

SECTION 13

MISSISSIPPI SOUND REMOTE SENSING STUDY

by

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As a part of the research program of the NASA Earth Resources Laboratory, a remote sensing study of the Mississippi Sound was initiated in April, 1971. The objective of the study is the development of remote sensing techniques to study near shore marine waters. In directing our efforts toward this general goal, the following specific elements have been included in our study plan: (1) evaluate existing techniques and instrument capabilities for remote measurement of parameters which characterize near shore water, (2) integrate these parameters into a system which will make possible the definition of circulation characteristics, (3) conduct applications experiments and (4) define hardware development requirements and/or system specifications.

A list of parameters which characterize coastal water bodies is shown in Table I. Determination of these parameters is prerequisite to evaluating the condition of near shore waters. Also shown in Table I are remote sensing techniques which have been developed to varying degrees to evaluate these parameters. It is our goal to continue this development, and furthermore, to integrate these techniques with conventional measurements into a system which will allow assessment of conditions to determine what effects natural and man-made stresses will have on a coastal water body.

DATA ACQUISITION

Aircraft Measurements

The data acquisition phase of this study was planned to be framed about a series of overflights by NASA aircraft equipped with remote sensing data systems.

The first overflight, Mississippi Sound I, took place July 22, 1971. Two aircraft were used: the NASA NP3A equipped with camera systems, PRT-5 radiation thermometer, RS-14 infrared scanner, and the multi-frequency microwave radiometer; and a light aircraft equipped with a second PRT-5.

Figure 1 shows a map of the test area including flight lines flown by the NP3A and the light aircraft. The aircraft and flight line altitudes are shown in the legend.

The flight lines were planned with the following objectives: (1) adequate PRT-5 coverage to develop a temperature contour map from aerial measurements, (2) RS-14 scanner imagery along one flight line at an altitude of 20,000 feet to assess temperature anomalies associated with waters being exchanged through passes connecting the Mississippi Sound to the Gulf of Mexico, (3) low altitude flight lines (800 ft) in areas where strong salinity gradients exist to evaluate effects of salinity on microwave emission from the water surface and (4) multiband photography coverage for sea color studies related to chlorophyll concentration.

Surface Measurements

Surface measurements were made by a total of 43 boats which occupied eighty-five (85) stations (Figure 1) throughout the Mississippi Sound. The measurements made by each of the boats are shown in Table II.

Meteorological data, including radiosondes, were taken at several stations adjacent to the Mississippi Sound as an aid in reduction of the remotely sensed data.

Surface water temperatures were obtained by taking "bucket" samples of water as near to the surface as possible and measuring the temperature of this water immediately with a thermometer.

Tide measurements were obtained from the U.S. Corps of Engineers for stations at Mobile, Alabama; Dauphin Island, Alabama; Gulfport, Mississippi and Pascagoula, Mississippi.

Laboratory Analysis

Water samples collected were subjected to laboratory analysis for parameters listed in Table III.

Salinities were run with a Bissett - Berman Laboratory Salinometer. Standard (35 ‰) sea water was used as a reference, and salinities were determined from the conductivity ratio of the sample to that of the standard. Temperature and instrument drift corrections were made according to the Bissett-Berman Instruction Manual.

Water samples at each station were analyzed for chlorophyll content, which gives a measure of the phytoplankton present. The

technique used was essentially that proposed by SCOR-UNESCO Working Group 17 in Determination of Photosynthetic Pigments in Sea-Water, UNESCO, Paris, 1969. Each water sample for chlorophyll analysis was filtered through a millipore 0.45 micron acetate filter. The filters and their residue were stored at -5°C over activated silica gel. Each filter and its residue was ground in a teflon tissue grinder. Ninety percent acetone was used as the extracting agent. The acetone homogenates were stored in the dark for ten minutes, then centrifuged at 2000 g for forty minutes instead of the recommended ten minutes because the extract was too turbid. The volume of each extract was recorded and the absorption spectrum of the chlorophyll extract measured against a blank acetate filter dissolved in 90% acetone. The measurements were made on a Cary 17 Spectrophotometer.

Scientists from Mississippi State University performed water chemistry analysis described below. Although these analyses may not be directly related to the remote measurements, there may be indirect relations and they were also of general interest to participants in the surface measurement study.

Light transmission measurements were made using a Bausch and Lomb Spectronic 20 at a wavelength of 625 nm.

Primary productivity and metabolic activity measurements were made by filling two 300 ml B.O.D. bottles with samples and the dissolved oxygen (in one of the bottles) determined using a YSI portable oxygen meter. The bottles were immediately stoppered and one of the pair covered with aluminum foil. Both bottles were placed in a circulating water bath (20 gal. aquarium) at $26 \pm 1^\circ\text{C}$; incubated for eight hours, and the dissolved oxygen determined on both bottles.

Turbidity measurements were conducted on a Coleman Nephcolorimeter. Total coliform, chloride ion, salinity, phosphate, and nitrate procedures used were those listed in Standard Methods for the Examination of Water and Wastewater, 12th ED. P. 234.

pH determinations were made using a Coleman Model 12 pH meter.

All measurements made by the "ground truth" boats, results of the laboratory analysis of water samples, and meteorological and tidal data have been published by the NASA Earth Resources Laboratory.¹ Copies of this report have been distributed to all participants of the study. Contour maps of surface temperature, surface salinity and surface chlorophyll content over Mississippi Sound were developed from the surface measurements and laboratory analysis. These maps are shown in Figures 2, 3, and 4 respectively.

Each of these contour maps has many interesting features. The contours of chlorophyll concentration show a variation from 2 to 20 mg/m^3 throughout Mississippi Sound. In general, there is a monotonic decrease in chlorophyll content with increasing distance from the coast; however, in areas where influxes of Gulf of Mexico water enter the Sound, variations to this pattern exist. The Gulf of Mexico waters have a much lower chlorophyll content, differing by an order of magnitude to the richest Mississippi Sound water.

Surface temperature, as measured by the "ground truth" boats, showed a variation of about 2°C throughout the Mississippi Sound. The patterns shown by the contour map indicate that most of the surface temperature variations are associated with waters being introduced into Mississippi Sound from the Gulf of Mexico on an incoming tide. The water in the Gulf of Mexico during this season of the year (late summer) is characteristically cooler than the Mississippi Sound water.

The surface salinities were lower in the western part of the Mississippi Sound near Lake Borgne. Salinities of 10 ‰ were measured here. The highest salinities were in the area of the passes and offshore islands; here the values approach normal open ocean salinities of 35 ‰. The fresh water influx from the Pearl River in the western part of the Mississippi Sound is shown very clearly. Also the effect of high salinity water entering through the passes is distinctly displayed by the contour maps.

These contour maps, and the data from which they were constructed provide an excellent set of "ground truth" data for evaluation of the remotely sensed data.

REMOTELY SENSED DATA

Radiometric Water Temperature

The NASA NP3A was equipped with a Barnes PRT-5 radiation thermometer and an RS-14 infrared scanner for the Mississippi Sound I experiment. The PRT-5 was operated on all NP3A flight lines shown in Figure 1; whereas the scanner was used only on flight lines at altitudes of 3,000 and 20,000 feet. The PRT-5 data at 20,000 ft. altitude contained noise (thought to be due to air frame vibration) that made the data unsuitable for further analysis. Thus the usable thermal data obtained from the NP3A was PRT-5 data on all flight lines at 800 and 3,000 feet and RS-14 Scanner imagery on the 3,000 and 20,000 foot altitude flight lines.

A light aircraft, equipped with a second PRT-5, flew flight lines in the eastern portion of the Mississippi Sound (Figure 1). The combined radiometric temperature data from both aircraft along with qualitative information from the RS-14 scanner imagery were used to develop a radiometric surface temperature contour map (Figure 5). Radiometric temperature data used to construct the contour map shown in Figure 5 were obtained from altitude of 800 and 3,000 feet. In order to combine these all temperatures were reduced to a surface datum. The corrections due to the atmosphere were $+3.2^{\circ}\text{C}$ and $+2.0^{\circ}\text{C}$ for the flight lines at 3,000 feet and 800 feet respectively. These corrections were determined empirically by an analysis of points where surface temperatures and radiometric temperatures from both altitudes were obtained within a 1/2 hour time interval.

The flight lines for the experiment were planned so that the high altitude line (20,000 feet) would provide infrared scanner imagery of the passes connecting Mississippi Sound to the Gulf of Mexico. It was assumed that surface temperature anomalies associated with waters being exchanged through these passes would provide information pertaining to the water circulation in the Mississippi Sound. Scanner imagery of Petit Bois Pass between Dauphin and Petit Bois Islands (Figure 6) provides an interesting illustration in this respect.

On July 22, 1971, the day of the experiment, the water in the Gulf of Mexico was generally cooler than that in the Mississippi Sound. On the day of the experiment, there had been an incoming tide all morning with high tide at approximately 12:00 Noon. The infrared scanner imagery shown in Figure 6 was collected between 11:51 a.m. and 11:52 a.m. The cool water from the Gulf of Mexico that entered the Mississippi Sound through Petit Bois Pass on the incoming tide and its course after entering the Sound is shown very clearly by this imagery.

From an analysis of both the scanner imagery and video signal from the scanner recorded on magnetic tape, the temperature difference between the incoming Gulf of Mexico water and the resident Mississippi Sound water was determined to be between 0.4°C and 0.6°C .² This difference compares very well with the temperature contour maps drawn from shipboard measurements (Figure 2) and remote radiometric measurements (Figure 5).

Chlorophyll Studies

The development of techniques to remotely determine the phytoplankton concentration of near shore waters has been an integral part of the Mississippi Sound Remote Sensing Study. A parameter related to the concentration of phytoplankton in marine water is the amount of phytoplankton pigments in the water, and, in particular, the various

types of chlorophylls present.³ In pure open ocean waters the wavelength of maximum reflectance is about 462 nm. As phytoplanktons are added there is a shift toward longer wavelengths. This phenomena has been the basis for much of the research done in remote sensing of marine phytoplankton concentrations. A similar approach has been followed in our study.

In open ocean waters the ratio of the Blue to Green reflectance as measured by photographic densitometry has been used with reasonable success as a measure of algal concentration.⁴ In the case of nearshore waters such as Mississippi Sound, however, complications exist which make modifications to this technique necessary. These factors are: (1) turbid waters with large sediment content, (2) high concentrations of phytoplankton which make scattering of light as well as absorbance important,⁴ and (3) in shallow water, bottom reflectance may introduce errors. In order to take some of these factors into account, we have used a ratio of Blue to Green*Red and have related this ratio to chlorophyll concentration.

Examination of the KA-62 multiband photography taken during the mission showed that photographs of 11 of the "ground truth" vessels had been obtained. The chlorophyll concentration determined from water samples collected by these surface vessels (method described in previous section) was plotted against the ratio of film densities Blue/Green*Red (Figure 7). The correlation between this ratio and chlorophyll concentration is generally encouraging although a few points show a wide divergence.

Salinity Measurement

Emissivity of Sea Water: Ionic solutes alter the real and imaginary part of the dielectric constant of pure water in the microwave region. A conductivity term is also introduced, as an addition to the imaginary term. The Debye type equation,^{6,7} with the conductivity term added, can be used to express the dielectric constant as a function of frequency.

$$\epsilon_c = \frac{\epsilon_s - \epsilon_\infty}{1 + j\lambda \frac{s}{\lambda}} + \epsilon_\infty + \frac{\alpha}{j\omega\epsilon_0}$$

ϵ_c - complex dielectric constant

ϵ_s - low frequency dielectric constant of the solution

ϵ_∞ - high frequency dielectric constant of the solution

- λ_s - relaxation wavelength
- λ - wavelength
- σ - conductivity
- ω - frequency
- ϵ_0 - permittivity of a vacuum
- α - spread parameter

The four parameters, ϵ_s , λ_s , σ , and α are functions of the normality and temperature of the solution. ϵ_s and λ_s decrease with increasing normality due to hydration;⁸ the conductivity increases almost directly with concentration, at least for dilute solutions, due to the increasing number of ions available. The importance of the spread parameter, α , is relatively minor and will be ignored for the present. At low microwave frequencies the dependence upon conductivity is strong enough to cause a measurable decrease in the radiation emissivity of the solution as normality increases. As an illustration of this effect, the emissivity of a NaCl solution at a temperature of 30°C is shown in Figure 8. The Fresnel reflection coefficient equations for a flat surface were used to relate the emissivity to ϵ_s . The incidence angle is 0°.

Sea water is a complex solution, containing every element presently known, although many only as trace elements.⁹ The complex dielectric constant of sea water as a function of salinity and temperature has not presently been measured. Since NaCl accounts for 78% of the salts in sea water, a NaCl solution is usually used as a sea water substitute. The substitution can be made in a manner to produce sea water and NaCl solutions of either equal normality, or equal salinity. The latter appears to be most often used.^{10,11} The gram equivalent weight of sea water is 57.85, that of NaCl is 58.45, so the substitutions are nearly equivalent. Since the effects on ϵ_s , λ_s , and α of some of the salts other than NaCl in sea water are not precisely known, both probably introduce error. Regarding these difficulties, a sea water salinity scale is added to Figure 8 positioned according to a equal normality substitution.

Radiometric and Salinity Measurements: Radiation upwelling from the Mississippi Sound was measured at the frequencies of 1.420, 10.625, and 31.4 GHz along flight lines 1, 2, 3, and 4 of the Mississippi Sound I mission. The flight lines are drawn in Figure 1. The aircraft altitude was 800 feet. The instrument used was the Multifrequency Microwave Radiometer, a conventional Dicke type radiometer, part of the instrument complement of the NP3A.

Surface values of salinity were obtained from water samples taken at the time of the aircraft overflight. The sampling positions are represented by large dots on the flight lines in Figure 1. The salinity of the samples was determined with a salinometer, as explained above. Standard sea water was used for calibration.

The apparent temperature at 1.42GHz and the measured salinity values along flight lines 1, 2, 3, and 4 are shown in Figures 9, 10, 11 and 12. The emissivity for sea water was calculated by substituting a NaCl solution of equal normality, except the conductivity of sea water rather than the salt solution was used. Hopefully, this improved the calculation accuracy. Each of the radiometric temperature data points is an average of the radiometer output voltage after calibration corrections were inserted. The averaging period is 16.6 sec., which corresponds to a ground distance of about 3,600 ft. Averaging over this distance would conceal any fine salinity structure which exists at the water surface. The averaging was necessitated by the high standard deviation (about 6°K) when the direct radiometer output with an averaging period of .20 sec. was used. Part of this large variance is believed due to interference from other equipment. It is not believed that sufficient fine salinity structure was present to appreciably affect the comparison of the average radiometric temperature with measured salinity. The radiometric temperature confidence interval shown in the graph is a 2σ interval for the averaged output variable, where σ is the standard deviation of the averaged output.

Actual surface temperatures along each flight line varied only slightly (about 1.5°K), hence water temperature was assumed to be a constant for each line. No corrections for either sea state or atmospheric effects have presently been made. Sea states were mild when the first four lines were flown. Wind velocities and wave heights for the four flight lines are shown in Table IV. Neither whitecaps nor sea foam, which has considerable effect upon apparent temperature,¹² were present. The four graphs demonstrate the correlation between salinity and apparent temperature obtained for this experiment. The fixed bias of about 30°K is probably due to a combination of system errors, uncertainties in the salinity/emissivity relationship, and to the reflected sky temperature, which has not been removed. It should be possible to eliminate this bias with the ground truth information and, in fact, if 30°K is subtracted from the measured apparent temperature, the salinity and apparent temperature curves align closely in many parts of the four graphs. However, discrepancies still exist, in particular in parts of Figures 9 and 12. Because of the large offset in the measured apparent temperature, and because of the larger than expected variance of the radiometer output, the authors hesitate to compare the data in an absolute sense. However, it is believed that the apparent temperature data maintains its relative integrity over the

short term, and the similarity of the curve shapes in the figures, especially the long flight line in Figure 9, demonstrate the sensitivity of apparent temperature to salinity and the possibility of measuring salinity values in this range remotely.

CONCLUDING REMARKS

The information presented thus far was primarily from the experiment which took place on July 22, 1971. Since that time there has been a second experiment on November 10, 1971. Aside from being at a different season of the year, there were other variations from the first experiment - the flight lines were revised (Figure 13) to provide complete infrared scanner coverage of Mississippi Sound. A different tide stage was chosen - an outgoing tide instead of the incoming tide occurring during the first experiment. It is hoped that viewing the Sound under these varying conditions will better aid us to understand the processes taking place.

At present, the status of the Mississippi Sound study is as follows: (1) we have developed a satisfactory system to gather "ground truth" over the entire area of Mississippi Sound to aid us in evaluating the remotely sensed data, (2) we have conducted two data acquisition experiments, (3) we are proceeding in analysis of individual sensor data from flights completed, and (4) we are pursuing methods which will allow interrelations between data from individual sensors in order to add another dimension to our study.

ACKNOWLEDGMENTS

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<u>Parameters</u>	<u>Applicable Remote Sensing Technique</u>
Circulation	
Sediment Plumes	Visible Imagery and Radiometry
Thermal Patterns	Infrared
Salinity	Microwave Radiometry
Tides	
Winds	
Fresh Water Inflow	
Water Chemistry	
Biological Productivity	
Chlorophyll	Visible Imagery and Radiometry
Bathymetry	

Table I

Parameters Characterizing Coastal Waters
and Related Remote Sensing Technique

Surface Water Temperature
Air Temperature
Humidity
Wind-Direction and Speed
Secchi Transparency
Sea State Observation
Water Sample Collection

Table II

Measurements From Boats at Each Station

<u>Parameters</u>	<u>Performed By</u>
Salinity	ERL/LEC
Chlorophyll	ERL/NOVA Univeristy
Primary Productivity	Mississippi State University
Metabolic Activity	"
Turbidity	"
Coliform	"
pH	"
Chloride Ion	"
Sodium	"
Potassium	"
Calcium	"
Magnesium	"
Iron	"
Phosphate	"
Nitrate	"
Total Solid	"
Suspended Solids	"

Table III

Laboratory Analysis of Water Samples

Line		Wind Speed	Wind Direction	Wave Height
1		0-5 knots	Variable	6 in
2		5-10	NE	6
3		3-5	NE	6-12
4		3-5	NE	6

TABLE IV
Wind velocities and wave heights for flight lines
1, 2, 3, and 4 of Mississippi Sound I Mission

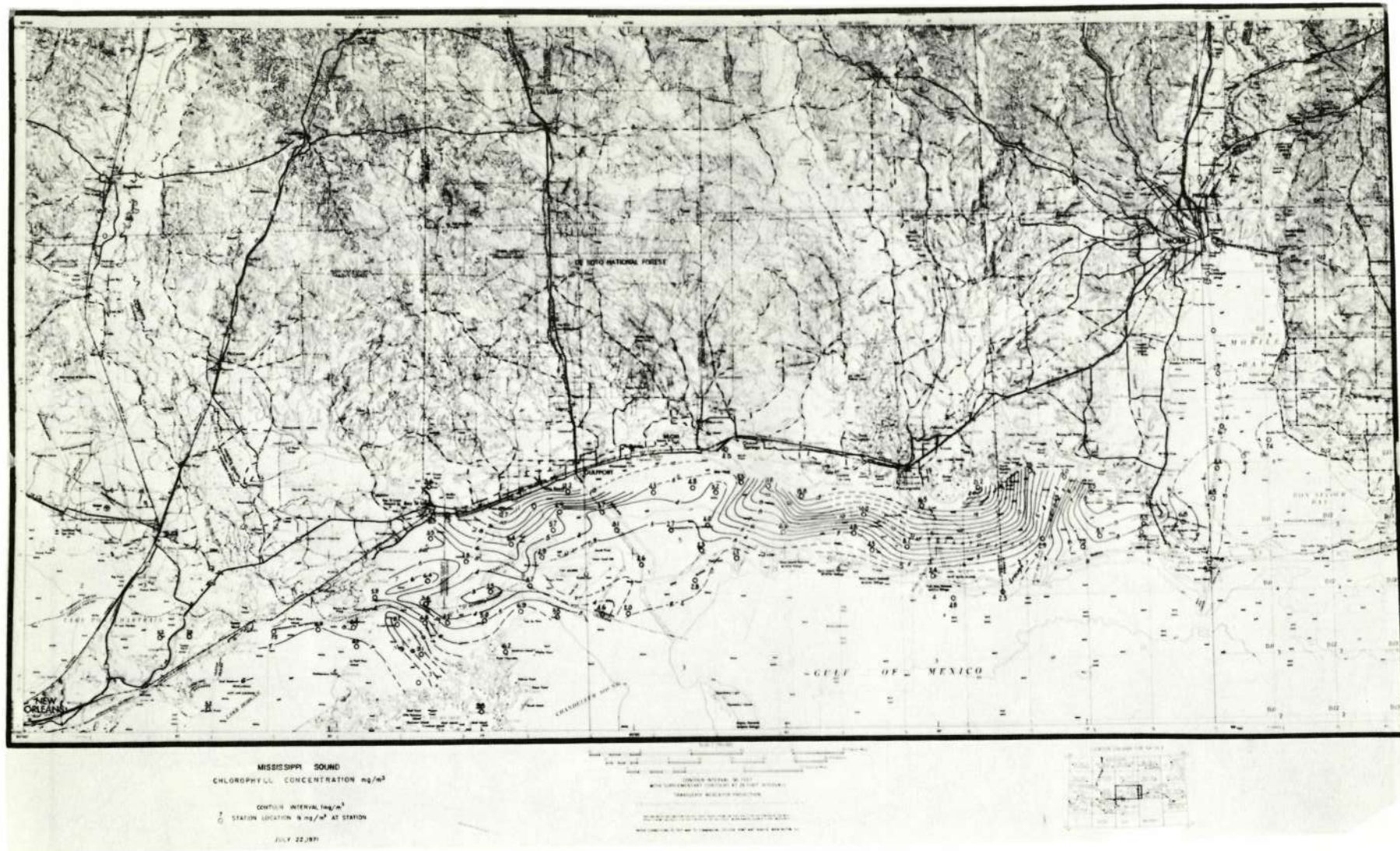


FIGURE 4
Mississippi Sound Surface Chlorophyll Concentration mg/m^3 ,
July 22, 1971 - Laboratory Analysis

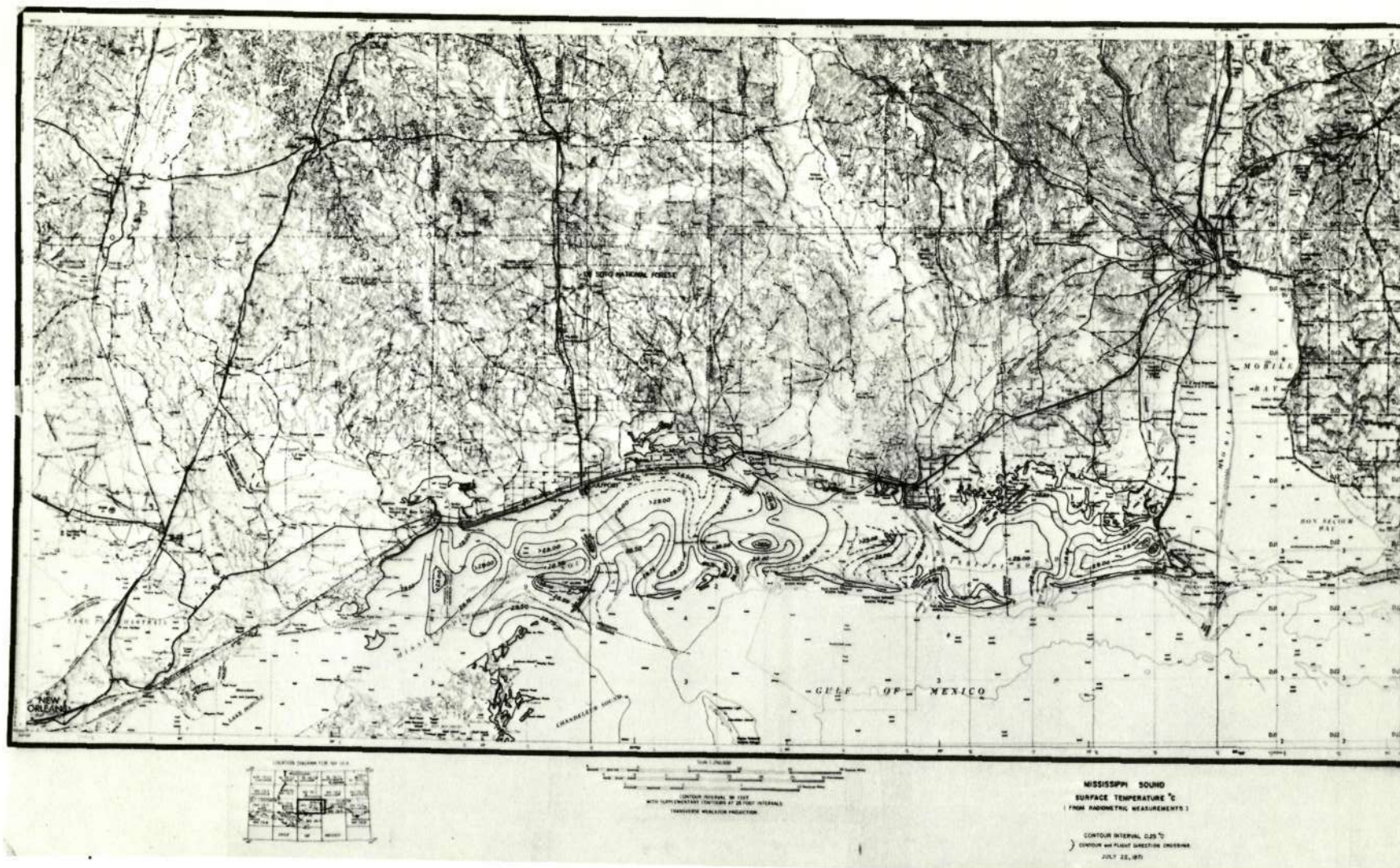


FIGURE 5
Mississippi Sound Surface Temperature °C,
July 22, 1971 - From Radiometric Measurements

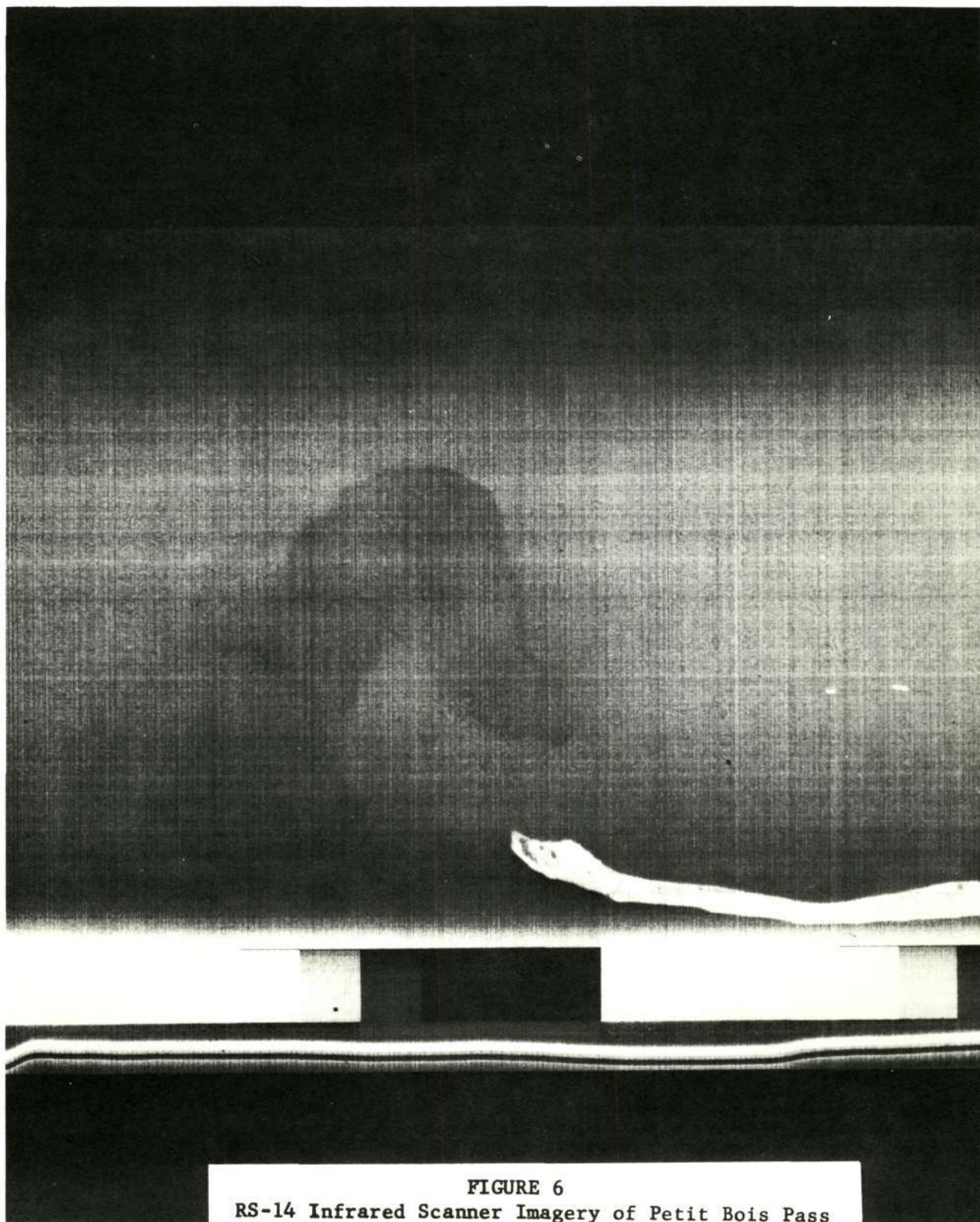


FIGURE 6
RS-14 Infrared Scanner Imagery of Petit Bois Pass
(Between Petit Bois and Dauphin Island)

MISSISSIPPI SOUND I
JULY 22, 1971
FILM DENSITY CHLOROPHYLL CURVE

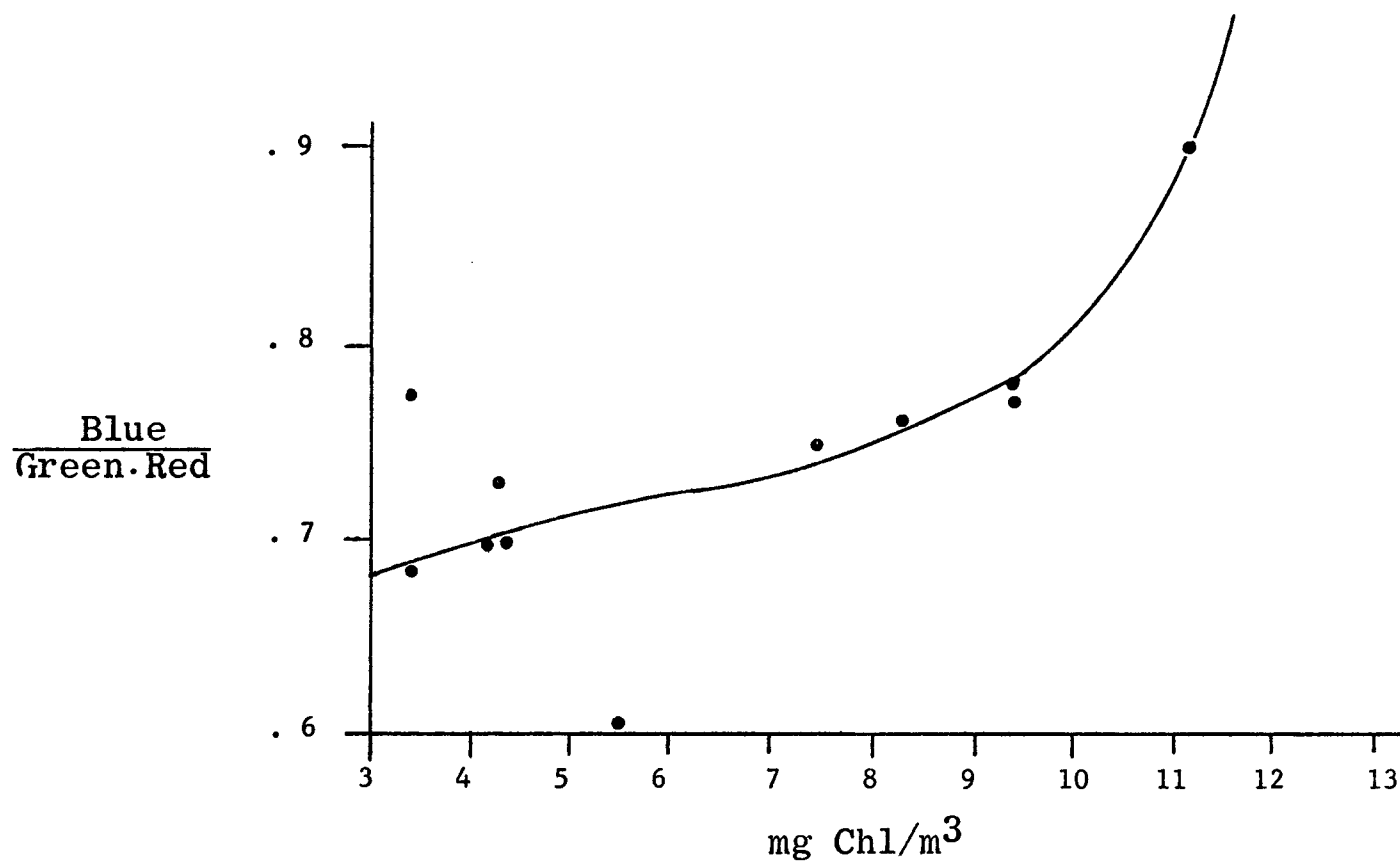


Figure 7

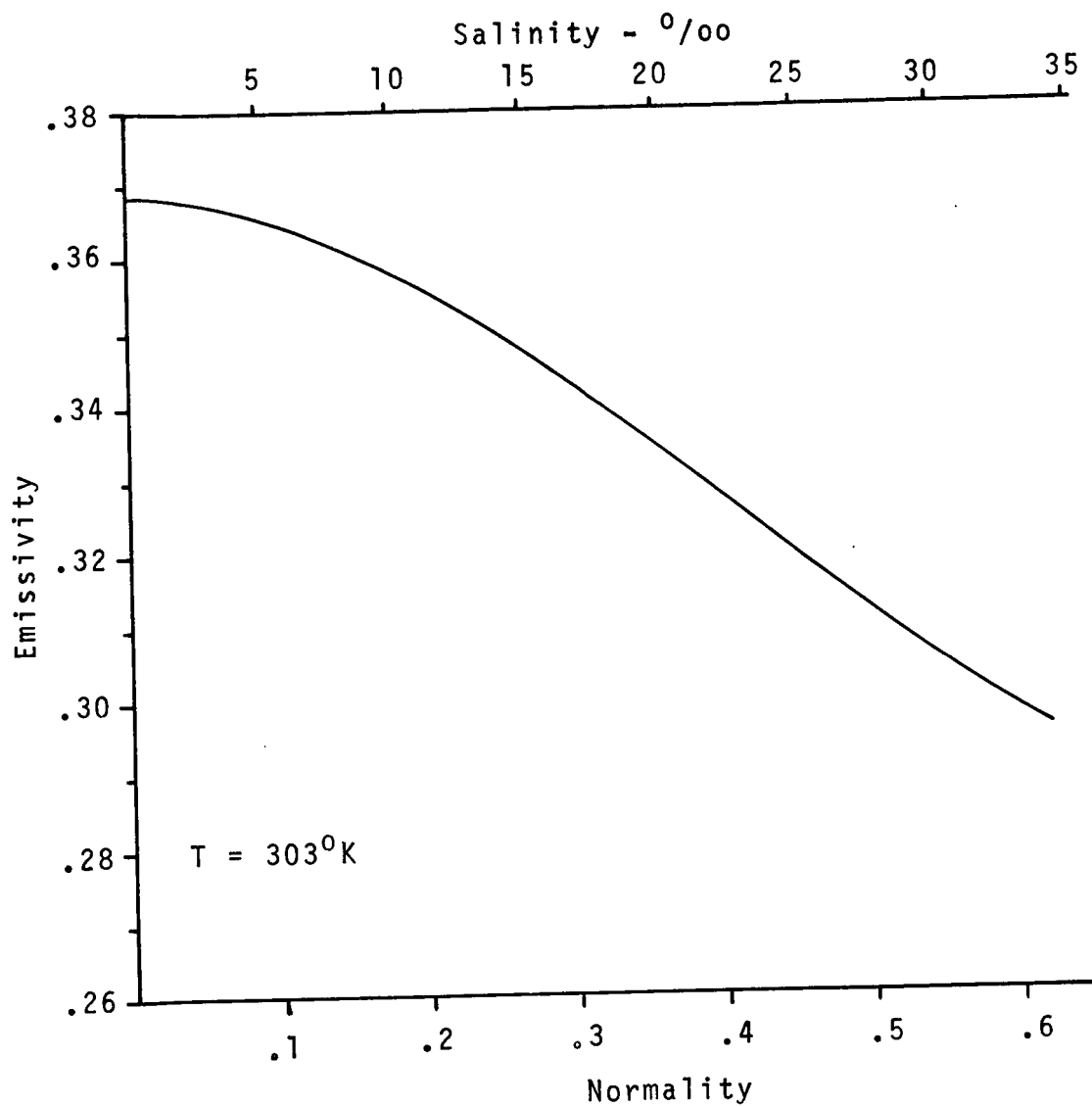


FIGURE 8
Emissivity of a 30°C NaCl Solution as a function
of normality

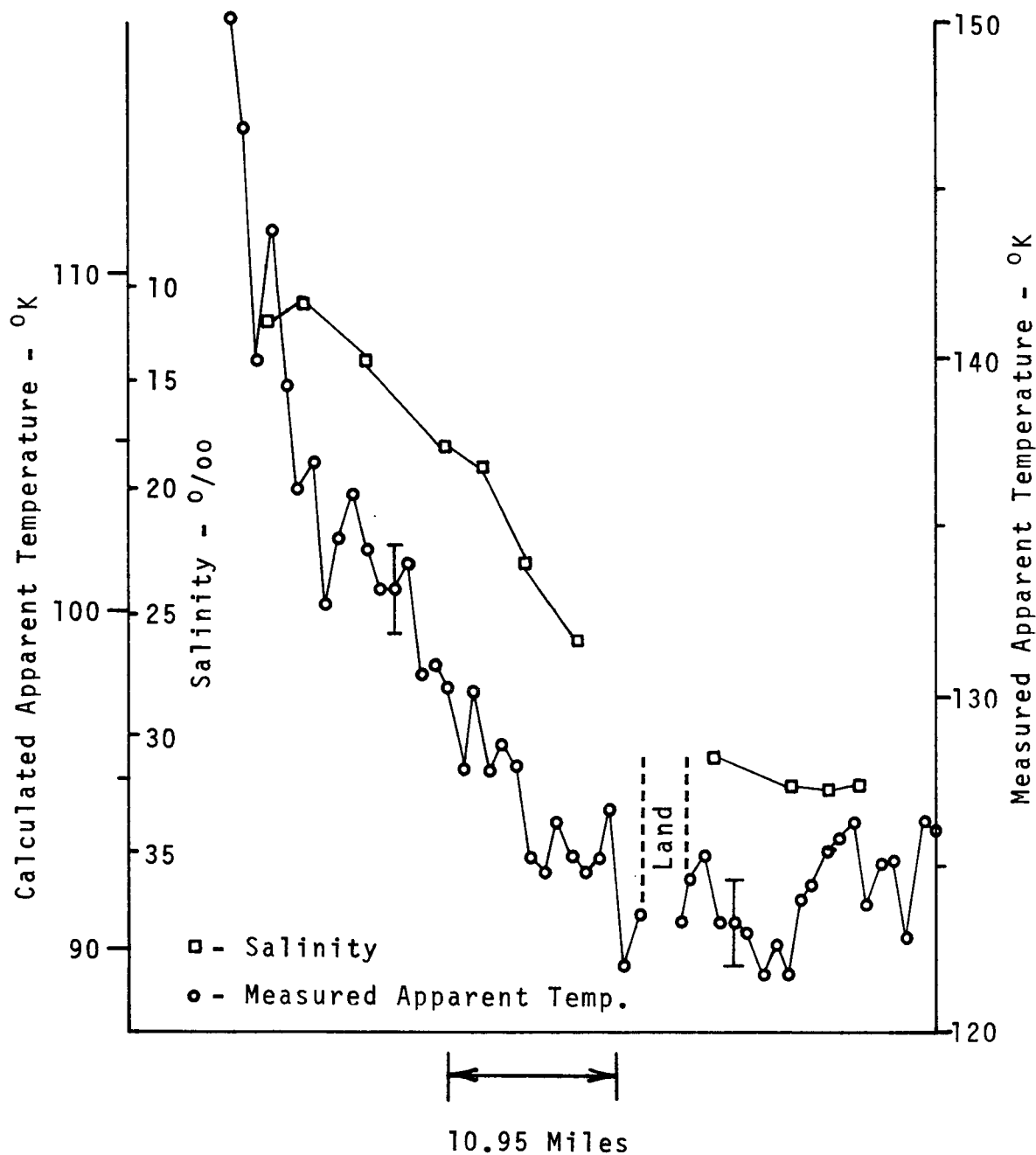


FIGURE 9
 Measured apparent temperature and salinity for
 line 1 of Mississippi Sound I Mission. Water
 temperature = 28.8°C, incidence angle = 9.33°,
 vertical polarization

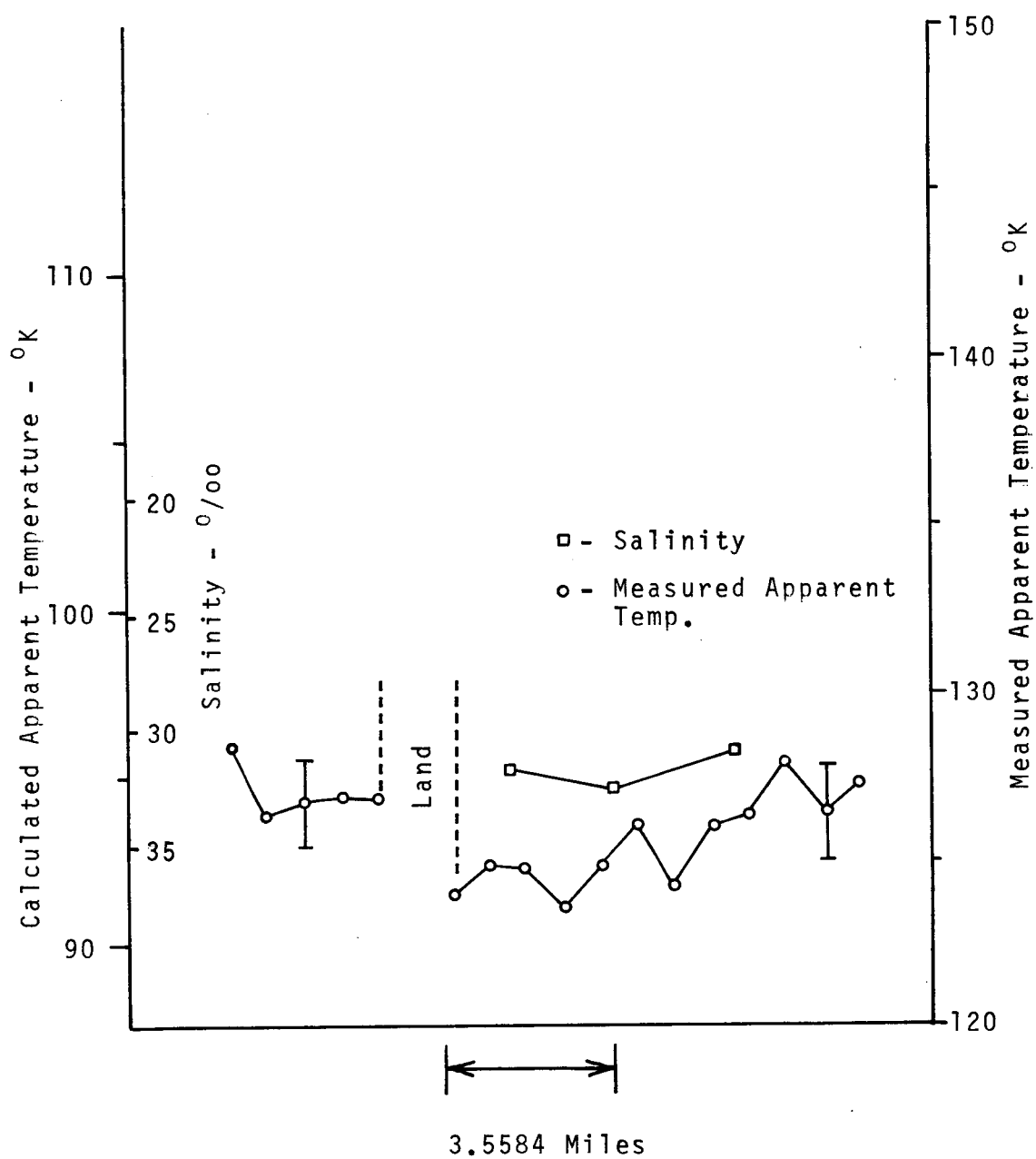


FIGURE 10
 Measured apparent temperature and salinity for
 line 2 of Mississippi Sound I Mission. Water
 temperature = 28°C, incidence angle = 9.33°,
 vertical polarization

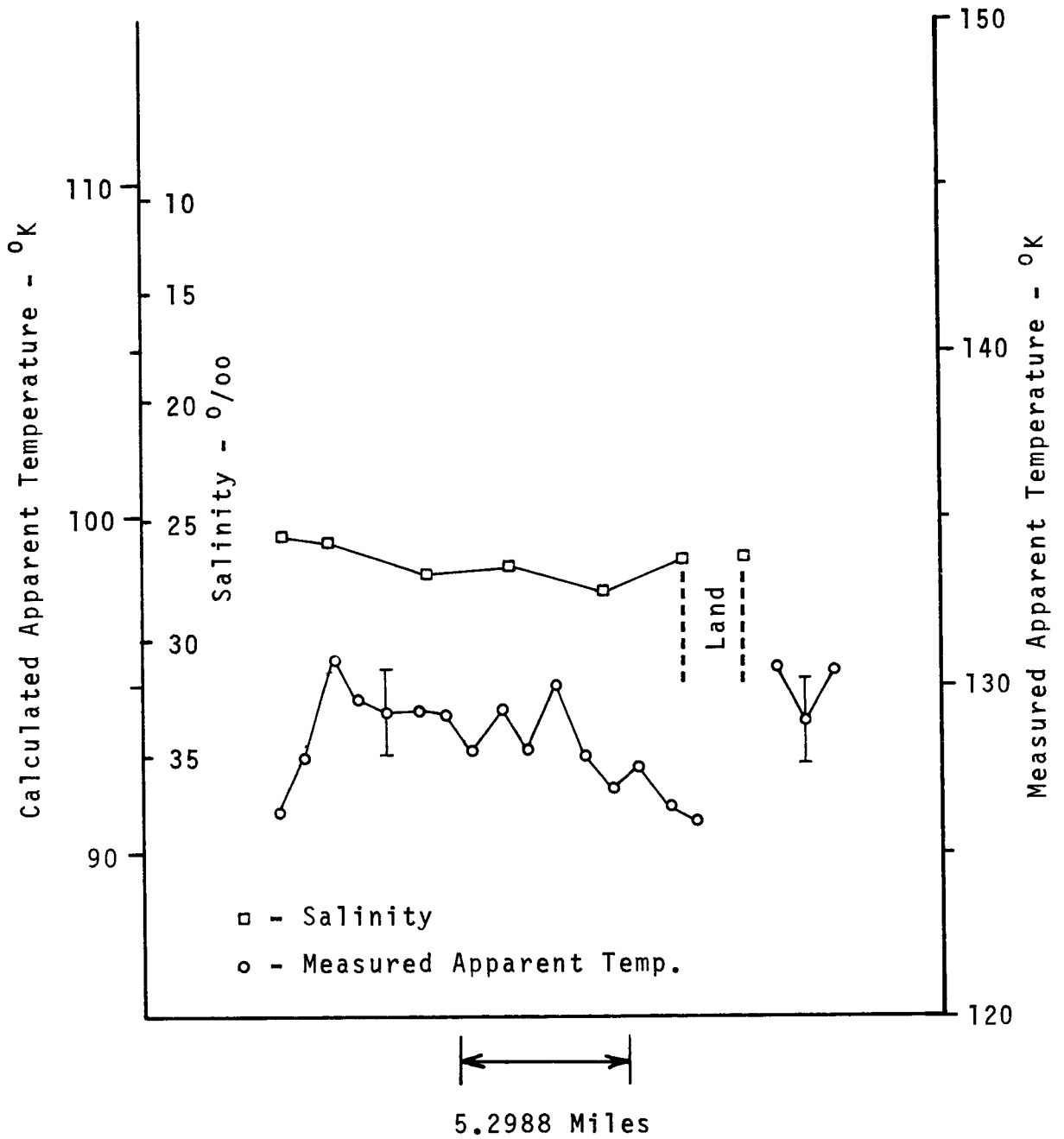


FIGURE 11
 Measured apparent temperature and salinity for
 line 3 of Mississippi Sound I Mission. Water
 temperature = 28.5°C , incidence angle = 9.33° ,
 vertical polarization

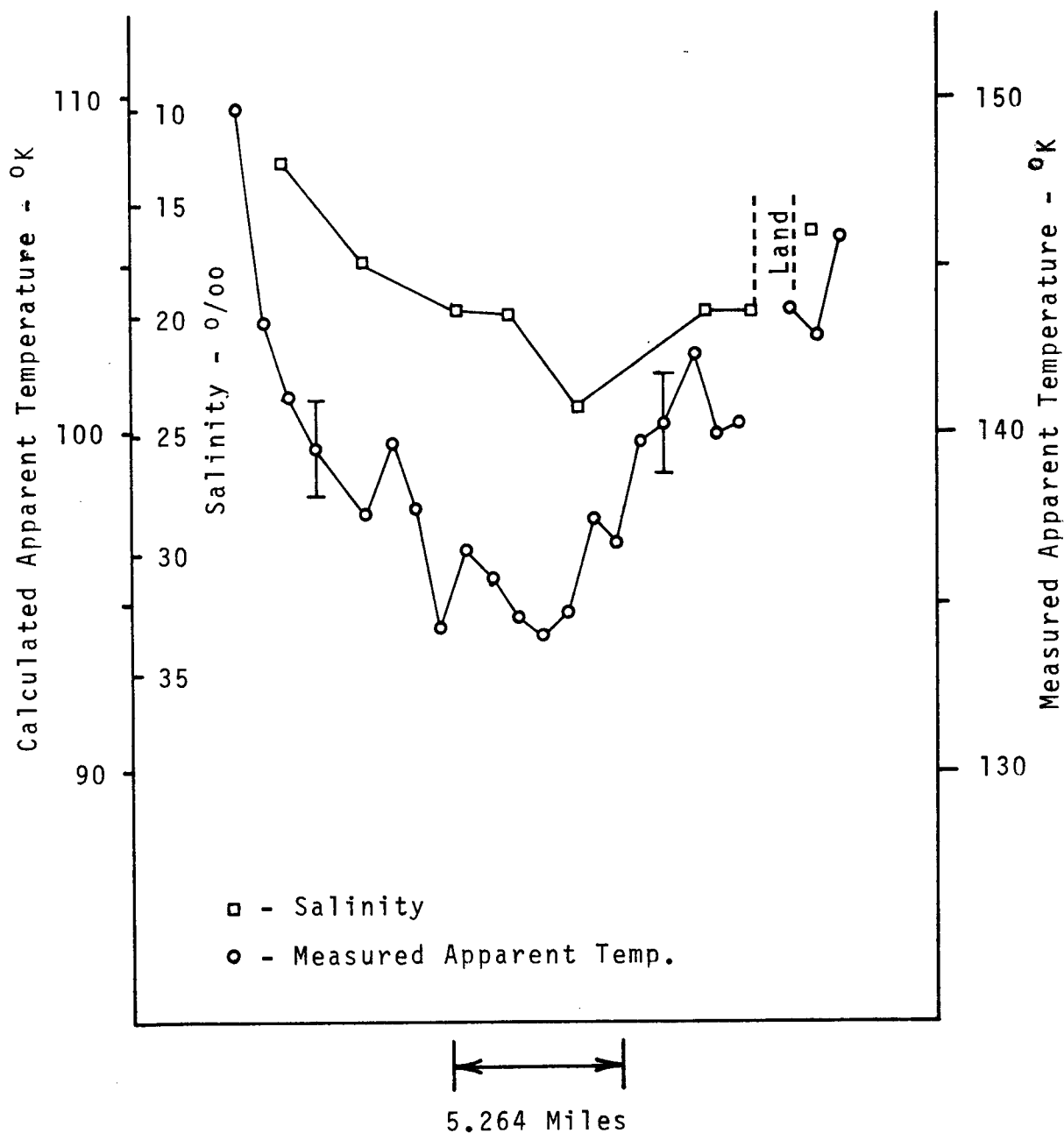


FIGURE 12
 Measured apparent temperature and salinity for
 line 3 of Mississippi Sound I Mission. Water
 temperature = 28.5°C, incidence angle = 9.33°,
 vertical polarization

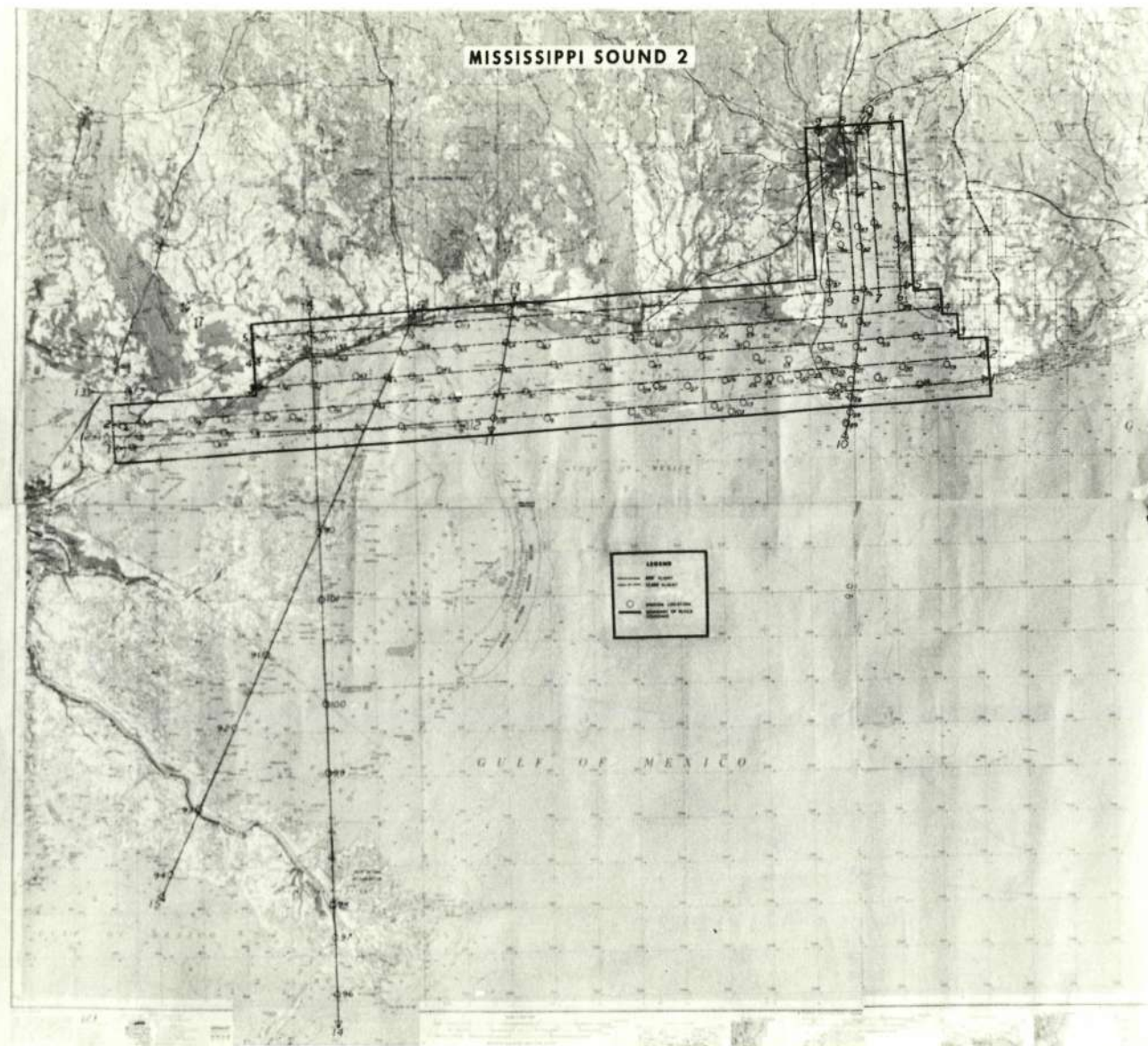


FIGURE 13
Mississippi Sound I, Flightline and Station Map,
November 10, 1971