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LORAN-C SIGNAL STABILITY STUDY: NORTHEAST AND SOUTHEAST U.S.

FINAL REPORT

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16. Abstract

Since 1977, the U.S. Coast Guard has been conducting studies of the suitability of Loran-C as a precision aid to navigation in the harbor-harbor entrance (HHE) areas of the continental U.S. The final phase of this effort involves an assessment of the stability of the signals of the existing Loran-C system along with an examination of stability improvement methods. The final efforts were begun in early 1981 with the deployment of loran data collection sets (the so-called "harbor monitors") in select harbor areas. In this report, the harbor monitor data collected at 14 sites located along the northeast U.S. and southeast U.S. (N.E.U.S./S.E.U.S.) coast is presented. Extensive analyses are conducted to obtain a model of the loran signal variations and extend the results to allow the determination of system performance throughout the region. The report shows the "HHE level" performance requirements can be met, at most with a moderate set of system improvements, in almost all major harbor areas. The effects of adverse system geometry, unfortunately, exclude the achievement of adequate performance in the major ports of the east coast of Texas. An analysis shows how the addition of another chain, requiring the installation of one more transmitting station would solve the problems along the Texas coast. The report also shows that the repeatable accuracy of existing Loran-C is better than 40-meters, 2-drms, in 50% of the N.E.U.S./S.E.U.S. coverage area. It is better than 80-meters in over 90% of the same coverage area. This means that GPS, at the 100-meter, 2-drms accuracy levels presently being planned for release to the public, does not qualify as a bona fide replacement for Loran-C.

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Loran-C, Harbor Monitor, Temporal Variations, Harbor-Harbor Entrance Double Range Difference

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METRIC CONVERSION FACTORS

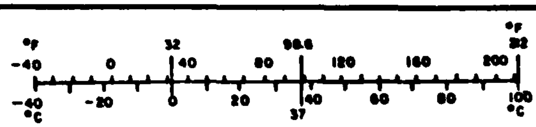
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION

1.1 The Loran-C System of Navigation

Loran-C is a potentially high accuracy long-range radionavigation system which was developed to satisfy U.S. military requirements. In this sense, it is similar to Loran-A, Omega, and several other "originally military" radionavigation systems. As is generally the case, no extraordinary measures were taken to prevent civilian users from exploiting the capabilities of the system (except for the fact that in the early days of the system, user equipments were prohibitively expensive). By the early 1970's, however, technology had progressed to the point at which reasonably priced Loran-C receivers could be commercially procured. Thus, just as had happened with Loran-A two decades earlier, a civilian Loran-C user community began to grow.

The emergence of a civilian user community, for a military system, is a considerable thorn in the side of government planners/auditors: what is to be done with the system once the military no longer requires it but the civilian community still wants it? This problem was addressed on a large scale for the first time in the early 1970's and set into motion a series of events and studies, some of which continue to this day. Indeed, this report documents work conducted under one such study. To properly understand the reasons for, and the results of, this study, therefore, we need to take some time to present what transpired in the early 70's.

Reference 1 was the Department of Transportation (DOT) planning document of concern at the time. As that document points out, there was more to the problem than the simple question of what to do with systems the military no longer needed. Technology was producing additional systems which were capable of solving very precise commercial navigation problems so there was a general "proliferation" of radionavigation systems for which federal sponsorship existed or was being sought. Whereas DOT conceded that the federal government had a role in providing the means to achieve safety in the navigable waters of the U.S., it emphasized that the "proliferation of systems," with resulting overlap of service/"dissipation of federal funds" had to be brought under control.

The first step in bringing the problem under control was to initiate a structured requirements analysis. As a result of this analysis, marine navigation requirements were broken down into three broad categories: High Seas, Coastal Confluence Zone (CCZ), and Harbor and Harbor Entrance (HHE). The next step was to establish the accuracy and coverage requirements for each of these categories. In short, as one proceeds from the high seas to the HHE area, the requirements become more demanding. The next step was to establish the goal that one system was desired to satisfy all requirements. With that system identified and in-operation, all other federally sponsored systems would be terminated. With these requirements and goals stated, the search was on.

As the search proceeded, several things became clear. First, it was observed that the stated requirements for the high seas and CCZ arenas could be met by existing or upgraded versions of systems available at the time. No single (existing) system, however, could satisfy requirements in all three arenas. Loran-C, for example, was adequate for CCZ purposes and could probably be made adequate for HHE applications (so the arguments ran). It could not, however, satisfy the worldwide coverage requirement needed on the high seas. Alternatively, Omega featured worldwide coverage and could probably be made adequate for CCZ applications. It was fundamentally incapable, however, of satisfying HHE requirements. Thus, it became clear that, for the reasonably foreseeable future, at least two federally sponsored systems would be required.

The next fact that became clear in the course of the requirements analysis was that there is no neat solution to the navigation problems in the HHE arena, "the most demanding of categories." This led to the following statement of reference 1:

> "Quantitative statements of the needs for radionavigation services in this environment can only be made in general terms and must reflect the uniqueness of the environment in each area. The question of coverage, i.e., whether the technique will be provided at all, is an administrative question, dependent for decision upon the degree of benefit accruable in any particular locality, versus the cost of acquiring it."

This critically important statement is as true today as it was in 1972 and remains the central HHE policy statement of DOT. The only additional question remaining is "what is the HHE system?"

This question was partially answered in 1974 when the DOT/USCG decision regarding marine radionavigation systems was announced. Omega was to be the system for use on the high seas and Loran-C was to be the system for CCZ and HHE use. It was acknowledged that the answers to all of the "HHE questions" were not known so that it was not possible, in 1974, to establish that Loran-C was capable of satisfying all HHE requirements. Nevertheless, it was DOT/USCG's announced intention that unless Loran-C proved inadequate in a particular application, it constituted the federally sponsored HHE system.

At the same time this policy statement was made, USCG began a long term "HHE Loran-C R&D" project to explore the suitability of the system for the HHE application. That project continues to this day and has resulted in a series of studies and reports, including this one.

1.2 The U.S. Coast Guard HHE Loran-C R&D Program

The HHE Loran-C R&D Program, begun in the mid-70's, has comprised a sizable effort, beginning in the St. Marys River (Michigan) area and, more recently, extending throughout the continental U.S. The bulk of the effort is described in the series of reports provided as references 2 through 14. Reference 14 provides an overview of the entire effort, with particular emphasis on the St. Marys River work. We can summarize that discussion by noting that over the years, the HHE Loran-C R&D program has evolved into the 4 major areas described in reference 2: HHE Guidance Equipment, HHE Trackline Surveying, Loran-C Chain Augmentation Techniques, and Loran-C Stability Studies.

In the first project area we examined several generations of Loran-C guidance equipment to determine the best method of presenting Loran-C derived position information to the HHE navigator. This issue having been resolved to USCG satisfaction, the next question involved the determination of the best way to obtain the Loran-C coordinates needed by typical guidance equipment in HHE applications. After several unsuccessful prediction techniques were examined, an effective Trackline Survey Technique was developed.

Once these two project elements were completed, we had the ability to exploit the high accuracy of the Loran-C system - wherever that high accuracy could be found. Several other parts to the puzzle remained. A major one, involved examining the efficacy of Loran-C Chain Augmentation Techniques - i.e., methods to improve system accuracy where such improvements were needed. These methods included techniques such as so-called Supplemental LOPs, Mini-Chains, and Differential Loran-C. With these issues explored, we had demonstrated methods of improving the system if necessary and, as stated in 1972, if such improvements could be shown to be cost-beneficial.

The final HHE Loran-C R&D project element, the so-called Stability Studies, attempted to determine the accuracy of the current system throughout the HHE areas of the continental U.S. Such a determination, assuming a cost-beneficial need can be established for a particular HHE area, will allow us to determine whether or not chain augmentation of some sort is necessary.

As reference 14 indicates, whereas we consider these the essential ingredients of the HHE Loran-C study, we recognize they do not provide all the answers to all "HHE questions." Several "non-Loran-C" questions remain and, particularly as we exhaust our list of "Loran-C per se" questions, we feel the need to repeatedly emphasize this point. To illustrate the point, let us consider, for example, the matter of the cost/benefit determination. A timely example involves the Santa Barbara channel (assuming we can properly call this an HHE area). A Loran-C cost/benefit study in 1984 or 1986 might feature a completely different conclusion than a similar study conducted in 1979. The point worth emphasizing is that we anticipate no significant changes in Loran-C accuracy in Santa Barbara between 1979 and 1986 (thus, no significant change to the cost side of the equation). What can change very significantly, however, is the benefit provided by the availability of a high accuracy navigation system.

The result illustrated by the above example is that we anticipate concluding the HHE Loran-C R&D studies without answering the ultimate question "where should we implement it." An understanding of this idea will go a long way towards explaining the seemingly exhaustive presentation of results we make in this and other stability study reports. We are attempting, within reason, to provide "Loran-C details" to support all present and future decisions that need to be made about HHE applications.

As reference 14 further points out, there are other questions that will remain, it appears, long after the HHE Loran-C studies are over. We characterize these as "requirements questions." Specifically, we note that to this day, we do not possess a definitive statement of how much of the problem associated with transiting a restricted waterway is a "positioning problem." To see an example of the problem, suppose we are transiting a restricted waterway and, to avoid grounding, must keep the centerline of our vessel within 20 meters of the channel centerline. Suppose we are going to use Loran-C to help us do this. Suppose finally, there is no Loran-C error, i.e., if the Loran-C says we are on the centerline, then, indeed we are - precisely. All of these "supposes" out of the way, the question remains: can we make it? What we are really asking is "how well can we maneuver a (presumably large) vessel to perfectly follow the Loran-C indications?"

Once we have completed the HHE Loran-C Stability Studies, we should be able to state, in fairly concrete terms, the expected Loran-C system error in any given HHE area. The "total allowable error," in any given channel is determined by knowing the channel width and the size of the vessel. Certainly, if the Loran-C error exceeds the total allowable error the system can be concluded to be inadequate. Also certainly, if the Loran-C error is small enough relative to the channel width that several hundred meters are left over, we can easily argue the system is adequate. The problem is that we don't know what to say when the error margin is 10, 20, or 30 meters. Are any of those figures "good enough?" Are all of them?

There are no simple, universal answers to these questions. Certainly factors such as channel depth, wind and/or ice conditions contribute to the determination of the answer. The exact method of combining these factors to arrive at an answer, however, is not known. Independent studies are being conducted to address such considerations but it is safe to say there will be no concrete answers until long after our Loran-C studies are completed (we hope). Unfortunately, we must use some estimate of this "guidance error margin" in presenting Loran-C study results. Thus, in this report, as in the previous Stability Study reports, we pick an assumed set of requirements. Specifically, we assume it is realistic to demand the guidance error, the inability of the mariner to follow the Loran-C indications, can be kept less than 10 meters. As described in later sections of this report, this also causes us to be somewhat elaborate in presenting our results. We will take considerable care to tabulate the results in a format readily amenable to update in case future studies show our assumptions warrant revision.

To summarize, we have presented a description of the four elements of the HHE Loran-C project. We emphasize we feel these will adequately address "Loran-C peculiar" questions but simply cannot answer all HHE-related questions. As a consequence, we recognize the need to be somewhat elaborate in both the analysis techniques and the method of presenting the results. We also feel the need to caution the reader, at the beginning, to our motives. These having been established, we can review where we are in the multi-year HHE Loran-C project and how the results discussed herein fit into the big picture.

1.3 Status of the HHE Loran-C R&D Project Elements

At the conceptual level, the development of PILOT, the key product of the guidance equipment project element, was completed by the time of the St. Marys River mini-chain demonstration of 1980. PLAD development was completed within an additional year. The major thrust of the guidance equipment project since 1981 has been to simply use the available equipment for "target of opportunity" demonstrations of Loran-C capabilities. PILOT units have been used by U.S. Navy Units in Seattle and in Charleston and by the St. Lawrence Seaway Development Corporation. PLAD use by the Delaware pilots continues. PLAD's have also been used by the State of Florida DOT in Tampa and by the St. Lawrence Seaway Development Corporation.

The only problem with the guidance equipment is that it features hardware that is about 5 years old and machine language software. The equipment is rugged enough to last for several more years but, since it is essentially comprised of a microprocessor/graphics terminal, 5 years comprises almost three generations and the need for an upgrade can be argued. We are pursuing the development of an off-the-shelf, high-level language PILOT as a prelude to developing a GPS based PILOT. This low-profile effort, along with further target of opportunity demonstrations is all that remains of the guidance equipment element.

The Trackline Survey techniques fall into two categories: the visual survey technique developed in the St. Marys River in the late 1970's, and the combined microwave/visual technique developed for use in New York Harbor in 1980. Additional visual surveys have since been conducted in support of guidance equipment demonstrations in the Delaware River, the St. Lawrence Seaway, Tampa, and the St. Marys River (using the Great Lakes Loran-C chain). Additional combination surveys have been conducted in the Strait of Juan de Fuca/Hood Canal, Narragansett Bay and Charleston. The R&D phase is considered complete and further surveys will be conducted only as required for future guidance equipment demonstrations.

Having explored the concept of the Mini-chain and the Supplemental LOP in the St. Marys River, all planned Chain Augmentation demonstrations are complete. Differential Loran-C, on paper, will be considered as part of all Stability Studies. With the possible exception of a short Differential Loran-C experiment in the St. Lawrence Seaway, no further Chain Augmentation project work is anticipated.

The above three HHE Loran-C R&D project elements were brought to maturity by use of the St. Marys River "test bed." The remaining element, the Stability Studies, of course, must be conducted outside the St. Marys River and are just reaching a reasonably mature level.

Development of the Stability Study equipment and experiment methodology was actually begun in the St. Marys River but, we must admit, not in a fully planned manner. Quite frankly, it was not originally believed that there would be a signal instability problem over such a small area as that covered by a mini-chain. The last 3 of the 5 years of the Mini-chain experiment were spent finding out this belief was wrong. In the process, several studies were conducted (references 9 through 12) to arrive at the understanding of the nature of Loran-C time difference variations needed to proceed with the Stability Studies. Although these reports comprised the main contribution of the St. Marys River project to the final HHE Loran-C R&D project element, a further contribution was made in the development of a first generation "harbor monitor set."

Section 2 of this report provides a detailed description of the harbor monitor sets - the equipment used to obtain Loran-C signal stability measurements. While the first generation equipment was being used in the 1979-80 timeframe to conduct the final Mini-chain performance data, an upgraded version was being developed for use throughout the continental U.S. The prototype installation of the second generation equipment was achieved at Point Allerton, Mass. in the Fall of 1980 and "production" units were deployed throughout 1981.

By early 1982, enough harbor monitor experience had been accrued to convince us we needed another development phase. The development of this final generation was completed in mid-1982 and installations completed over the past year have featured this latest equipment.

At present we plan to publish six Loran-C signal stability studies. Three of the studies have been completed thus far, the results being reported in references 13 and 14 and herein. A detailed discussion of these studies begins in the next Section.

2. HHE LORAN-C SIGNAL STABILITY STUDY OVERVIEW

2.1 Harbor Monitor Program Overview

In the previous Section, we established how the HHE Loran-C Stability Study relates to the broader subject of HHE Loran-C. It was important to establish this so that the results of this report can be viewed in proper context. As a further refinement of this same concept, we should establish that the subject matter of this report (Loran-C Signal Stability in the Northeast and Southeast U.S.) is but a part of the total Stability Study effort and that some further background discussion is called for. Specifically, we should note that the Stability Studies consist of what can be viewed as a series of experiments, most aspects of which have been evolving over the past few years and continue to evolve. This experiment is a growing, dynamic undertaking. The most obvious evolutionary aspect of the project is in the monitoring equipment and the monitoring sites. However, there is more to it than these obvious factors and it is important that these be addressed at the outset of the discussions.

An important additional factor to consider is the way that the experiment methodology has evolved. We should also discuss the evolution of the goals of the study. Finally, we should note the evolution of the analysis techniques and the refinement of the Loran-C model used in the analysis. We will discuss all of these factors in this Section and the best way to start is by presenting and discussing the site installation schedule.

2.2 Harbor Monitor Sites

Figure 2-1 shows the location of all Harbor Monitor Sets as of 1 July 1983. We should mention that the figure does not show all the sites there ever were: some have been removed - but that is another part of the story which we will get to. First, we should present Table 2-1 and start our discussions at the beginning.

As the table shows, there are three "types" of Harbor Monitor Sets: A, C, and D (following in the loran tradition, we skip B - for the present). In Section 2.3 we will give a detailed description of type C and type D Harbor Monitor Sets. For now we will simply note they involve a complete Loran-C receiver installation, a micro-computer, and a phone line interface. The equipment requires no routine operator intervention. A type A installation is different in that only the micro-computer and phone line interface are involved - the receivers are "already provided." Specifically, the receivers (e.g., those located at Sandy Hook, Cape Elizabeth, etc) are those which have been long since installed and operated for routine control of the Loran-C chain. These receivers are located at "unmanned" sites with the readings being sent to chain control stations (e.g., Seneca, Middletown) via phone lines. Thus, for a type A installation, we simply install equipment at the control station to "listen in" on the existing phone line and gather and store the data to suit our own purposes.

HARBOR MONITOR SYSTEM SITES

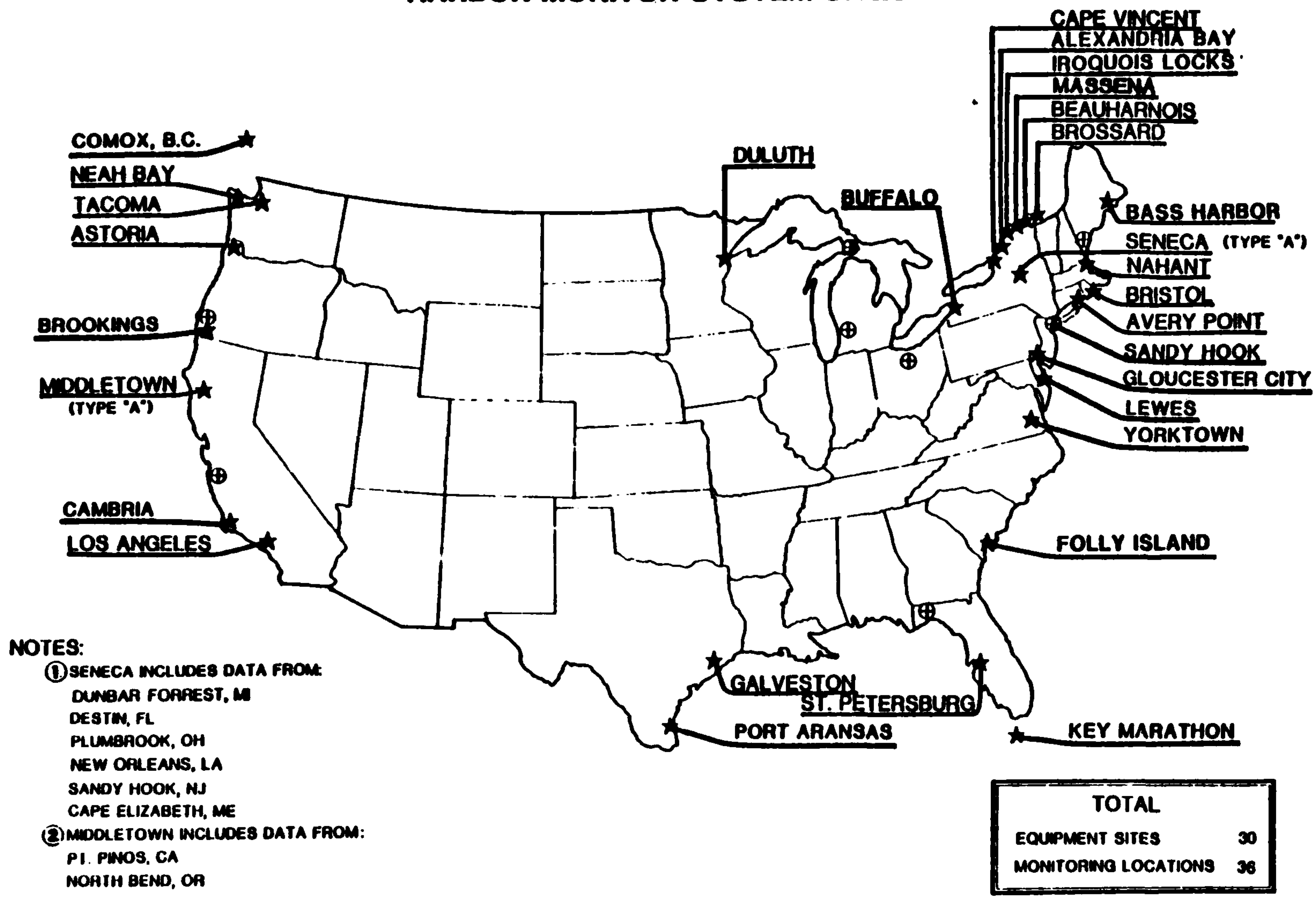


Figure 2-1 Location of Harbor Monitor Sites

Type C/D Sites

Site	Installed	Removed	Type	Chain	Comment
Pt. Allerton	8/27/80	12/1/81	C	9960	Replaced by Nahant
Pt. Iroquois	2/12/81	5/23/82	C	8970	Removed at completion
Dunbar	2/12/81	5/23/82	C	8970	of Supplemental LOP
Rocky Pt.	2/12/81	5/23/82	C	8970	Experiment
Detour	2/12/81	5/23/82	C	8970	
Avery Pt.	5/12/81	N/A	C	9960	Type D Also Available
Yorktown	9/20/81	N/A	C	9960	
Lewes	9/21/81	N/A	C	9960	Site moved 3/2/82
Gloucester	10/7/81	N/A	C	9960	
Nahant	9/25/81	N/A	C	9960	Replaced Pt. Allerton
Massena	10/21/81	N/A	C/D	9960	In cooperation w/SLSDC
Cape Vincent	2/2/82	N/A	C/D	9960	These upgraded 9/16/82
Charleston	4/23/82	N/A	C/D	7980	Switched to Type D 2/8/83
St. Petersburg	4/27/82	N/A	C/D	7980	Switched to Type D 2/9/83
Galveston	4/27/82	N/A	C	7980	
Duluth	5/28/82	N/A	C	8970	
Bristol	7/9/82	N/A	D	9960	Hi-Density Data Site
Astoria	8/6/82	N/A	D	9940	
Neah Bay	8/9/82	N/A	D	5990	
Point Vicente	8/10/82	N/A	D	9940	
Tacoma	9/7/82	N/A	D	5990	Initial Site Problems
Iroquois Lock	9/11/82	N/A	D	9960	Hi-Density Data
Brossard	9/12/82	N/A	D	9960	Hi-Density Data
Alexandria Bay	9/14/82	N/A	D	9960	Hi-Density Data
Beauharnois	9/14/82	N/A	D	9960	Hi-Density Data
Bass Harbor	10/14/82	N/A	D	9960	
Buffalo	10/20/82	N/A	D	8970	
Key Marathon	5/13/83	N/A	D	7980	
Corpus Christi	5/14/83	N/A	D	7980	
Cambria	5/19/83	N/A	D	9940	
Brookings	5/21/83	N/A	D	9940	
Comox	5/25/83	N/A	D	5990	
Sandy Hook	6/7/83	N/A	D	9960	Phase-Mod Tests

Type A Sites

Site	Installed	Removed	Type	Chain	Comment
Muskegon	9/1/80	3/3/83	A	9960	Site Replaced by Riverside
Sandy Hook	9/1/80	N/A	A	9960	Data Obtained at Seneca
Cape Elizabeth	9/1/80	N/A	A	9960	
Plumbrook	9/1/80	N/A	A	9960	
Muskegon	9/1/80	3/3/83	A	8970	Site Replaced by Riverside
Destin	9/1/80	N/A	A	8970	Data Obtained at Seneca
Plumbrook	9/1/80	N/A	A	8970	
Riverside	4/7/81	N/A	A	8970	Replaces Muskegon
Destin	8/26/81	N/A	A	7980	
Pt. Pinos	8/10/82	N/A	A	9940	Data Obtained at Middleton
North Bend	8/10/82	N/A	A	9940	

Table 2-1 Harbor Monitor Site Installation Summary

By use of a separate phone line, the data stored in the type A computer set is periodically retrieved.

The Statement of Work for the Harbor Monitor project element was sent to the USCG R&D Center in Groton, Ct. in the Fall of 1979, just after the instrumentation for the final St. Marys River Mini-Chain stability study was installed and verified to be operating properly. We should emphasize, as reference 14 points out, that the equipment used in the Mini-Chain Stability Study, although similar, cannot be called a true Harbor Monitor Set in that a considerable amount of "post-data-collection-processing" was done by the mini-chain operational personnel before the data was sent to the R&D Center. Additionally, with mini-chain electronics technicians nearby, the equipment received (for better or worse) considerable attention. The development of a computer-based system to obviate the need for this type of local support was the key challenge facing R&D Center.

As can be seen from the dates listed in Table 2-1, R&D Center had accomplished the prototype A (at Seneca) and C (at Pt. Allerton, Mass.) installations by 1 September 1980 - right on the desired schedule. Particularly in the case of the Pt. Allerton installation, this was considered a major milestone: USCG R&D personnel now had new Loran-C data (i.e., the basis of papers/reports) from some place other than the St. Marys River! (Although the Seneca installation was also pleasing, the Seneca data was already available in hard copy vice the desired electronic form.)

With these milestones out of the way, we had to concentrate on: a) monitoring the installations for evidence that modifications to the prototypes were necessary, b) proceeding with the development of a Harbor Monitor data base management system, and, c) planning for future installations. The highest priority of the follow-on installations were in the St. Marys River area. As discussed in reference 14, the mini-chain was to be secured on 31 December, 1980 and the Supplemental LOP experiment begun immediately thereafter. With the reduction in number of transmitting stations to be maintained/operated there came a reduction in assigned personnel. Since the Supplemental LOP experiment was essentially a stability study, Harbor Monitor Sets were required. Since the Supplemental signal was being provided (at an expense) for the sole purpose of the experiment, the St. Marys River sets were of the highest priority.

The dates shown in Table 2-1 hint to the fact that problems were encountered: if the Supplemental LOP experiment started in early January, why weren't the four Soo sites installed until mid-February? Indeed, there were several problems with the type C sites and it was not until early May 1981 that they were resolved in the Soo (see reference 14 for further discussions). Once the Soo problems were resolved, serious attention was returned to the Pt. Allerton site. Whereas Pt. Allerton was reasonably convenient to the R&D Center, there were so many problems encountered and such uncertainty as to the cause that a site was established right at Avery Point (the R&D Center). Within a month it was clear that all major problems with the Harbor Monitors had been resolved and that the remaining problems with Pt. Allerton were site-related (the equipment was installed on a USCG base with a heavy industrial environment).

The summer of 1981 was spent refining the data base management system, locating a replacement site for the Pt. Allerton installation, and preparing for several more Northeast U. S. installations - expanding cautiously from the "homebase" of the support personnel in Connecticut. Installation preparation involved considerably more than simply getting the equipment ready. A pre-installation survey was needed to find a suitable/convenient location for the equipment. A suitable location was one which featured freedom from antenna obstructions and/or heavy industrial noise along with the often conflicting requirements of physical security and easy access (to phone lines, etc.) Once such a site was found, arrangements for reasonably long-term occupancy, the installation of phone lines, etc. had to be made - all of this typically taking up to several months.

We belabor these time element considerations for reasons illustrated in the time sequence data shown in figure 2-2 below.

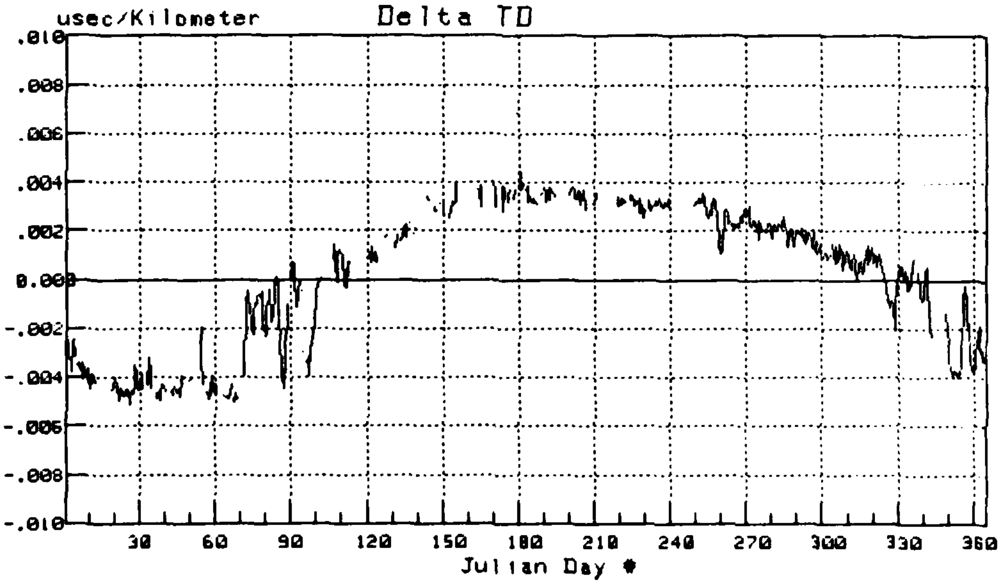


Figure 2-2 Typical Loran-C Propagation Speed Variation Record

The data record illustrates the expected variation in the Loran-C propagation speed - a prime component of the total Loran-C instability record these studies hope to measure. The parameter being plotted is actually the reciprocal of speed change as indicated by the units of nsec/km. There are several characteristics of the plot worth discussing. The first, and most important, characteristic is the peak-to-peak value of the variation over the course of a year. When considered in conjunction with the orientation of the Loran-C lines of position at a given point, this will determine the repeatable accuracy of the system at the point - a prime goal of the study. Notice next that the data record is relatively steady in the summer months - say from Julian Day (J.D.) 120 through 280 (May through early October). Outside that period, rapid, erratic variations can occur. We derive significant information from the variations in the winter months but the peak-to-peak magnitude of the year-long data record is our prime concern.

To state the above concepts differently, we can say our prime concern is to determine how positive the dTD gets in the summer and how negative it gets in the winter. If we are clever, we do not need a full year of data to make this determination - particularly if we start the data record sometime in the summer. As an example, suppose we have only a 4 month portion of the data record of figure 2-2 available. We illustrate two such possibilities in figure 2-3 below. In figure 2-3(a) the 4 months extend from 1 October of one year to 1 February of the next. In figure 2-3(b) the 4 months extend from 1 November to 1 March of the next year.

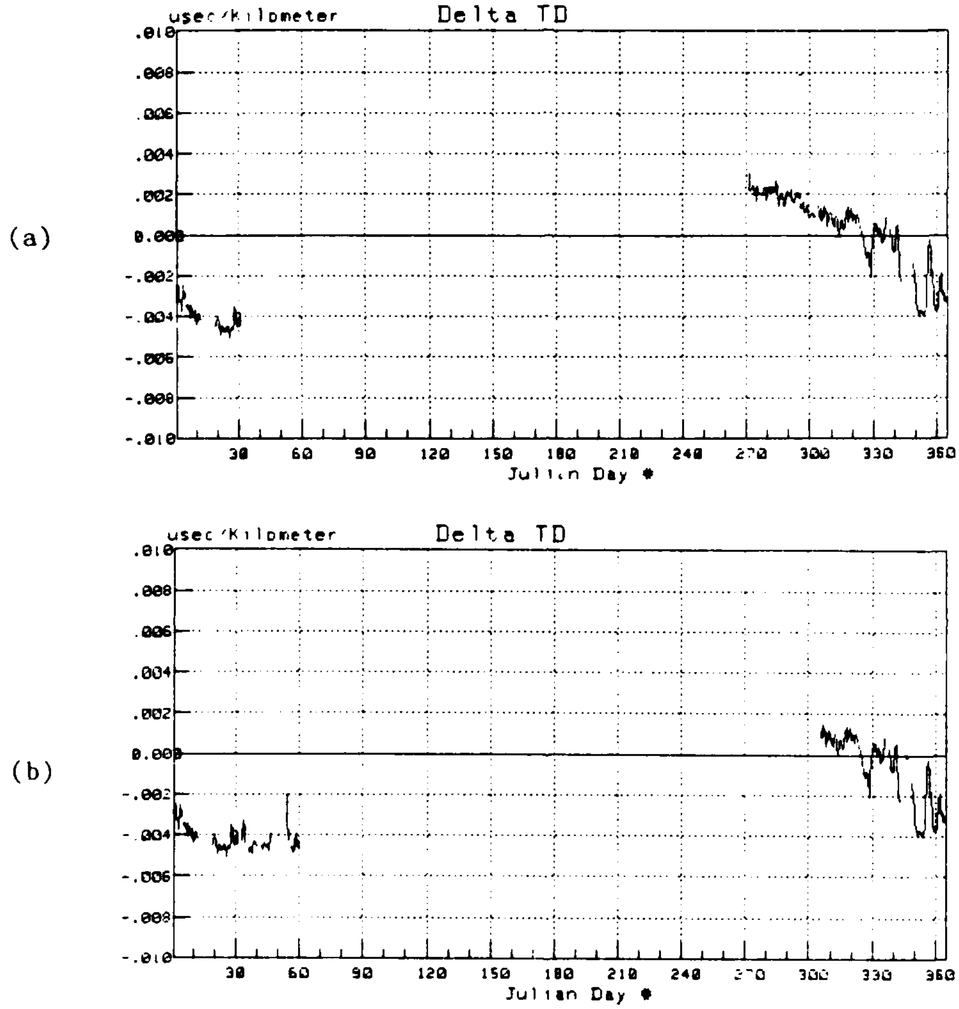


Figure 2-3 Segments of the Data Record of Figure 2-2

In the first case, the record started so close ("Loran-C variation-wise") to the "summer state" that a good estimate of the total variation can be readily obtained by the end of January. In the second case, we really do not have a good indication of where the summer record will steady out. Thus, we must wait - until about May - to make our most important finding.

In comparing the two cases, we see a delay in starting the data record of 1 month caused a 3-month delay in "knowing the answer." When we consider that we are presently talking about events which transpired 20 months before this writing, the importance of the 3-month delay is obscured. Note, however, that there is more to all of this than writing the report: first we need to insure that the experiment is properly designed. Even more important, however, we need to insure the experiment is properly funded.

To see the significance of the above statement we must recognize that the data record of figure 2-2 is what we expect will represent a major component of the Loran-C instabilities - assuming there are no propagation surprises. Since we had no reason to expect "no surprises" and had no in-depth knowledge of Loran-C signal stability outside the St. Marys River, we needed to overcome this first major obstacle as soon as possible. Specifically, we anticipated a possible need for additional sites but did not know where they needed to be located. Resources being limited, and with a well-documented need to proceed cautiously in expanding the scope of the effort, we had to wait for the preliminary results so that we could determine the most cost-effective location for further installations.

Recalling the earlier discussion, we see we are "in a loop" with all of this. We need to install sites in the summer so that by mid-winter we will know if we need to install more sites the next summer. Why the next summer? That's so by mid-winter... etc. etc. The net results of doing all of this the right way (i.e., installations complete by the end of the summer) is that one year is saved from the total length of the project. A consideration of the federal budgetary situation in the late 1981 timeframe (more on this later) explains the intense concern of the time.

With all of this background, the late September/early October 1981 installation of the next four sites indicated in Table 2-1 tells a considerable tale: things were not proceeding smoothly. Indeed, if you truly desire to have a good data record starting by the end of the summer, you should accomplish the installations in mid-August at the latest. No matter how much effort is expended in the site survey, there will very likely be problems discovered during the first month of 24-hour-a-day operations that simply could not be anticipated. The comment on the Lewes site illustrates this point precisely. Due to a high local noise environment, we had to move the site in March 1982. Fortunately, the original data was marginally usable and we found a satisfactory site within a mile of the original location so that, through a correlation process, we could combine the two data records in a meaningful way.

The period of time we are now discussing, i.e., the late summer of 1981, was a critical one for the HHE Loran-C project. A careful project review indicated the stability study project element was approaching the two year point. It had taken almost all of the first year to simply get prototype installations in. Nearly a year later, we still did not have a reasonable data record from a site outside the St. Marys River area. We had to ask whether or not the scope of the desired effort exceeded the capabilities of our available resources. In pondering the difficulty of the question, recognize that a knowledge of the potential accuracy of the Loran-C system throughout the coverage area is an extremely valuable piece of information to have in conducting long-term evaluations of the worth of the system (as was, and continues, being done). The fact that the studies to provide this valuable information had never been done (for a system approaching an age of 25 years) testifies to the fact that the effort is non-trivial.

The determination was made to exert one final effort to accomplish the task and this was supported by two significant actions over the next half-year. The first action was taken in mid-August 1981 when the R&D Center's foremost instrumentation engineer and technician joined the project team on a full-time basis. The success these individuals had in overcoming problems with the Harbor Monitor Set is the single most important reason the program was not cancelled. In passing, we must mention that in several cases, the engineer admitted to not fully understanding the source of the problems that were being solved - time being too critical to devote to such details. As it developed, however, the problems were temporarily beaten into submission and the project proceeded.

Within a month after the Lewes/Gloucester/Yorktown/Nahant installations, the true significance of the success with those installations became apparent. In view of the need to accomplish budget cuts, the Coast Guard determined it had to close its R&D Center in Groton at the end of May 1982. Since the HHE Loran-C program was budgeted around the assumption that equipment support, installations, etc. could be accomplished "in-house" at the Center, this determination had severe impact on the Stability Study project. If those four sites had not been established, all installation plans would have been cancelled in October 1981, with support of the St. Marys River sites comprising the final actions of USCG HHE Loran-C efforts.

Since the sites had been successfully established, however, the project continued, albeit on a reduced level. Plans were modified to feature no future installations. However, R&D Center work in the production of additional Harbor Monitor Sets continued. The idea was that once the Center closed, the authors could use these "shelf spares" - "cannibalizing" when necessary, to obtain a reasonable, though reduced, Harbor Monitor data base. We should mention that the type C Harbor Monitor Sets involved "custom" modifications to the micro-computer - of the "still in the R&D phase" variety. Thus, long-term support had to be considered impossible once the R&D Center closed.

Between October 1981 and late April 1982, no "planned" Harbor Monitor installations were accomplished. The listing of Table 2-1 does indicate, however, installations at Massena and Tibbetts Point, N.Y. These were accomplished for the St. Lawrence Seaway Development Corporation, as discussed in reference 13, and were not, formally, a part of the suspended HHE Loran-C R&D project installation schedule.

In late 1981/early 1982, the second significant action to insure the continued success of the Harbor Monitor program was taken (even as the project appeared to be dying). The personnel resources previously devoted to the "winding up" elements of the HHE project (i.e., the guidance equipment and survey elements) were temporarily made available to the stability studies. Since it was clear that continuation of the studies after the Center was closed was threatened because of the type C set "supportability" problems, these newly available project personnel were directed to develop an "off-the-shelf" (or nearly so) Harbor Monitor. Development of this unit, eventually dubbed the "type D" set, was begun in January 1982 and a test installation at Avery Point was made in May 1982. A 1-month test proved successful. Meanwhile, fabrication of additional type C sets continued as a parallel effort.

On 20 April, 1982, USCG/DOT announced that plans to close the Center at the end of May 1982 were cancelled - the Center would remain in use at least until the end of September 1982. At this point, the true significance of the September 1981 installation success became apparent. Since a "low visibility" effort had continued, in addition to the initiation of the parallel effort to develop the type D set, immediate resumption of the installation schedule was possible. Although the question of long-term (i.e., beyond September) supportability was not yet answered, type D set development was far enough along to indicate type C "cannibalization spares" could be deployed as originally planned. The three S.E.U.S. sites were installed immediately and the Duluth installation followed within a month.

The Bristol site, like the Massena and Tibbetts Point sites, was not on the original Harbor Monitor installation schedule. It was installed as part of an "off-line differential Loran-C experiment" as will be discussed later. Although the initial installation purpose was unusual, the data is available to the Stability Study project.

The prototype type D installation test was completed in early June 1982 - just after USCG announced the decision to retain the R&D Center indefinitely (again, this meant "beyond September 1982"). At this point, a decision had to be reached: should future installations be type C or D? As in the past, there was a little bit of "breathing room" available before the final decision had to be made. We had just installed four new sites and had a project strategy of waiting for the "smoke to clear" before biting off more installations. At the same time, however, we had to get the installations done before the Fall. We decided to order parts for additional type D installations and go with type C equipment only if delivery problems were encountered.

In July 1982 the conclusions of reference 13 were available and it was decided that the data collection effort along the St. Lawrence Seaway should be expanded - using type D sets. As indicated in Table 2-1, the initial West Coast/Canadian West Coast chain type D monitor installations were completed by mid-August. We encountered difficulties in locating a suitable Tacoma site, but the problem was resolved by early September 1982. By the end of September, we had completed the St. Lawrence Seaway installations and were ready for our final actions before the winter set in.

By the end of the summer, 1982, we had a chance to review the N.E.U.S. and Great Lakes chains' data bases to look for coverage "holes" in our site selection scheme. Our basic conclusion was that we were in pretty good shape except for a small gap along the north coast of Maine and the extreme eastern portion of the Great Lakes. Thus, the Bass Harbor and Buffalo installations were accomplished. Although difficulty in finding a suitable site in Maine makes it questionable whether we got the sites in on time, a valuable lesson regarding signal coverage may have been learned.

By the Spring of 1983 we were able to review the S.E.U.S. and West Coast data bases and determine we needed the additional sites which were installed in May 1983. A final type D set installation was accomplished at Sandy Hook so that we could conduct the "phase modulation" tests we will discuss in future reports.

Regarding the type A sites, we have already mentioned the prototype installations at Seneca in September 1980. In August 1981 we discovered a way that Destin S.E.U.S. data could be obtain by the micro-computer at Seneca. In view of the difficulty we were having at the end of 1981, we decided we would postpone the type A equipment installation at Malone (the Seneca counterpart in the S.E.U.S. chain) and consider the availability of the Destin data a temporary solution. In doing this we sacrificed the availability of so-called "Alpha-1" site data. This is data from the sites that the chain is controlled at. Although, under normal circumstances, we want Alpha-1 site data, the Alpha-2 site data, by far, contains the most information and is the compromise solution when there is a "squeeze" on resources. S.E.U.S. chain Alpha-1 data used in the report was obtained manually by reviewing chain control strip charts.

By August of 1982, we were out of the "compromise" mode and, with plenty of hardware available (the type A microcomputer is the same as that of the type C set), we accomplished the West Coast control station installation.

In "breezing through" the above discussion, we have touched upon most of the key issues of the Harbor Monitor program. We should now devote a few sections to a discussion of key details. Specifically, we want to describe the evolution of the equipment, the project goals, the sampling strategy and the analysis model. We begin with the equipment.

2.3 USCG Harbor Monitor Sets.

As previously noted, there are three types of Harbor Monitor Sets presently in use. We have described all three types briefly and will now discuss the details of the types C and D. First, however, we should describe the most recent predecessor to the Harbor Monitor Set - the data collection set used in the Mini-Chain experiment reported in reference 3. Many of the features designed into the Harbor Monitors were included because of our experiences with these earlier sets.

Figure 2-4 shows the original "Mini-Chain Stability Study" data collection set in block diagram form. Figure 2-5 shows the actual equipment as installed at the Mini-Chain Stability Study data collection site at Dunbar Forest. As described in reference 14, and mentioned above, a delay in the delivery of the original type C sets caused the use of this same equipment at the beginning of the St. Marys River/Great Lakes Chain Stability Study (the AN/BRN-5 portion of the set shown in the figures was not used in the Great Lakes Chain experiment).

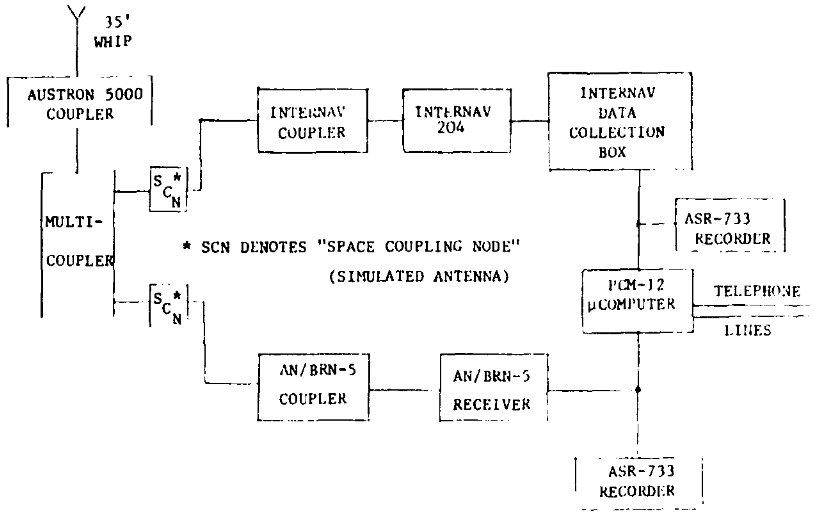


Figure 2-4 Original Data Collection Set Block Diagram

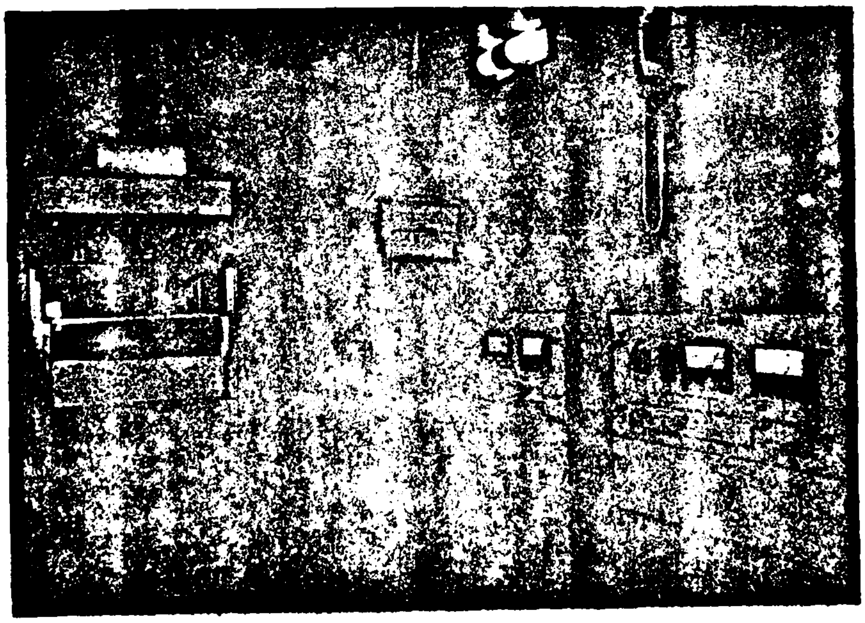


Figure 2-5 Original Data Collection Set at Dunbar Forest Site

As indicated earlier, the need for a Stability Study as part of the Mini-Chain experiment came as a surprise. Significant propagation variations over so small an area were not anticipated. Once it became almost an inescapable fact that there were large variations, the results of earlier (obscure) studies were scrutinized and it was recognized that variations like those suspected were possible. At that point the scramble was on to document the instabilities so corrective action, if possible, could be identified. After early attempts using temporary data collection sites proved fruitless, "permanent," though "Ad Hoc" data collection sets were deployed.

The Internav Corporation had conducted Differential Loran-C experiments for Coast Guard R&D in 1973/1974 and some instrumentation - specifically the data collection sets identified in figure 2-3 were still owned by the Coast Guard. These sets were upgraded to work with the Internav 204 receivers and after some "jury-rigging," the heart of the set of figure 2-3 was born. The key addition was the PCM-12 microcomputer which is, basically, a PDP-8 emulator. The ASR-733 recorders shown in the figure were required for the so-called "high density analysis" we will discuss later. The AN/BRN-5 receiver was used, in part, because the Internav 204 could only track 2 secondary stations. This is the first of several annoying features of this equipment set which, in the form of "what not to do," became Harbor Monitor Set design goals. To point out other undesirable features, we should describe the operation of the set in figure 2-3.

The Internav 204 receiver tracks the signals and provides the time difference readings to the Internav data collection set. The data collection set has an internal clock which can be used to determine how often the set collects data from the receiver. For the St. Marys River (Mini-Chain and Great Lakes Chain) experiments, data collection was initiated every 10 minutes. When data collection began, the set obtained data from the receiver and averaged the reading over a 90 second period. The resulting average, for all stations being tracked, was sent to the PCM-12 micro-computer for storage. The same data was recorded (on casettes) on the ASR-733. Computer storage was adequate to hold readings for about 2 days. The computer was interfaced to a phone line so that readings could be retrieved by personnel stationed at Riverside without having to visit the site.

At Riverside, mini-chain personnel would call each data site at least once a day and obtain a printout on a local teleprinter of each 10 minute sample. Mini-chain personnel would scrutinize the data for signs of equipment problems and, if none were found, average six successive readings during a certain hour of the day to obtain a "system sample" hourly average. The system sample readings would be transmitted via teletype message to the U.S. Coast Guard R&D Center at Groton, Ct. where the data would be stored for analysis. (The adequacy of this "once per day" sampling for characterizing the system stability is discussed in references 1 and 10. It is what we refer to as "low density" sampling in the next section.) The ASR-733 cassettes were collected about once a week and mailed to the R&D Center for contractor analysis. These formed the basis for the "high density" analysis reported in reference 10 and also discussed in the next section. The high density data collection procedure terminated in May 1980 at the conclusion of the Mini-Chain Stability Study. The low density data collection procedure continued until July 1981 when the Internav 204-based data collection sets were removed and retired from service.

The approach to data collection outlined above was known from the start to be suboptimal - in general. Given the pressures of the Mini-Chain experiment and the timeframe involved, however, it was the best that could be done. Thus, we "limped along" through the Mini-Chain experience with the long-term benefit being derived from the fact that we had a good deal of experience by the time the Harbor Monitor Set Statement of Work was drafted in late 1979.

One of the first things we sought to avoid was the reliance upon local operators - and there is more to this than just a "luxury" we did not expect to encounter outside the St. Marys. By late 1979 it was clear that local operators simply did not have the expertise needed to avoid doing more harm than good. This refers to performance as operators, as data reducers and as repair technicians. In retrospect, if we try to list some features of the type C set which we do not like, we must begin with the extreme pains taken in the design to be completely compatible with remote control operations (at the expense, for example, of data storage capacity).

As an example of the excess, if an original version type C set had an I.C. failure that affected a particular memory location, that location could be isolated over the phone. With a quick software change (also loaded over the phone) the program could be rearranged so the affected memory location was never used. It should not be difficult to appreciate that whereas this type of system has some advantages, it also creates a problem in that the design engineer can never "hand-off" his design. This is what caused our "supportability" fears noted above when the R&D Center shutdown was announced. Part of the "paranoia" which led to inclusion of features like this was reflected in the Statement of Work. More, however, was simply built in as a "designer's choice" on the part of the R&D Center personnel. In their defense, we must emphasize they were the people being held responsible for the adequacy of the collected data base. The performance of delicate equipment under typically rural power conditions and the like was a serious consideration.

Another example of a problem with the type C design was that the Statement of Work insisted all data be stored in electronic memory. Part of the problem the S.O.W. wished to avoid, of course, is that associated with having to obtain local support to "change and mail" data tapes periodically. The Differential Loran-C studies of the early 70's were plagued with problems which occur with this approach and the Mini-Chain experience was even worse. The large number of "gaps" in the data used in reference 10 gives a hint of the problem but a true appreciation can probably only be learned by living through a project in which you are exposed to all possible ways data tapes can be lost. Even if we could somehow overcome our "handling" problems with magnetic memory, there is a much more basic reason for staying with electronic memory. This reason is discussed in detail in reference 13. Simply stated, you cannot afford the typical data transportation delays involved with magnetic tape storage - particularly in the early stages of the project as the data collection set is "maturing." If data is being lost on Tuesday, you need to know about it the next day, not the next week, since the problem typically will not "fix itself."

It is a remarkable comment on the times that, from a 1983 vantage point, it seems difficult to imagine electronic memory limitations. In considering all of this, however, we must recall that with mid-to-late 70's technology, the inclusion of an extensive "diagnostic" capability could almost wipe out available data storage space. Such was the case, however, and the memory limitation combined with the required high skill level of the operator comprises the prime limitation of the type C set.

Aside from these limitations, we must say the set (once successfully deployed) performed remarkably well. If it suffered from "overkill" in the "diagnostics" capability, that is a welcomed flaw for first generation equipment. This allowed the accumulation of a considerable data base at the same time valuable lessons about remote (moderate budget) Loran-C receiver operations were being learned. These lessons were applied directly to the design of the type D set.

A block diagram of a type C harbor monitor set is provided in figure 2-6. The set consists of a survey grade Loran-C receiver, the Internav 404, the PCM-12 micro-computer, and miscellaneous support equipment allowing battery back-up power and remote (via telephone) access to the collected data. Like the equipment set described above, the harbor monitor set is used to collect data suitable for a "low density data analysis." A difference is that hourly samples are automatically processed by the equipment and samples are taken twice a day - at noon and midnight (this was recently modified to four times a day).

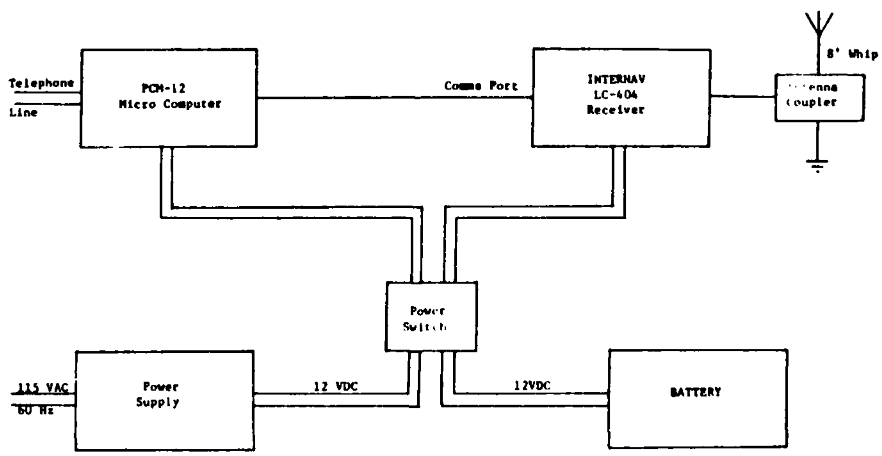


Figure 2-6 Type C Harbor Monitor Set Block Diagram

Simulator tests have shown the Internav 404 Loran-C receiver has a "servo loop time constant" of about 6-8 seconds under conditions typically encountered at harbor monitor sites. Thus the computer obtains a sample of the receiver output every 40 seconds so that the samples can be treated as statistically independent. The micro-computer uses a real-time clock to begin the sampling period at the prescribed time. At the end of the sampling period, the mean, standard deviation, and minimum and maximum values of each time difference are recorded. Depending upon the number of signals being observed, available memory will hold from 10 to 20 days of data (this figure has also varied as a function of software generation). Phone line access to the micro-computer allows retrieval of the stored data. It also allows a remotely located operator to prompt the computer to exercise any receiver command which a local operator could enter via the front panel controls. Finally, the entire micro-computer program can be changed via the phone line. The harbor monitor set at Dunbar Forest, Michigan is shown in figure 2-7.

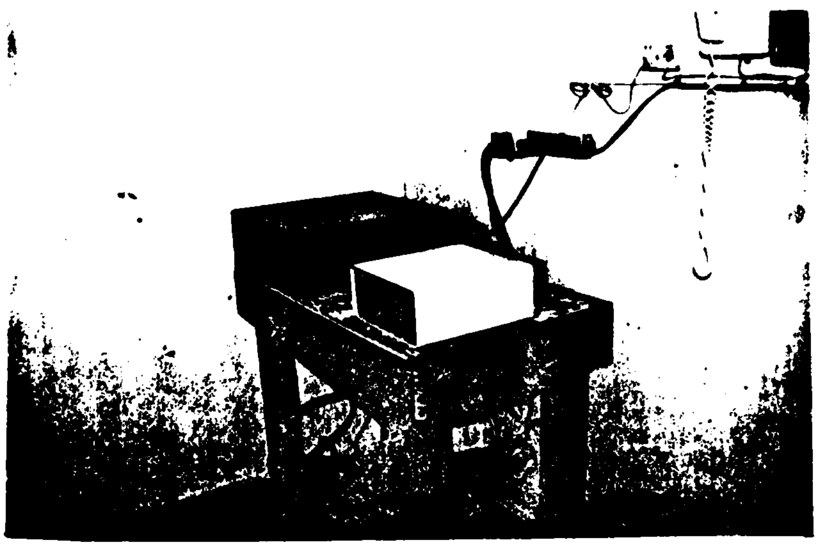


Figure 2-7 Type C Harbor Monitor Set at Dunbar Forest

As previously established, a prime feature of the type D set was its availability "off-the-shelf." A hidden feature here is the significant "firmware" built into the HP-9915 which makes it ideal for remote data collection applications. These features were not commercially available for the first three years of the Harbor Monitor project. A block diagram is shown in figure 2-8. The Pt. Vicente, California Type D set is shown in figure 2-9.

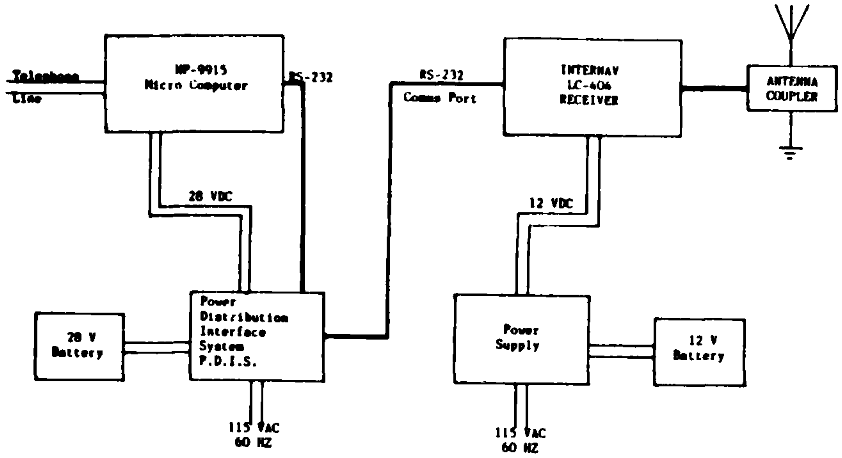


Figure 2-8 Type D Harbor Monitor Set Block Diagram

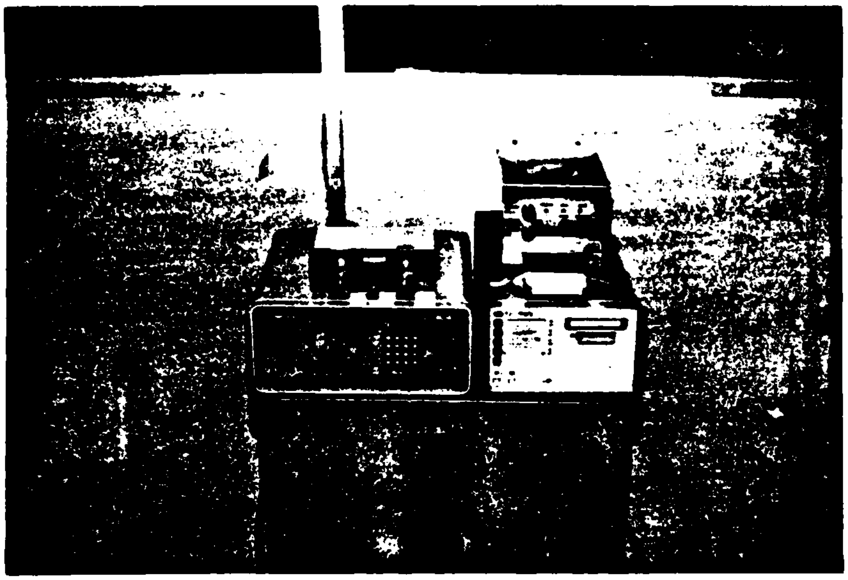


Figure 2-9 Type D Harbor Monitor Set at Pt. Vicente

We will relegate the presentation of specific type D set features to later reports and simply give highlights here. A key point worth mentioning is its simplicity. By early 1981, our experiences had confirmed similar conclusions arrived at by the engineers who designed/installed the Loran-C chain control monitors: the key to success has much less to do with the particular hardware than it does with site selection and preparation. A large part of the battle is won by obtaining a site which is clear of re-radiating elements, is free from high levels of local noise, and can provide a reasonably controlled temperature environment. Another large part is won by ensuring a good, maintainable ground system is established. A final major step towards ensuring success is obtained by minimizing operator interaction with the equipment. The rest is almost "equipment independent."

When the type C sets were designed, we had not yet learned these lessons and tried to solve the above "common sense" problems with software. We see the correct approach in retrospect and this experience was the key to the rapid, successful development of the type D set. Of course, the exponential growth in computer capability leading up to 1982 was also a major factor. The result was that the type D set software could be in a higher level language (Basic). Essentially all the required remote site overhead, e.g., battery backup, moderate (i.e., adequate) diagnostic capability, autostart bootstrap load from the built-in magnetic tape, an autodial modem, etc. was built in. Thus, the relatively large available memory was required to simply support a small data collection/pre-processing program and store data. This allows the type D set to execute either "low density" or "high density" data collection. Even with high density data collection, as discussed in a later section, memory is adequate to allow data retrieval as infrequently as about twice per week. The final, and most important feature, however, is that, except for the simple power supply/backup hardware, everything is "off-the-shelf-supportable."

Now that we have presented an overview of the site installation schedule and the types of equipment, we should proceed with a discussion of the experiment goals and strategy.

2.4 Harbor Monitor Experiment Goals and Strategy

As Loran-C chain operators have known for years, almost all the time, and in almost all areas, watching the output of a Loran-C receiver at a fixed location is extremely boring. For easily 99+% of the time, other than the effects of what we can call "zero mean atmospheric noise," any variation in the reading occurs too slowly to be noticeable. Thus, when people with chain operations experience become involved with Loran-C stability studies, they tend to prefer what we call a "low density" approach to data collection. In doing so, they act partly in recognition of their knowledge that "nothing interesting is happening" for the overwhelming majority of the time. Another reason for their preference of the low density approach comes from past experiences which, since they were done in the past, were probably not done with the type of data collection, reduction and storage capabilities available today. If such people were any good at what they did, they had to be very adept at extracting the maximum amount of information from the minimum amount of data. Thus, they develop a natural preference for the "low density" approach.

Alternatively, newcomers to Loran-C prefer to conduct these studies by attempting to obtain the maximum amount of Loran-C data per unit time. Particularly if we recognize these people suffer a bit from the fear of the unknown (e.g., "I wonder what we're neglecting"), we can understand this preference for the "high density" approach.

The above statements serve as background to the statement that the USCG adopted the "low density" approach at the beginning of the stability studies and that the adequacy of this approach is periodically challenged. Whereas we are adamant about the low density approach position, we have recognized the need to explain our motives. Indeed, in conducting the Mini-Chain stability study, we conducted the concurrent high density analysis reported in reference 10 - to substantiate the basis for the opinion. The difference between the two positions is significant enough that we recognize the need to periodically re-state our motives. Thus, the following discussion.

First, we conceed "the more useful data, the better - all other things being equal." All other things, of course, are not equal. The cost of the effort, as well as the risk of equipment failure/loss of data, increases as a nearly direct function of the amount of data we attempt to collect. With the Internav 404 receiver, for example, we could obtain and record a sample (essentially, a line of teletype code) every second. If we were to try to retrieve data of this intensity, at reasonable telephone line data rates, we would have to have a computer "on the phone" (actually, on several phones) 24 hours a day. We could do this (it's within the state-of-the-art) but the phone bills would have put us out of business long ago. Thus it is a matter of marginal utility: 95% of the available information which can be extracted from a single monitor site can be obtained for about 10% of the cost of obtaining "100%" of the info. Under these conditions, we maximize the amount of information obtained by settling for the 95% from as many sites as possible.

To substantiate some of the above claims, we can draw upon some results from reference 10. Again, those results were based on Mini-Chain data and, although there were the previously noted data collection problems, these do not obscure the important points. Among other things, the report carried out one of the classic time series analyses: compute and plot the TD data record autocorrelation function and its Fourier Transform, the power density spectrum. Two pages of such plots, comprising figures 3.3-2 and 3.3-3 in reference 10, are reproduced herein as figures 2-10 and 2-11.

Before commenting on the plots, we should mention some facts which are well known to Loran-C operators. Because of recent advances, much of chain control is presently computerized. We can go back over the years, however, and notice that the procedures manuals outline two basic control policies: one for daytime conditions and one for nighttime. Indeed, standard practice called for "posting" of TD plots for the past few days so that a watchstander had "a feel" for what to expect throughout the watch. Even today when the chain control computers are "initialized," the operator is queried about control policy parameters. Provisions are made for two sets of parameters: one for day and one for night. Thus, it has been long since established that there is a systematic, repeatable "Loran-C difference" between day and night. Similar examples can be found in chain management documents to establish it is well known that significant Loran-C variations can occur over the course of a year. Thus, before scrutinizing the plots on the following page, we should recognize that chain operators have long known: a) there are significant, systematic Loran-C TD variations from day to night, b) there are even more significant, systematic, seasonal variations in the Loran-C TD's, and, c) the seasonal variations become larger as the observation point moves away from the system area monitor (SAM), the place at which the TD's are held steady.

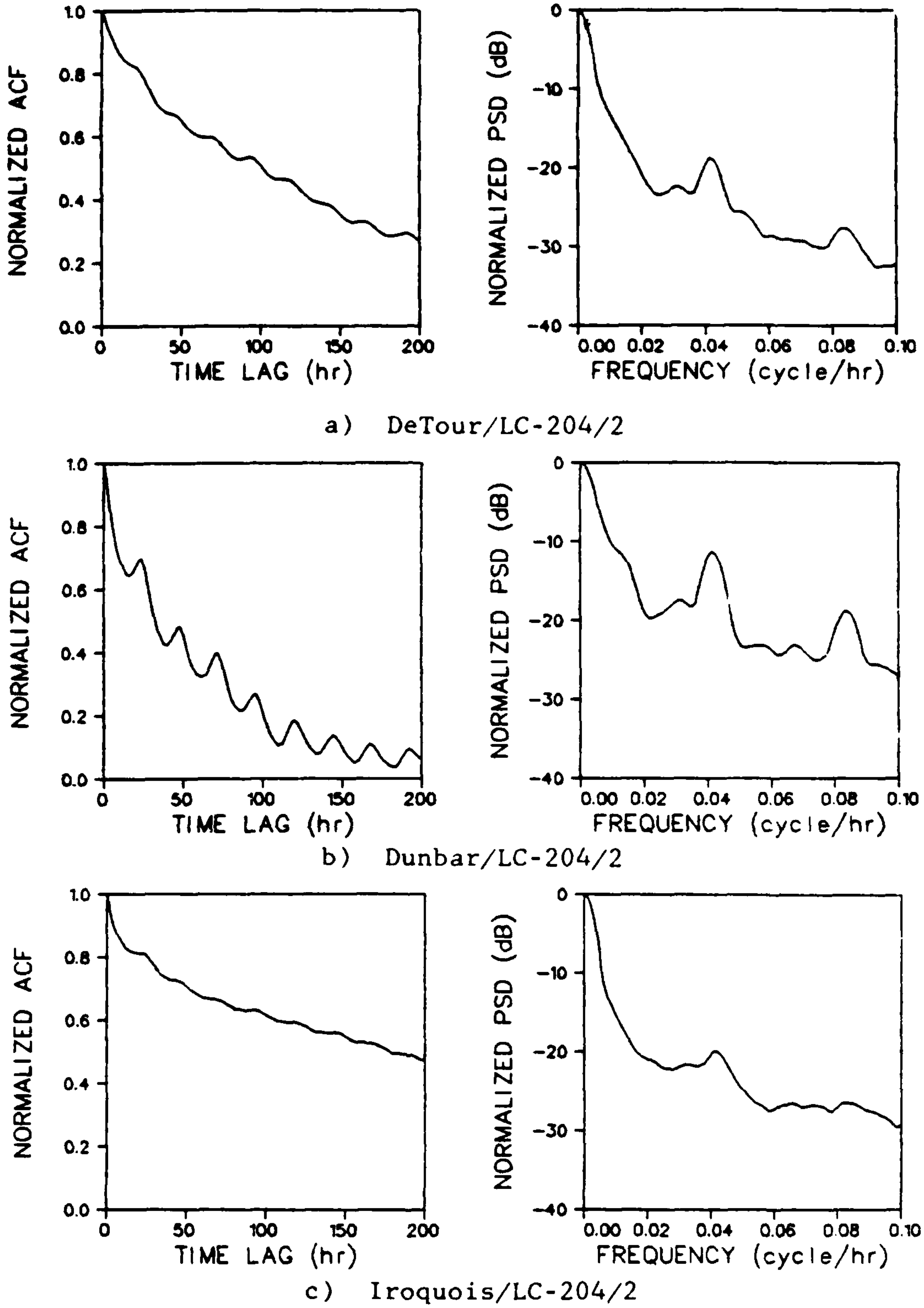
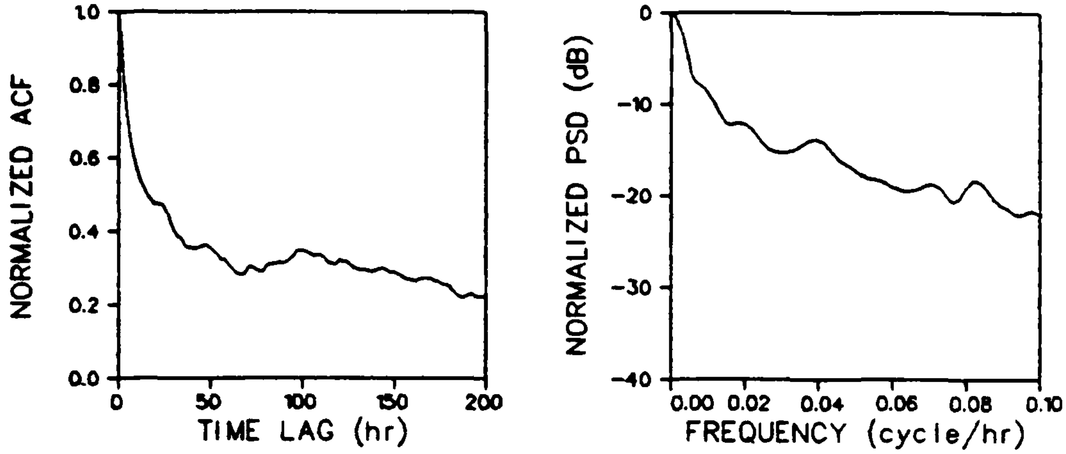
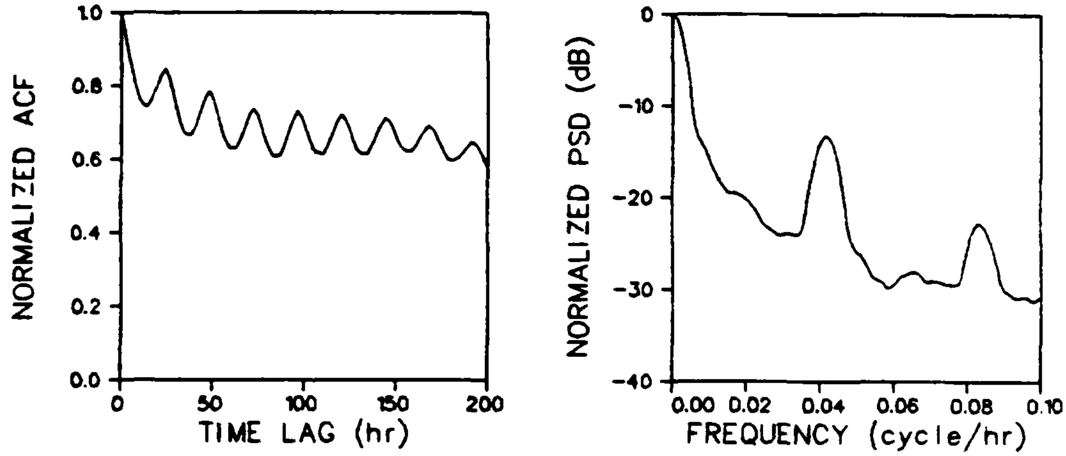


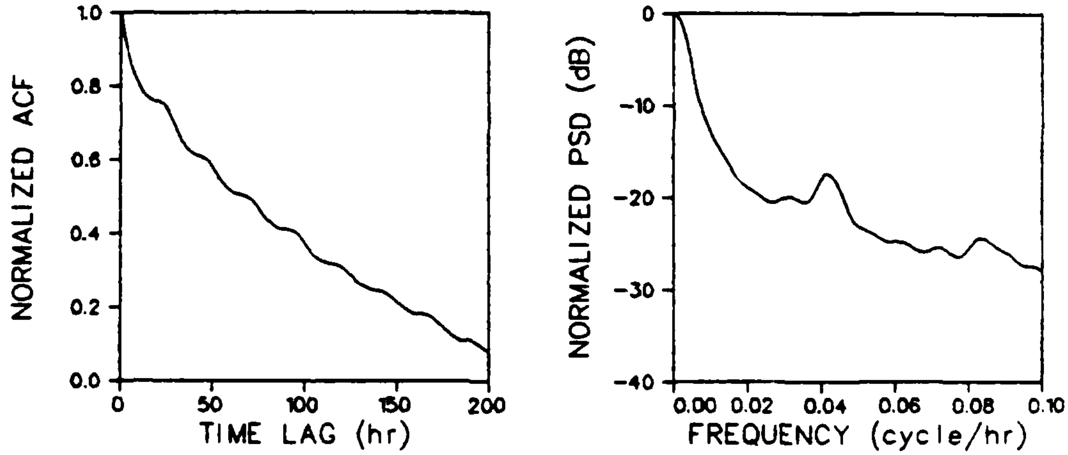
Figure 2-10 Autocorrelation Functions and Power Spectral Densities For Mini-Chain TDY - From Reference 10



a) DeTour/LC-204/2



b) Dunbar/LC-204/2



c) Iroquois/LC-204/2

Figure 2-11 Autocorrelation Functions and Power Spectral Densities For Mini-Chain TDZ - From Reference 10

In examining the plots, we concentrate on the frequency domain representations. We see all the plots show the most significant portion of the variation is in the "low frequency" part of the spectrum - the part contributed by components at, say, 0.01 cycles/hr or less. This frequency corresponds to a period of 4 days or more. This is the long term component of the variation, the part which the discussion on page 2-18 indicated has been long known by chain operators to be the most significant. The component which is particularly noticeable in the Dunbar data, but also discernible in the data from the other sites, is the one with a frequency of about 0.04 cycles/hr. This, with a period of 24 hours, is the diurnal component. The existence of "harmonics" of this component (only the second harmonic is shown in the plot but others are present) is to be expected if we realize the diurnal variation is not a pure sinewave. Again, the presence of this diurnal component is no surprise to chain operators.

We can take our scrutiny of the plots a bit further by examining the Dunbar TDZ autocorrelation function and imagining a game. Suppose we are asked to guess the TD at any point and can ask any question about the history of the TD up to, say, an hour ago. The plot of figure 2-11 b) indicates we should ask about the TD an hour ago and "feed this right back" as our guess. If the rules are changed so that we cannot ask about anything more recent than 2 hours ago, we should still ask for the most recent data. As the rules continue to be changed in this manner, we soon reach a point at which we should change our strategy. Specifically, note that knowledge of what happened 24 hours ago is much more "relevant" than what happened 12 hours ago. Indeed, Dunbar TDZ data indicates data obtained 48 hours ago is more highly correlated with what's happening now than data from 12 hours ago is. Again, this is a quantification of a Loran-C phenomenon long known to chain operators.

Further scrutiny shows the diurnal variations are most noticeable in the Dunbar data. This is the site closest to the SAM. Diurnal variations are also present in the other data records but these plots show relative effects. The other two sites feature significant seasonal components in the total variation and these obscure the diurnal effects. Again, this confirms a known fact.

One further point is worth mentioning. Notice that the autocorrelation function for Dunbar TDY in figure 2-10 is "sharper" than that for the TDZ data obtained at the same site. Following our line of arguing, this would mean that the TDY data suggests Dunbar is closer to the SAM than the TDZ data does - a seeming contradiction. Actually, as the discussion of the next section will show, this is exactly as expected. The trick in resolving the contradiction is in the peculiar way in which we must measure "nearness to the SAM." For now we will ignore this point and note the plots completely support documented (by virtue of existence in procedures manuals) chain operator experiences. The nice thing about having the plots is that we can now "quantify" some of the intuitive notions of the chain operators as they relate to stability study experiment strategy.

Sampling theory tells us that if we sample at least once a day, we can unambiguously characterize the bulk of the "low frequency" information shown in the plots of figures 2-10 and 2-11. Regarding the component with a period of one day, sampling theory tells us that unless we sample at least twice a day we will encounter problems. Note that sampling twice a day is a necessary, not sufficient, condition for success. To see this, imagine the variation being a perfect sinewave. Now imagine that we sample every twelve hours. Imagine finally that, through a stroke of particularly bad luck, we manage to sample right at the time of sinewave "zero-crossings." In this case, we will, literally, have "completely missed the point" - concluding there is no daily component.

There are at least two ways to avoid this problem. In one case, we obtain "in-phase" and "quadrature" samples, i.e., we sample every 6 hours. This guarantees success and is what was recommended by reference 10 as a general strategy. There is, however, a "cheaper" alternative (assuming cost increases with the number of samples). Specifically, we do not need to say we have no idea about the "phase" of the variations (autocorrelations plots, or the power spectrum - a completely reversible transformation of the same thing - "throw away" all phase information. This is an unfortunate disadvantage of using these classic (i.e., "canned program") analysis techniques). We know that by sampling at about mid-day and mid-night, we will be very close to "catching" the extremes of the TD swings. This is the approach taken at the start of the harbor monitor program.

With this sampling strategy, we claim to be able to obtain reasonable estimates of the TD variation information contained in the frequency band up to, and including, 0.04 cycles/hr. An "eyeball integration" of the spectra provided in figures 2-10 and 2-11 easily supports the claimed "95% information capture."

One final point should be established to explain the goals/strategy of the studies. Notice that we claim to have reasonable a priori knowledge about the "shape" of the autocorrelation/spectrum plots. We expect the "LF" component to be the major part. The relative strength of the diurnal component is determined by how close we are to the SAM. The key ingredient is missing from these plots since both are normalized. What we really want to know is the size of the variations in an absolute sense. More particularly, we are primarily concerned about the absolute size of the predominent component (i.e., the LF component). Once we know this - for all usable TD's at any given point, we can make a straightforward transformation to determine the absolute size of the positional variations.

This is the point we cannot overemphasize. Until these studies were begun, the absolute size of the year-round position variations throughout the CONUS HHE areas was not known. This has got to be step 1 in the Harbor Monitor program. We may need to obtain considerably more data to determine, for example, how good Differential Loran-C can be in a particular location. This latter determination, however, is about "step 4." We fully expect to complete step 1 and have found we need go no further (because it's good enough) in over half the locations examined. In several other locations (e.g., Galveston), we have always expected to find that even "full Differential Loran-C" will not do the trick. Thus, in most cases, step 4 is a "don't care." Shame on us if we botch step 1 because of preoccupation with step 4. This line of thinking has been the hallmark of our strategy since the beginning of this project. We recognized that if we could obtain a CONUS-wide Loran-C data base - of almost any reasonable quality - we would be making a significant contribution. Anything above that would be "gravy" - and worth pursuing only when such action posed absolutely no threat to the basic mission.

A re-examination of the installation schedule of Table 2-1 indicates we started collecting high-density data at Bristol. This site was installed in support of a short-range aid to navigation "performance study." Carry-on Loran-C equipment was being used by contractor personnel to measure how well Narragansett Bay Pilots were able to perform with various buoy configurations. To allow "post mission" application of differential corrections, the Bristol site type D set is operated in the "high density mode" - obtaining 15 minute samples throughout the day. This was the type D set high density mode prototype installation.

We should emphasize that no such modifications to the basic strategy of the experiment were allowed until mid-1982 when, after considerable "blood, sweat, and tears," it was determined that "the light at the end of the tunnel was not a train coming the other way." Later in the summer of 1982, as also indicated in Table 2-1, high density data collection was begun in the St. Lawrence Seaway. Notice, however, that the west coast sites installed a month earlier still featured the low density strategy. There is an underlying principle here which is worth elaborating upon.

We still feel the low density data collection approach, in general, represents the most cost effective utilization of funds. In the case of the St. Lawrence Seaway, the low density analysis, as reported in reference 13, had been completed. The analysis had shown that existing Loran-C coverage was inadequate. Moreover, it had shown that even the application of real-time Differential Loran-C would be inadequate. The only Loran-C solution (to an assumed set of requirements) that could be identified involved the installation of another Loran-C transmitting station, the installation of another Loran-C chain monitor site, and the installation of a network of additional monitor stations to allow full Differential Loran-C. This is an expensive solution and, thus, the conclusion had enormous importance. Recalling the cost/benefit question presented in Section 1 as DOT's HHE system implemetation policy, the St. Lawrence Seaway Development Corporation was in a position wherein it simply had to provide the additional funds required for a 1-year high density data collection effort. The question of "what would the last few percent of information say?" had to be asked. When viewed in this light, this can be seen to be the type of approach that may well prove necessary in any important waterway in which Stability Study results are "borderline."

We should also mention two recent developments not reflected in the comments of Table 2-1. We recently switched - temporarily - to high density data collection in support of previously mentioned Trackline Surveys in Tampa Bay (St. Peterburg) and Charleston. Again, however, as in the previous two cases (Bristol/St. Lawrence), we have developed this capability and expend the resources to use it in special cases. Once the special "justification" is over, however, we return to the much more cost effective low density methods - without concern that anything important is being sacrificed.

Having outlined the goals and strategy of the data collection efforts, we should turn to a discussion of the model of Loran-C TD variations which forms the heart of our analysis.

2.5 The Loran-C Stability Study Model/Analysis Technique

The Loran-C time difference variation model we use has been discussed many times in the Loran-C literature. It is used in references 3 and 10 and reference 13 devotes a full Appendix to it. Reference 14 provides an alternate presentation of the same concepts. With all of this background, we should not need an elaborate discussion of the model. We should however, present the essential concepts.

The basic quantity featured in the model is the so-called "Double Range Difference" and a consideration of some basic loran equations illustrates the basis of the name. The Loran-C time difference at any point can be computed as:

$$TD_P = ED + R_{S-P}/v_{S-P} - R_{M-P}/v_{M-P} \qquad (2\text{-}1)$$

where

R_{S-P} is the distance from the secondary station to the point

R_{M-P} is the distance from the master station to the point

v_{S-P} is the speed of the signal along the path from the secondary station to the point

v_{M-P} is the speed of the signal along the path from the master station to the point

ED is the Loran-C pair "emission delay." This is the difference in transmission times between the master and secondary signals.

The vital concept to understand is that ED is not a constant function of time. This is worth emphasizing since a considerable amount (though not all) of the literature tacitly assumes it is. To see how it varies we re-write equation 2-1 for the specific case of the SAM, i.e., let P = SAM.

$$TD_{SAM} = ED + R_{S-SAM}/v_{S-SAM} - R_{M-SAM}/v_{M-SAM}$$

or, (2-2)

$$ED = TD_{SAM} - R_{S-SAM}/v_{S-SAM} + R_{M-SAM}/v_{M-SAM}$$

In the above two equations there are 6 quantities, 3 of which may be considered constants. R_{S-SAM} and R_{M-SAM} typically do not change. As we have noted, some act as if ED is the other constant. This is not true: the other "constant" in the equations is TD_{SAM} (Chain control practice allows this to change somewhat to avoid "hunting." Such variations, however, are so small as to be considered negligible). Combining equation 2-2 with 2-1, we get

$$TD_P = TD_{SAM} - R_{S-SAM}/v_{S-SAM} + R_{M-SAM}/v_{M-SAM} + R_{S-P}/v_{S-P} - R_{M-P}/v_{M-P} \quad (2-3)$$

Let us now make the first simplifying assumptions: suppose all path velocities are equal. In this case equation 2-3 reduces to

$$TD_P = TD_{SAM} + [R_{S-P} - R_{M-P} - (R_{S-SAM} - R_{M-SAM})]/v \quad (2-4)$$

If we call the difference between two ranges a range difference, the quantity in brackets may be called a "double range difference" (DRD). Since $R_{S-SAM} - R_{M-SAM}$ defines the hyperbola on which the SAM is located and $R_{S-P} - R_{M-P}$ defines the hyperbola on which the point of interest is located, DRD can be seen to be the difference between the hyperbola of the point of interest and that of the SAM. We can simplify equation 2-4 by writing

$$TD_P = TD_{SAM} + DRD_P/v$$

In considering the above equation, we note that both TD_{SAM} and DRD_P are constant functions of time. Thus, we have

$$dTD_P/dt = DRD_P \, d(1/v)/dt$$

$$= - DRD_P \, (dv/dt)/v^2$$

or,

$$dTD_P = - DRD_P \, dv/v^2$$

The changes in v are extremely small with respect to v itself so we can approximate $-v^2$ with a constant in the above equation which then becomes

$$dTD_P = k \, DRD_P \, dv \quad (2-5)$$

In the traditional use that has evolved over the years, we have tried to simplify things by dropping the k from equation 2-5. This is awkward, however, since the left side of the equation clearly has units of time whereas DRD_p dv has units of "distance squared per time." Thus, in simplifying, we switch to the quantity

$$dTD = k\ dv$$

so that equation 2-5 becomes

$$dTD_p = DRD_p\ dTD. \qquad (2\text{-}6)$$

Recall that the DRD term appeared when we proceeded from equation 2-3 to equation 2-4, i.e., only after we assumed all velocities were equal. Thus, at least in the most basic form, this DRD explanation is valid only as a so-called "homogeneous" propagation model. A key feature of the Stability Studies is the approach we have used to extend the same method to the non-homogeneous case. For now, however, let us skip this technicality and assume the homogeneity assumption is applicable.

[Before proceeding with the discussions we can interject a comment relating the material just presented to a topic discussed in Section 2.4. Recall we claimed the "sharpness" of the Dunbar autocorrelation function for the Mini-Chain TDY data record implied that Dunbar was close to the SAM. Recall also, however, the TDZ autocorrelation function for the same site, with the same SAM, was not nearly as sharp - a seeming contradiction. We hinted the "trick" was in how to compute "closeness." We can see now that this must be measured in a DRD sense. As indicated in figure 3.5-2 of reference 10, Dunbar and the SAM were, essentially, on the same TDY hyperbola. Hence, essentially no DRD, no expected seasonal component to the variations, and a sharp autocorrelation function. Figure 3.5-3 of reference 10, however, indicates the straight line passing from Dunbar to the SAM is nearly perpendicular to the TDZ hyperbolas. Hence, a larger DRD, a noticeable seasonal component, and less "sharpness" in the autocorrelation function.]

When we consider the variations in Loran-C observations, we know there is more to the variations than just what is reflected in equation 2-6. Some of these are worth singling out in the model while others, too difficult to nail down, are simply lumped into a catch-all "noise" term. One of the terms we can single out has already been mentioned: the slight amount of error which the SAM control process does not remove. Via type A Harbor Monitor set observations, we can measure this term. More important, however, before conducting our analyses, we can subtract this data record from all the other data records, thus simulating "perfect control" and removing this known error source from the total variations we wish to examine further.

As descibed in references 3, 13, and 14, there is another well-known error source which has been found significant enough to include in the model - the so-called "common error" term. The model is used in recognition of the fact that all Internav 404 receivers (used in type C and type D sets) can be considered essentially equal, but must be considered different from the chain control Austron 5000 sets. Thus, so the model says, even if we simulate perfect (Austron 5000) chain control, there will be a residual error which all the Internav receivers see - regardless of dTD considerations. All other effects are considered "unmodelable" and are lumped in a general "error" term.

With this background established, we can present the model. We construct time series data records consisting of observations of TD variations - for several sites per baseline. We represent the observations with the notation, $\underline{z}(n)$ (a vector, time series version of the "dTD_P on the left side of equation 2-6), where

$$\underline{z}(n) = (z_1(n)\ z_2(n)\ z_3(n)\ \ldots\ )^T$$

We wish to model the observations as follows:

$$\underline{z}(n) = \underline{A} \begin{bmatrix} dTD(n) \\ \underline{C}(n) \end{bmatrix} + \underline{e}(n) \tag{2-7}$$

The elements of the $\underline{A}$-matrix which operate upon the dTD(n) term will represent the appropriate double range difference. The dTD(n) term is a time series version of the dTD of equation 2-6 and will have units of usec/km. The $\underline{C}(n)$-vector sequence represents "common error" terms - reflecting our expectation that the harbor monitor sets see the world differently than the Austron 5000 does. The $\underline{e}(n)$-vector sequence represents the model errors, i.e., the remaining TD variation terms we do not attempt to include in the model.

The model can be applied in several forms. One simple way is to apply it to a single baseline. In this case, the $\underline{C}(n)$-vector sequence becomes a scalar sequence and the model is written:

$$\underline{z}(n) = \underline{A} \begin{bmatrix} dTD(n) \\ C(n) \end{bmatrix} + \underline{e}(n)$$

In this single baseline case, $z_1(n)$ is the data record from site 1, $z_2(n)$ is the data record from site 2, etc. C(n) represents the common error sequence for the baseline. $e_1(n)$ is the error in the model fit to the data of site 1, e_2 for site 2, etc, and,

$$\underline{A} = \begin{bmatrix} a_1 & 1 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ a_N & 1 \end{bmatrix}$$

where a_i is the double double range difference for site i.

If we wish to apply the model to several TD's simultanteously (e.g., TD_X, TD_Y, and TD_Z), we let $z_1(n)$ be the TD_X data record for site 1, $z_2(n)$ be the TD_Y data record for site 1, $z_3(n)$ be the TD_Z data record for site 1, $z_4(n)$ be the TD_X data record for site 2, etc. In this case the $\underline{C}$-vector sequence is:

$$\underline{C}(n) = (C_X(n)\ C_Y(n)\ C_Z(n))^T$$

and

$$\underline{A} = \begin{bmatrix} a_{x1} & 1 & 0 & 0 \\ a_{y1} & 0 & 1 & 0 \\ a_{z1} & 0 & 0 & 1 \\ a_{x2} & 1 & 0 & 0 \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ a_{zN} & 0 & 0 & 1 \end{bmatrix}$$

Notice that we imply there is a different common error term for each of the baseline signals. This is a defendable model of what takes place as discussed in the next section. Notice also that if we use the single baseline model and apply it to several baselines separately, we will obtain different results than those obtained with the combined-TD model. Specifically, in the first case we obtain a different dTD(n) sequence each time we run the model whereas in the latter case we say there is only one dTD. This second case is what we are forced to use if we claim changes in propagation speeds are uniform. In general applications under the harbor monitor program, with widely spaced monitors, we can expect to encounter difficulty with the uniform approach. Thus, we acknowledge that both approaches exist and simply note that once the model is applied, the "trick" is to generate some clever argument to interpret the results. Note finally, that the above A-matrix implies all data comes from type C or D Harbor Monitor sets - i.e., from Internav 404 receivers. In some cases we have "non-SAM" Austron 5000 data - i.e., data from Alpha-2 chain control sites. We expect these sites to suffer from "DRD effects" but, if the basis for the model is correct, assume there will be no common term. In such a case we modify the A matrix by replacing appropriate "1's" with "0's" in the last three columns.

As noted (and used to good advantage) in reference 14, we can use the model both ways: on a baseline-by-baseline basis and with all baseline data combined. A comparison of the two approaches can indicate anomalous behavior in a particular propagation path and, perhaps, steer us towards resolution of a problem.

To complete this discussion, we should note that the goal of the model analysis is to obtain an estimate of dTD(n) and $\underline{C}(n)$. We choose the minimum mean square estimate (MMSE) approach which yields:

$$\widehat{\begin{bmatrix} dTD(n) \\ \underline{C}(n) \end{bmatrix}} = (\underline{A}^T\underline{A})^{-1}\underline{A}^T \underline{z}(n)$$

This is a classical result which need not be derived here. A similar derivation is carried out in Appendix A of reference 14.

Having obtained this estimate, we obtain a measure of the applicability of the model by checking the residual vectors, $\underline{r}$, where

$$\underline{r}(n) = \underline{z}(n) - \underline{A} \widehat{\begin{bmatrix} dTD(n) \\ \underline{C}(n) \end{bmatrix}}$$

If the model has worked well, we should see that the residuals closely approximate a "white noise" sequence. This "whiteness of residuals" figure of merit will be amply illustrated in the analysis sections of this report.

At this point we should return to the matter of how the model can be applied when non-homogeneous propagation speed changes are expected. The first step is to not believe our expectations - i.e., simply run the model and examine the results. If the results say the model works fine, the rest of the analysis is simply comprised of seeking an explanation for this seeming contradiction. Alternatively, if the results show there is room for improvement, we have found success by modifying the DRD's. We do not do this, however, in an arbitrary manner. There is a systematic approach that should be discussed.

The basis of the approach is the recognition of the fundamental simplicity, for both conceptual and implementation purposes, of the model as reflected in the key equations 2-6 and 2-7. We could get good results by modifying the basic form of the model and introducing many more complexities. If possible, however, we prefer to keep things simple so that we never lose a place in the analysis for our intuition. Having stated this most noteworthy goal, we must admit to arriving at it in an evolutionary fashion (with a good deal of serendipity involved).

Once we recognize we are not dealing with homogeneous propagation paths, we are tempted to return to equation 2-3 and begin looking for different estimates for each propagation velocity. We were at this stage in early 1981 while examining available chain data records. Chain equipment includes TOA receivers at each transmitting station. By comparing the received TOA with a local timing trigger, a so-called "pseudo-TD" is obtained. A problem with data from these receivers is the classic problem with TOA measurements. Only one signal passes through the receiver. Thus, if anything is done to disturb the received signal path, a "pseudo-TD" offset occurs. (With a TD receiver, a receiving path change effects both stations - almost identically). Typically, the path change is a result of a receiver failure. Since these are non-critical portions of the system, there are no local spares and a few days pass before a new receiver is installed. Depending on the time of year, this constitutes passage of sufficient time to make precise calibration of receiver differences impossible. Thus, the pseudo-TD's must be viewed with great suspicion.

In spite of this problem, the data records exhibited a clearly discernible pattern which is best exemplified by the discussion of the 9960-X baseline carried out in reference 13. In summary, Sandy Hook, the SAM for that baseline, is nearly on the perpendicular bisector of the baseline. If the path variations were homogeneous, this would have caused essentially equal and opposite variations at each end of the baseline (Seneca, N.Y. is the master, Nantucket, Mass. is the secondary). Instead, we saw large variations in the master data but hardly any in the secondary data. This is what we might have expected had the SAM been very close to the secondary. Examination of the paths involved showed all the applicable paths were completely land paths - in "northern climes" - except for the path from Nantucket to the SAM which was almost all seawater. This suggested a simple modification to the DRD model: in calculating the ranges comprising the DRD, do not count any portion of the paths which pass over seawater.

As presented in reference 13, this caused a remarkable improvement in the "fit" of the model. We must admit the data, not available in electronic form, was not subjected to exhaustive scrutiny. There was, however, uniform agreement among available data sets that this was the "kind of thing to do."

As we were experiencing these findings, we re-examined the literature and found substantial reason to conclude the findings were reasonable. Moreover, we expected this simple modification to the model would be almost universally applicable - at least throughout the eastern portion of the U.S. One suspicion we had, however, was that there might have to be what we dubbed a "Mason-Dixon" effect. Particularly as it regards the effects when sub-freezing temperatures are encountered, the literature led us to believe we would not be able to count southeast U.S. land effects the same as northeast U.S. effects.

In reference 13, we had our first opportunity to report on this modified model. The results were extremely encouraging. We cannot read too much into this, however, since, because of the geography involved in the St. Lawrence Seaway, the difference between the "straight DRD's" and the "modified DRD's" is essentially constant. Combined with the extreme range from the SAM's for the stations being tracked, this made it impossible to fully test the worth of the modification - as elaborated upon in reference 13.

In reference 14, we tried the same approach. In the St. Marys River, there was a good deal of difference between the straight and modified versions of the model - and that difference changed significantly from site to site. Interestingly, as reported in reference 14, results indicated the straight approach was, by far, the better one. The explanation is that the Great Lakes freeze. Thus, we lose the moderating effects of seawater on winter temperature and humidity fluctuations. An exact optimum value could not be pinpointed, but it appears "we should count" freezing fresh water somewhere between about 90% and 115% as much as we count land.

In summary, the model has worked very well thus far. Even with no modifications, it has been found to "explain" a significant percentage of the observed TD variations - for the studies conducted thus far. The data examined in this report will present an opportunity to further examine the need for model modifications. Thus far, they have been straightforward, thus allowing us to maintain model simplicity. As we proceed with further studies, we will expend all reasonable efforts to retain this nice feature.

At this point we have said about *all that* need be said regarding the HHE applications of the Signal Stability Studies. Before proceeding with the analysis, however, we should add some short introductory remarks about applications outside the HHE realm. Although these did not comprise the original reasons for starting the project, the study results, as they apply to these other realms, are of significant importance.

2.6 Additional Uses of the Stability Study Results.

A detailed literature search may establish that reference 15 is not the original source document on the subject of loran stability/accuracy. It cannot be too far from it, however. A set of formulas are presented based on a foundation which prompted the following note.

> "In the experimental L.F. Loran System there was no apparent relationship of σ_x or σ_y to distance from the transmitters. This condition was probably due to the fact that long base-lines were used between the transmitters, and at all receiving locations there was at least one ionospheric path. It could, in that case, be

assumed that the average value of σ throughout the coverage area would be sufficiently acccurate for prediction purposes. The expected distance errors that are given in this report are expressed in terms of a σ which is assumed to be constant throughout the service area. In order to determine the absolute magnitude of the errors, the appropriate value of σ must be determined experimentally for each type of system. If σ is found to vary systematically with distance, the contours of constant accuracy must be modified accordingly; the contour shapes shown later in this report must thus be considered to be a first approximation to the correct shape..." (Our emphasis)

Thus, reference 15 identifies itself as the first approximation, noting we need some experimentation, after which the results it presents can be modified accordingly. Interestingly, in spite of the many significant events which have taken place since reference 15 (look at the date on that baby!), in 1983, Loran-C accuracy diagrams are still produced using the same "first approximation" approach. Standard USCG procedures, for example, assume that the Loran-C time difference readings in New York harbor (i.e., where the SAM is located) have a standard deviation of 0.1 usec. This is the same assumption the procedure makes about the variations in the St. Lawrence Seaway. As the equations of the preceeding section suggest, we expect the results reported herein to show how the actual standard deviation changes throughout the service area. Thus, our results, besides applying to HHE issues, can also constitute a long-awaited "next approximation."

Actually, we could argue there has already been a second attempt at the development of an accuracy contour generating procedure. In reference 18, D. Amos and D. Feldman described "A Systematic Method of Loran-C Accuracy Contour Estimation." A difference between that method and what we will be doing here is that the "Amos model" shows Loran-C accuracy to be totally independent of the location of the SAM. We know that this is not the case but, before we say the Amos method should be discarded, we should point out it does serve a purpose. To establish the point, we should recall, as planning documents do, there are (at least) three general categorizations of navigation system accuracy: absolute, repeatable, and relative. In assessing the absolute accuracy, we must account for all errors associated with tying the measurements to a physical location on earth. Thus, coordinate conversion/charting errors are included.

In assessing repeatable accuracy, we only need to address the ability to return to a location previously visited with the same system. This measure of accuracy, of course, does not depend on relating the spot to any other coordinate system and is ideally addressed by Harbor Monitor data. Relative accuracy relates to the ability of two separate users to rendezvous. Even if the Loran-C grid moves throughout the year (e.g., so that the rendezvous takes place a considerable distance from where the last one did - even though this was not intended), this does not affect relative accuracy. This is the type of accuracy addressed by the Amos method. In short, Amos worried only about what we like to call (e.g., in reference 13 or 14) "short term" or "jitter" error. We also like to try to make the distinction by saying Amos was describing "fix uncertainty" as opposed to position error. A final way of stating the difference is to note that the Amos method says all errors come from received noise - the signal being perfectly stable. In these "signal stability" studies, of course, we try to go beyond that stage.

Indeed, we can go so far as to say we will be attempting the "third approximation" to the accuracy determination (the first was accomplished by reference 15, the second by Amos and Feldman in the mid-70's) and laying the groundwork for understanding why the "fourth approximation" was done incorrectly. By the "fourth approximation," we mean the Coast Guard's recent attempt, through its "Chart Verification" program, to determine and correct charting errors. To see why this was done wrong, realize that, ideally, the absolute accuracy can be made as good as (in some cases, better than) the repeatable accuracy of the system. In order to do this, however, extreme care must be taken and proper account of the temporal variations of the systems must be made. This, unfortunately, was not done.

Now that we have said the chart verification was done incorrectly, for our purposes here, we should say there was a reason for the way it was done. When the "CCZ implementation chains" came on air, charts produced by using existing prediction methods proved totally inadequate. Such large errors were discovered that the verification effort (originally planned several years earlier but cancelled as non-cost-beneficial) was undertaken. In the rush, of course, there was no time to wait for the results reported herein to be known. Thus, the data collection was not accomplished in the best possible manner. For example, the Great Lakes chain chart verification data was taken over several seasons of the year. This caused "spatially related" variations to be mixed with "temporally related" variations. To avoid this problem in any future efforts of this nature, a verification methodology must be developed. The lessons learned in the stability studies can contribute to this development.

There are several other areas of the Loran-C program which can benefit by the lessons being learned in the stability studies. One such area involves the use of Loran-C for precise time transfer: users are just recognizing seasonal TD variations are worse than they suspected. Our results indicate this "newly discovered" problem may have an "even more newly discovered" solution. Wherever possible, we will attempt to address these auxiliary applications of the stability study results as they are encountered.

With the above, somewhat exhaustive background discussion complete, we will begin to examine the N.E.U.S./S.E.U.S. data - beginning up north.

3. Northeast U.S. Chain Harbor Monitor Data Analysis

3.1 Harbor Monitor Data

To begin to focus our attention on the area of interest, we provide a blow-up of figure 2-1, superimposing the essential elements of the N.E.U.S. Loran-C chain 9960. The 9960-W SAM (Alpha-1 control) is at Cape Elizabeth, the 9960-X and -Y SAM is at Sandy Hook, and the 9960-Z SAM is at Plumbrook.

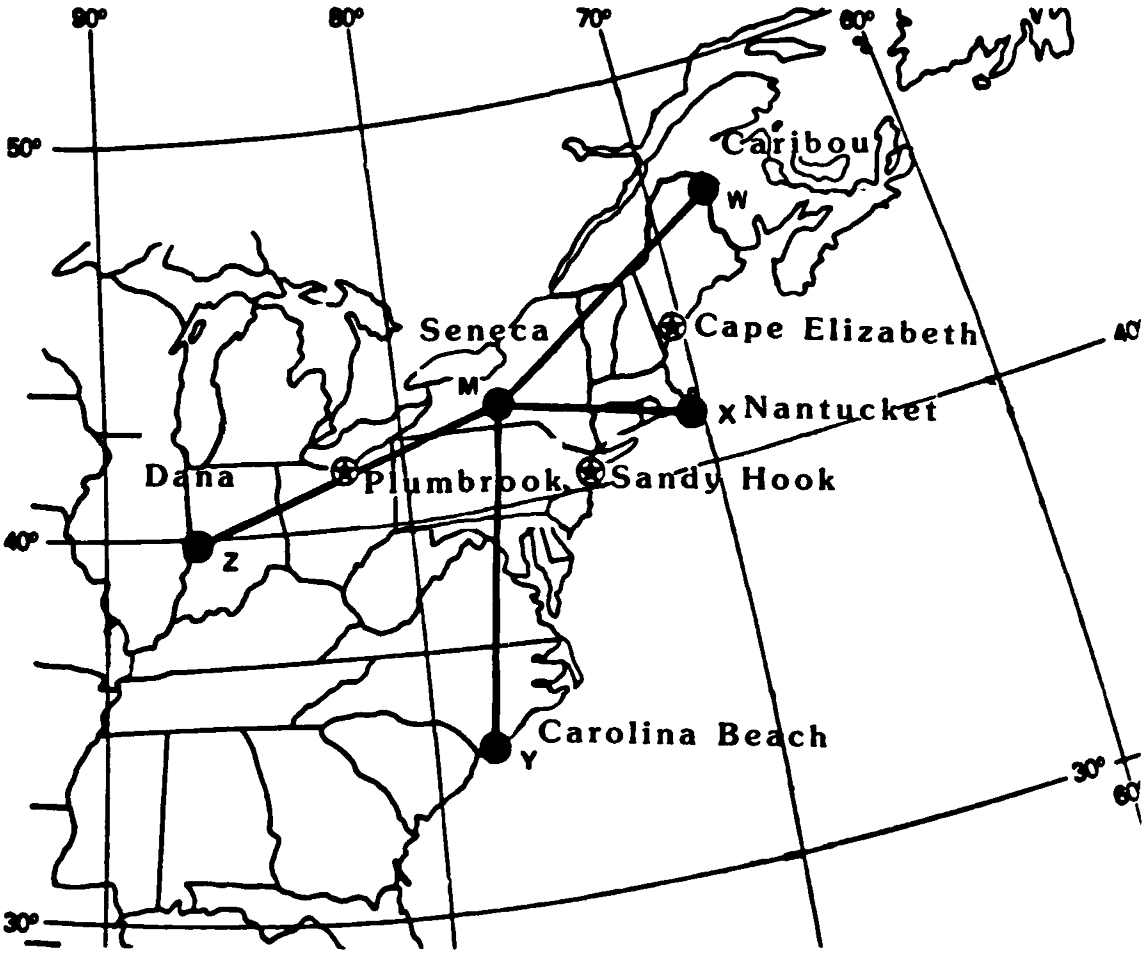


Figure 3-1 Northeast U.S. Loran-C Chain and Harbor Monitor Sites

As indicated in Table 2-1, the Harbor Monitor sites were placed in service at various times throughout the past 2 years. Some sites (e.g., Bass Harbor) were installed too recently to have a data base large enough to be included in the analysis of this section. Some sites do not track all stations of the chain, due to remoteness/SNR limitations. These details determine the size of the data base for each site as summarized in Table 3-1.

Site	Data Base Start Date	N.E.U.S. Stations Tracked	Comments
Yorktown	9/20/81	X, Y, Z	
Lewes	9/21/81	X, Y, Z	
Gloucester (NJ)	10/07/81	X, Y, Z	
Sandy Hook	9/01/80	W, X, Y	A-1 for 9960-X & -Y
Avery Point	5/12/81	W, X, Z	
Bristol	7/09/82	X, Y	Hi- Density Data Site
Nahant	9/25/81	W, X, Y	
Cape Elizabeth	9/01/80	W, X, Y	A-1 for 9960-W
Bass Harbor	10/14/82	W, X	
Massena	11/21/81	W, X	
Cape Vincent	2/02/82	W, X	
Plumbrook	9/01/80	Z	
Riverside	9/01/80	Z	Site Removed 3/01/83
Dunbar	3/01/83	Z	
Sandy Hook	6/07/83	W, X, Y, Z	Type D Site: Phase Mod

Table 3-1 Summary of N.E.U.S. Harbor Monitor Site Data Bases

We impose the requirement that a full year of data be available before we conduct an in-depth analysis of the data record. Thus, we will exclude the Sandy Hook (Type D), Dunbar, Bristol and Bass Harbor data records from the full analysis (note we have long since given up on the ill-fated Pt. Allerton site). This leaves a total of eleven sites. On a baseline by baseline basis, we have: W monitored by 6 sites, X monitored by 9 sites, Y monitored by 6 sites and Z monitored by 6 sites. We have concurrent data from all the sites over the period from 2 February 1982 to 1 March 1983. In the analysis, we will concentrate on the period from 1 March 1982 to 1 March 1983.

Plots of the TD records for each site are provided in Appendix A. We will examine the TD's in greater detail in the next section. At this stage we should make the transformation to positional error, a more important and informative way of presenting the basic results. The plots of Figure 3-2 show the positional errors as a "Radial Error" time series. The same data is also presented in "scatter plot" form.

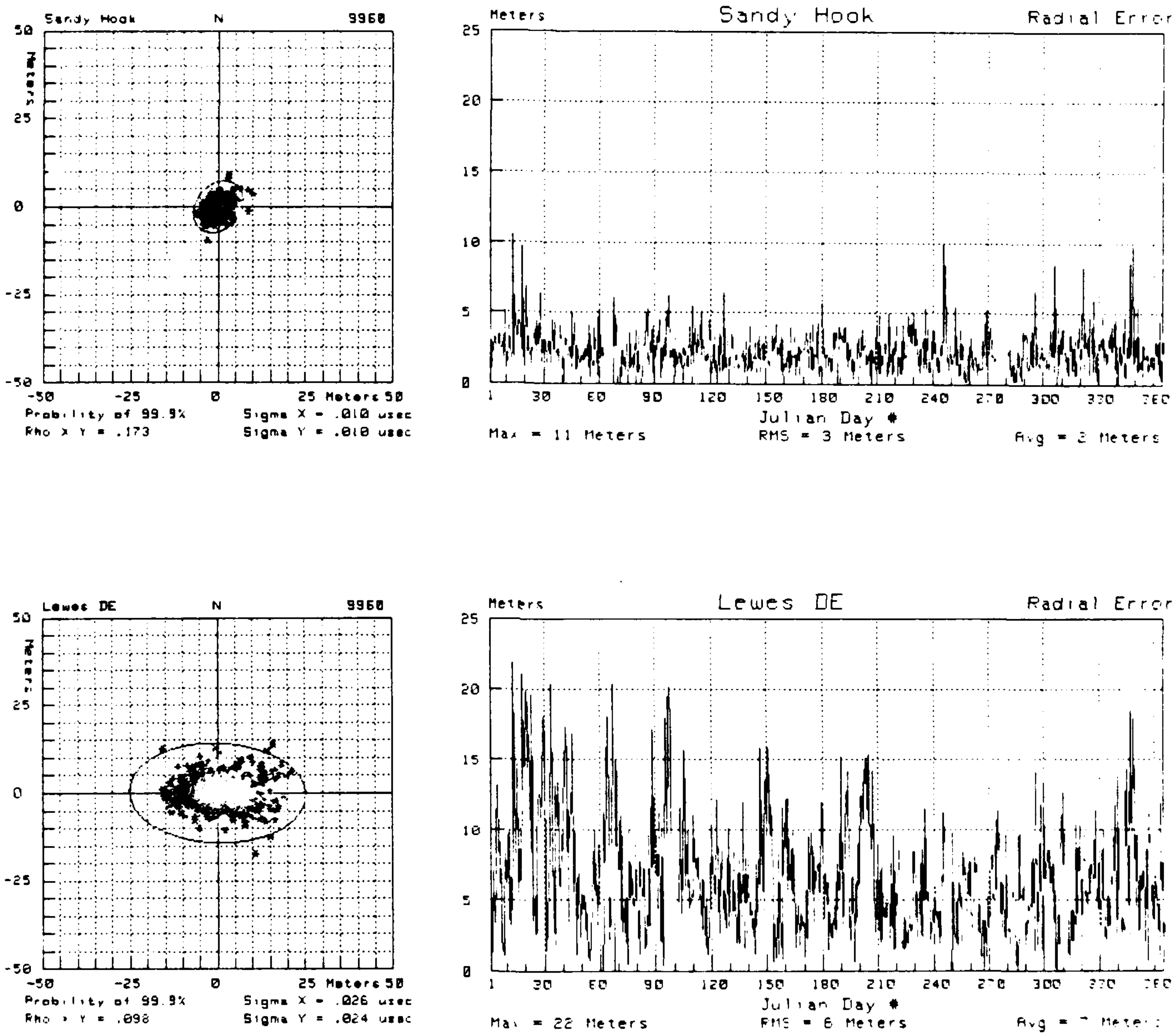


Figure 3-2 N.E.U.S. Harbor Monitor Site Radial Error and Fix Scatter Plots

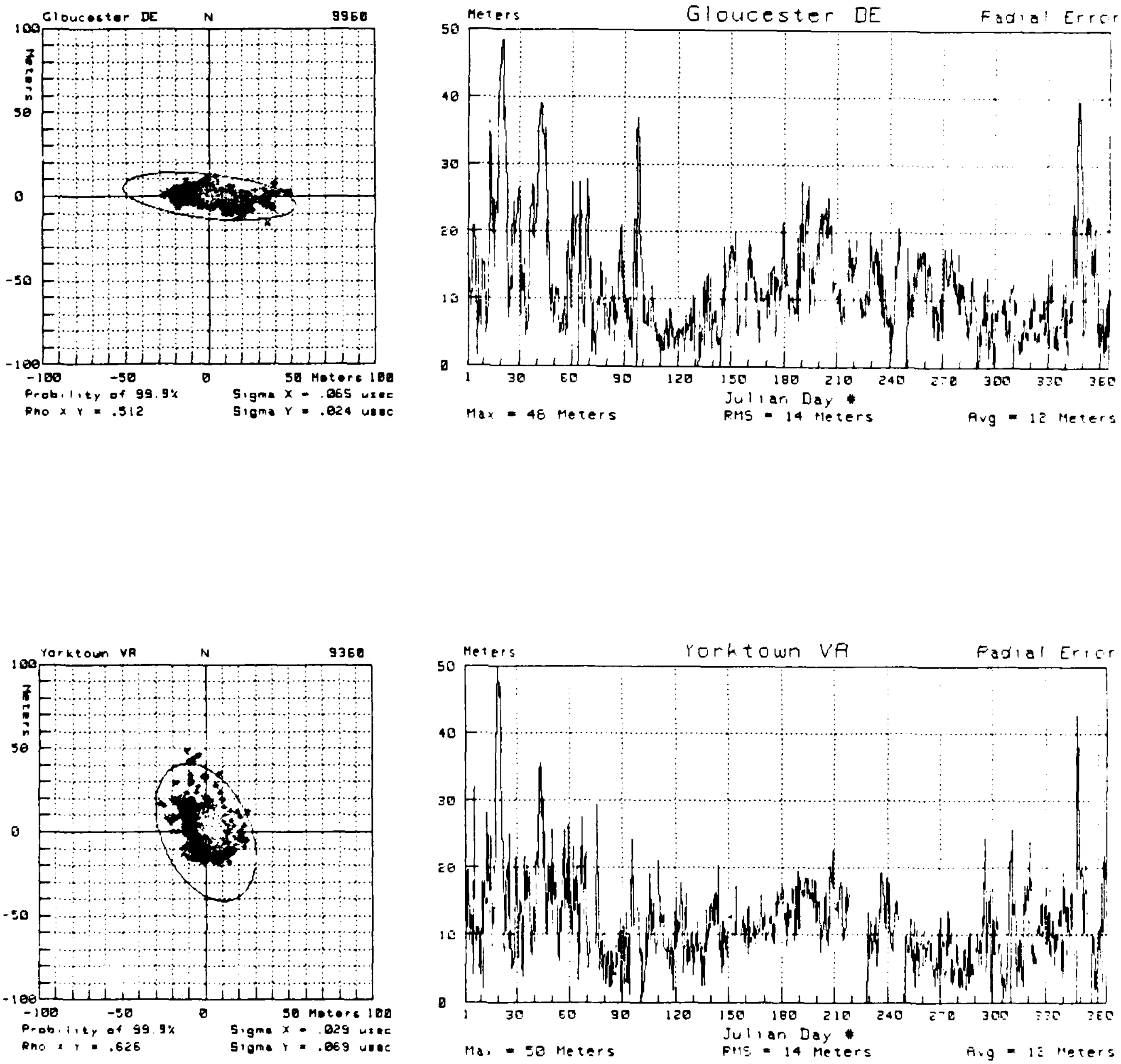


Figure 3-2 N.E.U.S. Harbor Monitor Site Radial Error and Fix Scatter Plots (Con't)

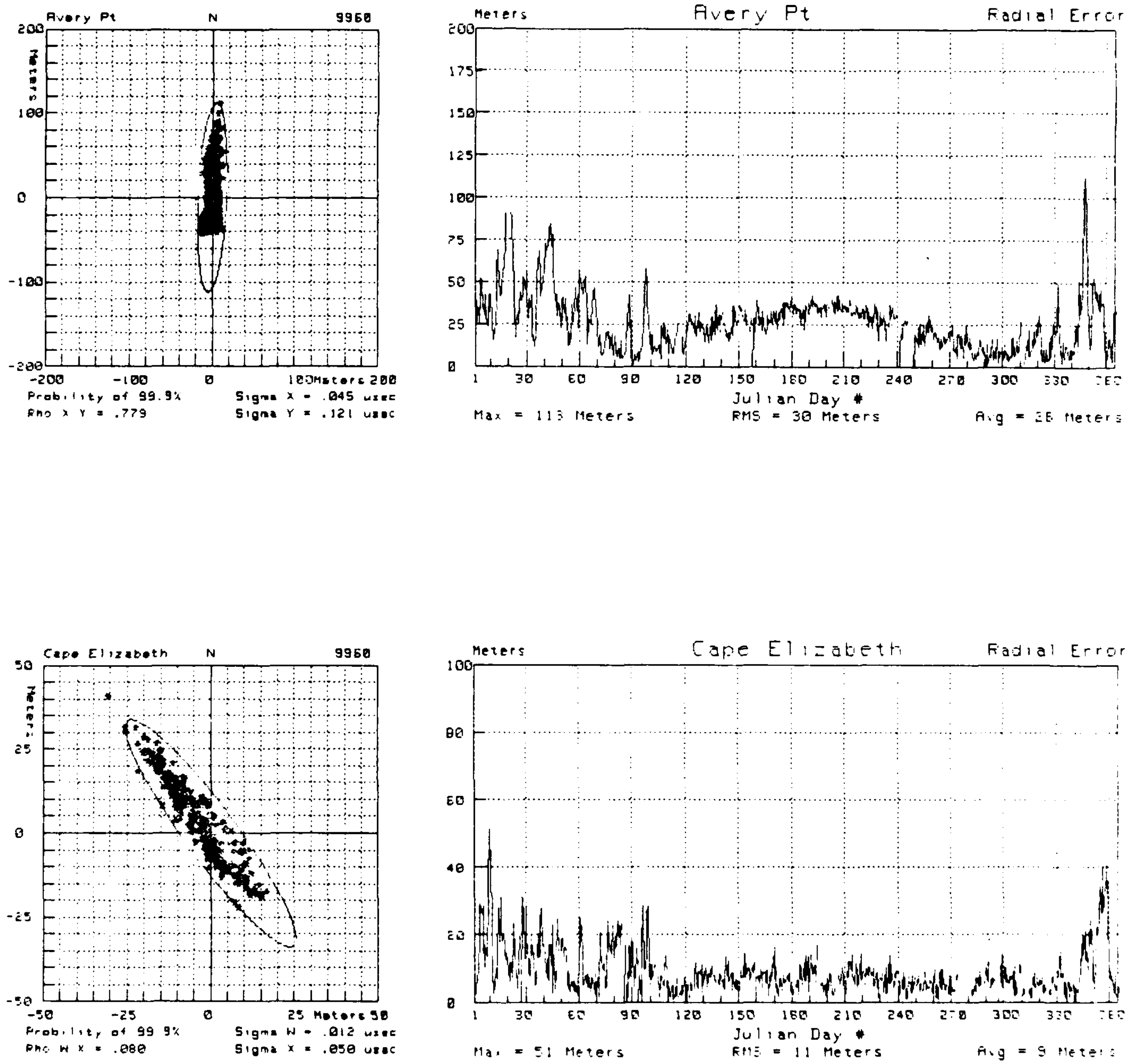
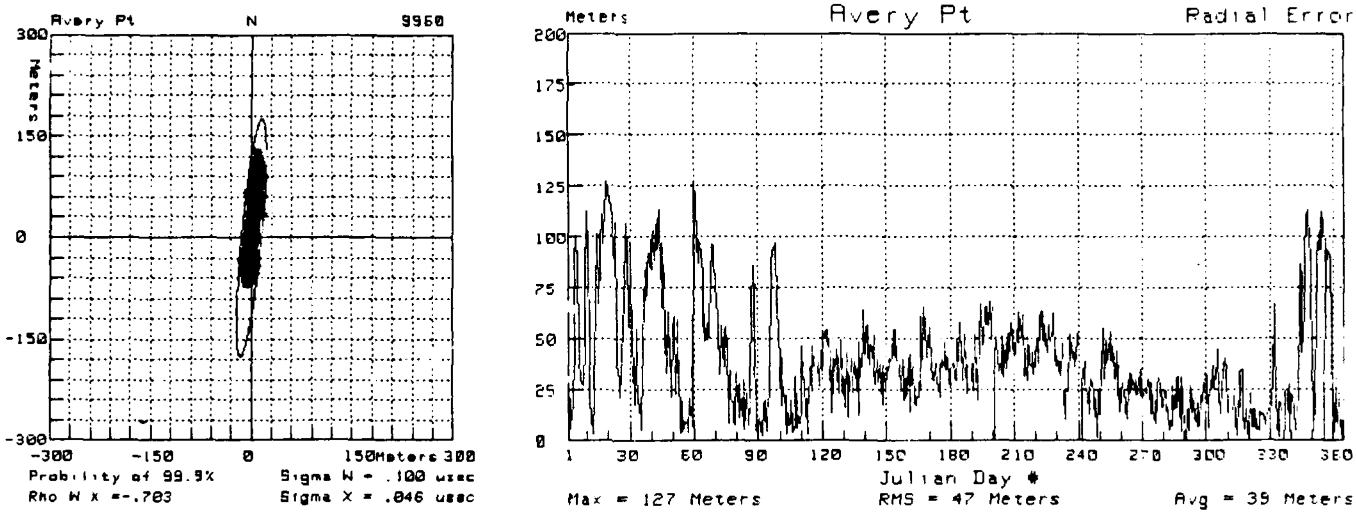


Figure 3-2 N.E.U.S. Harbor Monitor Site Radial Error and Fix Scatter Plots (Con't)



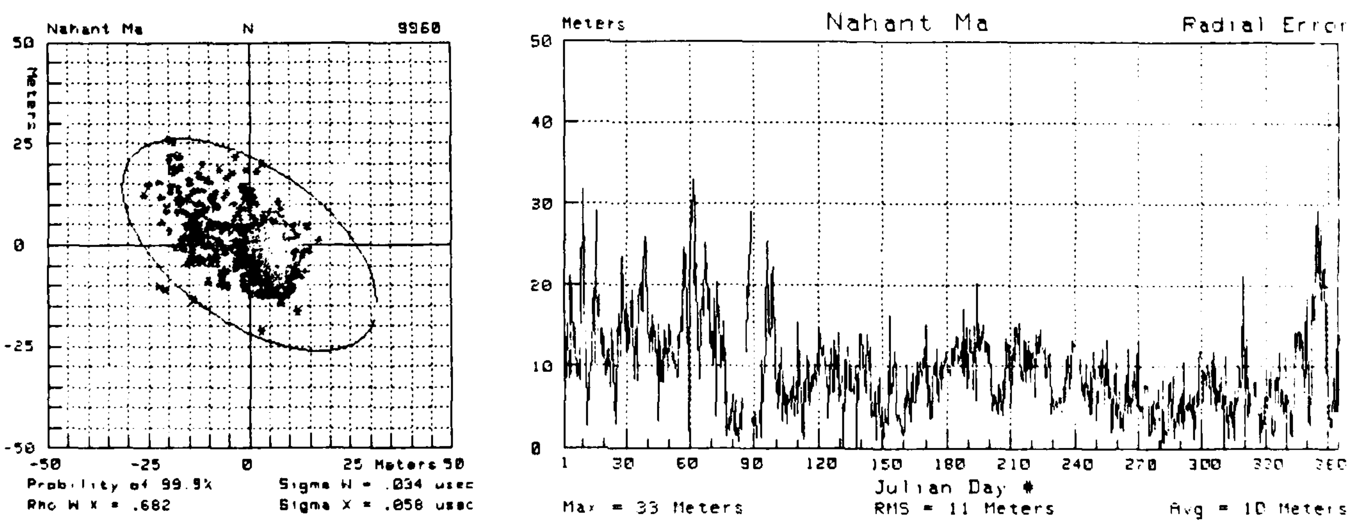


Figure 3-2 N.E.U.S. Harbor Monitor Site Radial Error and Fix Scatter Plots (Con't)

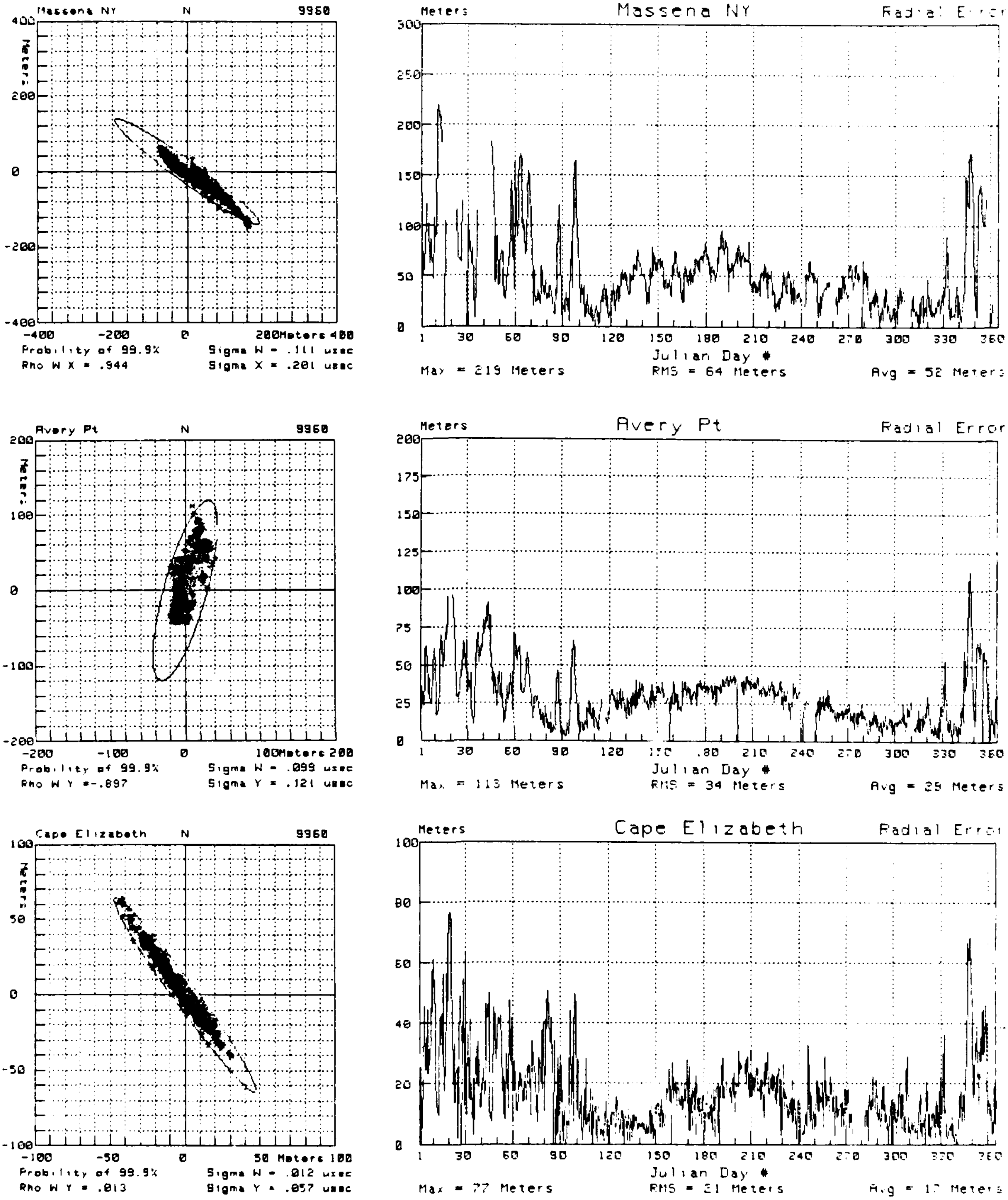


Figure 3-2 N.E.U.S. Harbor Monitor Site Radial Error and Fix Scatter Plots (Con't)

We have developed a certain fondness for the plots presented on the previous pages. The radial error time sequence plots provide an indication of the temporal nature of the variations (effect, not cause). The scatter plot gives an indication of the spatial nature of the effect. Note, radial error is d, as in "drms," a popular measure of position error. We can see how the need to create measures such as this arises as we try to make the next point. We want to discuss the "relative goodness" of the results for each site. To avoid having to say, for example, "the plot for site A looks better than the plot for site B," we try to obtain a less subjective, more quantifiable performance metric. "drms" is one such metric. There are others, however. Notice the ellipse we have superimposed on the scatter plots. If the variations were of a certain nature (Gaussian), we would expect the pattern of dots to "fill in the ellipse" almost perfectly. (Under the Gaussian assumption, 99.9% of the fixes would fall inside the ellipse. Like the quantity drms, the parameters defining the ellipse being plotted are computed from the actual data. Unlike the circle defined by the single statistic drms, however, the ellipse is defined by more than one statistic (i.e., by three).

The point here is that we can make the "quantification" of the information contained in the plots as simple or as difficult as we chose. The more we simplify, however, the more we restrict the conclusions we can make (in general). References 13 and 14 made extensive use of the ellipse parameters and we will return to a discussion of the elliptical nature of the variations in subsequent sections of this report. For now, we will try to concentrate on the single quantity drms. Table 3-2 "ranks" the sites by baseline pair producing the fix and by increasing order of drms.

Site	Triad	drms
Sandy Hook	XY	2.7 meters
Lewes	XY	7.0
Gloucester	XY	12.2
Yorktown	XY	12.7
Avery Point	XY	30.5
Nahant	WX	11.0
Cape Elizabeth	WX	11.5
Avery Point	WX	47.4
Massena	WX	63.1
Cape Elizabeth	WY	13.1
Avery Point	WY	34.2

Table 3-2 Summary of N.E.U.S. Harbor Monitor Site Fix Performance

The data we have presented thus far would go a long way towards achieving all our goals if all we were after was a statement of what fix quality we have at the Harbor Monitor sites. Unfortunately, we want more. We want more than, for example, being able to say what we have at Lewes and Gloucester. Specifically, and as done in references 13 and 14, we need to be able to say what we have at all points along the (shipboard) journey from Lewes to Gloucester (i.e., the entrance from the CCZ to the Philadelphia harbor). Of course, we want to be able to make similar statements about all major harbors and their entrances. With a finite number of data collection sites, therefore, we are faced with what we might call an "interpolation job."

But how does one interpolate? We have a 7-meter system, 1-drms, at Lewes and a 12-meter system, 1-drms, by the time we reach Gloucester. The critical question regards the manner in which the increase has taken place along the way. Does drms "monotonically" increase as one passes from Lewes to Gloucester? Is there any "trick" in determining the way to go from Lewes to Gloucester to achieve this monotonic increase? (e.g., recall the "trick question" of Section 2.4 regarding Dunbar's autocorrelation function and the "answer" of 2.5 which established the trick was to consider DRD's).

To take this line of questioning a bit further, suppose we had no site at Gloucester but wished to "interpolate" between Lewes and Sandy Hook. How would we carry out the interpolation? Notice that the fix performance <u>improves</u> as one moves from Lewes to Sandy Hook. By most methods of reckoning distances, Gloucester seems to be between Sandy Hook and Lewes. Thus why isn't the performance at Gloucester, as indicated by the 1-drms statistic, somewhere between that of Lewes and Sandy Hook?

A hint at possible answers to these questions comes from the introductory remarks of Section 2: perhaps we have to take into account the exact amount of water involved in the Loran-C paths involved.

The point we are trying to establish is that there is a need to examine all of this in a very careful, structured manner. We need to break the total problem down into its constituent parts. As it regards the cause of TD variations, the driving force behind all of this, this means we need a model. As noted in Section 2, we have one. Beyond that, however, we recognize the model, as a practical matter, can never be refined to a perfect state. Thus, we need to develop a method of measuring how well the model performs. As a result of these developments, we will have a method to predict, or, if you prefer, to "interpolate" so that we can state the expected performance throughout the areas we are studying - along with a means of showing the degree of confidence we should have in the predictions.

This is what we hope to achieve with the analyses beginning in the next section. Before we start, however, we should note that the Loran-C performance indicated in Table 3-2 is encouraging. Loran-C is advertised as a 1/4-nm accuracy (2-drms) system with repeatable accuracy "considerably better" in most places. At least along the N.E.U.S. coast, we seemed to have confirmed that. Indeed, our results indicate we have repeatable accuracies considerably better than 1/4-nm, 2-drms, "almost everywhere."

Let us try to be a little more specific.

3.2 Application of Model to 9960-X Data Records.

9960-X is the baseline for which we have the largest amount of data. It is also a baseline which has an easy-to-illustrate combination of land-paths/water-paths. Let us then use an analysis of this baseline as a way of introducing the analysis concepts. We can then proceed to more exhaustive investigations.

We begin by packing the 9960-X TD data records (plotted in Appendix A) into the $\underline{z}(n)$ vector sequence as described in Section 2.5. As also described, we subtract the SAM (Sandy Hook) data record from all sequences to emulate perfect control (or, viewed differently, to remove this known error source). Using the MMSE estimation approach, we obtain the estimated dTD(n) and C(n) sequences:

$$\widehat{\begin{bmatrix} dTD(n) \\ C(n) \end{bmatrix}} = (\underline{A}^T\underline{A})^{-1}\underline{A}^T\,\underline{z}(n)$$

Next, we compute the estimation process residuals. These represent, for each site, how much of the total variation the model failed to explain. We carry out this whole process, first, using the "straight DRD's," i.e., we assume a perfectly homogeneous propagation process. The results of the estimation process are shown in figures 3-3 and 3-4. Figure 3-3 contains the estimate of the model components, dTD(n) and C(n), and Figure 3-4 contains the residual sequence, r(n) for each site.

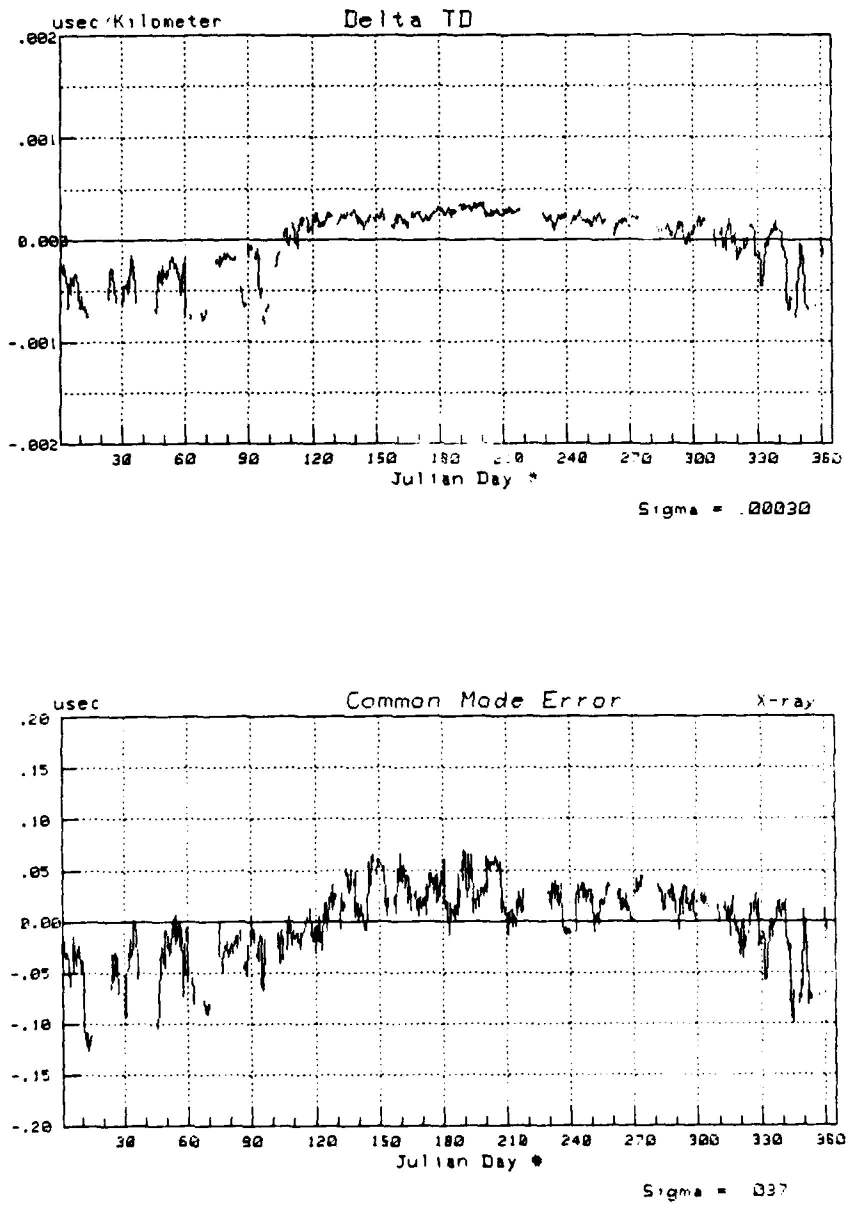


Figure 3-3 Straight DRD Model MMSE Estimates, 9960-X

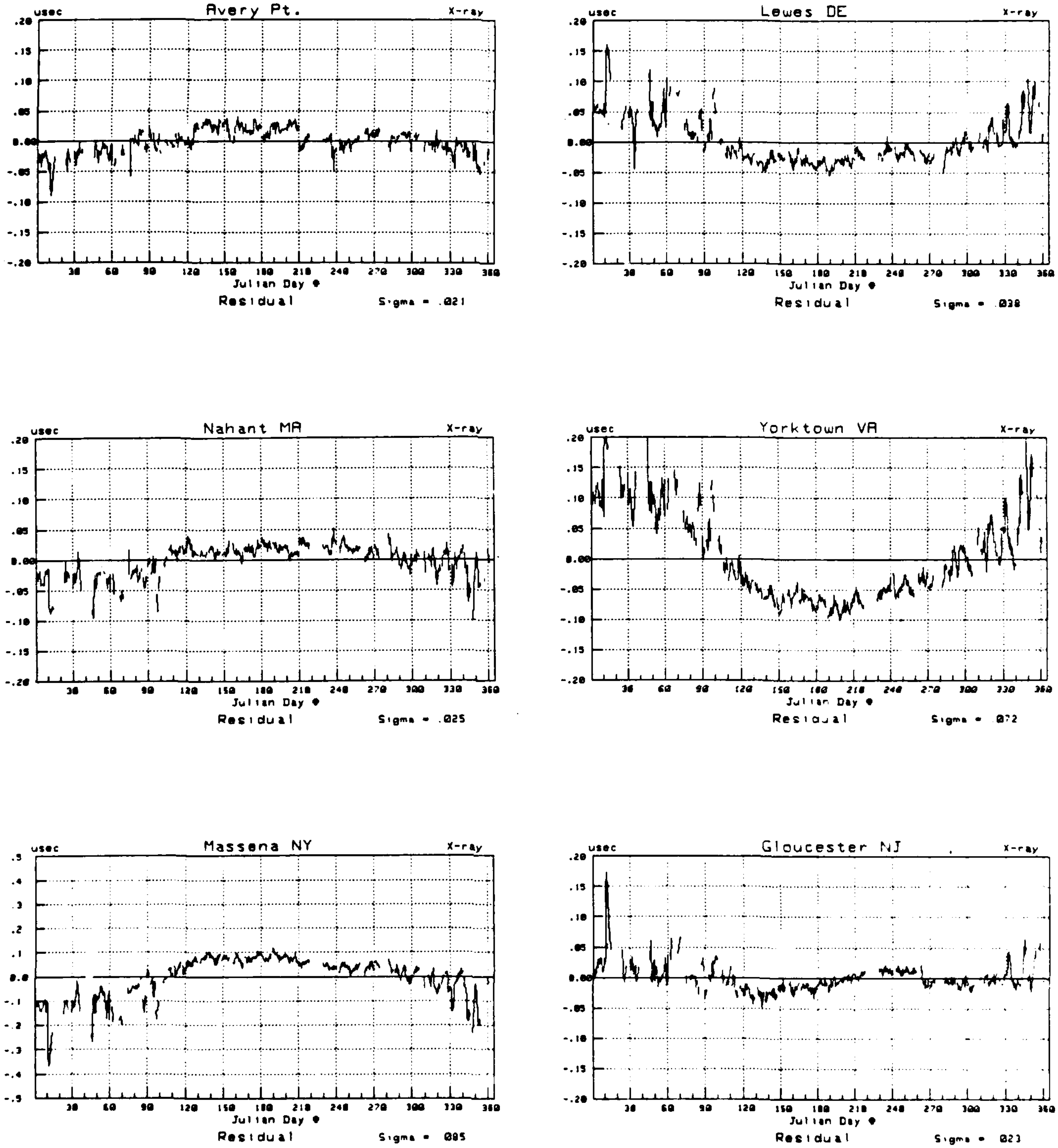


Figure 3-4 Straight DRD Model MMSE Estimate Residuals - 9960-X

After awhile one becomes practiced at "scoring" the estimation process by making a visual inspection of the residuals plot. In this case the score is very low: there is far too much structure (i.e., "non-whiteness") in the residuals. Closer examination shows the structure present in the residuals, in many cases, resembles the dTD sequence. The problem is that too much of the dTD trend has been removed in some cases, too little in some others. This is the finding that suggested our approach to model refinements: the basic model architecture is fine, we simply need a better way to compute the DRD's.

Of course, we have mentioned all of this in Section 2.5, along with the statement that the "seawater" modification seemed to make substantial improvements. We will examine that matter but, first, ought to establish a more objective metric for assessing "goodness of fit." We suggest a good figure of merit is an average, in a "root-sum-square sense," of the standard deviation of the residual sequences. We can see an application of the process by examining Table 3-3.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Percent Reduction
Lewes	22 nsec	38 nsec	- 73 %
Yorktown	26	72	- 177%
Gloucester	54	23	57 %
Avery Point	41	21	49 %
Nahant	53	25	53 %
Massena	196	85	57 %
RMS Standard Deviation	88	51	43 %

Table 3-3 Tabulation of Straight DRD Model Estimation Results - 9960-X

In the table we imply that the "zeroth-order" model says there is no explanation for any of the variations. Thus, the original data sequences themselves are the "zeroth order residuals." After the application of the model in its simplest form, we have a different set of residuals. The decrease in the "size" of the residuals is the model performance measure we seek.

One of the things the table clearly illustrates in the "non-homogeniety" of the results: in some cases the residuals have decreased, as hoped, whereas in some others, they have actually increased. In a global sense however, as measured by the "rms" reduction, the straight DRD model has made an improvement over simply saying "here are the results, we see no pattern."

At this point we are ready to make the advertised correction to the DRD calculations. In calculating ranges, we do not count any seawater paths. This results in a change to the A-matrix. Carrying out the MMSE estimation calculations under these circumstances, we obtain the results indicated in figure 3-5 and 3-6.

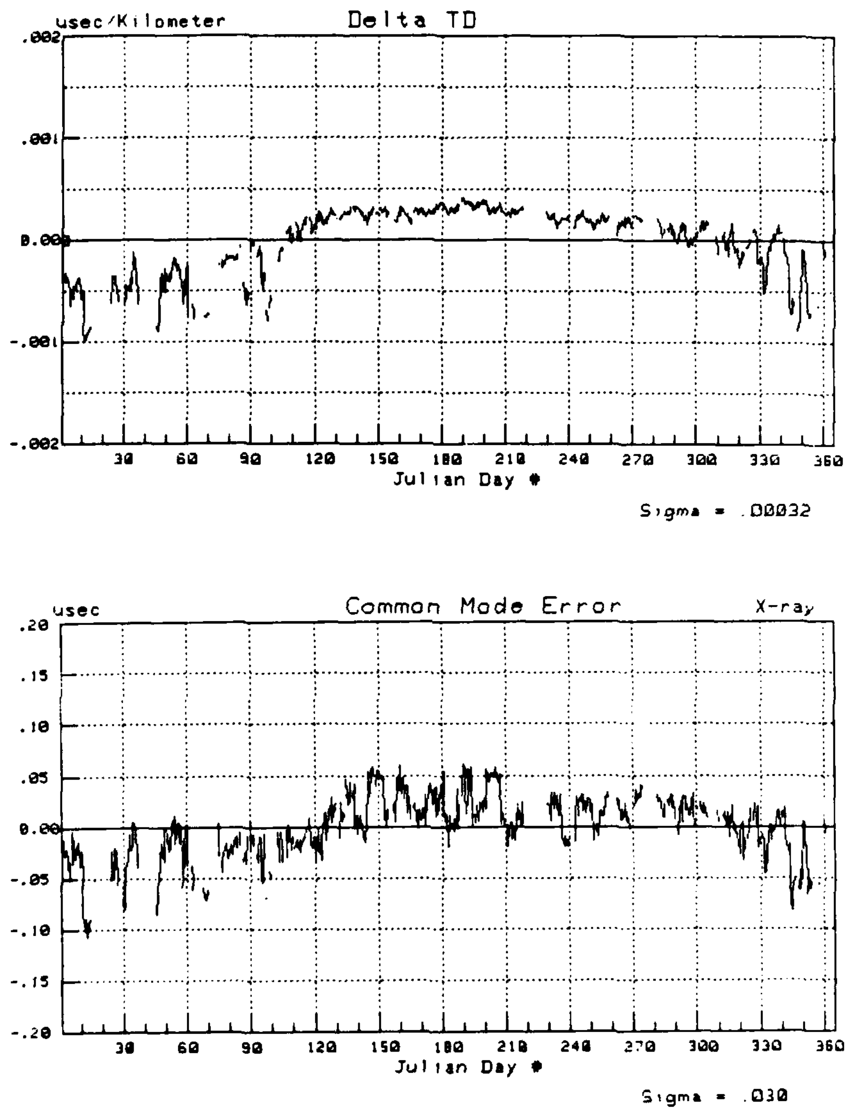


Figure 3-5 MOD 1 DRD Model MMSE Estimates - 9960-X

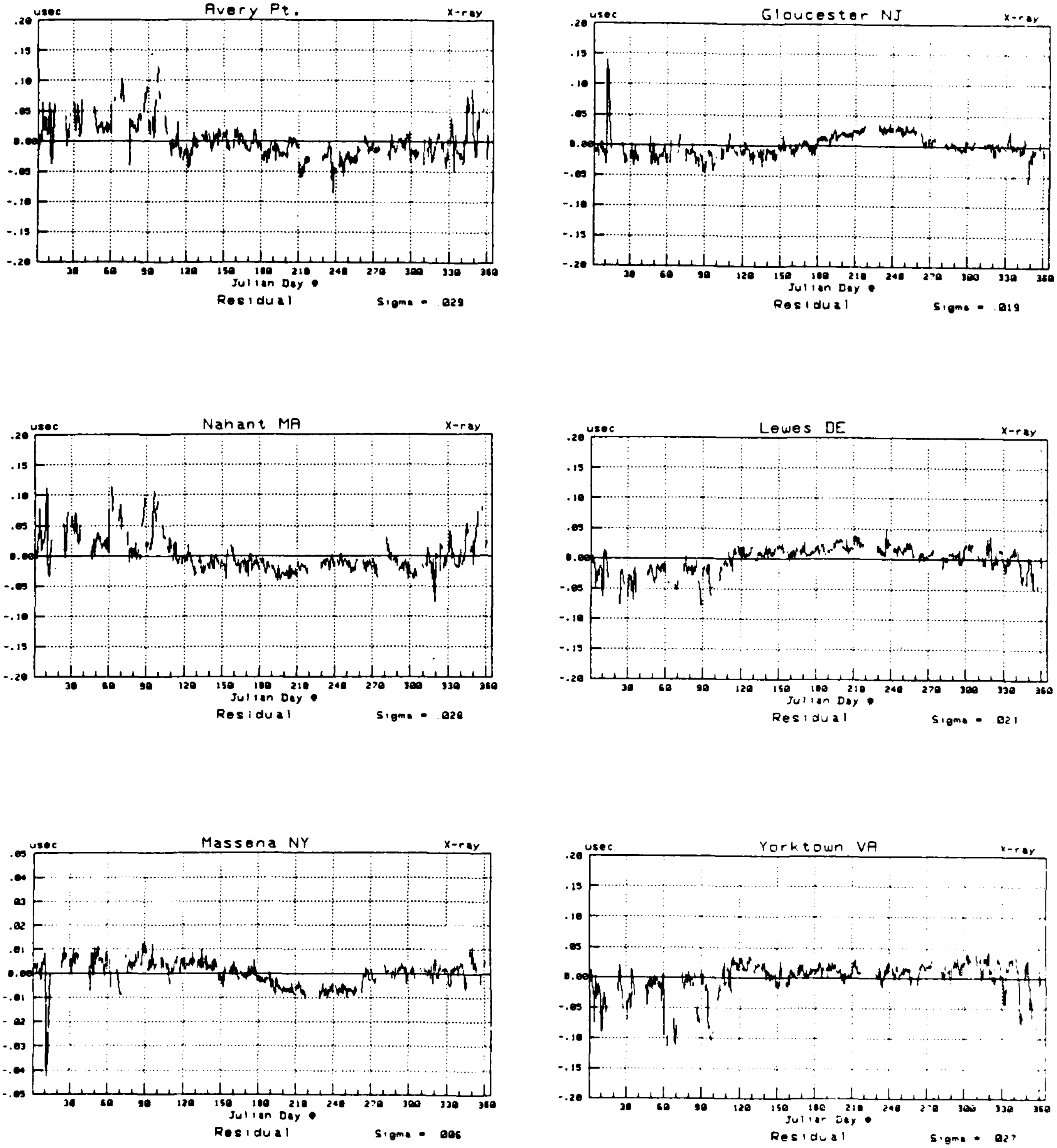


Figure 3-6 MOD 1 DRD Model MMSE Estimate Residuals - 9960-X

A visual inspection shows the modelling results are clearly superior to the previous attempt. Our more quantitative "goodness" measurement process is indicated in Table 3-4.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Percent Reduction	Mod 1 DRD Model Residuals Standard Deviation	Percent Reduction
Lewes	22 nsec	38 nsec	- 73 %	21 nsec	5 %
Yorktown	26	72	-177 %	27	- 4 %
Gloucester	54	23	57 %	19	65 %
Avery Point	41	21	49 %	29	29 %
Nahant	53	25	53 %	28	47 %
Massena	196	85	57 %	6	97 %
RMS Standard Deviation	88	51	43 %	23	74 %

Table 3-4 Tabulation of "Mod 1" DRD Model Estimation Results - 9960-X

As the table clearly indicates this simple modification produces enormously powerful results. Indeed, we are at the point that we must ask: how far must we take this estimation process? As we try to answer this, we wonder: perhaps there is a better way of stating the improvement than the "percent reduction." We can notice that in even coming up with this somewhat non-standard "percent reduction" (of standard deviation) term, we have avoided such standard factors as, for example, the "coefficient of determination." To explain our motives, we must reveal the goal we are attempting to reach with the model.

Basically, we are trying to explain as much of the variation as is practical, consistent with our originally stated goal of keeping the model simple. In refining our practicality requirement, we must realize there is an assumed "floor" to Loran-C variations - a level below which we do not expect (certainly in a practical implementation) to be able to reduce the observed TD standard deviation. In reference 13, we began the analysis by assuming this "floor" corresponded to a TD standard deviation of 11 nsec. The results indicated we could come close to achieving this.

In reference 14, we began with this same assumption but eventually realized we could not achieve it. The difference between the St. Lawrence Seaway analysis of reference 13 and the St. Marys River analysis of reference 14 relates to the term called "phase modulation." In the St. Lawrence Seaway, we were hypothesizing Differential Loran-C corrections from shore based monitors which featured the same receiver type as the user receiver. Under the assumption of corrections from a single monitor station, we found a standard deviation of 16 nsec was about the best to be expected.

In the St. Marys River, we hypothesized the fix quality obtained by users equipped with Internav 404 receivers in an Austron 5000 controlled chain. This is a more realistic example of what our initial investigations should concentrate on herein. In reference 14, we accomplished a more quantitative application of the DRD model. The standard deviation of the residuals varied from site to site over a range from about 13 nsec up to just under 35 nsec. This seemed to be about the best results we could achieve.

With these results stated, we must conclude a practical limitation on the model is achieved by getting the model residuals below a floor which is somewhere in the range from 11 to 35 nsec. We illustrate this "floor region" by the dashed lines in 3-7 along with the resulting residuals from each stage of the model application. The left-most cluster of points is comprised of the standard deviations of the "zeroth-order model" residuals, i.e., the standard deviations of the original TD data records. The middle cluster represents the standard deviations of the records after the "variations explained" by the straight DRD model have been removed. The cluster to the right represents the standard deviations of the records after the "Mod 1" DRD model has been applied.

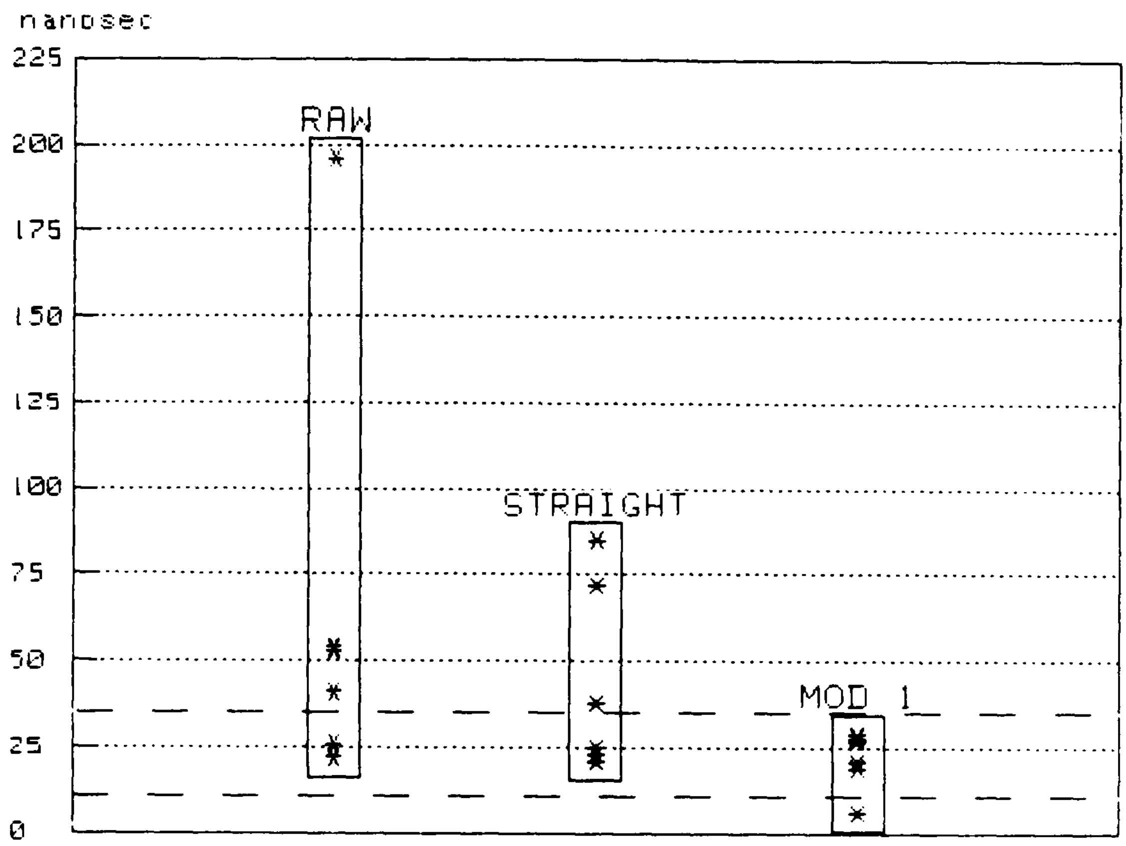


Figure 3-7 Summary of Model Results - 9960-X

The figure clearly shows the improvement of each succeeding version of the model over the previous one. Moreover, it shows how we have essentially reached the point of diminished returns after MOD 1 to the model. At least based on everything we know so far, the residuals after this mod are "in the system noise."

At this point in the discussion we note we have not gone as far as we intend to go with the model. We have simply used the convenient 9960-X baseline data to illustrate the important points we wish to establish before proceeding with more elaborate presentations. Specifically, we have presented a reasonably concrete set of "figures of merit" which we can employ in subsequent sections. This allows us to avoid visual inspection of the residuals as our only method of evaluating the success of our modelling efforts. We now turn to a more detailed analysis of the entire 9960 chain.

3.3 Application of Model to All 9960 Data Records

We begin the analysis by noting that, under ideal circumstances, there should be one dTD term which applies throughout the chain coverage area. Thus, the elements we wish to estimate are represented by the vector

$$\begin{bmatrix} dTD(n) \\ \underline{C}(n) \end{bmatrix} = [dTD(n) \quad C_W(n) \quad C_X(n) \quad C_Y(n) \quad C_Z(n)]^T$$

We carry out the estimation process, as indicated in Section 2 and as carried out in the previous section, for both the straight and the Mod 1 DRD models. For ease in presenting the results, Table 3-5 is arranged on a baseline-by-baseline basis. The results for all the baselines are combined in the "cluster plot" of Figure 3-8.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Percent Reduction	Mod 1 DRD Model Residuals Standard Deviation	Percent Reduction
Avery Point - W	85	28	67 %	22	74 %
Nahant - W	31	65	-110	15	52
Massena - W	107	47	56	23	79
Lewes - X	21	26	-24	19	10
Yorktown - X	27	52	-93	21	22
Gloucester - X	52	20	62	19	63
Avery Point - X	40	39	2	29	28
Nahant - X	52	50	4	30	42
Massena - X	195	144	26	23	88
Yorktown - Y	63	42	33	46	27
Lewes - Y	21	53	-152	27	-29
Gloucester - Y	20	52	-160	15	25
Avery Point - Y	108	78	28	37	66
Nahant - Y	88	67	24	38	57
Yorktown - Z	153	31	80	49	68
Lewes - Z	163	24	85	20	93
Gloucester - Z	122	46	62	58	52
RMS Std. Dev.	95.5	58.0	39 %	31.5	67 %

Table 3-5 Tabulation of Model Results - "Combined Model" - Entire 9960 Chain

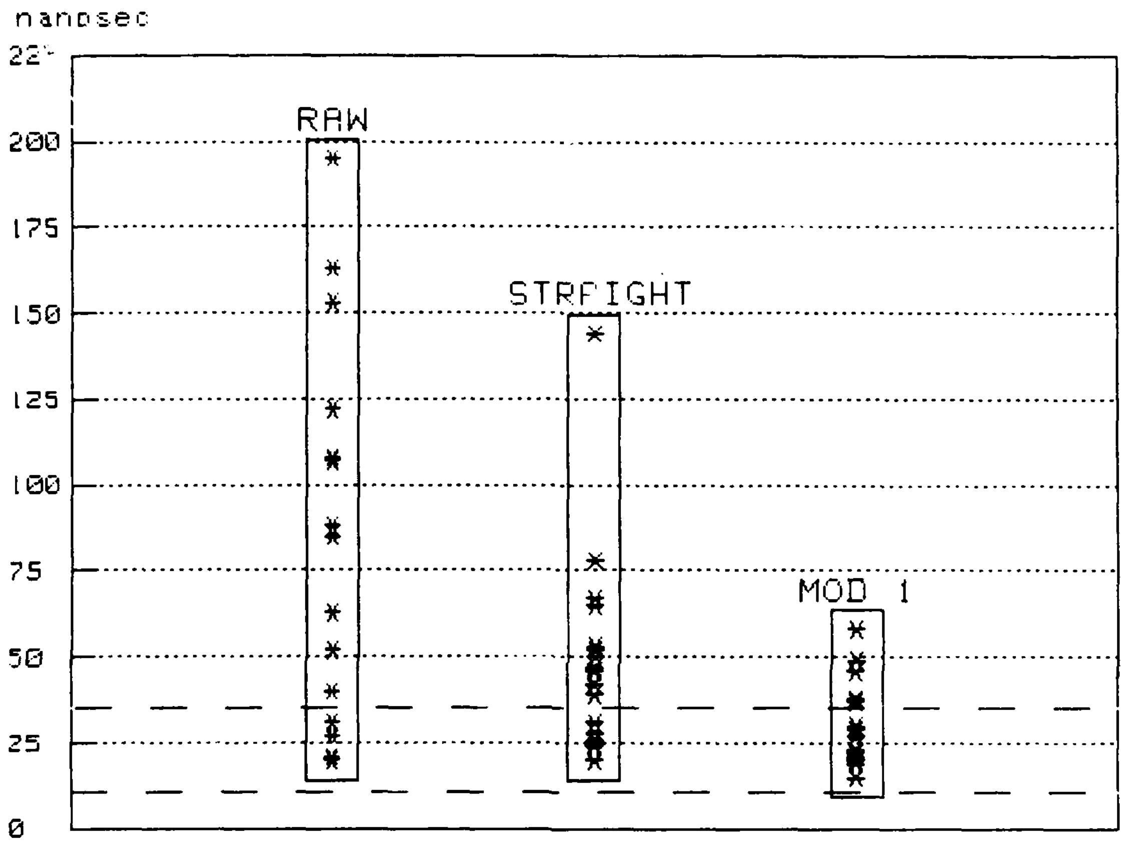


Figure 3-8 Summary of Model Results - Entire 9960 Chain, Combined Model

The results indicated in the Table and the Figure are not as encouraging as those of the previous section. Indeed, the variations remaining in the residuals after the application of the Mod 1 model are so large we can no longer support the claim there is no sense trying to refine the model. We are clearly not in the system noise at this stage and must try something beyond what we have done thus far. One possible explanation for the problem, of course, is the reduction in the number of "degrees of freedom" we have accomplished by forcing there to be only one propagation term (i.e. dTD). As discussed in Section 2, we may obtain some insight into the problem by conducting the baseline-by-baseline analysis. When this is accomplished, the results are as shown in Table 3-6 and Figure 3-9.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Percent Reduction	Mod 1 DRD Model Residuals Standard Deviation	Percent Reduction
Avery Point - W	102	22	78 %	22	78 %
Nahant - W	33	1	97	-0-	100
Massena - W	118	21	82	22	81
Lewes - X	22	31	-41 %	21	5 %
Yorktown - X	26	106	-308	27	-4
Gloucester - X	54	21	61	19	65
Avery Point - X	41	23	44	29	29
Nahant - X	53	27	49	28	47
Massena - X	196	96	51	6	97
Yorktown - Y	65	36	45 %	45	31 %
Lewes - Y	22	34	-55	29	-32
Gloucester - Y	21	68	-224	11	48
Avery Point - Y	120	50	58	44	63
Nahant - Y	95	21	78	41	57
Yorktown - Z	159	9	94 %	7	96 %
Lewes - Z	167	29	83	30	82
Gloucester - Z	129	20	85	23	82
RMS Std. Dev.	100.2	45.6	54 %	26.8	73 %

Table 3-6 Tabulation of DRD Model Estimation Results - 9960 Baseline-by-Baseline Application of the Model

As a general comment, we should note that whereas the results of Figure 3-9 look better than those of Figure 3-8, we have achieved the improvement by what can almost be described as "artificial means." Recognizing we have introduced three more degrees of freedom in the model (which now features dTD_W, dTD_X, dTD_Y, and dTD_Z vice the original dTD), we must admit the improvement has not been all that wonderful. On a more detailed basis, we see the residuals are pretty small for 9960-W and 9960-Z but the model has two variables and there are only three data point for these baselines! The 9960-X and 9960-Y baselines, having more data points, give a clearer indication of what is happening with the model.

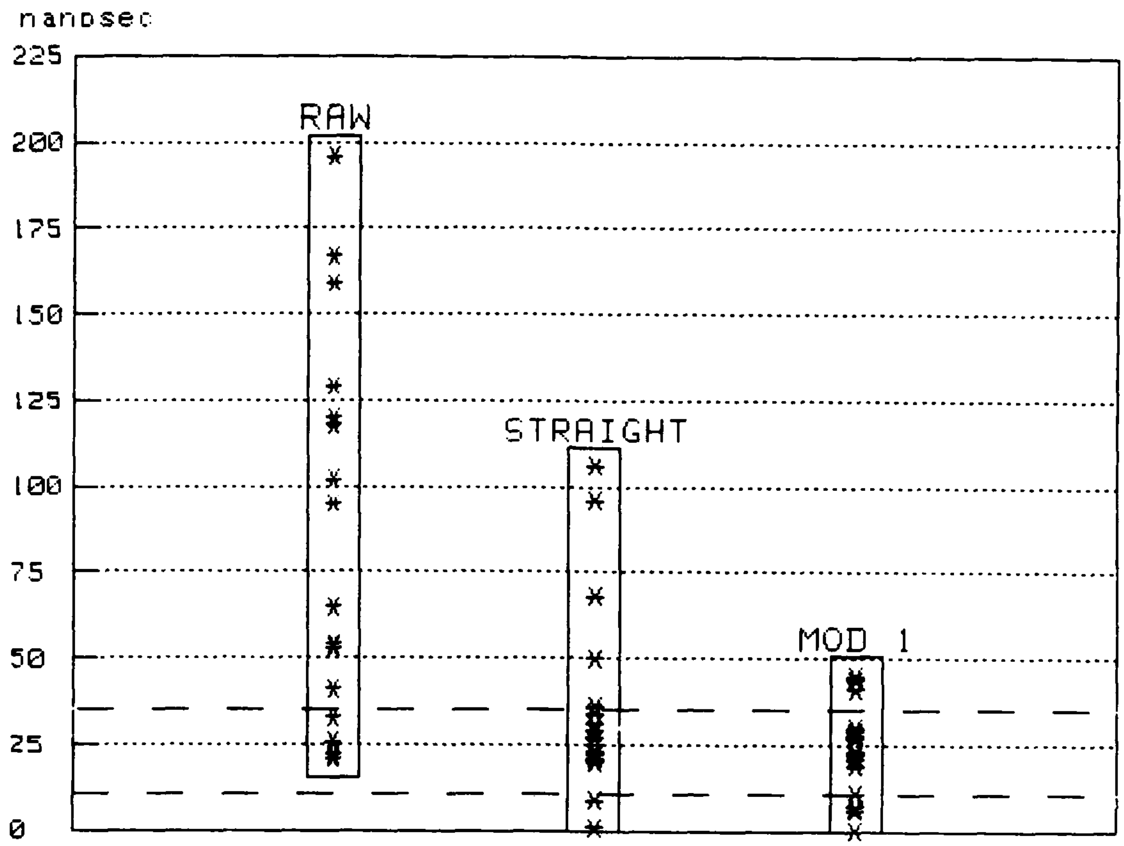


Figure 3-9 Summary of Model Results - 9960
Baseline-by-Baseline Model

Careful scrutiny of the results for the 9960-X and -Y baselines indicates a pattern which, in retrospect, can be seen to be consistent with results of the last few examples. In particular, we can see how we seem to have decent results for the northerly baselines. The southern baselines seem to present most of the problem. This tends to agree with our preconceived notion of the way things would turn out: recall the discussion of Section 2.5 where we said we expected a "Mason-Dixon effect."

The suspicions about different land-path effects that arose as we collected the data were corroborated by observations from the S.E.U.S. sites. As will be shown in Section 4, the S.E.U.S. data suggests a much milder dTD term than had been observed in the Great Lakes and reported in reference 14. All of this leads to the conclusion that the "all land is equal" assumption of "mod 1" to the model could not be supported in an area such as that of the N.E.U.S. chain. Again, we suspected this would be the case all along. The next step, once we confirmed this suspicion, was to see if some simple modification to the model could be arrived at.

After considerable trial and error, we became convinced that a simple "there are two types of land - north and south" modification could be found. The trick was to find the "dividing line" between north and south. We must emphasize, of course, that all of this is completely arbitrary. We fully recognize that the "transition" from north to south is a gradual one so that whatever we come up with will be simply a gross approximation to what actually occurs. A key point, however, is that we are implying it is the weather (temperature and humidity) of the air mass over the land, rather than the land itself, that is the driving factor. Once this "weather" point is established, we recognize we should concentrate our efforts on weather charts rather (for example) than conductivity charts.

Reference 16 contains an extensive series of generalized maps which, especially because they are so generalized/small scale, are suited to our purposes. The maps shown in figures 3-10 and 3-11 are selected as representative of the type of generalization we seek to make. Detailed examination shows there is a strong degree of correlation from map to map. In a very subjective process, but after extensive perusal of reference 16, we have developed the contour indicated in figure 3-12. Some features of the "dividing line" are worth discussing.

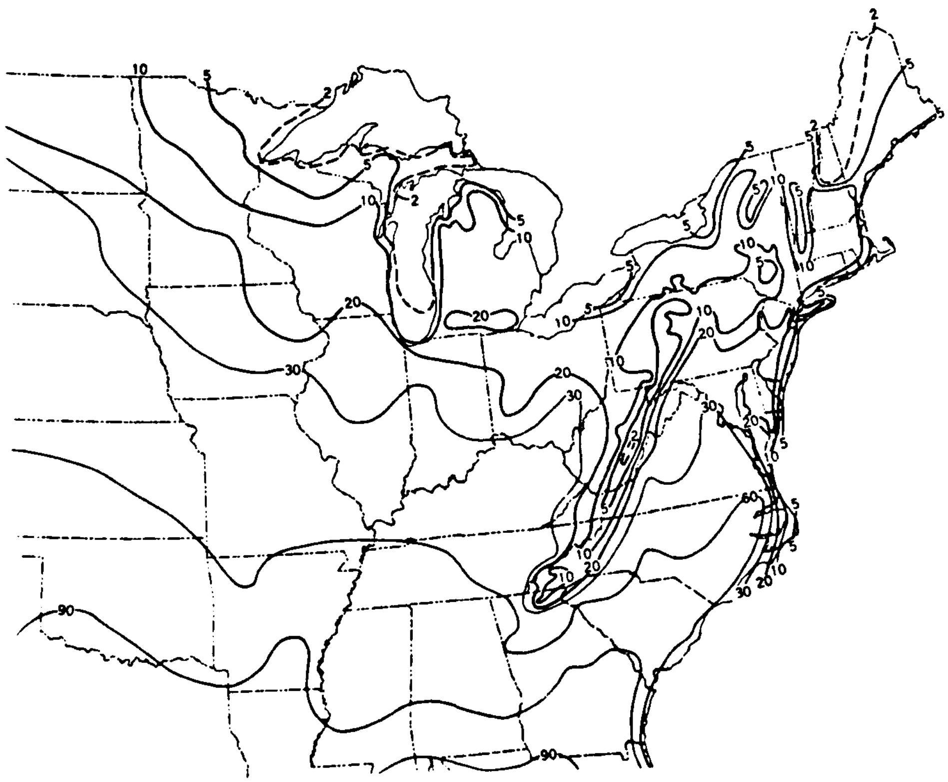


Figure 3-10 Representative Climate Map from Reference 16

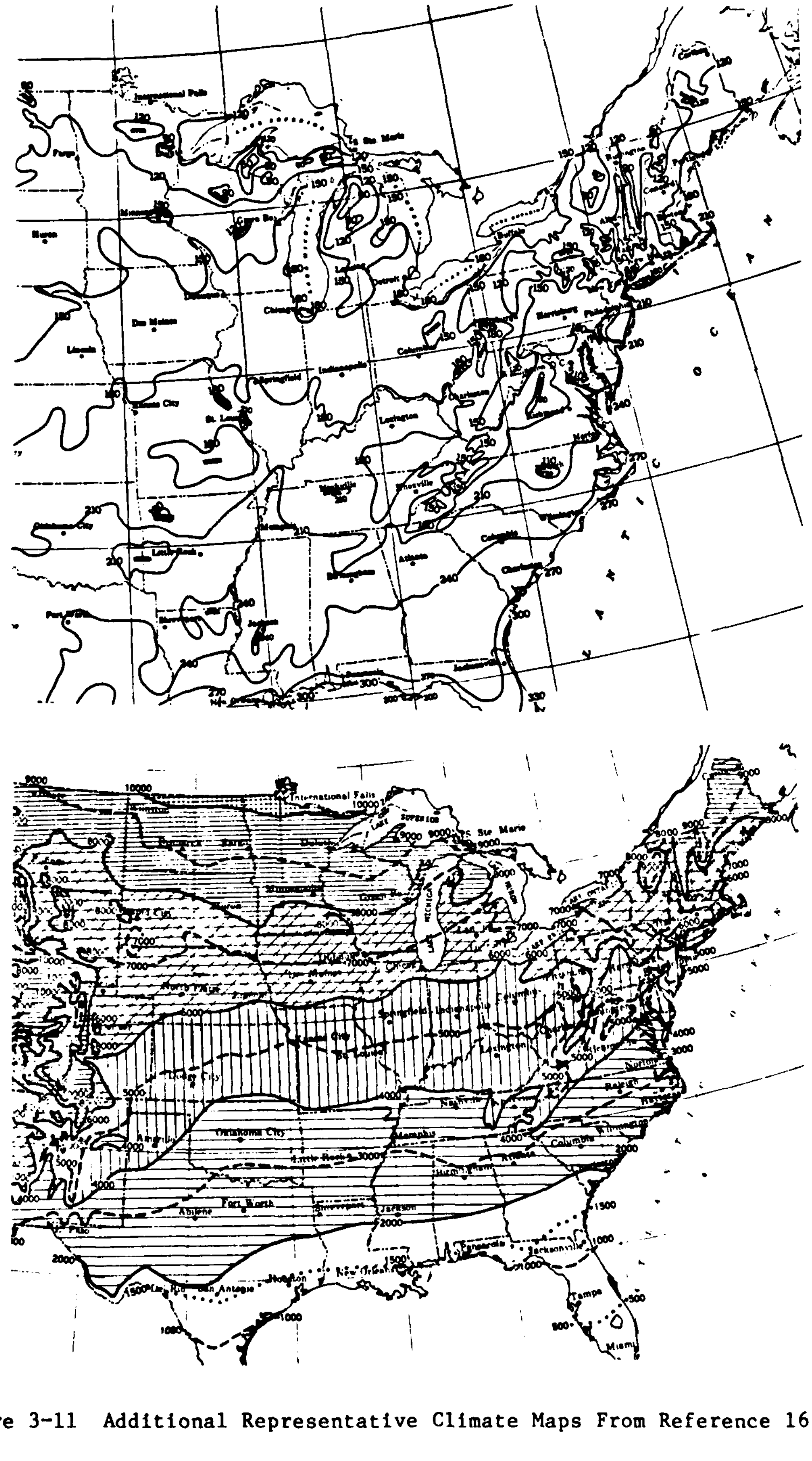


Figure 3-11 Additional Representative Climate Maps From Reference 16

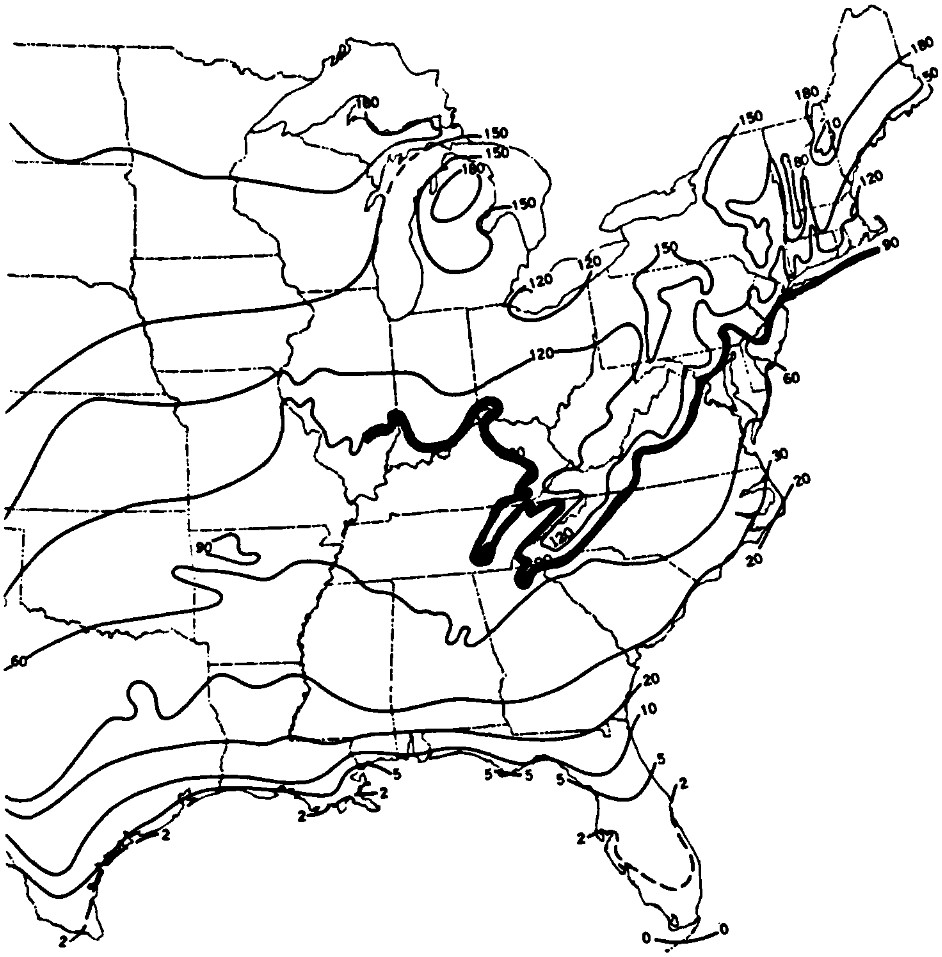


Figure 3-12 Estimated Dividing Line Between Type 1 and Type 2 Land

The "dividing line" contour is, essentially, the "Mean Annual Number of Days Minimum Temperature 32°F and Below = 90" contour. Although this is a vague, generalized parameter, its use is consistent with observations made throughout the St. Marys River Mini-Chain studies. Year-round data taken during those studies routinely suggested the TD records were almost "two-state processes" - corresponding to freezing and non-freezing surface temperature periods. Reference 11 presents a rigorous treatment of the subject which, in simplified form, is consistent with what we propose herein. Thus, with one additional statement, the authors claim to be comfortable with the model represented by figure 3-12.

The additional statement is an emphasis that the contour need not have any direct tie to some physical quantity to be a valid and acceptable part of a model. In this sense, we can argue for a status similar to that enjoyed, for example, by complex numbers. There is no such thing, in a physical sense, as a line which denotes an abrupt shift from "propagation speed variation type I" to "propagation speed variation type II." In an empirically refined model, however, the existence of the contour(s) cannot be challenged: it (they) have whatever shape is necessary to reconcile the model with the observed data.

Here we encounter, in a strictly mathematical sense, somewhat of a problem: we do not have anywhere near enough data collection sites to empirically derive a detailed contour. Thus, we have sought to relate the data, via the contour, to a vague set of physical parameters. Fortunately, almost every weather map we can find suggests a consistent approach to drawing the contour, one that is also consistent with all observations and theoretical studies made throughout the 9 years of precision Loran-C studies. It is, perhaps, this final fact - the strong agreement between the high quality data we now are obtaining (at long last!) and what we expected all along based on piecemeal observations/theoretical studies/hunches - that prevents us from passing up this opportunity to attempt this "mod 2." This "justification statement" out of the way, let us proceed with a presentation of the "mod 2" results.

After a reasonable amount of trial-and-error experimentation, we decided the next modification to the model should be to "weight" the constituents of the paths according to the rule:

type I land range = 1.0 x actual range

type II land range = 0.5 x actual range

(non-freezing) seawater range = 0 x actual range

With this modification, a new <u>A</u>-matrix is computed and the estimation process is re-run. The results are summarized in Table 3-7 and Figure 3-13.

[Note: We would be remiss if we failed to provide one further bit of explanation here. We do not mean to imply the seasonal variation in "dTD" at any point is caused, exclusively, by the surface weather at that point. Reference 11 explains with considerable detail how changes in the index of refraction <u>and</u> the lapse rate of the index of refraction, along the <u>entire</u> length of the propagation paths involved provides the true cause/ effect explanation. As further noted in reference 11, however, there is a significantly strong correlation among all of these parameters. As a results, assuming one is seeking a <u>simple</u> explanation for the <u>bulk</u> of the variation <u>trend</u>, an examination of typical weather <u>trends</u> provides the strongest clues. This suits our present purposes and leads to our model.]

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Mod 1 DRD Model Residuals Standard Deviation	Mod 2 DRD Model Residuals Standard Deviation
Avery Point - W	85	28	22	25
Nahant - W	31	65	15	15
Massena - W	107	47	23	21
Lewes - X	21	26	19	18
Yorktown - X	27	52	21	18
Gloucester - X	52	20	19	25
Avery Point - X	40	39	29	22
Nahant - X	52	50	30	21
Massena - X	195	144	23	16
Yorktown - Y	63	42	46	27
Lewes - Y	21	53	27	28
Gloucester - Y	20	52	15	26
Avery Point - Y	108	78	37	35
Nahant - Y	88	67	38	39
Yorktown - Z	153	31	49	38
Lewes - Z	163	24	20	21
Gloucester - Z	122	46	58	49
RMS Std. Dev.	95.5	58.0	31.5	27.6

Table 3-7 Tabulation of "Mod 2" DRD Model Estimation Results - Combined Model - Entire 9960 Chain

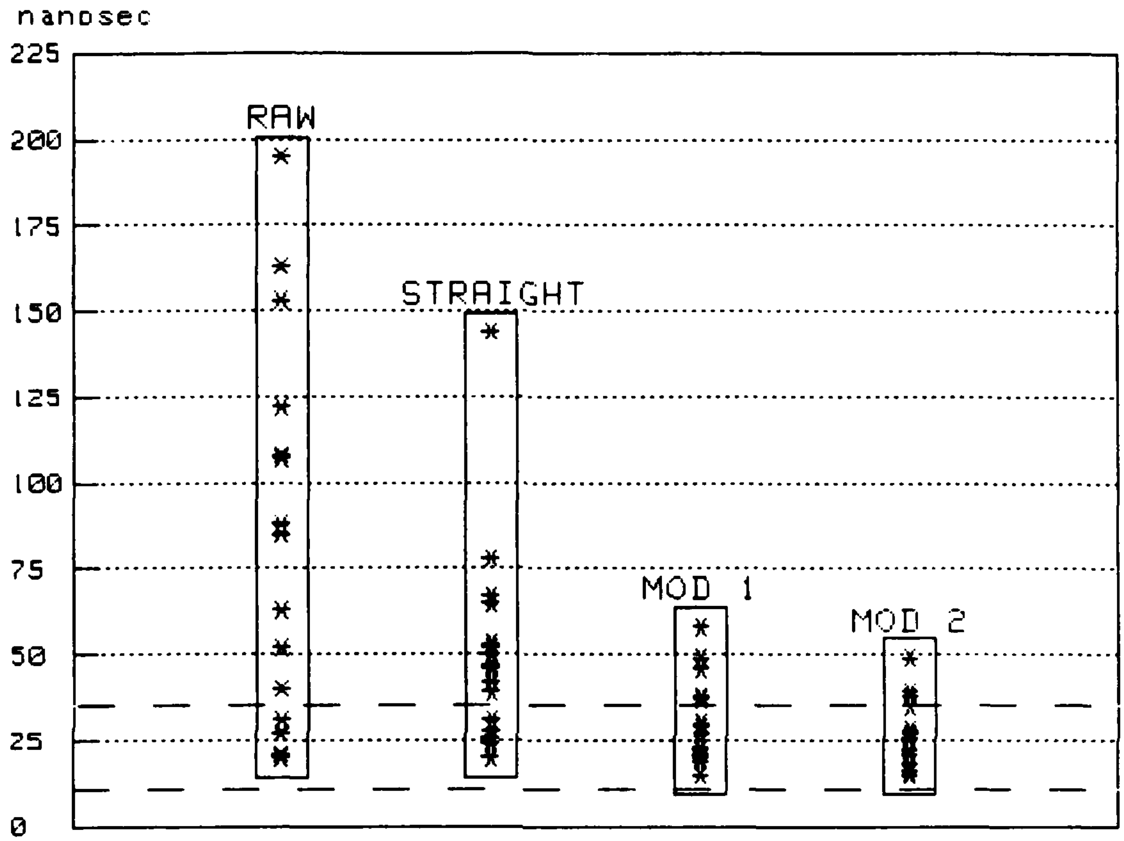


Figure 3-13 Summary of Mod 2 Model Results - Combined Model - Entire 9960 Chain

Although the results of the modification show a definite improvement, there still seems to be a problem. Careful examination of Table 3-7 suggests the problem is with the 9960-Z data record. Ideally, we would want our model to feature one simple propagation term that would apply to all baselines. Results thus far suggest this may not be possible. To check this suggestion, we can re-run the model, using only the 9960-W, -X, and -Y data records. The results are summarized in Table 3-8 and Figure 3-14.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Mod 1 DRD Model Residuals Standard Deviation	Mod 2 DRD Model Residuals Standard Deviation
Avery Point - W	86	28	24	26
Nahant - W	31	65	14	16
Massena - W	108	48	23	21
Lewes - X	22	27	21	19
Yorktown - X	27	53	25	19
Gloucester - X	53	20	19	26
Avery Point - X	41	39	29	23
Nahant - X	54	49	29	21
Massena - X	198	144	17	16
Yorktown - Y	62	48	50	28
Lewes - Y	21	55	25	27
Gloucester - Y	20	51	16	25
Avery Point - Y	108	80	35	34
Nahant - Y	89	71	39	39
RMS Std. Dev.	81.1	62.8	28.1	25.1

Table 3-8 Tabulation of "Mod 2" DRD Model Estimation Results - Combined Model - 9960-W, -X, and -Y only

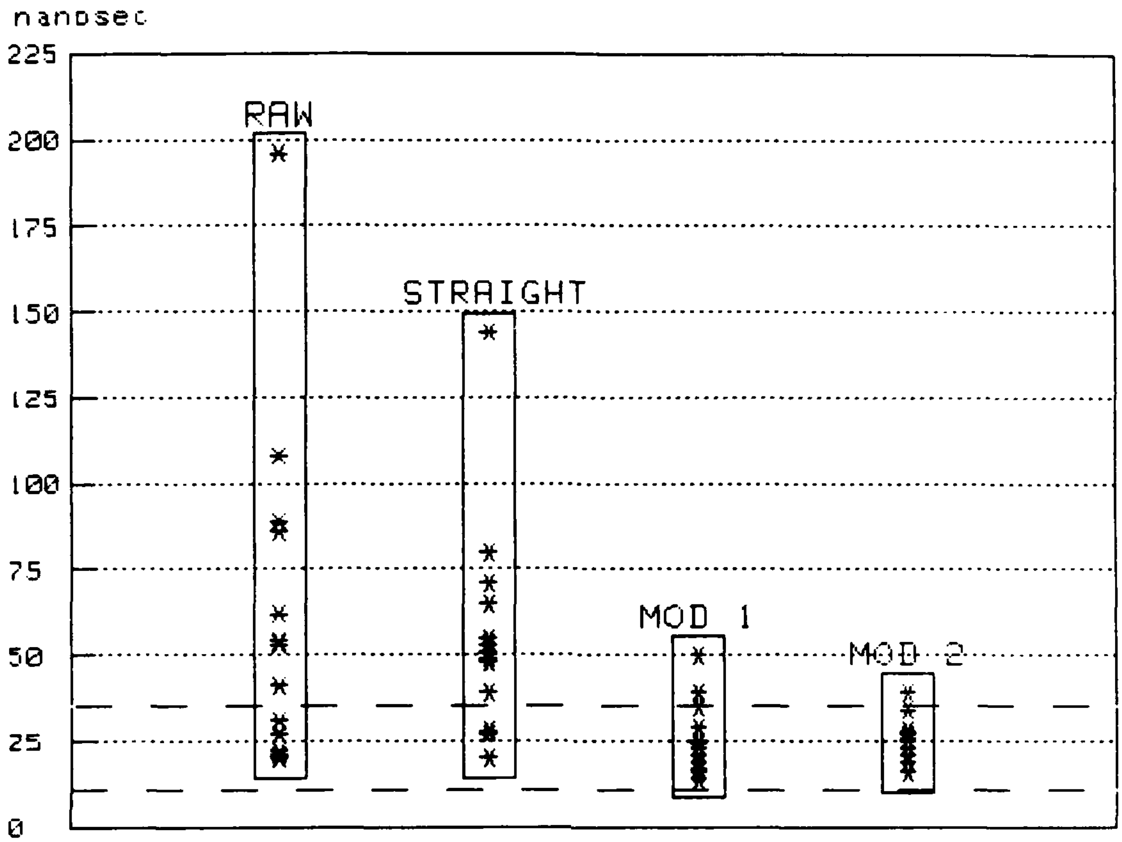


Figure 3-14 Summary of Model Results - 9960-W, -X, and -Y only

From the figure, we can see we are now obtaining very reasonable results - the residuals are "grouping" at a level which is, essentially, within the system noise. We have achieved this success by ignoring 9960-Z data, an undesirable action. Whereas this is undesirable, it is not too difficult to justify. The "dividing line" we have drawn is "very busy" in the Shenandoah Valley region - certainly far too busy for our small number of monitors to adequately characterize. Rather than "leaving it at that," however, we have done some further investigation and found we can obtain reasonable results by simply omitting the "Gloucester-Z" record. The results of this approach are shown in table 3-9 and figure 3-15.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Mod 1 DRD Model Residuals Standard Deviation	Mod 2 DRD Model Residuals Standard Deviation
Avery Point - W	86	28	22	25
Nahant - W	31	64	14	16
Massena - W	108	47	23	21
Lewes - X	22	26	21	19
Yorktown - X	27	52	24	18
Gloucester - X	52	20	19	26
Avery Point - X	40	39	29	23
Nahant - X	53	48	30	21
Massena - X	196	142	19	16
Yorktown - Y	62	47	49	28
Lewes - Y	21	55	26	28
Gloucester - Y	20	51	15	25
Avery Point - Y	107	80	36	34
Nahant - Y	88	70	38	39
Yorktown - Z	152	16	25	19
Lewes - Z	161	16	25	19
RMS Std. Dev.	93.4	58.2	27.2	24.5

Table 3-9 Tabulation of "Mod 2" DRD Model Estimation Results - Combined Model - Omitting Gloucester-Zulu

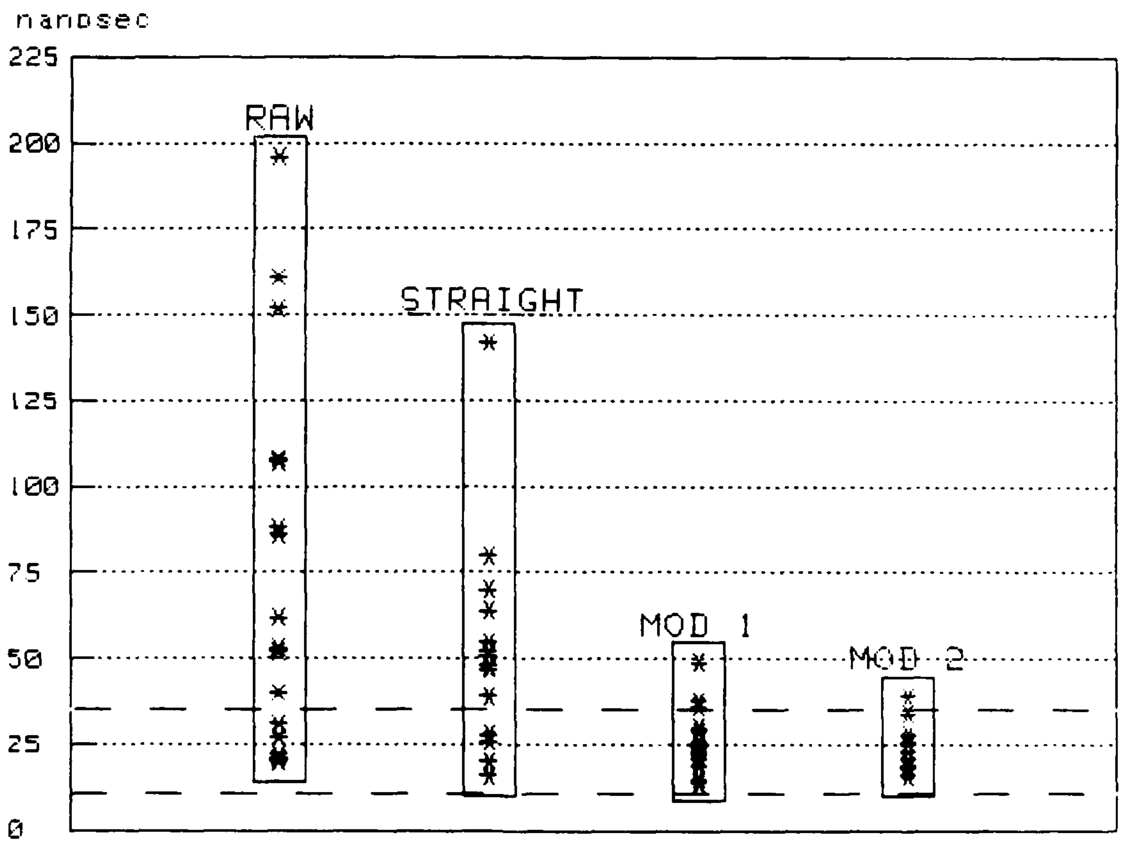


Figure 3-15 Summary of Model Results - Combined Model Without Gloucester-Zulu

Again, the figure shows we have "reasonable" results. We are, essentially, "in the system noise" with the cluster of residuals. Ideally, we would not have had to "ignore" the Gloucester TD_Z data record. We note, however, that we have used 16 of 17 available data records and finding the Glocester-Seneca-Dana anomaly is a potentially useful result. Specifically, we have a hint at where to look in future work if it becomes important to estimate the "dividing line" with greater precision.

We claim we have gone as far as it is reasonable to go in modifying the basic DRD model. Before leaving this section, however, we should mention the results of one further analysis. In this analysis, we assume the basic model (i.e., equation 2-7) is adequate to describe the available data. Within this framework, we should attempt to find "optimal" DRD's to use in the construction of the $\underline{A}$-matrix. In carrying out the optimization, we do not require there be any particular rhyme or reason to how the DRD's are chosen, other than that the resulting residuals, in a MMSE sense as always, are minimized.

When the above analysis is carried out, we find an "RMS STD Dev" of 18 nsec. We can use this result, first, to be more concrete in support of our claim to have gone as far as we should go. Besides arguing we are "in the system noise," we can now indicate the relationship of the 24.5 nsec "rms std dev" indicated in table 3-9 for Mod 2 to the 18 nsec of "Mod ∞." An additional use is to obtain an updated "representative" figure for the best we feel we can expect from Loran-C: the figure being associated with a TD standard deviation, over the course of a full year, of 18 nsec.

Now that we have explained the model in its most refined state, we will want to use it to predict the Loran-C performance at places other than Harbor Monitor sites. As indicated earlier, however, we would like to accompany the predictions with an indication of the confidence we have in the predictions. The next section will address that matter.

3.4 Model Prediction Performance

As a result of the methodology indicated in Section 3.3, we conclude the analysis in possession of five data sequences for the 9960 chain: dTD(n), $C_W(n)$, $C_X(n)$, $C_Y(n)$, and $C_Z(n)$. These each contain 730 data points, corresponding to two sample periods per day for the year-long period beginning 1 March 1982. As described in Reference 14 and reviewed in Section 2, we use these sequences for predictions as follows:

1. For any location, compute the "Mod 2" DRD for a baseline of interest. Multiply this by the dTD(n) sequence.

2. Add the appropriate "C(n)" sequence.

3. Add the appropriate SAM data record.

4. Add in a Gaussian white noise sequence with a standard deviation of 20 nsec.

The result is the predicted TD record for the baseline at the location of interest. This can be used, in conjunction with predictions of other baselines to produce a sequence of fix predictions from which statistics relating to cross-track error (CTE), drms, etc. can be obtained.

One concept discussed in reference 14 is worth noting and repeating. Notice that the "bottom line" of table 3-9, i.e., the 24.5 nsec RMS Std. Dev. suggests the 20 nsec standard deviation used in step 4 above is somewhat low and may cause overly optimistic results. Actually, quite the opposite is true because of the "maximum disorder" quality of the white Gaussian noise process. Thus, we are actually being somewhat conservative with our predictions and we prefer this condition.

We have indications of how well the prediction process will work from the residuals listed in table 3-9. The indications, however, are only useful if one can think in the "TD domain." We will be more interested in positioning performance and should thus find the plots of figure 3-16 more informative. In the figure, we provide a scatter plot of fixes, for each site. derived from the actual data. Alongside that plot, we provide a scatter plot obtained by using the four step prediction procedure outlined above. The CTE and ATE figure listed under each plot come off the 95% error ellipse contour which was calculated from the TD statistics shown. The assumed course is true north.

Actually, in producing the predictions of figure 3-16, we have employed one slight wrinkle to the "standard procedure." Instead of using the sequences we will use for predictions in subsequent sections, we have computed new sequences. Specifically, we do not include the data from the site of interest in computing the estimated sequences to be used for the prediction. Thus, our prediction for Yorktown for example, is based on dTD(n), $C_X(n)$, and $C_Y(n)$ sequences which were computed by running the model on all available data other than Yorktown data (and, of course, not considering Gloucester-Zulu data). We do this because we want to be able to assess how well the model will predict the performance at a given site, without access to information from that site. The only way to simulate that situation for a harbor monitor site is to ignore some available data.

We conclude the results are not too bad, but do leave something to be desired. A detailed examination of the implications of errors of varying sizes in the ATE or CTE components cannot be made directly from the plots because of the arbitrary selection of the course. Nevertheless, we can draw some conclusions from the results obtained thus far and should comment further on what we have. We begin the discussion by collecting the statistics of figure 3-16 in table 3-10.

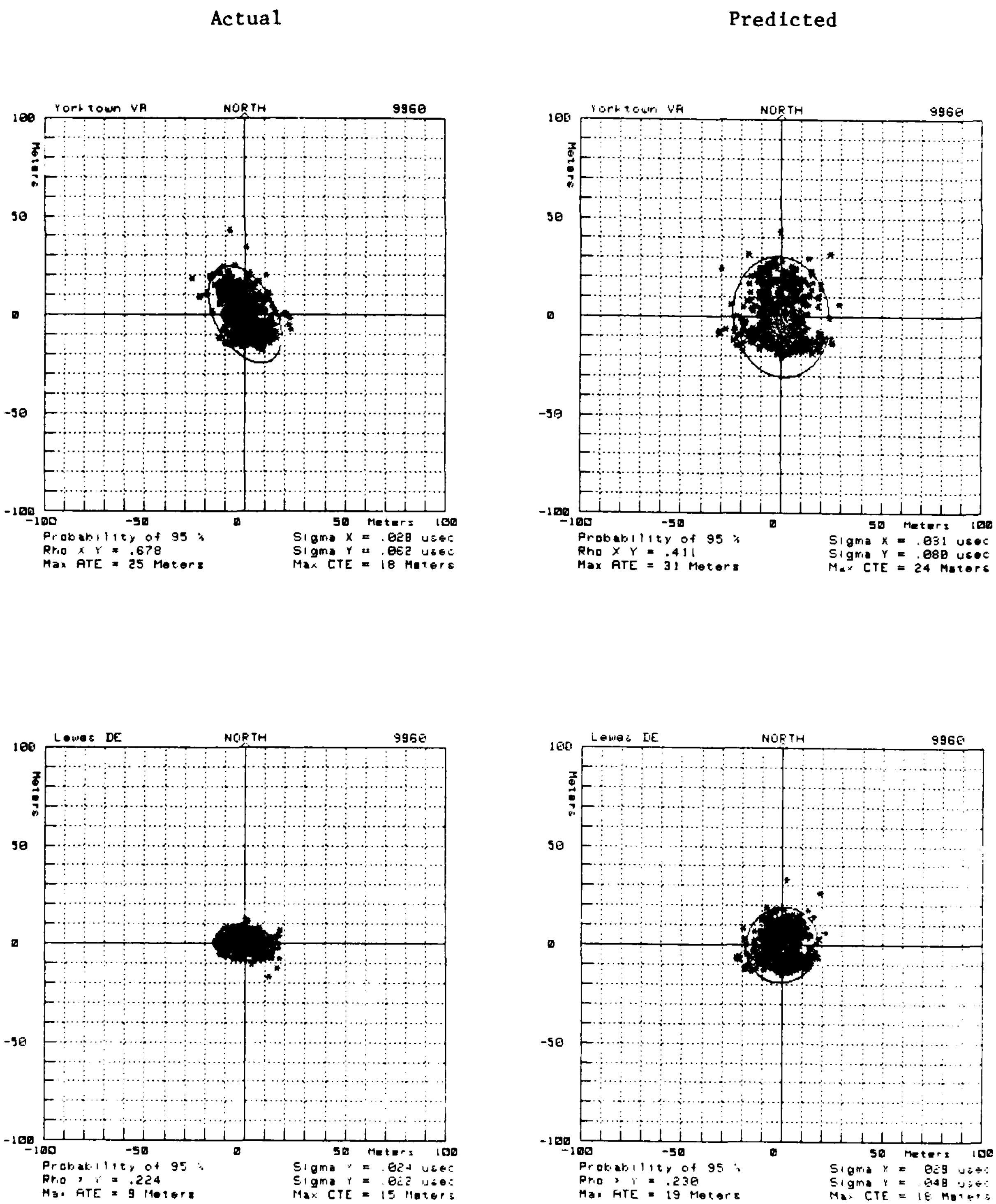


Figure 3-16 Comparison of Actual and Predicted Scatter Plots

Actual | Predicted

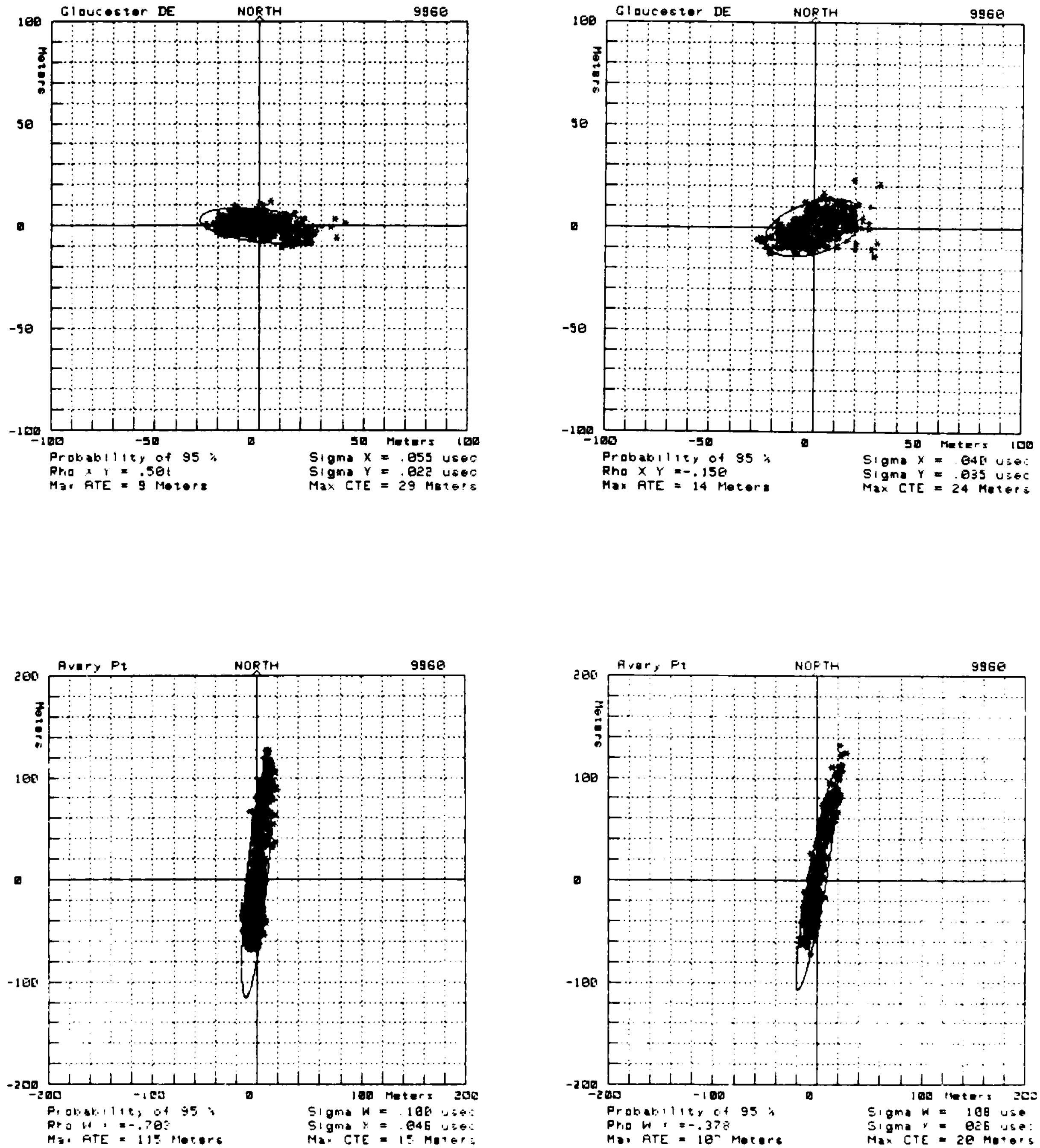


Figure 3-16 (Con't) Comparison of Actual and Predicted Scatter Plots

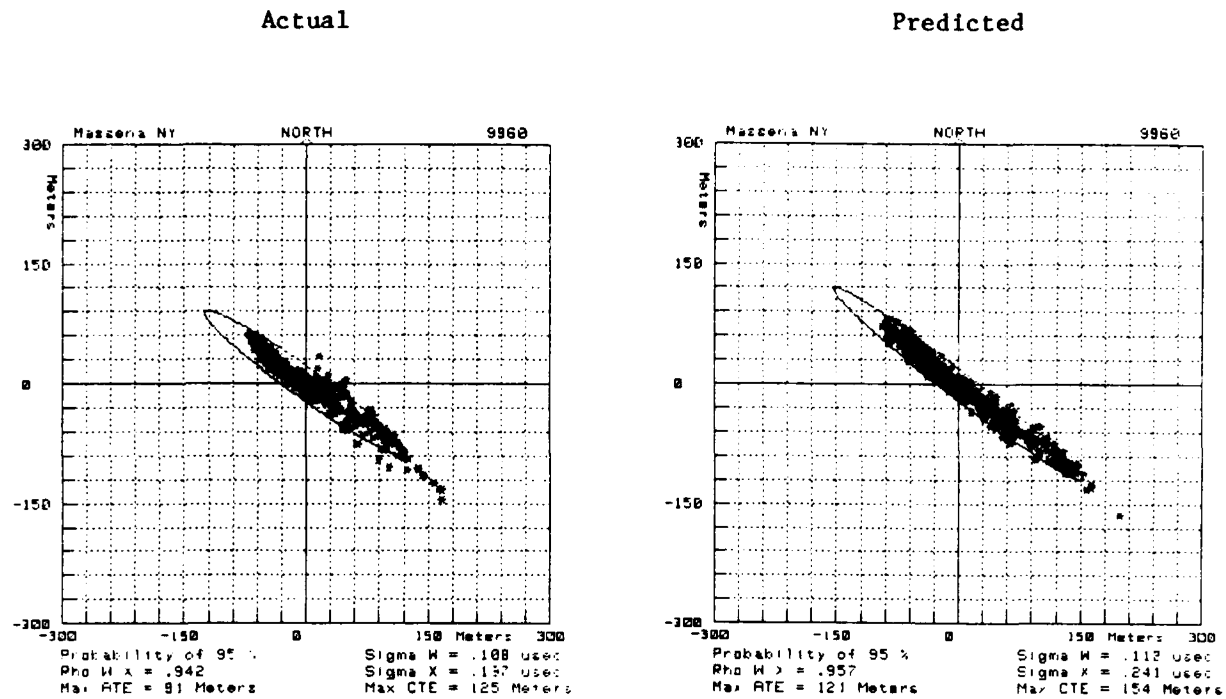


Figure 3-16 (Con't) Comparison of Actual and Predicted Scatter Plots

Site	Parameter	Actual	Predict	Error
Yorktown	ATE	25	31	+6
	CTE	18	24	+6
Lewes	ATE	9	19	+10
	CTE	15	18	+3
Gloucester	ATE	9	14	+5
	CTE	29	24	-5
Avery Pt.	ATE	115	107	-8
	CTE	15	20	+5
Massena	ATE	91	121	+30
	CTE	125	154	+31
Nahant	ATE	17	18	+3
	CTE	21	21	0

Table 3-10 Comparison of Predicted vs Actual CTE and ATE Statistics
(All values in meters)

From the comparison of table 3-10, we see support of the claim that our estimates are conservative: in 9 out of 12 cases, our predictions are larger than the actual error. In the two cases wherein we predicted better performance than was actually observed, we still had small errors. Scanning the data further, we see the largest prediction errors are in the Massena case. At first glance we might attribute this to the fact that the performance errors themselves are large at Massena. They are, however, also large at Avery Point where our predictions are much more accuracte.

Digesting all of this we recognize the problem with the Massena predictions, when we do not have any Massena data, is that we are trying to extrapolate model results over a large distance.

We mention all of this because we claim our predictions will be much better than indicated in figure 3-16 and table 3-10. It will have to remain the subject of future reports to show how much better (after adequate data from recently installed sites - not considered herein - is available). We can provide an approximate indication by considering a revision of the results of figure 3-16 and table 3-10 when we include the site of interest in the prediction model. These results are shown in figure 3-17 and table 3-11.

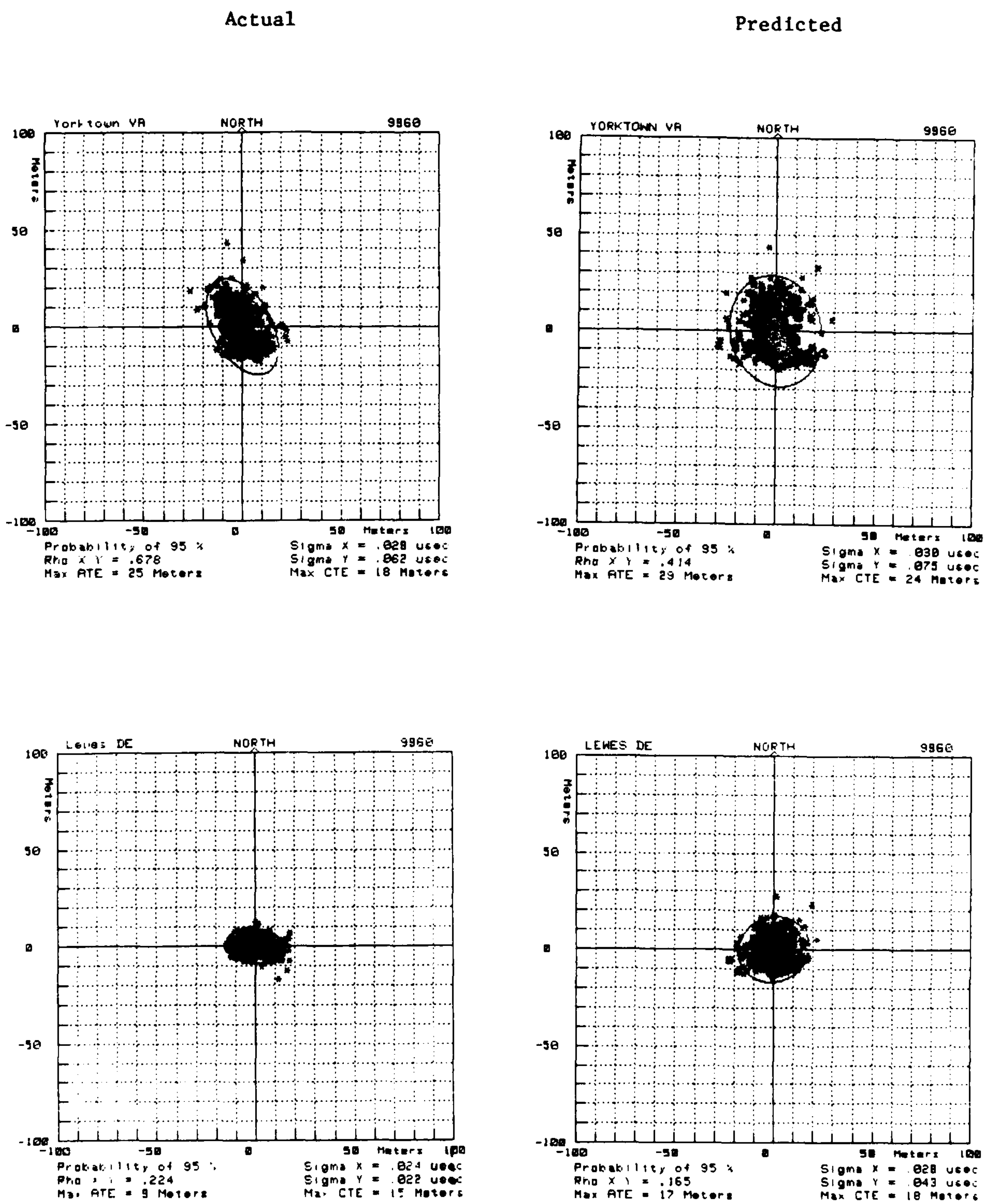


Figure 3-17 Comparison of Actual and Revised Predicted Scatter Plots

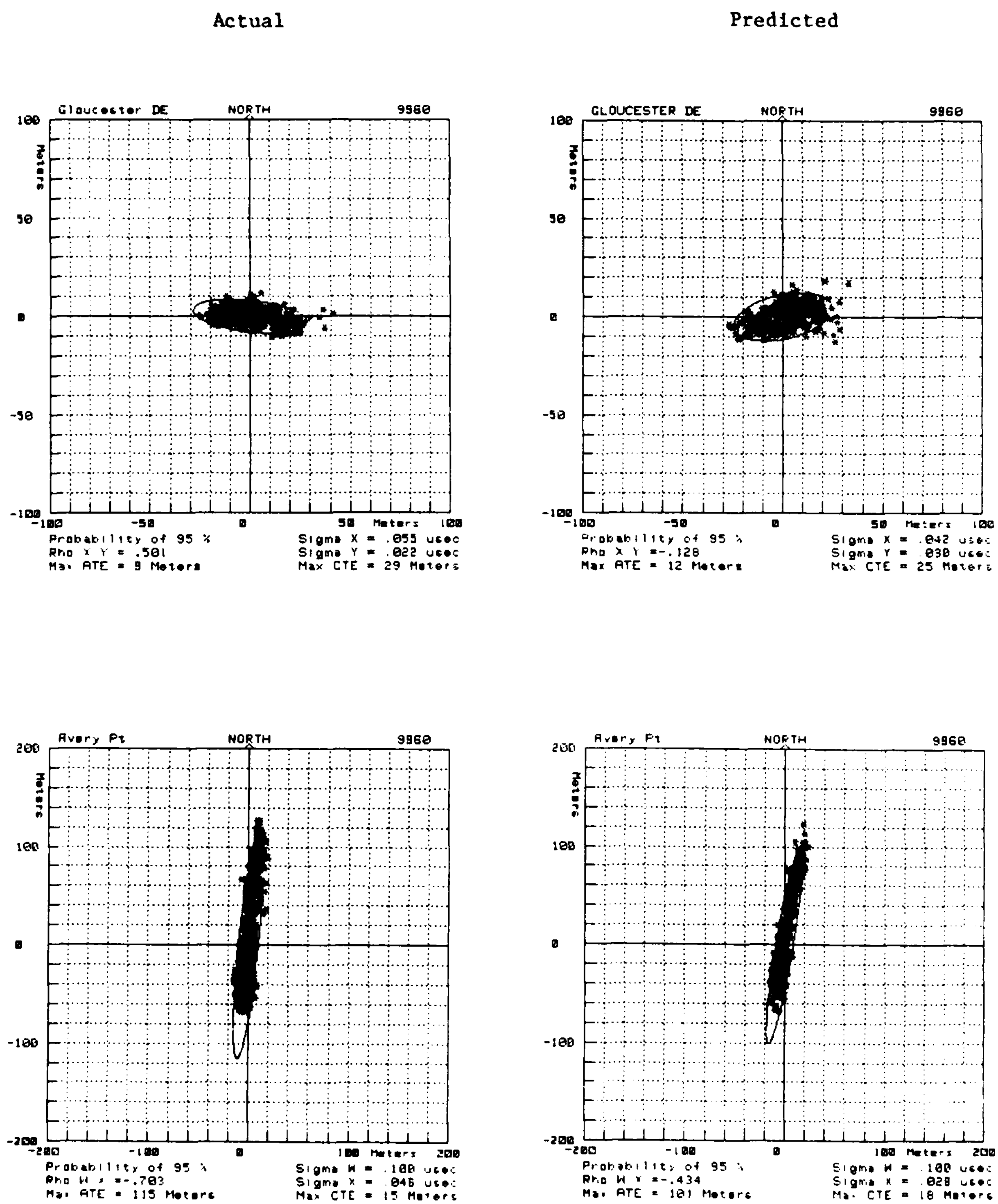


Figure 3-17 (Con't) Comparison of Actual and Revised Predicted Scatter Plots

Actual   Predicted

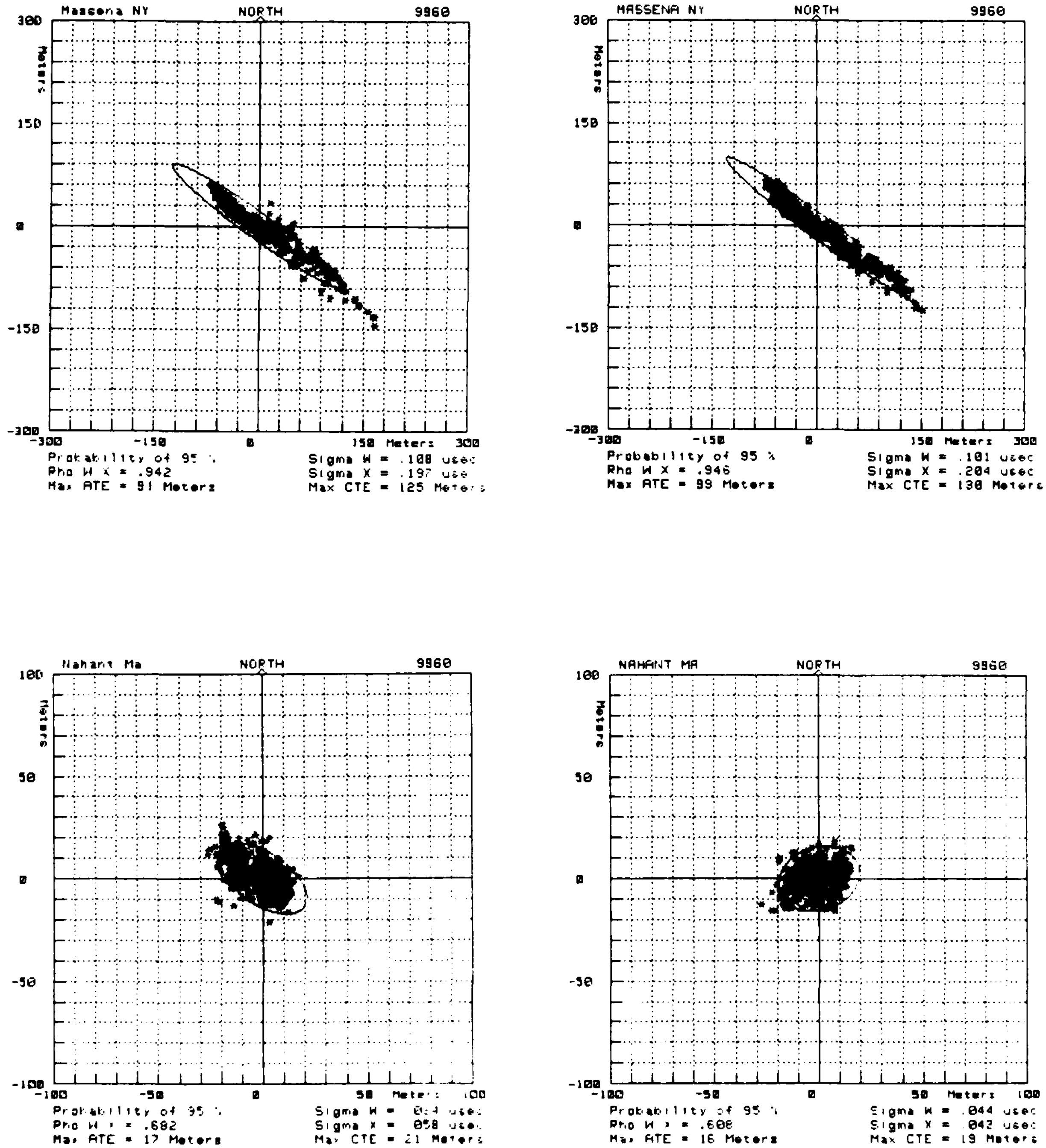


Figure 3-17 (Con't) Comparison of Actual and Revised Predicted Scatter Plots

Site	Parameter	Actual	Predict	Error
Yorktown	ATE	25	29	+4
	CTE	18	24	+6
Lewes	ATE	9	17	+8
	CTE	15	18	+3
Gloucester	ATE	9	12	+3
	CTE	29	25	-4
Avery Pt.	ATE	115	101	-14
	CTE	15	18	+3
Massena	ATE	91	99	+8
	CTE	125	130	+5
Nahant	ATE	17	16	-1
	CTE	21	19	-2

Table 3-11 Revised Comparison of Predicted vs Actual CTE and ATE Statistics

Besides there being better agreement between the predictions and the observations in general, we also have a slight decrease in the bias towards positive prediction errors (the score now being 8 to 4). Nevertheless, we still tend to err on the conservative side.

In figures 3-16 and 3-17, as well as tables 3-10 and 3-11, we have a large amount of information. A good way to present the information in digestible form is by a regression analysis wherein we attempt a straight line "explanation" to the relationship between our predictions and the actual performance. Figure 3-18 contains the regression line plot in the case wherein the predictions are based on estimates not using the location of interest. Figure 3-19 contains the results in the case wherein even the location of interest was used in making the prediction.

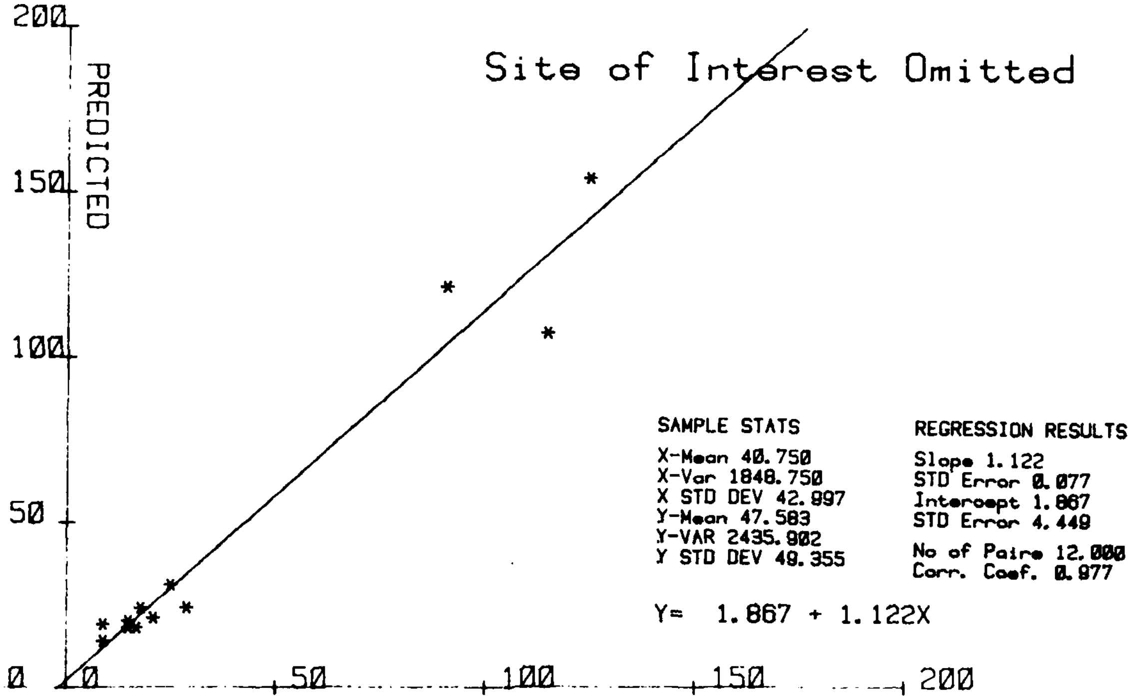


Figure 3-18 Regression Analysis Results, Actual ATE and CTE vs Predicted, Site of Interest Omitted from Prediction Estimates

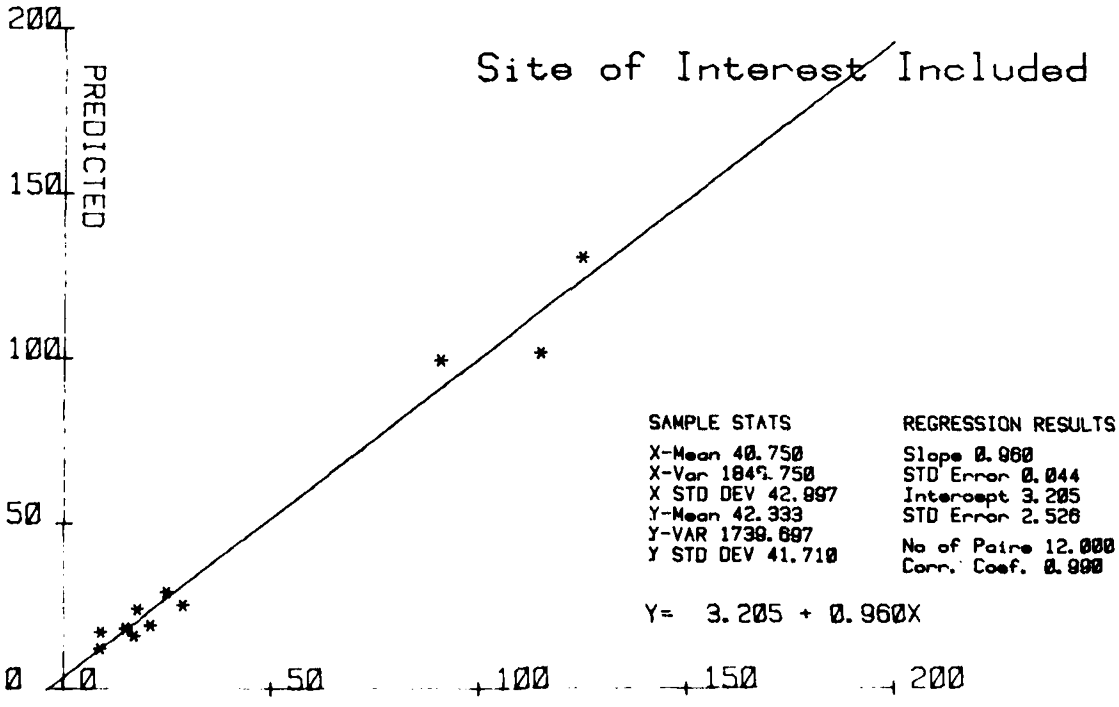


Figure 3-19 Regression Analysis Results, Actual ATE and CTE vs Predicted, Site of Interest Included in Prediction Estimates

Before speaking about the the conclusions, we should note that we will want to use the model to make drms predictions as well as CTE and ATE predictions. Thus, we have computed actual and predicted drms statistics (both types of predictions) and present the results in figures 3-20 and 3-21.

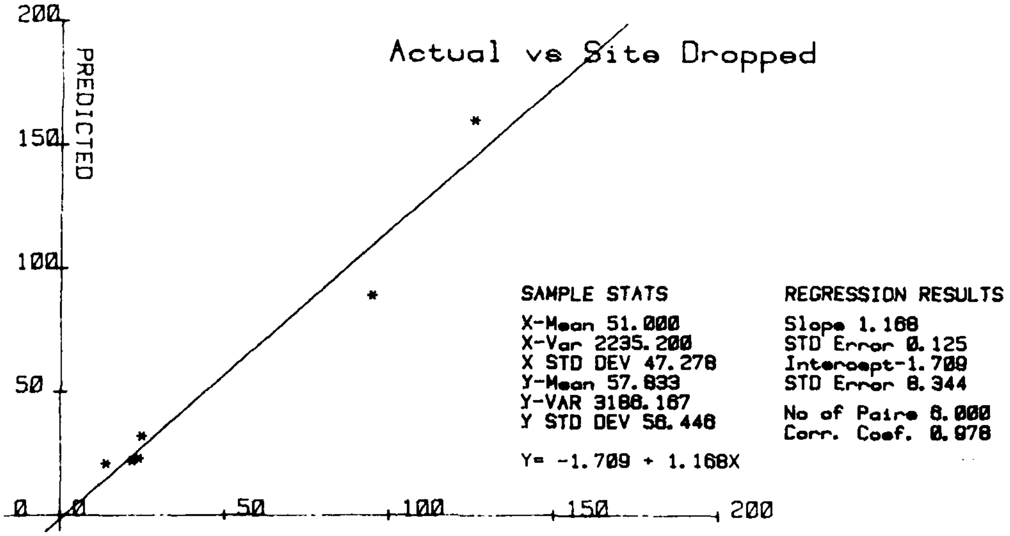


Figure 3-20 Regression Analysis Results, Actual 2-drms vs Predicted, Site of Interest Omitted from Prediction Estimates

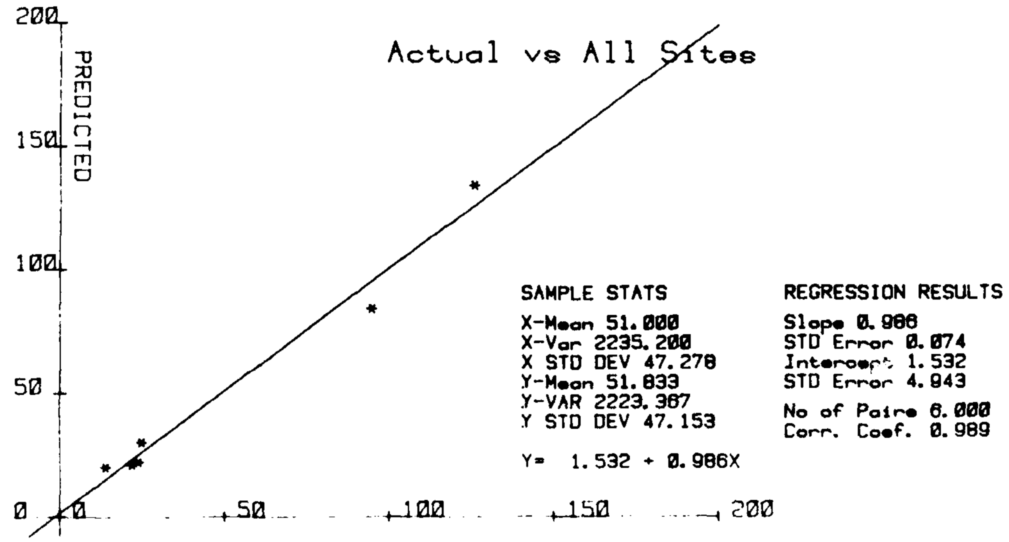


Figure 3-21 Regression Analysis Results, Actual 2-drms vs Predicted, Site of Interest Included in Prediction Estimates

Examining the 2-drms regression results, we see a "residual sigma" of 8 meters (it is important to recall this is for 2-drms) when the site of interest is exluded from the prediction process. We fully expect to do a better job of predicting than this. We also see a "residual sigma" of just under 5 meters (again, 2-drms) when we include the site of interest in the prediction process. We expect the "true confidence indicator" to be somewhere in this region.

Regarding the CTE and ATE predictions, the residual sigma is 4.4 meters (for the 95% probability ellipse) when the site is excluded from the prediction process and 2.5 meters when it is included. Again, we expect the "true confidence indicator" to be somewhere in between. As a slight distinction to the drms comment, we can be a little more specific. When we are generating CTE predictions for a given harbor, and that harbor features a Harbor Monitor site, we expect the lower figure to be representative of the confidence to expect. If the harbor being considered does not feature a Harbor Monitor, the larger figure is probably more representative. This line of thinking is consistent with the common sense thought that, all other things being equal, it makes sense to put Harbor Monitors in major harbors of interest.

The results presented in this section should be kept in mind in evaluating the predictions we will make in Section 5. Before presenting the predictions, we will present an analysis of the S.E.U.S. data.

4. Southeast U.S. Chain Harbor Monitor Data Analysis

4.1 Harbor Monitor Data

We turn our attention to the S.E.U.S. Loran-C chain 7980 shown in figure 4-1 with the Harbor Monitor sites superimposed. The 7980-W and -X SAM is at New Orleans and the 7980-Y and -Z SAM is at Mayport.

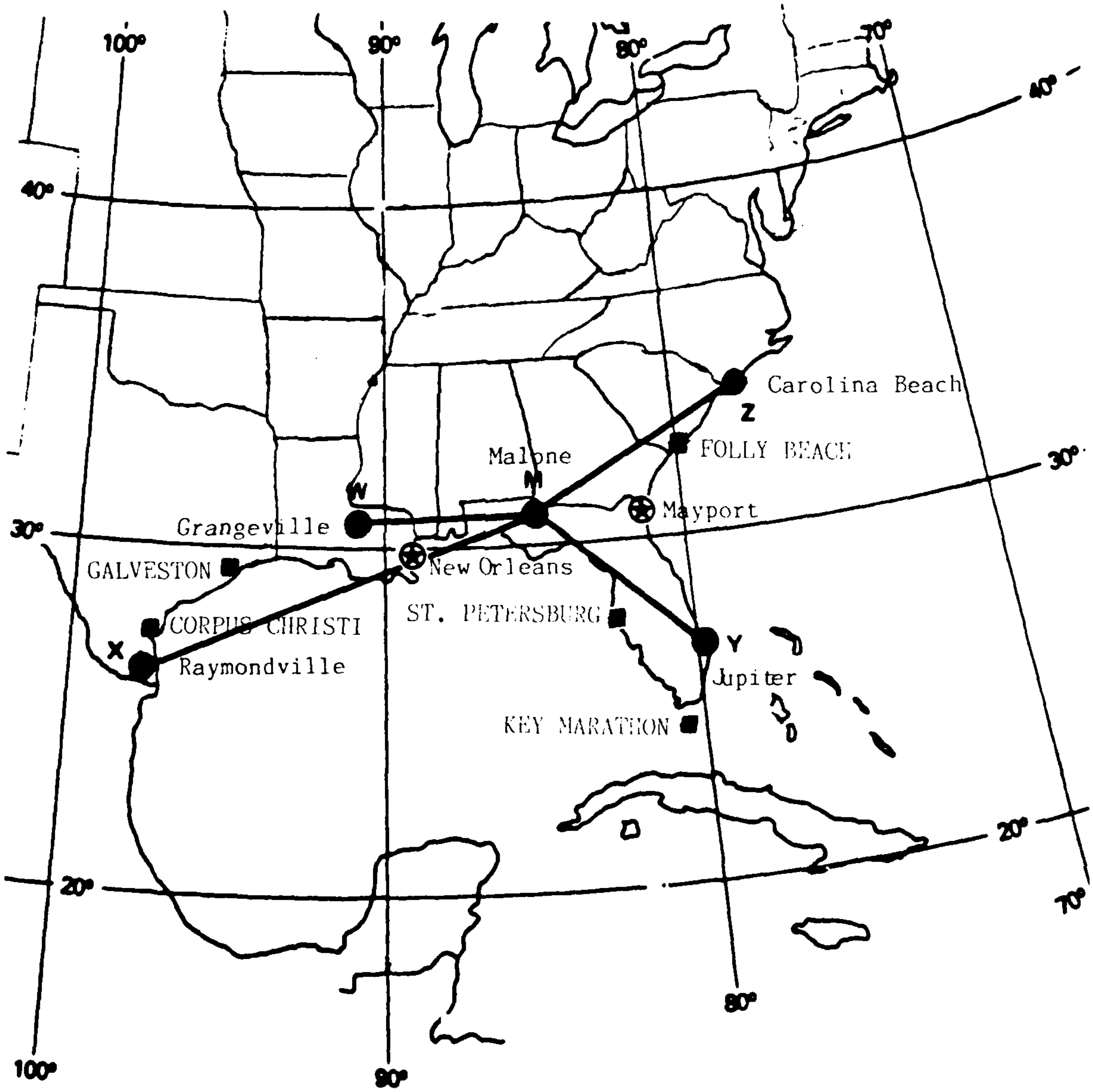


Figure 4-1 Southeast U.S. Loran-C Chain and Harbor Monitor Sites

As discussed in Section 2, we did not begin to obtain S.E.U.S. data until the late Spring of 1982. Thus, we have obtained a full year of data just before "press time." A summary of the data base for each site is provided in Table 4-1.

Site	S.E.U.S. Data Base Start Date	Stations Tracked	Comments
Charleston	4/23/82	W, Y, Z	
St. Petersburg	4/27/82	W, Y, Z	
Galveston	4/27/82	W, X, Y	
Destin	8/26/81	X, Y, Z	A-2 Control Site 7980X record incomplete
Key Marathon	5/13/83	W, Y, Z	
Corpus Christi	5/14/83	W, X, Y	
Mayport	5/01/82	Y, Z	A-1 for Y and Z
New Orleans	5/01/82	W,X	A-1 for W and X

Table 4-1 Summary of S.E.U.S. Harbor Monitor Site Data Bases

As in the previous section, we will require a full year of data before including the site in the analysis. Thus we perform the analysis with data collected over the year beginning 1 May 1982. The actual data records are provided as Appendix B.

4.2 Application of the Model to the 7980 Chain Data Records

Following the presentation technique established in Section 3, let us examine the results of the application of both the straight and "Mod 1" models to the "combined chain" data. The results are presented in Table 4-2 and figure 4-2.

Site	Original Data Record Standard Deviation	Straight DRD Model Residuals Standard Deviation	Percent Reduction	Mod 1 DRD Model Residuals Standard Deviation	Percent Reduction
Charleston - W	135	67	50 %	25	81 %
St. Petersburg - W	38	32	16	15	61
Galveston - W	35	38	-9	20	45
Galveston - X	51	20	61	16	70
Destin - X	24	20	17	16	36
Charleston - Y	23	21	9	24	-2
St. Petersburg - Y	41	49	-20	27	33
Galveston - Y	43	42	2	27	37
Charleston - Z	26	22	15	12	52
St. Petersburg - Z	67	22	67	12	81
RMS Std. Dev.	57.6	36.4	37 %	20.2	65 %

Table 4-2 Tabulation of Mod 1 Model Estimation Results - Entire 7980 Chain

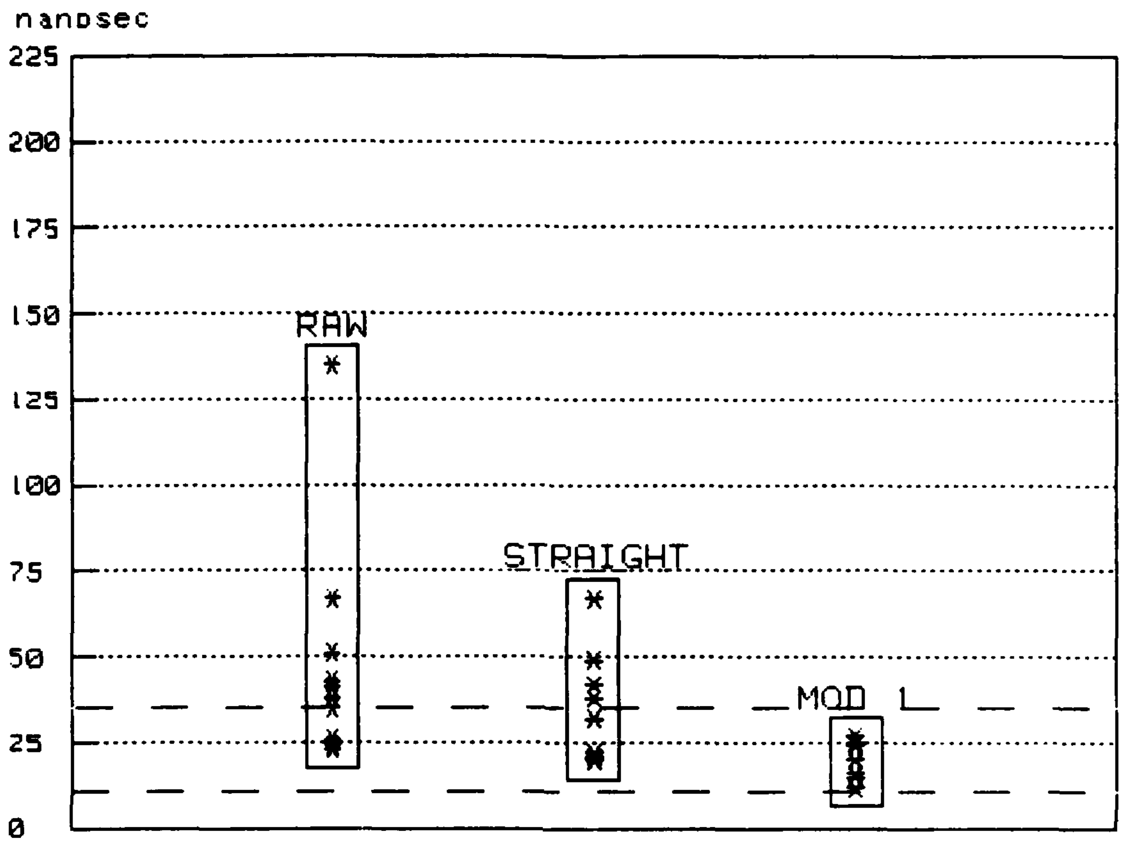


Figure 4-2 Summary of Model Results - Entire 7980 Chain - Combined Model

One "administrative" matter should be mentioned right away. In the previous section we avoided using data from A-2 monitor sites, prefering to use only Internav 404 based data. For the 7980-X baseline, however, we will only have one data site (excluding the A-1 site) if we stick to this policy. As originally designed, the experiment was to include 7980-X data from St. Petersbug. Indeed a large 7980-X data base from that site is available. Unfortunately, it was deemed necessary to temporarily stop 7980-X data collection and the site so that high-density data could be collected in support of an aborted attempt by the State of Florida to explore precision Loran-C in Tampa. Since there is a large "gap" in the St. Petersburg 7980-X data record, we have avoided analysis complexity by simply ignoring the available data. We use the Destin data as the second 7980-X record by making the model modification discussed in Section 2.5 - i.e., by modifying the $\underline{A}$-matrix to reflect our conviction that the Destin data will contain no "common-error" term.

That matter noted, we should concentrate on the excellence of the results. The residual "RMS STD. DEV.," after Mod 1, is considerably better than we were able to achieve with the N.E.U.S. data. Indeed, we are essentially at the "optimal level" indicated by the 18 nsec standard deviation estimate of the previous section. To see how this came about, we should examine the actual estimates and the data record residuals. These are provided in figures 4-3 and 4-4.

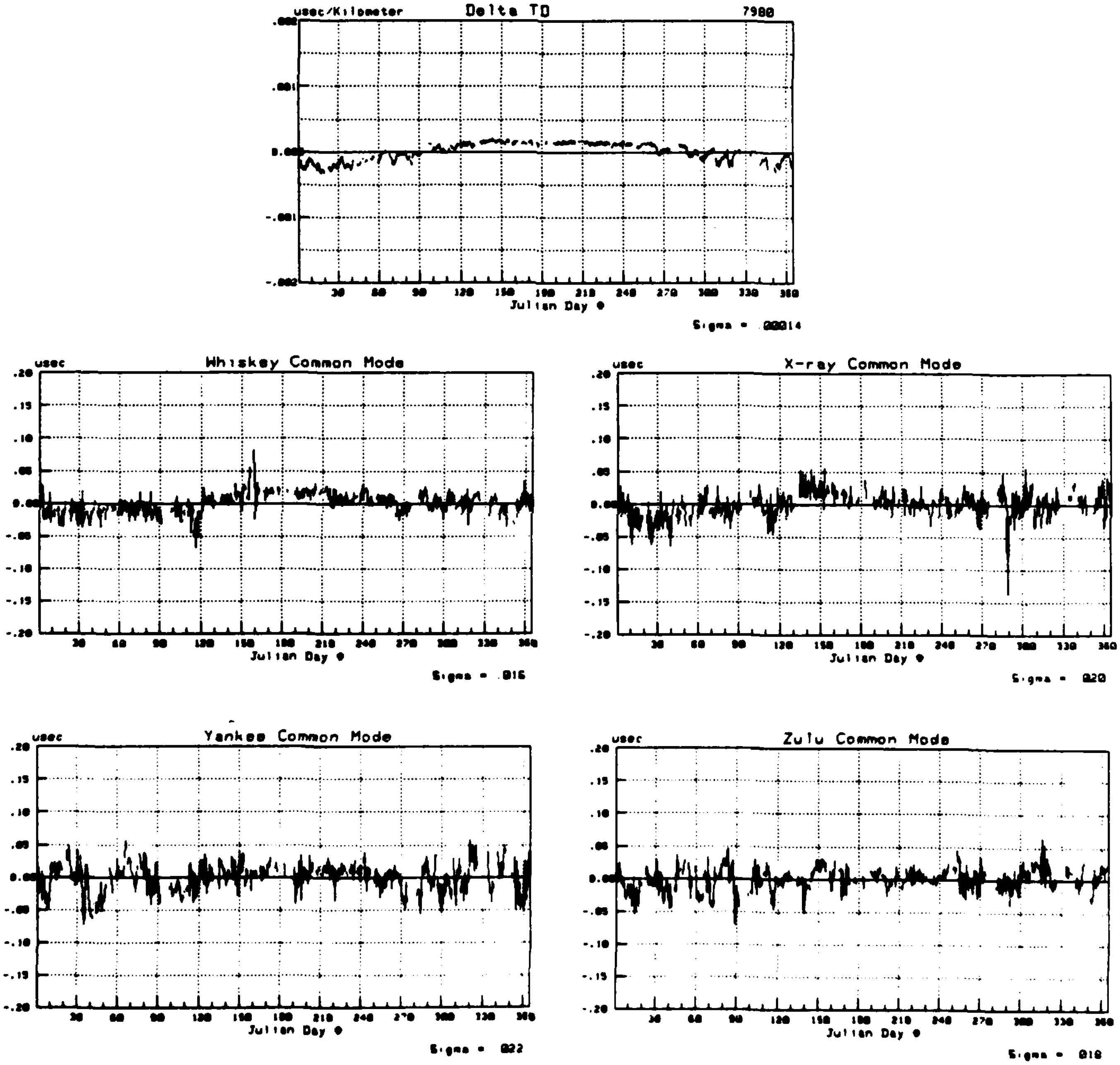


Figure 4-3 "Mod 1" DRD Model MMSE Estimates, 7980 Chain

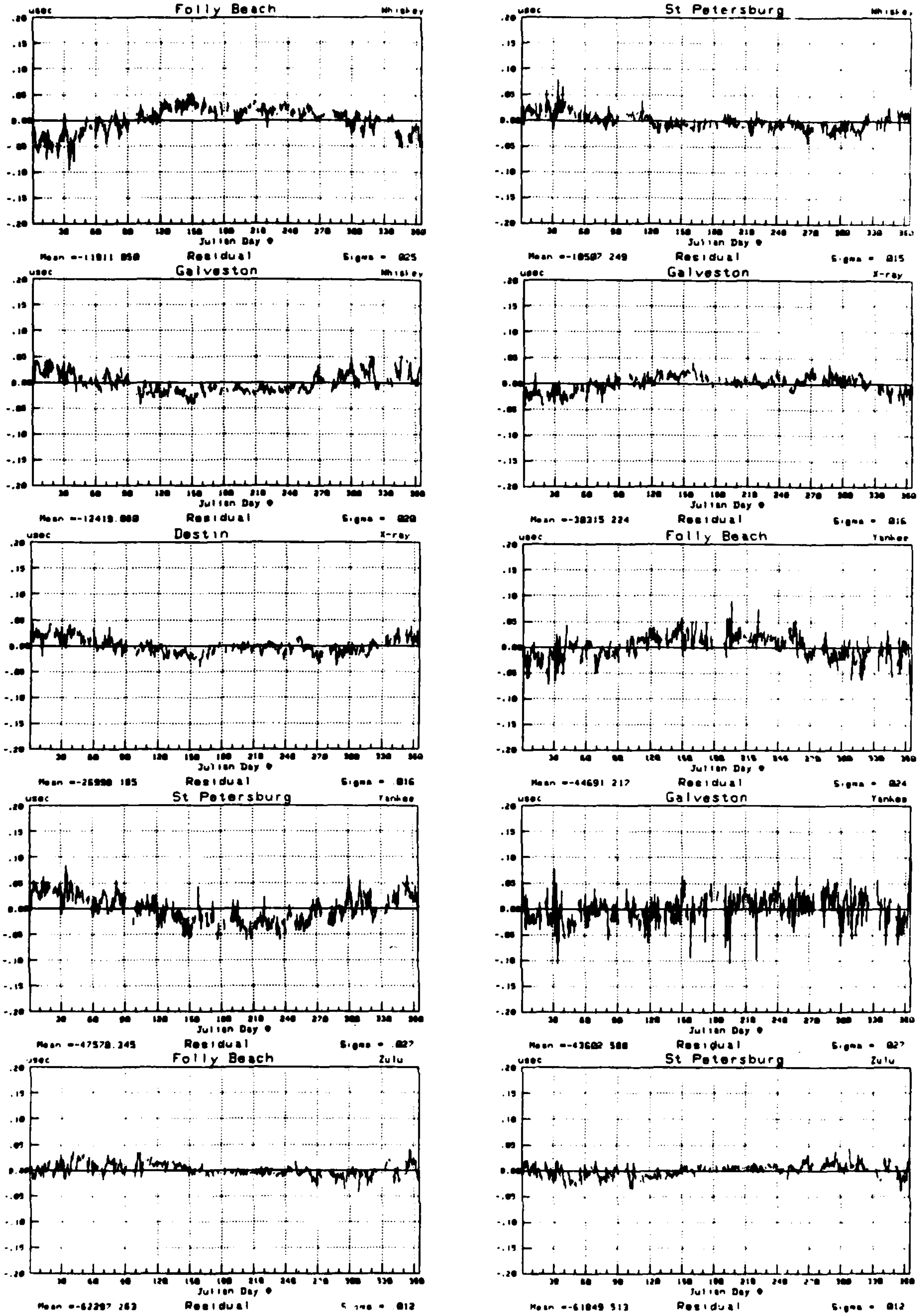


Figure 4-4 "Mod 1" DRD Model MMSE Estimate Residuals - 7980 Chain

A striking feature of the model components is the dominance of (some of) the common error terms. By northern standards, there just does not seem to be much of a dTD term. From one point of view, the low dTD term is as expected. Thus, the model results are pleasing. From another point of view, however, we feel there is just a little too much structure in the common error terms for us to be completely satisfied. Since we have a relatively low number of data sites, we have concern that we are not doing an adequate job of sampling the signals.

There is nothing we can do to eliminate these concerns for purposes of this report. We should note, however, that they provided the motivation for us to proceed with the installations of the two new sites noted in Table 4-1. For now, we will simply use the estimates indicated in Figure 4-3 as the basis of our predictions and note a future report, based on data being collected now, should provide verification.

There is one further analysis we should not pass up the opportunity to perform. In the S.E.U.S. region, we have a very temperate climate. As indicated in Table 4-1, we also have a reasonable amount of high quality data upon which our present model works very well (in spite of the gloomy sentiments expressed in the above two paragraphs, we cannot ignore the 65% reduction in the standard deviation - that's 9 db). Thus, we apparently have a good data base, no seeming propagation anomalies, and a temperate climate. This is an ideal time to challenge the validity of the "seawater counts for naught" assumption of the model.

We can carry out the challenge by applying the model many different times to the same data. Each different time we run the model analysis, we will let seawater count a different fraction of how much land counts in the DRD calculations which produce the A-matrix. We will let the residuals' root-sum-square be the figure of merit used to resolve the issue. The results of the iteration are indicated in figure 4-5.

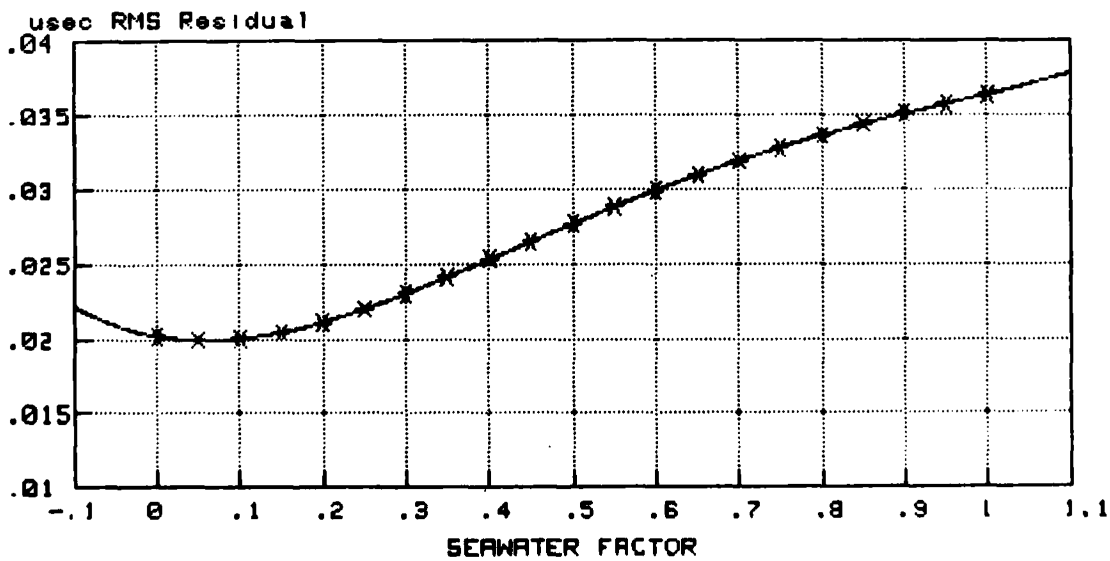


Figure 4-5 Effect of Varying "Seawater Factors" on DRD Model Performance

The results of the analysis, as indicated in the plot of figure 4-5 definitely show there is some factor, other than zero, that we should be using for the "seawater weight." Interestingly, however, we notice that, at a value of about 0.05, it is essentially negligible. We note further that this result was obtained with data taken in the mild climates of the south. The seawater effects can be easily argued as even more negligible in northern regions. Thus, we have further confirmation of the applicability of our primary mod to the basic DRD model.

4.3 Model Prediction Performance

As was done with the N.E.U.S. data, we want to obtain some measure of how well the estimates will perform as the bases for predictions. We will begin by generating predicted fix scatter plots and comparing them with the observed results. As before, we use an assumed course of due north and generate 95% probability ellipse ATE and CTE statistics. Unlike the analysis for the N.E.U.S. data, here we do not really have enough data points to omit the site of interest from the estimation process. Thus, we will present only the "site of interest included" plots. To apply the results, we simply need bear in mind the results of the more detailed comparison done with the N.E.U.S., tempered by the fact that the model is performing much better in the S.E.U.S. region.

Site	Parameter	Actual	Predict	Error
Charleston	ATE	17 m	24 m	+7 m
	CTE	14	18	+4
St. Petersburg (YZ)	ATE	42	34	-8
	CTE	47	46	-1
St. Petersburg (WY)	ATE	50	66	+16
	CTE	24	27	+3
Galveston (WX)	ATE	138	122	-16
	CTE	96	83	-13
Galveston (XY)	ATE	91	64	-27
	CTE	54	37	-17

Table 4-3 Comparison of Predicted vs Actual CTE and ATE Statistics

Actual

Predicted

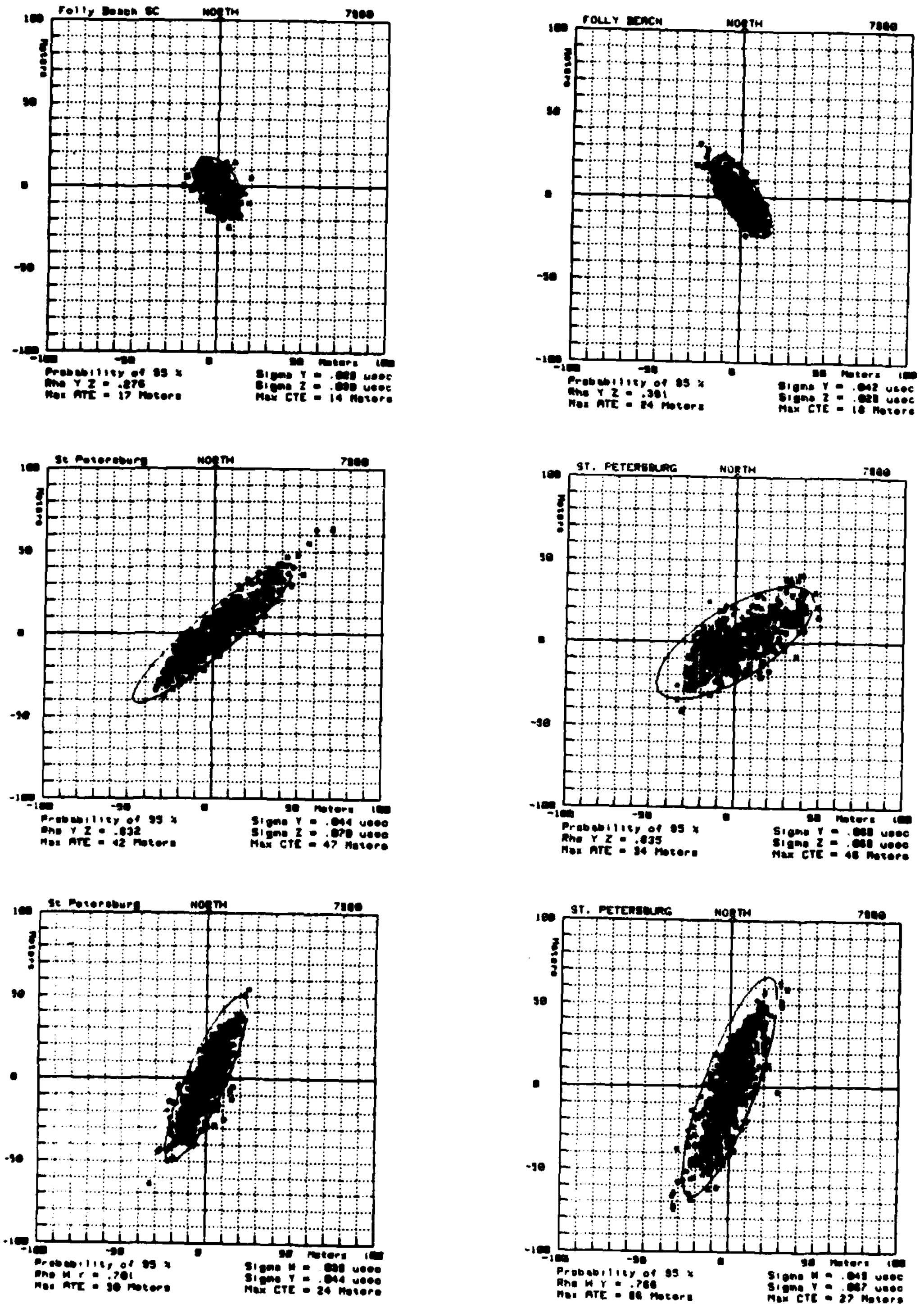


Figure 4-6 Comparison of Actual and Predicted Scatter Plots

Actual | Predicted

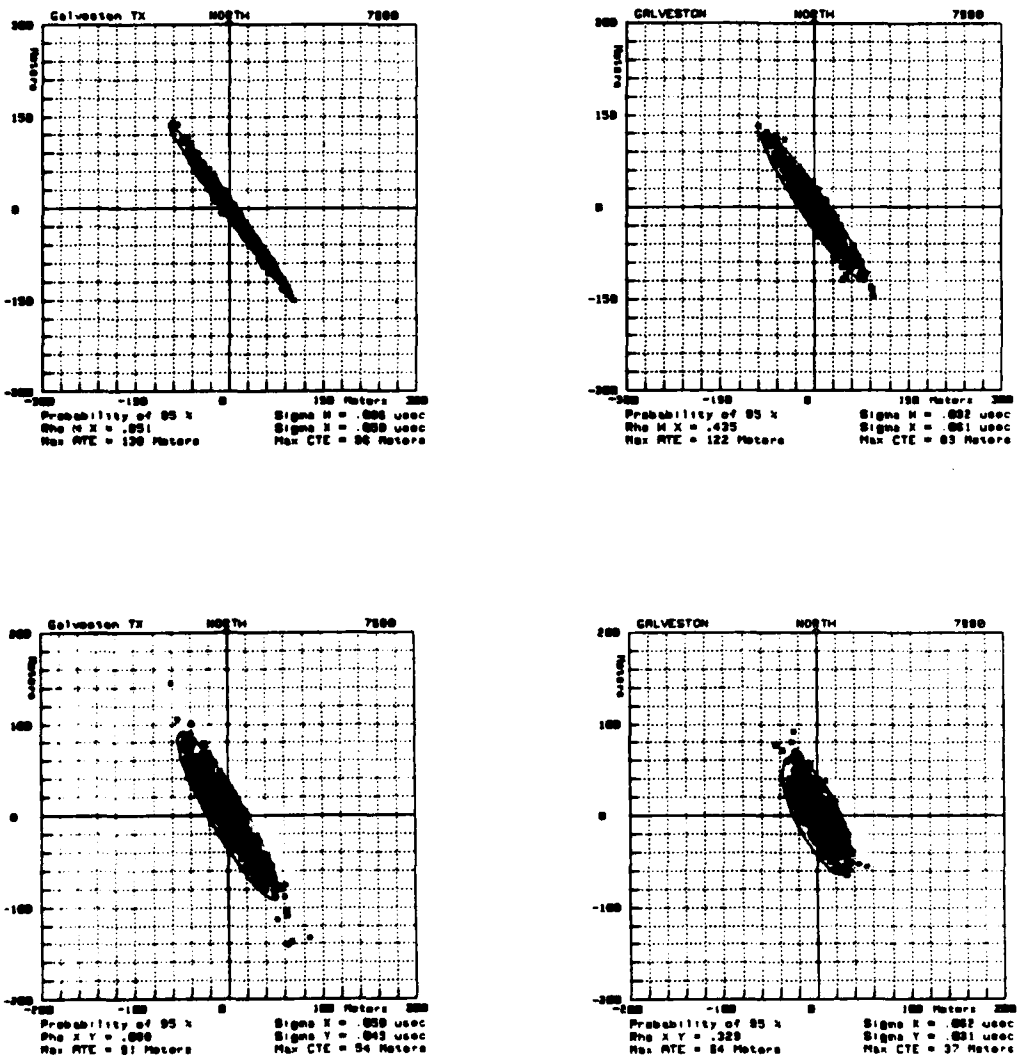


Figure 4-6 (Con't) Comparison of Actual and Predicted Scatter Plots

Although the results are adequate for our purposes, they are not as good as the results from the similar NEUS analysis. This finding, coming just after we have claimed excellent results "in the TD domain," is a good illustration of the major problem with Loran-C in the Gulf of Mexico: geometry. In particular, we have problems with the geometry at Galveston. This geometry issue will be discussed in further detail in the next section. For now we simply note it in passing as the reason for the larger than usual prediction errors.

Proceeding with the evaluation of the estimation procedures, we summarize the data of figure 4-6 with the regression analysis whose results are depicted in figure 4-7.

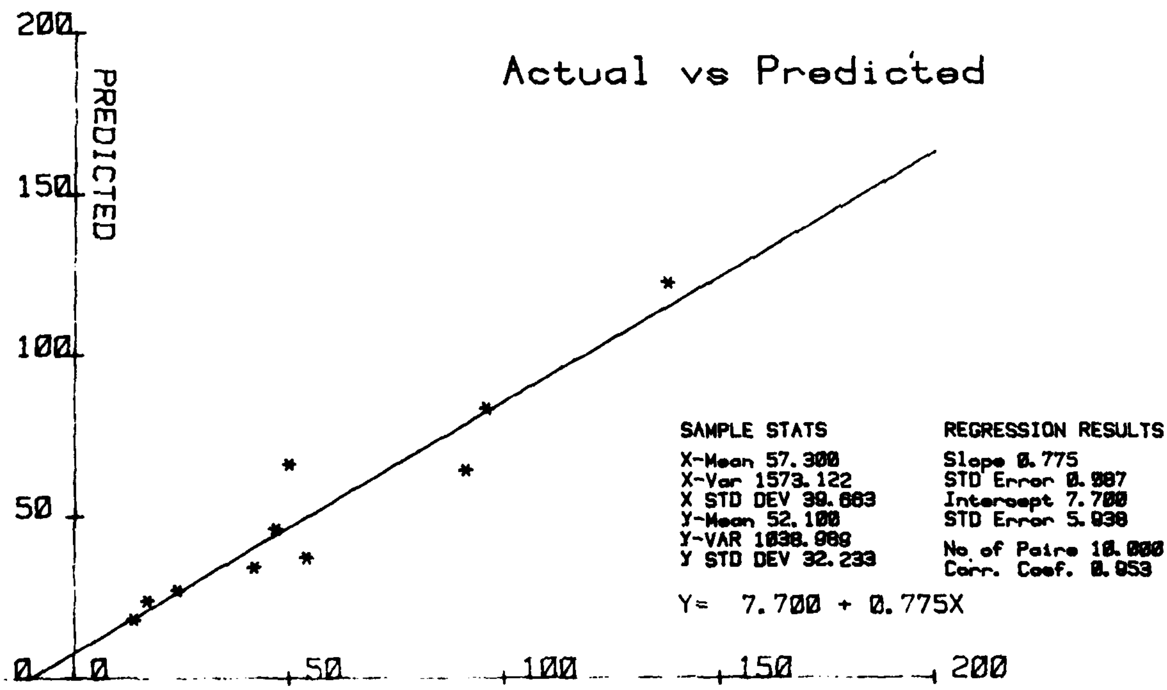


Figure 4-7 Regression Analysis Results, Actual ATE and CTE vs Predicted,

Before offering specific comments on these results, let us predict the drms statistics and, via another regression analysis plot, compare the predictions with the observed results. This is carried out in figure 4-8.

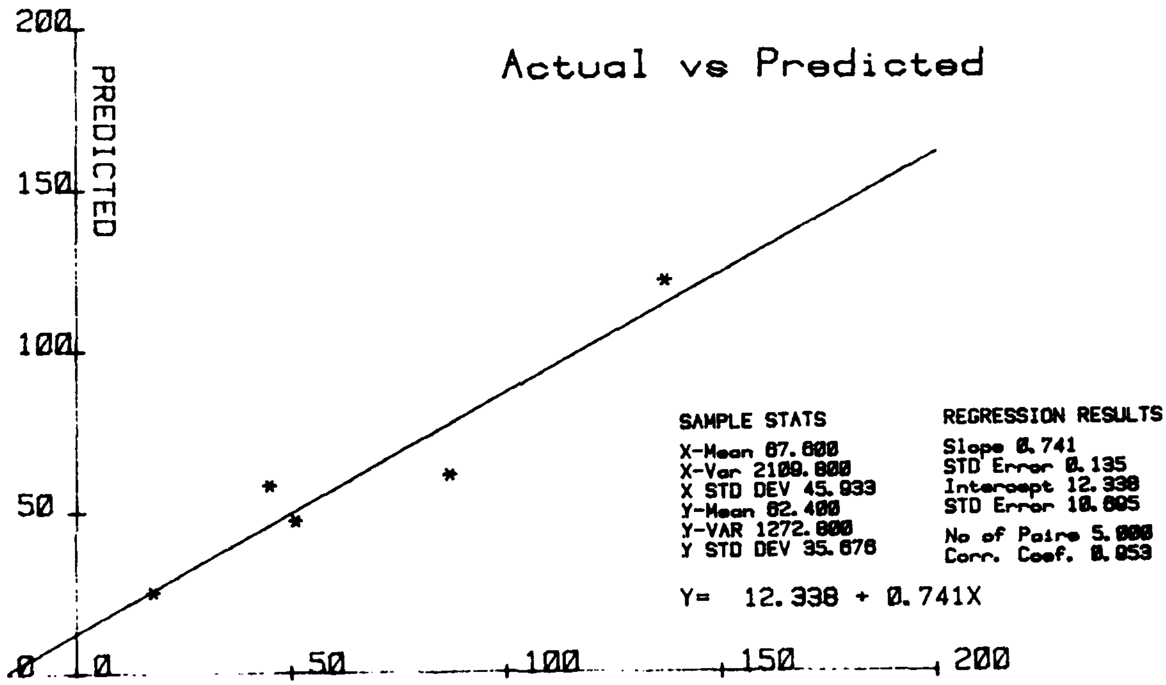


Figure 4-8 Regression Analysis Results, Actual 2-drms vs Predicted

The results of these analyses show we have a "residual sigma" of 10.7 meters for the 2-drms estimate and of 5.9 meters for the ATE/CTE estimates. Because of the aforementioned geometry problems, these are not as nice as the NEUS residuals. Again, however, they are adequate and must be stated so that the reults of subsequent sections can be properly interpreted.

At this point, we are fully armed and ready to apply the results of the several years spent collecting data, or struggling to get ready to collect data. We have estimates, in year-long sequence form, necessary for the prediction of the Loran-C signal variations at any point for which we are provided the correct DRD's. Additionally, we have presented analyses which indicate the confidence we can have in these predictions. Thus, we begin the prediction process.

5. Loran-C Performance: Northeast and Southeast U.S.

5.1 Application to Major Ports, Northeast and Southeast U.S.

There is nothing particularly glamorous about the steps which take us from the last two sections to the results to be presented herein. Basically, we had to compute modified DRD's at about 1000 points. Unfortunately, at this stage of the process, the range modifications (what percentage is type I land, type II land, seawater) had to be calculated manually. Perhaps even more of a burden was the requirement to create an adequate description of the channels comprising the major ports of the U.S. As many times as this may have been attempted - in one form or another - it had never been done in the manner exactly suited to our purposes.

We recognize that this is not the last time this (and future) Loran-C data will be processed. If we can help it, however, this is the last time anybody should ever have to do the calculations we have suffered through. We will accomplish this via the extensive set of Appendices we will publish herein and in subsequent reports.

In Appendix C, we provide a "package" for each of the major river/harbor areas of the N.E.U.S./S.E.U.S. region. Each package begins with a "reach description" table such as illustrated in Table 5-1 (for Corpus Christi). We name and number the channel for future reference and identify its midpoint position and course. Finally, we note its "half-width." Armed with this information and the Loran-C signal component estimates from Section 3 or 4, we are ready to predict how well Loran-C can keep a vessel inside the channel.

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Aransas Pass	27-49-50 N 97-01-59 W	301°T	92 m
2	Corpus Christi Cut A	27-49-37 N 97-08-52 W	258	61
3	Corpus Christi Cut B	27-48-36 N 97-18-32 W	270	61
4	Corpus Christi Hwy Br	27-48-45 N 97-23-46 W	281	46
5	Turning Basin	27-48-47 N 97-24-25 W	268	126
6	Industrial Canal	27-48-55 N 97-25-09 W	294	61
7	Avery Pt. Turning Basin	27-49-07 N 97-25-35 W	316	110
8	Industrial Canal	27-49-17 N 97-25-52 W	294	61

Table 5-1 Corpus Christi Reach Description

The next section of the package tabulates the predicted, 99.9% probability CTE statistic for each reach. When compared to the channel half-width, adjusted for vessel half-width, this CTE prediction allows the computation of an expected error margin. The entries in the error margin column are marked with asterisks as discussed in Section 2. Figure 5-2 shows an example of the performance prediction listing.

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
1	76 m	75 m	0 **
2	45	197	-142***
3	45	171	-126***
4	30	136	-106***
5	110	179	-69***
6	45	86	-41***
7	94	20	74
8	45	86	-41***
9	15	231	-216***
10	15	128	-113***
11	15	76	-61***
12	15	30	-15***
13	25	128	-103***

Table 5-2 Loran-C Performance Predictions, Corpus Christi

The final part of each package is the channel plot. As illustrated in figure 5-1, this contains information similar to that shown in Table 5-2 but also gives a graphical indication of the lengths of the channel reaches. We will examine the results of the port-by-port analysis in a later section. First, however, we should discuss a further use of the performance prediction methodology we now have available.

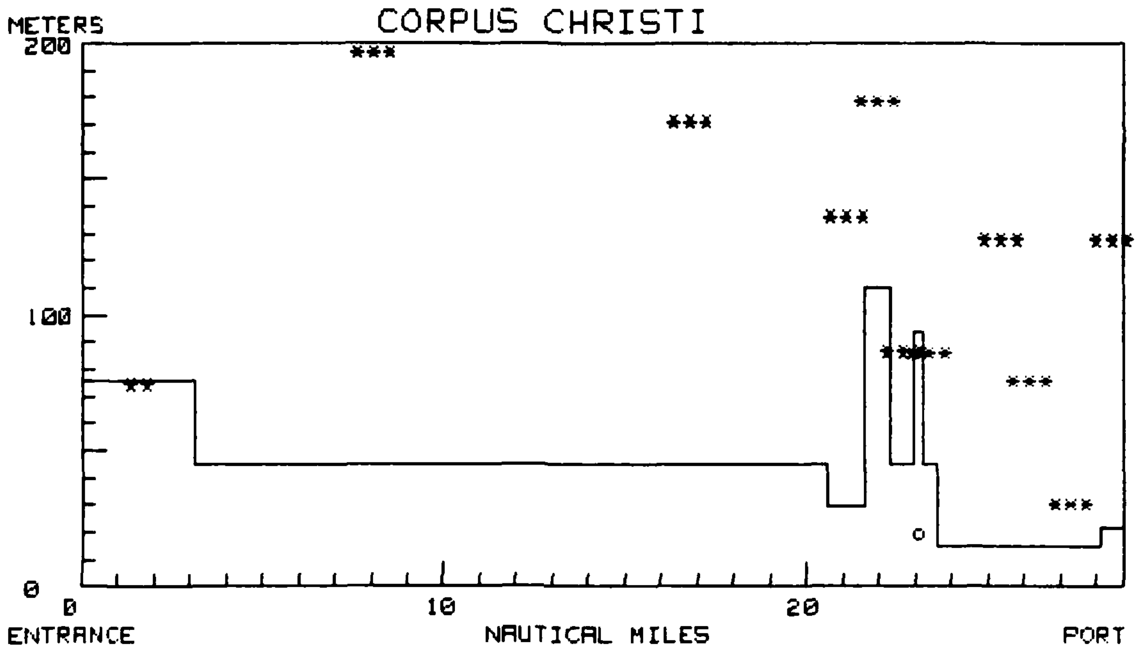


Figure 5-1 Channel Plot, Loran-C Predicted Performance, Corpus Christi

5.2 Application to the Generation of Loran-C Accuracy Contours

At the end of Section 2 we mentioned the need, first identified in reference 15, to obtain a better methodology for predicting TD variation statistics throughout a chain coverage area. From this would come more realistic "chain accuracy contours." Whereas this matter is not, strictly speaking, an "HHE Loran-C" one, it is a very important radionavigation one. As part of ongoing efforts in the federal radionavigation planning process discussed briefly in Section 1 and formally in reference 17, the following question is being posed: how good would a system (e.g., GPS) have to be to qualify as a bona fide replacement for Loran-C? With questions like this being posed, any improvements we can make in the methodology to generate Loran-C accuracy contours would be most welcome.

Also near the end of Section 2, we mentioned some of the different types of accuracies that are associated with navigation systems, e.g., absolute, repeatable, relative. To be most correct, we should call what we are about to present "HHE philosohy accuracy." We use this term because, under the HHE R&D project (GPS or Loran-C), we have long since concluded that an "HHE survey" is required. Thus, we are not concerned with what is called the "predictability" problem and thus are not really discussing "absolute accuracy."

Actually, we will be considering accuracy which is related to, but slightly different than, "repeatable accuracy." To see the relationship, recall that "repeatable accuracy" refers to the ability to return to a location previously determined by use of the same locating system. In assessing this type of accuracy, we must note that the difference in extremes must be included in the calculations. For example, note that by the strictest definition of repeatability, one could visit a place for the first time in late January and return in mid-July and no account of the known nature of the TD variation should be taken. For our purposes, however, we assume knowledge of the concepts illustrated herein and, thus assume we need simply be concerned with the ability to return, at any time, to an optimally determined location.

As a practical matter, what all this means is that when we generate year-long scatter plots such as those shown in figure 3-2, we use the year-long average to determine the plot origin. To relate what we present to the strict-sense definition of repeatability, we can note that under worst-case conditions, we would have to multiply our results by a factor of $\sqrt{2}$ to obtain repeatable accuracy figures. More on this later.

To generate the contours, we have used our model to predict the 2-drms statistics at various locations throughout the eastern coastal regions of the U.S. This procedure was carried out, on a triad-by-triad basis for the N.E.U.S. chain. The results were used to draw 40 meter, 80 meter, and 120 meter, 2-drms contours. These contours are plotted in figures 5-2 through 5-4.

We can begin the discussion of these plots by noting that we have not considered use of the 9960-Z baseline along the east coast. One reason for the omission is that, at present, we are not comfortable with our model of this baseline. Perhaps more important, however, is our concern about how far out to sea, if at all, this signal is usable for "precision" applications. Realistically, it must be conceded that the signal barely makes it to the east coast. Finally, we note that, with control of the 9960-Z baseline at Plumbrook, the stability of that baseline is such that it contributes only marginally to the overall Loran-C stability along the east coast.

Another point worth noting is the way we have terminated the WY 120 meter contour of figure 5-4 in northern New England. Data from the Nahant site indicates the 9960-Y signal-to-noise ratio (SNR) is still "decent" by the time the signal reaches Boston. For the large part, however, the signal goes from Carolina Beach to Boston over water. As the path rotates counter-clockwise only a few degrees, however, the signal encounters a large amount

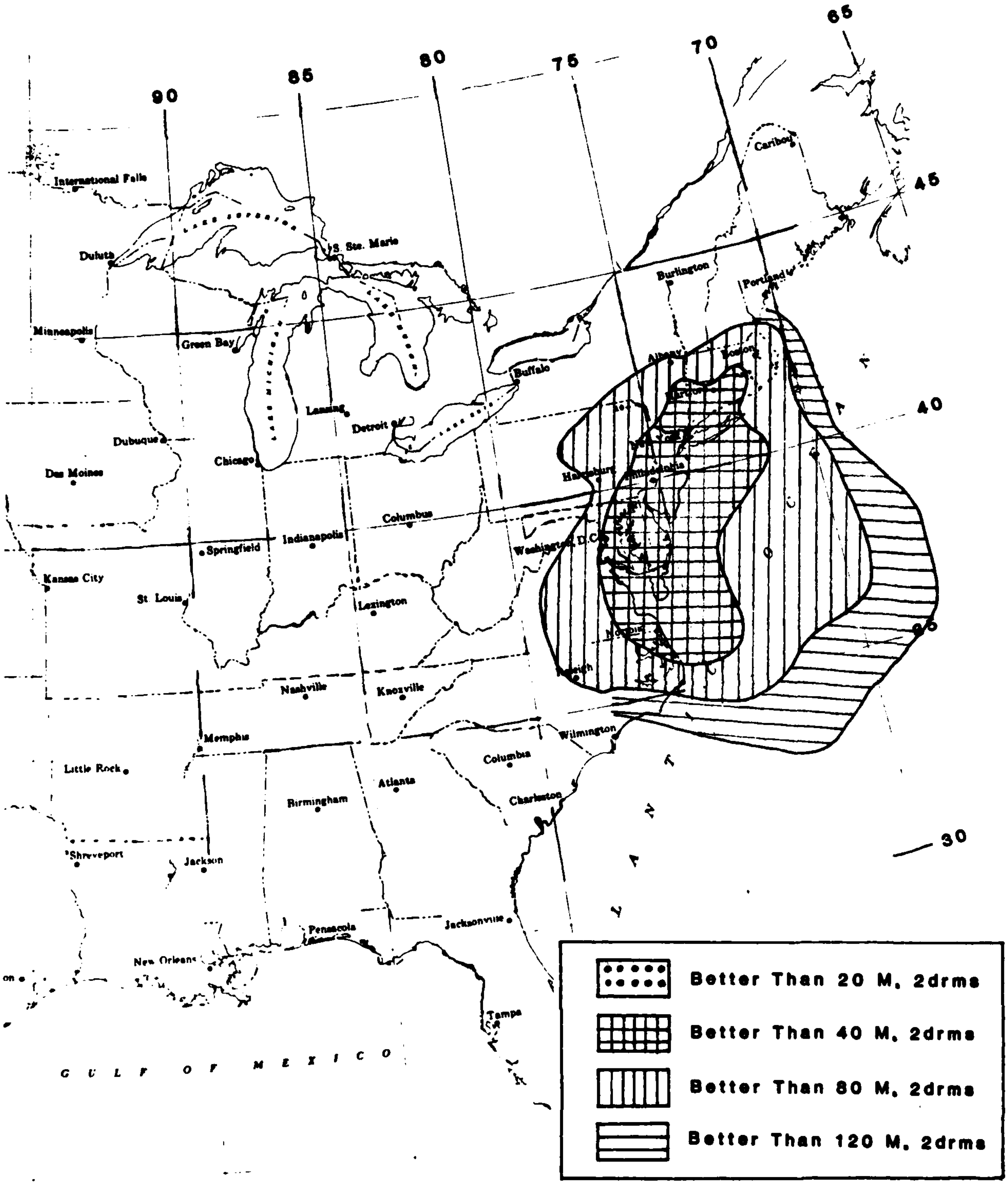


Figure 5-2 DRD Model Derived 2-drms Accuracy Contour, 9960-XY Contour

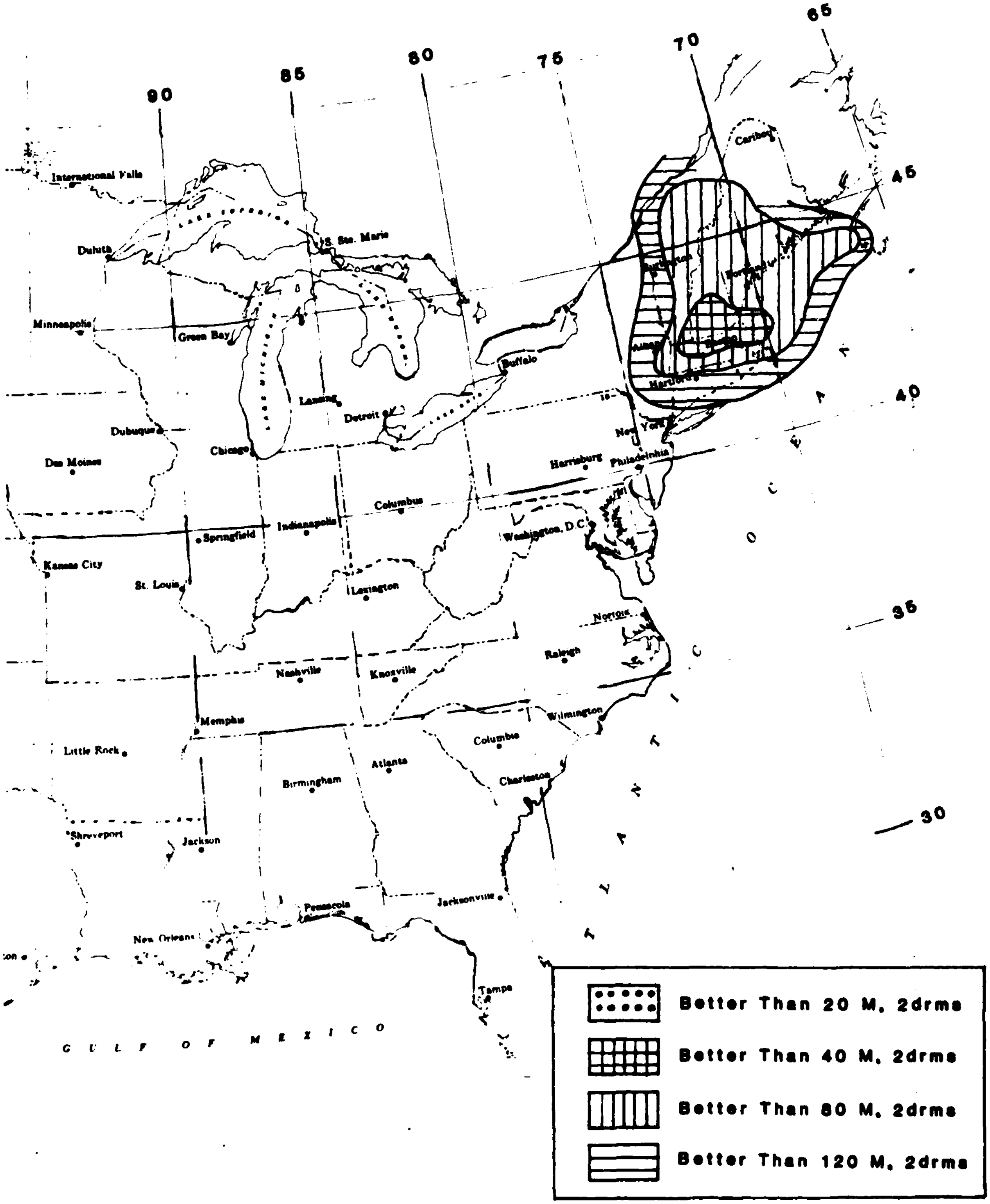


Figure 5-3 DRD Model Derived 2-drms Accuracy Contour, 9960-WX Contour

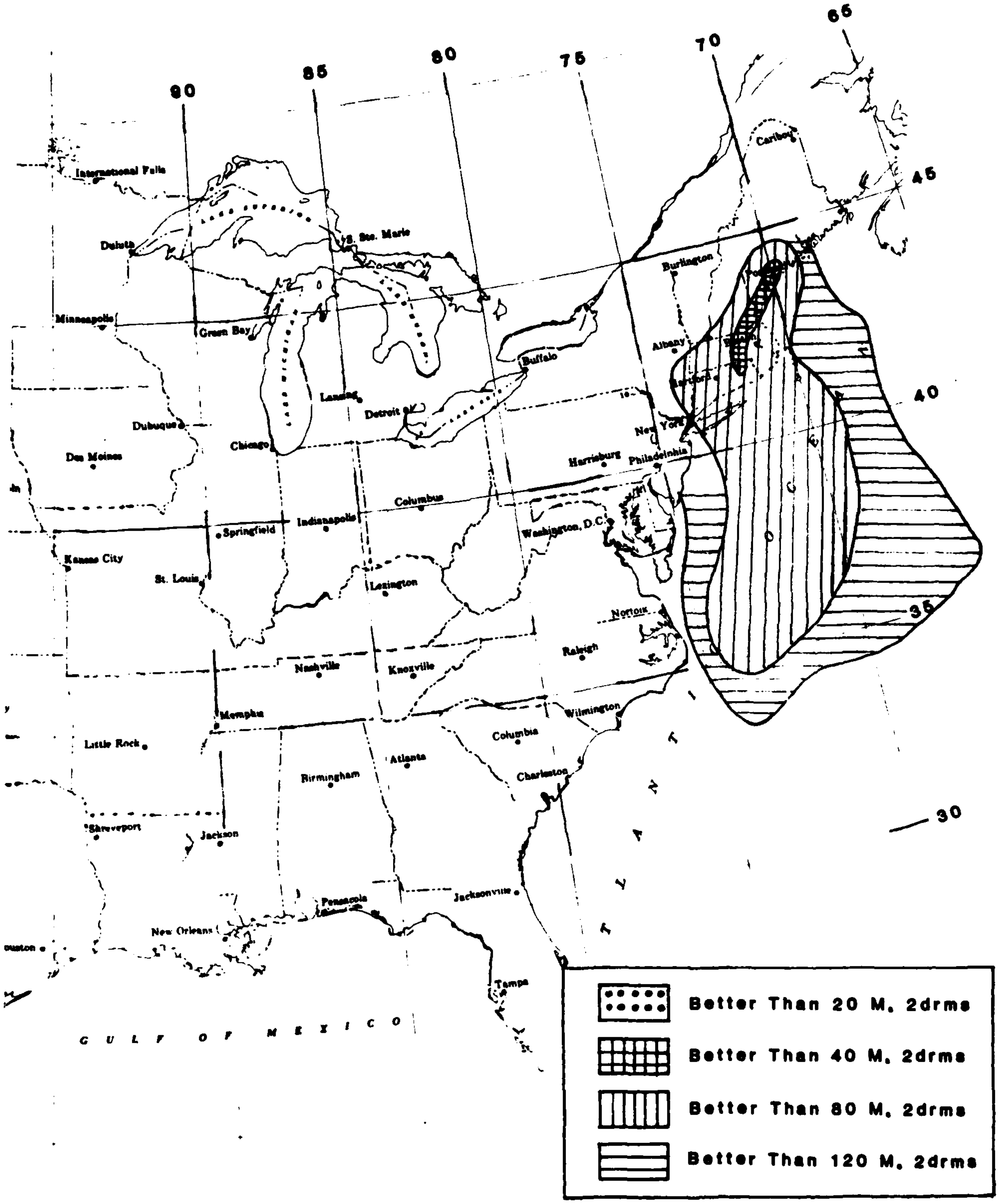


Figure 5-4 DRD Model Derived 2-drms Accuracy Contour, 9960-WY Contour

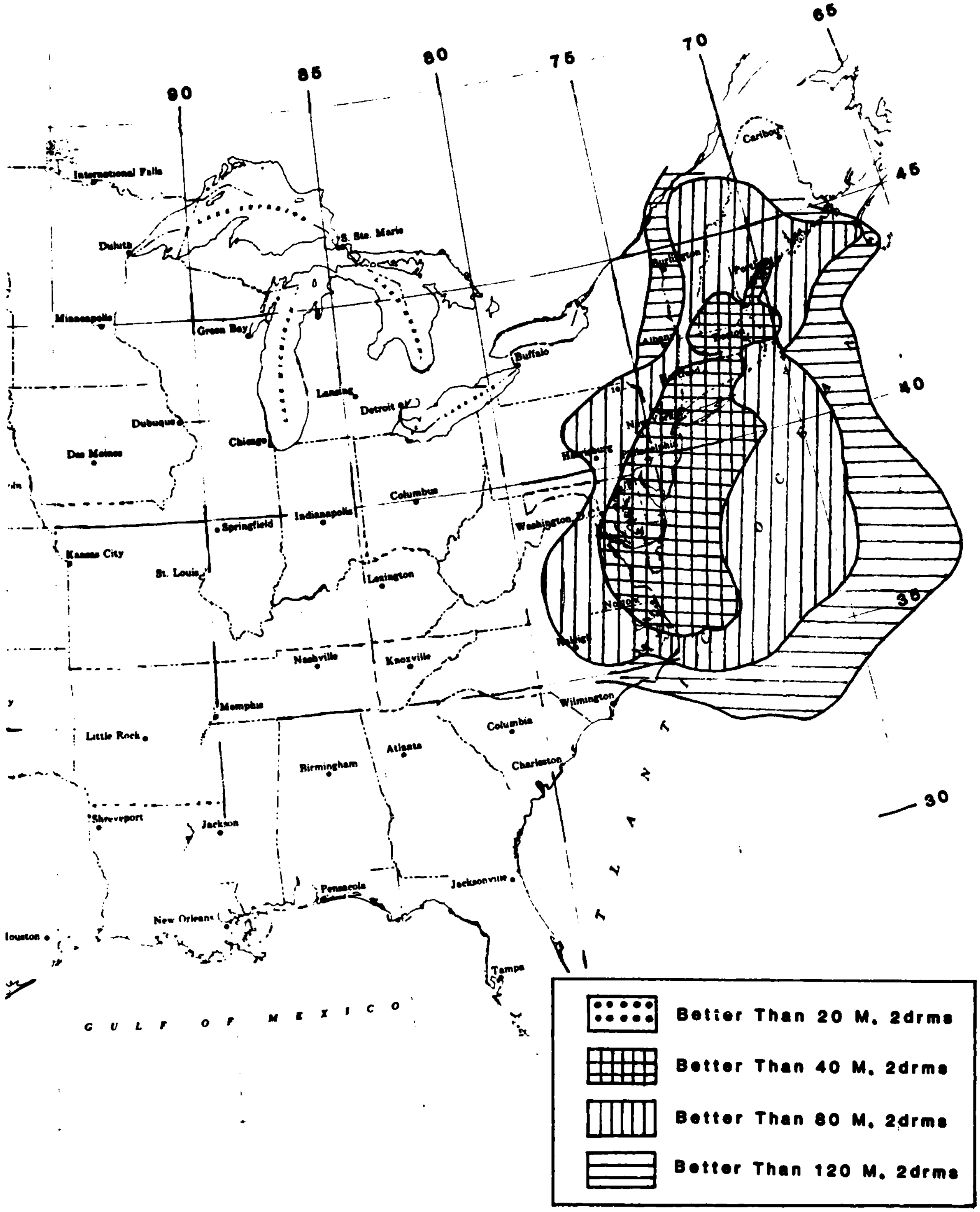


Figure 5-5 DRD Model Derived 2-drms Accuracy Contour, 9960-XY, -WX, -WY Composite Contour

of land. We have established no hard, fast rules for a minimum SNR but note we have assumed that "transmitter noise" dominates the "residuals" of our model so that the 20 nsec standard deviation, 0.5 pair correlation coefficient assumptions were defendable. Thus, we must be cautious about how far we claim the signals go. A similar amount of caution can be observed in the 9960-WX contour of figure 5-3. In figure 5-5, we have provided a composite contour of the 9960 chain accuracy throughout the northeast coastal region.

One final note must be made. It is somewhat clear from the figures that we have been cautious about accuracy claims over inland regions. This can be seen from the way we have terminated the 120 meter contours, but is further relected by the fact that we did not bother to plot any "larger error" contours. The primary reason for this is that we are principally concerned with the marine applications of Loran-C - this is, after all, an "HHE" project. As a related result of this marine emphasis, we simply do not have an adequate number of inland data points to go much further inland with the predictions. Without those sites, we are extremely cautious about the fidelity of the "Mod 2 DRD Model." Additionally, of course, we should be concerned about the more basic question of SNR limitations. As an overall comment, therefore, we must concede our reluctance to make extensive inland predictions.

One thing that is clear, of course, is the general pattern: the NEUS chain has been designed to optimize accuracy along the coast. The accuracy degrades as one proceeds inland. We feel confident that with an adequate number of inland monitors, we could extend the contours. We save that action, however, for the subject of future research should adequate interest in the issue materialize.

Turning our attention to the S.E.U.S. chain, we generate the "triad-by-triad" accuracy contours indicated in figure 5-6 through 5-9. A composite S.E.U.S. accuracy contour is shown in figure 5-10 and a combined N.E.U.S./S.E.U.S. contour is provided as figure 5-11.

Regarding the S.E.U.S. triads, notice that we do not generally consider any contours beyond the 80 meter contour. As a general comment, and as previously noted, the accuracy (or lack thereof) is primarily geometry-driven in the S.E.U.S. Thus, we have problem areas only in the "baseline extension" areas of the coverage regions whereas the overwhelming majority of the coverage area features high accuracy. Under these conditions, the largest portions of the "larger error" contours exist only if we make wild claims about how far the signals travel. We avoid the issue by simply stopping with the 80 meter contour.

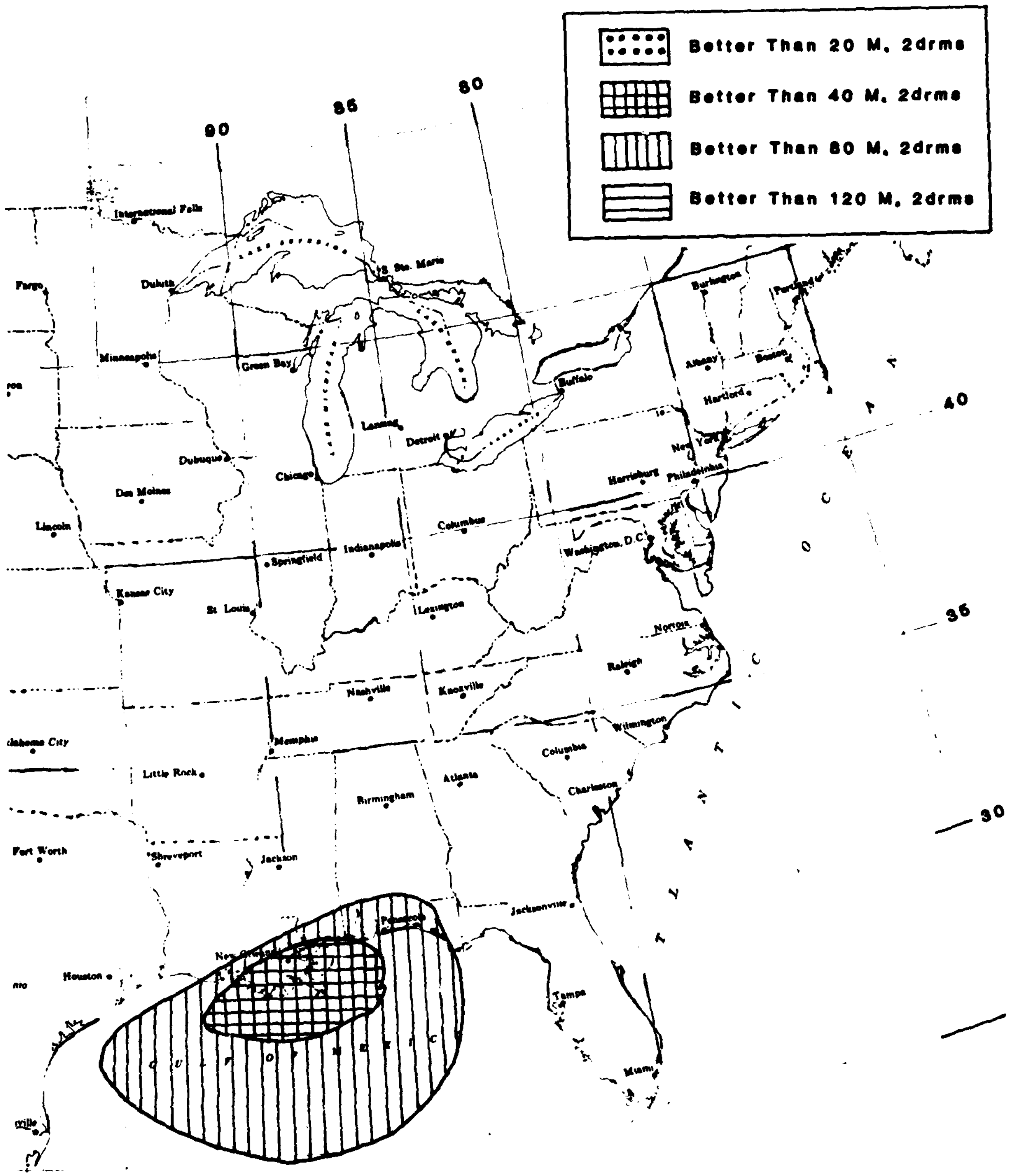


Figure 5-6 DRD Model Derived 2-drms Accuracy Contour, 7980-WX Contour

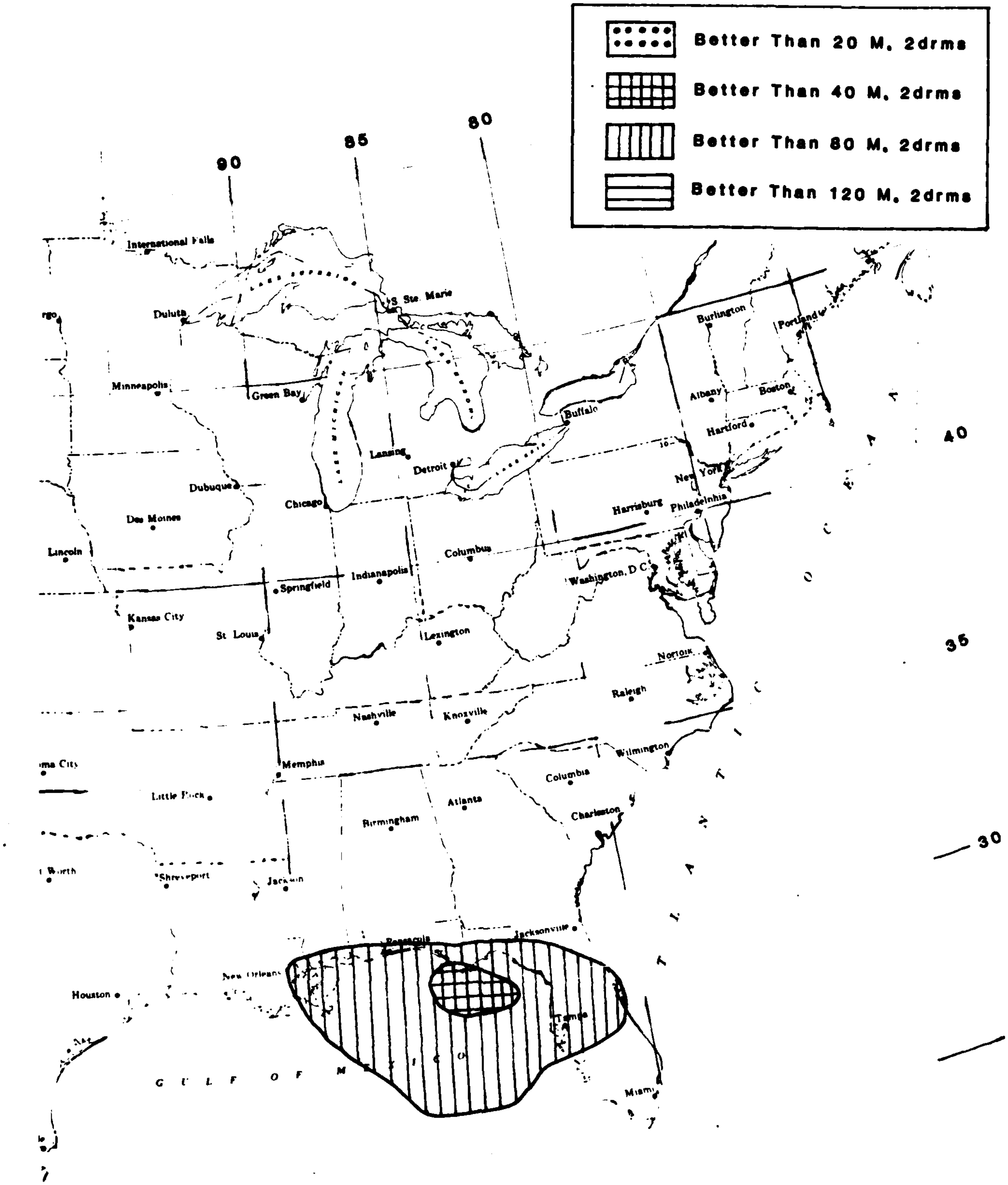


Figure 5-7 DRD Model Derived 2-drms Accuracy Contour, 7980-WY Contour

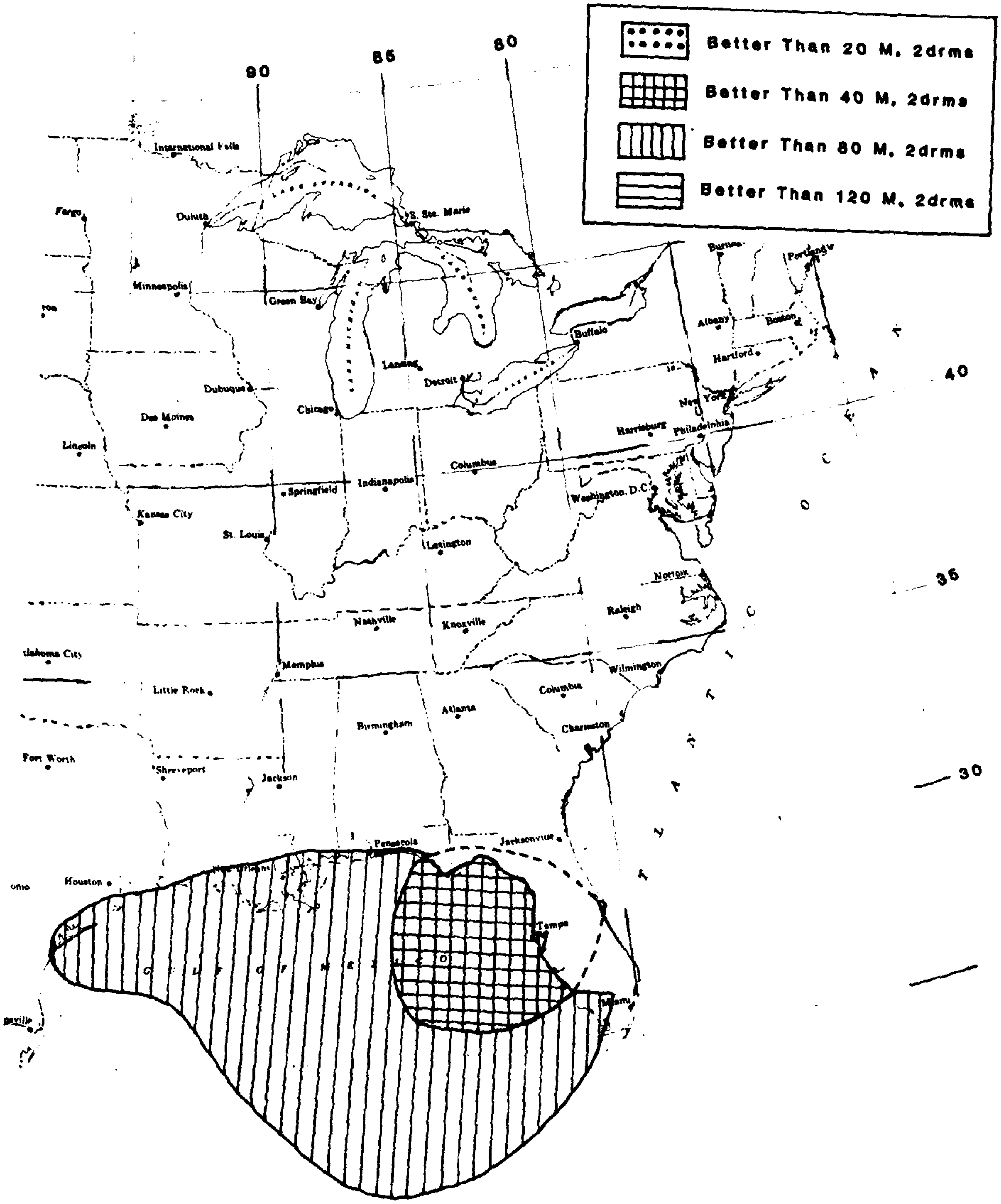


Figure 5-8 DRD Model Derived 2-drms Accuracy Contour, 7980-XY Contour

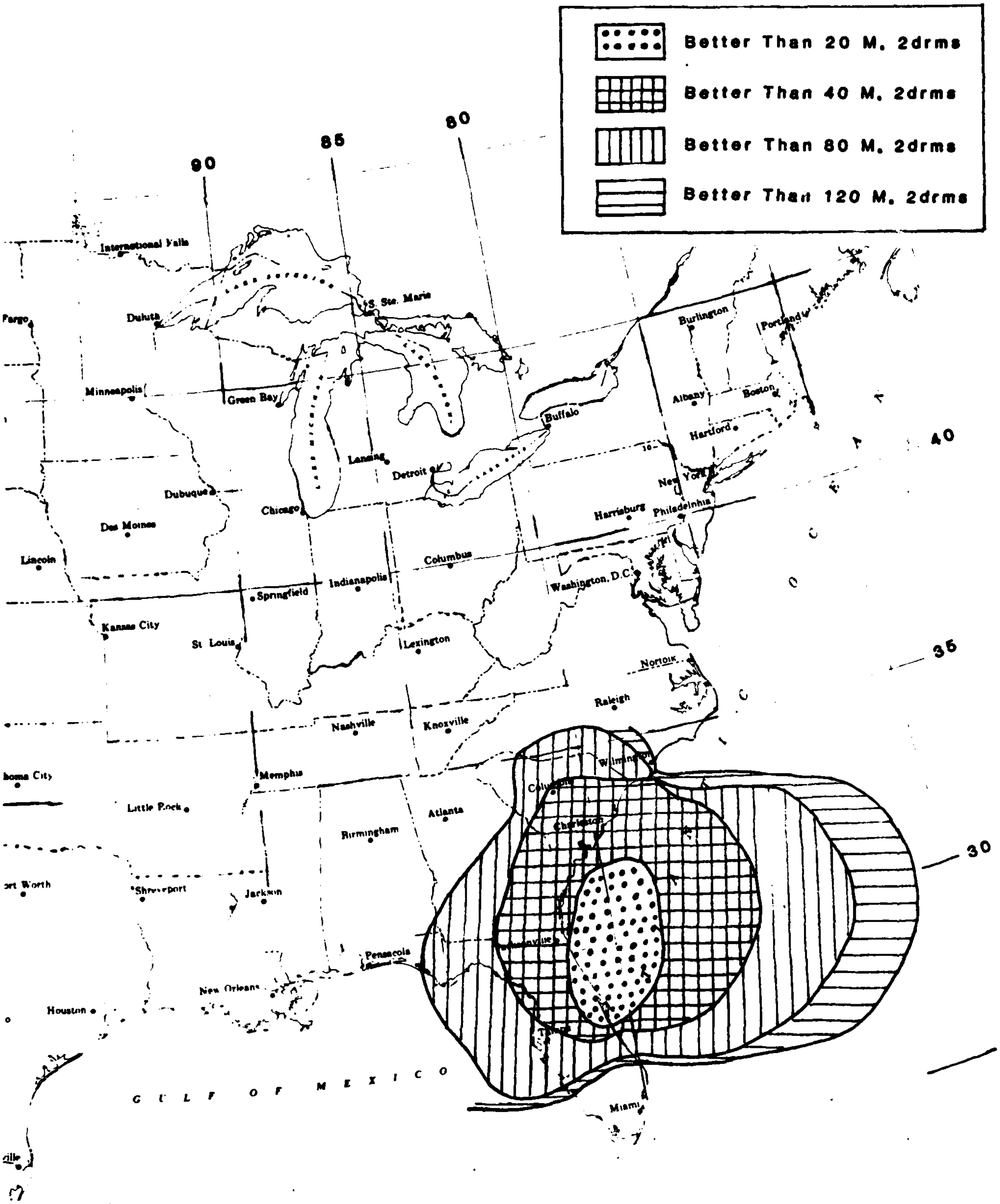


Figure 5-9 DRD Model Derived 2-drms Accuracy Contour, 7980-YZ Contour

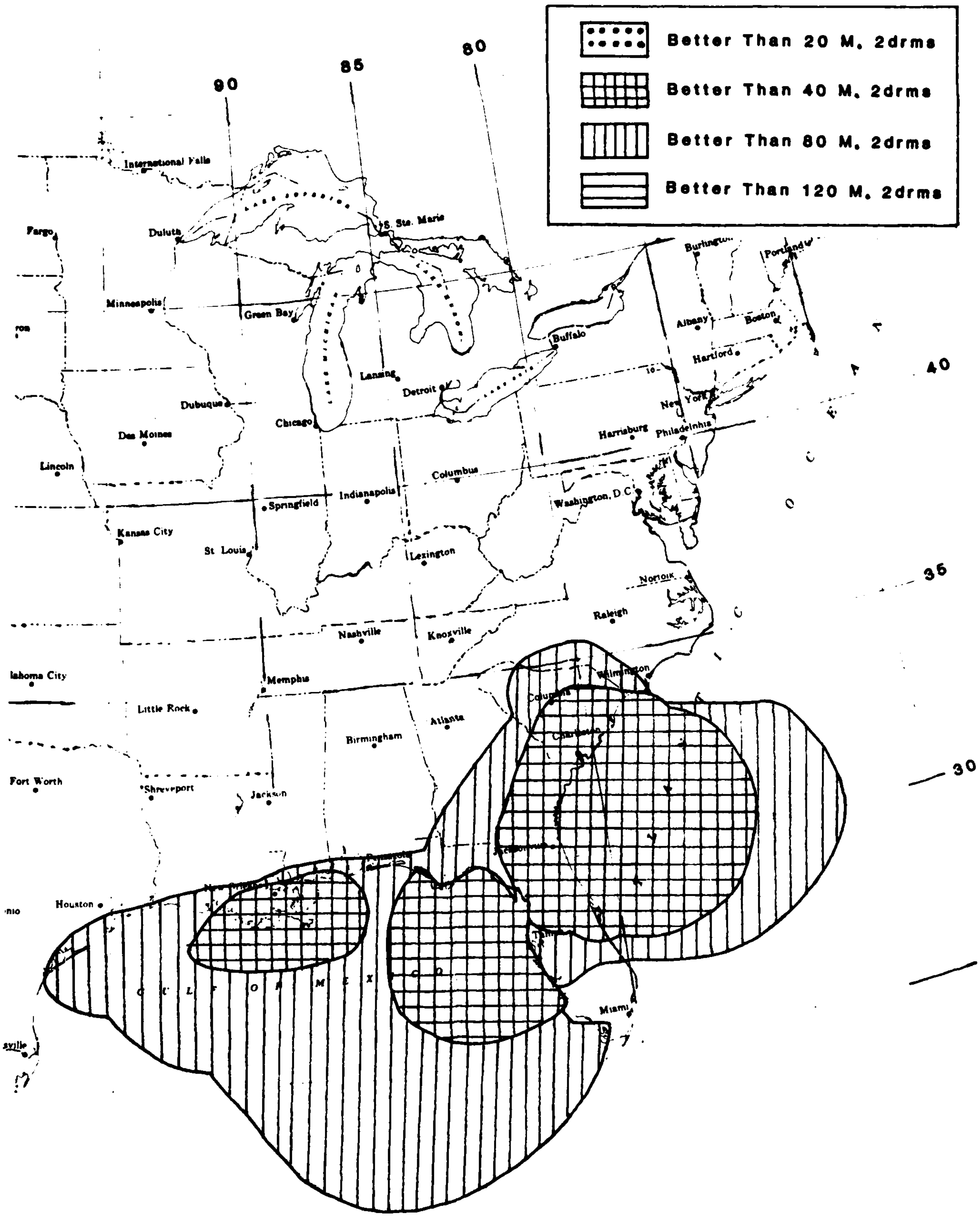


Figure 5-10 DRD Model Derived 2-drms Accuracy Contour,
7980-WX, -WY, -XY, -YZ Composite Contour

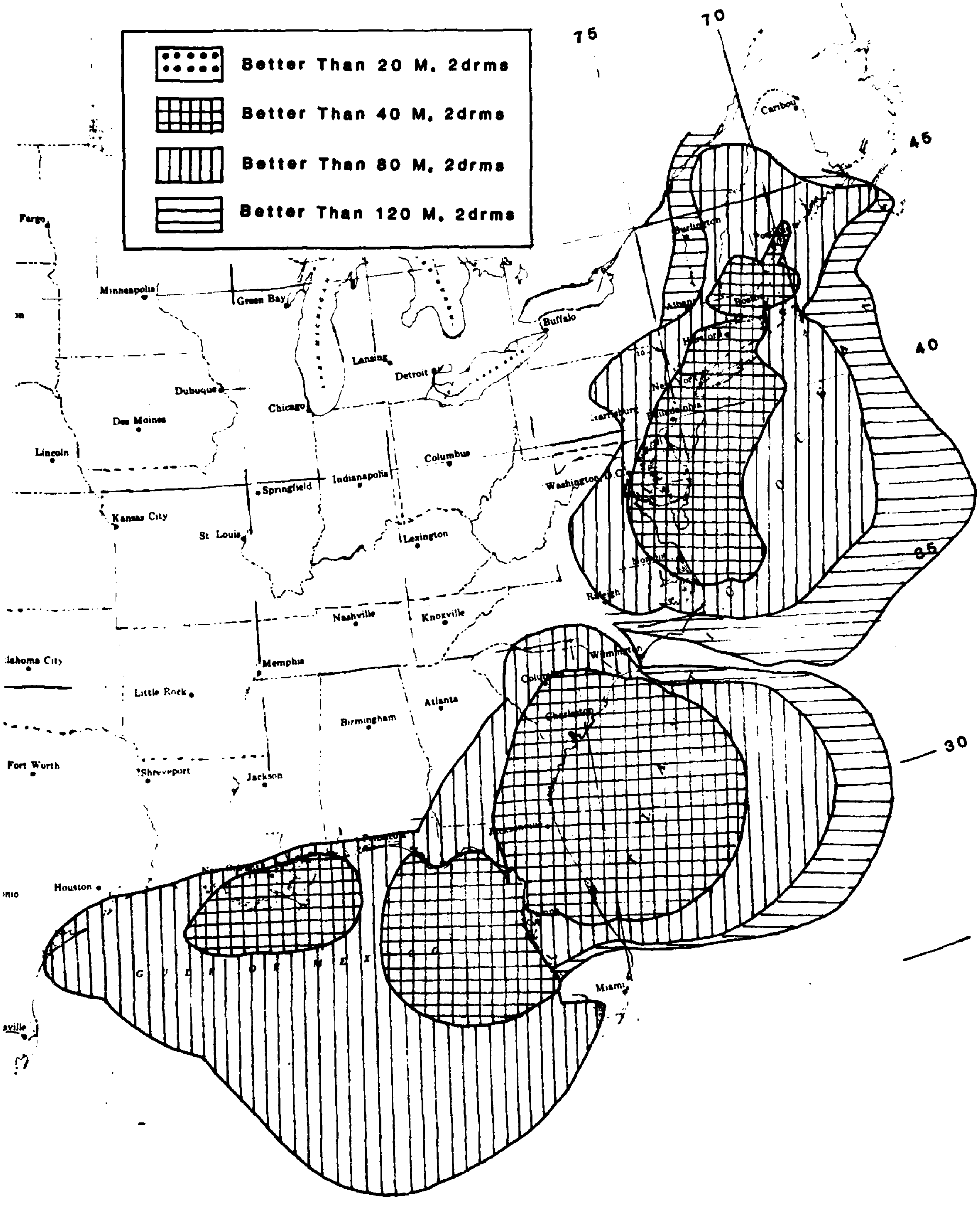


Figure 5-11 DRD Model Derived 2-drms Accuracy Contour, N.E.U.S. and S.E.U.S. Composite Contour

5.3 Implications Regarding Required GPS Performance

As outlined in reference 17, the NAVSTAR-GPS system, under development by the U.S. Department of Defense, is a potential replacement for Loran-C. As was illustrated dramatically during the "Loran-A shutdown," the termination of a popular, federally sponsored radionavigation system is not something that is easily accomplished. Making plans such as reference 17 is the easy part - carrying them out, when they involve unpopular actions, is another matter. All of this was shown to be true when Loran-A was being replaced by Loran-C - a clearly higher performance system. Relating this lesson to future actions of an analogous nature yields the inevitable conclusion that GPS will have to be shown to provide better performance than Loran-C before the switchover is allowed to take place.

An unfortunate problem associated with the GPS system is that it may be too good. Tests have now shown that the "clear" portion of the system could provide performance which is "as good as that of Loran-C - where Loran-C is at its best - but throughout the world." This expected performance is so good that it has raised concerns that it may be effectively used against the U.S. Department of Defense. Thus, there are plans being made to purposely degrade the accuracy of the system to all but select "customers." This degraded performance level, unfortunately, will conflict with the goal of out-performing Loran-C. Thus, the whole planning process becomes confused.

Up until mid-1983, the stated position was that the accuracy of GPS would be degraded to 500 meters, 2-drms. This is consistent with the stated "CCZ Loran-C" design goal - the only concrete statement of how good Loran-C is. Proponents of Loran-C have pointed out, as noted in reference 17, that the "repeatable accuacy" of Loran-C is considerably better than 1/4-nm in many areas and, therefore, Loran-C cannot be replaced by a 500-meter GPS system. Until now, the proponents would have been on shaky ground if challenged to be more specific about how much better Loran-C is and where. To counteract some of the Loran-C high performance claims, reference 17 notes that the level to which GPS accuracy will be degraded will be reviewed annually.

A first annual review of the GPS accuracy plan was announced in late summer, 1983: the intentional degradation will only be to the 100 meters, 2-drms level. In view of this new policy statement, the question of the day is: is that good enough? It is when questions like this are pondered, that the true value of the contours provided in the preceding section can be appreciated.

As a specific application of the contour data, we have calculated the percentage of the N.E.U.S./S.E.U.S. CCZ which falls within the 80-meter contour of figure 5-11. The figure is 90% (actually, 90.8%). The same calculation is carried out for the 40-meter contour where the result is, essentially, 50% (actually, 48.3).

In the preceding section, we mentioned that what we were plotting was not exactly "repeatable accuracy" and noted "more on this later." Before discussing the "more," let us simply suppose those plots are repeatability plots. Now let us also suppose the repeatability of GPS is allowed to be 100 meters, 2-drms. In that case, a switch from Loran-C to GPS would cause a reduction in performance in over 90% of the Loran-C coverage area. Clearly, if such a denial-of-accuracy level is implemented, GPS cannot be claimed as a replacement system for Loran-C. Even if a subsequent annual review of the "security requirements" allows the GPS repeatable accuracy to be improved to 50 meters, 2-drms, that still constitutes a reduction in performance in over 50% of the Loran-C coverage area and, thus, GPS still could not be cannot be considered a bona fide replacement system.

[Note: What we are presenting here are simple performance facts. Administrative policy decisions may dictate GPS as a replacement for Loran-C no matter how good Loran-C is/how bad GPS is. What we wish to establish/ substantiate is how good GPS would have to be allowed to be to constitute an "in good faith" replacement for Loran-C.]

To summarize what we have presented thus far:

- If the contours plotted in the preceding section represent the repeatable accuracy of Loran-C, and,

- If GPS has to out-perform Loran-C in all major performance criteria (repeatable accuracy is certainly a major performance criteria) in most areas, then

- The repeatable accuracy of GPS will have to be better than 40 meters, 2-drms.

With all this established, and without delving too deeply into GPS system engineering questions, we can state what this implies about overall GPS accuracy:

- If the performance of the GPS system is degraded to the point at which the absolute accuracy of system is worse than 28 meters, 2-drms, then GPS cannot be considered a bona fide replacement for Loran-C as it exists throughout most of the the N.E.U.S./S.E.U.S. region.

The above statement is an extremely strong statement which, in essence, says no artificial degradation of performance can be tolerated! The statement is important enough that we should explain where the 28 meter figure comes from.

First, we make the assumption (not truly defendable at the accuracy levels being discussed) that non-man-made errors in the GPS system are small enough to be considered negligible. Next, suppose we have 14-meter, 1-sigma, positional errors being introduced into the system as "noise." If the "denial-of-accuracy" scheme is intelligently applied in a manner which cannot be defeated, it will have to be "white noise" (if we do not consider time intervals of less than, say, 1-hour). Note, therefore, that the random processes "position determined at time T_1" and "position determined at time T_2" are independent processes with identical statistics - for T_1 different from T_2. Since a sample of either process has a "sigma" of 14 meters, a sample of the process representing the vector difference will have a "sigma" of $14\sqrt{2} = 20$ meters.

This vector difference is the statistical definition of the repeatable accuracy which yields a 1-drms of 20 meters, or a 2-drms of 40 meters - equivalent to the Loran-C in 50% of the N.E.U.S./S.E.U.S. For any performance worse than this, therefore, GPS fails to meet the replacement criteria. (Q.E.D.)

In offering the above explanation, we established that for GPS, at least where the error is predominantly "artificially induced," repeatable accuracy is a factor of $\sqrt{2}$ worse than absolute accuracy. At this point we should ponder the question: if that is true, why does it not follow that the repeatability of Loran-C is a factor of $\sqrt{2}$ worse than that indicated in figure 5-11 (and preceding plots)?

The answer is : because the Loran-C variations contain considerable structure. The result is that in some applications, with some definitions of repeatability, Loran-C is even better than that indicated in figure 5-11. To illustrate the concept, ask the question: how does the ability of Loran-C to return me to the place I visited yesterday compare with its ability to return me to where I was 6 months ago?

In the case of (accuracy denied) GPS, the answer to the above comparison question would be: there is no difference. In the case of Loran-C, the difference can be enormous.

To illustrate the concept in more concrete terms, consider the Massena data. As indicated in figure 3-2 on page 3-7, the "RMS Radial Error" is 64 meters. Thus, the "raw data" 2-drms is 128 meters. Now let us suppose we take the Massena TD records (listed in Appendix A), subtract them from "themselves displaced 30 days," and transform the result into a scatter plot. The result, which indicates the ability to return to a place visited 30 days earlier with Loran-C, is indicated in the plot of figure 5-12.

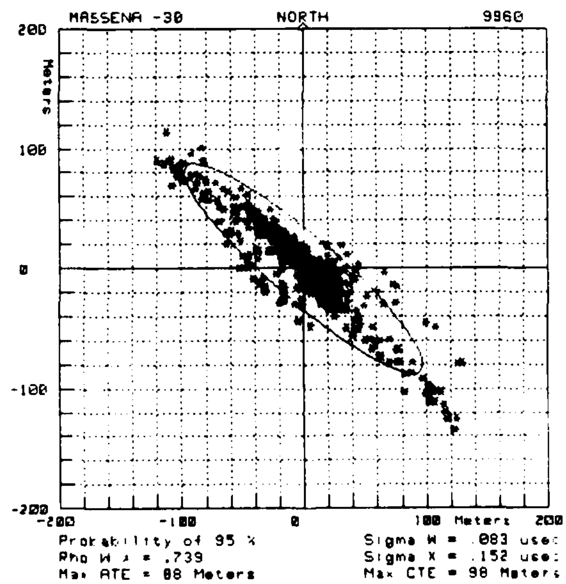


Figure 5-12 Massena Scatter Plot With 30-Day Old Corrections Applied

Calculations show the 2-drms figure has been reduced to 107 meters. Extending the concept, we carry out the same analysis for 7-day and 1-day displacements between the two readings. In these cases we measure "the ability of Loran-C to return us to where it brought us 1-week ago" and "the ability of Loran-C to return us to where it brought us yeaterday." The results are shown in figure 5-13 and 5-14. The corresponding 2-drms figures are 80 meters (1-week figure) and 56 meters (1-day figure).

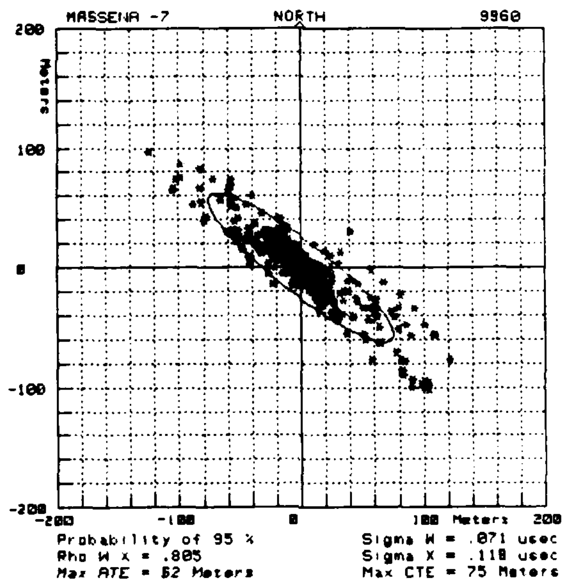


Figure 5-13 Massena Scatter Plot With 7-Day Old Corrections Applied

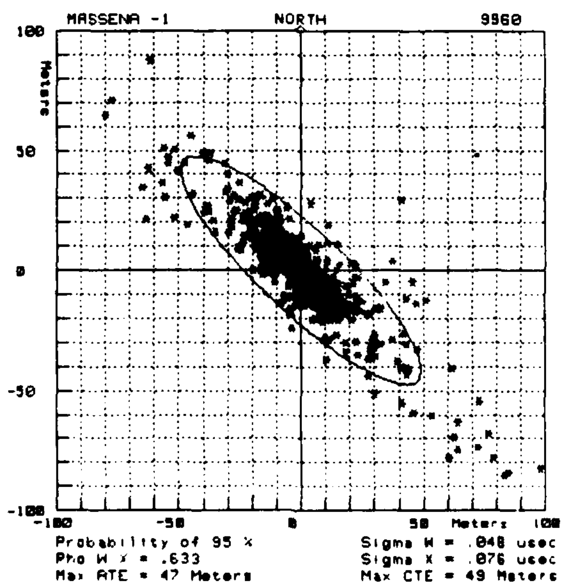


Figure 5-14 Massena Scatter Plot With 1-Day Old Corrections Applied

Before we attempt to read some meaning into all of this, we should consider the opposite extreme. Specifically, consider the Alpha-1 SAM at Sandy Hook. The scatter plot on page 3-3 indicates a 1-drms of 3 meters (to a decimal place, it is 2.7 meters). The 2-drms figure is 5.4 meters. Since the site is a SAM, we expect no "structure" in the TD data (to speak of). Thus, we expect the TD sequence to approximate a "white noise" process - a la "purposely degraded" GPS. Thus, we would expect analyses such as those which led to figures 5-12, 5-13, and 5-14, to yield 2-drms figures of about $5.4\sqrt{2}$ = 7.6 meters - independent of the time lag - when applied to Sandy Hook. The actual results indicate a 2-drms of 7.7 meters when the lag is 30-days, 7.4 meters when the lag is 7-days and 7.3 meters when the lag is 1-day. The differences among all of these figures are statistically insignificant - confirming the essential "whiteness" of the Sandy Hook data.

The point is that the relationship between the parameter plotted on the accuracy contours of the previous section and "strict sense repeatable accuracy" is a varying one. Worst case, strict repeatable accuracy is bigger than what is plotted by a factor of $\sqrt{2}$. This occurs, however, only under near ideal Loran-C conditions (i.e., when there is no significant seasonal component). In some cases, Loran-C repeatable accuracy is better than that indicated. In general, we claim the parameter plotted, besides being the exact parameter we wanted to plot for "HHE purposes," is truly representative of repeatable accuracy in an average sense.

From the discussion thus far, we note that GPS appears to be "getting no breaks" in our comparisons. For example, we are not taking into account many of the definite advantages GPS has over Loran-C. There are two very specific reasons for our approach. The *first* is that we are not simply comparing two systems to see which, in a general sense, is better. We are not asking whether or not Loran-C can replace GPS. Instead, we are considering replacing Loran-C with GPS. One system may be "better" than another in many ways but still not qualify as a replacement for that system. What we must consider is what service is presently being provided by Loran-C and determine whether or not a switch to GPS will result in present users being deprived of this service. Again, our findings may not prevent that "deprivation of service" from happening. We want, however, to at least be aware of what is being proposed.

The second reason for not considering some of the "nice" features of GPS is that, for civil applications in U.S. waters, they are simply not important. To see this, we can consider a few examples. Right now, the Delaware pilots are able to use Loran-C to determine their position with respect to all critical channel boundaries within about 25 meters. Let us suppose that GPS is offered at an accuracy which allows them to make the same determinations to within about 50 meters. Clearly, the pilots will prefer Loran-C. They will even prefer Loran-C if the GPS performance is improved to the 30 meter level!

But suppose we point out that with GPS, the Delaware pilots can achieve the same 50 or 30 meter accuracy in the Indian Ocean, where Loran-C coverage simply does not exist - does that change their opinion? The answer, not surprisingly, is no. Suppose we also point out that with GPS, they would also get to know their position in an absolute sense to within 30 or 50 meters - does that make a difference? Again, the answer is no - they are concerned only with their position relative to the channels they wish to traverse. The simple fact of the matter is that the Delaware pilots will prefer GPS to Loran-C when the GPS system accuracy is allowed to tell them where they are, in the Delaware River, better than Loran-C does. That's all it takes!

To summarize the conclusion of this section, we can state that for GPS to qualify as a bona fide replacement for Loran-C in the N.E.U.S./S.E.U.S. region, it must be offered at an absolute accuracy of 28 meters, 2-drms or better. Essentially, this means there can be no artificial degradation of accuracy.

5.4 Harbor Navigation Performance

In this section we want to discuss the implications of the data presented in Appendix C. We should emphasize immediately that this simply cannot be an in-depth treatment of the subject. As witnessed by references 13 and 14, it is possible to devote entire reports to individual HHE areas. With over 20 major harbors being considered, what we present herein can only be considered a start. We feel, however, we can make a very good start.

Upon careful consideration of the results indicated in Appendix C, we find the key conclusion is that we can make several classifications, or groupings, of the harbors as determined by the Loran-C performance featured. The first group contains those harbors, such as New York, in which the Loran-C performance is clearly satisfactory. Another group would include those in which we would say Loran-C performance is "OK with a modifier." The modification might be that a mild form of differential correction is required. Alternatively, it might be that Loran-C provides adequate performance in all but one or two reaches.

Another group would feature those for which "Major Surgery is Required." Corpus Christi is a prime example. A final group would be those which are "Not OK - but it probably doesn't matter." Miami is such a case.

We claim a major result of the study to be the identification of which harbors fall into which category. We suggest that there need be no further consideration of those which fall into the group called "clearly satisfactory." Similarly, we have probably said all that need be said about those in the group "Not OK but it probably doesn't matter." For the category called "Major Surgery Required," we will address what form of "surgery" is recommended. Unless that action takes place, those harbors need no longer be considered.

The final group of harbors, i.e., those whose performance need slight improvement should be discussed. As indicated in Section 1, the question of whether or not the service is to be provided at all depends on the degree of benefit accruable versus the cost of implementation. For these harbors, the improvements will entail costs. The costs can be examined in detail in future reports should sufficient interest arise. For now, we will simply review what the performance problems are. We begin with the presentation of Table 5-3 which indicates which harbors fall into which categories.

Definitely OK	OK With a Modifier	Not OK - Major Surgery Required	Not OK - But It Probably Doesn't Matter
Boston	Delaware	Corpus Christi	Miami
Providence	Baltimore	Houston	Wilmington
New Haven	Chesapeake	Galveston	Upper Hudson
New York	Norfolk	Port Arthur	New London
Lower Hudson	Charleston		
Jacksonville	Savannah		
New Orleans	Kings Bay		
	Tampa		
	Mobile		

Table 5-3 Loran-C Performance Classification of Major N.E.U.S./S.E.U.S. HHE Areas

If we compare the entries in the table with the harbor details of Appendix C, we see things are actually somewhat better than indicated above - several harbors classified in the "OK With a Modifier" group could very easily be claimed to be "Definitely OK." Significant problems occur in the Delaware, for example, only near the end of the list - and in reaches wherein the channel half-width (corrected) is only 30 meters. In these reaches, there are adequate alternatives to Loran-C. Similar comments apply to the situation in Baltimore (actually, no serious problems are indicated in Baltimore - the final reach features a CTE error margin of only 9 meters and that violates our assumed requirements criterion), the Chesapeake, Norfolk, Charleston, Savannah, Kings Bay and Mobile.

There is really only one harbor in the "OK With Modifier" group which definitely needs performance improvements before Loran-C could be claimed to be a viable HHE system: Tampa/St. Petersburg. Careful examination of the TD data records shows that there is considerable "structure" in the TD variation - easily enough to conclude that some form of Differential Loran-C would allow adequate performance. If this were a study along the lines of reference 13 or 14, we would begin a discussion of a Tampa Differential Loran-C network at this point. Since this is a "general area" report, however, we will avoid the issue. This "excuse" lets us avoid singling out one separate harbor area for special attention herein. If adequate need can be demonstrated in the Tampa area, a separate study can be commissioned. With the data base we now have, the design can proceed in a straightforward manner.

One final matter is worth paying special attention to: the east coast of Texas. The problem is clearly one of "horrible" geometry and no realistic claims about the effects of differential corrections can be made in good faith. If there is ever to be HHE-quality Loran-C for the major ports of Texas, another (high powered) transmitting station will have to be installed. This is what we have refered to as "major surgery."

To illustrate this concept, we have hypothesized what would happen if we installed a station at Waco Texas. We suppose this station becomes the master of a new chain and that the stations at Grangeville and Raymondville are dual-rated so they too become part of the new chain (which could, with additional stations, extend to the mid-continent - if desired). We hypothesize control of the two baselines from a monitor site at Galveston.

All of the hypothesizing mentioned thus far involves simple geometry considerations. The next step has historically been very difficult: we must predict the expected TD variations of the new chain. Of course, all of that has now changed: predicting the TD variation record is now a straightforward matter. We can use the previously estimated S.E.U.S. dTD sequence as the "New Chain dTD" component. For common terms, we can use the average of those determined for the 7980-W and -X baselines for one of the new TDs and the average of those determined for the 7980-Y and -Z baselines for the other. Proceding with our standard prediction techniques, we then obtain the performance predictions indicated in figures 5-15, 5-16, and 5-17.

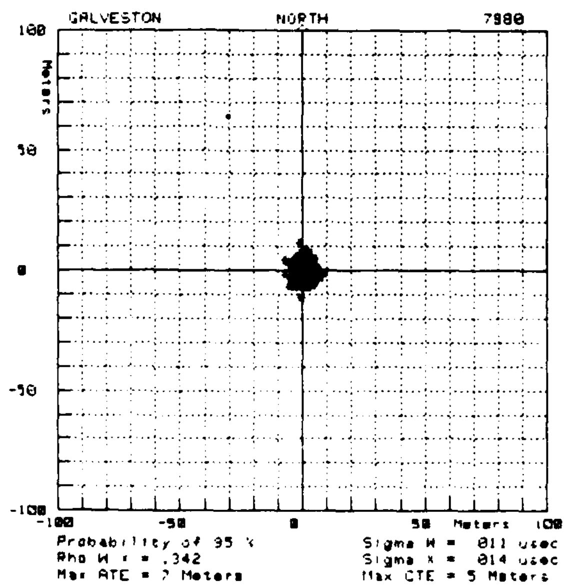


Figure 5-15 Predicted Scatter Plot - Proposed New Chain - Galveston

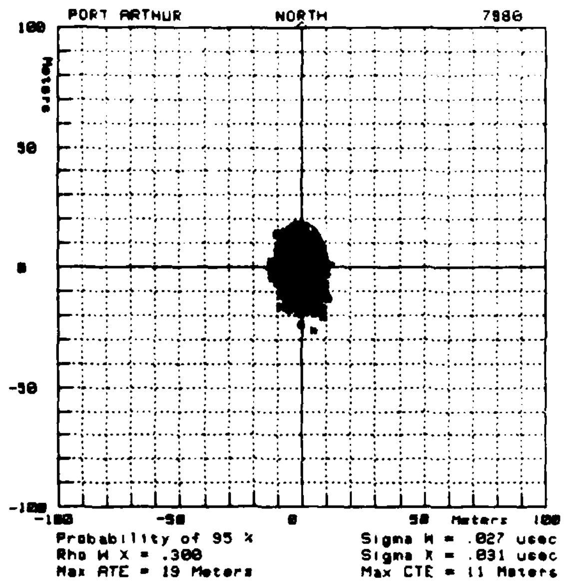


Figure 5-16 Predicted Scatter Plot - Proposed New Chain - Port Arthur

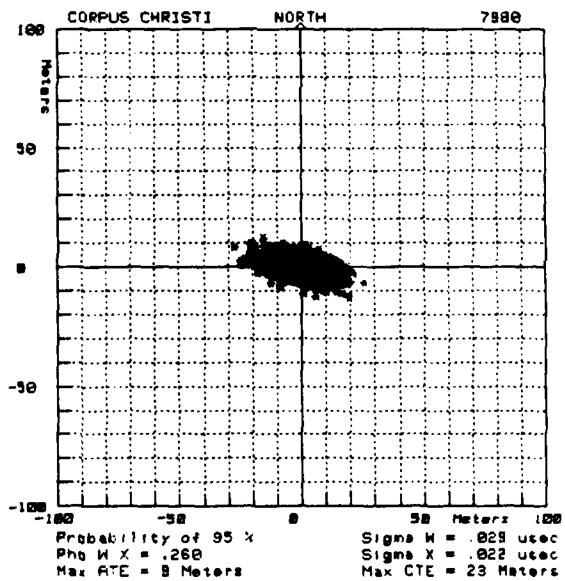


Figure 5-17 Predicted Scatter Plot - Proposed New Chain - Corpus Christi

The indicated performance is clearly capable of satisfying any requirements in all reaches of these harbors.

We should note that Waco is not the only site which would allow adequate performance - any number of locations in the general area could be selected to do the job. This being stated, we should re-emphasize the policy stated in reference 1 and quoted in Section 1. We have identified a solution to the east Texas coast Loran-C problem. Whether or not this, or any other, solution is implemented is, again, an "administrative question."

6. Summary and Conclusions

6.1 Overview

For what we like to think comprise very good reasons, this report is long-winded. Good reasons aside, there is a risk that the prime contribution of the report can be obscured unless we take care to emphasize it. The prime purpose we want to accomplish with the report is to announce that the U.S. Coast Guard has recently obtained a massive, high quality data base from which extensive conclusions about the performance of the Loran-C system can be derived. Furthermore, that data base will continue to grow for the next few years.

By itself, of course, the data does not comprise information in readily usable form. Thus, we would accomplish very little if we were to simply publish a "data dump" report. Moreover, the data, in raw form, does not suggest exactly what can and should be done to transform the massive data base into useful information. Consequently, we must accompany the data presentation with at least the start of the analyses which should be performed.

Once we begin the task, we soon recognize that the analyses which can, and should, be performed are so extensive that if we were to hold off on publishing anything until all analyses were completed, we would probably not publish anything during this decade. This situation is to be avoided: there are presently too many decisions about the future of radionavigation systems being contemplated to allow the data to go unpublished. The consequence of all of this is that we are perfectly justified in publishing a report with an extensive series of analyses - even though many of them only begin to scratch the surface.

In this regard, we find ourselves "like kids in a candy shop." There are any number of things to do - all of which constitute "new results." By simply having provided year-round plots of TD readings at the harbor monitor sites, for example, we have made an enormous increase in the amount of Loran-C data available in the literature - and that is just the start. By publishing the data in the "more processed" scatter plot and radial error plot form, we have contributed large increases to the "empirically supported" Loran-C positioning accuracy knowledge pool. All of this and the computer is not even warmed up yet!

Beyond these simple first steps, we proceed to apply the data to our model. With a few refinements, we discover we have the ability to generate Loran-C performance predictions with a high degree of (documented) confidence. At that point, we really begin to roll. We can generate "repeatable accuracy" contours. We can state the expected ATE/CTE at any point in any reach in any N.E.U.S./S.E.U.S. harbor/harbor entrance.

Even at that point, we have just begun. We can hypothesize the effects of periodic TD corrections - obtained in any number of ways. We can hypothesize the results obtained by the use of additional transmitting stations. We can use all of these analyses to fully explore the capabilities of the Loran-C system - for the purpose of exploring its use as an HHE aid to navigation and/or for indicating the level of performance GPS must be allowed to achieve to qualify as a bona fide replacement system.

Some of the items from this list of things we can (and should) do have been completed and reported herein. Others have only been started. Since this is the first "wide area" stability study report, we have made a conscious attempt to touch upon every important analysis technique we could think of. Thus, even more so than is usual, we need a summarizing section to emphasize the findings, how they relate to past work, and what they suggest should be the direction of future work.

6.2 Context

We began the report by tracing the history of the ongoing precision Loran-C studies. We showed the relationship to precision radionavigation studies of the late 1960's/early 1970's, the relationship to the National Plan for Navigation and how that resulted in the 1974 "CCZ decision." We noted how that CCZ Loran-C decision was also an HHE decision. The difference can be illustrated by paraphrasing the decision: "If there is to be a CCZ system - and there is - it will be Loran-C. If there is to be an HHE system - and there may be - it will be Loran-C."

We have discussed the role of the St. Marys River project and the relationship of the stability studies to the other elements of the HHE Project. Specifically, we note that stability is only part of the overall picture - and this applies from both technological and policy points of view. Even where Loran-C is found to be stable, or can be made stable through chain augmentation, proper HHE guidance equipment and a carefully conducted HHE Trackline survey are required. All of these technical matters aside, the implementation decision depends on cost/benefit determinations and administrative policy. An understanding of this background is necessary for a proper appreciation of the nature of the conclusions/recommendations to be found in reports such as this.

Next the report focuses attention on the various elements of the HHE Loran-C R&D project, with emphasis on the Signal Analysis element. We note that the CONUS-wide stability study, the one element that could not be completed in the St. Marys River "test bed" while the CCZ implementation was slowly taking place, comprises the last part of the overall project. An attempt is then made to emphasize there is more to the "lateness" of the signal stability study than the wait for the CCZ implementation: stability study equipment and methodologies were being developed in the St. Marys River. The major reason this effort is still going on is that it is an enormous task.

Testimony to the scope of the undertaking is observed by pondering the excerpt from reference 16 which was presented near the end of Section 2. Since 1946 people have been talking about "further studies" to determine the way in which the signal stability varies throughout a chain coverage area. By the time this project element was being planned, 30 years had passed but the question remained unanswered. Getting from those first days of the stability study project to the present has been an enormously difficult process - as the history related in Section 2 indicates.

With the project history established, we begin detailed discussions of the data collection equipment and the analysis methodology, specifically, the DRD model. Some care is taken to emphasize this model is consistent with a long line of theoretical and empirical studies conducted over the years - both before and during the St. Marys River mini-chain effort.

Next we present the data and begin the analysis. After some refinement to the basic model, we obtain the sequence estimates which allow us to make performance predictions. The predictions are then carried out in specific HHE areas as well as throughout the coverage areas of the chains. With these results established, we show how they relate to "policy matters" being discussed under the Federal Radionavigation Plan. Particularly as they relate to the comparisons between GPS and Loran-C, the results of analyses conducted under this project will continue to be of direct interest to the navigation planners. Since the plan identifies a final "future mix" decision in 1986, the role of this project for the next 3 years is established.

6.3 Findings

The analysis sections of the report indicate the following regarding the N.E.U.S./S.E.U.S. stability study results:

- The data base is of high quality: there were no major analyses which were hampered by lack of data. Considering the scope of this project, a good deal of praise goes to the project personnel at the Coast Guard R&D Center.

- The "modified DRD" model which was used in reference 13 has served us well - it was all that was needed in the S.E.U.S. analysis, resulting in residual sequence standard deviations in the "low 20's" (nsec). A special analysis was performed to confirm that non-freezing seawater paths should not be counted in DRD calculations.

- In the N.E.U.S. region, the "Mod 1" results were decent. Improvement was obtained by refining the model to recognize two types of land. It is important to note it is not the conductivity of the land types as much as the types of weather found above the land that determines the effects.

- To obtain truly satisfactory results, the 9960-Z data record from one of the sites had to be ignored. The signal paths to that site involve the very complex portion of the "boundary" between the two land types. Thus, this result can be viewed as a sort of verification of the model -

there being a need to obtain data from additional sites in the region to resolve the issue. This is not a very strong concern for marine applications. The final N.E.U.S. model residuals had standard deviations tightly clustered about a mean in the "upper 20's" (nsec).

- The modelling results can be used to generate predicted TD records at any location throughout the N.E.U.S./S.E.U.S. coverage region. When converted to positional information, these can be used to predict HHE Trackline performance or repeatable accuracy contours. A short analysis showed agreement between the predicted and observed N.E.U.S. statistics, at the 1-sigma level, was 2.5 meters for the 95% probability CTE/ATE and 4.4 meters for 2-drms. These are extremely satisfactory results.

- In the S.E.U.S. analysis, even though the TD-domain residuals of the model were better than in the N.E.U.S., the position residual "sigmas" were just under 6 meters for CTE/ATE and just under 11 meters for 2-drms. Although we would prefer better results, these are satisfactory for our purposes. The incident illustrates the geometry differences between the two chains.

- With the estimates and confidence level indicators in hand, we generate our predictions. 2-drms plots are generated for the major "marine triads" of the N.E.U.S./S.E.U.S. chains (i.e., excluding Dana). The resulting contours indicate that about 50% of the N.E.U.S./S.E.U.S. CCZ area features better than 40-meter, 2-drms accuracy. About 90% of the area features better than 80-meter, 2-drms accuracy.

- It is shown how those contours reflect a type of accuracy which is "somewhat similar" to repeatable accuracy. The relationship is not direct: in most important cases, the contours are more pessimistic than true repeatability contours would be. In some cases they are more optimistic. On the average, however, they are claimed to be reasonably representative of the important "repeatability" parameter contours.

- It is also noted that "intentionally degraded" GPS repeatable accuracy is worse than GPS absolute accuracy by a factor of $\sqrt{2}$. Thus, we claim the absolute accuracy of GPS would have to be allowed to be better than 28 meters, 2-drms, for GPS to be considered a bona fide replacement for Loran-C as is presently exists throughout <u>most</u> of the N.E.U.S./S.E.U.S. marine coverage area. This implies so-called "selective availability" cannot be implemented.

- Regarding the harbor performance predictions, 6 out of 24 N.E.U.S./S.E.U.S. harbor areas are found to have clearly acceptable HHE Loran-C performance. 8 other harbors are found to be so close to satisfying assumed requirements that the required "improvements" (if any prove truly necessary upon closer than this "first cut" examination) should involve only minimal costs. Except for four Texas ports, these 14 harbors comprise all the "truly major" harbors in the N.E.U.S./S.E.U.S.

- The Texas ports suffer from such adverse geometry that even "full Differential Loran-C" cannot be assumed to come close to satisfying HHE-level performance requirements. We show how the installation of a station in Waco, combined with the dual-rating of two existing stations would easily solve all problems throughout the east Texas coastal region.

6.4 Conclusions

The Coast Guard's ongoing Harbor Monitor R&D Project is a success. Enormously valuable, and timely information can be extracted from the high quality, massive data base. The results thus far show:

- The performance of the Loran-C system throughout the N.E.U.S./S.E.U.S marine coverage area is truly impressive. There are some problem spots but, overall, performance is easily everything it's ever been claimed to be - and then some.

- The latest review of the GPS system has resulted in an improvement in the "to be released" accuracy from 500 meters, 2-drms, to 100 meters, 2-drms. This is not nearly good enough for GPS to qualify as a bona fide replacement for Loran-C.

- Indeed, to truly replace Loran-C, the full capability of GPS will have to be made available to the public.

- At worst with a few improvements (e.g., daily or weekly corrections applied as "altimeter corrections"), HHE Loran-C could become a reality in almost all major harbors of the N.E.U.S./S.E.U.S.

- Tampa/St. Petersburg appears to be the only major harbor that might require something approaching true Differential Loran-C.

- Because of adverse system geometry, the present Loran-C system is inadequate, for HHE purposes, in the major HHE areas along the east coast of Texas. Differential Loran-C is not a solution. The creation of another chain, involving one additional transmitting station would easily solve the problem.

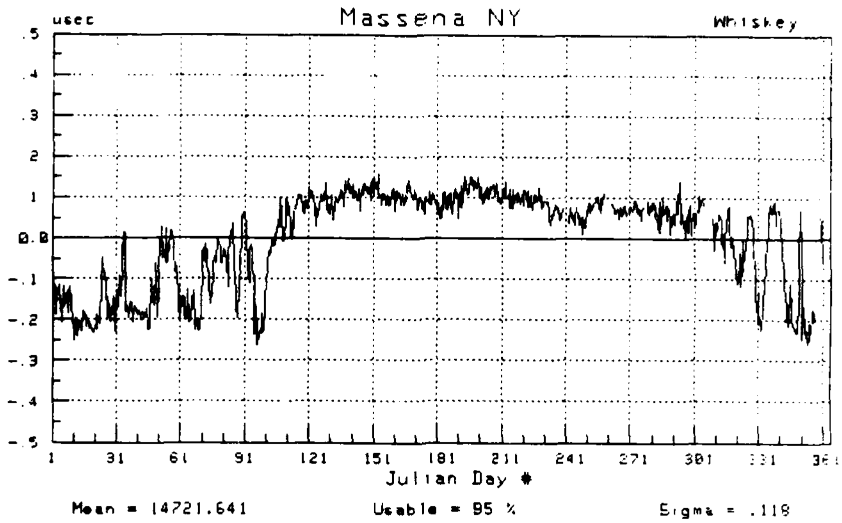
- The signal stability studies should continue for at least the next several years. Reports on the findings at West Coast/Canadian West Coast harbor monitor sites should be published in the near future. An analysis of the Great Lakes region should follow shortly thereafter. The analysis techniques used in this and previous reports should be used/refined.

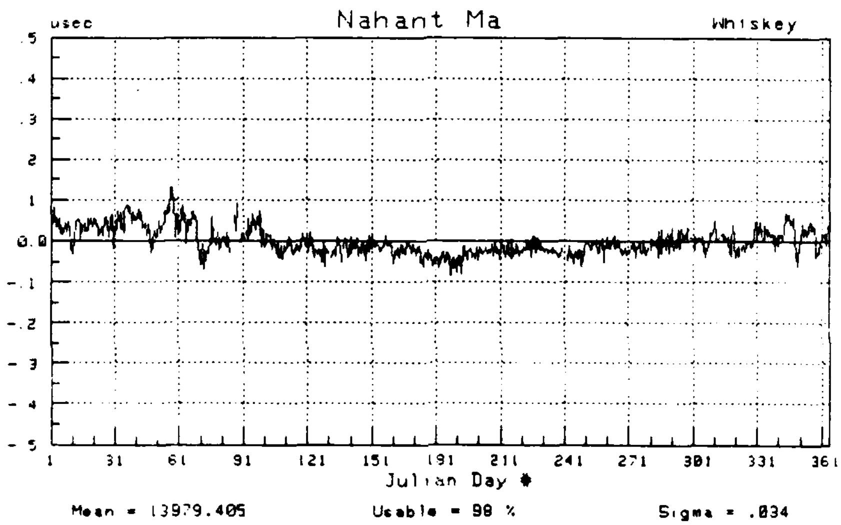
- The N.E.U.S./S.E.U.S. area should be "revisited" in the final report under this project. That report should discuss data obtained at recently installed sites. It should also compare seasonal TD variation components from year to year with the idea of obtaining a "seasonal correction" graph for use in areas remote from the chain control station.

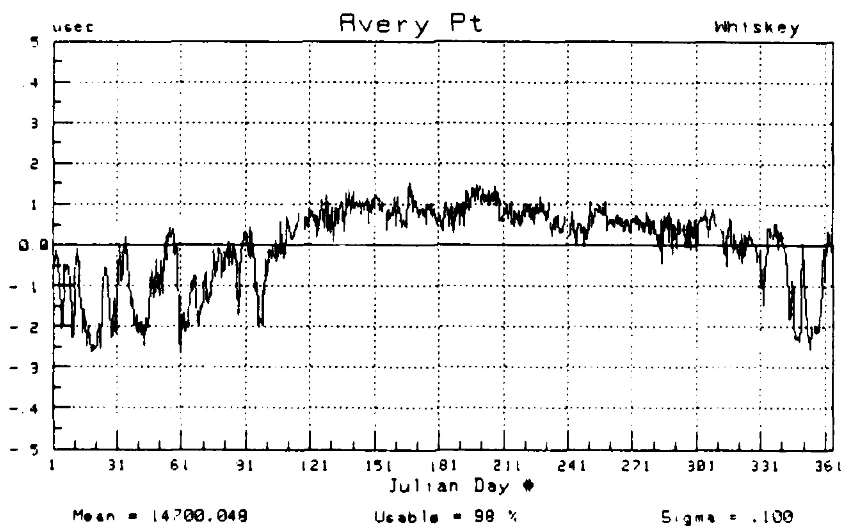
- The results of this, all signal stability studies, and all HHE Loran-C R&D project work should be included in the deliberations leading to the planned, 1986 "final decision" on the future mix of federally sponsored radionavigation systems.

APPENDIX A

N.E.U.S. HARBOR MONITOR DATA


Massena NY
usec
Whiskey
Julian Day #
Mean = 14721.641
Usable = 95 %
Sigma = .118


Nahant Ma
usec
Whiskey
Julian Day #
Mean = 13979.405
Usable = 98 %
Sigma = .034


Avery Pt
usec
Whiskey
Julian Day #
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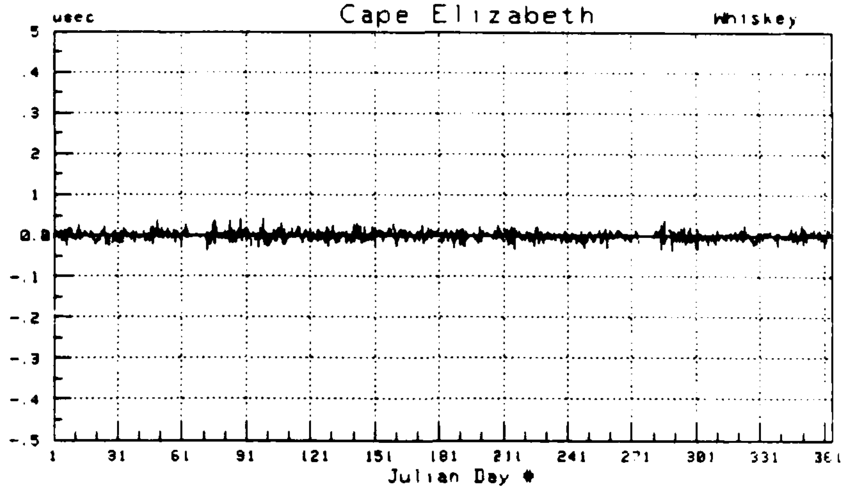
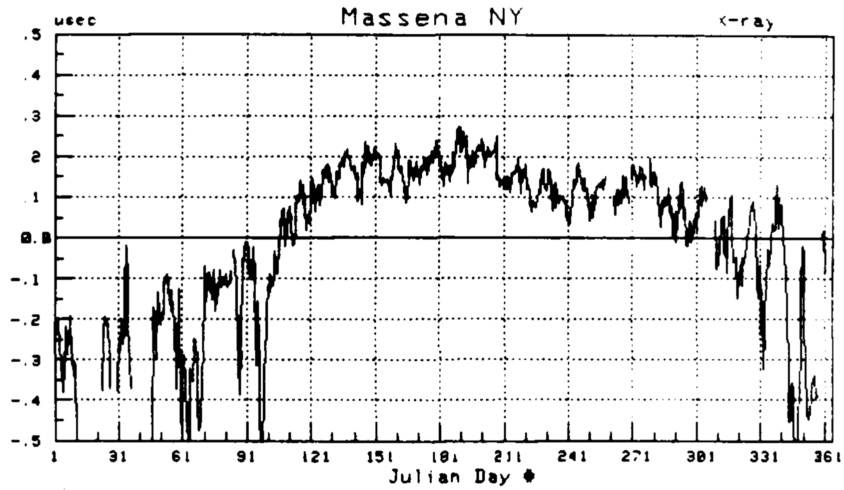
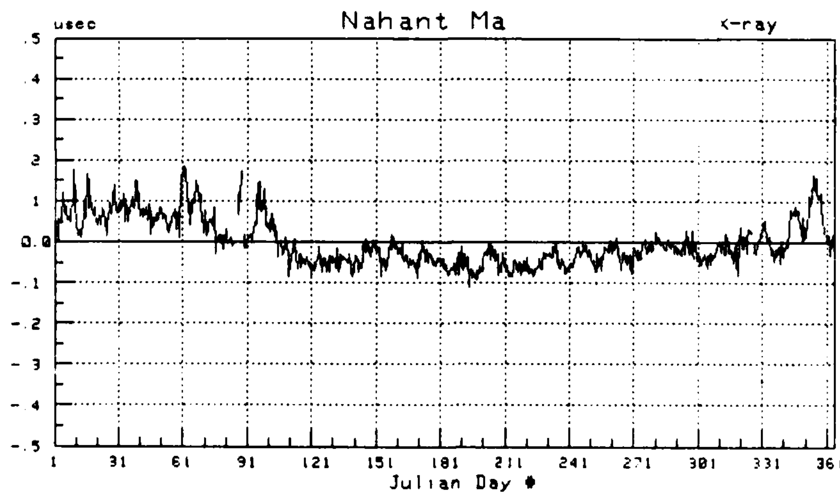
Usable = 98 %
Sigma = .100



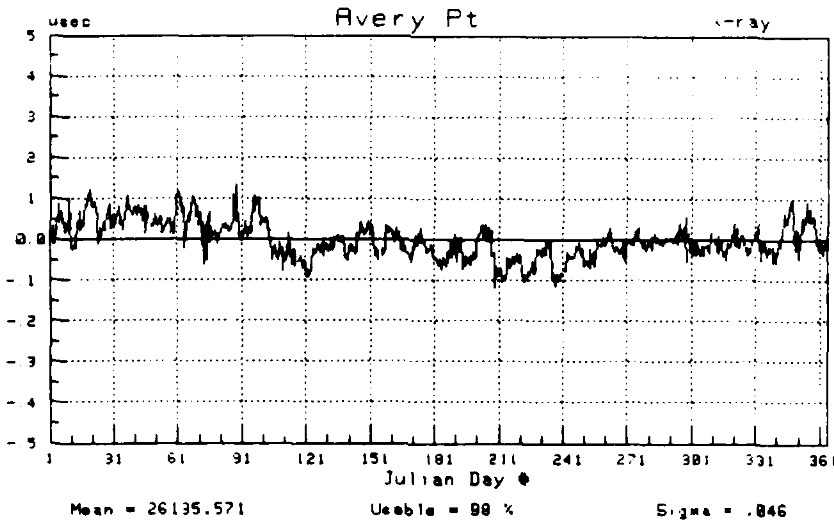
Mean = 13311.480 Useable = 86 % Sigma = .012

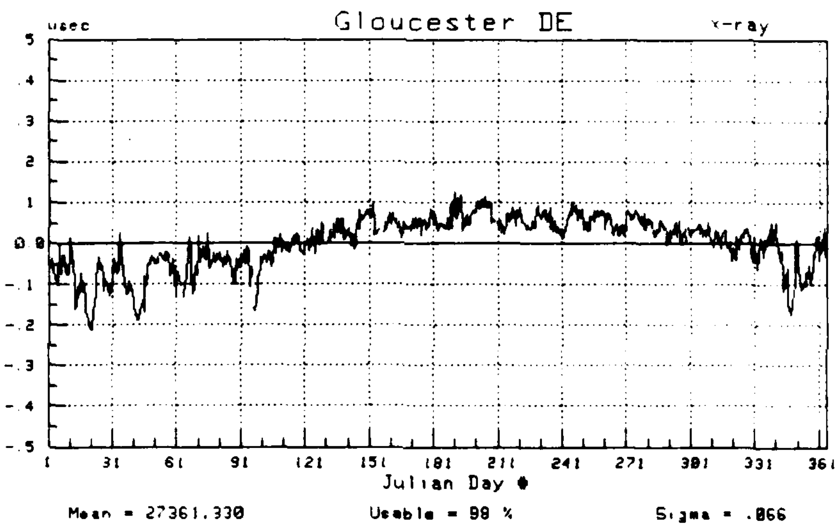


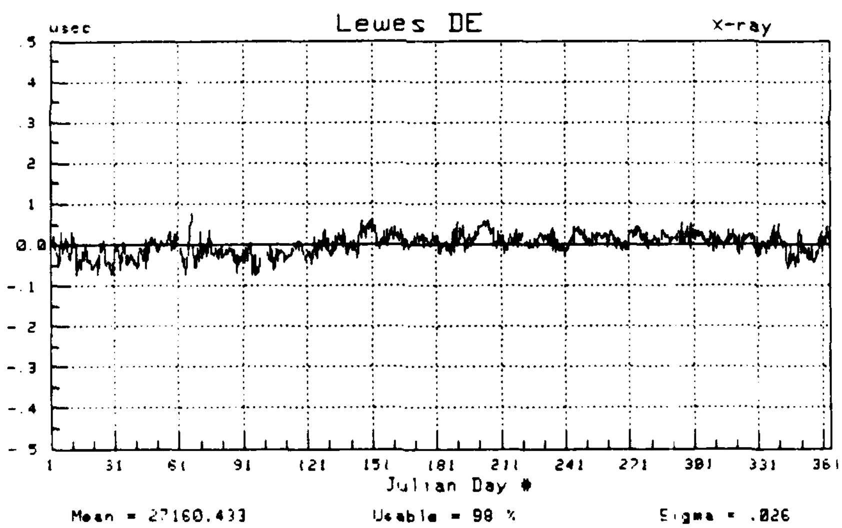
Mean = 27891.497 Useable = 80 % Sigma = .200

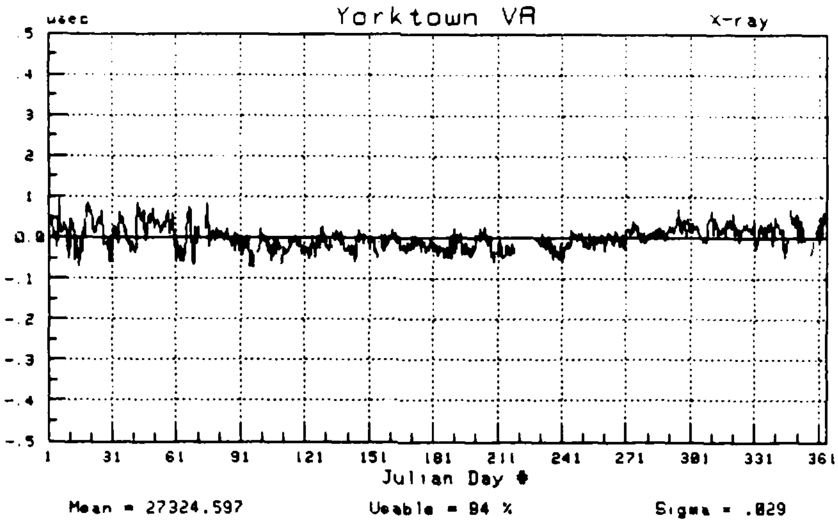


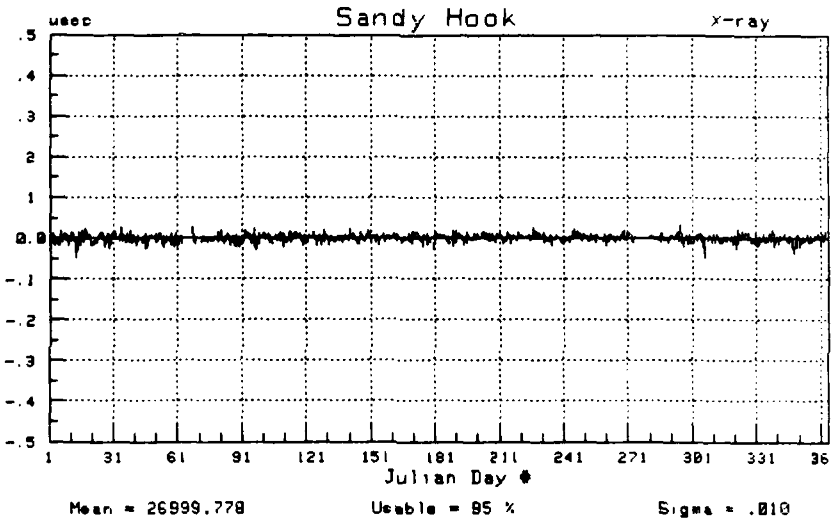
Mean = 25843.780 Useable = 98 % Sigma = .058

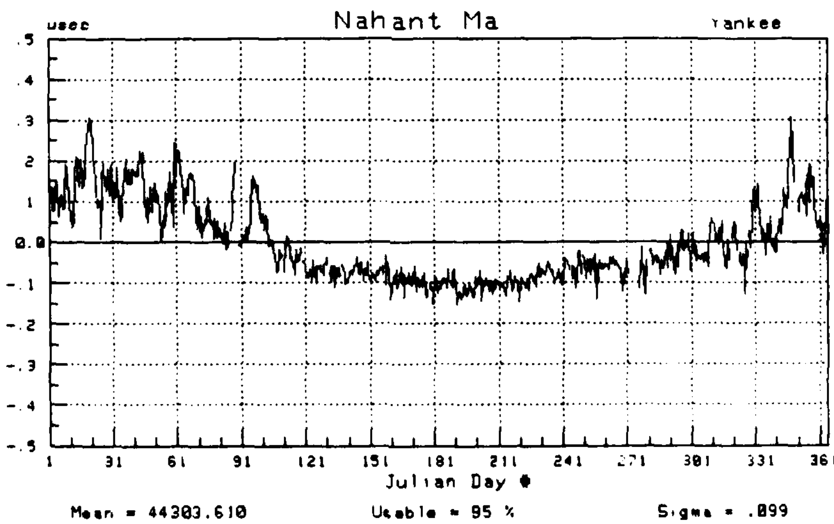

Avery Pt
usec
x-ray
5
4
3
2
1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 26135.571
Usable = 98 %
Sigma = .046

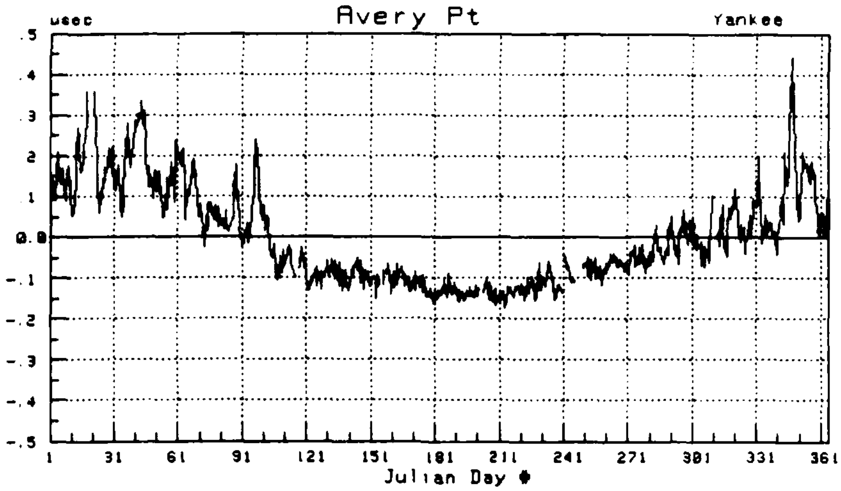

Gloucester DE
usec
x-ray
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 27361.330
Usable = 98 %
Sigma = .066


Lewes DE
usec
x-ray
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 27160.433
Usable = 98 %
Sigma = .026

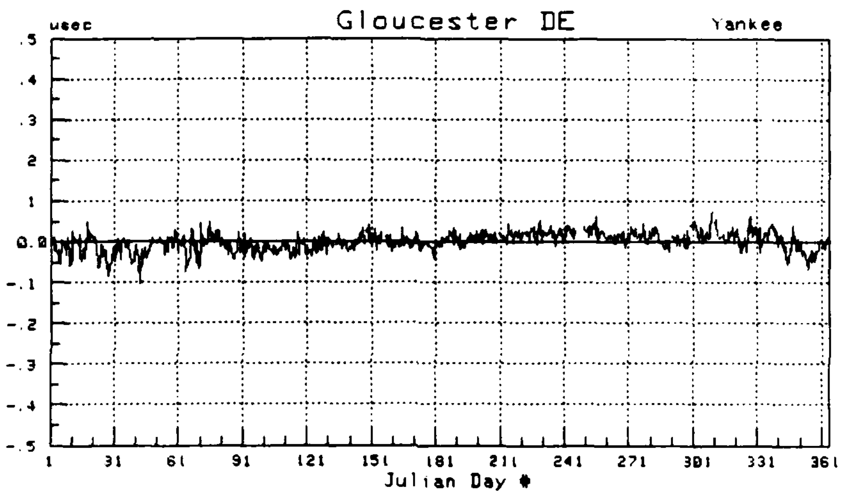

usec
Yorktown VA
x-ray
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 27324.597
Useable = 84 %
Sigma = .029


usec
Sandy Hook
x-ray
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 26999.778
Useable = 85 %
Sigma = .010

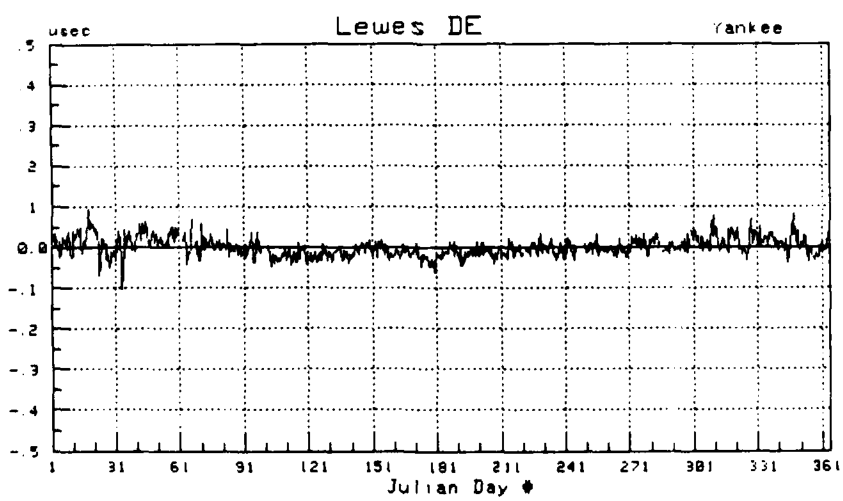

usec
Nahant Ma
Yankee
.5
.4
.3
.2
.1
0.0
-.1
-.2
-.3
-.4
-.5
1
31
61
91
121
151
181
211
241
271
301
331
361
Julian Day #
Mean = 44303.610
Useable = 85 %
Sigma = .099



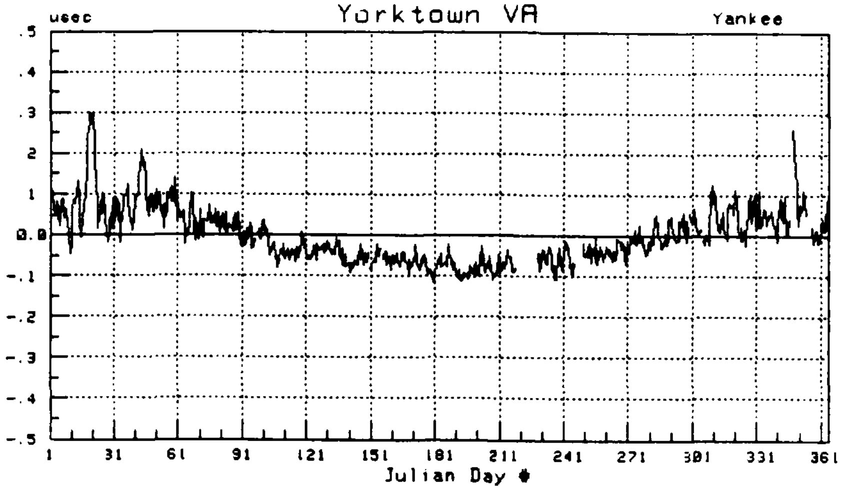
Mean = 43995.095 Useable = 96 % Sigma = .120



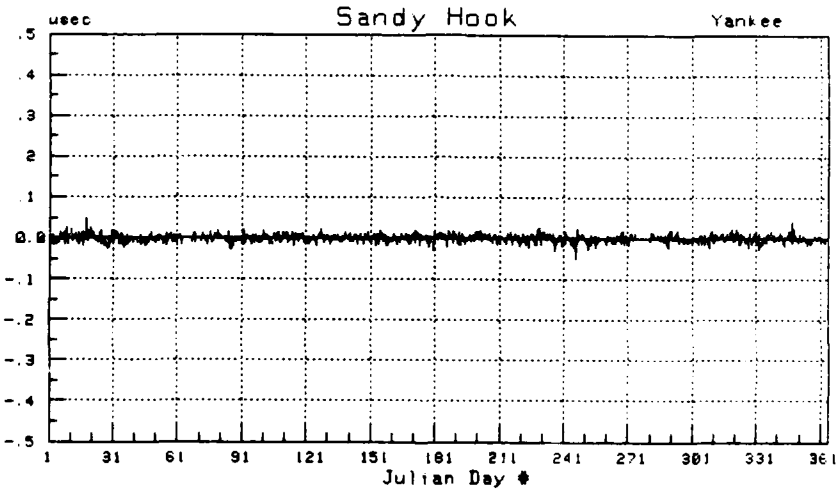
Mean = 43390.030 Useable = 98 % Sigma = .024



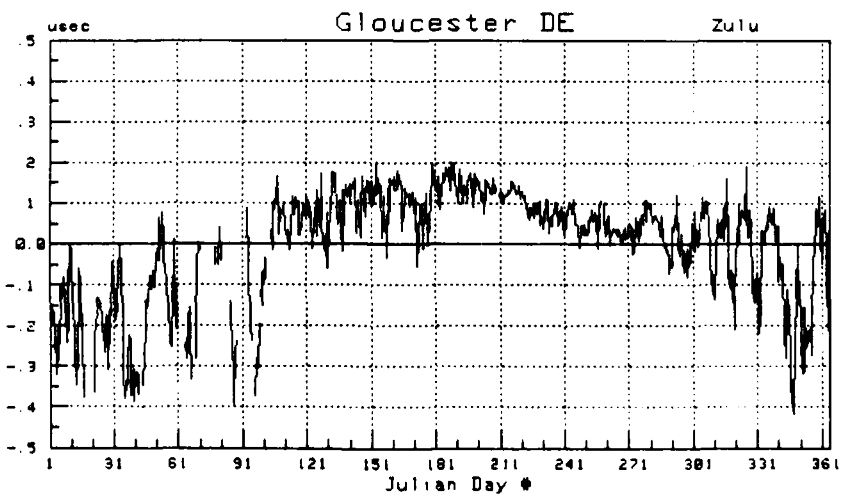
Mean = 42623.744 Useable = 97 % Sigma = .024



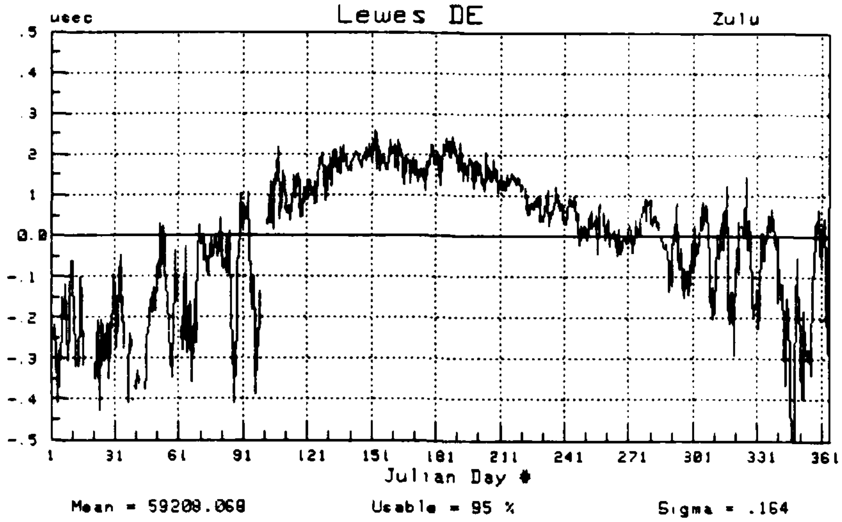
Mean = 41432.025 Usable = 94 % Sigma = .060



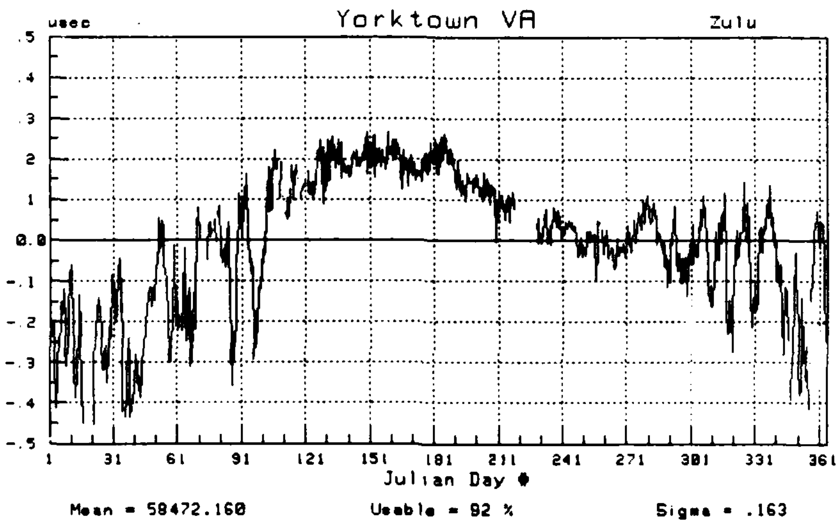
Mean = 43720.370 Usable = 85 % Sigma = .010



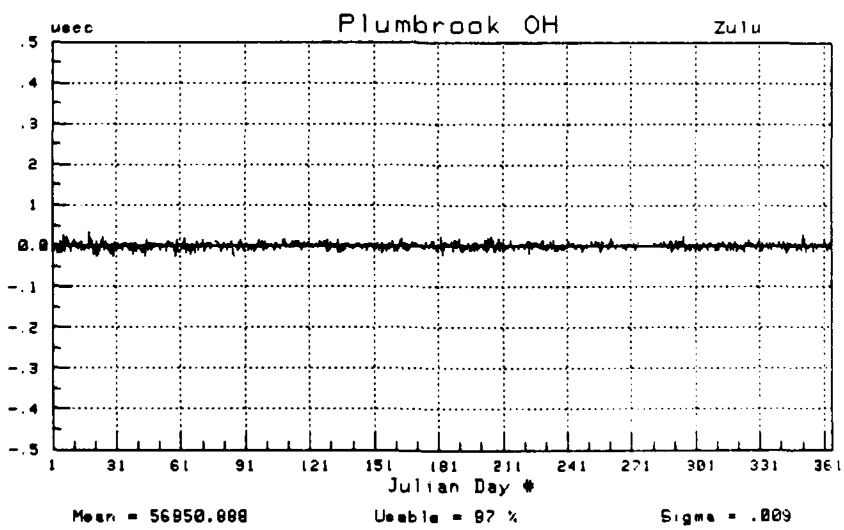
Mean = 59543.846 Usable = 92 % Sigma = .139



usec
Lewes DE
Zulu
Julian Day #
Mean = 59209.060
Usable = 95 %
Sigma = .164



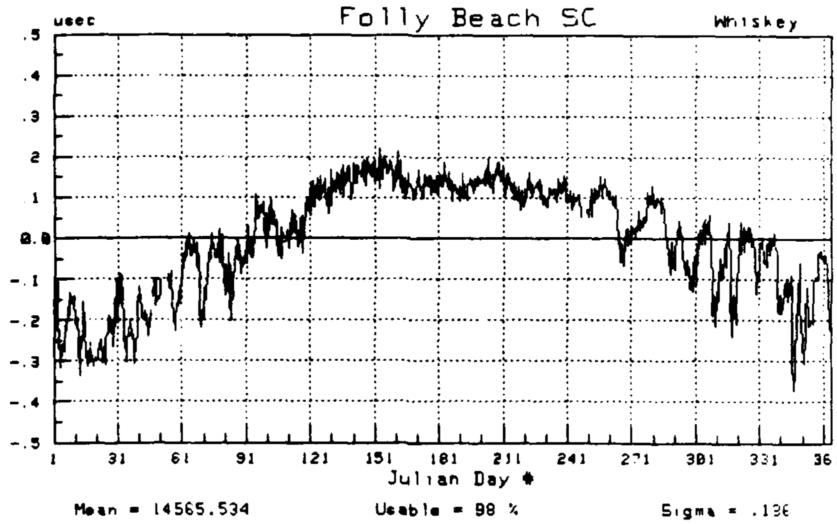
usec
Yorktown VA
Zulu
Julian Day #
Mean = 58472.160
Usable = 92 %
Sigma = .163

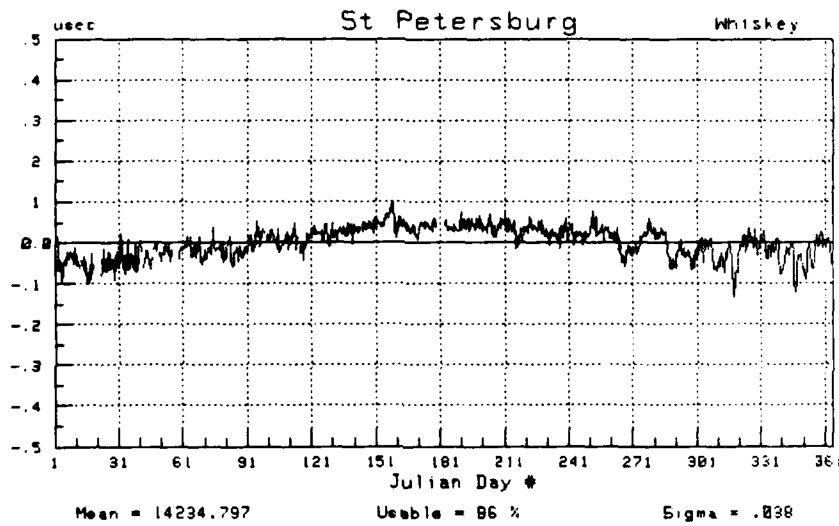


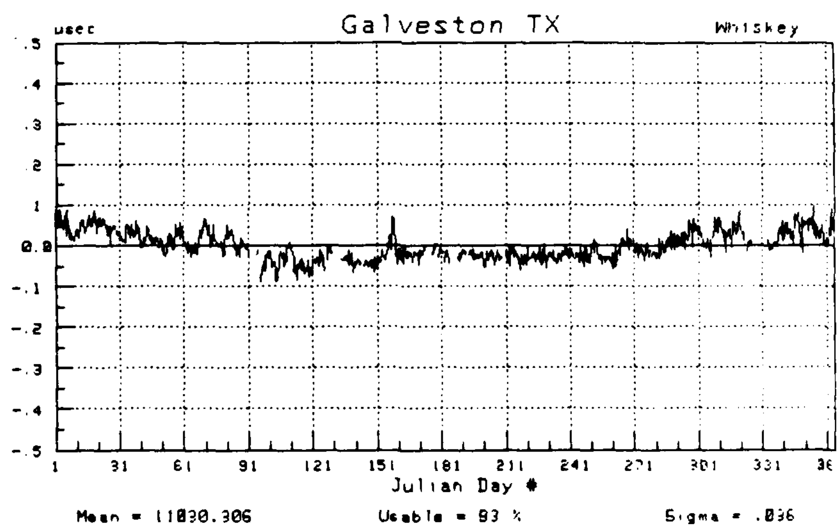
usec
Plumbrook OH
Zulu
Julian Day #
Mean = 56950.000
Usable = 97 %
Sigma = .009

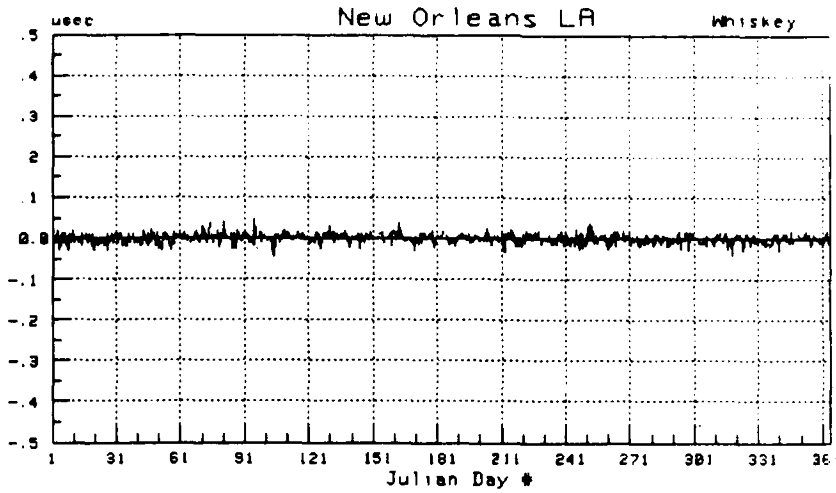
APPENDIX B

S.E.U.S. HARBOR MONITOR DATA

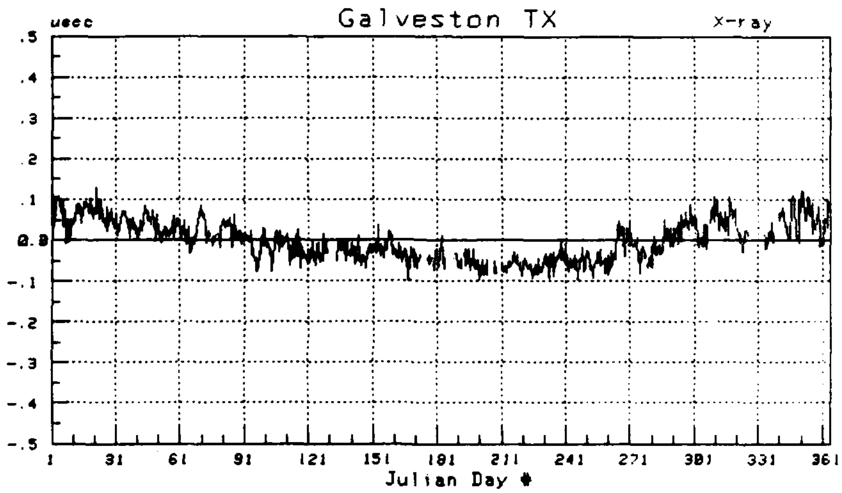

usec
Folly Beach SC
Whiskey
Julian Day #
Mean = 14565.534
Usable = 98 %
Sigma = .136


usec
St Petersburg
Whiskey
Julian Day #
Mean = 14234.797
Usable = 86 %
Sigma = .038

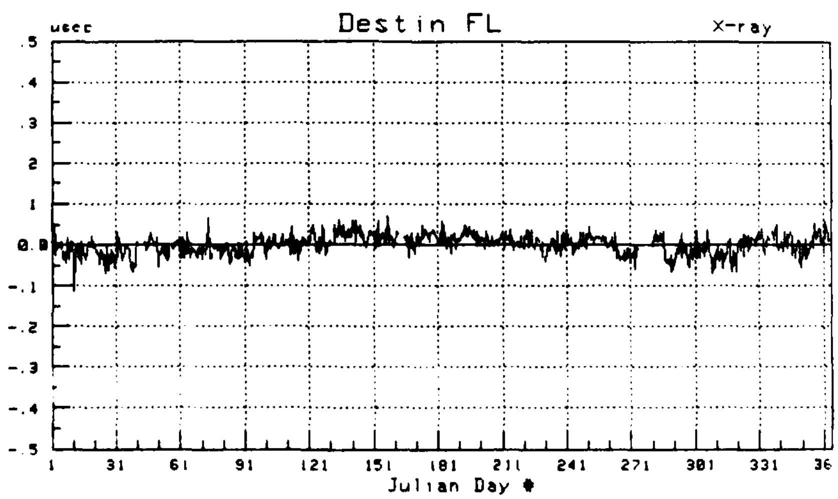

usec
Galveston TX
Whiskey
Julian Day #
Mean = 11030.306
Usable = 93 %
Sigma = .036



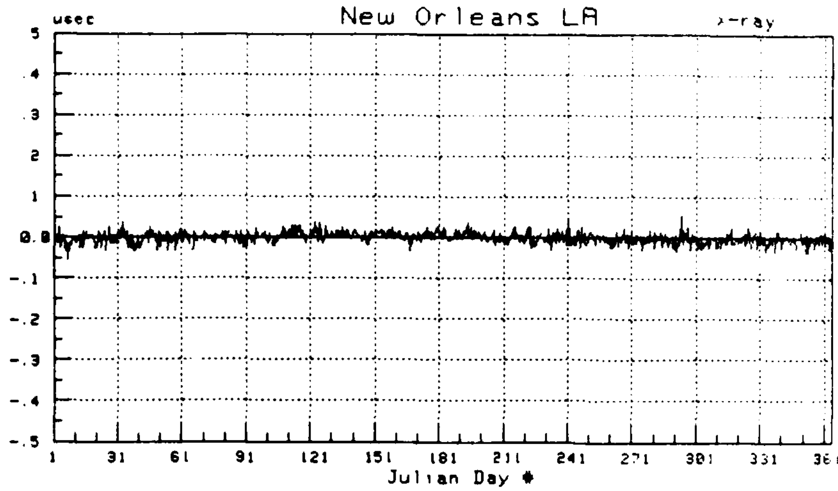
Mean = 11612.460 Usable = 97 % Sigma = .011



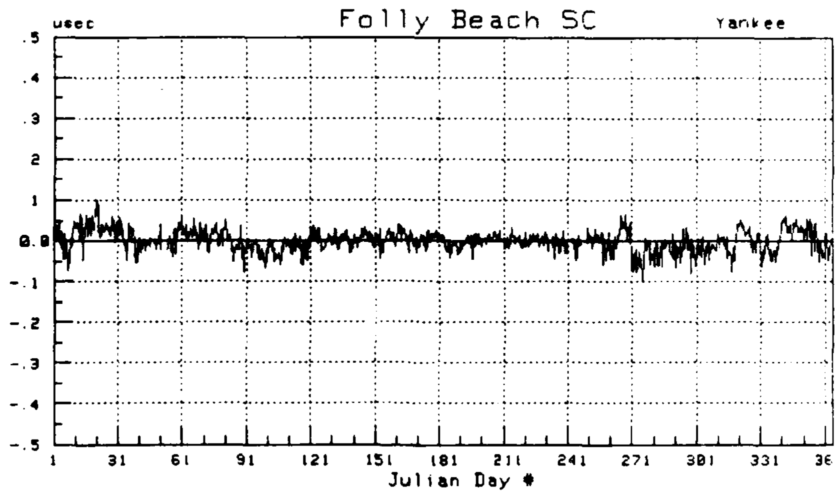
Mean = 25738.000 Usable = 92 % Sigma = .050



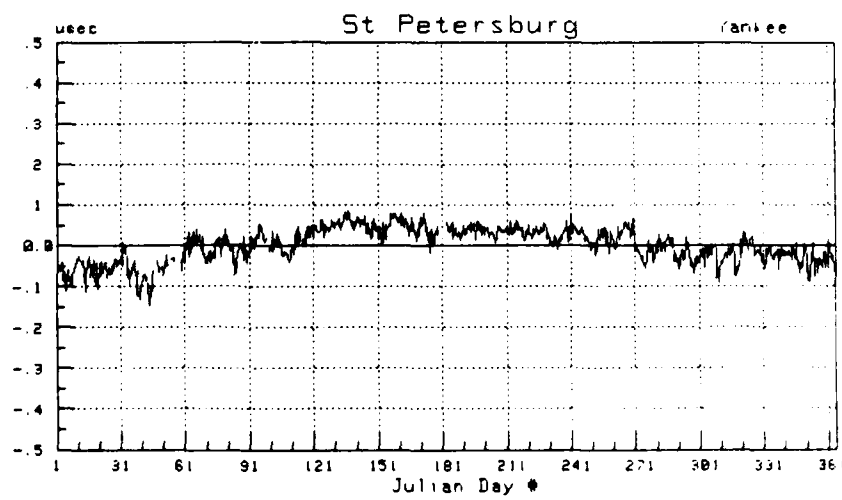
Mean = 30908.291 Usable = 95 % Sigma = .025



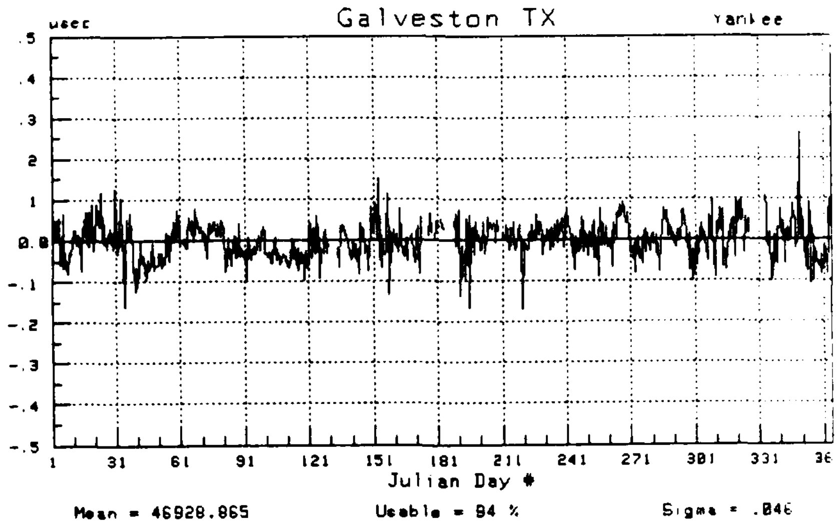
Mean = 28656.704 Useble = 97 % Sigma = .014



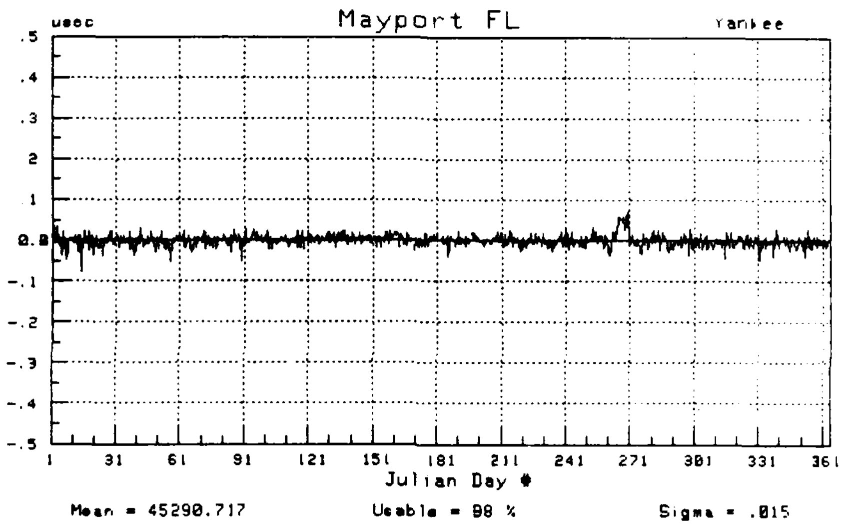
Mean = 45510.474 Useble = 98 % Sigma = .028



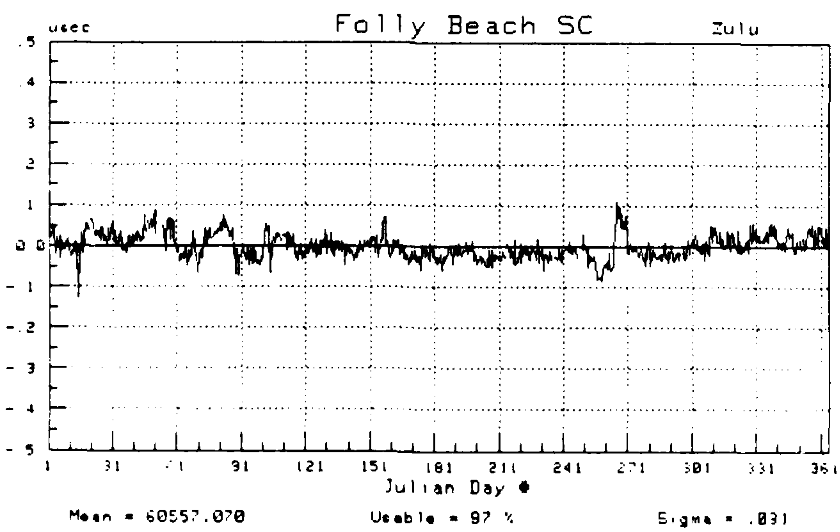
Mean = 44621.690 Useble = 97 % Sigma = .043



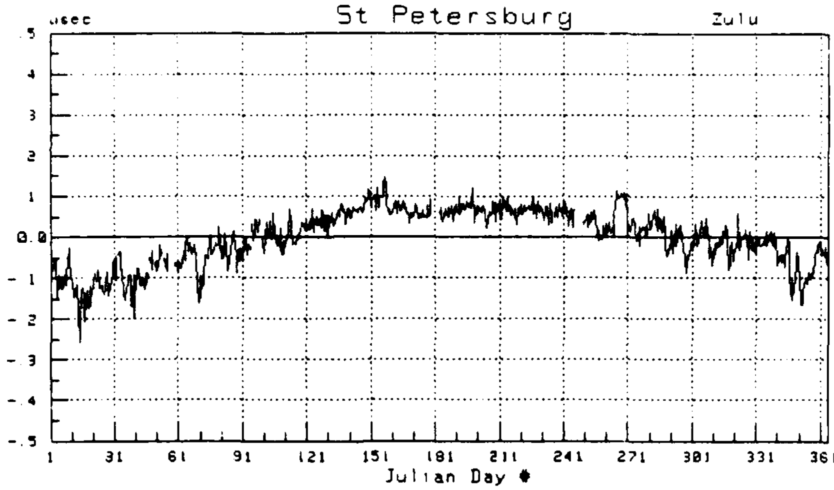
Galveston TX
Yankee
usec
.5
.4
.3
2
1
0.0
-.1
-.2
-.3
-.4
-.5
1 31 61 91 121 151 181 211 241 271 301 331 361
Julian Day #
Mean = 46928.865
Useable = 94 %
Sigma = .046



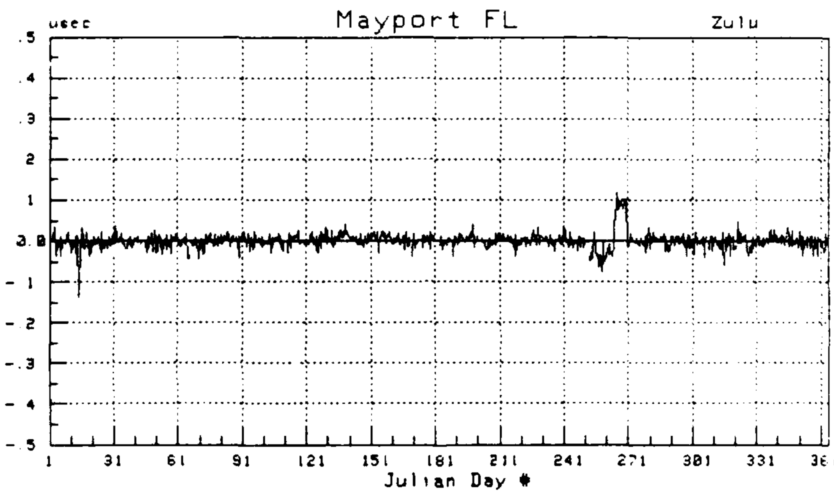
Mayport FL
Yankee
usec
.5
.4
.3
2
1
0.0
-.1
-.2
-.3
-.4
-.5
1 31 61 91 121 151 181 211 241 271 301 331 361
Julian Day #
Mean = 45290.717
Useable = 98 %
Sigma = .015



Folly Beach SC
Zulu
usec
.5
.4
3
2
1
0.0
-.1
-.2
-3
-4
-5
1 31 91 121 151 181 211 241 271 301 331 361
Julian Day #
Mean = 60557.070
Useable = 97 %
Sigma = .031



Mean = 62864.666 Usable = 96 % Sigma = .069



Mean = 62073.388 Usable = 98 % Sigma = .021

APPENDIX C

MAJOR N.E.U.S./S.E.U.S. HARBORS:

REACH DESCRIPTION AND PERFORMANCE PREDICTIONS

CORPUS CHRISTI

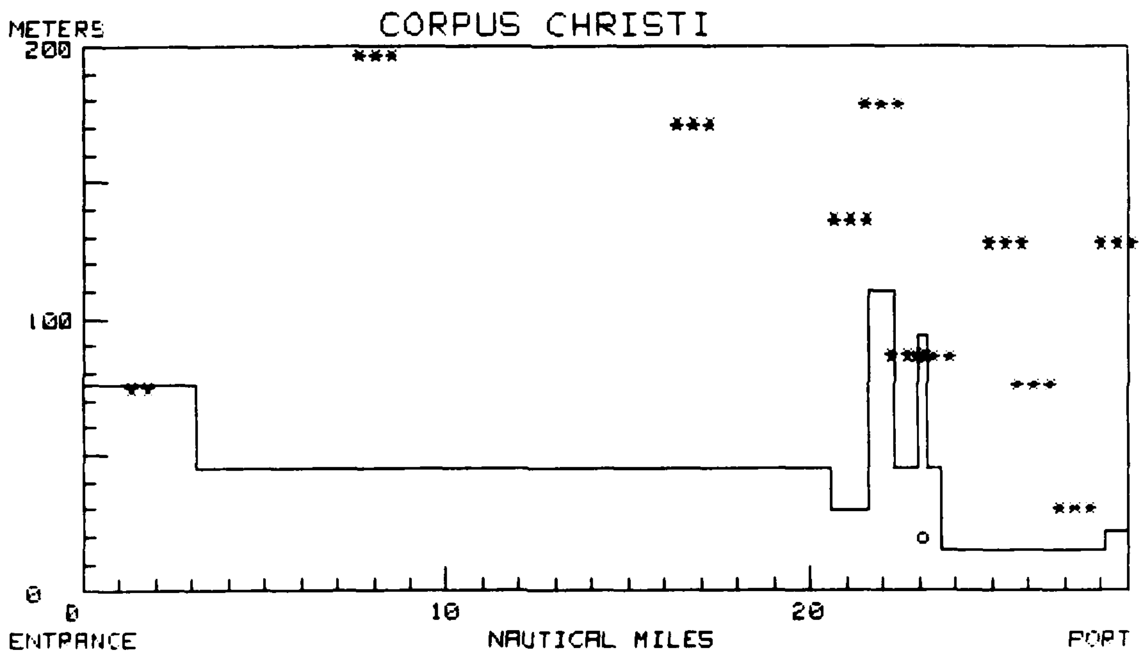
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Aransas Pass	27-49-50 N 97-01-59 W	301°T	92 m
2	Corpus Christi Cut A	27-49-37 N 97-08-52 W	258	61
3	Corpus Christi Cut B	27-48-36 N 97-18-32 W	270	61
4	Corpus Christi Hwy Br	27-48-45 N 97-23-46 W	281	46
5	Turning Basin	27-48-47 N 97-24-25 W	268	126
6	Industrial Canal	27-48-55 N 97-25-09 W	294	61
7	Avery Pt. Turning Basin	27-49-07 N 97-25-35 W	316	110
8	Industrial Canal	27-49-17 N 97-25-52 W	294	61
9	Tule Lake Range A	27-49-11 N 97-27-00 W	247	31
10	Tule Lake Range B	27-49-02 N 97-28-10 W	283	31
11	Tule Lake Range D	27-49-15 N 97-28-50 W	296	31
12	Viola Range G	27-49-53 N 97-29-53	307	31
13	Viola Range H	27-50-32 N 97-31-00	283	41

Reach MWX No.	Corrected Half-Width Minus 16·m	MWX CTE	Error Margin
1	76 m	75 m	0 **
2	45	197	-142***
3	45	171	-126***
4	30	136	-106***
5	110	179	-69***
6	45	86	-41***
7	94	20	74
8	45	86	-41***
9	15	231	-216***
10	15	128	-113***
11	15	76	-61***
12	15	30	-15***
13	25	128	-103***


CORPUS CHRISTI
METERS
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

PORT ARTHUR

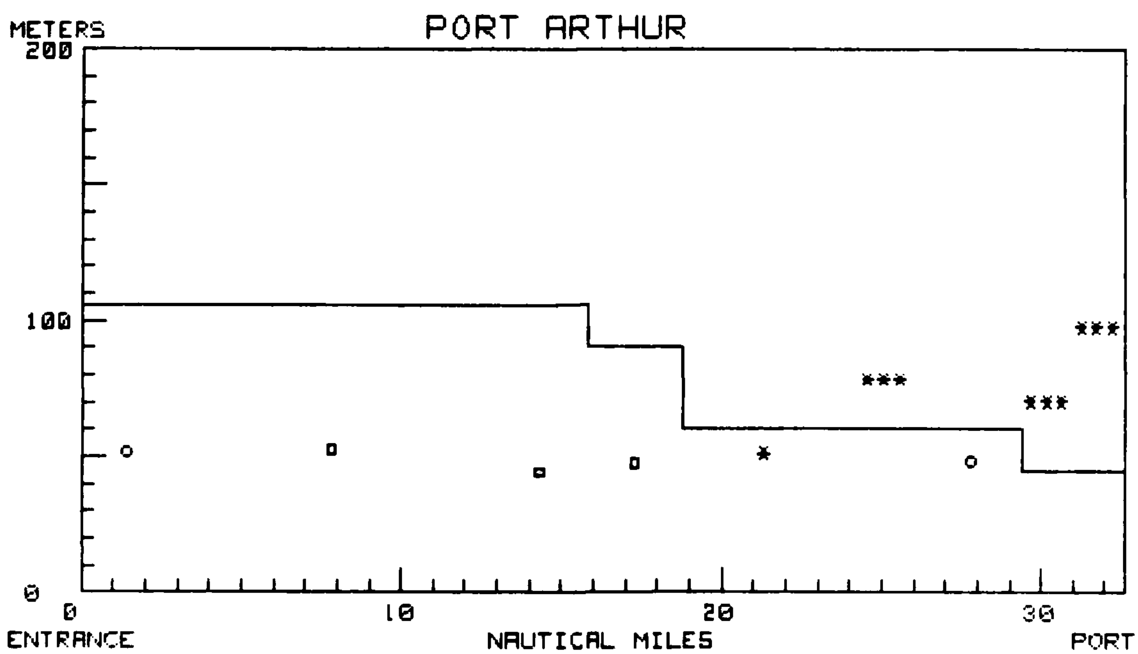
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Sabine Bank	29-27-30 N 93-40-00 W	000°T	122 m
2	Sabine Bank	29-32-23 N 93-44-00 W	314	122
3	Sea Bar	29-37-23 N 93-48-55 W	337	122
4	Jetty	29-39-55 N 93-44-49 W	347	107
5	Pass	29-43-20 N 93-51-46 W	326	76
6	Port Art Can Range D	29-45-45 N 93-54-31 W	291	76
7	Port Art Can Range F	29-48-03 N 93-57-09 W	342	76
13	Sabine Neches Canal	29-50-06 N 93-57-14 W	007	61
14	Sabine Neches Range H	29-51-21 N 93-56-31 W	040	61

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	106 m	53m	53 m
2	106	53	53
3	106	45	61
4	91	49	42
5	60	51	9 *
6	60	78	-18***
7	60	49	11
8	45	70	-15***
9	45	98	-53***


PORT ARTHUR
METERS
200
100
0
0
10
20
30
ENTRANCE
NAUTICAL MILES
PORT
***
***
***

GALVESTON - TEXAS CITY - HOUSTON

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

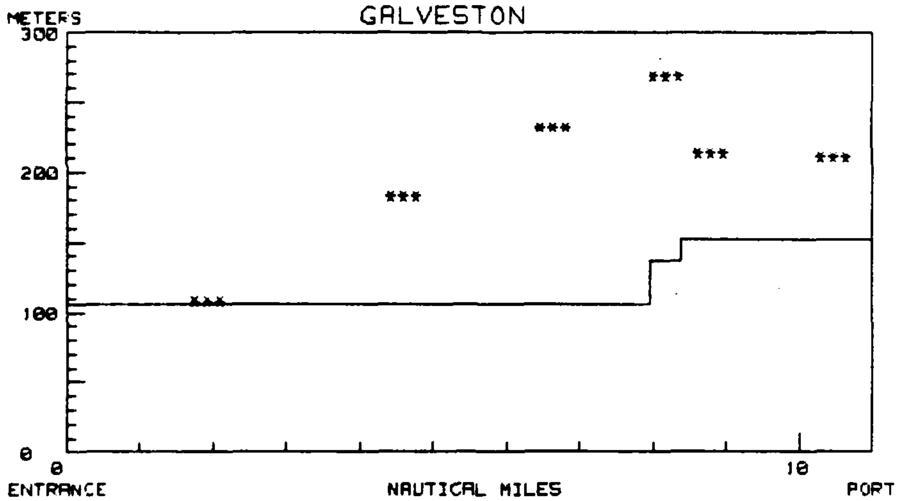
CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Galveston Bay Entrance	29-18-50 N 94-40-12 W	301°T	122 m
2	Outer Bar	29-20-34 N 94-42-06 W	282	122
3	Inner Bar	29-20-37 N 94-44-32 W	266	122
4	Bolivar Roads	29-20-42 N 94-46-33 W	296	122
5	Hou Ship Chan Entrance Range	29-21-27 N 94-47-32 W	318	61
6	Hou Ship Chan Red Fsh Bar Ran	29-27-04 N 94-50-38 W	336	61
7	Hou Ship Chan Gal By Upr Ran	29-33-02 N 94-54-33 W	326	61
8	Hou Ship Chan Gal By Range A	29-39-01 N 94-58-09 W	341	61
9	Houston Ship Range B	29-41-13 N 94-59-04 W	327	61
10	Houston Ship Range C	29-41-39 N 94-59-33 W	309	61
11	Houston Ship Range E	29-42-05 N 95-00-30 W	280	61
12	Houston Ship Range G	29-42-55 N 95-01-12 W	000	61
13	Houston Ship Range J	29-43-39 N 95-01-30 W	308	61
14	Houston Ship Range K	29-43-50 N 95-02-13 W	275	61
15	Houston Ship Range M	29-43-56 N 95-02-49 W	291	61
16	Houston Ship Range O	29-44-09 N 95-03-15 W	307	61
17	Houston Ship Range Q	29-44-27 N 95-03-34 W	327	61
18	Houston Ship Range S	29-44-54 N 95-03-48 W	344	61
19	Houston Ship Range U	29-45-19 N 95-04-02 W	322	61
20	Houston Ship Range W	29-45-38 N 95-04-28 W	303	61
21	Houston Ship	29-45-47 N 95-05-04 W	255	61
22	Houston Ship	29-45-22 N 95-05-32 W	211	61
23	Houston Ship	29-44-50 N 95-06-00 W	223	61
24	Houston Ship	29-44-23 N 95-06-44 W	248	61

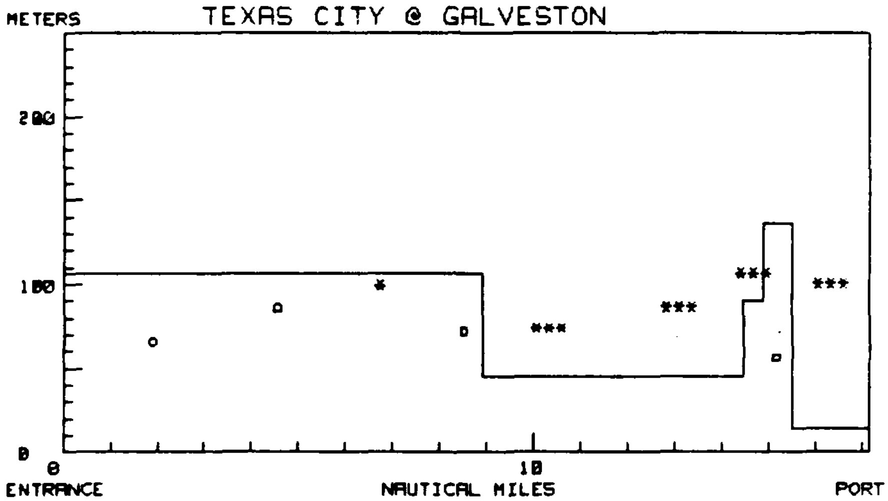
Reach No.	Channel Name	Reach Center	Course	Half-Width
25	Houston Ship	29-44-13 N 95-07-12 W	244	61 m
26	Houston Ship	29-44-06 N 95-08-24 W	276	46
27	Hou Ship at New Bridge	29-44-08 N 95-08-48 W	276	46
28	Houston Ship	29-44-27 N 95-09-32 W	311	46
29	Houston Ship	29-44-46 N 95-10-06 W	284	46
30	Houston Ship	29-44-46 N 95-10-39 W	256	46
31	Houston Ship	29-44-44 N 95-10-55 W	267	46
32	Houston Ship	29-44-31 N 95-11-46 W	249	46
33	Houston Ship	29-44-20 N 95-12-07 W	226	46
34	Houston Ship	29-43-55 N 95-12-25 W	203	46
35	Houston Ship	29-43-33 N 95-12-44 W	236	46
36	Houston Ship	29-43-29 N 95-13-19 W	281	46
37	Houston Ship	29-43-26 N 95-13-54 W	245	46
38	Houston Ship	29-43-18 N 95-14-10 W	234	46
39	Houston Ship	29-43-09 N 95-14-34 W	270	46
40	Houston Ship	29-43-22 N 95-15-02 W	322	46
41	Houston Ship	29-43-35 N 95-15-30 W	270	46
42	Houston Ship	29-43-32 N 95-15-48 W	251	46
43	Houston Ship	29-43-29 N 95-15-58 W	263	46
44	Houston Ship	29-43-33 N 95-16-21 W	302	46
45	Houston Ship	29-43-53 N 95-16-35 W	356	46
46	Houston Ship	29-44-09 N 95-16-41 W	337	46
47	Houston Ship Long Reach	29-44-30 N 95-16-55 W	324	46
48	Houston Ship	29-44-51 N 95-17-10 W	332	38

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	106 m	67 m	39 m
2	106	87	19
3	106	99	7 *
4	106	74	32
5	45	52	-7***
6	45	44	1 **
7	45	49	-4***
8	45	49	-4***
9	45	49	-4***
10	45	66	-21***
11	45	99	-54***
12	45	67	-22***
13	45	67	-22***
14	45	105	-60***
15	45	88	-43***
16	45	69	-24***
17	45	49	-4***
18	45	51	-6***
19	45	53	-8***
20	45	74	-29***
21	45	119	-74***
22	45	104	-59***
23	45	114	-69***
24	45	119	-74***

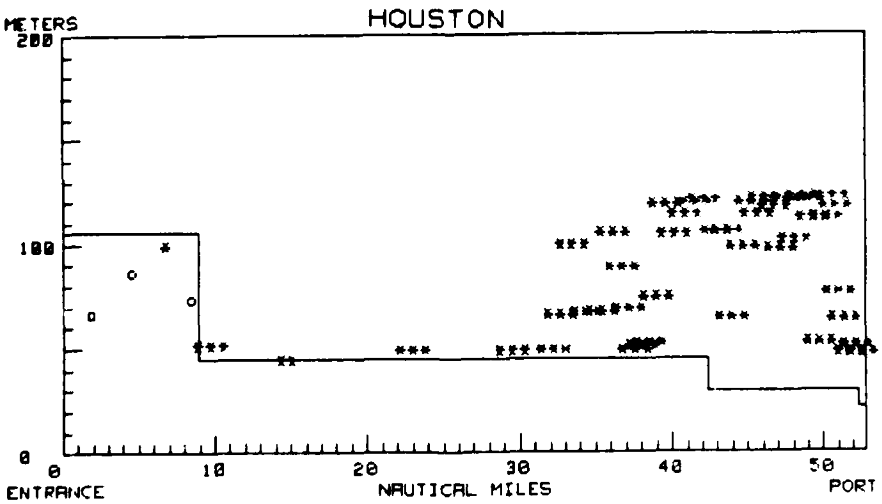
Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
25	45	121 m	-76 m ***
26	30	106	-76 ***
27	30	106	-73 ***
28	30	65	-35 ***
29	30	98	-68 ***
30	30	120	-90 ***
31	30	114	-84 ***
32	30	122	-92 ***
33	30	117	-87 ***
34	30	97	-67 ***
35	30	121	-91 ***
36	30	102	-72 ***
37	30	123	-93 ***
38	30	121	-91 ***
39	30	112	-82 ***
40	30	53	-23 ***
41	30	113	-83 ***
42	30	122	-92 ***
43	30	118	-88 ***
44	30	77	-47 ***
45	30	64	-34 ***
46	30	48	-18 ***
47	30	51	-21 ***
48	22	48	-26 ***



GALVESTON
METERS
300
200
100
0
0
10
ENTRANCE
NAUTICAL MILES
PORT



TEXAS CITY @ GALVESTON
METERS
200
100
0
0
10
ENTRANCE
NAUTICAL MILES
PORT



HOUSTON
METERS
200
100
0
0
10
20
30
40
50
ENTRANCE
NAUTICAL MILES
PORT

NEW ORLEANS

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

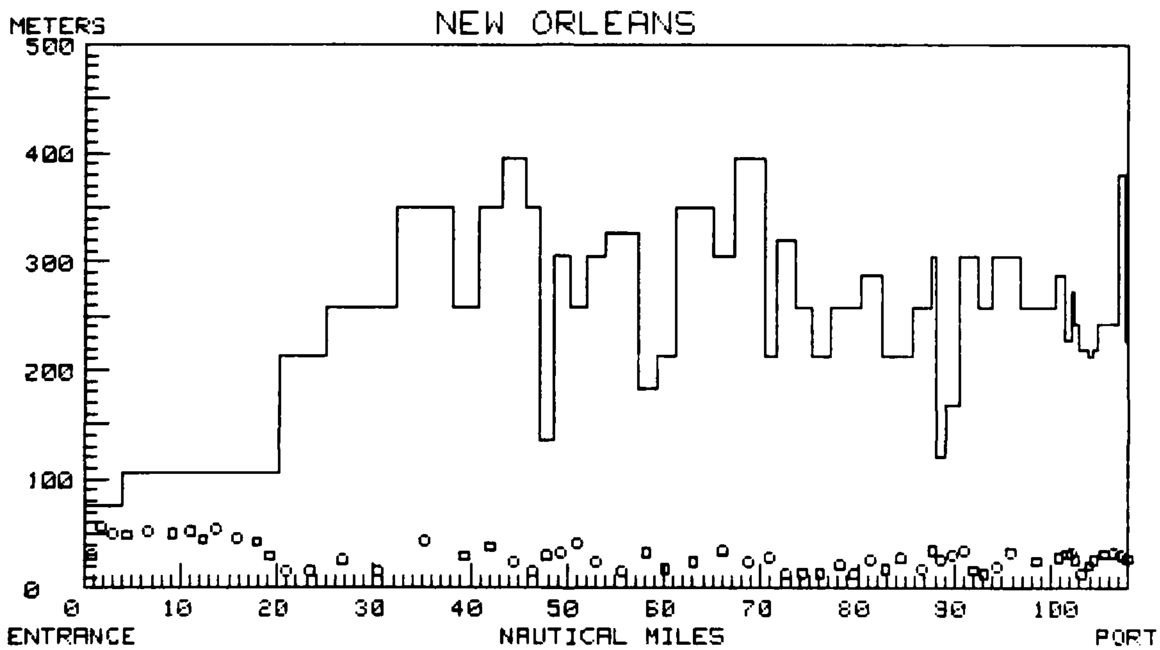
CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	SW Pass Entrance Range "A"	28-53-28 N 89-25-55 W	000°T	92 m
2	SW Pass Entrance Range "B"	28-54-30 N 89-25-42 W	049	92
3	Southwest Pass	28-55-13 N 89-25-06 W	033	92
4	Southwest Pass	28-56-39 N 89-24-06 W	030	122
5	Southwest Pass	28-58-50 N 89-22-23 W	037	122
6	Southwest Pass	29-00-55 N 89-20-38 W	034	122
7	Southwest Pass	29-02-02 N 89-19-41 W	039	122
8	Southwest Pass	29-03-06 N 89-18-54 W	024	122
9	Southwest Pass	29-04-17 N 89-17-50 W	047	122
10	Southwest Pass	29-05-12 N 89-16-15 W	026	122
11	Southwest Pass	29-07-48 N 89-15-36 W	021	122
12	Appr Range Hd of Passes	29-08-54 N 89-15-22 W	003	122
13	MS River	29-10-46 N 89-15-48 W	341	229
14	MS River	29-12-58 N 89-17-05 W	328	229
15	MS River	29-15-06 N 89-19-02 W	310	275
16	MS River	29-18-04 N 89-22-00 W	327	275
17	MS River	29-21-11 N 89-28-00 W	214	366
18	MS River	29-21-24 N 89-30-41 W	302	275
19	MS River	29-21-58 N 89-32-40 W	286	366
20	MS River	29-22-57 N 89-34-53 W	310	412
21	MS River	29-24-40 N 89-36-19 W	350	366
22	MS River	29-25-56 N 89-36-11 W	016	153
23	MS River	29-27-13 N 89-36-48 W	295	320
24	MS River	29-27-30 N 89-38-24 W	274	275

Reach No.	Channel Name	Reach Center	Course	Half-Width
25	MS River	29-28-12 N 89-40-52 W	308	320 m
26	MS River	29-30-07 N 89-42-27 W	324	343
27	MS River	29-31-53 N 89-44-31 W	291	199
28	MS River	29-33-00 N 89-46-07 W	322	229
29	MS River	29-34-49 N 89-48-21 W	306	366
30	MS River	29-36-17 N 89-51-32 W	281	320
31	MS River	29-37-31 N 89-54-48 W	306	412
32	MS River	29-38-30 N 89-56-36 W	293	229
33	MS River	29-39-42 N 89-57-34 W	354	186
34	MS River	29-41-11 N 89-58-02 W	329	275
35	MS River	29-42-45 N 89-59-00 W	335	229
36	MS River	29-44-26 N 90-00-25 W	311	275
37	MS River	29-45-42 N 90-01-29 W	352	275
38	MS River	29-47-23 N 90-00-48 W	032	305
39	MS River	29-48-41 N 90-00-14 W	008	229
40	MS River	29-50-03 N 89-59-30 W	036	229
41	MS River	29-51-57 N 89-58-30 W	009	275
42	MS River	29-52-52 N 89-58-00 W	078	320
43	MS River	29-52-32 N 89-57-07 W	122	138
44	MS River	29-52-02 N 89-55-49 W	109	183
45	MS River	29-52-02 N 89-54-40 W	065	320
46	MS River	29-52-42 N 89-54-07 W	007	320
47	MS River	29-53-53 N 89-54-21 W	338	275
48	MS River	29-54-55 N 89-55-07 W	319	320

Reach No.	Channel Name	Reach Center	Course	Half-Width
49	MS River	29-55-25 N 89-56-32 W	273	320 m
50	MS River	29-56-42 N 90-00-00 W	303	275
51	MS River	29-57-18 N 90-01-49 W	291	305
52	MS River	29-57-30 N 90-02-40 W	276	244
53	MS River	29-57-31 N 90-03-14 W	259	290
54	MS River	29-57-21 N 90-03-30 W	219	260
55	MS River Bridge	29-56-15 N 90-03-29 W	171	237
56	MS River	29-55-54 N 90-03-36 W	201	229
57	MS River	29-55-32 N 90-03-51 W	221	237
58	MS River	29-55-01 N 90-04-54 W	246	260
59	MS River	29-54-40 N 90-06-00 W	260	260
60	MS River	29-54-38 N 90-06-48 W	272	396
61	MS River	29-54-46 N 90-07-42 W	290	244

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
1	76 m	32 m	44 m
2	76	58	18
3	76	53	23
4	106	51	55
5	106	54	52
6	106	53	53
7	106	54	52
8	106	47	59
9	106	57	49
10	106	48	58
11	106	45	61
12	106	32	74
13	213	18	195
14	213	18	195
15	259	28	227
16	259	18	237
17	350	46	304
18	259	32	227
19	350	41	309
20	396	27	369
21	350	18	332
22	137	32	105
23	304	35	269
24	259	43	216


NEW ORLEANS
METERS
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
ENTRANCE
NAUTICAL MILES
PORT

MOBILE

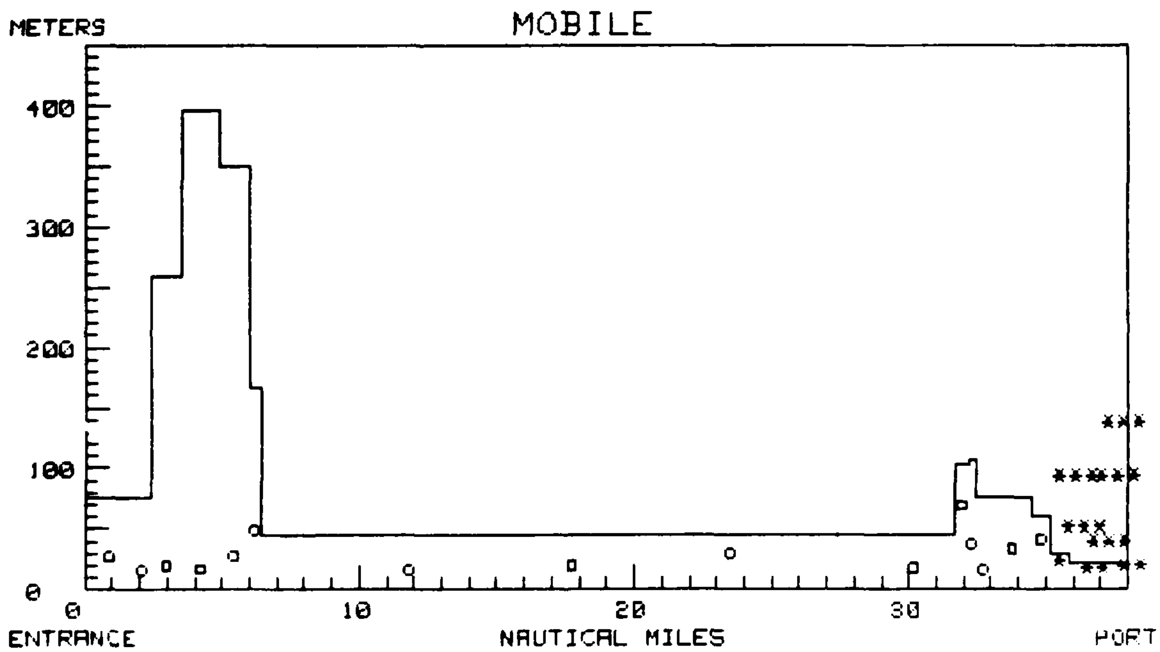
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Entrance Channel	30-09-37 N 88-03-12 W	000°T	92 m
2	Entrance Channel	30-10-43 N 88-02-51 W	049	92
3	Pelican Bay	30-11-36 N 88-02-38 W	016	276
4	Pelican Bay	30-12-45 N 88-02-18 W	012	414
5	Pelican Bay	30-14-00 N 88-02-12 W	355	368
6	Pelican Bay	30-14-44 N 88-02-20 W	341	184
7	Lower Reach	30-20-23 N 88-01-37 W	007	61
8	Bend	30-25-14 N 88-00-49 W	001	61
9	Middle Reach	30-31-55 N 88-01-24 W	354	61
10	Upper Reach	30-38-35 N 88-01-55 W	002	61
11	Pinto Isl Reach	30-40-17 N 88-02-00 W	333	118
12	Bend	30-40-39 N 88-02-11 W	350	122
13	Lower Mobile Channel	30-41-08 N 88-02-10 W	003	92
14	Upper Mobile Channel	30-41-57 N 88-02-14 W	352	92
15	Lowr Blakely Is Reach	30-43-09 N 88-02-27 W	348	76
16	St Louis Pt Br Lift	30-44-00 N 88-02-33	358	46
17	Swing Br	30-44-16 N 88-02-40 W	322	--
18	Chickasaw Creek	30-44-34 N 88-02-55 W	344	38
19	Chickasaw Creek	30-44-58 N 88-02-54 W	004	38
20	Chickasaw Creek	30-45-30 N 88-02-54 W	350	38
21	Chickasaw Creek	30-45-48 N 88-03-01 W	323	38
22	Chickasaw Creek	30-45-52 N 88-03-13 W	272	38
23	Chickasaw Creek	30-46-04 N 88-03-22 W	001	38

Reach No.	Corrected Half-Width Minus 16 m	MWY CTE	MWY Error Margin
1	76 m	29 m	47 m
2	76	19	57
3	260	23	237
4	398	19	379
5	352	30	322
6	168	52	116
7	45	18	27
8	45	22	23
9	45	32	13
10	45	20	25
11	102	71	31
12	106	39	67
13	76	19	57
14	76	35	41
15	60	43	17
16	30	24	6 *
17	--	94	- -
18	22	52	-30 ***
19	22	18	4 **
20	22	40	-18 ***
21	22	94	-72 ***
22	22	138	-116 ***
23	22	20	2 **


MOBILE
METERS
400
300
200
100
0
0
10
20
30
ENTRANCE
NAUTICAL MILES
PORT

ST. PETERSBURG - TAMPA

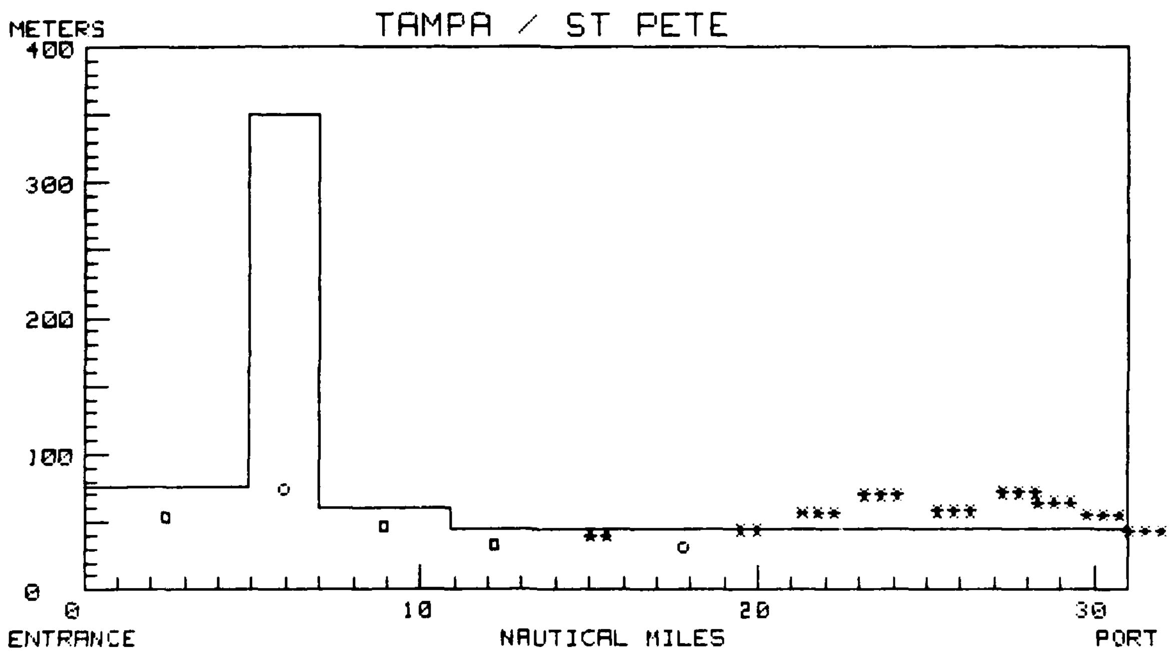
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Egmont	27-36-26 N 82-49-31 W	084°T	92 m
2	Egmont	27-36-27 N 82-45-38 W	106	366
3	Mullet Key	27-36-29 N 82-42-22 W	081	76
4	Cut A Sunshine Skwy	27-37-07 N 82-39-30 W	062	61
5	Cut B	27-39-25 N 82-36-19 W	038	61
6	Cut C	27-41-11 N 82-34-16 W	061	61
7	Cut D	27-42-32 N 82-32-44 W	033	61
8	Cut E	27-44-25 N 82-31-44 W	018	61
9	Cut F	27-46-13 N 82-31-24 W	000	61
10	Cut G	27-47-13 N 82-32-54 W	279	61
11	Cut J	27-48-00 N 82-34-24 W	359	61
12	Cut J-2	27-49-02 N 82-34-19 W	010	61
13	Cut K	27-50-39 N 82-33-42 W	022	61
14	Pt Tampa Dock	27-51-42 N 82-32-49 W	083	46

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	76 m	56 m	20 m
2	350	76	274
3	60	49	11
4	45	35	10
5	45	41	4 *
6	45	33	12
7	45	44	1 **
8	45	57	-12 ***
9	45	70	-15 ***
10	45	58	-13 ***
11	45	72	-27 ***
12	45	65	-20 ***
13	45	55	-10 ***
14	30	43	-13 ***


TAMPA / ST PETE
METERS
400
300
200
100
0
0
10
20
30
ENTRANCE
NAUTICAL MILES
PORT

MIAMI

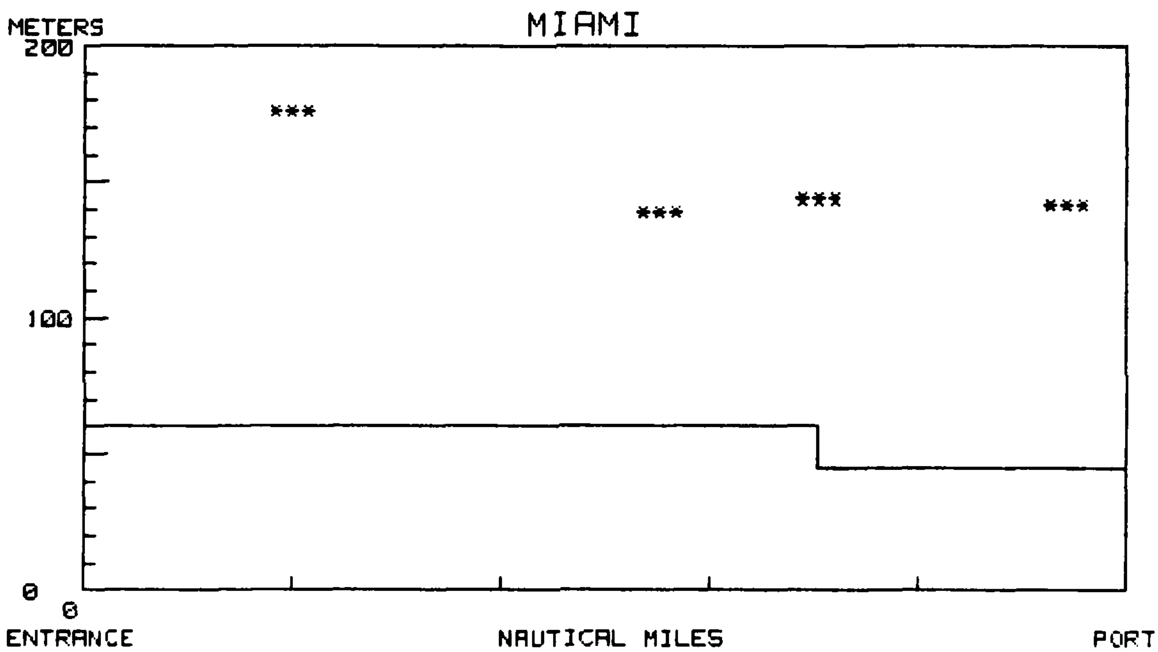
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Outer Bar Cut	25-45-35 N 80-06-08 W	250°T	76 m
2	Govmt Cut Range	25-45-36 N 80-07-34 W	295	76
3	Turning Basin	25-45-59 N 80-08-30 W	293	61
4	Main Channel	25-46-30 N 80-09-43 W	295	61

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	60 m	176 m	-116 m
2	60	139	-79
3	45	144	-99
4	45	142	-97


METERS
MIAMI
200
100
0
0
ENTRANCE
NAUTICAL MILES
PORT

JACKSONVILLE

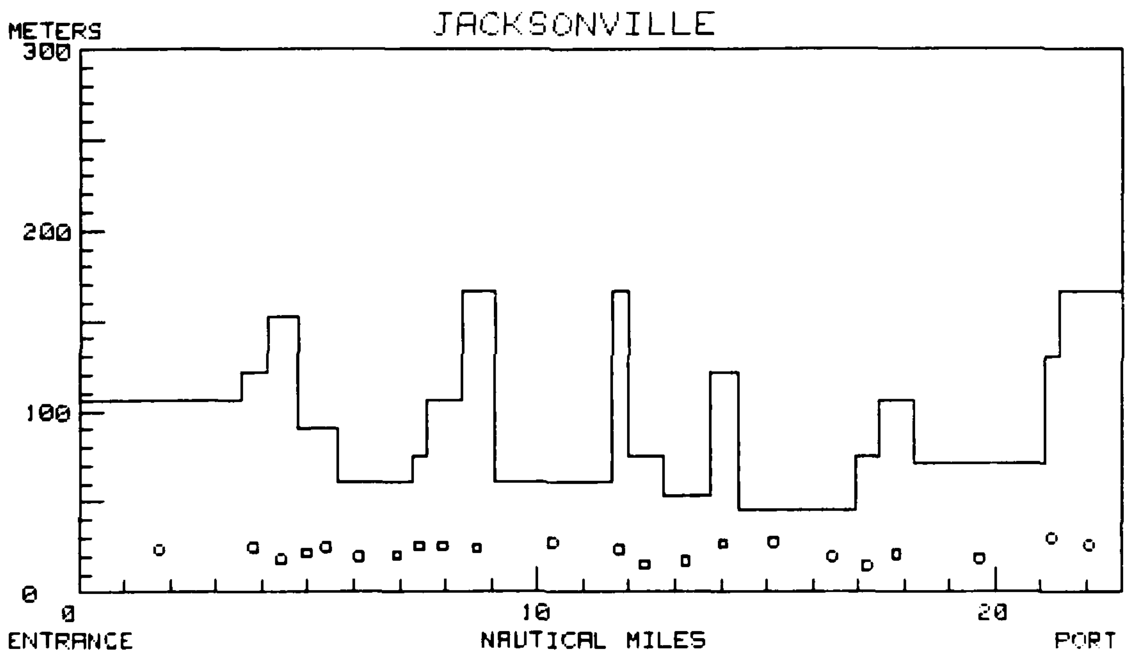
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	St. Johns Bar Cut	30-24-01 N 81-23-35 W	276°T	122 m
2	Pilot Town Cut	30-24-05 N 81-25-32 W	247	138
3	Mayport Cut	30-23-38 N 81-26-00 W	203	168
4	Sherman Cut	30-23-10 N 81-26-19 W	221	107
5	Mile Pt Lower Range	30-22-55 N 81-26-41 W	243	107
6	Mile Pt Upper Range	30-23-08 N 81-27-44 W	310	76
7	Training Wall Reach	30-23-29 N 81-28-16 W	306	76
8	Short Cut Turn	30-23-40 N 81-28-46 W	271	92
9	White Shells Cut	30-23-26 N 81-29-26 W	242	122
10	St Johns Bluff Reach	30-23-24 N 81-30-05 W	286	183
11	Dames Pt Fulton Cutoff	30-23-16 N 81-32-04 W	259	76
12	Dames Pt Turn	30-23-06 N 81-33-38 W	292	183
13	Quarantine 1 Upper Range	30-23-29 N 81-34-05 W	334	92
14	Brills Cut	30-24-06 N 81-34-39 W	324	69
15	Broward Pt Turn	30-24-34 N 81-35-30 W	278	138
16	Drummond Crk Range	30-24-09 N 81-36-43 W	238	61
17	Trout River Cut	30-23-15 N 81-37-36 W	197	61
18	Chaseville Turn	30-22-29 N 81-37-45 W	163	92
19	Long Branch Range	30-22-01 N 81-37-19 W	129	122
20	Trml Chan at Mathews Br	30-19-37 N 81-37-28 W	190	88
21	Commodore Pt Bridge	30-18-56 N 81-37-40 W	237	142
22	St Johns River	30-19-04 N 81-38-38 W	291	183

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	106 m	25 m	81 m
2	122	26	96
3	152	19	133
4	91	23	68
5	91	26	65
6	60	21	39
7	60	22	38
8	76	27	49
9	106	27	79
10	167	26	141
11	60	28	32
12	167	25	142
13	76	17	59
14	53	18	35
15	122	28	94
16	45	29	16
17	45	21	24
18	76	16	60
19	106	22	84
20	72	20	52
21	126	31	95
22	167	27	140



JACKSONVILLE
METERS
300
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

KINGS BAY

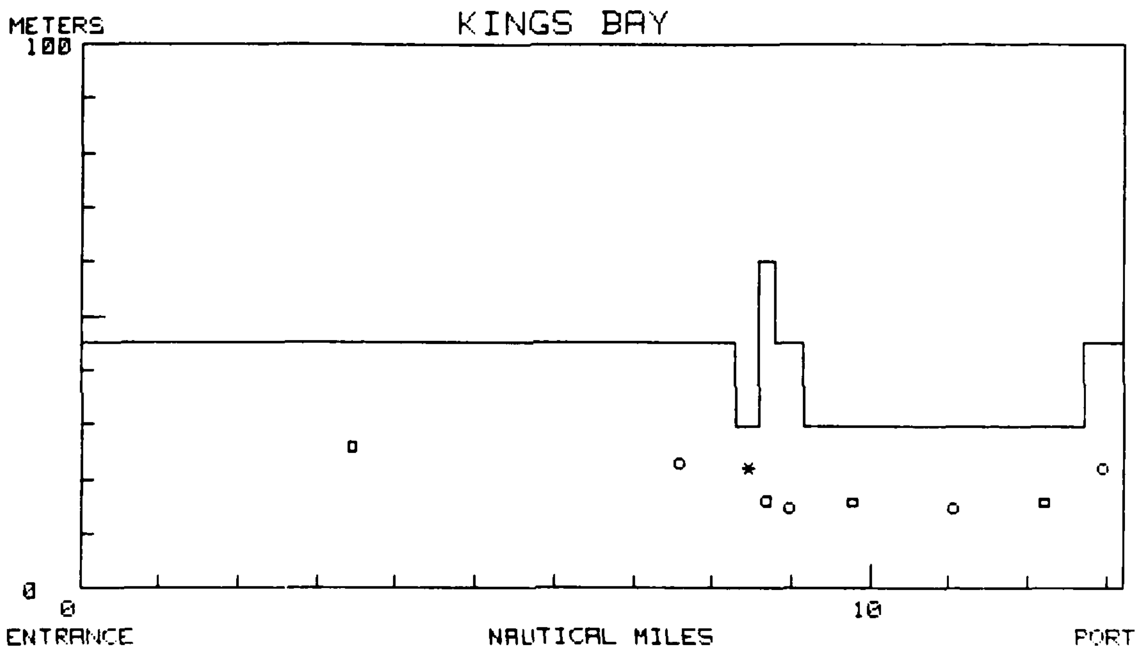
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Entrance Channel	30-42-38 N 81-23-02 W	268°T	61 m
2	Range "A"	30-42-46 N 81-27-48 W	294	61
3	Main Channel	30-43-10 N 81-28-42 W	302	46
4	Main Channel	30-43-22 N 81-28-55 W	332	76
5	Range B	30-43-45 N 81-29-04 W	350	61
6	Range C	30-44-39 N 81-29-04 W	004	46
7	Range D	30-45-55 N 81-29-08 W	351	46
8	Range E	30-47-02 N 81-29-32 W	332	46
9	Main Channel	30-47-36 N 81-30-04 W	298	61

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	45 m	26 m	19 m
2	45	23	22
3	30	22	8 *
4	60	16	44
5	45	15	30
6	30	16	14
7	30	15	15
8	30	16	14
9	45	23	22


KINGS BAY
METERS
100
0
0
10
ENTRANCE
NAUTICAL MILES
PORT

SAVANNAH

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Tybee Range	31-58-57 N 80-45-34 W	298°T	92 m
2	Bloody Pt. Range	32-00-49 N 80-48-09 W	322	92
3	Jones Isl Range	32-02-08 N 80-49-50 W	289	92
4	Tybee Knoll Cut Range	32-02-10 N 80-51-58 W	263	76
5	New Channel Range	32-02-11 N 80-54-26 W	279	76
6	L I Crossing Range	32-03-18 N 80-56-23 W	319	76
7	Lower Flats Range	32-04-20 N 80-57-53 W	280	76
8	Upper Flats Range	32-05-12 N 80-59-20 W	337	76
9	The Bight	32-05-46 N 80-59-47 W	315	92
10	The Bight	32-06-01 N 81-00-09 W	294	92
11	The Bight	32-06-04 N 81-00-25 W	273	92
12	The Bight	32-05-59 N 81-00-46 W	236	92
13	Ft Jackson Range	32-05-38 N 81-01-07 W	213	76
14	Oglethorpe Range	32-05-04 N 81-02-02 W	246	76
15	Wrecks	32-04-47 N 81-02-53 W	267	76
16	Wrecks	32-04-48 N 81-03-19 W	276	76
17	Wrecks	32-04-47 N 81-04-00 W	258	76
18	City Front	32-04-47 N 81-04-48 W	290	61
19	City Front	32-04-54 N 81-05-17 W	286	61
20	US Rt 17A Fixed Bridge	32-05-19 N 81-05-58 W	318	61
21	Marsh Island	32-05-50 N 81-06-33 W	312	61
22	Marsh Isl at Abandoned RR Brg	32-06-13 N 81-07-03 W	316	45
23	Kings Island	32-06-33 N 81-07-22 W	324	61
24	Kings Island	32-06-51 N 81-07-38 W	319	61
25	Kings Island	32-07-11 N 81-07-55 W	327	61
26	Kings Island	32-07-28 N 81-08-07 W	337	61
27	Kings Island	32-07-45 N 81-08-17 W	324	61

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	76 m	23 m	53 m
2	76	17	59
3	76	27	49
4	60	33	27
5	60	31	29
6	60	20	40
7	60	31	29
8	60	17	43
9	76	22	54
10	76	29	47
11	76	34	42
12	76	34	42
13	60	29	31
14	60	35	25
15	60	35	25
16	60	34	26
17	60	36	24
18	45	31	14
19	45	32	13
20	45	23	22
21	45	25	20
22	29	24	5 *
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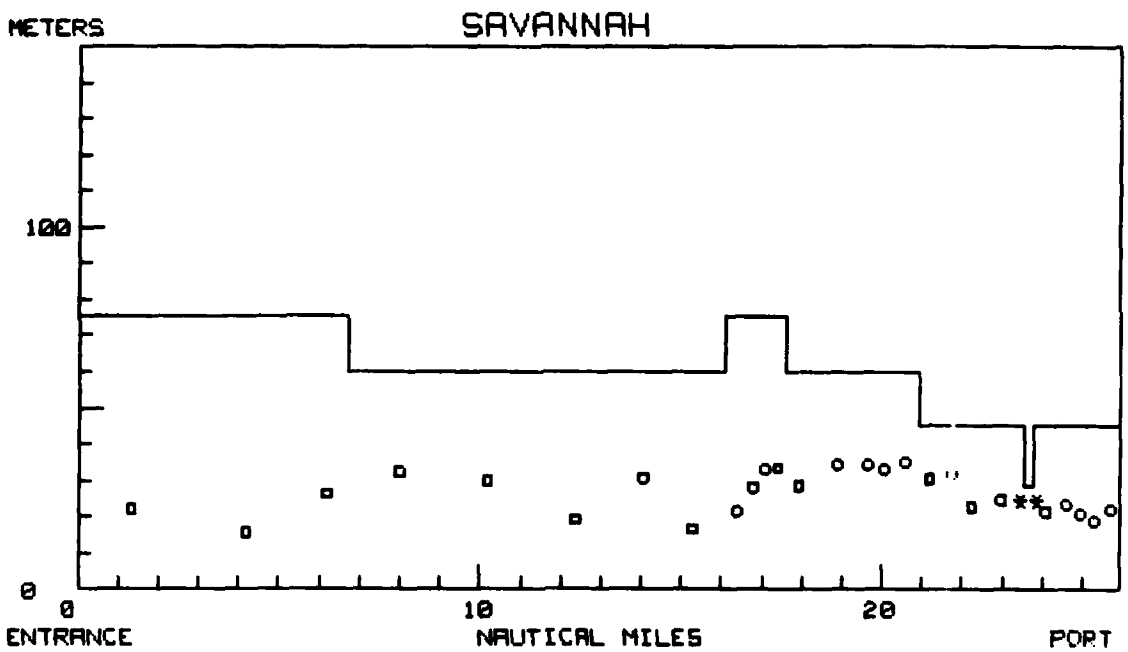
24	45	24	21
25	45	22	23
26	45	20	25
27	45	23	22



SAVANNAH
METERS
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

CHARLESTON

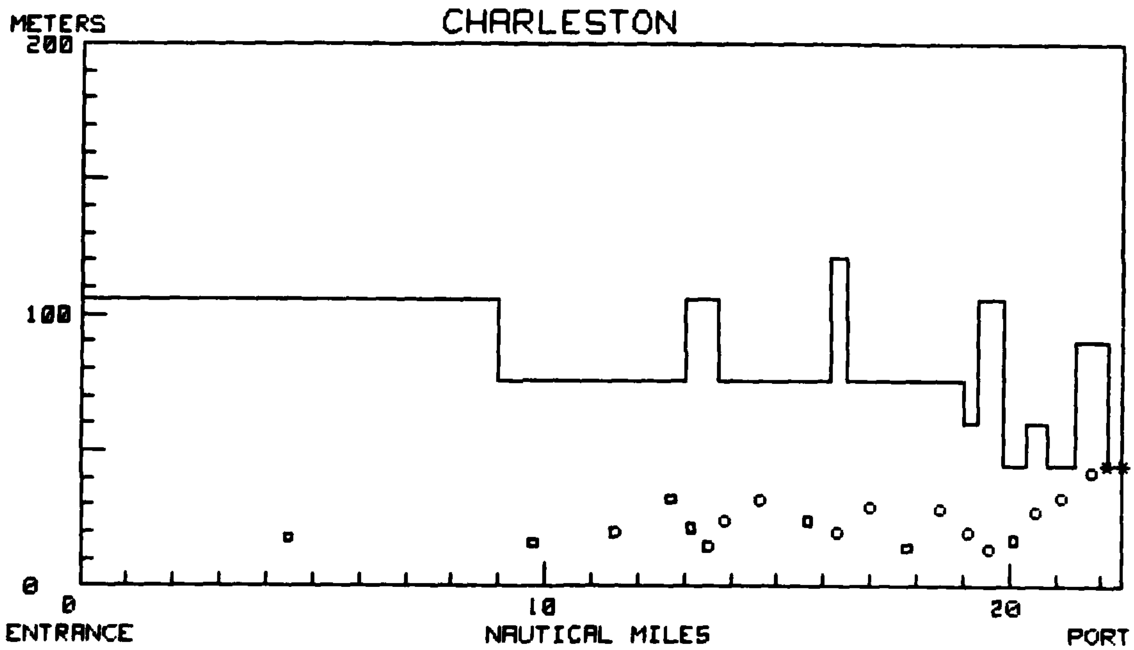
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Fort Sumter	32-42-05 N 78-46-00 W	299°T	122 m
2	Mount Pleasant Range	32-44-56 N 79-51-22 W	317	92
3	Rebellion Reach	32-46-05 N 79-52-55 W	306	92
4	Folly Reach	32-46-41 N 79-54-41 W	279	92
5	Shutes Reach	32-46-48 N 79-54-35 W	302	122
6	Horse Reach	32-47-04 N 79-54-52 W	326	122
7	Custom House Reach	32-47-26 N 79-55-02 W	355	92
8	Hog Island Reach	32-48-12 N 79-54-56 W	011	92
9	Drum Island Reach	32-48-58 N 79-55-15 W	298	92
10	Myers Bend	32-49-17 N 79-55-45 W	347	138
11	Daniel Isl Reach	32-50-02 N 79-55-46 W	006	92
12	Daniel Isl Bend	32-50-53 N 79-55-53 W	324	92
13	Clouter Crk Reach	32-51-12 N 79-56-34 W	290	92
14	Navy Yard Reach Lower	32-51-31 N 79-57-17 W	308	76
15	Navy Yard Reach Upper	32-51-57 N 79-57-42 W	331	122
16	No Charleston Lower	32-52-28 N 79-57-55 W	344	61
17	No Charleston Upper	32-52-58 N 79-58-01 W	004	76
18	Filbin Crk Reach	32-53-28 N 79-57-53 W	015	61
19	Pt Terminal Reach	32-54-05 N 79-57-31 W	041	107
20	Ordnance Reach	32-54-26 N 79-57-10 W	050	61

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	106 m	19 m	87 m
2	76	17	59
3	76	21	55
4	76	33	43
5	106	23	83
6	106	16	90
7	76	25	51
8	76	33	43
9	76	25	51
10	122	21	101
11	76	30	46
12	76	15	61
13	76	30	46
14	60	21	39
15	106	15	91
16	45	19	26
17	60	29	31
18	45	34	11
19	91	43	48
20	45	45	0 **


CHARLESTON
METERS
200
100
0
0
ENTRANCE
10
NAUTICAL MILES
20
PORT

WILMINGTON, NC

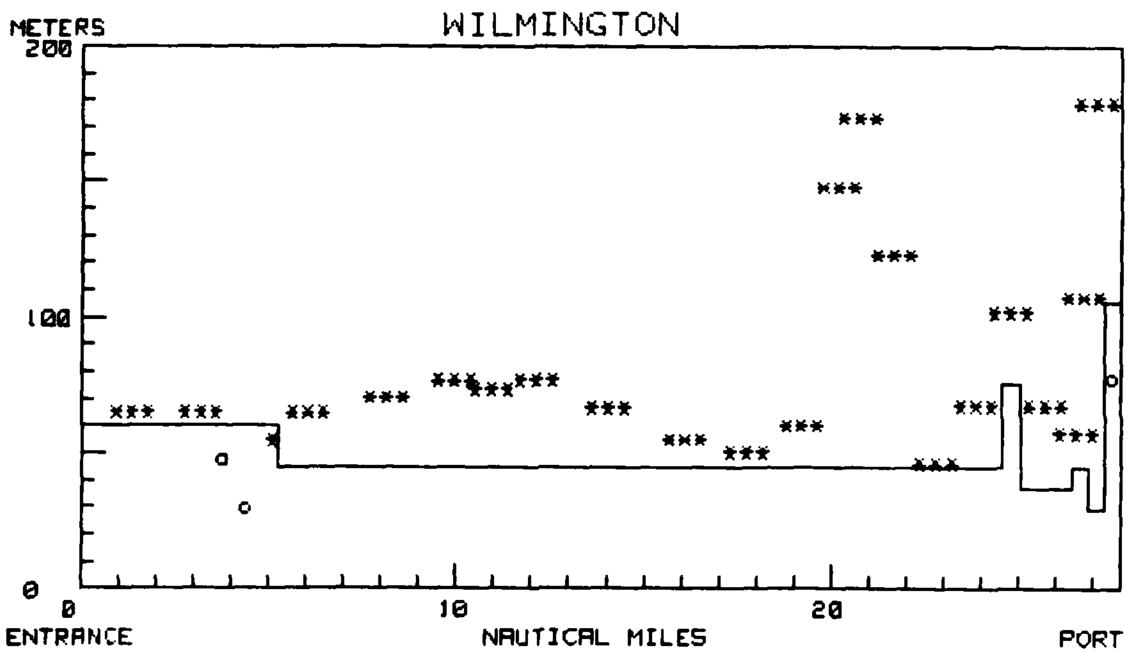
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Bald Head Shoal Range	33-51-16 N 78-01-45 W	044°T	76 m
2	Smith Island Range	33-52-46 N 78-00-27 W	008	76
3	Bald Head Caswell	33-53-21 N 78-00-25 W	340	76
4	Southport	33-53-52 N 78-00-51 W	320	76
5	Battery Island	33-54-23 N 78-01-13 W	351	76
6	Lower Swash Ch Range	33-55-03 N 78-00-30 W	056	61
7	Snows Marsh Ch Range	33-56-25 N 77-58-34 W	046	61
8	Horseshoe Shl Ch Range	33-57-47 N 77-57-47 W	024	61
9	Reaves Pt Ch Range	33-58-46 N 77-56-53 W	005	61
10	Lower Midnight Ch Range	33-59-58 N 77-56-36 W	014	61
11	Upper Midnight Ch Range	34-01-48 N 77-56-24 W	359	61
12	Lower Liliput Range	34-03-50 N 77-56-11 W	012	61
13	Upper Liliput Range	34-05-25 N 77-56-05 W	353	61
14	Keg Island Range	34-06-54 N 77-56-10 W	003	61
15	Big Island Lower Range	34-07-50 N 77-56-20 W	330	61
16	Big Island Upper Range	34-08-15 N 77-56-41 W	308	61
17	Lwr Brunswick Range	34-09-03 N 77-57-19 W	333	61
18	Upr Brunswick Range	34-10-03 N 77-57-36 W	012	61
19	Fourth East Jetty Range	34-11-02 N 77-57-27 W	004	61
20	Between Channel	34-11-55 N 77-57-25 W	354	92
21	Lift Bridge	34-13-38 N 77-57-07 W	012	54
22	Cape Fear River	34-13-46 N 77-57-05 W	017	61
23	Cape Fear River	34-13-57 N 77-57-03 W	000	61
24	NE Cape Fear River	34-14-17 N 77-57-09 W	337	46
25	Turning Basin	34-14-44 N 77-57-13 W	009	122

Reach No.	Corrected Half-Width Minus 16 m	MYZ CTE	MYZ Error Margin
1	60 m	65 m	-5 m ***
2	60	65	-5 ***
3	60	48	12
4	60	30	30
5	60	55	5 *
6	45	65	-20 ***
7	45	70	-25 ***
8	45	77	-32 ***
9	45	74	-29 ***
10	45	77	-32 ***
11	45	67	-22 ***
12	45	55	-10 ***
13	45	50	-5 ***
14	45	60	-15 ***
15	45	148	-103 ***
16	45	173	-128 ***
17	45	123	-78 ***
18	45	46	-1 ***
19	45	68	-13 ***
20	76	102	-26 ***
21	38	67	-29 ***
22	45	57	-12 ***
23	45	107	-62 ***
24	30	179	-149 ***
25	106	79	27


WILMINGTON
METERS
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

NORFOLK

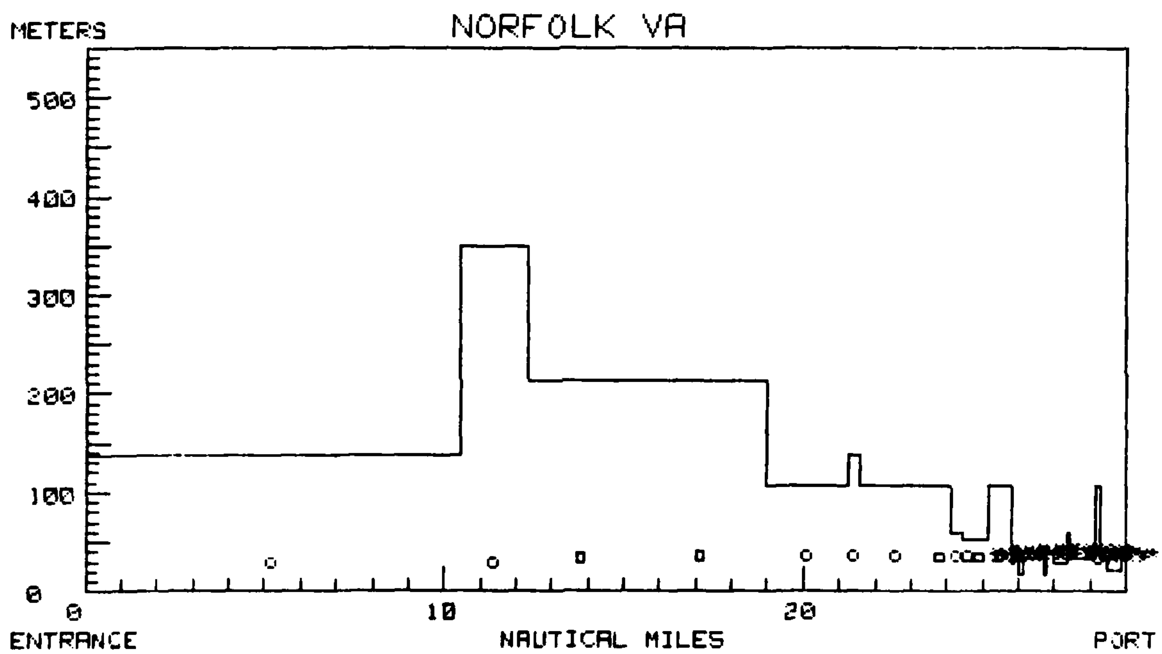
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Thimble Shoal	36-58-25 N 76-06-35 W	288°T	153 m
2	Appr To Norfolk Hrbr Entrance Rch	37-00-23 N 76-16-10 W	258	366
3	Entrance Reach	36-58-11 N 76-19-17 W	229	229
4	Norfolk Hrbr Reach	36-56-42 N 76-20-14 W	184	229
5	Craney Island Reach	36-53-45 N 76-20-13 W	172	122
6	Lambert Bend	36-52-18 N 76-19-56 W	151	153
7	Prt Norfolk Reach	36-51-31 N 76-18-51 W	130	122
8	Town Point Reach	36-50-39 N 76-17-48 W	154	122
9	Lwr Reach So Br E Riv	36-50-11 N 76-17-41 W	188	76
10	Lwr Reach So Br E Riv	36-49-56 N 76-17-41 W	169	69
11	Lwr Reach So Br E Riv	36-49-41 N 76-17-35 W	159	69
12	Middle Reach So Br E Riv	36-49-03 N 76-17-27 W	180	122
13	N&PBL RR Lft Br So Br E Riv	36-48-41 N 76-17-26 W	166	46
14	Sta Hwy 337 Lft Br So Br E Riv	36-48-34 N 76-17-25 W	178	61
15	Middle Reach So Br E Riv	36-48-29 N 76-17-25 W	173	34
16	Middle Reach So Br E Riv	36-48-10 N 76-17-29 W	192	57
17	N&W RR Lift Bridge	36-47-49 N 76-17-35 W	194	34
18	Upper Reach So Br E Riv	36-47-43 N 67-17-37 W	201	57
19	Upper Reach So Br E Riv	36-47-35 N 76-17-51 W	244	46
20	Upper Reach So Br E Riv	36-47-28 N 76-18-07 W	213	76
21	Upper Reach So Br E Riv	36-47-19 N 76-18-11 W	186	50
22	Upper Reach So Br E Riv	36-46-59 N 76-18-22 W	228	50
23	Upper Reach So Br E Riv	36-46-46 N 76-18-33 W	168	122
24	Upper Reach So Br E Riv	36-46-40 N 76-18-25 W	118	50
25	Upper Reach So Br E Riv	36-46-37 N 76-18-03 W	089	38
26	Upper Reach So Br E Riv	36-46-35 N 76-17-45 W	128	61
27	Bridges So Br E Riv	36-46-30 N 76-17-43 W	170	--
28	Upper Reach So Br E Riv	36-46-14 N 76-17-48 W	205	46

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	137 m	31 m	136 m
2	350	32	318
3	213	36	177
4	213	39	174
5	106	39	67
6	137	38	99
7	106	38	68
8	106	38	68
9	60	39	21
10	53	38	15
11	53	38	15
12	106	38	68
13	30	37	-7 ***
14	45	38	7 *
15	18	38	-20 ***
16	41	39	2 **
17	18	39	-21 ***
18	41	40	1 **
19	30	43	-13 ***
20	60	41	21
21	34	38	-4 ***
22	34	43	-9 ***
23	106	37	69
24	34	40	-6 ***
25	22	43	-21 ***
26	45	39	6 *
27	--	37	- -
28	30	41	-11 ***



METERS
NORFOLK VA
500
400
300
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

CHESAPEAKE BAY

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

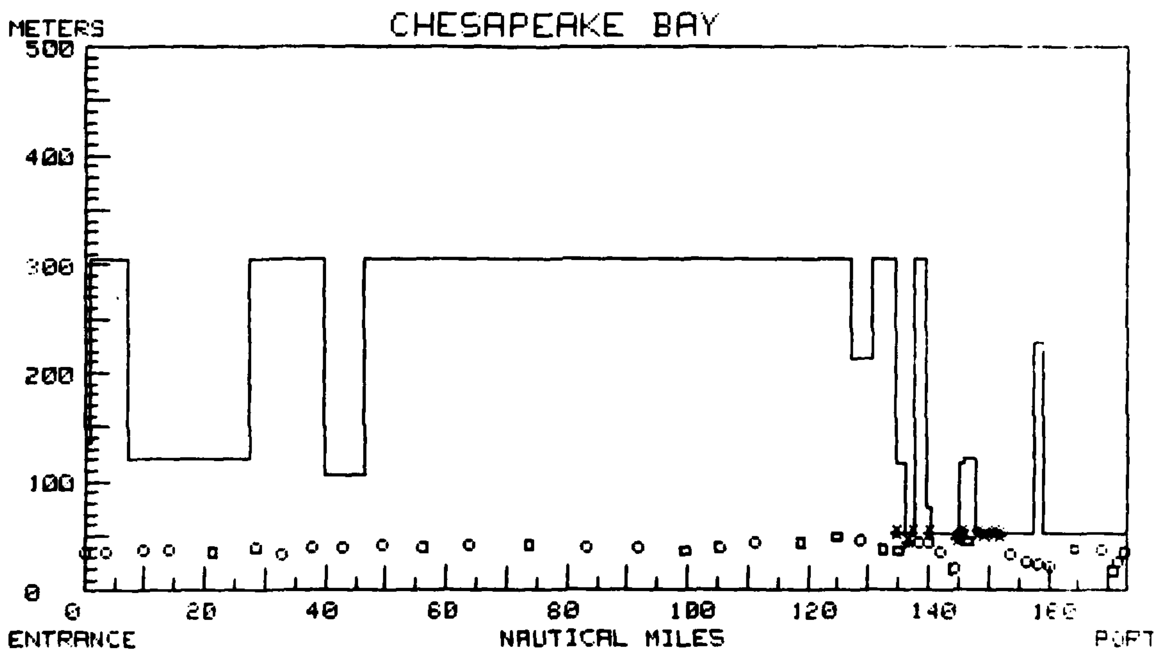
CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Chesapeake	36-58-37 N 76-00-00 W	334°T	153 m
2	Chesa Bay Tunnel	37-02-30 N 76-04-11 W	319	320
3	York Spit	37-07-34 N 76-08-08 W	330	138
4	York Spit	37-09-55 N 76-09-18 W	353	138
5	York Spit	37-13-19 N 76-08-28 W	017	138
6	Chesa Bay	37-24-25 N 76-04-57 W	345	OPEN
7	Chesa Bay	37-28-17 N 76-03-53 W	024	OPEN
8	Chesa Bay	37-32-58 N 76-02-52 W	347	OPEN
9	Chesa Channel	37-37-13 N 76-06-01 W	320	122
10	Chesa Bay	37-43-02 N 76-09-24 W	348	OPEN
11	Chesa Bay	37-49-39 N 76-09-29 W	011	OPEN
12	Chesa Bay	37-56-48 N 76-10-29 W	340	OPEN
13	Chesa Bay	38-06-37 N 76-13-17 W	353	OPEN
14	Chesa Bay	38-15-32 N 76-16-17 W	333	OPEN
15	Chesa Bay	38-23-29 N 76-20-17 W	342	OPEN
16	Chesa Bay	38-30-44 N 76-24-06 W	330	OPEN
17	Chesa Bay	38-35-56 N 76-25-24 W	008	OPEN
18	Chesa Bay	38-41-54 N 76-25-35 W	351	OPEN
19	Chesa Bay	38-49-18 N 76-24-56 W	014	OPEN
20	Chesa Bay	38-55-21 N 76-23-45 W	357	OPEN
21	1st of 2 Wm P Lane Mem Brdge	38-59-33 N 76-22-59 W	017	229
23	Chesa Bay	39-02-15 N 76-21-11 W	035	OPEN
24	Chesa Bay	39-04-21 N 76-19-13 W	038	OPEN

Reach No.	Channel Name	Reach Center	Course	Half-Width
25	Swan Point Ch	39-05-25 N 76-18-18 W	027	69
26	Swan Point Ch	39-06-10 N 76-18-08 W	349	69
27	Chesa Bay	39-07-22 N 76-18-58 W	322	OPEN
28	Chesa Bay	39-08-30 N 76-19-30 W	025	OPEN
29	Tolchester Ch	39-10-06 N 76-17-55 W	041	69
30	Tolchester Ch	39-11-35 N 76-15-58 W	065	69
31	Tolchester Ch	39-12-00 N 76-15-18 W	024	69
32	Chesa Bay	39-12-34 N 76-15-06 W	009	OPEN
33	Chesa Bay	39-13-40 N 76-14-37 W	024	OPEN
34	C&D Canal Appr	39-15-04 N 76-14-13 W	000	69
35	C&D Canal Appr	39-17-17 N 76-13-40 W	015	69
36	C&D Canal Appr	39-19-54 N 76-11-42 W	048	69
37	C&D Canal Appr	39-21-30 N 76-09-00 W	058	69
38	C&D Canal Appr	39-22-30 N 76-06-48 W	062	OPEN
39	C&D Canal Appr	39-23-24 N 76-04-29 W	066	69
40	C&D Canal Appr	39-25-33 N 76-00-36 W	042	69
41	C&D Canal Appr	39-29-08 N 75-56-42 W	046	69
42	C&D Canal Appr	39-30-27 N 75-54-30 W	075	69
43	C&D Canal Appr	39-30-42 N 75-53-41 W	061	69
44	C&D Canal Appr	39-31-13 N 75-52-45 W	049	69

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	137 m	38 m	99 m
2	304	37	267
3	122	39	83
4	122	40	82
5	122	37	85
6	OPEN	41	250+
7	OPEN	36	250+
8	OPEN	42	250+
9	106	41	65
10	OPEN	45	250+
11	OPEN	41	250+
12	OPEN	44	250+
13	OPEN	44	250+
14	OPEN	42	250+
15	OPEN	41	250+
16	OPEN	38	250+
17	OPEN	41	250+
18	OPEN	46	250+
19	OPEN	46	250+
20	OPEN	51	250+
21	213	48	165
23	OPEN	40	250+
24	OPEN	39	250+

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
25	53	44 m	9 m *
26	53	53	0 **
27	OPEN	47	250+
28	OPEN	46	250+
29	53	38	15
30	53	23	30
31	53	47	6 *
32	OPEN	52	250+
33	OPEN	47	250+
34	53	54	-1 ***
35	53	51	2 **
36	53	35	18
37	53	29	24
38	OPEN	26	250+
39	53	24	29
40	53	41	12
41	53	39	14
42	53	20	33
43	53	29	24
44	53	37	16


CHESAPEAKE BAY
METERS
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
ENTRANCE
NAUTICAL MILES
PORT

BALTIMORE

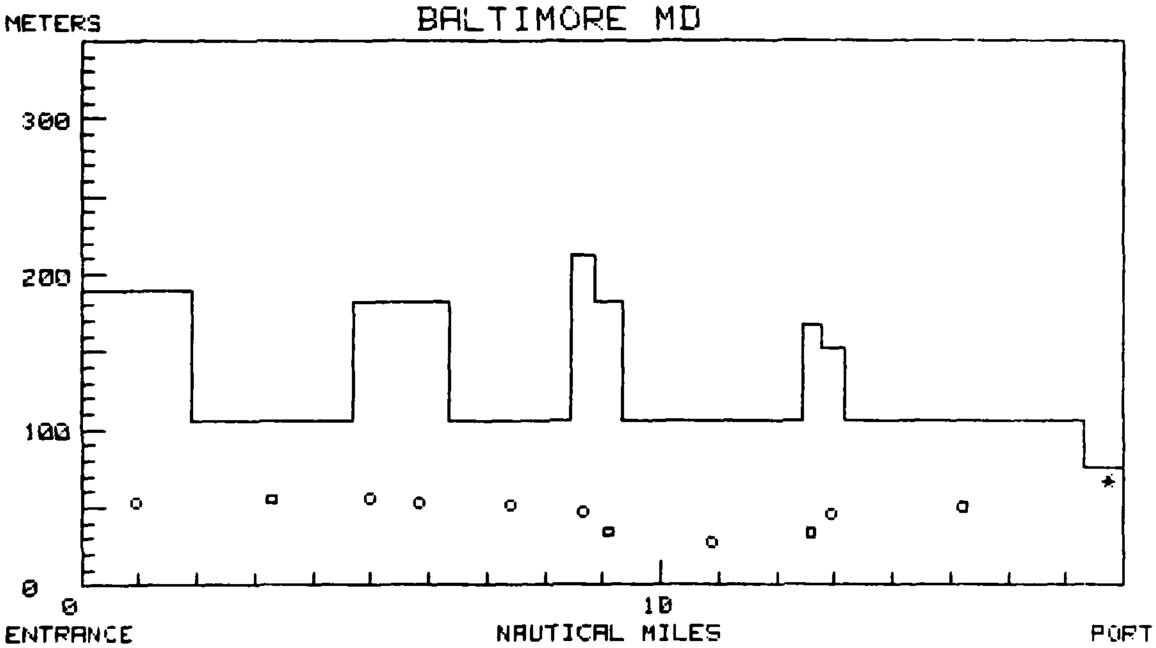
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Craighill Entrance	39-03-14 N 76-23-17 W	343°T	206 m
2	Craighill	39-05-37 N 76-23-41 W	000	122
3	Craighill Angle	39-07-14 N 76-23-45 W	350	199
4	Craighill Angle	39-08-00 N 76-24-05 W	335	199
5	Craighill Upper Range	39-09-24 N 76-25-05 W	329	122
6	Cutoff Angle	39-10-24 N 76-25-57 W	318	229
7	Cutoff Angle	39-10-45 N 76-26-21 W	300	397
8	Brewerton	39-11-26 N 76-28-30 W	291	122
9	Brewerton Angle	39-12-05 N 76-30-33 W	299	183
10	Brewerton Angle	39-12-17 N 76-30-55 W	315	168
11	Ft McHenry at I-695 Bridge	39-13-01 N 76-31-32 W	321	122
12	East Channel	39-16-16 N	357	91

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
1	190 m	55 m	135 m
2	106	57	49
3	183	58	125
4	183	55	128
5	106	53	53
6	213	48	165
7	381	36	345
8	106	29	77
9	167	35	132
10	152	47	105
11	106	52	54
12	76	67	9 *



METERS
BALTIMORE MD
300
200
100
0
0
10
ENTRANCE
NAUTICAL MILES
PORT

DELAWARE BAY - RIVER

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Brandywine Range	39-00-12 N 75-13-48 W	337°T	152 m
2	Miah Maul Range	39-07-59 N 75-13-48 W	325	152
3	Cross Ledge Range	39-12-24 N 75-17-12 W	336	152
4	Liston Range	39-23-03 N 75-28-36 W	318	122
5	Baker Range	39-28-10 N 75-33-44 W	355	122
6	Reedy Island Range	39-31-06 N 75-33-05 W	015	122
7	New Castle Range	39-35-05 N 75-33-35 W	334	122
8	Bulkhead Bar Range	39-37-18 N 75-34-45 W	008	244
9	Deepwater Pt Range	39-38-59 N 75-33-04 W	042	122
10	Cherry Isl Range	39-42-29 N 75-30-40 W	017	122
	Del Memorial Bridge	39-41-18 N 75-31-06 W	017	122
11	Bellevue Range	39-45-48 N 75-28-43 W	035	122
12	Marcus Hook Range	39-48-10 N 75-25-16 W	057	122
13	Chester Range	39-49-56 N 75-21-58 W	051	122
14	Eddystone Range	39-50-43 N 75-20-27 W	064	122
15	Tinicum Range	39-50-55 N 75-17-50 W	092	122
16	Billingsport Range	39-51-03 N 75-15-12 W	070	122
17	Mifflin Range	39-52-06 N 75-12-59 W	054	122
18	Eagle Point Range	39-52-52 N 75-10-23 W	094	122
19	Horeseshoe Bend	39-52-55 N 75-08-47 W	061	092
20	Horseshoe Range	39-53-13 N 75-08-25 W	026	76
21	Reach M at Walt Whitman Bridge	39-54-19 N 75-07-49 W	017	92
22	Camden	39-55-12 N 75-08-06 W	340	61
23	Camden	39-56-16 N 75-08-22 W	359	61
24	Reach M at Benj Franklin Bridge	39-57-10 N 75-08-07 W	016	61

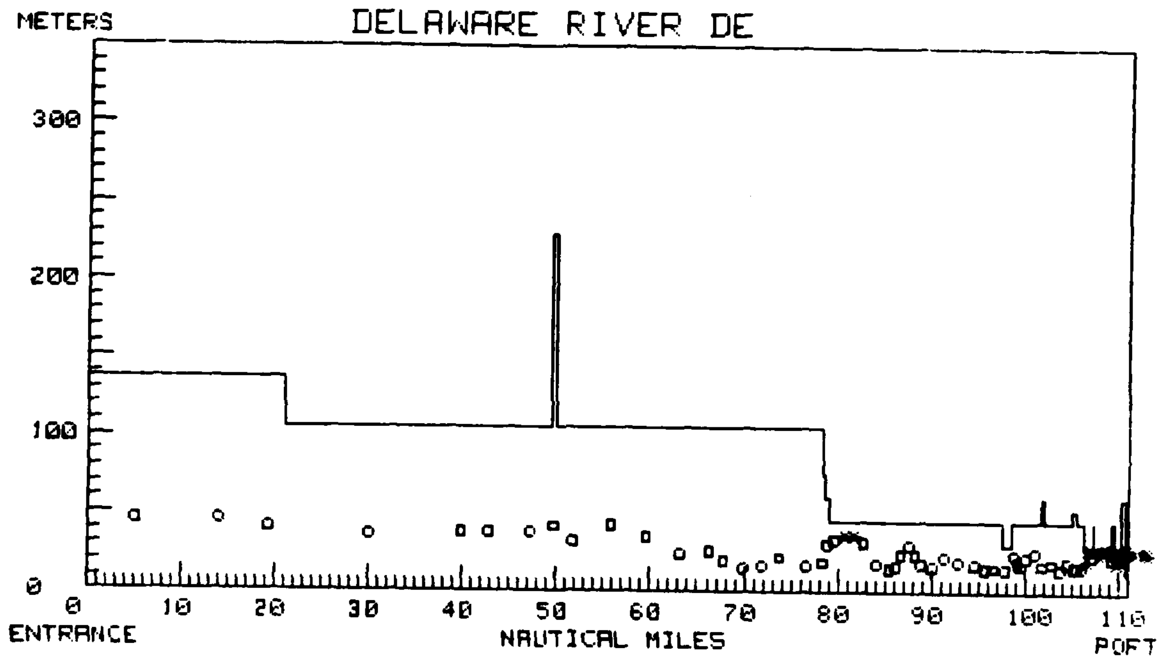
Reach No.	Channel Name	Reach Center	Course	Half-Width
25	Port Richmond	39-58-09 N 75-06-55 W	062	61
26	Fisher Point Range	39-58-30 N 75-05-34 W	081	61
27	Fisher Channel	39-58-38 N 75-04-39 W	069	61
28	Draw Channel at Conrail Lft Brdge	39-58-57 N 75-04-10 W	041	61
28A	Draw Channel at Betsy Ross Brdge	39-59-05 N 75-04-01 W	041	61
29	Delair Range	39-59-42 N 75-03-38 W	018	61
30	Bridesburg Channel	40-00-19 N 75-03-18 W	039	61 m
31	Frankfd Chan at Tacony-Palmyra Br	40-00-51 N 75-02-35 W	062	61
32	Tacony Channel	40-01-09 N 75-01-17 W	070	61
33	Torresdale Range	40-01-50 N 74-59-59 W	042	61
34	Mud Island Range	40-02-54 N 74-58-29 W	052	61
35	Enterprise Range	40-03-49 N 74-56-38 W	061	61
36	Beverly Channel	40-04-14 N 74-55-19 W	091	61
37	Edgewater Channel	40-04-26 N 74-54-04 W	070	61
38	Devlin Chann at Burlton-Bristl Br	40-04-51 N 74-52-11 W	078	46
39	Lehigh Channel	40-05-12 N 74-51-38 W	028	61
40	Canal Channel	40-05-34 N 74-51-19 W	048	61
41	Bristol Range	40-05-46 N 74-50-56 W	061	61
42	Keystone Range	40-06-06 N 74-50-21 W	039	61
43	At Turnpke Brdge Landreth Chann	40-07-01 N 74-49-51 W	018	61
44	Florence Bend	40-07-36 N 74-49-25 W	062	76
45	Florence Range	40-07-28 N 74-48-17 W	111	61
46	Roebling Range	40-07-14 N 74-47-10 W	080	61
47	Kinkora Range	40-07-34 N 74-46-28 W	050	61
48	Penn Channel	40-08-03 N 74-45-34 W	070	69

Reach No.	Channel Name	Reach Center	Course	Half-Width
49	Newbold Channel	40-08-05 N 74-45-02 W	096	61
50	Blake Channel	40-08-05 N 74-44-35 W	076	61
51	Whitehill Range	40-08-27 N 74-43-57 W	050	46
52	Raritan Channel	40-08-54 N 74-43-22 W	024	61
53	Bordentown Range	40-09-18 N 74-43-20 W	358	46
54	Duck Island Range	40-10-11 N 74-43-50 W	325	46
55	Perring Channel	40-10-45 N 74-44-25 W	312	61
56	Biles Island Channel	40-10-52 N 74-44-42 W	289	46 m
57	Cochran Channel	40-11-04 N 74-45-11 W	312	46
58	Moon Channel	40-11-20 N 74-45-25 W	346	76
59	Trenton Channel	40-11-41 N 74-45-31 W	349	31
60	Trenton Channel	40-11-55 N 74-45-36 W	340	31
61	Trenton Channel	40-12-12 N 74-45-48 W	328	31

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	136 m	47 m	89 m
2	136	47	89
3	136	42	94
4	106	38	68
5	106	40	66
6	106	39	67
7	106	40	66
8	228	43	185
9	106	34	72
10	106	44	62
11	106	37	69
12	106	26	80
13	106	27	79
14	106	21	85
15	106	18	88
16	106	19	87
17	106	24	82
18	106	18	88
19	76	21	55
20	60	33	27
21	76	35	41
22	45	36	9 *
23	45	36	9 *

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
24	45	34 m	11 m
25	45 m	20	25
26	45	17	28
27	45	18	27
28	45	26	19
29	45	32	13
30	45	26	19
31	45	20	25
32	45	18	27
33	45	25	20
34	45	22	23
35	45	20	25
36	45	18	27
37	45	18	27
38	30	17	13
39	45	27	18
40	45	22	23
41	45	19	26
42	45	24	21
43	45	28	17
44	60	19	41
45	45	21	24
46	45	18	27

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
47	45	22 m	23 m
48	53	19	34
49	45	18	27
50	45	18	27
51	30	22	8 *
52	45	27	18
53	30	29	1 **
54	30	26	4 **
55	45	24	21
56	30	20	10
57	30	24	6 *
58	60	28	32
59	15	28	-13 ***
60	15	28	-13 ***
61	15	26	-11 ***



METERS
DELAWARE RIVER DE
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
110
ENTRANCE
NAUTICAL MILES
PORT

NEW YORK

(AMBROSE TO GW BRIDGE)

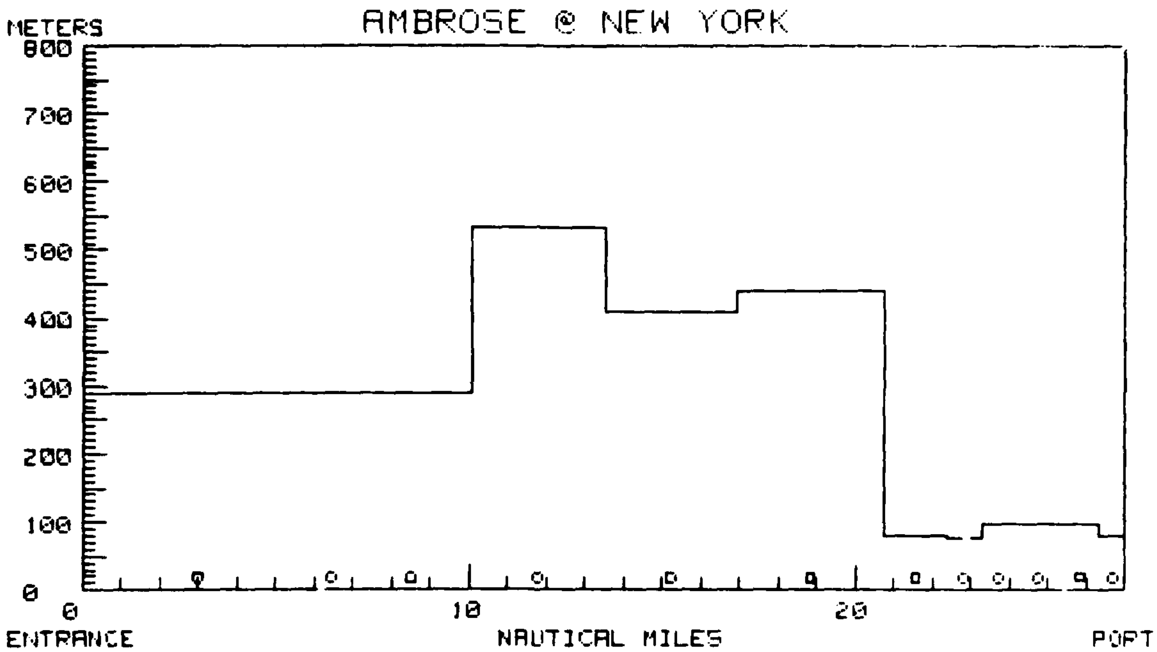
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Ambrose	40-30-09 N 73-57-08 W	297°T	305 m
2	Bend	40-31-53 N 74-01-05 W	322	305
3	Ambrose	40-33-48 N 74-01-50 W	348	305
4	The Narrows	40-36-23 N 74-02-42 W	343	549
5	Upper Bay	40-40-14 N 74-02-35 W	025	OPEN
6	Hudson River	40-43-35 N 74-01-15 W	009	458
7	Hudson River	40-46-11 N 74-00-27 W	024	95
8	Hudson River	40-47-19 N 73-59-43 W	032	91
9	Weehawken Edgewater	40-48-04 N 73-59-08 W	029	115
10	Weehawken Edgewater	40-49-00 N 73-58-24 W	027	115
11	Weehawken Edgewater	40-50-00 N 73-57-40 W	038	115
12	Geo Washington Bridge	40-51-04 N 73-57-02 W	018	95

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	289 m	23 m	266 m
2	289	22	267
3	289	21	268
4	533	21	512
5	411	21	390
6	441	21	420
7	79	22	57
8	75	23	42
9	98	23	75
10	98	23	75
11	98	24	74
12	79	22	57



AMBROSE @ NEW YORK
METERS
800
700
600
500
400
300
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

NEW YORK

(THE AMBOYS - ARTHUR KILL)

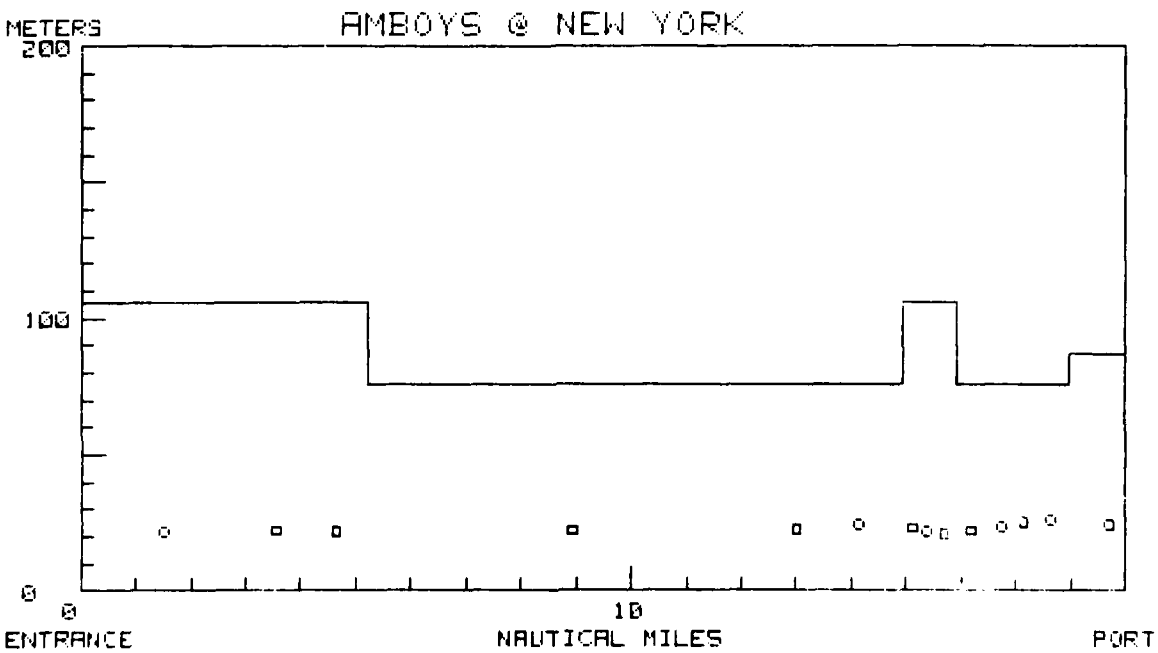
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Sandy Hook East Sec	40-28-10 N 73-57-50 W	308	122
2	Sandy Hook	40-29-02 N 74-00-02 W	258	122
3	Sandy Hook	40-28-51 N 74-01-25 W	248	122
4	Raritan Bay East & West Rchs	40-29-35 N 74-07-16 W	286	92
5	Seguine Pt Bend	40-30-29 N 74-12-01 W	267	92
6	Red Bank Reach	40-29-58 N 74-13-06 W	225	92
7	Ward Pt Bend East	40-29-20 N 74-14-05 W	258	122
8	Ward Pt Bend East	40-29-18 N 74-14-27 W	277	122
9	Ward Pt Bend East	40-29-23 N 74-14-46 W	294	122
10	Ward Pt Bend West	40-29-45 N 74-15-13 W	332	92
11	Ward Pt Bend West	40-30-15 N 74-15-30 W	347	92
12	Ward Pt Bend West	40-30-37 N 74-15-27 W	021	92
13	Ward Pt Bend West	40-31-03 N 74-15-08 W	037	92
14	Outerbridge Crossing	40-31-28 N 74-14-54 W	351	103

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	106	23 m	83 m
2	106	23	83
3	106	23	83
4	75	23	52
5	75	23	52
6	75	25	50
7	106	24	82
8	106	23	83
9	106	22	84
10	75	23	52
11	75	24	51
12	75	26	49
13	75	27	48
14	87	25	62



AMBOYS @ NEW YORK
METERS
200
100
0
0
10
ENTRANCE
NAUTICAL MILES
PORT

NEW YORK

(NEWARK)

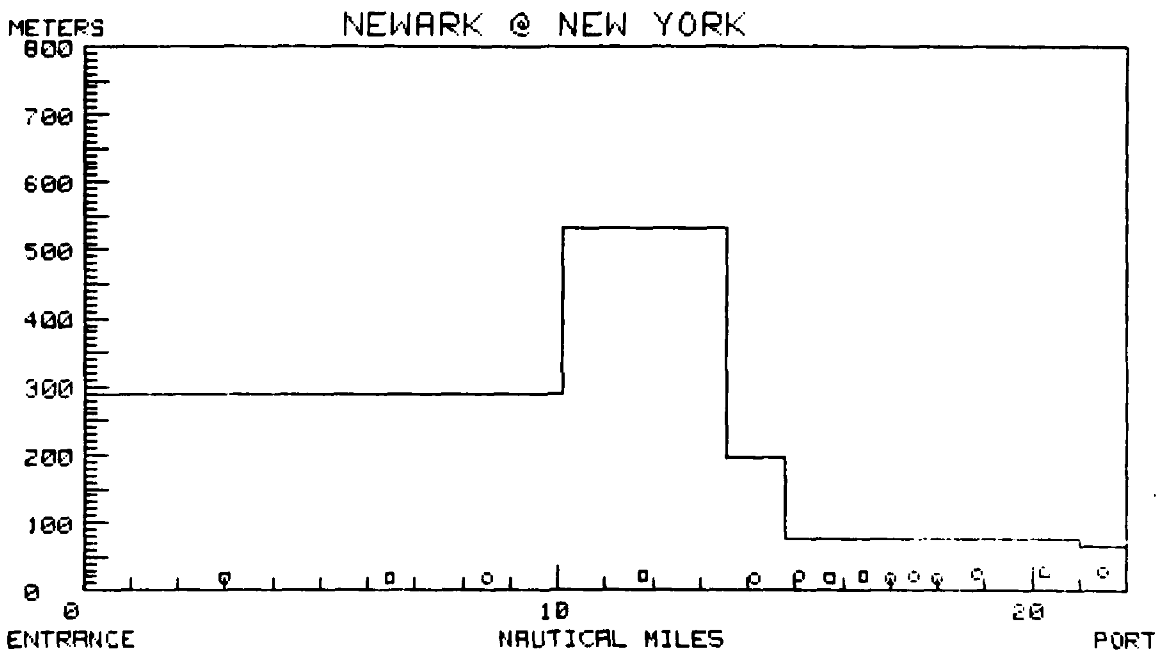
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Ambrose	40-30-09 N 73-57-08 W	297°T	305 m
2	Bend	40-31-53 N 74-01-05 W	322	305
3	Ambrose	40-33-48 N 74-01-50 W	348	305
4	The Narrows	40-36-23 N 74-02-42 W	343	549
5	Constable Hook Range	40-38-57 N 74-04-26 W	290	214
6	Constable Hook Reach	40-38-57 N 74-05-24 W	238	92
7	Constable Hook Reach	40-38-50 N 74-06-19 W	275	92
8	Bergen Pt East R	40-38-45 N 74-06-57 W	245	92
9	Bergen Pt East R	40-38-37 N 74-07-53 W	278	92
10	Bergen Pt West-Hwy Br	40-38-32 N 74-08-34 W	257	92
11	Shooters Isl North	40-38-34 N 74-09-03 W	302	92
12	Newark Bay So at RR Lift Brdge	40-39-17 N 74-08-44 W	029	--
13	Newark Bay Middle Rch	40-40-33 N 74-08-01 W	019	92
14	Newark Bay No at Hwy Bridge	40-41-46 N 74-07-19 W	028	82

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	289	23 m	266 m
2	289	23	266
3	289	23	266
4	533	24	509
5	197	23	174
6	76	26	50
7	76	23	53
8	76	26	50
9	76	23	53
10	76	25	51
11	76	23	53
12	---	30	---
13	76	31	45
14	66	32	44


NEWARK @ NEW YORK
METERS
800
700
600
500
400
300
200
100
0
0
10
20
ENTRANCE
NAUTICAL MILES
PORT

HUDSON RIVER - ALBANY

REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Hudson River	40-52-00N 73-56-13 W	028°T	138 m
2	Hudson River	40-57-29 N 73-54-10 W	014	184
3	Tappan Zee Bridge	41-04-11 N 73-52-50 W	000	168
4	Hudson River	41-08-31 N 73-53-00 W	333	137
5	Hudson River	41-09-49 N 73-54-33 W	315	122
6	Haverstraw Bay	41-11-28 N 73-56-20 W	336	92
7	Haverstraw Bay	41-12-47 N 73-57-02 W	342	92
8	Hudson River	41-14-28 N 73-57-56 W	329	290
9	Hudson River	41-15-22 N 73-58-20 W	000	336
10	Hudson River	41-16-18 N 73-57-36 W	047	321
11	Hudson River	41-17-09 N 73-57-00 W	346	343
12	Hudson River	41-18-19 N 73-58-03 W	317	198
13	Bear Mt Bridge	41-19-12 N 73-58-58 W	000	229
14	Hudson River	41-20-11 N 73-58-17 W	034	198
15	Hudson River	41-21-46 N 73-57-29 W	006	206
16	Hudson River	41-23-04 N 73-57-08 W	023	191
17	Hudson River	41-23-40 N 73-56-55 W	358	183
18	Hudson River	41-23-58 N 73-57-17 W	292	160
19	Hudson River	41-25-27 N 73-58-20 W	338	206
20	Hudson River	41-26-46 N 73-59-27 W	318	275
21	Newburgh Bridge	41-31-13 N 74-00-04 W	000	147
22	Hudson River	41-32-25 N 73-59-15 W	030	321
23	Hudson River	41-33-54 N 73-57-57 W	041	321
24	Hudson River	41-36-06 N 73-57-07 W	002	137

Reach No.	Channel Name	Reach Center	Course	Half-Width
25	Hudson River	41-38-07 N 73-56-57 W	009	137
26	Hudson River	41-39-20 N 73-56-47 W	001	137
27	Hudson River	41-40-20 N 73-56-39 W	015	122
28	Hudson River	41-41-20 N 73-56-38 W	350	122
29	Mid Hudson Suspen Br	41-41-11 N 73-56-44 W	005	115
30	Hudson River	41-45-48 N 73-56-45 W	338	176
31	Hudson River	41-48-13 N 73-56-55 W	004	137
32	Hudson River	41-50-26 N 73-56-47 W	354	382
33	Hudson River	41-51-25 N 73-56-31 W	025	206
34	Hudson River	41-52-22 N 73-56-20 W	344	298
35	Hudson River	41-53-17 N 73-57-02 W	323	366
36	Hudson River	41-55-37 N 73-57-32 W	001	252
37	Kingston Pt Reach	41-55-37 N 73-57-37 W	341	61
38	Kingston Pt Reach	41-56-06 N 73-57-45 W	352	61
39	Kingston Pt Reach	41-56-34 N 73-57-46 W	005	61
40	Fixed Bridge Hwy	41-58-43 N 73-57-04 W	014	116
41	Barrytown Reach	41-59-52 N 73-56-39 W	016	61
42	Hudson River	41-02-09 N 73-55-53 W	010	61
43	Hudson River	42-03-35 N 73-55-37 W	004	61
44	Hudson River	42-04-38 N 73-55-43 W	350	137
45	Hudson River	42-05-36 N 73-55-46 W	007	137
46	Malden On Hudson	42-06-15 N 73-55-37 W	015	61
47	Hudson River	42-07-51 N 73-54-50 W	022	61
48	No Germantown Reach	42-09-44 N 73-53-20 W	040	61

Reach No.	Channel Name	Reach Center	Course	Half-Width
49	Hudson River	42-10-41 N 73-52-16 W	043	61
50	Hudson River	42-11-00 N 73-51-49 W	048	61
51	Hudson River	42-11-20 N 73-51-28 W	029	61
52	Hudson River	42-11-56 N 73-51-10 W	013	61
53	Hudson River	42-12-40 N 73-51-09 W	347	61
54	Rip Van Winkle Fixed Bridge	42-13-26 N 73-51-09 W	010	61
55	Hudson River	42-13-35 N 73-51-05 W	016	61
56	Hudson River	42-14-02 N 73-50-45 W	033	61
57	Hudson River	42-14-36 N 73-49-50 W	062	61
58	Hudson River	42-15-00 N 73-48-45 W	067	61
59	Hudson River	42-15-14 N 73-48-10 W	047	61
60	Hudson River	42-15-32 N 73-47-50 W	037	61
61	Hudson River	42-15-53 N 73-47-31 W	030	61
62	Hudson River	42-16-22 N 73-47-14 W	019	61
63	Hudson River	42-17-31 N 73-46-58 W	006	61
64	Hudson River	42-18-44 N 73-46-58 W	348	61
65	Hudson River	42-19-43 N 73-47-05 W	358	61
66	Hudson River	42-20-36 N 73-47-17 W	347	61
67	Hudson River	42-21-42 N 73-47-30 W	358	61
68	Hudson River	42-22-18 N 73-47-35 W	348	61
69	Hudson River	42-22-47 N 73-47-38 W	006	61
70	Hudson River	42-23-56 N 73-47-11 W	017	61
71	Hudson River	42-25-21 N 73-46-50 W	355	61
72	Hudson River	42-26-14 N 73-46-59 W	349	61

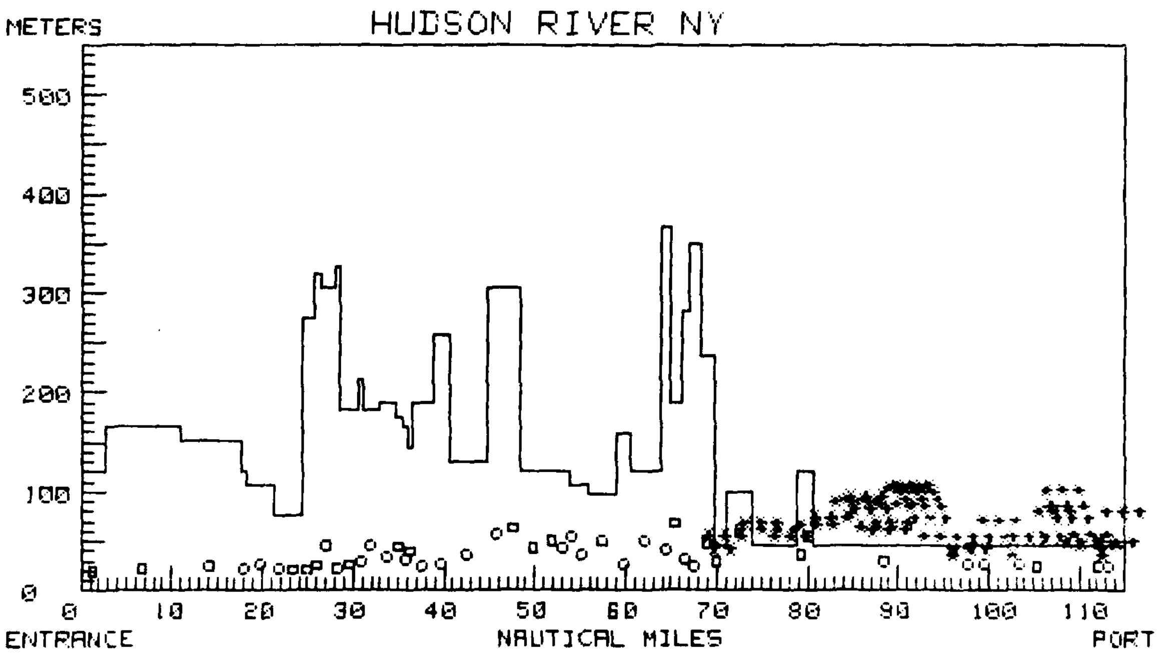
Reach No.	Channel Name	Reach Center	Course	Half-Width
73	Hudson River	42-27-12 N 73-47-03 W	006	61
74	Hudson River	42-28-15 N 73-47-07 W	347	61
75	Hudson River	42-29-01 N 73-47-13 W	006	61
76	Hudson River	42-30-00 N 73-46-49 W	022	61
77	Hudson River	42-30-52 N 73-46-18 W	036	61
78	Hudson River	42-31-15 N 73-45-53 W	025	61
79	Hudson River	42-31-49 N 73-45-37 W	017	61
80	Hudson River	42-32-43 N 73-45-23 W	004	61
81	Hudson River	42-33-41 N 73-45-15 W	008	61
82	Hudson River	42-34-23 N 73-45-08 W	002	61
83	Hudson River	42-34-37 N 73-45-10 W	348	61
84	Hudson River	42-35-00 N 73-45-21 W	334	61
85	Hudson River	42-35-41 N 73-45-37 W	348	61
86	Hudson River	42-36-28 N 73-45-43	004	61
87	Port of Albany Turning Basin Rch	42-37-15 N 73-45-27 W	020	61

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	122 m	22 m	100 m
2	168	25	143
3	152	26	126
4	121	25	96
5	106	29	77
6	76	24	52
7	76	23	53
8	274	23	251
9	320	28	292
10	305	48	257
11	327	25	302
12	182	28	154
13	229	32	197
14	182	49	133
15	190	37	153
16	175	47	128
17	167	34	133
18	144	42	102
19	190	26	164
20	259	29	230
21	131	39	92
22	305	60	245
23	305	66	339
24	121	45	66

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
25	121 m	52 m	69 m
26	121	47	74
27	106	58	48
28	106	38	68
29	99	52	47
30	160	30	130
31	119	52	67
32	366	43	323
33	190	71	119
34	282	34	248
35	350	27	323
36	236	51	185
37	45	32	13
38	45	42	3 **
39	45	56	-11 ***
40	100	65	35
41	45	68	-23 ***
42	45	62	-17 ***
43	45	55	-10 ***
44	121	39	82
45	121	58	63
46	45	67	-22 ***
47	45	75	-30 ***
48	45	90	-45 ***

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
49	45 m	93 m	-48 ***
50	45	96	-51 ***
51	45	83	-38 ***
52	45	65	-20 ***
53	45	33	12
54	45	61	-16 ***
55	45	69	-24 ***
56	45	88	-43 ***
57	45	104	-59 ***
58	45	106	-61 ***
59	45	100	-55 ***
60	45	93	-48 ***
61	45	86	-41 ***
62	45	73	-28 ***
63	45	55	-10 ***
64	45	36	9 *
65	45	43	2 **
66	45	29	16
67	45	42	3 **
68	45	30	15
69	45	54	-9 ***
70	45	72	-27 ***
71	45	37	8
72	45	29 m	16

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
73	45	54	-9 ***
74	45	27	18
75	45	54	-9 ***
76	45	81	-36 ***
77	45	102	-57 ***
78	45	86	-41 ***
79	45	73	-28 ***
80	45	50	-5 ***
81	45	57	-12 ***
82	45	46	-1 ***
83	45	27	18
84	45	37	8 *
85	45	26	19
86	45	49	-4 ***
87	45	80	-35 ***


HUDSON RIVER NY
METERS
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
110
ENTRANCE
NAUTICAL MILES
PORT

NEW HAVEN

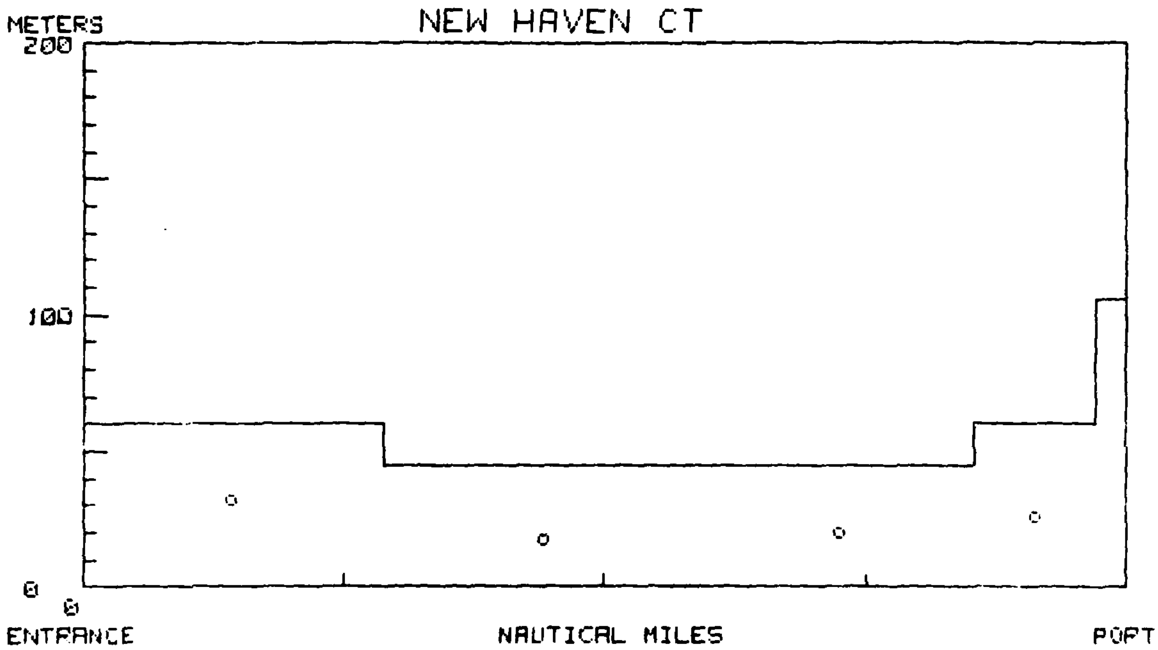
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Entrance Ch	41-13-34 N 72-54-46 W	334°T	76 m
2	Lighthouse Pt. Reach	41-14-39 N 72-54-58 W	007	61
3	Lighthouse Pt. Reach	41-15-47 N 72-54-48 W	005	61
4	Appr New Haven Reach	41-16-32 N 72-54-45 W	356	76
5	New Haven Reach	41-17-13 N 72-54-39 W	008	122
6	New Haven Reach	41-17-46 N 72-54-29 W	044	92

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	60 m	33 m	47 m
2	45	19	26
3	45	21	24
4	60	27	33
5	106	21	85
6	76	22	54



NEW HAVEN CT
METERS
200
100
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0
ENTRANCE
NAUTICAL MILES
PORT

NEW LONDON

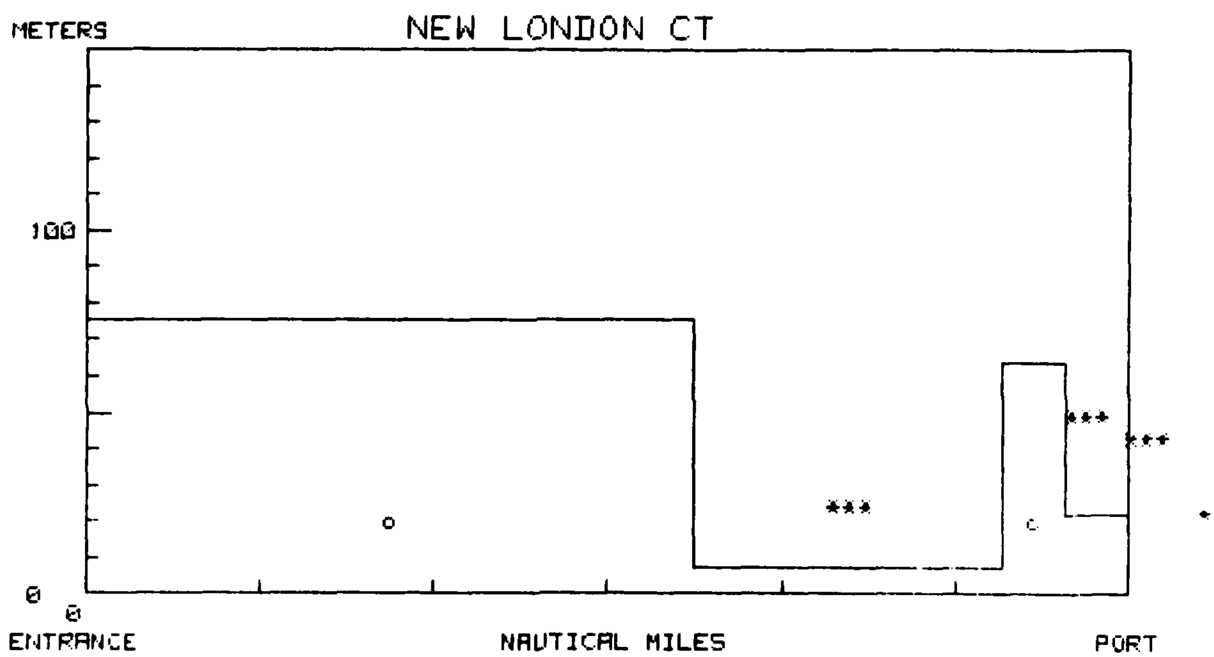
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Approach	41-19-35 N 72-04-59 W	355°T	92 m
2	RR Bascule Br	41-21-47 N 72-05-17 W	354	--
3	Thames River	41-23-00 N 72-05-24 W	000	80
4	Thames River	41-23-20 N 72-05-30 W	330	38
5	Thames River	41-23-30 N 72-05-37 W	337	38
6	Thames River	41-24-00 N 72-05-48 W	358	38

Reach No.	Corrected Half-Width Minus 16 m	MXY CTE	MXY Error Margin
1	76 m	20 m	56 m
2	--	24	---
3	64	20	44
4	22	49	-27 ***
5	22	43	-21 ***
6	22	23	-1 ***



METERS
NEW LONDON CT
100
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0
ENTRANCE
NAUTICAL MILES
PORT

PROVIDENCE

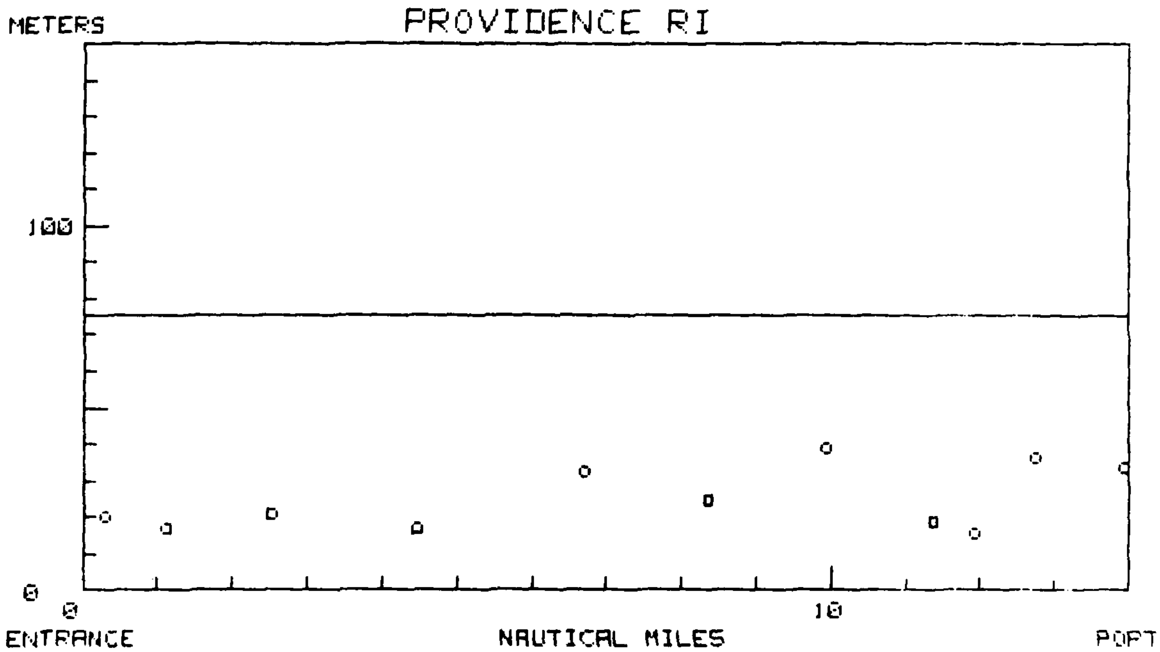
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Entrance	41-36-07 N 71-18-03 W	019°T	92 m
2	Entrance	41-36-56 N 71-17-56 W	000	92
3	Entrance	41-38-17 N 71-18-19 W	341	92
4	Entrance	41-40-12 N 71-18-45 W	357	92
5	Rumstick Neck	41-42-12 N 71-19-44 W	232	92
6	Conimicut Pt.	41-43-23 N 71-21-14 W	213	92
7	Bullock Pt.	41-44-42 N 71-22-14 W	252	92
8	Sabin Pt.	41-46-04 N 71-22-29 W	020	92
9	Bend	41 46-35 N 71-22-21 W	356	92
10	Fuller Rock	41-47-11 N 71-22-38 W	242	92
11	Fox Point	41-48-13 N 71-23-28 W	234	92

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
1	76 m	21 m	55 m
2	76	18	58
3	76	22	54
4	76	17	59
5	76	33	43
6	76	25	51
7	76	39	37
8	76	20	56
9	76	16	60
10	76	37	39
11	76	34	40



PROVIDENCE RI
METERS
100
0
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10
ENTRANCE
NAUTICAL MILES
PORT

BOSTON

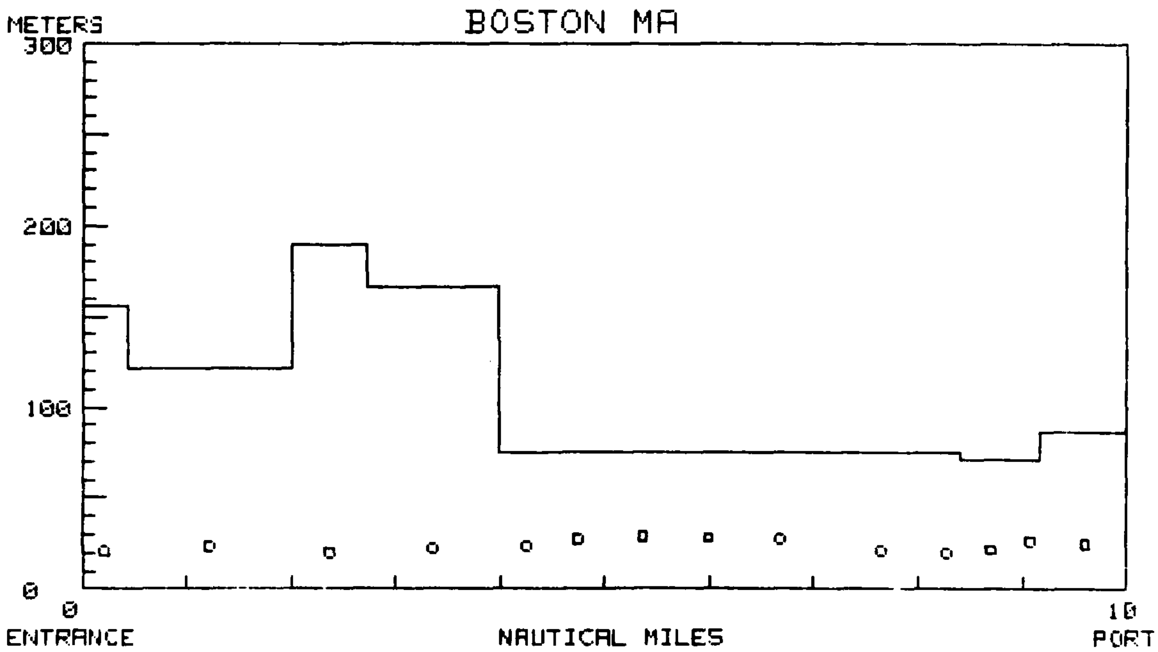
REACH DESCRIPTION

LORAN-C PERFORMANCE PREDICTIONS

CHANNEL PLOT

Reach No.	Channel Name	Reach Center	Course	Half-Width
1	Entrance	42-22-06 N 70-55-05 W	234°T	172 m
2	North Channel East Part	42-21-17 N 70-55-47 W	207	137
3	President Roads	42-20-23 N 70-56-43 W	239	206
4	President Roads	42-20-04 N 70-57-57 W	257	183
5	Inner Harbor Entrance	42-19-55 N 70-59-08 W	269	92
6	Inner Harbor Entrance	42-19-59 N 70-59-46 W	290	92
7	Inner Harbor Entrance	42-20-19 N 71-00-27 W	312	92
8	Inner Harbor Entrance	42-20-44 N 71-01-06 W	308	92
9	Inner Harbor Entrance	42-21-07 N 71-01-52 W	301	92
10	Inner Harbor Entrance	42-21-48 N 71-02-38 W	249	92
11	Inner Harbor Entrance	42-22-25 N 71-02-50 W	016	92
12	Inner Harbor Entrance	42-22-47 N 71-02-46 W	002	87
13	Mystic River - Tobin Bridge	42-23-06 N 71-02-53 W	303	87
14	Mystic River	42-23-12 N 71-03-34 W	280	103

Reach No.	Corrected Half-Width Minus 16 m	MWX CTE	MWX Error Margin
1	156 m	22 m	134 m
2	137	25	112
3	206	22	184
4	183	23	160
5	92	25	67
6	92	28	64
7	92	30	62
8	92	29	63
9	92	29	63
10	92	22	70
11	92	22	70
12	87	23	64
13	87	28	59
14	103	26	77


BOSTON MA
METERS
300
200
100
0
0
ENTRANCE
NAUTICAL MILES
10
PORT

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