APPLICATION OF LORAN-C POSITIONING TO HYDROGRAPHIC SURVEYING

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THESIS

APPLICATION OF LORAN-C POSITIONING TO HYDROGRAPHIC SURVEYING

by

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to Hydrographic Surveying

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ABSTRACT

The possible application of hyperbolic Loran-C as a positioning system for hydrographic surveys was investigated. It was found that the present capabilities of the system did not meet the 40 meter (drms) accuracy required for offshore surveys. The use of differential Loran-C techniques and geodetic calibration procedures was examined. A field test was conducted in Monterey Bay, California, using a microwave positioning system to test the accuracy of the West Coast Loran-C chain, specifically the 9940-W and Y rates. Overland propagation corrections for the test area are presented. It was found that scrupulous application of the differential technique and rigorous calibration procedures improved the absolute position accuracy of a mobile Loran-C receiver to something less than 100 meters (drms).

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I. ADVANTAGES OF THE LORAN-C SYSTEM

Present hydrographic survey procedures rely heavily upon electronic positioning systems, typically medium-frequency systems which require substantial shoreside installations for the antennas and ground planes. There are attendant problems with logistics, land use permits and vandalism. In addition, situations arise where the geometric configuration of the medium-frequency system being used for a particular survey leaves some portion of the area less than adequately covered. A positioning system based on Loran-C, or some combination of Loran-C and medium-frequency systems, could alleviate these problems. With its transmitters already in place and continuously operating, a Loran-C system would require none of the shoreside installations associated with medium-frequency stations. As discussed later, the differential Loran-C technique does require establishing shoreside receivers, but the installation would be much smaller and simpler than that of a medium-frequency transmitter. Used in a combined system, Loran-C could supplement the medium-frequency system by providing additional coverage. For example, the medium-frequency stations could be positioned to provide the best coverage in the near-shore areas of the survey while leaving the offshore areas to be covered by Loran-C. Additional scenarios can be imagined where the application of Loran-C would be advantageous.

Loran-C has not had widespread use as a hydrographic positioning system because of its comparatively poorer accuracy. The system was designed to provide a repeatable position accuracy of 0.25 nautical miles (463 meters) while most hydrographic applications require almost an order of magnitude better accuracy in absolute position. Because of improvements in equipment and data processing procedures, the potential accuracy of the system has been improving. Recent investigators have quoted positional accuracies in tens rather than hundreds of meters for some applications. This work was largely stimulated by one such study [Goddard, 1973] in which a position repeatability of 6 meters was obtained (one drms). It was decided to review the present and future potential of Loran-C in order to estimate its usefulness as a positioning system for hydrographic surveys.

As discussed in this report, it appears that absolute positional accuracies in the range of 40 to 100 meters (drms) are presently achievable in a Loran-C system if sufficient geodetic calibrations are obtained and differential correction techniques employed. Given these accuracies and caveats, such a system would be of little value in routine hydrographic survey operations in the coastal waters of the United States. It should be noted, however, that the system accuracy is highly sensitive to any improvements in receiver performance and the model used to account for the effects of overland propagation. Both of these aspects of the Loran-C system are being studied extensively and it

is likely that significant improvements will be forthcoming. The increase in research and development work has been stimulated by the Department of Transportation decision in 1974 to implement Loran-C as the radionavigation system for the Coastal Conference Zone of the United States. With this long-term commitment to the availability of Loran-C, new techniques and improved equipment designs are being pursued by both government and industry. The result will surely be an improved Loran-C system with wider applicability for use as a positioning system in hydrographic survey operations.

II. TIME DIFFERENCE EQUATION

The following discussion assumes considerable familiarity with the basic Loran-C system. General descriptions are widely available in government publications and texts on navigation. A comprehensive review may be found in the American Practical Navigator [DMA, 1975].

In its traditional application, Loran-C is a time difference, hyperbolic positioning system. Each observed time difference, or rate, provides one hyperbolic line-of-position. By observing the transmissions from three stations, two hyperbolic rates are measured and a position can be determined by either graphical or analytical techniques. The graphical solution technique is commonly used in conjunction with nautical charts where the rates are pre-plotted and the user merely locates the intersection of his observed rates. The analytical solution offers better precision and more flexibility than the graphical technique. The following discussion develops the basic time difference equations which are used to compute a geographic position from observed Loran rates.

The time difference observed at a receiver is the difference in arrival times for signals from the master and one secondary transmitter in the chain. Because all transmitters share the same frequencies, their signals must be separated in time to prevent interference. Each

station repetitively transmits a burst of pulses followed by a relatively longer silent period. The chain is synchronized so that the master transmits first followed by each of the secondaries in turn. The transmission of each secondary is delayed by a specified amount (the emission delay) so that nowhere in the coverage area will signals from one station overlap another.

Referring to Figure 1 with a receiver located at point R, the observed time difference using the master M and secondary W is,

$$TDW = ED_W + t_W - t_M \tag{1}$$

where ED_W is the emmission delay specified for secondary W, and t_W and t_M are the travel times from the secondary W to R and the master to R respectively.

In order to express the time difference as a function of geographic position, the travel time t is separated into additive terms,

$$t = \frac{n}{c} D + F \tag{2}$$

where c = free space propagation velocity, n = index of refraction for a standard atmosphere, D = geodesic distance from the transmitter to receiver, and F is the so called Phase Factor which corrects for the retarding effects of the earth's surface along the path. Substituting this form into the time difference equation gives a pair of equations,

$$TDW = ED_W + \frac{n}{c} (D_W - D_M) + F_W - F_M$$

$$TDY = ED_Y + \frac{n}{c} (D_Y - D_M) + F_Y - F_M$$

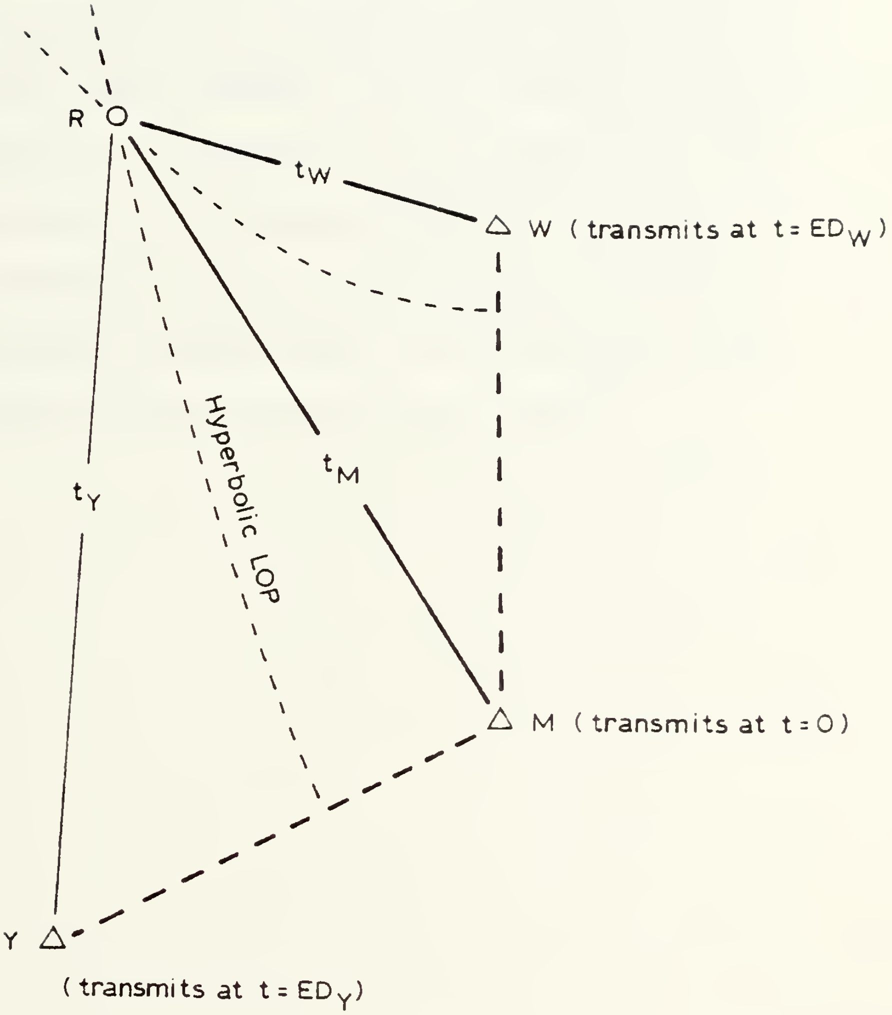

Figure 1. Components of Time Difference Measurement

Loran transmitters located at W, M and Y and Receiver at R. Refer to text for explanation.

which relate the Loran time differences TDW and TDY to the distances from each of the three transmitters. Several computational techniques have been used in order to solve these equations for the geographic position of the receiver [for example, Campbell, 1965]. Most are iterative in that time differences are computed using an estimated position of the receiver and then compared to the observed values. With this information, a new position is chosen and time differences recomputed. The process repeats until the computed and observed TDs agree to within some specified tolerance. Systematic errors result from inaccurate prediction of the Phase Factors as discussed later.

III. DIFFERENTIAL LORAN-C

The differential Loran-C technique is a method of improving the temporal stability and repeatability of the system. Fixed-monitor receivers are located in the geographic area of interest and average time differences determined. Changing propagation conditions and transmitter instabilities are detected as deviations from these average time difference values. These deviations are then used as differential corrections for other receivers in the nearby area.

It has been also suggested that this technique can be used to determine geographic corrections for an area. In concept, if the geographic position of the monitor receiver were known, then the differences between the computed and observed rates at the monitor would constitute corrections applicable to other nearby receivers. Applying these corrections should allow an accurate computation of the geographic position of the receiver. In the context of the subsequent discussion in this paper, this is equivalent to determining the systematic errors or overland propagation corrections of the Loran net at a single point in the area of interest. Because the overland corrections change significantly in passing across the land-sea interface, a shore-based monitor would be of little value in determining the systematic errors offshore where the survey vessel is operating. The implication for a hydrographic positioning system is that

the geographic position of the shore-based monitor need not be determined nor be a criteria in the selection of monitor sites.

The differential technique is necessary, however, in order to eliminate significant temporal fluctuations in the Loran rates. Several tests have shown that these temporal instabilities are well correlated over distances on the order of 100 kilometers even across the land-sea interface. One such test [Goddard, 1973] used a stationary receiver which was shifted among five different sites along the shore of Delaware Bay and one site at an offshore lighthouse over a six week period. Two fixed monitors were used in order to test the differential technique over a variety of separation distances from about 30 to 130 kilometers. When differential corrections were made at 100-second intervals using 100-second average values at the monitor and receiver, the temporal instability of the receiver was significantly reduced. Expressing the instability as the standard deviation of the observed values, the improvement was from a maximum of 0.07 microseconds uncorrected down to something less than 0.02 microseconds after correction. A similar improvement was observed on each of the separation distances tested.

This correlation is essential if a shore-based monitor is to provide useful corrections for a survey vessel operating offshore. Veronda [1977, p. 33] has suggested that this correlation distance may be as great as 240 kilometers if

the monitor is located along the signal path to the working area. Thus in choosing the monitor site or sites, due consideration must be given to differences in the paths from transmitter-to-monitor and transmitter-to-survey area. For example, situations where the path to the monitor is entirely over land while the one to the survey area is largely seawater should be avoided. By locating the monitors on peninsulas, headlands, or offshore islands, this situation should rarely develop.

It is interesting to note that the System Area Monitor (SAM) stations associated with each Loran chain apply differential-type corrections to the Loran rates in real-time. These SAM stations continuously monitor the signals from all transmitters in the chain. If the observed time difference deviates by more than 0.05 microseconds from its expected value, then the appropriate secondary is instructed to adjust its emission delay time in order to remove the error [WGA, 1976]. These real-time corrections are intended to control timing errors between stations, but they also pick up any changes in the propagation conditions which may occur on paths from the transmitter to the SAM site. In comments on the remarkable stability of the Loran rates in San Francisco Harbor, Illgen [1978] noted that the operation of the SAM at Point Pinos, which is some 180 kilometers to the south, produced a situation closely resembling differential Loran-C.

IV. ACCURACY CONSIDERATIONS

The sources of error in a Loran position can be discussed in terms of those effecting the repeatability of the system vis-a-vis those producing systematic or time invariant position errors. This separation corresponds to the way in which the corrections are applied. The temporal variations monitored by the differential technique are used to correct the observed rates; i.e., improve the repeatability of the observations. The systematic errors are determined by calibration and applied to correct the computed position.

The factors effecting repeatability are receiver errors, transmitter timing errors, and temporal changes in propagation conditions which result from weather related phenomena. Systematic errors, as defined here, result from geographic differences in propagation conditions, such as the conductivity and length of the overland portion of the signal path.

A. GEOMETRIC DILUTION OF PRECISION (GDOP)

The hyperbolic geometry implicit in the time difference equations affects the precision of the computed geographic position. The effect is expressed as a gradient in meters per microsecond which is termed the Geometric Dilution of Precision. Its functional form is derived in any of several

references [Atlantic Research Corp., 1962, p. 130]. The GDOP factor expresses the combined effect of lane expansion and decreasing intersection angles between the hyperbolic arcs as the distance from the baselines of the Loran chain is increased. For the purpose of this discussion it suffices to note that over the coastal waters of the United States, the GDOP varies from about 200 to 2000 meters/microsecond. The implication is that an accuracy of 0.1 microsecond in each rate gives a position accuracy between 20 and 200 meters. Thus the geometry of the Loran chain is significant in determining whether or not the system can provide survey quality position data. The Defense Mapping Agency has prepared charts for each Loran-C chain which depict the effective coverage area depending upon the variation in GDOP as well as maximum signal range and expected signal-to-noise conditions. These are published as Loran-C Reliability Diagrams in the ZLORK5000 chart series.

B. RECEIVER ERRORS

Receiver errors are a function of the signal strength, signal-to-noise ratio, amount of skywave and cross-chain interference, velocity and/or acceleration of the receiver, and receiver design. Interference problems are minimal because of phase coding applied to the transmitted pulses and timing relationships between adjacent chains [WGA Pub. No. 1, 1976]. The speed of typical hydrographic survey

vessels is less than 20 knots and its effect can be eliminated by appropriate sampling and filtering techniques.

Under favorable signal-to-noise conditions, several commercial receivers have exhibited time difference errors with a standard deviation of less than 0.1 microsecond [WGA, 1977]. This is obtained with averaging times on the order of a few seconds, corresponding to an average of 10 to 100 measurements depending on the repetition rate of the chain. Because of Loran geometry, significantly better performance is needed in order to obtain typical survey accuracies over much of the U. S. coastal waters. A performance goal of 0.05 microsecond is not unreasonable. Improved receivers can be expected in the next few years. Longer effective averaging times can be achieved by designing processing schemes which incorporate ship course and speed data. Improved performance in stationary receivers has already been demonstrated; for example, Goddard [1973] used 100-second averages and achieved standard errors on the order of 0.01 microsecond.

Signal-to-noise conditions also effect performance. Favorable conditions are -10dB or better. In designing the Loran transmitters, power outputs are chosen to provide suitable signal strengths in the coverage area. At about -4.8dB, most receivers begin to exhibit increasing errors until some minimum value is reached and the receiver ceases to track the signals. For more information on receiver performance under varying conditions, Veronda [1977] has a

comprehensive list of available literature. The implication for hydrographic work is that signal strength and signal-to-noise information must be collected in order to insure data quality. Several commercial receivers already provide these outputs.

C. TRANSMITTER TIMING ERRORS

Instability in chain timing and synchronization is the least significant source of error. Cesium frequency standards at each station provide a highly accurate timing reference. As noted in the discussion of differential Loran, the System Area Monitors control chain timing to within 0.05 microsecond. Field measurements have shown that the actual error is considerably less than this control tolerance. Data collected from the West Coast Loran chain gave a standard deviation of 0.02 microseconds due to transmitter fluctuations [Illgen, 1978]. In any case, the differential Loran technique readily corrects for any significant transmitter errors.

V. LORAN-C GROUND WAVE PROPAGATION

Loran-C is a low frequency radionavigation system which operates in the spectral band of 90 to 110 kHz with a 100 kHz carrier frequency. Propagation in this band has been studied extensively over the past thirty years in conjunction with a variety of navigation and communication systems. This discussion considers only propagation effects on the phase or travel time of the 100 kHz ground wave as seen by a sea-level receiver located in the far field of the transmitter. Considerations of signal strength, skywave propagation, receiver altitude, and inductive field effects near the transmitter are relatively unimportant for this application of Loran-C positioning. Any of the general references on Loran-C contain additional information on propagation including those aspects not specifically covered here.

Propagating as a ground wave, the Loran-C signal is sensitive to the geophysical properties of the earth/atmosphere medium through which it is traveling. Table I summarizes the important properties and describes their effect on the travel time of the signal relative to an assumed seawater path which is typically used in Loran computations. Those properties related to the earth's surface result in errors of up to two or three microseconds relative to the computed values [Sensus, 1976, and Eaton, 1979]. Atmospheric effects result in time dependent variations of up to 0.6

TABLE I - Geophysical Properties Effecting Ground Wave Travel Time

Property	Assumed Model	Typical Effects
Surface conductivity and permitivity	Seawater path with conductivity of 5 mho/m and relative permitivity of 80	Land values always lower significantly increasing travel time
Hypsography	Smooth earth	Ridges and high plateaus exaggerate conductivity effect increasing travel time
Index of Refraction	Standard atmosphere value of 1.000338	Changes have small effect except as accompanied by changes in lapse rate (below)
Vertical Lapse Rate of Atmosphere	Expressed as effective earth radius equals 4/3 actual radius in computation of Secondary Phase Factor	Passage of cold front can decrease travel time up to 0.6 microsecond; warm front can increase travel time by similar amount [Doherty and Johler, 1976]

microsecond per day with shorter period fluctuations of 0.1 microsecond per hour [Doherty and Johler, 1976]. Annual variations due to seasonal changes in both the atmosphere and underlying surface can be as large as 0.7 microsecond (Veronda, 1977, using information from several sources). By careful use of the differential Loran technique, these temporal variations can be reduced to something less than 0.02 microsecond.

A. PHASE FACTORS

Using the classical Van der Pol-Bremmer ground wave theory, it is possible to develop a computer program to calculate the actual travel time of a signal over complex land-sea paths with widely varying geophysical properties [Johler, 1969]. The method seems to be too cumbersome for routine use in the hydrographic survey application. Instead, it is realistic to approximate the travel time t as,

$$t = \frac{n}{c} D + \psi + \epsilon \qquad (3)$$

where the terms are the same as given in equation (2) except that the phase factor F has been split into two terms. In this form, the term $\frac{n}{c}$ D is called the Primary Travel Time with n=1.000338 for the standard atmosphere and c=299.7942 meters/microsecond. The secondary Phase Factor ψ describes

the delay of a signal propagating over a smooth seawater path relative to the primary travel time. National Bureau of Standards Circular 573 [Johler, 1956] describes the computation of ψ for varying distances. The Additional Secondary Factor ϵ represents the additional delay accumulated on non-seawater portions of the path; i.e., it describes the lag of the actual signal relative to an equivalent distance over seawater. The general time difference equation becomes,

$$TD + (\epsilon_M - \epsilon_S) = ED + \frac{n}{c}(D_S - D_M) + \psi_S - \psi_M \quad (4)$$

The advantage of this form is that the so called overland correction, $\epsilon_M - \epsilon_S$, is reduced to a relatively small term in the TD equation. Typical values are on the order of several microseconds or less while the total time difference is on the order of 10^4 microseconds. Figure 2 shows the theoretical form of the Additional Secondary Factor for three hypothetical paths with differing lengths of land path [Wait, 1963]. The land path lengths shown were chosen because they approximate the situation in Monterey Bay, California, where the field experiment described later in this report was conducted. The abrupt drop in the ϵ values upon crossing the coastline is the phase recovery effect which occurs at any conductivity discontinuity in the underlying surface.

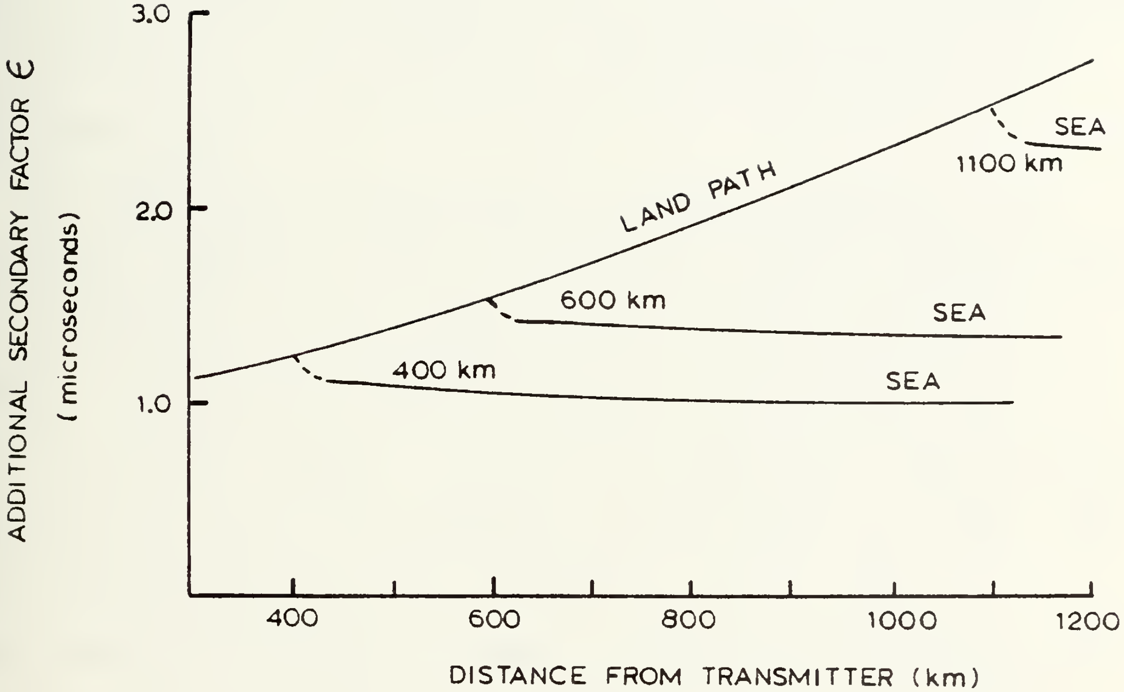

Figure 2. Variations of Additional Secondary Factor with Distance on Typical Land-Sea Paths

The curves assume a uniform conductivity of 0.01 mho/m and a permitivity of 15. The sea path values are 4 mho/m and 80, respectively. The phase recovery effect at the coastline is symbolized by the dashed portions of the curves.

B. OVERLAND PROPAGATION CORRECTION

In order to use the time difference equations to compute a position, it only remains to empirically measure the overland corrections for each rate. Terms on the right-hand-side of equation (4) are either constants or computed quantities depending on path distance. By subtracting observed and computed TDs at a known position, the overland corrections can be empirically determined for that position. The problem in calibration is to extrapolate these corrections to the surrounding area.

To complicate the problem, the spatial pattern of the overland correction is one of hills and valleys representing the subtraction of two independently varying ϵ fields. Several calibration procedures have been developed which use observed TD values, but none have produced survey quality corrections. The most promising method [Doherty, 1972] combines measurements and some physical constraints of ground wave propagation theory. Using 75 land based measurements in an area of 100 kilometers square, it achieved a R.M.S. position error of about 30 meters which is significantly worse than that needed for hydrography. Although the method requires a considerable degree of computational finesse, such methods deserve further study with offshore data sets to truly test their applicability to routine survey operations. It appears that for the time being at least, there is no method of reliably predicting overland corrections

from relatively few calibration measurements. The hydrographer is faced with the task of mapping the corrections over much of the area and then interpreting the pattern in order to extrapolate the corrections to the remainder of the survey area. The procedure is not unlike that presently employed with medium frequency positioning systems. While the hydrographic community has considerable experience with medium frequency systems, there has been little work with long baseline Loran chains in order to document the spatial variability of the corrections in offshore areas.

In one study off the west coast of Vancouver Island, [Eaton 1979] observed a variation of 0.1 microsecond/kilometer at about 25 kilometers offshore as the ship passed into the shadow of the island. This probably represents a worst-case situation. As discussed later in this report, measurements in Monterey Bay suggested variations of less than 0.02 microsecond/kilometer, once free of the phase recovery effects near the coast. Additional work with fine grid Loran prediction models and field measurements is needed in order to explore the spatial variability of the overland corrections in offshore areas.

Table II summarizes the preceeding discussions on sources of time difference errors and the effectiveness of the various techniques to correct for them. The reader is cautioned that these are estimated errors derived from many different sources. There have been few field tests in offshore areas with sufficient accuracy to validate some of these errors.

TABLE II - Estimated Loran-C Time Difference Errors (1)
(not statistical results but estimates
1 σ errors in microseconds)

Sources of Error	Potential Error	Residual Error after Correction by System Area Monitor	Residual Error(4) after Correction by Differential Monitor within Correlation Distance	Residual Error after Calibration by Measurements	Net Error Estimate after all Corrections
Mobile Receiver	0.1(2)	- -	- -	- -	0.10
Temporal Instability					
Transmitter Timing	- -	0.05	0.02	- -	0.02
Weather-related	0.6	0.2(3)	0.02	- -	0.02
Annual	0.7	0.05	- -	- -	0.05
Overland Propagation					
Typical Offshore Areas	0.4 - 2	- -	- -	0.05	0.05
Worst-case Areas	2 - 3	- -	- -	(5)	?

(1) Data summarized from text and similar table in Veronda [1977, p.31]

(2) Mobile receiver error may be reducible to 0.05 with proper velocity compensation

(3) Unusual weather patterns may increase this to 0.60 if operating away from SAM

(4) Data suggested by Goddard [1973]

(5) Probably impracticable to calibrate with sufficient density

VI. FIELD TEST

In order to test the use of differential Loran-C and potential calibration procedures in a typical survey operation, a series of tracklines were run in the southern portion of Monterey Bay, California. As shown in Figure 3, the lines extended from 20 kilometers offshore to within a few hundred meters of the beach in places. Position data was recorded simultaneously from two systems; an on-board Loran-C receiver and a range/range microwave system which was set-up over geodetic control points. The tracklines were run on two separate days, 12 June and 25 July 1979, during daylight hours. The vessel used was the R/V ACANIA which is operated by the Naval Postgraduate School. The positioning equipment consisted of a Micrologic ML-1000 Loran-C receiver, which has a 0.01 microsecond resolution, and a Motorola Mini Ranger III Microwave System; both of which were provided by the school.

Position data from both systems were manually logged at two minute intervals while the ship maintained constant course and speed. Traveling at speeds of nine to ten knots, this resulted in positions at roughly 0.5 kilometer intervals along each trackline.

Loran coverage in this area consists of the 9940-W, X and Y rates of the West Coast chain, Figure 4. Only the

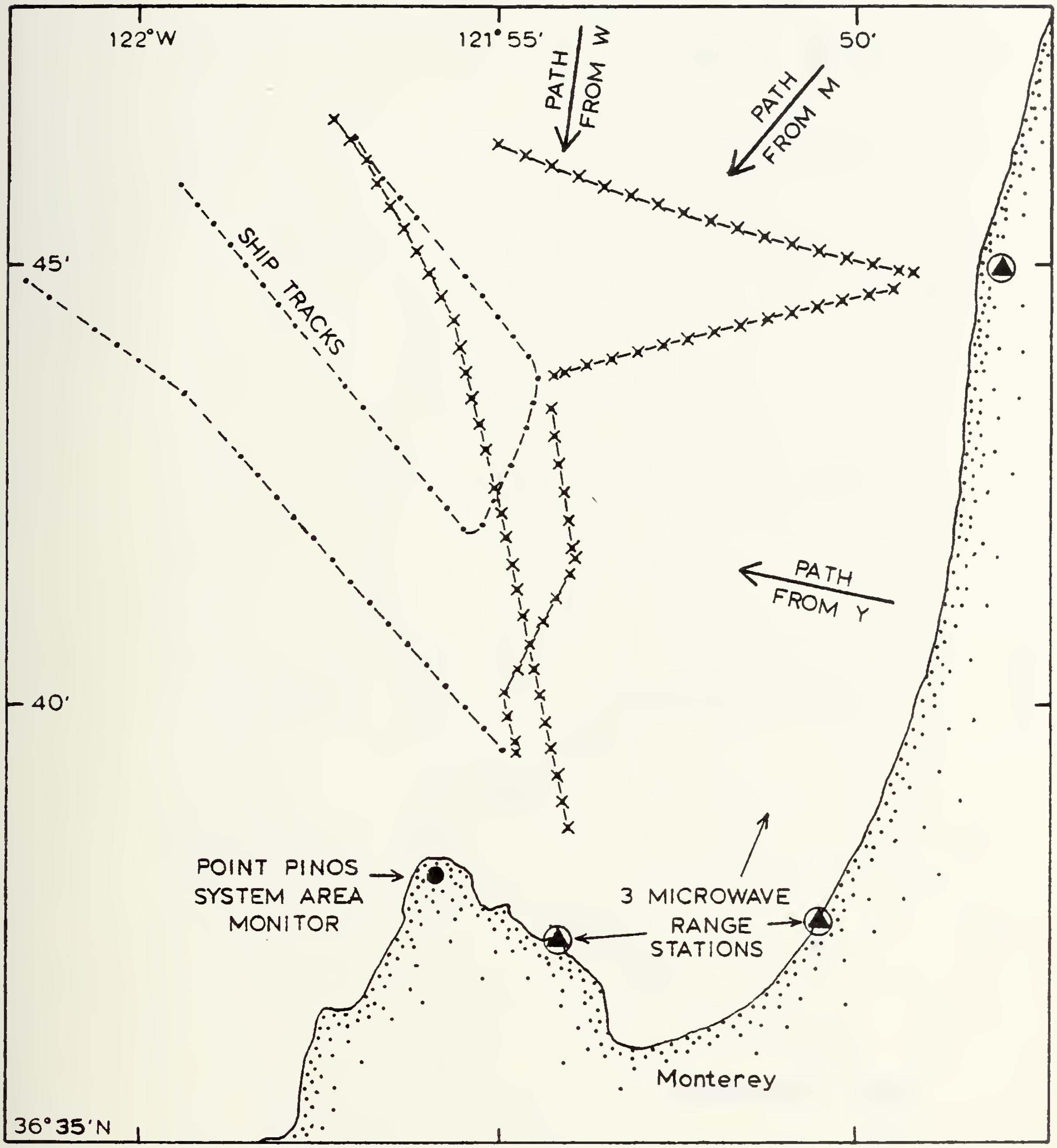

Figure 3. Location of Test Area in Monterey Bay

x positions from 12 June 1979
• positions from 25 July 1979

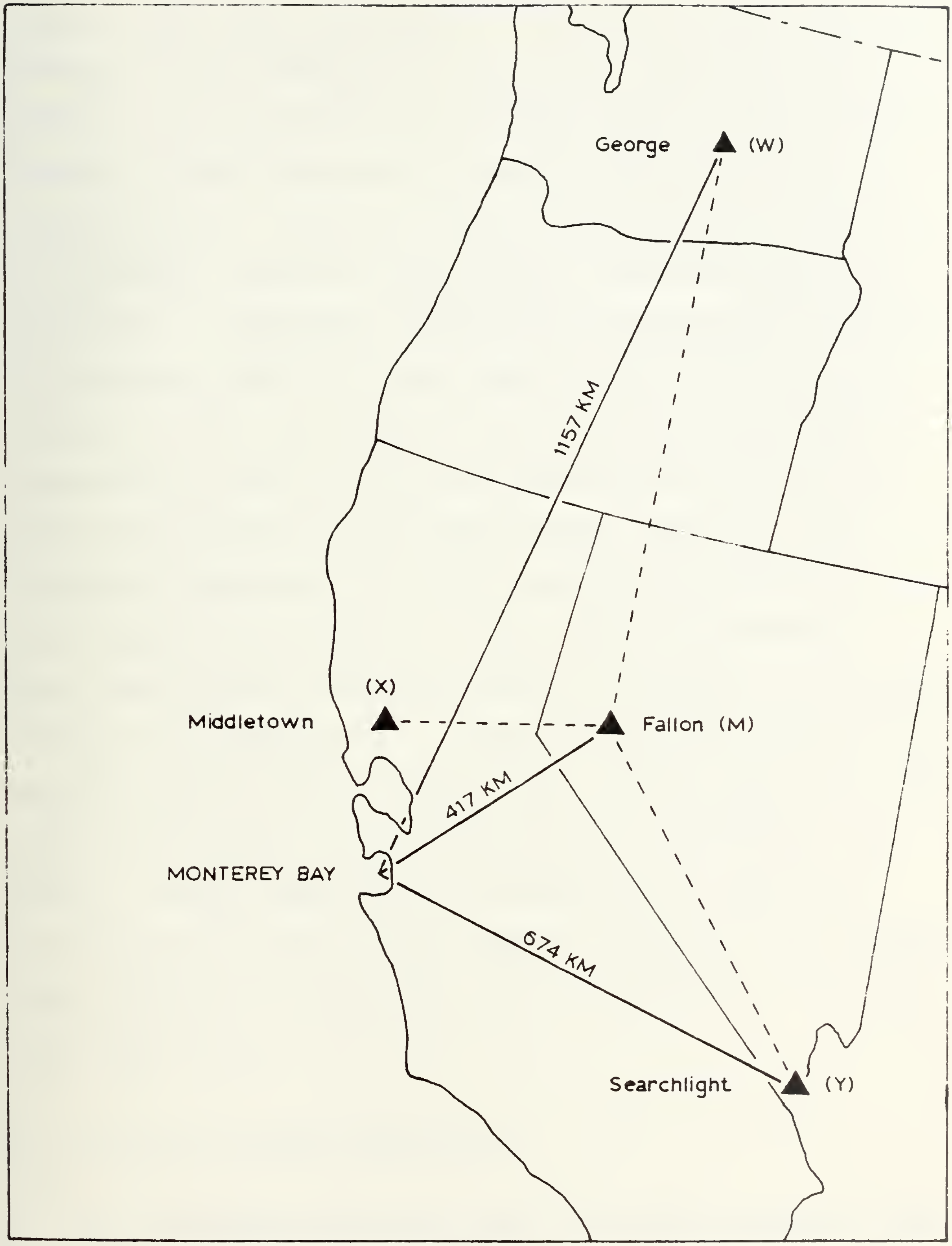

Figure 4. Location of West Coast Loran-C Stations

W and Y rates were recorded even though the X and Y pair provided better precision in this area. The W-rate was selected because of the close proximity of the System Area Monitor at Point Pinos which controls both the X and Y secondaries (see Figure 3). This control removes virtually all temporal variation in the X and Y rates over Monterey Bay making it impossible to test the differential technique. It was hoped that the W rate, which is controlled by a monitor on the Oregon coast, would show some significant variations. Records of the time differences of all three rates from the Point Pinos monitor were examined. None showed any variations over 0.04 microsecond during the tests, with typical fluctuations of less than 0.01 microsecond. This high degree of temporal stability resulted in negligible differential corrections. In order to test the potential for calibrating the Loran-C system over a limited area, the positions derived from the microwave system measurements were used to compute expected time differences at each point. The difference between these computed values and the observed time differences constituted a set of estimates of the overland corrections.

A. MICROWAVE SYSTEM POSITIONING

The microwave system was used to fix the geographic position of the ship by standard range/range computational techniques. The two ranging stations were set on known geographic

positions listed in Table III. Ship positions were computed on a Modified Transverse Mercator Grid which was centered in the survey area [Wallace, 1971]. In this way the errors in computed latitude and longitude due to grid distortions were minimized. Obviously bad positions which resulted from infrequent ranging errors in the microwave system were rejected. The microwave system had been calibrated over known baselines of 4683 and 17621 meters. With a ranging accuracy of ± 3 meters as claimed by the manufacturer, the ship positions have a R.M.S. position error of less than 10 meters over the area, which was adequate to test the accuracy of the Loran derived positions.

B. LORAN-C POSITION COMPUTATIONS

Time differences for each of the positions were computed assuming seawater path propagation using a fortran routine adapted from one supplied by the National Ocean Survey [Riordan, 1979]. The computed and observed time differences were compared and five positions were rejected because of obvious busts in the recorded Loran values. This left 130 positions for the subsequent analysis. The Loran system parameters used in the computations are listed in Table III. In order to be consistent with the National Ocean Survey charts of the area and the microwave system positions, all computations were done relative to North American Datum 1927 geographic positions.

TABLE III - Geographic Positions and Constants Used in Position Computations

Microwave System Stations	Geographic Position (NAD 1927)	Remarks
Mulligan (1932)	36 44 56.717 N 121 47 52.416 W	Used on both 12 June and 25 July
Mussel R.M. 2 (1932)	36 37 17.540 N 121 54 11.857 W	Used on 12 June
Monterey Bay 4 CHD (1972)	36 37 31.128 N 121 50 31.728 N	Used on 25 July

Loran-C 9940 Chain Data

Station	Geographic Position (NAD 1927)	Emission Delay (microseconds)
Master Fallon, NV	39 33 07.03 N 118 49 52.23 W	-
Secondary W George, WA	47 03 48.82 N 119 44 34.78 W	11,000.00 + 2796.90
Secondary Y Searchlight, NV	35 19 18.32 N 114 48 13.95 W	40,000.00 + 1967.27

C. ANALYSIS OF THE LORAN DATA

Receiver error and velocity effects were apparent in the data. Ship motion and the five second averaging time of the receiver resulted in observed TDs which were several seconds old in comparison to the microwave system measurements; i.e., the Loran readings represented the position of the ship several seconds before the microwave system fix was determined. In order to partially compensate for this effect, the observed TDs were advanced a distance equivalent to that traveled by the ship in 2.5 seconds. Depending upon the course and speed of the ship, the correction ranged between ± 0.07 microsecond for the W rate and ± 0.03 microsecond for Y. In future work, a computer based data logging system could perform this correction in real-time and obtain better results.

In order to study the spatial variation of the overland correction, the differences between computed and observed TDs were calculated at each point. Defining these differences as EY and EW for the TDY and TDW rates, respectively, it is apparent that,

$$EY = \epsilon_M - \epsilon_Y + \text{receiver error}$$

and similarly for EW. Thus these E values at each point contain the information on the overland correction, but it is masked by receiver errors. For reference, a listing of geographic position, the observed TDs and respective E values has been appended to this report.

Tests with the ship stopped gave a random receiver error of 0.05 and 0.07 microseconds (one standard deviation) on the Y and W rates, respectively, which was reasonable given the manufacturer's claim of 0.1 microsecond. In order to reduce the effect of receiver error, the computed E values were spatially averaged over a circular area of 1300 meter radius around each position. Assuming that receiver errors were randomly distributed, the increased number of estimates tended to bring out the spatial pattern of the overland corrections. The choice of a 1300 meter averaging radius was somewhat arbitrary. Given the 500 to 600 meter spacing of positions, this choice brought anywhere from 3 to 10 adjacent positions into the averaging process. It obviously suppresses variations with a scale of less than 3 kilometers, but monotonic trends in the pattern were preserved.

D. RESULTS

Figures 5 and 6, which depict the overland corrections for the test area, were derived from the spatially averaged values. The contours indicated a rapid change in the correctors in the nearshore area due to phase recovery of the signals after passing over the coast. At 12 kilometers offshore the variation had dropped to something less than 0.02 microsecond/kilometer. Using the 48 data points (not

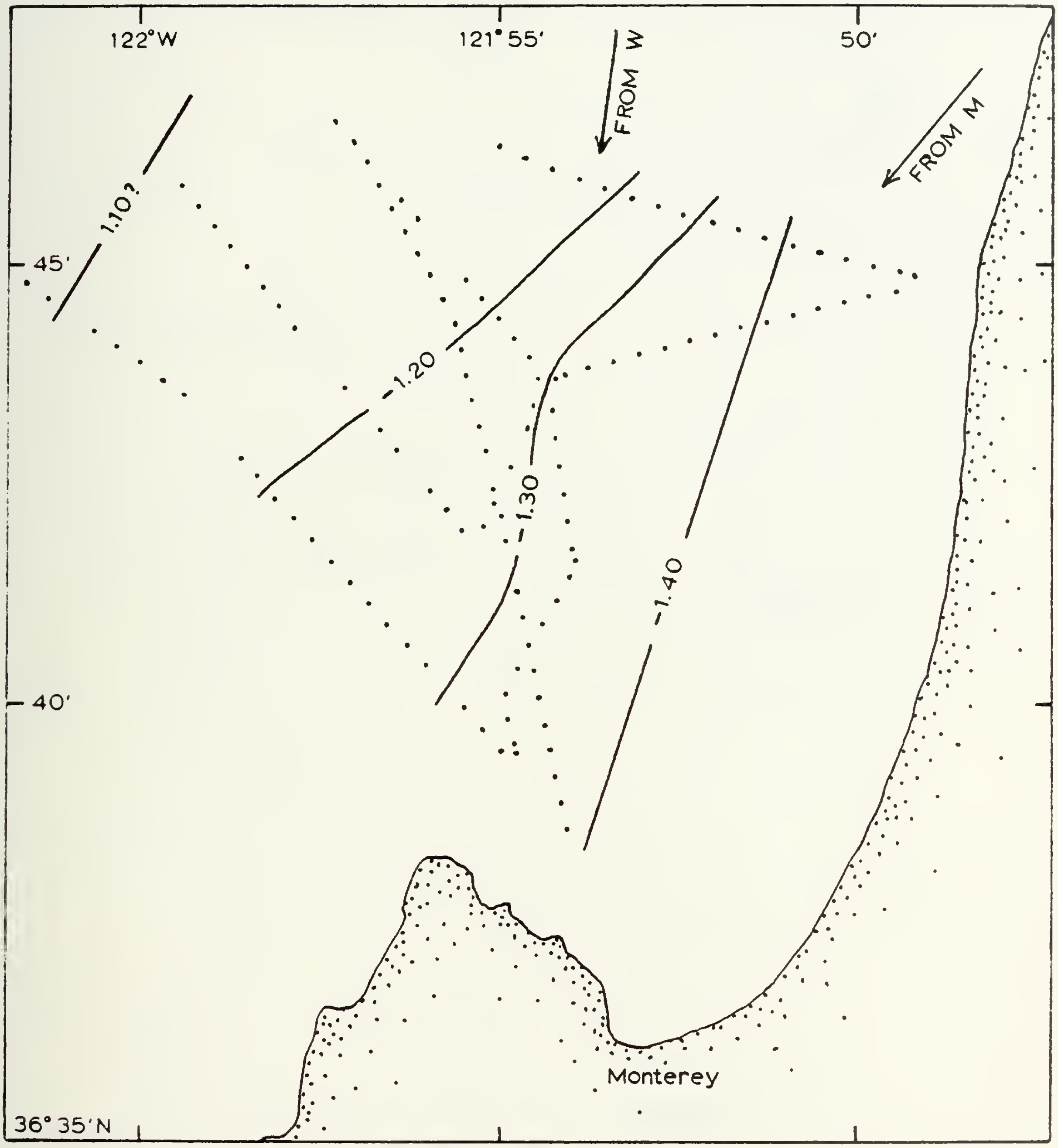

Figure 5. Overland Propagation Corrections, 9940-W Rate

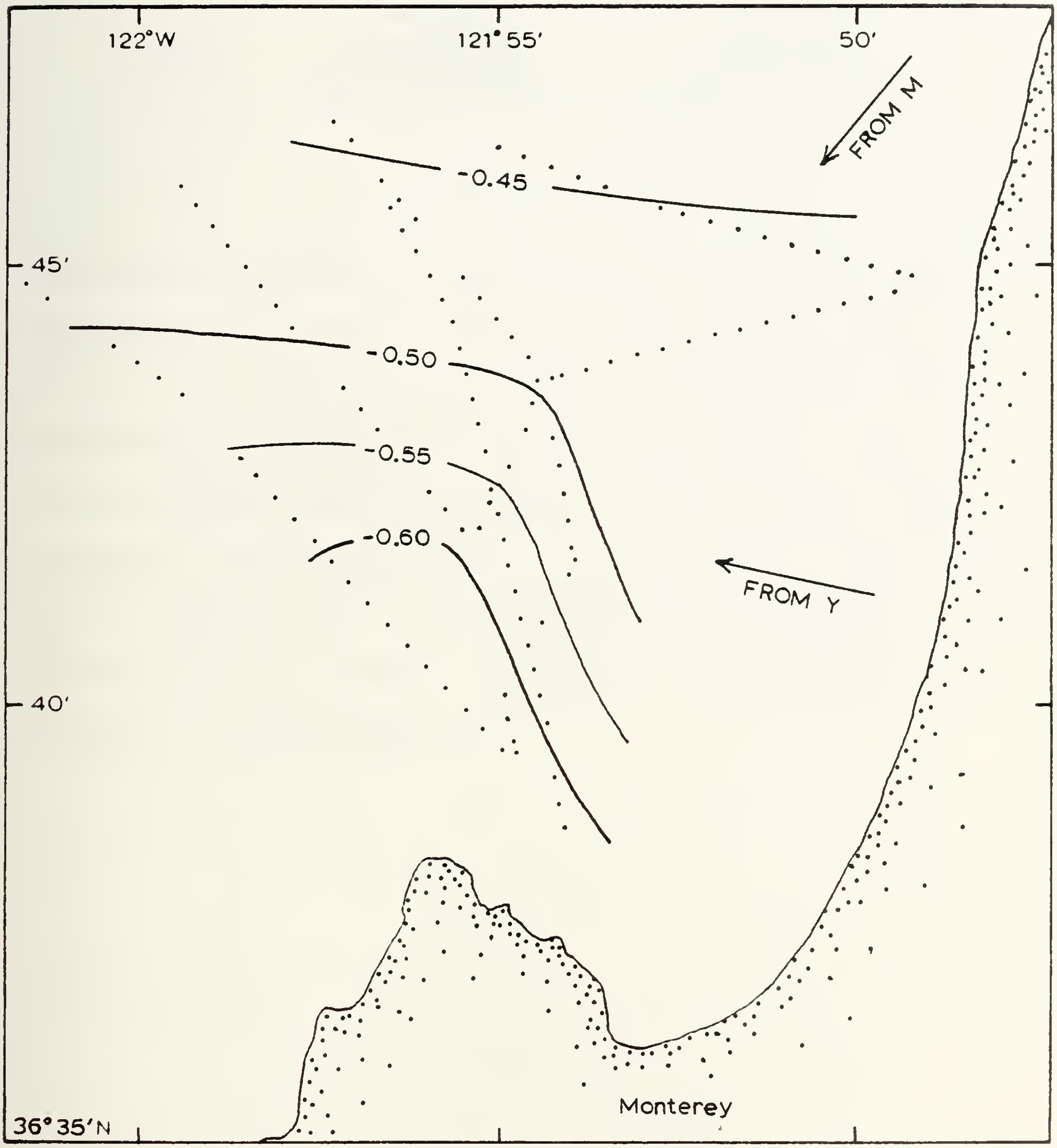

Figure 6. Overland Propagation Corrections, 9940-Y Rate

averaged) which were 10 kilometers or more offshore, the following overland corrections were determined:

Loran Rate	Average Correction (microseconds)	Standard Deviation (microseconds)
Y	-0.50	0.07
W	-1.16	0.08

The computed standard deviations were typical of those expected from a receiver with a standard error on the order of 0.1 microsecond or less. Applying these average corrections uniformly to the offshore positions gave a R.M.S. distance error of 66 meters in the derived Loran positions. If similar results had been obtained with the X and Y rates, which have better geometric precision in the test area, the R.M.S. distance error would have been reduced to about 42 meters.

VII. CONCLUSIONS

The National Ocean Survey has required that any electronic positioning system exhibit a R.M.S. distance error of less than 0.5 millimeter at the scale of the survey. The smallest scale routinely used for coastal surveys is 1:80,000 implying an allowable error of 40 meters. On this basis, it was concluded that a positioning system based on Loran-C in the hyperbolic mode is unsuitable for routine hydrographic use; given the R.M.S. distance error of 66 meters obtained in the field test. The 42 meter accuracy (drms) quoted in the results assumed an atypical improvement in Loran geometry which invalidated its use as a test of the routine hydrographic survey situation.

It should be noted, however, that these errors were largely due to random receiver errors which were estimated to be on the order of 0.07 microsecond. Any improvement in receiver design or data sampling procedures which would bring this random error down to something less than 0.05 microsecond could make a Loran-C positioning system for hydrography feasible.

The second largest source of error was found to be the unresolved spatial variations in the overland propagation correction. Further work is needed to determine whether or not these errors could be reduced to something less than

0.05 microsecond in offshore areas away from the coastline induced perturbations. The approach adopted in this study was to determine the overland corrections empirically from measurements. Other approaches are possible, such as Doherty [1972], which combine measurements with physical constraints of the ground wave propagation theory. Tests of such methods with offshore data bases would be extremely enlightening.

Temporal instability of the Loran rates was found to be an insignificant source of error. The investigations cited in this report have indicated that these errors can be reduced to something less than 0.02 microsecond by proper application of differential Loran techniques.

While it has been shown that the present capabilities of a Loran-C positioning system fall short of those needed for hydrographic surveys, that goal seems tantalizingly close.

APPENDIX: DATA LISTING

OFFSHORE OBSERVATIONS

SHIP POSITION		OBSERVED LORAN RATES & CORRECTIONS			
LATITUDE (D-M-S)	LONGITUDE (D-M-S)	9940-Y (µS)	EY (µS)	9940-W (µS)	EW (µS)
36 43 45.80	121 55 27.16	42789.34	-0.49	16294.04	-1.08
36 44 3.40	121 55 32.34	42791.13	-0.40	16293.46	-1.13
36 44 21.18	121 55 37.39	42793.04	-0.39	16292.73	-1.02
36 44 37.49	121 55 46.95	42795.13	-0.60	16292.03	-1.08
36 44 53.26	121 55 57.71	42796.93	-0.52	16291.43	-1.30
36 45 8.73	121 56 8.32	42798.67	-0.44	16290.44	-1.11
36 45 24.28	121 56 18.85	42800.59	-0.52	16289.82	-1.29
36 45 39.54	121 56 29.79	42802.29	-0.40	16288.75	-1.04
36 45 55.10	121 56 40.03	42804.10	-0.38	16288.07	-1.14
36 46 10.75	121 56 50.50	42805.90	-0.34	16287.34	-1.23
36 46 26.28	121 57 0.69	42807.88	-0.50	16286.59	-1.26
36 46 21.46	121 54 59.24	42804.05	-0.46	16291.70	-1.19
36 46 14.15	121 54 36.76	42802.73	-0.49	16292.74	-1.12
36 41 8.96	121 56 48.83	42776.29	-0.71	16294.50	-1.32
36 41 23.35	121 57 4.84	42778.04	-0.58	16293.46	-1.27
36 41 38.08	121 57 20.52	42779.86	-0.51	16292.27	-1.07
36 41 52.90	121 57 36.71	42781.88	-0.60	16291.46	-1.26
36 42 7.05	121 57 52.36	42783.64	-0.53	16290.43	-1.19
36 42 21.38	121 58 7.54	42785.47	-0.52	16289.45	-1.17
36 42 36.09	121 58 22.87	42787.41	-0.58	16288.56	-1.25
36 42 48.66	121 58 37.76	42789.13	-0.64	16287.58	-1.18
36 43 31.92	121 59 24.96	42794.46	-0.41	16284.50	-1.07
36 43 43.27	121 59 43.80	42796.20	-0.50	16283.55	-1.17
36 43 54.51	122 0 3.06	42797.93	-0.60	16282.59	-1.29
36 44 5.37	122 0 22.30	42799.46	-0.55	16281.48	-1.23
36 44 16.04	122 0 41.30	42800.88	-0.40	16280.29	-1.08
36 44 38.22	122 1 19.23	42804.21	-0.52	16278.14	-1.05
36 44 49.11	122 1 38.30	42805.84	-0.57	16277.11	-1.09
36 45 55.33	121 59 26.80	42808.76	-0.49	16281.07	-1.12
36 45 41.46	121 59 13.09	42807.10	-0.58	16282.05	-1.20
36 45 27.54	121 58 59.44	42805.23	-0.46	16282.80	-1.05
36 45 13.73	121 58 45.63	42803.53	-0.50	16283.95	-1.29
36 44 59.70	121 58 31.71	42801.74	-0.47	16284.66	-1.09
36 44 45.76	121 58 18.10	42799.97	-0.46	16285.58	-1.12
36 44 32.59	121 58 4.48	42798.21	-0.36	16286.60	-1.25
36 44 18.14	121 57 50.54	42796.59	-0.55	16287.39	-1.13
36 43 36.46	121 57 8.43	42791.20	-0.47	16290.14	-1.16
36 43 22.39	121 56 54.20	42789.45	-0.51	16291.01	-1.12
36 43 8.49	121 56 39.85	42787.67	-0.51	16292.02	-1.22
36 42 54.36	121 56 25.39	42785.91	-0.56	16293.04	-1.31
36 44 37.74	121 55 13.79	42794.16	-0.51	16293.51	-1.20
36 44 51.46	121 55 27.53	42795.90	-0.50	16292.73	-1.30
36 45 31.58	121 56 8.65	42801.01	-0.48	16289.91	-1.12
36 45 44.99	121 56 22.64	42802.73	-0.49	16289.05	-1.16
36 45 58.40	121 56 36.68	42804.49	-0.53	16288.00	-1.01
36 46 11.82	121 56 50.11	42806.18	-0.52	16287.17	-1.06
36 46 25.41	121 57 3.79	42807.82	-0.44	16286.27	-1.05
36 46 38.92	121 57 17.50	42809.51	-0.41	16285.45	-1.12

NEARSHORE OBSERVATIONS

SHIP POSITION		OBSERVED LORAN RATES & CORRECTIONS			
LATITUDE (D-M-S)	LONGITUDE (D-M-S)	9940-Y (µS)	EY (µS)	9940-W (µS)	EW (µS)
36 38 34.78	121 54 2.15	42756.10	-0.63	16304.91	-1.52
36 38 52.46	121 54 7.23	42758.11	-0.75	16304.10	-1.32
36 39 10.47	121 54 12.37	42759.88	-0.57	16303.51	-1.32
36 39 28.87	121 54 17.02	42761.96	-0.69	16302.98	-1.39
36 39 46.74	121 54 21.48	42763.70	-0.52	16302.37	-1.35
36 40 5.08	121 54 25.96	42765.64	-0.51	16301.51	-1.08
36 40 23.19	121 54 30.41	42767.71	-0.65	16301.24	-1.39
36 40 41.54	121 54 34.48	42769.55	-0.55	16300.54	-1.27
36 45 29.74	121 51 59.01	42793.77	-0.38	16300.57	-1.39
36 45 24.35	121 51 36.36	42792.73	-0.52	16301.54	-1.30
36 45 19.05	121 51 13.86	42791.46	-0.42	16302.66	-1.37
36 45 14.06	121 50 50.71	42790.39	-0.49	16303.66	-1.31
36 45 9.12	121 50 27.79	42789.23	-0.48	16304.76	-1.35
36 45 4.52	121 50 4.65	42788.16	-0.54	16305.84	-1.38
36 45 0.04	121 49 42.47	42787.08	-0.54	16306.97	-1.50
36 44 55.44	121 49 19.35	42785.77	-0.36	16307.83	-1.31
36 44 53.84	121 49 8.80	42785.39	-0.44	16308.46	-1.47
36 44 43.06	121 49 23.93	42784.82	-0.53	16308.02	-1.41
36 44 38.94	121 49 45.94	42784.91	-0.41	16307.30	-1.51
36 44 34.85	121 50 8.11	42785.10	-0.38	16306.41	-1.44
36 44 30.64	121 50 29.87	42785.42	-0.50	16305.64	-1.47
36 44 26.51	121 50 51.08	42785.66	-0.55	16305.03	-1.63
36 44 22.17	121 51 12.84	42785.68	-0.39	16304.08	-1.48
36 44 17.64	121 51 34.76	42785.97	-0.51	16302.97	-1.17
36 44 13.10	121 51 56.79	42786.20	-0.57	16302.34	-1.34
36 44 8.63	121 52 18.39	42786.31	-0.51	16301.65	-1.44
36 44 4.10	121 52 39.93	42786.31	-0.36	16300.80	-1.38
36 43 59.52	121 53 1.24	42786.67	-0.56	16300.15	-1.49
36 41 45.88	121 53 57.40	42774.88	-0.54	16300.65	-1.29
36 41 38.91	121 53 55.19	42774.14	-0.55	16301.00	-1.39
36 41 27.58	121 53 59.90	42773.15	-0.55	16301.17	-1.50
36 41 11.61	121 54 11.26	42771.85	-0.51	16300.71	-1.16
36 40 55.51	121 54 22.47	42770.50	-0.44	16300.86	-1.40
36 40 39.85	121 54 33.85	42769.34	-0.52	16300.68	-1.34
36 40 23.59	121 54 44.24	42767.98	-0.47	16300.59	-1.32
36 39 49.94	121 54 52.54	42765.09	-0.69	16300.98	-1.30
36 39 32.31	121 54 46.84	42763.11	-0.62	16301.82	-1.52
36 39 27.50	121 54 44.87	42762.58	-0.63	16302.00	-1.50
36 39 28.71	121 54 56.75	42763.09	-0.67	16301.07	-1.08
36 40 59.62	121 54 39.24	42771.52	-0.58	16299.93	-1.25
36 41 17.39	121 54 43.91	42773.43	-0.59	16299.36	-1.27
36 45 40.86	121 52 44.31	42796.14	-0.36	16298.30	-1.24
36 41 34.79	121 54 48.67	42775.27	-0.55	16298.74	-1.24
36 41 52.20	121 54 53.50	42777.16	-0.57	16298.24	-1.33
36 42 9.66	121 54 58.31	42779.02	-0.57	16297.52	-1.20

NEARSHORE OBSERVATIONS

SHIP POSITION — OBSERVED LORAN RATES & CORRECTIONS

LATITUDE (D-M-S)	LONGITUDE (D-M-S)	9940-Y (µS)	EY (µS)	9940-W (µS)	EW (µS)
36 42 27.04	121 55 3.22	42780.93	-0.61	16296.95	-1.22
36 42 53.16	121 55 10.47	42783.80	-0.67	16295.94	-1.10
36 43 10.66	121 55 16.16	42785.54	-0.50	16295.40	-1.18
36 43 28.21	121 55 21.57	42787.41	-0.47	16294.85	-1.28
36 46 6.99	121 54 14.07	42801.32	-0.42	16293.93	-1.20
36 45 59.82	121 53 51.35	42799.98	-0.42	16294.90	-1.06
36 45 52.68	121 53 29.25	42798.49	-0.26	16296.17	-1.25
36 45 46.82	121 53 6.78	42797.52	-0.51	16297.15	-1.16
36 45 35.36	121 52 21.83	42795.21	-0.60	16299.42	-1.31
36 43 54.84	121 53 23.15	42786.74	-0.49	16299.34	-1.48
36 43 50.02	121 53 44.34	42786.87	-0.49	16298.50	-1.40
36 43 45.19	121 54 5.83	42787.05	-0.55	16297.70	-1.37
36 43 43.41	121 54 12.26	42786.99	-0.49	16297.35	-1.25
36 43 21.47	121 54 15.34	42784.94	-0.54	16297.93	-1.46
36 43 2.21	121 54 11.96	42782.93	-0.55	16298.45	-1.40
36 42 43.38	121 54 8.25	42780.80	-0.41	16298.86	-1.23
36 42 24.10	121 54 4.72	42778.89	-0.53	16299.53	-1.32
36 42 4.95	121 54 1.27	42776.77	-0.40	16300.11	-1.33
36 40 7.43	121 54 54.37	42766.74	-0.54	16300.52	-1.30
36 39 43.17	121 55 12.59	42765.04	-0.73	16300.38	-1.35
36 39 57.51	121 55 28.88	42766.84	-0.64	16299.41	-1.37
36 40 12.03	121 55 45.32	42768.84	-0.73	16298.34	-1.29
36 40 26.35	121 56 1.30	42770.63	-0.63	16297.46	-1.38
36 40 40.19	121 56 17.08	42772.38	-0.57	16296.25	-1.13
36 40 54.66	121 56 32.98	42774.29	-0.58	16295.39	-1.25
36 42 26.44	121 55 56.84	42782.30	-0.52	16294.92	-1.38
36 42 12.66	121 55 42.86	42780.60	-0.59	16295.68	-1.25
36 41 59.02	121 55 28.93	42778.84	-0.58	16296.61	-1.30
36 42 1.87	121 55 13.58	42778.70	-0.59	16297.14	-1.26
36 42 18.24	121 55 3.92	42780.11	-0.64	16297.22	-1.31
36 42 42.74	121 54 49.26	42781.89	-0.40	16297.38	-1.42
36 43 7.54	121 54 35.92	42784.16	-0.58	16297.25	-1.31
36 43 24.95	121 54 30.55	42785.69	-0.52	16296.89	-1.12
36 43 42.42	121 54 25.39	42787.27	-0.51	16296.77	-1.19
36 43 57.08	121 54 33.58	42788.95	-0.48	16296.34	-1.43
36 44 10.34	121 54 46.95	42790.67	-0.50	16295.19	-1.14
36 44 24.16	121 55 0.33	42792.42	-0.50	16294.46	-1.28

LIST OF REFERENCES

Anderson, C. W., Pearce, D.C., and Walker, J.W., "Coastline Induced Loran-C Anomalies," U. S. Army Electronics Command, Ft. Monmouth, N. J., ECOM-4075, February 1973 (AD-757 142).

Atlantic Research Corporation, Jansky and Baily Division, "The Loran-C System of Navigation," Alexandria, VA, prepared for the U. S. Coast Guard, February 1962 (AD-281 804).

Campbell, A.C., "Non-Iterative Determination of Latitude and Longitude from Either Time or Phase Differences," *International Hydrographic Review Supplement*, v. 6, p. 113-119, September 1965.

Defense Mapping Agency, *American Practical Navigator*, DMA Publication Number 9, DMA Hydrographic Center, Washington DC 20390, Volume 1, p. 991-1002, 1977.

Doherty, R.H. and Johler, J.R., "Analysis of Ground Wave Temporal Variations in the Loran-C Navigation System," U. S. Dept. of Commerce, Office of Telecommunications, OT Technical Memorandum 76-222, June 1976.

Doherty, R.H. and Johler, J.R., "Unexploited Potentials of Loran-C," *Navigation*, v. 22, n. 4, p. 343-351, Winter 1975-76.

Doherty, R.H., "A Loran-C Grid Calibration and Prediction Method," Office of Telecommunications, Inst. for Telecommunication Sciences, Boulder CO, OT TRER25, February 1972 (COM-75 10824).

Eaton, R.M. and Mortimer, A.R., "Accurate Chart Latticing for Loran-C," *International Hydrographic Review*, LVI (1), p. 21-33, January 1979.

Fehlner, L.F. and McCarty, T.A., "How to Harvest the Full Potential of Loran-C," *Navigation*, v. 21, n. 3, p. 223-233, Fall 1974.

Goddard, R.B., "Differential Loran-C Time Stability Study," International Navigation Co., Bedford MA, prepared for U. S. Coast Guard, CG-D-80-74, November 1973 (AD-779 543).

Illgen, J.D. and Feldman, D.A., "Loran-C Signal Analysis Experiments," *Proceedings of 7th Annual Technical Symposium*, Wild Goose Association, New Orleans LA, p. 161-168, 18-20 October 1978.

Johler, J.R., "Loran-C, D Phase Corrections Over Irregular, Inhomogeneous Terrain by Simplified Computer Methods," *ESSA Technical Report ERL 116 ITS-83*, 1969.

Johler, J.R., Kellar, W.J. and Walters, L.C., "Phase of the Low Radiofrequency Ground Wave," *National Bureau of Standards Circular 573*, 26 June 1956.

Riordan, R., private communication forwarding copy of FORTRAN Program LORAN, National Ocean Survey, Code C64xZ, Rockville MD 20852, 24 May 1979.

Senus, J.W., "On Loran-C," on *Electronic Surveying and Navigation*, S.H. Laurila, John Wiley and Sons, Chapter 25, 1976.

Veronda, C., "Bibliography and Comments on Loran-C Ground Wave Propagation," U. S. Dept. of Transportation, Transportation Systems Center, Cambridge MA 02142, DOT-TSC-RSPD-77-2, December 1977 (PB-279 463).

Wait, J.R. and Walters, L.C. "Curves for Ground Wave Propagation Over Mixed Land and Sea Paths," *IEEE Transactions on Antennas and Propagation*, v. 11, n. 1, p. 38-45, January 1963.

Wallace, J.L., "Hydroplot/Hydrolog Systems Manual," U. S. Dept. of Commerce, National Oceanic and Atmospheric Administration, NOS Technical Manual No. 2, Volume 1, Section 3, September 1971 (revised 21 May 1974).

Wild Goose Association (WGA), *Radionavigation Journal*, 4 Townsend Road, Acton MA 01720, p. 17-18, 1977.

Wild Goose Association, "Loran-C System Characterization," *WGA Publication No. 1/1976*, 4 Townsend Road, Acton MA 01720, p. 21, September 1976.

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