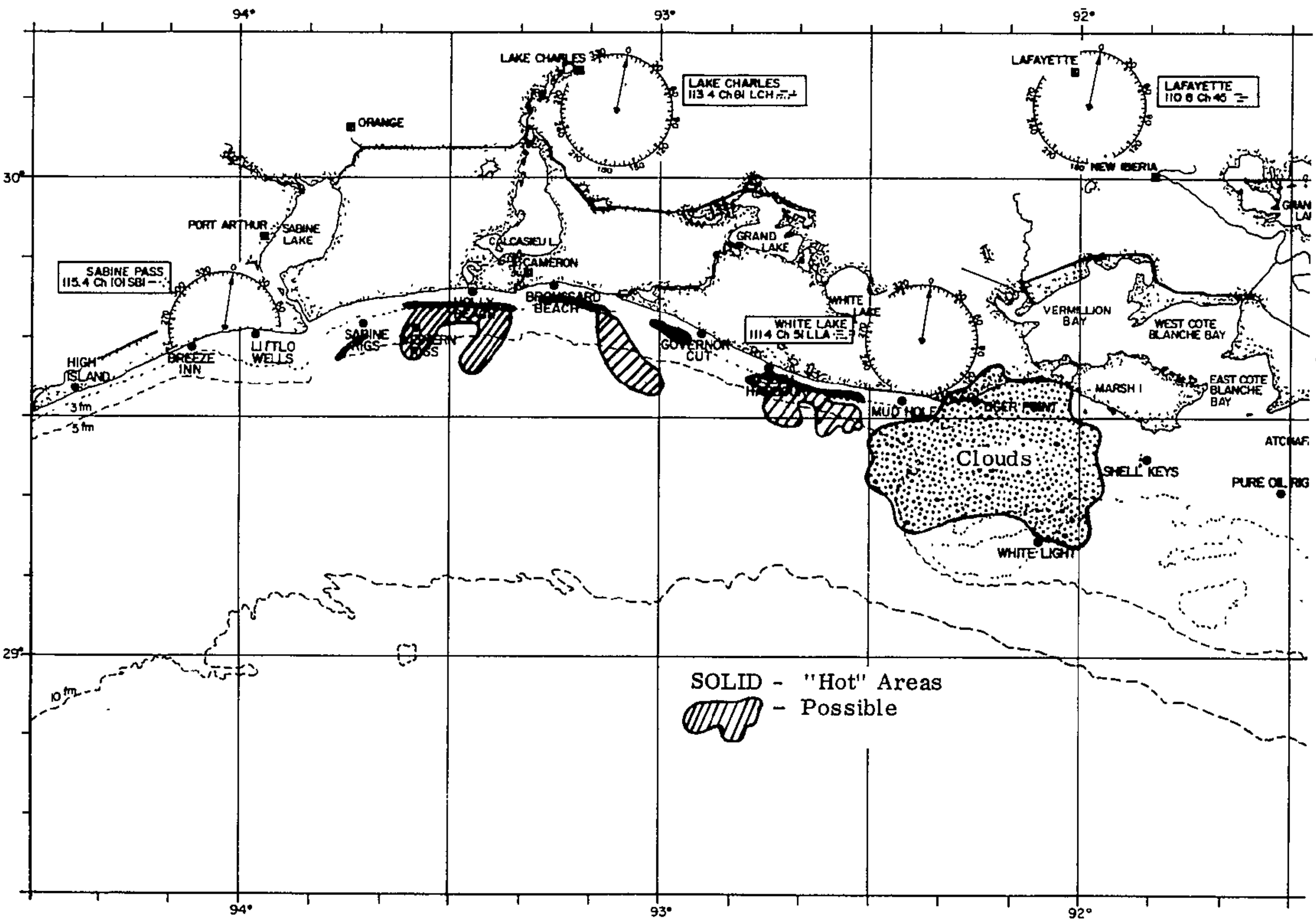

Figure 11-3. Inferred High Probability Fishing Areas for July 20, 1976, Developed from July 19, 1976, LANDSAT MSS Data.

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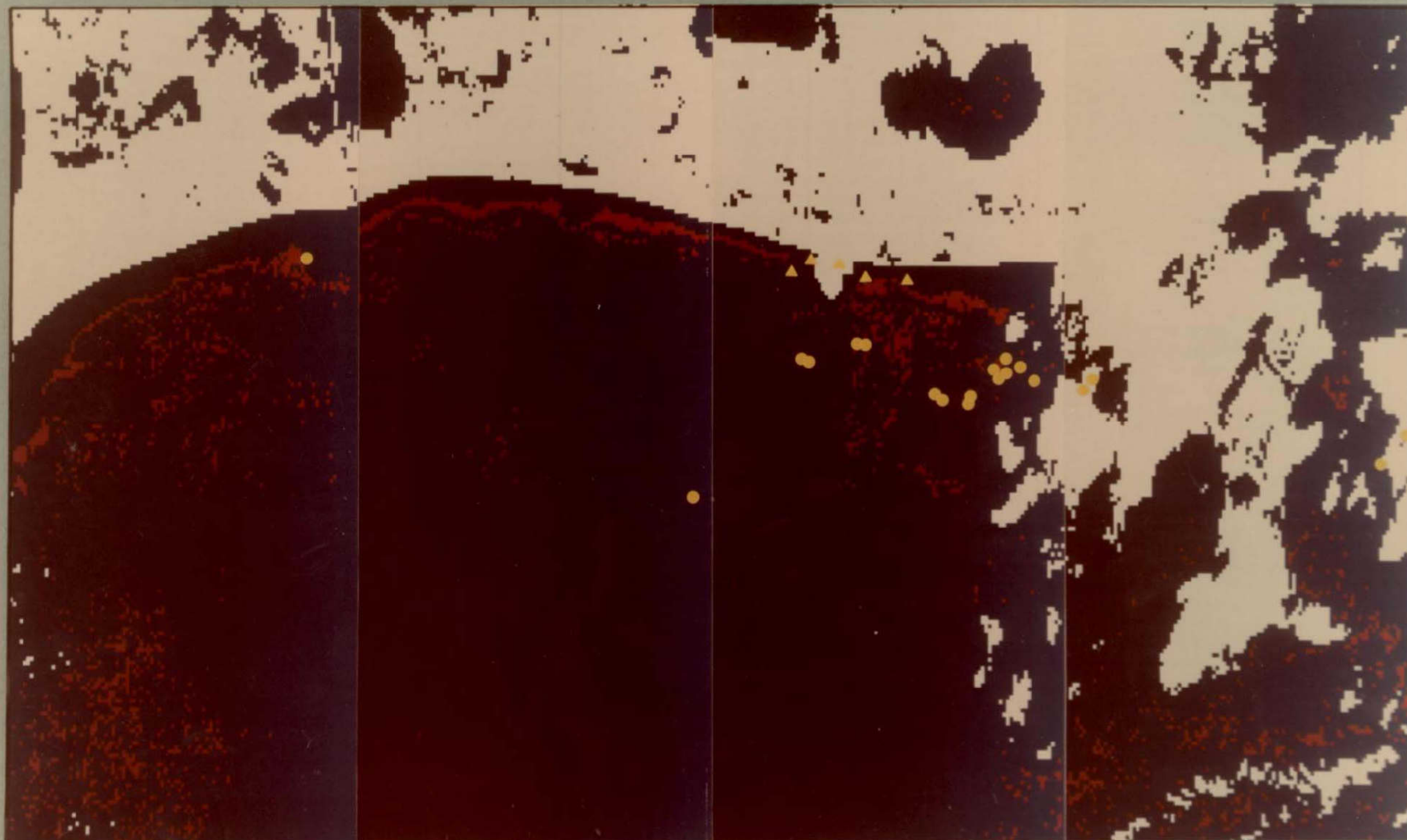
Figure 11-4. Reclassified (Corrected) LANDSAT Data from July 19, 1976

PREDICTED HIGH PROBABILITY FISHING AREAS USING LANDSAT DATA FROM 19 JULY 1976



Land and clouds

Water

Predicted high probability fishing areas

● Fish school locations on 20 July 1976 - vessels with observers

▲ Fish school locations on 20 July 1976 - spotter pilot reports

11.2.1 APPROACH

Two consecutive LANDSAT orbits over a given area have an approximate 25 percent overlap, separated by 24 hours. To investigate the persistence of predicted high probability fishing areas, LANDSAT data from two consecutive orbits of the Louisiana test area, July 27 and 28, 1976, were selected for analysis. The rationale was to classify each image separately through discriminant function analysis. The overlap area between the two images would then be examined for similarity and persistence of the patterns of predicted high probability fishing areas from one day to the next.

11.2.2 CLASSIFICATIONS

As in all previous analyses, fish school locations were converted to LANDSAT coordinates and training samples (144 pixels each) were selected for with and without-fish locations. Training data were grouped into one fish class and two no-fish classes for the July 27, 1976, overpass (Table 11-1).

Table 11-1. July 27, 1976, MSS Training Field Radiance Data (Mean Value in Counts)

CLASS	TRAINING AREA NO.	MSS BAND			
		B1	B2	B3	B4
FISH	1	24.500	18.500	9.400	1.000
	2	25.200	19.200	9.700	.900
	3	25.400	19.200	10.000	1.100
NO FISH 1	1	29.300	27.000	14.900	1.600
	2	30.300	29.200	16.200	1.700
	3	29.000	25.000	13.100	1.400
	4	31.000	27.800	14.600	1.700
	5	32.800	33.400	19.000	1.900
	6	33.100	34.000	21.000	1.500
	7	33.900	36.500	21.500	2.400
	8	34.100	33.100	16.300	1.300
NO FISH 2	1	20.800	14.400	8.100	.600
	2	21.900	15.100	8.400	.600
	3	20.700	14.200	7.800	.700
	4	20.100	15.000	8.000	.400
	5	20.800	15.000	7.900	.500

The discriminant function used for classification, and the plus or minus two standard deviation limits are presented in Tables 11-2 and 11-3, respectively, for July 27, 1976. For July 28, 1976, two fish classes and two no-fish classes were used. Training field data are presented in Table 11-4 and discriminant functions in Table 11-5. Table 11-6 gives the two standard deviation limits for July 29, 1976.

Table 11-2. Discriminant Function Classifiers for July 27, 1976, MSS Data

FUNCTION	INTERCEPT	MSS COEFFICIENTS			
		B4	B5	B6	B7
FISH	-449.368	56.545	-36.588	14.444	34.874
NO FISH 1	-535.373	59.416	-36.327	13.570	42.162
NO FISH 2	-338.649	49.734	-33.459	14.636	23.530

Table 11-3. Mean ($\overline{x}$) and Two Standard Deviation (2s) Limits for July 27, 1976, MSS Data

CLASS	MSS BAND ($\overline{x} \pm 2s$)			
	B4	B5	B6	B7
FISH	25.033 $\pm$ 0.946	18.967 $\pm$ 0.808	9.700 $\pm$ 0.600	1.000 $\pm$ 0.200
NO FISH 1	31.688 $\pm$ 4.090	30.750 $\pm$ 8.085	17.075 $\pm$ 6.174	1.688 $\pm$ 0.688
NO FISH 2	20.860 $\pm$ 1.301	14.740 $\pm$ 0.820	8.040 $\pm$ 0.460	0.560 $\pm$ 0.228

Table 11-4. July 28, 1976, MSS Training Field Radiance Data (Mean Value in Counts)

CLASS	TRAINING AREA NO.	MSS BAND			
		B4	B5	B6	B7
FISH 1	1	17.800	13.100	7.600	.600
	2	17.600	12.700	7.100	.400
	3	17.800	12.900	7.200	.500
	4	17.700	12.900	7.300	.700
	5	17.500	12.500	7.000	.300
	6	17.900	12.600	6.800	.300
	7	17.600	12.400	6.700	.300

Table 11-4. July 28, 1976, MSS Training Field Radiance Data (Mean Value in Counts) (Continued)

CLASS	TRAINING AREA NO.	MSS BAND B4	B5	B6	B7
FISH 1	8	18.900	14.200	8.000	.600
	9	18.800	13.300	7.200	.400
	10	18.800	13.200	7.200	.400
	11	18.600	13.000	7.400	.400
FISH 2	1	20.300	14.100	7.200	.400
	2	22.100	16.200	8.300	.800
	3	19.400	13.400	7.300	.400
	4	23.200	16.600	8.500	.500
NO FISH 1	1	16.600	12.000	6.200	.200
	2	16.200	11.200	5.900	.100
	3	16.500	11.300	5.700	.100
	4	16.100	11.100	5.600	.100
	5	16.600	11.700	6.200	.200
	6	16.800	11.900	6.300	.200
	7	16.500	11.500	5.800	.100
	8	16.600	12.000	6.200	.200
NO FISH 2	1	28.700	26.700	14.000	1.600
	2	29.200	30.100	17.900	2.100
	3	27.600	26.200	14.900	1.600
	4	27.800	27.000	14.900	1.500
	5	28.800	28.900	16.900	1.600
	6	26.800	25.000	14.000	1.600
	7	28.000	25.900	13.200	1.000
	8	28.400	26.000	13.800	1.200
	9	28.100	27.200	16.300	1.700
	10	28.100	27.300	16.000	1.500
	11	28.200	27.700	16.900	1.700

Table 11-5. Discriminant Function Classifiers for July 28, 1976, MSS Data

FUNCTION	INTERCEPT	MSS COEFFICIENTS B4	B5	B6	B7
FISH 1	-445.946	79.311	-62.959	37.569	0.260
FISH 2	-559.411	91.432	-70.455	39.874	6.124
NO FISH 1	-365.481	70.311	-54.130	33.045	-11.304
NO FISH 2	-777.005	78.629	-38.302	25.276	-8.208

Table 11-6. Mean ($\overline{X}$) and Two Standard Deviation (2s) Limits for July 28, 1976, MSS Data

CLASS	MSS BAND ($\overline{X} \pm 2s$)			
	B4	B5	B6	B7
FISH 1	18.091 ± 1.116	12.982 ± 0.992	7.227 ± 0.722	0.445 ± 0.274
FISH 2	21.250 ± 3.435	15.075 ± 3.130	7.825 ± 1.340	0.525 ± 0.379
NO FISH 1	16.488 ± 0.459	11.588 ± 0.729	5.988 ± 0.539	0.150 ± 0.107
NO FISH 2	28.155 ± 1.291	27.091 ± 2.877	15.345 ± 3.079	1.555 ± 0.561

The resulting classification for the overlap area between the July 27 and 28 data are shown in Figure 11-5. The fish schools used in developing the classification (training data) are plotted on both classifications. The similarities in shape and general position of the predicted high probability areas are quite evident. A total of 10 of 11 schools were classified correctly for July 27 and were also classified correctly when plotted on the July 28, 1976, classification. All three menhaden schools were classified correctly for the July 28, 1976, classification.

These results indicate the patterns of predicted high probability areas remain similar in size, shape, and general location over a 24-hour period. This lends further credence to efforts to use data from one day to predict fishing areas for the next.

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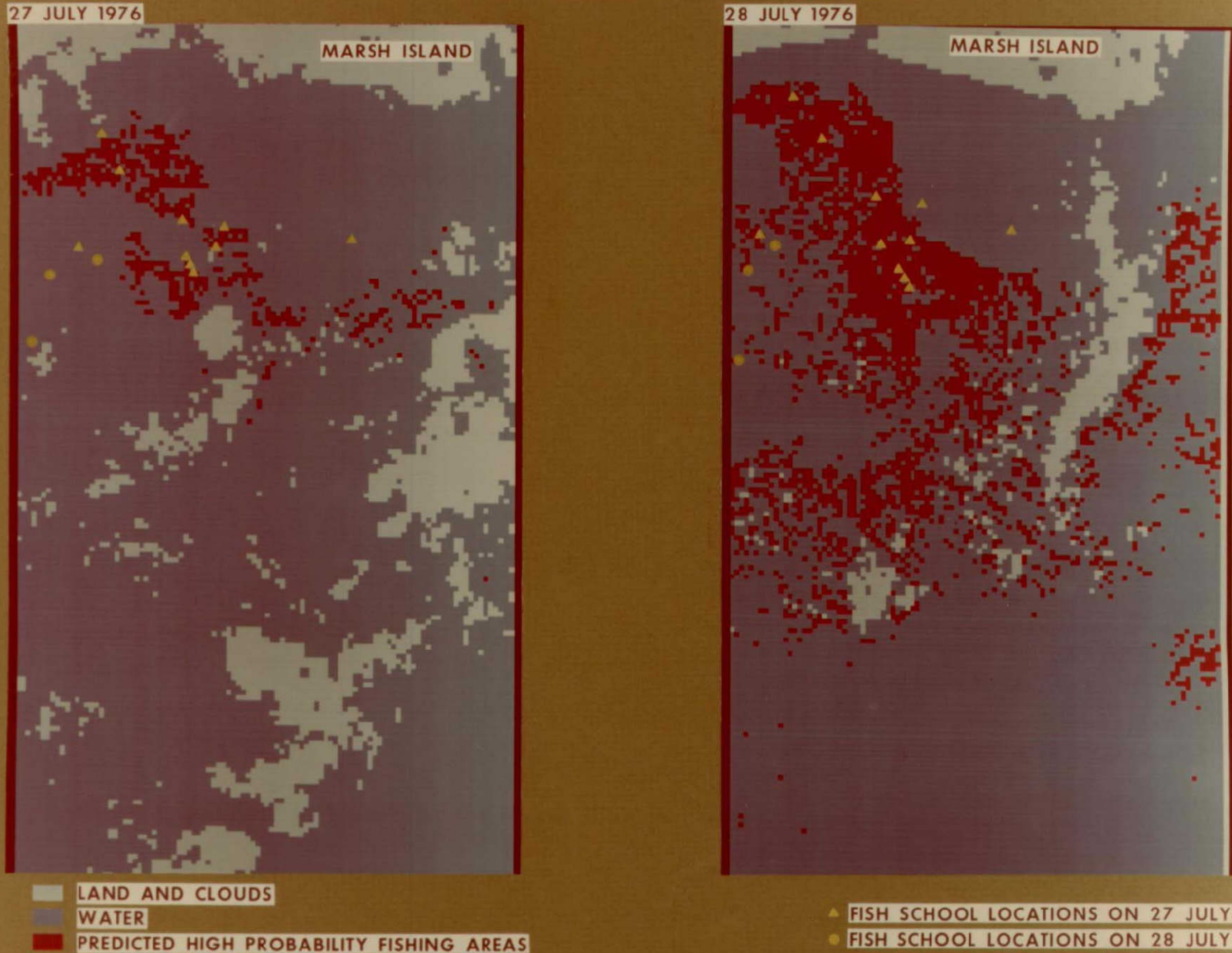
Figure 11-5. Discriminant Function Classification of Overlap Areas for July 27-28, 1976, LANDSAT MSS Data. (Louisiana)

PREDICTED HIGH PROBABILITY FISHING AREAS FOR OVERLAP REGION BETWEEN LANDSAT OVERPASS ON 27 AND 28 JULY 1976



SECTION 12

OBJECTIVE SUMMARY AND CONCLUSIONS

Objectives and sub-objectives of the investigation were met through extensive field operations and data analyses. These objectives and an evaluation of how well they were satisfied are addressed in the following paragraphs.

The primary objective of the follow-on phase was to establish and verify relationships between menhaden distribution and selected oceanographic parameters, and then to demonstrate how these relationships could be used to enhance menhaden management and utilization. Results showed that water turbidity, color, and possibly chlorophyll concentrations correlated with menhaden distribution. Because these parameters should manifest in satellite derived ocean color measurements, emphasis was placed on the development of algorithms to convert LANDSAT MSS data directly into derived menhaden distribution patterns. These attempts demonstrated that MSS data could be used to infer menhaden distribution patterns with accuracies approaching 90 percent. They also demonstrated that menhaden distribution correlated more precisely with MSS data than with classical oceanographic parameters. Thus, it appears that an operational system based on satellite obtained ocean color measurements could be used to enhance fishing operations and to develop efficient resource assessment designs by synoptically identifying areas preferred by menhaden.

The objective of establishing and verifying similar bio-environmental relationships for thread herring was not attained. This failure was due to the sparsity of thread herring data collected during field operations. Sufficient data were collected, however, to suggest thread herring prefer considerably different oceanographic conditions than those established for menhaden, and that satellite remote sensing may have practical management and utilization potentials for this resource.

All sub-objectives of the follow-on phase relating to menhaden management and utilization were achieved. Specifically, the value of satellite derived data for a distribution prediction model for menhaden in the Mississippi Sound was confirmed and the value of these data for predictions of menhaden distribution over the entire season of menhaden availability in the Mississippi Sound and off Louisiana was verified. This verification was important because an underlying assumption of the investigation was that if consistent relationships could be established for both study areas, these relationships would have significant predictive value for the entire northern Gulf of Mexico menhaden fishery.

An important sub-objective of the follow-on phase was to continue development of techniques for the application of remote sensing data to living marine resource assessment and utilization. This sub-objective was achieved through improved management and processing techniques for remotely sensed data (e.g. temperature, salinity and color), development and application of digital techniques for inferring fish distribution patterns from MSS data, and identification of basic approaches, techniques, and hardware systems for applications of remotely acquired data to fishery investigations.

The primary objective of the extension phase was to demonstrate a practical application of the results and methodology from the follow-on phase. It was successfully achieved. This achievement was made possible by near-real-time processing and analysis of LANDSAT MSS data for conversion into a fishing probability chart. Probability information was disseminated to the fishing fleet to tactically aid their fishing operations approximately 21 hours after satellite coverage. The fleet reported that high probability fishing areas identified in the fishing chart produced some of the best catches of the entire fishing season. The persistence of MSS inferred menhaden distribution patterns was examined by comparing patterns in the overlap region between two consecutive LANDSAT coverages. This examination showed the patterns remained relatively unchanged over a 24-hour period.

Each primary participant in the investigation had specific objectives. These objectives and an appraisal of how well they were satisfied follow.

National Fisheries Engineering Laboratory

- The investigation enabled a continued development of techniques for management of multidisciplinary fisheries research programs which rely on remotely sensed information. The value of active industry participation in these programs was demonstrated and methods for encouragement of this participation were tested.

- Development of a data management system to facilitate production of fisheries significant environmental information from remotely sensed data was achieved. This data management system has been expanded to handle many forms of fishery, ecological, and oceanographic data to support numerous investigations in the Gulf of Mexico.

- The relationship between the distribution of menhaden and selected oceanographic parameters (water color, turbidity, and possibly chlorophyll concentrations) was established. Similar relationships for thread herring were not established nor were relationships relating to the abundance of either species.

- The hypothesis that satellite data (i.e. color data) contains fishery-significant information was tested and accepted.

Earth Resources Laboratory

- Remotely sensed (aircraft and satellite) data were acquired for correlation with in situ and remote biological measurements (chlorophyll and fisheries). The remote measurements included color, salinity, and temperature.

- The use of aircraft and LANDSAT remote sensing instruments to measure or infer a set of basic oceanographic parameters was evaluated. Parameters which could be accurately inferred included surface water temperature, salinity, and color. Water turbidity (Secchi disc) was evaluated as marginally inferrable from the LANDSAT MSS data and chlorophyll-a concentrations as less than marginal. These evaluations considered the parameters only as experienced in the two test areas using available sensors and statistical techniques.

- Techniques for inferring water salinity, turbidity, and chlorophyll concentrations from remote measurements were applied and evaluated.

National Fish Meal and Oil Association

- An evaluation of potential applications of satellite data to commercial fishing operations and management was made possible through the intimate relationship between NFMOA cooperators and Federal investigators. This evaluation indicated satellite remote sensing has significant potential but current sensor systems lack sufficient temporal coverage for meaningful utilization, and essential cost effective data handling and processing facilities are lacking.

- An appreciation for the technical requirements to effectively use remotely sensed data in commercial fishing operations and management was obtained. The technical ability to directly utilize these data, however, was not developed due to the lack of appropriate sensors and data handling and processing facilities.

- Many technical requirements to enable the effective utilization of satellite data were identified. For example, increased temporal coverage and inexpensive data handling systems were highlighted as the most critical requirements. Inexpensive systems to relay information to and from the fishing vessels also are required.

SECTION 13

RECOMMENDATIONS

As a result of data acquisition and analysis efforts during this investigation, a number of recommendations for applications of investigative results and for future studies were identified. These recommendations follow:

1. The NMFS should develop a satellite data analysis system dedicated to fishery investigations. This system should be patterned after those currently in use at ERL and its development should be accomplished in cooperation with ERL.

2. The NMFS should encourage additional studies in the application of satellite remote sensing to fishery problems. These studies are necessary to fully evaluate the potential of satellite acquired data for satisfying fishery management and utilization needs. These studies should take advantage of approaches and techniques developed during this investigation. Candidate pelagic species include herrings, mackerel, salmon, tuna, porpoises, anchovies, billfishes, bluefish, Atlantic menhaden, and others. Bottom fishes which have shown potential for satellite applications include shrimp and related groundfish.

3. A return to fundamentals is encouraged for derivations of chlorophyll-a and turbidity measurements from remotely sensed data. A comprehensive understanding of the light scattering and attenuation properties of dissolved organics, detritus, inorganics, and phytoplankton will have to be developed before routine remote and synoptic measurements of these two parameters in coastal waters can be accomplished.

4. Increased attention should be given to signature extension algorithms so that remotely sensed color data from different areas and time periods can be compared directly.

5. Future satellite systems for fishery applications should be designed to provide daily coverage. Spatial resolutions of about 500 meters are probably adequate for coastal applications and of about 1 kilometer for open areas. Spectral resolution requirements are not defined as well, although initially a resolution similar to that provided by LANDSAT is considered minimum. Dynamic ranges should be optimized for water.

6. Real-time reception, processing, and analysis of satellite data is considered essential for fishing and resource assessment uses.

7. Fishery investigators should be encouraged to routinely collect oceanographic data in conjunction with assessment surveys. These data should include, as a minimum, surface measurements of temperature, salinity, water color (e.g. Forel-Ule), Secchi disc turbidity, and chlorophyll-a. These data could be used directly to evaluate potentials of aerospace remote sensing for derivations of fish distribution and abundance without the necessity of an expensive study involving satellite and/or aircraft systems.

8. Training programs should be developed and emphasized for introducing fishery biologists, ecologists, and oceanographers to potentials of remote sensing. These programs should capitalize on results obtained from this investigation.

SECTION 14

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APPENDIX A

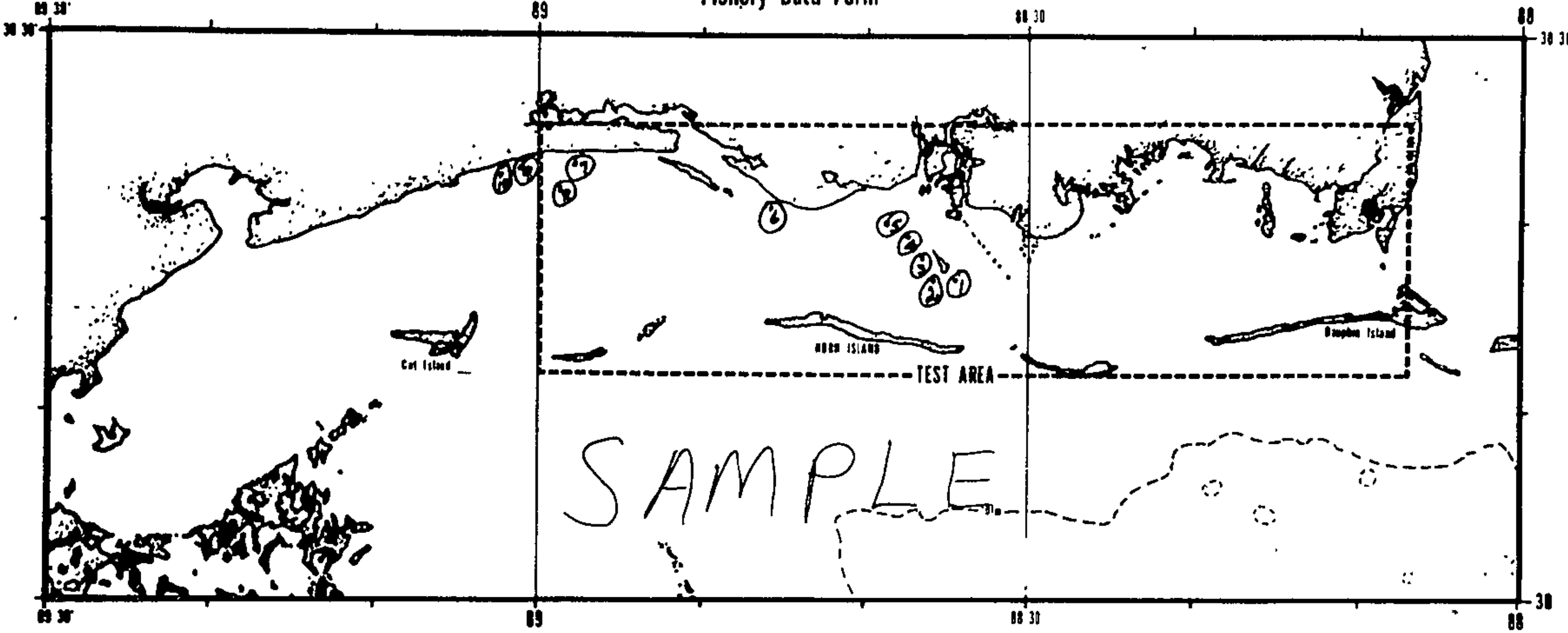
DATA FORMS

1. Fishing Vessel Data Form
2. Spotter Pilot's Data Form
3. Oceanographic Observer's Data Form
4. Environmental Vessel Data Form
5. Environmental Vessel Relative Irradiance Log

C-3

LANDSAT GULF OF MEXICO MENHADEN & THREAD HERRING EXPERIMENT

Fishery Data Form



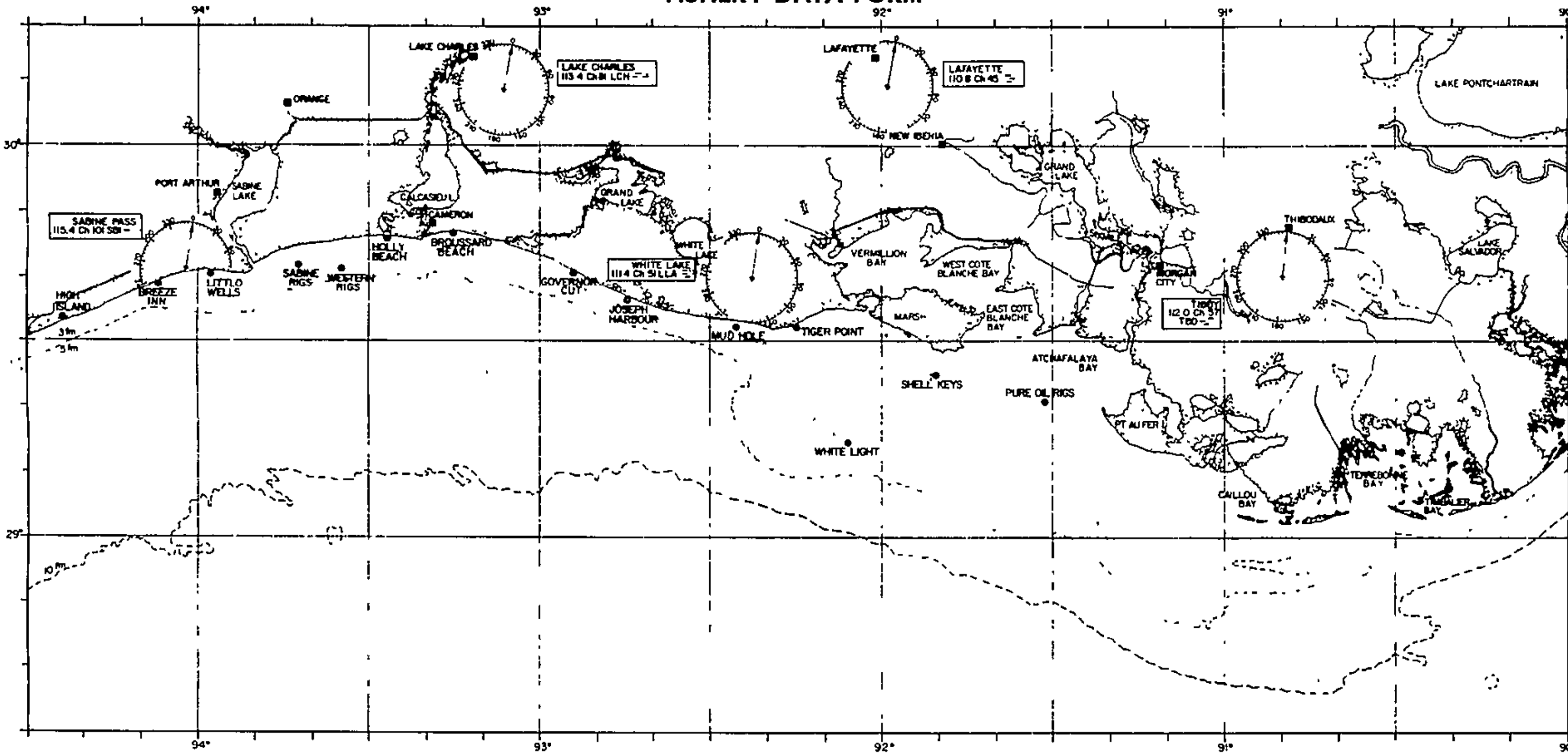
FISHING VESSEL'S SET INFORMATION Date 25 April Vessel "POGY BOAT" Data Recorded by A JONES

Location of Set	Time of Set	Species Caught		Number of Fish Thousands	Comments
		Menhaden Pogy	Thread Herring Wavy Backs		
1	5:30	✓		25	Tight School
2	6 15	✓		35	tight school
3	7:00	✓		30	Fish moving To Beach
4	7:45	✓		50	
5	9:00	✓		50	Fish quit Shoaling
6	12 00	✓		75	Clear sunny weather
7	3 00	✓		50	GOOD Color
8	3 45	✓		25	
9	4 45	✓		30	
10	6:15	✓		40	moving offshore

General Comments: Calm seas + Slack WIND
. Afternoon Sets without [illegible] because of [illegible]

A-1

FISHERY DATA FORM



● SPOTTER PILOT OBSERVATIONS

DATE	PILOT

*PLEASE WRITE IN SPECIES **PLEASE USE SIZE CATEGORIES [1] LESS THAN 25,000 [2] 25 000 - 50,000 [3] 50 000 - 100,000 [4] MORE THAN 100 000

OBSERVATION NO	TIME	OMNI DIRECTION FROM					LORAN C COORDINATES		FISH SPECIES			NO SCHOOLS	SCHOOL SIZE**	COMMENTS
		SABINE PASS	LAKE CHARLES	WHITE LAKE	LAFAYETTE	TIBBY	Z LINE	W LINE	MENHADEN (POGY)	THREAD HERRING	OTHER*			

LANDSAT GULF OF MEXICO MENHADEN AND THREAD HERRING EXPERIMENT

Oceanographic Observers Data Form

Boat/Platform ____________

Observer ____________

Sample Number		ID	Date	Time	LORAN C Coordinates		Surface Temperature °C	Secchi Disc (feet)	Forel Ule	Depth (feet)	Set Made	Species		Number of Fish (Thousands)	No. Seiners 1 mi. radius	Comments
Salinity	Chloro-phyll				Z Line	W Line						Men-haden	Thread Herring			

General Comments:

ORIGINAL PAGE IS OF POOR QUALITY

DATE ____________________

TIME ____________________

VESSEL ____________________

OBSERVER ____________________

LAT. ____________

LONG. ____________

LORAN A ____________ B ____________

Water Temp. (Thermometer) __________ °C

Air Temp. __________ °C

Relative Humidity: Wet __________ °F; Dry __________ °F

Wind Direction __________

Wind Speed __________ mph

Sea State __________ ft.

Water Depth __________ ft.

Forel-Ule __________

Visibility __________ miles

Barometric Pressure __________

Cloud Cover: Over Boat __________ %; Over Area __________ %

Type __________

Precipitation __________

RS-5

Depth ________ ft.

Temp. ________ °C

Salinity ________ ppt

Turbidity

Secchi (Shade) ft. (Sun) ft.

Transmissometer

Depth ______ ft. Xmissivity ______ %

Depth ______ ft. Xmissivity ______ %
(1/2 Secchi)

Depth ______ ft. Xmissivity ______ %
(1 Secchi)

Depth ______ ft. Xmissivity ______ %

Chlorophyll Sample Volume ______ ml
Number __________

Fluorometer __________

Bottle Numbers ________, ________

GENERAL OBSERVATIONS AND REMARKS

RELATIVE IRRADIANCE LOG

OPERATOR(S)____________________ INST. MODEL NO.____________________

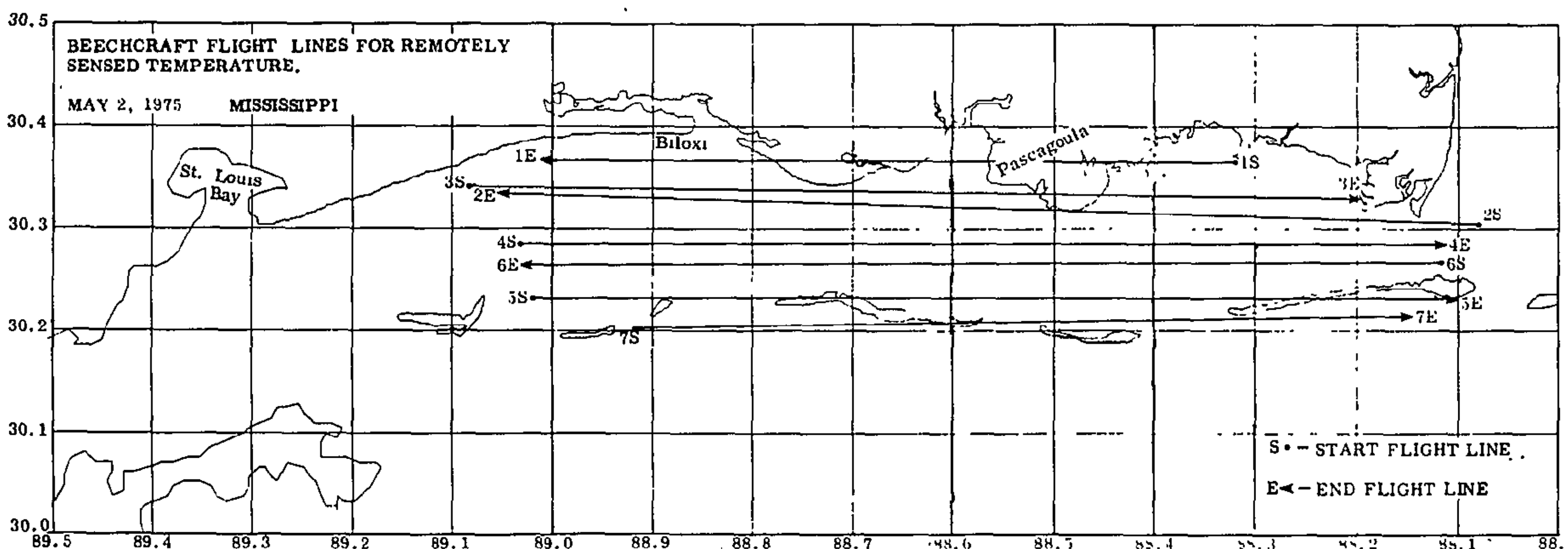
PLATFORM ____________________ INST. SERIAL NO.____________________

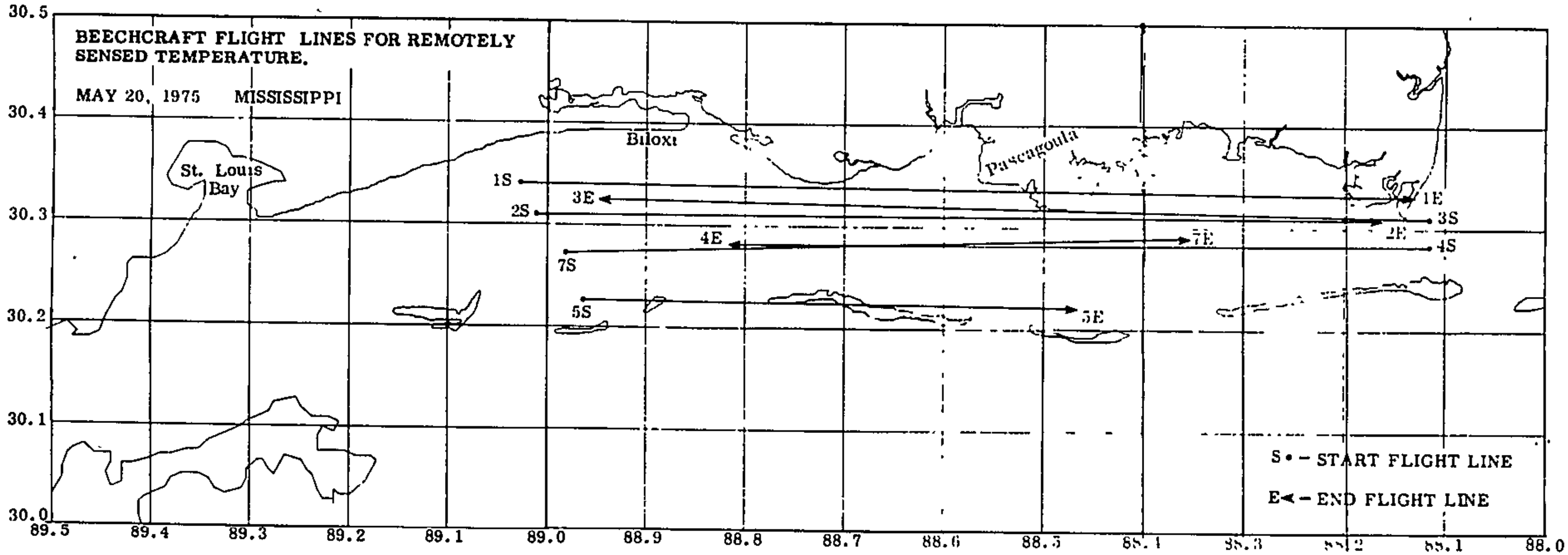
Location	Date	Time	% Rel. Irrad. Subsurface Depth	%	Photometer Deck Fil. / F. C	Photometer Subsurface Depth	F. C.	% Cld. Cover Over Boat	% Cld. Cover Entire Sky	% Haze	Sea State	Remarks
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									
			Deck Surface									

APPENDIX B

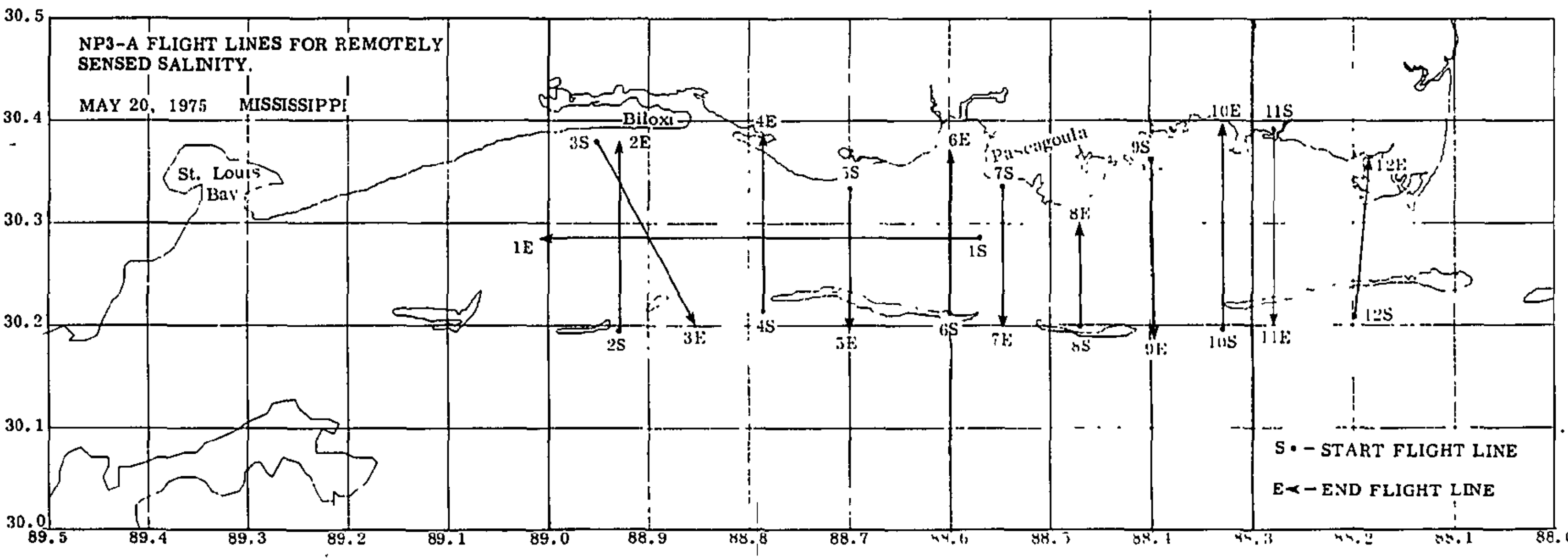
AIRCRAFT FLIGHT SUMMARY

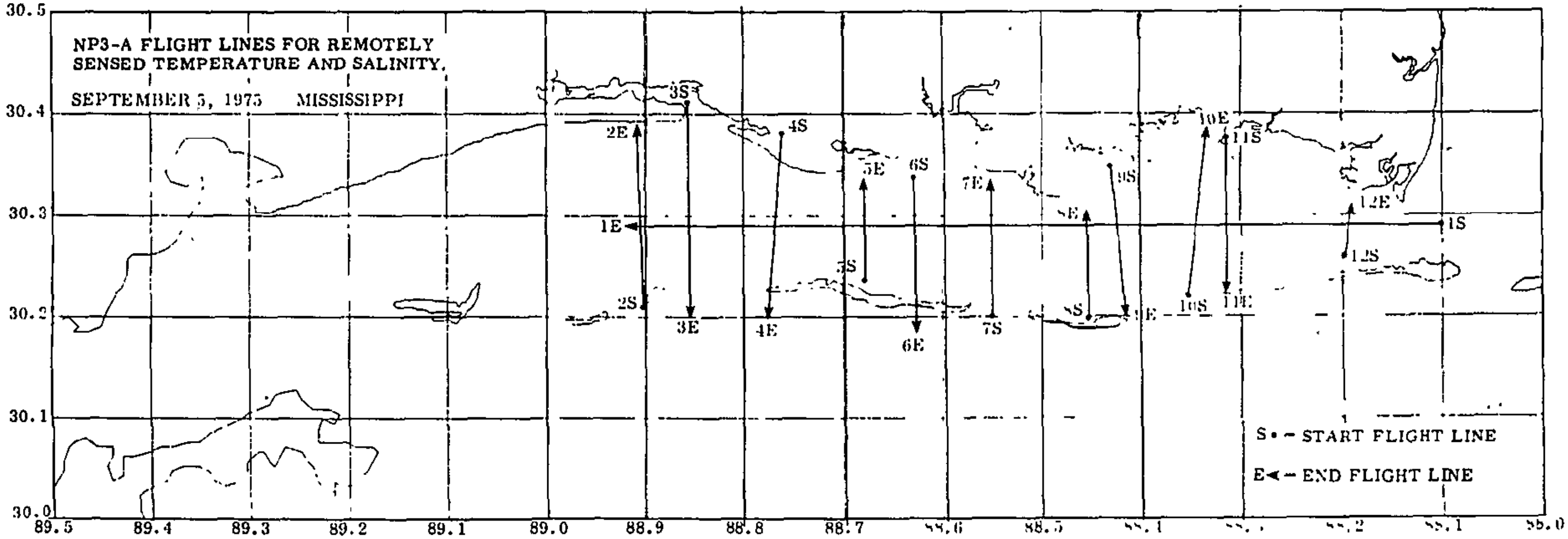
1. Beechcraft Flight Lines for Remotely Sensed Temperature - May 2, 1975 - Mississippi
2. Beechcraft Flight Lines for Remotely Sensed Temperature - May 20, 1975 - Mississippi
3. NP3-A Flight Lines for Remotely Sensed Salinity - May 20, 1975 - Mississippi
4. NP3-A Flight Lines for Remotely Sensed Temperature and Salinity - September 5, 1975 - Mississippi
5. Beechcraft Flight Lines for Remotely Sensed Temperature - May 13, 1975 - Louisiana
6. Beechcraft Flight Lines for Remotely Sensed Temperature - August 20, 1975 - Louisiana
7. NP3-A Flight Lines for Remotely Sensed Temperature and Salinity - April 25, 1975 - Louisiana
8. NP3-A Flight Lines for Remotely Sensed Temperature and Salinity - May 13, 1975 - Louisiana
9. NP3-A Flight Lines for Remotely Sensed Temperature and Salinity - August 20, 1975 - Louisiana

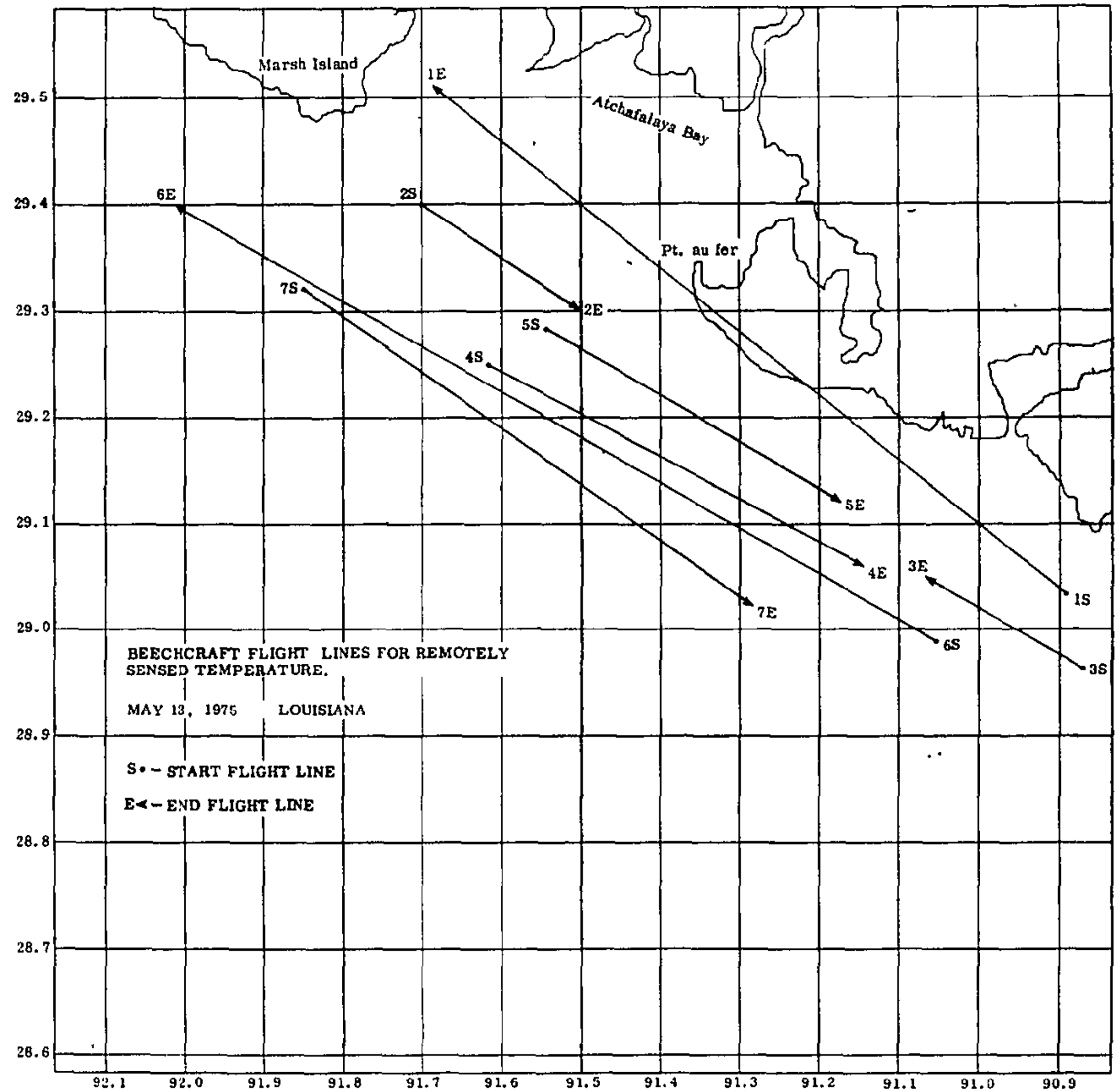

BEECHCRAFT FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE.
MAY 2, 1975
MISSISSIPPI
St. Louis Bay
Biloxi
Pascagoula
1E
1S
2E
2S
3S
3E
4S
4E
5S
5E
6E
6S
7S
7E
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.0



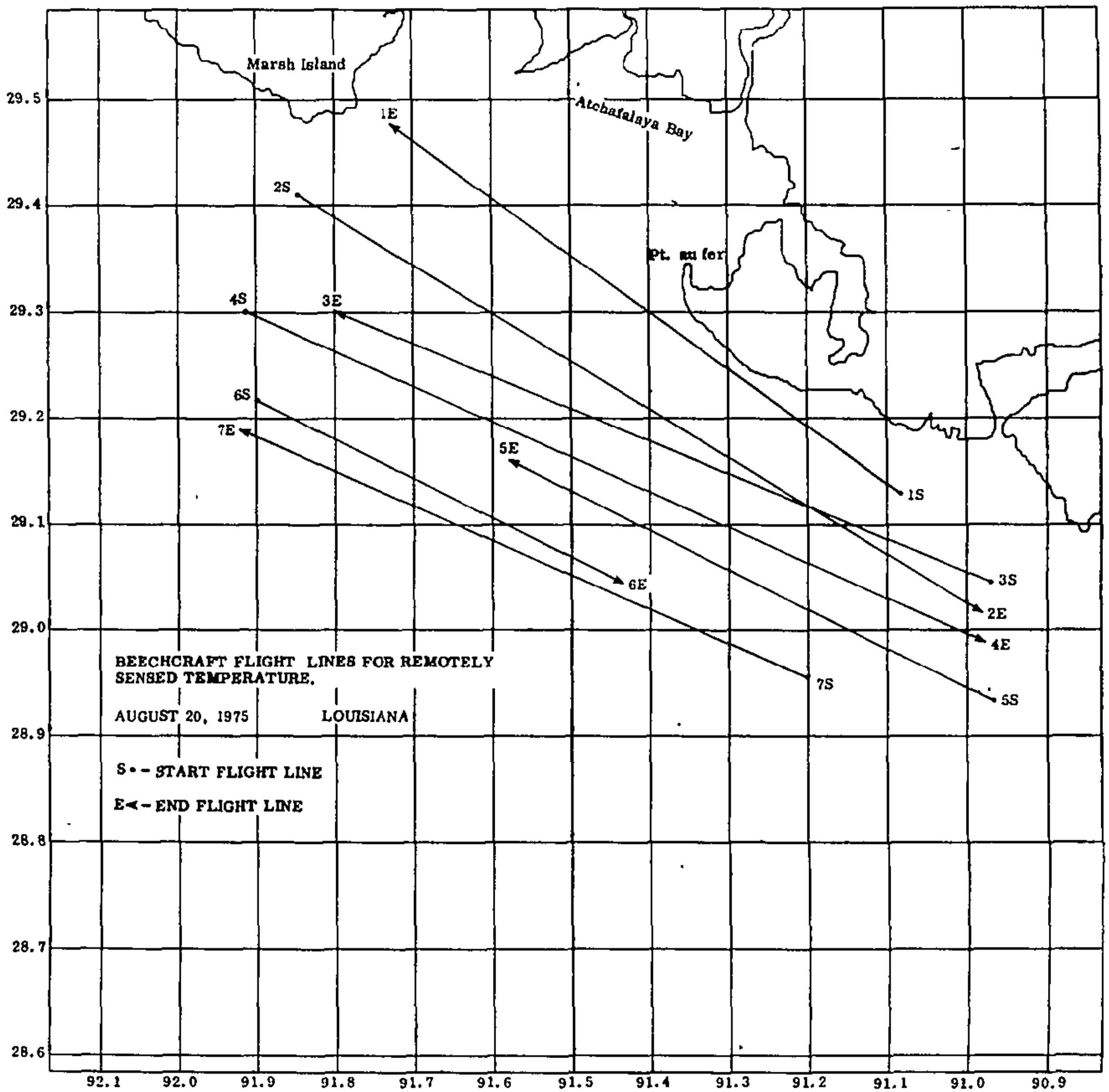
BEECHCRAFT FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE.
MAY 20, 1975 MISSISSIPPI
St. Louis Bay
Biloxi
Pascagoula
1S
1E
2S
2E
3S
3E
4S
4E
5S
5E
7S
7E
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.0

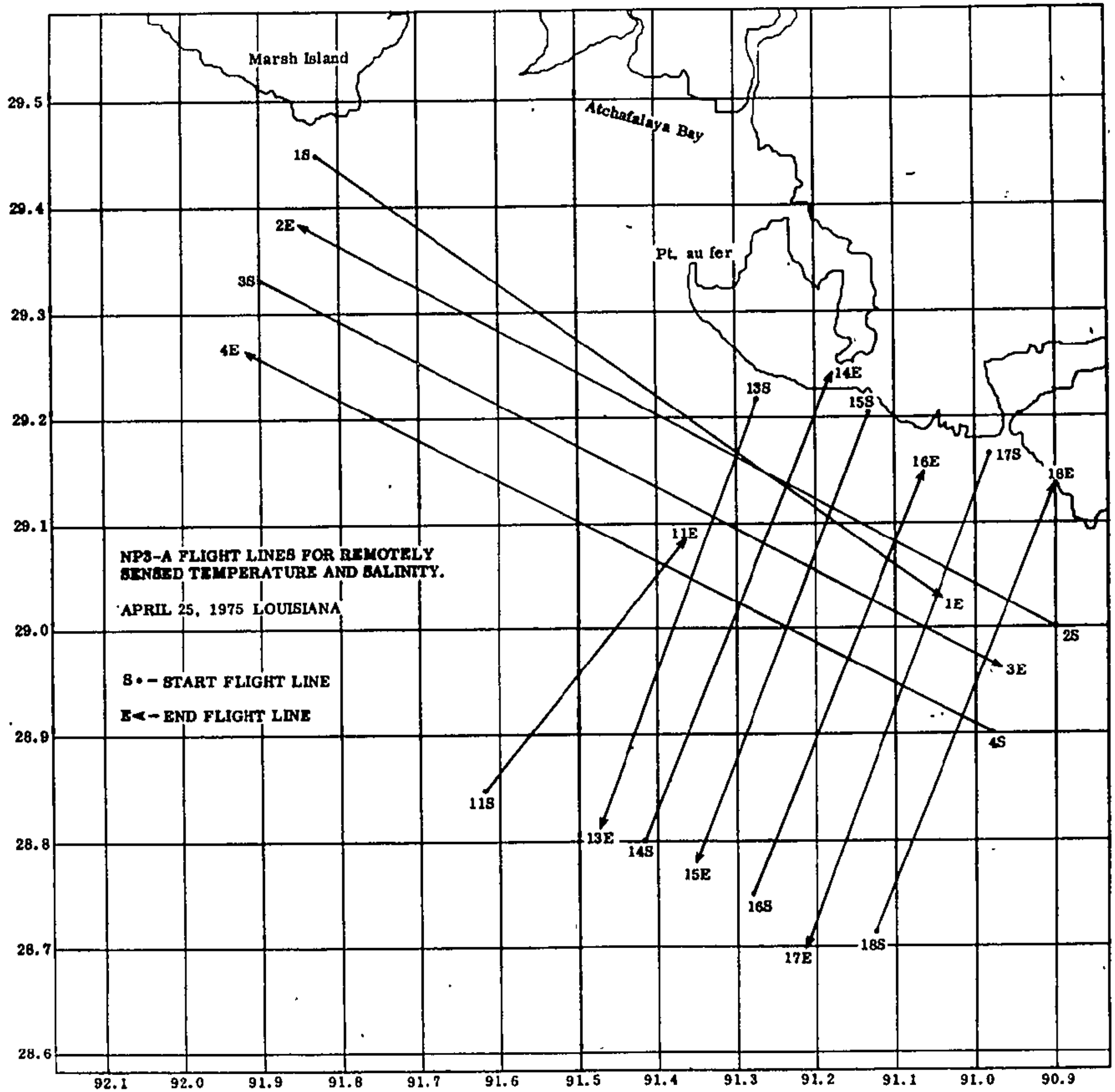

NP3-A FLIGHT LINES FOR REMOTELY
SENSED SALINITY.
MAY 20, 1975 MISSISSIPPI
St. Louis
Bay
Biloxi
Pascagoula
1S
1E
2S
2E
3S
3E
4S
4E
5S
5E
6S
6E
7S
7E
8S
8E
9S
9E
10S
10E
11S
11E
12S
12E
S • – START FLIGHT LINE
E ← – END FLIGHT LINE
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.4
88.3
88.2
88.1
88.0

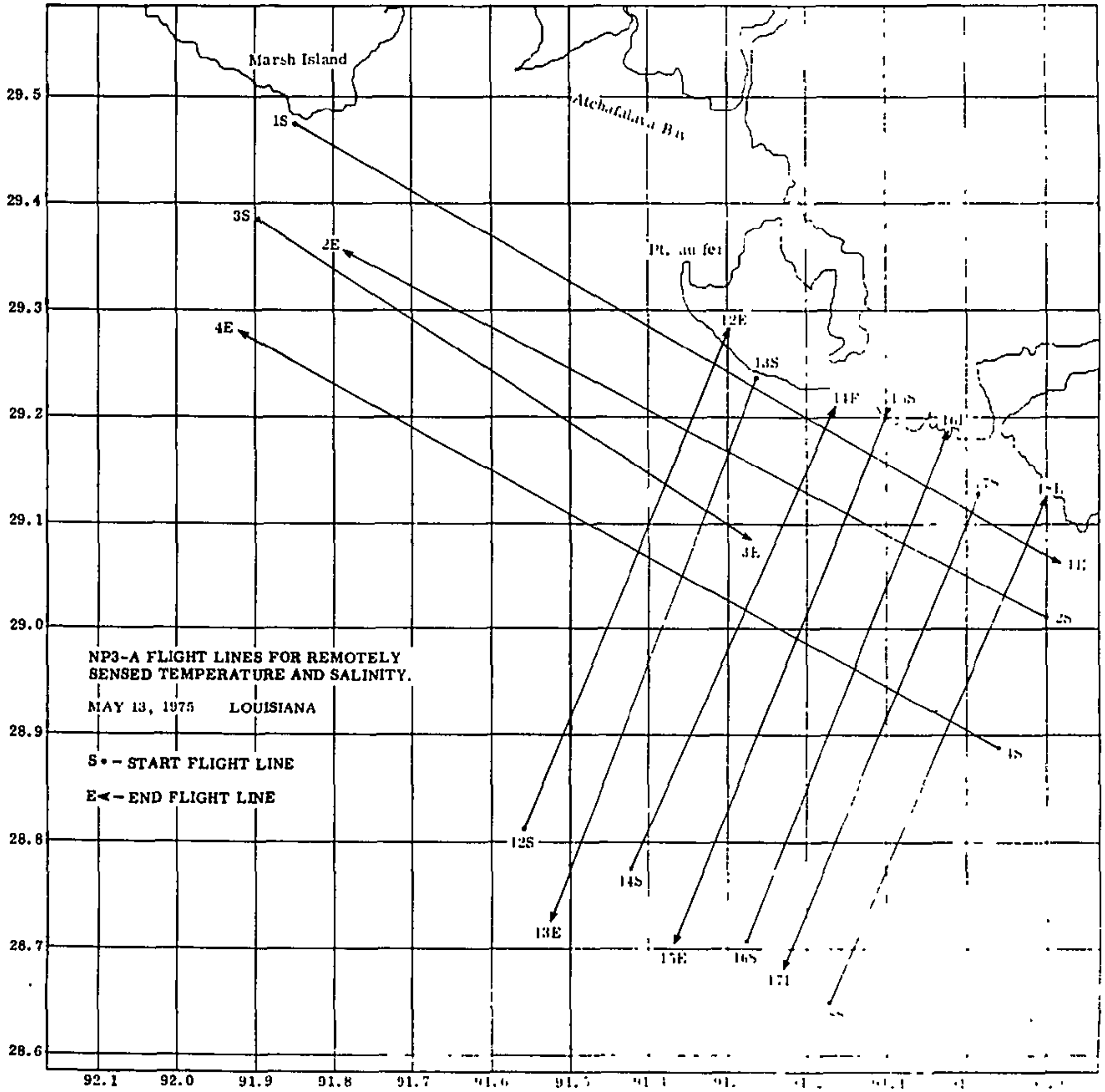

NP3-A FLIGHT LINES FOR REMOTELY
SENSED TEMPERATURE AND SALINITY.
SEPTEMBER 5, 1975
MISSISSIPPI
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.5
1S
1E
2S
2E
3S
3E
4S
4E
5E
6S
6E
7E
7S
9S
10E
10S
11S
11E
12E
12S



Marsh Island
Atchafalaya Bay
Pt. au fer
1E
1S
2S
2E
3E
3S
4S
4E
5S
5E
6E
6S
7S
7E
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9
BEECHCRAFT FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE.
MAY 13, 1975 LOUISIANA
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE

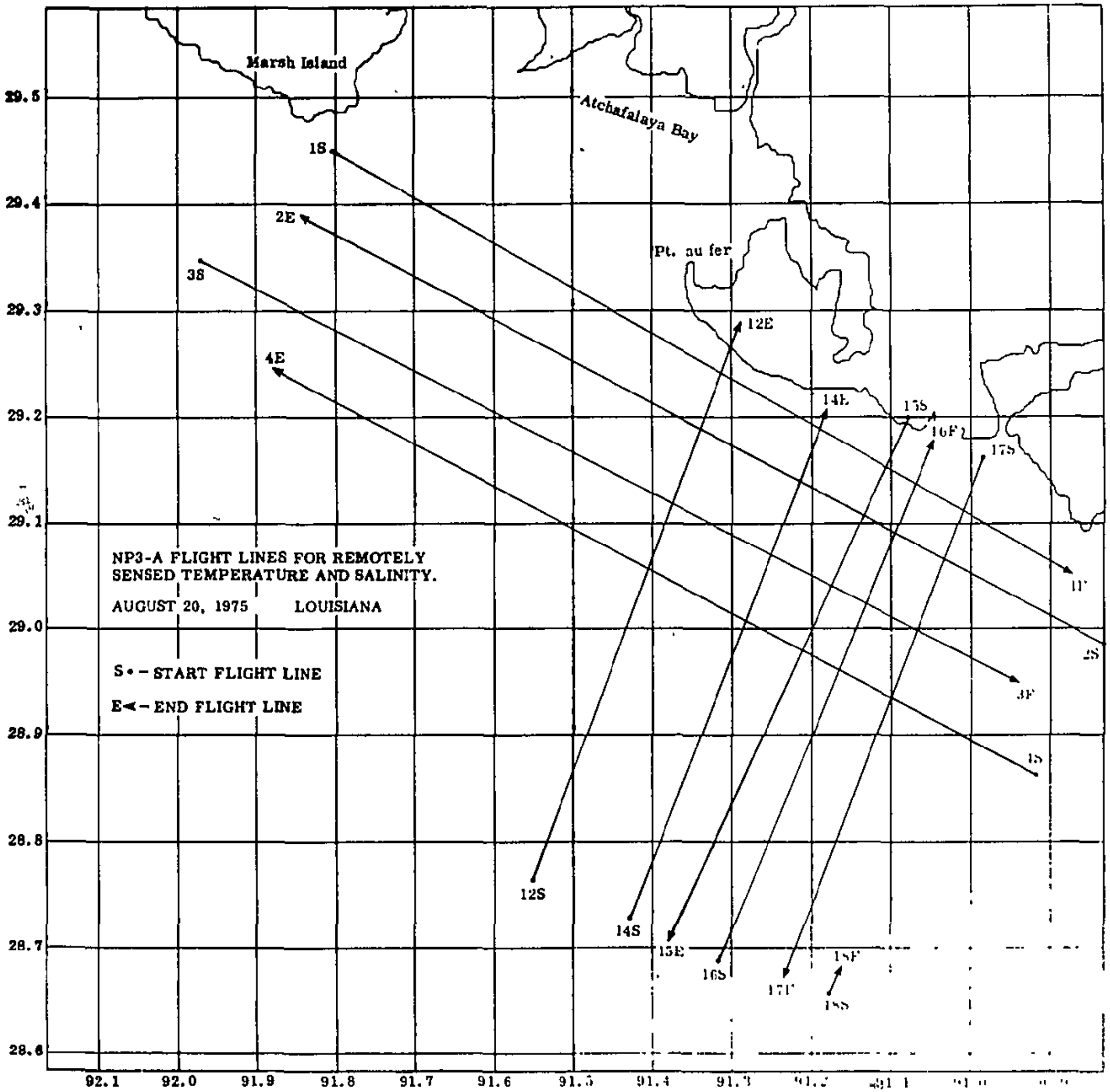

BEECHCRAFT FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE.
AUGUST 20, 1975
LOUISIANA
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
Marsh Island
Atchafalaya Bay
Pt. au fer
1E
1S
2S
2E
3S
3E
4S
4E
5S
5E
6S
6E
7S
7E
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9


NP3-A FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE AND SALINITY.
APRIL 25, 1975 LOUISIANA
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
Marsh Island
Atchafalaya Bay
Pt. au fer
1S
1E
2S
2E
3S
3E
4S
4E
11S
11E
13S
13E
14S
14E
15S
15E
16S
16E
17S
17E
18S
18E
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9



NP3-A FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE AND SALINITY.

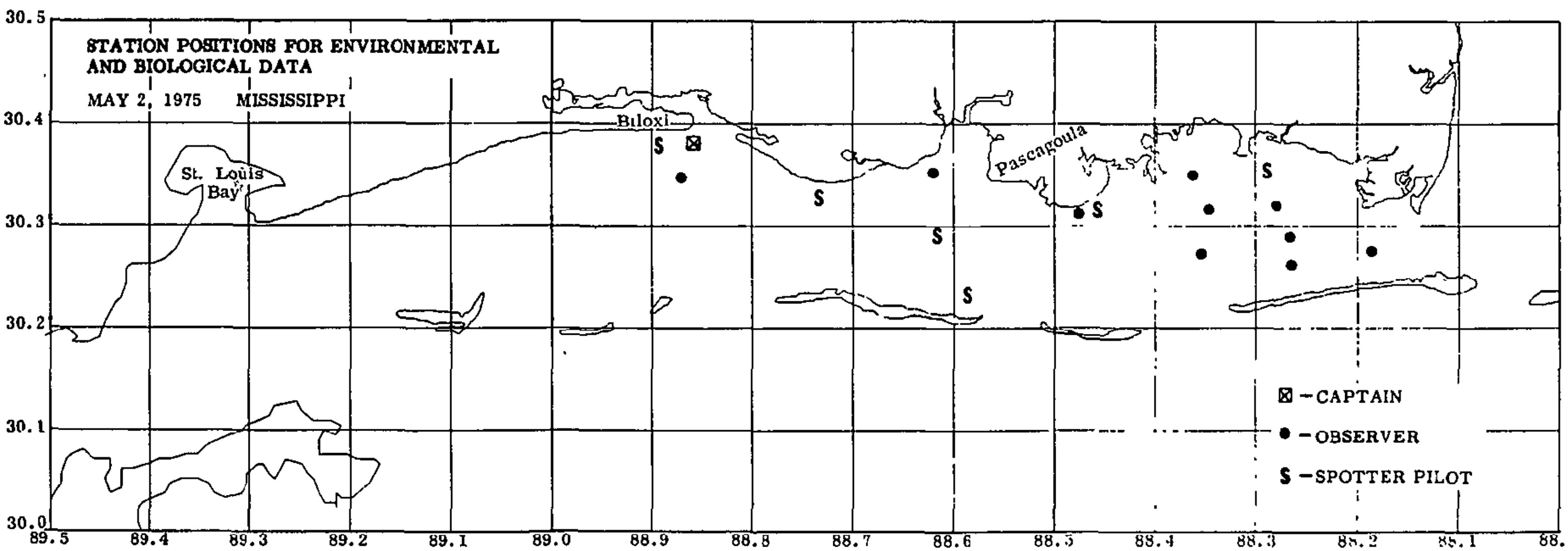
MAY 13, 1975 LOUISIANA

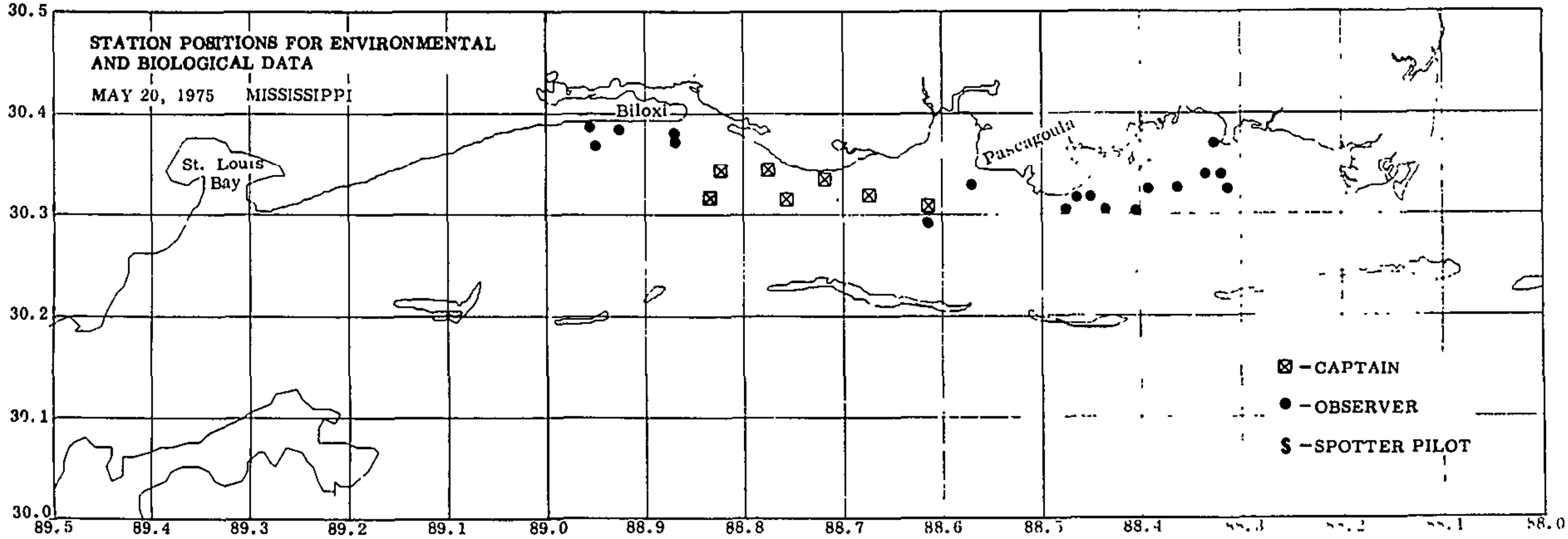

Marsh Island
Atchafalaya Bay
Pt. au fer
NP3-A FLIGHT LINES FOR REMOTELY SENSED TEMPERATURE AND SALINITY.
AUGUST 20, 1975
LOUISIANA
S• – START FLIGHT LINE
E◄ – END FLIGHT LINE
1S
2E
3S
4E
12E
14E
15S
17S
12S
14S
15E
16S
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.4

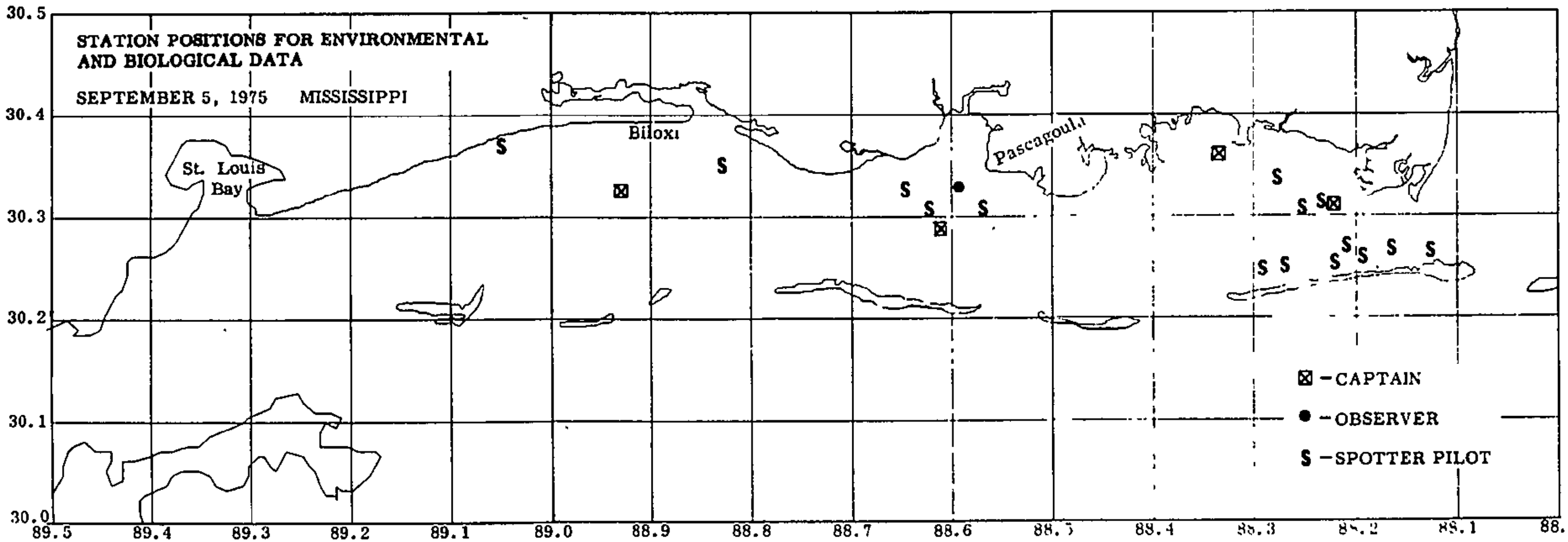
APPENDIX C

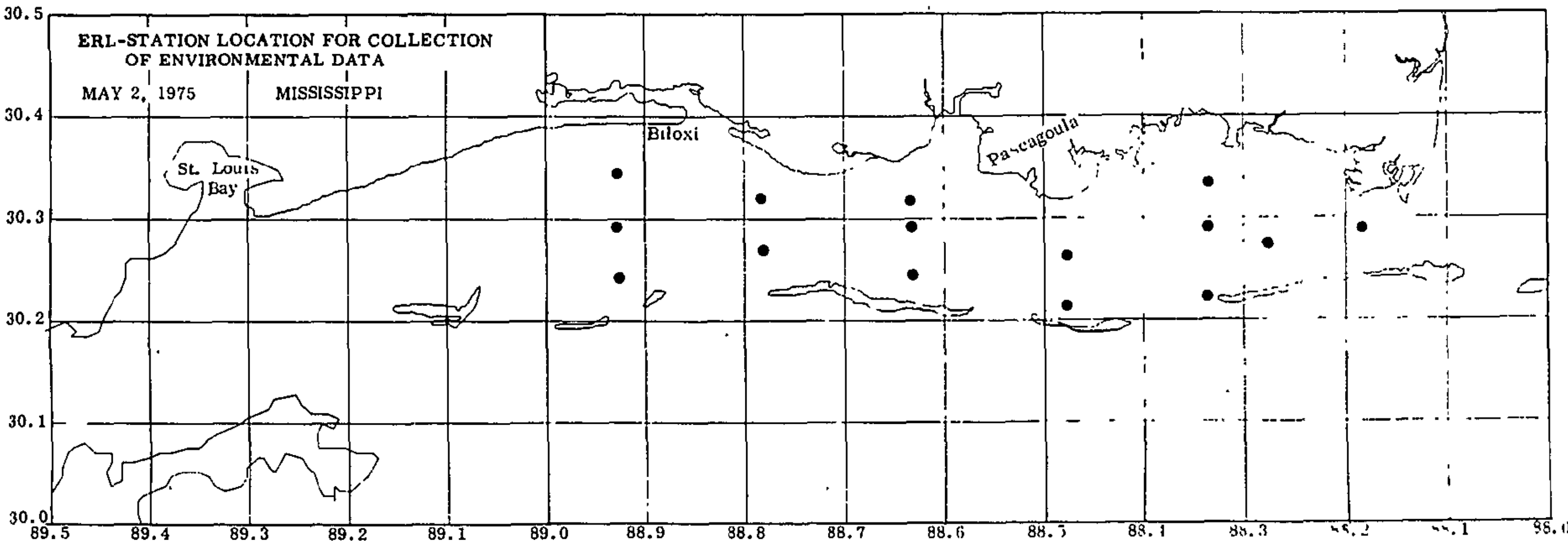
SURFACE TRUTH SUMMARY

1. Station Positions for Environmental and Biological Data - May 2, 1975 - Mississippi
2. Station Positions for Environmental and Biological Data - May 20, 1975 - Mississippi
3. Station Positions for Environmental and Biological Data - September 5, 1975 - Mississippi
4. ERL Station Location for Collection of Environmental Data - May 2, 1975 - Mississippi
5. ERL Station Location for Collection of Environmental Data - May 20, 1975 - Mississippi
6. ERL Station Location for Collection of Environmental Data - September 5, 1975 - Mississippi
7. Station Positions for Environmental and Biological Data - April 25, 1975 - Louisiana
8. Station Positions for Environmental and Biological Data - May 13, 1975 - Louisiana
9. Station Positions for Environmental and Biological Data - August 20, 1975 - Louisiana
10. ERL Station Location for Collection of Environmental Data - April 25, 1975 - Louisiana
11. ERL Station Location for Collection of Environmental Data - May 13, 1975 - Louisiana
12. ERL Station Location for Collection of Environmental Data - August 20, 1975 - Louisiana
13. Station Positions for Environmental and Biological Data - July 19, 1976 - Louisiana
14. Station Positions for Environmental and Biological Data - July 20, 1976 - Louisiana


STATION POSITIONS FOR ENVIRONMENTAL
AND BIOLOGICAL DATA
MAY 2, 1975 MISSISSIPPI
St. Louis Bay
Biloxi
Pascagoula
⊠ – CAPTAIN
● – OBSERVER
S – SPOTTER PILOT
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.4
88.3
88.2
88.1
88.0


STATION POSITIONS FOR ENVIRONMENTAL
AND BIOLOGICAL DATA
MAY 20, 1975 MISSISSIPPI
St. Louis
Bay
Biloxi
Pascagoula
⊠ −CAPTAIN
● −OBSERVER
S −SPOTTER PILOT
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.4


STATION POSITIONS FOR ENVIRONMENTAL
AND BIOLOGICAL DATA
SEPTEMBER 5, 1975 MISSISSIPPI
St. Louis
Bay
Biloxi
⊠ – CAPTAIN
● – OBSERVER
S – SPOTTER PILOT
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.0



ERL-STATION LOCATION FOR COLLECTION
OF ENVIRONMENTAL DATA
MAY 2, 1975
MISSISSIPPI
St. Louis Bay
Biloxi
Pascagoula
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.4
88.3
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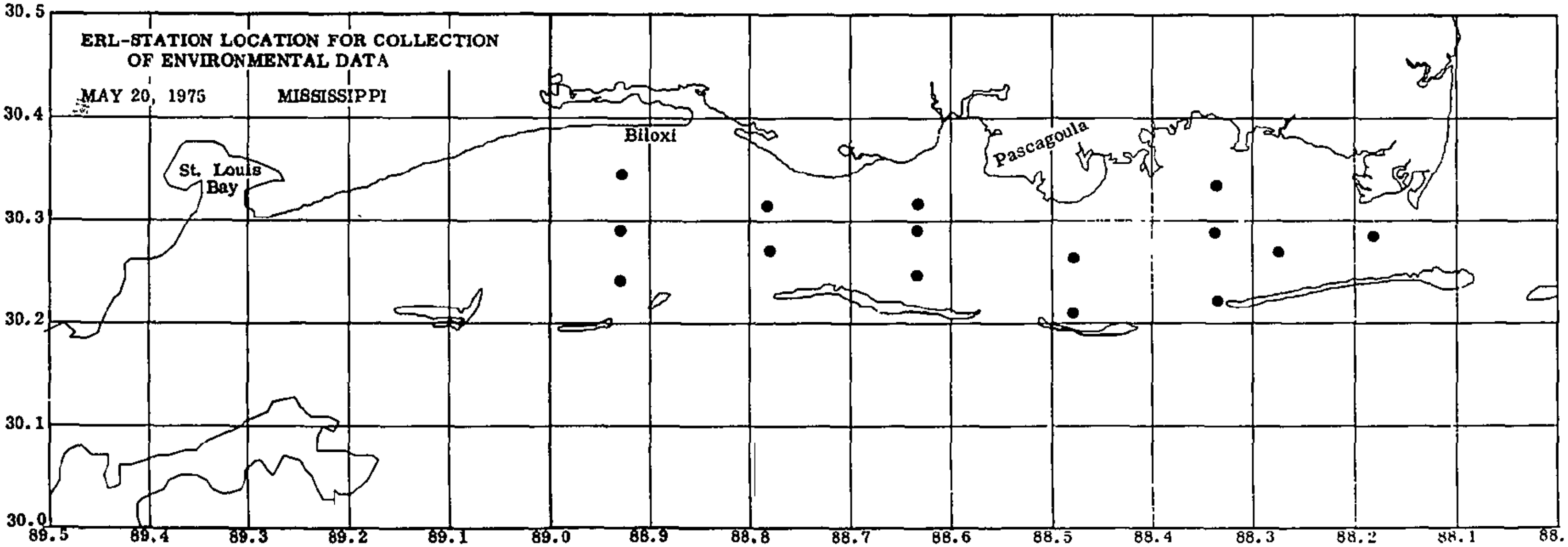
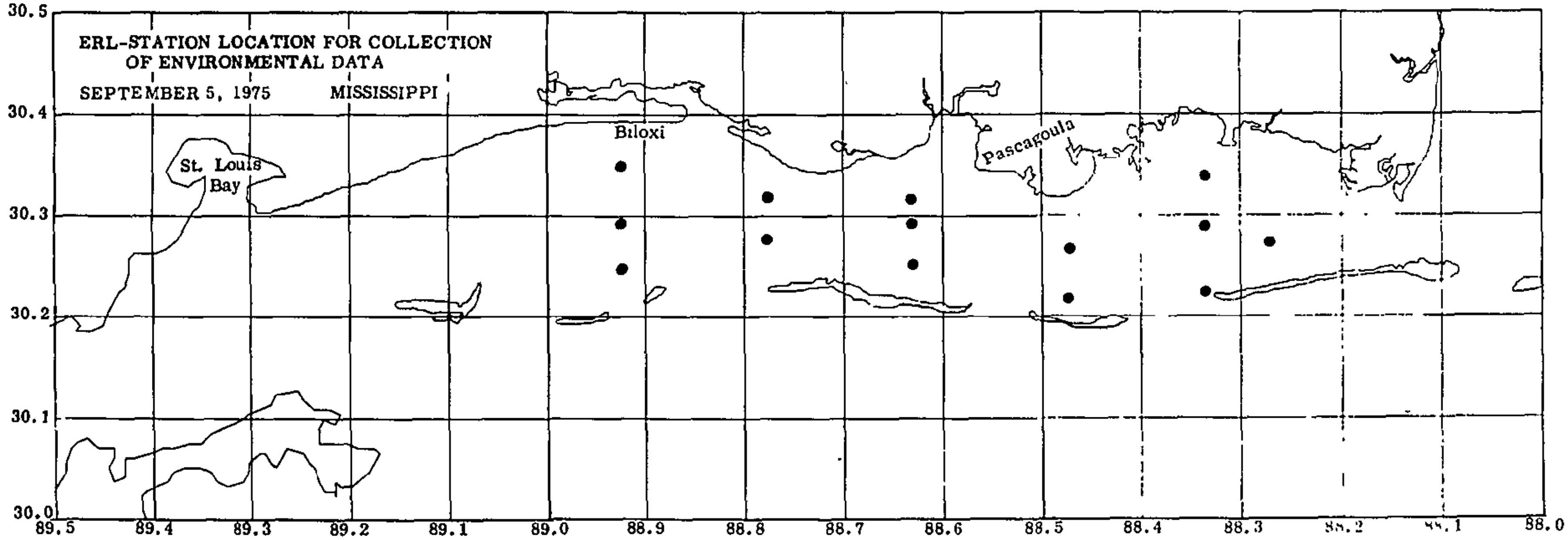
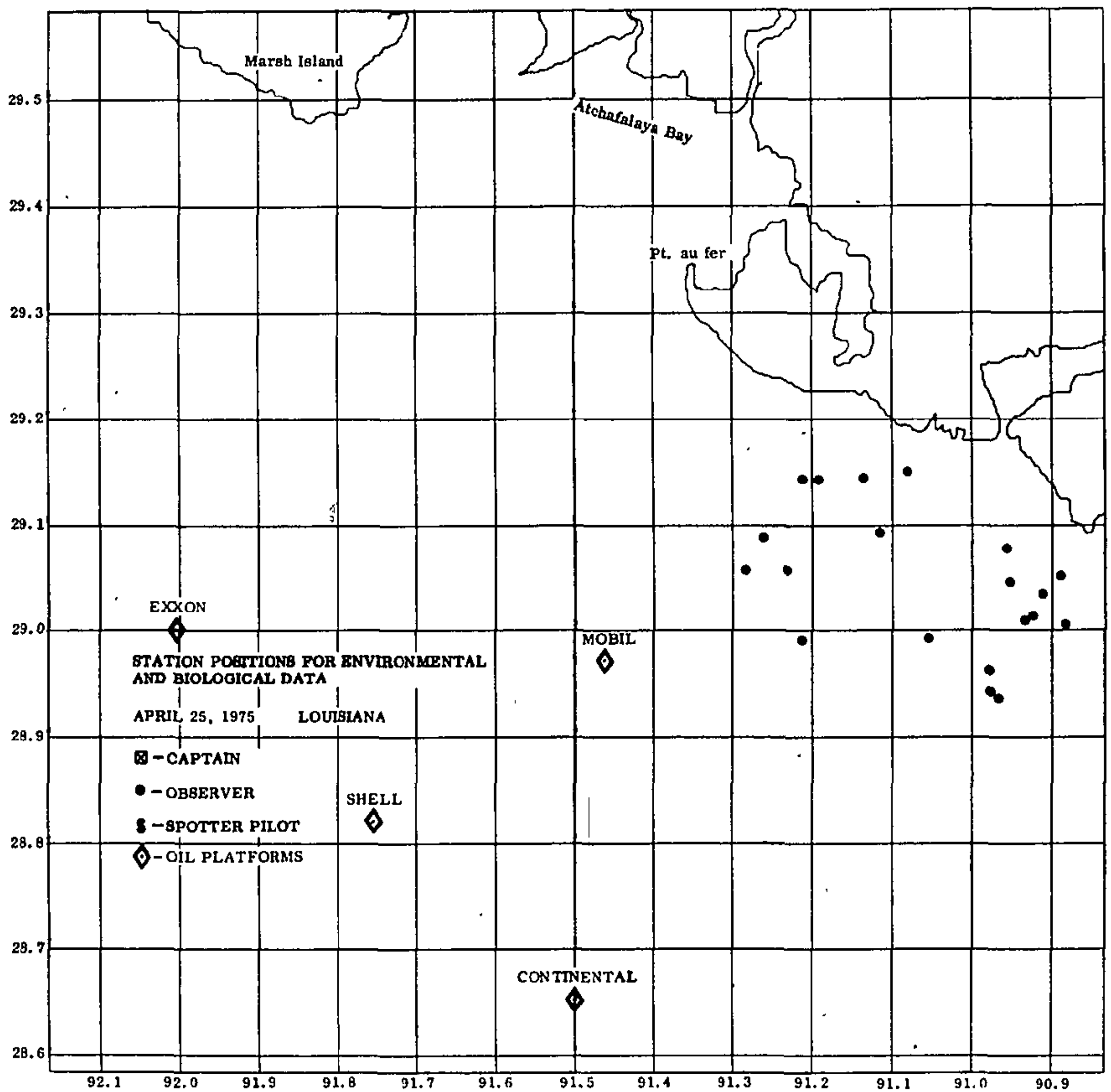
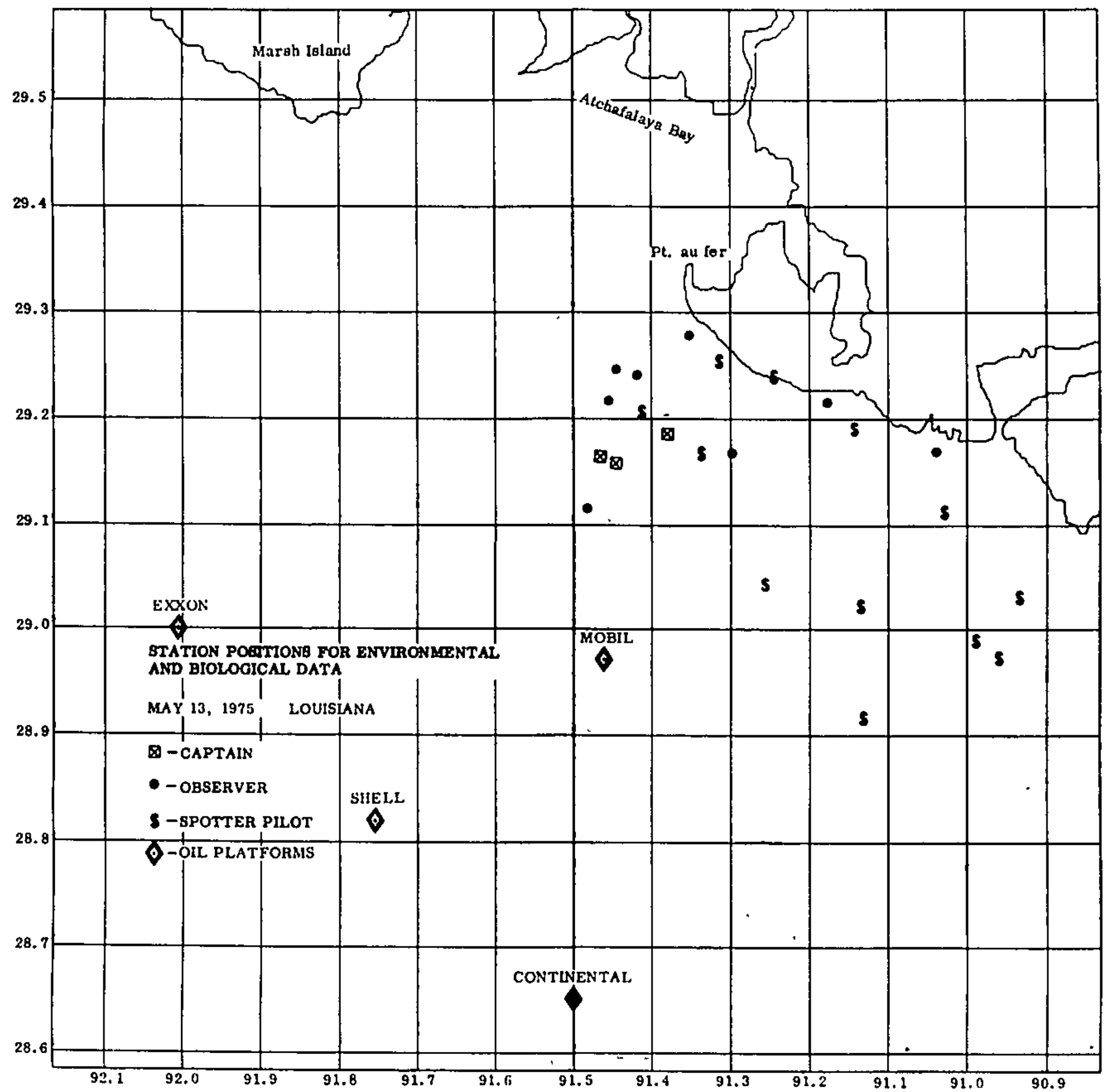
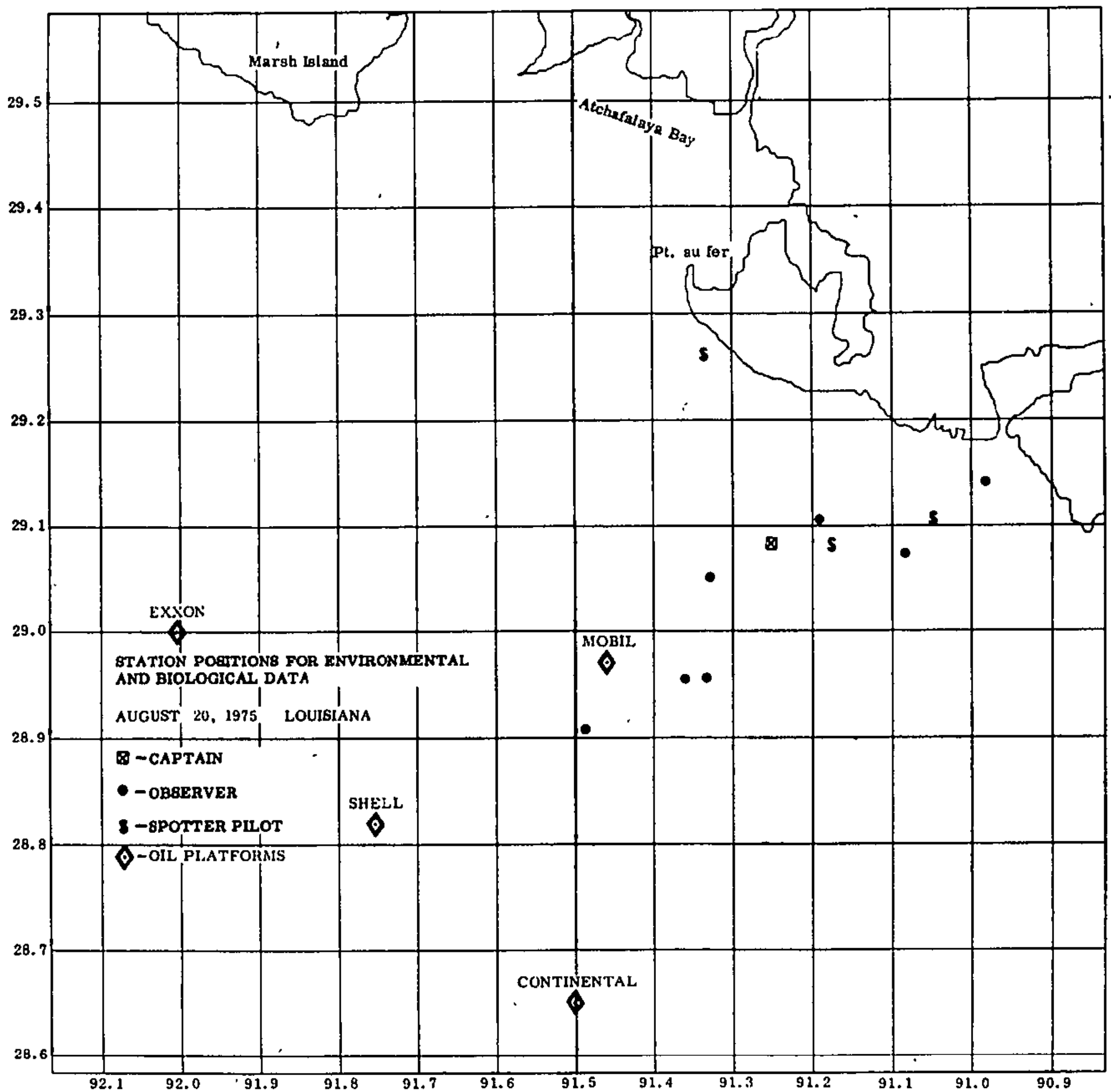
88.1
88.0


ERL-STATION LOCATION FOR COLLECTION
OF ENVIRONMENTAL DATA
MAY 20, 1975
MISSISSIPPI
St. Louis
Bay
Biloxi
Pascagoula
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.4
88.3
88.2
88.1
88.0


ERL-STATION LOCATION FOR COLLECTION
OF ENVIRONMENTAL DATA
SEPTEMBER 5, 1975
MISSISSIPPI
St. Louis
Bay
Biloxi
Pascagoula
30.5
30.4
30.3
30.2
30.1
30.0
89.5
89.4
89.3
89.2
89.1
89.0
88.9
88.8
88.7
88.6
88.5
88.4
88.3
88.0


Marsh Island
Atchafalaya Bay
Pt. au fer
EXXON
MOBIL
SHELL
CONTINENTAL
STATION POSITIONS FOR ENVIRONMENTAL
AND BIOLOGICAL DATA
APRIL 25, 1975
LOUISIANA
⊠ - CAPTAIN
● - OBSERVER
$ - SPOTTER PILOT
◇ - OIL PLATFORMS
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9


Marsh Island
Atchafalaya Bay
Pt. au fer
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9
EXXON
MOBIL
SHELL
CONTINENTAL
STATION POSITIONS FOR ENVIRONMENTAL AND BIOLOGICAL DATA
MAY 13, 1975 LOUISIANA
– CAPTAIN
– OBSERVER
– SPOTTER PILOT
– OIL PLATFORMS


Marsh Island
Atchafalaya Bay
Pt. au fer
EXXON
MOBIL
SHELL
CONTINENTAL
STATION POSITIONS FOR ENVIRONMENTAL AND BIOLOGICAL DATA
AUGUST 20, 1975 LOUISIANA
⊠ –CAPTAIN
● –OBSERVER
$ –SPOTTER PILOT
◈ –OIL PLATFORMS
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
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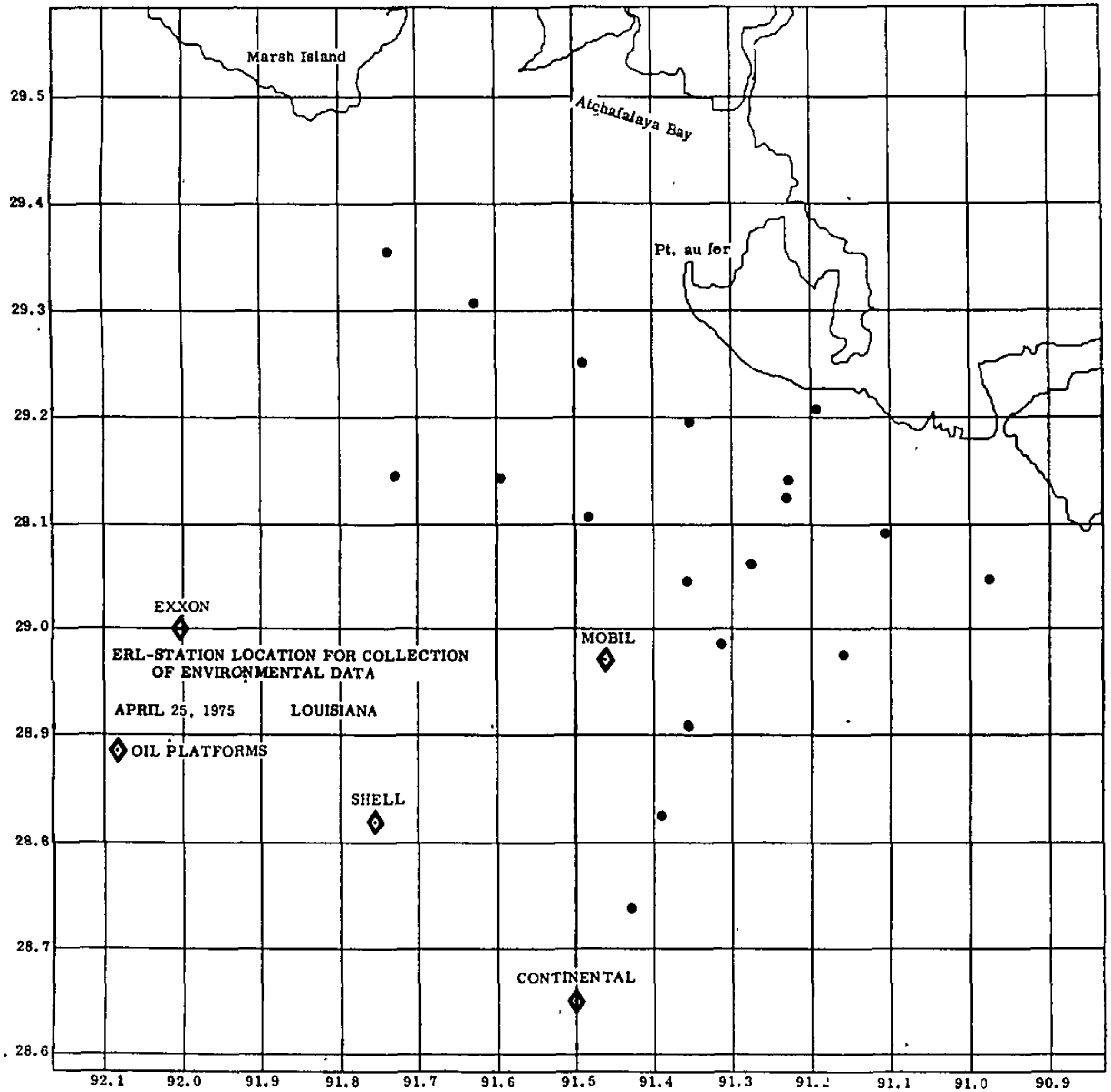
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9


Marsh Island
Atchafalaya Bay
Pt. au fer
EXXON
MOBIL
ERL-STATION LOCATION FOR COLLECTION
OF ENVIRONMENTAL DATA
APRIL 25, 1975
LOUISIANA
OIL PLATFORMS
SHELL
CONTINENTAL
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9

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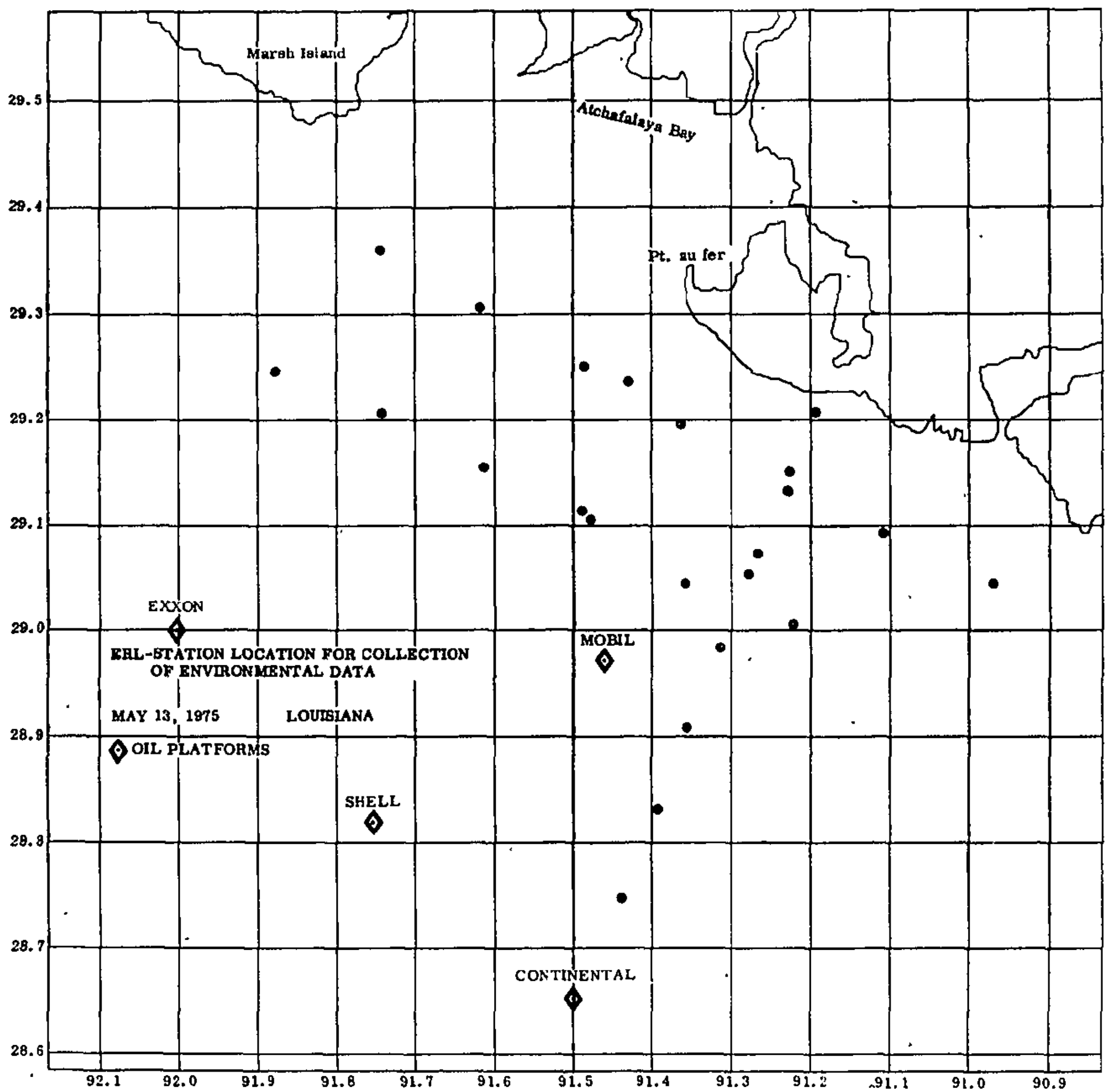
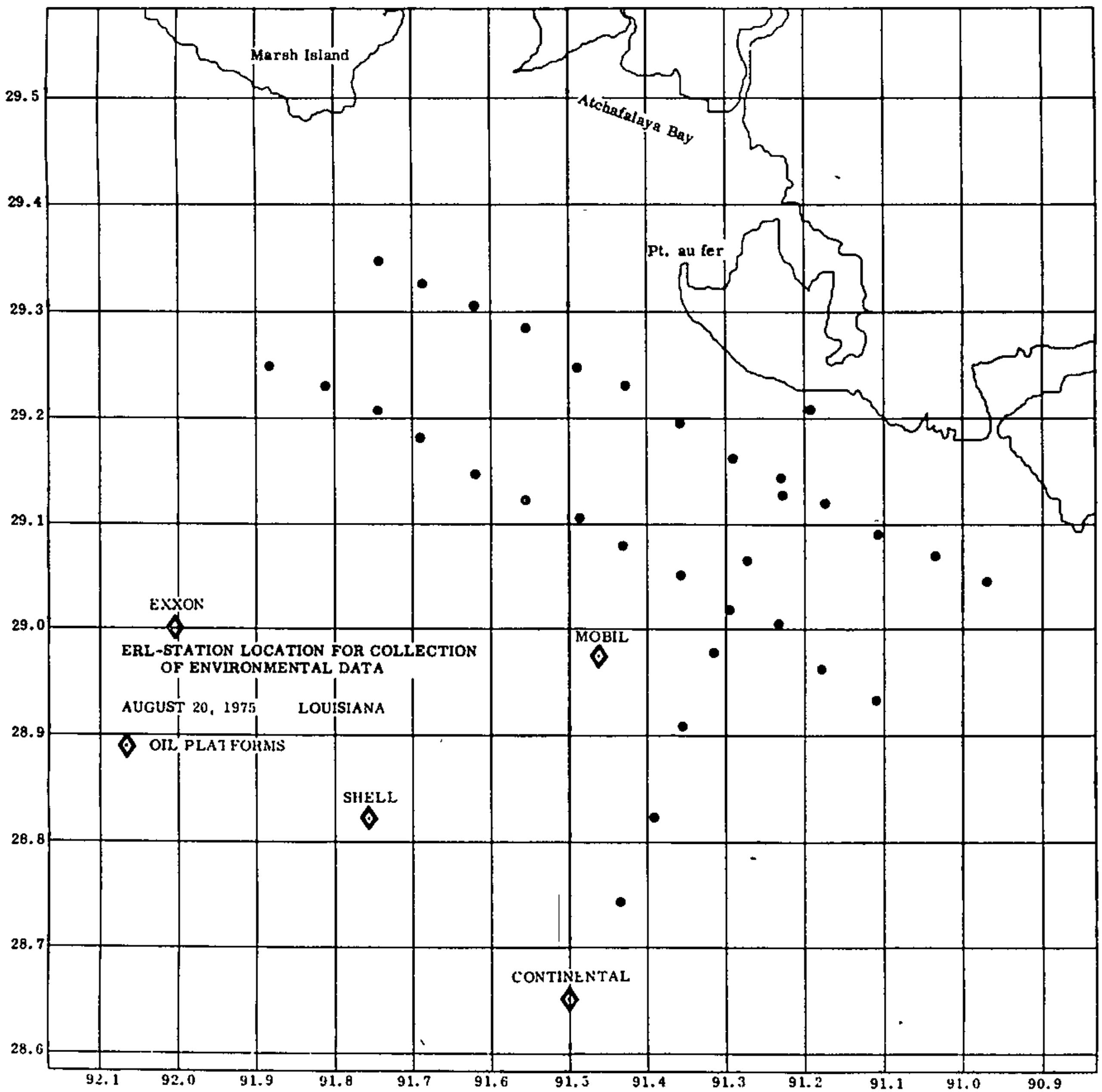
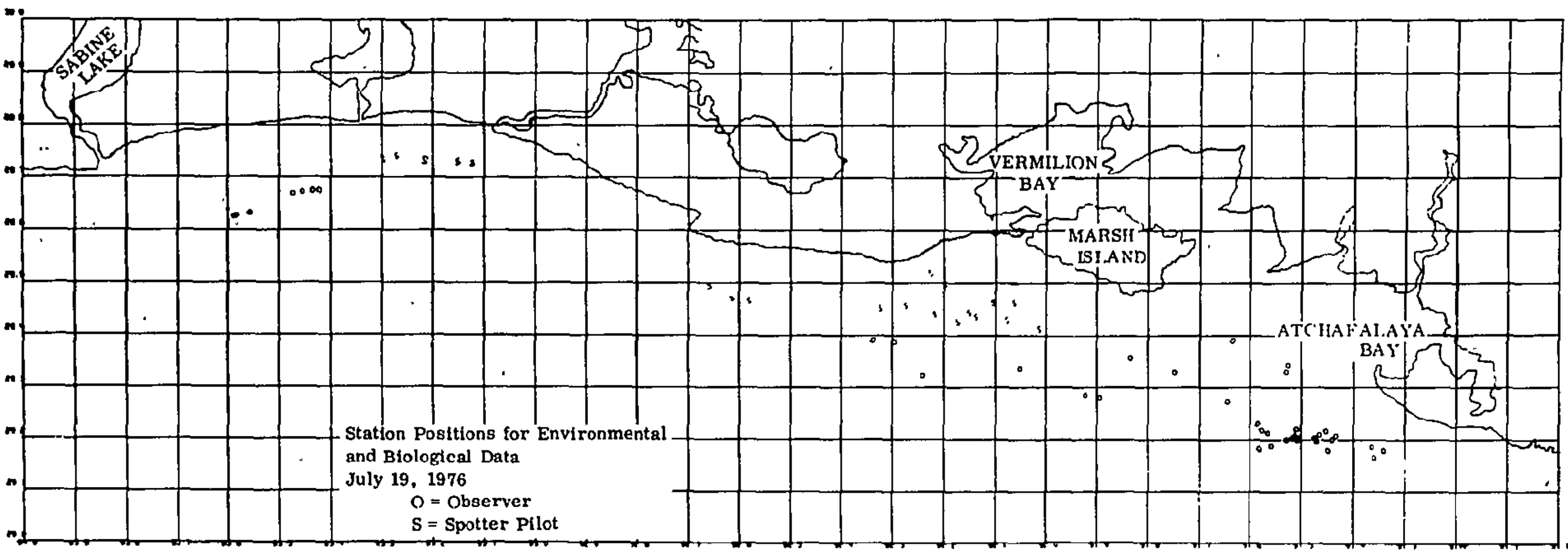
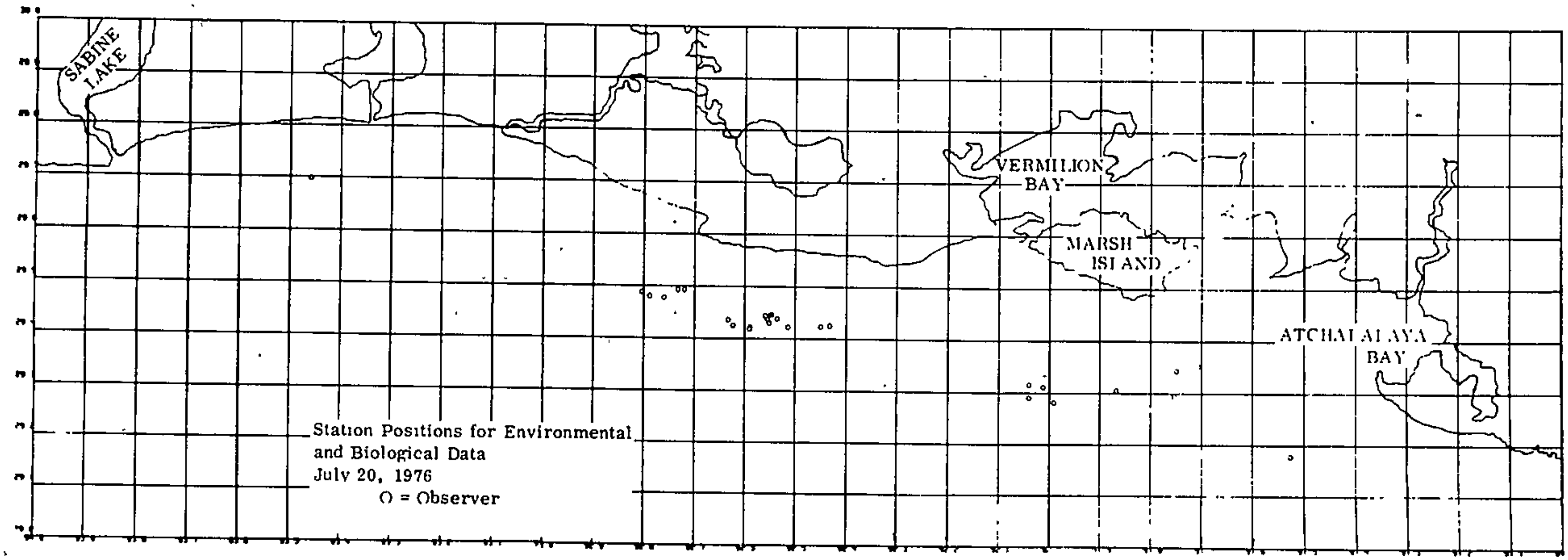



Marsh Island
Atchafalaya Bay
Pt. au fer
EXXON
MOBIL
SHELL
CONTINENTAL
ERL-STATION LOCATION FOR COLLECTION
OF ENVIRONMENTAL DATA
AUGUST 20, 1975 LOUISIANA
OIL PLATFORMS
29.5
29.4
29.3
29.2
29.1
29.0
28.9
28.8
28.7
28.6
92.1
92.0
91.9
91.8
91.7
91.6
91.5
91.4
91.3
91.2
91.1
91.0
90.9



Station Positions for Environmental
and Biological Data
July 19, 1976
O = Observer
S = Spotter Pilot



Station Positions for Environmental and Biological Data
July 20, 1976
O = Observer

APPENDIX D

CONTOURS OF SURFACE OCEANOGRAPHIC PARAMETERS

I. Data Acquired from Vessels

A. Louisiana Study Area

1. Temperature (^{o}C) April 25, 1975
2. Salinity (ppt) April 25, 1975
3. Chlorophyll (mg/m^3) April 25, 1975
4. Water Color (Forel-Ule indicator units) April 25, 1975
5. Sun Secchi Depths (ft.) April 25, 1975
6. Temperature (^{o}C) May 13, 1975
7. Salinity (ppt) May 13, 1975
8. Chlorophyll (mg/m^3) May 13, 1975
9. Water Color (Forel-Ule indicator units) May 13, 1975
10. Sun Secchi Depth (ft.) May 13, 1975
11. Temperature (^{o}C) August 20, 1975
12. Salinity (ppt) August 20, 1975
13. Chlorophyll (mg/m^3) August 20, 1975
14. Water Color (Forel-Ule indicator units) August 20, 1975
15. Sun Secchi Depth (ft.) August 20, 1975

B. Mississippi Study Area

16. Temperature (^{o}C) May 2, 1975
17. Salinity (ppt) May 2, 1975
18. Chlorophyll (mg/m^3) May 2, 1975
19. Water Color (Forel-Ule indicator units) May 2, 1975
20. Shade Secchi Depth (ft.) May 2, 1975
21. Sun Secchi Depth (ft.) May 2, 1975
22. Temperature (^{o}C) May 20, 1975
23. Salinity (ppt) May 20, 1975
24. Chlorophyll (mg/m^3) May 20, 1975
25. Water Color (Forel-Ule indicator units) May 20, 1975
26. Shade Secchi Depth (ft.) May 20, 1975
27. Sun Secchi Depth (ft.) May 20, 1975
28. Temperature (^{o}C) September 5, 1975
29. Salinity (ppt) September 5, 1975
30. Chlorophyll (mg/m^3) September 5, 1975
31. Water Color (Forel-Ule indicator units) September 5, 1975
32. Shade Secchi Depth (ft.) September 5, 1975
33. Sun Secchi Depth (ft.) September 5, 1975

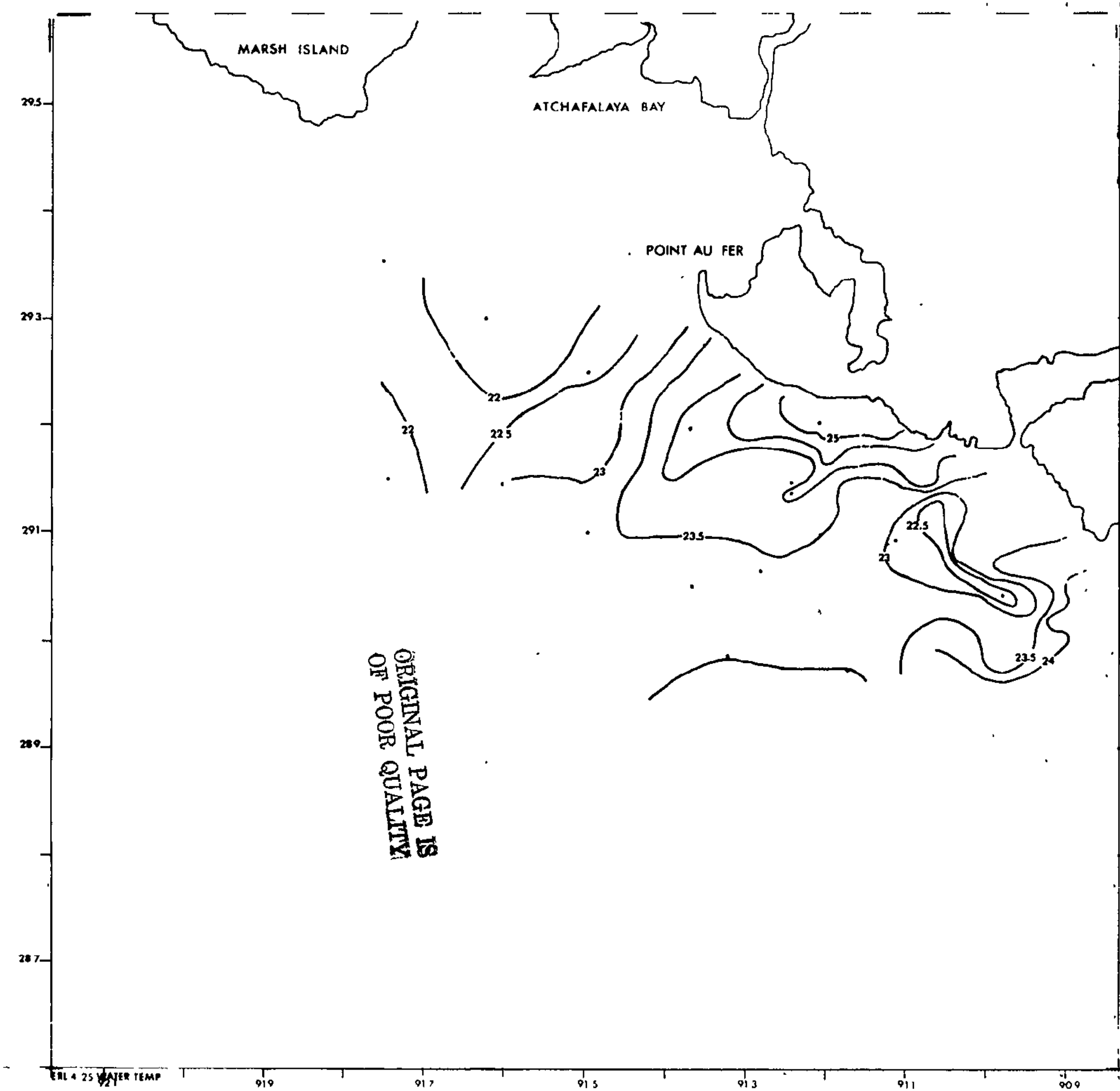
II. Remotely Sensed Data Acquired from Aircraft

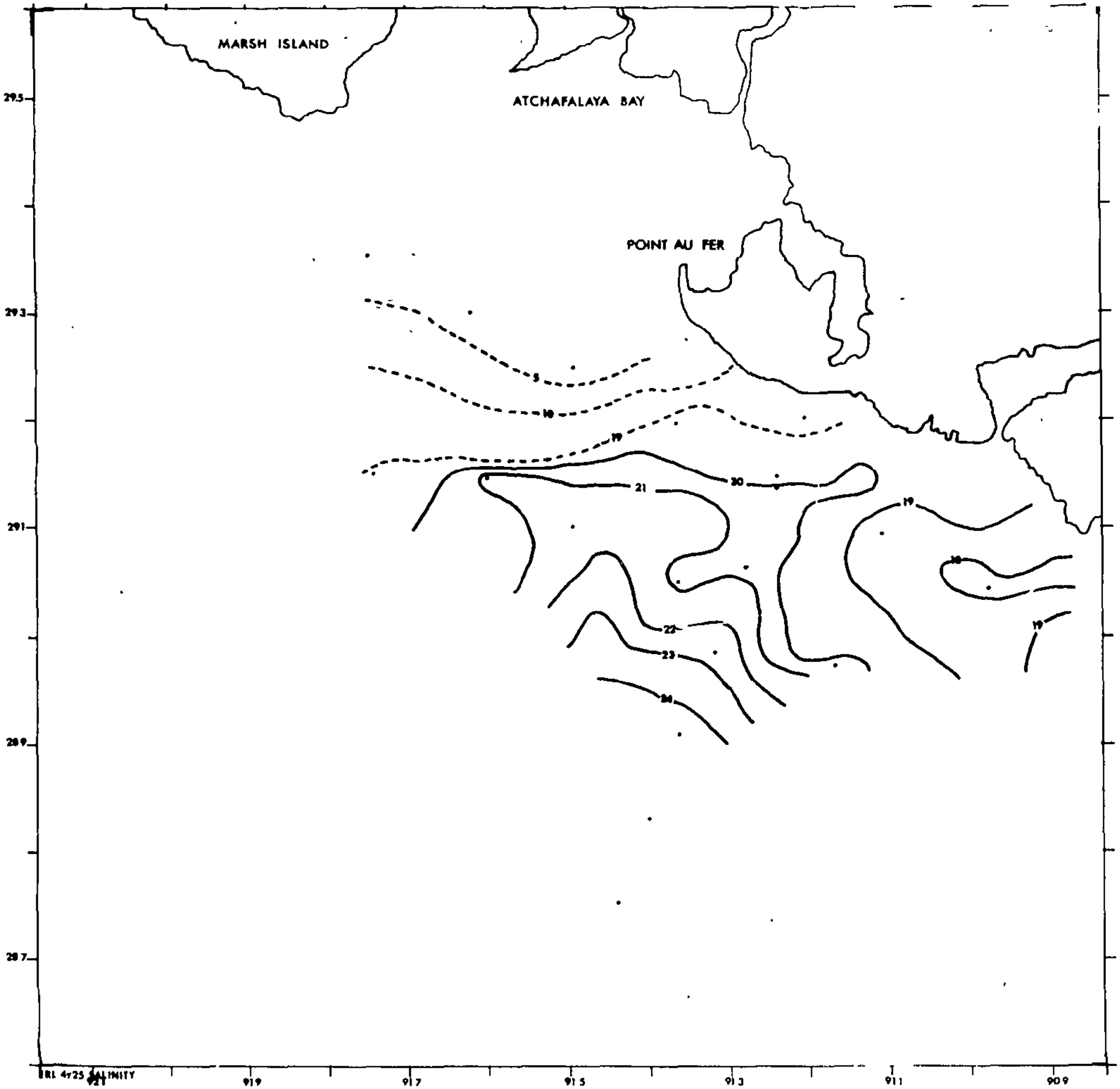
A. Mississippi Study Area

34. Temperature (^{o}C) May 2, 1975
35. Temperature (^{o}C) May 20, 1975
36. Salinity (ppt) May 20, 1975
37. Temperature (^{o}C) September 5, 1975
38. Salinity (ppt) September 5, 1975

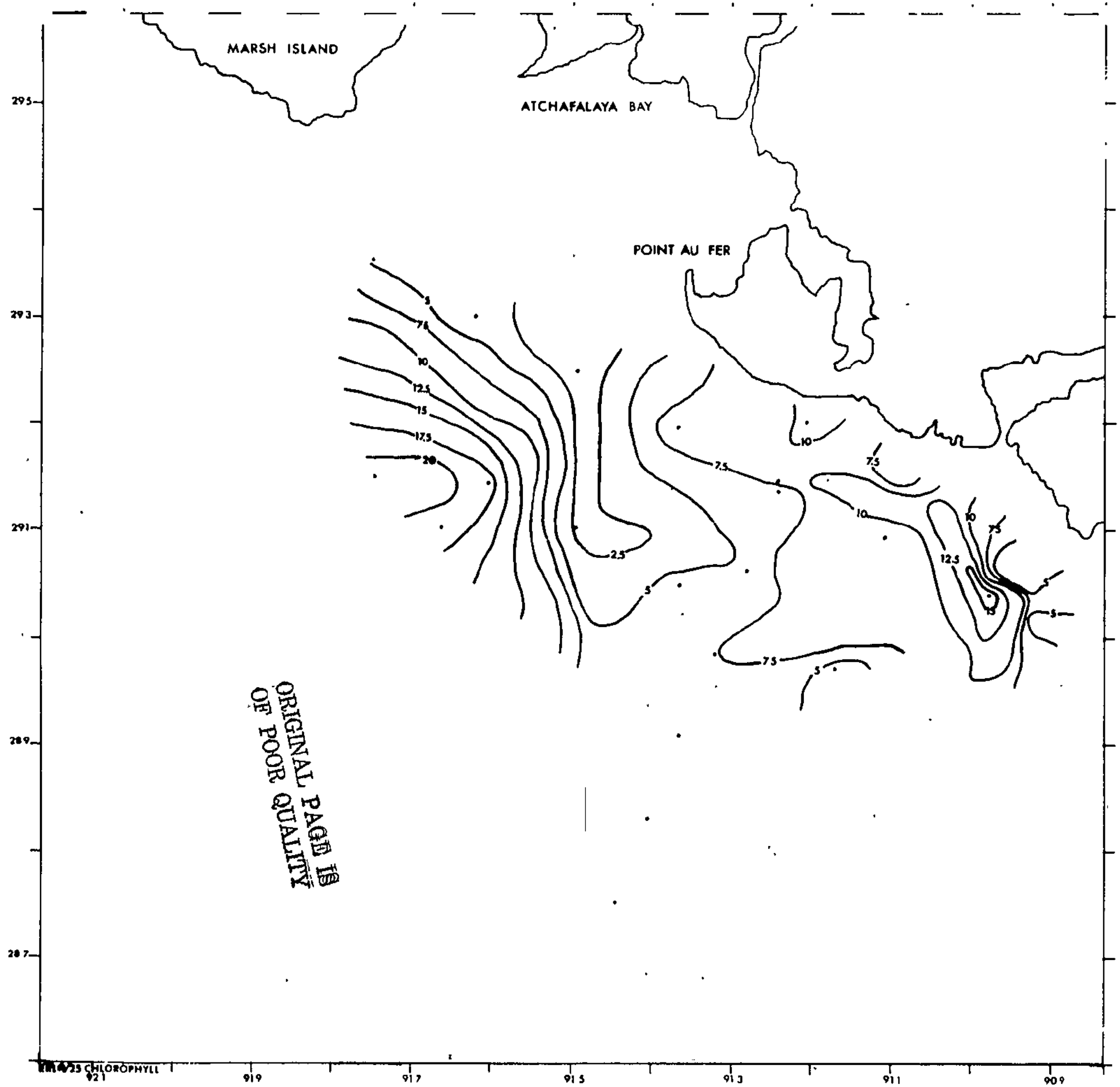
B. Louisiana Study Area

39. Temperature (^{o}C) April 25, 1975
40. Salinity (ppt) April 25, 1975
41. Temperature (^{o}C) May 13, 1975
42. Salinity (ppt) May 13, 1975
43. Temperature (^{o}C) August 20, 1975
44. Salinity (ppt) August 20, 1975


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
22
22
22.5
23
23.5
25
22.5
23
23.5
24
29.5
29.3
29.1
28.9
28.7
ERL 4 25 WATER TEMP
92.1
91.9
91.7
91.5
91.3
91.1
90.9



MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
29.5
29.3
29.1
28.9
28.7
5
10
19
20
21
22
23
24
18
ERL 4Y25 SALINITY
92.1
91.9
91.7
91.5
91.3
91.1
90.9


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
29.5
29.3
29.1
28.9
28.7
CHLOROPHYLL
92.1
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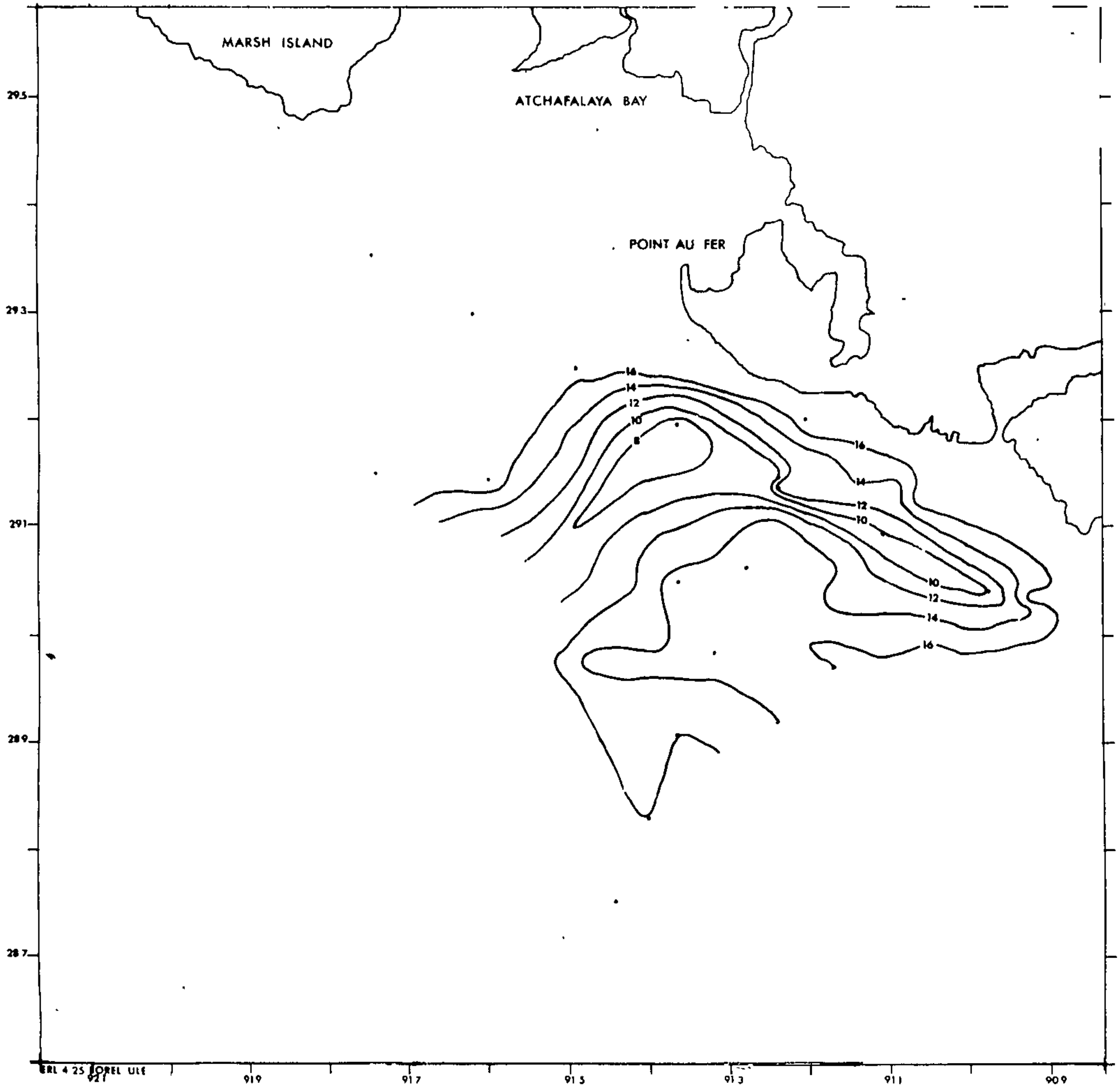
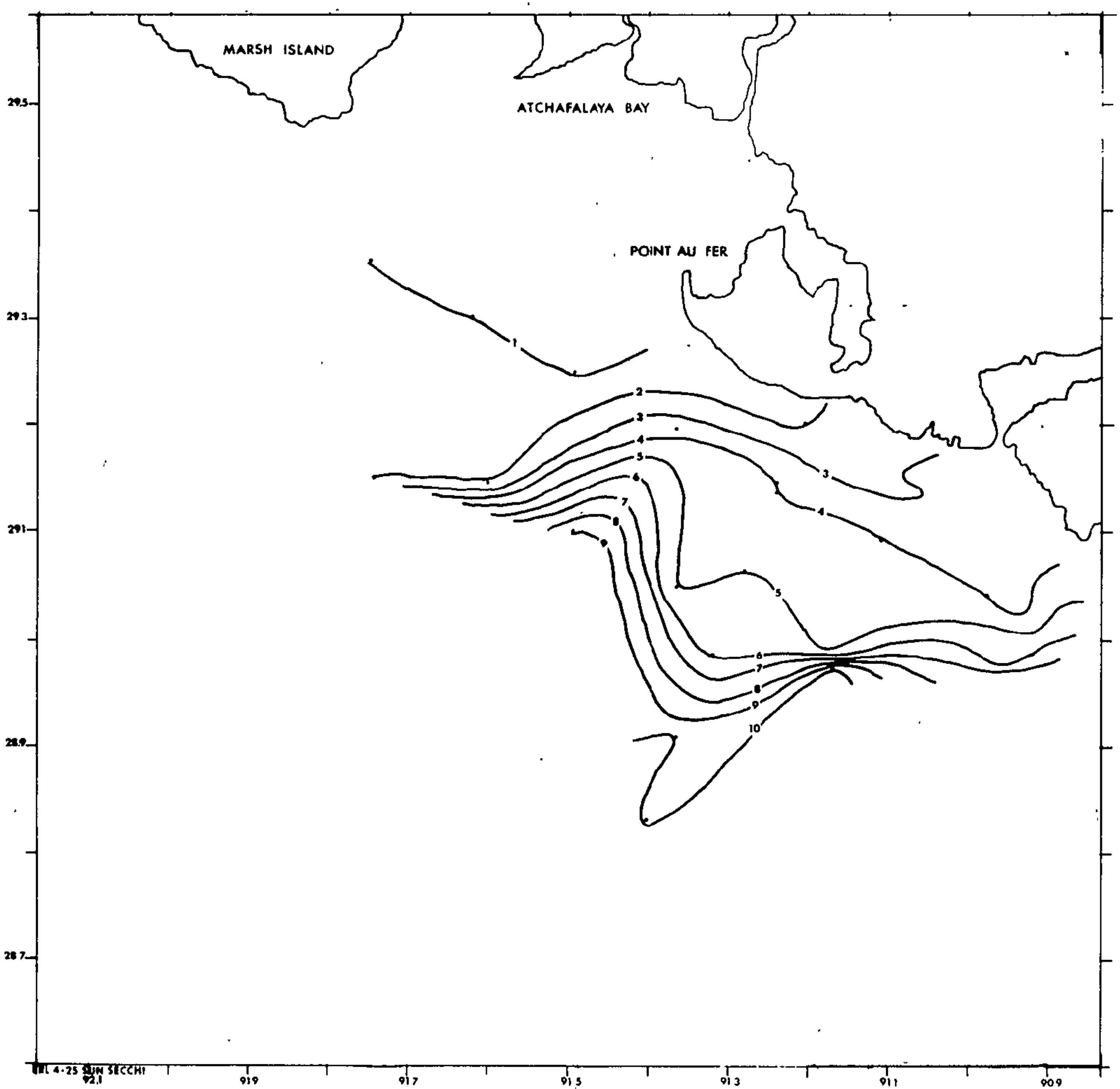
91.3
91.1
90.9


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
29.5
29.3
29.1
28.9
28.7
16
14
12
10
8
92.1
91.9
91.7
91.5
91.3
91.1
90.9



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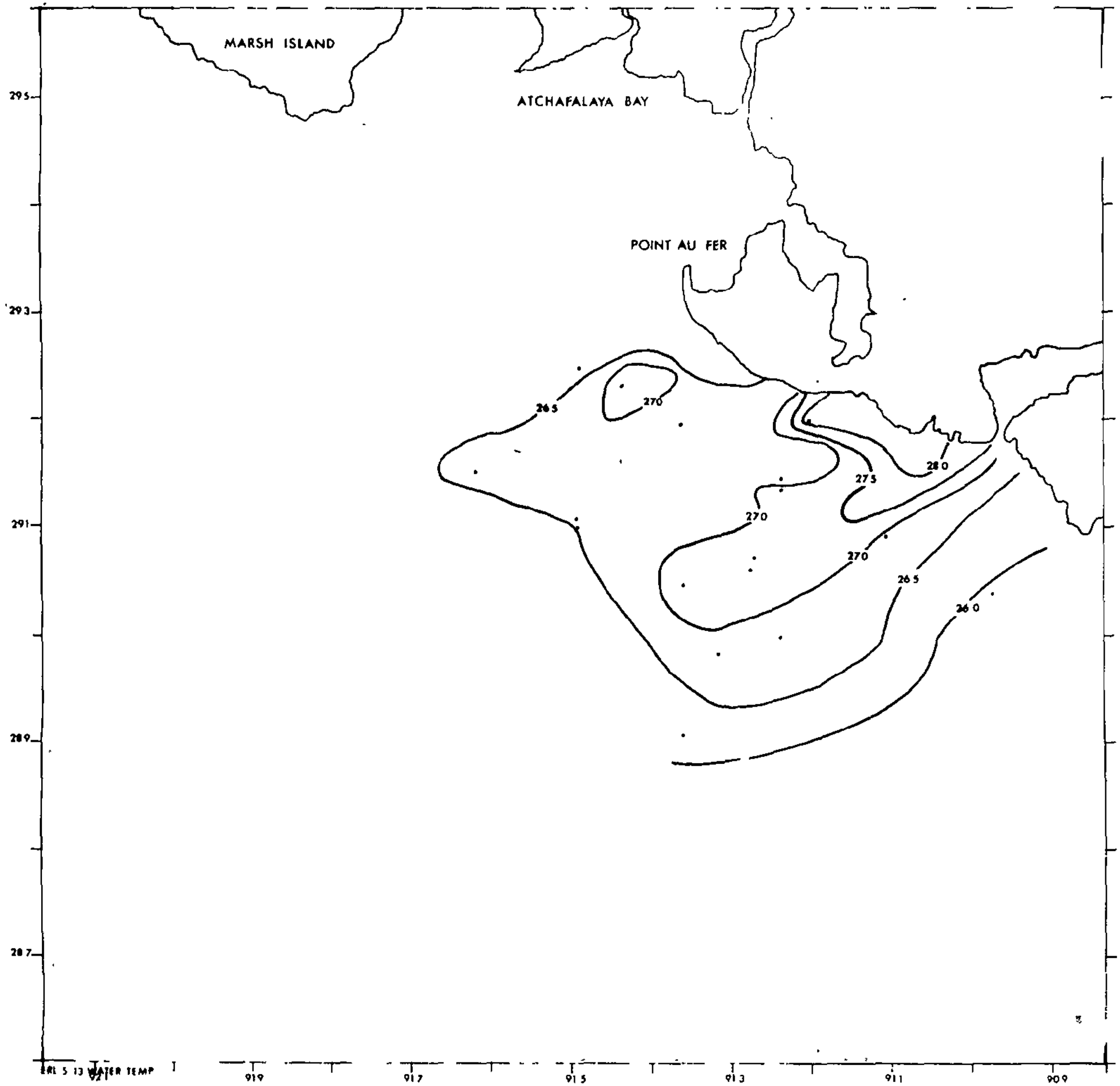
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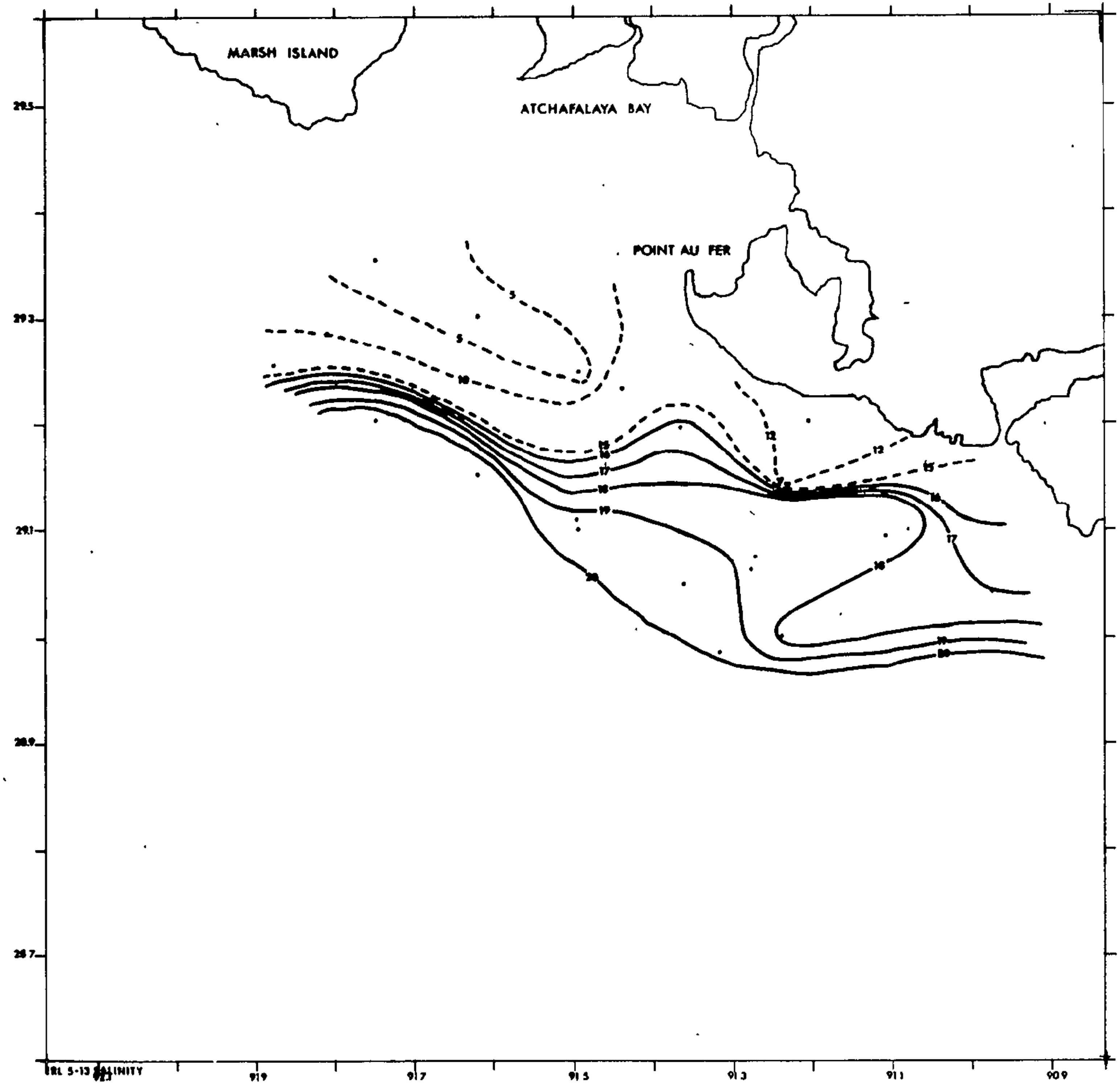
ATCHAFALAYA BAY
POINT AU FER
29 5
29 3
29 1
28 9
28 7
26 5
27 0
27 0
27 5
28 0
27 0
26 5
26 0
WATER TEMP
921
919
917
91 5
91 3
911
909



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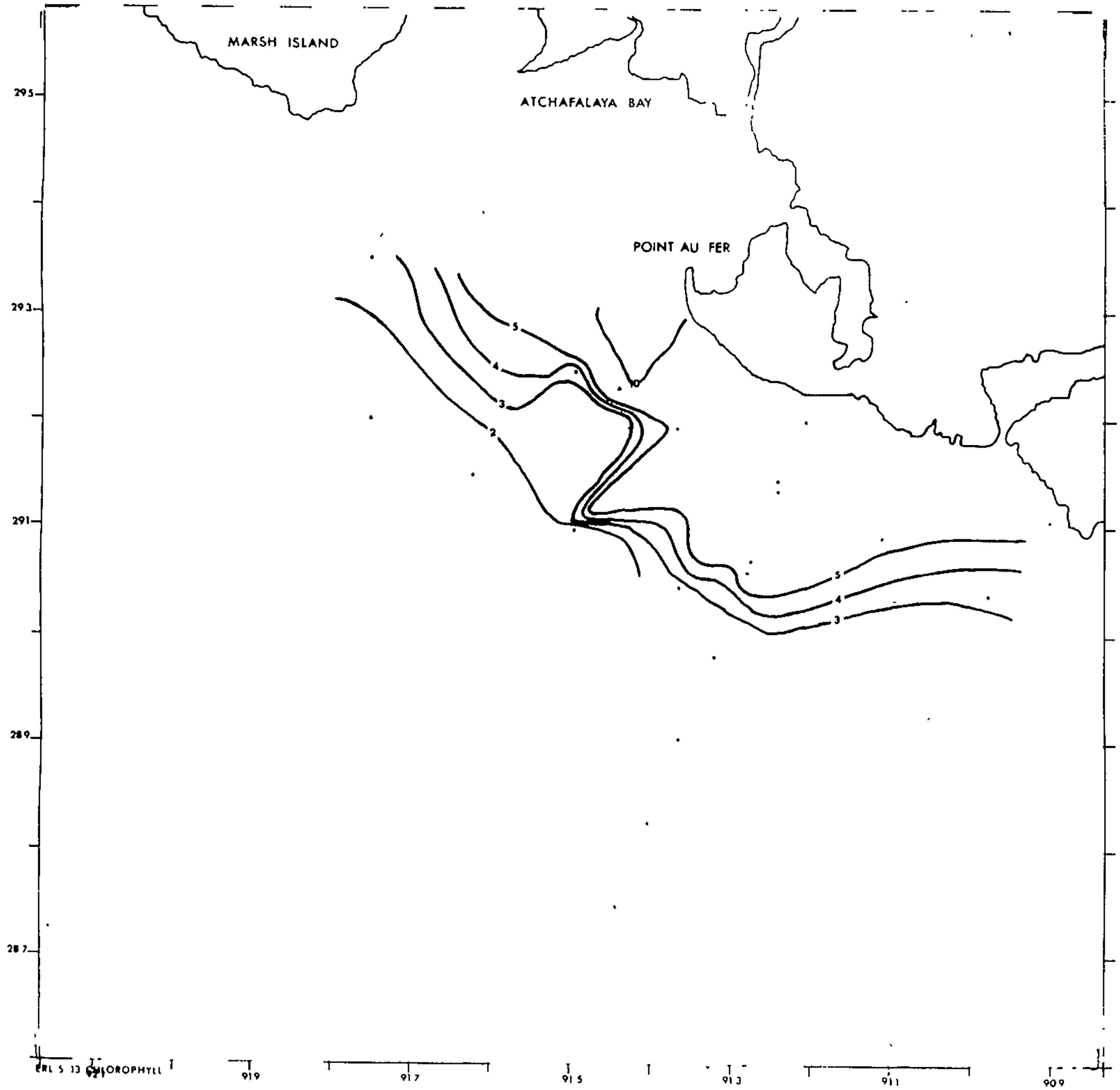
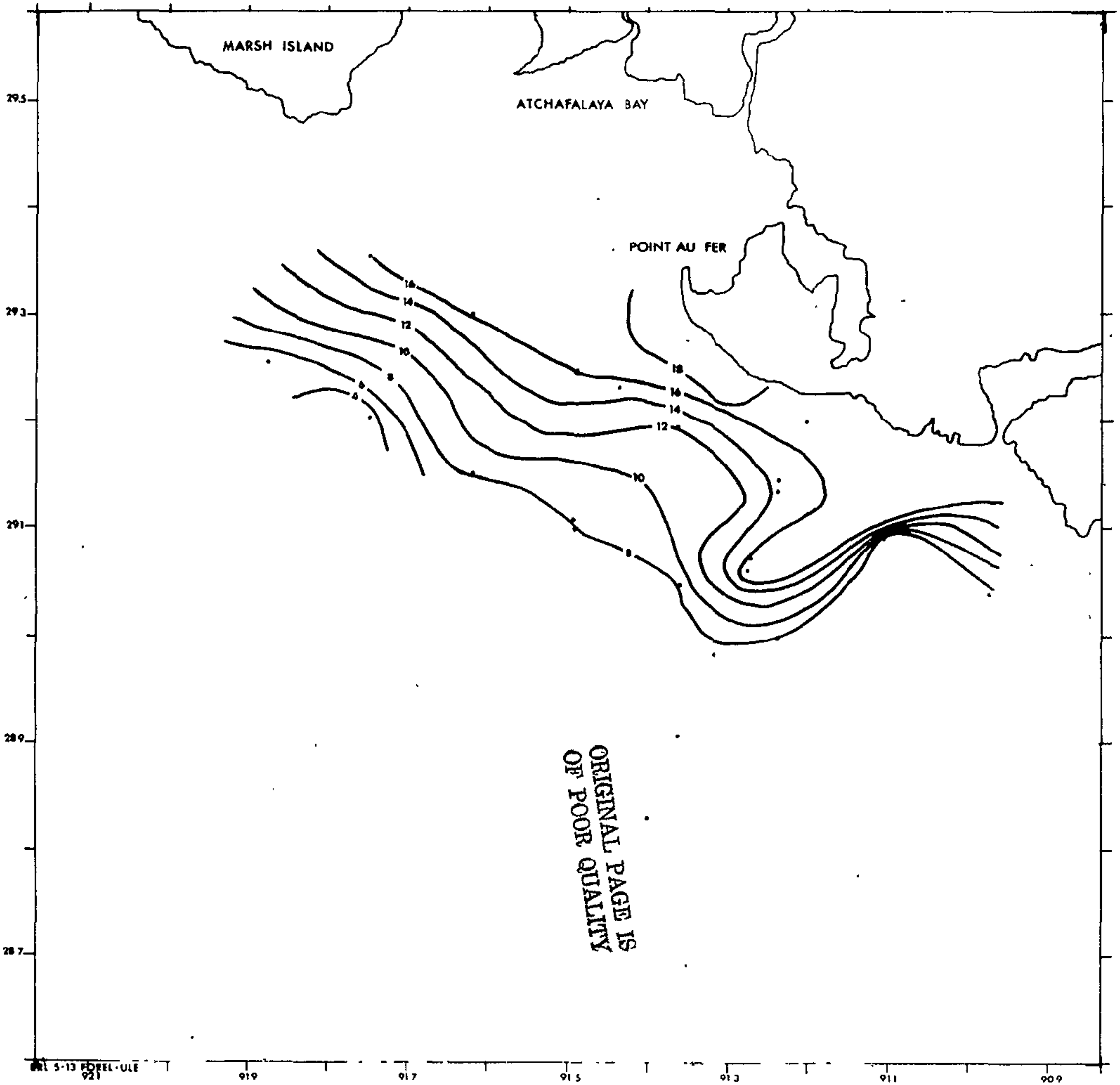

MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
29.5
29.3
29.1
28.9
28.7
5
4
3
2
10
91.9
91.7
91.5
91.3
91.1
90.9
ERL S 13 CHLOROPHYLL


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
29.5
29.3
29.1
28.9
28.7
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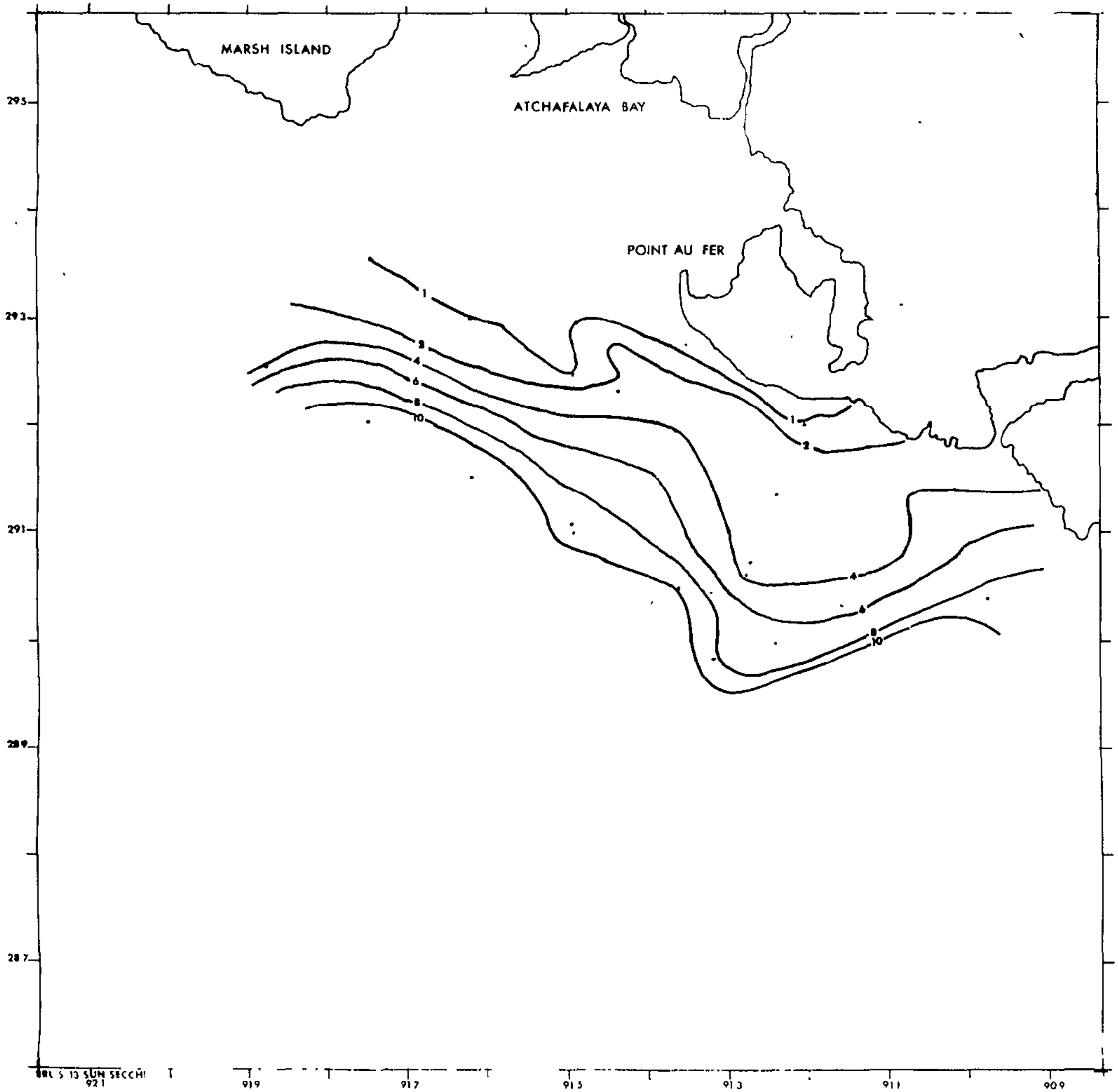
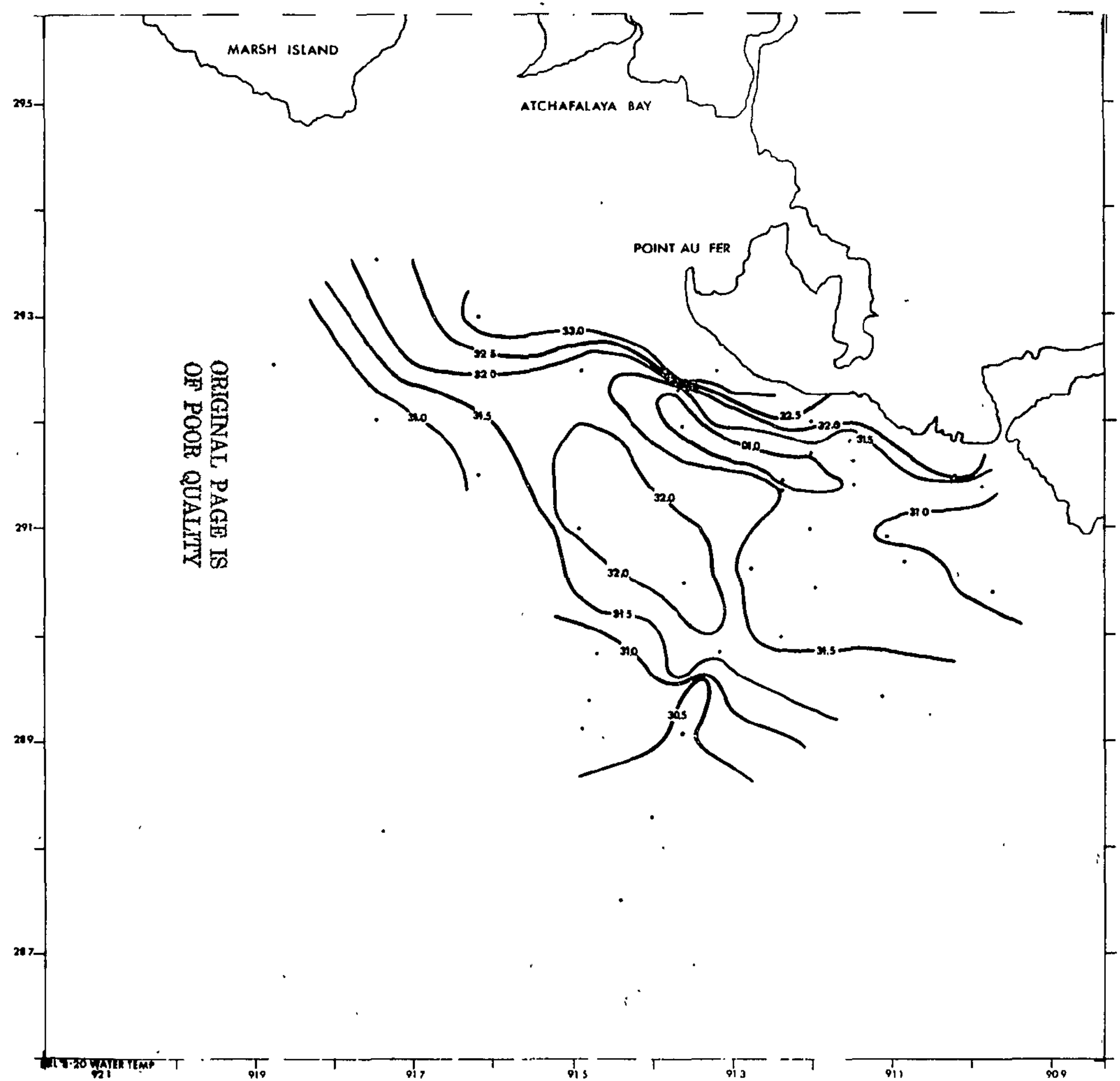
91.9
91.7
91.5
91.3
91.1
90.9
18
16
14
12
10
8
6
4


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
1
2
4
6
8
10
295
293
291
289
287
SUN SECCHI
921
919
917
915
913
911
909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ATCHAFALAYA BAY
POINT AU FER
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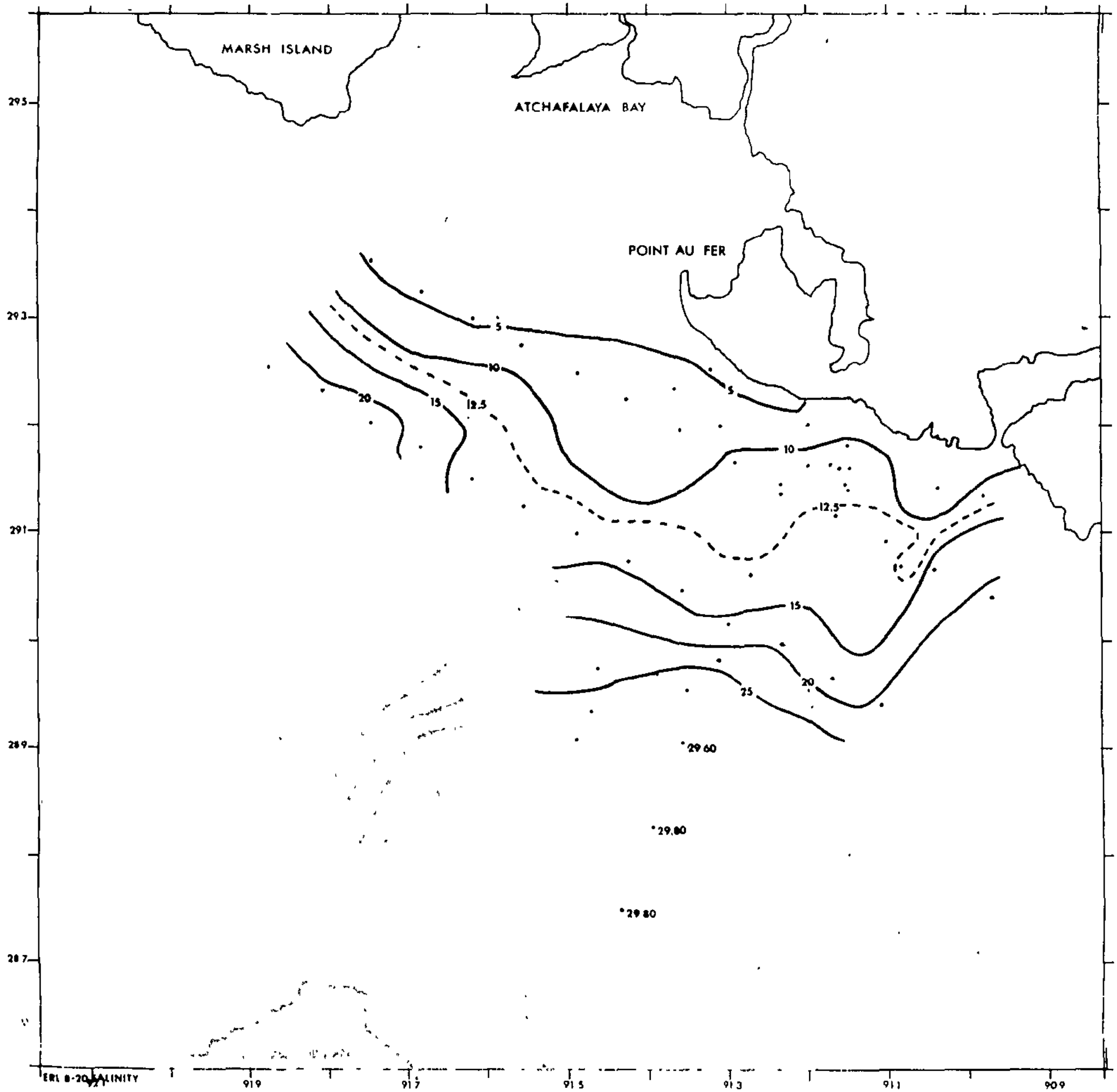
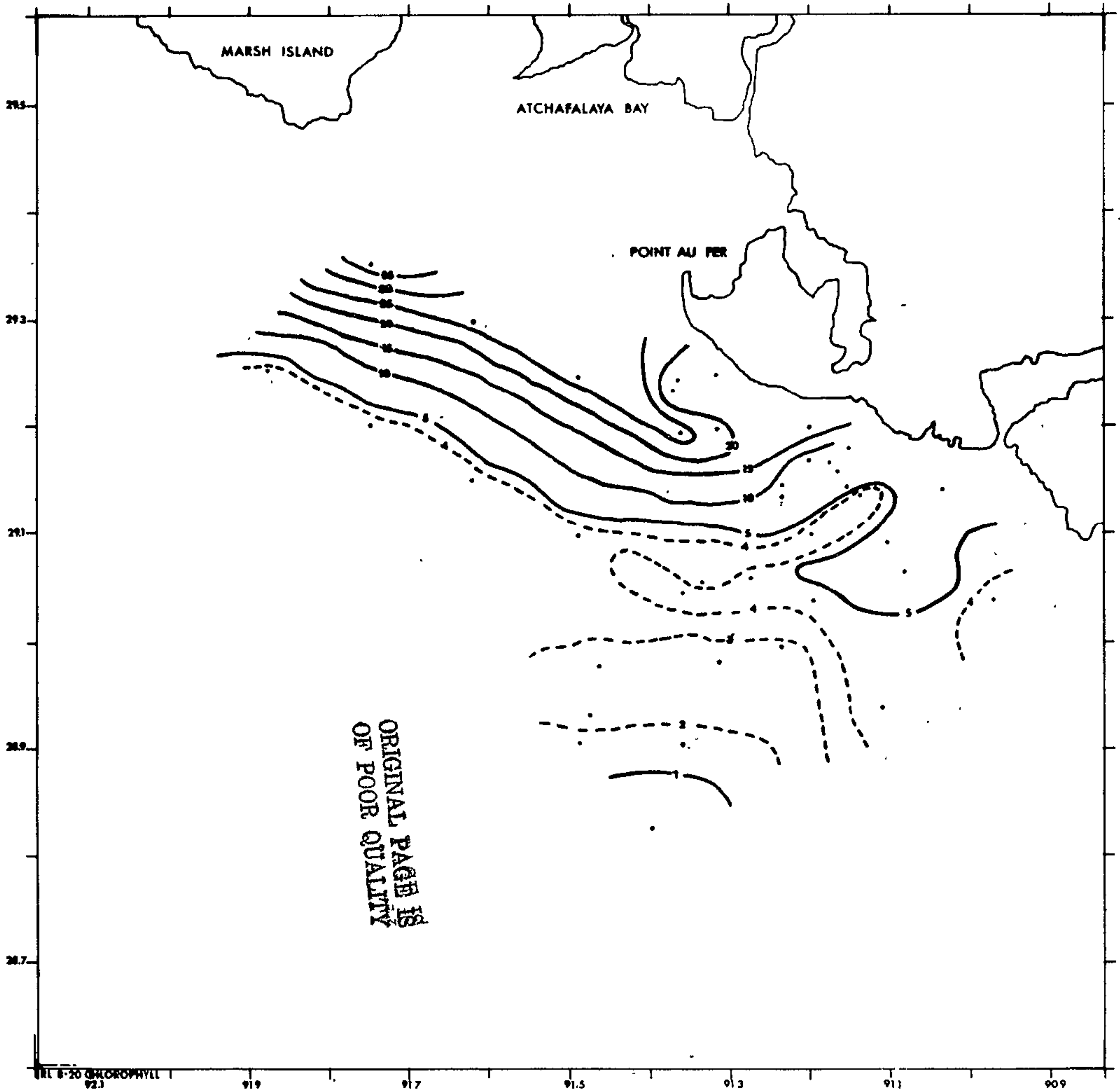
29.3
29.1
28.9
28.7
33.0
32.5
32.0
31.5
31.0
30.5
92.1
91.9
91.7
91.5
91.3
91.1
90.9



MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
5
10
12.5
15
20
25
29.60
29.80
29.80
29.5
29.3
29.1
28.9
28.7
91.9
91.7
91.5
91.3
91.1
90.9
ERL 8-20 SALINITY


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
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29.3
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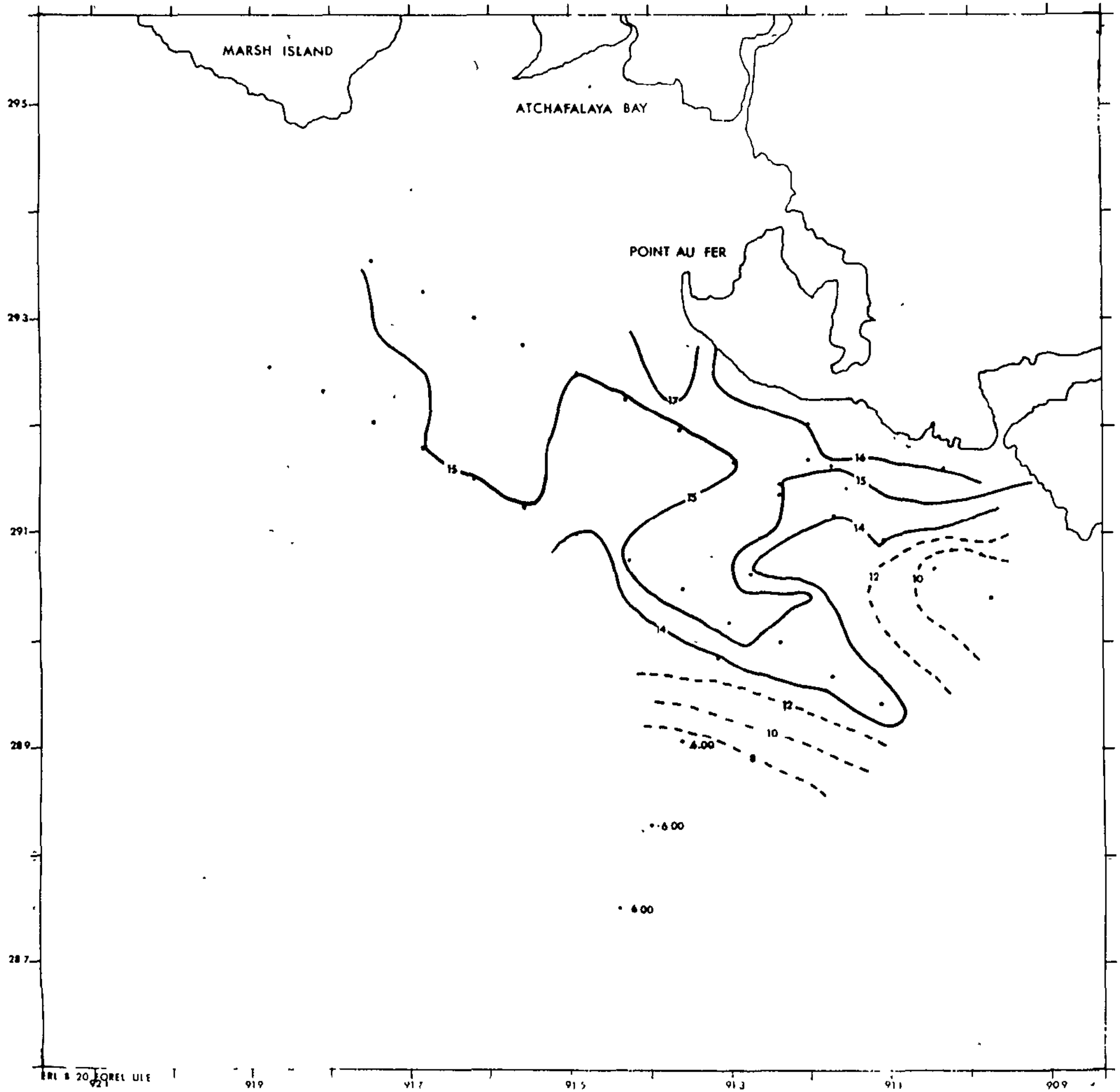
92.1
91.9
91.7
91.5
91.3
91.1
90.9
ERL 8-20 CHLOROPHYLL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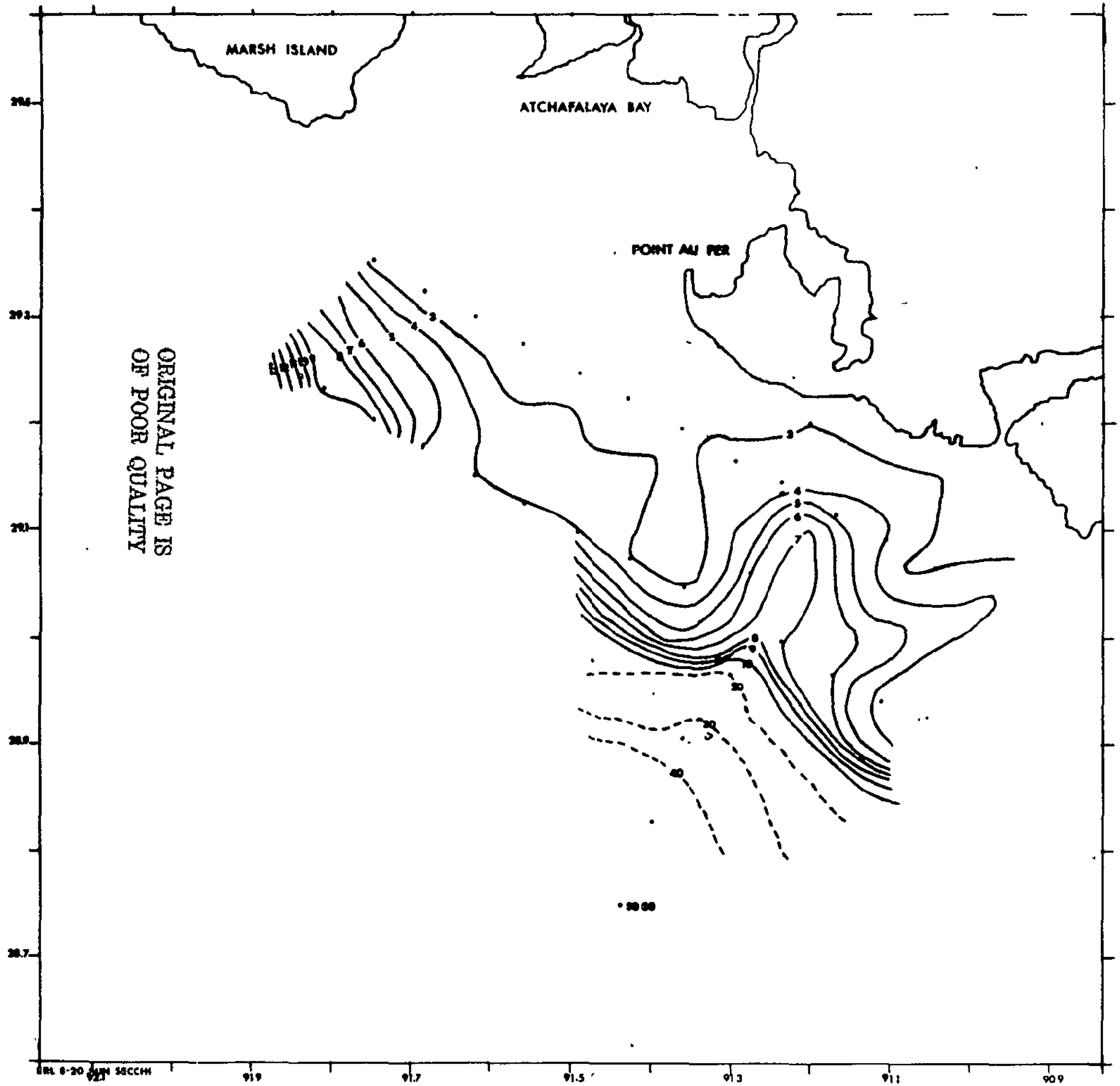
ATCHAFALAYA BAY
POINT AU FER


MARSH ISLAND
ATCHAFALAYA BAY
POINT AU FER
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29.1
28.9
28.7
92.1
91.9
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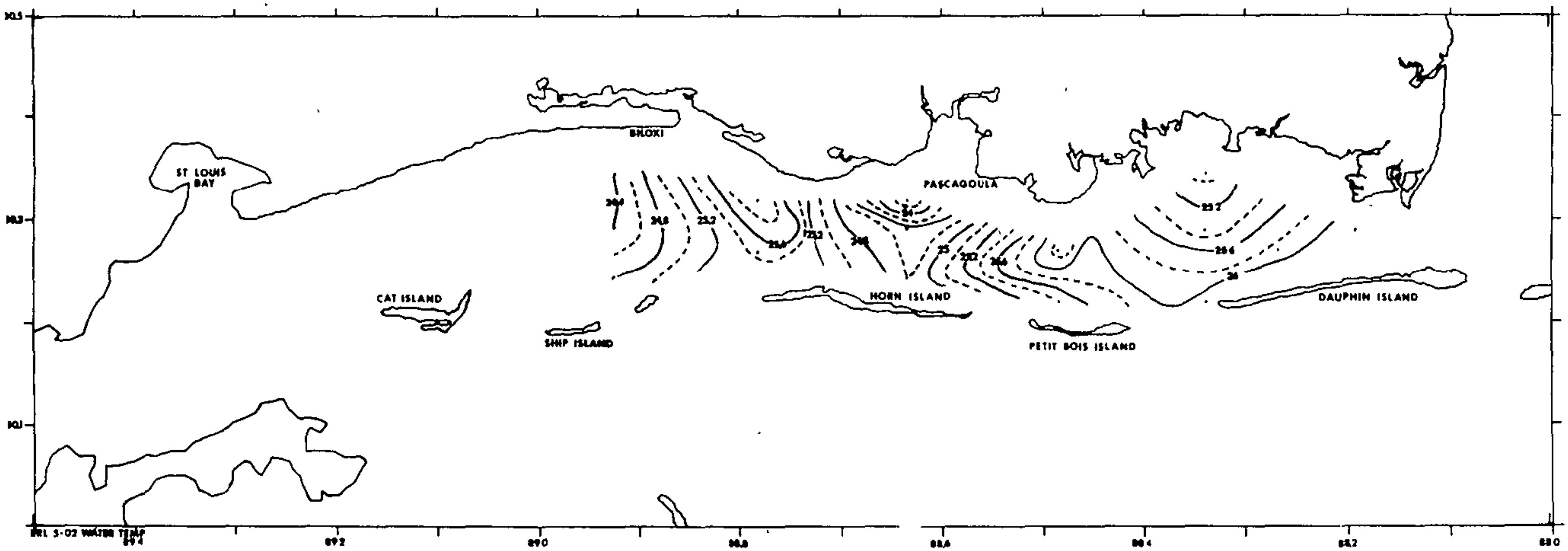
91.3
91.1
90.9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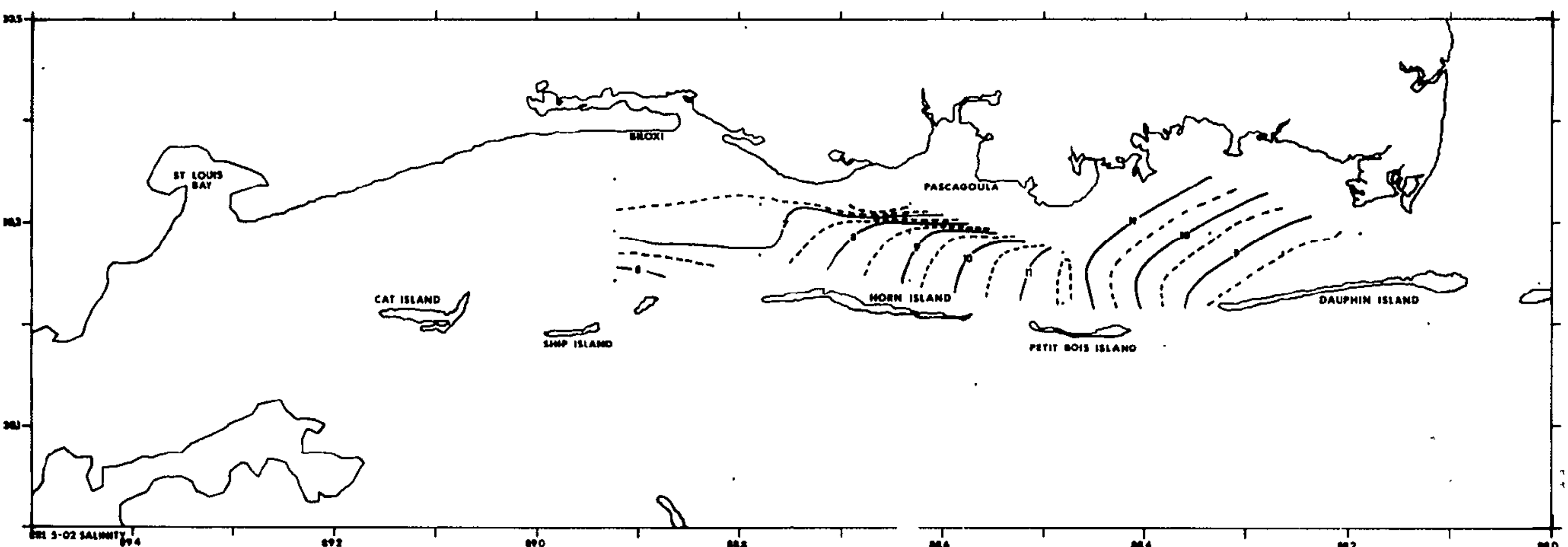
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
WATER TEMP



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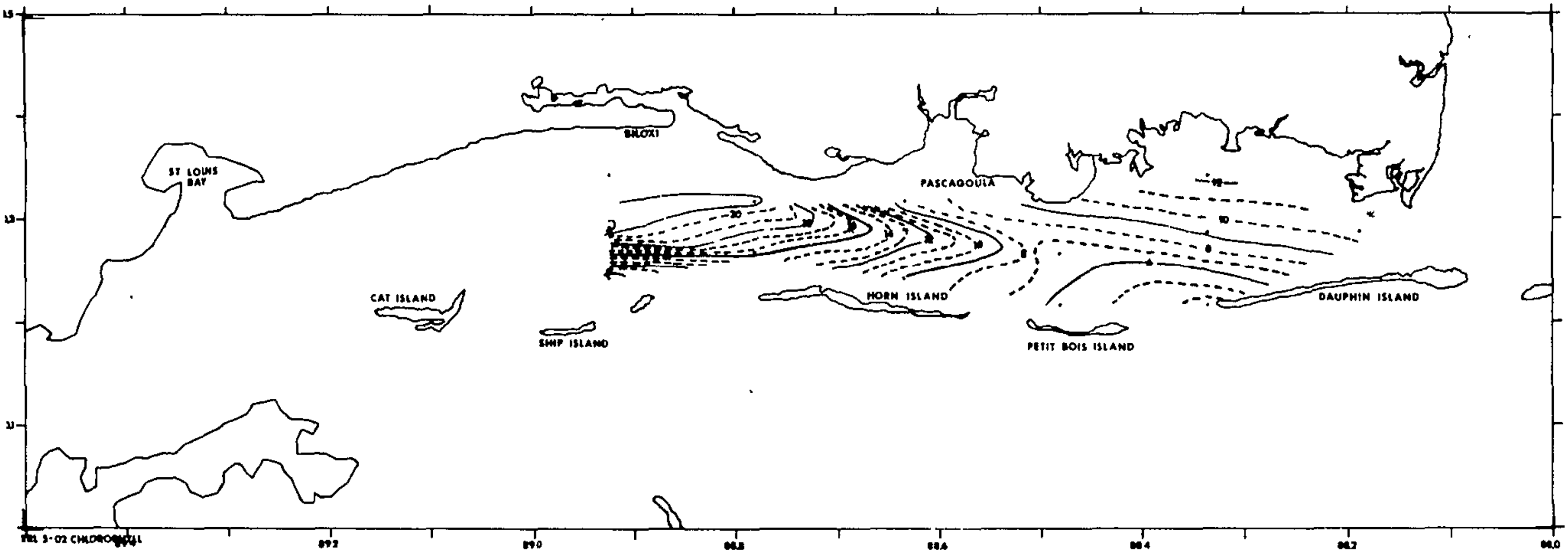
ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
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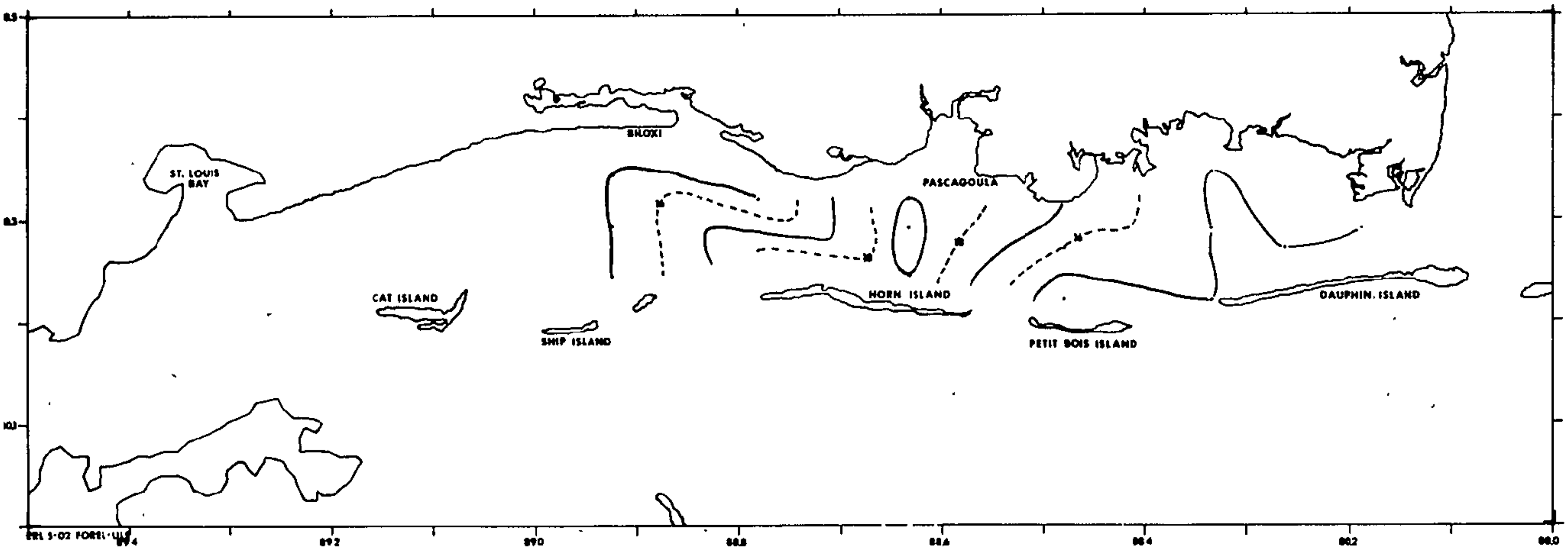
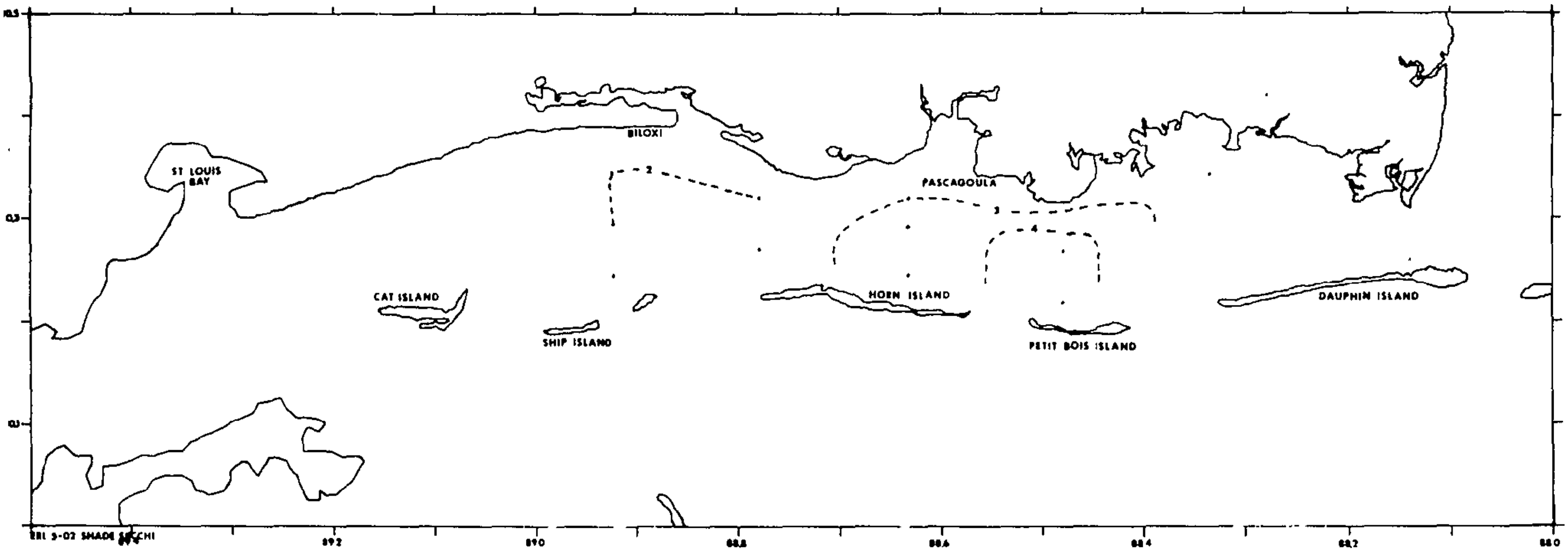
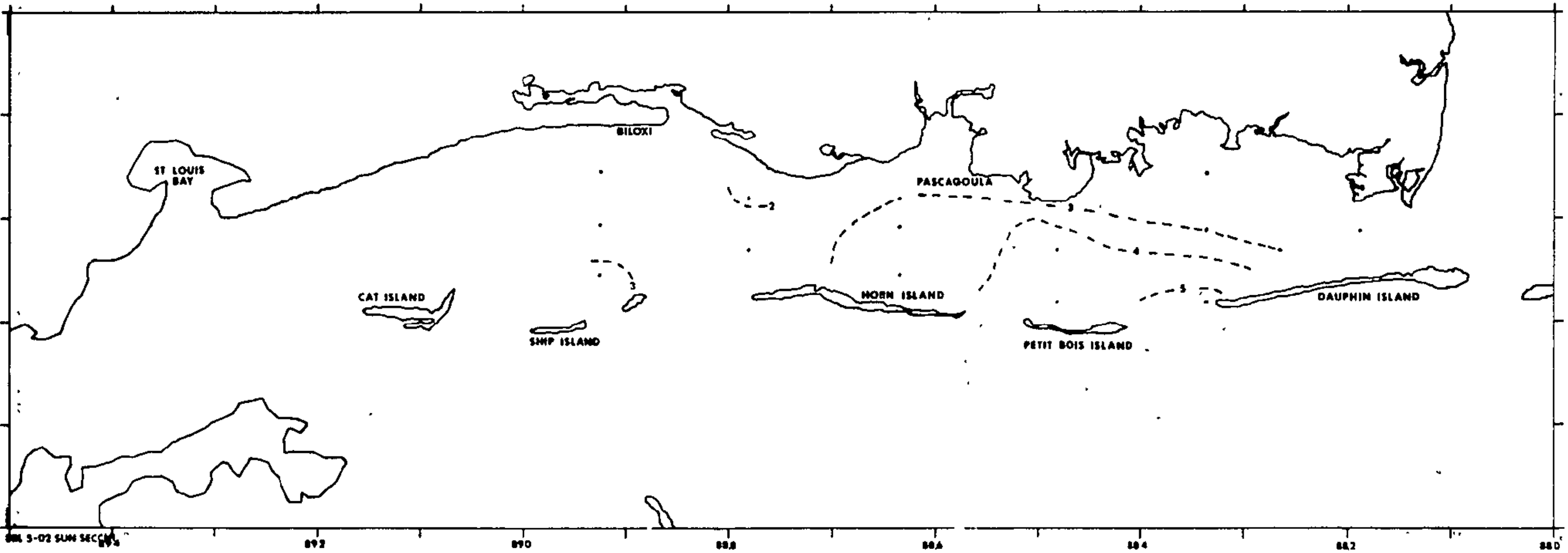
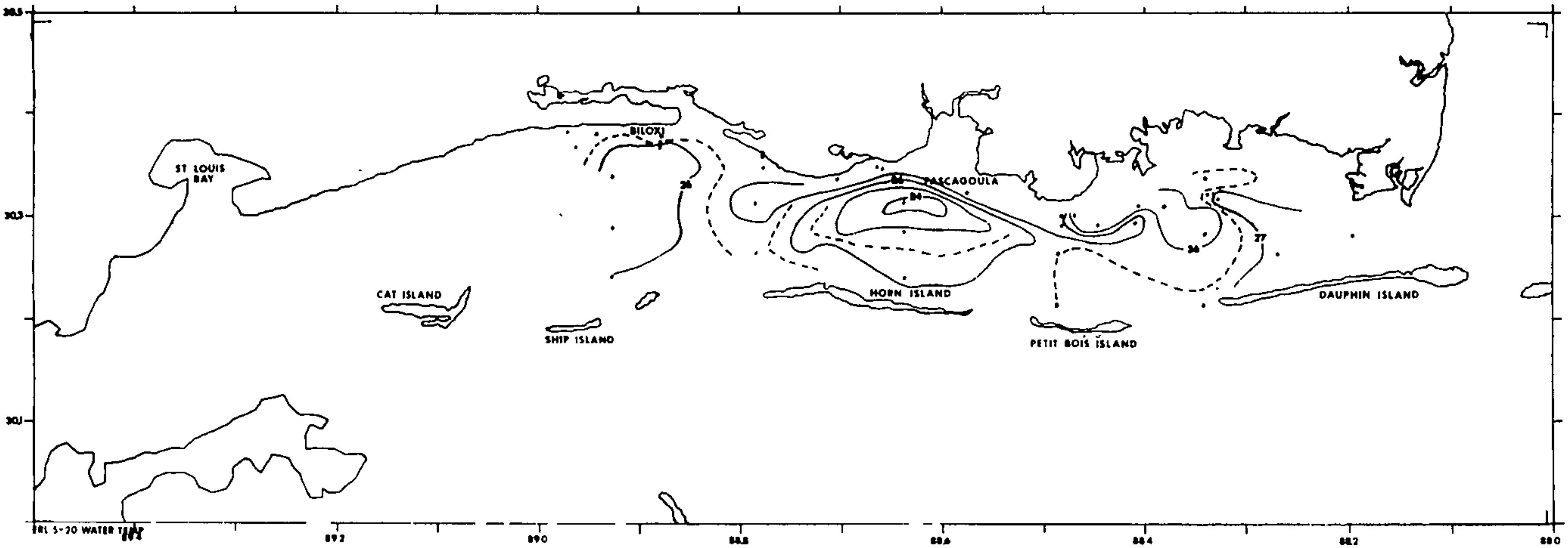
89.0
88.8
88.6
88.4
88.2
88.0


BILOXI
ST. LOUIS BAY
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND


ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
2
3
4
ERL 5-02 SHADE SECCHI


ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
89.2
89.0
88.8
88.6
88.4
88.2
88.0


ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
30.5
30.3
30.1
ERL 5-20 WATER TEMP
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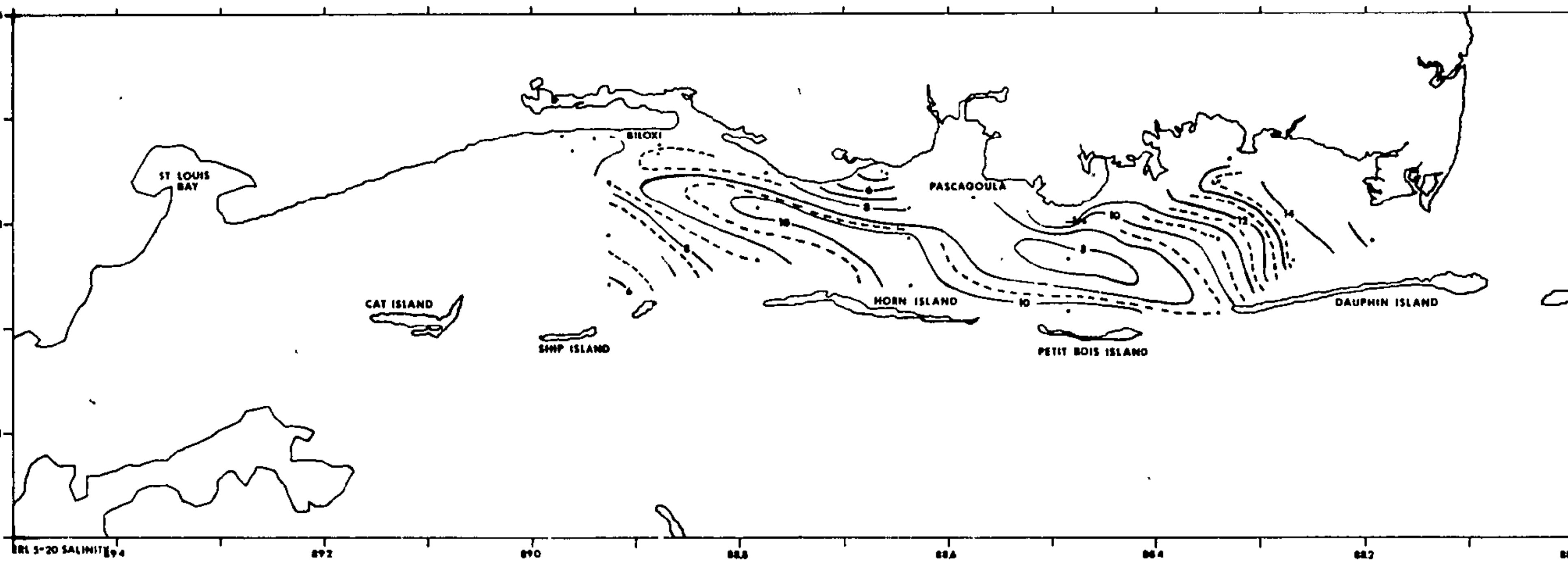
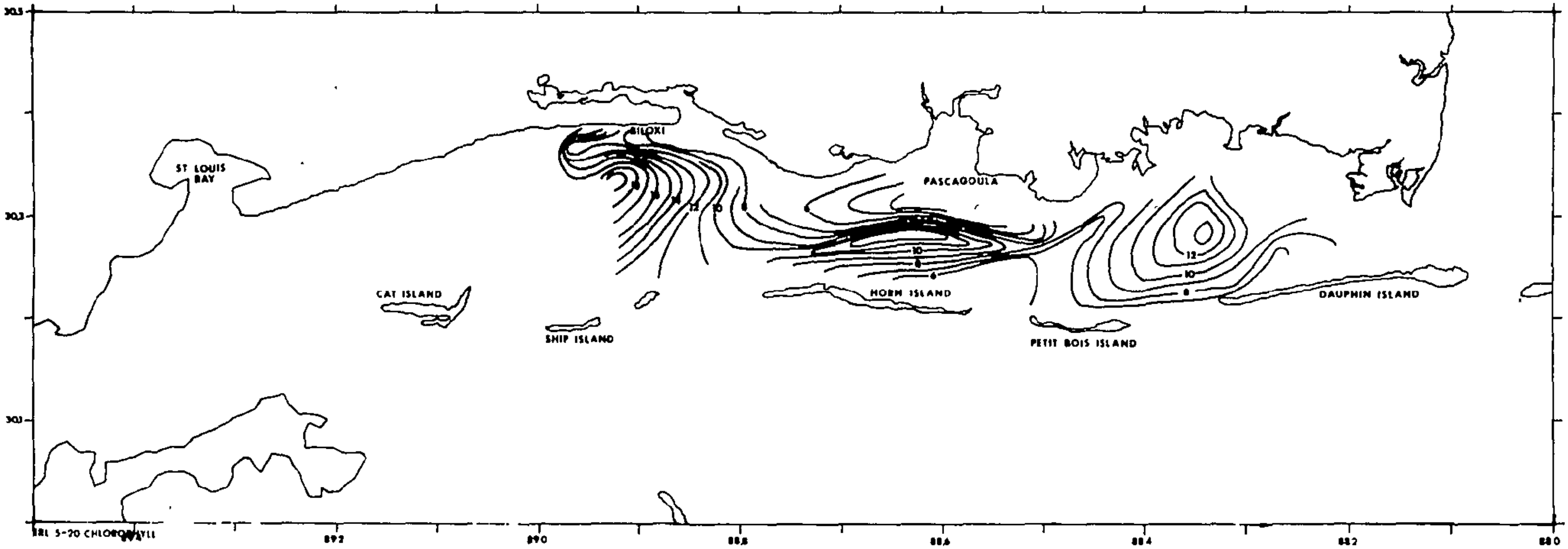
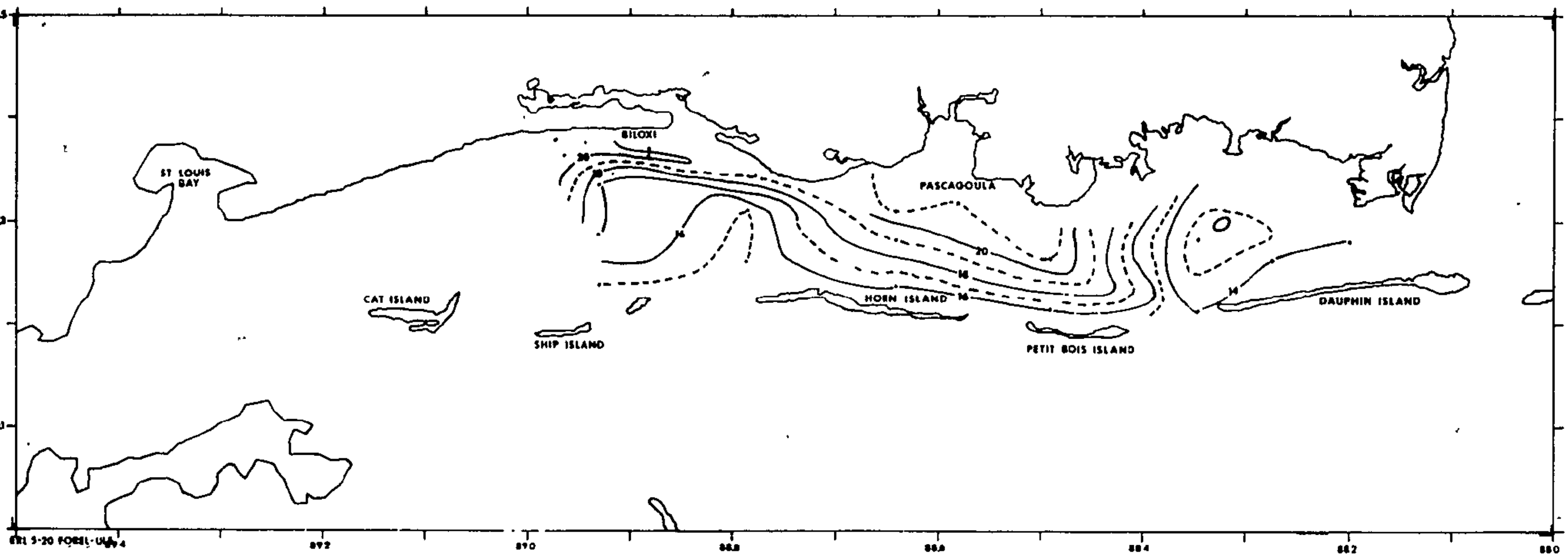
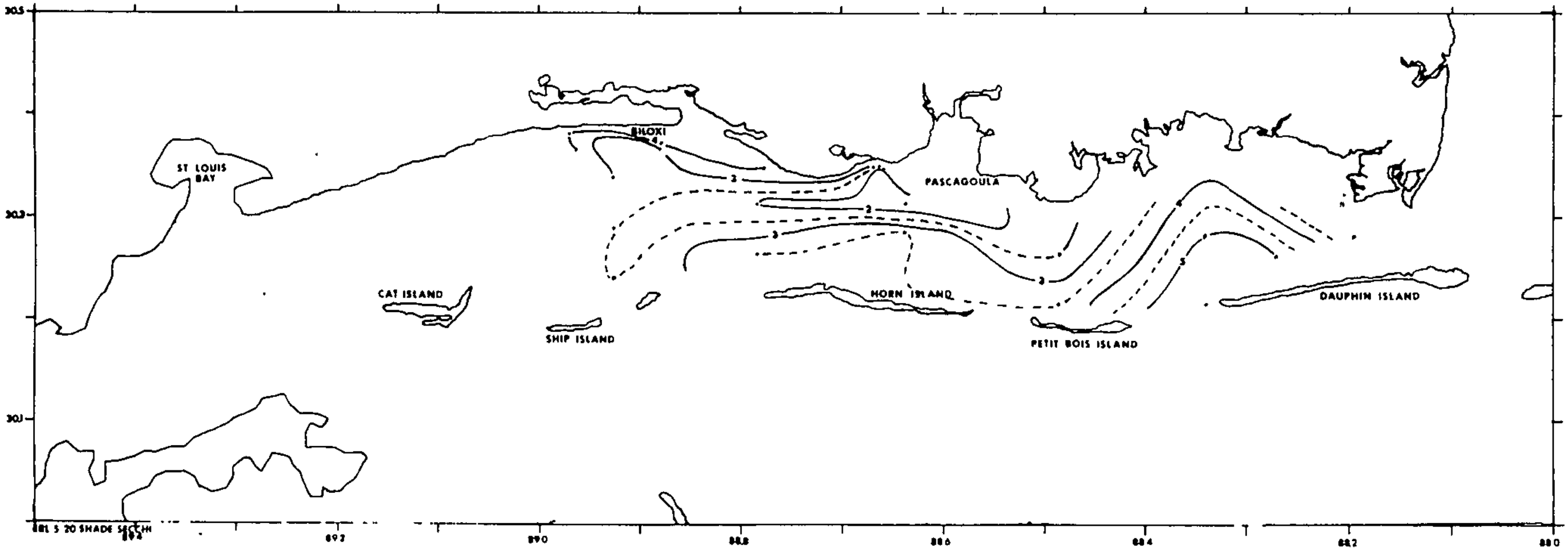
89.0
88.8
88.6
88.4
88.2
88.0

D-22

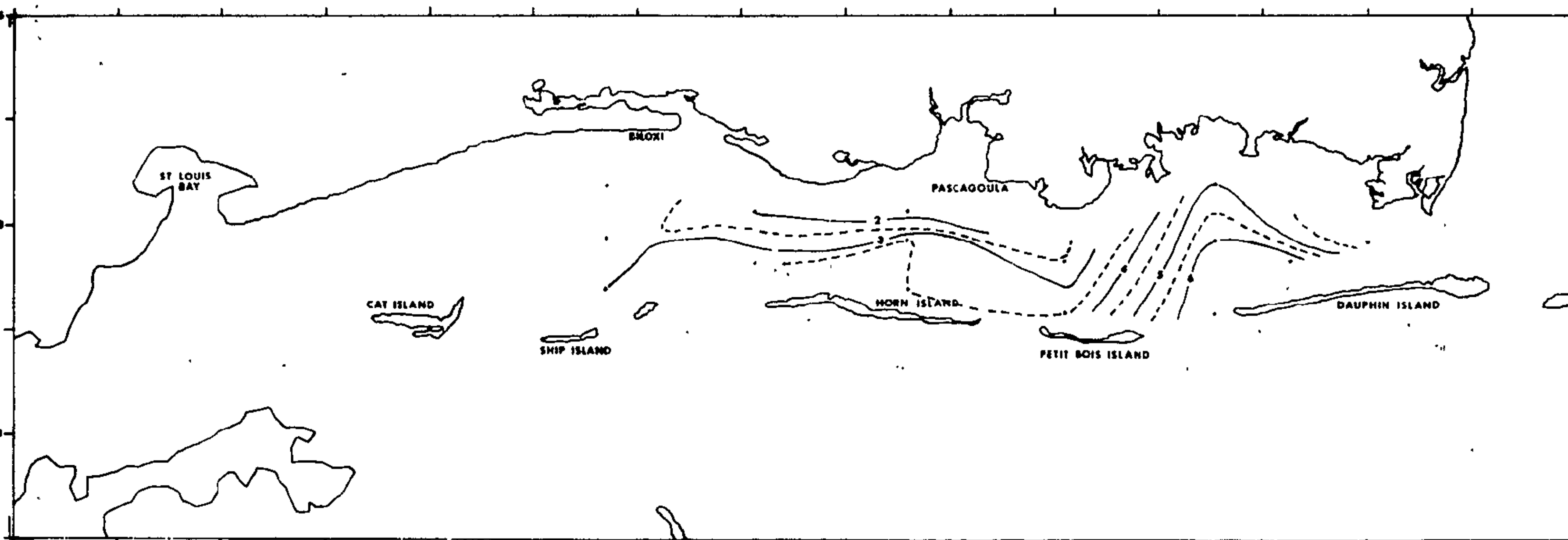

BILOXI
ST LOUIS BAY
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
ERL 5-20 SALINITY


ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
12
10
8
6
SRL 5-20 CHLOROPHYLL
892
890
88.8
88.6
88.4
88.2
88.0


ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
20
18
16
14
30.5
30.3
30.1
89.2
89.0
88.8
88.6
88.4
88.2
88.0



ST LOUIS BAY
BILOXI
PASCAGOULA
CAT ISLAND
SHIP ISLAND
HORN ISLAND
PETIT BOIS ISLAND
DAUPHIN ISLAND
SHADE SECCHI



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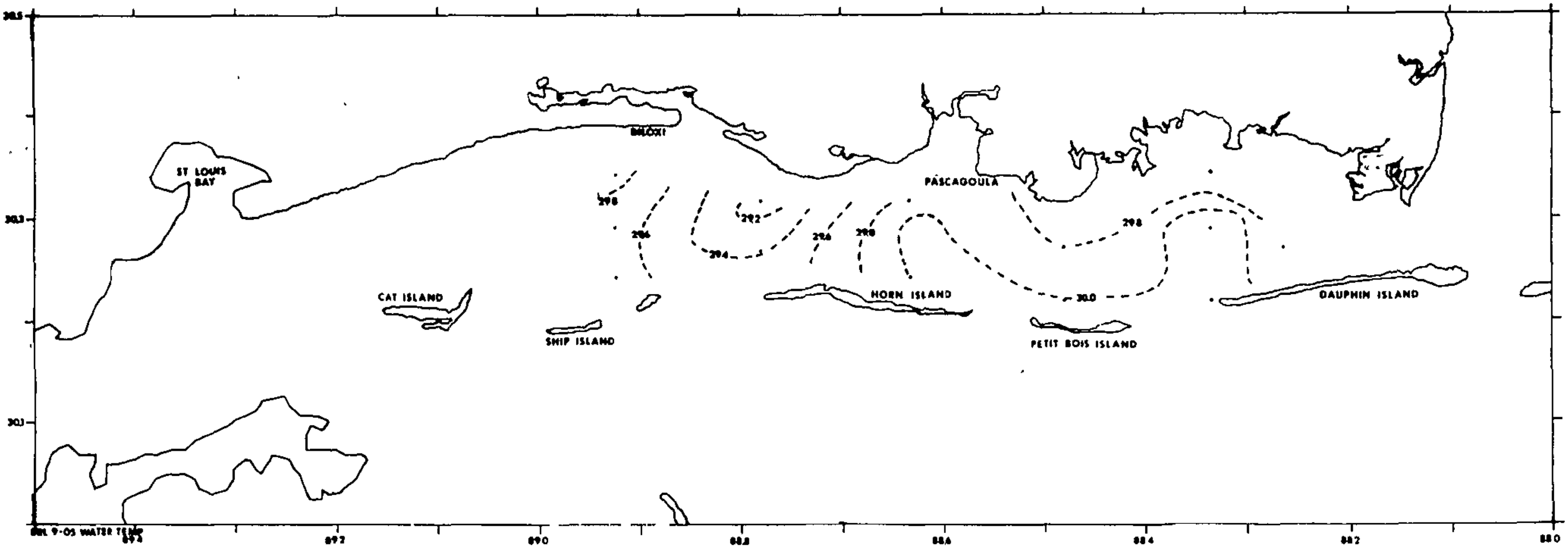
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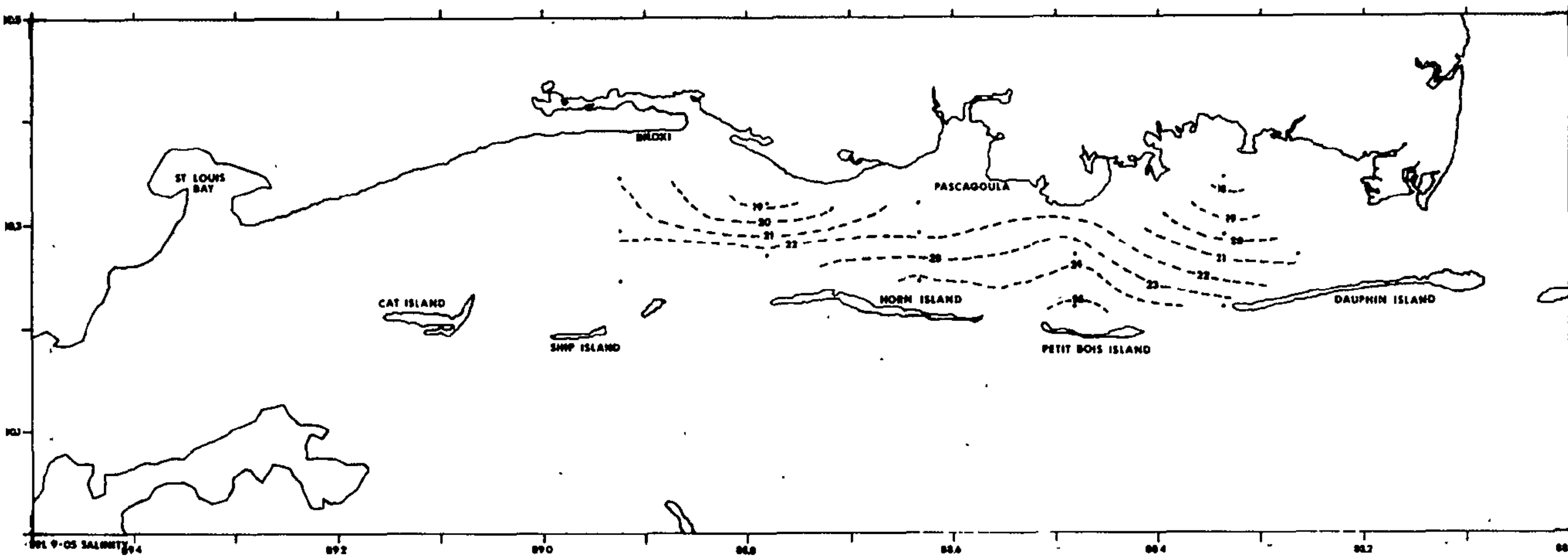
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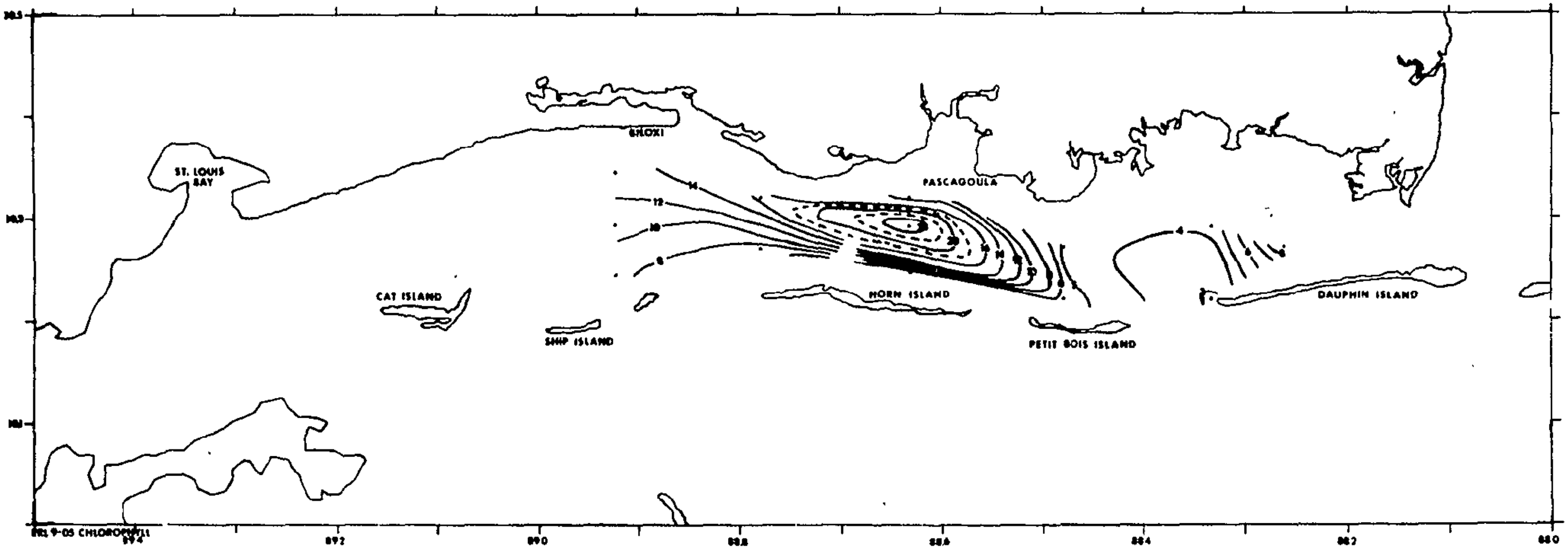
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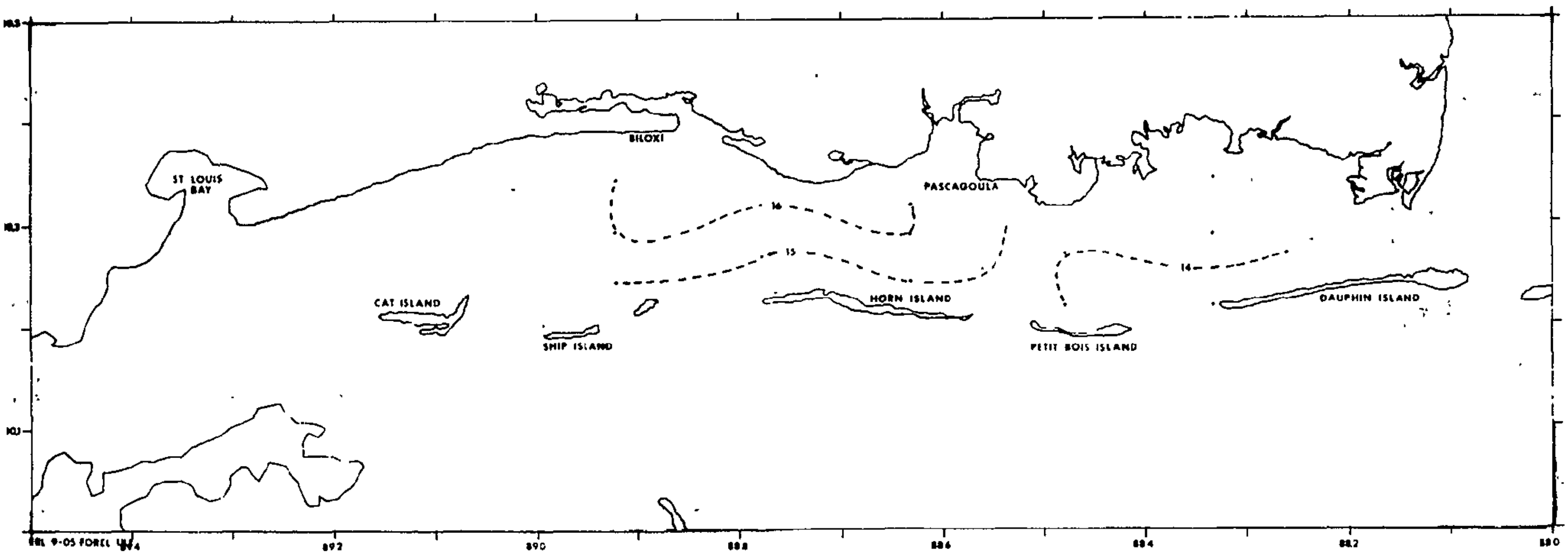
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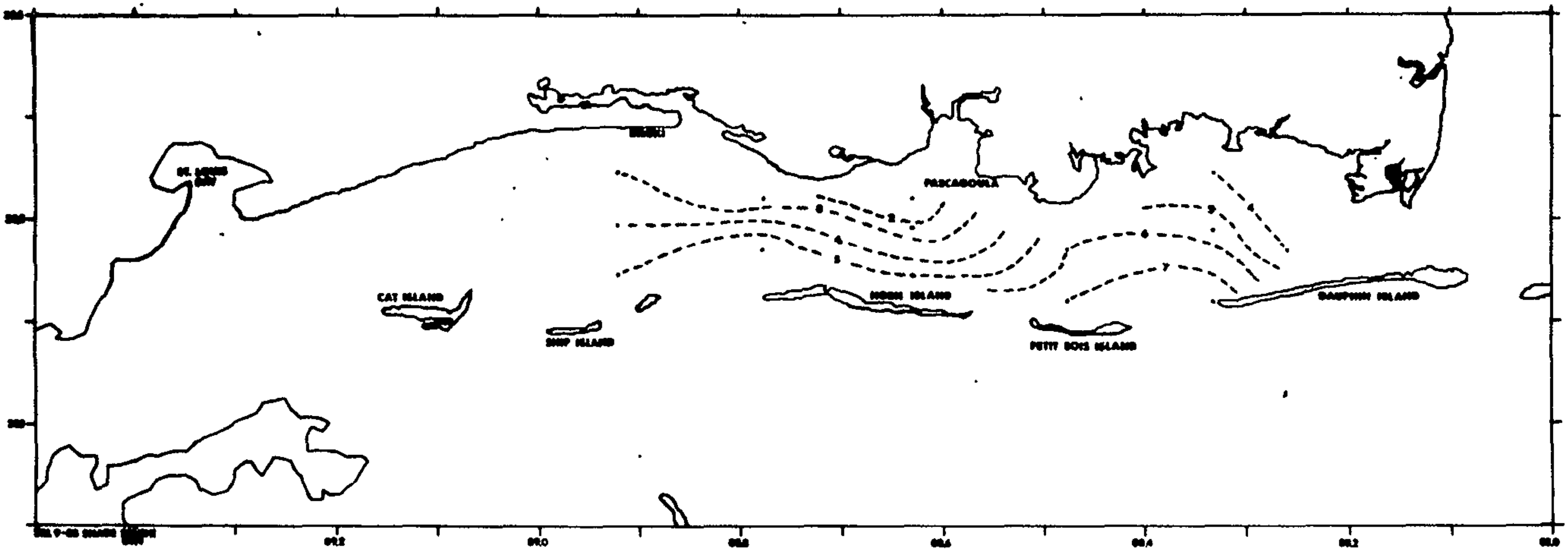
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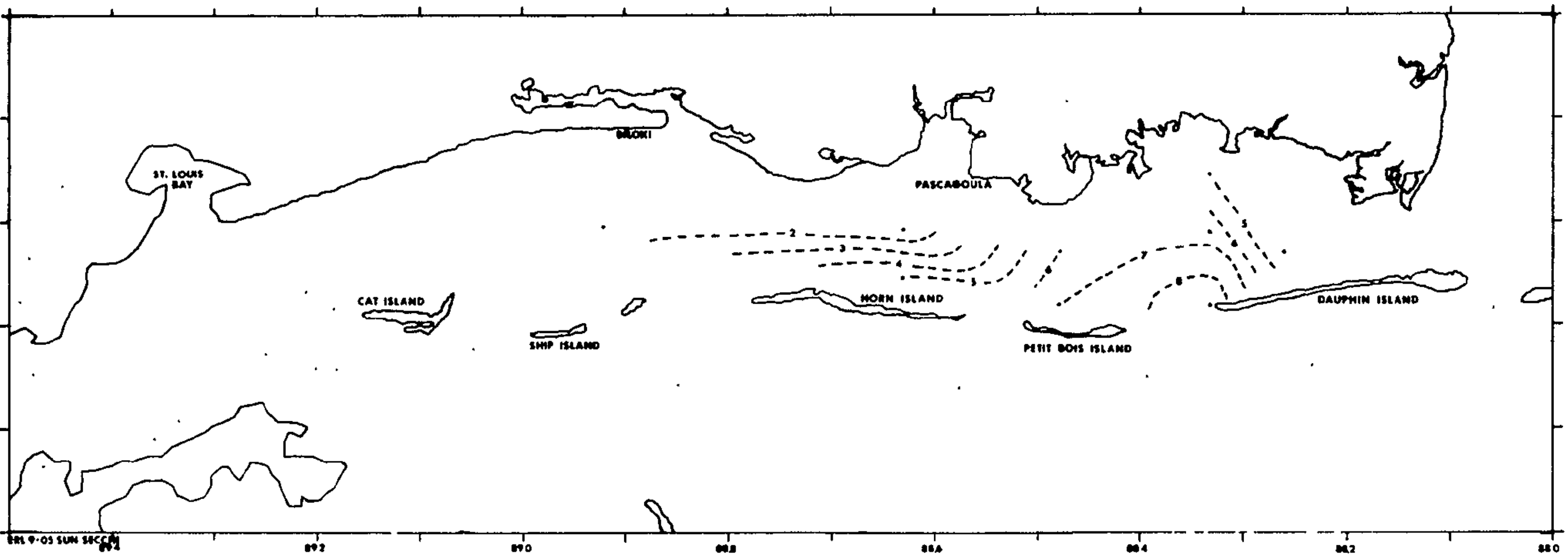
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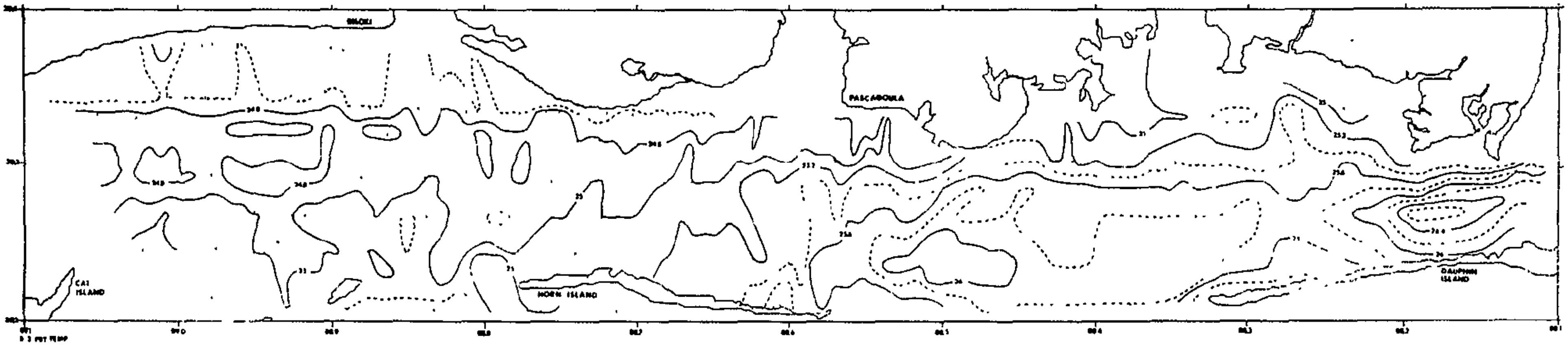
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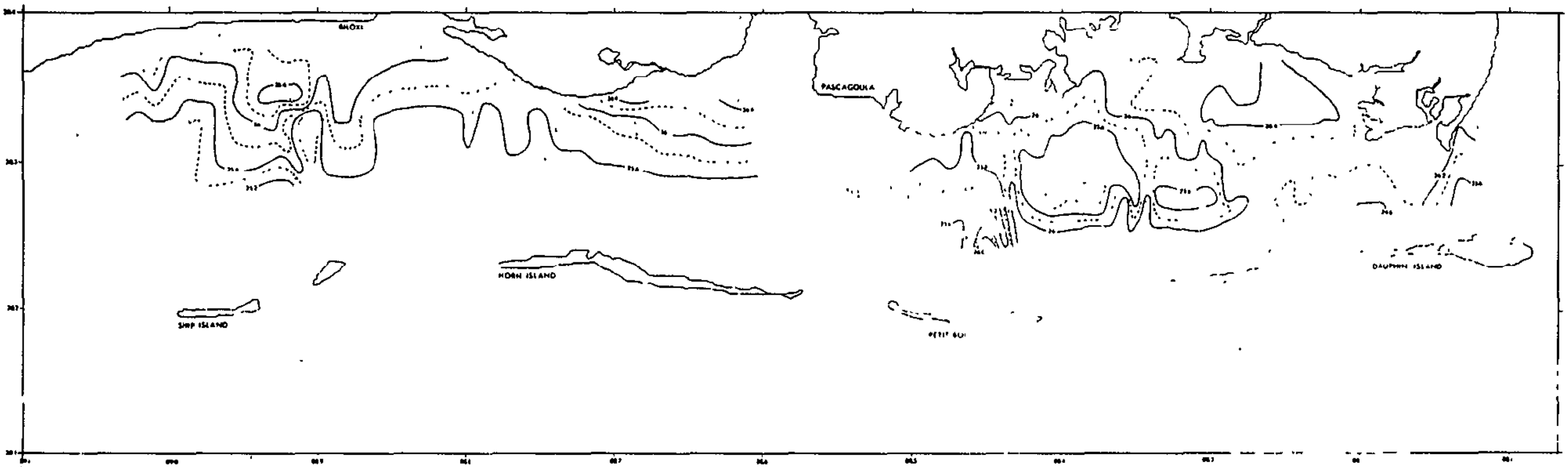
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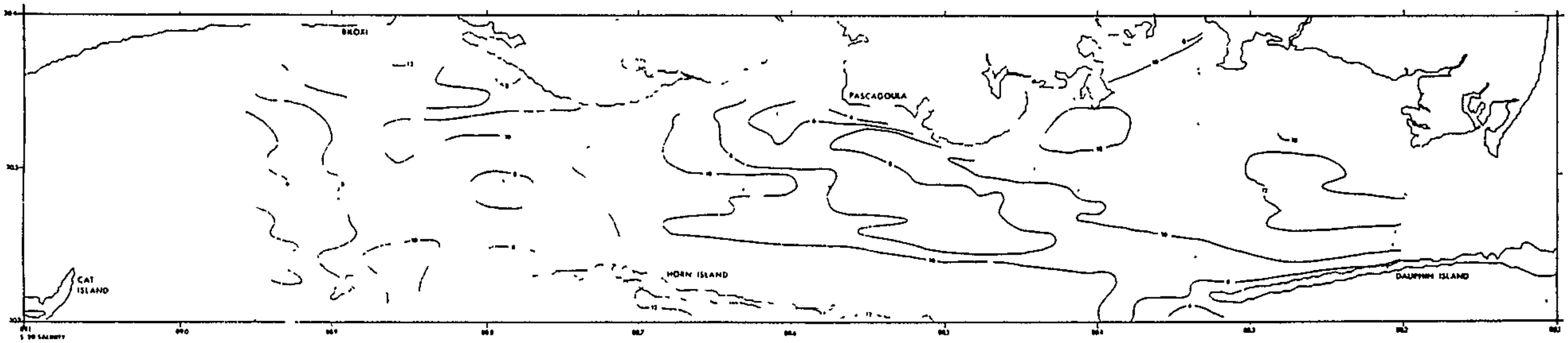
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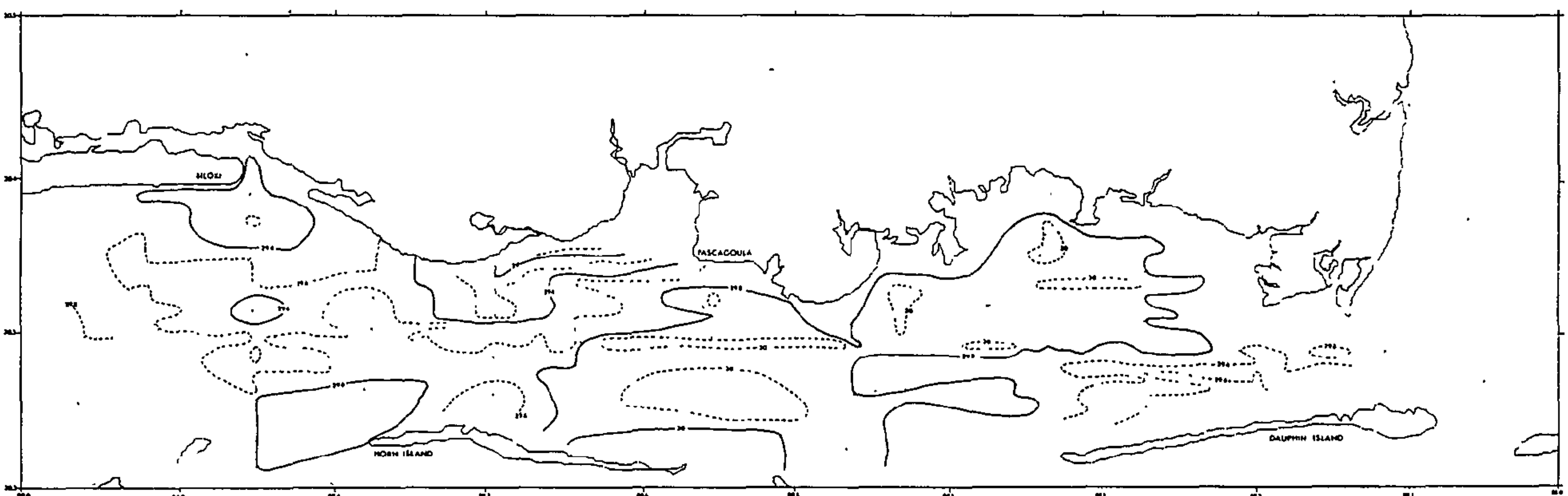
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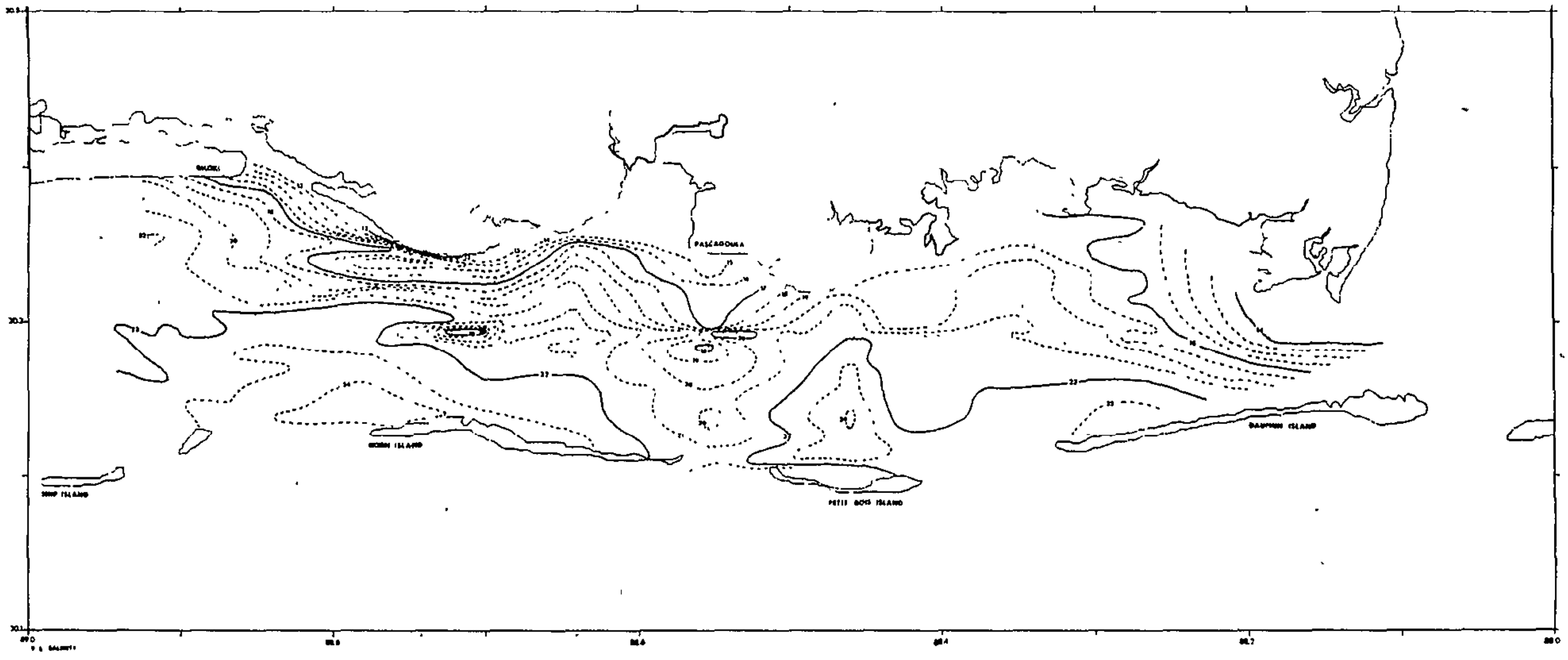
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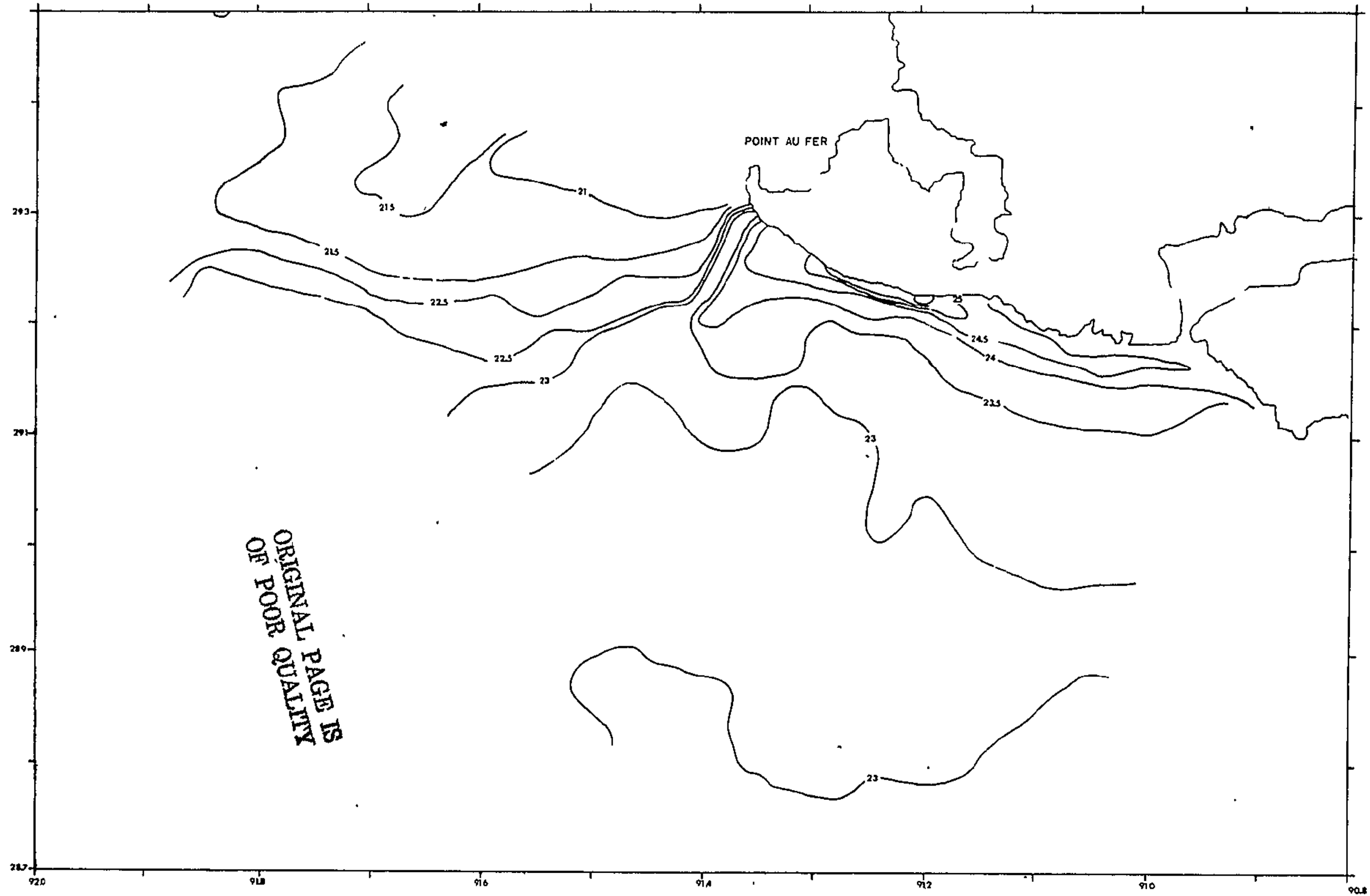

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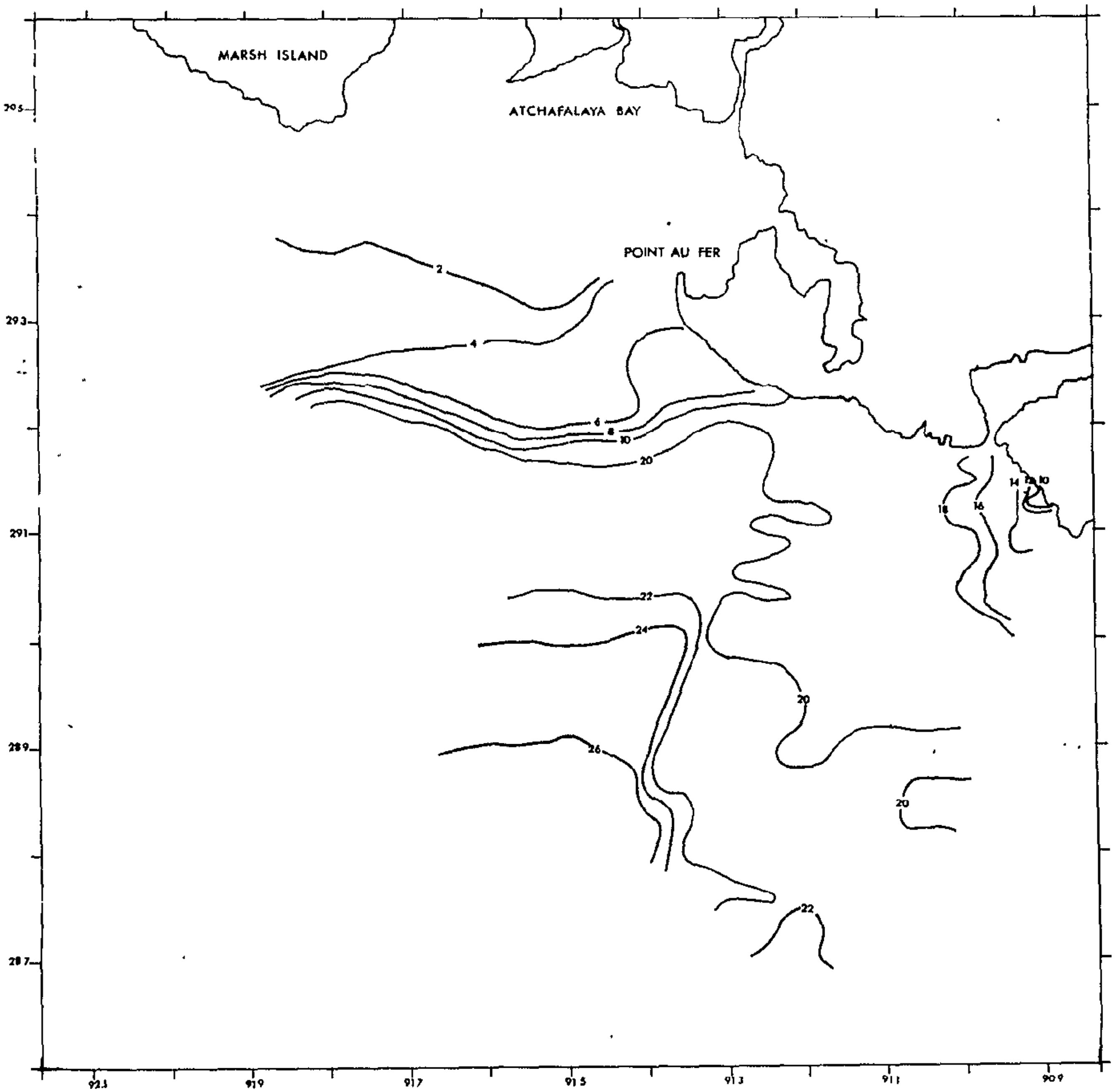

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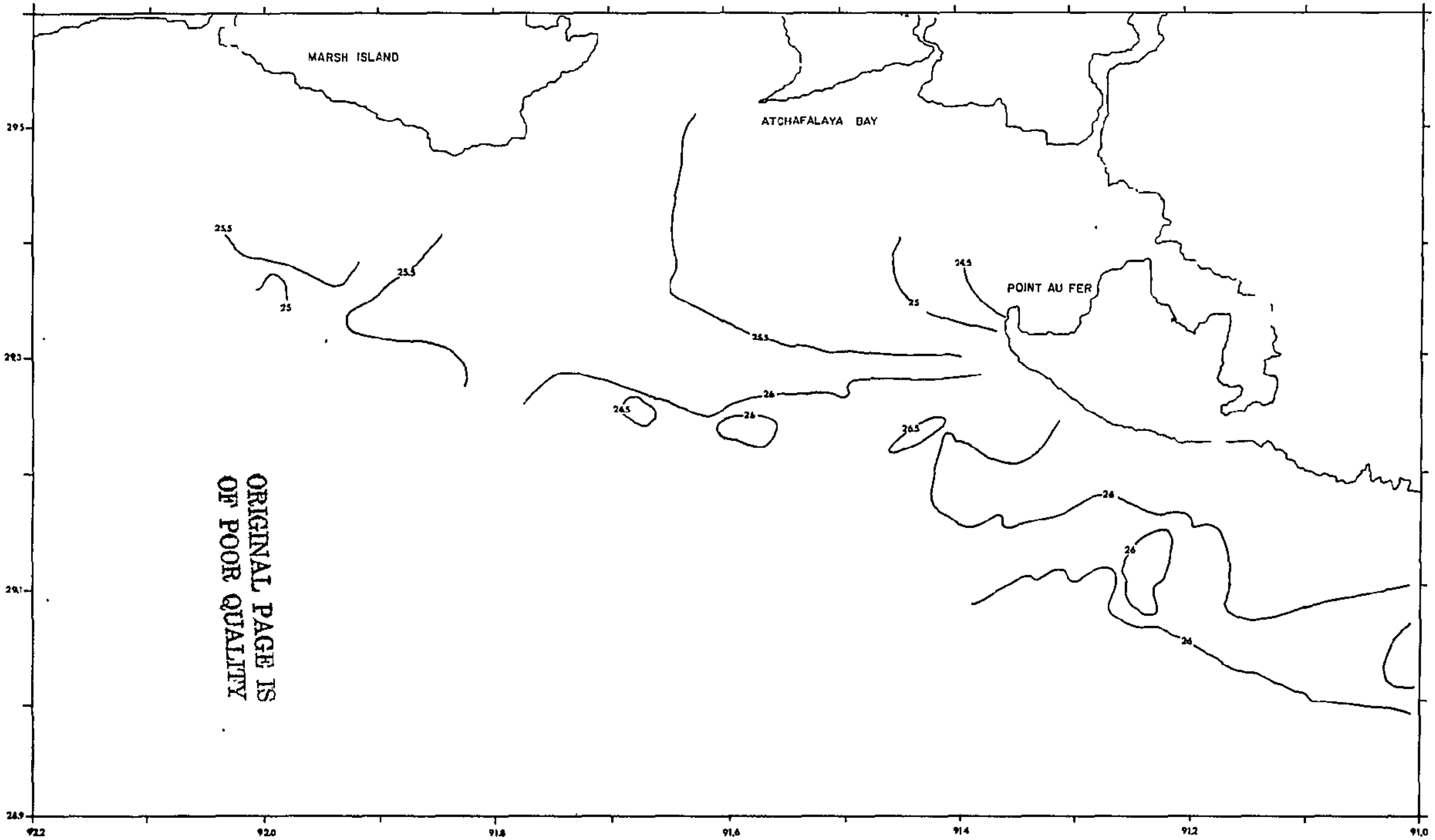

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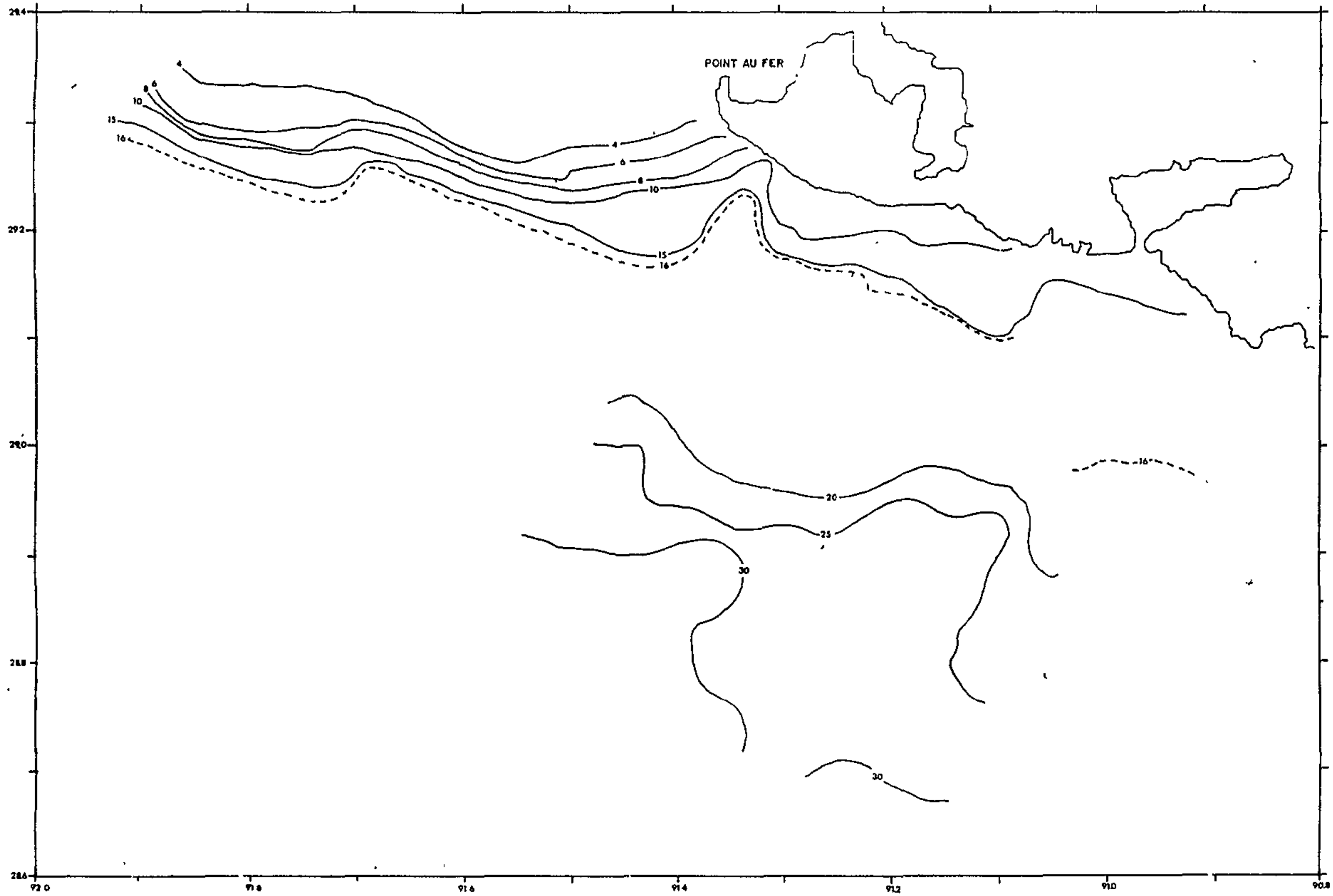

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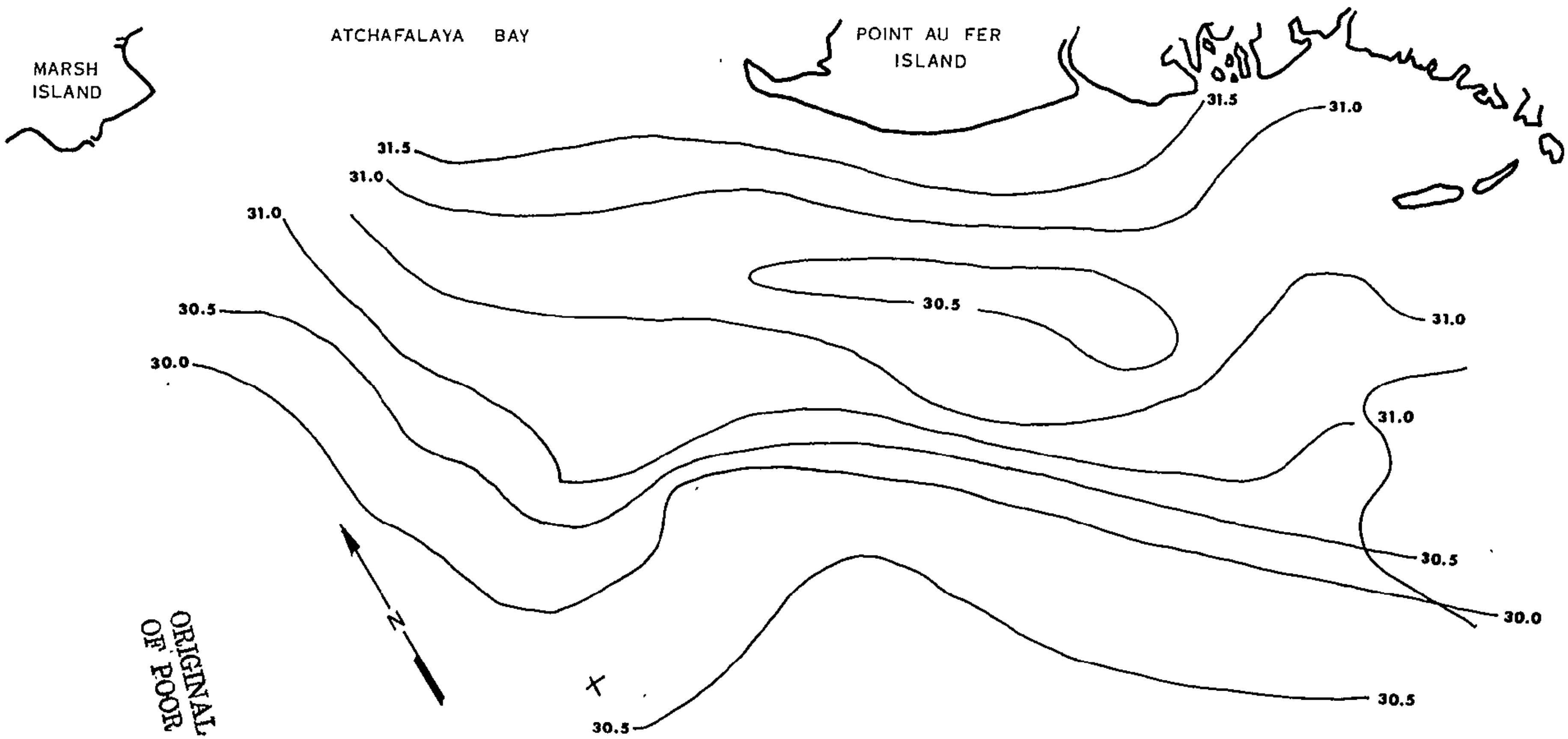

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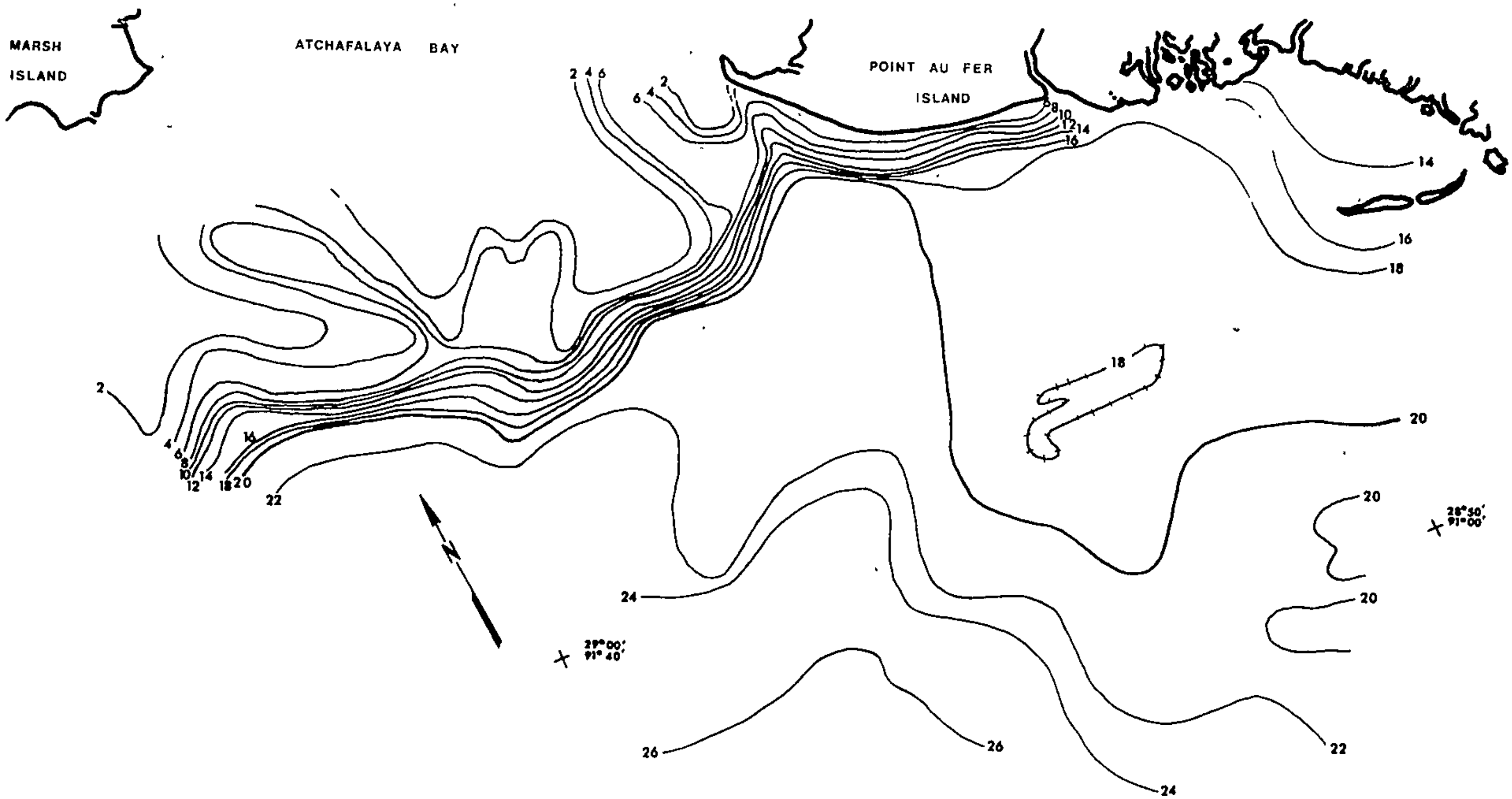

8/20 REMOTE SALINITY

APPENDIX E

MEETINGS, REPORTS, AND PUBLICATIONS

MEETINGS

FOLLOW-ON INVESTIGATION, 1975

November 1974 Meeting with NFMOA cooperators at NSTL to initiate the planning phase of the proposed LANDSAT Gulf of Mexico Menhaden and Thread Herring Investigation.

February 1975 Meeting with NFMOA cooperators at NSTL to review a draft plan for the LANDSAT Investigation.

Presentation of the plan for the LANDSAT Investigation at the annual meeting of the executive session of the NFMOA in Williamsburg, Virginia.

Presentation at the American Institute of Biological Sciences Workshop on Problems of Assessing Nektonic Populations which included a brief review of the LANDSAT Investigation.

March 1975 Meeting at NSTL with spotter pilots associated with member companies of the NFMOA to review the LANDSAT Investigation and coordinate aircraft operations.

April 1975 Meeting at NSTL with vessel captains associated with member companies of the NFMOA to review the LANDSAT Investigation.

Presentation of the results from the initial LANDSAT-1 Menhaden Experiment and plans for the LANDSAT Investigation at the Third Annual University of Southern Mississippi Seminar on Remote Sensing.

June 1975 Briefing on the LANDSAT Investigation to Mr. Joe Colson, Executive Director of the Gulf States Marine Fisheries Commission, New Orleans, LA.

July 1975 Meeting at NSTL with NFMOA cooperators to review results from the first four LANDSAT main-day missions.

Presentation at a joint NMFS-NESS briefing for Mr. Robert Schoning, Director, NMFS, on remote sensing in general and the LANDSAT Investigation specifically.

October 1975 A formal meeting was held at NSTL with industry and other investigation participants. The primary purpose of this meeting was to review the status of the LANDSAT Investigation with the NFMOA fishing vessel captains and spotter pilots.

November 1975 A briefing covering the Follow-On Investigation was given at the Second NMFS Remote Sensing Workshop in Monterey, California.

November 1975 A review of the field operations phase of the Follow-on Investigation was presented at the Executive Session of the NFMOA meeting in Biloxi, Mississippi.

A discussion of current water color analyses associated with the LANDSAT Investigation was given at a NASA Water Color Workshop at NSTL.

LANDSAT EXTENSION, 1976

February 1976 A series of informal meetings were held with representatives of menhaden fishing companies to discuss the investigation in New Orleans, Dulac, Houma, and Empire, Louisiana, and Pascagoula, Mississippi.

March 1976 A briefing on the investigation was given to NMFS Headquarters personnel in Washington, D.C.

A review of the investigation was given to NFMOA cooperators in Washington, D.C.

A review of the investigation was given at the Annual Meeting of the NFMOA in Washington, D.C.

A review of the investigation was presented to NASA Goddard personnel at NASA Goddard.

A review of the investigation was presented at the Gulf States Marine Fisheries Commission Meeting in Brownsville, Texas.

April 1976 A requested review of the investigation was given to four officials of the USSR at NSTL, Bay St. Louis, Mississippi.

A progress report was presented at the Annual NFMOA Spotter Pilot Safety Meeting in Houma, Louisiana.

A review of the investigation was presented to personnel of the NMFS Pascagoula Laboratory.

July 1976 Briefing of contractor personnel at GSFC on the LANDSAT Investigation with emphasis on the simulation objective.

Briefing of vessel captains and spotter pilots on the parent and extension portions of the LANDSAT Investigation in Cameron, Louisiana.

Briefing of vessel captains and spotter pilots on the parent and extension portions of the LANDSAT Investigation.

October 1976 Fall meeting of the National Fish Meal and Oil Association in Point Clear, Alabama.

Task force workshop for the development of a menhaden management plan in New Orleans, Louisiana.

February 1977 LANDSAT presentation to annual NFMOA Meeting, Bay Point, Florida.

September 1977 Coordination of LANDSAT Final Report with NFMOA Cooperators.

REPORTS

LANDSAT Follow-on Experiment, Gulf of Mexico Menhaden and Thread Herring Resource Investigation, January 1975 (Draft). This report was used as the initial planning document for the investigation and as a basis for the final plan.

LANDSAT Experiment, Gulf of Mexico Operations Plan, April 1975. This report provides the detail necessary for the efficient management, coordination and conduct of the data acquisition phase of the investigation.

LANDSAT Follow-on Experiment, Gulf of Mexico Menhaden and Thread Herring Resources Investigation, June 1975. This document provides a comprehensive overview of the entire investigation; e.g., objectives, benefits, rationale, technical approach, schedules, organization, and management.

LANDSAT Menhaden-Thread Herring Resource Investigation; Surface Management Report, ERL Report Number 154, December 1975. This report was prepared by ERL and includes data listings of environmental parameters.

Can Satellites Help Fishermen Find Fish? A Special Report on the LANDSAT Menhaden and Thread Herring Resources Investigation, April 1976.

LANDSAT Menhaden and Thread Herring Resources Investigation: LANDSAT Follow-on 1975; LANDSAT Extension 1976. Field Operations Report, April 15, 1977. This is a detailed report of all field operations and data acquisition activities.

Gulf of Mexico Menhaden and Thread Herring Resources Investigation Data Report, May 1977. This is a complete listing of all data collected in support of the LANDSAT Investigation.

LANDSAT Follow-on Experiment - Gulf of Mexico Menhaden and Thread Herring Resources Investigation, Quarterly Reports (Type II)

- Number 1 - July 1975
- Number 2 - October 1975
- Number 3 - January 1976
- Number 4 - April 1976
- Number 5 - July 1976
- Number 6 - October 1976
- Number 7 - January 1977

PUBLICATIONS

Several papers have been prepared that relate directly or indirectly to the investigations. These papers include:

Bullis, H.R. and A.J. Kemmerer. 1976. Examples of aerospace remote sensing applications to fisheries investigations. International Council for the Exploration of the Sea, Charlottenlund Slot, DK-2920 Charlottenlund, Denmark.

Faller, K.H., T.D. Leming, and J.T. Brucks. 1976. Synoptic oceanographic measurements in a coastal environment. Paper presented at the 39th Annual Meeting of the American Society of Limnology and Oceanography, Savannah, Georgia, June 21-24, 1976.

Glidden, W.S. and A.J. Kemmerer. 1976. Report of the Study Group on Remotely Sensed Data. International Council for the Exploration of the Sea, Charlottenlund Slot, DK-2920 Charlottenlund, Denmark.

Hill, G.D., Jr. 1977. Fisheries engineers explore new frontiers. NOAA Magazine. Volume 7(2).

Kemmerer, A.J. and J. Butler, 1976. Finding fish with satellites. Marine Fisheries Review, MFR paper 1230, Volume 39(1): 16-21.

Kemmerer, A.J., J.T. Brucks, T.D. Leming and E.G. Woods. 1976. Remote sensing for fishery applications. Paper presented to the Instrument Society of American International Conference and Exhibit.

Kemmerer, A.J., K.J. Savastano, and K.H. Faller. 1977. Applications of space observations to the management and utilization of coastal fishery resources. The COSPAR/IAMAP (IUGG) W. Nordberg Memorial Symposium on the Contribution of Space Observations to Global Food Information Systems, Tel Aviv, Israel, June 8-10, 1977.

Savastano, K.J. and T.D. Leming. 1977. Application of remote sensing technology to marine fisheries resources (in press). Proceedings of the Information/Brain Storming Sessions on Aerial/Spatial Remote Sensing and Living Marine Resource Present and Future Possibilities, Brest, France, March 14-17, 1977.

Vanselous, T.M. and A.J. Kemmerer. 1975. An overview of remote sensing applications to fisheries related problems. Proceedings of Symposium on the Utilization of Remote Sensing in Southeastern U.S., University of Georgia, January 29-30, 1975.

Vanselous, T.M., T.D. Leming, A.J. Kemmerer and K.J. Savastano. 1975. Fisheries utilization of remotely sensed data. Proceedings of Symposium, Machine Processing of Remotely Sensed Data, Purdue University, June 2-5, 1975.

Vanselous, T.M. 1977. Fishery engineering advancements. A 5-year SEFC progress report. Marine Fisheries Review, MFR paper 1245 (39(4)=12-24.

Woods, E.G., A.J. Kemmerer, and K.H. Faller. An operational overview of the LANDSAT Menhaden and Thread Herring Investigation. Paper No. OTC-2518. Eighth Annual Offshore Technology Conference, Houston, Texas, May 3-6, 1976.