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REMOTE MEASUREMENT OF SALINITY: REPEATED MEASUREMENTS OVER A SINGLE FLIGHT LINE NEAR THE MISSISSIPPI SOUND

by

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INTRODUCTION

During the past two years several experimental efforts have been made at the Earth Resources Laboratory (ERL) to remotely determine sea water salinity from measurements of the sea surface radiometric temperature at 21cm wavelength (Thomann, 1972). These experiments have met with variable success, depending, apparently, upon how well the 21cm radiometer operated. On the average, accuracies of 3-5^{o}/oo were obtained. For further testing of the accuracy and precision of the remote measurement technique, repeated measurements were made along a line near the Mississippi Sound on August 25, 1972. Boats stationed along the line took ground truth measurements and acted as line markers for the aricraft. The flight line is shown in Figure 1. It extends from the upper part of Lake Borgne near the Rigolets to south of Ship Island. It is usually a good line for salinity measurement testing because a marked increase in salinity occurs from west to east. On the western end water from Lake Pontchartrain, the Pearl River and other shore runoff keeps the water salinities relatively low (about 10^{o}/oo during this experiment). Between Grand Island and Isle au Pitre the salinity is more moderate, about 20^{o}/oo on August 25. Below the barrier islands of the Mississippi Sound the salinity is nearer to that of the Gulf of Mexico, on August 25 about 30^{o}/oo. At different times of the year overall salinity values change in response to river levels and shore runoff, but there is usually a gradient along the flight line. August is one of the drier months and salinities were higher than might occur at other times of the year.

The line was flown six times, the first from east to west, with successive passes in alternate directions. The aircraft altitude was 244m. The radiometric temperature of the sea surface was measured in two spectral intervals,

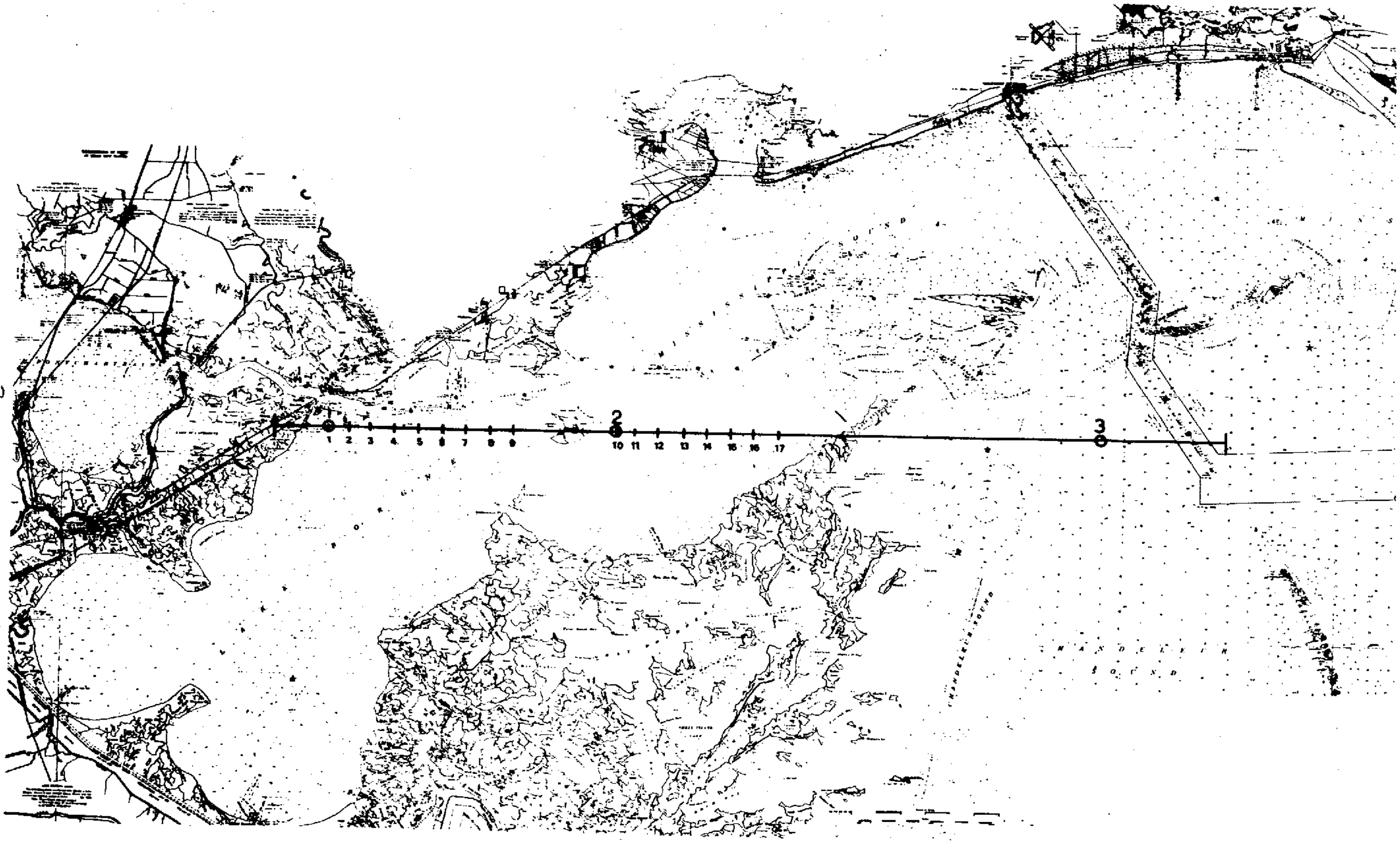

Figure 1. Aircraft flight line, positions of three stationary boats (circles) and positions of measurements taken by moving boat (smallest numbers).

one near 21cm using an L-band radiometer, the other from 8-14μ using a PRT-5. Ground truth boats were located at the circled positions numbered 1, 2, and 3 on Figure 1. In addition, a moving boat started at the west end of the line and took samples at positions approximately one mile apart; it was able only to get to Isle au Pitre before dark. The small numbers in Figure 1 show measurement positions. The measurements made by the boats were surface temperature, surface salinity, and sea state.

REMOTE MEASUREMENT OF SALINITY

The determination of sea water salinity from measurements of the sea surface radiometric temperature at microwave frequencies has been investigated by Paris (1970) and Thomann (1972), and a review can be obtained from these articles. The relationship between apparent temperature and sea water salinity for frequencies near 1.4GHz is shown in Figure 2 for several water temperatures. 1.4GHz (21cm) is a popular choice for salinity studies because of the availability of radiometers. (Theoretical constraints limit the frequencies to below 2GHz.)

The Earth Resources Laboratory procedure for remote salinity measurements consists of the following:

1. Measurement of the apparent temperature of the sea surface at 21cm and 8-14μm wavelength.
2. Correction of perturbations in the 21cm and 8-14μm data.
3. Determination of salinity using a table look-up procedure.

The L-band channel of the Multi-Frequency Microwave Radiometer (MFMR) was used for this experiment. This instrument is installed in the NASA/NP3A, an earth resources aircraft based at the Johnson Space Center. The radiometer is sensitive to radiation in a 100MHz band centered near 1.4GHz. The measurement of the sea surface apparent temperature at 8-14μm was done using a PRT-5. Perturbations in the 8-14μm data are due to instrument offset, atmospheric effects and sea surface effects. An offset correction is made to the 8-14μm temperature

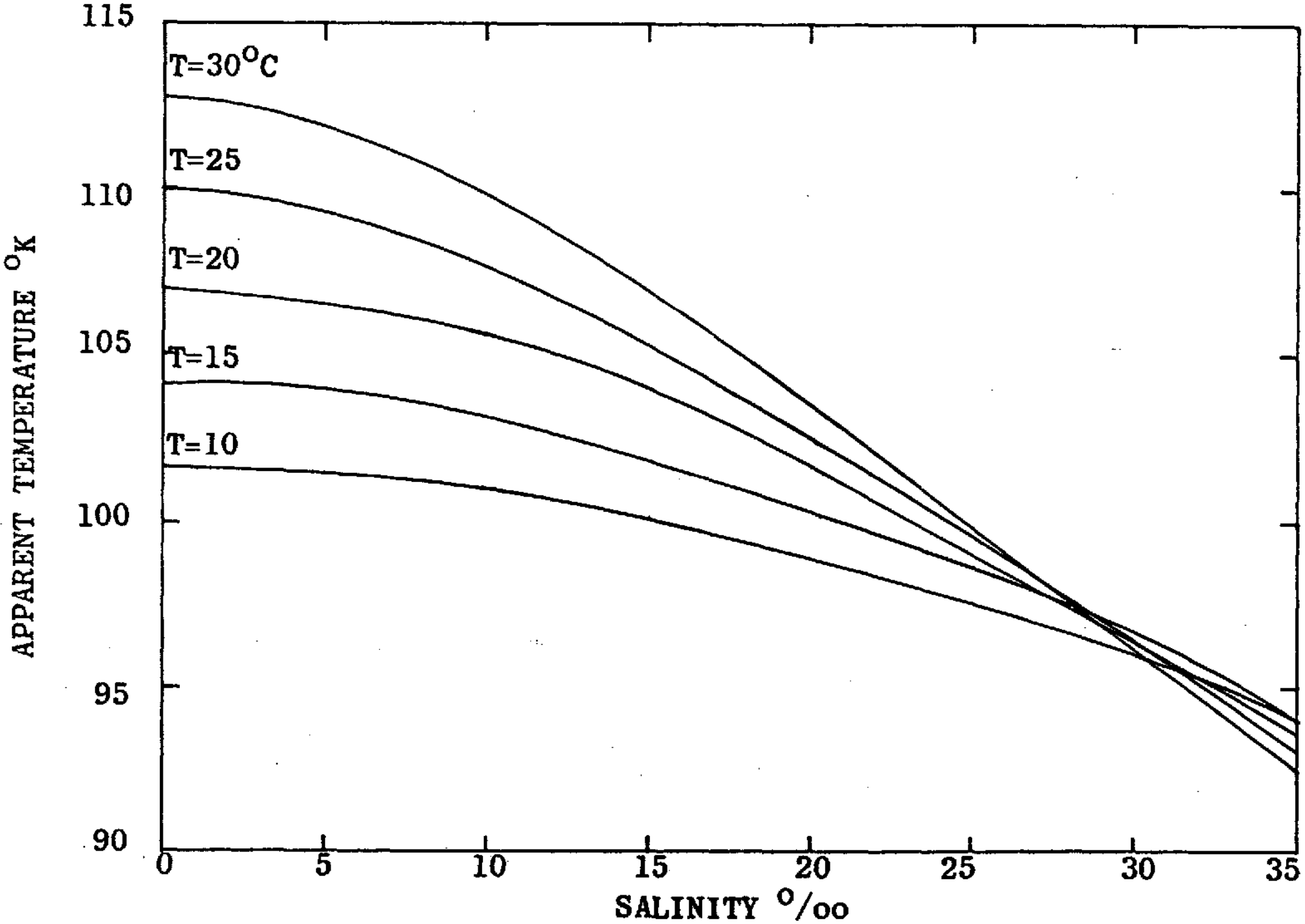

Figure 2. Apparent sea surface temperature as a function of salinity and water temperature for 21.1cm wavelength, 9.3° incidence angle, vertical polarization.

using ground truth data for calibration. Perturbations in the 21cm data are due to background galactic radiation, the sun, the atmosphere, clouds, sea state roughness, uncertainties in the radiometer gain and constant offsets in temperature the receiver electronics may introduce. The cumulative effect of these errors is removed using two calibration points. In this case boat measurements of salinity and temperature at each end of the line were taken for calibration. The measured 21cm apparent temperature is force fitted to the radiometric temperatures calculated from these boat measurements using a linear transformation of the data. Water salinity is determined using a two dimensional table look-up procedure. The correct salinity is found in the table corresponding to the measured 21cm radiometric temperature and corrected PRT-5 temperatures.

The remotely measured salinities for the six passes are shown in Figures 3 and 4. In Figure 3 the measurements over each pass are individually calibrated at boat positions one and three. Even though each pass is supposedly force fit at these two boat stations, the remotely measured values do not exactly align with ground truth measurements at boat positions one and three. This is due to the fact that a boat measured thermodynamic water temperature is used for calibration, while the corrected PRT-5 temperature is used when the remotely measured salinity values are actually plotted. The correction applied to the measured PRT-5 temperature removes the average offset and the PRT-5 temperature may not correspond exactly with the measured temperature at any particular boat. Each remote measurement point on the two figures represents about 15 seconds of averaged data. This long averaging time is used to increase the sensitivity of the radiometer and to reduce short term fluctuations.

On the west to east runs (even numbered) a considerable portion of land was overflown immediately before the beginning of the line. At L-band frequencies the land is radiometrically much hotter than the water. On these passes the radiometer did not quickly respond to the surface change, but took considerable

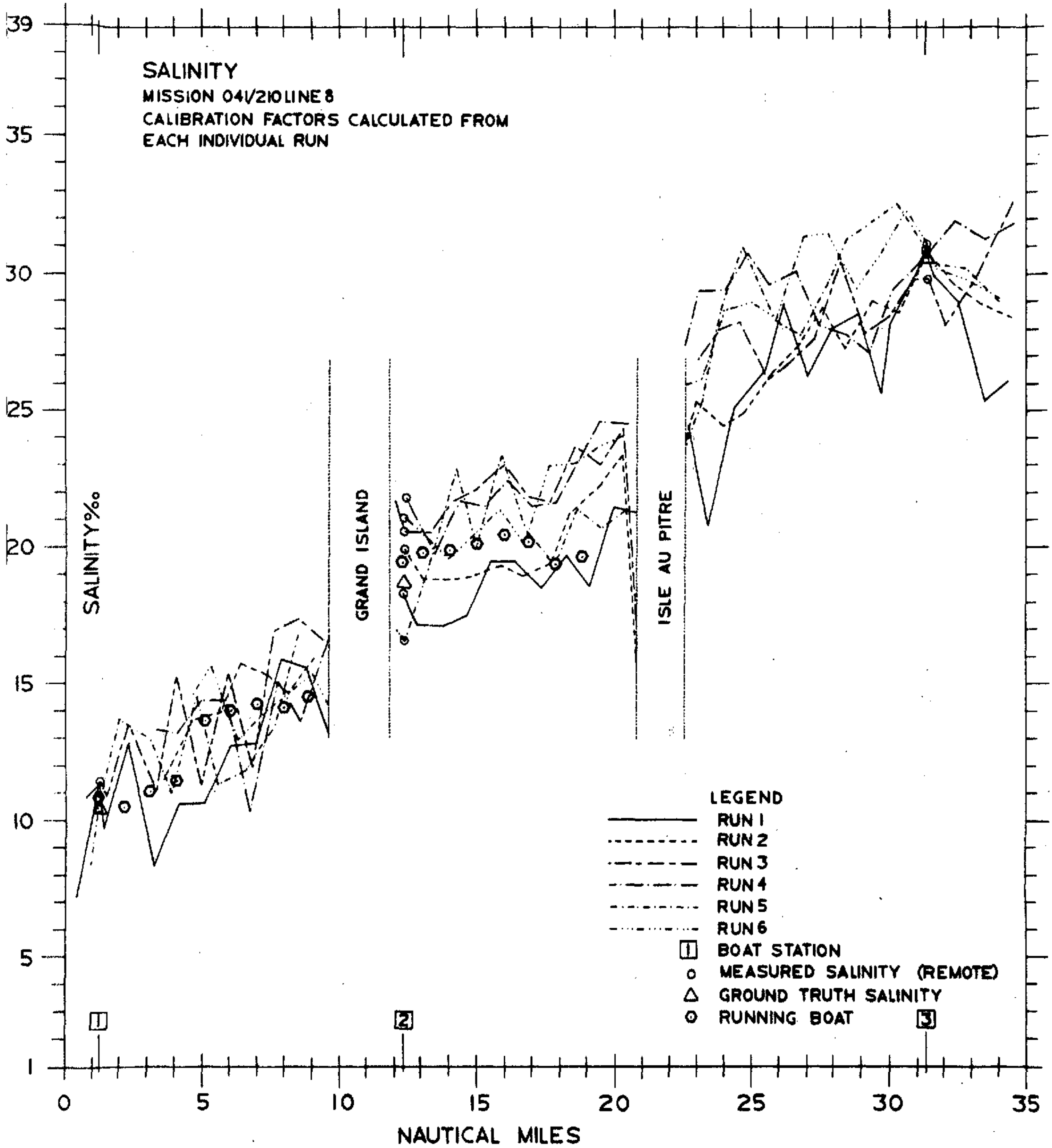

Figure 3. Remote and ground truth measurements of salinity, each run calibrated from measurements at positions 1 and 3.

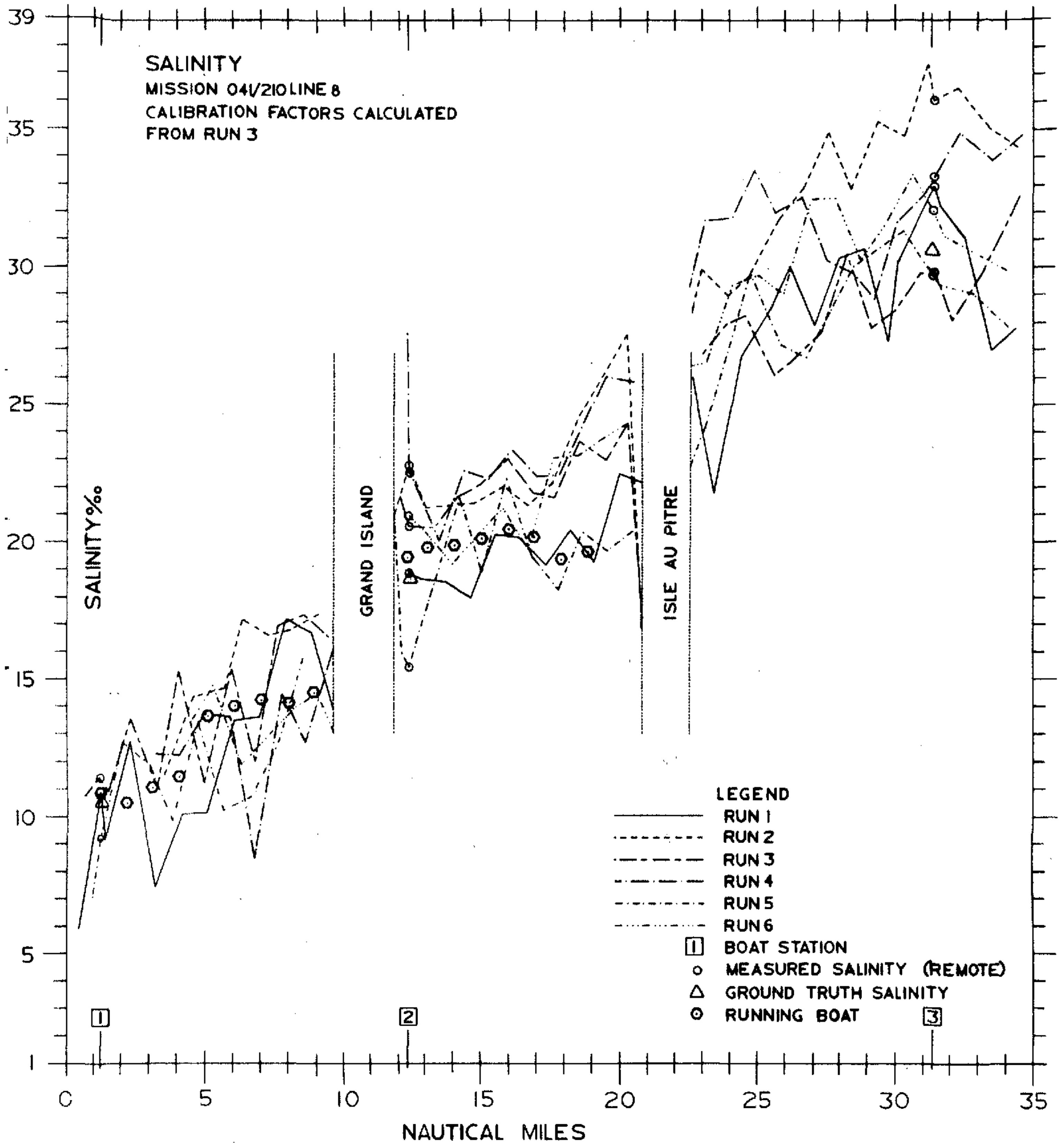

Figure 4. Remote and ground truth measurements of salinity, scale factors for all runs calculated for line 3.

time to adjust to the lower sea surface temperatures. Therefore, the 21cm data was not good for the first part of each of these runs and is not displayed. Ground truth boat 1 is within the area where the data is contaminated, therefore, direct calibration at point 1 is impossible. To calibrate these passes the radiometer reading from run 3 was used, hence any changes occurring during the time between run 3 and runs 2, 4, and 6 will be reflected in the data. No serious changes seemed to appear in the data, however.

The cause of the long radiometer settling time is uncertain. It is possible that minor lobes of the antenna are receiving radiation from the land after the interface is crossed. When the plane approaches the interface from the other direction, however, the radiometer output increases abruptly rather than gradually rising. Hence, it does not appear that antenna minor lobes are the cause. The radiometer does not always exhibit slow reaction times when the apparent temperature is dropping. When small islands along the flight line are encountered the radiometer output rises and falls quite quickly. These islands are quite small and are not seen for very long by the antenna, and may not even ever occupy a large enough solid angle to raise the measured apparent temperature to that of land alone. Thus it would appear that the long time constant appears after high land temperatures are sensed. High temperatures over a considerable length of time may be necessary to cause the radiometer saturation.

In Figure 4 the same data is displayed except that a single set of scale factors are applied to all the data. These are the scale factors calculated for run 3. Assuming little change in environmental conditions, this graph should show the amount of radiometer drift during the experiment. Little change in physical conditions did occur at the three ground truth boats and environmental changes can probably be neglected. The surface salinities measured at the three positions at various times are shown in Table 1. Each boat took a measurement at the time of each flyover.

Table 1. Variation in Surface Salinity at the Three Boat Positions

Sta.	CDT Time	Salinity	Sta.	CDT Time	Salinity	Sta.	CDT Time	Salinity
1	1649	10.5°/oo	2	1645	18.9°/oo	3	1645	30.8°/oo
1	1651	10.3°/oo	2	1658	18.8°/oo	3	1707	30.7°/oo
1	1716	10.9°/oo	2	1715	18.8°/oo	3	1713	30.4°/oo
1	1726	10.6°/oo	2	1731	18.7°/oo	3	1741	30.6°/oo
1	1750	10.5°/oo	2	1750	19.0°/oo	3	1747	30.7°/oo
1	1754	10.5°/oo	2	1801	18.9°/oo	3	1810	30.6°/oo

The moving boat began at the west end of the line and traversed the line during the course of the experiment, taking surface measurements at positions spaced about one nautical mile apart. The original plan was to have the boat run the entire line, but the late starting time precluded this, and measurements are available only over about two-thirds of the line. For analysis the line is divided into three sections - section 1 from the west shore of Lake Borgne to Grand Island, section 2 from Grand Island to Islé au Pitre, and section 3 west of Isle au Pitre. For sections 1 and 2 a linear least squares fit can be made to the measurements taken by the moving boat and are given by eqs. (1) and (2), respectively,

$$S = 10.4 + .32X \tag{1}$$

$$S = 19.9 + .004X \tag{2}$$

where S is salinity in parts-per-thousand and X is the distance in kilometers eastward from station ① for section 1 and eastward from station ② for section 2. Assuming that these regression lines are reasonable estimates of the actual salinity during the experiment, the RMS errors of the remote measurements can be obtained. These are shown in Tables 2 and 3. The number of remotely measured points used for the calculation is also shown. Those points used for calibration were not also used for error calculation, since the remote measurements had been force fitted to them.

Table 2. Remote salinity measurement RMS errors and number of calculation points for the six runs with individual calibration.

Section 1

Run	1	2	3	4	5	6
No. of Points	9	7	10	7	8	5
Erms	1.7%	1.2	2.1	1.8	1.6	

Section 2

Run	1	2	3	4	5	6
No. of Points	10	10	9	9	9	10
Erms	1.7%	1.6	2.4	2.5	2	2.4

Table 3. Remote salinity measurement RMS errors and number of calculation points for the six runs with calibration from line 3.

Section 1

Run	1	2	3	4	5	6
No. of Points	9	7	10	7	8	5
Erms	2.1%	2.3	2.1	2.2	1.9	1.5

Section 2

Run	1	2	3	4	5	6
No. of Points	10	10	9	9	9	10
Erms	1.5%	3.4	2.4	3.4	2.0	2.5

Theoretical considerations (Thomann, 1972) indicate that salinity measurement accuracies of about $1^{o}/oo$ can be obtained with a state-of-the-art radiometer if the effects of the atmosphere and other perturbing influences can be removed. The radiometer being used is not considered to be quite state-of-the-art, and during previous experiments (Thomann, 1972) accuracies of $3\text{-}5^{o}/oo$ or poorer were the usual case. The accuracies shown in Table 2 and 3 thus appear quite good for the present radiometer, although still not quite that desired for an operational technique. The composite accuracy (RMS) error calculated (using the points from all six lines) for the individual calibration case is $1.7^{o}/oo$ for section 1 and $2.1^{o}/oo$ for section 2. It takes about 10 minutes to fly each line and the radiometer need maintain its (relative) fidelity only for that length of time.

The stability over a slightly longer time is shown in Table 3. It took about one hour to fly all six lines. The composite accuracy is $2.1^{o}/oo$ for section 1 and $2.6^{o}/oo$ for section 2. These accuracies are poorer than those for individual calibration but not significantly so. From these values it appears, in fact, that the radiometer operated quite well for an hour, at least over sections 1 and 2. It appears from Figure 4 that there is more divergence of the remotely measured values over section 3. The only point available for a calculation is a boat position 3. The standard deviation for the five runs other than run 3 at this point is $3.0^{o}/oo$, which is poorer than the other two sections. It is difficult to draw any conclusions from a single point, however.

As presently envisioned, an operational system would have an accuracy of $1\text{-}2^{o}/oo$ over a one or two hour period with calibration at one point rather than two. Calibration at a single point removes only offset errors, thus the receiver gain must be known. (Atmospheric attenuation is small and in most cases can be ignored.) The performance during this experiment is easily the best exhibited by the radiometer during the ERL experiments. However, the performance characteristics necessary for an operational system have still not been demonstrated. The radiometer is currently being modified; the receiver electronics and the antenna are both being changed. Hopefully, the radiometer sensitivity and stability will be improved. After modification is complete, new experiments will be conducted. The results of this experiment should be a convenient yardstick for determining the effectiveness of the radiometer modifications.

SUMMARY

During this experiment the radiometer operated better than during any previous ERL experiment. Using two point calibration, accuracies of 1.5 - 2^{o}/oo were obtained over a ten minute period and 2-3^{o}/oo over a one hour period. Performance desired for an operational system has still not been attained. Experiments will continue after radiometer modifications are accomplished.

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