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NATIONAL DATA BUOY CENTER

PRELIMINARY DESIGN CRITERIA FOR EFFECTIVE SYNOPTIC-SCALE DATA BUOY NETWORKS BASED ON QUANTITATIVE EXPERIMENTAL RESULTS

SHORT TITLE: ENVIRONMENTAL MODELS/SYSTEMS EFFECTIVENESS STUDY (EM/SE)

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Report of

Determination of Aspects of Parameters and Parameter Characteristics, Using Environmental Numerical Analysis Models.

Short Title: Environmental Models/System Effectiveness Study (EM/SE)

PRELIMINARY DESIGN CRITERIA FOR EFFECTIVE SYNOPTIC-SCALE DATA BUOY NETWORKS BASED ON QUANTITATIVE EXPERIMENTAL RESULTS

by

Gaylord M. Northrop
Principal Investigator

and

Earl L. Davis
Edward R. Sweeton

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THE CENTER FOR THE ENVIRONMENT AND MAN, INC.
275 Windsor Street Hartford, Connecticut 06120

FOREWORD

In November 1969 The Travelers Research Corporation, now The Center for the Environment and Man, Inc. (CEM), undertook a contract with the National Data Buoy Center (NDBC)* to develop design criteria for specifying synoptic-scale data buoy networks. The objective of the study under Contract DOT-CG-02-007-A is to determine, for environmental data collection systems that include data buoys and other data collection platforms, the impact on overall system effectiveness of variations in data buoy system characteristics, including the following.

- Random errors in amplitudes of data buoy observations.
- Random failures of data buoys in networks.
- Geographic location and density of data buoy networks.
- Variation in redundancy of data buoys and ships-of-opportunity.

This report summarizes the accomplishment of the initial phase of this study. It describes the activities that have been performed in developing an experimental Monte Carlo statistical approach for determining data buoy network design criteria as a function of specified levels of system effectiveness and illustrates their use.

This study is one of the basic studies of the NDBC Mission Analysis activities. It is anticipated that these preliminary data buoy network design criteria will be used and will provide the basis for further work by the NDBC, in conjunction with results of other studies, to assist in specifying measurement characteristics (requirements) more precisely. The study has benefited from the close cooperation and guidance effort by members of the NDBC, particularly Mr. R. A. Zettel, who served as the Technical Representative, and Mr. A. Thomasell, Jr., formerly of CEM and now with the National Environmental Satellite Service, NOAA. The experimental computations were conducted at the U.S. Navy Fleet Numerical Weather Center, Monterey, California, with the competent assistance of Meteorology International, Inc.

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*The National Data Buoy Development Project was transferred to the National Oceanic and Atmospheric Administration (NOAA) by Executive Order 11564 on October 6, 1970, and to the National Ocean Survey (NOS) Office of Marine Technology on July 12, 1971, where it was designated the National Data Buoy Center.

EXECUTIVE SUMMARY

The National Data Buoy Center (NDBC) of the National Ocean Survey (NOS), National Oceanic and Atmospheric Administration (NOAA) has the responsibility to develop and demonstrate the national capability to deploy and operate National Data Buoy Systems. More explicitly, the mission of NDBC is to conduct the planning and analytical studies necessary for the formulation of mission goals and system concepts, and the conduct of the design, development, test, evaluation and operation of data buoy systems to automatically measure and report marine environmental data from oceanic, coastal zone and inland water areas to meet national needs.

Environmental data processing centers such as the NOAA National Meteorological Center (NMC) of the National Weather Service (NWS), the U.S. Navy Fleet Numerical Weather Central (FNWC) and the U.S. Air Force Global Weather Center (GWC) have need for environmental data from throughout the world and in particular from the oceanic areas where reports from island stations and ship traffic are sparse. The density and location of the unmanned data buoy networks, in conjunction with other data sources, needed to provide the necessary marine atmospheric and oceanic environmental data from the major ocean areas is a significant factor which influences the development and demonstration of the capability to deploy and operate National Data Buoy Systems effectively. In addition, other factors (such as the composite reliability of the sensor-buoy-maintenance-communication system, accuracy of environmental parameter values, and redundancy with complementary observing platforms) impact on this buoy system effectiveness. Development and operation costs greatly depend upon the level of performance specified in the design. Since the performance specifications for design are derived from the composite measurement requirements of the users, measures of effectiveness based on utility to the user will more precisely assist their specification (e.g., accuracy: $\pm$ 0.1 to $\pm$ 1.0 mb for sea level atmospheric pressure, etc.; and reliability: 50% to 90%, etc.; and location and spacing of data points). The various influences related to data buoy measurement requirements (performance specifications) can be directly related to the useful statistic, root-mean-square (RMS) analysis error, which is important to the significant class of data users who operate numerical analysis and prediction centers. This statistic can be utilized as a meaningful measure of effectiveness to assist specification of data buoy network and systems design parameters.

Recognizing the desirability of developing objective criteria for data buoy network and systems design, the NDBC contracted with The Center for the Environment and Man, Inc. (CEM) to conduct a series of controlled numerical experiments involving the use of existing and simulated data sources with the standard operational numerical analysis computer programs used by the FNWC. This report describes the results of the experiments and the data buoy network preliminary design criteria that evolved from this initial study. The results described herein, while generally presented in terms of "data buoy" systems, are equally applicable to networks of other data collection platforms having equivalent characteristics. In addition, limitations of this initial study are noted and a procedure is outlined for performing data buoy network and systems design (measurement requirements/performance characteristics), using criteria based upon reduction of the RMS analysis error.

Objective

The objective of the study is to determine, for marine environmental data collection systems that include data buoys and other data collection platforms, the impact on overall system effectiveness of variations in data buoy system characteristics, including the following.

- Random errors in the amplitudes of data buoy observations.
- Random failures of data buoys in networks.
- Geographic location and density of data buoy networks.
- Variations in redundancy of data buoys and ships-of-opportunity.

The ultimate objective is to permit, for any arbitrary level of performance of the network, the definition of several alternative buoy networks, among which some or all of the systems design characteristics (measurement requirements/performance specifications) vary. For a given level of performance, one buoy network, comprising a specific configuration of the design characteristics that best meet prescribed criteria, may be selected for actual implementation. The impact of these characteristics may then be related to cost in a cost effective sense.

Methodology

The measure of system effectiveness selected for use in this study is related to how well data from a given buoy network and from normal land and ship sources can define the geographical distribution (commonly referred to as an "analysis") of an environmental parameter. Specifically, in this study the selected measure of performance of a data network is the RMS analysis error. In terms of this measure, the results of the study allow an assessment of the impact of variations in the buoy network design characteristics on the resultant analysis accuracy. The companion problem of determining the impact of variations in analysis accuracy on forecast accuracy, although important, is not treated in this study; primarily because it requires an effort equal in magnitude to the network design problem, but also because the results would be dependent upon the particular prediction models employed, which would introduce further uncertainty. Furthermore, resolution of the network design problems is a logical first step in the observation-analysis-prediction-control chain that is the goal of much environmental research.

To facilitate the study of data networks and their impact on analysis accuracy, measures of performance are calculated not only for the total geographical region under consideration, i.e., the northern hemisphere, but also for sub-regions in which the natural variability of the environmental parameters is more or less homogeneous. Network design is accomplished separately for each sub-region.

The study presents data network performance results for three environmental parameters—Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature—all measured at the air-sea interface, a region where data buoys are complementary to numerous transient ship observations. (It was planned initially to conduct an experiment for Subsurface Sea Temperature at 600 ft, but this effort was discontinued due to lack of sufficient real data to define a meaningful "true" environment.) The effectiveness of buoy networks is discussed with respect to the parameters taken individually and collectively.

The basic approach of the overall study comprises the following steps.

- Define an ensemble of buoy networks in which the number of buoys and their geographical locations vary over a wide range.
- Define an ensemble of data sets, each incorporating data from the buoy networks and from normal land and ship sources. The buoy data in the ensemble reflect a wide range of the design characteristics: reliability (failure rate), accuracy (data error), and redundancy with ship observations. Use Monte Carlo methods to simulate random failure and random data error in the buoy data.
- For each data set in the ensemble, calculate an objective numerical analysis and its measure of performance (RMS analysis error). Calculate an average measure of performance for each unique configuration of the design characteristics in accordance with the Monte Carlo method employed.
- Present the results in a suitable format to allow the selection of alternative buoy networks for a given average level of performance.

The study was conducted within the framework of the existing data acquisition system and with the cooperation of the U.S. Navy Fleet Numerical Weather Central and its sub-contractor, Meteorology International, Inc. (MII). All computations were performed on the computer facilities of FNWC by MII, using the existing operational objective analysis models for Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature.

To calculate an accurate measure of performance of an analysis constructed with a particular data network (comprising buoy data with a unique combination of design characteristics and normally available ship and land data), it was necessary to have available an error-free reference or "True" Analysis constructed from perfect, totally adequate, data. Since such data are not available at the present time, it was necessary to create, by definition, a "True" Analysis for each of the three environmental parameters. Becuase of the large amount of manual effort involved in producing these analyses, only one "True" Analysis was defined for each of the three parameters, using as a basis actual analyses prepared for March 22, 1970, at 0000Z.

The "True" Analysis also serves the important function of supplying error-free data for the various data networks defined for the study. With the aid of a random number generator, the accuracy design characteristic may be specified with precision simply by adding random errors to the error-free data for prescribed magnitudes of the standard deviation of error. In this study all random data errors are gaussian, and their characteristic magnitude is expressed in terms of the standard deviation, which in this case (the error mean is zero) completely defines the probability distribution function. Standard deviations of errors up to 5 mb were investigated for the Sea Level Pressure parameter, and standard deviations of errors up to 3°C were investigated for the Surface Air Temperature and Sea Surface Temperature parameters.

The system reliability design characteristic is a function of failure rate. The concept of failure extends from the sensor collecting data on a parameter through the communications link back to a shore data collection facility. In this sense, buoy downtime during maintenance also is a possible contributor to system failure, if other means are not used to make the data available. All buoys are considered equally likely to fail. (Here, failure is defined as the inability to observe and transmit information for a given parameter to the shore data dissemination hub.) Buoys are removed from the buoy networks at random, using a uniformly distributed random number for a decision index, until a prescribed percentage of buoys is removed. In this study, system reliabilities of 100, 80, and 50 percent were investigated.

The buoy-ship redundancy design characteristic is expressed in terms of a prescribed minimum probability of occurrence of at least one ship report within a prescribed area around a buoy location. If the ship probability equals or exceeds the prescribed minimum value (threshold value) the buoy is removed from the network under the assumption that, on the average, sufficient ship reports are available to preclude the need for buoy data from that general region. Threshold levels of 50 and 75 percent were investigated.

Results

The results of this initial study apply for three parameters and one set of synoptic data collected on March 22, 1970, at 0000Z throughout the northern hemisphere. Ten data collection networks, ranging from 76 to 600 data collection points, have been investigated. The majority of the results in this report are based on the four networks judged best; these are networks with 76, 150, 300 and 600 data collection points distributed in an advantageous manner throughout the North Pacific and North Atlantic, between the equator and 60°N. The spacing of data collection points was more dense in the northern latitudes for the 76 and 150 data point networks; for the 300 data point network the spacing was a uniform 300 n mi and for the 600 data point network, a uniform 200 n mi.

Of the approximately 3500 objective analyses made during the experiments, about 87 percent were performed to show the effects of buoys reporting in conjunction with ships-of-opportunity and the effects of eliminating the redundance of data buoys and ships-of-opportunity in the Northern Hemisphere. However, the majority of results presented in this report are for networks without consideration of other data sources or ships-of-opportunity redundancy. They are therefore equally applicable to networks of any platform type with similar characteristics—including data buoys. For these networks, system design curves have been prepared for a measure of effectiveness which is defined as percent reduction of RMS analysis error relative to the Initial

Guess error.* However, since the actual reduction of RMS analysis error is also of interest, actual experimental results are also shown in many figures and tables. The design curves have been prepared as a function of the number of data collection points, standard deviation of data error and system reliability. The curves are essentially unique for each of the four principal verification areas studied, which are defined as High and Low Variability areas in the Pacific and Atlantic, north of the equator. However, there were general trends of results in each of the three experiments which were common to all four verification areas. The table below gives the approximate data spacing for a given number of data points in each of these areas.

DATA SPACING BY VERIFICATION AREA

Verification Area	Approximate Data Spacing (n mi)			
	No. of Data Collection Points			
	20	30	50	100
Pacific High Variability	565	450	360	260
Pacific Low Variability	750	580	440	300
Atlantic High Variability	460	375	290	200
Atlantic Low Variability	500	400	320	225

It has been possible to summarize the results of the experiments for networks distributed as noted in the table above into a set of approximate rules-of-thumb as follows.

- Percent reduction in RMS analysis error relative to Initial Guess RMS analysis error per data collection platform added:
  - Sea Level Pressure = 1—2%, for first 30 to 40 platforms
  - Surface Air Temperature = 2—3%, for first 20 to 30 platforms
  - Sea Surface Temperature = 0.2—0.8%, for first 30 to 50 platforms
- Percent reduction in RMS analysis error relative to Initial Guess RMS analysis error per data collection platform added beyond the first 20 to 50 platforms:
  - Sea Level Pressure = 0.2%, beyond 50 platforms
  - Surface Air Temperature = 0.1—0.2%, beyond 30 platforms
  - Sea Surface Temperature = 0.1—0.3%, beyond 30—50 platforms

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*Throughout this report, the difference between the Initial Guess RMS analysis error and the RMS analysis error for a given data collection system (or, systems) is defined as the "reduction in Initial Guess RMS analysis error." When this measure is normalized by dividing by Initial Guess RMS analysis error and multiplying by 100, it is referred to as the "percent reduction in Initial Guess RMS analysis error."

- Percent reduction in RMS analysis error relative to Initial Guess RMS analysis error per millibar or degree centigrade decrease in standard deviation of data error (in the range of 0—1 mb or °C), for the first 20 to 50 platforms:

  - Sea Level Pressure = 4%
  - Surface Air Temperature = 12%
  - Sea Surface Temperature = 8%

- Percent reduction in RMS analysis error relative to Initial Guess RMS analysis error per percent increase in system reliability, for the first 20 to 50 platforms:

  - Sea Level Pressure = 0.3%
  - Surface Air Temperature = 0.2 to 0.35%
  - Sea Surface Temperature = 0.1 to 0.5%

These approximate rules-of-thumb imply that a system of 30 platforms, with standard deviations of error of 0.5 mb and 0.5°C and system reliabilities of 80% for each parameter, implemented in one of the verification areas, might achieve reductions in Initial Guess RMS analysis error that typically might be:

- Sea Level Pressure: 60% - 2% - 6% = 53%
- Surface Air Temperature: 75% - 6% - 8% = 61%
- Sea Surface Temperature: 16% - 4% - 4% = 8%

These example values are close approximations to actual answers that would have been obtained by using the system design curves for the High Variability areas. It is reiterated that results such as these are strictly applicable only for the particular operational numerical analysis models used in the experiments.

During the experiments, effort was expended to determine the impact of acquiring data from both buoys and ships (or, more generally, from uniform networks of fixed data collection points and randomly distributed moving locations). At the present, about 90 ship reports are received from throughout the northern hemisphere during the first hour after a synoptic period. In this study, about 300 reports were assumed. This approximates the results potentially more applicable to some time in the future. In general, for equal numbers and quality of randomly-located and uniformly located observations, the more uniformly located reports are more effective in reducing RMS analysis error. In certain instances, a given number of essentially uniformly distributed fixed data buoys might provide the equivalence of approximately twice as many randomly distributed ships.

Investigations were also conducted to show the impact of eliminating fixed data collection platforms from areas where the probability of ship reports is quite high. In general, it was found that the impact of eliminating redundancy is most pronounced where there are networks of 15—30 platforms in a verification area. Reductions in Initial Guess RMS analysis error for non-redundant networks was at most about 0.1 mb for Sea Level Pressure and 0.2°C for Surface Air Temperature or Sea Surface Temperature. In many instances, negligible improvement was observed for dense networks, when redundancy was eliminated. It was found that the impact of reducing redundance between buoys and ships is a function of parameter variability, density of buoys, and data error—from both ships and buoys. In general, reduction of redundancy is more effective for lower variability areas, sparse data networks, and higher data errors.

Immediate Follow-on Work

The experimental data developed during the course of the study provides a methodology and the basis for development of a technique for utilizing the results for buoy network and system design which may proceed in successive stages of complexity. First, it may start with a three parameter system of surface variables only—Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature—and then expand to include the error estimates made for subsurface sea temperature and upper air pressure height. In parallel, a hierarchy of constraints may be imposed as development proceeds. These include constraints on network effectiveness, engineering constraints related to the state-of-the-art, and others such as economic and geographic constraints. Later, more complex forms of reliability and redundancy may be introduced.

The network design technique should accept whatever constraints are defined as input data and, on the basis of those constraints, provide a list of data networks whose characteristics satisfy the constraints. The goal is to arrive at the single "best" network for deployment.

The simplest system design technique involves the three surface parameters studied, i.e., Sea Level Pressure (SLP), Surface Air Temperature (SAT) and Sea Surface Temperature (SST). The network design characteristics are:

- number of buoys in a verification area
- overall system reliability
- parameter data error
- redundancy with ships-of-opportunity

The input constraints are the maximum allowable RMS analysis error—or some other suitable measure—for each of the surface parameters. For a network to be acceptable, the resulting analysis errors must satisfy the constraints for all three of the parameters. Thus, the RMS analysis Error, $\mathcal{E}$, for each parameter must be equal to or less than, the maximum error allowed: that is,

$$\mathcal{E}_{SLP} \leq \mathcal{E}_{MaxSLP}, \qquad \mathcal{E}_{SAT} \leq \mathcal{E}_{MaxSAT}, \qquad \mathcal{E}_{SST} \leq \mathcal{E}_{MaxSST}.$$

If the network satisfies the constraints it becomes a candidate for deployment. Further constraints can reduce the number of networks. For example, networks that are beyond the state-of-the-art can be eliminated immediately; cost can be introduced to eliminate too-expensive networks or to select the most cost effective networks.

It is obvious that for a given set of constraints an infinite number of networks can be defined that satisfy the constraints. It is equally obvious that most of such networks do not differ from one another enough to warrant their consideration. A finite, tractable number of networks can be defined simply by assigning a number of discrete values to the network characteristics. The guiding principle here is to define discrete values such that whatever discrete network is ultimately chosen for deployment does not differ significantly from the one that would have been chosen from the infinite ensemble of networks.

A computer program for the simplest design technique would comprise a data bank containing the design characteristics of each defined network and its corresponding routine for selecting those networks that satisfy the input constraints. Implicit in this effort is translation of the range of values for accuracy and reliability toward estimates of more definitive measurement requirements (performance specifications) as an initial step followed by consideration of buoy network data in addition to ship-of-opportunity data at various levels of threshold.

Limitations

It is recognized that several biases exist in the present results which could, by obtaining additional experimental results, be removed prior to utilization in specifying data buoy network and system design criteria more definitively.

One bias was introduced through the use of a fixed analysis model and a fixed Initial Guess field in each experiment, regardless of data density or data quality. In an operational numerical analysis center, with sufficient time and resources available, effort would be expended to optimize both the analysis model and the Initial Guess field as a function of data density or data quality. The results described in this report from a fixed analysis model reflect project constraints of time and resources. The Initial Guess fields used for this study are the result of available ship reports for 0000Z March 22, 1970. The experimental results, therefore, underestimate the analysis error for data densities less than the ships-only density and overestimate the analysis error for data densities greater than the ships-only density. Thus, the results with the buoy-ship network and with buoys-only networks should be interpreted as upper bounds on the errors that would be encountered if buoy networks are implemented. The actual operational analysis error can be expected to be less because both analysis models and Initial Guess fields would be improved and, therefore, the buoy effectiveness should show a corresponding increase. In summary, this bias produces underestimates of RMS analysis error for data networks with density less than that of the present day data network and overestimates of RMS analysis error for higher density data networks. The magnitudes of these departures are unknown but could be established with a few well-chosen experiments.

Another bias was introduced by the use of a ship network that contained more ships than are normally available within one hour of synoptic map time, the present requirement for return of buoy data. This gives a favorable bias toward the present-day system and an unfavorable bias toward the decrease in RMS analysis error that would be obtained by adding data buoys to the present ship reporting system. The following table shows the average number of ship reports received at FNWC during November and December 1970. In particular, the table shows that an average of 90 ship reports were received within one hour of the 0000Z synoptic time.

In this study, the number of ship reports used was 348 for the Sea Level Pressure experiment and 302 for the Surface Air Temperature and Sea Surface Temper-

Hours After Synoptic Period	Total Number of Ship Reports Received							
	0000Z		0600Z		1200Z		1800Z	
	Avg.	Stan. Dev.	Avg.	Stan. Dev.	Avg.	Stan. Dev.	Avg.	Stan. Dev.
0.5	24	—[1]	12	—	14	—	10	—
1.0	90	25	92	23	84	27	56	22
1.5	197	37	180	24	173	26	146	41
2.0	322	—	287	—	294	—	264	—
2.5	397	39	331	36	344	47	327	40
3.5	503	—	398	—	468	—	411	—
4.0	538	27	441	38	496	51	451	50
6.5	586	—	447	—	586	—	437	—

[1] Dashes in the table indicate that statistical data were not available.

ature experiments. Some experiments should be repeated with a smaller ship set, representative of the one-hour time constraint, to establish the magnitude of this bias.

A third bias was introduced by the use of a set of fixed locations for ships in each experiment. Day-to-day variations in the locations of ship reports with respect to the horizontal distribution of variability in the environmental parameter may cause substantial fluctuations in analysis accuracy, especially for smaller numbers of ship reports. To remove the influence of these fluctuations, some experiments should be repeated several times, each with a different set of ship locations, and these Monte Carlo results averaged.

Finally, a fourth bias occurred in the experimental tests involving the removal of buoys from networks in regions where the probability of ship reports is high, due to the use of all ship reports received for a synoptic time, regardless of time of arrival. An additional effort should be made to determine the probability of obtaining ship reports from various regions as a function of time after the synoptic reporting period. These results would provide a more realistic basis for determining the overall effectiveness of combined buoy and ship reports, after removing buoys from regions in which there is a high probability of ship reports.

Later Follow-on Work

In later follow-on work related to this study, it is anticipated that first the four major limitations discussed above will be eliminated by performing a highly selective set of additional experiments. Then, the computer program developed for immediate follow-on work could be refined to accept other desired constraints and specification of specific buoy networks and system design criteria from an arbitrary ensemble. Estimates of meaningful reduction of RMS analysis error would then be obtained with the cooperation of the numerical analysis centers. With this information, various networks of any type of data collection platform and data buoy plus ship (at various thresholds of redundancy) collected data may then be analyzed to develop criteria for use in optimizing data buoy network system design.

ACKNOWLEDGMENTS

A fundamental objective of this study was to carry out the experiments within an operational numerical analysis and prediction center. To achieve success in this venture required a high level of cooperation from many people. This study has benefited from the cooperation, contributions and guidance of Capt. Paul M. Wolff, U.S. Navy, Commanding Officer, and members of his staff, U.S. Navy Fleet Numerical Weather Central, Monterey, California. Dr. Manfred Holl and Mr. Charles Tilden of Meteorology International, Inc., ably accomplished the necessary computer programming and computations for the experiments at FNWC. Mr. L. H. Clem, now with the National Data Buoy Center, NOAA, made substantive contributions in the first phase of this study. Mr. A. Thomasell, Jr., now with the National Environmental Satellite Service, NOAA, was Principal Scientist throughout the major part of this study and has made major contributions through his review of this report. Mr. R. A. Zettel, Technical Representative for this study, has provided welcomed contributions and guidance throughout the course of this study, and this report has benefited from his thorough review. Any errors in the presentation, interpretation, and use of information described in this report, are, of course, solely the responsibility of the authors.

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1.0 INTRODUCTION

1.1 Background

In November 1967, the U.S. Coast Guard was designated by the National Council on Marine Resources and Engineering Development (successor to the Interagency Committee on Oceanography) as the lead agency for the development of a capability to implement national data buoy systems. This action followed the completion in October 1967 of the 10-month Study of the Feasibility of National Data Buoy Systems which, under U.S. Coast Guard management, was prepared by The Travelers Research Center, Inc., now The Center for the Environment and Man, Inc. (CEM). In January 1968, the National Data Buoy Development Project (NDBDP) was formed in U.S. Coast Guard Headquarters. In October 1970, the Project was transferred by Executive Order 11564 to the newly-formed National Oceanic and Atmospheric Administration and in July 1971 it bacame the National Data Buoy Center (NDBC) within the Office of Marine Technology of the National Ocean Survey. The NDBC is located at the Mississippi Test Facility, Bay St. Louis, Mississippi, with some staff elements located in the Washington, D.C. area (Rockville, Maryland).

The National Data Buoy Development Project was established for the purpose of developing a national capability to deploy and operate networks of automatic data buoys to retrieve useful information describing the marine environment on a reliable, near real-time basis. More specifically, the mission of the NDBC of the National Ocean Survey, National Oceanic and Atmospheric Administration (NOAA) is to: "...conduct the planning and analytical studies necessary for the formulation of mission goals and system concepts, and the conduct of the design, development, test, evaluation and operation of data buoy systems to automatically measure and report marine environmental data from oceanic, coastal zone and inland water areas to meet national needs."

During early 1969, two meetings were held to discuss the advisability of undertaking several experiments to determine the feasibility of basing certain aspects of data buoy system design on the quantity and quality of environmental data delivered. Participants in the meetings included members of the NDBDP staff, Sperry Systems Management Division (NDBC Engineering Support Contractor), Sperry-Rand Research Center, and CEM. It was concluded in these meetings that the experiments should be undertaken, with the following conditions observed.

- The experiments should be carried out using the data bases, numerical analysis computer models, and facilities that are in day-to-day operation in an environmental data processing center.
- The measure of effectiveness to be used would most likely be improvement in root-mean-square analysis error.
- System design parameters to be considered would include
  - Geographical location of data buoy networks
  - Data buoy network density
  - Accuracy of data delivered by data buoy networks
  - Reliability of data collection and delivery by data buoy networks.

- The parameters to be considered would be
  - Sea-level pressure
  - Surface air temperature
  - Sea surface temperature
  - Sub-surface sea temperature (600 ft)*

In November 1969, CEM was awarded a contract (DOT-CG-02007-A) to perform a study to determine aspects of various parameters and parameter characteristics on system effectiveness, using environmental numberical analysis models. (The short title is the Environmental Models/System Effectiveness Study [EM/SE].)

The EM/SE study was conducted in two phases. Phase I was conducted during the first two months and embraced literature review and provided for contacts with potential "host" organizations to determine where the experiments might be conducted. The final product of Phase I was a detailed plan of action for conducting Phase 2, which comprised the experiments and analysis of results.

During Phase I, the National Meteorological Center (NMC) of the National Weather Service, Suitland, Maryland, and the U.S. Navy Fleet Numerical Weather Central (FNWC), Monterey, California, were contacted to see if either or both could provide numerical analysis models and computational support. NMC was interested in the study, but could not devote to it the requisite manpower and computer time, because of scheduled implementation of new computer facilities, entailing program transfer activities. FNWC agreed to make available facilities,on a reimbursable basis, to support the proposed experiment. The NDBC arranged for an interagency transfer of funds to cover computer time at FNWC and programming support provided by Meteorology International, Inc., operating under separate contract to FNWC.

The numerical analysis experiments were preceded by a pilot model program conducted at CEM. The pilot model study investigated the resolution characteristics of uniformly distributed data collection networks operating in the presence of random noise, while simultaneously suffering from random failures. The experiments at FNWC were initiated in September 1970, following preparation of data inputs by CEM. Computer processing of data was completed in April 1971. The experimental design and analysis techniques and the preliminary data collection system design curves presented herein for data buoy systems are equally applicable to other types of data collection platforms. Appendix E lists interim informal reports that were prepared during the course of the study; these documents are on file with the NDBC.

1.2 Definition of the Problem

Today's global environmental data acquisition system comprises a mix of data collection platforms, distributed relatively densely over the land masses, but sparsely over the oceans. The most dense data collection takes place over land in the northern

*Once the experimental process was begun, it was determined that inadequate data were available to conduct a meaningful experiment for sub-surface sea temperature at 600 ft. Details are given in Appendix A. The general results for the other experiments are given for Sea Level Pressure in Appendix B, for Surface Air Temperature in Appendix C, and for Sea Surface Temperature in Appendix D.

hemisphere. In spite of the lack of adequate data from ocean regions, numerical analysis and prediction models use available data to produce outputs for both hemispheres, and the entire world.

It is anticipated that data buoys will be one of the means used to acquire additional data from ocean areas. It is, therefore, desirable to determine through use of present environmental numerical analysis models, the impact of adding postulated data from some data collection system such as a buoy system. In turn, it is desirable to determine the overall effect of postulated random errors in the hypothetical buoy data; the effects of random failures of data collection and/or delivery; and alternative distributions of buoys. In general, the buoy systems would provide data from regions at least partially surrounded by data acquired by land-based platforms, where accuracy of data and reliability of reporting should (in theory) be high because of the relative ease of maintenance. Other data are available from island stations, ocean station vessels, and ships-of-opportunity.

There are many ways to define the effectiveness of a data collection system. A typical definition might be related to the system's capability to satisfy a given set of data requirements. Errors in data collection, probability of sensor and/or communications failure, and density and location of data buoys, are all elements of buoy system effectiveness, if the measure of effectiveness is based on the ability to reproduce the "true" environmental state as the output of an objective analysis model. It is anticipated that the effects of errors, data delivery failures, and density of locations of buoys on this measure of effectiveness can be determined by summing mean-square deviations of analysis model outputs at the field grid points. This measure of effectiveness is satisfactory for determining the ability of the postulated data buoy system, when working in conjunction with the actual data collection network, to resolve certain scales of natural phenomena.

System designers need information which will help answer such questions as the following.

- To obtain maximum resolution with fixed resources, what are the trade-offs between small numbers of high-cost, high-accuracy observing platforms and larger numbers of low-cost, low-accuracy platforms?
- How reliable should be the instruments, power supplies, communications, etc.?
- What is the best deployment for a fixed number of platforms?
- What scales of natural variability can the design system resolve?

Quantitative information is needed for obtaining insight into answers to the above questions, particularly as they apply to data collected at or near the ocean surface. This information should make possible identification of those aspects of the design problem that are independent of a particular set of requirements and hence require only one solution, as opposed to those aspects which must be solved for each new set of requirements.

1.3 Objective and Scope

The objective of this study was to determine, with operational numerical analysis models, the impact of variations in buoy-collected data on the total data collection system effectiveness.

The variations in the buoy data included:

- Gaussianly distributed random data errors
- Uniformly distribured failure of data delivery
- Total number of buoys in the system
- Geographical location of the buoys.

The results of this study will be directed toward aiding the development of design specifications for buoy network deployment and instrumentation and for determining the potential impact of the volume, quality, and reliability of buoy-collected data on existing environmental analysis models. The environmental parameters considered in this study were:

- Sea Level Pressure
- Surface Air Temperature, and
- Sea Surface Temperature.

The objective analyses for the study were produced on grids with a spacing of either (approximately) 100 or 200 n mi at mid-latitides, covering the northern hemisphere, with the equator as an inscribed circle at the boundaries. Analyses were computed and evaluated for a suitably large selection of buoy data variations to achieve the program objective. The aspects of the study requiring global-scale numerical analyses models were performed using the computer facilities at FNWC. Preparation of data, analysis of results and preparation of reports took place at CEM.

1.4 Key Conditions, Assumptions and Definitions

1. The numerical analysis grids employed are those used operationally.

2. The numerical analysis models (or, objective analysis models) employed are those in daily operational use.

3. The "True" Analysis for each parameter comprised data values as follows:

   - Sea Level Pressure - 15,625 data values (125 × 125 grid)
   - Surface Air Temperature - 3,969 data values (63 × 63 grid)
   - Sea Surface Temperature - 15,625 data values (125 × 125 grid)

4. The "True" Analyses (sets of gridpoint data values) for all three parameters were derived from actual analyses produced for the maptime 0000Z March 22, 1970, which was considered to be a typical "worst case" day in the northern hemisphere. The "True" Analyses include realistic small-scale features which were manually introduced into the actual analyses in selected areas.

5. The operational Initial Guess analyses for each of the actual analyses were modified to make them agree within normal limits with the corresponding "True" Analyses and were used as Initial Guess fields in the experiments.

6. Both the "True" Analysis fields and the Initial Guess fields remained unchanged throughout all experiments.

7. Input data values for land and island stations, ocean station vessels, ships-of-opportunity, and data buoys were obtained by computer interpolation from the "True" Analysis fields.

8. Additive data errors in amplitude were introduced in ship-of-opportunity and data buoy input data using an FNWC-provided random number generator with zero mean, Gaussian amplitude statistical characteristics. The amplitude of the standard deviation of errors added to "True" Analysis values was under the control of the systems analyst.

9. Random failure of buoy data collection and/or delivery was achieved using random withholding of buoy data, based on an FNWC-provided random number generator with uniform statistical characteristics over the interval 0 to 1. Exactly 20% and 50% of all buoys within each of eight specified regions were "failed," so that system reliabilities of 100%, 80%, and 50% could be investigated. Thus, to the degree that there is equality of natural variability, results for similar regions should be similar.

10. An objective analysis (or, simply, "analysis") is the complete field of output data values produced by a numerical analysis model given a set of input data values and an Initial Guess field.

11. The principal measure of data collection system effectiveness used in this report is the root-mean-square (RMS) analysis error, determined by comparing in an RMS sense the "True" Analysis field with a computed objective analysis field for a set of prescribed input data. However, the Initial Guess RMS analysis error is determined by comparing in an RMS sense the "True" Analysis directly with the Initial Guess field. For all other objective analyses, the data from land, island, ocean station vessel, ship, and hypothetical buoy locations replace Initial Guess data where appropriate. In general, the resulting RMS analysis errors will be smaller than the appropriate Initial Guess RMS analysis error, this giving a measure of improvement in the objective analysis. In this report, the difference between the Initial Guess RMS analysis error and the RMS analysis error for a given data collection system (or, systems) is defined as the "reduction in Initial Guess RMS analysis error." When this measure is normalized by dividing by Initial Guess RMS analysis error and multiplying by 100, it is referred to as the "percent reduction in Initial Guess RMS analysis error."

12. Eight different verification areas were defined, within which RMS analysis errors were determined. The eight areas are defined to be:

- All Northern Hemisphere
- All North Pacific
- Pacific High Variability
- Pacific Low Variability
- All Atlantic
- Atlantic High Variability
- Atlantic Low Variability
- Gulf of Mexico

1.5 Limitations of the Study

1. All numerical experimental results presented in this report apply specifically only for those numerical analysis models in use during the period the experiments were conducted: September 1970 through April 1971.

2. Experimental results for each parameter are the result of an investigation of a single field of synoptic information, i.e., one "True" Analysis field. Also, only one Initial Guess field, characteristic of what is obtainable by the present day data network, was used for each parameter to initiate all analyses.

3. After an initial investigation of 10 global data collection networks to determine preferred distributions of data collection platforms, the "best" four networks were used to obtain all subsequent experimental results. These four global networks comprised 600, 300, 150, and 76 data collection platforms (or, data points), distributed between 60°N and the equator in the North Atlantic and North Pacific. Uniform spacings of 200 n mi and 300 n mi were used for the data collection networks comprising 600 and 200 platforms, respectively. The data collection networks of 150 and 76 platforms were essentially uniformly distributed in any 10°—20° latutude band, with greater density in the northern latitudes than near the equator.

4. Only one set of locations for data from ships was used for the experiment associated with each parameter. Actual ship locations for 0000Z, March 22, 1970, were used for Sea Level Pressure. A hypothetical set of probable ship locations—based on a statistical analysis of the occurrence of ship reports—was used for Surface Air Temperature and Sea Surface Temperature.

5. In conducting the Sea Level Pressure experiment, the wind field inputs were not used, although under normal operating practice they are used.*

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*A brief investigation was carried out in which duplicate runs were made with and without wind field inputs. No differences of amplitudes significant enough to influence this study were observed. Hence, the wind field input was omitted to conserve computer time.

6. The number of ship reports used in the experiment (348 or 302) is considered optimistically high by a factor of 3 to 6, if the requirement is to obtain the ship reports within 60 minutes of the synoptic time, as in the case for National Data Buoy Systems. However, at some point in the future, a method may be employed which will provide more timely reporting by ships.
7. The study results for data densities less than the ships-only density tend to underestimate the analysis error and for data densities greater than ships-only density tend to overestimate the analysis error. Thus, all the results with buoy-ship networks and with buoys-only networks where the data density is greater than ships-only should be interpreted as upper bounds. The actual operational analysis errors can be expected to be less than these errors and, therefore, the buoy effectiveness should show a corresponding increase.

1.6 Outline of the Report

The remainder of this report contains the following categories of information. Conclusions of the study are given in Section 2, which follows. The technical approach used in conducting the three experiments involving the Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature parameters is presented in Section 3. The results of the experiment conducted for Sea Level Pressure are given in Section 4, which also contains detailed system design curves and examples illustrating their use.

Section 5 contains the experimental results for Surface Air Temperature, system design curves, and examples of their use. The results of the Sea Surface Temperature experiment are presented in Section 6, along with system design curves and examples of how they can be used.

Section 7 describes the results of investigating the impact on system effectiveness that might derive from eliminating the redundancy of buoys and ships, in those regions where the probability of obtaining ship reports is high.

Finally, Section 8 presents several examples of the use of the system design curves from Sections 4, 5, and 6 in the design and cost effectiveness analysis of hypothetical data buoy networks.

Supporting documentation is contained in the Appendices.

2.0 CONCLUSIONS

This study has covered a very wide range of topics. In addition to conclusions related to the basic purposes of the study, a number of other concepts have been verified that were intuitively recognized but generally unsubstantiated.

The conclusions presented herein have been derived for the High and Low Variability areas of the North Pacific and the North Atlantic. The approximate data point spacing for these areas is shown in Table 2-1 for pertinent numbers of platforms. Verification areas covering the entire North Pacific and North Atlantic are too large to draw equally definitive conclusions regarding specific data collection system characteristics.

TABLE 2-1
APPROXIMATE AVERAGE SPACING BETWEEN DATA POINTS (n mi)

Verification Area	Number of Platforms			
	20	30	50	100
Pacific High Variability	565	450	360	255
Pacific Low Variability	750	560	440	310
Atlantic High Variability	460	375	290	200
Atlantic Low Variability	500	400	320	225

Specific conclusions derived from this study are:

1. Objective analysis models can be used to determine the impact of variations in such data collection system characteristics as

   - Number of data collection platforms in the system,
   - Distribution of locations of data collection platforms,
   - Reliability of the data system to collect and deliver the expected data,
   - Total system error in the data delivered to the analysis model, and
   - Redundancy of data collection platforms with probable ship-of-opportunity data.

   Simulated data sets can be used with Monte Carlo techniques to test these system characteristics.

2. A relatively small number (20—50) of accurate and reliable data collection platforms essentially uniformly distributed in the High and Low Variability areas of the North Atlantic and the North Pacific can achieve the following percent reduction in Initial Guess

RMS analysis error for the analysis models used:

- Sea Level Pressure—50% or more
- Surface Air Temperature—65% or more, and
- Sea Surface Temperature—25% or more, except in the Atlantic High Variability area, where 15% or more applies.

3. A limited number (20—40) of data collection platforms essentially uniformly distributed throughout a verification area is more effective than concentrating the same number of platforms in a small percent of the total area of interest.

4. It is possible that additional data collection platforms should not be placed in regions where the probability of acquiring ship-of-opportunity data is more than 75%, although not enough facets of this question have been considered in this study to draw significant conclusions.

5. The effectiveness of an accurate and reliable data collection system is directly due to the number of observational data values and their distribution (location relative to analysis grid points) which in turn determines the average number of analysis gridpoints that will be influenced by each data platform.

6. Except in cases where the numerical analysis model includes considerable smoothing (filtering) of input data, the RMS analysis error approaches the data error standard deviation as the number of data points increases, assuming the errors are essentially Gaussianly distributed.

7. For essentially uniformly distributed data networks in a verification area, the RMS analysis error can be approximated by a straight line as the data error standard deviation goes from 0.0 to 1.0 units (mb or °C). For the experimental data, deviations from the straight line approximation in this range are less than 0.1 unit. Linear interpolation for error values is completely adequate. Rough rules-of-thumb for improvement in percent reduction of Initial Guess RMS analysis error per unit improvement in standard deviation of data error are as follows:

   - Sea Level Pressure : 1-40%/mb (avg. ≅ 2%/mb)
   - Surface Air Temperature: 1-18%/°C (avg. ≅ 6%/°C)
   - Sea Surface Temperature: 1-28%/°C (avg. ≅ 10%/°C)

   In general, the small end of the range applies to small numbers of data points (i.e., about 20) and the large end of the range applies to about 50 to 100 data points. However, the high and low ends of the range do not apply in all four verification areas.

8. For essentially uniformly distributed data networks in a verification area, the effect of data system reliability is essentially linear for variations of up to about ± 15%. Tests were made where the postulated data system reliabilities were 100%, 80%, and 50%. Linear interpolations for data systems with intermediate reliability values is adequate. Rough rules-of-thumb for improvement in percent reduction of RMS Initial Guess analysis error per percent improvement in reliability are as follows:

   - Sea Level Pressure : 0.1 to 0.35 %/% Rel.
   - Surface Air Temperature: 0.1 to 0.28 %/% Rel.
   - Sea Surface Temperature: 0.05 to 0.40 %/% Rel.

   In general, the small end of the range applies to small numbers of data points (i.e., about 20) and the large end of the range applies to about 50 to 100 data points. However, the high and low ends of the range do not apply in all four verification areas.

9. A number of alternative data collection systems can be defined that will produce the same effectiveness score, especially when all three parameters are combined to form a single system score. The alternatives involve

   - Parameters measured,
   - Number of platforms,
   - Data system error standard deviation, and
   - Data system reliability.

   Extensive tradeoffs are possible among these variables for a total average effectiveness specified for a given verification area or a combination of verification areas.

10. Experimental results derived for some verification areas appear to be sufficiently unique to prohibit translation of results from one verification area to another with high percision.

11. On the basis of the experiments conducted, when fixed networks of accurate and reliable data collection platforms become available, it is anticipated that marked changes will be made in numerical analysis to match more adequately the accurate and reliable data and the natural variability of specific parameters.

3.0 MONTE CARLO EXPERIMENTAL APPROACH

3.1 Overview

One of the objectives of this study was to see if objective analysis models could be used to evaluate the impact of various postulated data collection systems. Since data buoy networks do not exist at the present time, it was necessary to simulate data from hypothetical data buoy networks, using controlled data accuracy and system reliability.* For each set of Monte Carlo simulated data, a hemispheric objective analysis was prepared using the FNWC operational model. This analysis was scored against a "True" Analysis for the parameter by means of the root-mean-square difference between the two maps (defined as the RMS analysis error) in each verification area. To obtain representative Monte Carlo RMS analysis error values, a number of data-error and buoy-failure fields with a known distribution were prepared by means of random number generators. The RMS analysis error for each of these variations was then used to compute an average experimental RMS analysis error.

Figure 3-1 illustrates the sequence of events as they occurred for each experiment. The variables under control of the system analyst include: the parameter to be studied; the choice to include or exclude data for ship-of-opportunity locations, and if included, the standard deviation of errors added to the ship data; buoy data obtained by interpolating values from the "True" Analysis field for a number of buoy network configurations; the accuracy of the buoy system data; and the buoy data system reliability. When ship reports were used, it was possible to eliminate buoy data from those locations where the probability of receiving a ship report exceeded a specified value. These variables and conditions established the basic control for the oceanic input data for each of the three experiments.

The input oceanic data, as specified above, is merged with "perfect" (i.e., reliable and error-free) observations from land stations and islands to constitute an input data set to the FNWC operational objective analysis computer models. The output is an analysis value at each of the gridpoints in the grid array used for the parameter.

An evaluation of each analysis was made by computing the root-mean-square difference between the analysis gridpoint values and the gridpoint values for a previously established "True" Analysis. After sufficient Monte Carlo variations were made in the controlled input, an average RMS analysis error was computed by taking the square root of the summed and averaged mean-square values for the individual analyses.

A complete description of the fixed and variable elements in the experiments is presented in Sections 3.2 and 3.3, respectively. The Monte Carlo procedures and the measures of effectiveness used are also presented in greater detail in later sections.

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*System reliability in this study is defined as the ratio obtained by dividing the number of observations from a network input to the analysis model by the total number of platforms deployed in the network. Experimental results for system reliabilities of 100%, 80%, and 50% were obtained in this study.

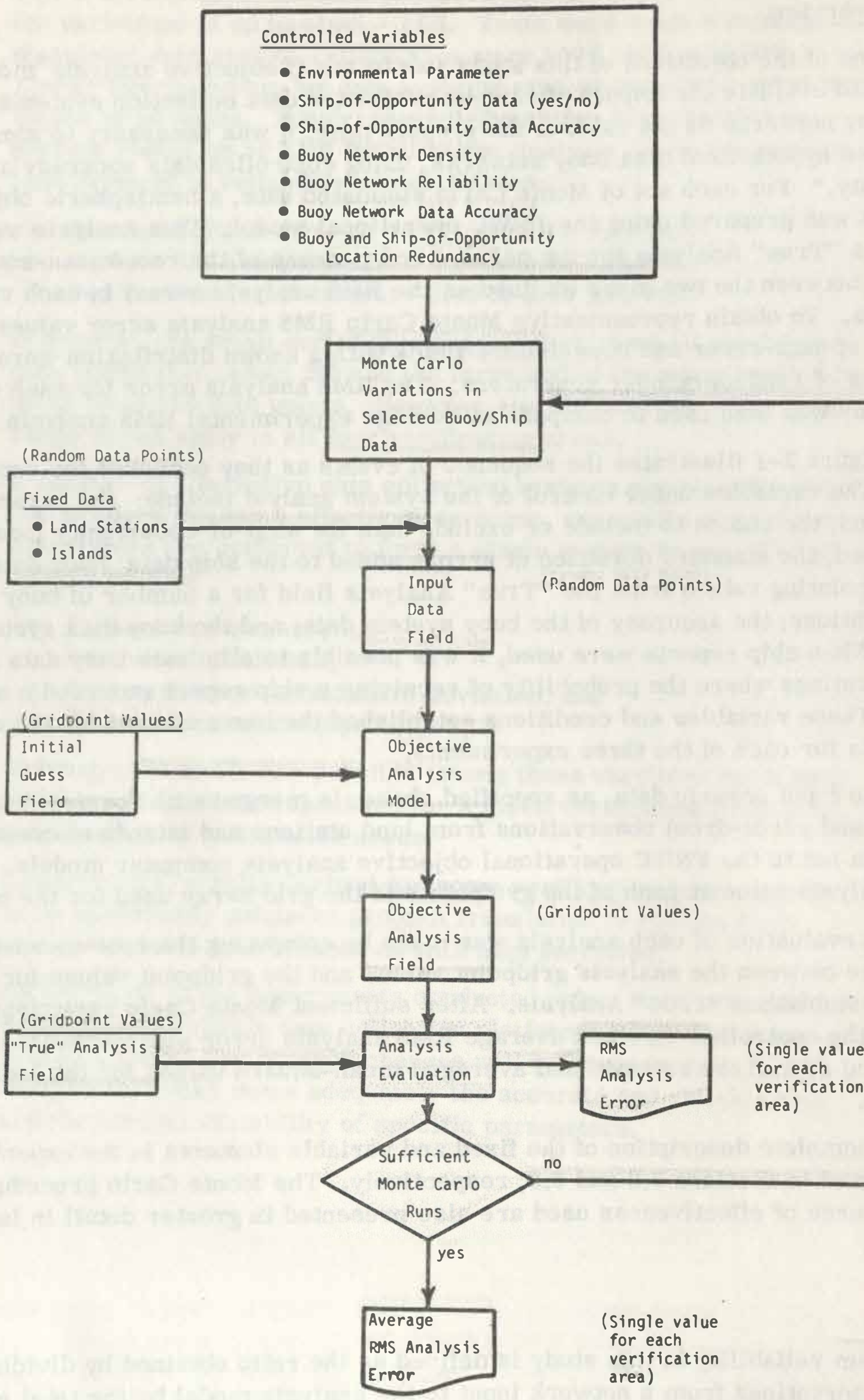

Fig. 3-1. Schematic flow of elements in the experiments.

3.2 Fixed Elements in the Experiments

The elements of the experiments shown in Fig. 3-1 are listed in Table 3-1. Some of the elements remained fixed for all experiments,* while others varied according to controlled Monte Carlo procedures.

TABLE 3-1
ELEMENTS OF THE EXPERIMENTS

Fixed Elements	Variable Elements
1. Objective Analysis Models	1. Buoy Networks (Density)
2. Initial Guess Fields	2. Buoy Data Accuracy
3. "True" Analysis	3. Buoy Network Reliability
4. Verification Area	4. Ship-of-Opportunity Data Availability (Yes or No)
5. Land and Island Data	5. Ship-of-Opportunity Data Accuracy
6. Measure of Effectiveness	6. Buoy and Ship-of-Opportunity Location Redundancy

The following paragraphs in this section describe those elements that remained fixed for all the experiments.

3.2.1 Objective Analysis Models

In order to evaluate a series of postulated data collection systems, arrangements were made by the NDBC to use the operational objective analysis models at FNWC. The Sea Level Pressure and Surface Air Temperature models that were used are described in detail in Reference 1. These models use the Carstenson relaxation procedure for interpolating analysis values among data points and cycle through a series of steps involving error checking, interpolation, and smoothing. The degree of smoothing and error tolerances is a function of the cycle. The models allow a variable reliability factor to be assigned to data from different sources which also affects the error tolerances used in the error checking procedures. In both models, a factor was selected to preclude exclusion of simulated data with large errors.

*The word "experiment" is used in this report to describe all of the computer runs (numerical analyses) performed for a single environmental parameter. Approximately 2000 analyses were preformed in the Sea Level Pressure experiments, while about 750 analyses were performed in the Surface Air Temperature experiment and the Sea Surface Temperature experiment, respectively.

The Sea Surface Temperature model was a new model being developed for FNWC [2, 3], which has subsequently become the operational model. This model calculates a best guess at a gridpoint from the data in the immediate vicinity. Data from different sources are assigned appropriate reliability weights and the best estimate is the weighted average of the different data sources. The impact of highly reliable data is spread to neighboring regions by successive updating of the best estimate field. This technique forces the analysis to reflect the most reliable data sources.

All three of the above models operate on a hemispheric grid which is an orthogonal array on a polar stereographic map projection. The Sea Level Pressure model and the Sea Surface Temperature model use a grid of 125 x 125 gridpoints. For this grid mesh, the distance between gridpoints at 60°N is approximately 100 n mi and at the equator is approximately 50 n mi. Surface Air Temperature uses a grid of 63 x 63 gridpoints; the corresponding grid interval is 200 and 100 n mi for 60°N and 0°N, respectively.

3.2.1.1 Review of Numerical Analysis Procedures

A rudimentary review of the characteristics of objective analysis models provides insight into the relationship between input observations, initial guess fields, grid mesh, and the objective analysis models. The models require a previously prepared initial guess with a value at each gridpoint that is a first approximation of the analysis being prepared. Observations from random data points are used by the models to modify all initial guess values within a prescribed distance from the data point. A relaxation numerical analysis technique is then used to generate new field values wherever initial guess values occur. Gridpoints influenced by observational data are considered as internal boundary conditions and remain unchanged by the relaxation process. The resultant field is usually smoothed after each relaxing pass to remove small-scale noise. The resulting gridpoint values may then be used as a new initial guess and the cycle repeated according to specified criteria.

3.2.1.2 Impact of Numerical Analysis Model Grid Mesh

The grid interval used by the models determines the minimum scale features of the parameter than can be resolved. An estimate of the smallest scale that can be resolved for a given grid network can be derived from the Scale Resolution Study [4] performed during the early part of this contract.

Figure 3-2, taken from an interim report on the Scale Resolution Study, shows the error incurred in reconstructing a one-dimensional sinusoidal waveform of given wavelength and amplitude from equally-spaced error-free data for a range of grid mesh sizes. Similar wave forms may be obtained from a "True" Analysis field simply by plotting temperature or pressure along a line connecting two suitably chosen points. In this one-dimensional sense, it is of value to know how accurately shorter-wavelength features can be depicted from error-free data on a specified grid mesh. In Fig. 3-2, points A and B represent two combinations of wavelength and grid mesh with an equivalent error E_1. That is, a 400 n mi wavelength on a 100 n mi grid mesh is depicted with the same accuracy as an 800 n mi wavelength on a 200 n mi grid mesh. Obviously, other combinations may be defined along the line E_1, and the results hold

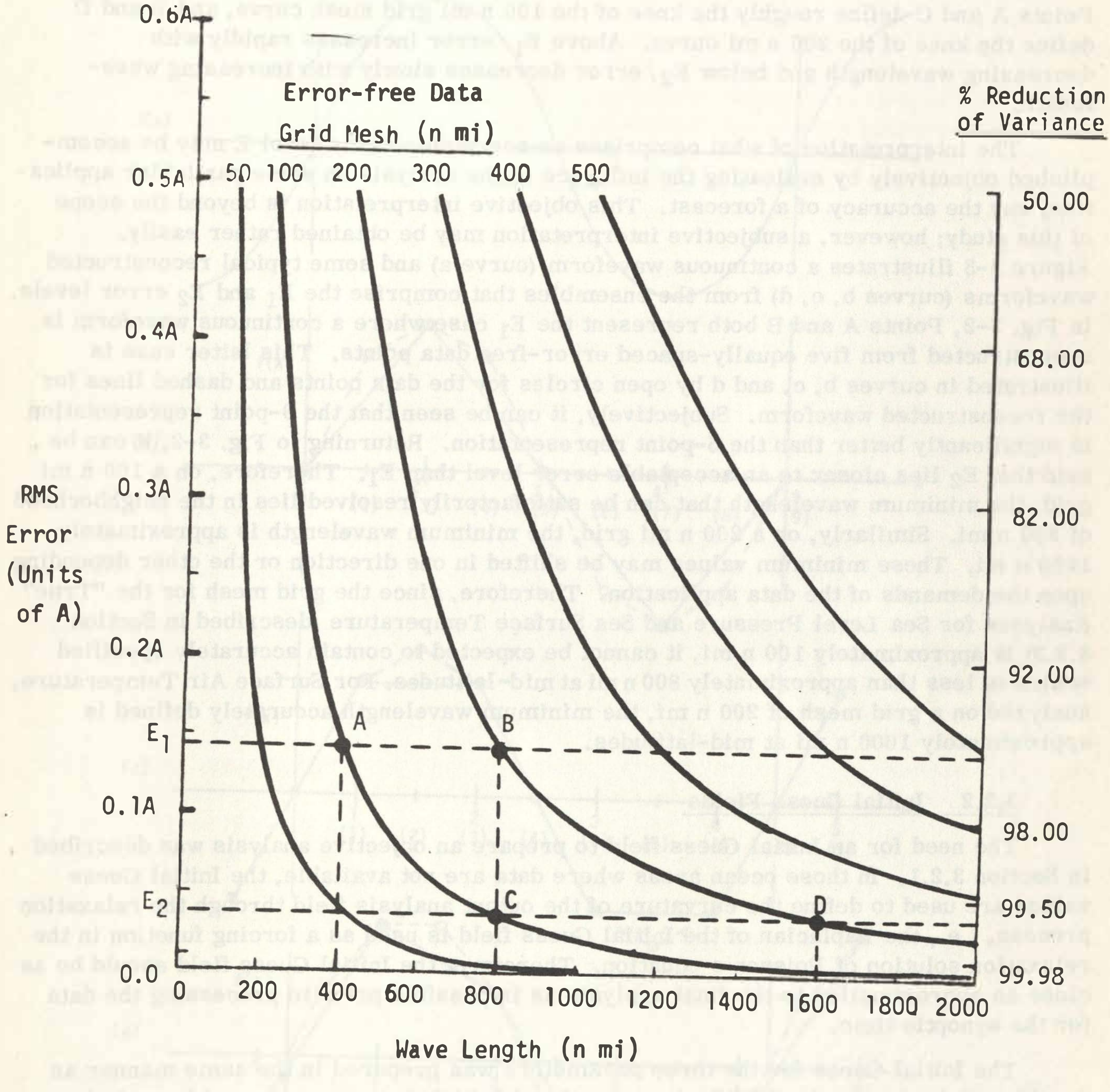

Fig. 3-2. RMS error of sinusoidal waveform with amplitude A reconstructed with error-free data on the indicated grid mesh.

for arbitrary unit of length for wavelength and grid mesh. If the parameter is atmospheric pressure, E_1 is given in millibars as a function of the waveform amplitude, A, on the left-hand ordinate, or as percent reduction of variance on the right-hand ordinate. Points C and D represent similar combinations for a smaller error E_2. Points A and C define roughly the knee of the 100 n mi grid mesh curve, and B and D define the knee of the 200 n mi curve. Above E_1, error increases rapidly with decreasing wavelength and below E_2, error decreases slowly with increasing wavelength.

The interpretation of what comprises an acceptable error level E may be accomplished objectively by evaluating the influence of the analysis on some particular application, say the accuracy of a forecast. This objective interpretation is beyond the scope of this study; however, a subjective interpretation may be obtained rather easily. Figure 3-3 illustrates a continuous waveform (curve a) and some typical reconstructed waveforms (curves b, c, d) from the ensembles that comprise the E_1 and E_2 error levels. In Fig. 3-2, Points A and B both represent the E_1 case where a continuous waveform is reconstructed from five equally-spaced error-free data points. This latter case is illustrated in curves b, c, and d by open circles for the data points and dashed lines for the reconstructed waveform. Subjectively, it can be seen that the 9-point representation is significantly better than the 5-point representation. Returning to Fig. 3-2, it can be said that E_2 lies closer to an acceptable error level than E_1. Therefore, on a 100 n mi grid, the minimum wavelength that can be satisfactorily resolved lies in the neighborhood of 800 n mi. Similarly, on a 200 n mi grid, the minimum wavelength is approximately 1600 n mi. These minimum values may be shifted in one direction or the other depending upon the demands of the data application. Therefore, since the grid mesh for the "True" Analyses for Sea Level Pressure and Sea Surface Temperature (described in Section 3.2.3) is approximately 100 n mi, it cannot be expected to contain accurately specified scales of less than approximately 800 n mi at mid-latitudes. For Surface Air Temperature, analyzed on a grid mesh of 200 n mi, the minimum wavelength accurately defined is approximately 1600 n mi at mid-latitudes.

3.2.2 Initial Guess Fields

The need for an Initial Guess field to prepare an objective analysis was described in Section 3.2.1. In those ocean areas where data are not available, the Initial Guess values are used to define the curvature of the output analysis field through the relaxation process, i.e., the Laplacian of the Initial Guess field is used as a forcing function in the relaxation solution of Poisson's equation. Therefore, the Initial Guess field should be as close an approximation to the final analysis as is possible prior to processing the data for the synoptic time.

The Initial Guess for the three parameters was prepared in the same manner as the "True" Analysis. At FNWC, the operational Initial Guess is prepared by updating the forecast field for that maptime with data received after the analysis and forecast models have been run. For this study, the operational Initial Guess for each parameter was manually modified to reflect the greater detail defined in the "True" Analysis. In this manner, a consistency was maintained between the Initial Guess and the expected "True" Analysis and the Initial Guess field, as it occurs in routine FNWC operations.

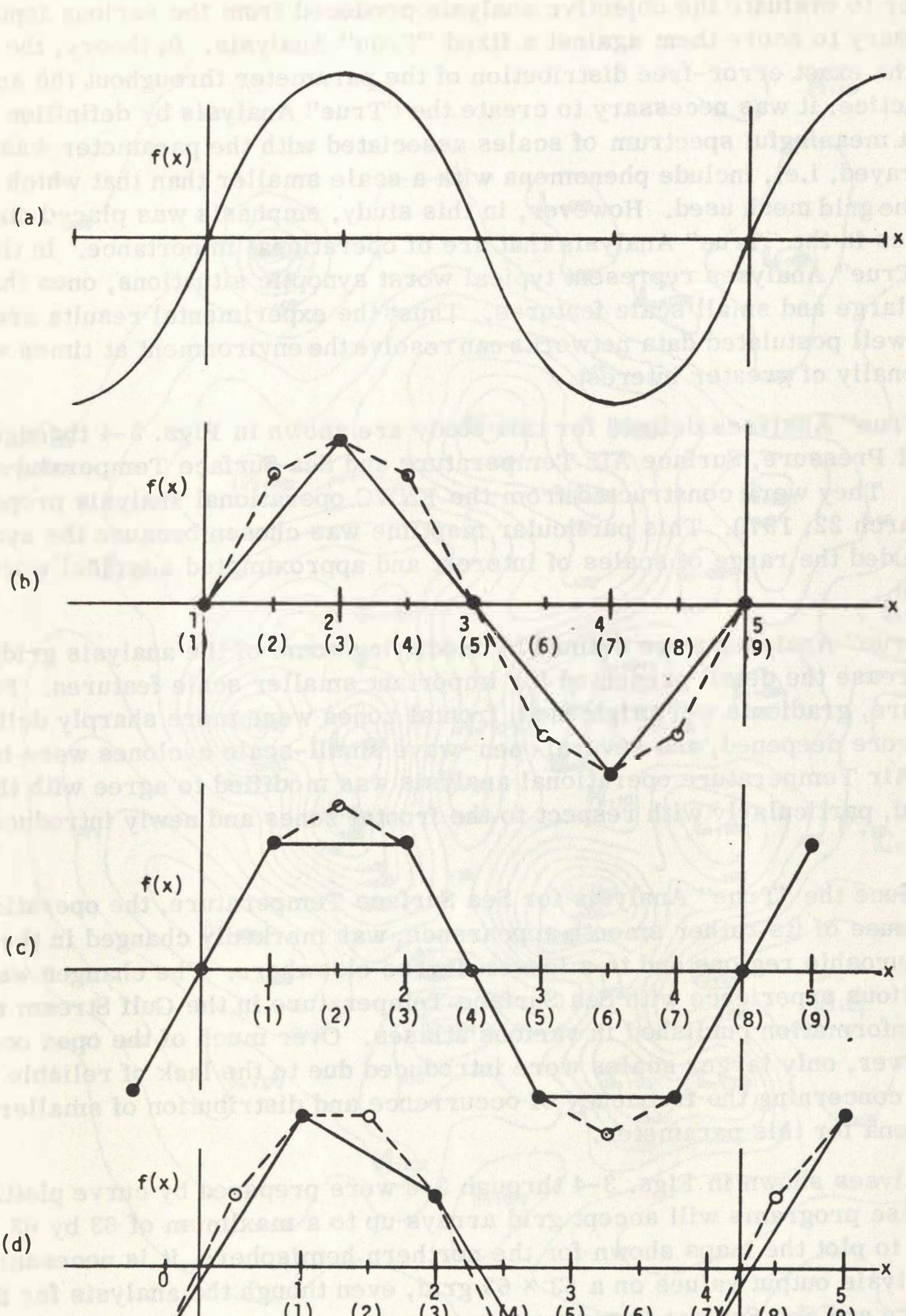

Fig. 3-3. Various configurations of a sinusoidal waveform reconstructed from 5 and 9 data points per wavelength.

3.2.3 "True" Analysis

In order to evaluate the objective analysis produced from the various input data it was necessary to score them against a fixed "True" Analysis. In theory, the "True" Analysis is the exact error-free distribution of the parameter throughout the analysis area. In practice, it was necessary to create the "True" Analysis by definition to assure that a meaningful spectrum of scales associated with the parameter was adequately portrayed, i.e., include phenomena with a scale smaller than that which can be resolved by the grid mesh used. However, in this study, emphasis was placed on defining scales in the "True" Analysis that are of operational importance. In this sense, the "True" Analyses represent typical worst synoptic situations, ones that include both large and small scale features. Thus, the experimental results are indicative of how well postulated data networks can resolve the environment at times when it is operationally of greater interest.

The "True" Analyses defined for this study are shown in Figs. 3-4 through 3-6 for Sea Level Pressure, Surface Air Temperature and Sea Surface Temperature, respectively. They were constructed from the FNWC operational analysis prepared for 0000Z March 22, 1970. This particular maptime was chosen because the synoptic patterns included the range of scales of interest and approximated a typical worst case situation.

The "True" Analyses were defined by modifying some of the analysis gridpoint values to increase the detail presented for important smaller scale features. For Sea Level Pressure, gradients were tightened, frontal zones were more sharply delineated, low centers were deepened, and several open-wave small-scale cyclones were introduced. The Surface Air Temperature operational analysis was modified to agree with the new pressure field, particularly with respect to the frontal zones and newly introduced cyclones.*

To produce the "True" Analysis for Sea Surface Temperature, the operational analysis, because of its rather smooth appearance, was markedly changed in the Gulf Stream and Kuroshio regions and to a lesser degree elsewhere. The changes were based on previous experience with Sea Surface Temperature in the Gulf Stream and from cruise information published in various atlases. Over much of the open ocean regions, however, only larger scales were introduced due to the lack of reliable synoptic data concerning the frequency of occurrence and distribution of smaller scale phenomena for this parameter.

The analyses shown in Figs. 3-4 through 3-6 were prepared by curve plotting routines. These programs will accept grid arrays up to a maximum of 63 by 63 gridpoints. This, to plot the maps shown for the northern hemisphere, it is necessary to define the analysis output values on a 63 × 63 grid, even though the analysis for Sea Level Pressure and Sea Surface Temperature are computed on a 125 × 125 grid. This

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*For the experiments conducted, the analysis field for Sea Level Pressure is independent of the analysis field for Surface Air Temperature, i.e., the analysis models did not force a consistency between the analysis for the two parameters.

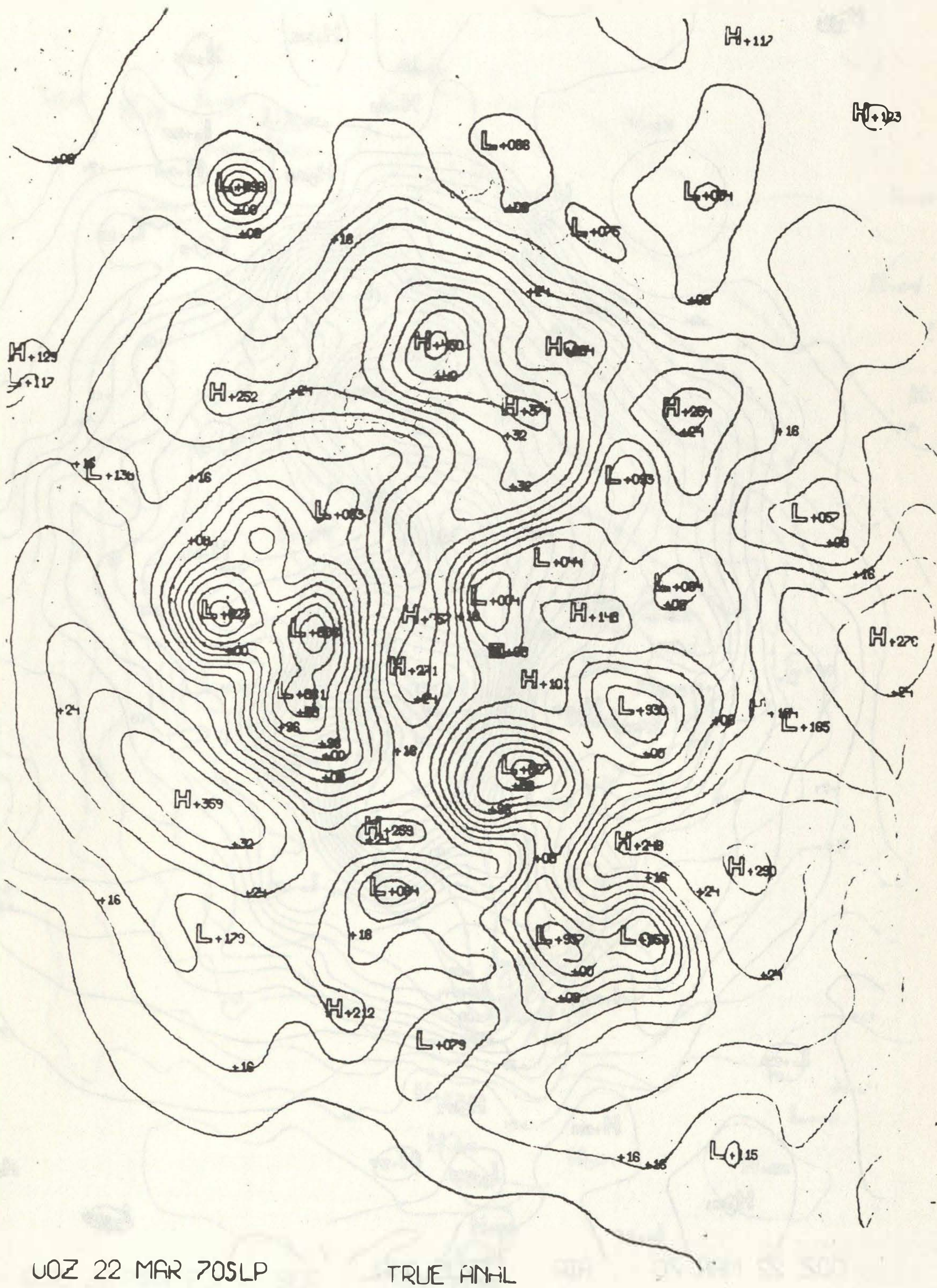


Fig. 3-4. "True" Analysis for Sea Level Pressure: 0000Z March 22, 1970.

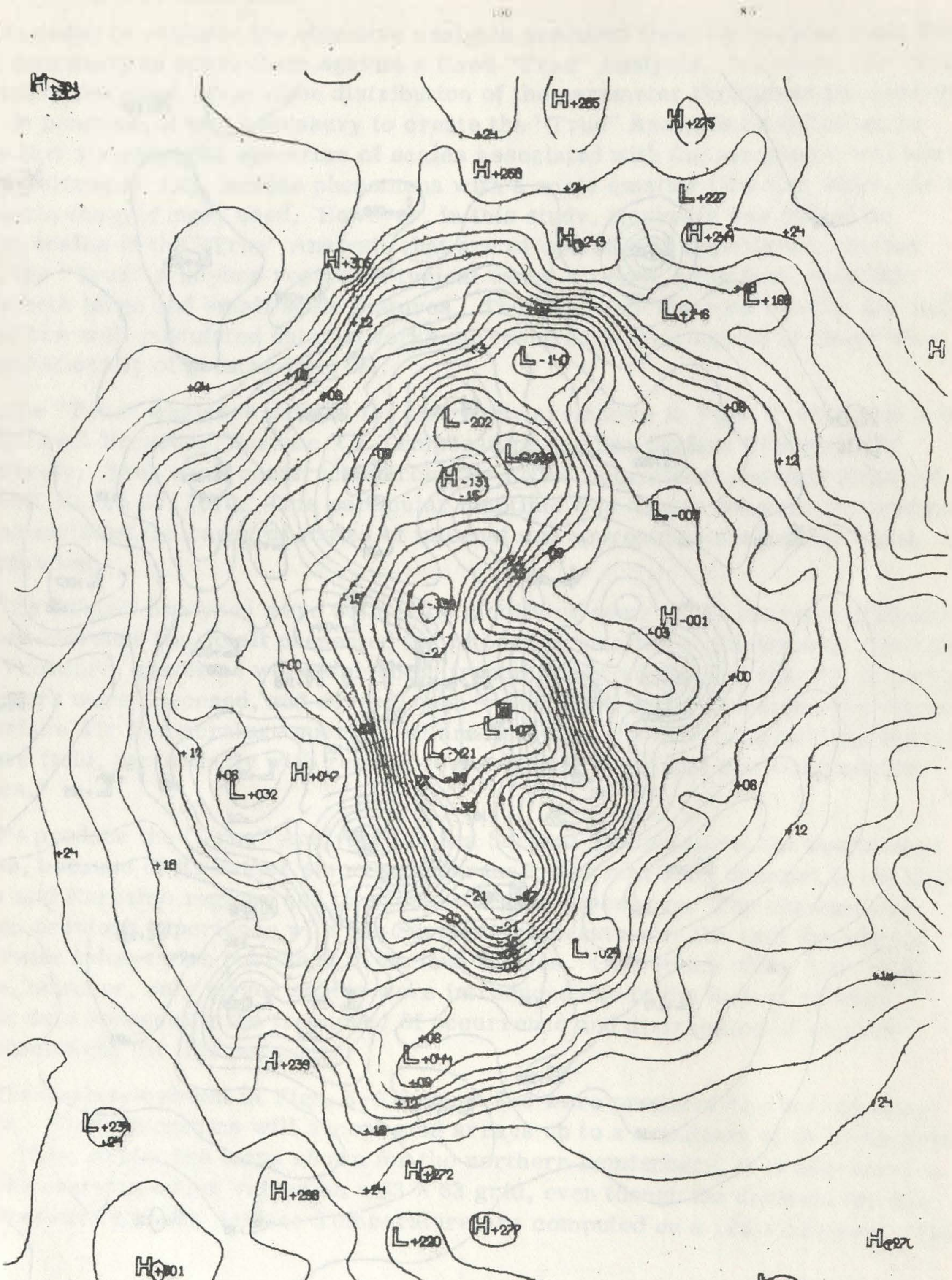


Fig. 3-5. "True" Analysis for Surface Air Temperature: 0000Z March 22, 1970.

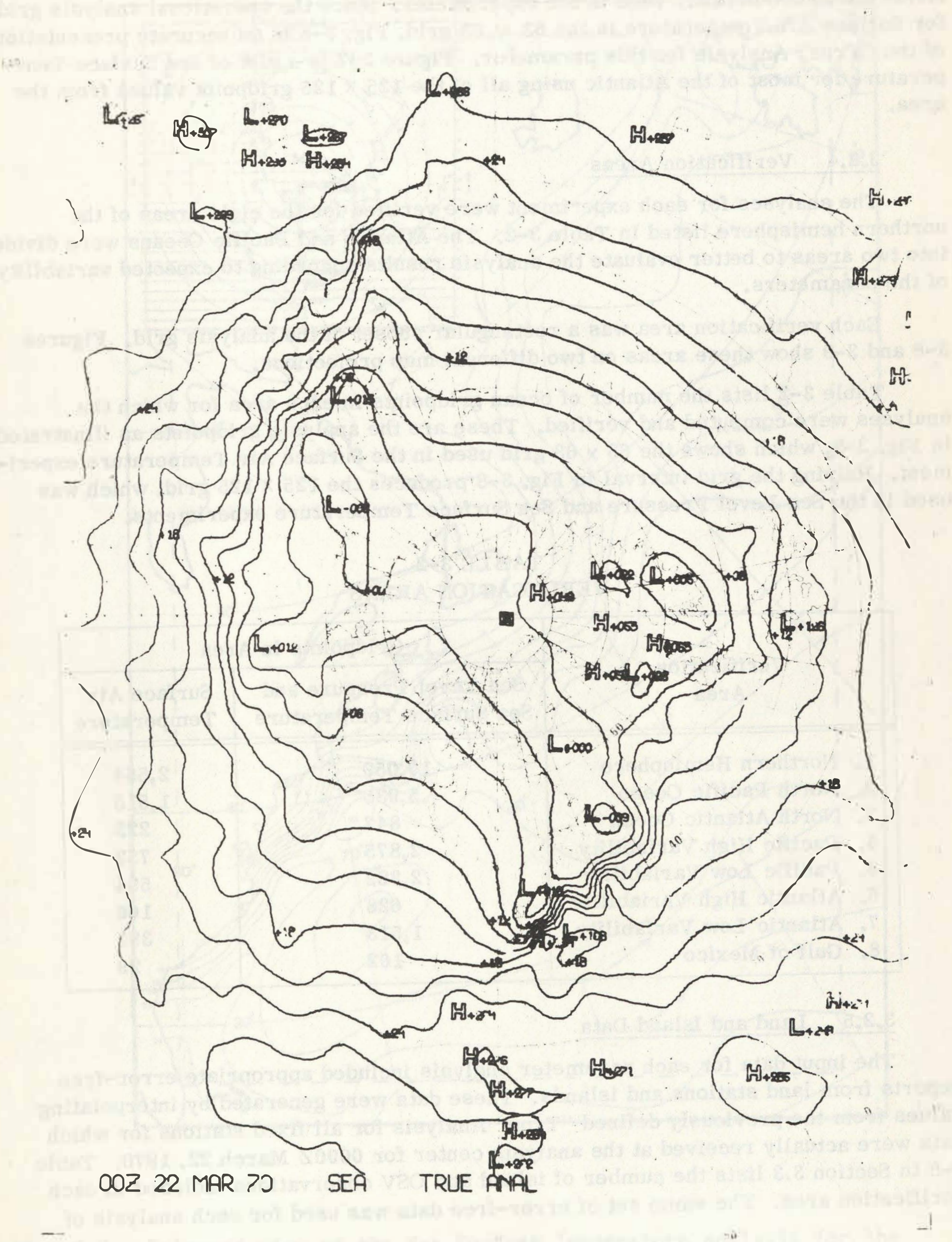


Fig. 3-6. "True" Analysis for Sea Surface Temperature: 0000Z March 22, 1970.

means that the contours shown in Figs. 3-4 and 3-6 are based on the values at every other gridpoint, thus presenting more smoothed versions of the "True" Analysis fields than were actually used in the experiments. Since the operational analysis grid for Surface Air Temperature is the 63 × 63 grid, Fig. 3-5 is an accurate presentation of the "True" Analysis for this parameter. Figure 3-7 is a plot of Sea Surface Temperature for most of the Atlantic using all of the 125 × 125 gridpoint values from the area.

3.2.4 Verification Areas

The analyses for each experiment were verified for the eight areas of the northern hemisphere listed in Table 3-2. The Atlantic and Pacific Oceans were divided into two areas to better evaluate the analysis results according to expected variability of the parameters.

Each verification area was a rectangular subset of the analysis grid. Figures 3-8 and 3-9 show these areas on two different map projections.

Table 3-2 lists the number of ocean gridpoints in each area for which the analyses were computed and verified. These are the analysis gridpoints as illustrated in Fig. 3-8, which shows the 63 x 63 grid used in the Surface Air Temperature experiment. Halving the grid interval in Fig. 3-8 produces the 125 × 125 grid, which was used in the Sea Level Pressure and Sea Surface Temperature experiments.

TABLE 3-2
VERIFICATION AREAS

Verification Area	Gridpoints in Area	
	Sea Level Pressure and Sea Surface Temperature	Surface Air Temperature
1. Northern Hemisphere	10,059	2,554
2. North Pacific Ocean	5,935	1,515
3. North Atlantic Ocean	847	223
4. Pacific High Variability	2,875	752
5. Pacific Low Variability	2,322	594
6. Atlantic High Variability	628	166
7. Atlantic Low Variability	1,513	382
8. Gulf of Mexico	102	29

3.2.5 Land and Island Data

The input data for each parameter analysis included appropriate error-free reports from land stations and islands. These data were generated by interpolating values from the previously defined "True" Analysis for all fixed stations for which data were actually received at the analysis center for 0000Z March 22, 1970. Table 3-8 in Section 3.3 lists the number of island and OSV observations included in each verification area. The same set of error-free data was used for each analysis of

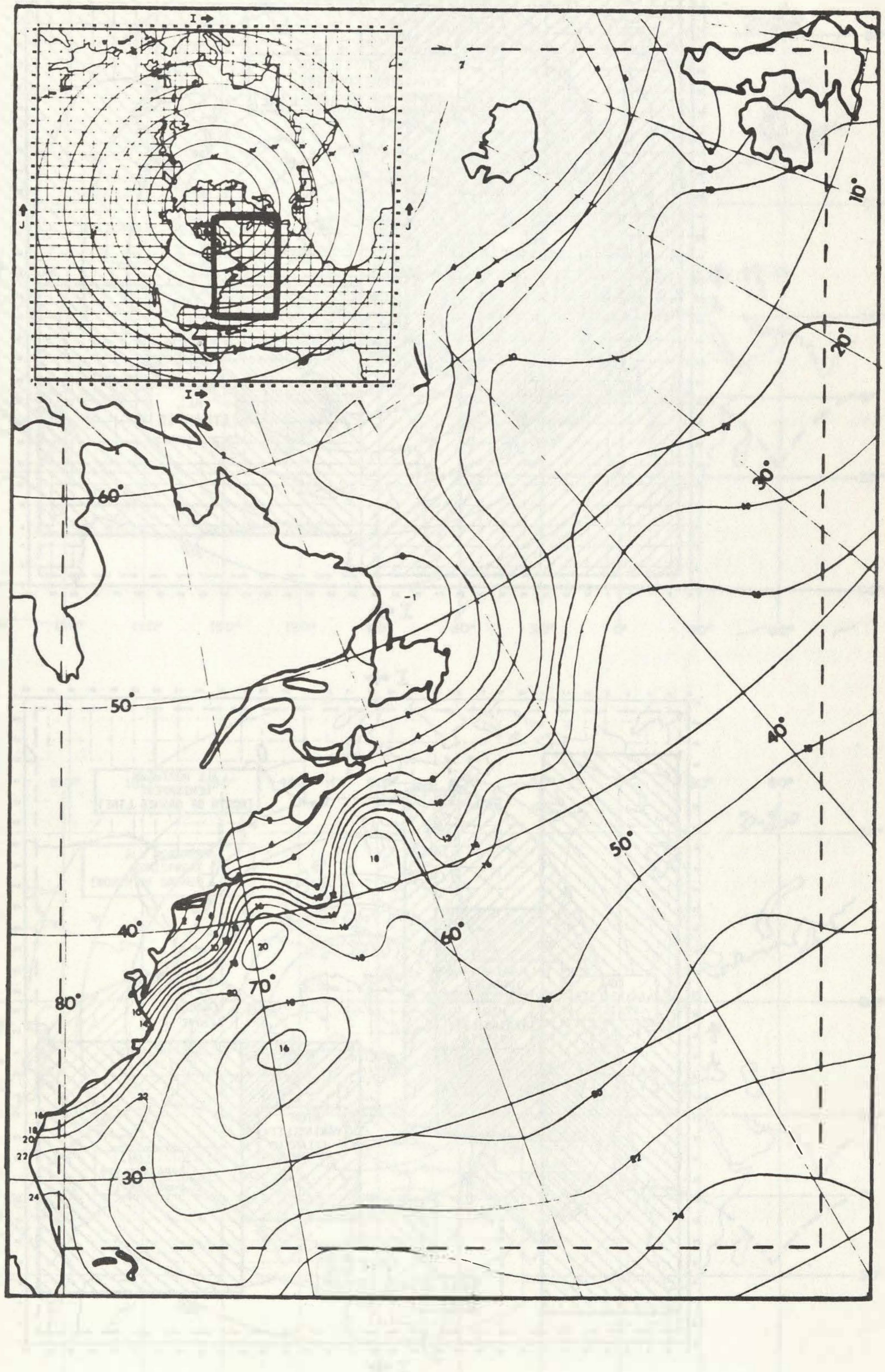


Fig. 3-7. Enlarged view of the Sea Surface Temperature analysis for the Atlantic High Variability area.

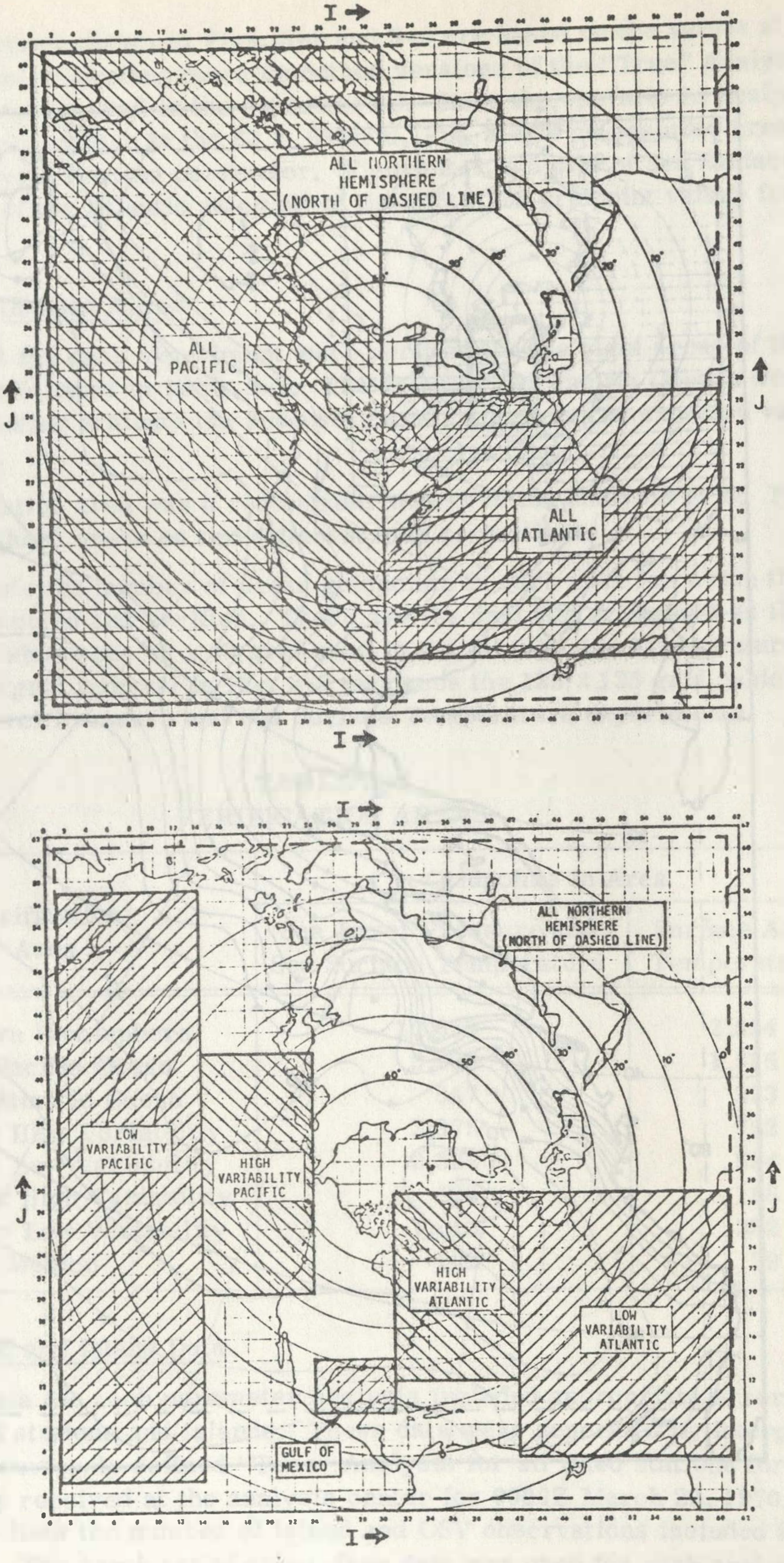


Fig. 3-8. Verification areas as defined by subset of the FNWC 125 x 125 grid (polar stereographic projection).

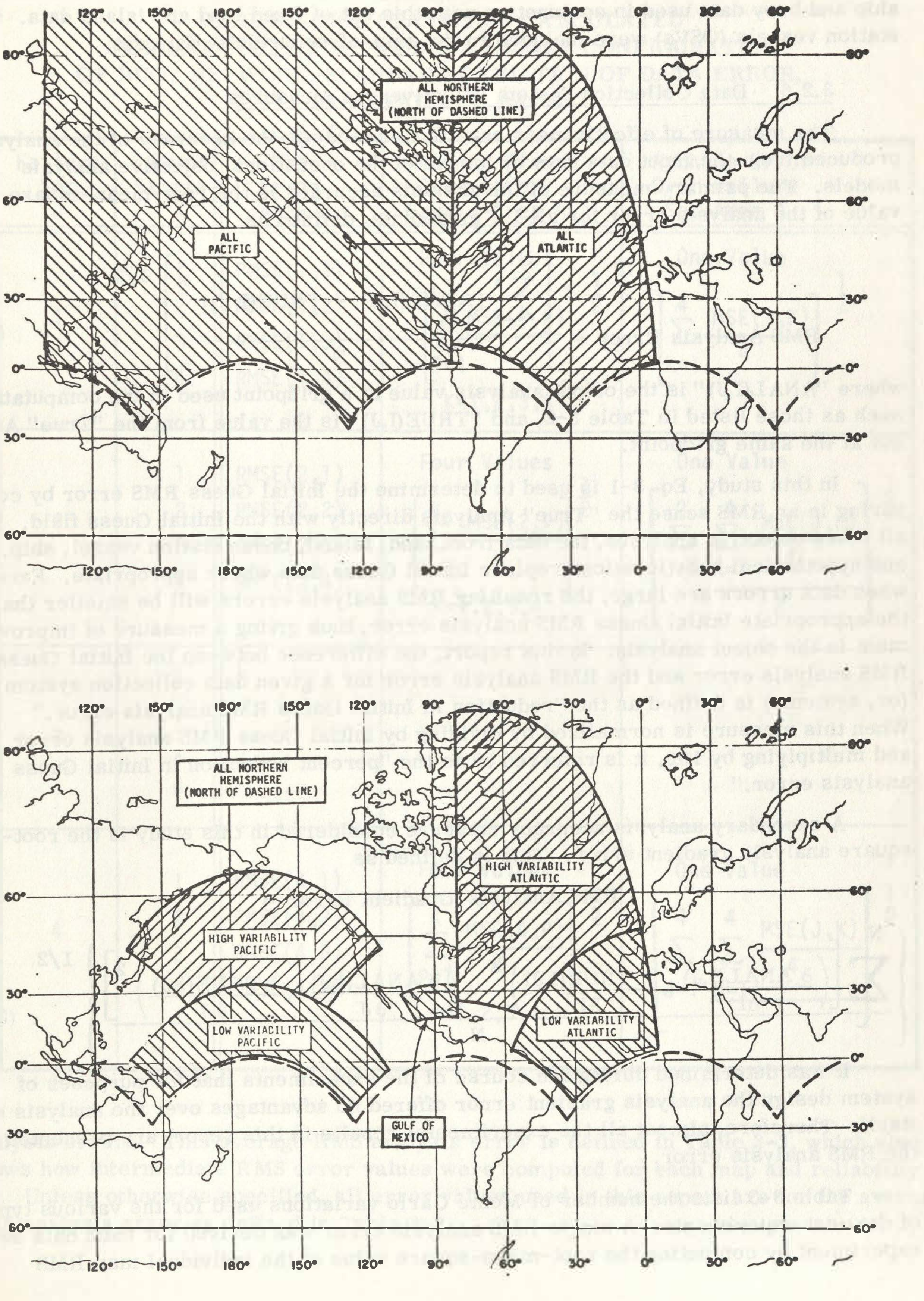


Fig. 3-9. Verification areas shown on a Mercator projection.

the parameter. Therefore, all variations in the analysis results can be ascribed to the ship and buoy data used in conjunction with this set of fixed land and island data. Ocean station vessels (OSVs) were included in the ship-of-opportunity data set.

3.2.6 Data Collection System Effectiveness Measures

The measure of effectiveness used in this study is the accuracy of the analysis produced from the input data sets by means of the operational objective analysis models. The primary measure of the analysis accuracy is the root-mean-square value of the analysis error for all I, J gridpoints, defined as

$$\text{RMS Analysis Error} = \left[\frac{\sum^{N} [\text{ANAL}(I,J) - \text{TRUE}(I,J)]^2}{N} \right]^{1/2} \qquad (3\text{-}1)$$

where "ANAL(I,J)" is the output analysis value at a gridpoint used in the computation such as those listed in Table 3-2, and "TRUE(I,J)" is the value from the "True" Analysis at the same gridpoint.

In this study, Eq. 3-1 is used to determine the Initial Guess RMS error by comparing in an RMS sense the "True" Analysis directly with the Initial Guess field. For all other objective analyses, the data from land, island, ocean station vessel, ship, and hypothetical buoy locations replace Initial Guess data where appropriate. Except when data errors are large, the resulting RMS analysis errors will be smaller than the appropriate Initial Guess RMS analysis error, thus giving a measure of improvement in the object analysis. In this report, the difference between the Initial Guess RMS analysis error and the RMS analysis error for a given data collection system (or, systems) is defined as the "reduction in Initial Guess RMS analysis error." When this measure is normalized by dividing by Initial Guess RMS analysis error and multiplying by 100, it is referred to as the "percent reduction in Initial Guess RMS analysis error."

A secondary analysis accuracy measure considered in this study is the root-mean-square analysis gradient error. This is defined as

RMS Analysis Gradient Error =

$$\left\{ \frac{\sum^{N} \left[\left(\frac{\partial\, \text{ANAL}(I,J)}{\partial I} - \frac{\partial\, \text{TRUE}(I,J)}{\partial I} \right)^2 + \left(\frac{\partial\, \text{ANAL}(I,J)}{\partial J} - \frac{\partial\, \text{TRUE}(I,J)}{\partial J} \right)^2 \right]}{N} \right\}^{1/2} \qquad (3\text{-}2)$$

It was determined during the course of the experiments that for purposes of system design the analysis gradient error offered no advantages over the analysis error itself. Therefore, almost all the experimental results in this report are presented for the RMS analysis error.

Table 3-3 lists the number of Monte Carlo variations used for the various types of data set experiments. A single RMS analysis error was derived for each data set experiment by computing the root-mean-square value of the individual map RMS

TABLE 3-3

VERIFICATION STATISTICS CALCULATED
FOR DATA SETS COMPRISING A UNIQUE CONFIGURATION
OF BUOY NETWORK, STANDARD DEVIATION OF DATA ERROR,
AND FAILURE RATE

Failure Set J	Error Sample K	Map Error Area A	Running Error Over Error Sample-Area A	Running Error Over Failure Set-Area A
1	1	RMSE(1,1)	Four Values	One Value
	2	RMSE(1,2)	$\left[\sum_{P=1}^{K} \frac{MSE(1,P)}{K}\right]^{\frac{1}{2}}$	$\left[\sum_{K=1}^{4} \frac{MSE(1,K)}{4}\right]^{\frac{1}{2}}$
	3	RMSE(1,3)		
	4	RMSE(1,4)	K=1,2,3,4	
2	1	RMSE(2,)	Four Values	One Value
	2	RMSE(2,2)	$\left[\sum_{P=1}^{K} \frac{MSE(2,P)}{K}\right]^{\frac{1}{2}}$	$\left[\frac{\sum_{J=1}^{2} \sum_{K=1}^{4} \frac{MSE(J,K)}{4}}{2}\right]^{\frac{1}{2}}$
	3	RMSE(2,3)		
	4	RMSE(2,4)	K=1,2,3,4	
3	1	.	.	.
	.	.	.	.
	.	.	.	.
	4	.	.	.
4	1	RMSE(4,1)	Four Values	One Value
	2	RMSE(4,2)	$\left[\sum_{P=1}^{K} \frac{MSE(4,P)}{K}\right]^{\frac{1}{2}}$	$\left[\frac{\sum_{J=1}^{4} \sum_{K=1}^{4} \frac{MSE(J,K)}{4}}{4}\right]^{\frac{1}{2}}$
	3	RMSE(4,3)		
	4	RMSE(4,4)	K=1,2,3,4	

analysis errors. This average RMS analysis error is defined in Table 3-3, which also shows how intermediate RMS error values were computed for each map and reliability set. Unless otherwise specified, all error values used in this report are for the average RMS analysis error as defined in Table 3-3.

3.3 Variable Elements of the Experiments

3.3.1 Data Buoy Networks

Ten buoy networks were defined at the start of the experiments. These ten networks had the following gross characteristics:

- 2 hemispheric networks with 600 buoys each,
- 2 hemispheric networks with 300 buoys each,
- 3 hemispheric networks with 150 buoys each, and
- 3 hemispheric networks with 76 buoys each.

The differences between networks with the same number of buoys was the spacing of the buoys as shown in Table 3-4. The ten networks are identified by the total number of buoys in the network and a modification letter; networks 150A, 150B, and 150C are the three variations of a hemispheric network of 150 buoys. From the ten networks, it was expected that the experimental results would indicate the more effective pattern for each fixed number of buoys. Experimental results indicated, however, that different distributions of the same number of buoys were not as critical as other system characteristics.

The buoy locations in the ten networks took into consideration the location of island stations and ocean station vessels; redundancy with probable locations for ship-of-opportunity reports were not considered. To account for the redundancy between the buoy locations and the most probable areas for ship-of-opportunity data, one network for each basic number of buoys (600, 300, 150 and 76) was modified to account for areas of probable ship-of-opportunity data. As a result of initial experiments with all ten networks, networks 600B, 300C, 150A and 76B were selected as preferred for all experiments. These four networks are shown in Figs. 3-10 through 3-13; the other six networks are shown in Appendix F. Figure 3-14 relates the number of data buoys to an average spacing between buoys in the four verification areas of primary interest.

Figures 3-10 through 3-13 show the buoy locations by three different symbols. The purpose of these symbols is to delineate areas of redundancy with probable ship-of-opportunity data. Section 3.3.5 describes how these networks were modified to reduce the buoy data redundancy with ship-of-opportunity data. Suffice to say, the buoy networks are defined by the complete set of circles and solid dots shown in Figs. 3-10 through 3-13.

3.3.2 Errors in Buoy Data

One aspect of the experiments was to determine the impact of errors in the simulated buoy data system. Error-free data were first obtained for each buoy location by interpolation from the "True" Analysis. This data set was then corrupted by adding a list of error values composed of random numbers with a specified Gaussian distribution. The resulting data set was then characterized by data system errors that have the standard deviation of the set of random numbers that were generated. Error fields with a standard deviation of 0.1, 0.5, 1.0, 2.0, 3.0, and 5.0 units were created and used in addition to the error-free data. To average out possible biases in the error fields, several Monte Carlo versions of each standard deviation of error were generated. For Sea Level Pressure, four error fields were used to derive a single analysis

TABLE 3-4
BUOY NETWORK CHARACTERISTICS

Net-work	Latitude Zone	Average Buoy Spacing (n mi)	No. of Buoys Atlantic	No. of Buoys Pacific	Total No. Buoys
600A	0°-30°N	300	66	167	
	30°N-45°N	200	90	143	
	45°N-60°N	140	54	80	600
600B*	0°-60°N	200	182	418	600
300A	0°-35°N	500	36	73	
	35°N-60°N	225	70	121	300
300C*	0°-60°N	300	89	211	300
150A*	0°-25°N	500	16	39	
	25°N-35°N	400	15	15	
	35°N-60°N	300	17	48	150
150B	0°-39°N	600	17	36	
	39°N-60°N	200	31	66	150
150C	0°-60°N	400	48	102	150
76A	0°-60°N	600	24	52	76
76B*	0°-36°N	700	13	32	
	36°N-60°N	300-400	10	21	76
76C	0°-30°N	500	15	46	
	30°N-60°N	600-800	3	12	76

*Networks used for all experiments.

score; for Surface Air Temperature and Sea Surface Temperature, three error fields were used. Section 3.4 presents details of the Monte Carlo procedures that were used.

Note
• For Redundancy Threshold = 100%, all circular buoy symbols are in the network.
• For Redundancy Threshold = 75%, open-circle buoys are eliminated.
• For Redundancy Threshold = 50%, open-circle and open-circle-with-dot buoys are eliminated.

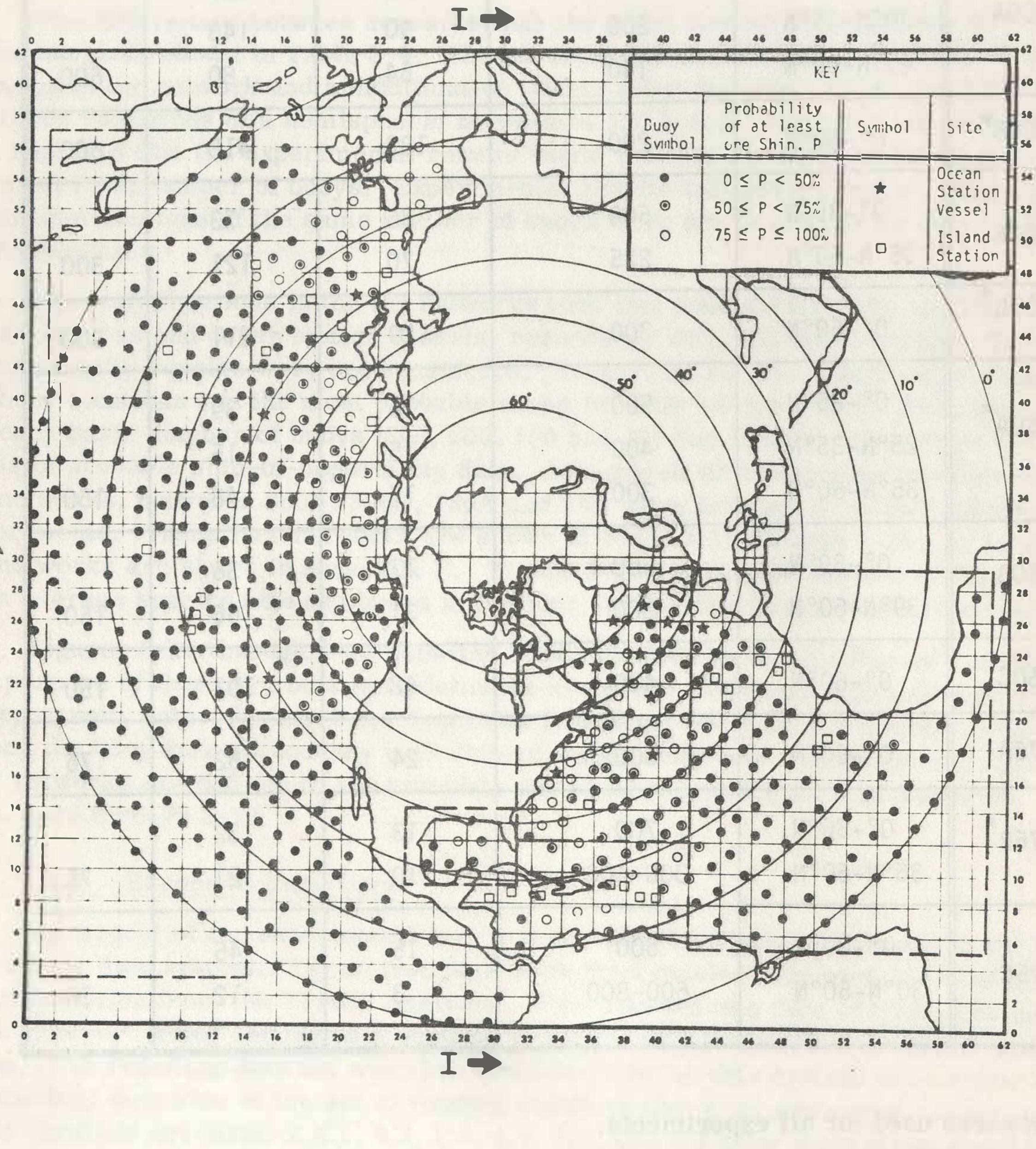


Fig. 3-10. Postulated buoy network 600B.

Note
• For Redundancy Threshold = 100%, all circular buoy symbols are in the network.
• For Redundancy Threshold = 75%, open-circle buoys are eliminated.
• For Redundancy Threshold = 50%, open-circle and open-circle-with-dot buoys are eliminated.

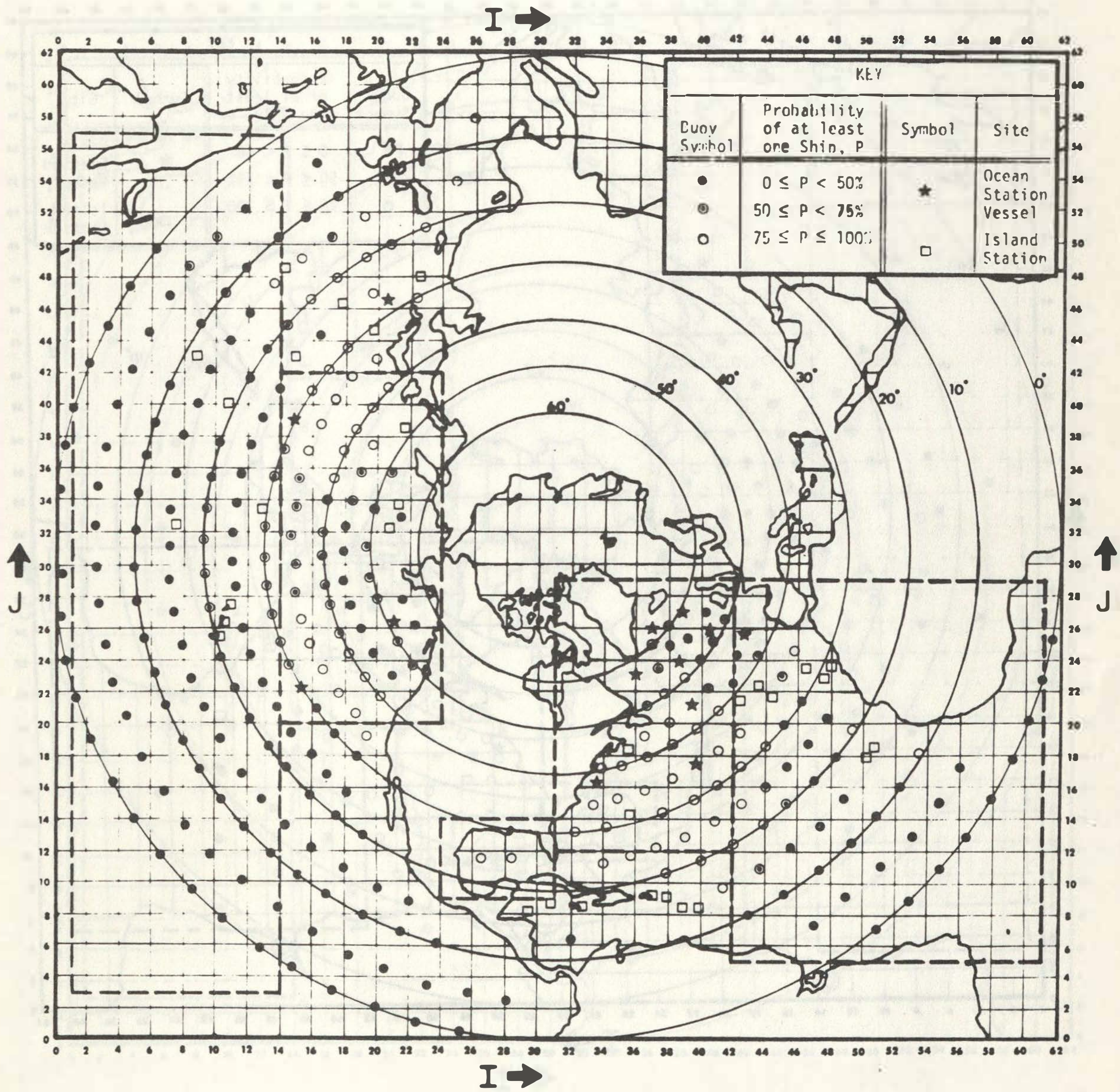


Fig. 3-11. Postulated buoy network 300C.

Note
• For Redundancy Threshold = 100%, all circular buoy symbols are in the network.
• For Redundancy Threshold = 75%, open-circle buoys are eliminated.
• For Redundancy Threshold = 50%, open-circle and open-circle-with-dot buoys are eliminated.

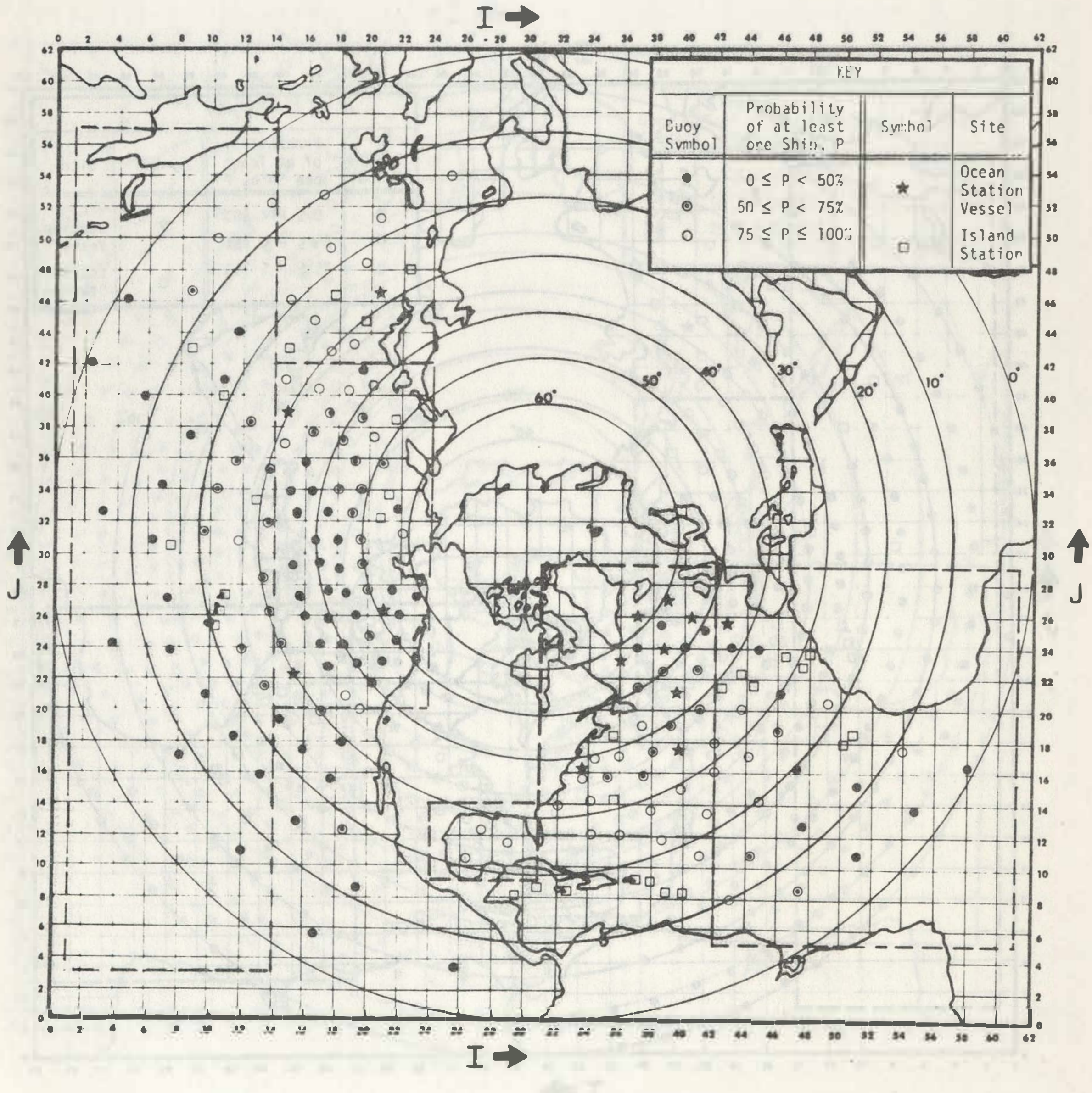


Fig. 3-12. Postulated buoy network 150A.

Note
• For Redundancy Threshold = 100%, all circular buoy symbols are in the network.
• For Redundancy Threshold = 75%, open-circle buoys are eliminated.
• For Redundancy Threshold = 50%, open-circle and open-circle-with-dot buoys are eliminated.

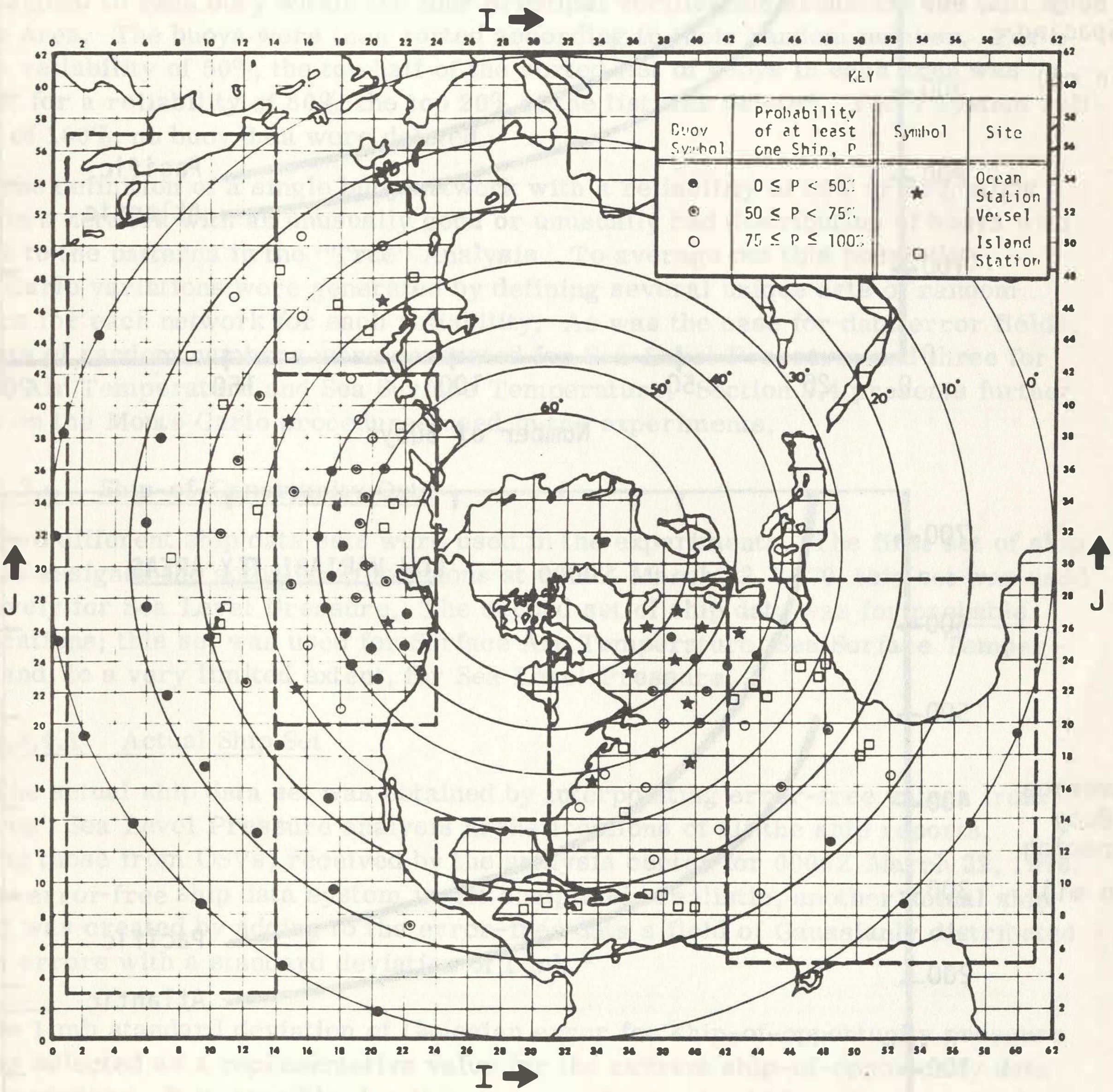
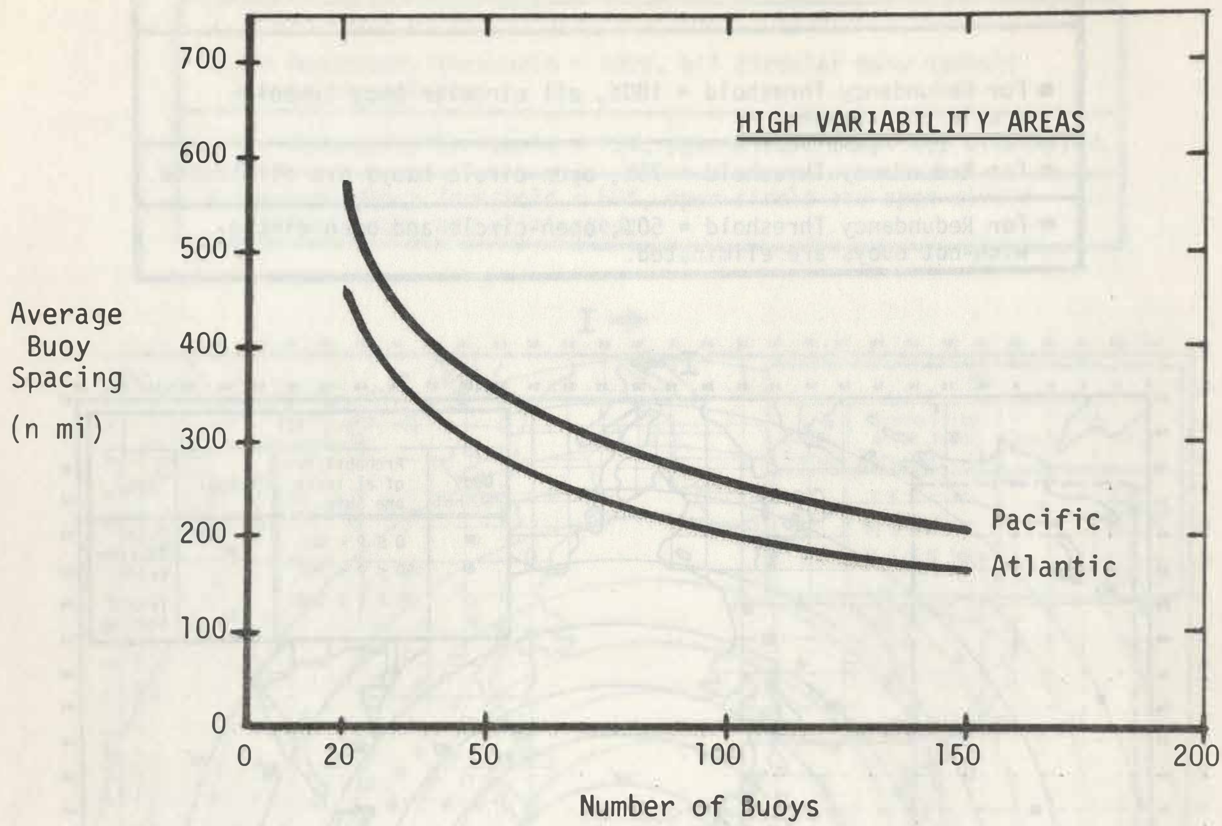


Fig. 3-13. Postulated buoy network 76B.



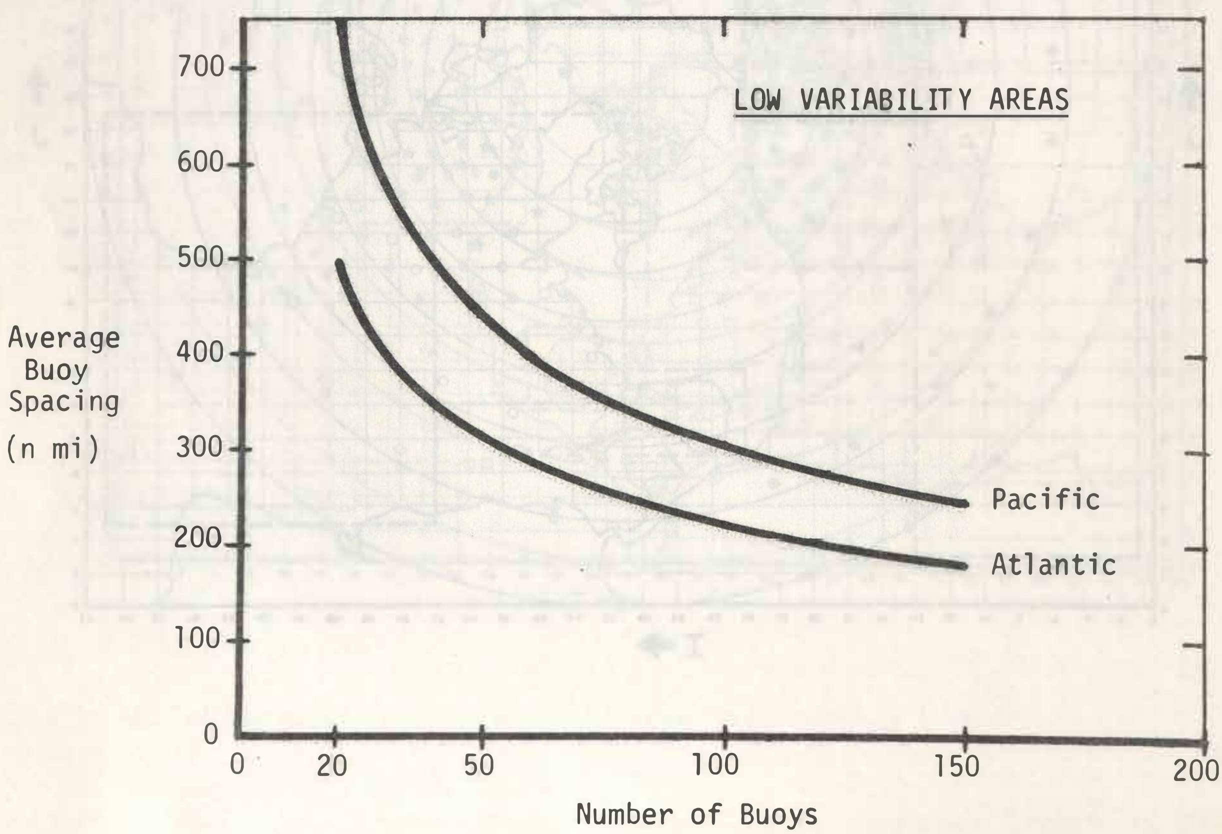


Fig. 3-14. Relationship of the number of uniformly spaced data buoys and the average distance between them.

3.3.3 Data Buoy System Reliability

The effect of reliability within an overall data buoy system was simulated. For the experiments conducted, reliability was defined as the percentage of the total data received from the data buoy network for the analysis. Failure to receive data from a particular buoy location is considered as a failure somewhere in the data system without regard to whether the failure was due to the sensor, platform, communications, etc.

The experiments used data buoy system reliability values of 100%, 80%, and 50%. To define a single buoy reliability network, a uniformly distributed random number was assigned to each buoy within the four principal verification areas and the Gulf of Mexico area. The buoys were then sorted according to their random number. For a system reliability of 50%, the top half of the sorted list of buoys in each area was deleted; for a reliability of 80%, the top 20% of the list was deleted. For a system reliability of 100%, no buoy data were deleted.

The definition of a single buoy network with a reliability of 80% or 50% might result in a network with an unusually good or unusually bad distribution of buoys with respect to the patterns in the "True" Analysis. To average out this possibility, Monte Carlo variations were generated by defining several unique sets of random numbers for each network for each reliability. As was the case for data error fields, four sets of random numbers were generated for Sea Level Pressure, and three for Surface Air Temperature and Sea Surface Temperature. Section 3.4 presents further details on the Monte Carlo procedures used in the experiments.

3.3.4 Ship-of-Opportunity Data

Two different ship data sets were used in the experiments. The first set of ship data was assigned the actual ship locations at 0000Z March 22, 1970; this set was used exclusively for Sea Level Pressure. The second set of ship data was for probable ship locations; this set was used for Surface Air Temperature, Sea Surface Temperature, and, to a very limited extent, for Sea Level Pressure.

3.3.4.1 Actual Ship Set

The actual ship data set was obtained by interpolating error-free values from the "True" Sea Level Pressure analysis at the locations of all the ship reports, including those from OSVs, received by the analysis center for 0000Z March 22, 1970. Since an error-free ship data system is not completely realistic, another actual ship data set was created by adding to the error-free data a field of Gaussianly distributed random errors with a standard deviation of 1 mb.*

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*The 1 mb standard deviation of Gaussian error for ship-of-opportunity pressure data was selected as a representative value for the current ship-of-opportunity data system accuracy. It is possible that this error estimate should have been revised upward, perhaps by a factor of 2. If the current ship-of-opportunity data system does have a representative error larger than 1 mb then the results presented will be overestimates of the effectiveness of ship data. If this is true, the effectiveness presented for buoy data when compared to ship data will be on the conservative side.

Ship locations at 0000Z on March 22, 1970, are shown in Fig. 3-15; Fig. 3-16 shows the locations of ships that reported 12 hours earlier. Multi-reports from the same location or area are shown as a single dot. The distribution of ship reports shown on these two plots is typical of the total number of ships that eventually report, and show that more reports are received from a region during daylight hours (1200Z in the Atlantic, 0000Z in the Pacific) than during the nighttime.

Table 3-5 gives statistics of the ship reports received at FNWC at various times after the synoptic hour. This table was compiled for the months of November and December 1970, and shows that the average total number of ship reports received within 6.5 hours is the same for the primary synoptic times of 0000Z and 1200Z. The larger number of ships reporting earlier for 0000Z is probably due to the fact that it is daylight in the Pacific Ocean, which normally has more ships reporting than does the Atlantic.

TABLE 3-5

AVERAGE NUMBER OF SHIP REPORTS RECEIVED AT FNWC, NOV-DEC 1970

Hours After Synoptic Period	Number of Ship Reports Received							
	0000Z		0600Z		1200Z		1800Z	
	Avg.	Stan. Dev.	Avg.	Stan. Dev.	Avg.	Stan. Dev.	Avg.	Stan. Dev.
0.5	24	—[1]	12	—	14	—	10	—
1.0	90	25	92	23	84	27	56	22
1.5	197	37	180	24	173	26	146	41
2.0	322		287		294		264	
2.5	397	39	331	36	344	47	327	40
3.5	503	—	398	—	468	—	411	—
4.0	538	27	441	38	496	51	451	50
6.5	586	—	447	—	586	—	437	—

[1] Dashes in the table indicate that statistical data were not available.

Note: Ships reporting in close proximity
are shown as a single dot.

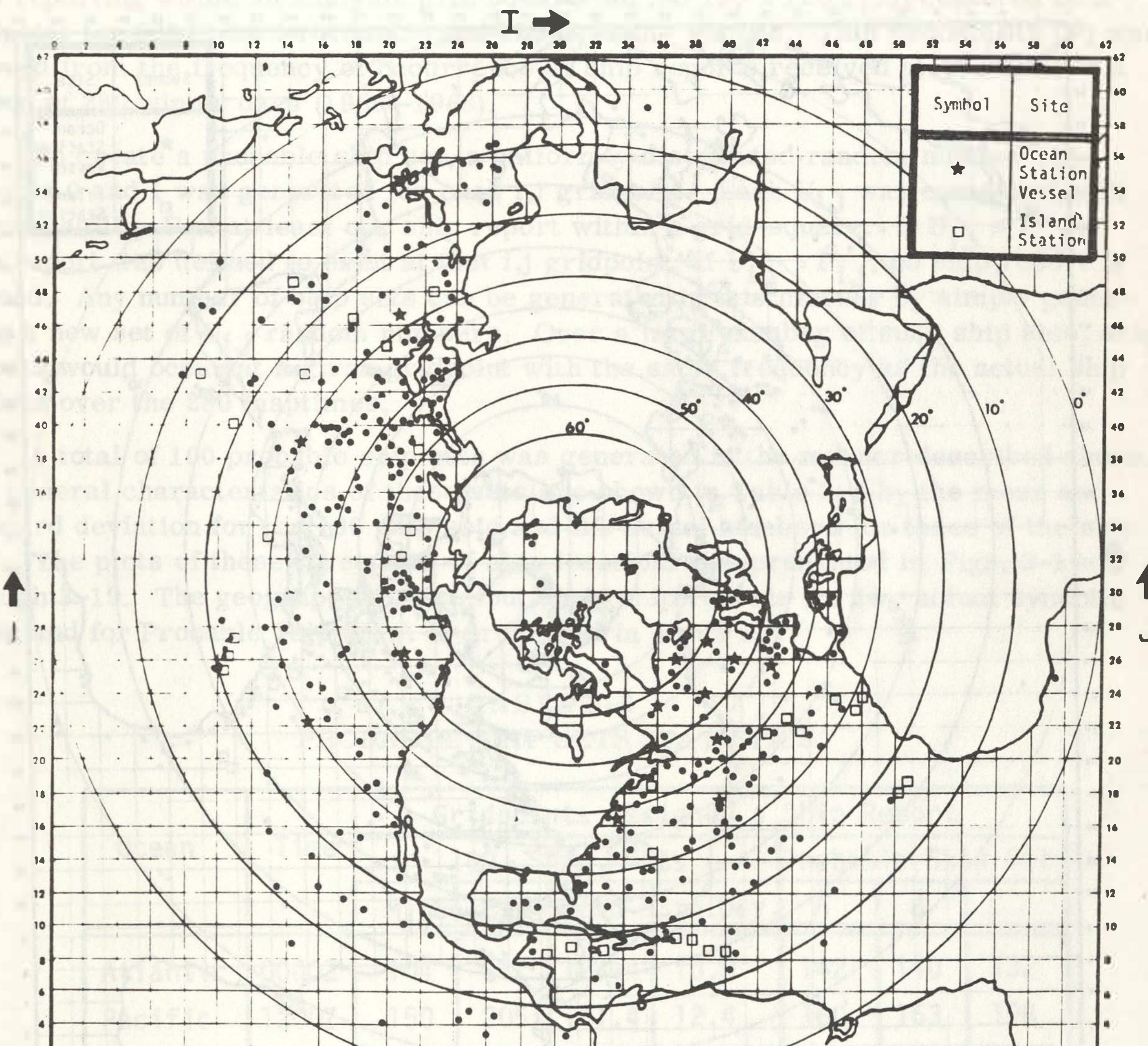

Fig. 3-15. Location of all ships reporting at 0000Z March 22, 1970.

Note: Ships reporting in close proximity
are shown as a single dot.

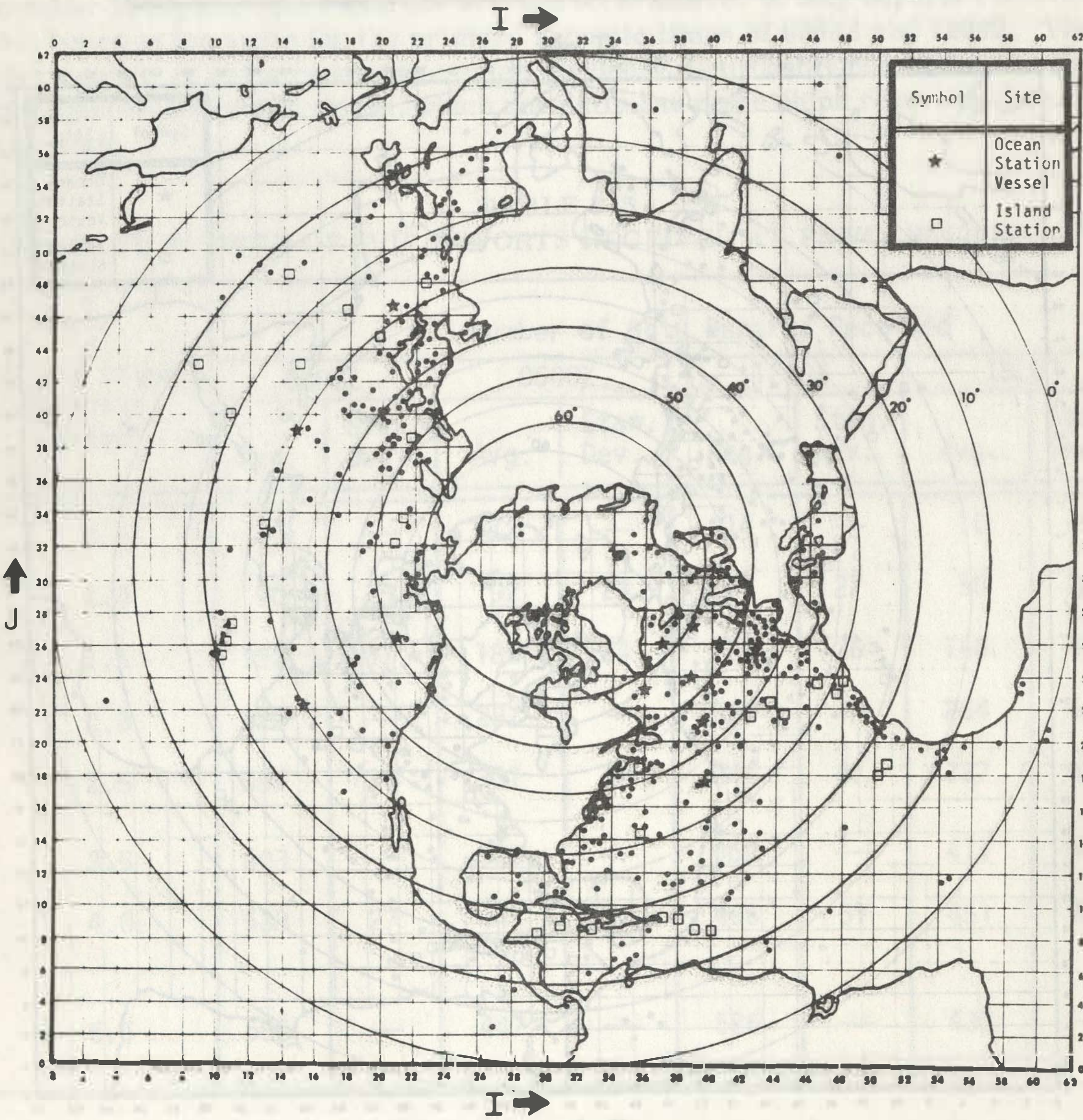

Fig. 3-16. Location of all ships reporting at 1200Z March 21, 1970.

3.3.4.2 Probable Ship Sets

During the study of ship-of-opportunity reports, it was noted that frequently more than one ship report occurred at, or near, the same location. This indicated either multiple reports from the same ship or reports from ships in close proximity. Therefore, a set of probable ship locations was determined [5] to eliminate the occurrence of multiple reports at a point and to be representative of the nighttime (worst) distribution of the ship reports.

Probable ship locations were computed by the probability of at least one ship ship reporting within an analysis grid square (on the 125 x 125 grid) centered on a gridpoint for 0000Z in the Atlantic and 1200Z in the Pacific. This probability (P) was derived from the frequency of occurrence of ship reports received at FNWC over a period of 280 winter days (1966—1968).

To create a probable ship set, a uniformly distributed random number (U) between 0 and 1 was generated for each i,j gridpoint. Each $U_{i,j}$ was compared with the probability P of at least one ship report within a grid-square. If $U_{i,j} \leq P_{i,j}$ a ship report was defined to exist at that i,j gridpoint; if $U_{i,j} > P_{i,j}$, no ship report is defined. Any number of ship sets can be generated in this manner by simply generating a new set of $U_{i,j}$ random numbers. Over a large number of such ship sets, ship reports would occur at a given gridpoint with the same frequency as the actual ship reports over the 280 maptimes.

A total of 100 probable ship sets was generated in the manner described above. The general characteristics of these sets are shown in Table 3-6 by the mean and standard deviation for the 100 ship sets and the actual numbers for three of the ship sets. The plots of these three sets of ship locations are presented in Figs. 3-17 through 3-19. The geographical distribution of ship reports for two actual synoptic times and for Probable Ship Set A is presented in Table 3-7.

TABLE 3-6
PROBABLE SHIP SETS STATISTICS

Ocean	Time	Gridpoints Assigned a Ship Report						
		100 Ship Sets				Probable Ship Set		
		Min	Max	Mean	Std.Dev.	A	B	C
Atlantic	0000Z	104	152	128.4	10.0	142	140	132
Pacific	1200Z	150	205	171.4	12.4	160	163	198
Total	-	-	-	299.8	-	302	303	330

Probable Ship Set A, the 100th ship set generated, was used for the locations of ship-of-opportunity reports for Surface Air Temperature and Sea Surface Temperature. Error-free ship data values were obtained for these locations from the "True" Analysis. Gaussian random errors with a standard deviation of 1°C were added to the error-free data for both parameters to create a more realistic set of ships-of-opportunity data.

Note: Ship locations used were for 0000Z in the Atlantic, and 1200Z in the Pacific.

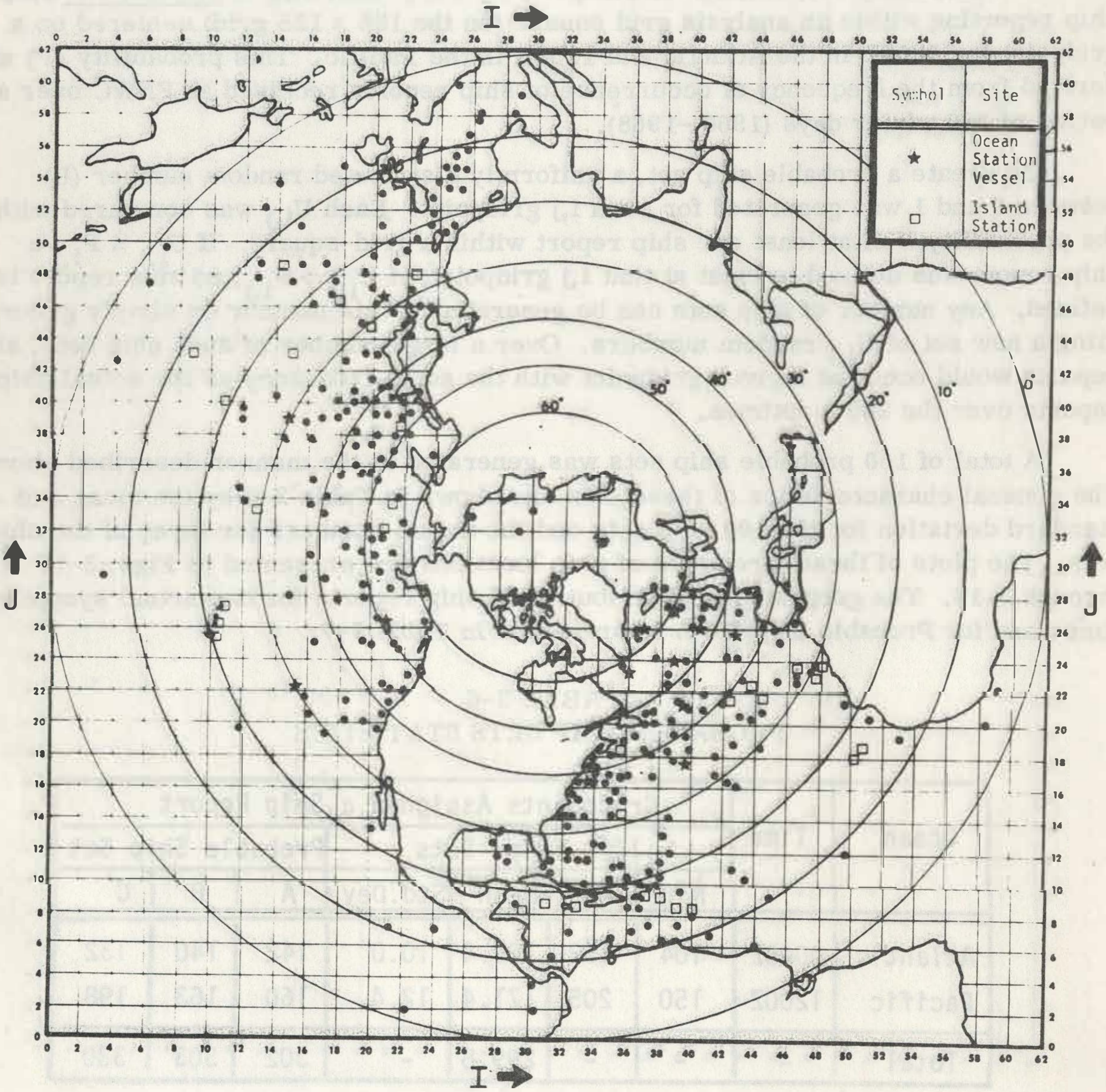

Fig. 3-17. Probable Ship Set A.

Note: Ship locations used were for 0000Z in the Atlantic, and 1200Z in the Pacific.

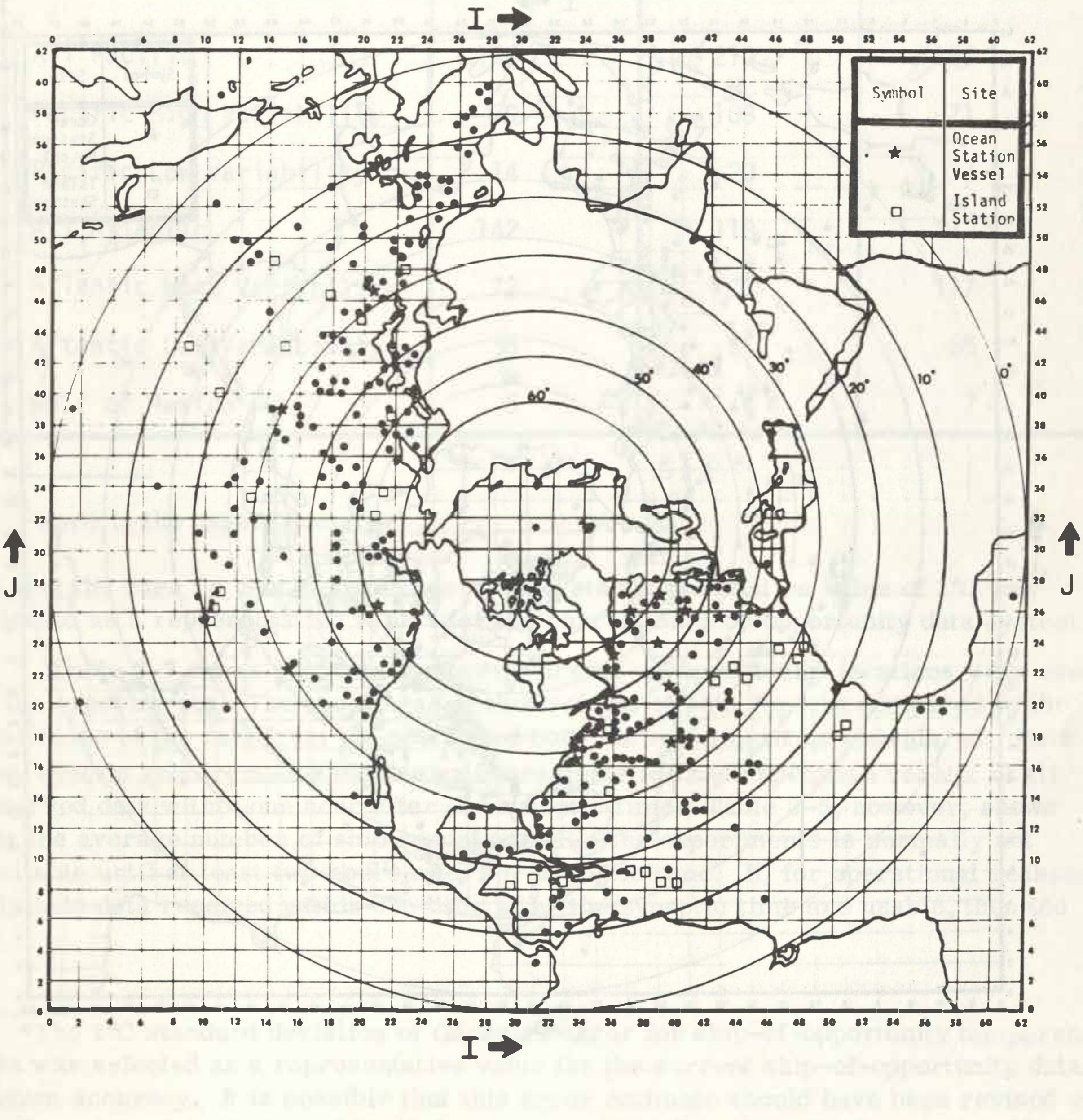

Fig. 3-18. Probable Ship Set B.

Note: Ship locations used were for 0000Z in the Atlantic, and 1200Z in the Pacific.

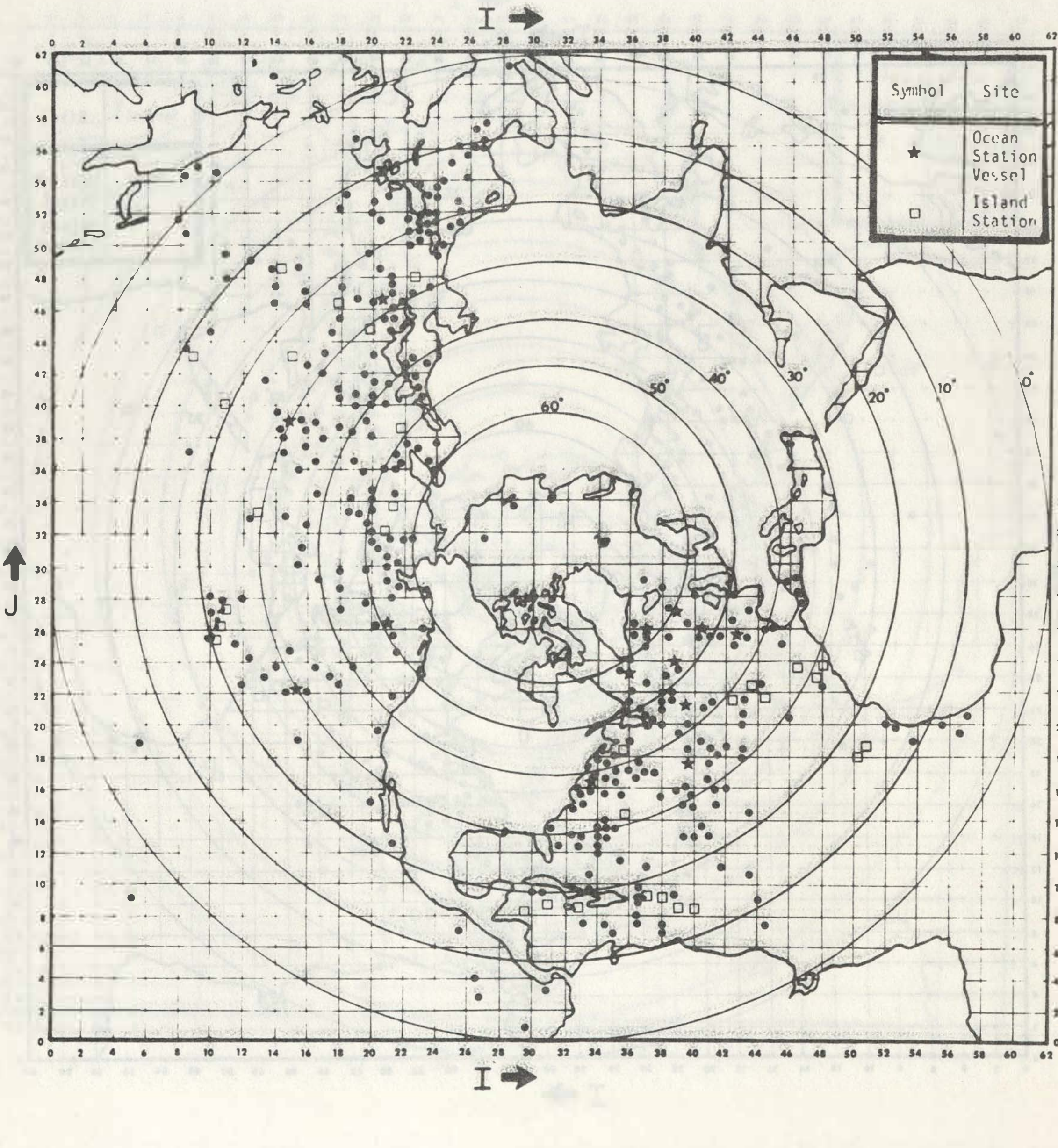

Fig. 3-19. Probable Ship Set C.

TABLE 3-7
GEOGRAPHICAL DISTRIBUTION OF SHIP REPORTS
(Number of Reports)

Verification Area	Probable Ship Set A	Actual Ship Reports 0000Z March 22,1970[1]	Actual Ship Reports 1200Z March 21,1970
Northern Hemisphere	302	348	406
All Pacific	160	210	152
Pacific High Variability	79	108	71
Pacific Low Variability	14	20	11
All Atlantic	142	118	213
Atlantic High Variability	72	72	117
Altantic Low Variability	36	31	86
Gulf of Mexico	5	6	7

[1] Used in the experiments.

As was the case for Sea Level Pressure, the standard deviation value of 1°C was selected as a representative value* for the current ship-of-opportunity data system.

Table 3-7 shows that data for over 300 ship-of-opportunity locations were used in the experiments. The timeliness of this volume of ship reports compared to the timeliness of the data from the postulated buoy networks must be considered. Data buoy system requirements and design characteristics have specified receipt of all observed data within one hour after the synoptic time. Table 3-5, however, shows that the average number of ship reports used in the experiments is normally not available until at least two hours after the synoptic time. If, for operational reasons, only ship data received within one hour after the synoptic time are usable, then too

*The 1°C standard deviation of Gaussian error for ship-of-opportunity temperature data was selected as a representative value for the current ship-of-opportunity data system accuracy. It is possible that this error estimate should have been revised upward, perhaps by a factor of 2. If the current ship-of-opportunity data system does have a representative error larger than 1°C then the results presented will be overestimates of the effectiveness of ship data. If this is true, the effectiveness presented for buoy data when compared to ship data will be on the conservative side.

many ships have been assumed for the ship data sets. A reduction in the number of ship reports used would cause an undetermined decrease in the effectiveness of ship data when compared to the effectiveness of data buoys.

3.3.5 Redundancy of Ships-of-Opportunity and Data Buoys

Initial experimental results indicated considerable redundancy between some of the data buoys and ship-of-opportunity reports. To reduce this redundancy, four of the original ten networks were modified to eliminate buoys in those areas in which ships-of-opportunity data were most probable.

From the probability of ship report computations outlined in the previous section, it was possible to draw isopleths to show those areas where the probability of a ship report was 75% or more and 50% or more (see Appendix G). Since each network had a different gridpoint spacing, the probability pattern was slightly different for each network.* Redundancy threshold (RT) levels of 75% and 50% were selected as the criteria for removing buoys from the original network configurations. For the RT = 75% network, buoys were deleted from those locations where the probability of at least one ship report was 75% or more. Another network was derived by eliminating buoys where the probability of at least one ship report was 50% or greater. Table 3-8 lists the number of buoys in each network for the three Redundancy Threshold values. The definition of redundancy threshold networks is illustrated in Fig. 3-26. The upper left corner of Fig. 3-20 shows the Pacific High Variability area on the FNWC grid. Superimposed above the grid are the probability contours for ship reports for the 150A buoy network. Note that the probabilities range from less than 50% to over 75% for this area. The bottom left plot in Fig. 3-26 shows the locations of all the buoys in this area for the 150A network. This plot corresponds to a redundancy threshold of 100%, since no buoys have been removed. The RT = 75% plot shows the same network after all buoys within the equal to or greater than 75% contour have been removed. The bottom right plot shows the RT = 50% buoy locations, where the only buoys remaining are in areas where the probability of a ship report is less than 50%.

Figure 3-20 also shows a plot of the actual ship set of 0000Z March 22, 1970, and the probable ship set that was used. These maps are shown here to illustrate how ships-of-opportunity are expected to provide data from those areas where buoys were removed. The reader is cautioned not to confuse the ship probability contours with an actual probable ship position plot. The probability contours in Fig. 3-20 were derived from 280 days of data whereas the plots shown are for a single maptime and probability set. Similarly, the buoy locations are independent of the ship locations for a single maptime since the buoys were removed for a Redundancy Threshold by means of the probability of receiving at least one ship report within a specified area derived from 280 winter days of data.

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*A detailed description of how the four buoy networks were modified to reduce buoy-ship redundancy is given in Reference 5, which is on file at the NDBC.

TABLE 3-8

DATA POINTS PER VERIFICATION AREA

Area	Island Stns.	Number of Ships			Redun. Thresh-old	Buoys Per Network			
		OSVs	Actual Ships	Probable Ships		600B	300C	150A	76B
Northern Hemisphere	32	13	348	342	100% 75 50	600 542 434	300 224 172	150 125 66	76 58 37
All Pacific	15	4	210	160	100% 75 50	423 397 345	212 176 136	104 81 54	53 44 30
High Variability Pacific	3	3	108	79	100% 75 50	111 98 65	54 33 11	53 45 27	26 19 12
Low Variability Pacific	7	0	20	14	100% 75 50	206 206 205	107 103 89	31 28 17	18 18 14
All Atlantic	17	9	118	142	100% 75 50	177 145 89	88 48 36	46 24 12	23 14 7
High Variability Atlantic	2	8	72	72	100% 75 50	67 44 8	37 12 5	25 12 3	12 7 2
Low Variability Atlantic	8	1	31	36	100% 75 50	96 95 81	47 38 33	20 12 9	11 8 6
Gulf of Mexico	0	0	6	5	100% 75 50	6 5 3	3 0 0	3 0 0	0 0 0

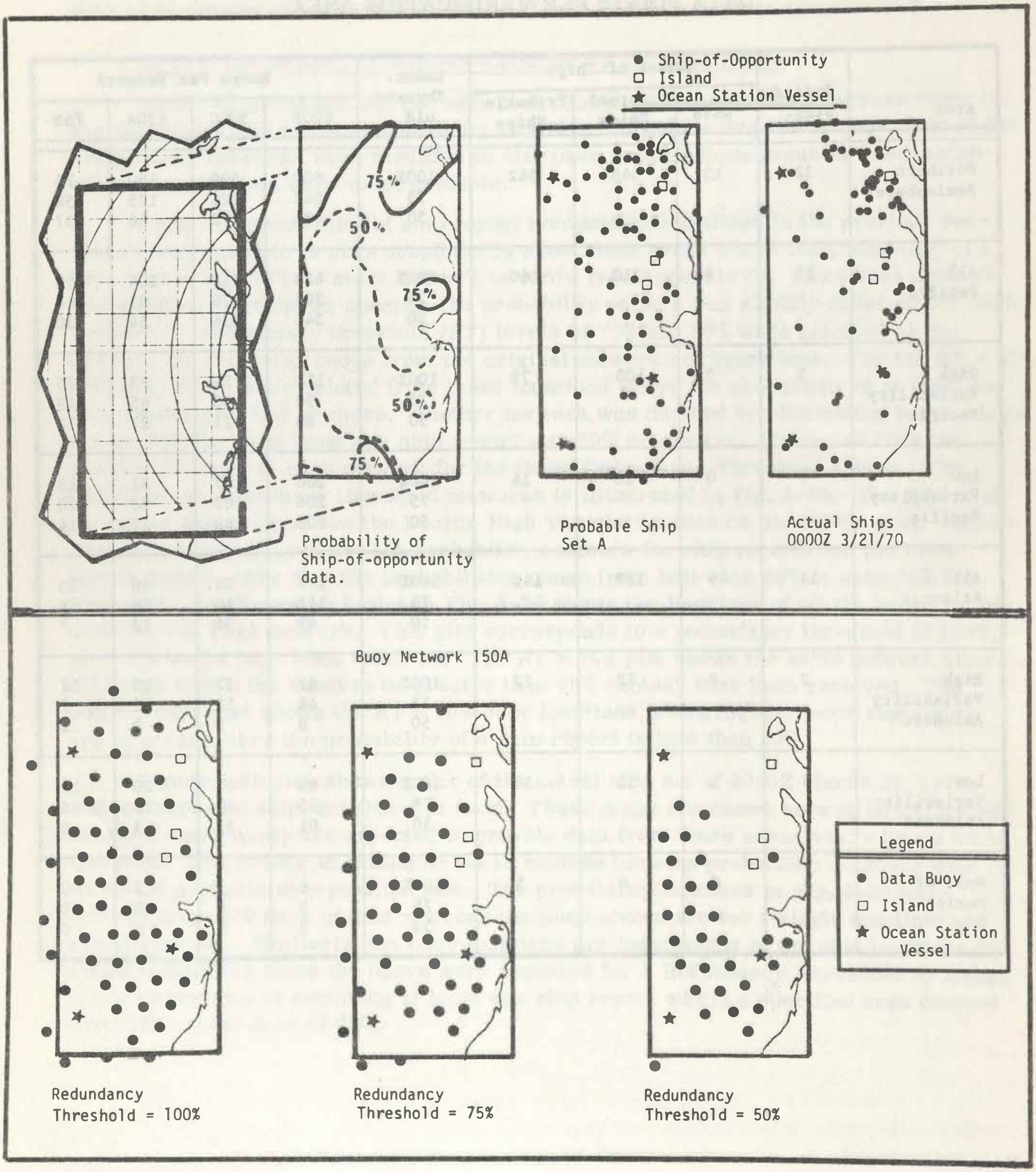


Fig. 3-20. Derivations of the 150A Redundancy Threshold networks for the Pacific High Variability area.

3.4 Monte Carlo Experiment Procedures

To study the impact of buoy data system accuracy and reliability it was necessary to simulate data with the appropriate system characteristics. The effect of any biases present in a particular set of simulated data was reduced by using a number of Monte Carlo variations in the input data for each experiment.

Results of the pilot model study [6] conducted prior to production analyses indicated a fairly small number of Monte Carlo runs would be required to obtain reasonably stable statistics. Table 3-9 lists the number of Monte Carlo runs selected for each error and reliability value.

TABLE 3-9
MONTE CARLO VARIATIONS IN SIMULATED DATA

Data Frror Standard Deviation	Data System Reliability	Monte Carlo Runs For Each Error Value	Monte Carlo Runs For Each Reliability	Total Data Sets
Sea Level Pressure*				
0.0 mb	100%	1	1	1
	80	1	4	4
	50	1	4	4
0.5, 1.0, 2.0, and 5.0 mb	100	4	1	4
	80	4	4	16
	50	4	4	16
Surface Air Temperature and Sea Surface Temperature				
0.0°C	100%	1	1	1
	80	1	3	3
	50	1	3	3
0.5, 1.0, and 3.0°C	100	3	1	3
	80	3	3	9
	50	3	3	9

*A limited number of experiments were also conducted for pressure with three variation fields, as shown for the temperature parameters.

Obviously, for error-free data and all buoys reporting, only one set of data is required. For Sea Level Pressure, four sets of data were normally prepared for each data error value. Each of these error fields was applied to four independent reliability fields, when the system reliability was less than 100%. The same approach was applied to the temperature parameters except that three error and three reliability variations were used instead of four. These numbers (three and four) were chosen as the minimum number of Monte Carlo runs that could be used and still obtain representative results. Figure 3-21 shows the progression of the average RMS analysis error for a Sea Surface Temperature experiment. For this example, the average RMS analysis error has stabilized within 0.02°C.

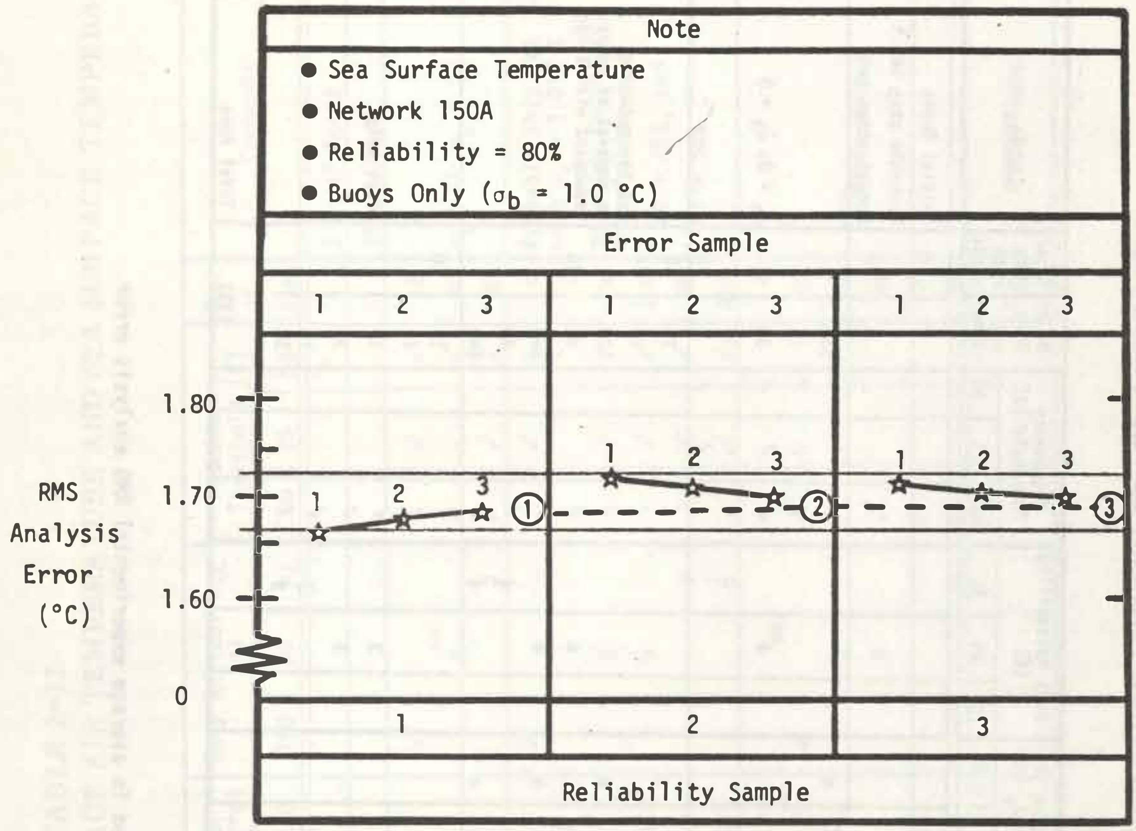
The last column in Table 3-9 shows the total number of input data sets that were used in each type of experiment (the number of data sets is the number of maps analyzed to produce an average experiment score). Table 3-9 shows all the variations in input data sets that were used. The numbers in the elements of Tables 3-10 and 3-11 are the number of Monte Carlo runs that were used for each data system accuracy and reliability. In the Sea Level Pressure experiment four Monte Carlo runs were made for most buoy data error sets and most buoy reliability sets. In a few cases only three runs were made. In the Surface Air Temperature and Sea Surface Temperature experiments, three Monte Carlo runs were made for each buoy data error set and three runs for each buoy reliability set. The last column in Tables 3-10 and 3-11 lists the total number of maps that were analyzed considering all the variations in buoy system accuracy, reliability, and ship-buoy redundancy.

3.5 Idealized Analysis Error Curves

Two idealized RMS analysis error curves are shown in Fig. 3-22. Curve A shows expected results if both the Initial Guess and the Analysis Model were constantly optimized to the available data density. Curve B shows a typical buoys-only result in this study in which both the Initial Guess and the Analysis Model were held fixed over the entire range of data density. For simplicity, all data are assumed to be error-free and uniformly distributed throughout a region.

Curve A at zero data density starts at the no-data Initial Guess RMS analysis error. The Initial Guess might have been obtained from climatology or from whatever prior knowledge one has about the environment. As the availability of the data increases over time, the ability to generate a better Initial Guess is improved, and the Analysis Model is changed to take advantage of the new data density. The RMS analysis error for this new Initial Guess capability is shown as Curve A. The new Initial Guess error on the ordinate (a function of data density) is connected with an arbitrary Point D by a dashed line. Curve A achieves zero error when the data density provides one observation for every grid point. At this density, the Analysis Model does nothing whatsoever to the data, i.e., there is no need for "smoothing" in the model, because there is accurate data available at every grid point. Therefore, the Initial Guess exerts no influence on the final analysis, because all Initial Guess values are replaced by data values.

Curve B at zero density starts at the ships-only, Initial Guess error, an unrealistically low value for zero data. As the data density increases, both the Initial Guess and the Analysis Model are held fixed. Curve B intersects Curve A at a point that corresponds approximately to the ships-only data density and analysis error. At this point, the Initial Guess for both curves is the ships-only Initial Guess. For larger data densities, Curve B lies above Curve A, primarily because the Analysis Model is not optimal, but also because the Initial Guess has too large an error for the data density. However, the influence of the Initial Guess on the final analysis rapidly diminishes with



$\overset{n}{☆}$ Average RMS Analysis Error for n error samples.

① Average RMS Analysis Error for first reliability sample.

② Average RMS Analysis Error for first two reliability samples.

③ Average RMS Analysis Error for all three reliability samples.

Fig. 3-21. Example of the derivation of an average RMS analysis error.

TABLE 3-10
MONTE CARLO DATA SETS ANALYZED FOR SEA LEVEL PRESSURE

Actual Ships	Prob Ship Set A	σ_s* (mb)	Basic Buoy Networks				Other Six Buoy Networks	Standard Deviation of Buoy Data Error, σ_b (mb)					Buoy Reliability (%)			Redundancy Threshold (%)			No. of Runs w/o Winds	No. of Runs with Winds	Comments
			600B	300C	150A	76B		0	0.5	1.0	2.0	5.0	100	80	50	100	75	50			
																			1		Initial Guess
	✓	1.0																	1		Probable ship Set A
✓		1.0																	1		Actual ships only
✓		1.0	✓	✓	✓	✓	✓		4**	4	4	4	✓						160		
✓		0.0	✓	✓	✓	✓		✓					✓			✓	✓	✓	12		
✓		0.0	✓	✓	✓	✓		✓						3**		✓	✓	✓	36		$\sigma_s = 0$; $\sigma_b = 0$
✓		0.0	✓	✓	✓	✓		✓							3	✓	✓	✓	36		
	✓	1.0	✓	✓	✓	✓		✓					✓				✓	✓	8	8	
✓		1.0	✓	✓	✓	✓	✓	✓					✓			✓			10	10	
✓		1.0	✓	✓	✓	✓	✓	✓					✓			✓			10	10	
✓		1.0	✓	✓	✓	✓	✓		4	4	4	4	✓			✓			160		All ten networks; no removal of buoys redundant with ships.
✓		1.0	✓	✓	✓	✓	✓	✓						4		✓			40	40	
✓		1.0	✓	✓	✓	✓	✓		4	4	4	4		4		✓			640		
✓		1.0	✓	✓	✓	✓	✓	✓							4	✓			40		
✓		1.0	✓	✓	✓	✓	✓		4	4	4	4			4	✓			640		
			✓	✓	✓	✓		✓					✓			✓			10	10	
			✓	✓	✓	✓				3			✓			✓			12		
			✓	✓	✓	✓		✓						3		✓			12		Buoys only
			✓	✓	✓	✓				3				3		✓			36		
			✓	✓	✓	✓		✓							3	✓			12		
			✓	✓	✓	✓				3					3	✓			36		
																			1991		Total Runs

* Standard deviation of ship data error.

** Monte Carlo variations of specified condition included in average experimental RMS analysis error.

TABLE 3-11
MONTE CARLO DATA SETS ANALYZED FOR SURFACE AIR TEMPERATURE AND SEA SURFACE TEMPERATURE

Prob Ship Set A	σ_s* (°C)	Buoy Network				Standard Deviation of Buoy Data Error, σ_b(°C)				Buoy Reliability (%)			Redundancy Threshold (%)			No. of Runs	Comments
		600B	300C	150A	76B	0	0.5	1.0	3.0	100	80	50	100	75	50		
																1	Initial Guess
✓	1.0															1	Ships Only
✓	0	✓	✓	✓	✓	✓				✓			✓	✓	✓	12	
✓	0	✓	✓	✓	✓	✓					3**		✓	✓	✓	36	$\sigma_s = 0$; $\sigma_b = 0$
✓	0	✓	✓	✓	✓	✓						3	✓	✓	✓	36	
✓	1.0	✓	✓	✓	✓	✓				✓				✓	✓	8	Probable Ship Set A with σ_s = 1.0°C & only two Redundancy Thresholds: RT = 75%, and RT = 50%
✓	1.0	✓	✓	✓	✓		3**	3	3							72	
✓	1.0	✓	✓	✓	✓	✓					3			✓	✓	24	
✓	1.0	✓	✓	✓	✓		3	3	3		3			✓	✓	216	
✓	1.0	✓	✓	✓	✓	✓						3		✓	✓	24	
✓	1.0	✓	✓	✓	✓		3	3	3			3		✓	✓	216	
		✓	✓	✓	✓	✓							✓			4	Buoys Only
		✓	✓	✓	✓			3		✓			✓			12	
		✓	✓	✓	✓	✓					3		✓			12	
		✓	✓	✓	✓			3			3		✓			36	
		✓	✓	✓	✓	✓						3	✓			12	
		✓	✓	✓	✓			3				3	✓			36	
																758	Total Runs

* Standard deviation of ship data error.

** Monte Carlo variations of specified condition included in average experimental RMS analysis error.

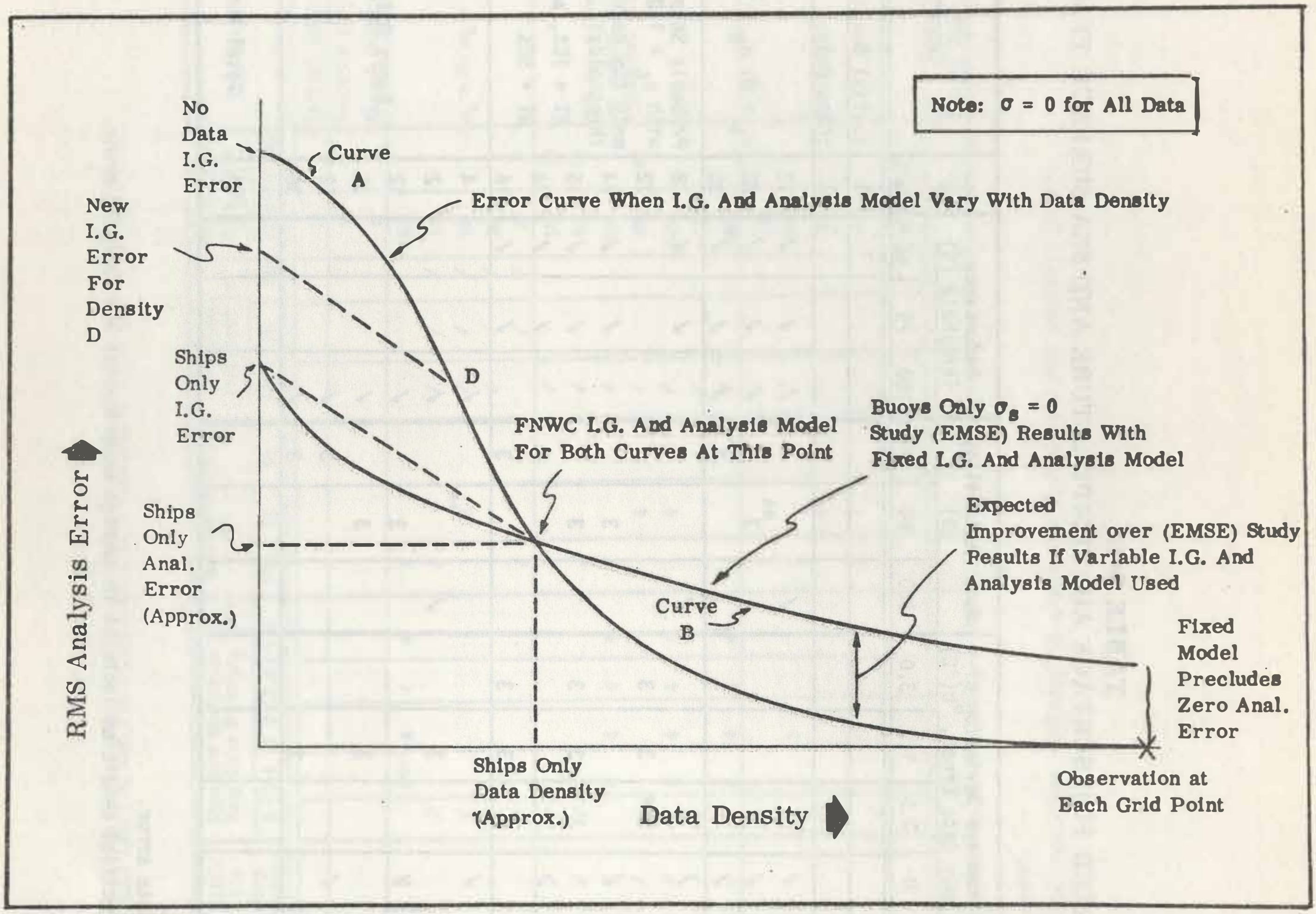


Fig. 3-22. Idealized RMS analysis error curves.

increasing data density. At maximum data density, Curve B is non-zero, because the analysis model has not been modified to take advantage of the available data, i.e., it still contains a "smoothing" operator.

Curve A represents what could be done with the data in an operational system where time and resources were available to optimize the Analysis Model and Initial Guess generation procedures. Curve B represents what was done in this study within the project constraints of time and resources, although the exact impact of "smoothing" in the analysis models was not explicitly determined.

From Fig. 3-22, it is seen that the study results for data densities less than the ships-only density tend to underestimate the analysis error and for data densities greater than ships-only density tend to overestimate the analysis error. Thus, all the results with buoy-ship networks and with buoys-only networks where the data density is greater than ships-only should be interpreted as upper bounds. The actual operational analysis errors can be expected to be less than these errors and, therefore, the buoy effectiveness should show a corresponding increase.

4.0 RESULTS OF THE SEA LEVEL PRESSURE EXPERIMENT

4.1 Overview of the Experiment

The Sea Level Pressure (SLP) experiment was the first in a series of three experiments conducted. Initially, data for ten global networks of data buoy locations were prepared. Simultaneously, the "True" Analysis was prepared, based on sea level pressure data for the synoptic time 0000Z March 22, 1971, which was provided by the analysis center. Modifications were made in the data to introduce a tropical cyclone in the western Pacific, sharpen frontal systems and tighten gradients. Other appropriate data provided by the analysis center were used to prepare an Initial Guess field of data which was commensurate with the "True" Analysis.

Once the "True" Analysis had been prepared, utility programs were used to determine by interpolation "true" values for all land, island, ocean weather station, ship-of-opportunity and buoy networks that would be used in the experiment. For a single analysis, the total number of input data locations varied between 4000 and 5000, of which approximately 4000 were land and island stations. These locations were constant throughout all runs in the experiment, and these input data values were always "true" values, obtained by interpolation from the "True" Analysis.

Buoy network and ship-of-opportunity data fields of zero mean Gaussianly-distributed errors were added to the "true" values. During various parts of the experiment, standard deviations of 0, 0.5, 1.0, 2.0, and 5.0 mb were used for errors added to buoy data, while standard deviations of 0 and 1.0 mb were used for errors added to ship data. All buoy network and ship-of-opportunity data fields for Monte Carlo runs were prepared and maintained on magnetic tape.

Other buoy network data fields were prepared in which given fractions of the number of buoys in each verification area were randomly "failed." That is, data for only 80% and 50% of the data buoy locations were included in these fields. Of course, several sets of data for random failures of buoys were prepared for each network in order to perform several Monte Carlo runs in the system reliability dimension. These data fields were also maintained on magnetic tape.

The RMS analysis error for the Initial Guess field was computed first, by directly comparing in an RMS sense the Initial Guess and the "True" Analysis. Verification was carried out only over ocean grid points, by using an available "mask" which eliminates verification over land areas. The RMS analysis error for the Sea Level Pressure Initial Guess field is shown below in Table 4-1.

Having obtained the RMS analysis error for the Initial Guess field, the next step was to obtain similar information for the data for Actual Ships, with an assumed standard deviation of 1.0 mb in the random errors.* Random errors in ship-of-opportunity data were not Monte Carloed; only one run each was made for Actual Ships and Probable Ships, with RMS analysis error results shown in Table 4-2, along with the Initial Guess RMS

*It is stressed that the actual ship data for 0000Z March 21, 1970, were not used in this experiment. Locations for the 348 reporting ships were used to obtain "true" values for ship data by interpolating from the "True" Analysis field.

TABLE 4-1
RMS ANALYSIS ERROR FOR THE
SEA LEVEL PRESSURE INITIAL GUESS FIELD

Verification Area	Initial Guess RMS Analysis Error (mb)	Number of Verification Grid Points
All Nor. Hem	2.07	10,059
All Pacific	2.30	5,935
Pacific Hi Var	5.21	847
Pac Lo Var	0.82	2,875
All Atlantic	2.03	2,322
Atl Hi Var	3.54	628
Atl Lo Var	1.03	1,513
Gulf of Mexico	1.51	102

TABLE 4-2
NUMBER OF VERIFICATION GRID POINTS AND SHIPS;
AND RMS ANALYSIS ERROR VALUES

Verification Area	No. of Verification Grid Points	No. of Actual Ships	No. of Probable Ships	RMS Analysis Error (mb)		
				Initial Guess	Actual Ships (σ_s =1.0 mb)	Prob. Ships (σ_s =1.0 mb)
All Nor. Hem	10,059	348	302	2.07	0.62	0.91
All Pacific	5,935	210	160	2.30	0.60	0.80
Pac Hi Var	847	108	79	5.21	0.98	1.32
Pac Lo Var	2,875	120	14	0.82	0.42	0.66
All Atlantic	2,322	118	142	2.03	0.79	1.34
Atl Hi Var	628	72	72	3.54	1.27	2.33
Atl Lo Var	1,513	31	36	1.03	0.60	0.85
Gulf of Mexico	102	6	5	1.51	0.59	0.28

analysis error and the number of points in the 125 × 125 grid over which verification took place in each area.

Table 4-2 clearly indicates the favorable impact that randomly distributed data collection platforms, such as ships-of-opportunity can have in reducing RMS analysis error, relative to the RMS analysis error of the Initial Guess field. Of course, it must be held in mind that, at present, FNWC is not experiencing the accumulation of more than 300 ship reports until about 2 hours after a synoptic reporting period, as indicated previously in Table 3-5. Furthermore, as can be seen for the Atlantic High Variability area, equal numbers of ship reports (72) can have much different impact on reducing Initial Guess RMS analysis Error, depending on the distribution of ships. (As will be shown later, 72 highly accurate and reliable data collection platforms, essentially uniformly distributed throughout the Atlantic High Variability area, could reduce the RMS analysis error to about 0.7 mb, which compared with the Initial Guess error of 2.54 gives an improvement of 80%.)

After the preliminary Initial Guess and Actual Ships runs had been made, the 10 data buoy networks were evaluated, each used in conjunction with Actual Ships. Four Monte Carlo runs were made for each case where there were non-zero errors in buoy data; also four Monte Carlo runs were made for each case where the system reliability was 80% or 50%. This resulted in a total of 16 analyses being performed and 16 mean-square analysis error values summed, averaged, and the square root taken in order to produce one value for RMS analysis error of a buoy-ship combination, in which the buoys had non-zero random errors and less than 100% system reliability. When buoys had 100% reliability and zero data error (i.e., when they were "perfect"), it was necessary to make only one computer run. When buoys had 100% reliability and non-zero data error, or zero data error and less than 100% reliability, four Monte Carlo runs were performed in the appropriate dimension. Buoy system reliabilities of 100%, 80%, and 50% were investigated, for buoy system random error standard deviations of 0, 0.5, 1.0, 2.0, and 5.0 mb. A total of 1600 analyses were performed in this phase of the experiment.

Results were analyzed, and four data buoy networks (600, 300, 150, and 76 buoys) were selected for the remainder of this experiment and for use in the Surface Air Temperature and Sea Surface Temperature experiments. This was done to conserve computer time, due to limitations of resources. General experimental results are found in Appendix B.

Following the first set of computer runs made with buoys and ships, two additional features were considered. First, it was decided to investigate the effect of reducing the redundancy of ships and buoys in the ocean regions where ship reports are most probable. Second, an effort was made to determine the effectiveness of data obtained from buoys alone. The details of developing probabilities for ship reports have been presented in Section 3 (page 39). The rationale for investigating the condition of "buoys only" data is severalfold.

- Requirements for National Data Buoy Systems state that all buoy data are to be received within one hour after a synoptic observation time. Substantial changes will have to be made in the volunteer ship-of-opportunity program in order that a substantial fraction of the total number of ship reports be received within the first hour following a synoptic time, as indicated in Table 3-5.

- Ships have a tendency to avoid areas of intensive weather conditions. Reports from data buoys or other data collection platforms in these areas could be of critical use in detecting, locating, analyzing and predicting storm conditions.
- Environmental data users prefer data obtained from a fixed point, rather than from a moving data collection platform. Not only can data from a fixed point be used to establish a climatological base, but such data are also important for sensing sudden changes in the environment, such as the passage of a front, a surface trough, or a tropical cyclone.

The remainder of this section is intended to achieve four aims.

(1) Typical experimental results for buoys-only are presented and discussed.

(2) System design curves based on experimental results for buoys only are presented, emphasizing percent reduction in Initial Guess RMS analysis error as a function of number of data buoys (or, data collection platforms), data buoy system reliability, and standard deviation of data error.

(3) Examples of system design are given, and implications of variations in system reliability, system data error and number of data buoys (or, data collection platforms) are explored.

(4) Experimental results for mixes of ship-of-opportunity and buoy data are presented and discussed.

In Section 8, system designs are undertaken in which Sea Level Pressure and the other two parameters are all taken into consideration. This section, then, prepares the reader for consideration of the more difficult, but meaningful, problem of preliminary system design and analysis of system tradeoffs, such as those involving reliability, data error, and number and location of data buoys.

4.2 Typical Experimental Results for Buoys Only*

Figure 4-1 shows the impact of increasing the number of data buoys and varying system reliability for each of the eight verification areas. All experimental results in Fig. 4-1 are for zero data error. For the Pacific High and Low Variability areas and the Atlantic High and Low Variability areas, average grid spacing between buoys (or, data points) in the areas is also indicated. Similar information is not presented for the other verification areas, because the actual distribution of buoys throughout

*These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

various parts of the verification area differs considerably from the average for an entire region, such as All Pacific, All Atlantic and All Northern Hemisphere.

General conclusions drawn from Fig. 4-1 are as follows:

- Within the scope of the number of data buoys considered in each verification area, substantial reductions in Initial Guess RMS analysis error were achieved in each verification area.

- Networks of fifty data buoys in each of the four verification areas of principal interest (Pacific High and Low Variability, and Atlantic High and Low Variability) are sufficient to provide 50% or more reduction in Initial Guess RMS analysis error.* Fifty "perfect" data buoys (100% reliability; zero data error), distributed in consonance with the pattern described for the four basic networks in Section 3 (page 28, et seq.) could achieve the percent reductions in RMS analysis error given in Table 4-3, which also shows the ratio of gridpoints per data buoy in the area in which the verification was computed.

The verification areas where the average number of grid points per data buoys is low prove to be the areas with greatest reduction in Initial Guess RMS analysis error, even though they are also the areas of high natural variability. This is, of course, to be expected, because in a numerical analysis model in which data points are treated as internal boundary conditions, the number of grid points substantially influenced by an isolated data point is twelve to twenty-four, e.g., two to three grid lengths from the data point. Thus, the experimental data suggest as a rule of thumb that error-free data from 100% reliable data buoys (data collection platforms) that are essentially uniformly distributed throughout an area, with a density that averages about twelve or less grid points per data buoy (data point) will provide more than 70% reduction in RMS analysis error. This statement holds for the Sea Level Pressure numerical analysis model used during the experiment. From Table 4-3, a similar statement can be made that for the case of data buoys distributed to give an average of 60 or less grid points per "perfect" buoy, the reduction in Initial Guess RMS analysis error will be 60% or greater.

Figure 4-1 shows that the reduction of Initial Guess RMS analysis error diminishes as a function of decreasing system reliability, although not on a one-to-one basis. That is, a data buoy system with a data-collection-and-transfer-to-shore reliability

*Throughout this report the following definition is used:

$$\text{Percent Reduction in Initial Guess RMS Analysis Error} = \frac{\text{Initial Guess RMS Error} - \text{Experimental RMS Analysis Error}}{\text{Initial Guess RMS Error}} \times 100,$$

where the experimental RMS analysis error is a function of natural variability of the parameter, goodness of the Initial Guess, the characteristics of the numerical analysis model, number and distribution of buoys and/or ships, data errors for buoys and/or ships, system reliability for buoys, and the area over which the verification statistic (RMS analysis error) is computed.

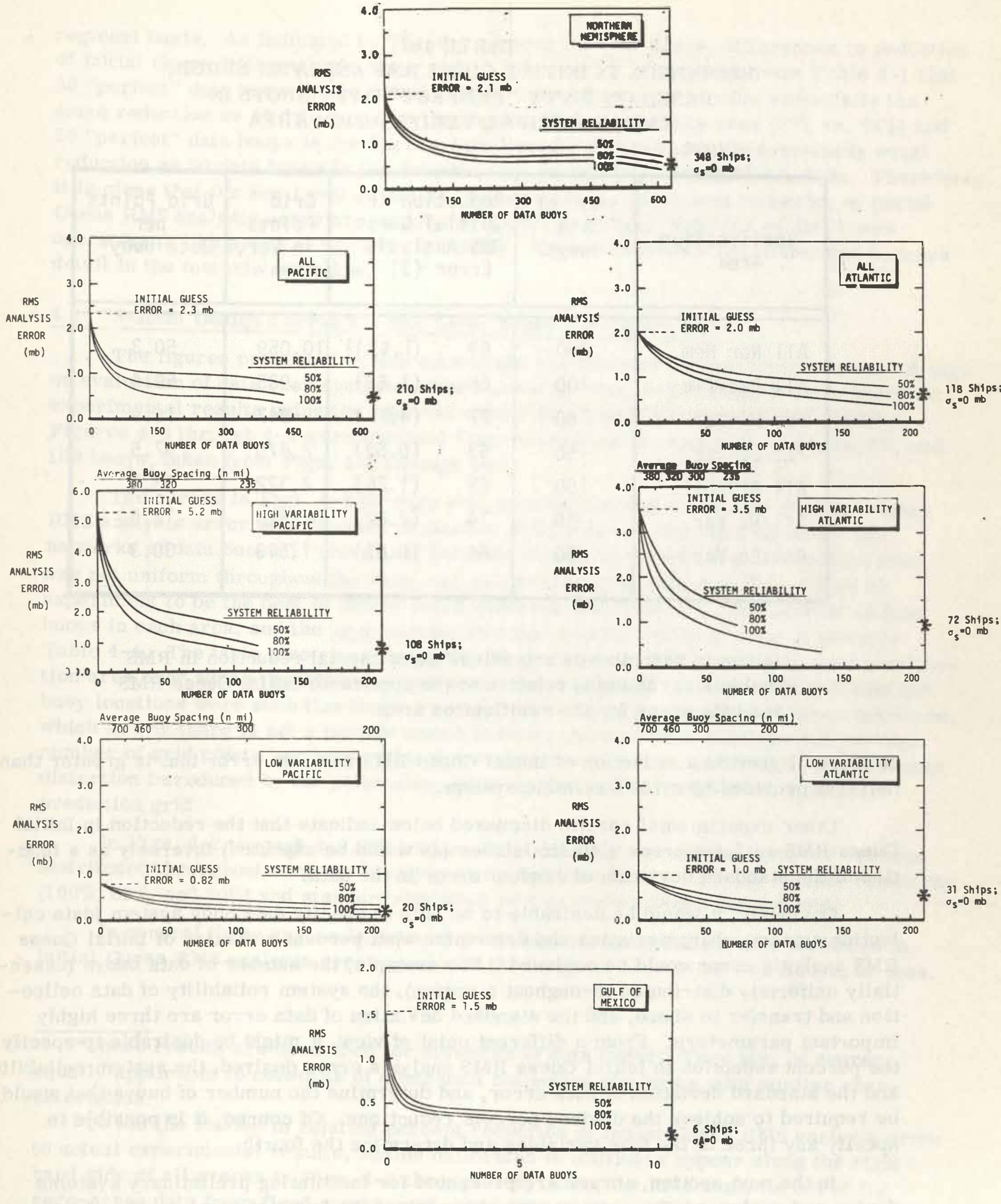


Fig. 4-1. Experimental results for Sea Level Pressure: Buoys Only; σ_b = 0 mb.

TABLE 4-3
REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR, BASED ON FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No. of Data Buoys	Reduction in Initial Guess RMS Analysis Error (%)		Grid Points in Ver. Area	Grid Points per Data Buoy
All Nor Hem.	200	69	(1.43)[1]	10,059	50.3
All Pacific	100	68	(1.56)	5,935	59.4
Pac Hi Var	50	77	(4.01)	847	16.9
Pac Lo Var	50	63	(0.52)	2,875	57.5
All Atlantic	100	62	(1.26)	2,322	23.2
Atl Hi Var	50	74	(2.62)	628	12.6
Atl Lo Var	50	65	(0.67)	1,513	30.3

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

of 50% will provide a reduction of Initial Guess RMS analysis error that is greater than half that provided by a 100% reliable system.

Other experimental results discussed below indicate that the reduction in Initial Guess RMS analysis error also diminishes (as would be expected) inversely as a function of the standard deviation of random error in the data.

Obviously, it would be desirable to be able to specify data buoy system (data collection system) characteristics and determine what percent reduction of Initial Guess RMS analysis error could be achieved. For example, the number of data buoys (essentially uniformly distributed throughout a region), the system reliability of data collection and transfer to shore, and the standard deviation of data error are three highly important parameters. From a different point of view, it might be desirable to specify the percent reduction in Initial Guess RMS analysis error desired, the system reliability and the standard deviation of data error, and determine the number of buoys that would be required to achieve the desired percent reductions. Of course, it is possible to specify any three of the four variables and determine the fourth.

In the next section, curves are presented for facilitating preliminary systems design and analyses. Curves are given for each of the four principal verification areas, because it is anticipated that systems design would be carried out essentially on a regional basis. As indicated by Fig. 4-1, among the four areas, differences in reduction of Initial Guess RMS analysis error exist. However, it is apparent from Table 4-1 that 50 "perfect" data buoys in the Atlantic High Variability area provide essentially the same reduction as 50 data buoys in the Pacific High Variability area (77% vs. 74%) and 50 "perfect" data buoys in the Pacific Low Variability area provide essentially equal reduction as 50 data buoys in the Atlantic Low Variability area (63% vs. 65%). Therefore, it is clear that for Sea Level Pressure, the differences in percent reduction of Initial Guess RMS analysis error are small, for systems of equal numbers of data buoys operating in like areas of natural variability. These comments are illustrated in more detail in the material to follow.

4.3 System Design Curves for Sea Level Pressure—Buoys Only*

The figures presented in this subsection are intended for use in preliminary design or evaluation of data buoy systems. The curves in Figs. 4-2 through 4-5 are based on experimental results using the analysis center Sea Level Pressure analysis model. Figures 4-6 through 4-8 were obtained from crossplots for networks of 20, 30, 50, and 100 buoys, taken from Figs. 4-2 through 4-5.

The curves in Figs. 4-2 through 4-5, showing percent reduction in Initial Guess RMS analysis error as a function of number of data buoys, are each based on four networks of data buoys.† The actual location of data buoys within a verification area was not uniform throughout the area, but was arranged in what was determined by experiment to be the best of two or three different distributions. The number of data buoys in each area, and the approximate average spacing between buoys is given in Table 4-4. The table also gives the approximate number of grid points in each verification area over which the RMS analysis error was computed. It is emphasized that the buoy locations were such that these average values were not realized in many instances, which is why there is not a perfect match between average data spacings and average number of grid points per buoy. The conversions are also complicated by the nonlinear distortion introduced by the polar stereographic projection used for the numerical prediction grid.

In Figs. 4-2 through 4-5, the curves show directly the effect of number of buoys distributed throughout each verification area, and the effect of varying system reliability (100%, 80%, and 50%) and standard deviation of data errors (zero and 1.0 mb).

In general these curves indicate that the highest marginal percent reduction in Initial Guess RMS analysis error occurs in the range of zero to 50 data buoys, or less.

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*These results are described for networks of data buoys. They are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

†To aid the reader in relating percent reduction of Initial Guess RMS analysis error to actual experimental results, scales calibrated in millibars appear along the right-hand side of all graphs in Figs. 4-2 through 4-8. Also, the RMS analysis error for zero-error data from fixed numbers of ships-only is shown in these figures.

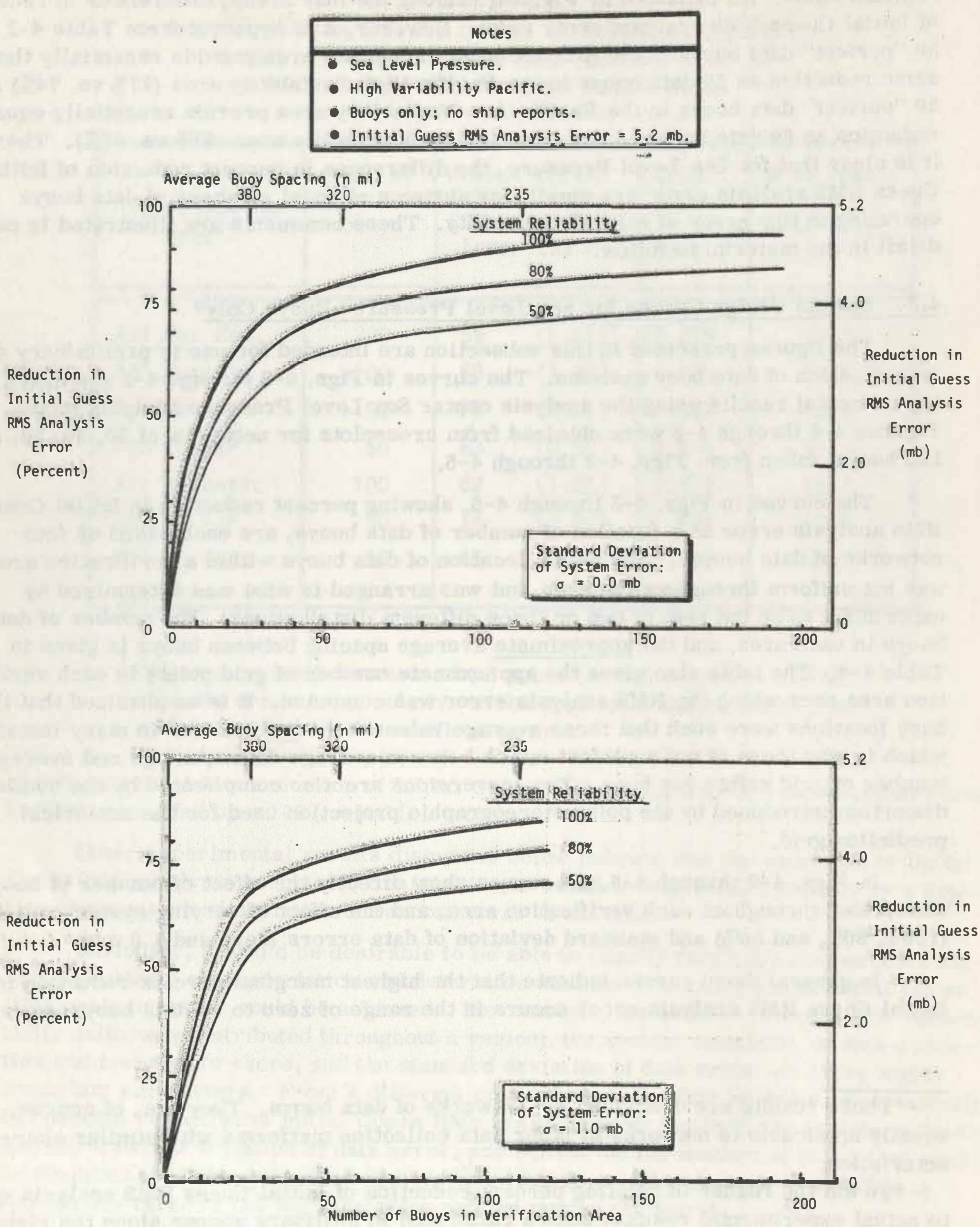
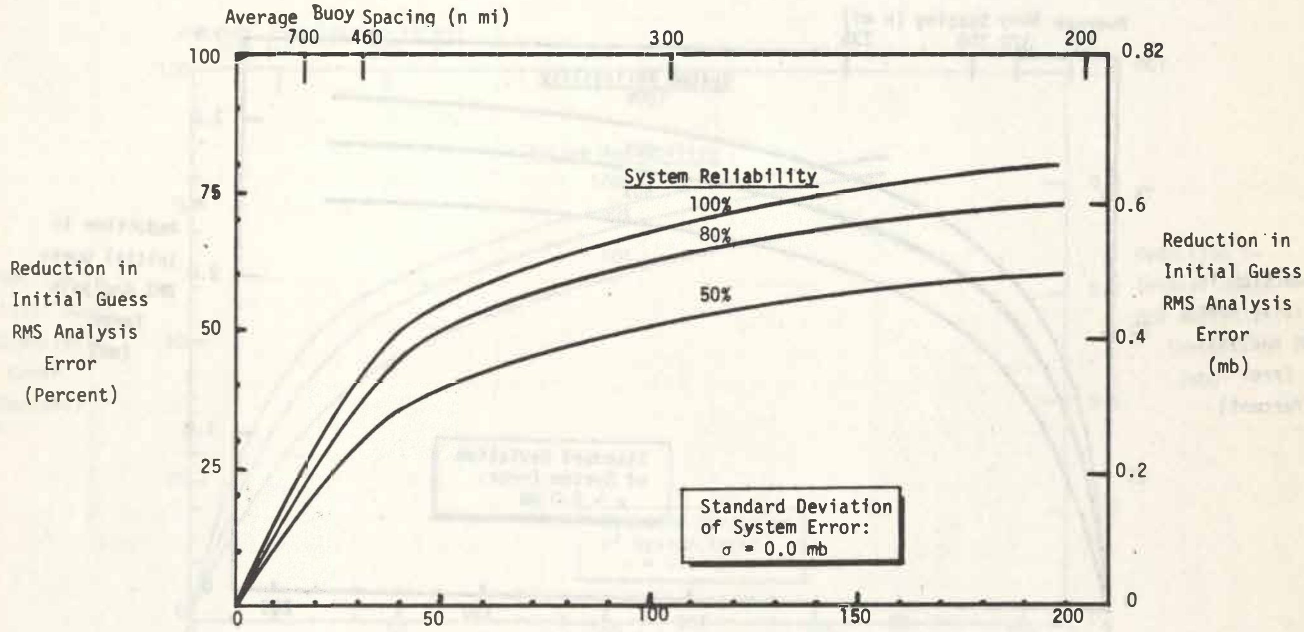


Fig. 4-2. System design curves for Sea Level Pressure in the Pacific High Variability verification area.

Notes
● Sea Level Pressure.
● Low Variability Pacific.
● Buoys only; no ship reports.
● Initial Guess RMS Analysis Error = 0.82 mb.



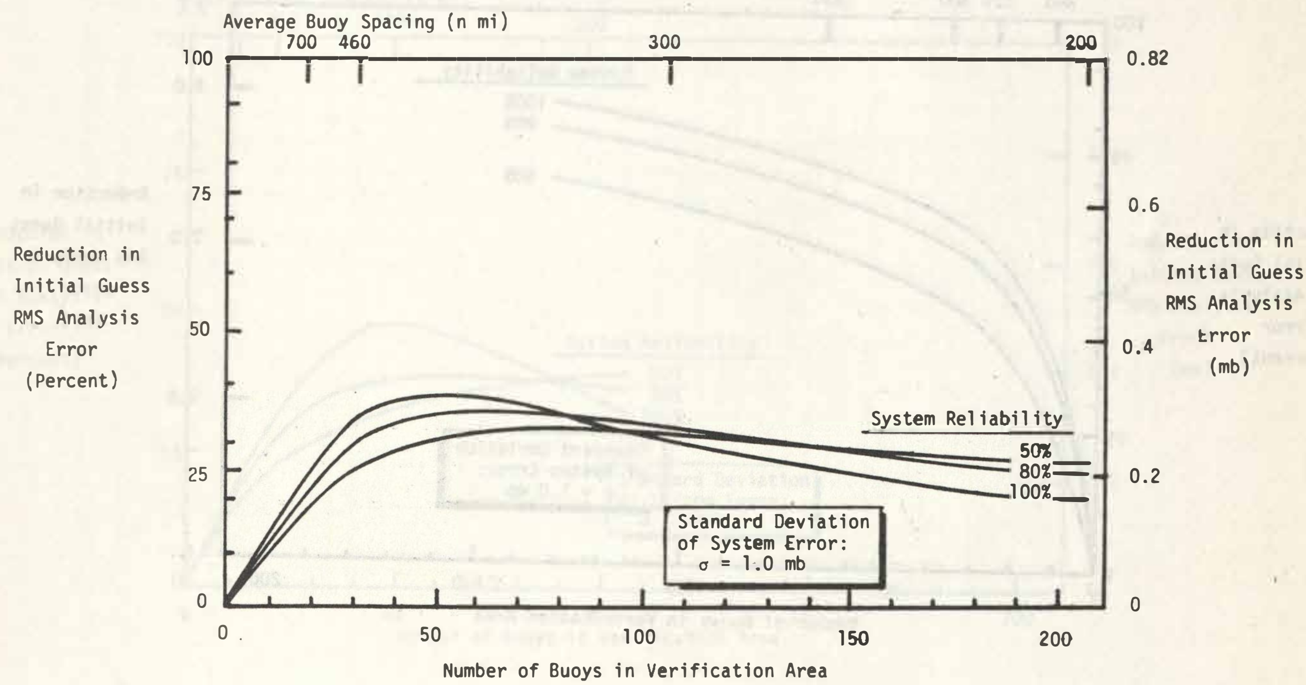


Fig. 4-3. System design curves for Sea Level Pressure in the Pacific Low Variability verification area.

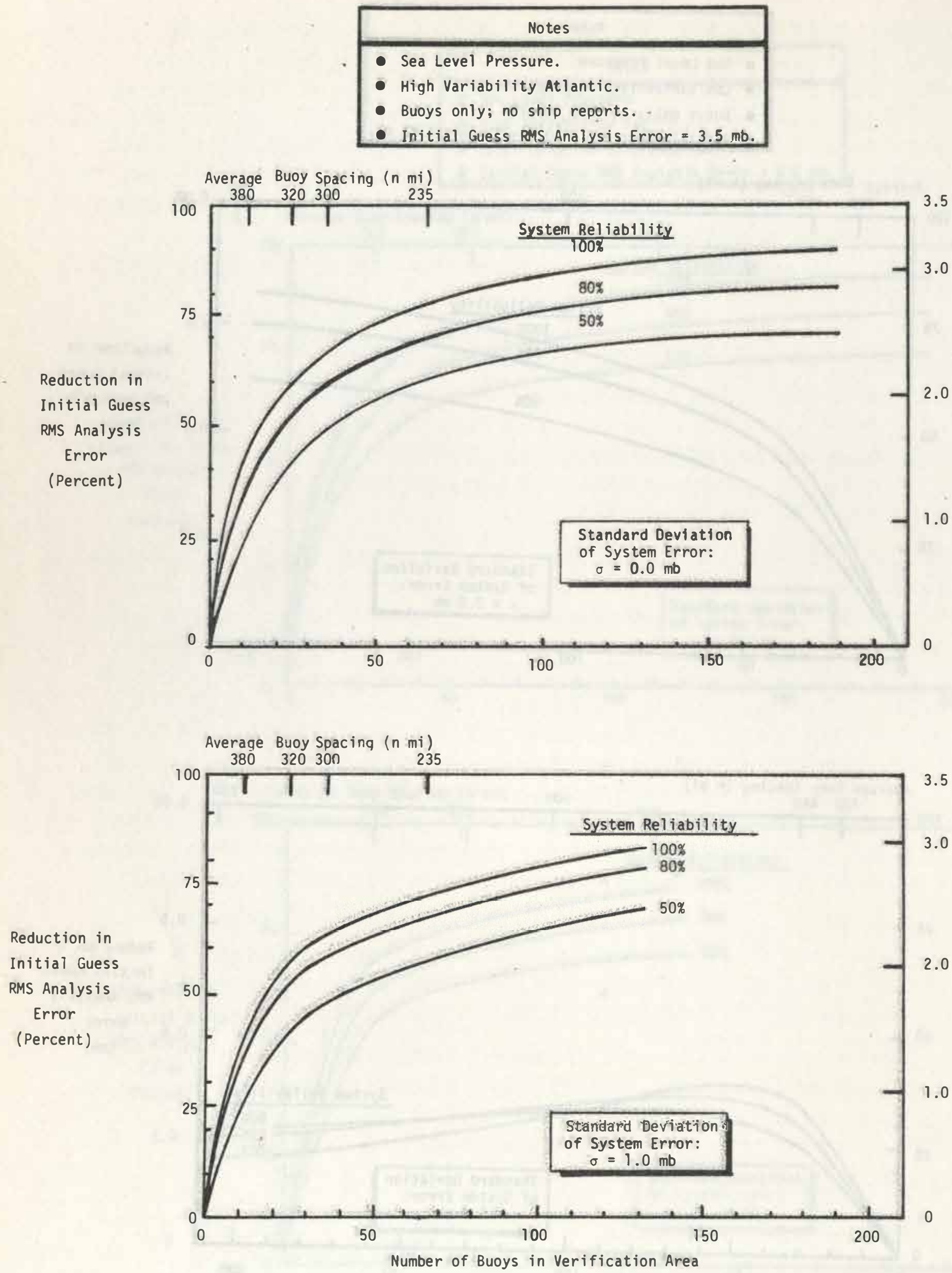


Fig. 4-4. System design curves for Sea Level Pressure in the Atlantic High Variability verification area.

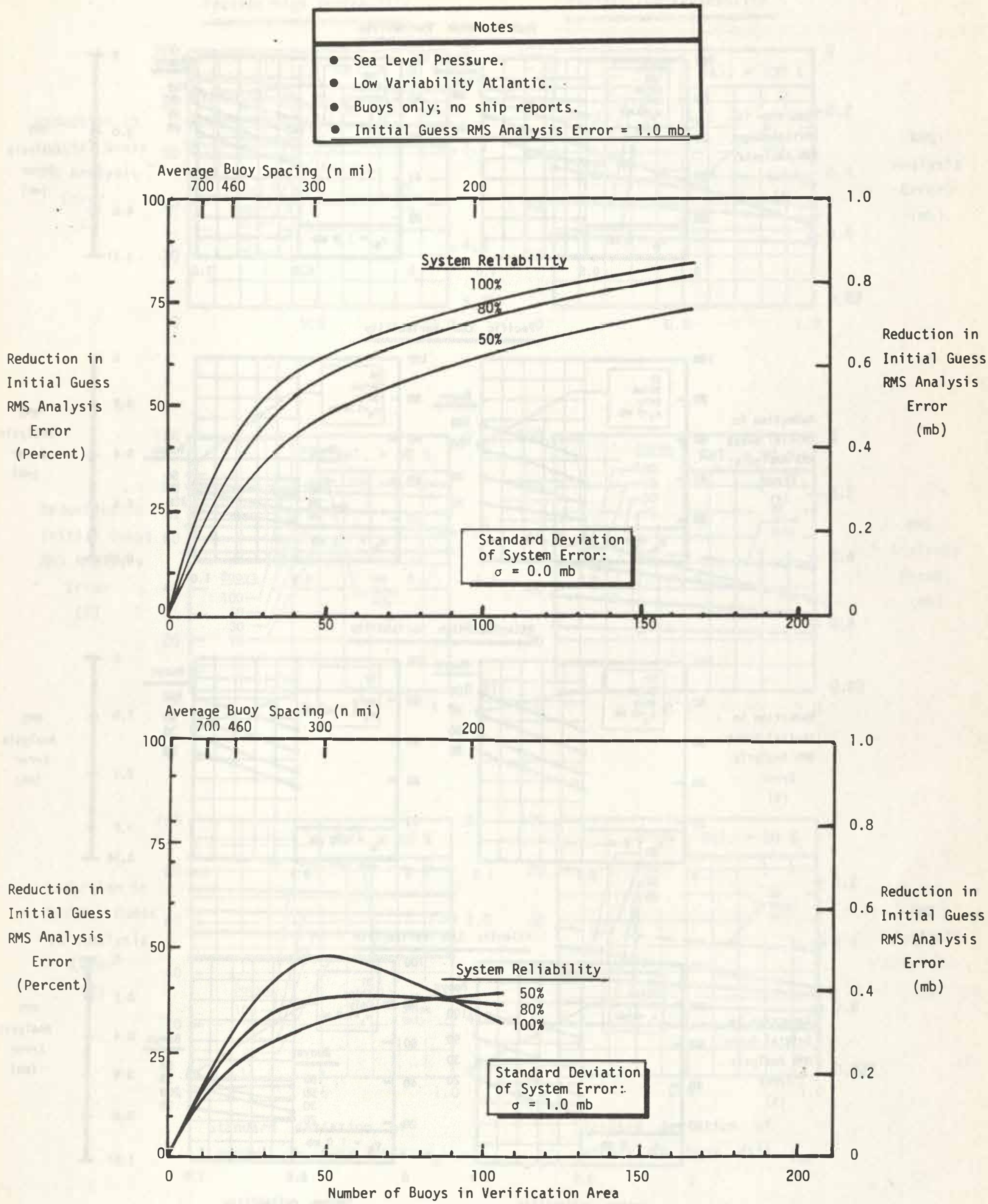


Fig. 4-5. System design curves for Sea Level Pressure in the Atlantic Low Variability verification area.

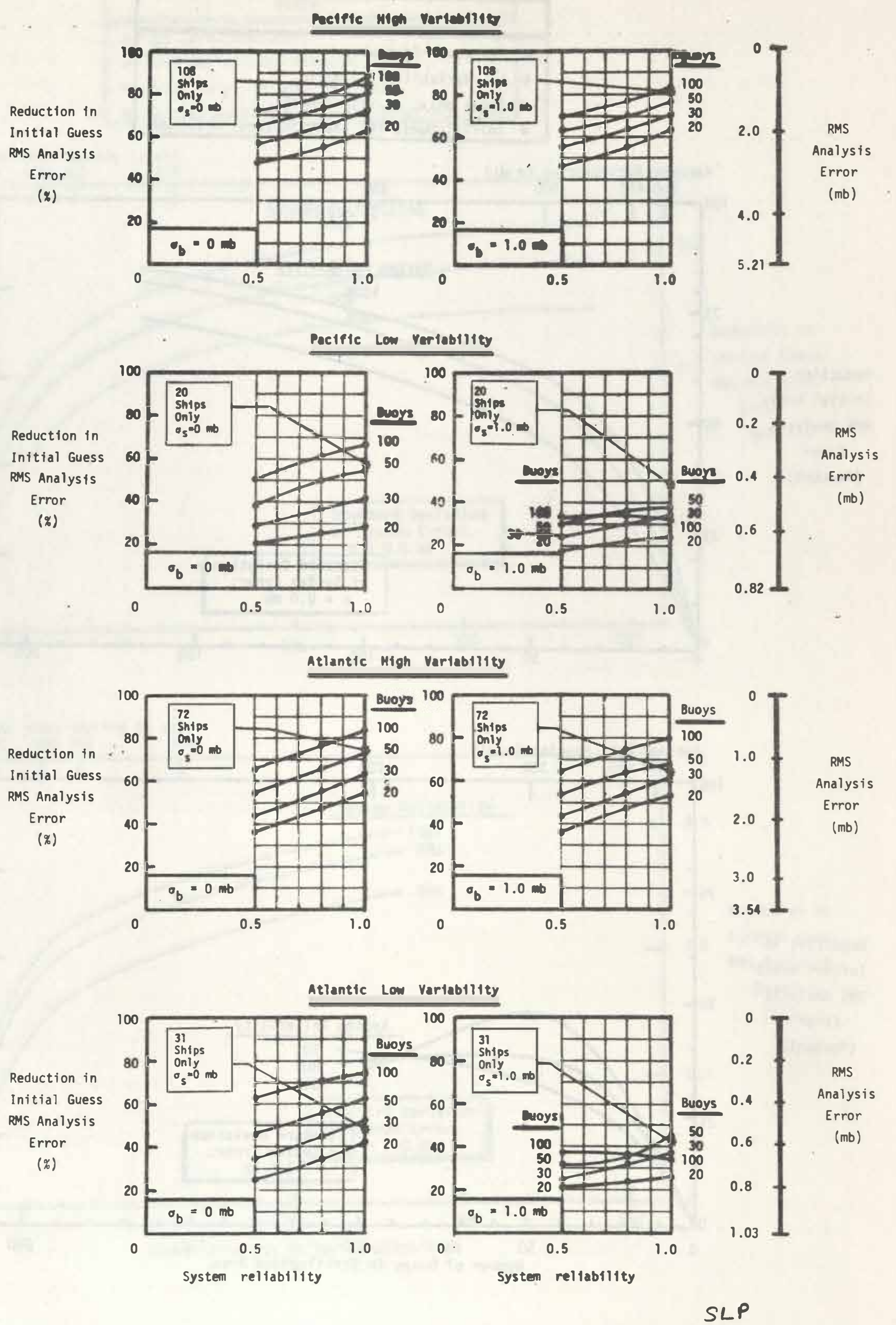


Fig. 4-6. System design curves for Sea Level Pressure, emphasizing reliability: Buoys Only.

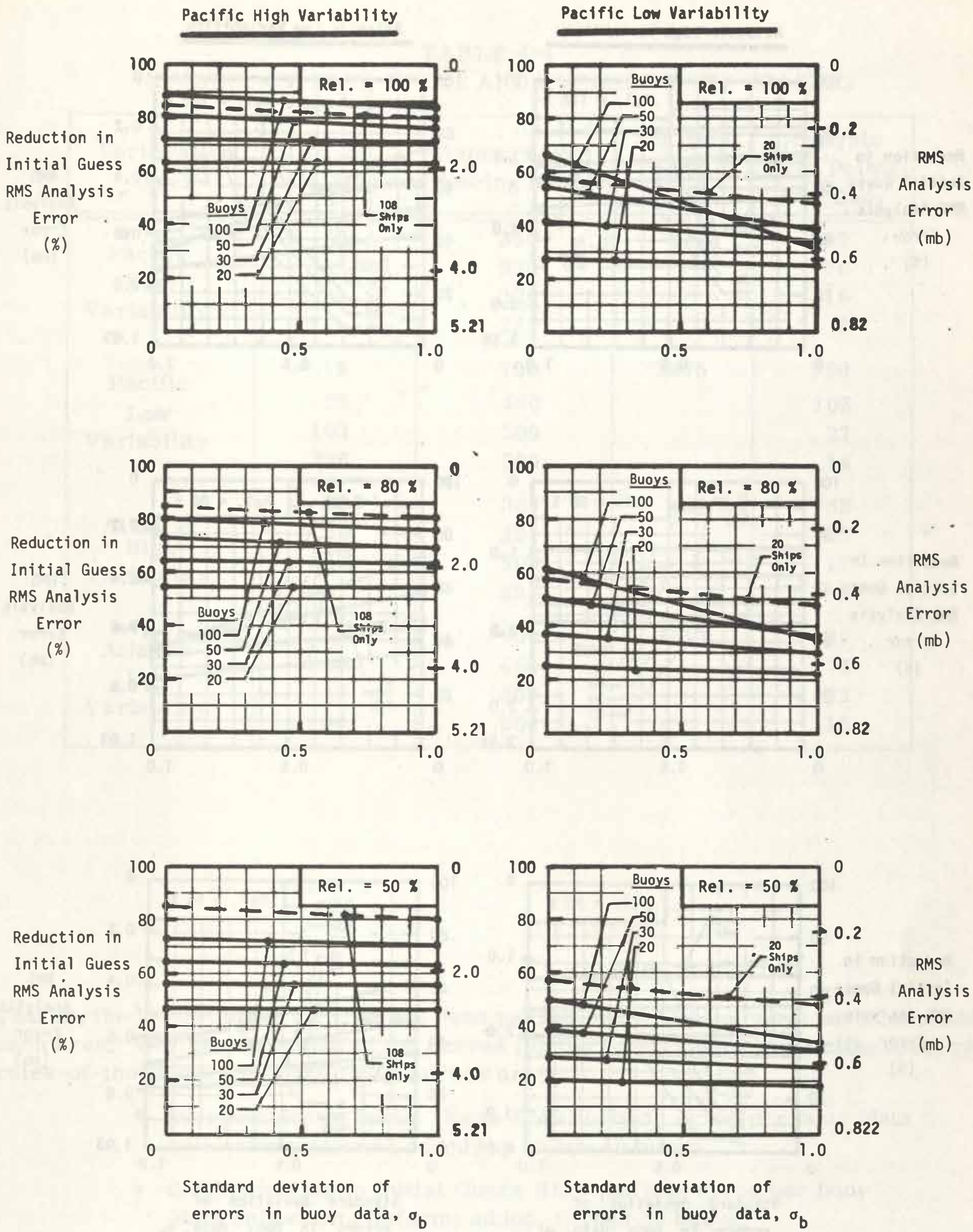


Fig. 4-7. System design curves for Sea Level Pressure, emphasizing errors in buoy data: Buoys Only.

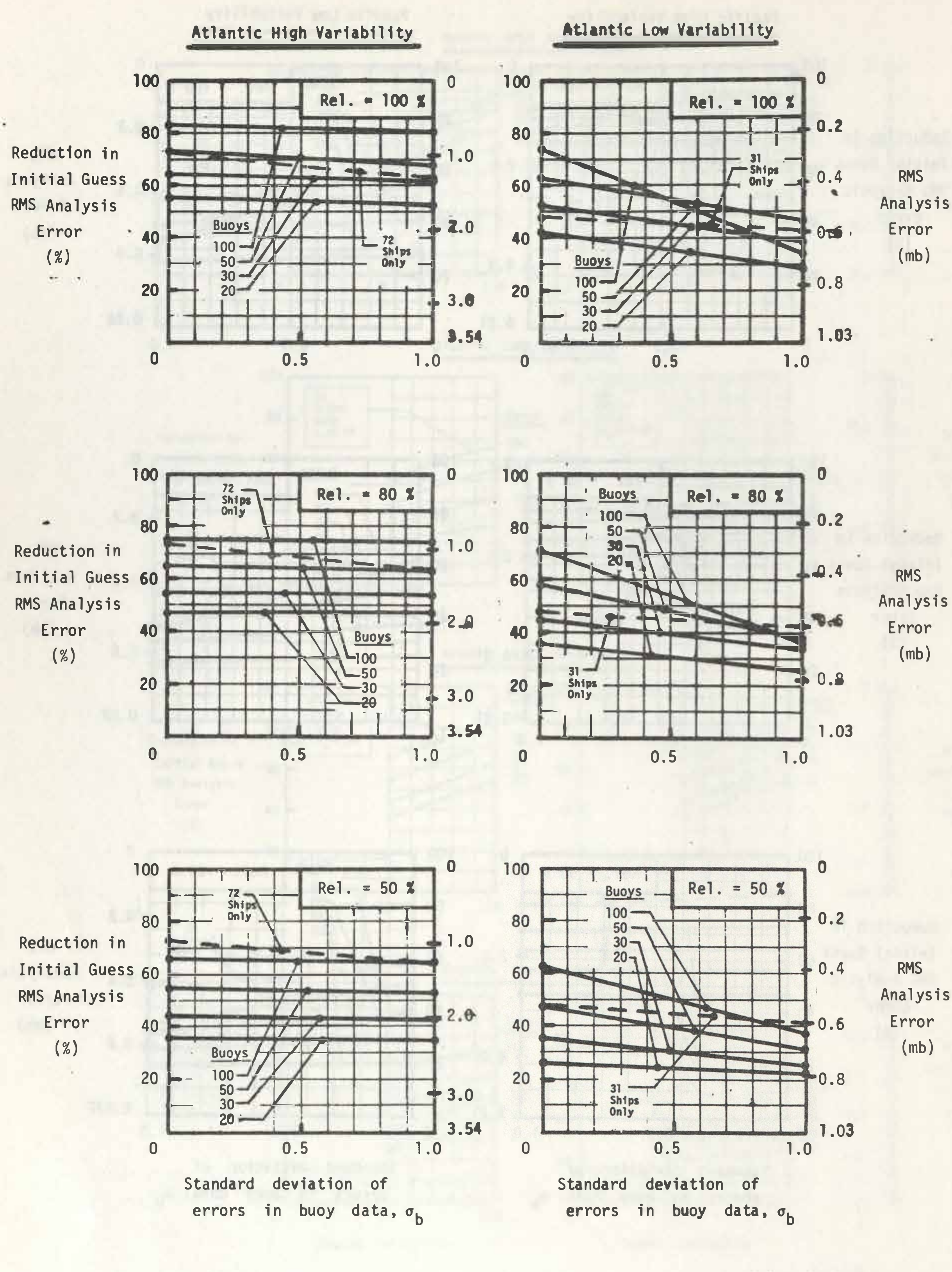


Fig. 4-8. System design curves for Sea Level Pressure, emphasizing errors in buoy data: Buoys Only.

TABLE 4-4
NUMBERS OF DATA BUOYS AND AVERAGE DATA SPACING

Verification Area	No. of Data Buoys	Average Data Spacing (n mi)	Analysis Grid Points	Analysis Grid Points Per Buoy
Pacific High Variability	26	380	847	33
	53	320		16
	54	320		16
	111	235		8
Pacific Low Variability	18	700	2875	160
	28	460		103
	103	300		27
	206	200		14
Atlantic High Variability	12	380	628	52
	25	320		25
	37	300		17
	67	235		9
Atlantic Low Variability	11	700	1513	137
	20	450		76
	47	300		32
	96	200		16

That is, the "knee" of each curve has been passed, once 50 data buoys have been added to each area. With the exception of the curves for the Low Variability Pacific area, rough rules-of-thumb derived from these curves are:

- 2% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, up to 30—40 buoys,
- 0.2% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, beyond 50 buoys,
- 4% loss in reduction of Initial Guess RMS analysis error per millibar increase in standard deviation for data error,
- 0.3% loss in reduction of Initial Guess RMS analysis error per percent reduction in system reliability.

The curves in Figs. 4-3 and 4-5 for a standard deviation of 1.0 mb for data error in the Low Variability areas may be explained as follows. The Initial Guess RMS analysis errors were low in both of these areas (0.82 mb for Pacific and 1.0 mb for Atlantic). It is believed that for the case of a few data points, the data from buoys improve the analysis because the distribution of Initial Guess errors is by no means Gaussian in nature, as are the data errors. However, after a transition point has been passed—apparently at about 50 buoys—the amount of error-containing data becomes sufficient to eliminate the improvement and drive the curve back towards zero, or into the negative half-plane, in the case where the Initial Guess RMS analysis error is 0.82 mb. It was demonstrated many times during the various phases of the experiment that uniformly distributed data, having standard deviations of data error in excess of the initial guess, will tend asymptotically towards an RMS analysis error commensurate with the standard deviation of data error and the amount of "smoothing" performed on the data. This is, of course, to be expected.

Non-monotonic curves, such as these shown in Figs. 4-3 and 4-5, exhibit a double-valued characteristic, as a function of constant percent reduction of Initial Guess RMS analysis error. That is, there are two different networks of data buoys that would, under the stated conditions, produce the same reduction in Initial Guess RMS analysis error. For example, in Fig. 4-5, with 100% system reliability and a standard deviation of data error of 1.0 mb, 40% reduction (0.4 mb) in Initial Guess RMS analysis error can be achieved by networks of 40 and 82 data buoys (data collection platforms). Of course, in a system design, the lower number of data buoys would be chosen.

It is of interest to note that the double-valued curve characteristics do not occur in any of the other data for buoys-only experiments. Therefore, for the purposes of this report, concern for this type of phenomenon is limited to these two Low Variability area cases for Sea Level Pressure.

Crossplot data from the curves in Figs. 4-2 through 4-5 were made for 20, 30, 50, and 100 data buoys in each verification area, and are plotted as a function of reliability in Fig. 4-6. The same crossplot data are presented as a function of standard deviation of Gaussian data error in Figs. 4-7 and 4-8. It is stressed that, in principle, it should be possible to carry out preliminary systems design and/or analysis using any one of these three sets of curves. However, depending upon which three variables are given, in order to find the fourth variable, one set of curves may prove to be more convenient to use than the others. An effort has been made to accommodate all possibilities. To solve a problem in system design or analysis, it is apparent that interpolation may have to be used. The next subsection presents a number of systems design and analysis examples, using the curves in Figs. 4-2 through 4-8. In all instances where required, linear interpolation has been used. This has been done because it is considered that there is adequate data, and the data are sufficiently well-behaved so that a higher order interpolation scheme would introduce more apparent accuracy in the results than is warranted by the accuracy of the original data.

4.4 Examples of System Design: Buoys Only*

To illustrate the use of the system design curves presented in the previous subsection, four typical system design and/or tradeoff examples are presented.

Case 1—Buoys with equal capabilities: 20-buoy and 30-buoy networks

For Sea Level Pressure, determine the percent reduction in Initial Guess RMS analysis error that can be achieved by using 30 data buoys, rather than 20 data buoys, in each of the four verification areas. Assume the system reliability of the data buoys is 80%, and the overall system data error is Gaussianly distributed with zero mean and a standard deviation of $\sigma_b = 0.5$ mb.

Solution

For the conditions described, the system design curves in Figs. 4-7 and 4-8 are most applicable. The table below shows the marginal improvement in reduction of I.G. RMS analysis error for Sea Level Pressure that can be achieved by adding 10 data buoys to networks containing 20 data buoys in each verification area. (It is assumed that all buoy networks are essentially uniformly distributed throughout each verification area.)

TABLE 4-5
DATA FOR CASE 1

Verification Area	Reduction in I.G. RMS Analysis Error (%) Rel.=80%; σ_b=0.5 mb		Marginal Improvement (%)	Marginal Improvement per Buoy Added (%)	Approx. Data Spacing (n mi)	
	20 buoys	30 buoys			20 buoys	30 buoys
Pac Hi Var	54 (2.81)[1]	63 (3.28)	9 (0.47)	0.9 (.05)	565	450
Pac Lo Var	23 (0.19)	33 (0.27	10 (0.08)	1.0 (.008)	750	580
Atl Hi Var	47 (1.66)	54 (1.91)	7 (0.25)	0.7 (.003)	460	375
Atl Lo Var	31 (0.32)	39 (0.40)	8 (0.08)	0.8 (.008)	500	400

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

For data buoys with equivalent characteristics, it is possible to determine readily the marginal reduction in I.G. RMS analysis error that will be contributed by each buoy added. Of course, in this example, the marginal change of approximately one percent per buoy added is valid only in the range of 20 to 30 buoys in each of the four verification areas. The parabolic nature of the design curves in Figs. 4-2 through 4-5 clearly indicates that the marginal reduction in I.G. RMS analysis error per buoy added decreases rapidly after 30 to 50 buoys have been deployed uniformly throughout a verification area.

Case 2—Effect of reduction in reliability: 30-buoy networks

Problem Statement

For the 30-buoy networks of Case 1 (80% reliable; 0.5 mb standard deviation of data error), determine for the four verification areas the marginal loss in reduction in I.G. RMS analysis error that would occur for Sea Level Pressure, should the system reliability decrease from 80% to 60%.

Solution

For the conditions presented, the system design curves in Fig. 4-6 are most applicable. Reduction in I.G. RMS analysis error can be found easily for buoy systems with standard deviation of data error of $\sigma_b = 0$ and $\sigma_b = 1.0$ mb. Linear interpolation is then used to find the desired values for $\sigma_b = 0.5$ mb.

TABLE 4-6
DATA FOR CASE 2

Verification Area	Reduction in Initial Guess RMS Analysis Error (%)						Reduction of I.G. RMS Analysis Error (%)
	σ_b = 0 mb		σ_b = 1.0 mb		σ_b = 0.5 mb		
	Rel=80%	Rel=60%	Rel=80%	Rel=60%	Rel=80%	Rel=60%	
Pac Hi Var	65 (3.39)[1]	59 (3.07)	63 (3.28)	57 (2.97)	64 (3.33)	58 (3.02)	6.5 (0.34)
Pac Lo Var	37 (0.30)	32 (0.26)	37 (0.30)	30 (0.25)	34.5 (0.28)	31 (0.25)	3.5 (.029)
Atl Hi Var	55 (1.95)	48 (1.70)	54 (1.91)	47 (1.66)	54.5 (1.93)	47.5 (1.68)	7.0 (0.25)
Atl Lo Var	45 (0.46)	37 (0.38)	32 (0.33)	27 (0.28)	38.5 (0.40)	32 (0.33)	6.5 (0.07)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

With the exception of the Pacific Low Variability area, one percent reduction in system reliability will result in a downward change of about 0.35% in reduction of I.G. RMS analysis error for networks of about 30 buoys and standard deviations of data error ranging from $\sigma_b = 0$ to $\sigma_b = 1.0$ mb. In the Pacific Low Variability area, the downward change is about one-half of that in the other three areas, i.e., about 0.17% (.0014 mb) per one percent change in reliability. This may be due to less variability in Sea Level Pressure in this area, when compared to the other three areas. Of course, improvement in system reliability produces the same relative improvements in reduction of I.G. RMS analysis error—namely, 0.17% to 0.35% per one percent increase in system reliability.

Case 3—Tradeoff comparison of 20-buoy and 30-buoy networks

Problem Statement

For Sea Level Pressure, compare the reduction in I.G. RMS analysis error for a 30-buoy-network having a system reliability of 60% and a 0.5 mb standard deviation of data error with a 20-buoy network having a system reliability of 90% and a 0.1 mb standard deviation of data error, for each of the four areas.

Solution

Data for the 30-buoy networks (R = 60%; σ_b = 0.5 mb) can be taken directly from Case 2. Data for the 20-buoy networks (R = 90%; σ_b = 0.1 mb) is most conveniently obtained from the curves for 100% and 80% reliability. Note that, on the average, in each network, 18 buoys would be delivering data to the shore data dissemination hub.

TABLE 4-7
DATA FOR CASE 3

Verification Area	Reduction in I.G. RMS Analysis Error (%)				Col. A—Col. B (%)
	20 buoys; σ_b = 0.1 mb			30 buoys; σ_b = 0.5 mb	
	Rel=100%	Rel=80%	Rel=90%	Rel=60%	
Pac Hi Var	62 (3.23)[1]	54 (2.81)	58 (3.02)	58 (3.02)	0.0 (0)
Pac Lo Var	27 (0.22)	24 (0.20)	25.5 (0.21)	31 (0.25)	-5.5 (-0.05)
Atl Hi Var	65 (2.30)	48 (1.70)	51.5 (1.82)	47.5 (1.68)	4.0 (0.14)
Atl Lo Var	41 (0.42)	34 (0.35)	37.5 (0.39)	32 (0.33)	5.5 (0.057)
			Column A	Column B	

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

In the Pacific High Variability area, the more reliable and accurate 20-buoy network is an exact tradeoff, when compared with the 30-buoy network. The 20-buoy network is less satisfactory in the Pacific Low Variability area. However, in both the Atlantic High Variability and Low Variability areas, the more accurate 20-buoy network will achieve a greater reduction of I.G. RMS analysis error as might be expected.

It is apparent that the marginal development, implementation and operational costs required to increase system reliability from 60% to 90%, and reduce the standard deviation of system data error from 0.5 mb to 0.1 mb (the present requirement), can be traded off against the marginal implementation and operational cost of 10 buoys having 60% system reliability and σ_b = 0.5 mb.

Case 4—Alternative systems producing the same reduction in I.G. RMS analysis error

Problem Statement

Determine the number of data buoys required to achieve a 50% reduction of Initial Guess RMS analysis error in each of the four verification areas, for the following conditions: zero standard deviation of data error and system reliabilities of 100%, 80%, and 50%; and 1.0 mb standard deviation of data error and system reliabilities of 100%, 80%, and 50%.

Solution

For the conditions described, the system design curves in Figs. 4-2 through 4-5 are most applicable. The table below shows the number of data buoys required in each verification area to achieve 50% reduction in I.G. RMS analysis error.

TABLE 4-8
DATA FOR CASE 4

Verification Area	No. Buoys Required for 50% Reduction in RMS Analysis Error					
	σ_b = 0 mb			σ_b = 1.0 mb		
	Rel=100%	Rel=80%	Rel=50%	Rel=100%	Rel=80%	Rel=50%
Pac Hi Var	11	17	22	13	17	22
Pac Lo Var	41	52	101	N.A.[1]	N.A.	N.A.
Atl Hi Var	12	22	36	18	24	40
Atl Lo Var	28	37	56	N.A.	N.A.	N.A.

N.A. = Not Achievable under stated conditions.

Comment

The table indicates that a 50% reduction in Initial Guess RMS analysis error cannot be achieved in the Low Variability areas with systems that introduce random errors having standard deviations of 1.0 mb or more. In Low Variability areas, the Initial Guess RMS analysis errors are generally lower than 1 mb; buoys with random errors having standard deviations of less than 1.0 mb are required to improve the analysis in these areas.

4.5 Typical Experimental Results for Buoys and Ships

For the Sea Level Pressure experiment, most of the analyses performed were made using actual ship locations for 0000Z March 22, 1970. During the 12-hour period following 0000Z, 348 ship reports were received. For the experiment, the ship locations were used to determine by interpolation from the "True" Analysis what the ship data would have to have been in order to fit perfectly into the "True" Analysis. Two fields of ship data were prepared: one with zero data error and one in which zero mean Gaussian random errors with a standard deviation of 1.0 mb were introduced.

As noted elsewhere in this report, statistical data received from FNWC after the experiments were completed indicate that, on the average, two to two-and-a-half hours elapse after the synoptic period before a total of 348 ship reports are received. Requirements for National Data Buoy Systems state that all observations are to be returned to the shore data dissemination hub within one hour following the synoptic time. Therefore, the number of ship reports assumed for this part of the experiment can be construed as an optimistic concept (by about a factor of three to four) of the volume of ship reports that may in the future be received within the same time frame as reports from data buoys.

Actual ship reports have several characteristics that are different from the buoys-only data networks discussed in the previous subsections.

- Density of locations of ship observations tends to be very high in the shipping lanes between the U.S. and Europe, and the U.S. and the Orient, particularly between the U.S. and Japan.
- Very large data errors appear relatively frequently in ship reports, sometimes because an observation is in error, and sometimes because the ship location data are in error, thus placing an accurate observation at the wrong location.
- Bias in ship observations, rather than Gaussianly distributed random errors, occurs rather frequently.
- Often, ships are within very close proximity of one another when they make observations, thus introducing redundancy in reports.

From the experimental results, it appears that large networks of data buoys that are essentially uniformly distributed throughout each of the four principal verification areas in the northern Pacific and northern Atlantic will, under "perfect" conditions (100% reliability; zero data error), considerably enhance ship data and effect substantial reductions in the Initial Guess RMS analysis error. Figure 4-9 shows a typical set of experimental results for both ships and buoys with zero data error, and buoy system reliabilities of 100%, 80%, and 50%. Table 4-9 shows the percent reduction of Initial Guess RMS analysis error achieved by the ships alone, the percent reduction in Initial Guess RMS analysis error achieved by 50 "perfect" buoys in each verification area (see Section 4.2); and the percent reduction in Initial Guess RMS analysis error stemming from the combined "perfect" ship data and the "perfect" data from 50 buoys in each principal verification area.

The data in Table 4-9 are intended primarily to convey an impression of the percent reduction in Sea Level Pressure Initial Guess RMS analysis error that might be achieved under conditions of perfect reliability and zero data error for both buoy and ship reports. The information in Table 4-9 and the graphical results in Fig. 4-9 indicate that, for the most part, data from buoy networks and ships-of-opportunity would

TABLE 4-9

REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR FOR "PERFECT" SHIPS AND FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No. of Actual Ships	No. of Data Buoys	Reduction in I.G.RMS Analysis Error(%)		
			Actual Ships	Buoys Only	Buoys + Ships
All Nor.Hem.	348	200	76 (1.57)[1]	69 (1.43)	88 (1.82)
All Pacific	210	100	79 (1.82)	68 (1.56	84 (1.93
Pac Hi Var	108	50	84 (4.38)	77 (4.01)	95 (4.95)
Pac Lo Var	20	50	57 (0.42)	63 (0.52)	76 (0.62)
All Atlantic	118	100	70 (1.42)	62 (1.26)	85 (1.73)
Atl Hi Var	72	50	73 (2.58)	74 (2.62)	87 (3.08)
Atl Lo Var	31	50	46 (0.47)	65 (0.67)	75 (0.77)

[1] **Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.**

be rather redundant, if

- the data from each type of platform were of equal quality, and
- the data from both types of platform were received in the volumes indicated in Table 4-9 within a one-hour period after each synoptic reportime time.

Of course, neither of these conditions is being met at present. Nor is there a program under way at present that would upgrade ship reports in quality or timeliness of reporting to meet the same performance standards that are being required of data buoys.*

*There is no question of the technical feasibility of being able to obtain observations from a ship and transmitting them to a shore data dissemination hub in a timely manner. It could be done. But it is noted that it would be an expensive process to install and maintain the necessary equipment on board ship that would duplicate the capabilities being required of data buoys. Manned data collection aboard ship costs about $50,000 per year per ship, not including the cost of data collection and transmission equipment implementation and maintenance. To keep only 67 ships operating at sea on the average with high performance has been estimated to cost about $35 million for implementation and $7.5 million per year for basic operations. Other important operational costs could include about $5 million per year for two rawinsonde releases per ship per day, and $1.6 million per year for four expendable bathythermograph observations per ship per day. (See Reference 7 for details of costs.) These comments are introduced only to put into proper context the cost of obtaining in a timely manner several hundred accurate ship reports each synoptic period. It is this cost that should be compared with obtaining equally accurate, reliable, and timely reports from unmanned data buoys, or whatever other data collection platform may be under consideration. Furthermore, it is not yet clear that large sums of money should be invested in obtaining data from relatively small numbers (50 or less per verification area) of moving platforms, rather than fixed platforms which provide data of greater benefit to data users.

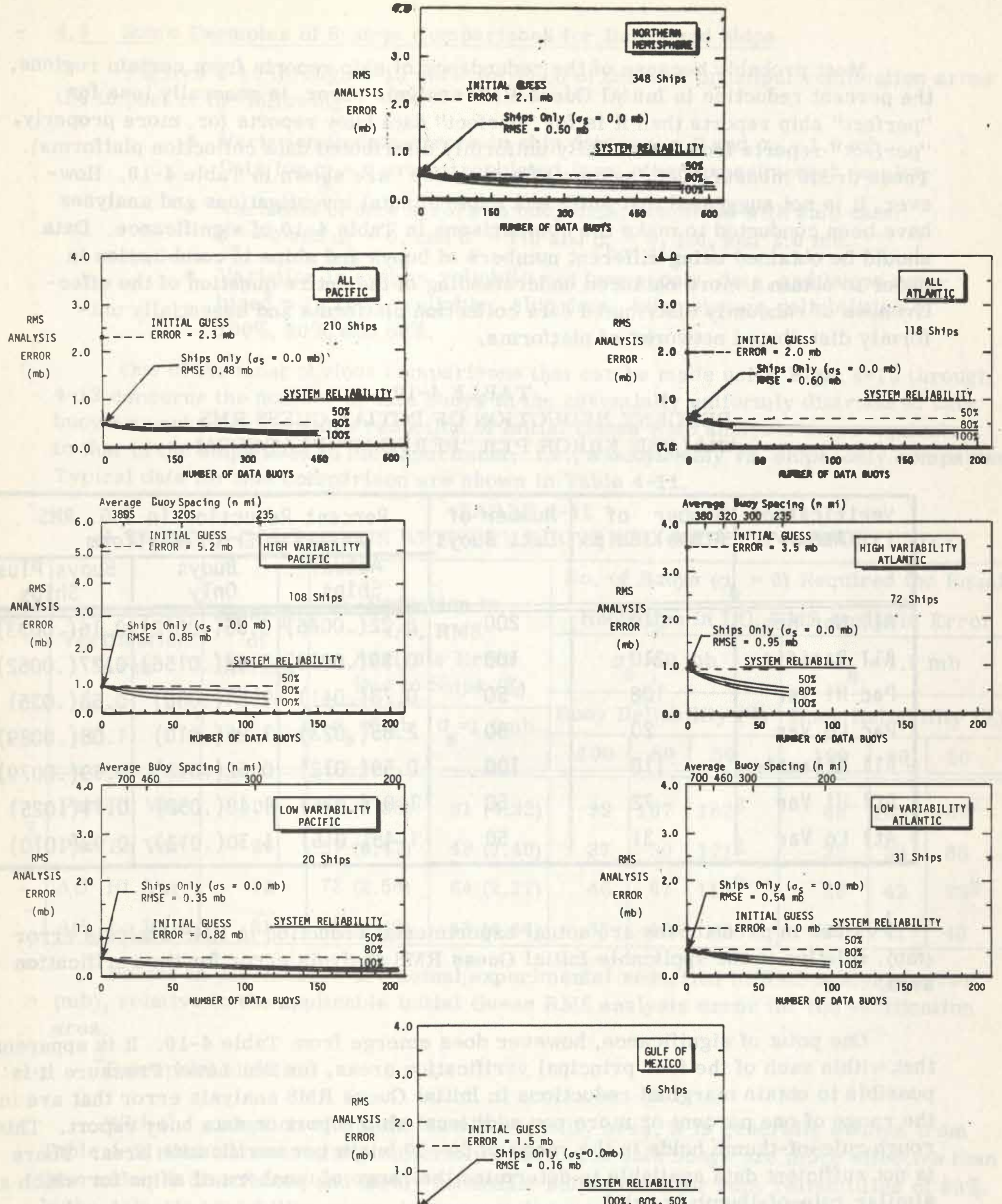


Fig. 4-9. Experimental results for Sea Level Pressure: Buoys and Ships; σ_b = 0 mb; σ_s = 0 mb.

Most probably because of the redundancy of ship reports from certain regions, the percent reduction in Initial Guess RMS analysis error is generally less for "perfect" ship reports than it is for "perfect" data buoy reports (or, more properly, "perfect" reports from essentially uniformly distributed data collection platforms). These crude measures of "system effectiveness" are shown in Table 4-10. However, it is not suggested that sufficient experimental investigations and analyses have been conducted to make the comparisons in Table 4-10 of significance. Data should be obtained using different numbers of buoys and ships in combination in order to obtain a more balanced understanding of the entire question of the effectiveness of randomly distributed data collection platforms and essentially uniformly distributed networks of platforms.

TABLE 4-10
PERCENT REDUCTION OF INITIAL GUESS RMS ANALYSIS ERROR PER "PERFECT" PLATFORM

Verification Area	Number of Actual Ships	Number of Data Buoys	Percent Reduction in I.G. RMS Analysis Error/Platform		
			Actual Ships	Buoys Only	Buoys Plus Ships
All Nor Hem	348	200	0.22(.0046)[1]	0.35(.0072)	0.16(.0033)
All Pacific	210	100	0.39(.0090)	0.68(.0156)	0.27(.0062)
Pac Hi Var	108	50	0.78(.041)	1.54(.080)	0.68(.035)
Pac Lo Var	20	50	2.85(.023)	1.26(.010)	1.08(.0089)
All Atlantic	118	100	0.59(.012)	0.62(.013)	0.39(.0079)
Atl Hi Var	72	50	1.0.(.036)	1.48(.052)	0.71(.025)
Atl Lo Var	31	50	1.48(.015)	1.30(.013)	0.93(.010)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

One point of significance, however does emerge from Table 4-10. It is apparent that, within each of the four principal verification areas, for Sea Level Pressure it is possible to obtain marginal reductions in Initial Guess RMS analysis error that are in the range of one percent or more per additional ship report or data buoy report. This rough rule-of-thumb holds in the range of 20—50 buoys per verification area. There is not sufficient data available to determine the range of numbers of ships for which a similar rule-of-thumb is valid.

The next subsection looks at the impact of data errors and data buoy system reliability on the percent reduction of Initial Guess RMS analysis error achieved by combinations of ship reports and data buoy reports.

4.6 Some Examples of System Comparisons for Buoys and Ships

Figures 4-10 through 4-13 show for each of the four principal verification areas the impact of the following.

- Variation in data errors in ship data: $\sigma_s = 0$ and $\sigma_s = 1.0$ mb. Data for $\sigma_s = 0$ are extrapolated from other experimental results.
- Variation of data errors in buoy data, combined with ship data: $\sigma_s = 0$ and $\sigma_b = 0$, and $\sigma_s = 1.0$ and $\sigma_b = 0, 1.0$, and 2.0 mb.
- Variation in system reliability of buoys-only data, and buoys combined with 100% reliable ship data: buoy system reliabilities of 100%, 80%, and 50%.

One of the most obvious comparisons that can be made using Figs. 4-10 through 4-13 concerns the number of data buoys in the essentially uniformly distrubuted data buoy networks that provides reduction of Initial Guess RMS analysis error equivalent to that of the ships used in the experiment: i.e., a buoys-only vs. ships-only comparison. Typical data for this comparison are shown in Table 4-11.

TABLE 4-11

A TYPICAL COMPARISON BETWEEN BUOYS AND SHIPS-OF-OPPORTUNITY

Verification Area	Number of Actual Ships	Reduction in I.G. RMS Analysis Error Due to Ships (%)		No. of Buoys ($\sigma_b = 0$) Required for Equal Reduction in I.G. RMS Analysis Error					
				$\sigma_s = 0$ mb			$\sigma_s = 1.0$ mb		
		σ_s =0mb	σ_s =1.0mb	Buoy Reliability (%)			Buoy Reliability (%)		
				100	80	50	100	80	50
Pac Hi Var	108	84 (4.38)[1]	81 (4.22)	89	107	182[2]	68	103	167[2]
Pac Lo Var	20	57 (0.47)	49 (0.40)	37	50	171[2]	23	38	83
Atl Hi Var	72	73 (2.58)	64 (2.27)	46	67	112[2]	28	42	73[2]
Atl Lo Var	31	47 (0.48)	43 (0.44)	33	49	65	27	41	43

[1]Values in parentheses are actual experimental reduction in RMS analysis error (mb), relative to the applicable Initial Guess RMS analysis error for the verification area.

[2]Extrapolated data.

With the exception of Pacific Low Variability area, it is generally evident from Table 4-11 that the essentially uniformly distributed data buoys are more effective than the randomly distributed and highly redundant ships, even for buoy reliabilities of 80%. In the Atlantic variability areas, it appears that equal numbers of 100% reliable ships and buoys that are about 50% reliable perform essentially equally. In the Pacific High Variability area, it appears the comparison is between equal numbers of ships and buoys that are about 80% reliable. The data for the Pacific Low Variability area appear to give almost opposite results. Comparison of the "True" Analysis and the location of these 20 ships (see Figs. 3-4 and 3-15) shows that the ships are located

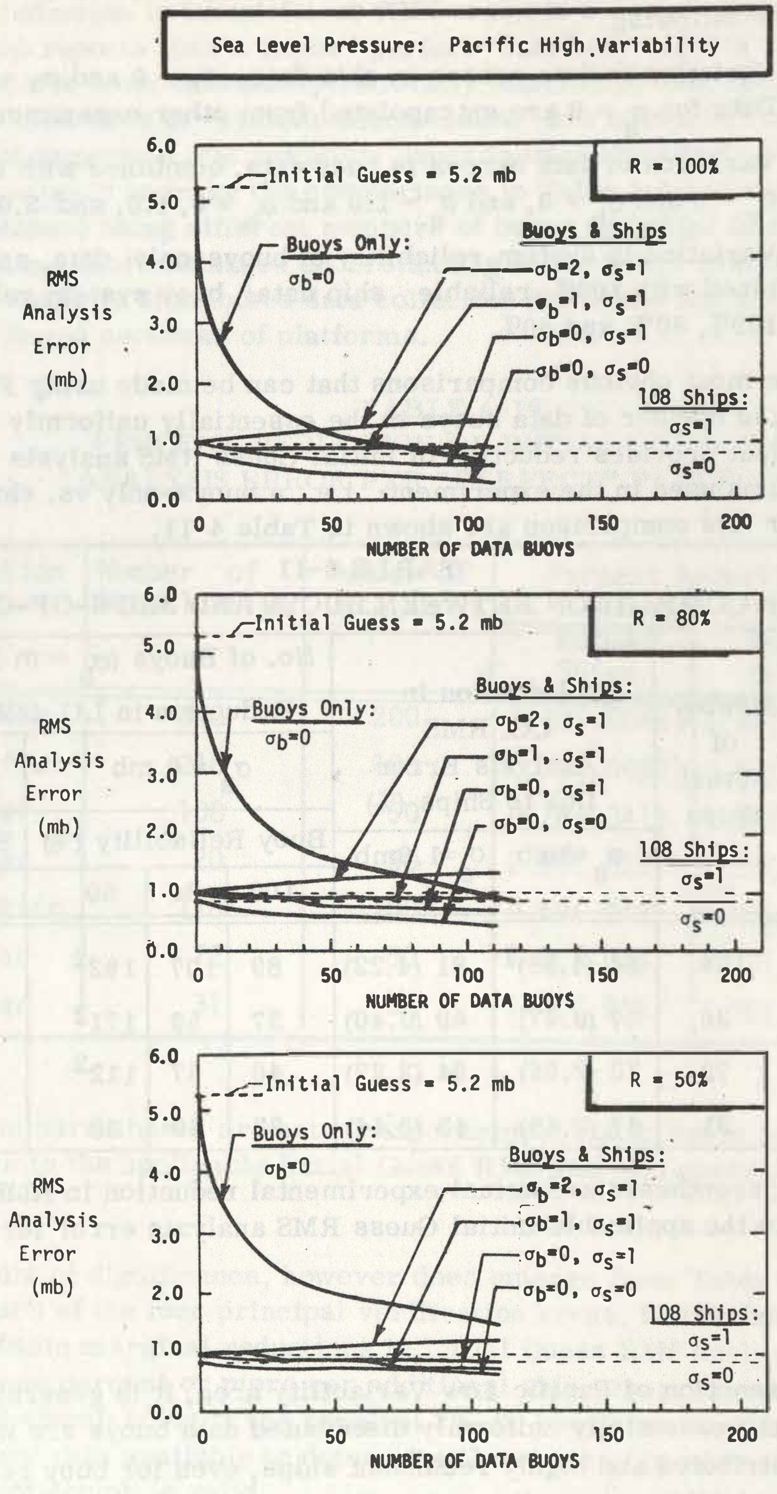


Fig. 4-10. Experimental results for Sea Level Pressure: Buoys and Ships in the Pacific High Variability area.

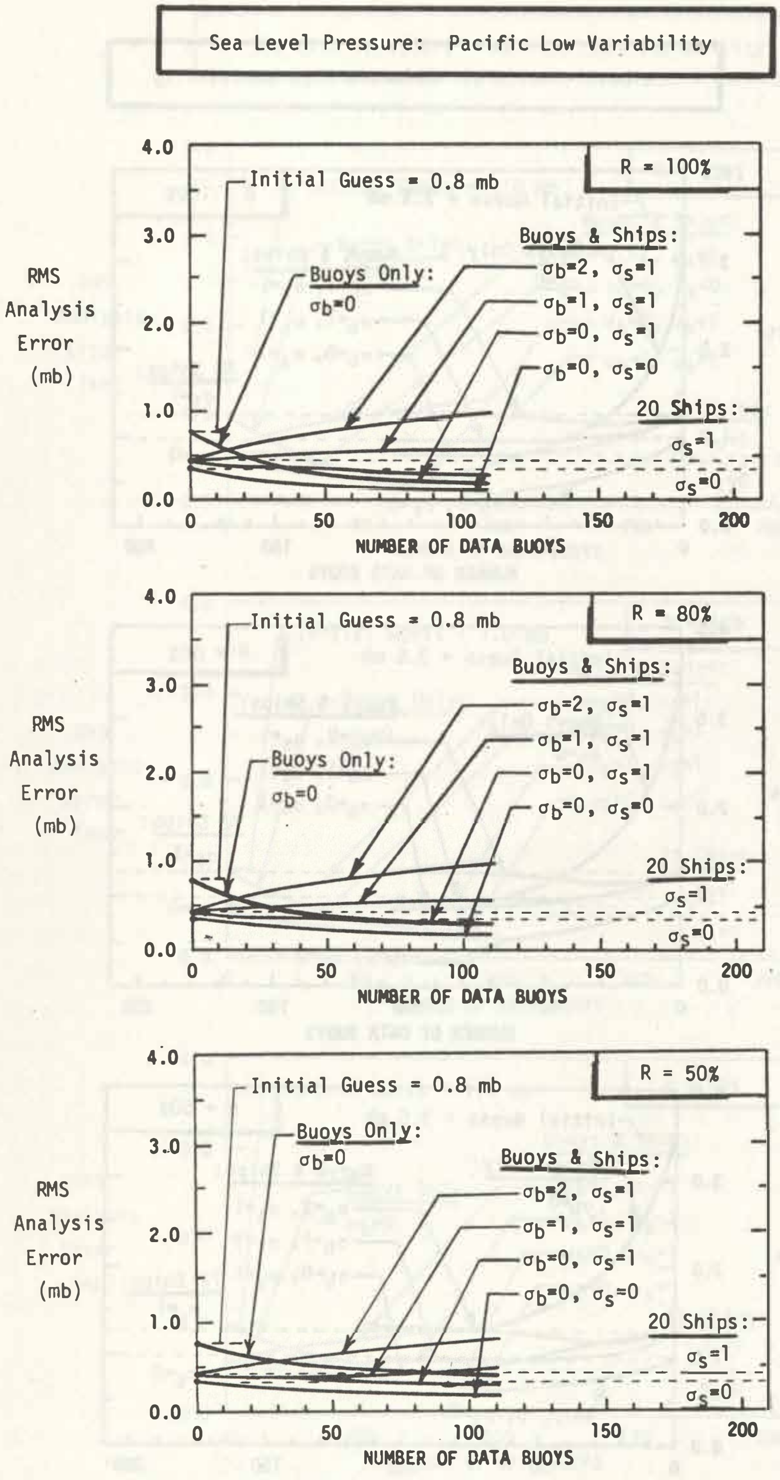


Fig. 4-11. Experimental results for Sea Level Pressure: Buoys and Ships in the Pacific Low Variability area.

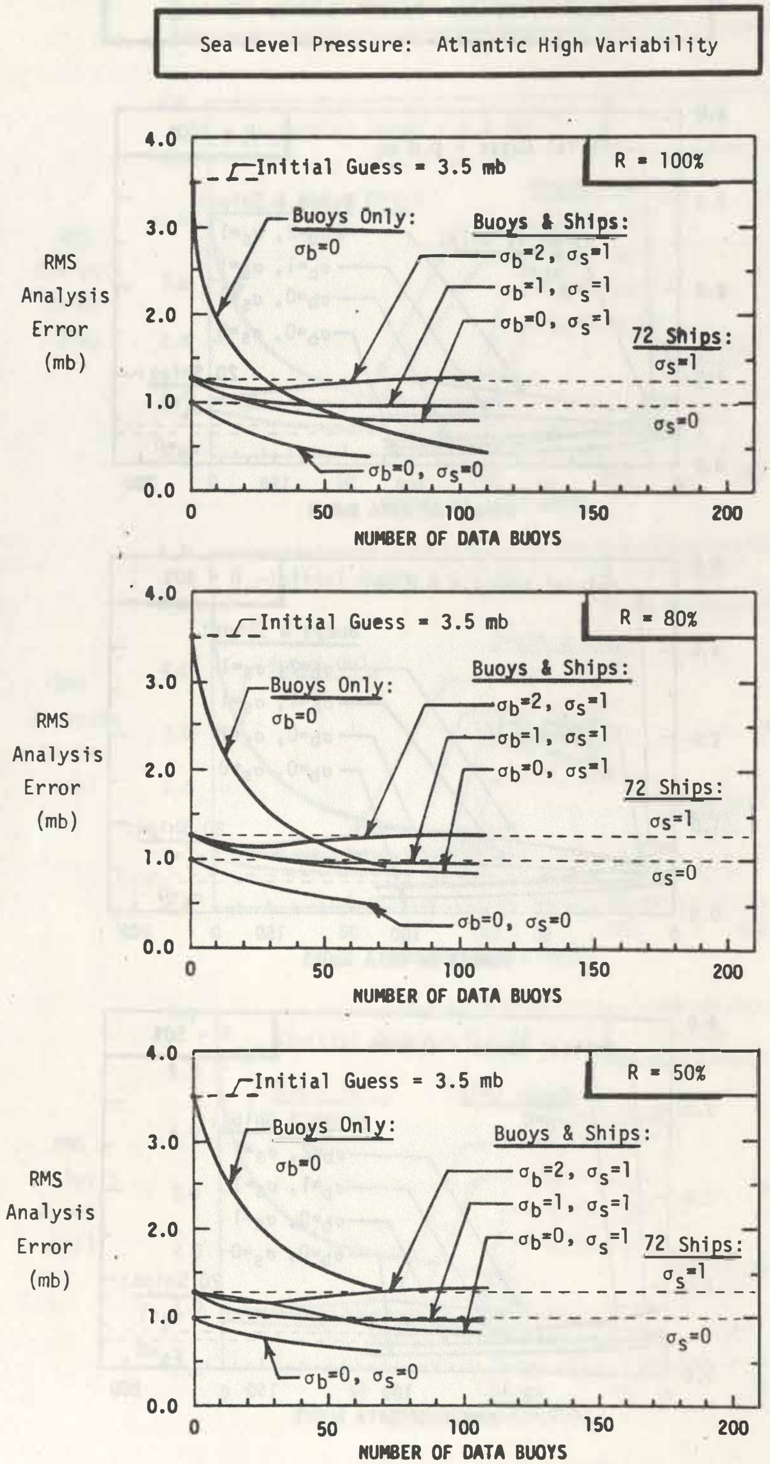


Fig. 4-12. Experimental results for Sea Level Pressure:
Buoys and Ships in the Atlantic High Variability area.

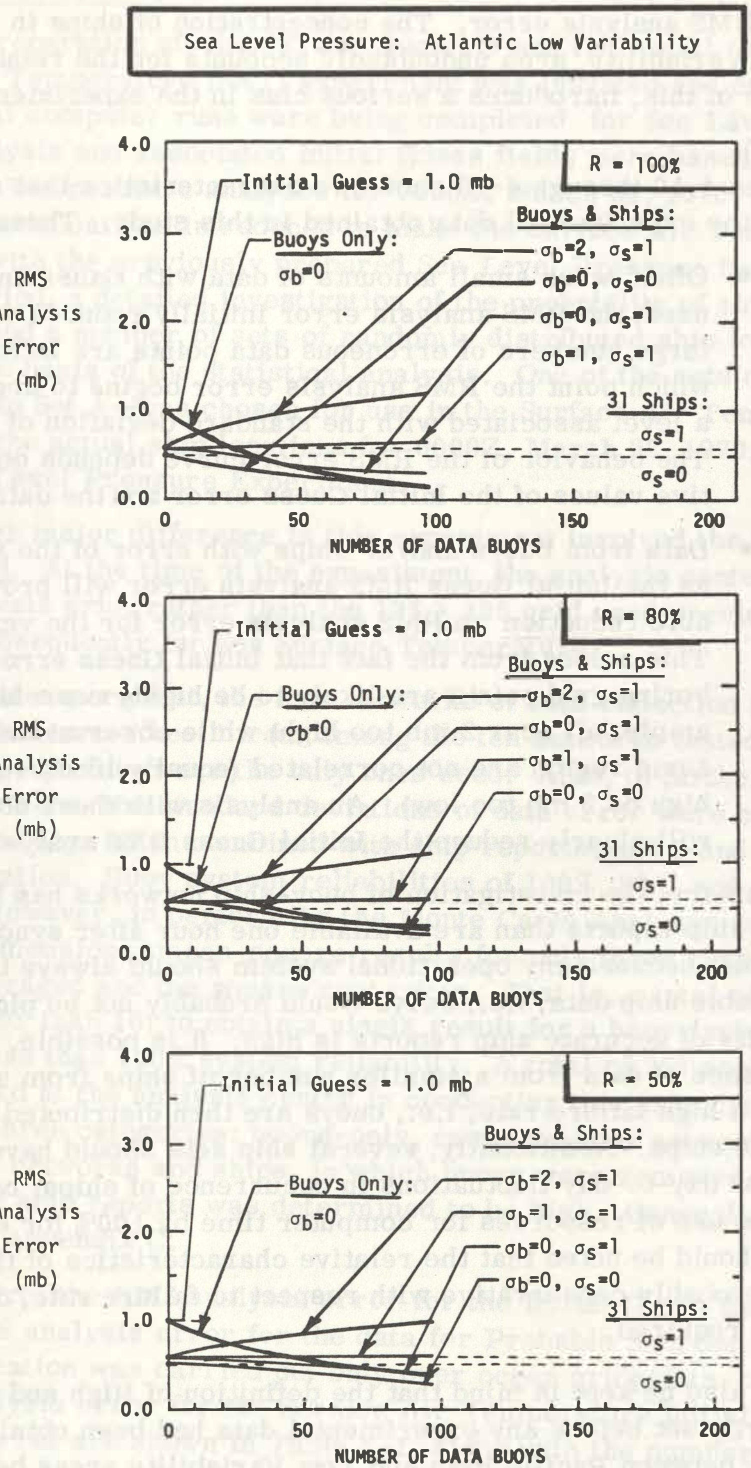


Fig. 4-13. Experimental results for Sea Level Pressure: Buoys and Ships in the Atlantic Low Variability area.

rather densely in the regions of highest variability in the Pacific Low Variability area. That is, by "chance" this small number of ships is in excellent position to reduce I.G. RMS analysis error. The concentration of ships in this portion of the Pacific Low Variability area undoubtedly accounts for the relatively high variability and, because of this, introduces a serious bias in the experimental results obtained for the area.*

Figures 4-10 through 4-13 show two characteristics that are prevalent throughout much of the experimental data obtained in this study. These are as follows.

- Often, when small amounts of data with Gaussian error are used, the RMS analysis error initially reduces until rather large numbers of erroneous data points are introduced, at which point the RMS analysis error begins to degrade toward a level associated with the standard deviation of data error. The behavior of the RMS error curve depends on the relative values of the Initial Guess error and the data error.
- Data from buoys and/or ships with error of the same magnitude as the Initial Guess RMS analysis error will provide considerable reduction in RMS analysis error for the verification area. This arises from the fact that Initial Guess errors at neighboring grid points are likely to be highly correlated (for example, all near 2 mb too high) while observations in the same region are not correlated (equally likely to be 2 mb too high or 2 mb too low). An analysis with these observations will clearly reduce the Initial Guess RMS analysis error.

In summary, the investigation of buoy-ship networks has been complicated by the use of more ship reports than are available one hour after synoptic time. This is an important point because any operational system should always take maximum advantage of available ship data, i.e., buoys would probably not be placed in regions where the probability of accurate ship reports is high. It is possible, however, to estimate the performance of data from a smaller number of ships from appropriate buoys-only results with a high failure rate, i.e., buoys are then distributed in a random manner, not too unlike ships. Additionally, several ship sets should have been used in the study to account for day-to-day fluctuations in occurrence of ships; however, this would have increased the use of resources for computer time by 100% for each new ship set. In general, it should be noted that the relative characteristics of the buoy-ship error curves are probably conservative with respect to failure rate, data error and number of platforms required.

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*It must also be kept in mind that the definition of High and Low Variability areas was arbitrarily set before any experimental data had been obtained. For example, had the boundary between Pacific High and Low Variability areas been set two grid lengths to the left (south, in the mid-Pacific)—a distance of about 300 ni mi—then only 6 ships (instead of 20) would have been in the Pacific Low Variability area, and the results would have been considerably different. In future experimental work of this kind, it would be desirable to Monte Carlo both the natural variability (i.e., use more than one "True" Analysis) and the location of ship reports. However, that would increase the number of computer runs by an order of magnitude or more.

5.0 RESULTS OF THE SURFACE AIR TEMPERATURE EXPERIMENT

5.1 Overview of the Experiment

The preparation of the "True" Analysis and the Initial Guess field for the Surface Air Temperature (SAT) experiment was initiated and completed while the experimental computer runs were being completed for Sea Level Pressure. The "True" Analysis and associated Initial Guess fields were based on the actual FNWC Surface Air Temperature analyses for 0000Z, March 22, 1970, with a limited amount of manual modifications introduced to make the Surface Air Temperature fields commensurate with the previously prepared Sea Level Pressure fields. During this preparation period, a detailed investigation of the probability of ship reports was conducted, and a number of sets of randomly distributed ship locations were generated on the basis of the statistical analysis. One of the sets of ship locations—Probable Ship Set A—was chosen for use in the Surface Air Temperature experiment, rather than the actual ship locations for 0000Z, March 22, 1970, which had been used for the Sea Level Pressure Experiment.

Another major difference in this experiment involved the Surface Air Temerpature analysis grid. At the time of the experiment, the analysis center was employing a 63 × 63 analysis grid, rather than the 125 × 125 grid used previously for Sea Level Pressure, and subsequently for Sea Surface Temperature.

For this experiment, the four networks of data collection platform locations—previously chosen as "best" from among the ten networks tested in the Sea Level Pressure experiment—were the only ones used. Also, to further conserve resources for computer runs, the standard deviations of data error were confined to 0, 0.5, 1.0, and 3.0°C for buoys when combined with ship reports, and 0 and 1.0°C for the buoys-only investigation. Buoy system reliabilities of 100%, 80%, and 50% were investigated, as before. However, in performing the Monte Carlo Analyses in the data error and reliability dimensions, mean-square results for only three runs (rather than four) were summed, averaged and the square root taken. That is, a total of nine analyses was performed (rather than 16) to obtain a single result for a buoy system with non-zero data error and less than 100% system reliability. A total of 758 analyses (computer runs) was performed at the analysis center in conducting this experiment. These runs were divided into three categories; buoys-only, complete buoy networks and ships, and reduced buoy networks and ships, in which buoys were removed from regions where the probability of ship reports was determined to be high. General experimental results are shown in Appendix C.

As before, the RMS analysis error for the Initial Guess field was computed first. Next, the RMS analysis error for the data for Probable Ship Set A was determined. Again, verification was carried out only over ocean gridpoints, by using the land "mask." The RMS analysis error for the Surface Air Temperature Initial Guess field and the Probable Ship Set are shown in Table 5-1, along with the number of verification grid points and number of probable ships.

As can be seen from the table, the introduction of the ship data in the volume shown generally improves the RMS analysis error over that of the Initial Guess field by more than 60% in every verification area. Note also, that in those instances where the average number of verification gridpoints per ship is low, the RMS analysis error

TABLE 5-1
NUMBER OF VERIFICATION GRID POINTS AND SHIPS;
AND RMS ANALYSIS ERROR VALUES

Verification Area	Number of Verification Grid Points	Number of Probable Ships	RMS Analysis Error (°C)		
			Initial Guess	Probable Ship Set A	
				$\sigma_s = 0°C$	$\sigma_s = 1.0°C$
All Nor. Hem	2554	302	2.52	0.87*	0.89
All Pacific	1515	160	2.42	0.92	0.98
Pac Hi Var	223	79	2.83	0.95	1.06
Pac Lo Var	752	14	1.84	0.65	0.84
All Atlantic	594	142	2.25	0.62	0.85
Atl Hi Var	166	72	2.76	0.62	0.85
Atl Lo Var	382	36	2.12	0.60	0.79
Gulf of Mexico	29	5	2.82	0.32	0.40

*Data in this column obtained by extrapolation of buoy plus ship results.

for ships is also low, e.g., the Atlantic High Variability area and the Gulf of Mexico area. Of course, in most of the verification areas, a considerable amount of redundancy may exist, for the probable ship set is generated in a manner that allows up to five ship reports to influence a single gridpoint in the 63 × 63 grid. As will be shown subsequently, in general, good reduction in RMS analysis error can be achieved for the Surface Air Temperature Parameter, in part because of the large scales of natural variability of the parameter, and in part because the ratio of average number of verification gridpoints per data collection platform can be made low with relatively small numbers of platforms (i.e., buoys and/or ships).

5.2 Typical Experimental Results for Buoys Only*

Figure 5-1 shows the impact of increasing the number of data buoys and varying system reliability for each of the eight verification areas. All experimental results in Fig. 5-1 are for zero data error. As in Fig. 4-1, average spacing between data buoys in the Pacific and Atlantic High and Low Variability areas is indicated.

*These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

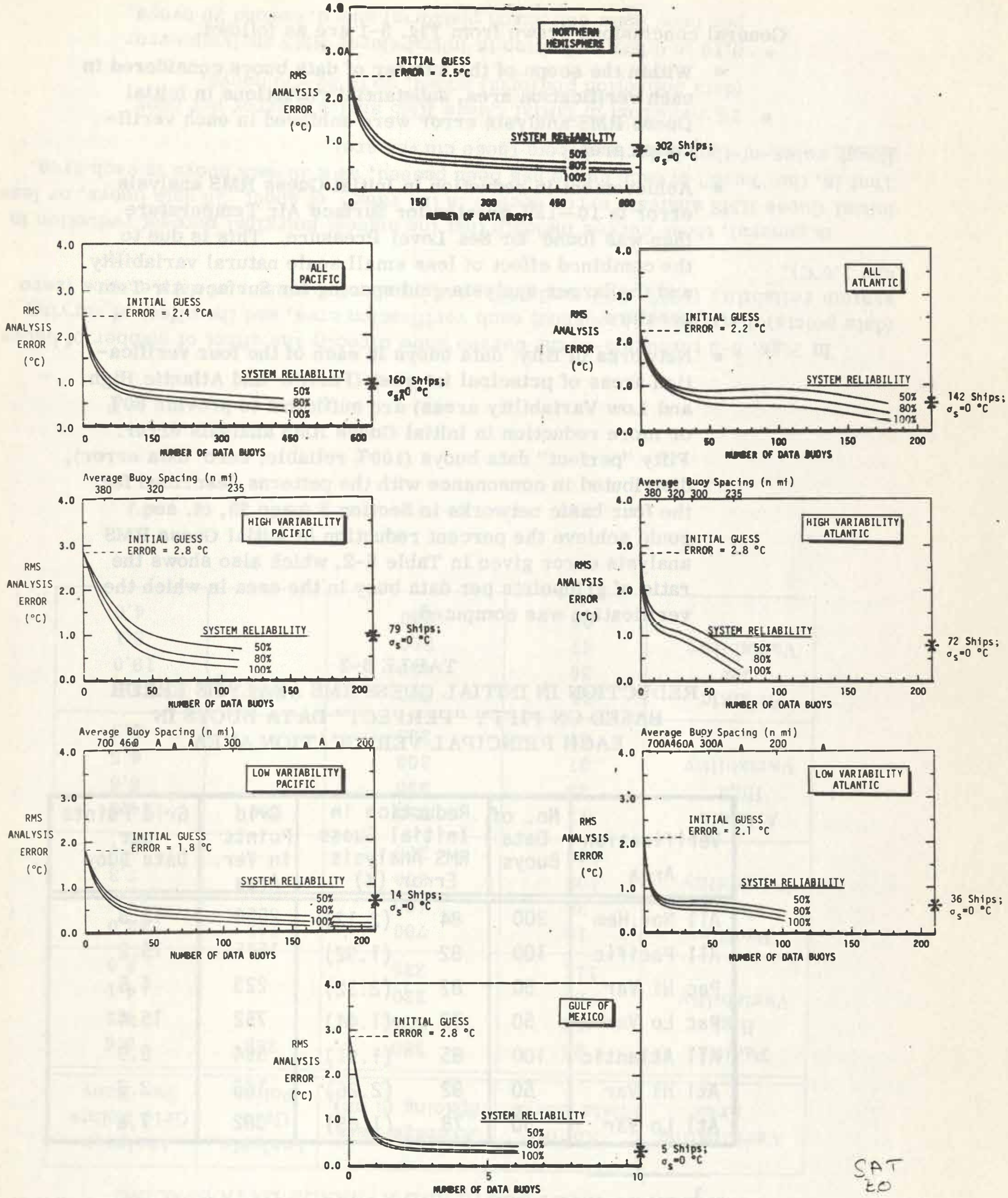

Fig. 5-1. Experimental results for Surface Air Temperature: Buoys Only; σ_b = 0 °C.

General conclusions drawn from Fig. 5-1 are as follows.

- Within the scope of the number of data buoys considered in each verification area, substantial reductions in Initial Guess RMS analysis error were achieved in each verification area.
- Achievement in reduction in Initial Guess RMS analysis error is 10—15% greater for Surface Air Temperature than was found for Sea Level Pressure. This is due to the combined effect of less small scale natural variability and the larger analysis grid spacing for Surface Air Temperature.
- Networks of fifty data buoys in each of the four verification areas of principal interest (Pacific and Atlantic High and Low Variability areas) are sufficient to provide 60% or more reduction in Initial Guess RMS analysis error. Fifty "perfect" data buoys (100% reliable; zero data error), distributed in consonance with the patterns described for the four basic networks in Section 3 (page 28, et. seq.) could achieve the percent reduction in Initial Guess RMS analysis error given in Table 5-2, which also shows the ratio of gridpoints per data buoy in the area in which the verification was computed.

TABLE 5-2
REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR BASED ON FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No. of Data Buoys	Reduction in Initial Guess RMS Analysis Error (%)		Grid Points in Ver. Area	Grid Points per Data Buoy
All Nor.Hem	200	84	(2.12)[1]	2554	12.8
All Pacific	100	82	(1.92)	1515	15.2
Pac Hi Var	50	82	(2.32)	223	4.5
Pac Lo Var	50	78	(1.44)	752	15.4
All Atlantic	100	85	(1.91)	594	5.9
Atl Hi Var	50	82	(2.26)	166	3.3
Atl Lo Var	50	78	(1.65)	382	7.6

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

It is apparent, both from the results in Table 5-2 and the curves in Fig. 5-1, that 50 "perfect" data buoys per verification area provide sufficient coverage to achieve most of the possible improvement in reduction of Initial Guess RMS analysis error. For example, when the average number of gridpoints per data point falls below 12, then each non-data gridpoint is being influenced considerably by more than one data point. This condition exists for three of the four principal verification areas noted in Table 5-2, assuming 50 "perfect" buoys (or, data collection platforms) essentially uniformly distributed throughout each area.

It is of interest to note that in all but the Pacific High Variability area the "knee" of the RMS analysis error curve occurs in the range of networks comprising 20—30 data buoys. Also, the data in Table 5-2 shows that approximately equal reductions in Initial Guess RMS analysis error are achieved for essentially equal ratios of gridpoints per data buoy. This is consistent with the fact that analysis error is a monotonic function of effor-free data.

The remainder of this section presents design curves and examples of system design, compatible with similar material for Sea Level Pressure in Section 4.

5.3 System Design Curves for Surface Air Temperature—Buoys Only*

The figures presented in this subsection are intended for use in preliminary design or evaluation of data buoy systems (or any other type of data collection platform having similar measurement and reliability characteristics). The curves in Figs. 5-2 through 5-5 are based on experimental results using the FNWC Surface Air Temperature analysis model. Subsequent Figs. 5-6 through 5-8 were obtained from crossplots of the curves in Figs. 5-2 through 5-5.

The curves in Figs. 5-2 through 5-5, showing percent reduction in Initial Guess RMS analysis error as a function of number of data buoys, are each based on four networks of data buoys.† The actual location of data buoys within a verification area was not uniform throughout the area, but was arranged in what was determined in the Sea Level Pressure experiment to be the best of two or three different distributions. For the number of data buoys in each area, the approximate average spacing between buoys is given in Table 5-3. The table also gives the approximate number of grid points in each verification area over which the RMS analysis error was computed. It is emphasized that the buoy locations were such that these average values were not realized in many instances, which is why there is not a perfect match between average grid spacings and average number of grid points per buoy. The conversions are considerably complicated by the nonlinear distortion introduced by the polar stereographic projection used for the numerical weather prediction grid.

*These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

†To aid the reader in relating percent reduction of Initial Guess RMS analysis error to actual experimental results, scales calibrated in degrees Centigrade appear along the right-hand side of all graphs in Figs. 5-2 through 5-8. Also, the RMS analysis error for zero-error data from fixed numbers of ships-only is shown in these figures.

TABLE 5-3
NUMBER OF DATA BUOYS AND AVERAGE DATA SPACING

Verification Area	No. of Data Buoys	Average Data Spacing (n mi)	Analysis Grid Points	Analysis Grid Points Per Buoy
Pacific High Variability	26	380	223	8.6
	53	320		4.2
	54	320		4.1
	111	235		2.0
Pacific Low Variability	18	700	752	42.0
	28	460		27.0
	103	300		7.3
	206	200		3.7
Atlantic High Variability	12	380	166	14.0
	25	320		6.6
	37	300		4.5
	67	235		2.5
Atlantic Low Variability	11	700	382	35.0
	20	450		19.0
	47	300		8.1
	96	200		4.0

In Figs. 5-2 through 5-5, the curves show directly the effect of number of buoys (data points) distributed throughout each verification area, and the effect of varying system reliability (100%, 80%, and 50%), and standard deviation of data errors (zero and 1.0°C).

In general, these curves indicate that the highest marginal percent reduction in Initial Guess RMS analysis error occurs in the range of about 30 data buoys, or less. That is, the "knee" of each curve has been passed, with 30 data buoys in each area. Rough rules-of-thumb derived from these curves are:

- 2% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, up to 20—30 buoys,
- 0.10 to 0.20% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, beyond 30 byoys,

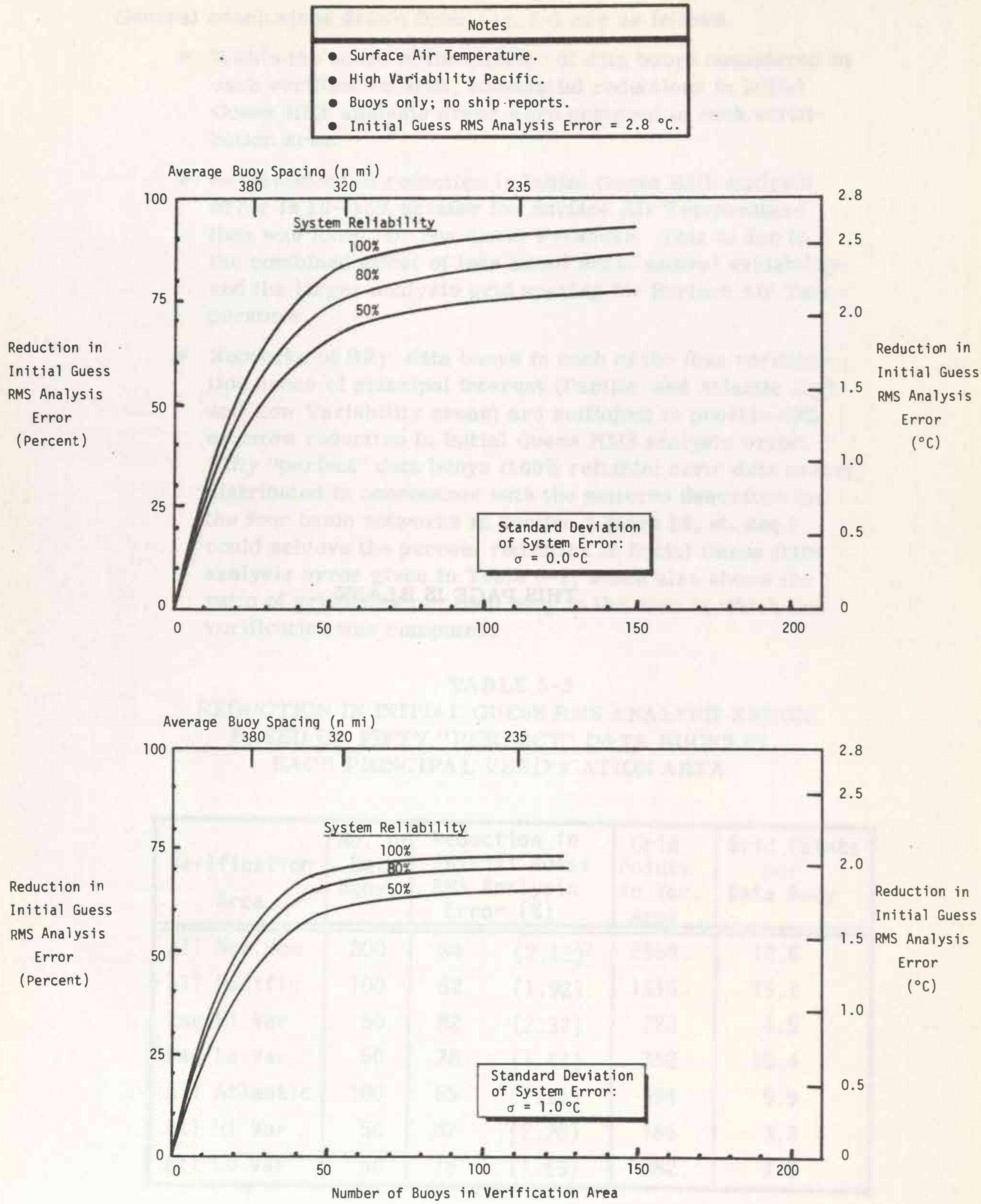

Fig. 5-2. System design curves for Surface Air Temperature in the Pacific High Variability verification area.

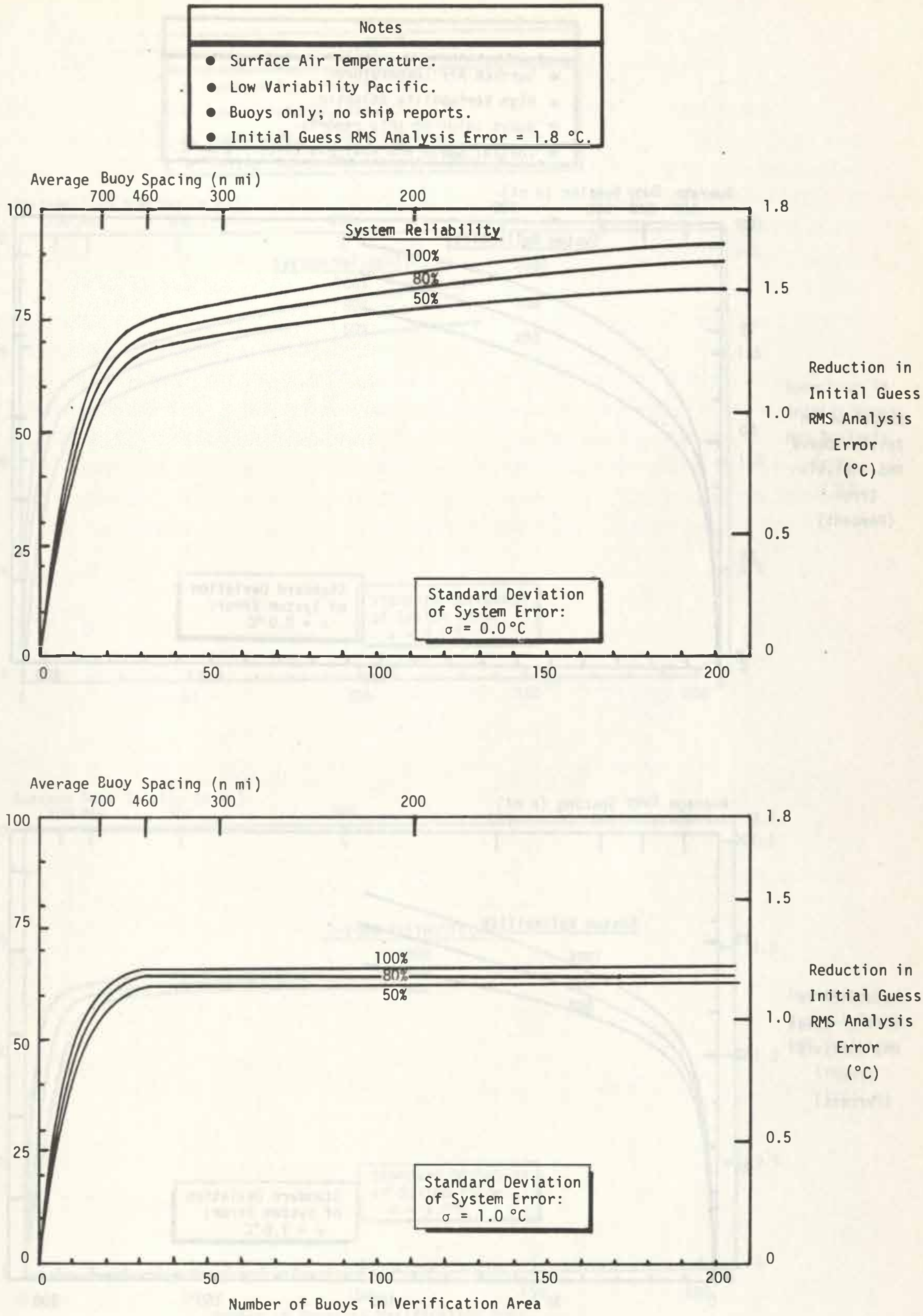

Fig. 5-3. System design curves for Surface Air Temperature in the Pacific Low Variability verification area.

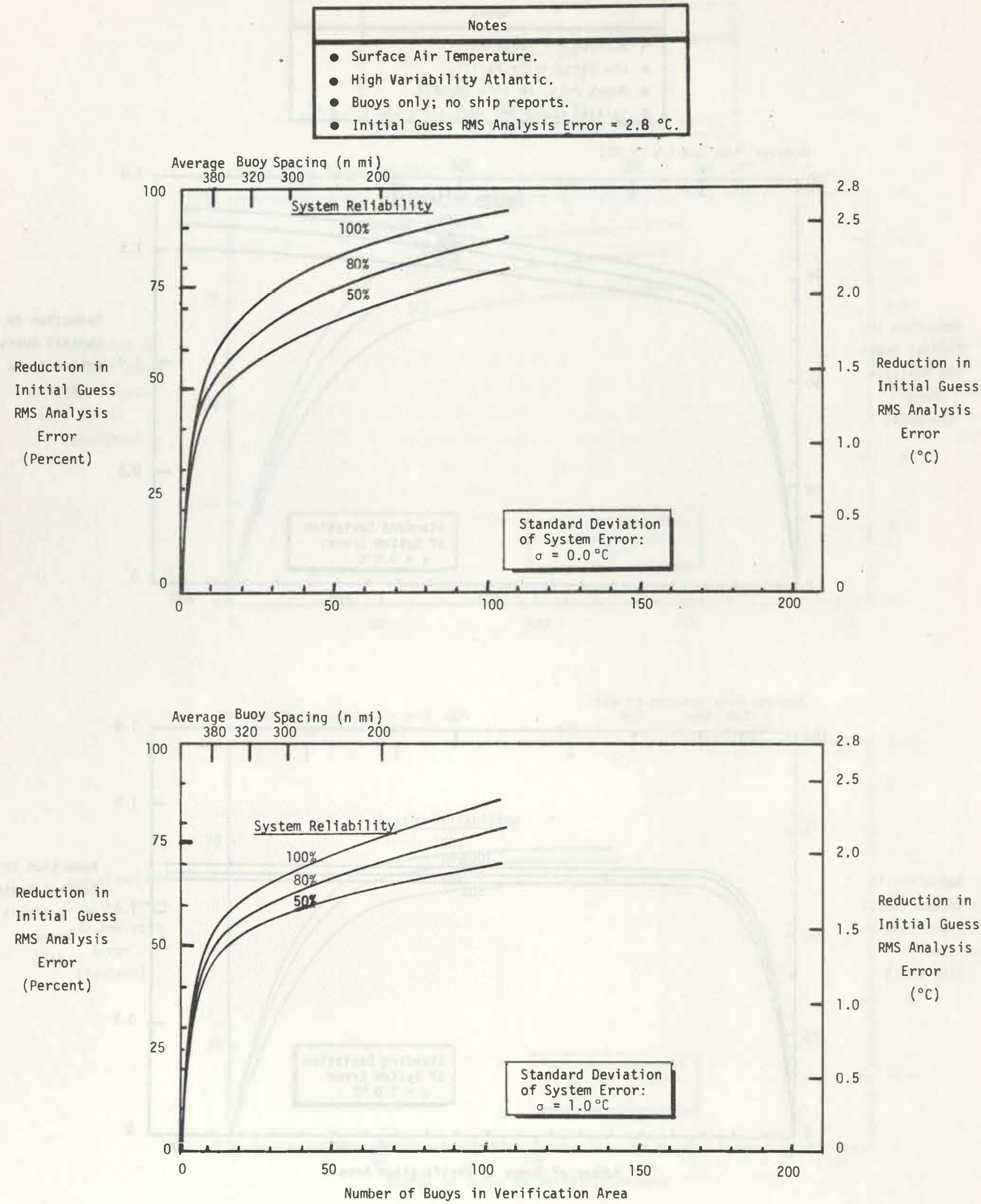

Fig. 5-4. System design curves for Surface Air Temperature in the Atlantic High Variability verification area.

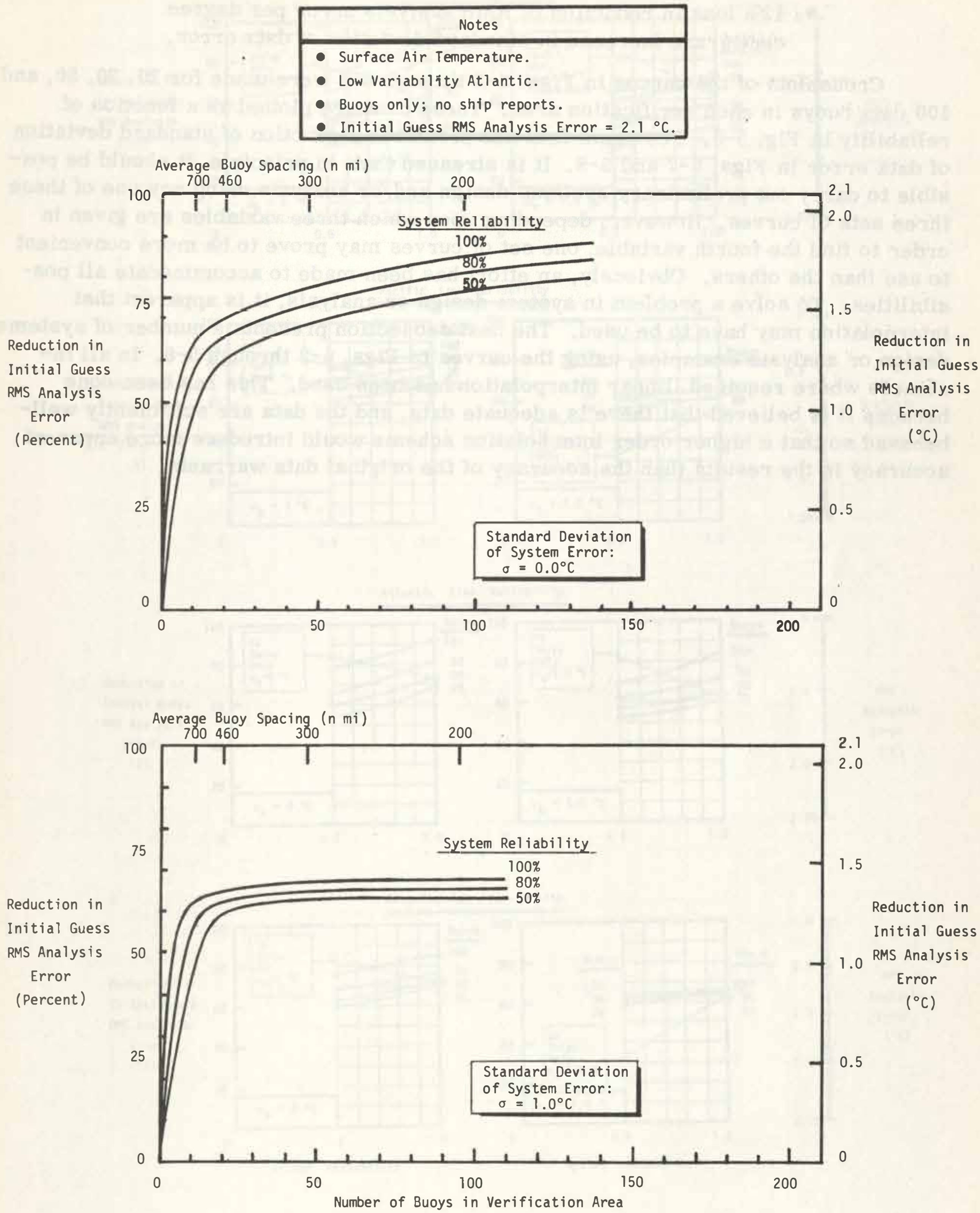

Fig. 5-5. System design curves for Surface Air Temperature in the Atlantic Low Variability verification area.

- 12% loss in reduction of RMS analysis error per degree centigrade increase in standard deviation of data error,

Crossplots of the curves in Figs. 5-2 through 5-5 were made for 20, 30, 50, and 100 data buoys in each verification area. These data are plotted as a function of reliability in Fig. 5-6. The same data are plotted as a function of standard deviation of data error in Figs. 5-7 and 5-8. It is stressed that, in principle, it should be possible to carry out preliminary systems design and/or analysis using any one of these three sets of curves. However, depending upon which three variables are given in order to find the fourth variable, one set of curves may prove to be more convenient to use than the others. Obviously, an effort has been made to accommodate all possibilities. To solve a problem in system design or analysis, it is apparent that interpolation may have to be used. The next subsection presents a number of systems design or analysis examples, using the curves in Figs. 5-2 through 5-8. In all instances where required, linear interpolation has been used. This has been done because it is believed that there is adequate data, and the data are sufficiently well-behaved so that a higher order interpolation scheme would introduce more apparent accuracy in the results than the accuracy of the original data warrants.

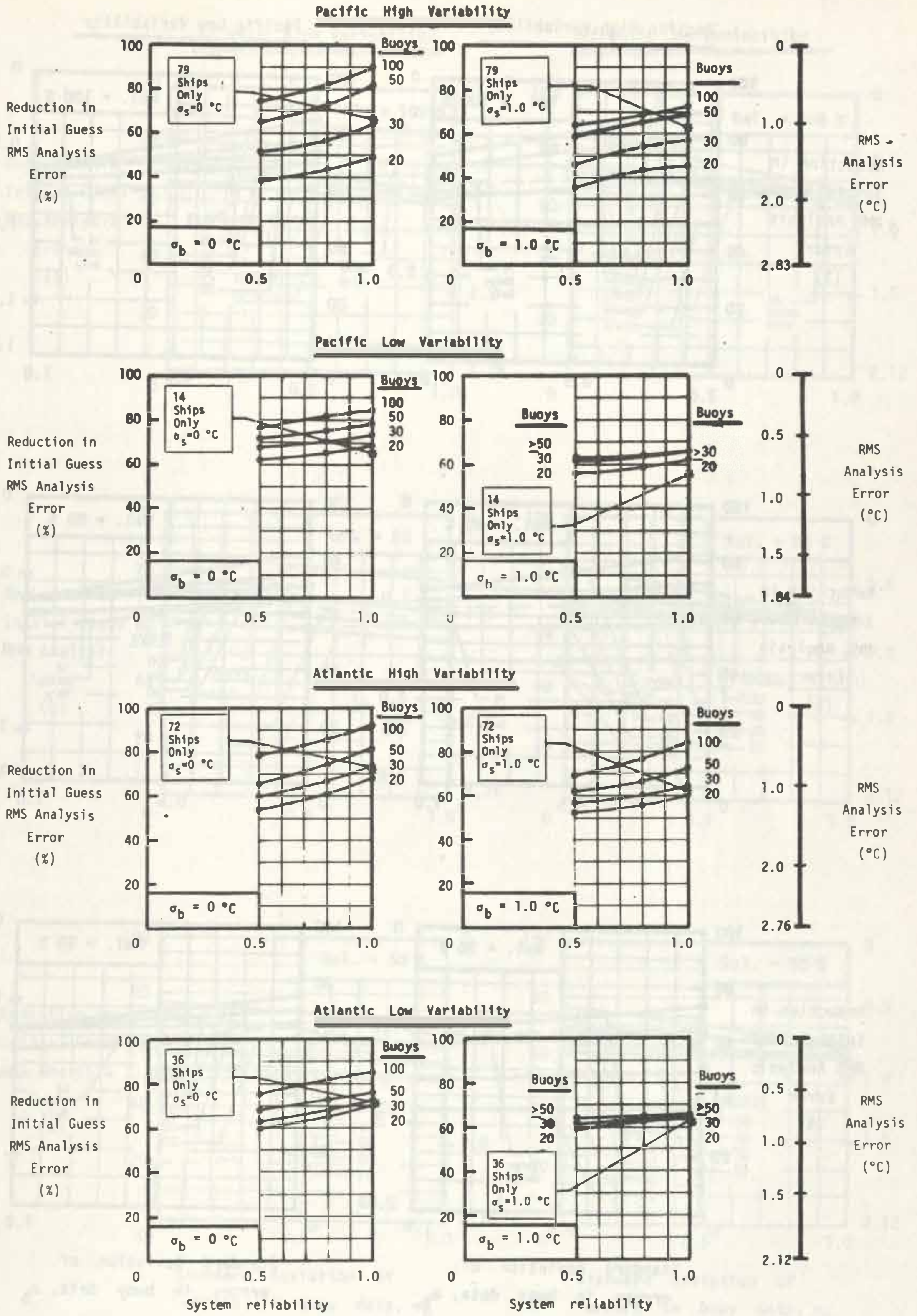

Fig. 5-6. System design curves for Surface Air Temperature, emphasizing reliability: Buoys Only.

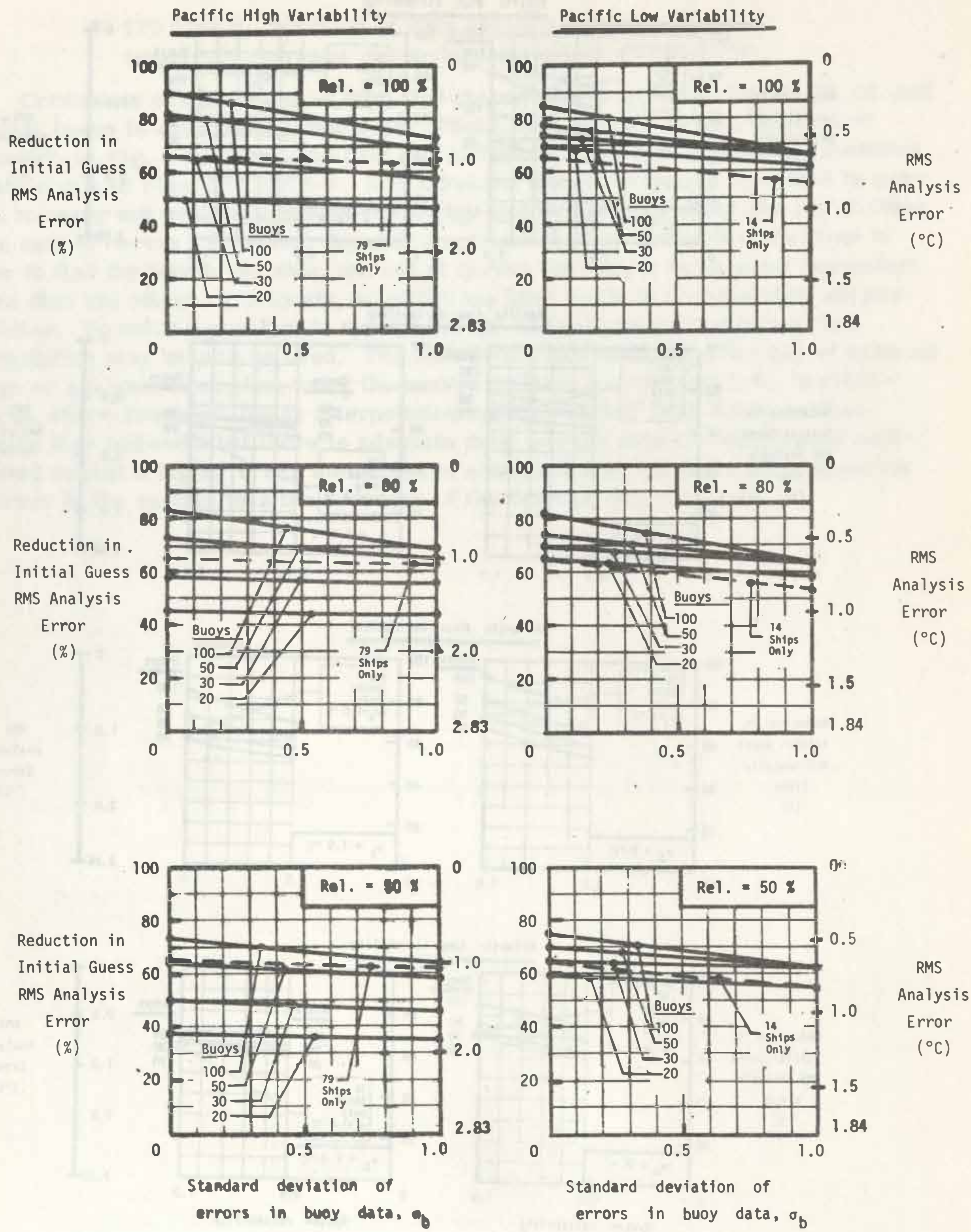

Fig. 5-7. System design curves for Surface Air Temperature, emphasizing errors in buoy data: Buoys Only.

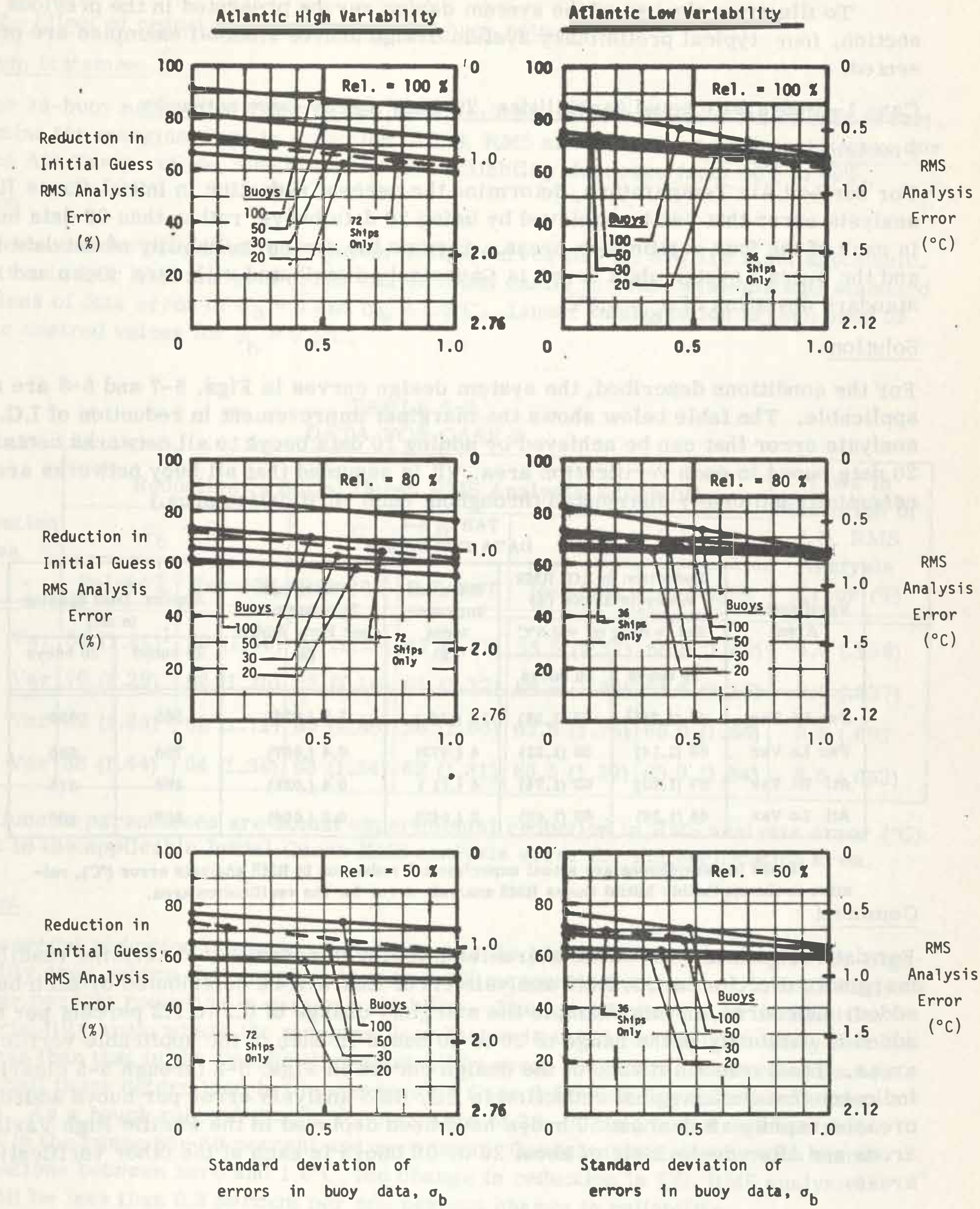

Fig. 5-8. System design curves for Surface Air Temperature, emphasizing errors in buoy data: Buoys Only.

5.4 Examples of System Design: Buoys Only*

To illustrate the use of the system design curves presented in the previous subsection, four typical preliminary system design and/or tradeoff examples are presented.

Case 1—Buoys with equal capabilities: 20-buoy and 30-buoy networks

Problem Statement

For Surface Air Temperature, determine the percent reduction in Initial Guess RMS analysis error that can be achieved by using 30 data buoys, rather than 20 data buoys, in each of the four verification areas. Assume the system reliability of the data is 80%, and the overall system data error is Gaussianly distributed with zero mean and a standard deviation of $\sigma_b = 0.5°C$.

Solution

For the conditions described, the system design curves in Figs. 5-7 and 5-8 are most applicable. The table below shows the marginal improvement in reduction of I.G. RMS analysis error that can be achieved by adding 10 data buoys to all networks containing 20 data buoys in each verification area. (It is assumed that all buoy networks are essentially uniformly distributed throughout each verification area.)

TABLE 5-4
DATA FOR CASE 1

Verification Area	Reduction in I.G. RMS Analysis Error (%) Rel. = 80%; σ_b = 0.5°C		Marginal Improvement (%)	Marginal Improvement per Buoy Added (%)	Approx. Data Spacing (n mi)	
	20 buoys	30 buoys			20 buoys	30 buoys
Pac Hi Var	44 (1.25)[1]	56 (1.58)	12 (.34)	1.2 (.034)	565	450
Pac Lo Var	62 (1.14)	66 (1.21)	4 (.073)	0.4 (.007)	750	580
Atl Hi Var	59 (1.63)	63 (1.74)	4 (.11)	0.4 (.011)	460	375
Atl Lo Var	64 (1.36)	66 (1.40)	2 (.042)	0.2 (.004)	500	400

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

For data buoys with equivalent characteristics, it is possible to determine readily the marginal reduction in I.G. RMS analysis error that will be contributed by each buoy added. Of course, in this example the marginal change of 0.2 to 1.2 percent per buoy added is valid only in the range of 20 to 30 buoys in each of the applicable verification areas. The parabolic nature of the design curves in Figs. 5-2 through 5-5 clearly indicates that the marginal reduction in I.G. RMS analysis error per buoys added decreases rapidly after about 50 buoys have been deployed in the Pacific High Variability areas and after deployment of about 20 or 30 buoys in each of the other verification areas.

*These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

Case 2—Effect of reduction in reliability: 30-buoy network

Problem Statement

For the 30-buoy network of Case 1 (80% reliable; 0.5°C standard deviation of data error), determine the marginal loss in reduction of I.G. RMS analysis error that would occur for Surface Air Temperature, should the system reliability decrease from 80% to 60%.

Solution

For the conditions presented, the system design curves in Fig. 5-6 are most applicable. Reduction in I.G. RMS analysis error can be found easily for buoy systems with standard deviations of data error of $\sigma_b = 0$ and $\sigma_b = 1.0$°C. Linear interpolation is then used to find the desired values for $\sigma_b = 0.5$°C.

TABLE 5-5
DATA FOR CASE 2

Verification Area	Reduction in Initial Guess RMS Analysis Error (%)						Loss in Reduction of I.G. RMS Analysis Error (%)
	$\sigma_b = 0$		$\sigma_b = 1.0$		$\sigma_b = 0.5$		
	Rel=80%	Rel=60%	Rel=80%	Rel=60%	Rel=80%	Rel=60%	
Pac Hi Var	57 (1.61)[1]	53 (1.50)	54 (1.53)	47 (1.33)	55.5 (1.57)	50.0 (1.42)	5.5 (.156)
Pac Lo Var	70 (1.29)	68 (1.25)	63 (1.16)	61 (1.12)	66.5 (1.22)	64.5 (1.19)	2.0 (.037)
Atl Hi Var	67 (1.85)	62 (1.71)	60 (1.66)	58 (1.60)	63.5 (1.75)	60.0 (1.66)	3.5 (.097
Atl Lo Var	68 (1.44)	64 (1.36)	63 (1.34)	62 (1.31)	65.5 (1.39)	63.0 (1.34)	2.5 (.053)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C) relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

The 20 percent reduction in system reliability has its highest impact in the Pacific High Variability area, where the marginal loss is 0.275 percent reduction in I.G. RMS analysis error per percent reduction in system reliability. The least impact is in the Pacific Low Variability area, where the marginal loss factor is 0.075, or approximately four times less than that in the Pacific High Variability area. In general, these factors are roughly half those determined in the comparable Case 2 for Sea Level Pressure (see page 72). As a rough rule-of-thumb, for networks of 20—30 data buoys, system reliabilities in the range 60—80 percent and zero mean Gaussian data errors with standard deviations between zero and 1.0°C, the change in reduction in I.G. RMS analysis error will be less than 0.3 percent per one percent change in reliability.

Case 3—Tradeoff comparison of 20-buoy and 30-buoy networks

Problem Statement

For Surface Air Temperature, compare the reduction in Initial Guess RMS analysis error for a 30-buoy network having a system reliability of 60% and an 0.5°C standard deviation of data error with a 20-buoy network having a system reliability of 90% and a 0.1°C standard deviation of data error, for each of the four verification areas.

Solution

Data for the 30-buoy networks (R = 60%; σ_b = 0.5°C) can be taken directly from Case 2. Data for the 20-buoy networks (R = 90%; σ_b = 0.1°C) is most conveniently obtained from the curves for 100% and 80% reliability in Figs. 5-7 and 5-8, with linear interpolation used to determine the data for 90% reliability. Note that, on the average, in each network, 18 buoys would be delivering data to the shore data dissemination hub.

TABLE 5-6
DATA FOR CASE 3

Verification Area	Reduction in RMS Analysis Error (%)				Col. A—Col. B (%)
	20 buoys; σ_b = 0.1°C			30 buoys; σ_b = 0.5°C	
	Rel=100%	Rel=80%	Rel=90%	Rel=60%	
Pac Hi Var	49 (1.39)[1]	44 (1.25)	46.4 (1.32)	50 (1.42)	-3.5 (-.099)
Pac Lo Var	68 (1.25)	64 (1.18)	66 (1.21)	64.5 (1.19)	1.5 (.028)
Atl Hi Var	67 (1.85)	61 (1.68)	64 (1.77)	60 (1.66)	4 (.11)
Atl Lo Var	70 (1.48)	65 (1.38	67.5 (1.43)	63 (1.34)	4.5 (.095)
			Column A	Column B	

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C) relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

In the Pacific Low Variability area, the two networks are almost exact tradeoffs. In the Pacific High Variability area, the less reliable and accurate 30-buoy network has a slight edge over the less densely deployed 20-buoy network. In both Atlantic High and Low Variability areas, the more reliable and accurate 20-buoy networks appear to be somewhat preferable.

It is apparent that the marginal development, implementation, and operational costs required to increase system reliability from 60% to 90%, and reduce the standard deviation of system data error from 0.5°C to 0.1°C (the present requirement), can be traded off against the marginal implementation and operational cost of 10 buoys having 60% system reliability and σ_b = 0.5°C.

Case 4—Alternative systems producing the same reduction in I.G. RMS analysis error

Problem Statement

For Surface Air Temperature, determine the number of data buoys required to achieve a 60% reduction of Initial Guess RMS analysis error in each of the four verification areas, for the following conditions: zero standard deviation of data error and system reliabilities of 100%, 80%, and 50%, and 1.0°C standard deviation of data error and system reliabilities of 100%, 80%, and 50%.

Solution

For the conditions described, the system design curves in Figs. 5-2 through 5-5 are most applicable. The table below shows the number of data buoys required in each verification area to achieve 60% reduction in I.G. RMS analysis error.

TABLE 5-7
DATA FOR CASE 4

Verification Area	No. Buoys Required for 60% Reduction in RMS Analysis Error					
	$\sigma_b = 0°C$			$\sigma_b = 1.0°C$		
	Rel. = 100%	Rel. = 80%	Rel. = 50%	Rel. = 100%	Rel. = 80%	Rel. = 50%
Pac Hi Var	20	31	40	30	36	51
Pac Lo Var	13	17	20	18	21	26
Atl Hi Var	12	19	31	19	38	41
Atl Lo Var	7	12	20	8	10*	13*

*Results questionable.

Comments

The desired 60% reduction in I.G. RMS analysis error can be achieved with modest numbers of buoys, even with system reliability as low as 50%, and standard deviation of error of 1.0°C. This is probably due both to the large scales of natural variability of Surface Air Temperature and to the use of a 63 × 63 analysis grid at FNWC. Should the 125 × 125 grid be used, it is expected that the resulting design curves would show that more data buoys would be required to achieve 60% reduction in I.G. RMS analysis error.

The data for $\sigma_b = 1.0°C$ and Rel. = 80% and 50% for the Atlantic Low Variability area are suspect. It would be expected that these values of 10 and 13 data buoys should be greater than 12 and 20, respectively, in order to make them commensurate with the data for $\sigma_b = 0°C$. In general, insufficient data were run during the experiments at FNWC to put a high level of credibility in system designs that result in less than 20 data buoys in a verification area.

5.5 Typical Experimental Results for Buoys and Ships

For the Surface Air Temperature experiment, the analyses performed were made using Probable Ship Set A, described in Section 3.3.4. There were 302 ships distributed throughout the northern hemisphere, at least one grid length apart (125 x 125 grid). All Probable Ship locations were at grid points; hence, there was no interpolation error involved in going from the "True" Analysis to data for Probable Ship locations. Two fields of Probable Ship Set A data were prepared: one with zero data error and one in which zero mean Gaussian random errors with a standard deviation of 1.0°C were introduced.

As noted in Section 4.5, the concept of obtaining 302 non-redundant ship reports within one hour after a synoptic period is optimistic, in comparison to present conditions. However, this may be possible in the future.

As noted in Section 4.5, for the Sea Level Pressure experiment, adding data buoys in essentially uniformly distributed networks throughout the four principal verification areas in the northern Pacific and the northern Atlantic will, under ideal conditions, considerably enhance ship data, reducing the Initial Guess RMS analysis error very close to zero. Figure 5-9 shows a typical set of experimental results for both ships and buoys with zero error, and buoy system reliabilities of 100%, 80%, and 50%. Table 5-8 shows the percent reduction of Initial Guess RMS analysis error achieved by the ships alone; the percent reduction in Initial Guess RMS analysis error achieved by 50 "perfect" buoys in each verification area; and the percent reduction in Initial Guess RMS analysis error stemming from the combined "perfect" ship data and the "perfect" data from 50 buoys in each principal verification area.

The data in Table 5-8 are intended primarily to convey the impression that under ideal conditions buoy and ship reports in large numbers would be rather redundant. Of course, as noted elsewhere, it is not clear at what period in the future ship reports will be received with the timeliness and accuracy being required of data from buoys. Furthermore, it is evident that buoy data considerably enhance that from ships. In general, data from smaller numbers of essentially uniformly distributed buoys appear to do better than the data from Probable Ship Set A.

Most probably because of the redundancy of ship reports from certain regions, the percent reduction in Initial Guess RMS analysis error is generally less for "perfect" ship reports than it is for "perfect" data buoy reports (or, more properly, "perfect" reports from essentially uniformly distributed data collection platforms). These crude measures of "system effectiveness" are shown in Table 5-9. However, it is not suggested that sufficient experimental investigations and analyses have been conducted to make the comparisons in Table 5-9 of great significance. Data should be obtained using different numbers of buoys and ships in combination in order to obtain a more balanced understanding of the entire question of the effectiveness of randomly distributed data collection platforms and essentially uniformly distributed networks of platforms.

A major point illustrated by Table 5-9 is that it is possible, within each of the four principal verification areas, to obtain marginal improvements in Surface Air Temperature Initial Guess RMS analysis error that are in the range of one percent or

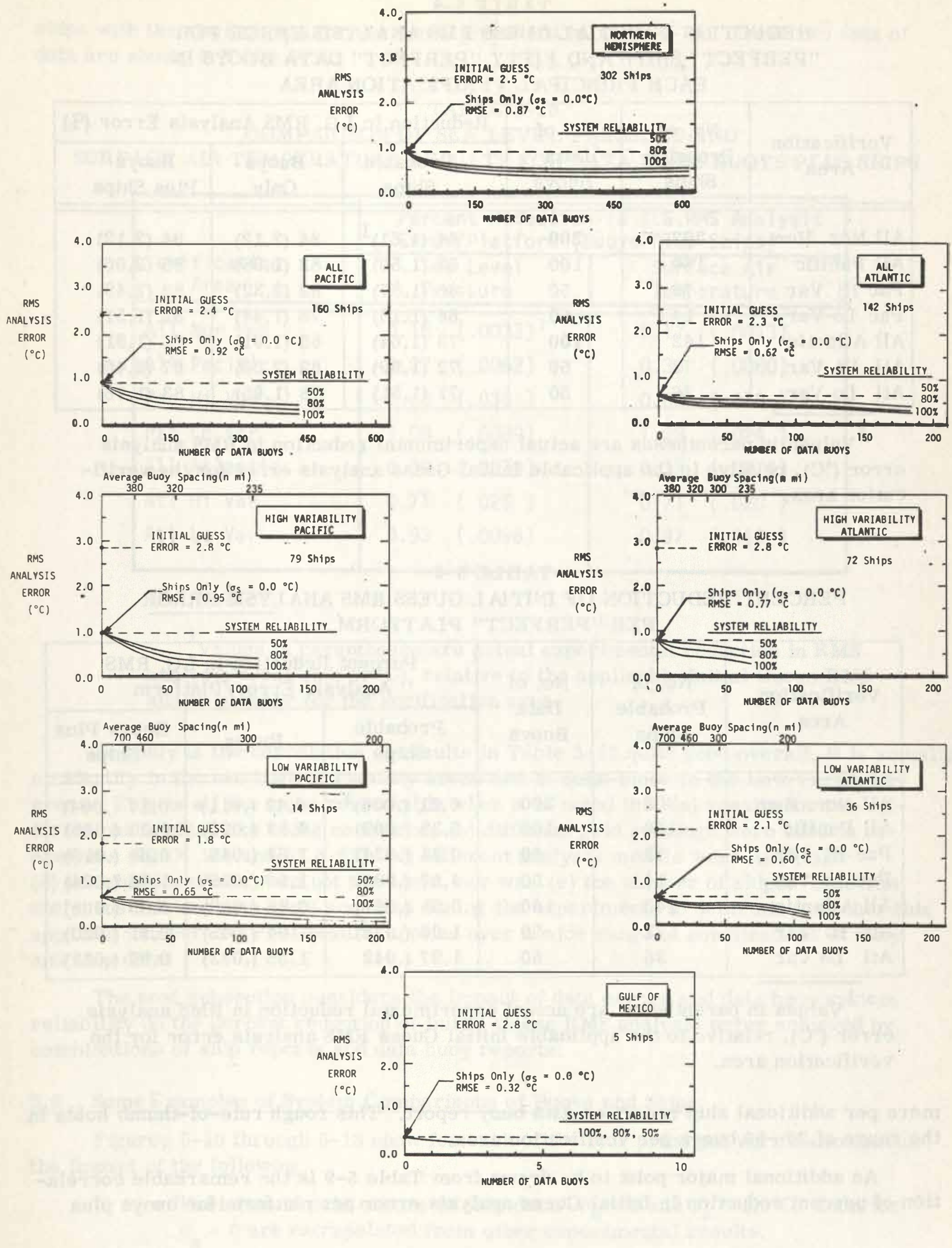

Fig. 5-9. Experimental results for Surface Air Temperature: Buoys and Ships; σ_b = 0 °C; σ_s = 0 °C.

TABLE 5-8

REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR FOR "PERFECT" SHIPS AND FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No. of Probable Ships	No. of Data Buoys	Reduction in I.G. RMS Analysis Error (%)		
			Probable Ships	Buoys Only	Buoys Plus Ships
All Nor. Hem.	302	200	64 (1.61)[1]	84 (2.12)	84 (2.12)
All Pacific	160	100	62 (1.50)	82 (1.98)	85 (2.06)
Pac Hi Var	79	50	66 (1.87)	82 (2.32)	88 (2.49)
Pac Lo Var	14	50	64 (1.18)	78 (1.44)	82 (1.51)
All Atlantic	142	100	73 (1.64)	85 (1.91)	85 (1.91)
Atl Hi Var	72	50	72 (1.99)	82 (2.26)	87 (2.40)
Atl Lo Var	36	50	71 (1.51)	78 (1.65)	83 (1.76)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess analysis error for the verification area.

TABLE 5-9

PERCENT REDUCTION OF INITIAL GUESS RMS ANALYSIS ERROR PER "PERFECT" PLATFORM

Verification Area	No. of Probable Ships	No. of Data Buoys	Percent Reduction in I.G. RMS Analysis Error/Platform		
			Probable Ships	Buoys	Buoys Plus Ships
All Nor. Hem.	302	200	0.21 (.005)[1]	0.42 (.011)	0.17 (.004)
All Pacific	160	100	0.39 (.009)	0.82 (.020)	0.33 (.008)
Pac Hi Var	79	50	0.84 (.024)	1.64 (.046	0.68 (.019)
Pac Lo Var	14	50	4.57 (.084)	1.56 (.029)	1.28 (.024)
All Atlantic	142	100	0.51 (.011)	0.85 (.019)	0.35 (.008)
Atl Hi Var	72	50	1.00 (.028)	1.64 (.045)	0.71 (.020)
Atl Lo Var	36	50	1.97 (.042	1.56 (.033)	0.97 (.021)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

more per additional ship report or data buoy report. This rough rule-of-thumb holds in the range of 20—50 buoys per verification area.

An additional major point to be drawn from Table 5-9 is the remarkable correlation of percent reduction in Initial Guess analysis error per platform for buoys plus ships with the similar data for Sea Level Pressure in Table 4-10. These two sets of data are shown in Table 5-10.

TABLE 5-10
COMPARISON OF SEA LEVEL PRESSURE AND
SURFACE AIR TEMPERATURE RESULTS FOR DATA FROM BUOYS PLUS SHIPS

Verification Area	Percent Reduction in I.G.RMS Analysis Error/Platform (Buoys Plus Ships)	
	Sea Level Pressure	Surface Air Temperature
All Nor Hem	0.16 (.0033)[1]	0.17 (.0043)
All Pacific	0.27 (.0062)	0.33 (.0080)
Pac Hi Var	0.68 (.035)	0.68 (.019)
Pac Lo Var	1.08 (.0089)	1.28 (.024)
All Atlantic	0.39 (.0079)	0.35 (.0079)
Atl Hi Var	0.71 (.025)	0.71 (.020)
Atl Lo Var	0.93 (.0096)	0.97 (.048)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb or °C), relative to the applicable Initial Guess RMS analysis error for the verification area.

Not only is the correlation of results in Table 5-10 quite good overall, it is actually an identity in the two High Variability areas and is quite close in the Low Variability areas. This is all the more remarkable when it is noted that (a) results for two different parameters are being compared; (b) different grid spacings were used in the analyses (125 × 125 and 63 × 63); (c) different analysis models were used; and (d) the ship locations were not the same, nor was (e) the number of ships. Unfortunately, insufficient data were acquired during the experiments to determine whether this apparent "universality" of results applies over a wide range of combinations of buoy and ship data.

The next subsection considers the impact of data errors and data buoy system reliability on the percent reduction of Initial Guess RMS analysis error achieved by combinations of ship reports and data buoy reports.

5.6 Some Examples of System Comparisons of Buoys and Ships

Figures 5-10 through 5-13 show for each of the four principal verification areas the impact of the following:

- Variation in data errors in ship data: $\sigma_s = 0$ and $\sigma_s = 1.0$°C. Data for $\sigma_s = 0$ are extrapolated from other experimental results.

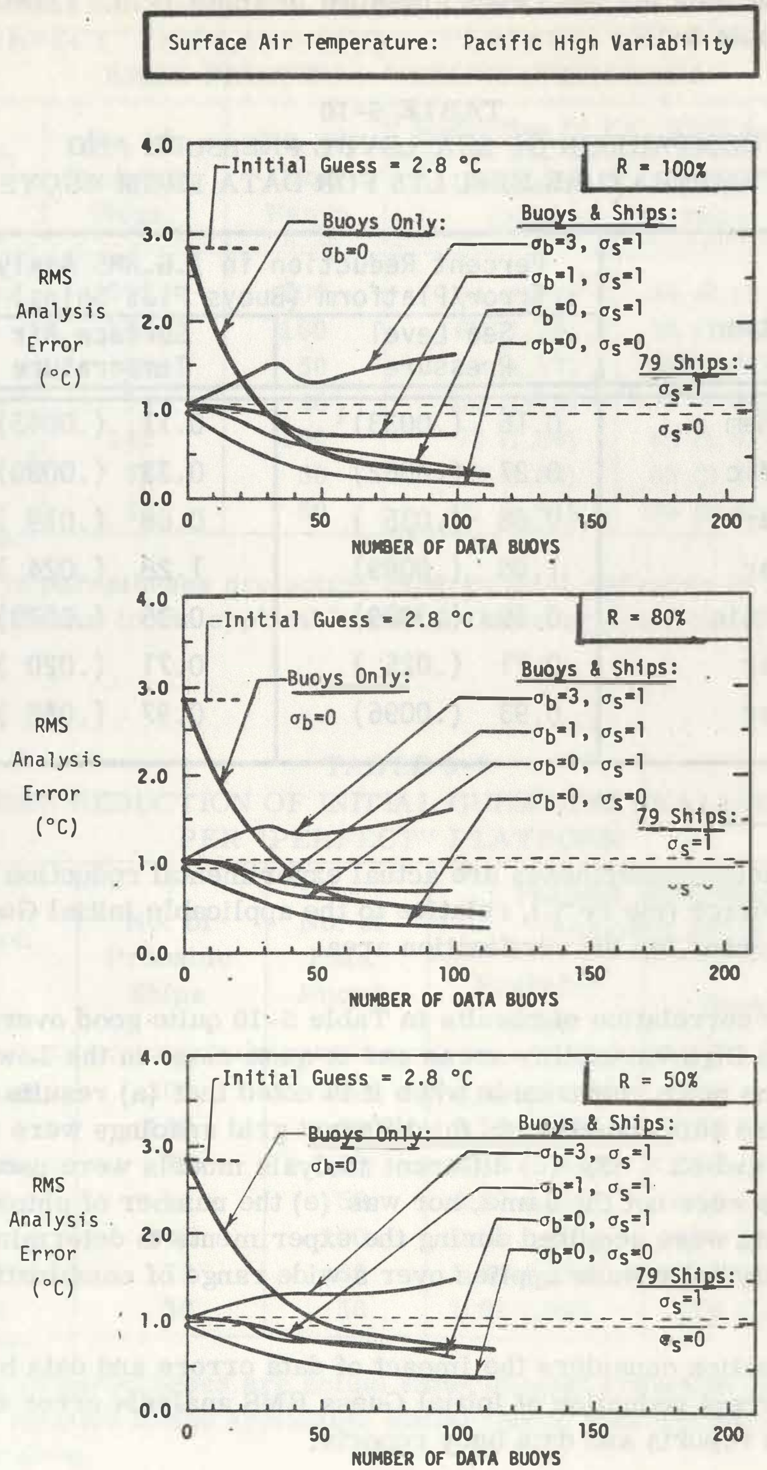

Fig. 5-10. Experimental results for Surface Air Temperature: Buoys and Ships in the Pacific High Variability area.

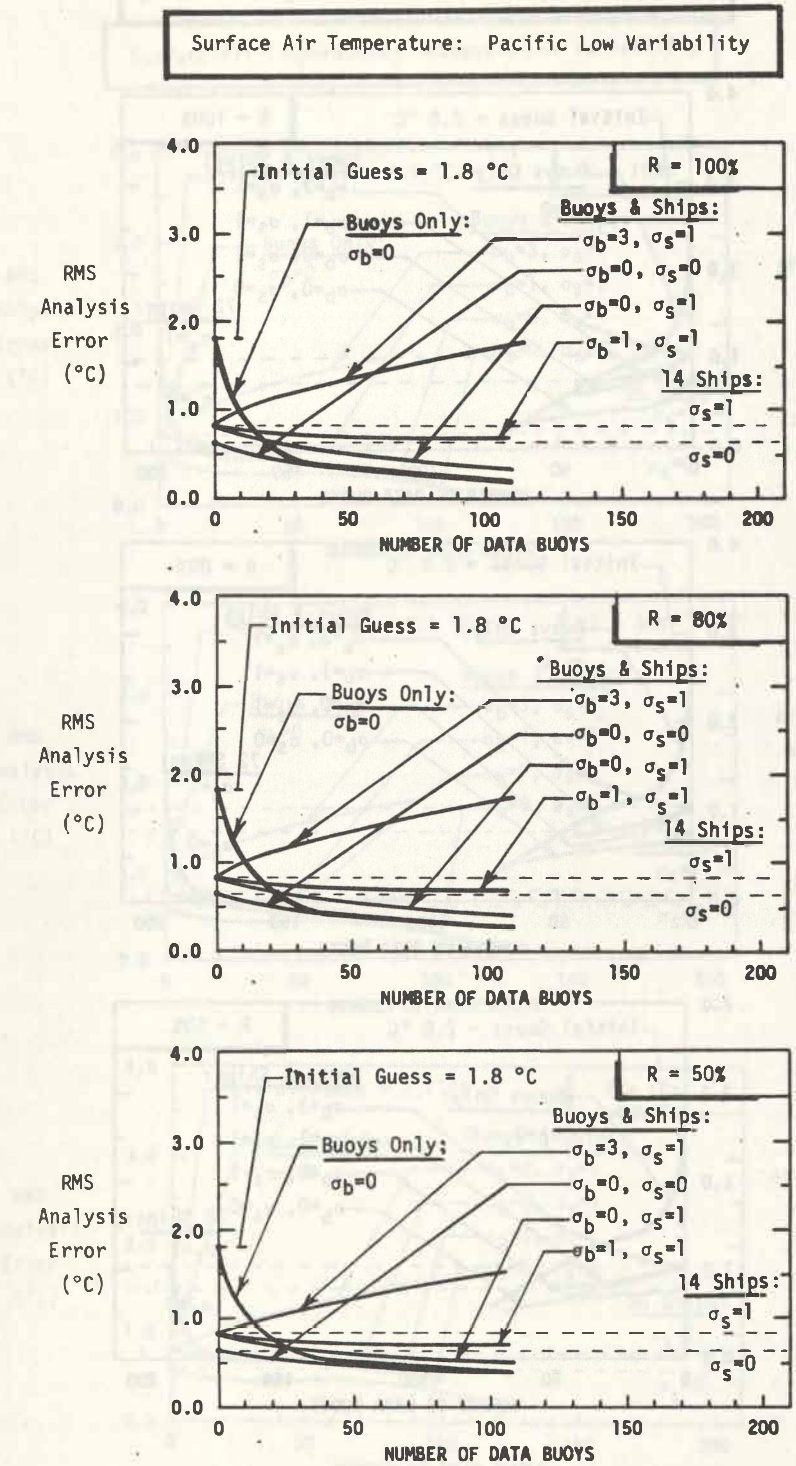

Fig. 5-11. Experimental results for Surface Air Temperature: Buoys and Ships in the Pacific Low Variability area.

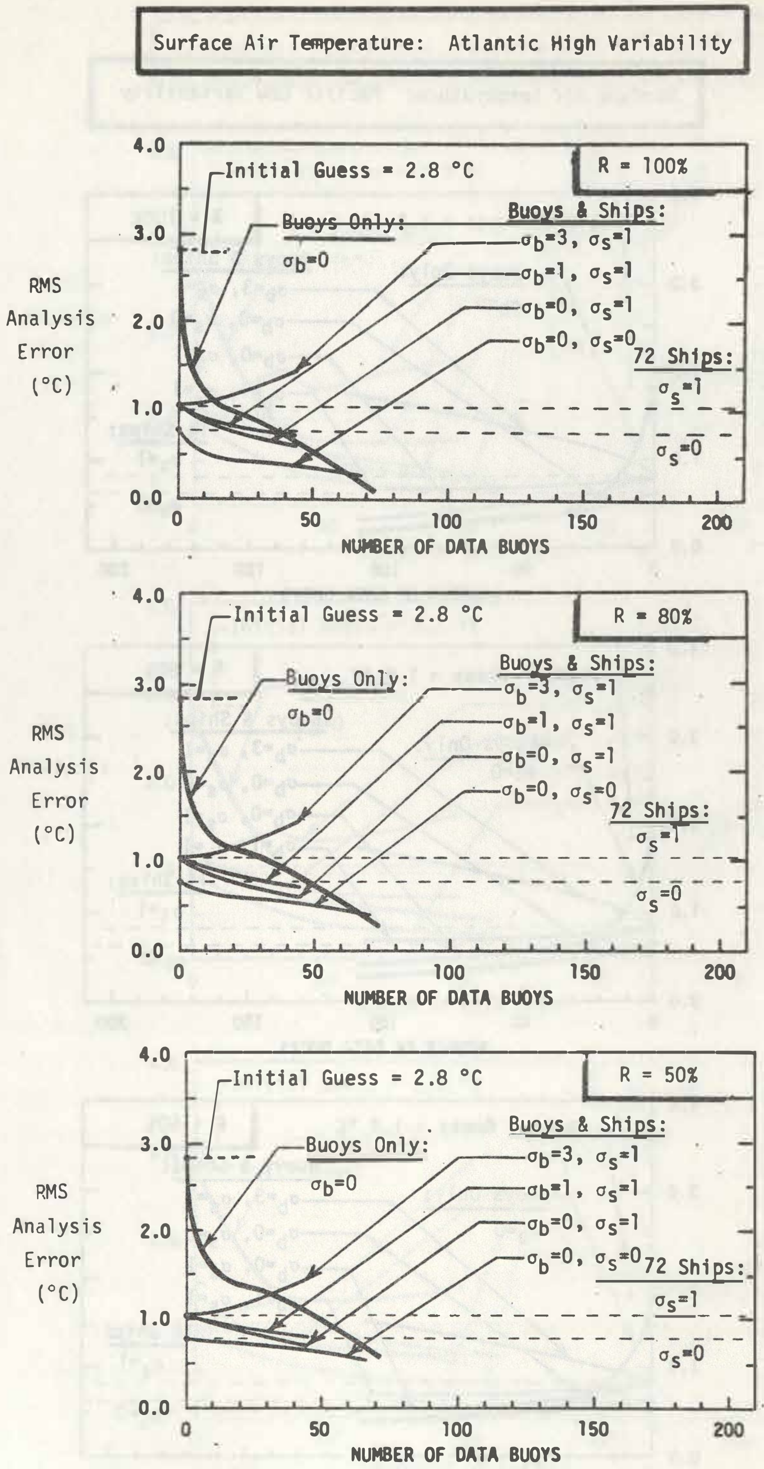

Fig. 5-12. Experimental results for Surface Air Temperature: Buoys and Ships in the Atlantic High Variability area.

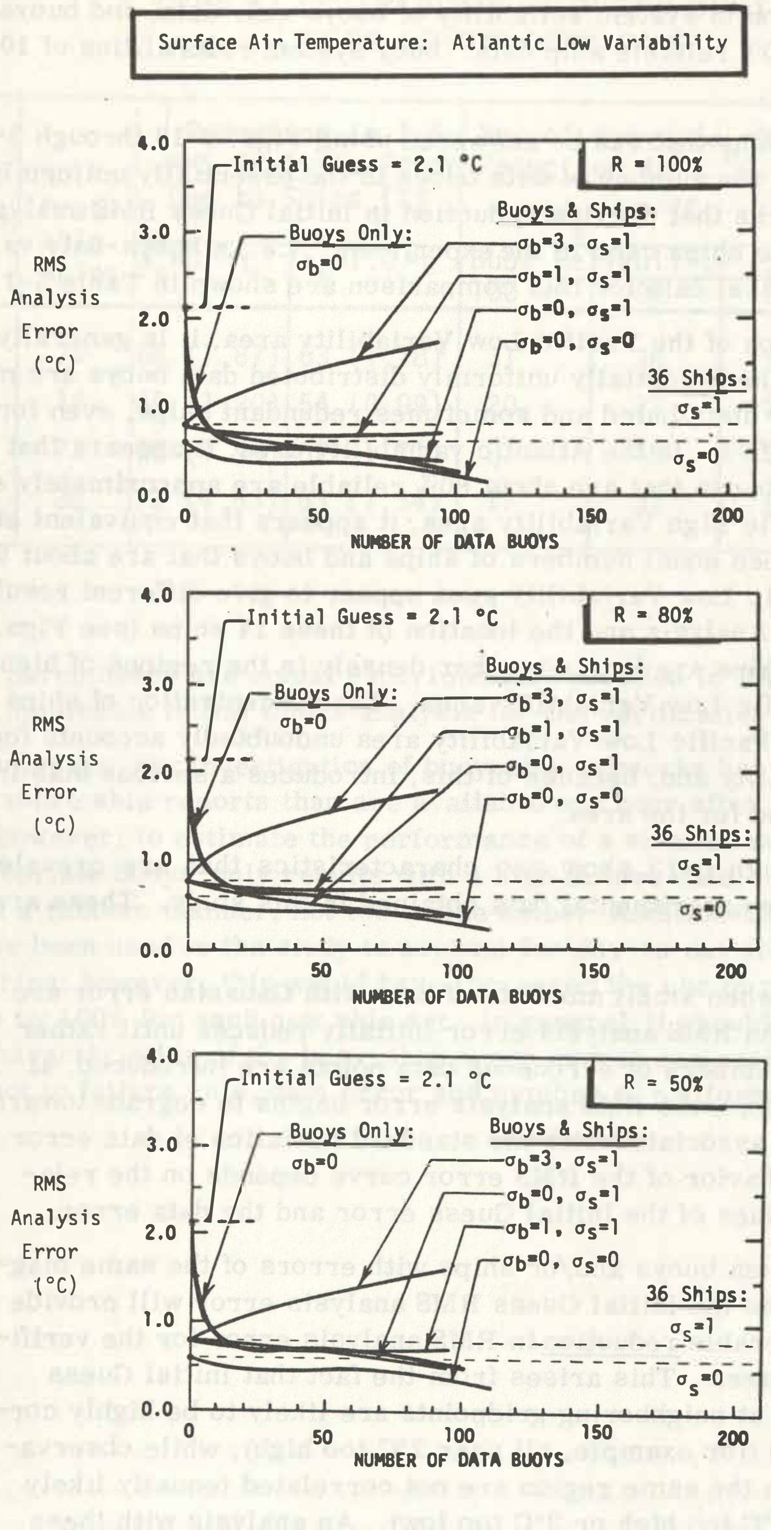

Fig. 5-13. Experimental results for Surface Air Temperature: Buoys and Ships in the Atlantic Low Variability area.

- Variation of data errors in buoy data, combined with ship data: $\sigma_s = 0$ and $\sigma_b = 0$; and $\sigma_s = 1.0$ and $\sigma_b = 1.0$ and 3.0°C.
- Variation in system reliability of buoys-only data, and buoys combined with 100% reliable ship data: buoy system reliabilities of 100%, 80%, and 50%.

One of the questions that can be answered using Figs. 5-10 through 5-13 concerns a comparison of the number of data buoys in the essentially uniformly distributed data buoy networks that provide reduction in Initial Guess RMS analysis error equivalent to that of the ships used in the experiment: i.e., a buoys-only vs. ships-only comparison. Typical data for this comparison are shown in Table 5-11.

With the exception of the Pacific Low Variability area, it is generally evident from Table 5-11 that the essentially uniformly distributed data buoys are more effective than the randomly distributed and sometimes redundant ships, even for buoy reliabilities of 80% to 50%. In the Atlantic variability area, it appears that equal numbers of ships and buoys that are about 80% reliable are approximately equally effective. In the Pacific High Variability area, it appears that equivalent effectiveness is achieved between equal numbers of ships and buoys that are about 50% reliable. The data for the Pacific Low Variability area appear to give different results. Comparison of the "True" Analysis and the location of these 14 ships (see Figs. 3-5 and 3-17) shows that the ships are located rather densely in the regions of highest variability in the Pacific Low Variability area. The concentration of ships in this portion of the defined Pacific Low Variability area undoubtedly accounts for the apparent relatively high variability and, because of this, introduces a serious bias in the experimental results obtained for the area.

Figs. 5-10 through 5-13 show two characteristics that are prevalent throughout much of the experimental data obtained in this study. These are as follows:

- Often, when small amounts of data with Gaussian error are used, the RMS analysis error initially reduces until rather large numbers of erroneous data points are introduced, at which point the RMS analysis error begins to degrade toward a level associated with the standard deviation of data error. The behavior of the RMS error curve depends on the relative values of the Initial Guess error and the data error.
- Data from buoys and/or ships with errors of the same magnitude as the Initial Guess RMS analysis error will provide considerable reduction in RMS analysis error for the verification area. This arises from the fact that Initial Guess errors at neighboring gridpoints are likely to be highly correlated (for example, all near 2°C too high), while observations in the same region are not correlated (equally likely to be 2°C too high or 2°C too low). An analysis with these observations will clearly reduce the Initial Guess RMS analysis error.

TABLE 5-11
A TYPICAL COMPARISON BETWEEN BUOYS AND SHIPS-OF-OPPORTUNITY

Verification Area	No. of Probable Ships	Reduction in I.G. RMS Analysis Error Due to Ships (%)		No. of Buoys (σ_b=0) Required for Equal Reduction in I. G. RMS Analysis Error					
				σ_s = 0 °C			σ_s = 1.0 °C		
		σ_s=0 °C	σ_s=1.0 °C	Buoy Reliability (%)			Buoy Reliability (%)		
				100	80	50	100	80	50
Pac Hi Var	79	66 (1.87)	63 (1.78)[1]	31	38	53	28	34	46
Pac Lo Var	14	65 (1.20)	54 (0.99)	20	22	27	13	16	17
Atl Hi Var	72	72 (1.99)	62 (1.71)	37	48	62	17	31	47
Atl Lo Var	36	72 (1.53)	63 (1.34)	17	31	84	8	12	13

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess analysis for the verification area.

In summary, the investigation of buoy-ship networks has been complicated by the use of more ship reports than are available one hour after synoptic time. It is possible, however, to estimate the performance of a smaller number of ships-only from appropriate buoys-only results with a high failure rate, i.e., buoys are then distributed in a random manner, not too unlike ships. Additionally, several ship sets should have been used in the study to account for day-to-day fluctuations in occurrence of ships; however, this would have increased the use of resources for computer time by 100% for each new ship set. In general it should be noted that the relative characteristics of the buoy-ship error curves are probably conservative with respect to failure rate, data error and number of platforms required.

6.0 RESULTS OF THE SEA SURFACE TEMPERATURE EXPERIMENT

6.1 Overview of the Experiment

The procedure followed in conducting the Sea Surface Temperature (SST) experiment was essentially the same as that used for Surface Air Temperature. The "True" Analysis and Initial Guess fields—based on results for 0000Z, March 22, 1970—were prepared while the Surface Air Temperature computer runs were being performed. The "True" Analysis and the Initial Guess field were manually modified in the vicinity of strong ocean currents such as the Gulf Stream by introducing a limited amount of small scale features and more pronounced gradients in the Sea Surface Temperature structure.

The analysis was carried out on a 125 × 125 grid, similar to that used for Sea Level Pressure. The 302 ship locations comprising Probable Ship Set A were used in introducing simulated ship-of-opportunity data. Ship data were introduced with standard deviations of data error of zero at 1.0°C. The standard deviations of data error were 0, 0.5, 1.0, and 3.0°C for buoy data when combined with ship reports, and 0, and 1.0°C for the buoys-only computer runs. (As noted elsewhere in this report, the so-called "buoys-only" portions of the experiments are equally representative of any types of data collection platforms having similar characteristics.) Buoy system reliabilities of 100%, 80%, and 50% were investigated, as before. As was done in the Surface Air Temperature experiments, in performing the Monte Carlo analyses in the data error and reliability dimensions, only three runs were cumulatively averaged. That is, a total of nine analyses was performed to obtain a single result for a buoy system (data collection system) with non-zero data error and less than 100% system reliability. As was the case with the Surface Air Temperature experiment, a total of 758 analyses (computer runs) was performed. These runs were divided into three categories: buoys-only, complete buoy networks and ships, and reduced buoy networks and ships, in which buoys were removed from regions where the probability of ship reports was determined to be high. General experimental results are shown in Appendix D.

The RMS analysis error for the Initial Guess field was determined first, by direct comparison in an RMS sense with the "True" Analysis. This was followed by an analysis of the ships-only data using the ship locations for Probable Ship Set A. Verification was carried out only over ocean grid points, by using the land "mask." This analysis was also compared in an RMS sense with the "True" Analysis. The RMS analysis error for the Sea Surface Temperature Initial Guess field and the probable ship set are shown in Table 6-1, along with the number of verification grid points and the number of probable ships in each verification area.

The table indicates that very little reduction in Sea Surface Temperature Initial Guess RMS analysis error is achieved by introducing the ship data, especially in comparison with the 50% to 70% reduction relative to Initial Guess RMS error achieved for the other two parameters. As will be seen subsequently, this same statement will continue to hold as the buoys-only and buoys-plus-ships networks are discussed. This difference between the experimental results for Sea Surface Temperature and the results for Sea Level Pressure and Surface Air Temperature is probably due to a

TABLE 6-1
NUMBER OF VERIFICATION GRID POINTS AND SHIPS; AND RMS ANALYSIS ERROR VALUES

Verification Area	No. of Verification Grid Points	No. of Probable Ships	RMS Analysis Error (°C)		
			Initial Guess	Probable Ship Set A	
				$\sigma_s = 0°C$	$\sigma_s = 1.0°C$
All Nor. Hem	10,059	302	0.90	0.66*	0.75
All Pacific	5,935	160	0.94	0.70	0.79
Pac Hi Var	847	79	1.94	1.35	1.49
Pac Lo Var	2,875	14	0.68	0.65	0.67
All Atlantic	2,322	142	1.12	0.79	0.90
Atl Hi Var	628	72	1.83	1.16	1.34
Atl Lo Var	1,513	36	0.65	0.60	0.64
Gulf of Mex.	102	5	1.38	0.94	1.12

*Data in this column obtained by extrapolation of buoy-plus-ship data.

combination of factors:

- In the Sea Surface Temperature analysis model, data from ships and buoys were combined with Initial Guess values, using different weights for each. The "reliability" assigned to various parts of the Initial Guess field on 0000Z March 22, 1970, determined the weights assigned to those values. The standard deviations of errors in buoy and ship data were used to determine weights assigned for those data. A weighting factor of $A = 1/(2\sigma^2)$ was used. Thus, for buoy or ship standard deviations of error much greater than $\sigma = 1$, the introduction of data had reduced effect on the Initial Guess values.

- In the Sea Surface Temperature model, the values (both Initial Guess values plus buoy and/or ship data, and Initial Guess values alone) were "blended" rather than relaxed by the Carstenson method.

- The scales of variability appearing in the Sea Surface Temperature "True" Analysis were smaller than those in the Sea Level Pressure, and Surface Air Temperature experiments. None of the networks investigated was sufficiently dense to resolve these small scales of variability.

- The Initial Guess field was a more smooth (or, average) approximation to the "True" Analysis than was the case in the Sea Level Pressure and Surface Air Temperature experiments.

The experimental results are not sufficiently comprehensive to delineate the contribution of each of these factors to the overall differences seen when comparing Sea Surface Temperature and Sea Level Pressure or Surface Air Temperature percent reductions in Initial Guess RMS analysis error. In general, the Sea Surface Temperature reductions in Initial Guess RMS analysis error for complete verification areas and numbers of data buoys are less by a factor of about 2 to 4, or more in certain cases. These issues will be discussed in greater detail in the remainder of this section.

6.2 Typical Experimental Results for Buoys-Only*

Figure 6-1 shows the impact of increasing the number of data buoys and varying system reliability for each of the eight verification areas. All experimental results in Fig. 6-1 are for zero data error. As in Figs. 4-1 and 5-1, average data spacing between data buoys in the Pacific and Atlantic High and Low Variability areas is indicated.

General conclusions drawn from Fig. 6-1 are as follows.

- Within the scope of the number of data buoys considered in each verification area, substantial reductions in Initial Guess RMS analysis error (i.e., more than 50%) were achieved only in the Pacific High Variability areas.
- With the exception of the Pacific High Variability areas, the achievement in reduction of Initial Guess RMS analysis error is less by a factor of 2 to 4 than that achieved in the Sea Level Pressure and Surface Air Temperature experiments. This is likely due in part to the four points noted above: the numerical analysis techniques used which resulted in mixing data with Initial Guess values and "blending;" the fact that Sea Surface Temperature exhibits more small scale natural variability than Sea Level Pressure or Surface Air Temperature; and the smoothness of the Sea Surface Temperature Initial Guess field.
- Networks of 100 to 200 (or more) data buoys in each of the four verification areas would be required in order to achieve a reduction in RMS analysis error to less than half the Initial Guess error. Fifty "perfect" data buoys (100% reliable;

* These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

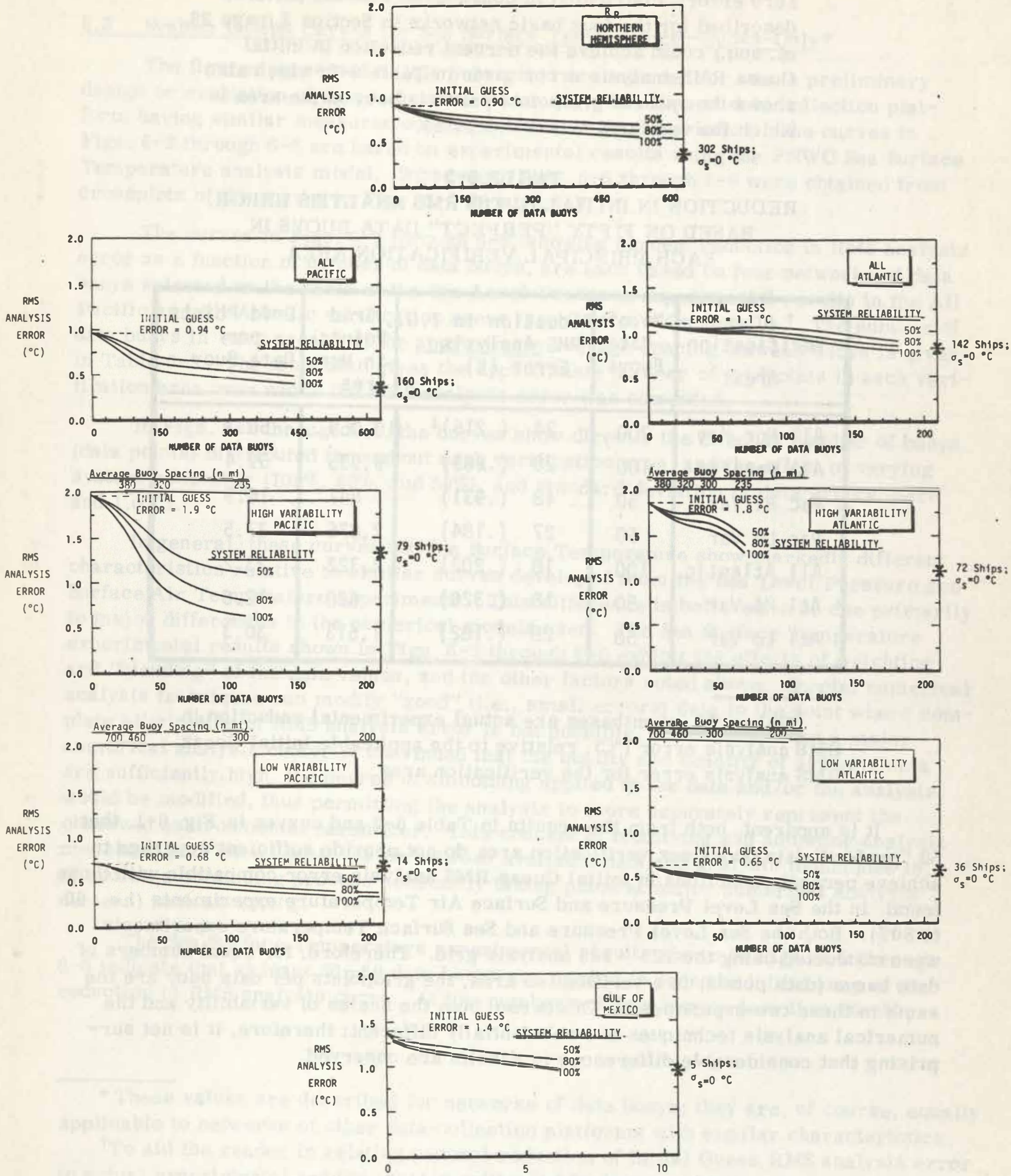

Fig. 6-1. Experimental results for Sea Surface Temperature: Buoys Only; σ_b = 0 °C.

zero error), distributed in consonance with the patterns described for the four basic networks in Section 3 (page 28, et. seq.) could achieve the percent reduction in Initial Guess RMS analysis error given in Table 6-2, which also shows the ratio of gridpoints per data buoy in the area in which the verification was computed.

TABLE 6-2
REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR, BASED ON FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No.of Data Buoys	Reduction in I.G. RMS Analysis Error (%)	Grid Points in Ver. Area	Grid Points per Data Buoy
All Nor.Hem	200	24 (.216)[1]	10,059	50.3
All Pacific	100	28 (.263)	5,935	59.4
Pac Hi Var	50	48 (.931)	847	16.9
Pac Lo Var	50	27 (.184)	2,875	37.5
All Atlantic	100	18 (.202)	2,322	23.2
Atl Hi Var	50	18 (.329)	628	12.6
Atl Lo Var	50	28 (.182)	1,513	30.3

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

It is apparent, both from the results in Table 6-2 and curves in Fig. 6-1, that 50 "perfect" data buoys per verification area do not provide sufficient coverage to achieve percent reductions in Initial Guess RMS analysis error compatible with those found in the Sea Level Pressure and Surface Air Temperature experiments (i.e., 60 to 80%). Both the Sea Level Pressure and Sea Surface Temperature experiments were conducted using the 125 × 125 analysis grid. Therefore, for equal numbers of data buoys (data points) in a verification area, the gridpoints per data buoy are the same in these two experiments. Of course, both the scales of variability and the numerical analysis techniques are substantially different; therefore, it is not surprising that considerable differences in results are observed.

6.3 System Design Curves for Sea Surface Temperature—Buoys-Only*

The figures presented in this subsection are intended for use in preliminary design or evaluation of data buoy systems or any other type of data collection platform having similar measurement and reliability characteristics. The curves in Figs. 6-2 through 6-5 are based on experimental results using the FNWC Sea Surface Temperature analysis model. Subsequent Figs. 6-6 through 6-8 were obtained from crossplots of the curves in Figs. 6-2 through 6-5.

The curves in Figs. 6-2 through 6-5, showing percent reduction in RMS analysis error as a function of number of data buoys, are each based on four networks of data buoys selected on the basis of the Sea Level Pressure experimental results in the All Pacific and All Atlantic verification areas (see Section 3 for details).† The number of data buoys in each area, and the approximate average spacing between buoys is given in Table 6-3. The table also gives the approximate number of gridpoints in each verification area over which the RMS analysis error was computed.

In Figs. 6-2 through 6-5, the curves show directly the effect of number of buoys (data points) distributed throughout each verification area, and the effect of varying system reliability (100%, 80%, and 50%), and standard deviation of data errors (zero and 1.0°C).

In general, these curves for Sea Surface Temperature show markedly different characteristics relative to similar curves developed from the Sea Level Pressure and Surface Air Temperature experiments. This difference is believed to be due primarily to major differences in the numerical models used. The Sea Surface Temperature experimental results shown in Figs. 6-2 through 6-5 exhibit the effects of weighting and "blending" of the data values, and the other factors noted above. Special numerical analysis techniques can modify "good" (i.e., small errors) data to the point where complete elimination of RMS analysis error is not possible. Obviously, when a major numerical analysis center is convinced that the quality and quantity of synoptic data are sufficiently high, the degree of smoothing applied to the data and/or the analysis would be modified, thus permitting the analysis to more accurately represent the observed environmental parameter. This concept of modifying and adjusting analysis models to provide a "best" match between available data and analysis techniques is, of course,a continuing process constantly taking place at major numerical analysis centers, such as FNWC.

The Sea Surface Temperature experimental results shown in Figs. 6-2 through 6-5 indicate that at least 30—50 data buoys are needed to pass the initial knee of the reduction in RMS analysis curve. At low numbers of data buoys—less than 20—50,

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*These values are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

†To aid the reader in relating percent reduction of Initial Guess RMS analysis error to actual experimental results, scales calibrated in degrees Centigrade appear along the right-hand side for all graphs in Figs. 6-2 through 6-8. Also, the RMS analysis error for zero-error data from fixed numbers of ships-only is shown in these figures.

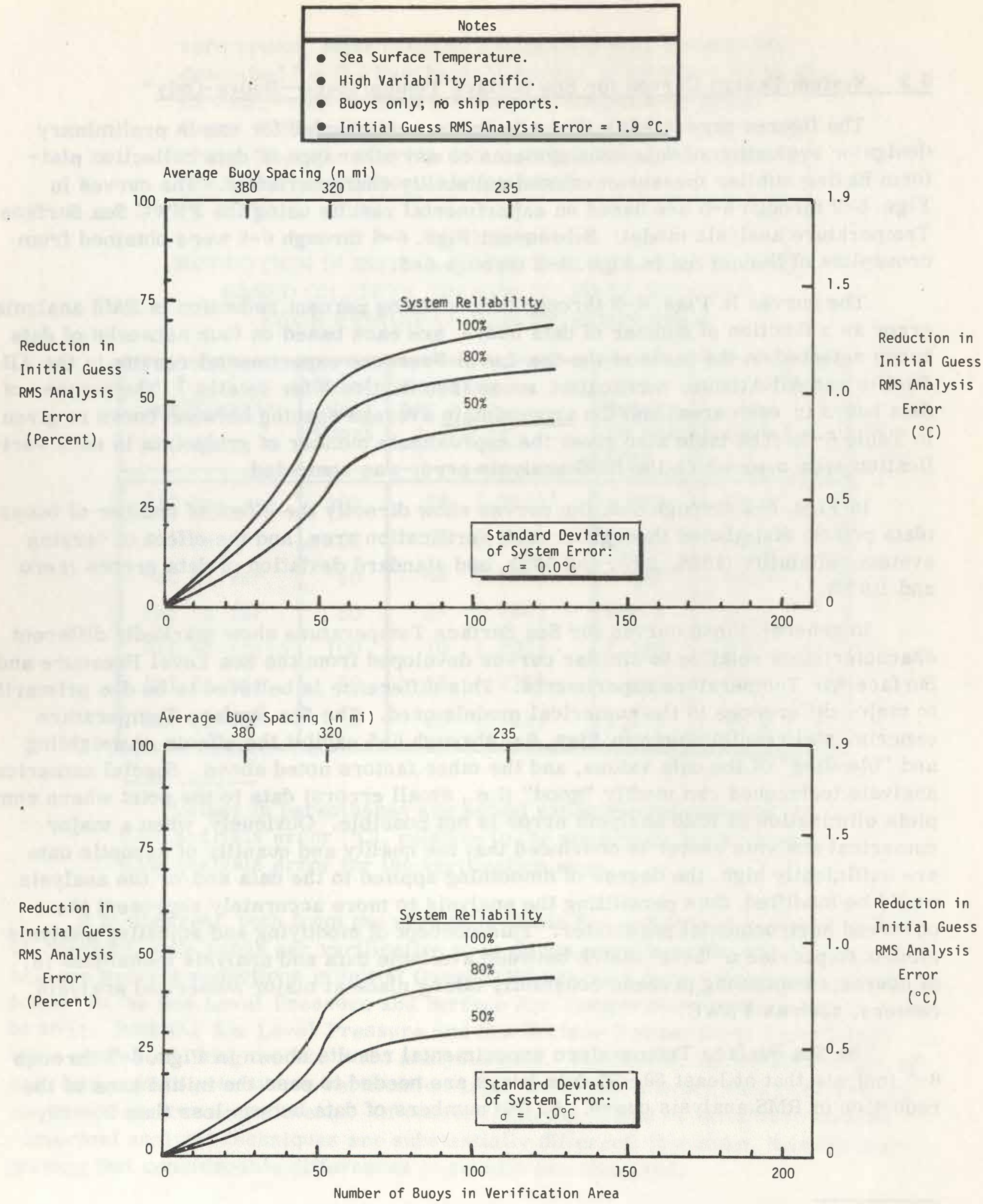

Fig. 6-2. System design curves for Sea Surface Temperature in the Pacific High Variability verification area.

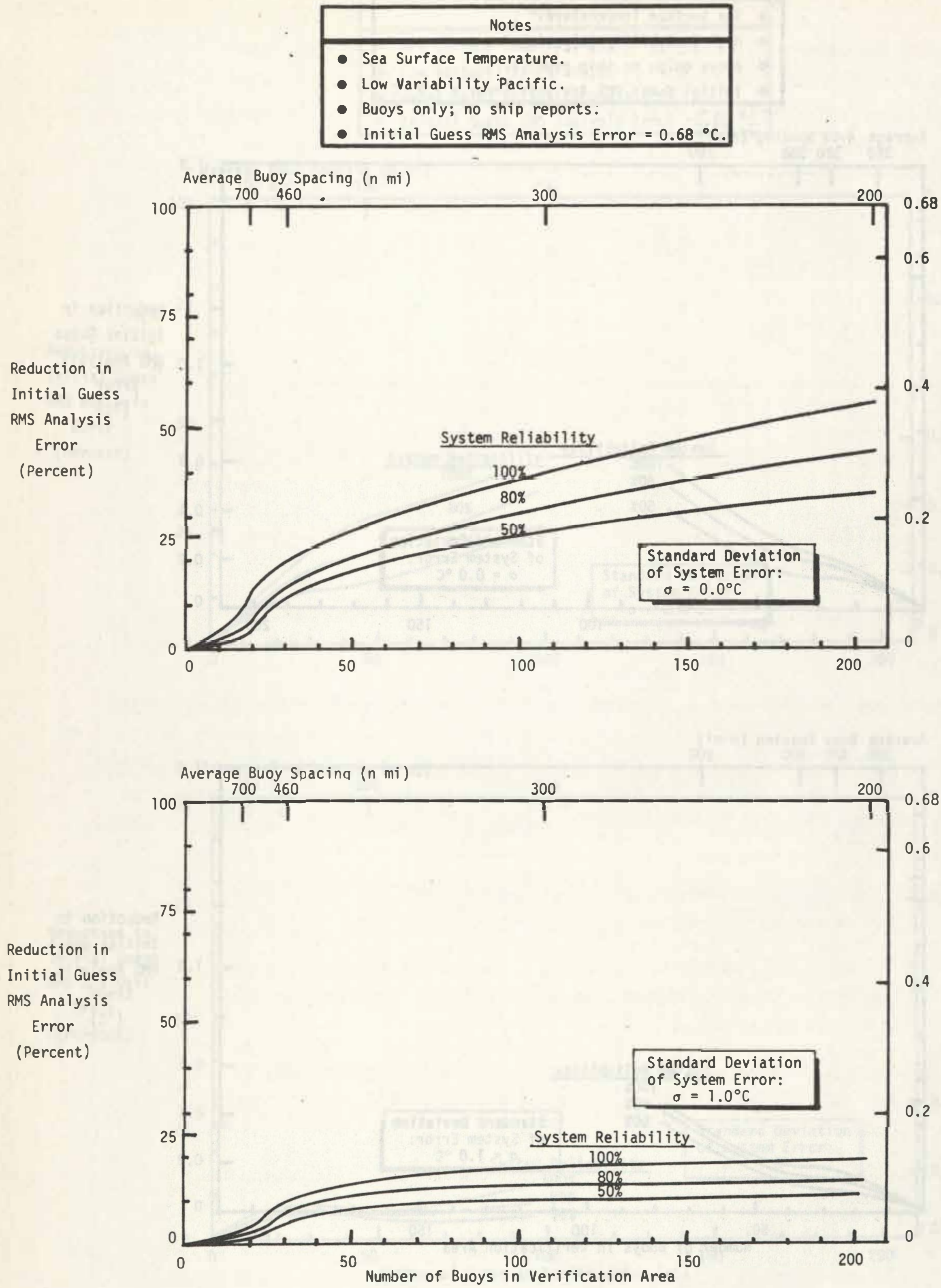

Fig. 6-3. System design curves for Sea Surface Temperature in the Pacific Low Variability verification area.

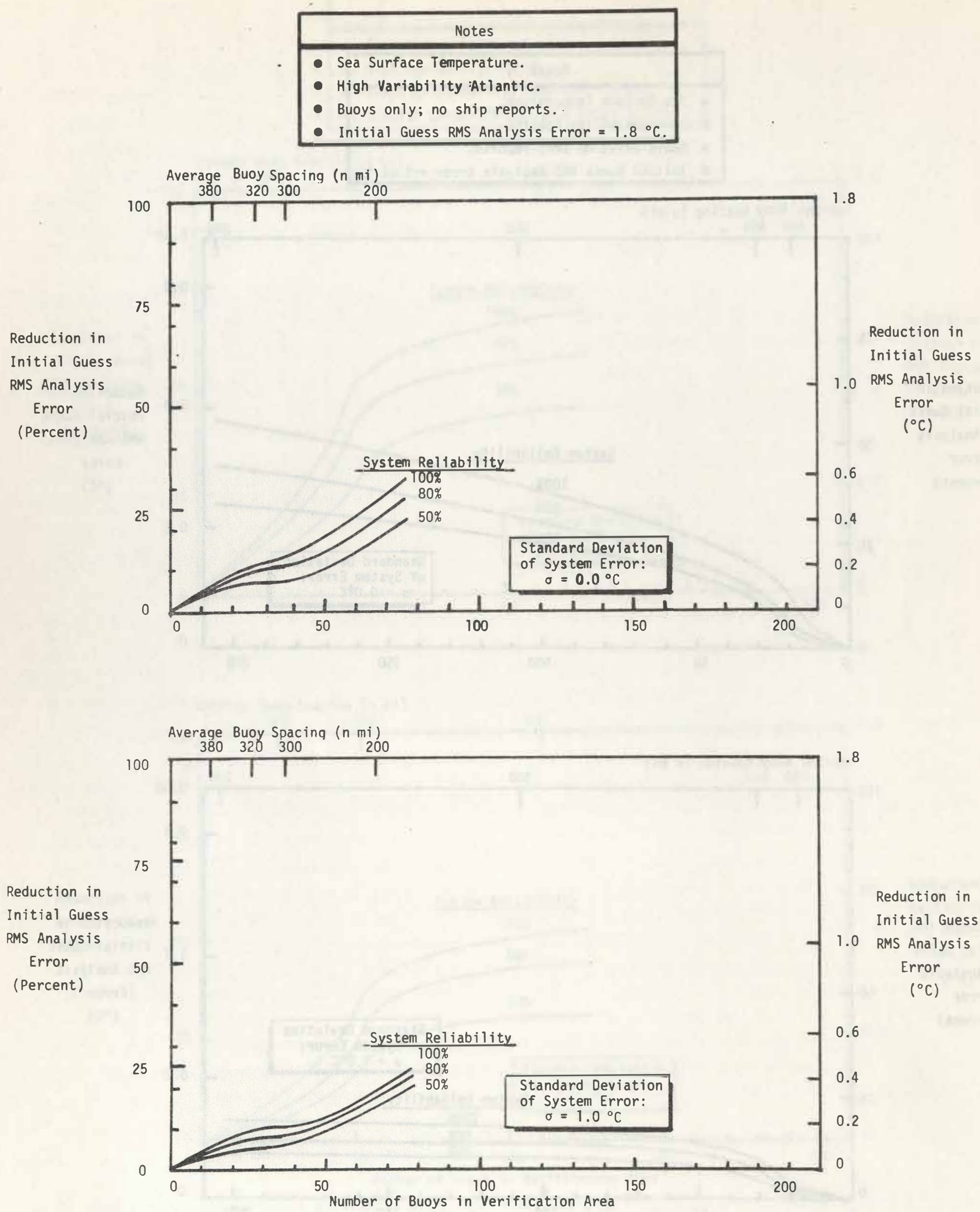

Fig. 6-4. System design curves for Sea Surface Temperature in the Atlantic High Variability verification area.

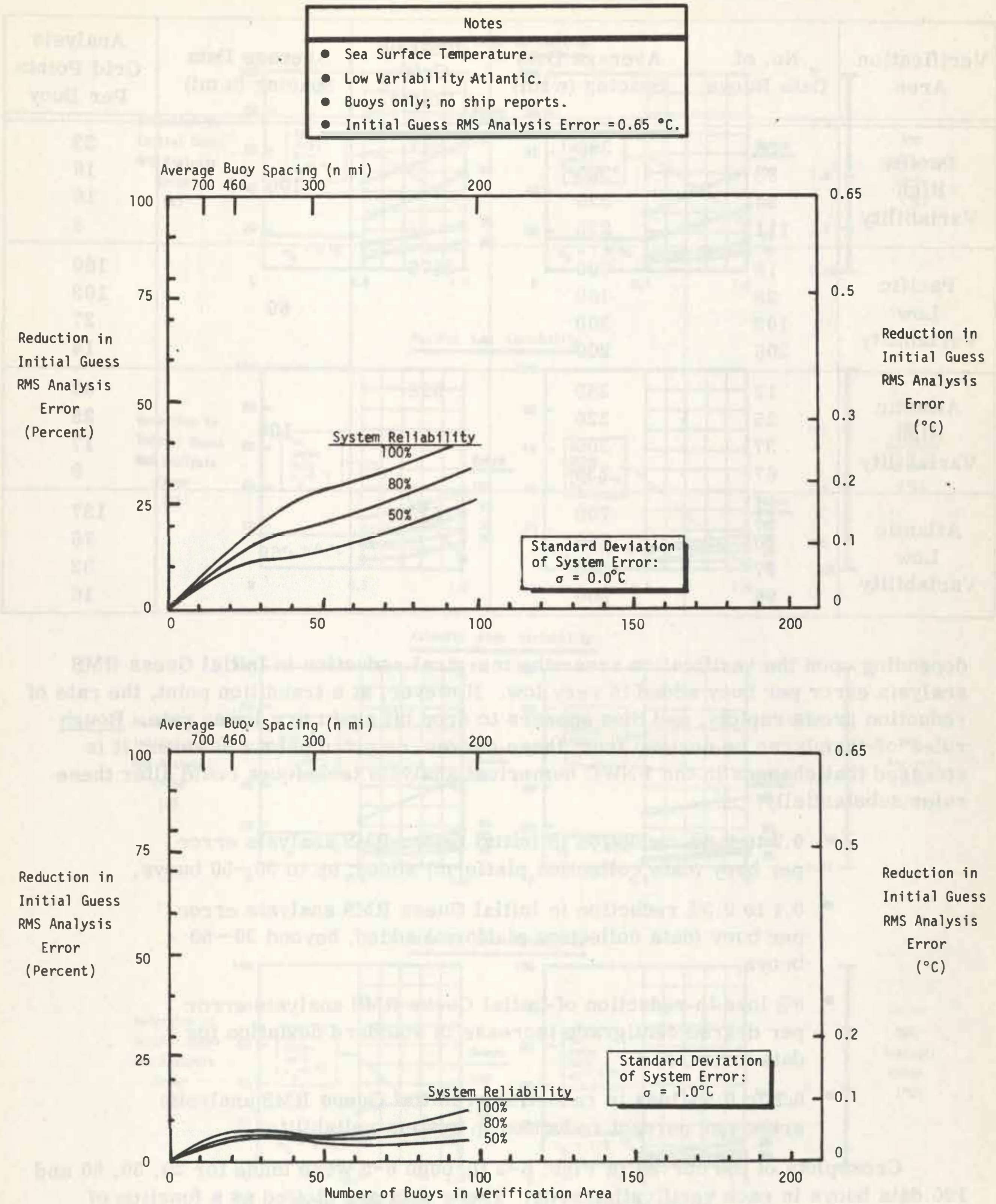

Fig. 6-5. System design curves for Sea Surface Temperature in the Atlantic Low Variability verification area.

TABLE 6-3
NUMBERS OF DATA BUOYS AND AVERAGE DATA SPACING

Verification Area	No. of Data Buoys	Average Data Spacing (n mi)	Analysis Grid Points	Average Data Spacing (n mi)	Analysis Grid Points Per Buoy
Pacific High Variability	26	380	847	100	33
	53	320			16
	54	320			16
	111	235			8
Pacific Low Variability	18	700	2875	60	160
	28	460			103
	103	300			27
	206	200			14
Atlantic High Variability	12	380	628	100	52
	25	320			25
	37	300			17
	67	235			9
Atlantic Low Variability	11	700	1513	60	137
	20	450			76
	47	300			32
	96	200			16

depending upon the verification area—the marginal reduction in Initial Guess RMS analysis error per buoy added is very low. However, at a transition point, the rate of reduction grows rapidly, and then appears to drop off again to a lower rate. Rough rules-of-thumb can be derived from these curves, as noted below; however, it is stressed that changes in the FNWC numerical analysis techniques could alter these rules substantially:

- 0.2 to 0.8% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, up to 30—50 buoys,
- 0.1 to 0.3% reduction in Initial Guess RMS analysis error per buoy (data collection platform) added, beyond 30—50 buoys,
- 8% loss in reduction of Initial Guess RMS analysis error per degree centigrade increase in standard deviation for data error, and
- 0.1 to 0.5% loss in reduction of Initial Guess RMS analysis error per percent reduction in system reliability.

Crossplots of the curves in Figs. 6-2 through 6-5 were made for 20, 30, 50 and 100 data buoys in each verification area. These data are plotted as a function of reliability in Fig. 6-6. The same data are plotted as a function of standard deviation of data error in Figs. 6-7 and 6-8. It is stressed that, in principle, it should be possible to carry out systems design and/or analysis using any one of these three

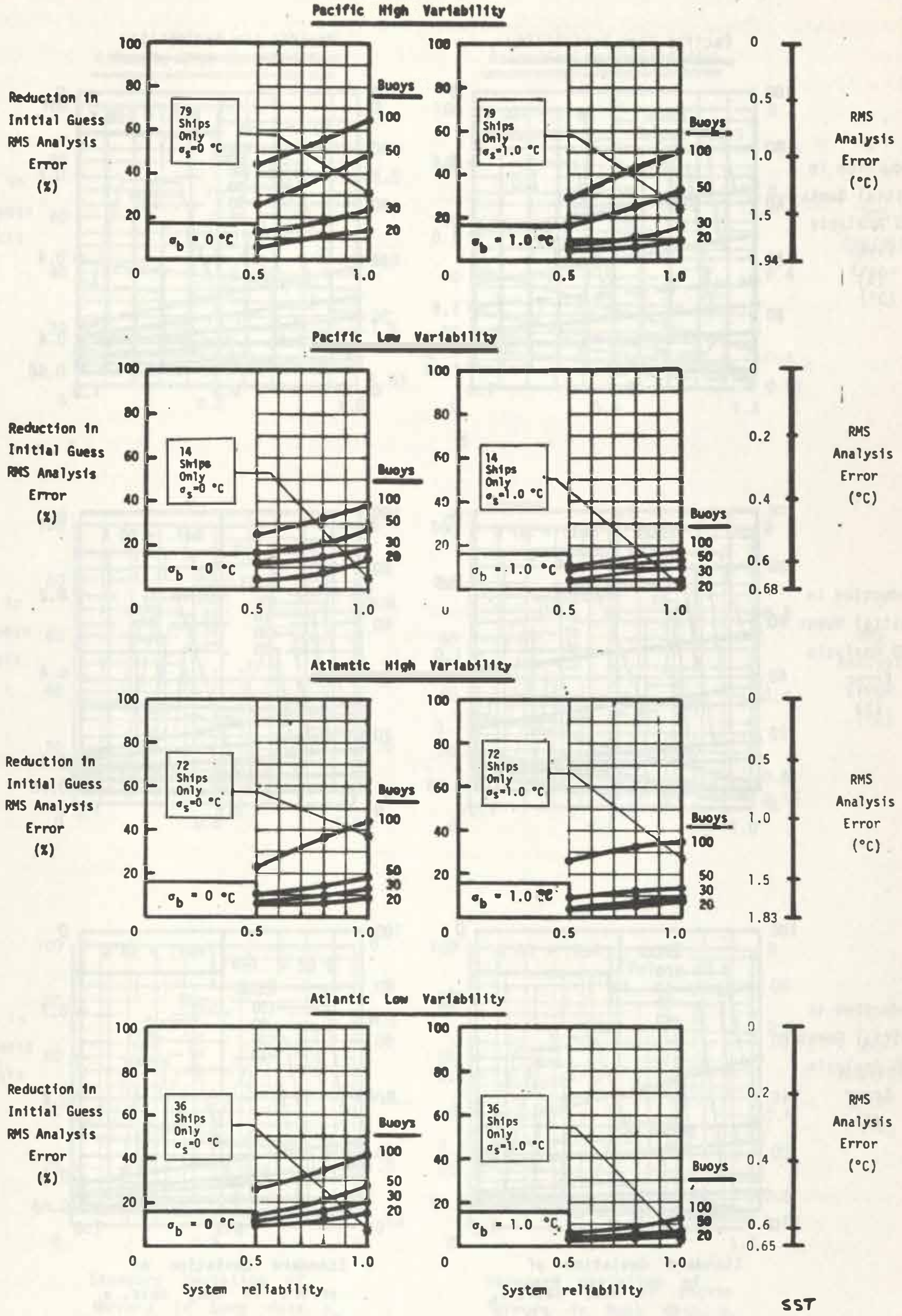

Fig. 6-6. System design curves for Sea Surface Temperature, emphasizing reliability: Buoys Only.

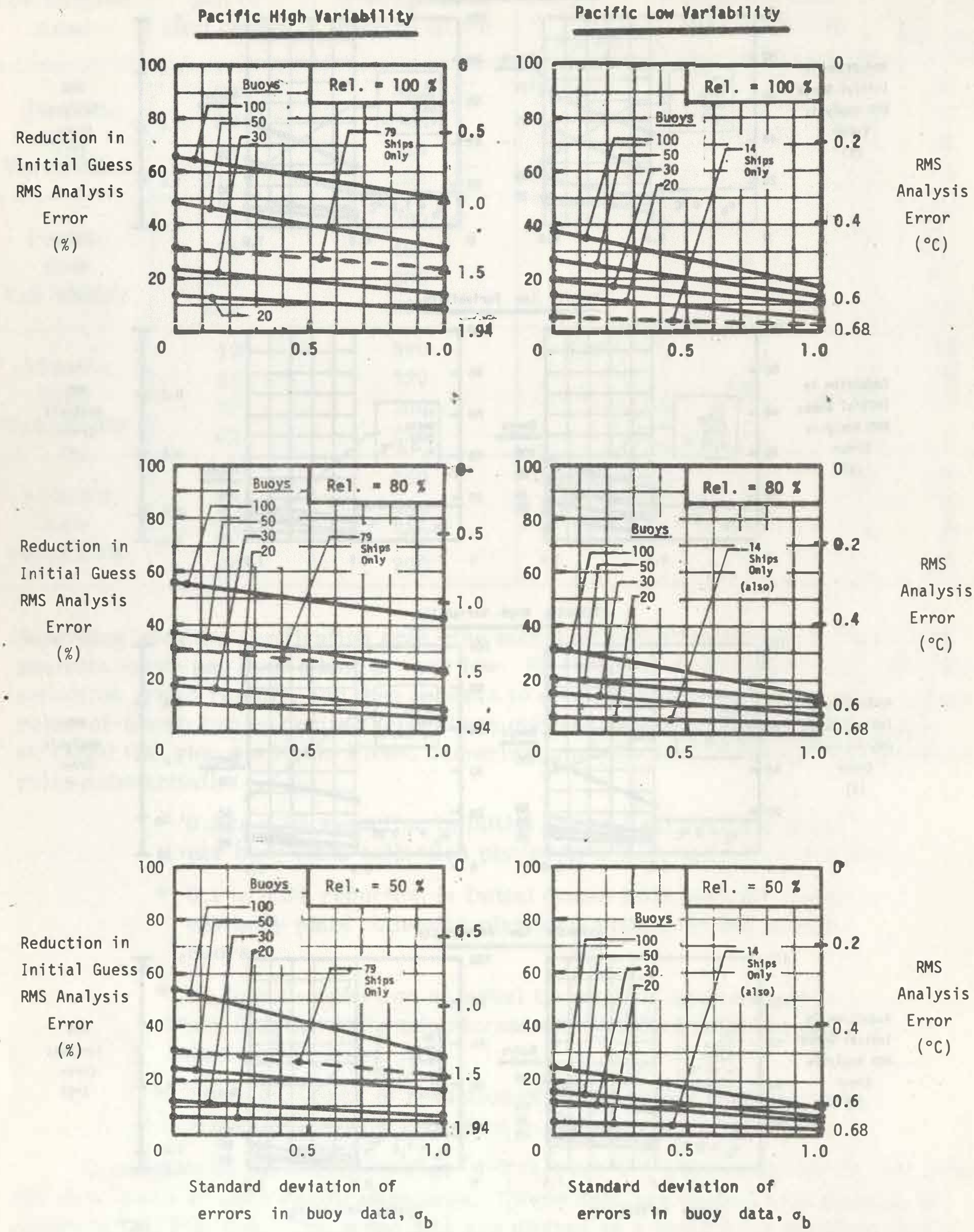

Fig. 6-7. System design curves for Sea Surface Temperature, emphasizing errors in buoy data: Buoys Only.

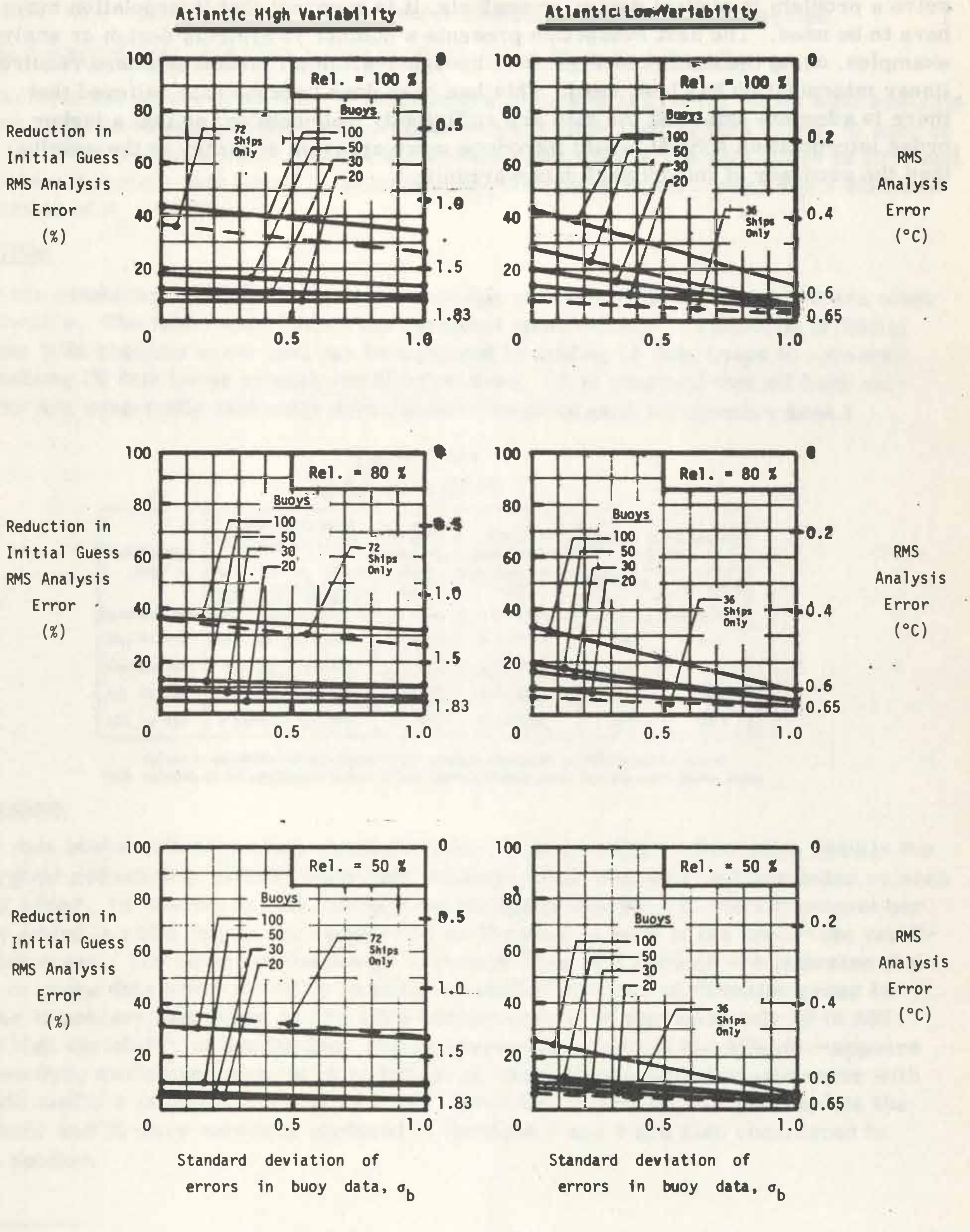

Fig. 6-8. System design curves for Sea Surface Temperature, emphasizing errors in buoy data: Buoys Only.

sets of curves. However, depending upon which three variables are given in order to find the fourth variable, one set of curves may prove to be more convenient to use than the others. Obviously, an effort has been made to accommodate all possibilities. To solve a problem in system design or analysis, it is apparent that interpolation may have to be used. The next subsection presents a number of systems design or analysis examples, using the curves in Figs. 6-2 through 6-8. In all instances where required, linear interpolation has been used. This has been done because it is believed that there is adequate data, and the data are sufficiently well-behaved so that a higher order interpolation scheme would introduce more apparent accuracy in the results than the accuracy of the original data warrants.

6.4 Examples of System Design: Buoys-Only*

To illustrate the use of the system design curves presented in the previous subsection, four typical system design and/or tradeoff examples are presented.

Case 1—Buoys with equal capabilities; 20-buoy and 30-buoy networks

Determine the percent reduction in Sea Surface Temperature Initial Guess RMS analysis error that can be achieved by using 30 data buoys, rather than 20 data buoys, in each of the four verification areas. Assume the system reliability of the data buoys is 80%, and the overall system data error is Gaussianly distributed with zero mean and a standard deviation of $\sigma_b = 0.5°C$.

Solution

For the conditions described, the system design curves in Figs. 6-7 and 6-8 are most applicable. The table below shows the marginal improvement in reduction of Initial Guess RMS analysis error that can be achieved by adding 10 data buoys to networks containing 20 data buoys in each verification area. (It is assumed that all buoy networks are essentially uniformly distributed throughout each verification area.)

TABLE 6-4
DATA FOR CASE 1

Verification Area	Reduction in RMS Analysis Error (%) Rel. = 80%; σ_b = 0.5°C		Marginal Improvement (%)	Marginal Improvement per Buoy Added (%)	Approx. Grid Spacing (n mi)	
	20 buoys	30 buoys			20 buoys	30 buoys
Pac Hi Var	8 (.155)	13 (.252)[1]	5 (.097)	0.5 (.010)	565	450
Pac Lo Var	5 (.034)	11 (.075	6 (.041)	0.6 (.004)	750	580
Atl Hi Var	4 (.073)	7 (.128)	3 (.055)	0.3 (.006)	460	375
Atl Lo Var	6 (.039)	10 (.065)	4 (.026)	0.4 (.003)	500	400

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

For data buoys with equivalent characteristics, it is possible to determine readily the marginal reduction in Initial Guess RMS analysis error that will be contributed by each buoy added. Of course, in this example the marginal change of 0.3 to 0.6 percent per buoy added is valid only in the range of 20 to 30 buoys in each of the applicable verification areas. The nature of the design curves in Figs. 6-7 through 6-8 indicates that 100 or more data buoys would be required in each of the four verification areas in order to achieve reductions in I.G. RMS analysis error of approximately 50 to 60%. The high variability of Sea Surface Temperature—especially in the Atlantic—appears to preclude much improvement in reduction of Initial Guess RMS analysis error with small numbers of buoys, such as 20 to 30. However, to provide compatible data the 20-buoy and 30-buoy networks explored in Sections 4 and 5 are also considered in this section.

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*These results are described for networks of data buoys; they are, of course, equally applicable to networks of other data collection platforms with similar characteristics.

Case 2—Effect of reduction in reliability: 30-buoy network

Problem Statement

For the 30-buoy network of Case 1 (80% reliable; 0.5°C standard deviation of data error), determine the marginal loss in reduction of Initial Guess RMS analysis error that would occur for Sea Surface Temperature, should the system reliability decrease from 80% to 60%.

Solution

For the conditions presented, the system design curves in Fig. 6-6 are most applicable. Reduction in Initial Guess RMS analysis error can be found easily for buoy systems with standard deviations of data error of $\sigma_b = 0$ and $\sigma_b = 1.0$°C. Linear interpolation is then used to find the desired values for $\sigma_b = 0.5$°C.

TABLE 6-5
DATA FOR CASE 2

Verification Area	Reduction in Initial Guess RMS Analysis Error (%)						Loss in Reduction of I.G. RMS Analysis (%)
	σ_b = 0°C		σ_b = 1.0°C		σ_b = 0.5°C		
	Rel=80%	Rel=60%	Rel=80%	Rel=60%	Rel=80%	Rel=60%	
Pac Hi Var	18 (.349)[1]	13 (.252)	11 (.213)	8 (.155)	15.5 (.301)	10.5 (.204)	5.0 (.097)
Pac Lo Var	14 (.095)	12 (.082)	8 (.054)	6 (.041)	13.0 (.088)	9.0 (.061)	4.0 (.027)
Atl Hi Var	10 (.183)	7 (.128)	8 (.146)	5 (.092)	8.5 (.156)	6.0 (.110)	2.5 (.046)
Atl Lo Var	16 (.104)	12 (.078)	5 (.033)	3 (.020)	10.5 (.068)	7.5 (.049)	3.0 (.020)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comment

The 20 percent reduction in system reliability has its highest impact in the Pacific, where the marginal loss is between 0.25 and 0.20 percent reduction in Initial Guess RMS analysis error per percent reduction in system reliability. The impact in the Pacific verification areas is almost twice that in the Atlantic verification areas. However, this is probably because a given number of buoys in the Pacific have almost twice the impact in reducing Initial Guess RMS analysis error as it does in the Atlantic, emphasizing that Sea Surface Temperature has higher variability in the Atlantic than in the Pacific, at least as reflected by the "True" analysis in this experiment.

It must be stressed that in the four verification areas, the percent reduction in Initial Guess RMS analysis error was quite low—in the range of 6 to 16 percent, for the situation of $\sigma_b = 0.5$°C. This is lower by a factor of about 4 to 10, when compared with similar results for Sea Level Pressure and Surface Air Temperature. This is possibly due to essentially the same differences in the scales of natural variability of these parameters.

Case 3—Tradeoff comparison of 20-buoy and 30-buoy networks

Problem Statement

Compare the reduction in Sea Surface Temperature Initial Guess RMS analysis error for a 30-buoy network having a system reliability of 60% and a 0.5°C standard deviation of data error with a 20-buoy network having a system reliability of 90% and a σ_b = 0.01°C standard deviation of data error, for each of the four verification areas.

Solution

Data for the 30-buoy networks (R = 60%; σ_b = 0.5°C) can be taken directly from Case 2. Data for the 20-buoy networks (R = 90%; σ_b = 0.01°C) is most conveniently obtained from the curves for 100% and 80% reliability in Figs. 6-7 and 6-8, with linear interpolation used to determine the data for 90% reliability. Note that, on the average, in each network 18 buoys would be delivering data to the shore data dissemination hub.

TABLE 6-6
DATA FOR CASE 3

Verification Area	Reduction in I.G. RMS Analysis Error (%)				
	20 buoys; σ_b = 0.01°C			30 buoys; σ_b = 0.5°C	Col. A—Col. B (%)
	Rel=100%	Rel=80%	Rel=90% (Column A)	Rel=60% (Column B)	
Pac Hi Var	13 (.252)[1]	11 (.213)	12 (.233)	10.5 (.204)	1.5 (.029)
Pac Lo Var	13 (.088)	6 (.041)	9.5 (.065)	9 (.061)	0.5 (.003)
Atl Hi Var	8 (.146)	4 (.073)	6 (.110)	6 (.110)	0 (0)
Atl Lo Var	13 (.085)	10 (.065)	11.5 (.075)	7.5 (.049)	4 (.026)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

Comments

In the Atlantic High Variability area, the 20-buoy and 30-buoy networks are exact tradeoffs. They are both also least effective in comparison to networks of equal numbers of buoys in the other three verification areas. In the Pacific High and Low Variability areas the more reliable and accurate 20-buoy network is slightly better than an even tradeoff with the less reliable and much less accurate 30-buoy network. In the Atlantic Low Variability area, the 20-buoy network is decidedly preferable to the 30-buoy network.

It is apparent that the marginal development, implementation, and operational costs required to increase system reliability from 60% to 90%, and reduce the standard deviation of system data error from 0.5°C to 0.01°C (the present requirement), can be tradeoff against the marginal implementation and operational cost of 10 buoys having 60% system reliability and σ_b = 0.5°C.

Case 4—Alternative systems producing the same reduction in Initial Guess RMS analysis error

Problem Statement

Determine the number of data buoys required to achieve a 40% reduction of Sea Surface Temperature Initial Guess RMS analysis error in each of the four verification areas, for the following conditions: zero standard deviation of data error and system reliabilities of 100%, 80%, and 50%; and 1.0°C standard deviation of data error and system reliabilities of 100%, 80%, and 50%.

Solution

For the conditions described, the system design curves in Figs. 6-2 through 6-5 are most applicable. The table below shows the number of data buoys required in each verification area to achieve 40% reduction in Initial Guess RMS analysis error.

TABLE 6-7
DATA FOR CASE 4

Verification Area	No. Buoys Required for 40% Reduction in RMS Analysis Error					
	σ_b = 0°C			σ_b = 1.0°C		
	Rel = 100%	Rel = 80%	Rel = 50%	Rel = 100%	Rel = 80%	Rel = 50%
Pac Hi Var	45	50	73	57	79	N.A.*
Pac Lo Var	106	160	N.A.	N.A.	N.A.	N.A.
Atl Hi Var	90	104†	118†	110†	119†	132†
Atl Lo Var	93	117†	150†	N.A.	N.A.	N.A.

*N.A. = Not Achievable under stated conditions with reasonable numbers of data buoys.
†Extrapolated from experimental data.

Comment

To achieve 40% reduction in Sea Surface Temperature Initial Guess RMS analysis error would require rather dense data buoy networks, even in the so-called Low Variability areas. For standard deviations of 1.0°C or greater, it would not be possible within reasonable numbers of data buoys (i.e., 200 or less) based on the experimental results. In the High Variability areas, 45—60 highly reliable data buoys would be required in the Pacific and about 100 or more data buoys would be required in the Atlantic. This latter value undoubtedly reflects the impact of the small scale natural variability of the Gulf Stream which was present in the "True" Analysis for this experiment. Of course, in an actual case, the analysis model operational characteristics would probably be modified to accommodate the additional accurate and reliable data.

6.5 Typical Experimental Results for Buoys and Ships

For the Sea Surface Temperature experiment, the analyses performed at FNWC were made using Probable Ship Set A, described in Section 3.3.4. There were 302 ships distributed throughout the northern hemisphere, at least one grid length apart (125 × 125 grid). All Probable Ship locations were at gridpoints; hence, there was no interpolation error involved in going from the "True" analysis to data for Probable Ship locations. Two fields of Probable Ship Set A data were prepared: one with zero data error and one in which zero mean Gaussian random errors with a standard deviation of 1.0°C were introduced. These conditions are the same as those used in the Surface Air Temperature experiment.

As noted in Section 4.5, the concept of obtaining 302 non-redundant ship reports within one hour after a synoptic period is optimistic, in comparison to present conditions. However, this may be possible in the future.

Unlike the experimental results for Sea Level Pressure and Surface Air Temperature, where "perfect" (zero error; 100% reliable) ship reports alone or approximately equal numbers of data buoys produced marked reduction of Initial Guess RMS analysis error, the use of relatively large numbers of "perfect" ship and buoy reports provides less than 50% reduction in Initial Guess RMS analysis error. This is probably due to the analysis model characteristics noted previously and the natural variability of Sea Surface Temperature, which contains small scales and steep gradients. The smoothness of the Initial Guess field may also be a contributing factor. Figure 6-9 shows a typical set of experimental results for both ships and buoys with zero error, and buoy system reliabilities of 100%, 80%, and 50%. Table 6-8 shows the percent reduction of Initial Guess RMS analysis error achieved by the ships alone; the percent reduction in Initial Guess RMS analysis error achieved by 50 "perfect" buoys zero error; 100% reliable) in each verification area; and the percent reduction in Initial Guess RMS analysis error stemming from the combined "perfect" ship data and the "perfect" data from 50 buoys in each principal verification area.

The data in Table 6-8 are intended to convey several possible observations. These include the following:

- With the exception of the Pacific High Variability area, over 100 data collection platforms would be required in each of the principal verification areas in order to reduce the Initial Guess RMS analysis error by more than 50% (assuming use of the Sea Surface Temperature analysis model that was used in this experiment). This point is reinforced by reviewing Figs. 6-3, 6-4, and 6-5.
- The greatest percent reduction of Initial Guess RMS analysis error for buoys andfor buoys plus ships occurs in the Pacific High Variability area (48% and 62% respectively).
- Essentially uniformly distributed networks of buoys are more effective on a per platform basis than the essentially randomly distributed ship reports stemming from Probable Ship Set A, especially in the Low Variability areas.

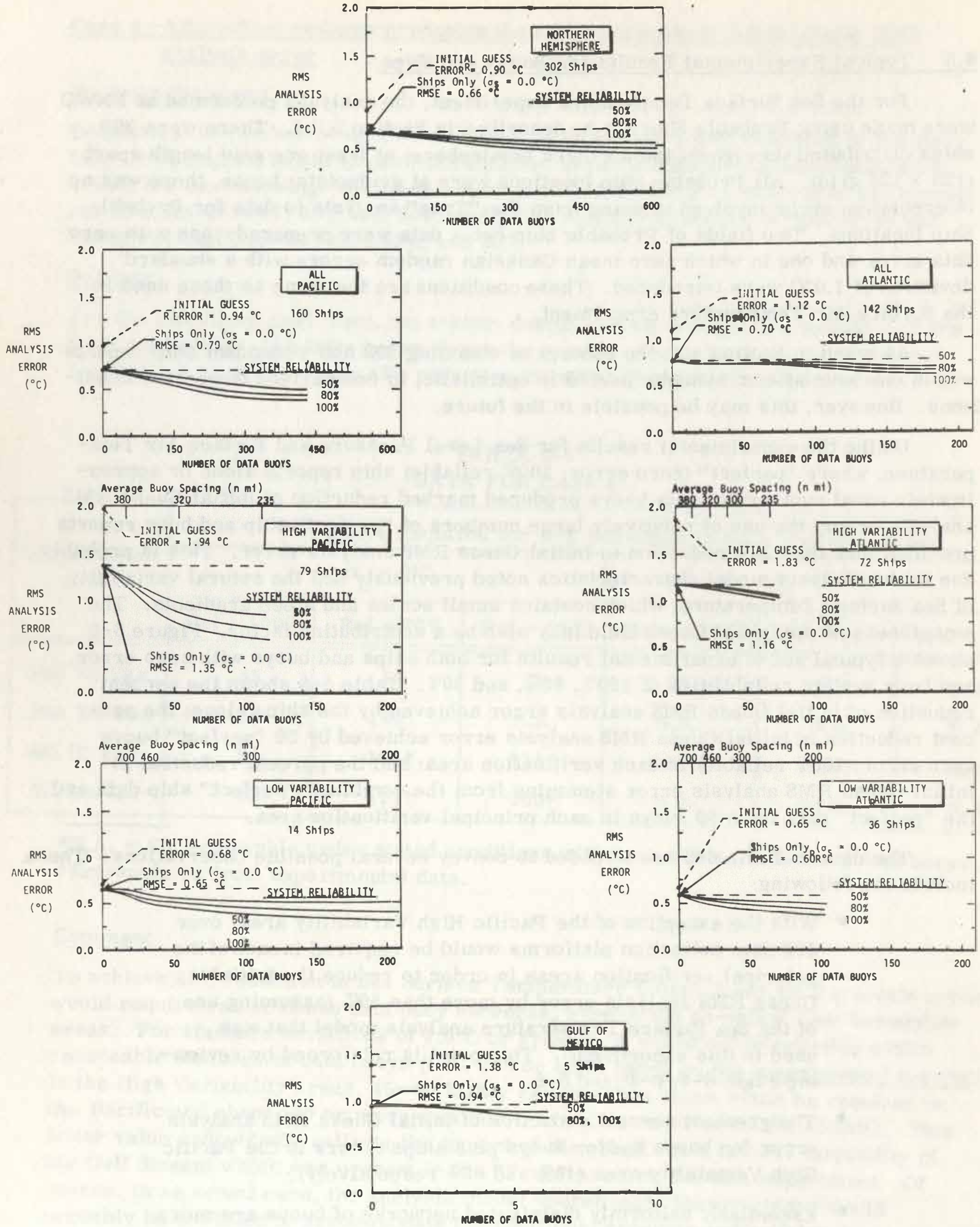

Fig. 6-9. Experimental results for Sea Surface Temperature: Buoys and Ships; σ_b = 0 °C; σ_s = 0 °C.

TABLE 6-8
REDUCTION IN INITIAL GUESS RMS ANALYSIS ERROR FOR "PERFECT" SHIPS AND FIFTY "PERFECT" DATA BUOYS IN EACH PRINCIPAL VERIFICATION AREA

Verification Area	No. of Probable Ships	No. of Data Buoys	Reduction in I.G.RMS Analysis Error(%)		
			Probable Ships	Buoys Only	Buoys Plus Ships
All Nor.Hem.	302	200	37 (.333)[1]	24 (.216)	40 (.360)
All Pacific	160	100	26 (.244)	28 (.263)	37 (.348)
Pac Hi Var	79	50	30 (.582)	48 (.931)	62 (1.202)
Pac Lo Var	14	50	3 (.020)	27 (.184)	34 (.231)
All Atlantic	142	100	37 (.414)	18 (.202)	39 (.436)
Atl Hi Var	72	50	37 (.677)	18 (.329)	43 (.786)
Atl Lo Var	36	50	8 (.052)	28 (.182)	34 (.221)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

These observations are more fully delineated by determining the percent reduction of Initial Guess RMS analysis error contributed on the average by each buoy. These crude measures of "system effectiveness" are shown in Table 6-9. However, it is not suggested that sufficient experimental investigations and analyses have been conducted to make the comparisons in Table 6-9 of great significance.

TABLE 6-9
PERCENT REDUCTION OF INITIAL GUESS RMS ANALYSIS ERROR PER "PERFECT" PLATFORM

Verification Area	No. of Probable Ships	No. of Data Buoys	Percent Reduction in I.G. RMS Analysis Error/Platform		
			Probable Ships	Buoys Only	Buoys Plus Ships
All Nor Hem	302	200	.12 (.0011)[1]	.12 (.0011)	0.08 (.0007)
All Pacific	160	100	.16 (.0015)	.28 (.0026)	0.14 (.0013)
Pac Hi Var	79	50	.39 (.0076)	.96 (.019)	0.48 (.0093)
Pac Lo Var	14	50	.21 (.0014)	.54 (.0037)	0.53 (.0036)
All Atlantic	142	100	.26 (.0029)	.18 (.0020)	0.16 (.0018)
Atl Hi Var	72	50	.51 (.0093)	.36 (.0066)	0.35 (.0064)
Atl Lo Var	36	50	.22 (.0014)	.56 (.0036)	0.40 (.0026)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area

A major point illustrated by Table 6-9 is that within three of the four principal verification areas, it is not possible to obtain marginal percent reductions in Sea Surface Temperature Initial Guess RMS analysis error that are greater than one percent per additional ship report or data buoy report. For buoy reports, a rough rule-of-thumb is 0.4 to 1.0 percent reduction in Initial Guess RMS analysis error per additional buoy report. This holds in the range of 20—50 buoys per verification area. There is not a sufficient range of experimental results available to specify a similar range for ship reports.

There is correlation only in the general trends that are found in comparing the buoys plus ship report columns of Tables 4-10, 5-9, and 6-9. These comparisons are shown in Table 6-10.

TABLE 6-10
COMPARISON OF SEA LEVEL PRESSURE, SURFACE AIR TEMPERATURE, AND SEA SURFACE TEMPERATURE RESULTS FOR DATA FROM BUOYS PLUS SHIPS

Verification Area	Percent Reduction in I.G.RMS Analysis Error/Platform (Buoys Plus Ships)		
	Sea Level Pressure	Surface Air Temperature	Sea Surface Temperature
All Nor Hem	0.16 (.0033) [1]	0.17 (.0043)	0.08 (.0007)
All Pacific	0.27 (.0062)	0.33 (.0082)	0.14 (.0013)
Pac Hi Var	0.68 (.0354)	0.68 (.0192)	0.48 (.0093)
Pac Lo Var	1.08 (.0089)	1.28 (.0236)	0.53 (.0036)
All Atlantic	0.39 (.0079)	0.35 (.0079)	0.16 (.0018)
Atl Hi Var	0.71 (.0251)	0.71 (.0196)	0.35 (.0064)
Atl Lo Var	0.93 (.0096)	0.97 (.0206)	0.40 (.0026)

[1] Values in parentheses are actual experimental reduction in RMS analysis error (mb or °C), relative to the applicable Initial Guess RMS analysis error for the verification area.

With the exception of results for the Pacific High Variability area, the percent reduction of Sea Surface Temperature Initial Guess RMS analysis error per platform for buoys plus ships is very nearly one-half that found for Sea Level Pressure and Surface Air Temperature. This is considered to be due to the four factors discussed previously.

The next subsection considers the impact of data errors and data buoy system reliability on the percent reduction of Initial Guess RMS analysis error achieved by combinations of ship reports and data buoy reports.

6.6 Some Examples of System Comparisons for Buoys and Ships

Figures 6-10 through 6-13 show for each of the four principal verification areas the impact of the following:

- Variation in data errors in ship data: $\sigma_s = 0$ and $\sigma_s = 1.0$°C. Data for $\sigma_s = 0$°C are extrapolated from other experimental results.
- Variation of data errors in buoy data, combined with ship data: $\sigma_s = 0$ and $\sigma_b = 0$; and $\sigma_s = 1.0$ and $\sigma_b = 0$, 1.0, and 3.0°C.
- Variation in system reliability of buoys-only data, and buoys combined with 100% reliable ship data: buoy system reliabilities of 100%, 80%, and 50%.

One of the most obvious comparisons that can be discussed using Figs. 6-10 through 6-13 concerns the number of data buoys in the essentially uniformly distributed data buoy networks that provide reduction of Initial Guess RMS analysis error equivalent to that of the randomly-located ships used in the experiment. Typical data for this comparison are shown in Table 6-11.

TABLE 6-11
A TYPICAL COMPARISON BETWEEN BUOYS AND SHIPS-OF-OPPORTUNITY

Verification Area	No. of Probable Ships	Reduction in I.G. RMS Analysis Error Due to Ships (%)		No. of Buoys ($\sigma_b = 0$) Required for Equal Reduction in I.G. RMS Analysis Error					
				$\sigma_s = 0$°C Buoy Reliability (%)			$\sigma_s = 1.0$°C Buoy Reliability (%)		
		σ_s =0°C	σ_s =1.0°C	100	80	50	100	80	50
Pac Hi Var	79	30 (.582)[1]	23 (.446)	33	42	57	29	37	45
Pac Lo Var	14	3 (.020)	1 (.007)	13	16	18	11	13	14
Atl Hi Var	72	37 (.677)	27 (.494)	80	87	91	68	75	79
Atl Lo Var	36	8 (.052)	1 (.007)	6	10	12	2	4	5

[1] Values in parentheses are actual experimental reduction in RMS analysis error (°C), relative to the applicable Initial Guess RMS analysis error for the verification area.

With the exception of Atlantic High Variability area, it is noted from Table 6-11 that the essentially uniformly distributed data buoys are more effective than the randomly distributed ships, even for buoy reliabilities of 80% to 50%. In the Atlantic High Variability area, it appears that the more closely spaced ship reports in the Gulf Stream region tend to dominate the verification statistic. Unless the errors in ship data are very small, this would imply that a non-uniform grid of highly accurate

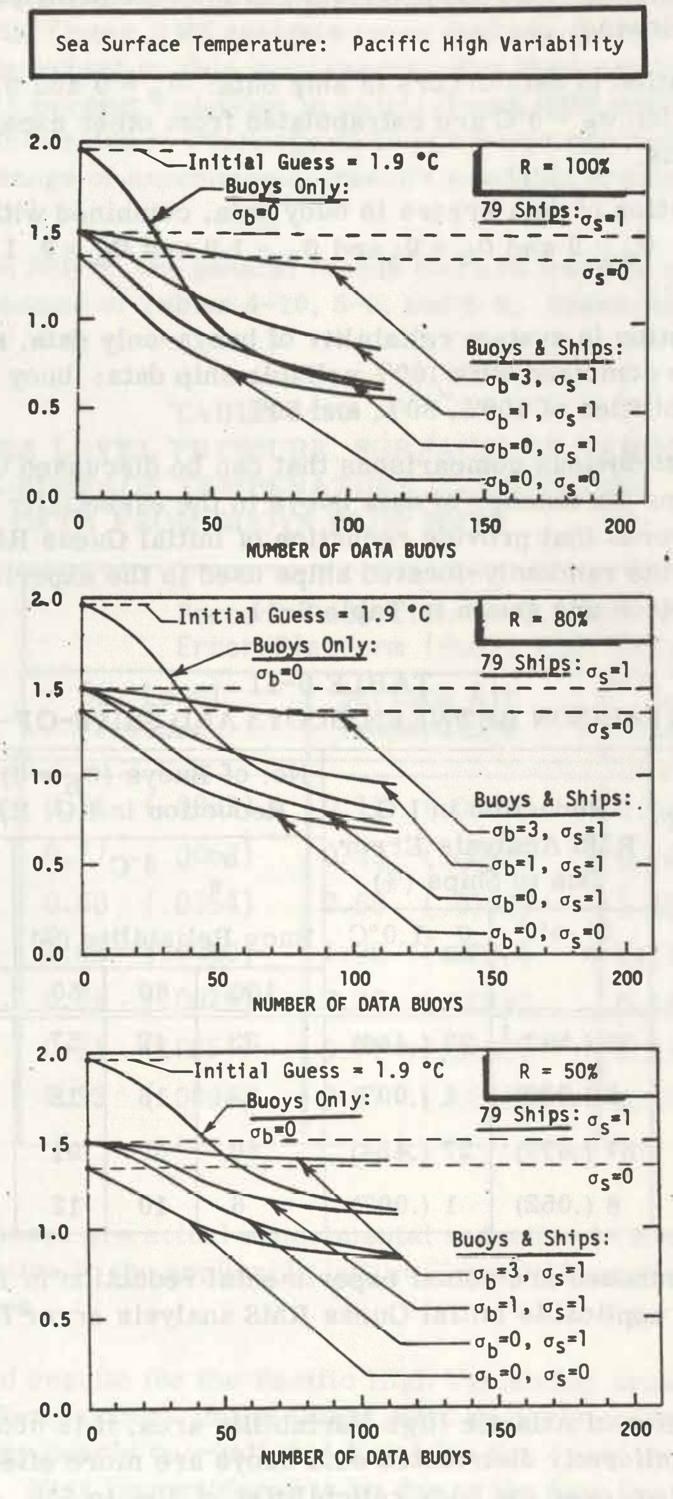

Fig. 6-10. Experimental results for Sea Surface Temperature: Buoys and Ships in the Pacific High Variability area.

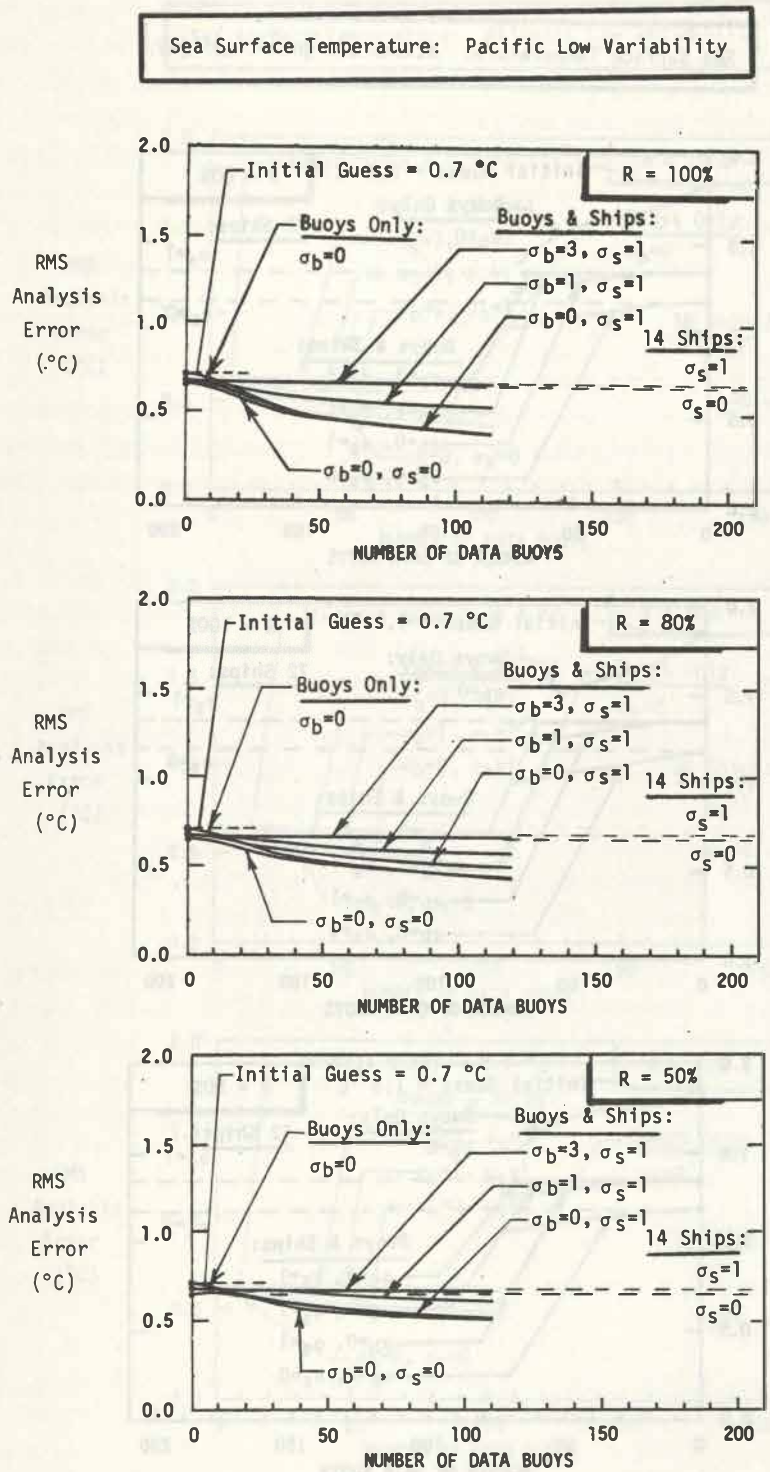

Fig. 6-11. Experimental results for Sea Surface Temperature: Buoys and Ships in the Pacific Low Variability area.

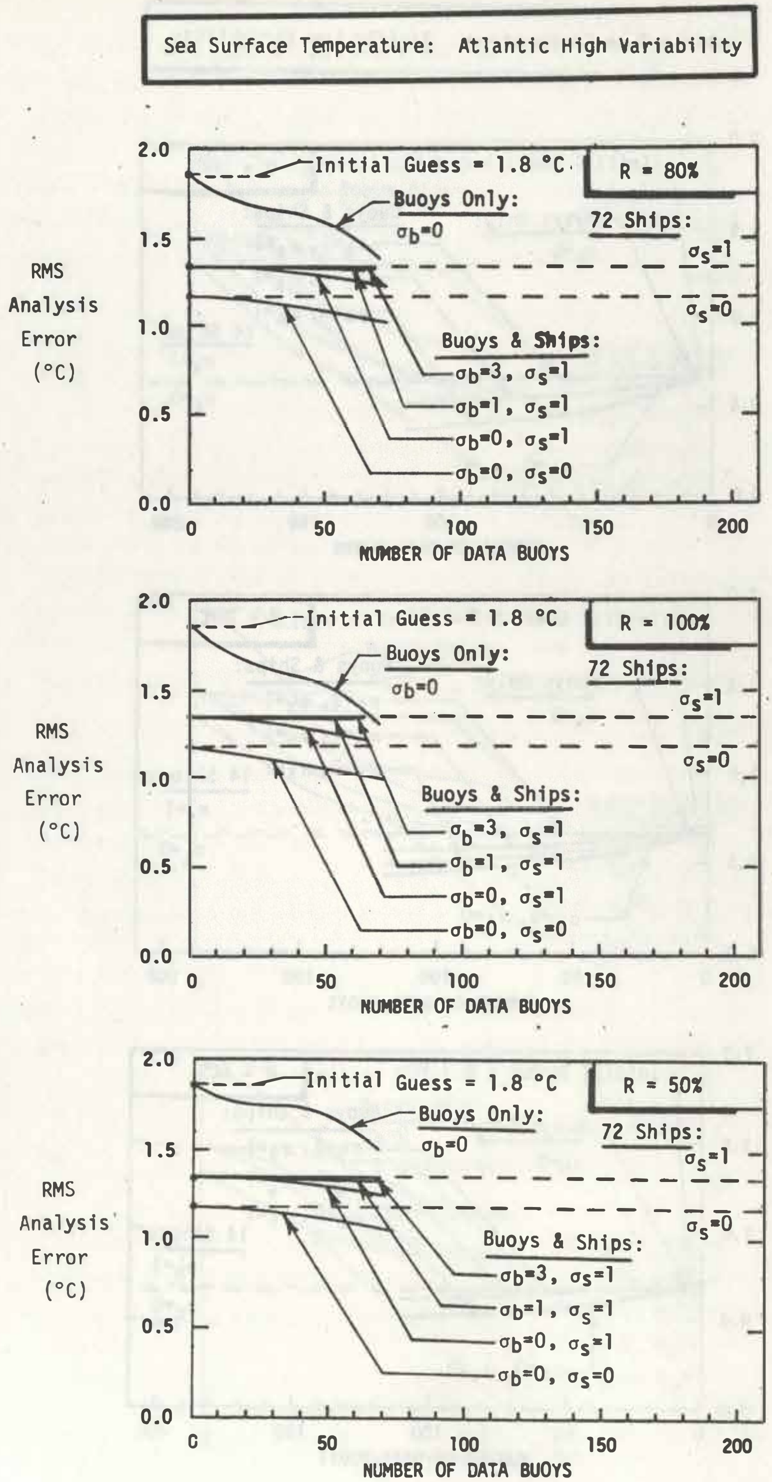

Fig. 6-12. Experimental results for Sea Surface Temperature: Buoys and Ships in the Atlantic High Variability area.

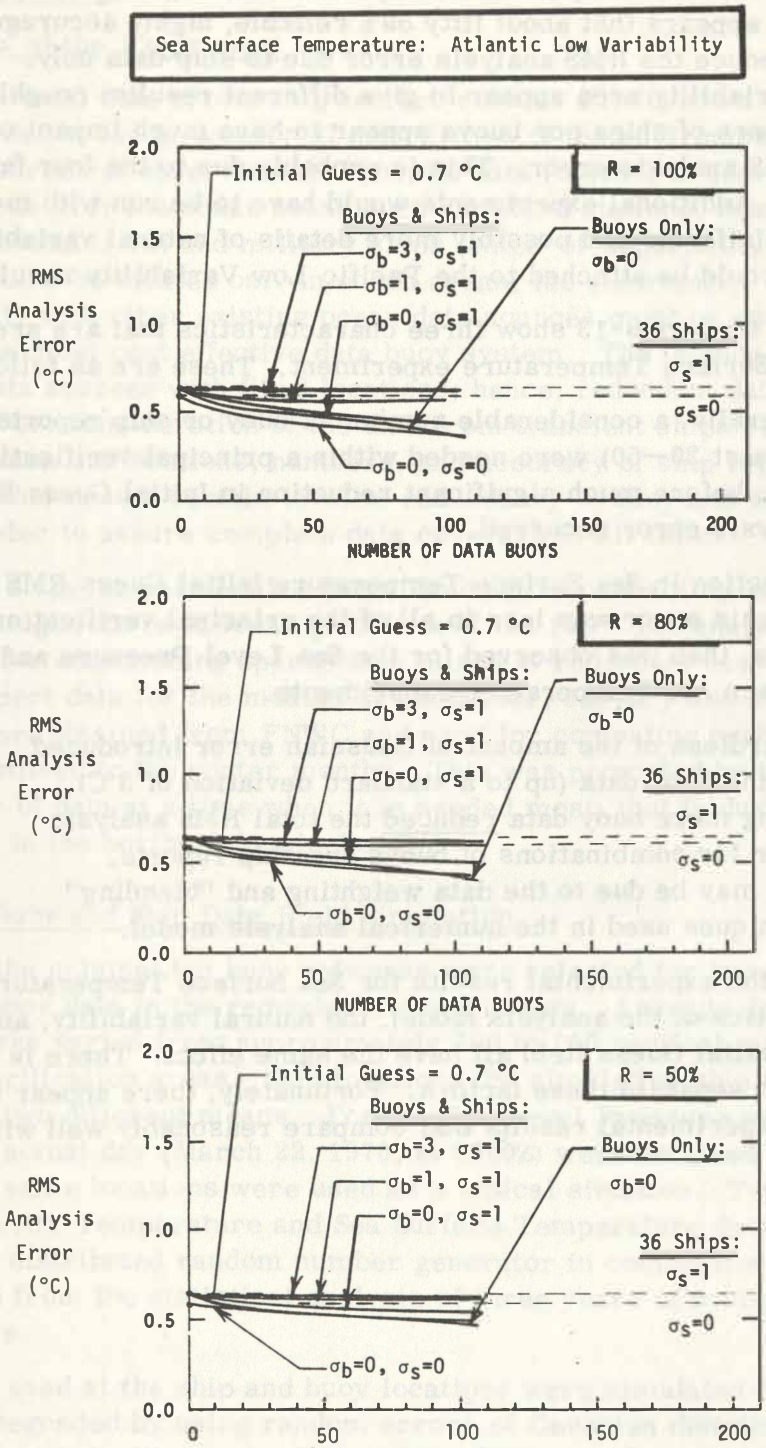

Fig. 6-13. Experimental results for Sea Surface Temperature: Buoys and Ships in the Atlantic Low Variability area.

and reliable data buoys with greatest density in the Gulf Stream region would be needed to improve the Sea Surface Temperature analysis in that region. In the Pacific High Variability area, it appears that about fifty 50% reliable, highly accurage data buoys can substantially reduce the RMS analysis error due to ship data only. The data for the Pacific Low Variability area appear to give different results; roughly speaking, neither small numbers of ships nor buoys appear to have much impact on reduction of Initial Guess RMS analysis error. This is probably due to the four factors discussed previously. Additional experiments would have to be run with more networks of data collection platforms and possibly more details of natural variability before great significance could be attached to the Pacific Low Variability results.

Figures 6-10 through 6-13 show three characteristics that are prevalent throughout the Sea Surface Temperature experiment. These are as follows.

- Generally, a considerable number of buoy or ship reports (at least 20—50) were needed within a principal verification area, before much significant reduction in Initial Guess RMS analysis error occurred.
- Reduction in Sea Surface Temperature Initial Guess RMS analysis error was less in all of the principal verification areas, than was observed for the Sea Level Pressure and Surface Air Temperature experiments.
- Regardless of the amount of Gaussian error introduced into the buoy data (up to a standard deviation of 3°C), adding more buoy data <u>reduced</u> the total RMS analysis error for combinations of buoys and ship reports. This may be due to the data weighting and "blending" techniques used in the numerical analysis model.

In summary, the experimental results for Sea Surface Temperature indicate that the characteristics of the analysis model, the natural variability, and the smoothness of the Initial Guess field all have the same effect. There is not sufficient experimental data to separate these factors. Fortunately, there appear to be general trends in the experimental results that compare reasonably well with the other two experiments.

7.0 EFFECT OF ELIMINATING REDUNDANCY OF DATA BUOYS AND SHIPS-OF-OPPORTUNITY

7.1 Overview of the Experiment

Environmental data processing centers such as FNWC use all data available in their effort to define the geographical distribution of the environmental parameters. The present sources of observational synoptic data include, in addition to land stations, sources over the ocean areas such as island stations, fixed weather ships and transient commercial and military ships (ships-of-opportunity). Since a data buoy system would be located only in ocean areas, the desirability of buoys reporting data redundantly with other existing ocean data sources must be established in order to construct the most cost effective data buoy system. The islands and weather ships are reliable data sources with fixed locations; hence, redundant data buoys are not needed. However, consideration of the data from transient ships requires different treatment because the locations, numbers, and accuracy of ship report sources vary over time. In this case a certain level of redundancy in buoy and ship reports must be tolerated in order to assure complete data coverage at all times.

For this study, it was decided that a field of the probability of at least one ship report originating from each ocean gridblock of the 125 × 125 analysis grid would best suit the needs for establishing appropriate mixes of redundant buoy and ship reports. Actual ship report data for the months of December, Janyary and February for three recent years were obtained from FNWC and used for computing probabilities with the time period confined to the winter months. This was prompted by the desire to establish the availability of data at a time when it is needed most; that is during the period of severe storms in the northern hemisphere.

7.1.1 Buoy and Ship Data Field Simulation

Four of the original ten buoy networks were selected for buoy locations in the simulation of buoy data in the redundancy experiments. Average data spacing of buoys in these networks varied from approximately 700 to 200 nautical miles in the Pacific and Atlantic verification areas. Ship locations for simulating ship data ship data were established by two different means. For the Sea Level Pressure analyses, ship reports for an actual day (March 22, 1970, at 0000Z) were obtained from the analysis center and the same locations were used as a typical situation. Typical ship locations for the Surface Air Temperature and Sea Surface Temperature data were established by a uniformly distributed random number generator in conjunction with the probability field generated from the statistical analysis of three years of winter ship reports as described above.

The data used at the ship and buoy locations were simulated by using "True" Analysis data degraded by using random errors of Gaussian distribution. Ship data fields were generated with standard deviation of errors of zero and 1.0 mb or °C. Buoy data fields were generated with standard deviations of error ranging from zero to 5.0 mb and zero to 3.0°C. Details of the generation of ship and buoy data fields are given in Section 3.0 of this report.

7.1.2 Control of Redundancy

The probability field generated from the location of actual ship reports was used to delineate areas by level of probability of occurrence of at least one ship report originating from each grid block as thresholds at which to remove buoys to reduce redundancy of reports. Three levels of probability were selected; 100%, 75%, and 50%. Contour lines enclosed the areas so that within the lines, the probabilities were equal to or greater than these values. The four basic buoy networks were revised to correspond with each of these levels by removing buoys located within the areas defined by the three probability levels. For the 100% threshold, no buoys were removed; for the 75% and 50% thresholds, buoys were removed in the regions where the probability of at least one ship report was equal to or greater than 75% and 50%, respectively. The area of the region under consideration was essentially the area represented by a square of average buoy network spacing, centered on each buoy. Thus, the area around buoys varied both by network density, and by density within a given network, in some cases. Buoy data fields corresponding with these revised networks were then combined with the ship data fields to measure the effect of reducing redundancy of buoy and ship reports. Table 7-1 shows the reduction in number of buoys for each redundancy level for each verification area. (Table 7-1 is Table 3-8, repeated here for convenience.)

7.2 Typical Experimental Results

To set the stage for the discussion of the experimental results, consider the following hypothetical examples.

Conditions

(1) In a given region, the RMS analysis error for the Initial Guess is 4 mb.

(2) Use of 50 ship reports with zero data error, randomly distributed throughout the area, produces an analysis with RMS analysis error of 1.0 mb.

(3) When error-free data from three hypothetical 100% reliable data buoy networks of 15, 30, or 50 data buoys (each network essentially uniformly distributed in the region) are introduced in addition to the ship data, the RMS analysis error values are 0.50 mb, 0.39 mb and 0.20 mb, respectively. This is shown as Curve A in Fig. 7-1.

(4) Assume that data buoys in the 30-buoy network are removed from those locations where the statistical probability of at least one ship is 75% or greater, and that this entails the removal of 10 buoys and the resulting analysis for this combination of ships and 20 buoys produces an RMS analysis error of 0.33 mb. (The remaining 20 buoys are still located and spaced as they were in the original 30-buoy network.) For the 50% probability threshold, assume that a total of 20 buoys is removed, and

TABLE 7-1
DATA POINTS PER VERIFICATION AREA

Area	Island Stns.	Number of Ships: OSVs	Number of Ships: Actual Ships	Number of Ships: Probable Ships	Redun. Thresh-old	Buoys Per Network: 600B	Buoys Per Network: 300C	Buoys Per Network: 150A	Buoys Per Network: 76B
Northern Hemisphere	32	13	348	342	100% 75 50	600 542 434	300 224 172	150 125 66	76 58 37
All Pacific	15	4	210	160	100% 75 50	423 397 345	212 176 136	104 81 54	53 44 30
High Variability Pacific	3	3	108	79	100% 75 50	111 98 65	54 33 11	53 45 27	26 19 12
Low Variability Pacific	7	0	20	14	100% 75 50	206 206 205	107 103 89	31 28 17	18 18 14
All Atlantic	17	9	118	142	100% 75 50	177 145 89	88 48 36	46 24 12	23 14 7
High Variability Atlantic	2	8	72	72	100% 75 50	67 44 8	37 12 5	25 12 3	12 7 2
Low Variability Atlantic	8	1	31	36	100% 75 50	96 95 81	47 38 33	20 12 9	11 8 6
Gulf of Mexico	0	0	6	5	100% 75 50	6 5 3	3 0 0	3 0 0	0 0 0

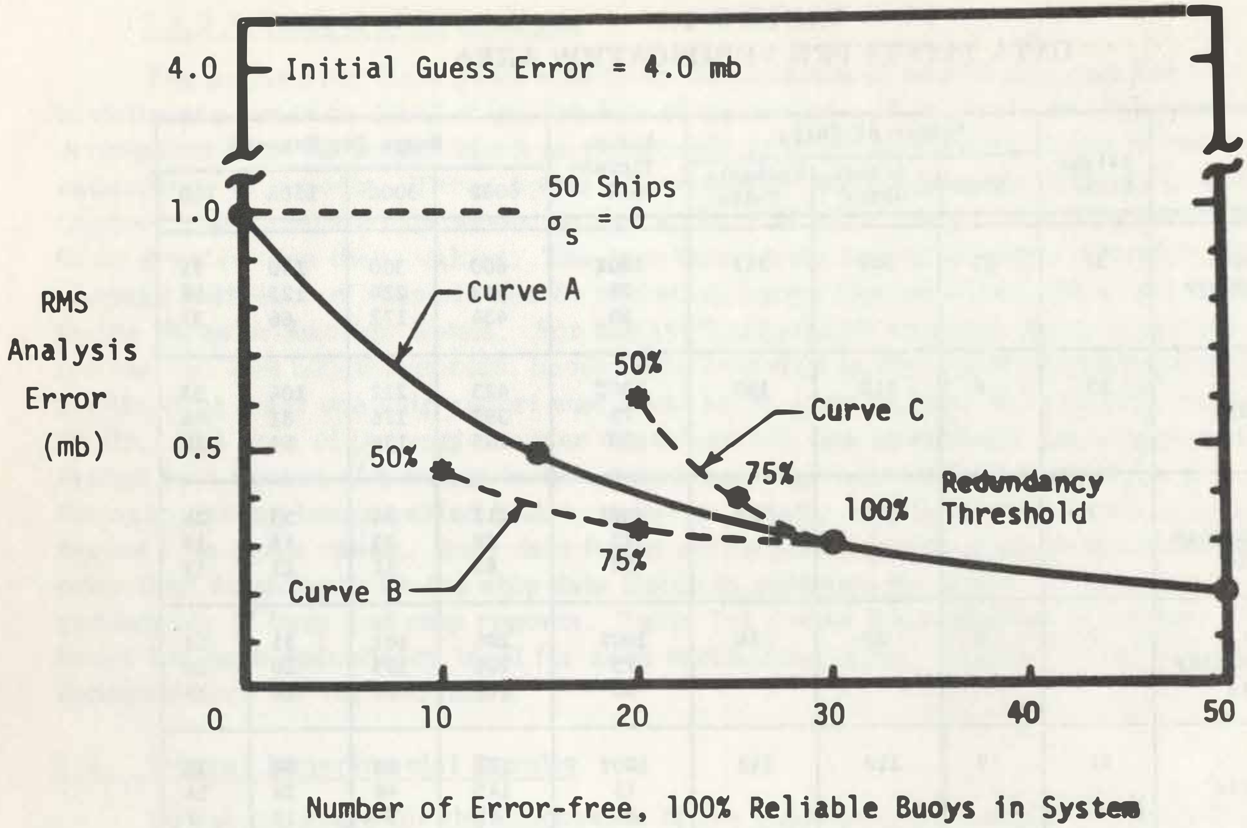

Fig. 7-1. Example of potential effects of reducing the redundancy of buoy and ship reports.

the resulting RMS analysis error for 50 ship reports and 10 buoy reports is 0.46 mb. These results are plotted as Curve B in Fig. 7-1. Curve B falls below Curve A, which indicates that for a given number of buoys, it appears to be better to space the buoys densely in areas where the probability of at least one ship report is low, than to space them essentially uniformly throughout the entire region.

(5) Next, again assume that data buoys in the 30-buoy network are removed from areas where the probability of at least one ship report is 75% or greater and 50% or greater, with the result that 5 and 10 buoys are removed respectively. But in this case, assume that these mixes of 50 ships and 25 data buoy reports and 50 ship and 20 buoy reports produce RMS analysis curves of 0.40 mb and 0.60 mb, respectively. This is shown as Curve C in Fig. 7-1. Curve C occurs above Curve A, which suggests that the "holes" created in the 30-buoy network are not being filled by ship

reports, and suggests that it would be better to have buoys essentially uniformly distributed throughout the region, even though buoy and ship reports would be received redundantly from some areas.

Results such as both the hypothetical examples given above (Curve B and Curve C results) occurred in the Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature experiments. In general, it was found in these experimental results (discussed below) that the potential for improvement fit into three types: (a) a small improvement (less than 0.1 mb or 0.2°C); (b) essentially no improvement was found; or (c) a Curve C situation occurred, suggesting that a uniform distribution of buoys was the better choice.

The comments above reflect the <u>results</u> of the experiments. However, it is stressed that these comments cannot be taken as <u>conclusions</u>, because in each experiment only a <u>single</u> set of random ship locations and number of ships was used. Several sets of random ship locations would be needed to provide enough experimental data to draw well-founded conclusions concerning the desirability of removing data buoys from networks, especially for the 50% probability threshold. In addition to the need for Monte Carloing the locations of ship reports, it might be advisable to use reduced numbers of ship reports (i.e., about 90, rather than an average of about 348 to 302, as were used in the experiments), commensurate with the information in Table 3-5 for the average number of ship reports received within one hour of synoptic reporting time.

<u>7.2.1 Impact of Reducing Redundancy of Buoy and Ship Reports</u>

Figures 7-2 and 7-3 show Sea Level Pressure experimental results for the four major verification areas. Each figure shows two graphs, comparing results in contiguous high and low variability areas of the Pacific or Atlantic. Each graph shows the ship reports under two conditions: error-free ship and buoy data, and ship data with Gaussian errors of 1.0 mb standard deviation combined with buoy data with Gaussian errors of 1.0 mb standard deviation. All buoy networks are 100% reliable. For the zero error case, curves are plotted for redundancy thresholds of 100%, 75%, and 50%. No 75% or 50% redundancy threshold data were obtained in the Sea Level Pressure experiment for the case where buoy and ship data had errors with $\sigma_b = \sigma_s = 1.0$ mb. Solid dots in solid curves in the graphs are actual experimental RMS analysis errors for the four buoy networks used in all three experiments. Open squares give RMS analysis errors for the ships and a reduced number of buoys that are in areas where the probability of at least one ship report is less than 75%. (The locations of the remaining buoys are the same as in the 100% redundancy case.) Open circles show RMS analysis errors for ships and a smaller number of buoys that are in areas where the probability of at least one ship report is less than 50%. If an open square or open circle falls <u>below</u> the 100% redundancy threshold line (which passes through the solid dots), then removing buoys to avoid redundancy of reports is preferable to distributing that same number of buoys essentially uniformly throughout the verification area. If the open square or open circle falls <u>above</u> the 100% redundancy threshold line through the solid dots, then an essentially uniform buoy network throughout the verification area is preferably to a buoy network that is dense in areas where ship report probabilities are low, and sparse in areas where ship report probabilities are high.

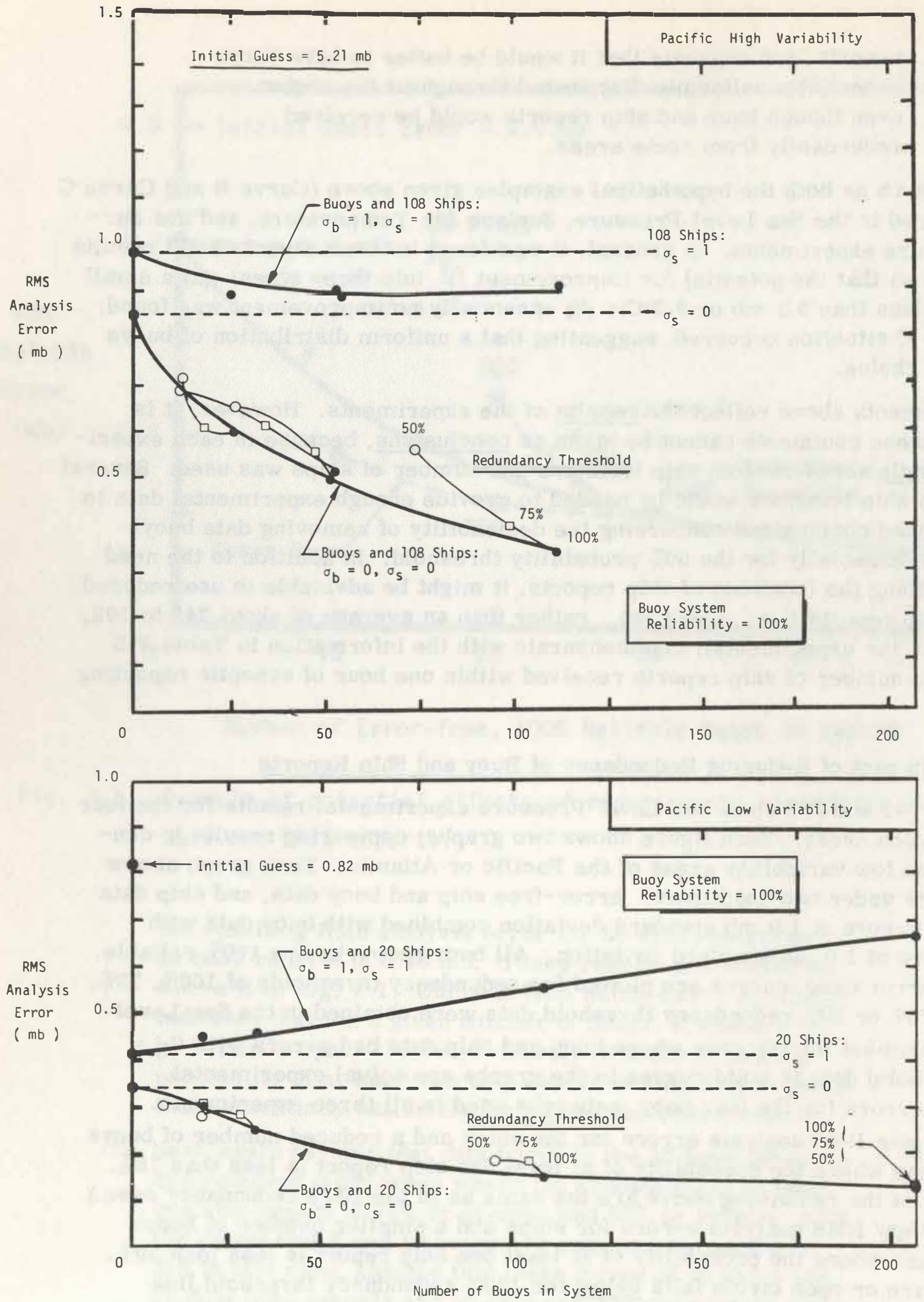

Fig. 7-2. Experimental results for Sea Level Pressure, showing the impact of reducing data redundancy of buoys and ships.

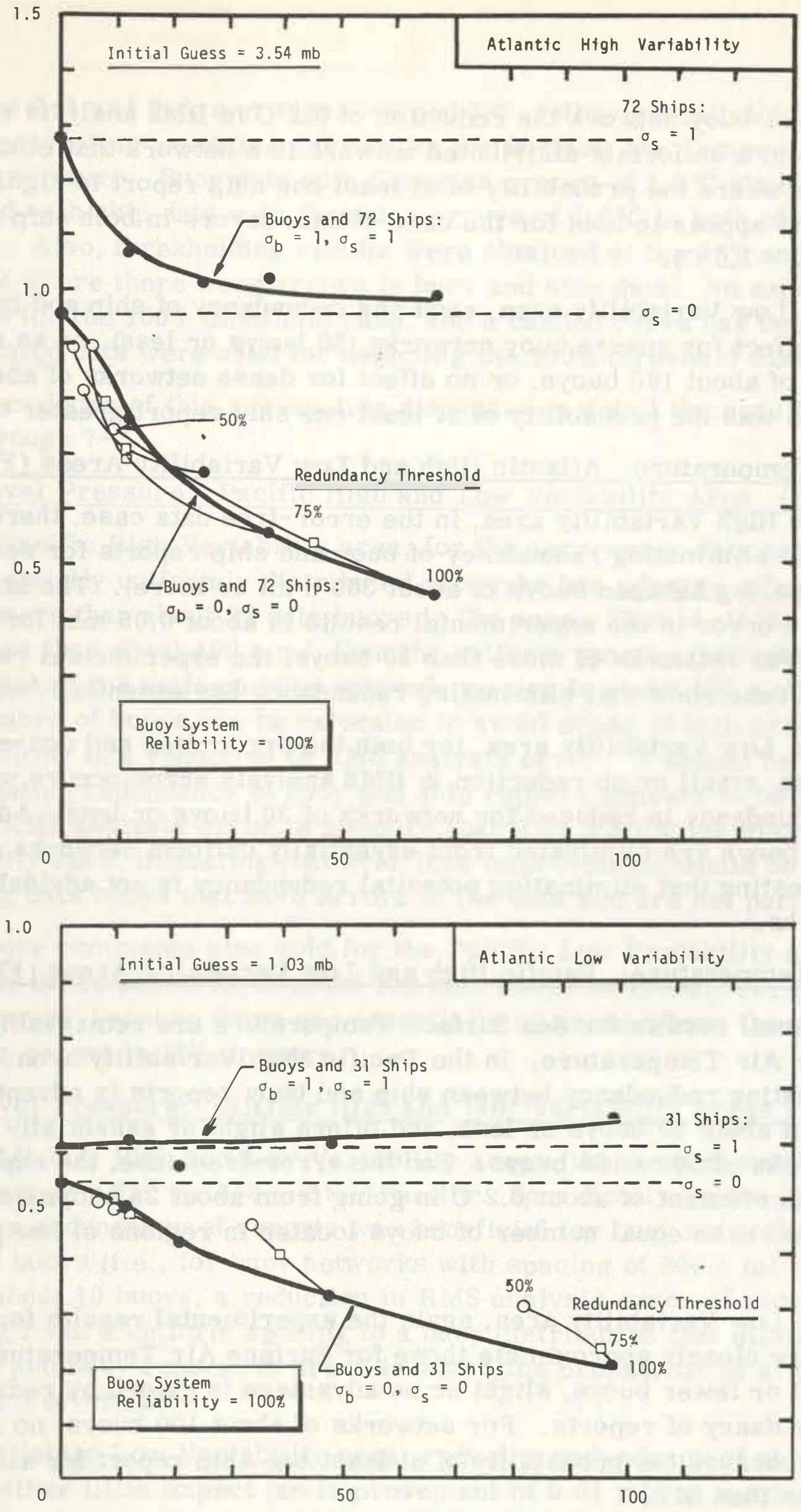

Fig. 7-3. Experimental results for Sea Level Pressure, showing the impact of reducing data redundancy of buoys and ships.

indicates that for a 25-buoy network the reduction of 0.2°C in RMS analysis error is obtained in going from a uniformly distributed network to a network that eliminates redundance in areas where the probability of at least one ship report is high. Essentially similar results appear to hold for the case of data errors in both ship and buoy data (σ_s = 1.0°C; σ_b = 1.0°C).

In the Pacific Low Variability area, reducing redundancy of ship and buoy reports had essentially no effect for sparse buoy networks (50 buoys or less), or an adverse effect for networks of about 100 buoys, or no effect for dense networks of about 200 buoys (because in no areas was the probability of at least one ship report greater than 50%).

Surface Air Temperature: Atlantic High and Low Variability Areas (Fig. 7-5)

In the Atlantic High Variability area, in the error-free data case, there is seen to be an advantage in eliminating redundancy of buoy and ship reports for networks of 30 buoys or less (spacing between buoys of about 300 n mi or more). The largest reduction in RMS analysis error in the experimental results is about 0.05 mb, for a network of about 12 buoys. For networks of more than 30 buoys, the experimental results for the error-free data case show that eliminating redundancy has essentially no impact.

In the Atlantic Low Variability area, for both the error-free and non-error-free experimental results, small or no reduction in RMS analysis error occurs when ship and buoy report redundancy is reduced for networks of 30 buoys or less. Adverse effects occur when buoys are eliminated from essentially uniform networks of 40 buoys or more, thus suggesting that eliminating potential redundancy is not advisable for the denser buoy networks.

Sea Surface Temperature: Pacific High and Low Variability Areas (Fig. 7-6)

The experimental results for Sea Surface Temperature are remarkably similar to those for Surface Air Temperature. In the Pacific High Variability area, it appears that eliminating redundancy between ship and buoy reports is advantageous for buoy networks of about 50 buoys or less, and offers slight or essentially no advantage for buoy networks of 50 to 100 buoys. For the error-free case, the experimental results show an improvement of about 0.2°C in going from about 25 buoys (essentially uniformly distributed) to an equal number of buoys located in regions of low probability of ship reports.

In the Pacific Low Variability area, again the experimental results for Sea Surface Temperature closely approximate those for Surface Air Temperature. For buoy networks of 30 or fewer buoys, slight or no advantage is gained by redistributing buoys to avoid redundancy of reports. For networks of about 100 buoys, no redistribution takes place, because the probability of at least one ship report for all areas around buoys is less than 50%.

The above general comments hold for both the error-free and non-error-free data cases.

Sea Surface Temperature: Atlantic High and Low Variability Areas (Fig. 7-7)

In both the Atlantic High and Low Variability areas, the experimental results indicate either very slightly adverse effects from eliminating redundancy of buoy and ship reports, or essentially no impact at all. Since there are small scales of variability involved, due to the Gulf Stream, these experimental results do not appear to be unusual.

Figures 7-4 and 7-5, and Figs. 7-6 and 7-7, follow essentially the same format as above in presenting experimental results for Surface Air Temperature and Sea Surface Temperature. Buoy data with Gaussian errors of 1.0°C standard deviation are combined with ship data with Gaussian errors of 1.0°C in both of the temperature experiments. Also, thresholding results were obtained at the 75% and 50% levels for the cases where there were errors in buoy and ship data. No experimental data are available for the 100% threshold case, and a dashed curve has been used to show that extrapolated data were used for depicting the 100% threshold case.

The remainder of this sub-section discusses in detail the results shown in Figs. 7-2 through 7-7.

Sea Level Pressure: Pacific High and Low Variability Area (Fig. 7-2)

In the Pacific High Variability area, for the zero-error data case, removing buoys from the essentially uniformly distributed networks has adverse effects on networks comprising more than about 25 data buoys in the area. That is, if the buoy network spacing is less than about 400 n mi, then the uniform spacing throughout the area is preferred. But, if the uniform buoy network spacing is about 400 n mi or greater, then the same number of buoys can be relocated to avoid areas of high probability of ship reports, resulting in a reduction of RMS analysis error. It should be noted that even where eliminating redundancy of buoy and ship reports appears to be preferred, the reduction in RMS analysis error is no more than 0.05 mb for the error-free data, 100% reliability case, indicating that even less improvement would be expected from redistributing data buoys that have errors in the data and are not perfectly reliable.

The above comments also hold for the Pacific Low Variability area. Figure 7-2 shows that for dense networks of about 100 data buoys or more, few, if any, data buoys would be removed, because there are essentially no areas where the probability of at least one ship report is 50% or more.

Sea Level Pressure: Atlantic High and Low Variability Areas (Fig. 7-3)

In the Atlantic High and Low Variability areas, the general results for zero error data were similar to those in the Pacific. Specifically, in the High Variability area, reducing redundancy of reports was beneficial for buoy networks numbering less than about 30 buoys (i.e., for buoy networks with spacing of 300 n mi or more). For networks of about 10 buoys, a reduction in RMS analysis error of about 0.1 mb was found in going from a uniform spacing to a buoy distribution that eliminated redundancy of ship and buoy reports in areas in which the probability of at least one ship report was 50% or more.

In the Atlantic Low Variability area, reducing redundancy of ship and buoy reports had either little impact (an improvement of 0.01 mb, at most) or an adverse effect, in the case of the denser buoy networks.

Surface Air Temperature: Pacific High and Low Variability Areas (Fig. 7-4)

In the Pacific High Variability area for the zero-error data case, it appears that relocating data buoys to avoid redundancy with ships is beneficial for networks of 100 buoys or less (i.e., a network spacing of about 250 n mi or greater). Figure 7-4

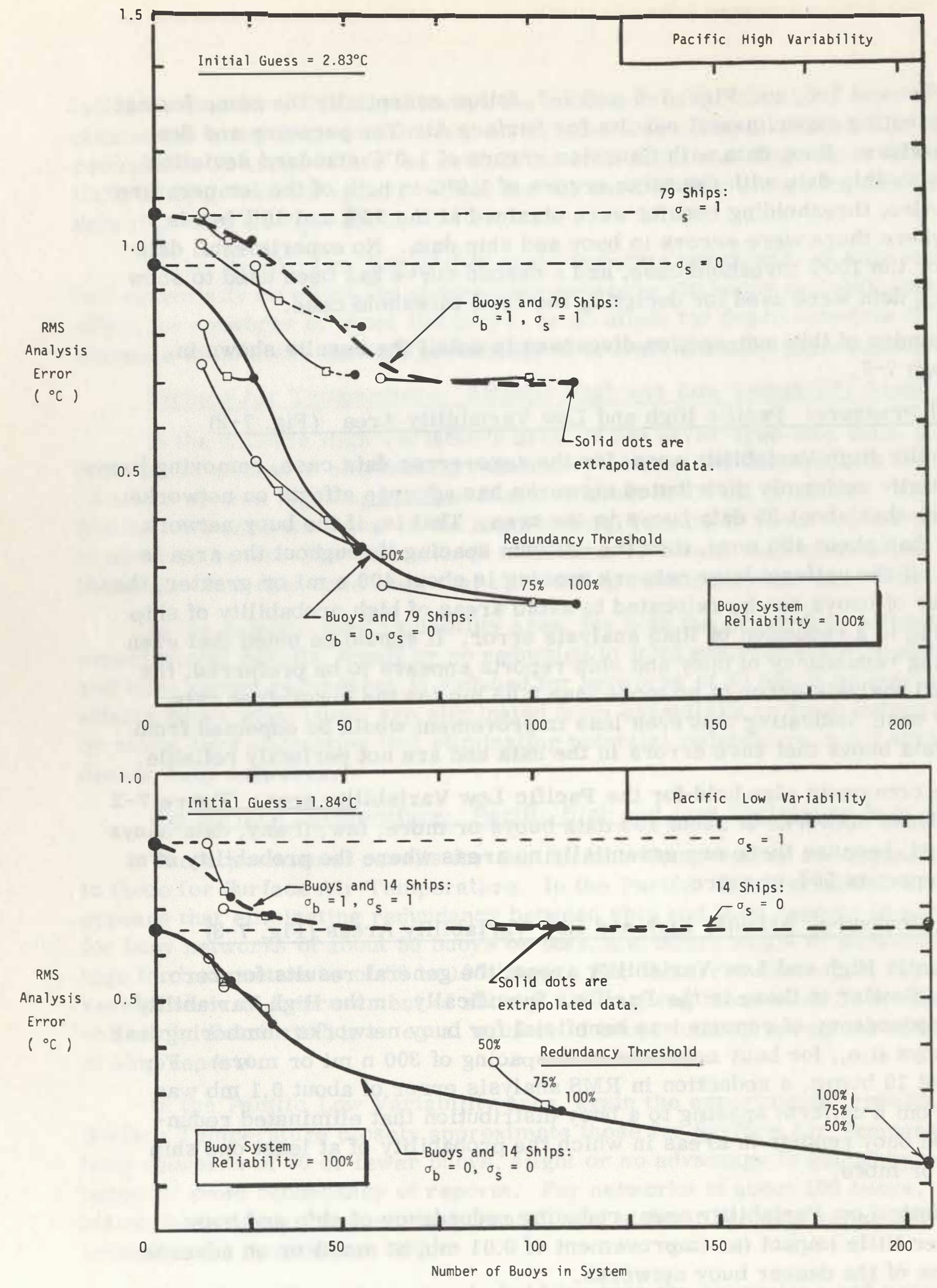

Fig. 7-4. Experimental results for Surface Air Temperature, showing the impact of reducing data redundancy of buoys and ships.

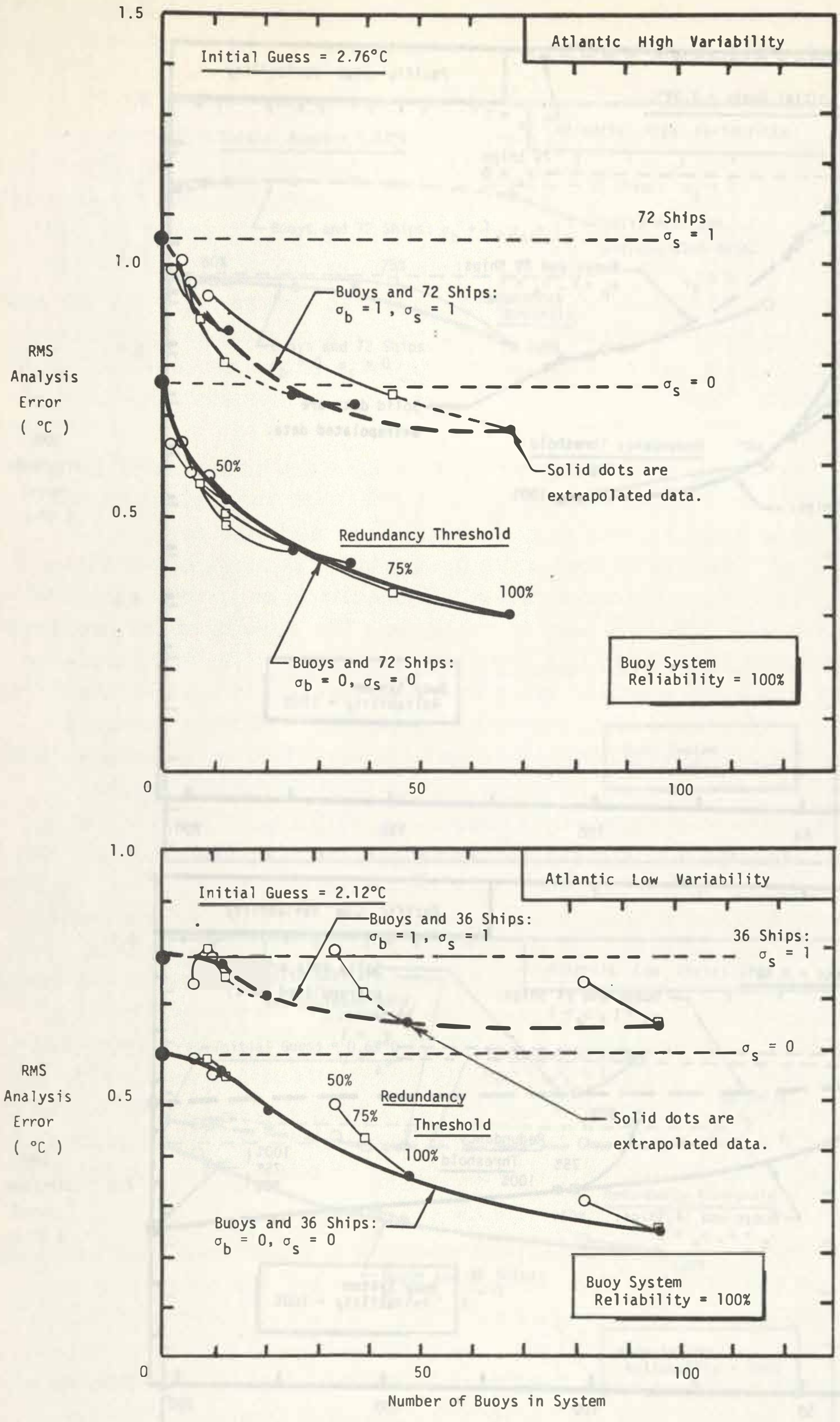

Fig. 7-5. Experimental results for Surface Air Temperature, showing the impact of reducing data redundancy of buoys and ships.

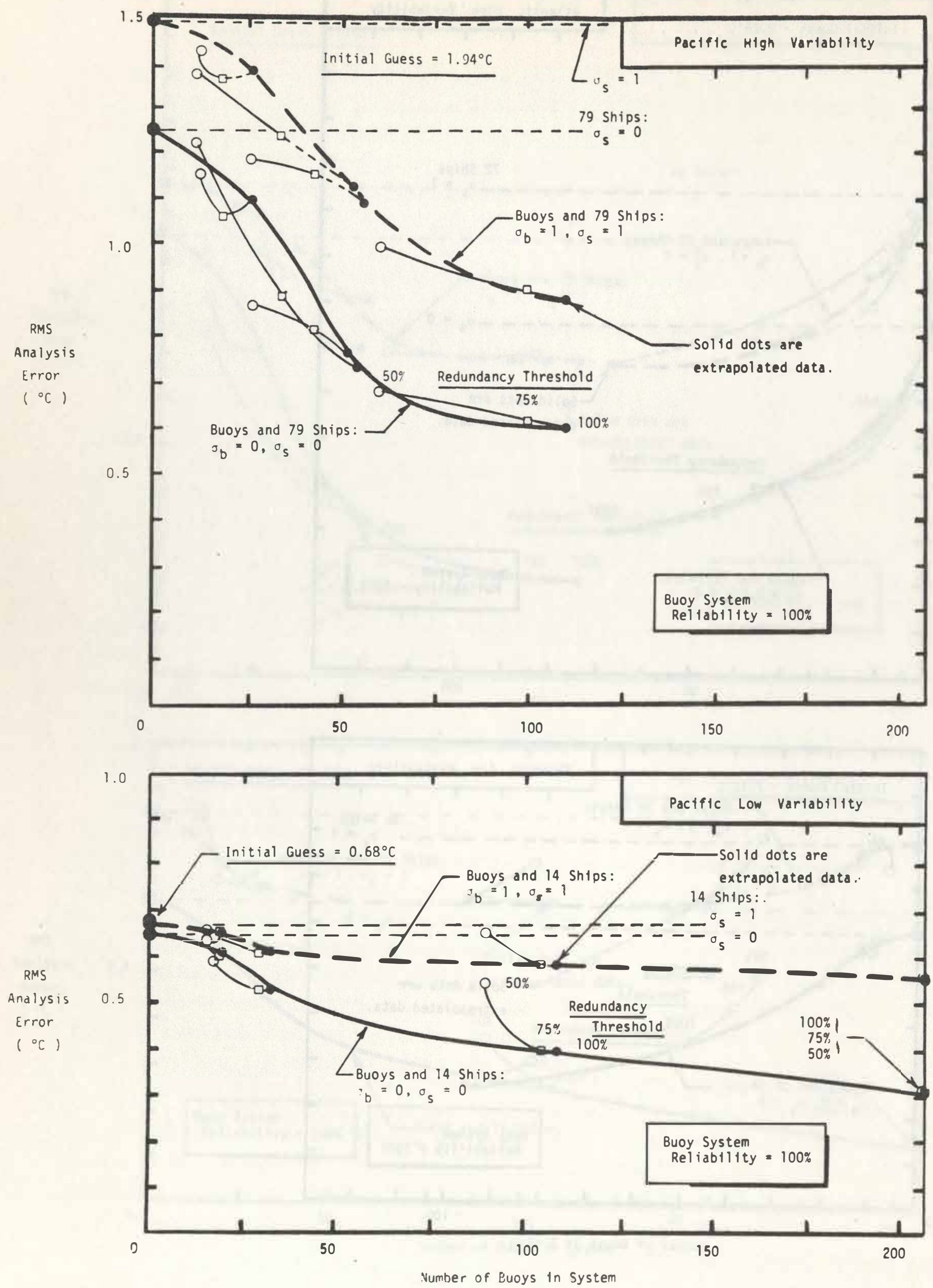

Fig. 7-6. Experimental results for Sea Surface Temperature, showing the impact of reducing data redundancy of buoys and ships.

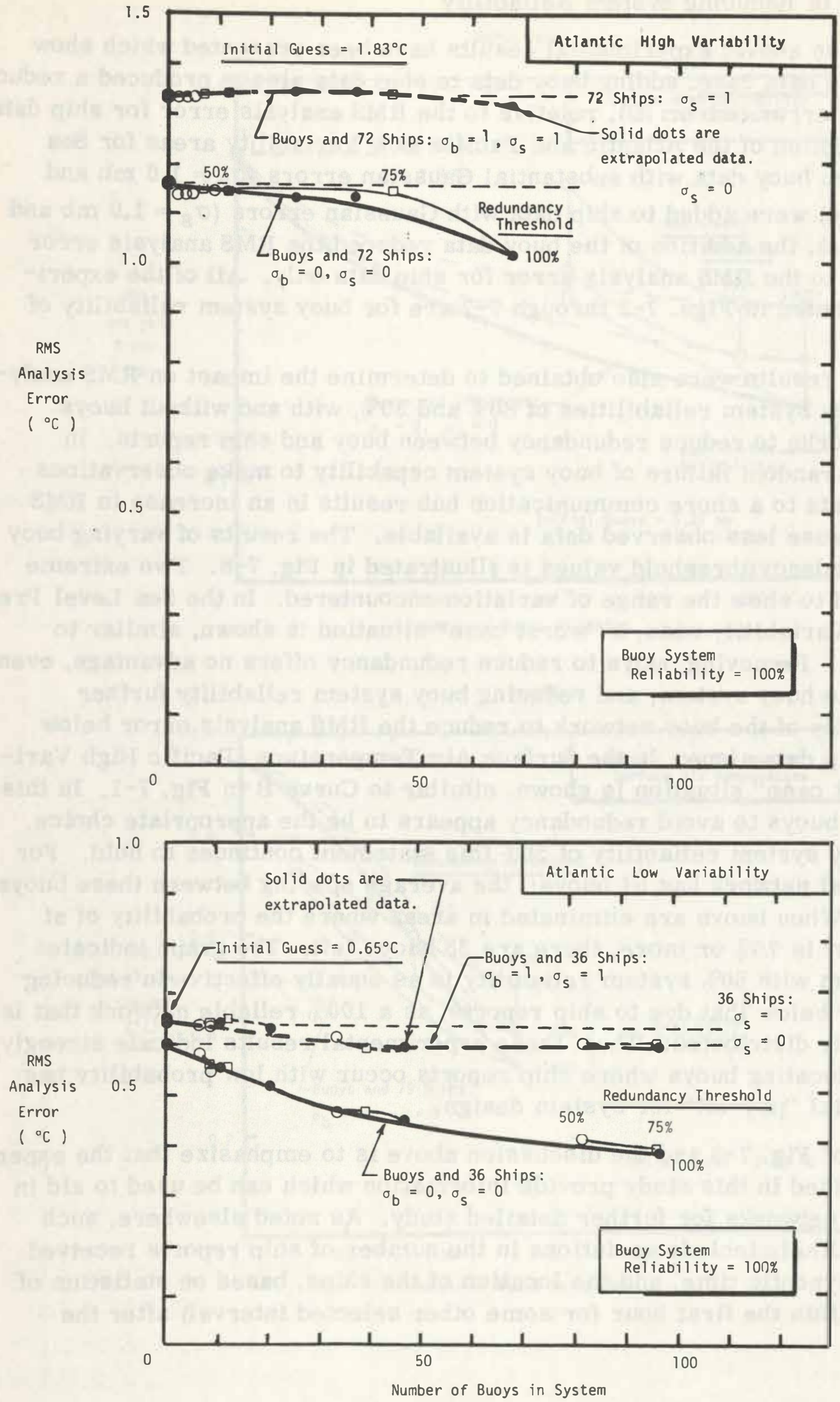

Fig. 7-7. Experimental results for Sea Surface Temperature, showing the impact of reducing data redundancy of buoys and ships.

7.2.2 Impact of Reducing System Reliability

In the discussion above, experimental results have been presented which show that in the error-free data case, adding buoy data to ship data always produced a reduction in RMS analysis error (mb or °C), relative to the RMS analysis error for ship data alone. With the exception of the Atlantic and Pacific Low Variability areas for Sea Level Pressure, when buoy data with substantial Gaussian errors (σ_b = 1.0 mb and 1.0°C, as appropriate) were added to ship data with Gaussian errors (σ_S = 1.0 mb and 1.0°C, as appropriate), the addition of the buoy data reduced the RMS analysis error (mb or °C), relative to the RMS analysis error for ship data only. All of the experimental results presented in Figs. 7-2 through 7-7 are for buoy system reliability of 100%.

Experimental results were also obtained to determine the impact on RMS analysis error due to buoy system reliabilities of 80% and 50%, with and without buoys removed from networks to reduce redundancy between buoy and ship reports. In general, increasing random failure of buoy system capability to make observations and/or return the data to a shore communication hub results in an increase in RMS analysis error, because less observed data is available. The results of varying buoy reliability and redundancy threshold values is illustrated in Fig. 7-8. Two extreme cases were selected to show the range of variation encountered. In the Sea Level Pressure, Pacific High Variability case, a "worst case" situation is shown, similar to Curve C in Fig. 7-1. Removing buoys to reduce redundancy offers no advantage, even for the 100% reliable buoy system, and reducing buoy system reliability further reduces the capability of the buoy network to reduce the RMS analysis error below that achieved by ship data alone. In the Surface Air Temperature, Pacific High Variability case, a "best case" situation is shown, similar to Curve B in Fig. 7-1. In this instance, removing buoys to avoid redundancy appears to be the appropriate choice, and even with a buoy system reliability of 50% this statement continues to hold. For example, the original network has 54 buoys: the average spacing between these buoys is about 300 n mi. When buoys are eliminated in areas where the probability of at least one ship report is 75% or more, there are 33 buoys left. The graph indicates that this buoy system with 50% system reliability is as equally effective in reducing RMS analysis error below that due to ship reports, as a 100% reliable network that is essentially uniformly distributed. Thus, these experimental results indicate strongly that the concept of locating buoys where ship reports occur with low probability has considerable potential "pay-off" for system design.

The purpose of Fig. 7-8 and the discussion above is to emphasize that the experimental results obtained in this study provide information which can be used to aid in selecting candidate networks for further detailed study. As noted elsewhere, such studies would most likely include variations in the number of ship reports received within one hour of synoptic time, and the location of the ships, based on statistics of ships that report within the first hour (or some other selected interval) after the synoptic time.

7.3 Summary

This section described the impact on RMS analysis error of removing from essentially uniformly distributed networks buoys that are in areas where the probability of

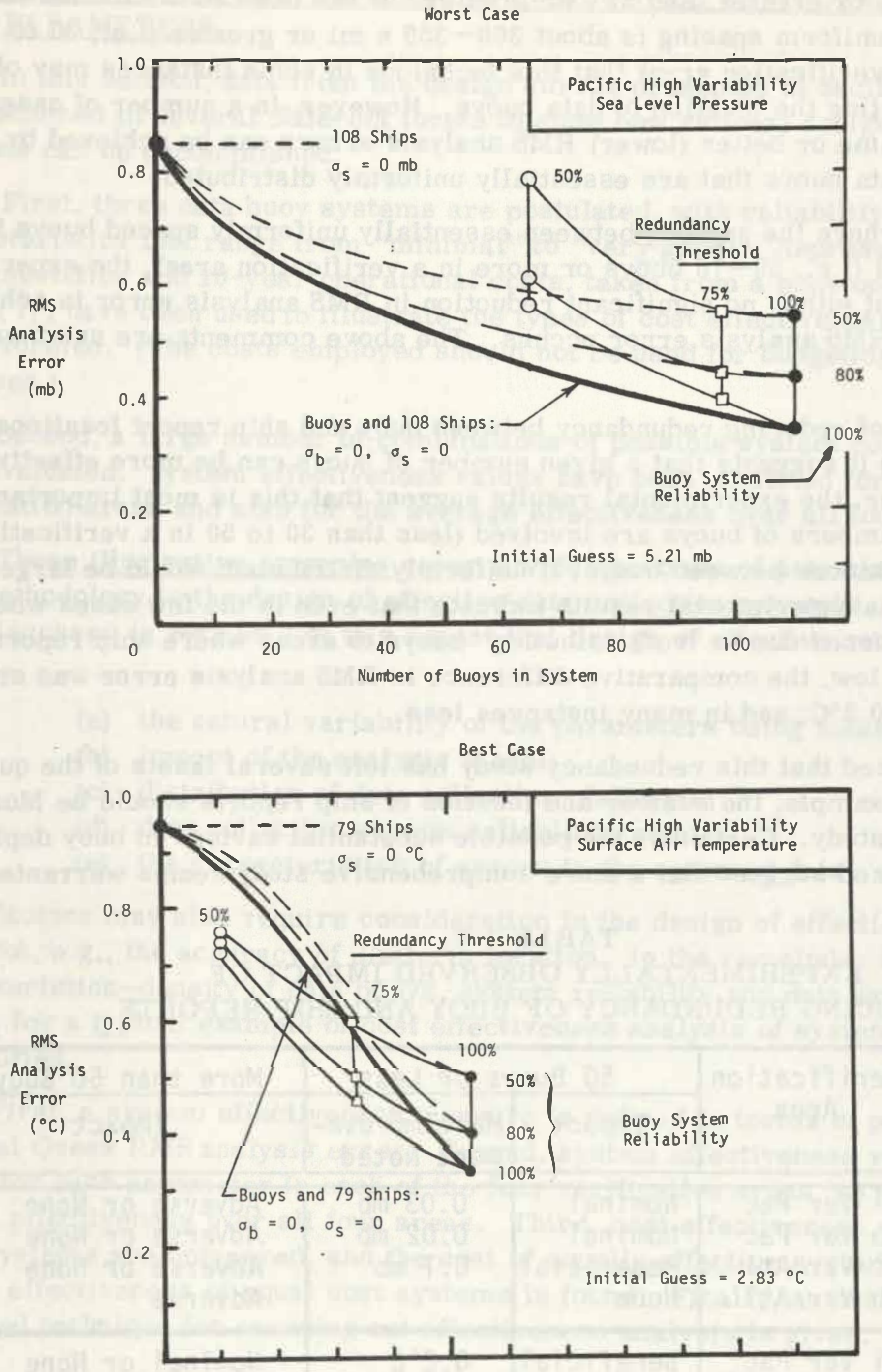

Fig. 7-8. Experimental results showing worst and best conditions experienced in reducing data redundancy of buoys and ships.

ship reports is 75% or greater, and 50% or greater. It has been shown for networks in which the original uniform spacing is about 300—350 n mi or greater (i.e., 30 to 50 buoys or less in a verification area) that this technique in some instances may offer a better way of selecting the location of data buoys. However, in a number of cases, it appears that the same or better (lower) RMS analysis errors can be achieved by an equal number of data buoys that are essentially uniformly distributed.

In the case where the spacing between essentially uniformly spaced buoys is less than about 300 n mi (i.e., 50—70 buoys or more in a verification area), the experimental results indicate that either no significant reduction in RMS analysis error is achieved, or worse (higher) RMS analysis error occurs. The above comments are summarized in Table 7-2.

The concept of reducing redundancy between buoy and ship report locations is attractive, because it suggests that a given number of buoys can be more effectively employed. However, the experimental results suggest that this is most important when only small numbers of buoys are involved (less than 30 to 50 in a verification area) and, hence, the distances between buoys, if uniformly distributed, would be large (300 n mi or more). The experimental results indicate that even in the few cases where improvements occurred due to "redistributing" buoys to areas where ship report probabilities were low, the comparative difference in RMS analysis error was small— at most 0.1 mb or 0.2°C, and in many instances less.

It is recognized that this redundancy study has left several facets of the question unexplored. For example, the number and location of ship reports should be Monte Carloed in a later study. Certainly, the possible substantial savings in buoy deployment that might be realized suggest that a more comprehensive study seems warranted.

TABLE 7-2
EXPERIMENTALLY OBSERVED IMPACT OF
REDUCING REDUNDANCY OF BUOY AND SHIP REPORTS

Parameter	Verification Area	50 Buoys or Less		More than 50 Buoys
		Impact	Max. Improvement Noted	Impact
Sea Level Pressure	Hi Var Pac	Nominal	0.03 mb	Adverse or None
	Lo Var Pac	Nominal	0.02 mb	Adverse or None
	Hi Var Atl	Beneficial	0.1 mb	Adverse or None
	Lo Var Atl	None		Adverse
Surface Air Temperature	Hi Var Pac	Beneficial	0.2°C	Nominal or None
	Lo Var Pac	None		Adverse
	Hi Var Atl	Nominal	0.06°C	None
	Lo Var Atl	None		Adverse
Sea Surface Temperature	Hi Var Pac	Beneficial	0.2°C	Nominal or None
	Lo Var Pac	Nominal	0.04°C	Adverse or None
	Hi Var Atl	None		Adverse or None
	Lo Var Atl	None		None

8.0 EXAMPLES OF SYSTEM DESIGN, USING THREE ENVIRONMENTAL PARAMETERS

In this section, data from the design curves presented in Sections 4, 5, and 6 are combined in several different forms to show how rational design of data buoy systems can be accomplished.

First, three data buoy systems are postulated, with reliability and data error characteristics that range from "minimal" to "very good." Representative system implementation and 10-year operational costs, taken from a previous cost effectiveness study [7], have been used to illustrate the types of cost effectiveness analyses that can be performed. (The costs employed should not be used for budgeting or planning purposes.)

Second, a large number of combinations of possible system configurations has been evaluated. System effectiveness values have been tabulated for each of the four verification areas and also for the average effectiveness over all four areas.

These illustrative examples cover a wide spectrum of potential applications of this methodology to the design of effective data collection networks. However, it has been discussed in Section 3 of this report that design of effective networks is influenced by:

(a) the natural variability of the parameters being measured;
(b) impact of the analysis model;
(c) distribution of data collection platforms;
(d) data collection system reliability; and
(e) the characteristics of errors in the returned data.

Other factors may also require consideration in the design of effective data collection networks, e.g., the accuracy of platform location. In the remainder of this section three characteristics—density of data buoys, system reliability and data error—are used as a basis for a typical example of cost effectiveness analysis of systems with alternative capabilities.

First, a system effectiveness measure is defined in terms of percent reduction of Initial Guess RMS analysis error. Second, system effectiveness values are presented for each parameter in each of the four verification areas, as well as total system effectiveness over all four areas. Third, cost effectiveness ratios for the three systems are compared, and the cost of equally effective systems is determined and the effectiveness of equal cost systems is found. Finally, an outline of a computerized technique for carrying out effectiveness analysis is given.

8.1 Typical System Designs in Each Verification Area, Using Three Environmental Parameters

The assumed characteristics of three data buoy systems of increasingly greater capabilities are listed in Table 8-1.

For this example, it is assumed that each of the parameters is of equal importance. It is recognized that the relative importance of these parameters in a par-

TABLE 8-1

CHARACTERISTICS OF THREE DATA BUOY SYSTEMS

System Number	System Measuring and Reporting Characteristics					
	Sea Level Press.		Surf. Air Temp.		Sea Surf. Temp.	
	Rel. (%)	$\sigma_{b_{SLP}}$ (mb)	Rel. (%)	$\sigma_{b_{SAT}}$ (°C)	Rel. (%)	$\sigma_{b_{SST}}$ (°C)
1	50	1.0	50	1.0°C	50	1.0
2	80	0.5	80	0.5	80	0.1
3	90	0.1	90	0.1	90	0.01

ticular system may vary significantly. Effectiveness is defined to be an additive function of the reduction in Initial Guess RMS analysis error achieved for each parameter:

$$\text{System Effectiveness} = E = \frac{E_{SLP} + E_{SAT} + E_{SST}}{3}$$

where the effectiveness for each parameter is given by

$$E_{Parameter} = \frac{\text{Percent Reduction in Initial Guess RMS Analysis Error}}{100}$$

For the purpose of analysis, it is further assumed that networks of 20, 40, and 100 data buoys are implemented in each verification area.* The approximate average network spacing in each verification area is given in Table 8-2. To demonstrate how cost effectiveness comparisons can be performed, representative system costs (implementation cost plus ten years of operational costs) will be used for three alternative Limited Capability Buoys Systems, moored in the deep ocean. The analyses leading to these system costs have been given in detail in Reference 7. The system cost values presented in Table 8-3 are based on the assumption that costs divide equally among the four verification areas. While this assumption is probably not strictly true, it is considered to be a reasonably good approximation for these illustrative examples. Finally, it is emphasized that the system costs used in this section are not suitable for budgeting or planning purposes.

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*As noted elsewhere in this report, it is stressed that the system design techniques demonstrated in this section are applicable to other types of data collection platforms, such as satellites, ships, balloons, and aircraft. However, the system characteristics used in this section are representative of data buoy systems. Also, the costs are typical of Limited Capability Buoys, moored in the deep ocean. Therefore, the discussion is presented in terms of data buoy system design, rather than a more general data collection platform.

TABLE 8-2
APPROXIMATE AVERAGE NETWORK SPACING

No. of Data Buoys	Pacific Hi Var	Pacific Lo Var	Atlantic Hi Var	Atlantic Lo Var
20	565	750	460	500
40	400	500	325	350
100	260	300	200	225

TABLE 8-3
TYPICAL LIMITED CAPABILITY BUOY SYSTEM COSTS
Implementation and Ten Years of Operation
(Millions of Dollars)

Each Verification Area				Total for Four Verification Areas			
Number of Buoys	System Cost			Number of Buoys	System Cost		
	Sys. #1	Sys. #2	Sys. #3		Sys. #1	Sys. #2	Sys. #3
20	16	18	20	80	64	71	80
40	28	32	35	160	110	127	138
100	49	58	66	400	196	230	262

For the given system reliabilities, standard deviations of data error, and numbers of buoys, Figs. 4-7, 4-8, 5-7, 5-8, 6-7, and 6-8 are most appropriate for extracting effectiveness values for each parameter (i.e., percent reduction in Initial Guess RMS analysis error, divided by 100). These parameter effectiveness values are shown in Table 8-4, together with (average) system effectiveness, as defined in Eq. 8-1, for each verification area and the total system effectiveness over all four verification areas. All average effectiveness values are based on the assumption that data for parameters are of equal importance (or, worth) and that data from the verification areas are of equal importance.

Based on the assumed costs for the three systems, typical cost effectiveness curves for each system in each verification area are shown in Figs. 8-1 and 8-2. The following comments are representative of cost effectiveness analysis results, but should not be construed as factual conclusions at this time.

- For system costs in excess of $30 million (in each verification area), System #3 (high performance) dominates all system choices, except in the Atlantic High Variability area. In that

TABLE 8-4

DATA FOR SYSTEM ANALYSIS, USING THREE ENVIRONMENTAL PARAMETERS

System No.	No. of Buoys per Verif. Area	System Reliability (%)	Standard Deviation of Param. Data Error (σ_b)	Parameter	Effectiveness (%) Pacific High Var	Pacific Low Var	Atlantic High Var	Atlantic Low Var	Average Param. Effect. (%)	Average Total Effect. (%)
			1.0 mb	SLP	47.00	18.00	36.00	22.00	30.50	
	20	50	1.0°C	SAT	37.00	56.00	52.00	59.00	51.00	28.40
			1.0°C	SST	4.00	2.00	4.00	4.00	3.50	
	System Eff. for Each Verif. Area				29.30	25.30	30.60	28.30		
			1.0 mb	SLP	59.5	28	48	29	41.13	
	40	50	1.0°C	SAT	49	61.5	59.5	62	57.9	35.5
			1.°C	SST	12	6	6.5	5	7.38	
1	System Eff. for Each Verif. Area				40.17	31.83	38.0	32.0		
			1.0 mb	SLP	70	32	64	38	51.25	
	100	50	1.0°C	SAT	64	62	70	63	64.75	44.7
			1.0°C	SST	29	10	27	6	18.0	
	System Eff. for Each Verif. Area				54.33	35.0	53.7	35.7		
			0.5 mb	SLP	54	23	48	30.5	38.9	
	20	80	0.5°C	SAT	44	62	59	64	57.25	34.55
			0.1°C	SST	10	6	5	9	7.5	
	System Eff. for Each Verif. Area				36.0	30.33	37.33	34.5		
			0.5 mb	SLP	68	39	59	44	52.5	
	40	80	0.5°C	SAT	62	67	68	68	66.25	45.38
			0.1°C	SST	25	17	10.5	17	17.38	
2	System Eff. for Each Verif. Area				51.67	41.0	45.83	43.0		
			0.5 mb	SLP	78	48	85	54	66.25	
	100	80	0.5°C	SAT	76	73	81	74	76.0	60.1
			0.1°C	SST	54	30	37	31	38.0	
	System Eff. for Each Verif. Area				69.33	50.33	67.67	53.0		
			0.1 mb	SLP	58	25.5	51.5	37.5	43.1	
	20	90	0.1°C	SAT	46.5	66	64	67.5	61.0	38.0
			0.01°C	SST	12	9.5	6	11.5	9.8	
	System Eff. for Each Verif. Area				38.83	33.67	40.5	38.83	37.97	
			0.1 mb	SLP	72.5	44.5	64.5	53	58.6	
	40	90	0.1°C	SAT	69	73	73.5	71.5	71.8	50.7
			0.01°C	SST	31	21	13	21.5	21.6	
3	System Eff. for Each Verif. Area				57.5	46.17	50.33	48.67		
			0.1 mb	SLP	83.5	61	79.5	68.5	73.13	
	100	90	0.1°C	SAT	85	81.5	87.5	82	84.0	66.84
			0.01°C	SST	61.5	34.5	40.0	37.5	43.38	
	System Eff. for Each Verif. Area				76.67	59.0	69.0	62.67		

area, System #2, with about 80 buoys, is at a cost effective tradeoff when compared to System #3, with about 30 buoys. (Cost of about $50 million; effectiveness of about 0.61.) Beyond an effectiveness of 0.61, System #2 is more cost effective than System #3.

- In both the Pacific and Atlantic, greater effectiveness is achieved for a given number of buoys in the High Variability areas. This occurs because, for a given number of buoys, the ratio of buoys to gridpoints is higher in the High Variability areas, i.e., as more Initial Guess values are replaced by accurate data values, the RMS analysis error diminishes. This suggests that the ratio of average number of reporting buoys (or, data points) may be of more importance in the reduction of Initial Guess RMS analysis error (%) than the differences in natural variability, at least on a synoptic scale. This statement holds more strongly for Sea Level Pressure and Surface Air Temperature, than it does for Sea Surface Temperature.

- Reference to the system design curves in Sections 4, 5, and 6 (or reference to Table 8-4) shows clearly that System #3, with 100 highly accurate and reliable data buoys in each verification area, is providing a reduction in Initial Guess RMS analysis error of 61—84% for Sea Level Pressure, 82—88% for Surface Air Temperature, and 35—62% for Sea Surface Temperature. It is obviously this latter parameter which holds the system effectiveness to the range 0.59 to 0.76 throughout the four verification areas. (See set of values at the bottom of Table 8-4.)

- In all verification areas, the lowest cost effectiveness ratio (most cost effective system) is achieved using System #2 with 20 buoys. The highest cost effectiveness ratios (least cost effective systems) are produced by System #1, with 100 buoys in each verification area, with the exception of the Atlantic High Variability area, where System #3 with 100 buoys has the highest cost effectiveness ratio. The minimum and maximum cost effectiveness ratios are compared in Table 8-5. It must be held in mind that the cost effectiveness ratios in Table 8-5 are dependent on the assumptions that system costs are equal in each verification area, and that the costs are, indeed, representative of a moored limited capability data buoy system.

- Table 8-5 shows very clearly that, given the assumption that reduction of RMS analysis is a good criterion for measuring system effectiveness, then it is a poor strategy to implement a system comprising many buoy data collection platforms that

Note:

Costs are for illustrative purposes only;
they should not be used for budgeting or planning.

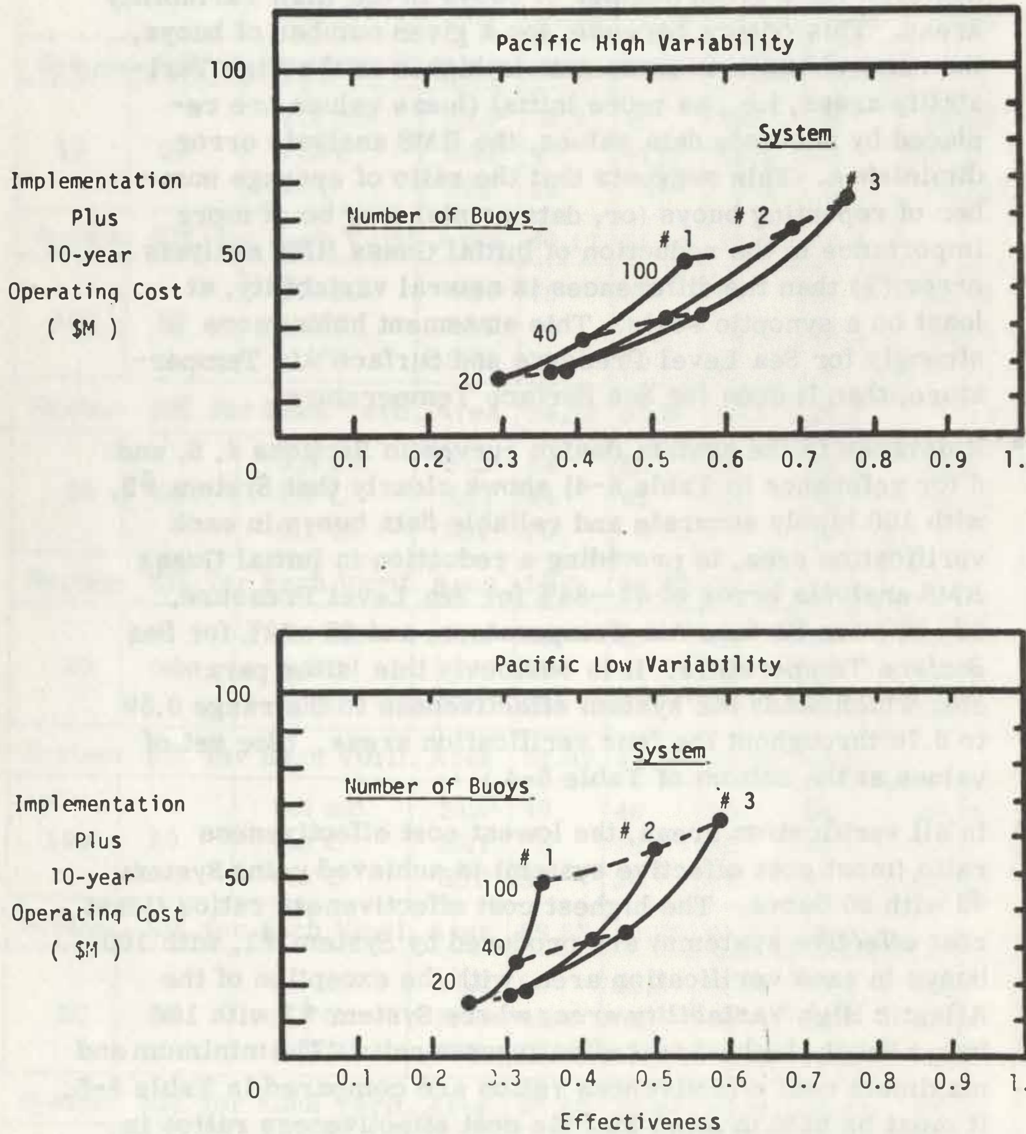

Fig. 8-1. Cost effectiveness comparisons for Pacific areas.

area, System #2, with about 80 buoys, is at a cost effective tradeoff when compared to System #3, with about 30 buoys. (Cost of about $50 million; effectiveness of about 0.61.) Beyond an effectiveness of 0.61, System #2 is more cost effective than System #3.

- In both the Pacific and Atlantic, greater effectiveness is achieved for a given number of buoys in the High Variability areas. This occurs because, for a given number of buoys, the ratio of buoys to gridpoints is higher in the High Variability areas, i.e., as more Initial Guess values are replaced by accurate data values, the RMS analysis error diminishes. This suggests that the ratio of average number of reporting buoys (or, data points) may be of more importance in the reduction of Initial Guess RMS analysis error (%) than the differences in natural variability, at least on a synoptic scale. This statement holds more strongly for Sea Level Pressure and Surface Air Temperature, than it does for Sea Surface Temperature.

- Reference to the system design curves in Sections 4, 5, and 6 (or reference to Table 8-4) shows clearly that System #3, with 100 highly accurate and reliable data buoys in each verification area, is providing a reduction in Initial Guess RMS analysis error of 61—84% for Sea Level Pressure, 82—88% for Surface Air Temperature, and 35—62% for Sea Surface Temperature. It is obviously this latter parameter which holds the system effectiveness to the range 0.59 to 0.76 throughout the four verification areas. (See set of values at the bottom of Table 8-4.)

- In all verification areas, the lowest cost effectiveness ratio (most cost effective system) is achieved using System #2 with 20 buoys. The highest cost effectiveness ratios (least cost effective systems) are produced by System #1, with 100 buoys in each verification area, with the exception of the Atlantic High Variability area, where System #3 with 100 buoys has the highest cost effectiveness ratio. The minimum and maximum cost effectiveness ratios are compared in Table 8-5. It must be held in mind that the cost effectiveness ratios in Table 8-5 are dependent on the assumptions that system costs are equal in each verification area, and that the costs are, indeed, representative of a moored limited capability data buoy system.

- <u>Table 8-5 shows very clearly that, given the assumption that reduction of RMS analysis is a good criterion for measuring system effectiveness,</u> then it is a <u>poor strategy</u> to implement a system comprising many buoy data collection platforms that

Note:

Costs are for illustrative purposes only; they should not be used for budgeting or planning.

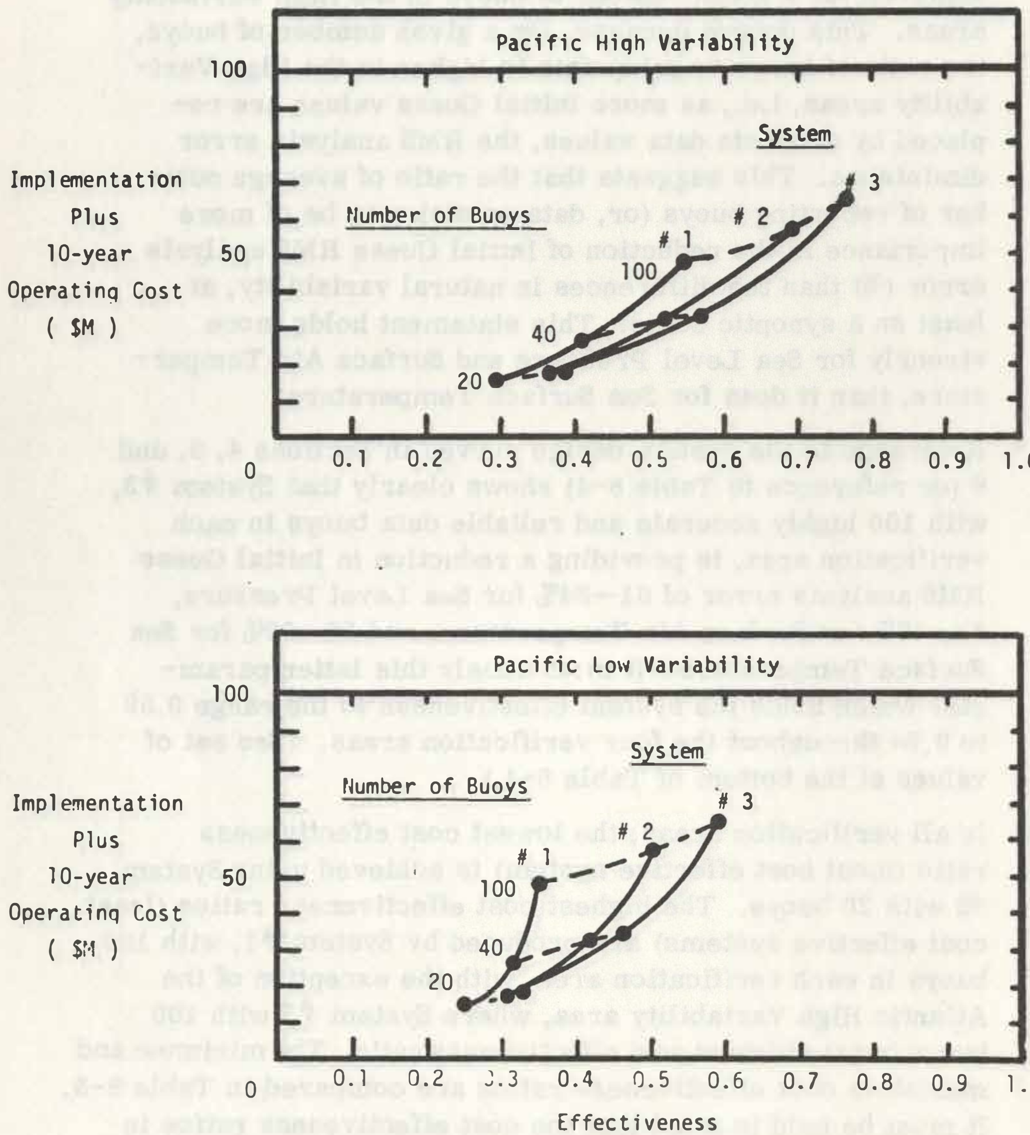

Fig. 8-1. Cost effectiveness comparisons for Pacific areas.

Note:

Costs are for illustrative purposes only; they should not be used for budgeting or planning.

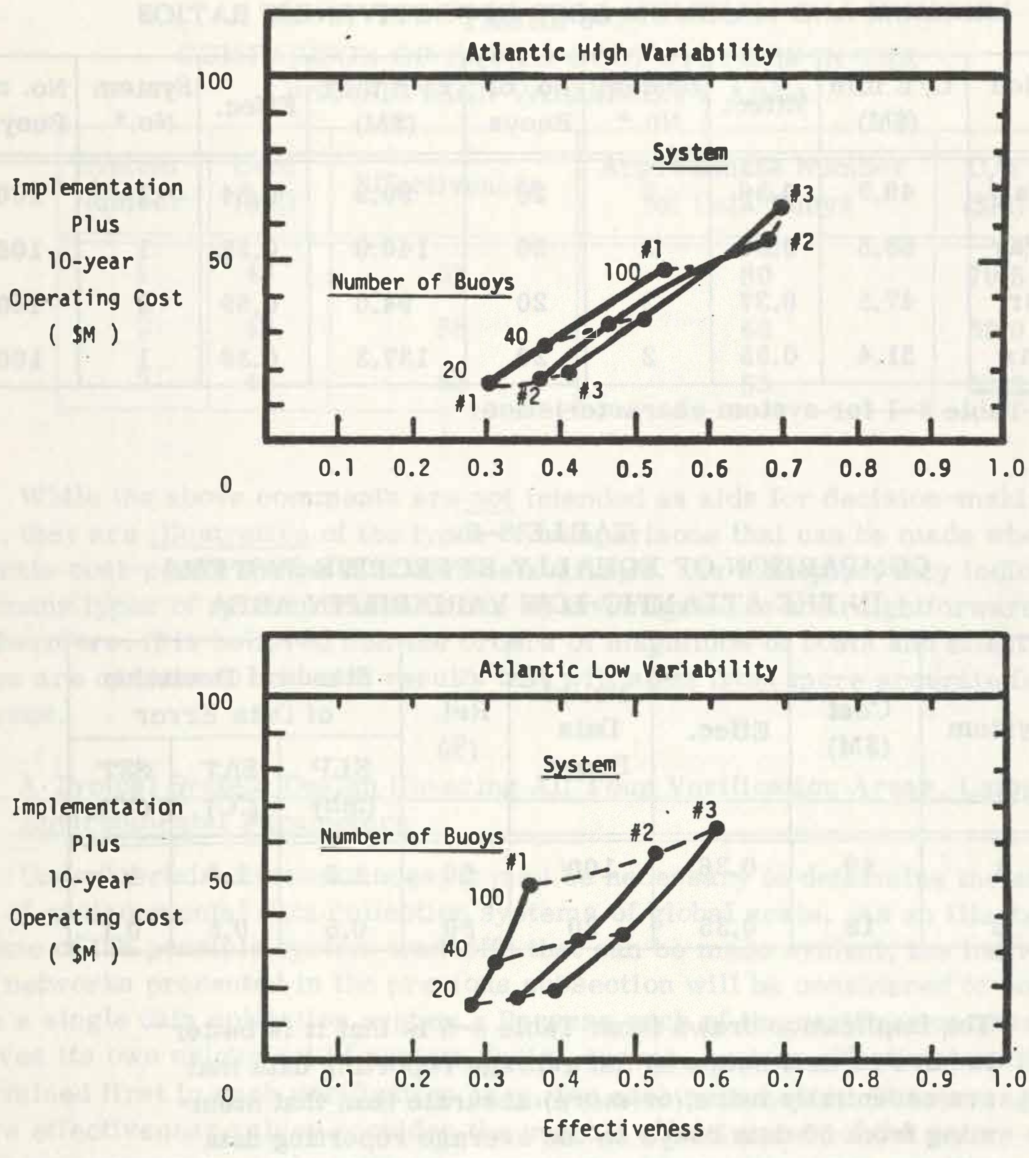

Fig. 8-2. Cost effectiveness comparisons for Atlantic areas.

have low reliability and introduce considerable errors in the data. A preferred strategy is to implement a few highly reliable and accurate buoys. This is exemplified by noting that in the Atlantic Low Variability area, 20 buoys in System #2 produce essentially the same system effectiveness as 100 buoys in System #1. The system capabilities and (assumed) costs are shown in Table 8-6.

TABLE 8-5
MINIMUM AND MAXIMUM COST EFFECTIVENESS RATIOS

Verification Area	C/E min ($M)	Effec.	System No.*	No. of Buoys	C/E max ($M)	Effec.	System No.*	No. of Buoys
Pac Hi Var	49.3	0.36	2	20	90.2	0.54	1	100
Pac Lo Var	58.5	0.30	2	20	140.0	0.35	1	100
Atl Hi Var	47.5	0.37	2	20	94.0	0.69	3	100
Atl Lo Var	51.4	0.35	2	20	137.3	0.36	1	100

* See Table 8-1 for system characteristics.

TABLE 8-6
COMPARISON OF EQUALLY EFFECTIVE SYSTEMS
IN THE ATLANTIC LOW VARIABILITY AREA

System	Cost ($M)	Effec.	No. of Data Buoys	Rel. (%)	Standard Deviation of Data Error		
					SLP (mb)	SAT (°C)	SST (°C)
1	49	0.36	100	50	1.0	1.0	1.0
2	18	0.35	20	80	0.5	0.5	0.1

The implication drawn from Table 8-6 is that it is better to have 16 data buoys on the average reporting data that are essentially twice (or more) accurate than that stemming from 50 data buoys on the average reporting data with errors having standard deviations of the order of 1 mb and 1°C. Furthermore, the indicated level of effectiveness can be achieved with 20 System #2 buoys at a cost that is 60% less than the cost of 100 System #1 buoys.

- In many instances, it may be desirable to set a level of funding and determine what system effectiveness can be achieved. For example, assume that $40 million can be spent for implementation and 10 years of operations for a data buoy system in the Pacific High Variability area. Table 8-7 compares the effectiveness of the three systems on this constant cost basis. Clearly, the more reliable and accurate System #3 is the preferred choice, with 53 data buoys.

TABLE 8-7
COMPARISON OF EQUAL-COST SYSTEMS IN THE PACIFIC HIGH VARIABILITY AREA

System Number	Cost ($M)	Effectiveness	Approximate Number of Data Buoys	C/E ($M)
1	40	51	80	79.5
2	40	58	60	69.0
3	40	63	53	63.5

While the above comments are not intended as aids for decision-making at this time, they are illustrative of the types of comparisons that can be made when more accurate cost-performance data become available. As examples, they indicate that many types of system tradeoffs can be investigated in a straightforward manner. Furthermore, it is believed that the orders of magnitude of costs and effectiveness values are commensurate with results that will stem from more accurate future analyses.

8.2 A Typical System Design Covering All Four Verification Areas, Using Three Environmental Parameters

Under certain circumstances, it may be necessary to determine the effectiveness of environmental data collection systems of global scale. As an illustration of some of the possible system tradeoffs that can be made evident, the individual-buoy networks presented in the previous subsection will be considered to comprise a single data collection system. Because each of the verification areas involves its own unique set of system design curves, system effectiveness must be determined first in each verification area, for each parameter. The average of the twelve effectiveness values provides the overall effectiveness of the entire system, assuming parameters and verification areas are of equal importance.*

*If desired, it is a simple matter to use relative importance weights for parameters within areas, and additional relative importance weights for the verification areas. See Ref. 7 for a detailed discussion of the use of relative importance weights in cost effectiveness analyses.

The average total effectiveness values have been given in Table 8-4. They are summarized below for convenience in Table 8-8, along with total system costs and cost effectiveness ratio values. These data are plotted in Figs. 8-3 and 8-4.

TABLE 8-8
TOTAL SYSTEM COST AND
EFFECTIVENESS CHARACTERISTICS

System Number	Number of Data Buoys	Average Total Effective.	System Cost ($M)	C/E ($M)
	80	0.284	64	225
1	160	0.354	110	311
	400	0.447	196	438
	80	0.346	71	205
2	160	0.454	127	280
	400	0.601	230	383
	80	0.380	80	211
3	160	0.507	138	272
	400	0.668	262	392

Figure 8-3 shows that for constant system costs (implementation plus 10 years of operations) in excess of $80 million, System #3 is preferred, because if gives the greatest effectiveness for a given system cost. For specified total system effectiveness in the range 0.38 to 0.67, System #3 dominates the other systems; that is, System #3 provides the desired effectiveness at the lowest cost.

Figure 8-4 indicates that minima in cost effectiveness ratios do not exist for each of the systems. Indeed, the case of 20 data buoys in each verification area provides the lowest cost effectiveness ratio for each system. However, in comparing the three systems, with constant numbers of buoys in each system, it is apparent that System #2 has the lowest cost effectiveness ratio at the 20-buoy and 100-buoy per verification area. But for 40 buoys per verification area, System #3 has the lowest cost effectiveness ratio.

In all cases, it is evident, for these assumed cost figures, that System #1 is the least preferred strategy; that is, higher reliability and lower standard deviation of data error is preferred on a cost effectiveness basis. This generally stems from the fact that the design curves in Sections 4, 5, and 6 have shown that, for Sea Level Pressure and Surface Air Temperature, the knee of the curve of percent reduction of Initial Guess RMS analysis error (effectiveness) is achieved with about 20 to 40 data buoys (or, equivalent data collection platforms) in each verification area. The design curves also make it apparent that for 40 buoys per verification area the loss in parameter effectiveness in going from a reliability of 90% and a standard deviation of error of 0.1 to 0.01 (mb or °C) can result in a loss of more than

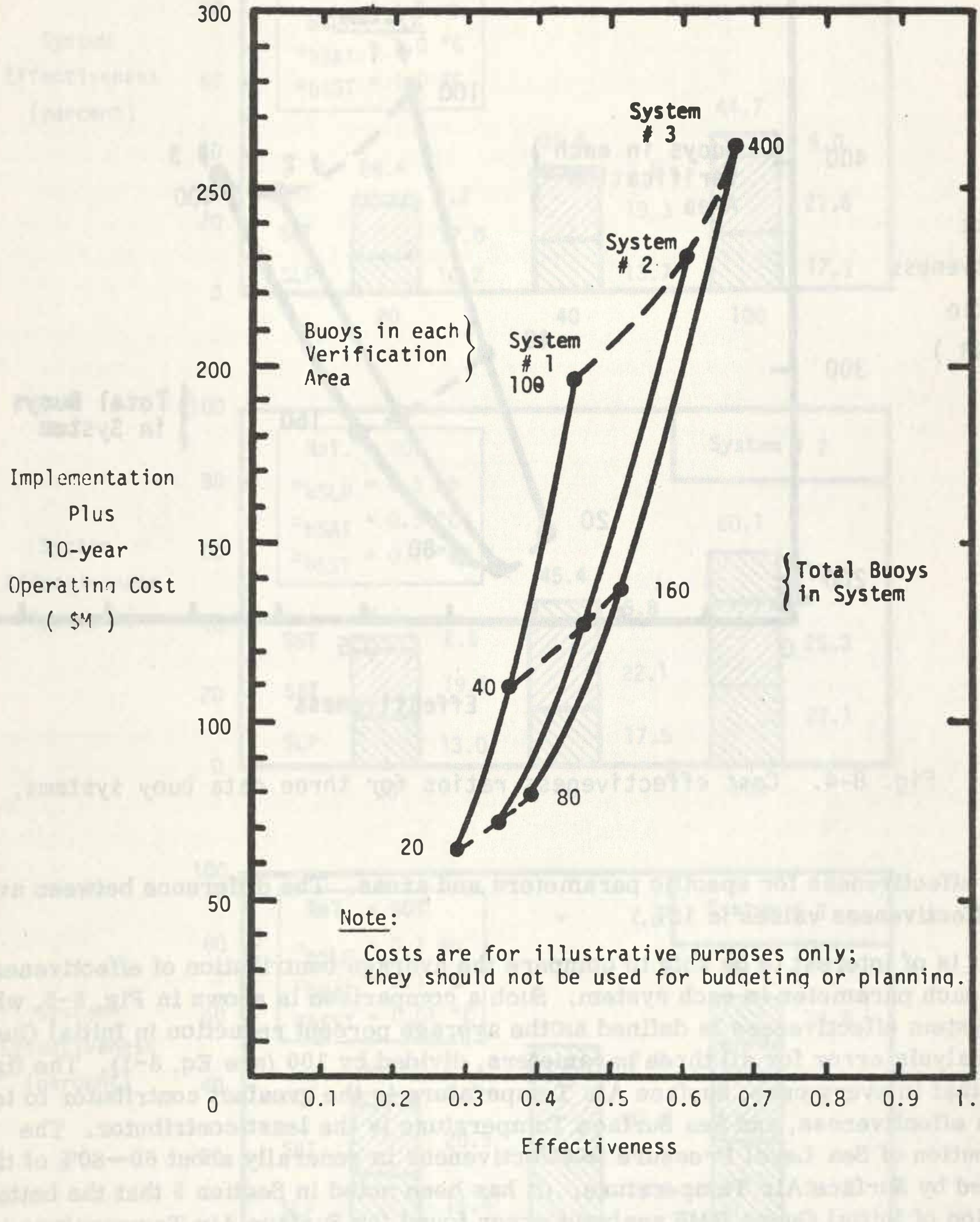

Fig. 8-3. Cost effectiveness comparisons for total systems.

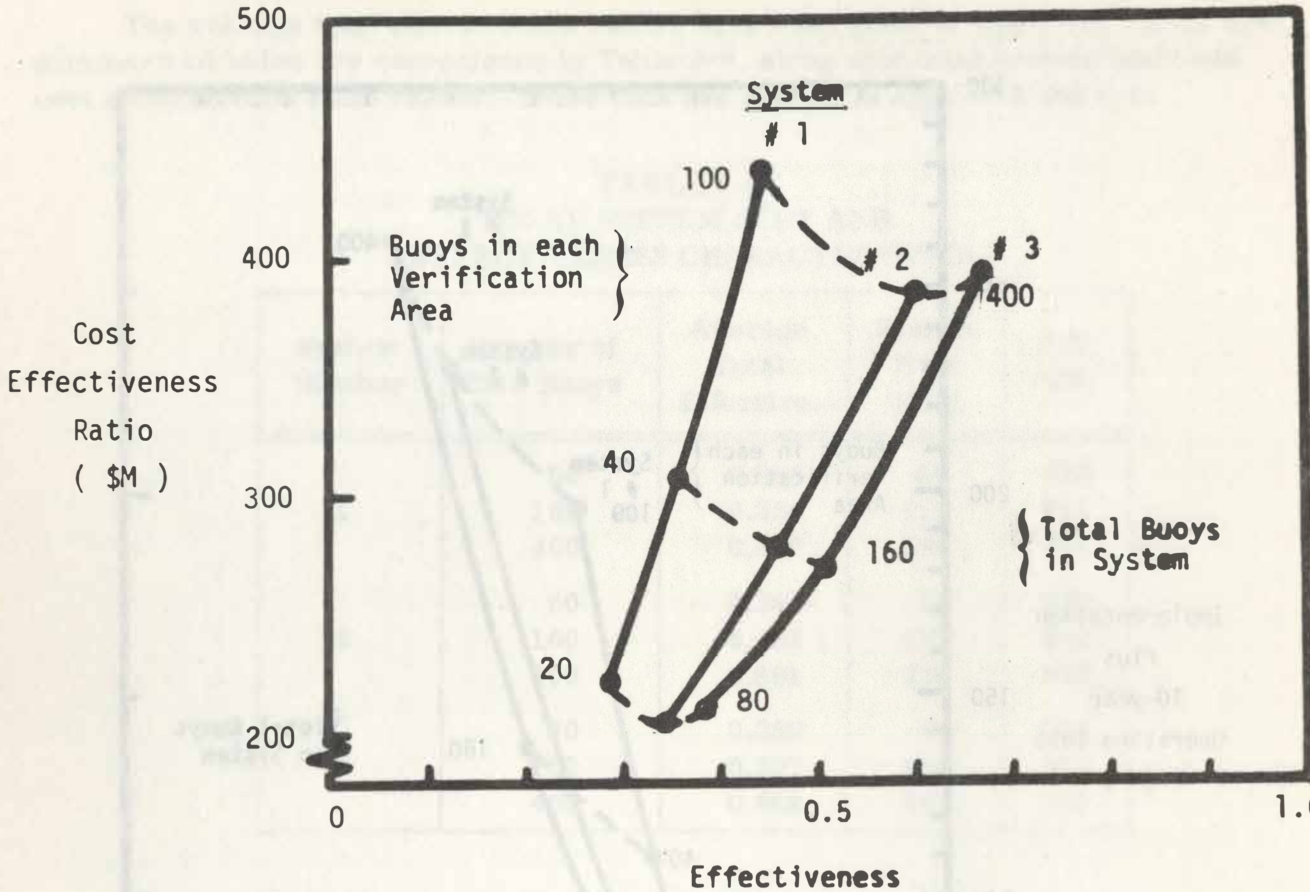

Fig. 8-4. Cost effectiveness ratios for three data buoy systems.

20% in effectiveness for specific parameters and areas. The difference between average total effectiveness values is 15%.)

It is of interest to be able to compare the average contribution of effectiveness due to each parameter in each system. Such a comparison is shown in Fig. 8-5, where total system effectiveness is defined as the average percent reduction in Initial Guess RMS analysis error for all three parameters, divided by 100 (see Eq. 8-1). The figure shows that in every case, Surface Air Temperature is the greatest contributor to total system effectiveness, and Sea Surface Temperature is the least contributor. The contribution of Sea Level Pressure to effectiveness is generally about 60—80% of that provided by Surface Air Temperature. (It has been noted in Section 5 that the better reduction of Initial Guess RMS analysis error found for Surface Air Temperature is probably due both to the use of the 63 × 63 analysis grid and the fact that the natural variability of Surface Air Temperature does not possess the finer scales found in Sea Level Pressure and Sea Surface Temperature. Therefore, the comparative results shown in Fig. 8-5 are in keeping with the findings presented elsewhere in this report.)

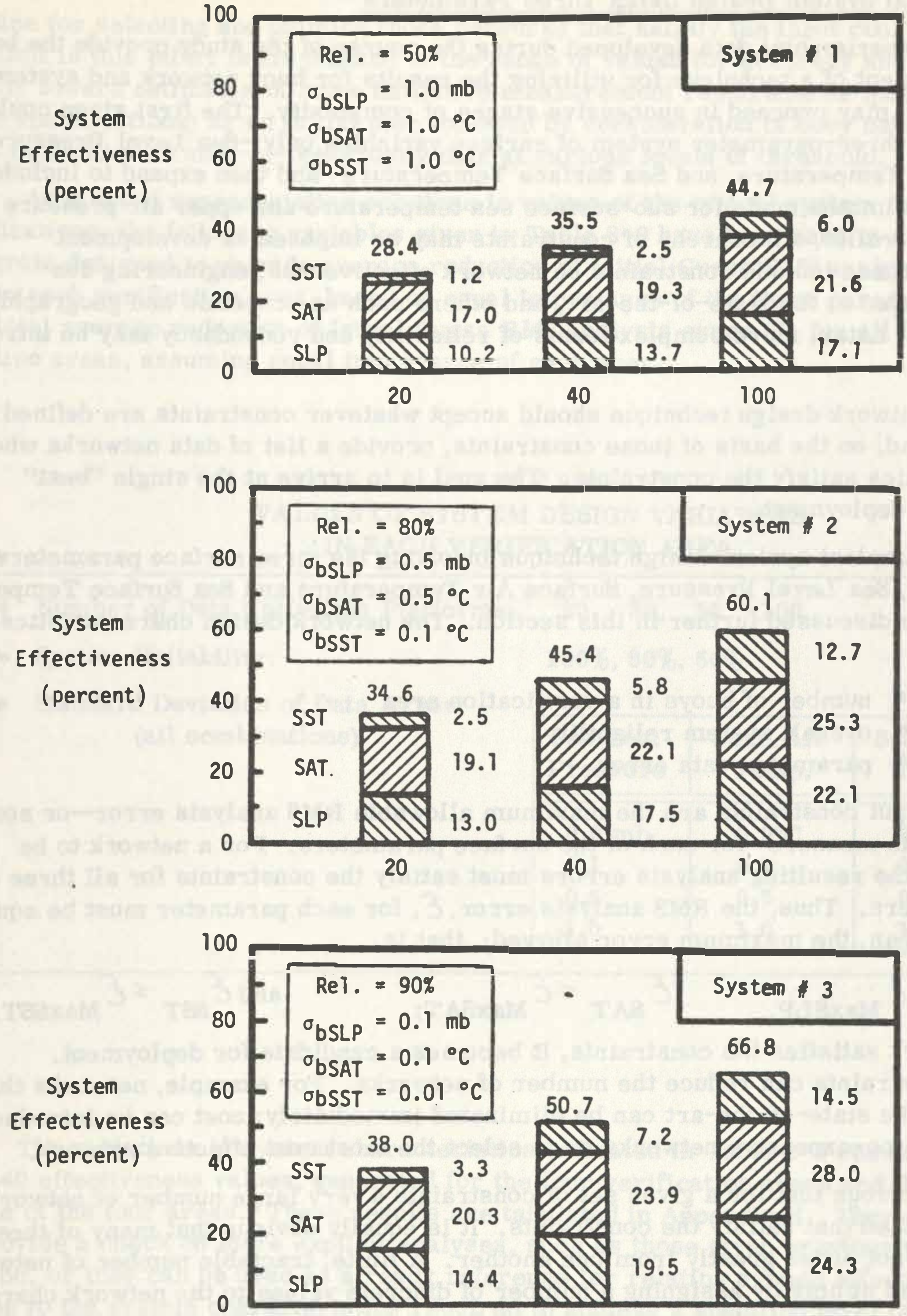

Fig. 8-5. Comparison of parameter contributions to total effectiveness.

8.3 General System Design Using Three Parameters

The experimental data developed during the course of the study provide the basis for development of a technique for utilizing the results for buoy network and system design which may proceed in successive stages of complexity. The first stage could start with a three-parameter system of surface variables only—Sea Level Pressure, Surface Air Temperature, and Sea Surface Temperature—and then expand to include the error estimates made for sub-surface sea temperature and upper air pressure height. In parallel, a hierarchy of constraints may be imposed as development proceeds. These include constraints on network effectiveness, engineering constraints related to the state-of-the-art, and others such as economic and geographic constraints. Later, more complex forms of reliability and redundancy may be introduced.

The network design technique should accept whatever constraints are defined as input data and, on the basis of those constraints, provide a list of data networks whose characteristics satisfy the constraints. The goal is to arrive at the single "best" network for deployment.

The simplest system design technique involving the three surface parameters studied (i.e., Sea Level Pressure, Surface Air Temperature and Sea Surface Temperature)will be discussed further in this section. The network design characteristics are:

- number of buoys in a verification area
- overall system reliability
- parameter data error

The input constraints are the maximum allowable RMS analysis error—or some other suitable measure—for each of the surface parameters. For a network to be acceptable, the resulting analysis errors must satisfy the constraints for all three of the parameters. Thus, the RMS analysis error, $\mathcal{E}$, for each parameter must be equal to, or less than, the maximum error allowed: that is,

$$\mathcal{E}_{SLP} \leq \mathcal{E}_{MaxSLP}, \quad \mathcal{E}_{SAT} \leq \mathcal{E}_{MaxSAT}; \quad \text{and } \mathcal{E}_{SST} \leq \mathcal{E}_{MaxSST}.$$

If the network satisfies the constraints, it becomes a candidate for deployment. Further constraints can reduce the number of networks. For example, networks that are beyond the state-of-the-art can be eliminated immediately; cost can be introduced to eliminate too-expensive networks or to select the most cost effective network.

It is obvious that for a given set of constraints a very large number of networks could be defined that satisfy the constraints. It is equally obvious that many of these networks do not differ greatly from one another. A finite, tractable number of networks can be defined simply by assigning a number of discrete values to the network characteristics. The guiding principle here is to define discrete values such that the discrete network ultimately chosen for deployment does not differ significantly from the one that would have been chosen from an infinite ensemble of networks.

A computer program for the simplest design technique would comprise a data bank containing the design characteristics of each defined network and its corresponding routine for selecting and printing those networks that satisfy the input constraints. Implicit in this effort is translation of the range of values for accuracy and reliability toward estimates of more definitive measurement requirements (performance specifications) as an initial step followed by consideration of buoy network data in addition to ship-of-opportunity data at various levels of threshold.

As a set of representative solutions to values of the typical system design applications, the following variables given in Table 8-9 have been used in a computer program designed to provide average reduction of Initial Guess RMS analysis error (%) in each verification area, based on equal importance of the three parameters, and the total average reduction of Initial Guess RMS analysis error (%) for all four verification areas, assuming equal importance of each area.

TABLE 8-9
VALUES OF SYSTEM DESIGN VARIABLES
IN EACH VERIFICATION AREA

- Number of Data Collection Platforms: 20, 30, 50, 100
- System Reliability: 100%, 80%, 50%
- Standard Deviation of Data Error: (all combinations)

Sea Lev. Pressure	Surf. Air Temp.	Sea Surf. Temp.
0.0 mb	0.0°C	0.0°C
0.1	0.1	0.01
0.5	0.5	0.1
1.0	1.0	1.0

The variations in system characteristics indicated in Table 8-9 results in a total of 3840 effectiveness values, generated for the four verification areas and the composite of the four areas. These results are tabulated in Appendix H. They can be used to provide a check on more explicit analyses, such as those given previously in this section, or they can be used as a ready reference for relating system effectiveness values to the system characteristics required to achieve a specified level of effectiveness.

Ultimately, it will be desirable to develop a computer program that will provide complete flexibility for specifying different characteristics for each of the parameters in each of the verification areas. Such a program is feasible, and has been structured in principal. However preparation and checkout of the computer program does not fall within the scope of the present study effort. It is anticipated that this useful system design tool may be prepared in the near future.

8.4 Summary

This section has used assumed system costs for three typical data buoy systems. Numerous examples of systems cost effective analyses, system tradeoffs, and preferred systems design have been presented. In most instances, based on the assumed costs, it has been apparent that the preferred systems were those with higher reliability and lower standard deviation of data error. This implies that fewer "good" data buoys are preferable to more "poor" data buoys, even though the system cost of the "good" buoys was as much as 34% higher than the system cost of "poor" buoys.

The examples presented in this section have been couched in terms of moored limited capability data buoy systems. It should be evident to the reader that the effectiveness analyses are actually independent of data collection platform type. Any other platform, having similar reliability and data error characteristics would produce the same effectiveness results. Only the costs—taken from Reference 7—are directly associated with data buoy systems. In this sense then, the effectiveness results presented here are essentially universal in character and could be used for similar system studies associated with other data collection platforms.

9.0 REFERENCES

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2. Danard, M., M. Holl, and J. Clark, 1968: "Fields by correlation assembly—a numerical analysis technique," Monthly Weather Review, 96, 3, pp. 141—149.

3. Mendenhall, Bruce R., 1970: "Design of a structure parameterization method for application to the three-dimensional analysis of ocean temperature," Meteorology International, Inc., Monterey, California.

4. Thomasell, A. Jr., and G. M. Northrop, 1970: "Results of the Environmental Models/System Effectiveness Scale Resolution and Pilot Model Program Studies," TRC DWN 232 (Contract DOT-CG-02007-A). (On file with the NDBC.)

5. Thomasell, A. Jr., and G. M. Northrop, 1971: "Study of Ship Report Distributions," The Center for the Environment and Man, Inc., Hartford, Connecticut, (Contract DOT-CG 02007-A). (On file with the NDBC.)

6. Thomasell, A. Jr., and G. M. Northrop, 1970: "First Interim Report for Phase II of the Environmental Models/System Effectiveness Study," TRC DWN 210 (Contract DOT-CG-02007-A). (On file with the NDBC.)

7. Northrop, G. M., E. L. Davis, E. R. Sweeton, and F. L. Bartholomew, 1970: "A Cost Effectiveness Methodology for Environmental Data Collection Systems, CEM Report 4053-430, The Center for the Environment and Man, Inc., Hartford, Connecticut (Contract DOT-CG-02006-A). AD-722-596.

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* An extensive review of pertinent background information is given in

Thomasell, A. Jr., L. H. Clem and G. M. Northrop, 1970: "Bibliography from a Literature Survey of Published Articles Relevant to the EM/SE Study," TRC DWN 166 (Contract DOT-CG-02007-A). (On file with the NDBC.)

See Appendix E for titles of other TRC/CEM DWNs.

APPENDIX A

JUSTIFICATION FOR THE ELIMINATION FROM THE STUDY OF THE PARAMETER SEA TEMPERATURE At 600 FT

The EM/SE Study is based on two assumptions:

- A typical, realistic "true" analysis of an environmental parameter can be postulated; and
- The accuracy of an operational analysis of the environmental parameter using conventional data sources can be estimated with the aid of the postulated "true" analysis and used as a benchmark for evaluating the impact of additional data sources, such as automatic data buoys.

For the parameters Sea-Level Pressure, Surface Air Temperature, and Sea Surface Temperature, the assumptions appear valid. These parameters are known well enough to permit the definition of "true" analyses with representative scales and variability. Further, the analysis models depend heavily upon actual observations of the parameters for definition of the operational analyses. Often, enough observations are available to produce useful analyses, although they are not necessarily totally adequate. By using a normally available collection of synoptic data in conjunction with the postulated "true" analysis, an estimate of the accuracy of operational analyses produced with particular analysis models may be made.

For the parameter Sea Temperature at 600 ft (T600 ft) or any other sub-surface temperature parameter, however, there does not exist enough synoptic or near-synoptic information to permit the definition of a realistic postulated "true" analysis. The bathythermographic data normally available for analysis usually comprise a 4-or 5-day collection of observations that tend to occur in a few string-like patterns along ship tracks over the collection period. Or, they are concentrated in relatively small regions and, in general, are totally inadequate to describe the overall T600 ft field accurately. To overcome the lack of data, the FNWC analysis model estimates the T600 ft field by extrapolating downward from the sea surface where more abundant data exist, using climatological and physical constraints and actual data where available.

To incorporate the T600 ft parameter into the EM/SE Study, it would be necessary to postulate the three-dimensional temperature structure from the sea surface to a depth of 600 ft in a physically consistent and realistic manner. This is necessary to evaluate and implement the extrapolation procedures of the FNWC analysis model and to evaluate the final operational T600 ft analysis. It is the opinion of both CEM and MII that the large uncertainties involved in postulating this required three-dimensional temperature structure would make the results of the T600 experiments highly questionable. For this reason, CEM recommended the elimination of the T600 ft parameter experiment from the EM/SE Study.

APPENDIX B

SEA-LEVEL PRESSURE
GENERAL EXPERIMENTAL RESULTS

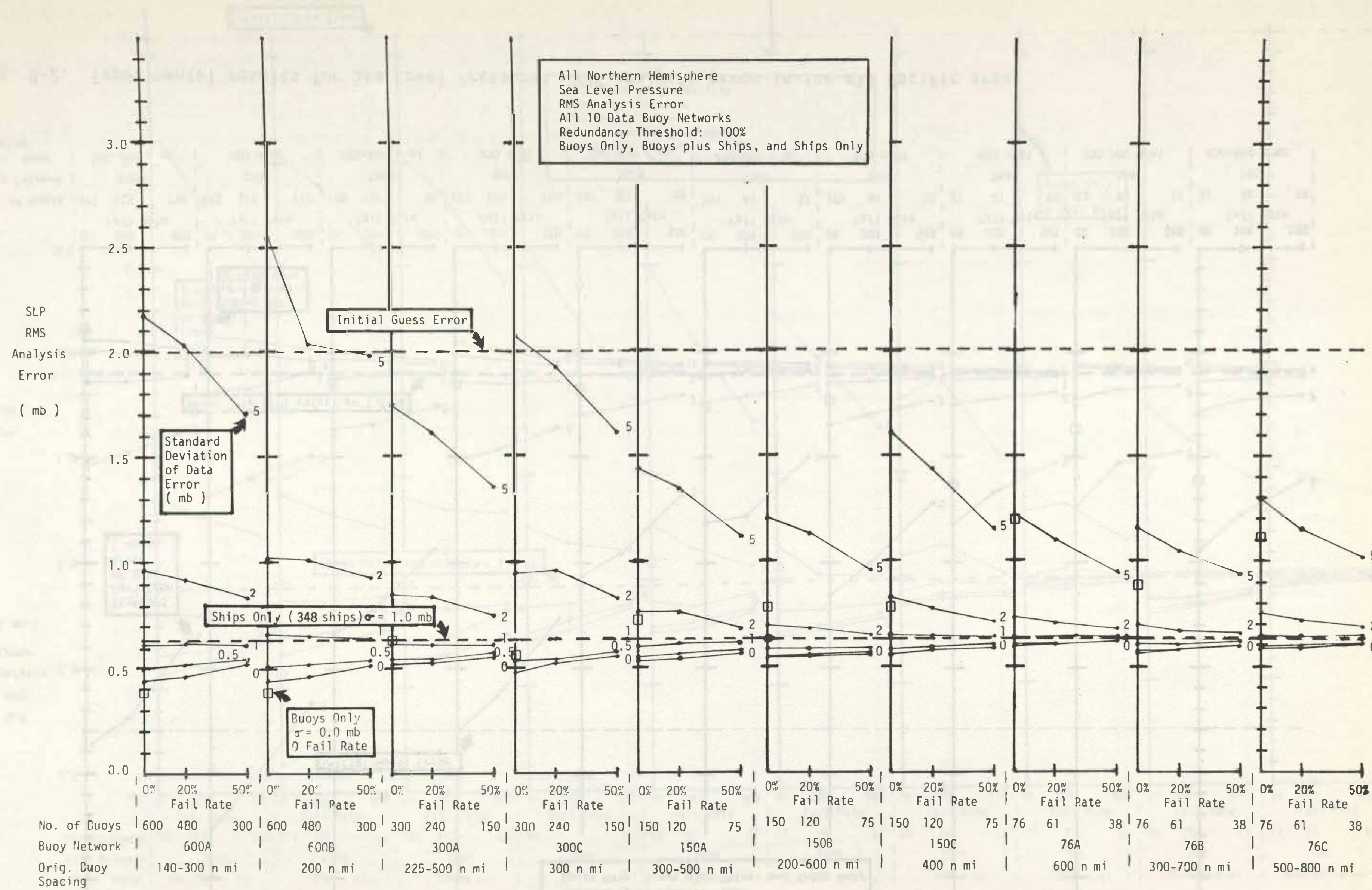

Fig. B-1. Experimental results for Sea Level Pressure: RMS analysis error in the all Northern Hemisphere area.

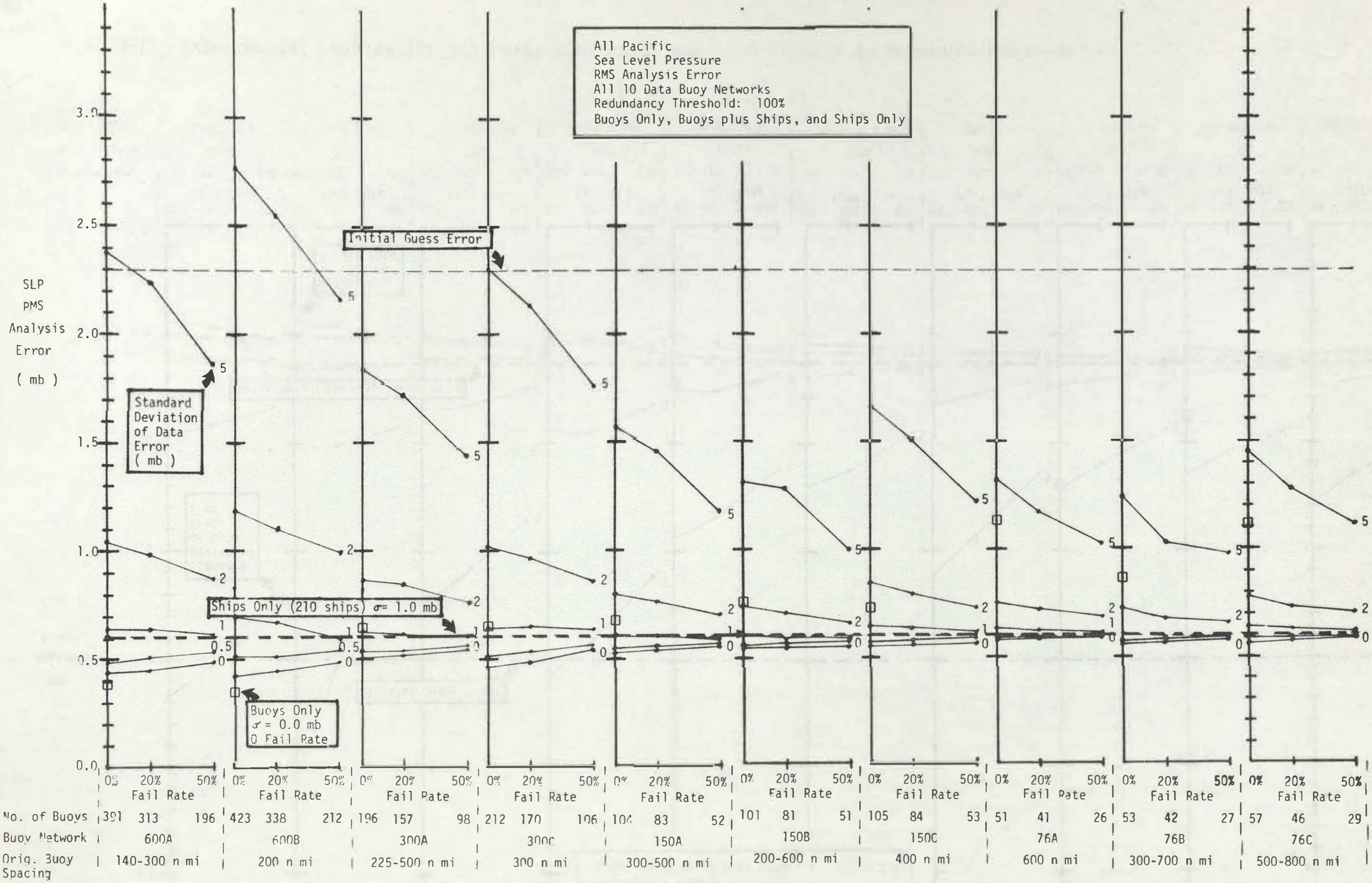

Fig. B-2. Experimental results for Sea Level Pressure: RMS analysis error in the all Pacific area.

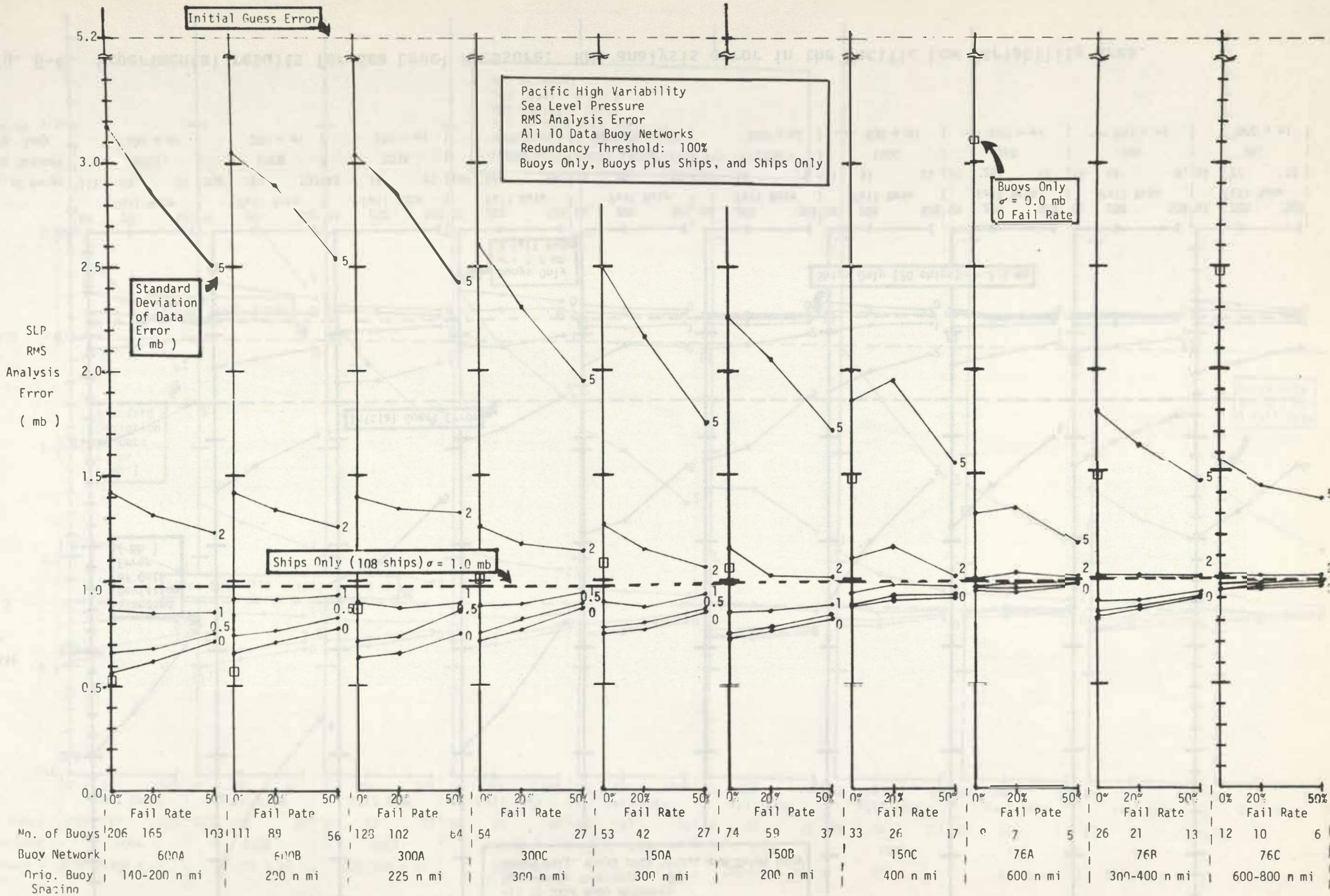

Fig. B-3. Experimental results for Sea Level Pressure: RMS analysis error in the Pacific High Variability area.

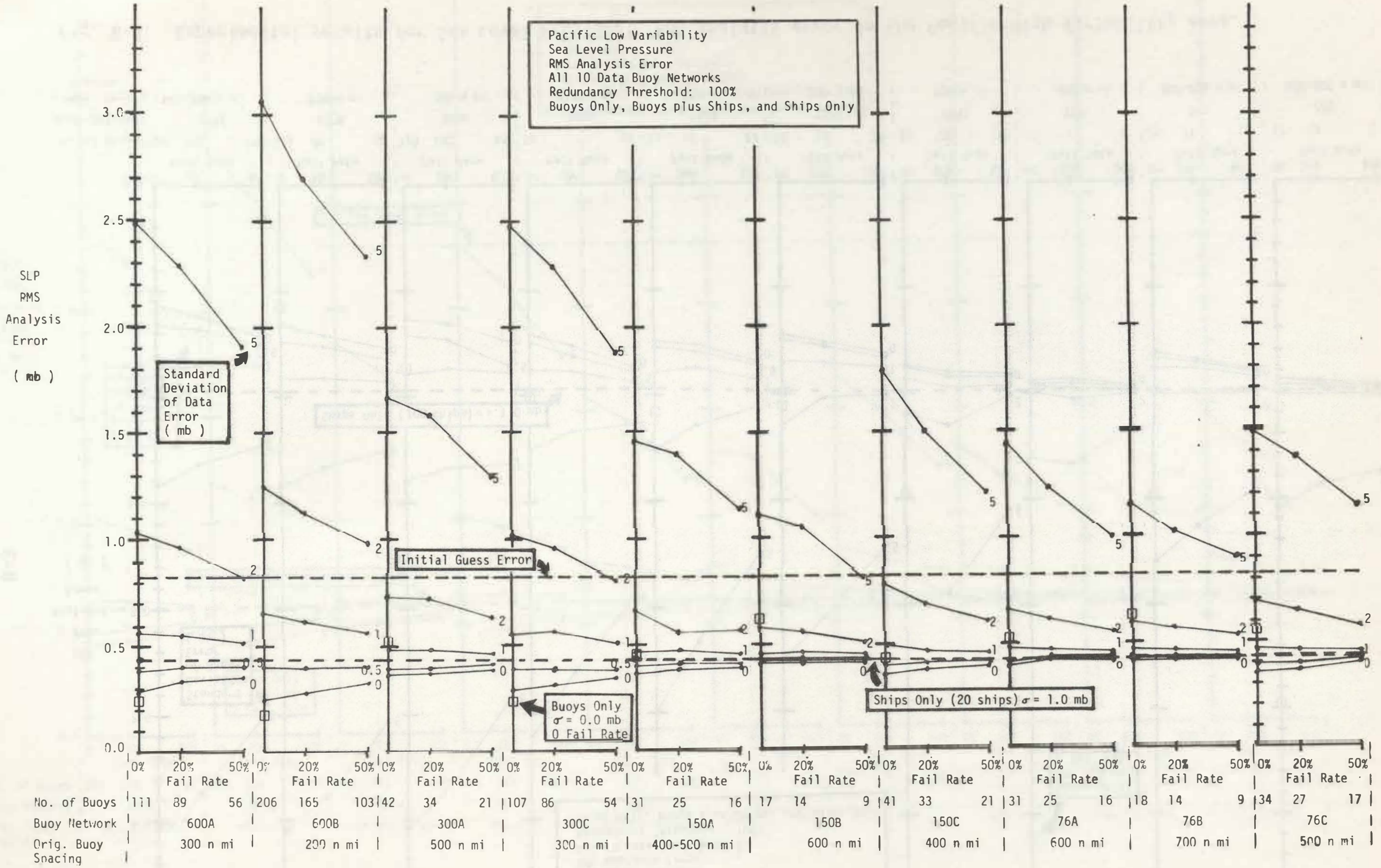

Fig. B-4. Experimental results for Sea Level Pressure: RMS analysis error in the Pacific Low Variability area.

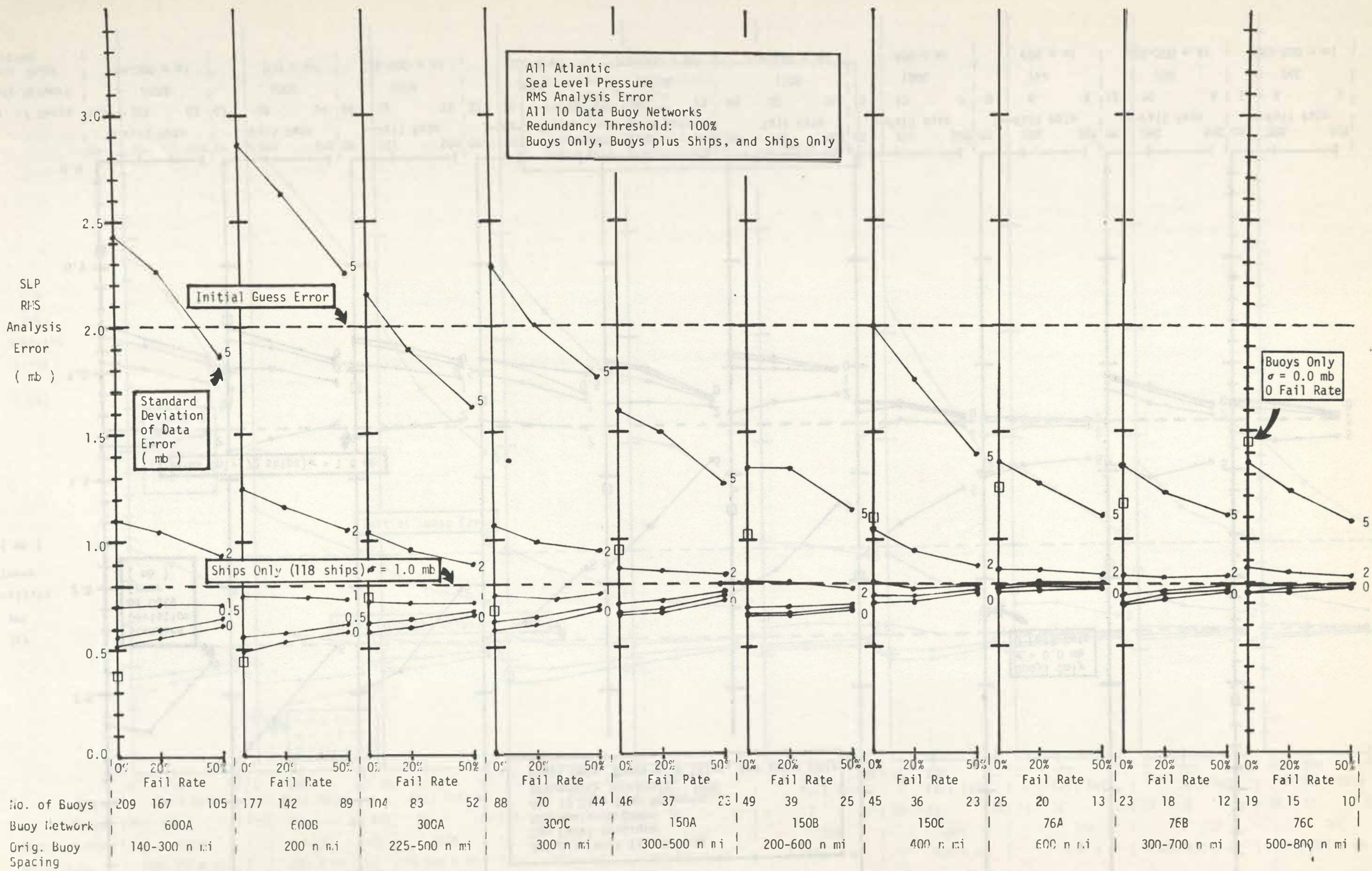

Fig. B-5. Experimental results for Sea Level Pressure: RMS analysis error in the all Atlantic area.

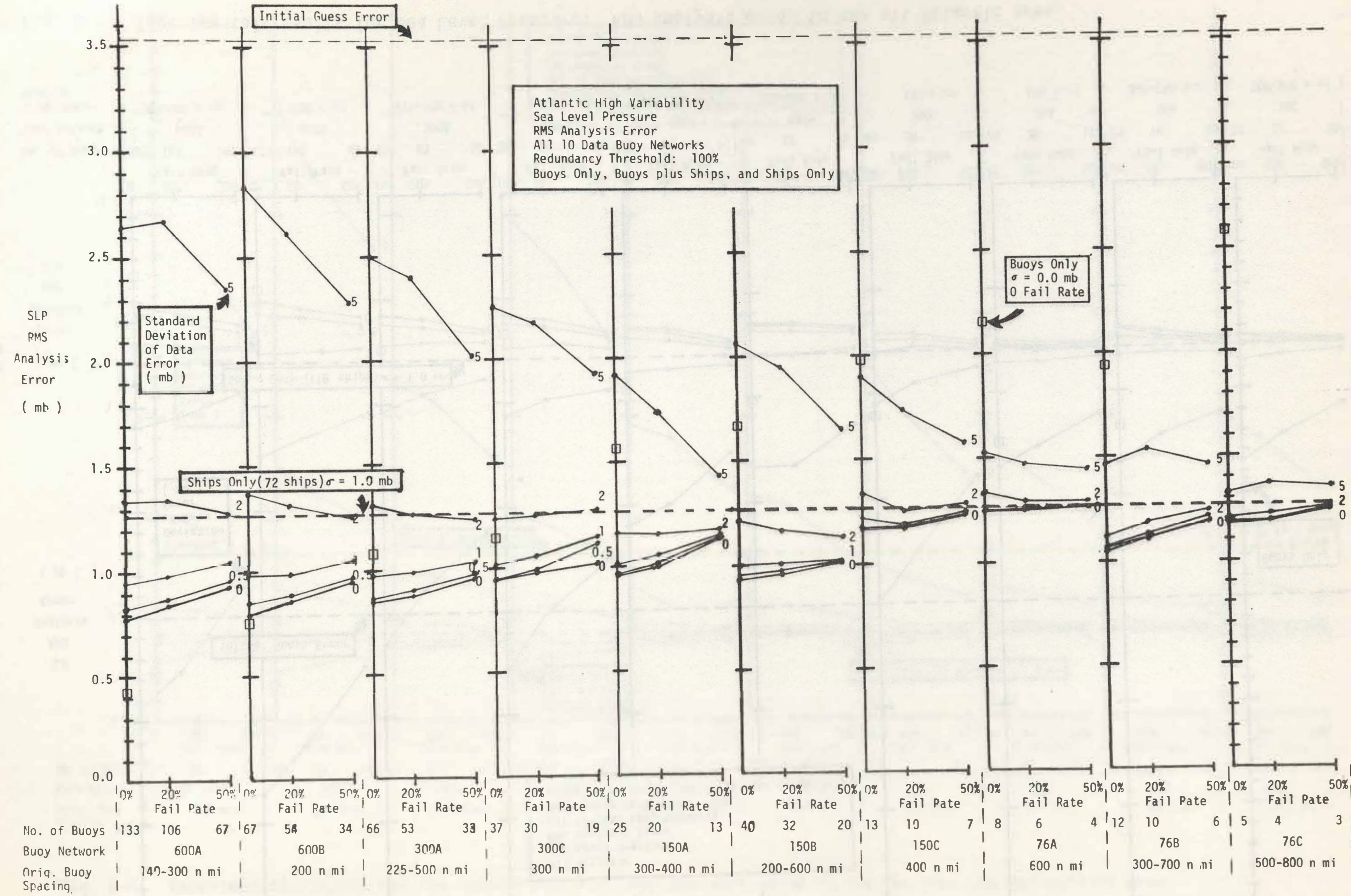

Fig. B-6. Experimental results for Sea Level Pressure: RMS analysis error in the Atlantic High Variability area.

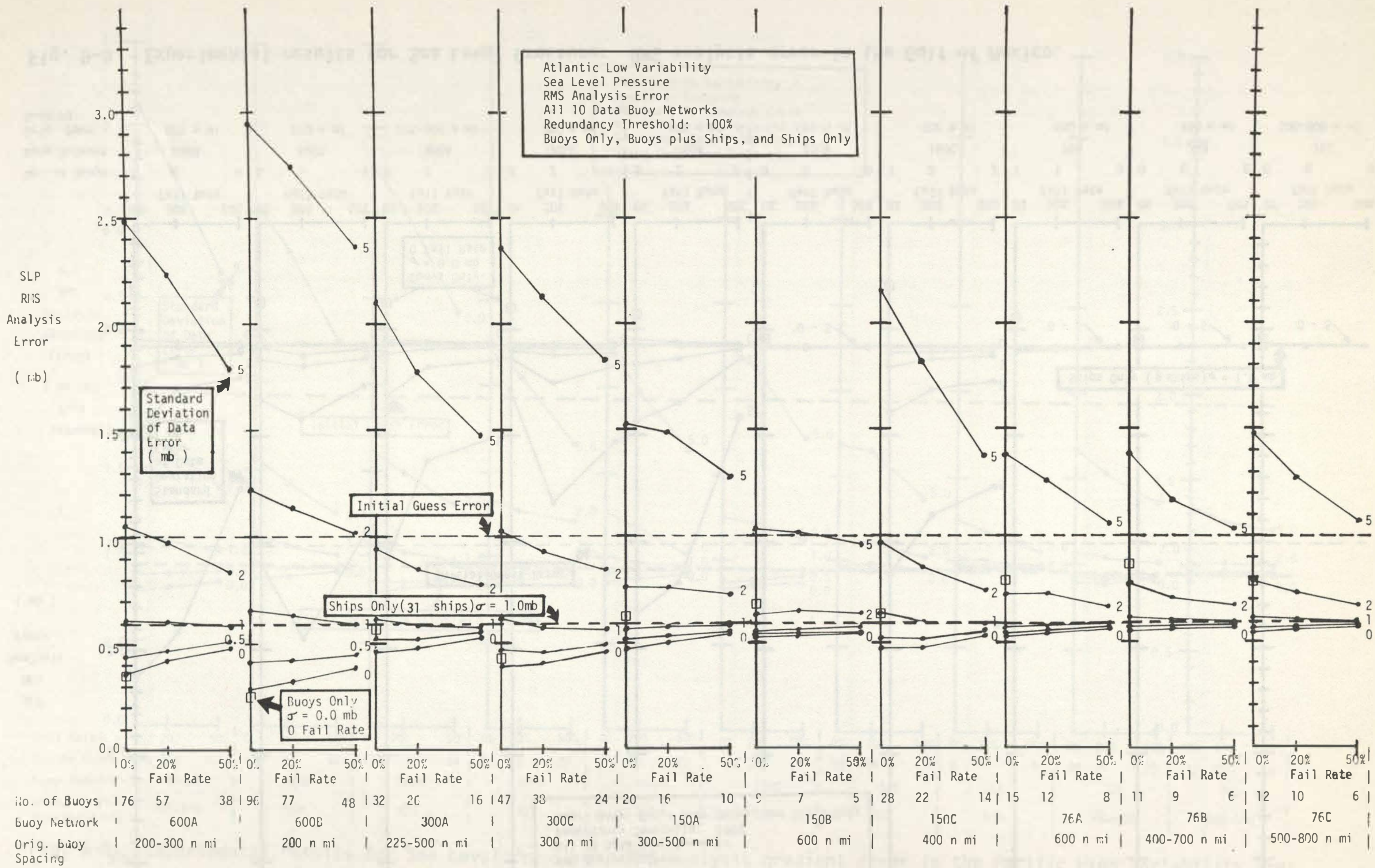

Fig. B-7. Experimental results for Sea Level Pressure: RMS analysis error in the Atlantic Low Variability area.

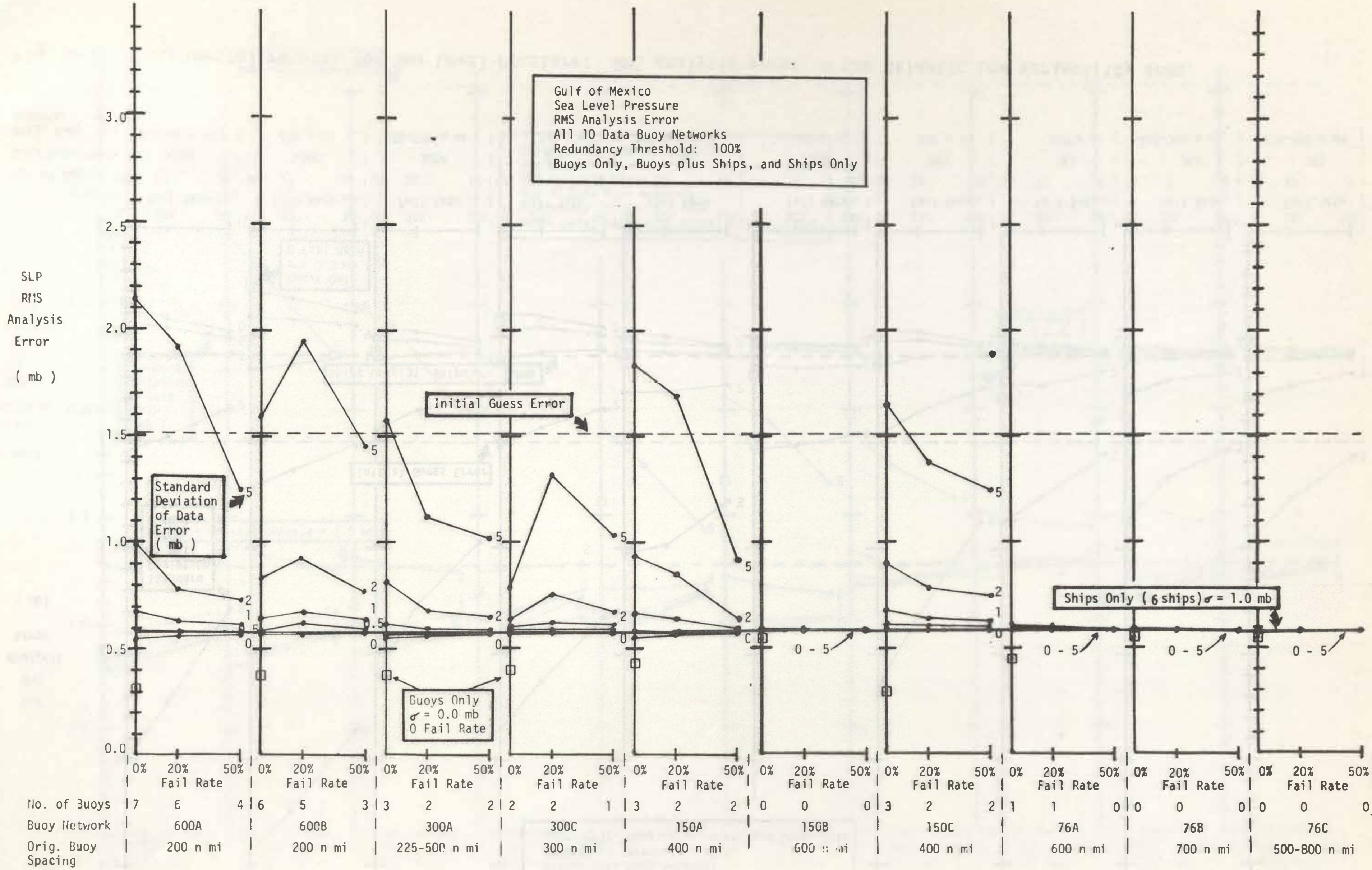

Fig. B-8. Experimental results for Sea Level Pressure: RMS analysis error in the Gulf of Mexico.

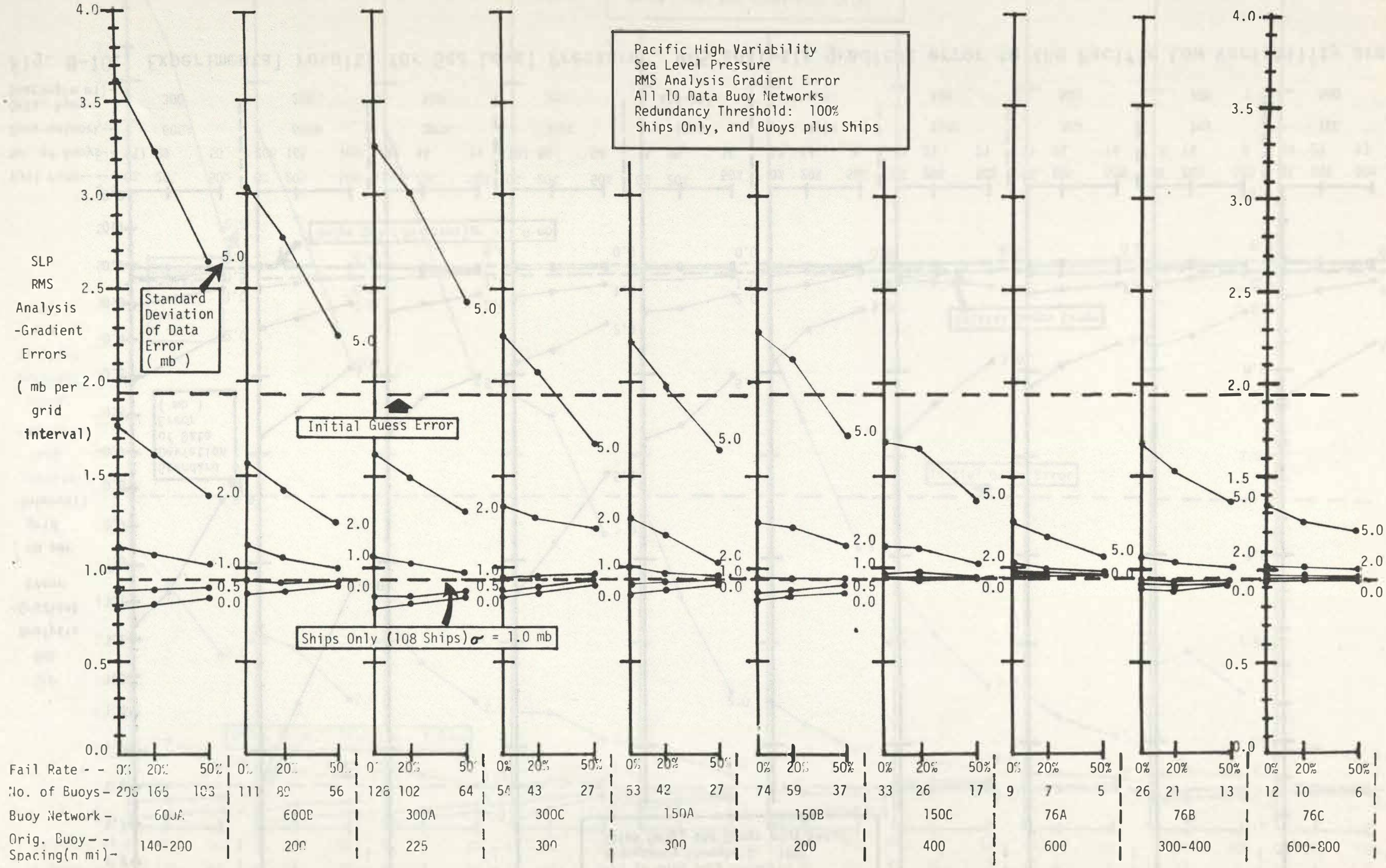

Fig. B-9. Experimental results for Sea Level Pressure: RMS analysis gradient error in the Pacific High Variability area.

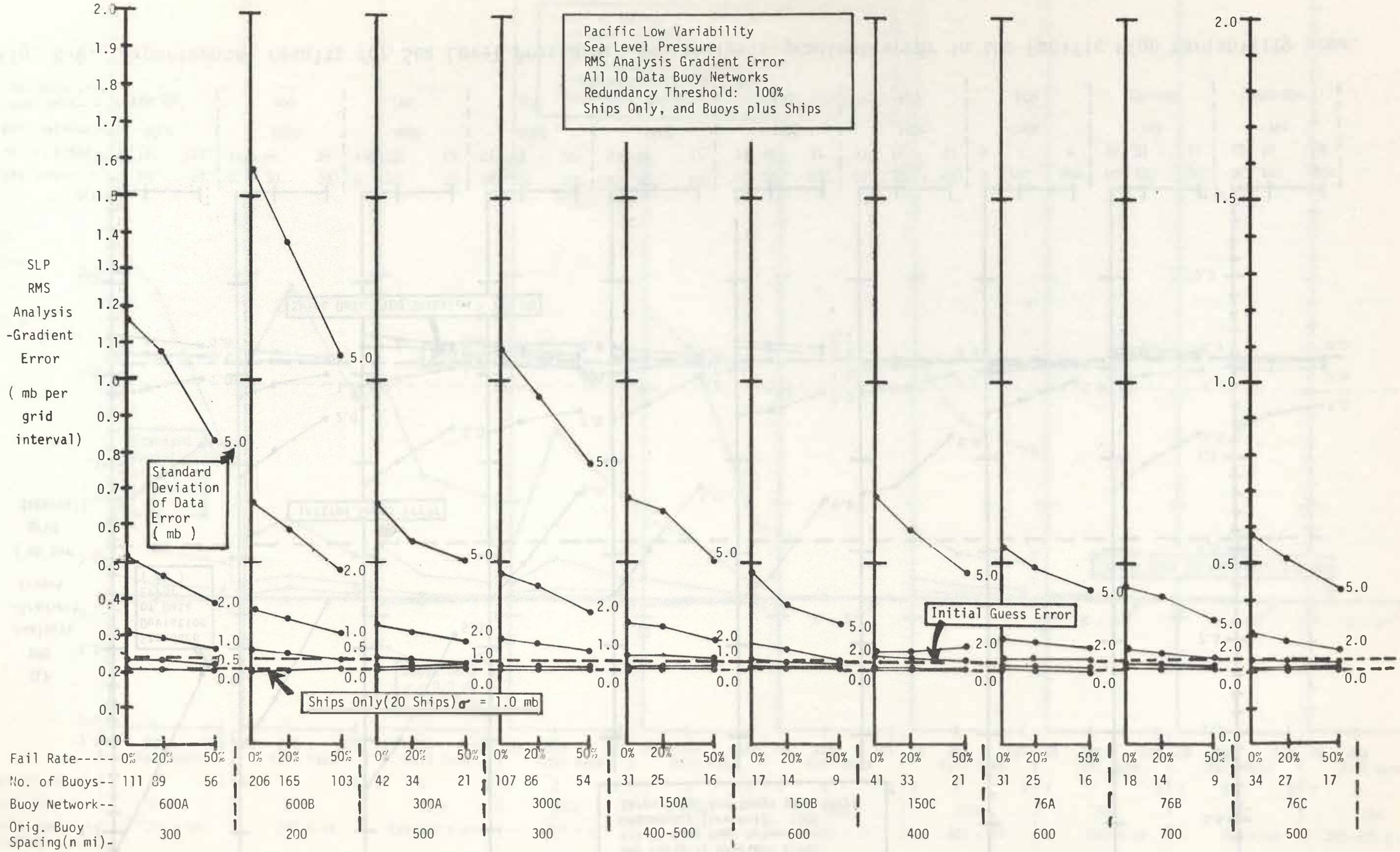

Fig. B-10. Experimental results for Sea Level Pressure: RMS analysis gradient error in the Pacific Low Variability area.

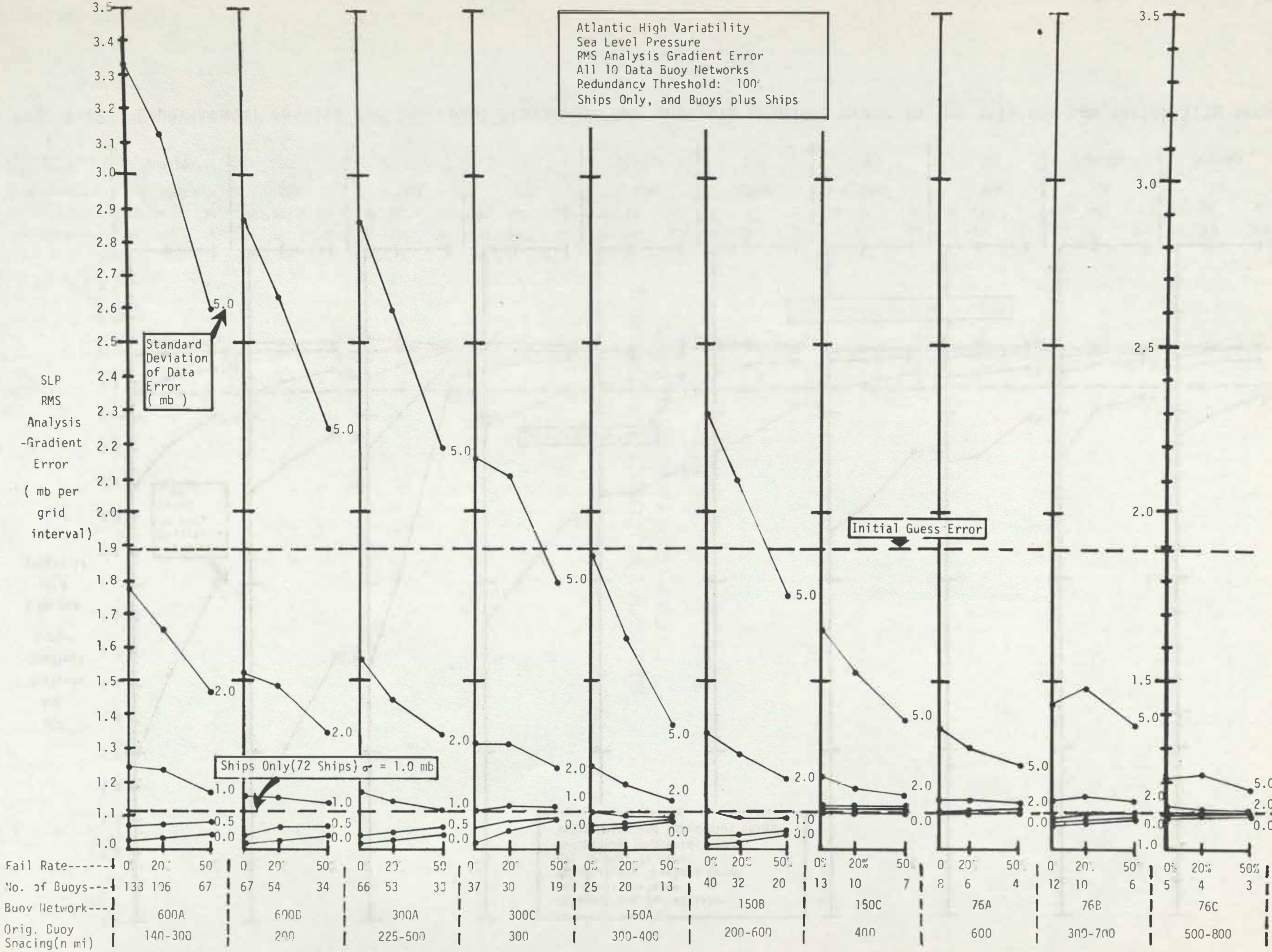

Fig. B-11. Experimental results for Sea Level Pressure: RMS analysis gradient error in the Atlantic High Variability area.

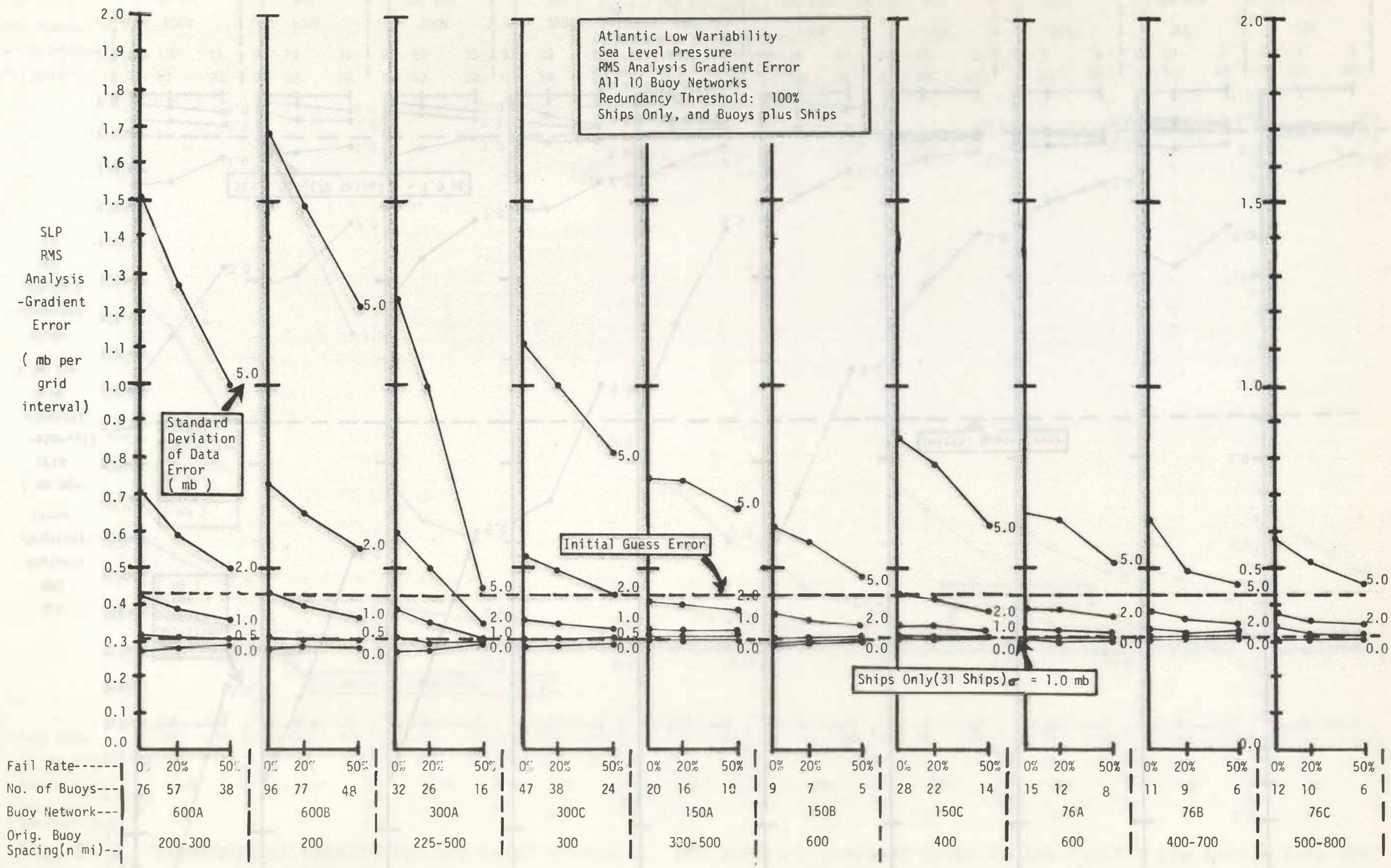

Fig. B-12. Experimental results for Sea Level Pressure: RMS analysis gradient error in the Atlantic Low Variability area.

APPENDIX C

SURFACE AIR TEMPERATURE
GENERAL EXPERIMENTAL RESULTS

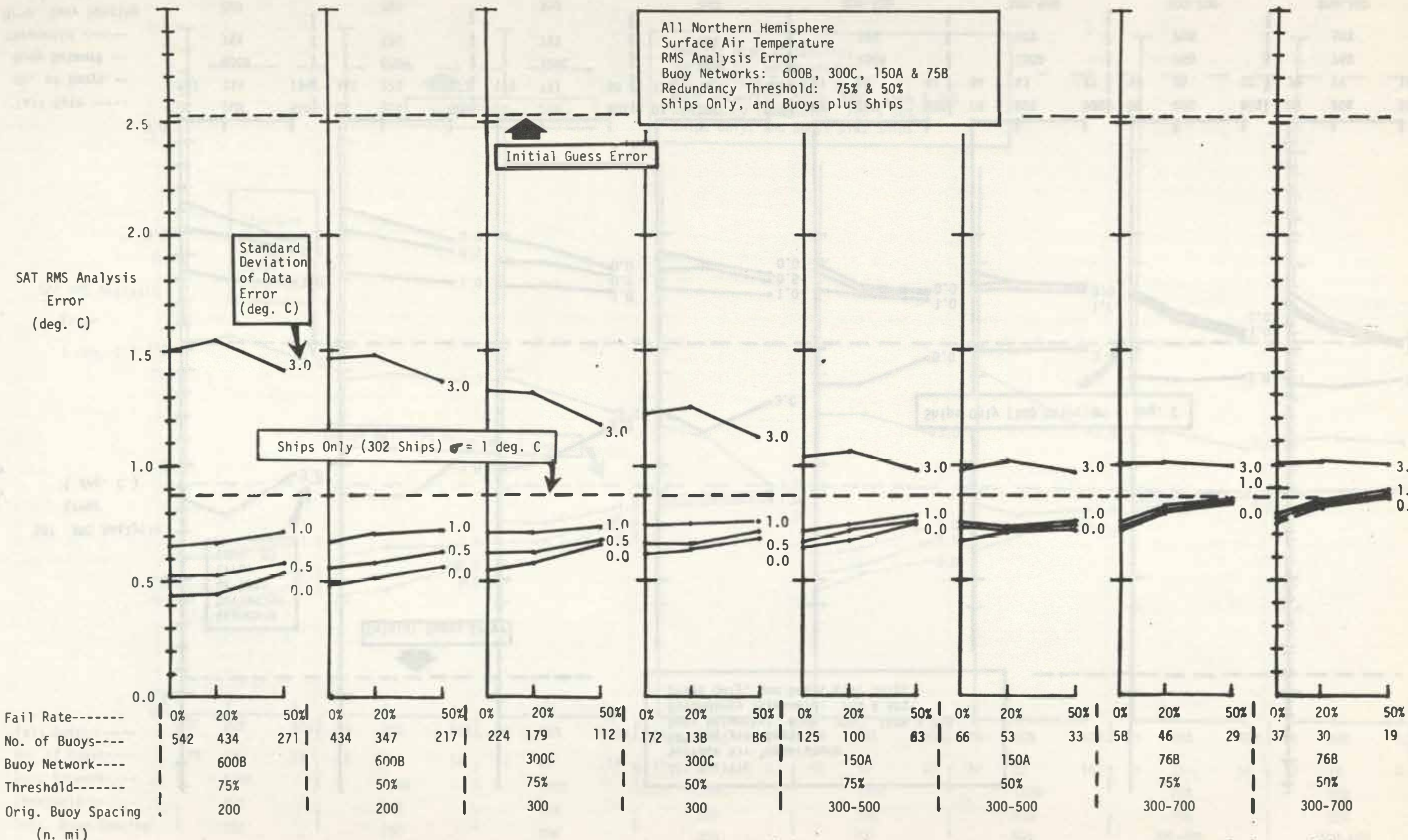

Fig. C-1. Experimental results for Surface Air Temperature: RMS analysis error in the all Northern Hemisphere area.

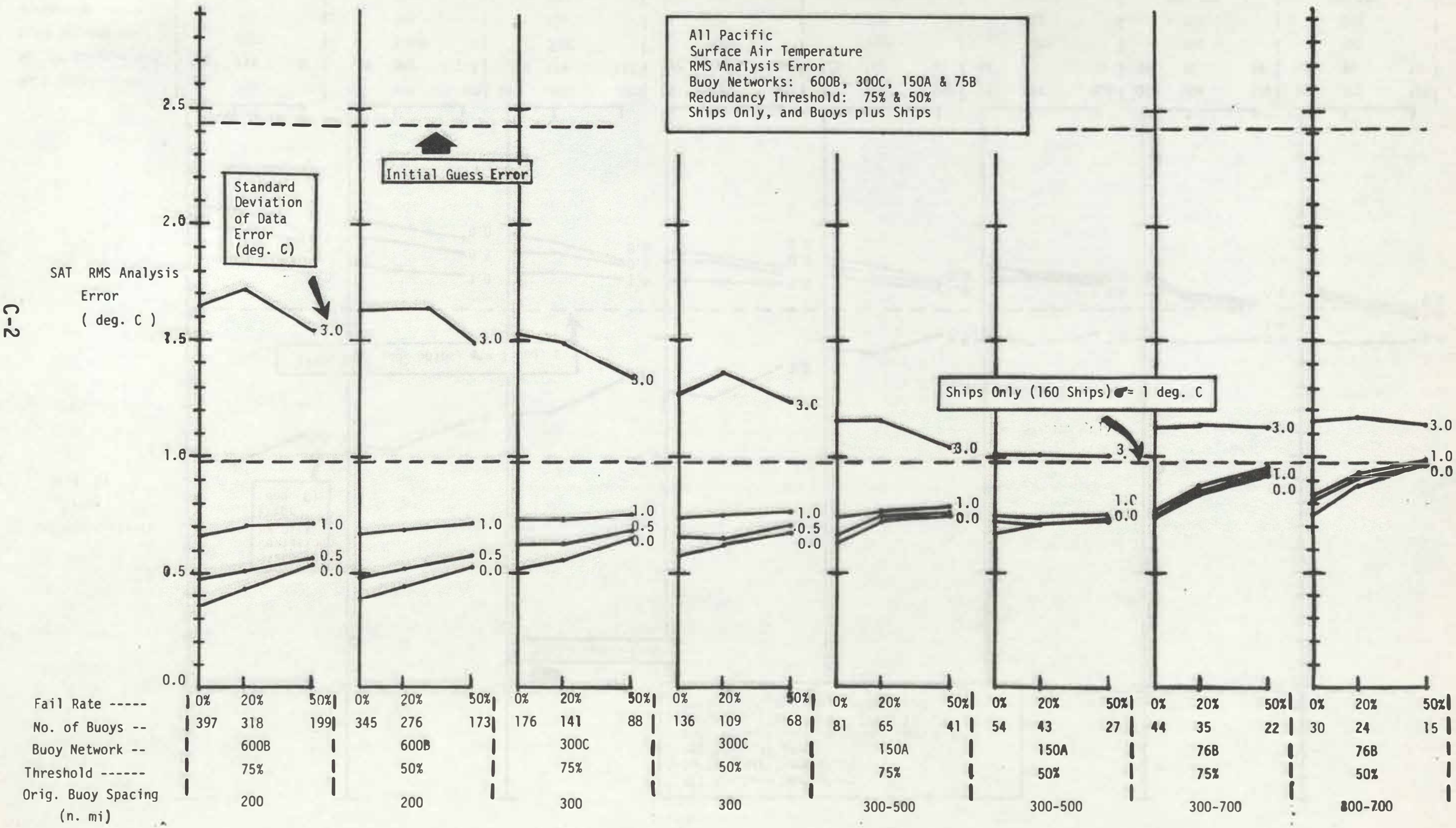

Fig. C-2. Experimental results for Surface Air Temperature: RMS analysis error in the all Pacific area.

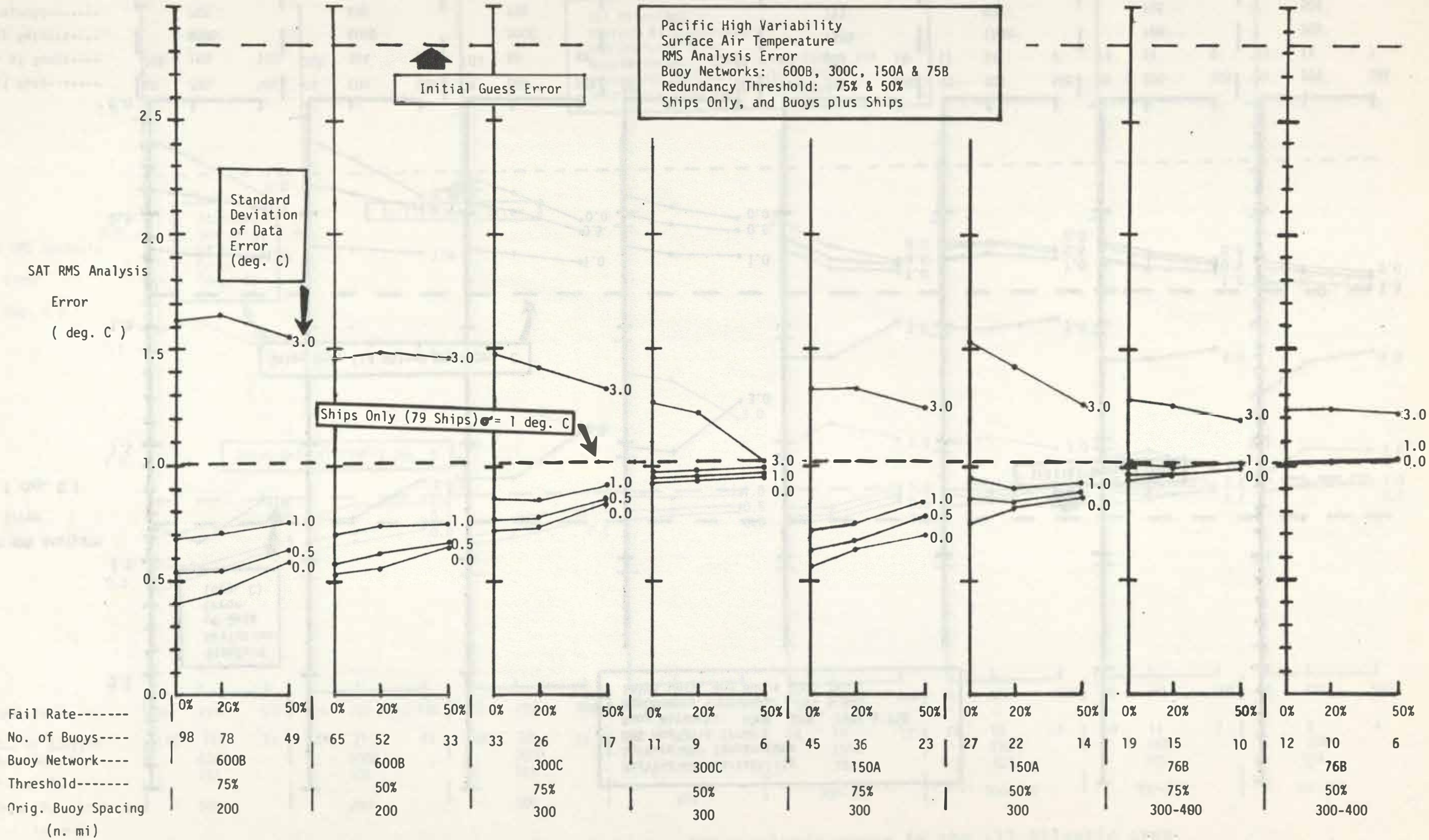

Fig. C-3. Experimental results for Surface Air Temperature: RMS analysis error in the Pacific High Variability area.

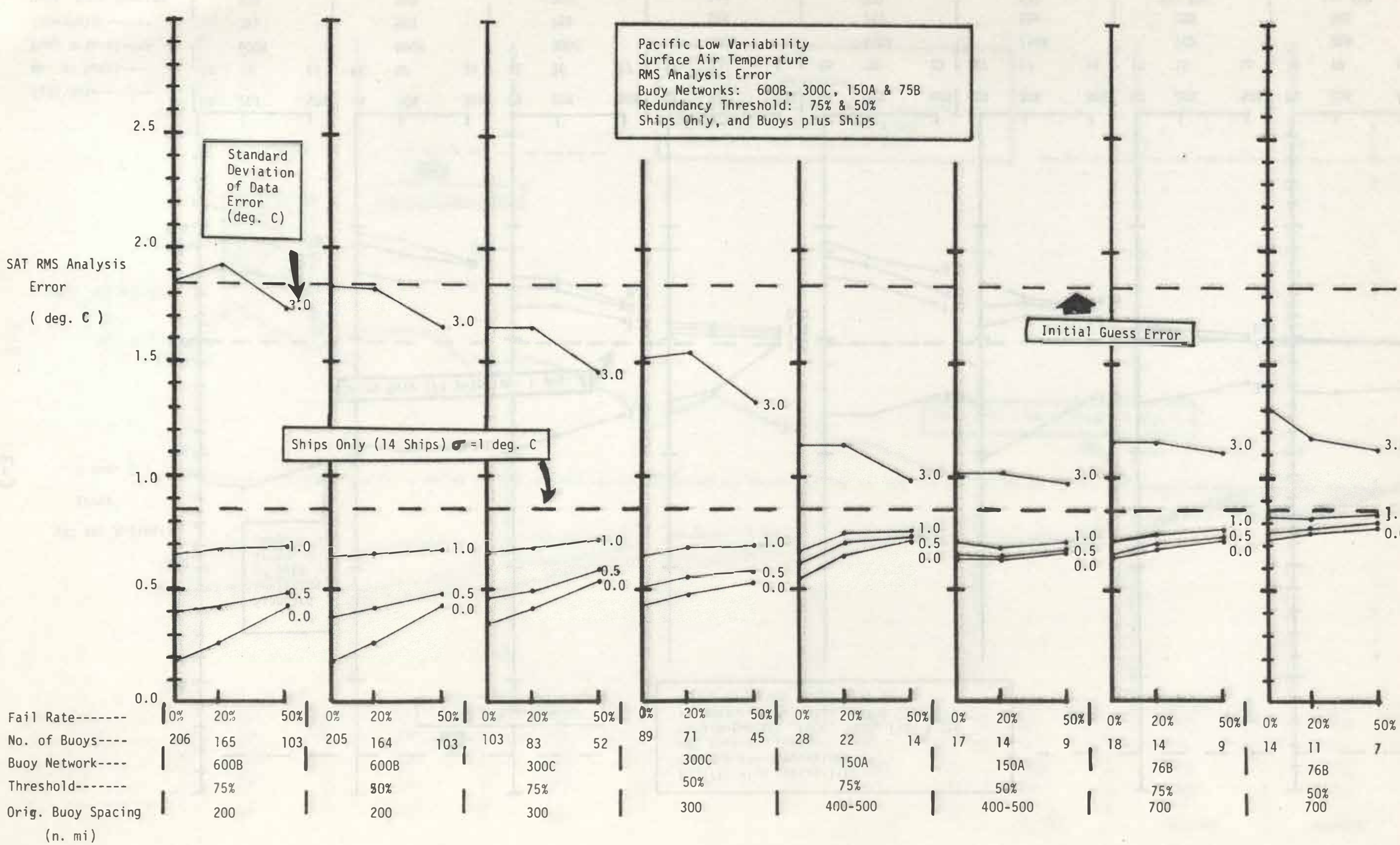

Fig. C-4. Experimental results for Surface Air Temperature: RMS analysis error in the Pacific Low Variability area.

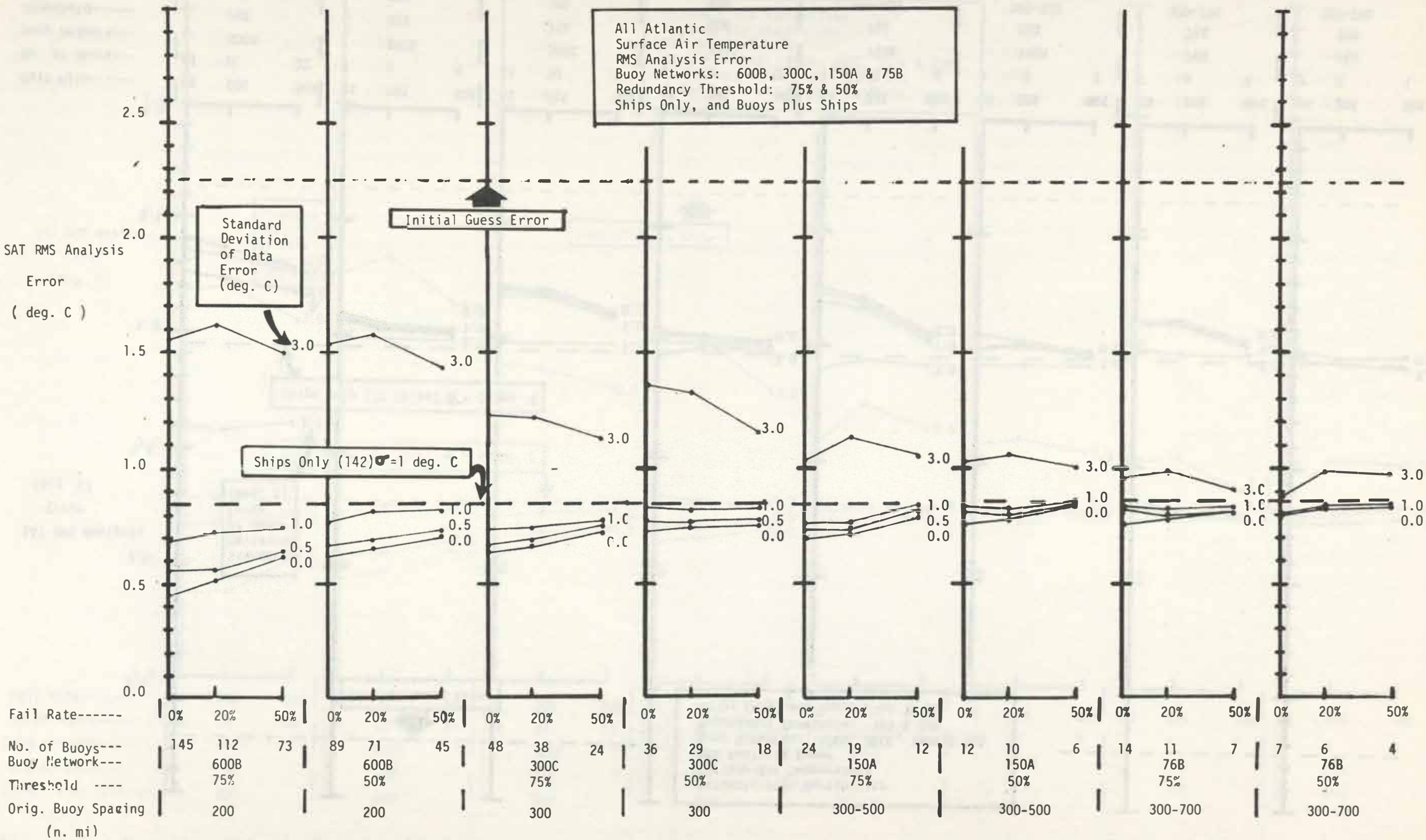

Fig. C-5. Experimental results for Surface Air Temperature: RMS analysis error in the all Atlantic area.

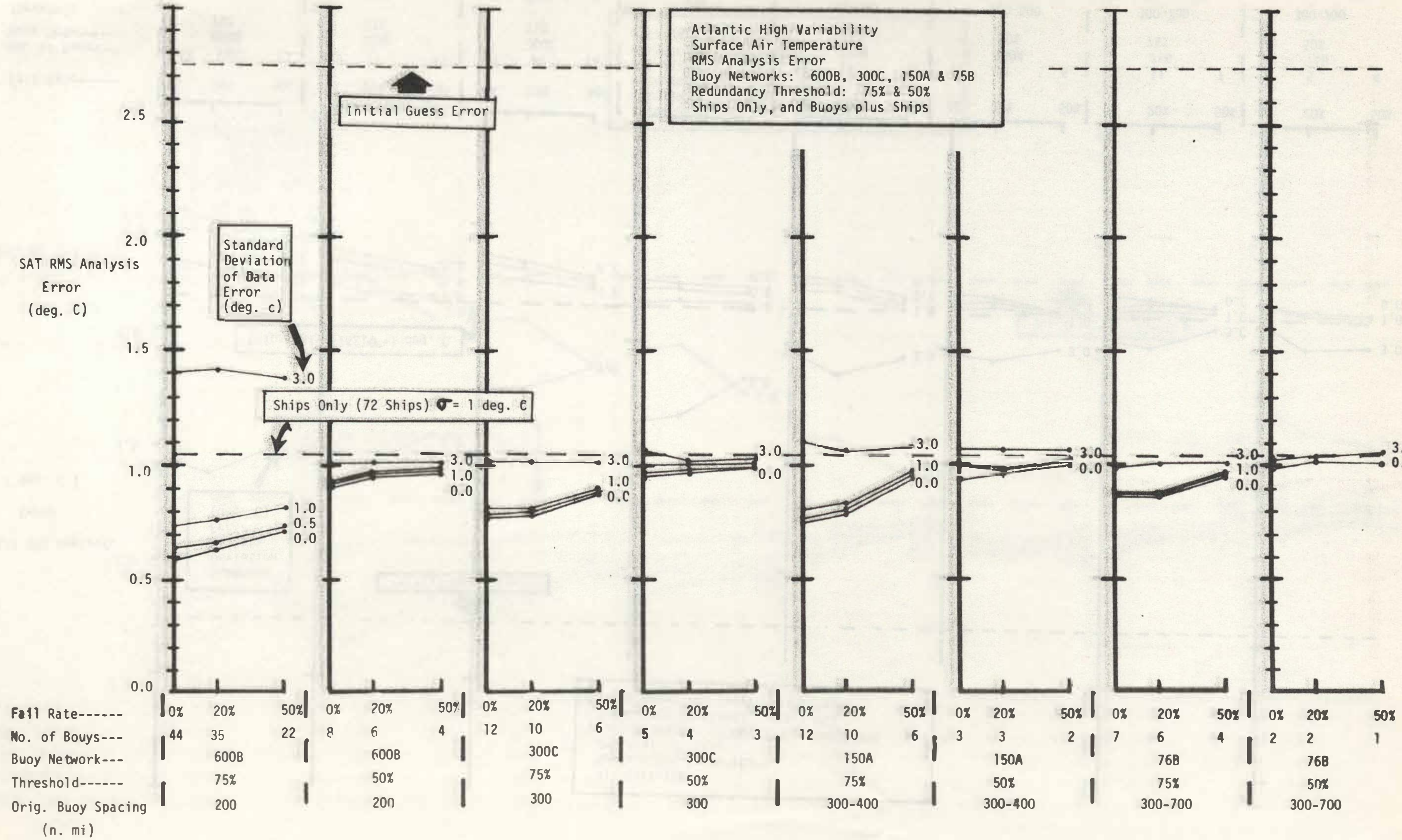

Fig. C-6. Experimental results for Surface Air Temperature: RMS analysis error in the Atlantic High Variability area.

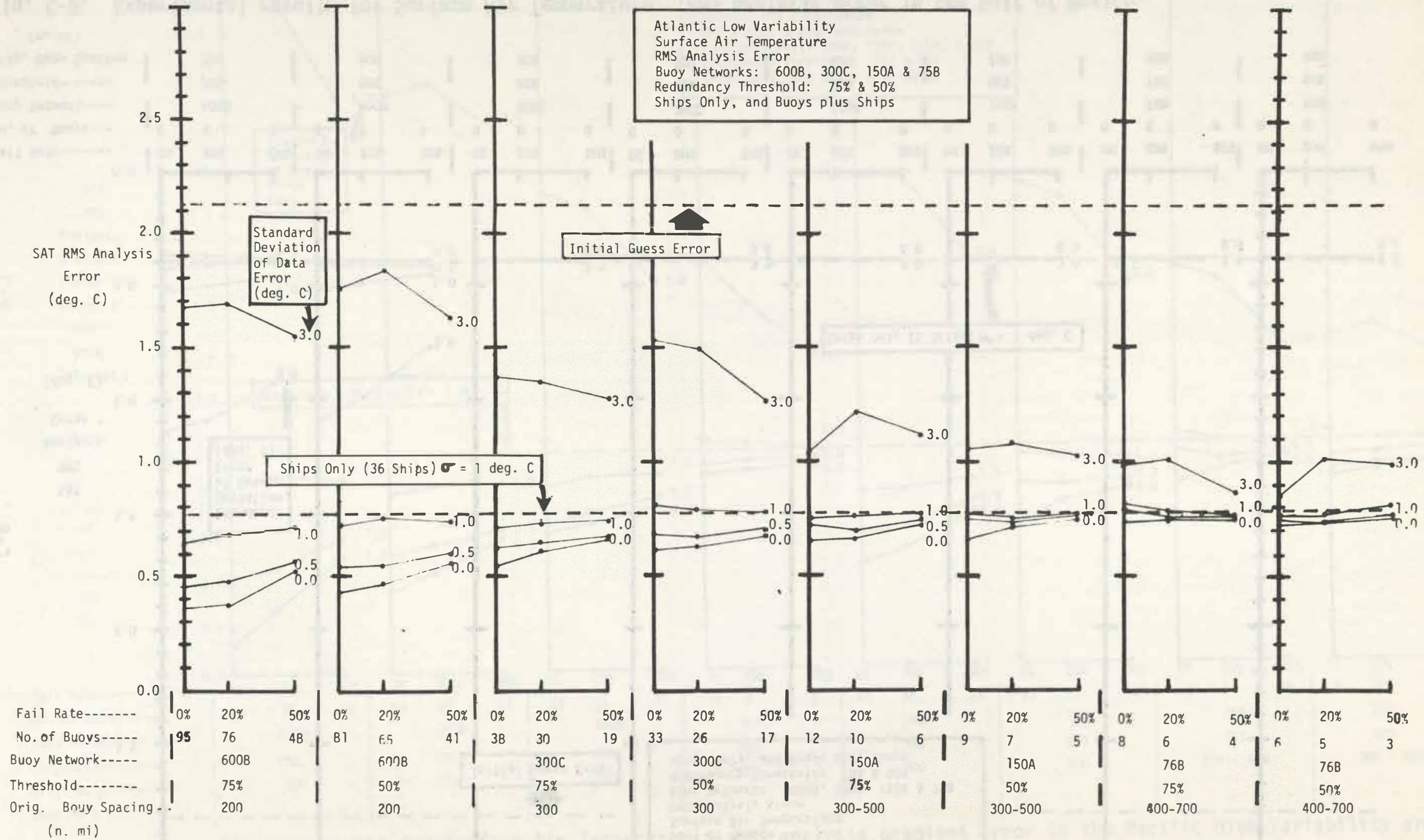

Fig. C-7. Experimental results for Surface Air Temperature: RMS analysis error in the Atlantic Low Variability area.

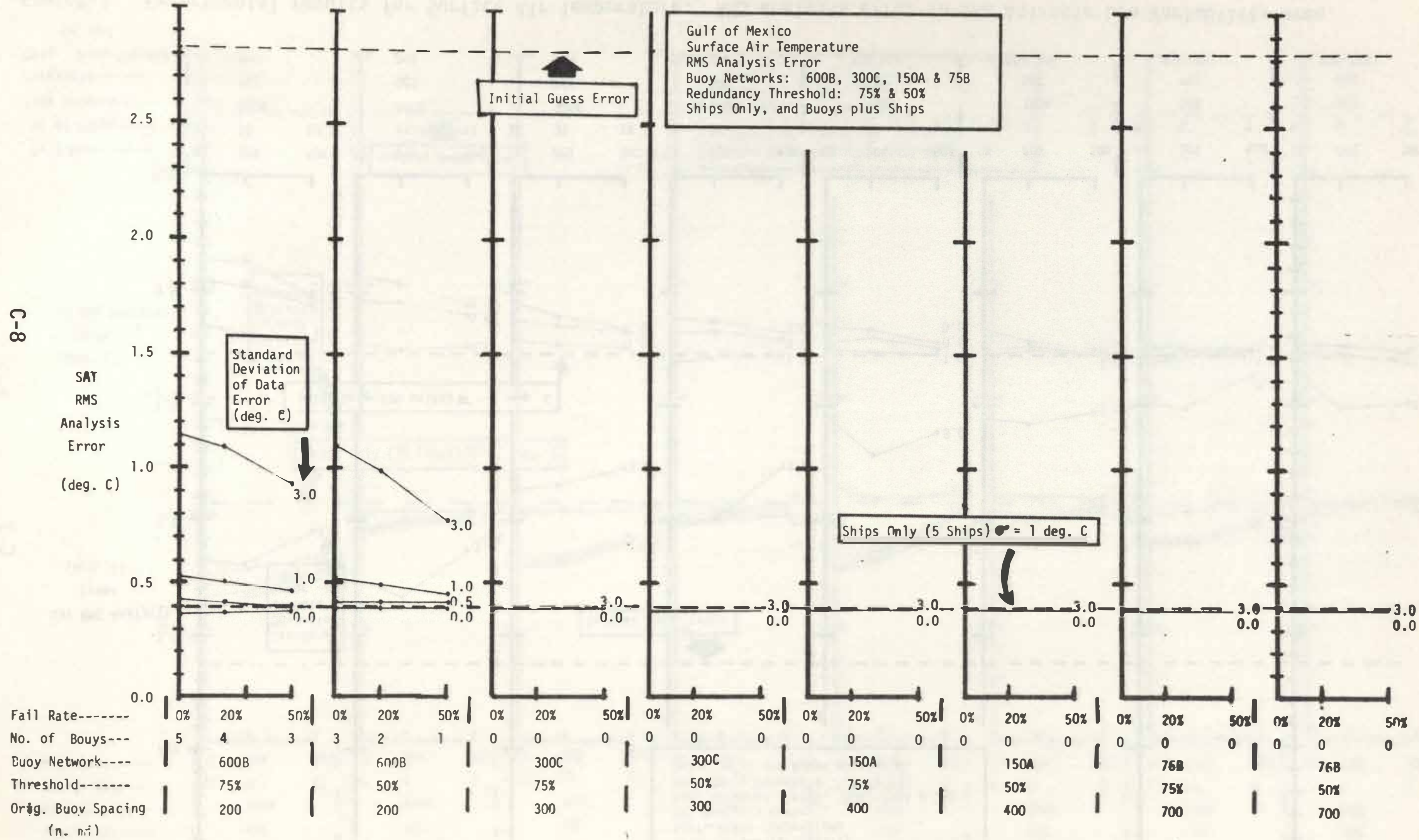

Fig. C-8. Experimental results for Surface Air Temperature: RMS analysis error in the Gulf of Mexico.

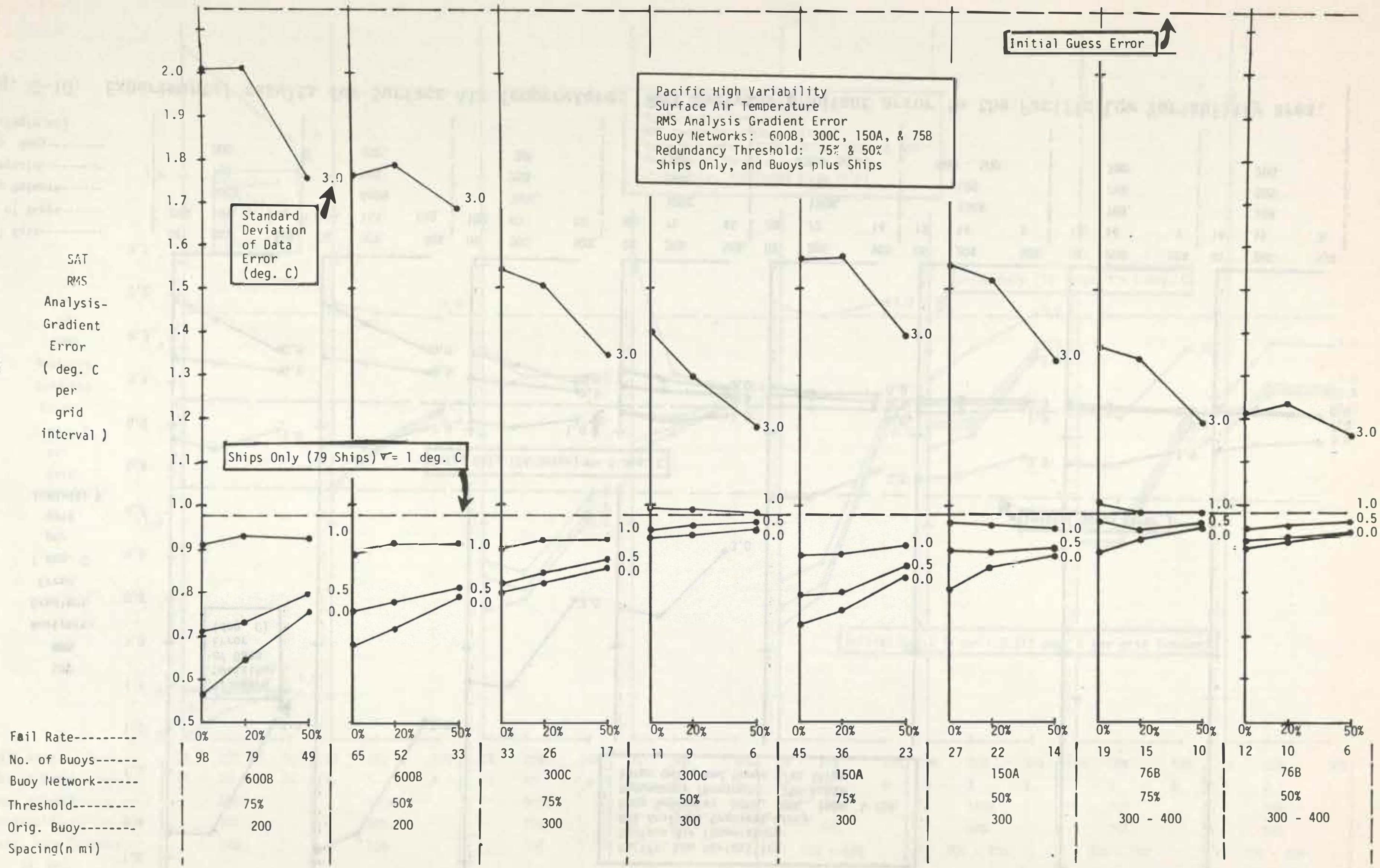

Fig. C-9. Experimental results for Surface Air Temperature: RMS analysis gradient error in the Pacific High Variability area.

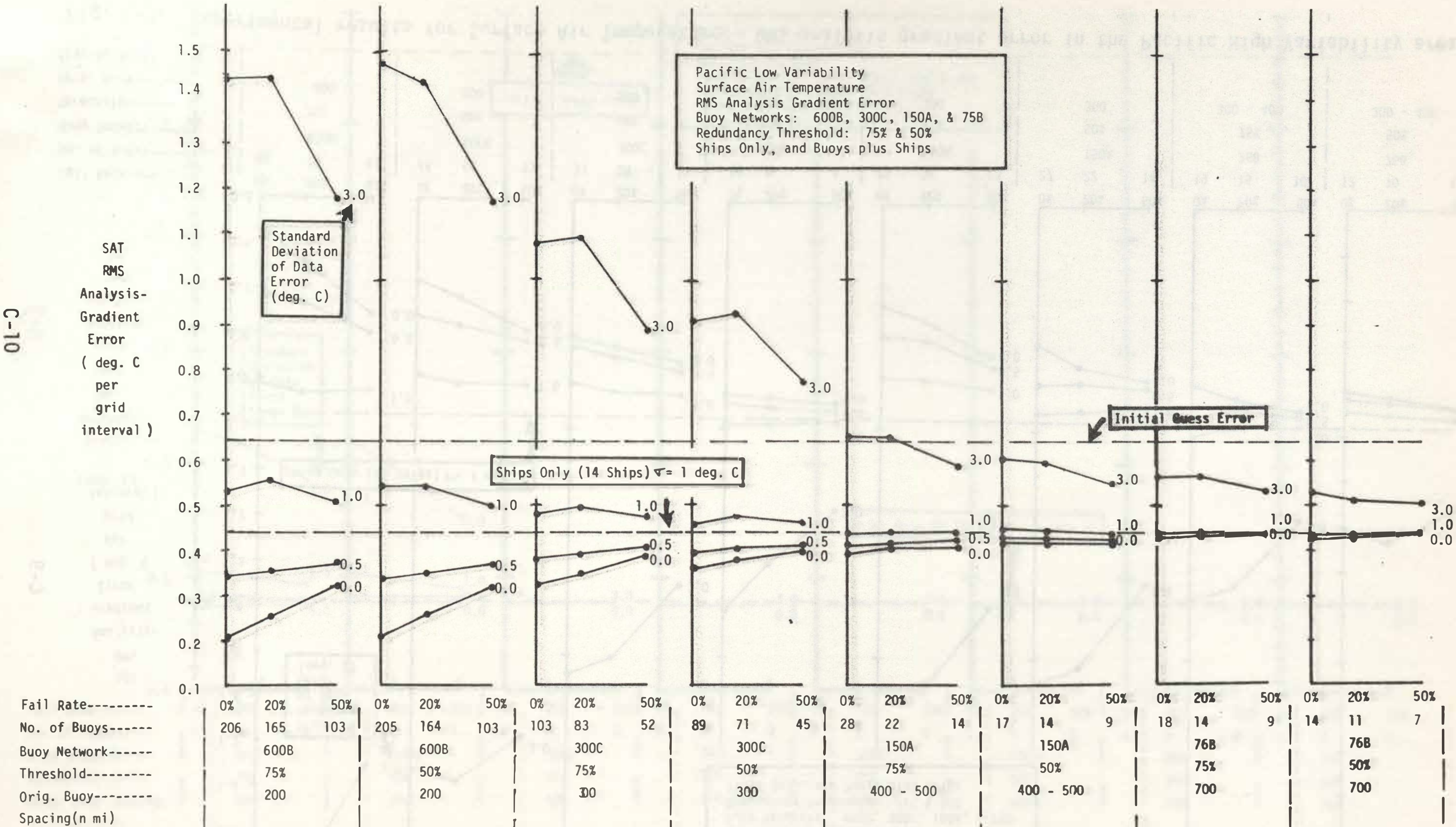

Fig. C-10. Experimental results for Surface Air Temperature: RMS analysis gradient error in the Pacific Low Variability area.

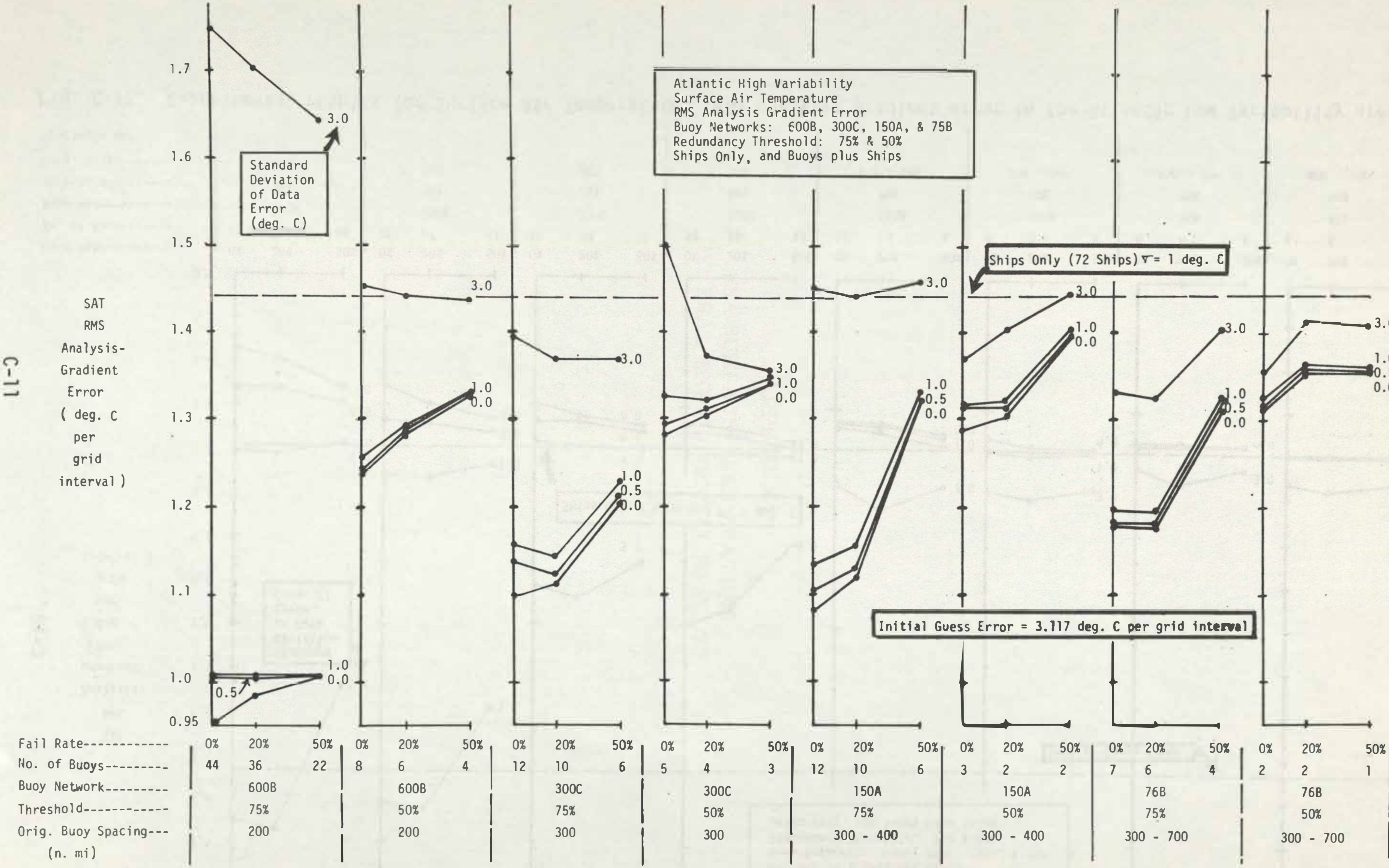

Fig. C-11. Experimental results for Surface Air Temperature: RMS analysis gradient error in the Atlantic High Variability area.

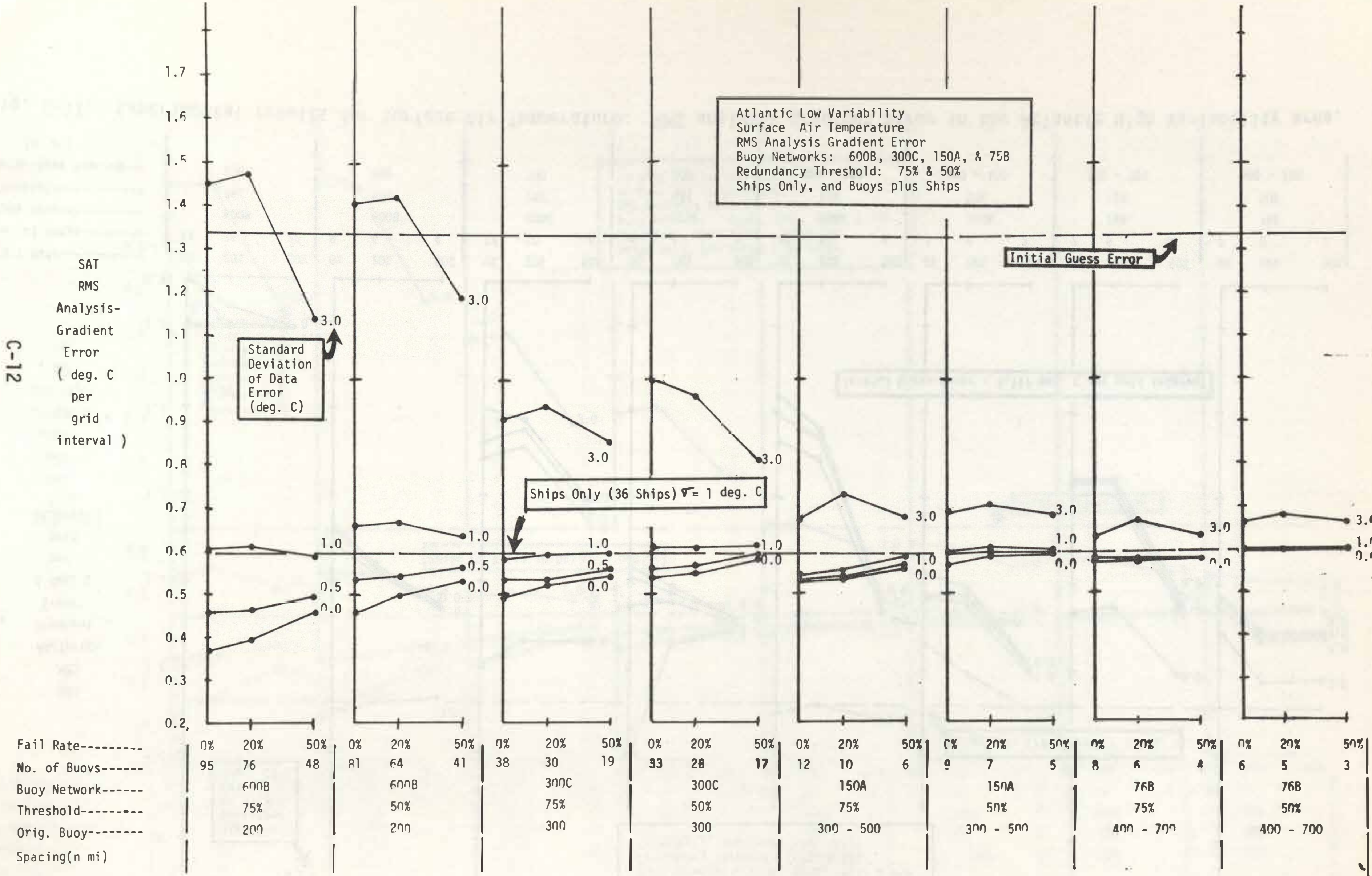

Fig. C-12. Experimental results for Surface Air Temperature: RMS analysis gradient error in the Atlantic Low Variability area.

APPENDIX D

SEA SURFACE TEMPERATURE
GENERAL EXPERIMENTAL RESULTS

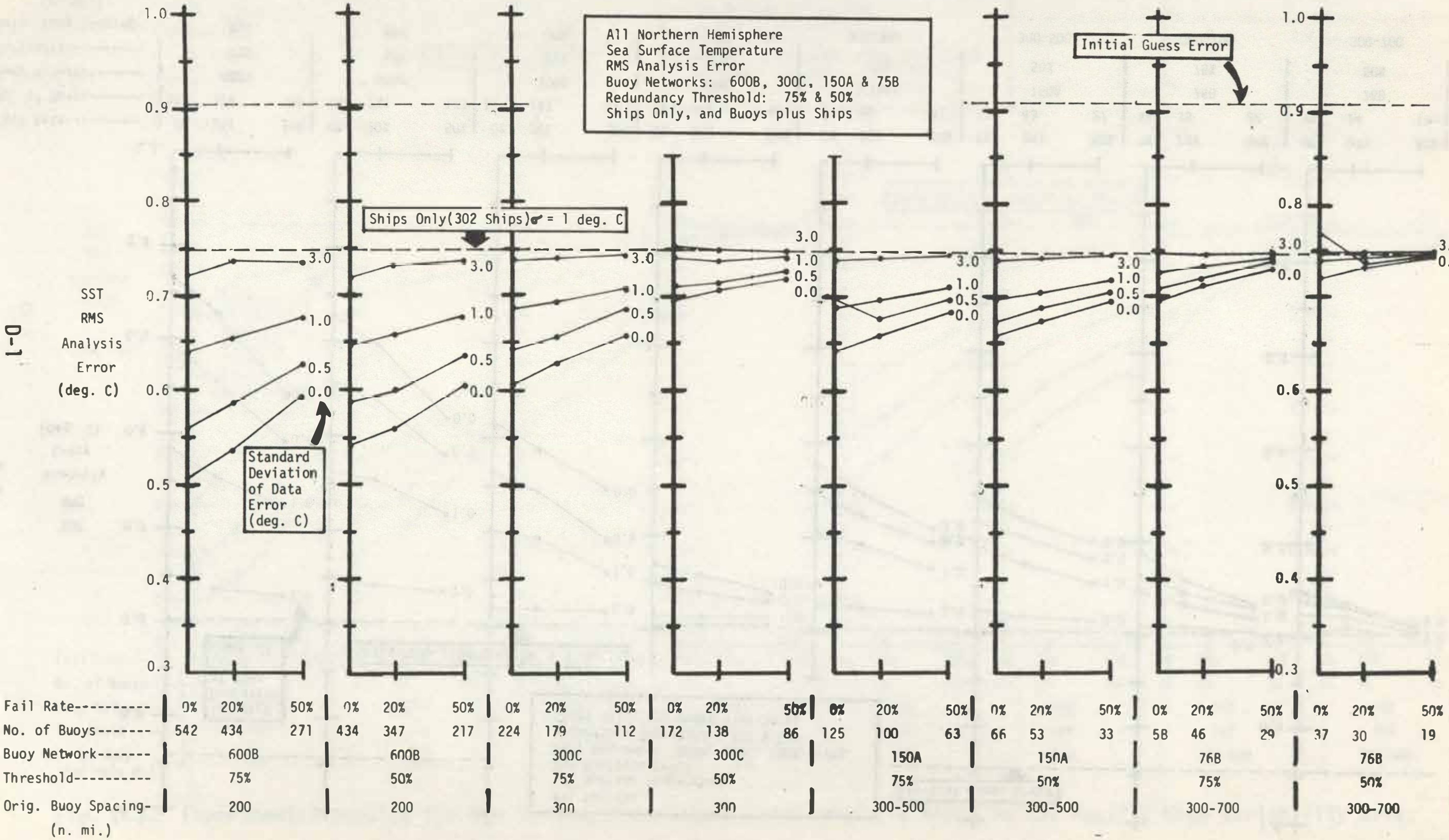

Fig. D-1. Experimental results for Sea Surface Temperature: RMS analysis error in the all Northern Hemisphere area.

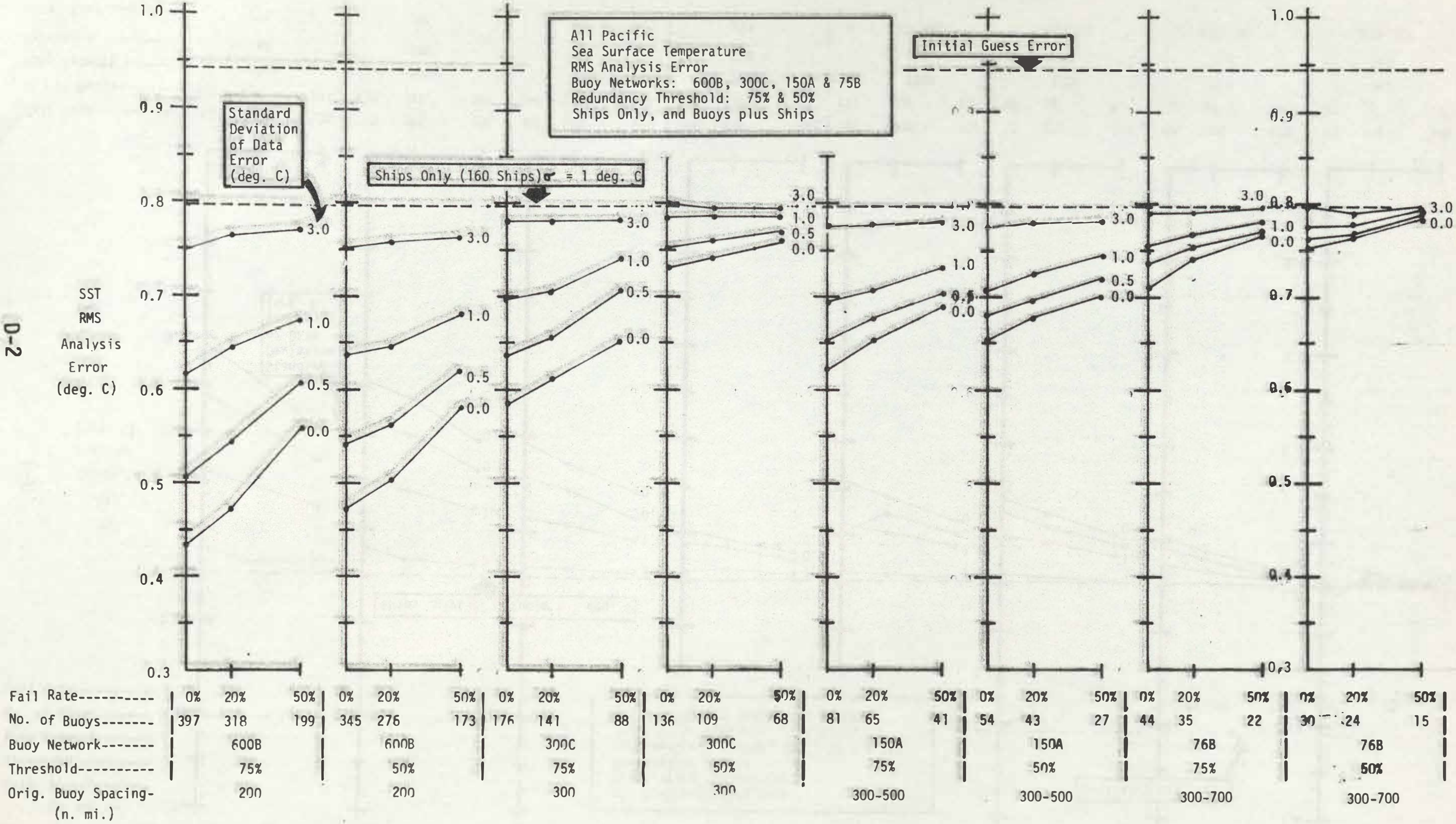

Fig. D-2. Experimental results for Sea Surface Temperature: RMS analysis error in the all Pacific area.

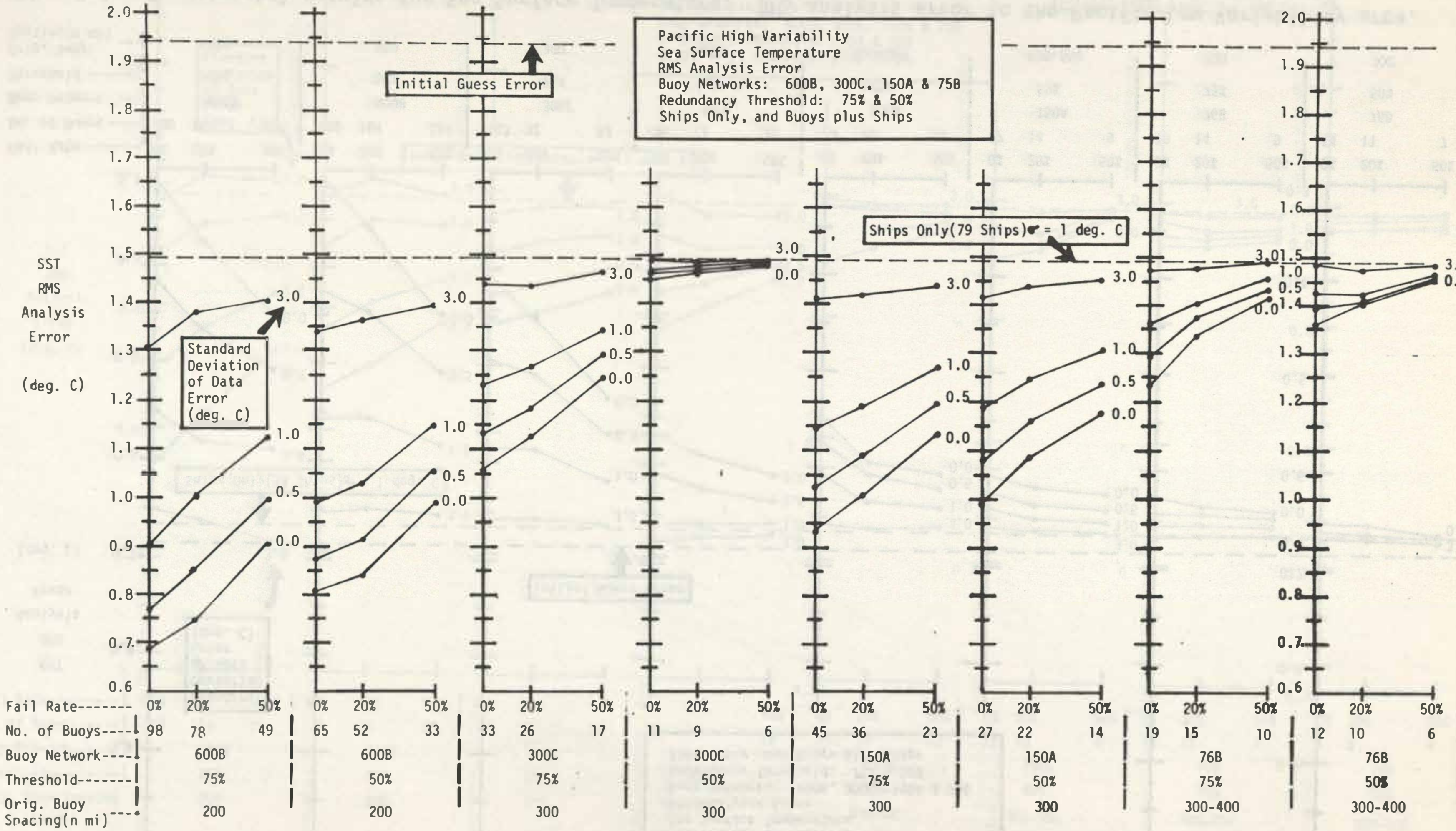

Fig. D-3. Experimental results for Sea Surface Temperature: RMS analysis error in the Pacific High Variability area.

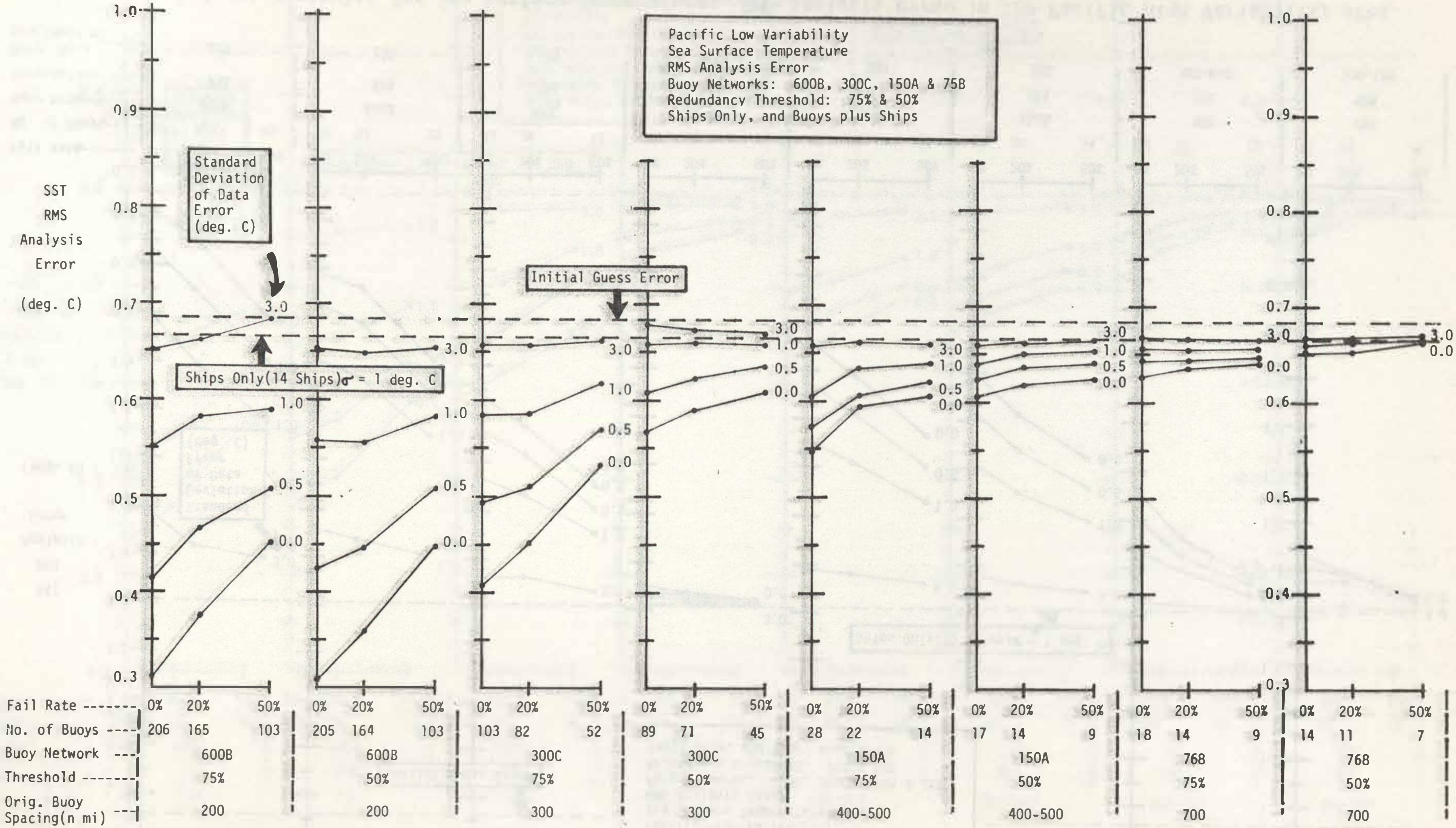

Fig. D-4. Experimental results for Sea Surface Temperature: RMS analysis error in the Pacific Low Variability area.

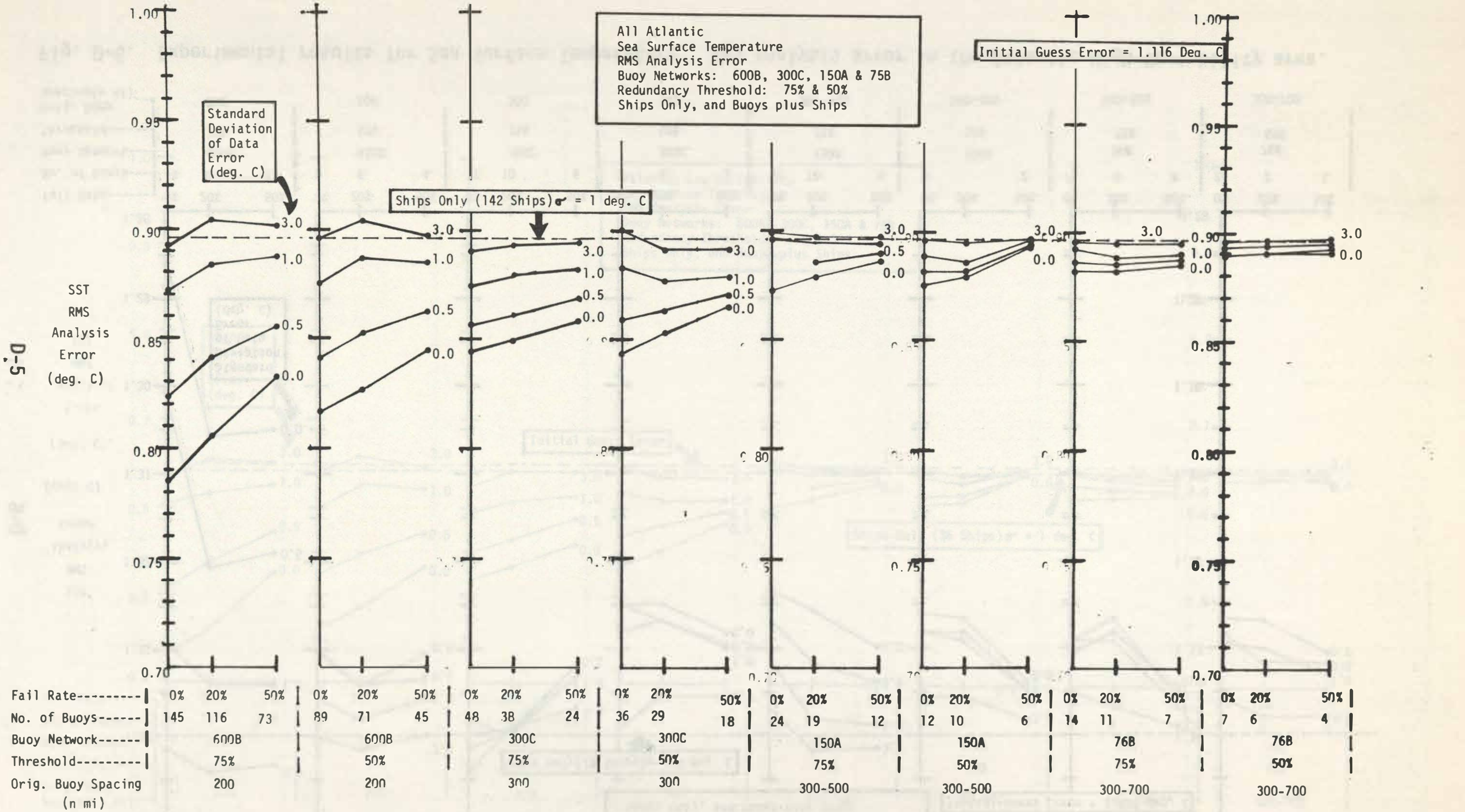

Fig. D-5. Experimental results for Sea Surface Temperature: RMS analysis error in the all Atlantic area.

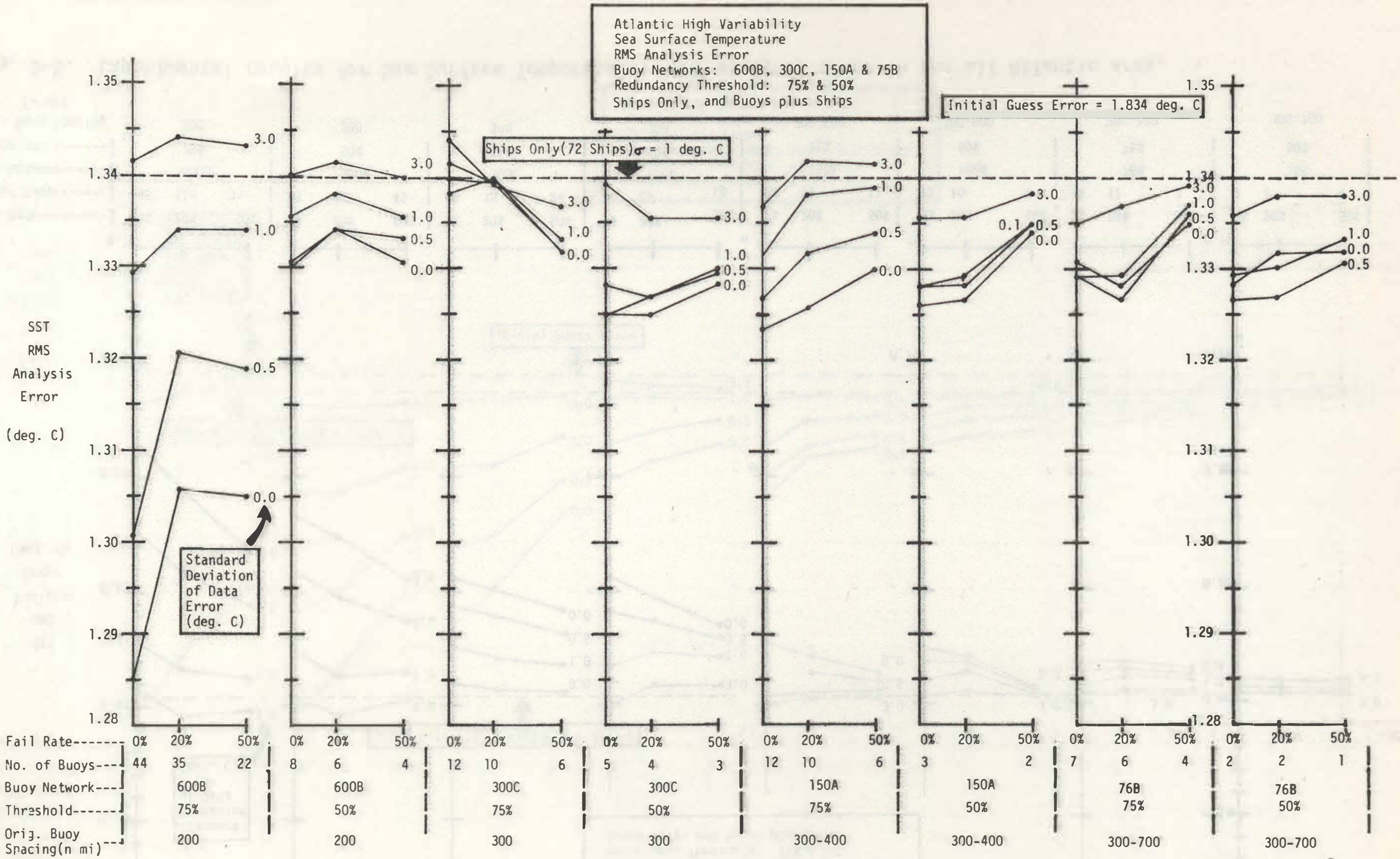

Fig. D-6. Experimental results for Sea Surface Temperature: RMS analysis error in the Atlantic High Variability area.

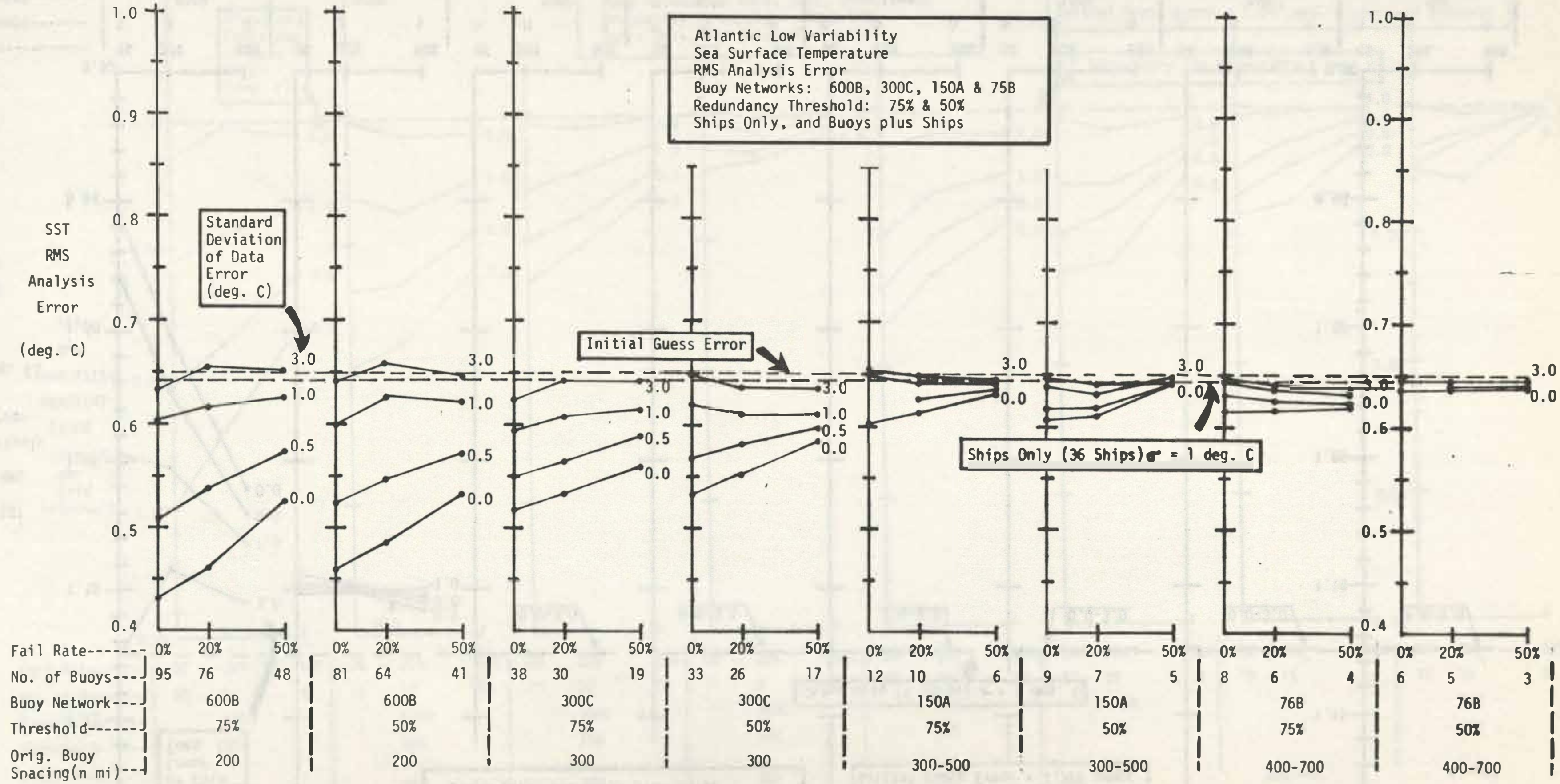

Fig. D-7. Experimental results for Sea Surface Temperature: RMS analysis error in the Atlantic Low Variability area.

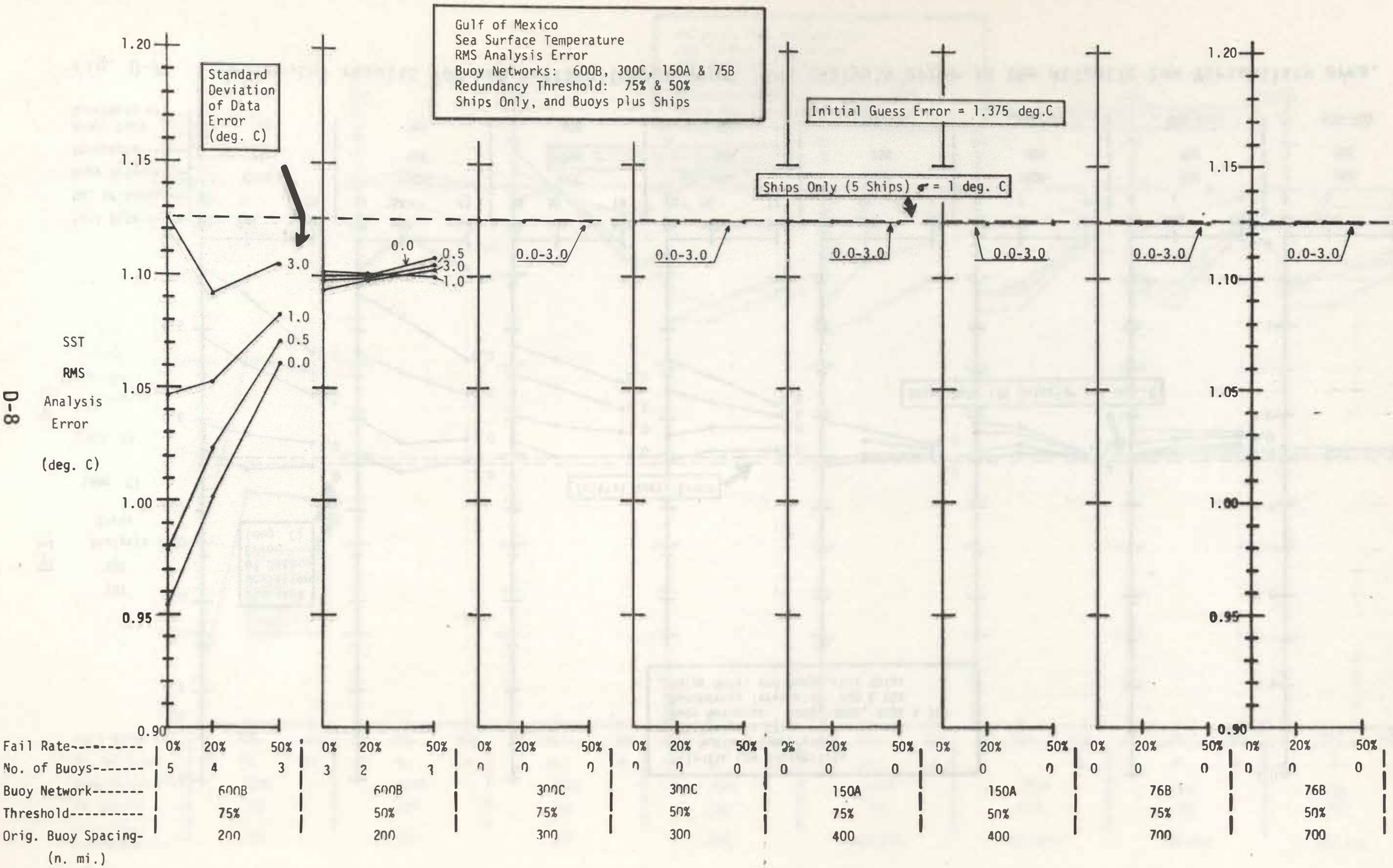

Fig. D-8. Experimental results for Sea Surface Temperature: RMS analysis error in the Gulf of Mexico.

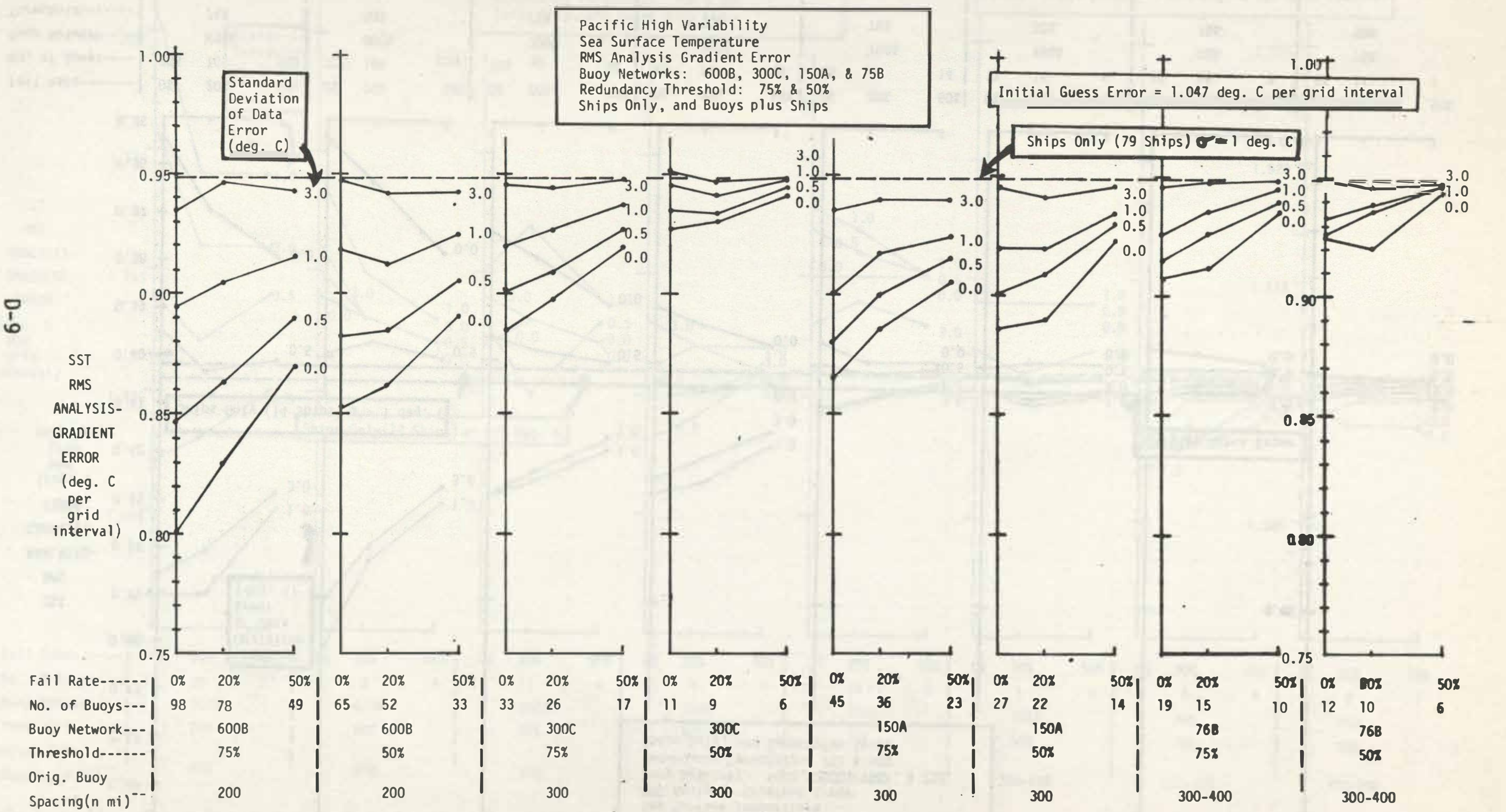

Fig. D-9. Experimental results for Sea Surface Temperature: RMS analysis gradient error in the Pacific High Variability area.

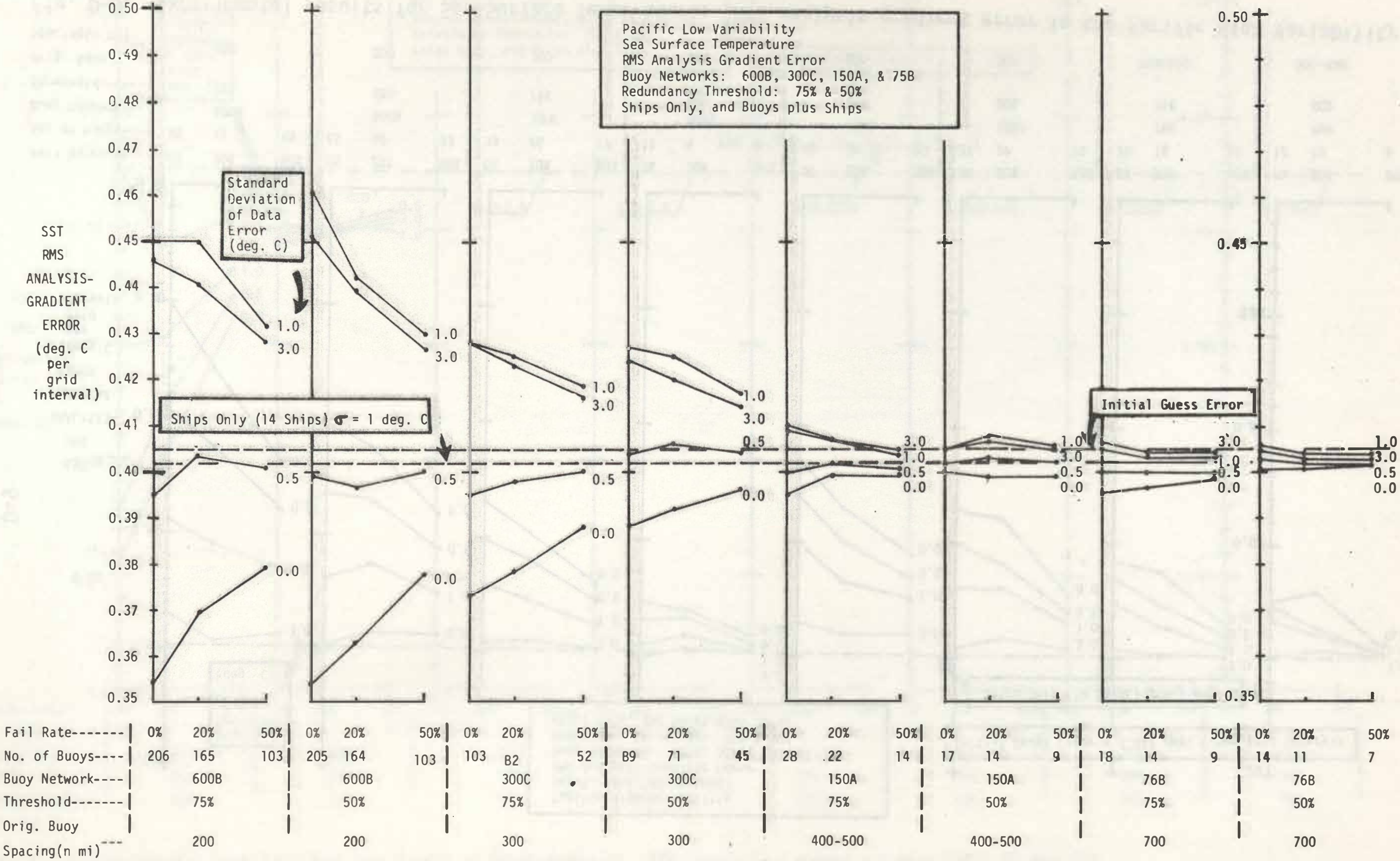

Fig. D-10. Experimental results for Sea Surface Temperature: RMS analysis gradient error in the Pacific Low Variability area.

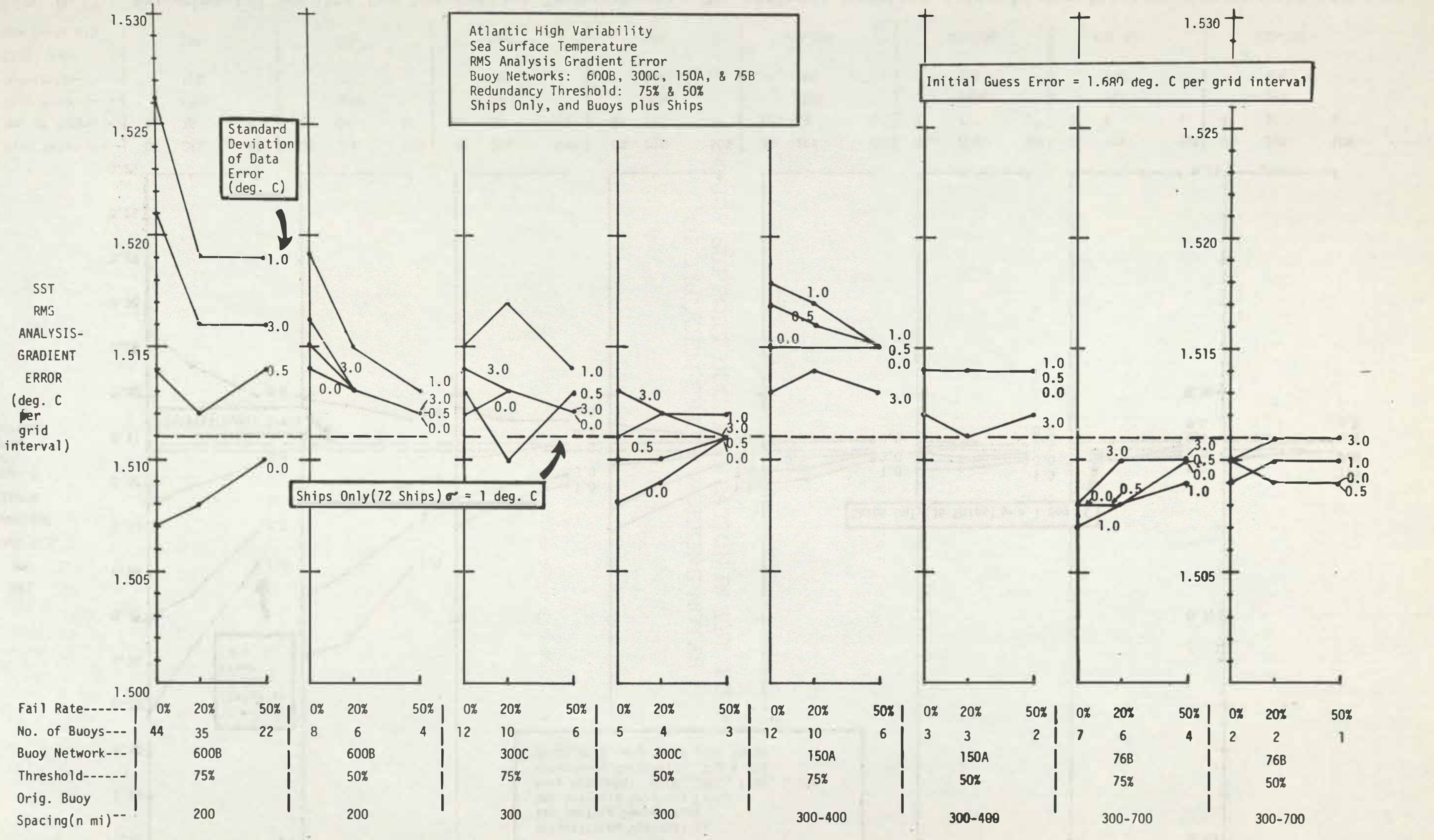

Fig. D-11. Experimental results for Sea Surface Temperature: RMS analysis gradient error in the Atlantic High Variability area.

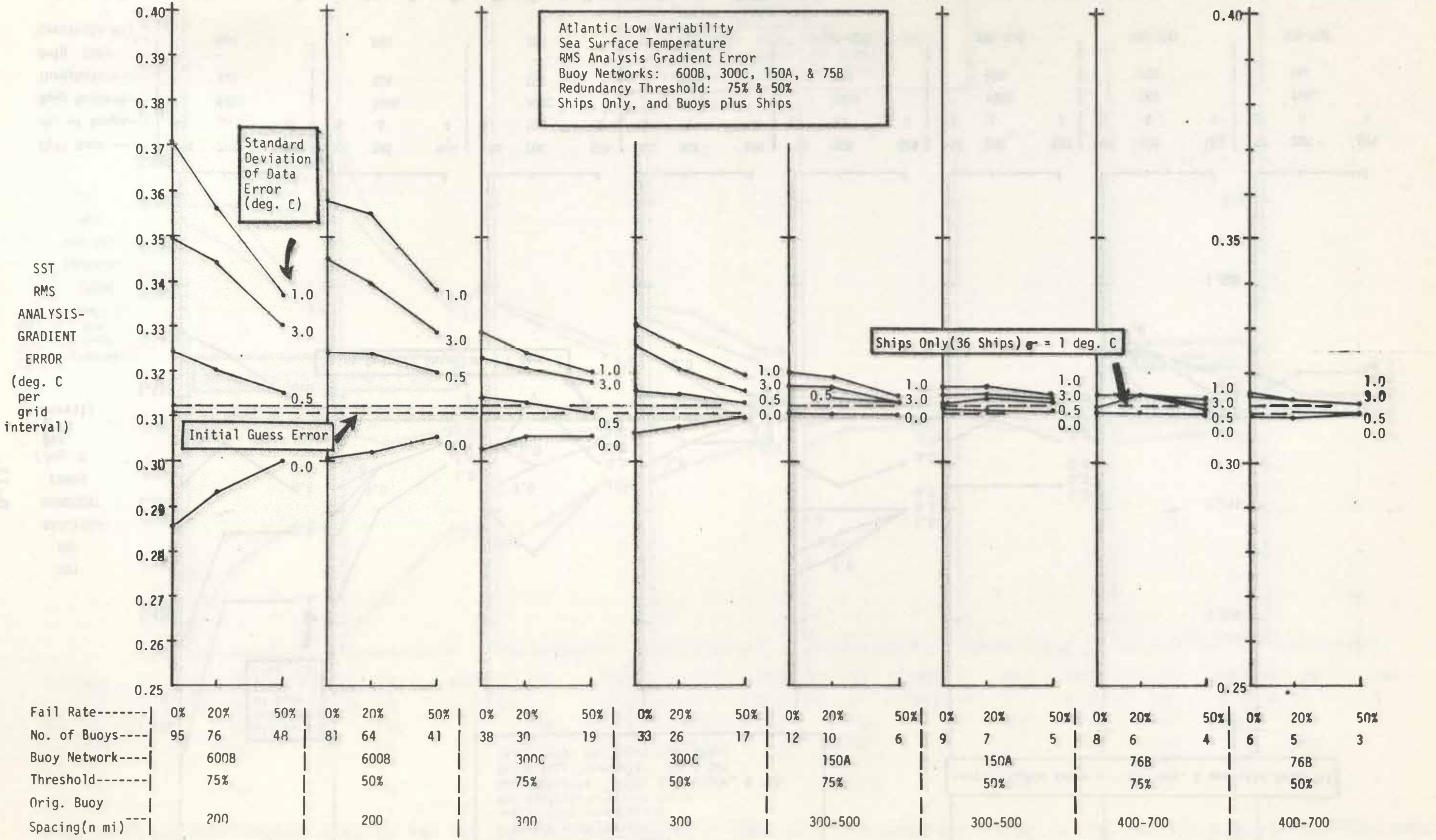

Fig. D-12. Experimental results for Sea Surface Temperature: RMS analysis gradient error in the Atlantic Low Variability area.

APPENDIX E

STUDY SUPPORT DOCUMENTATION IN THE FORM OF TRC/CEM DRAFT WORKING NOTES

APPENDIX E. STUDY SUPPORT DOCUMENTATION IN THE FORM OF TRC/CEM DRAFT WORKING NOTES

DRAFT WORKING NOTES					
Act. No.	Activity Subject	DWN No.	Title	Author	Date
1.b	Initial Detailed Program	150	A Typical Example of the Use of ANAL 68 in the Study of EM/SE	Thomasell	11/06/69
		154	Environmental Models/Systems Effectiveness (Initial Program Objectives and Procedures)	Thomasell	11/26/69
3.a	Prepare Final Detailed Program	165-3	Phase II Plan EM/SE Study (Revised)	Thomasell Clem Northrop	1/16/70
1.a	Literature Review	166	Bibliography from a Literature Survey of Published Articles Relevant to the EM/SE Study	Thomasell Clem Northrop	1/21/70
3.a	Prepare Final Detailed Program	167-1	Briefing Vu-Graphs for Summary Report on Phase II Plan for EM/SE Study	Thomasell Clem Northrop	1/16/70
		168	Summary of Phase I of a Study to Determine the Impact of Various Parameters and Parameter Characteristics on System Effectiveness, Using Environmental Numerical Analysis Models	Thomasell Clem Northrop	1/20/70
7	TRC Pilot Model Program	169	Graphical Results from Initial Pilot Model Program for the EM/SE Study	Thomasell	1/22/70
6	TRC Scale Resolution Study	201	Initial Scale Resolution Computations	Thomasell Welsh	1/19/70
4	Coordination with Hosts	204	Tentative Work Statement for Government Furnished Support to TRC for the EM/SE Study	Northrop	2/19/70

DRAFT WORKING NOTES (Continued)

Act. No.	Activity Subject	DWN No.	Title	Author	Date
7	TRC Pilot Model Program	202	Initial Pilot Model Computations	Thomasell	1/18/70
	Interim Report	210	First Interim Report of EM/SE Study	Thomasell	3/31/70
7	TRC Pilot Model Program	216	Some Additional Results of the TRC Pilot Model Study with Uniformly Distributed Data Networks	Thomasell	5/13/70
8	Measures of System Effectiveness	217	Measures of System Effectiveness in the EM/SE Study	Northrop Thomasell Davis	5/21/70
	EM/SE Study	218	Briefing Vue-Graphs: USCG/ Sperry/TRC Joint Working Meeting on System Effectiveness and Cost Effectiveness	Thomasell	5/21/70
		222	Second Interim Report for Phase II of the EM/SE Study	Thomasell Northrop	6/30/70
11	FNWC Experiments	236	Detailed Instructions for Computing Verification Statistics for the EM/SE Study	Thomasell	7/29/70
6 & 7	Scale Resolution & Pilot Model	232	Results of the EM/SE Scale Resolution and Pilot Model Program Studies	Thomasell Northrop	8/21/70
10	Buoy Network Data	237	Ten Postulated Buoy Networks	Thomasell Hattersley	9/ 8/70
11	FNWC Experiments	239	Verification Areas for EM/SE Experiment at FNWC	Thomasell	9/18/70
		242	Proposal for Initiation of Activity 16 and Associated Modifications of the EM/SE Study	Northrop Thomasell	10/20/70
		241	Third Interim Report for Phase II of the EM/SE Study	Thomasell	9/30/70

DRAFT WORKING NOTES (Continued)

Act. No.		DWN No.	Title	Author	Date
		253	Fourth Interim Report for Phase II of the EM/SE Study	Thomasell Northrop	12/ 1/70
16	Study of Ship Report Distribution	257	Study of Ship Report Distribution (Activity 16)	Thomasell	2/ 1/71
11.a	SLP Experiment at FNWC	256	Fifth Interim Report for Phase II of the EM/SE Study	Thomasell Northrop	2/ 1/71
		259	Proposal for Modifications of the EM/SE Study	Thomasell	3/ 1/71
15	Prepare Draft Final Report	265	Summary Briefing of Phase II of the Environmental Model/System Effectiveness Study	Thomasell Northrop	5/26/71
17	System Design	269	EM/SE Study: System Design Curves	Northrop	7/26/71
		279	Tentative Design Curves for Data Buoy Systems Based on Buoys-Only Data from the EM/SE Study	Northrop Sweeton Davis	9/10/71
		289	Outline and Sketches of Figures for the EM/SE Final Report	Northrop Sweeton Davis	11/ 2/71
		290	Effectiveness Scores and Data for Postulated Data Collection System	Northrop Davis	12/ 6/71

APPENDIX F

ADDITIONAL BUOY NETWORKS

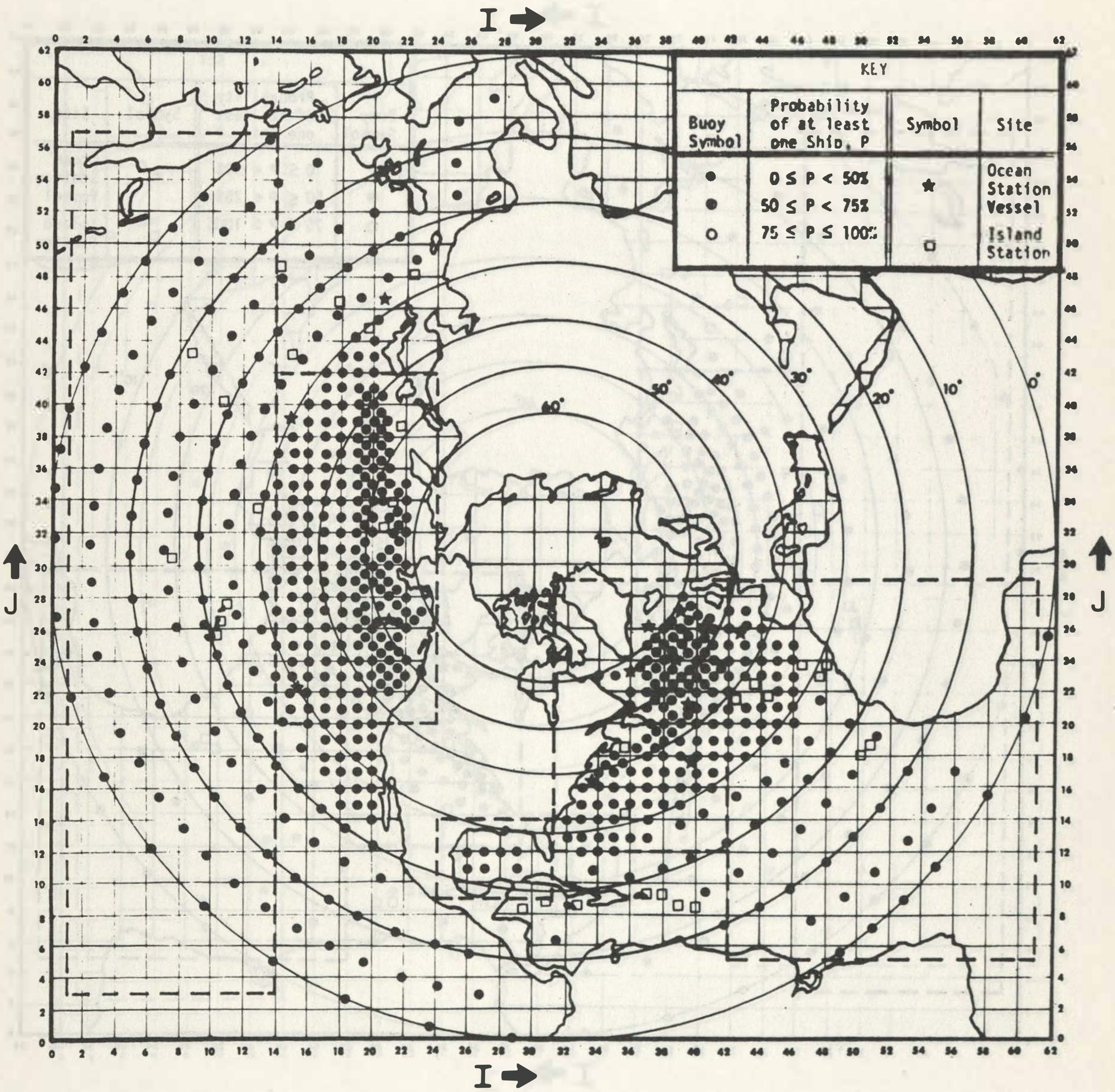

Fig. F-1. Postulated buoy network 600A.

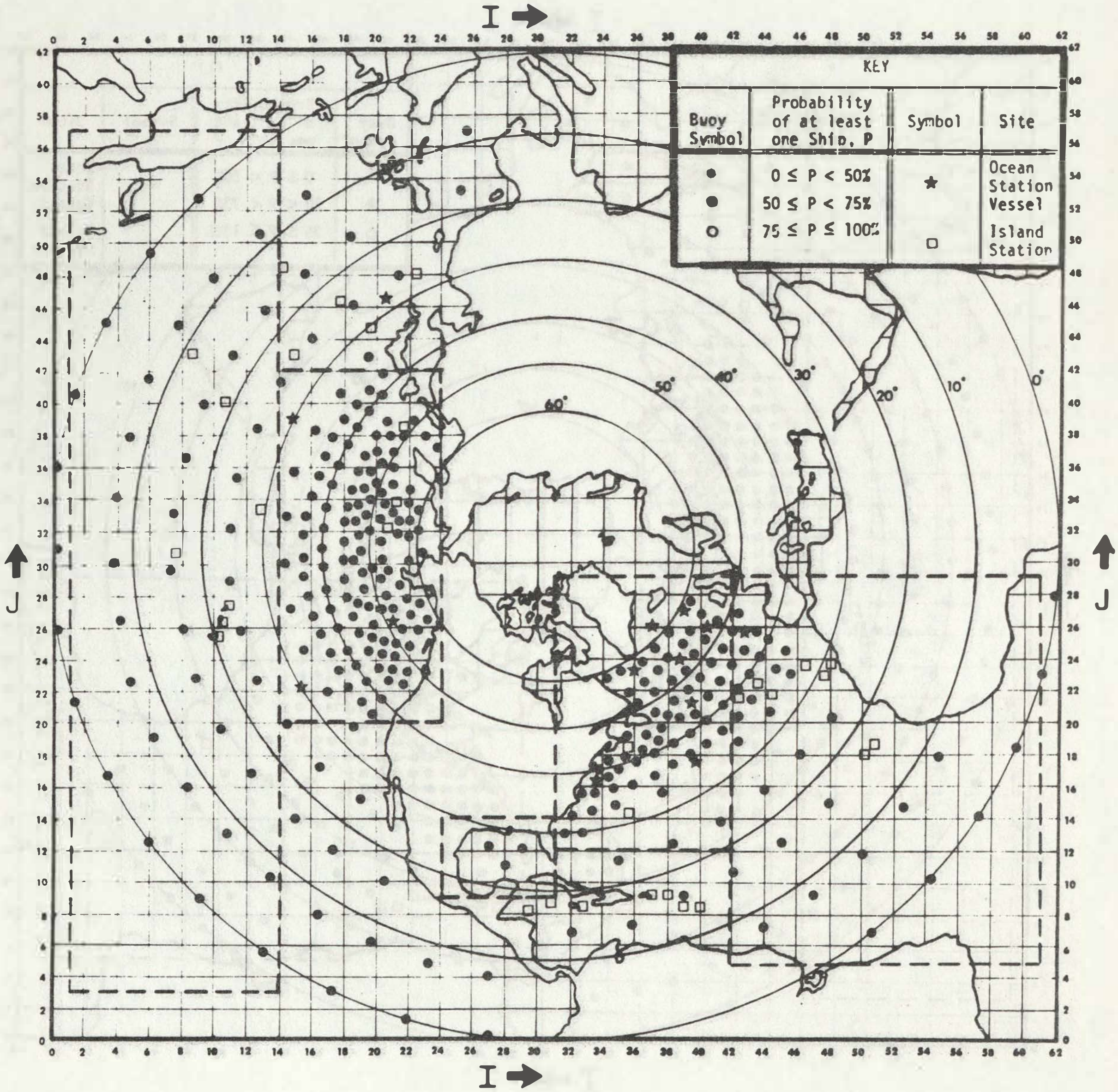

Fig. F-2. Postulated buoy network 300A.

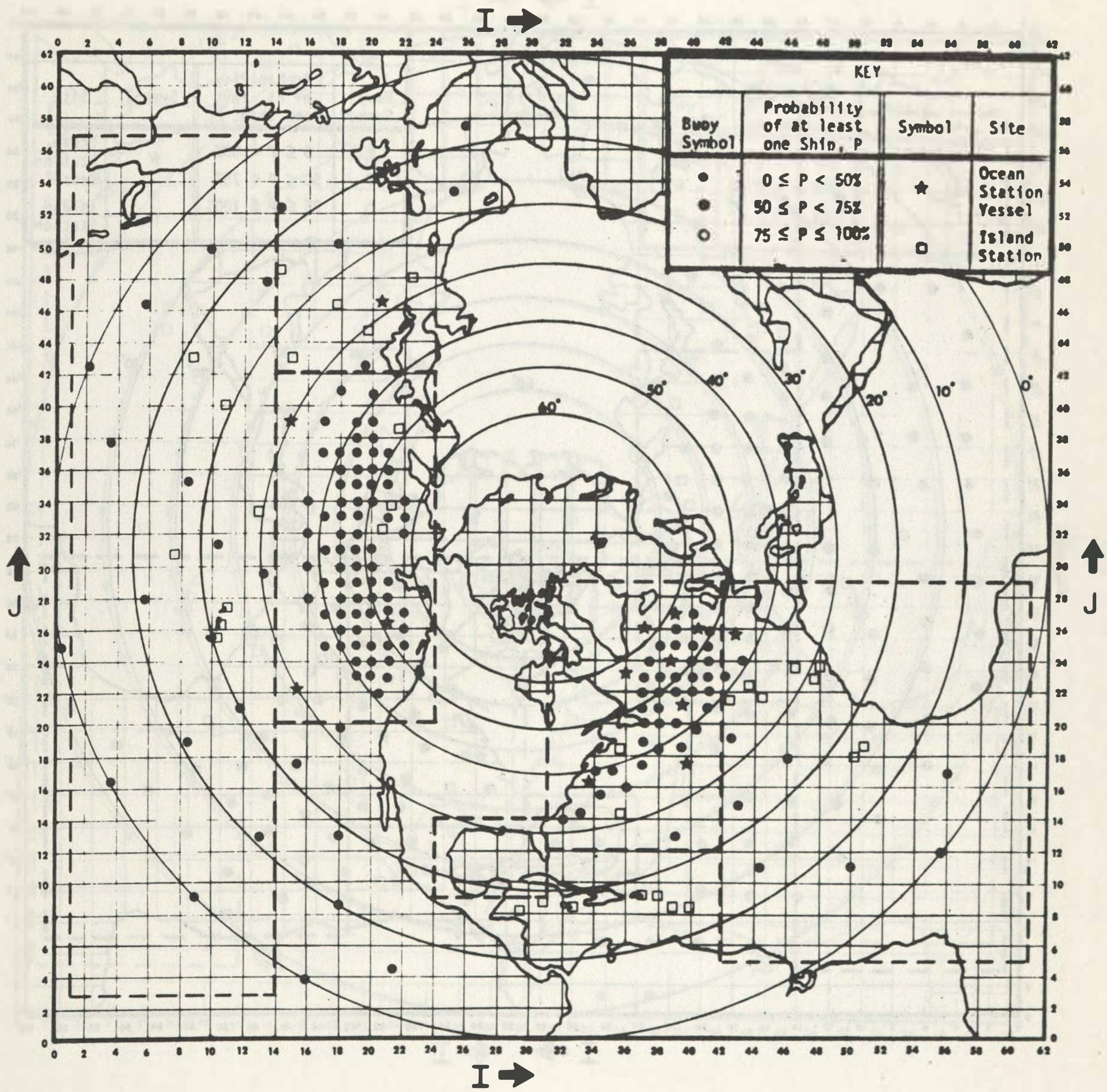

Fig. F-3. Postulated buoy network 150B.

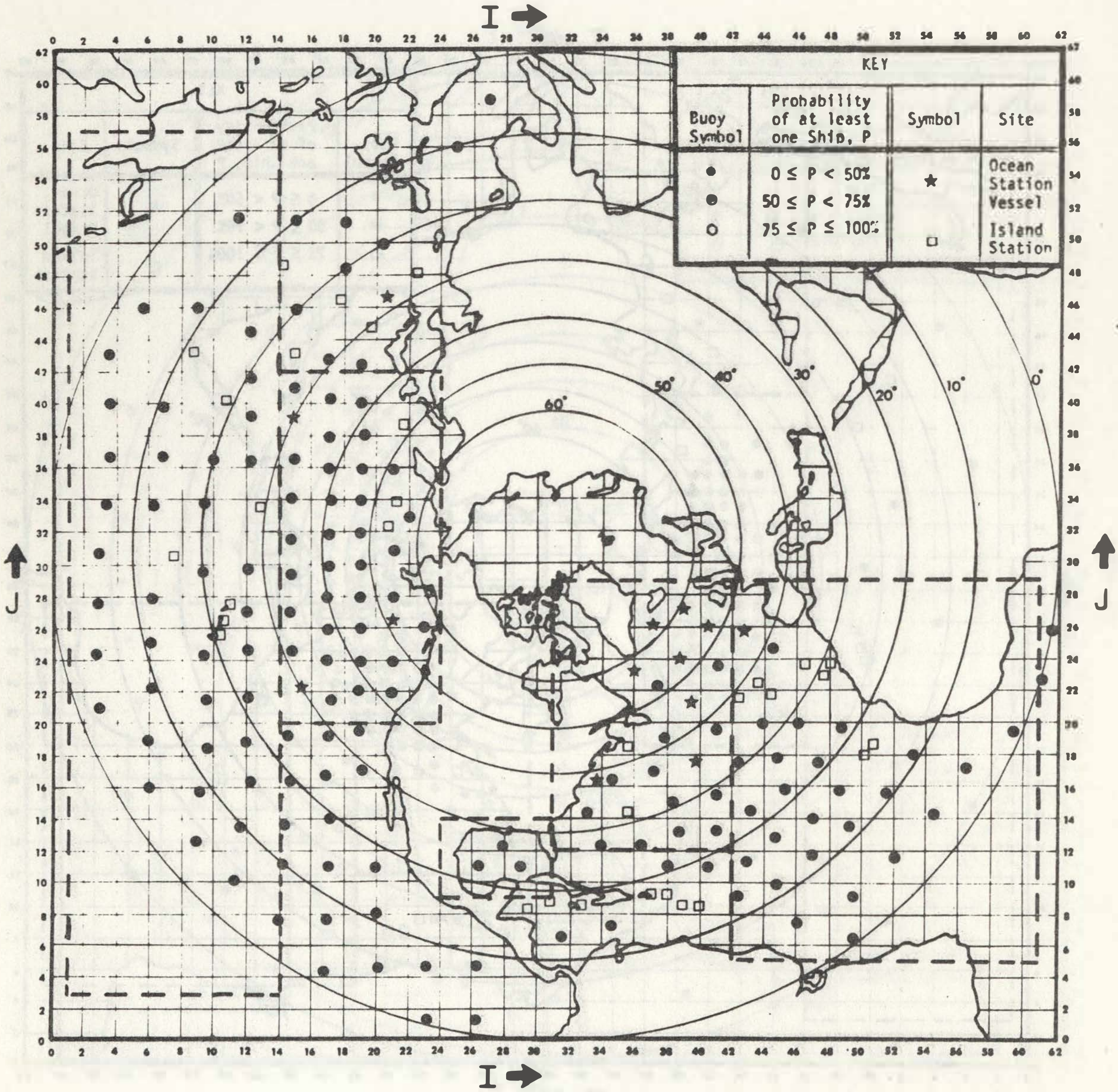

Fig. F-4. Postulated buoy network 150C.

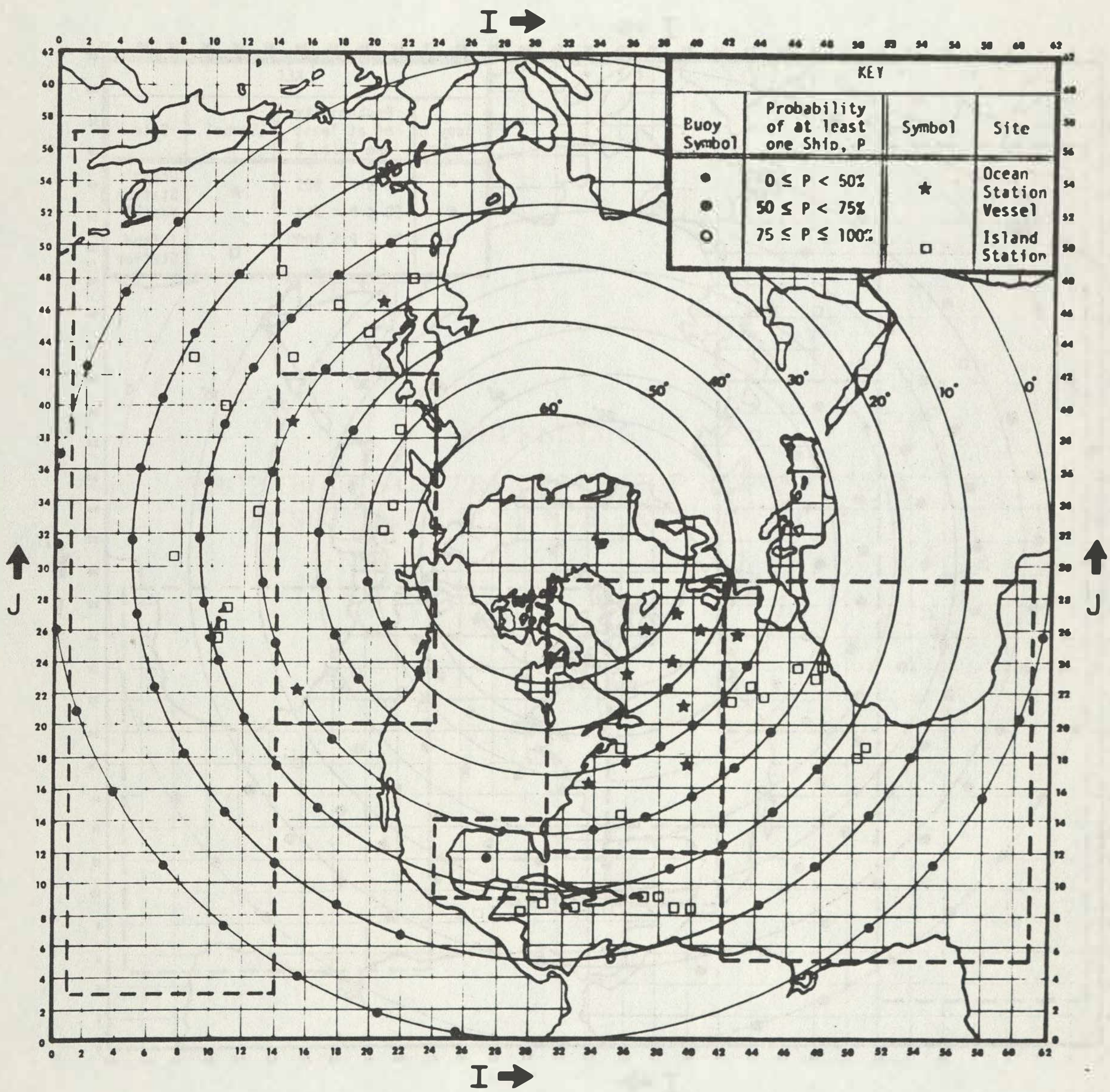

Fig. F-5. Postulated buoy network 76A.

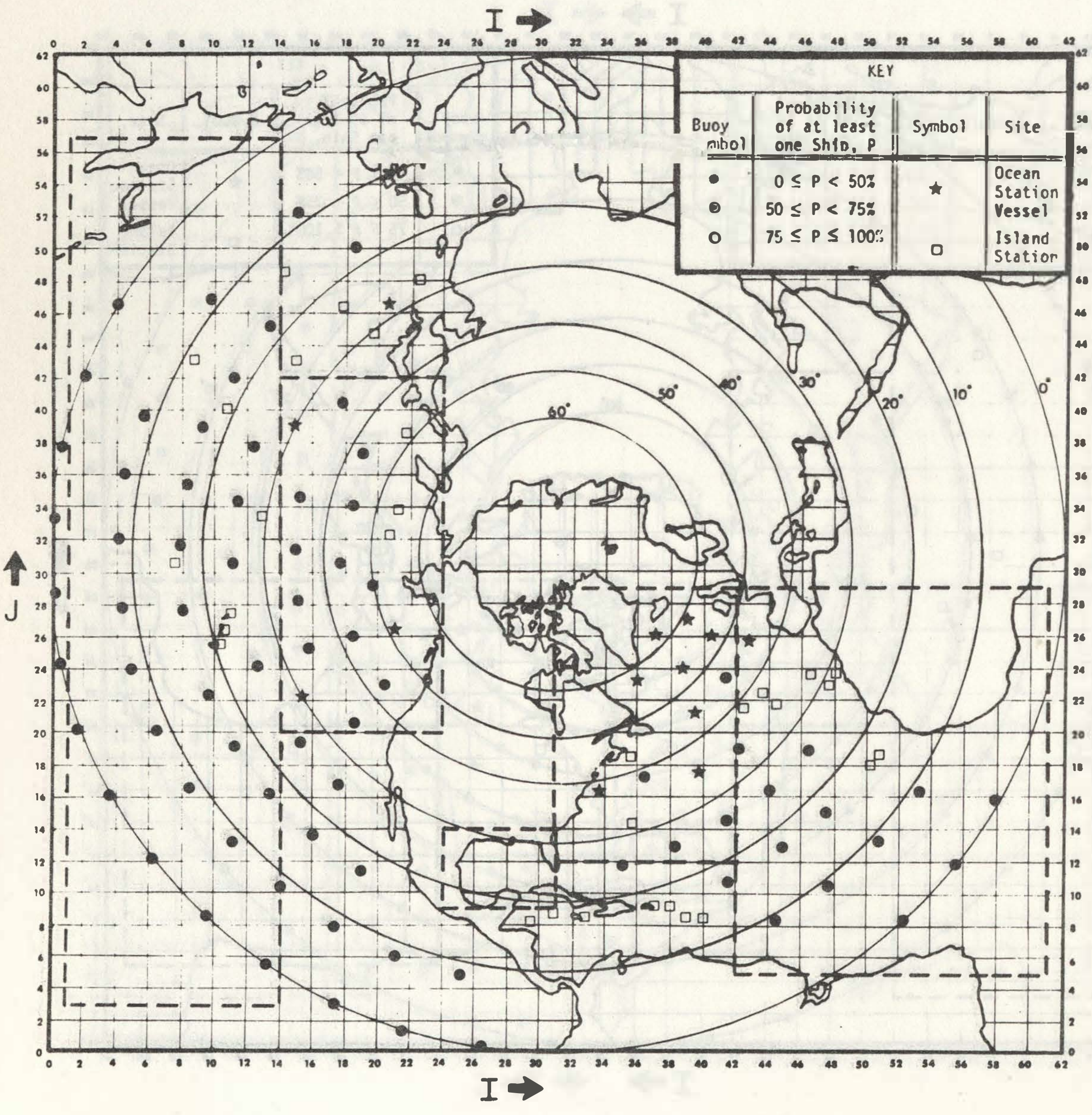

Fig. F-6. Postulated buoy network 76C.

APPENDIX G

PROBABILITY OF TRANSIENT SHIP REPORTS AS A FUNCTION OF DISTANCE BETWEEN SHIPS

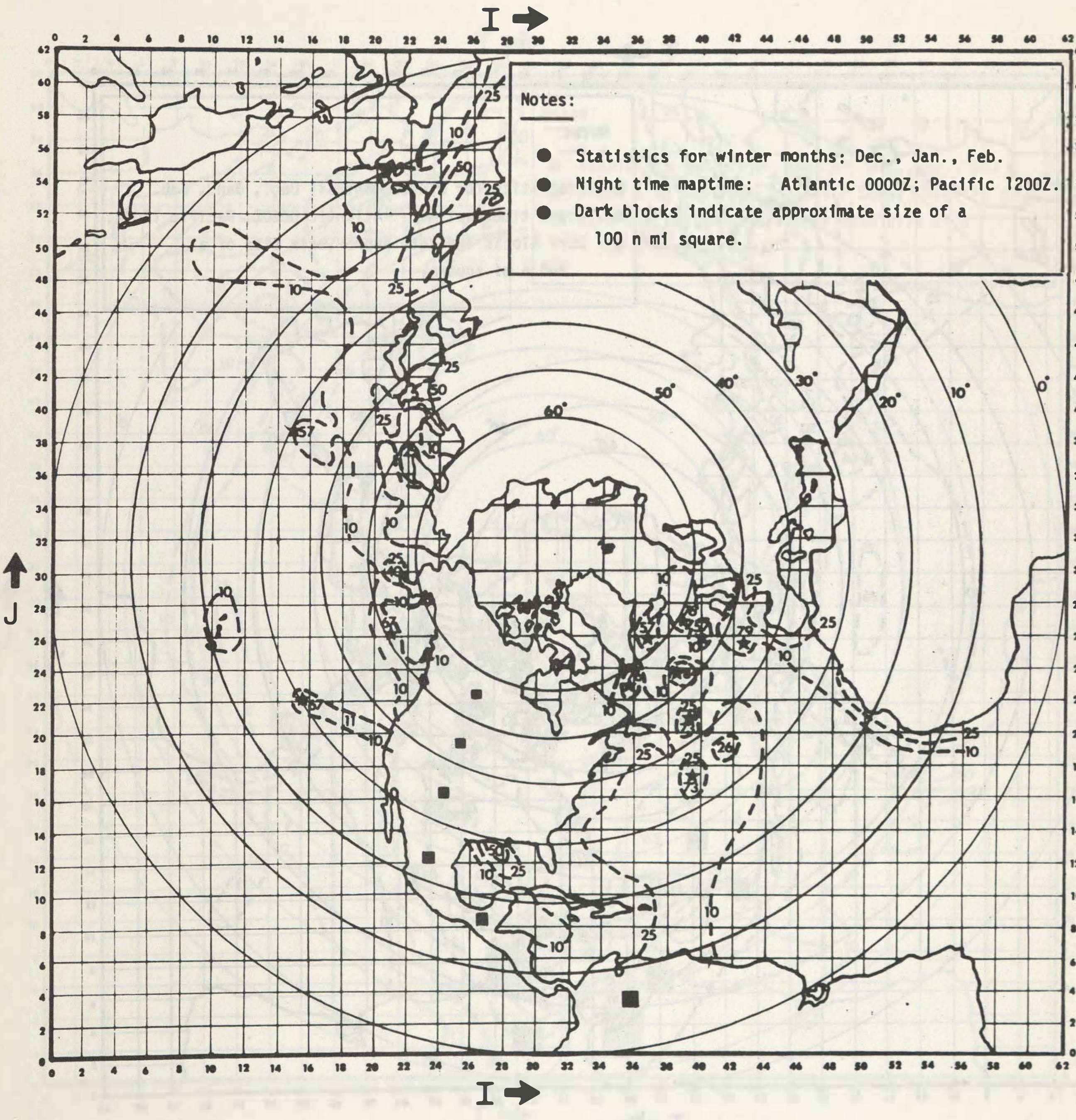

Fig. G-1. Probability of at least one ship in a 100 n mi square.

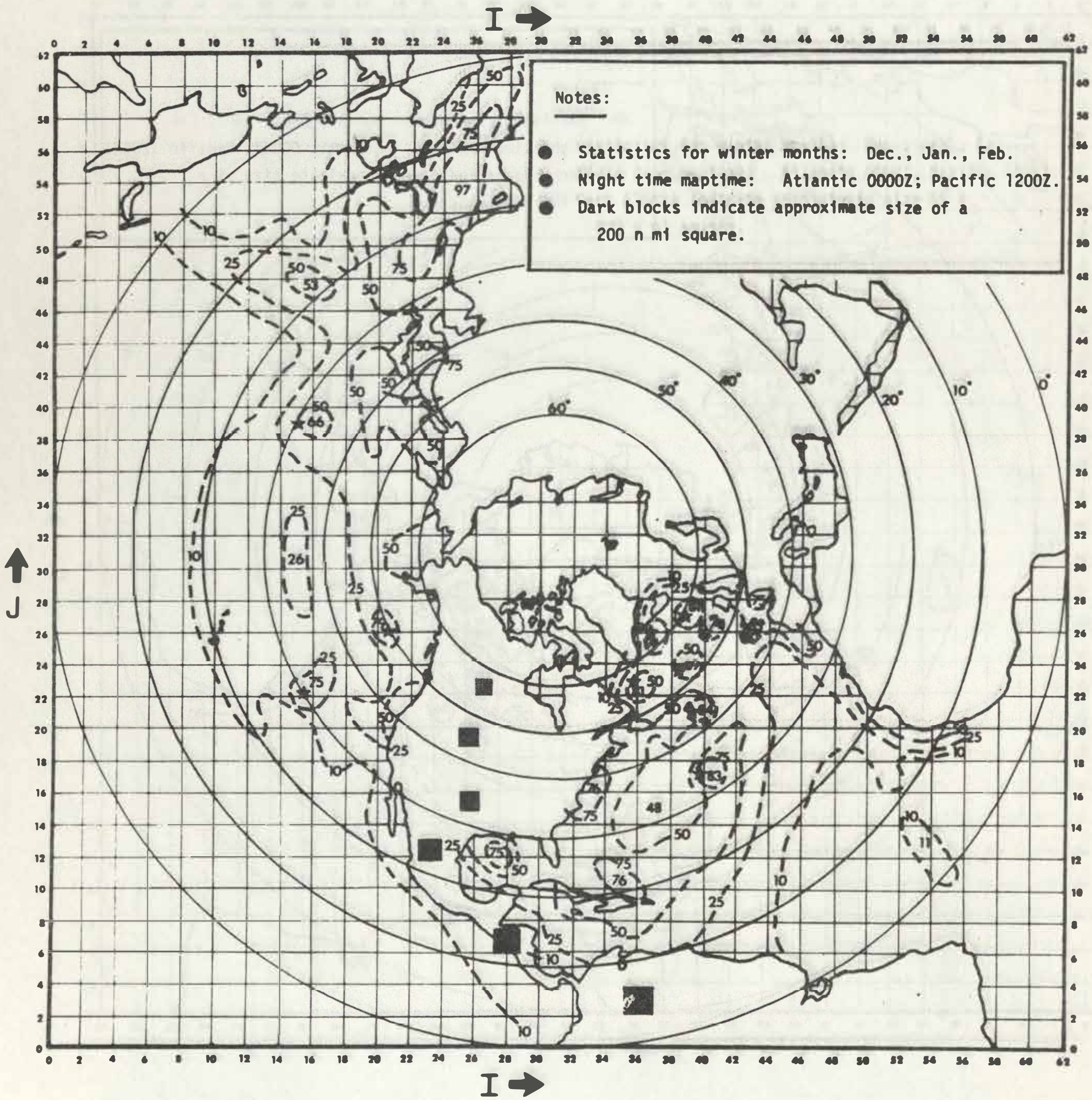

Fig. G-2. Probability of at least one ship in a 200 n mi square.

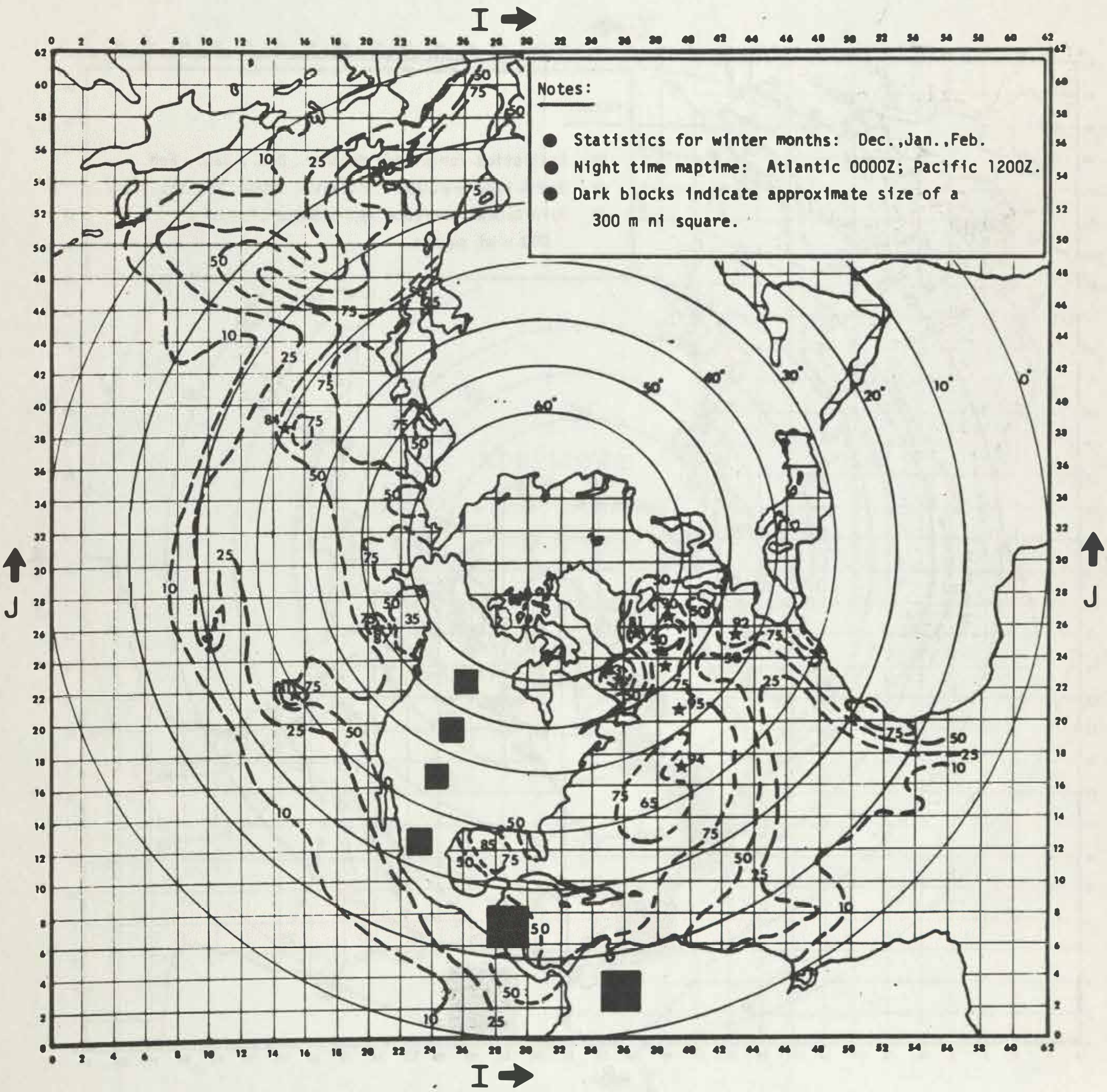

Fig. G-3. Probability of at least one ship in a 300 n mi square.

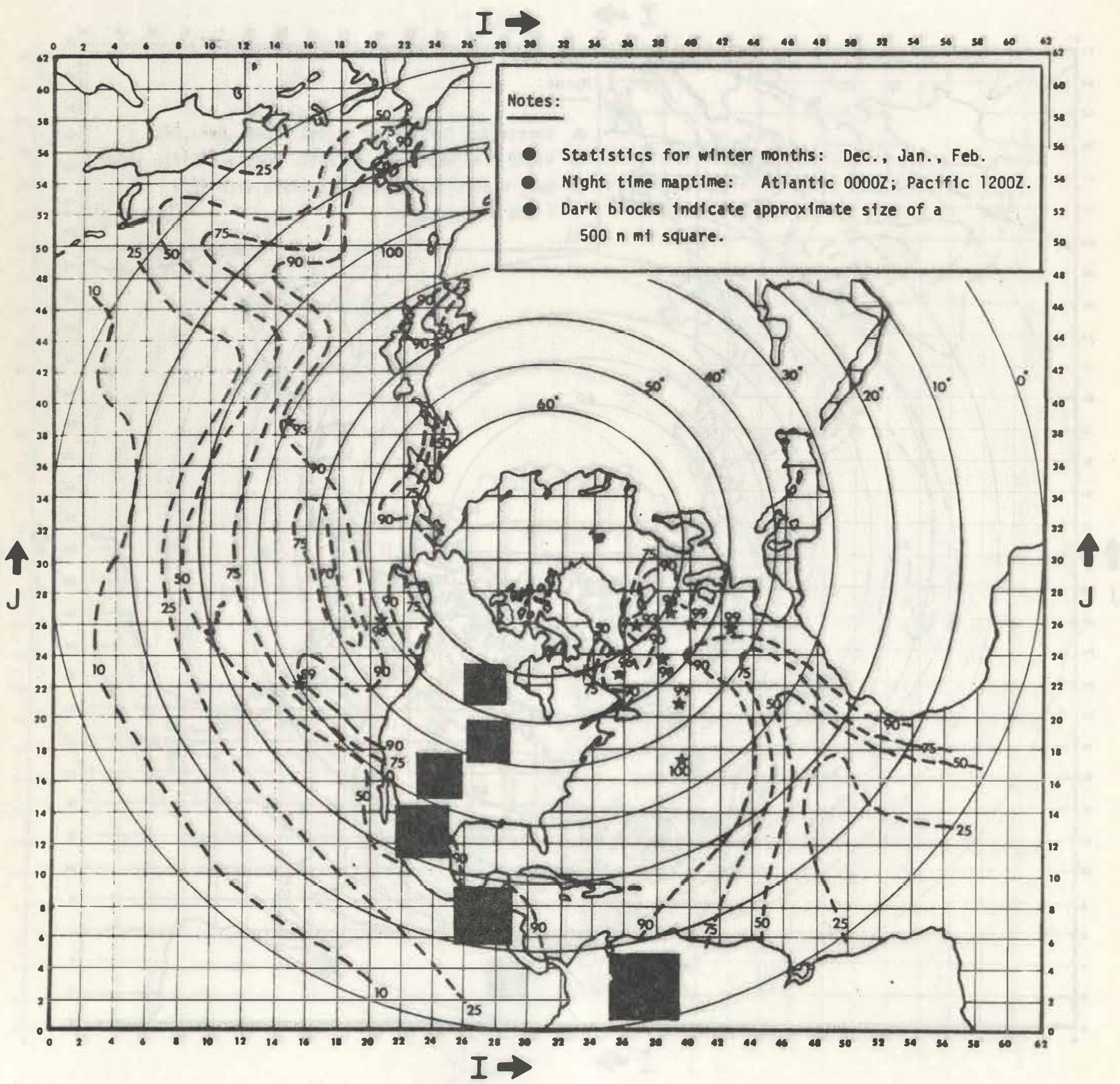

Fig. G-4. Pr›bability of at least one ship in a 500 n mi square.

APPENDIX H

EFFECTIVENESS SCORES FOR POSTULATED DATA COLLECTION SYSTEMS

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
20	100	0.0	0.0	0.0	0.60	0.28	0.56	0.42	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.0	0.01	0.60	0.28	0.56	0.42	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.0	0.10	0.60	0.28	0.56	0.42	0.50	0.68	0.68	0.70	0.13	0.12	0.08	0.13	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.0	1.00	0.60	0.28	0.56	0.42	0.50	0.68	0.68	0.70	0.09	0.04	0.08	0.04	0.40	0.33	0.44	0.39	0.39
20	100	0.0	0.1	0.0	0.60	0.28	0.56	0.42	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.1	0.01	0.60	0.28	0.56	0.42	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.1	0.10	0.60	0.29	0.56	0.42	0.50	0.67	0.67	0.69	0.13	0.12	0.08	0.13	0.41	0.36	0.44	0.42	0.41
20	100	0.0	0.1	1.00	0.60	0.28	0.56	0.42	0.50	0.67	0.67	0.69	0.09	0.04	0.08	0.04	0.40	0.33	0.44	0.39	0.39
20	100	0.0	0.5	0.0	0.60	0.28	0.56	0.42	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.43	0.41	0.40
20	100	0.0	0.5	0.01	0.60	0.28	0.56	0.42	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.43	0.41	0.40
20	100	0.0	0.5	0.10	0.60	0.28	0.56	0.42	0.48	0.65	0.64	0.67	0.13	0.12	0.08	0.13	0.40	0.35	0.43	0.41	0.40
20	100	0.0	0.5	1.00	0.60	0.28	0.56	0.42	0.48	0.65	0.64	0.67	0.09	0.04	0.08	0.04	0.39	0.32	0.43	0.38	0.38
20	100	0.0	1.0	0.0	0.60	0.28	0.56	0.42	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.40	0.34	0.41	0.40	0.39
20	100	0.0	1.0	0.01	0.60	0.28	0.56	0.42	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.40	0.34	0.41	0.40	0.39
20	100	0.0	1.0	0.10	0.60	0.28	0.56	0.42	0.47	0.62	0.60	0.64	0.13	0.12	0.08	0.13	0.40	0.34	0.41	0.40	0.39
20	100	0.0	1.0	1.00	0.60	0.28	0.56	0.42	0.47	0.62	0.60	0.64	0.09	0.04	0.08	0.04	0.39	0.31	0.41	0.37	0.37
20	100	0.1	0.0	0.0	0.60	0.28	0.56	0.41	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.1	0.0	0.01	0.60	0.28	0.56	0.41	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.42	0.41
20	100	0.1	0.0	0.10	0.60	0.28	0.56	0.41	0.50	0.68	0.68	0.70	0.13	0.12	0.08	0.13	0.41	0.36	0.44	0.41	0.41
20	100	0.1	0.0	1.00	0.60	0.28	0.56	0.41	0.50	0.68	0.68	0.70	0.09	0.04	0.08	0.04	0.40	0.33	0.44	0.38	0.39
20	100	0.1	0.1	0.0	0.60	0.28	0.56	0.41	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.41	0.41
20	100	0.1	0.1	0.01	0.60	0.28	0.56	0.41	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.44	0.41	0.41
20	100	0.1	0.1	0.10	0.60	0.28	0.56	0.41	0.50	0.67	0.67	0.69	0.13	0.12	0.08	0.13	0.41	0.36	0.44	0.41	0.40
20	100	0.1	0.1	1.00	0.60	0.28	0.56	0.41	0.50	0.67	0.67	0.69	0.09	0.04	0.08	0.04	0.40	0.33	0.44	0.38	0.39
20	100	0.1	0.5	0.0	0.60	0.28	0.56	0.41	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.43	0.41	0.40
20	100	0.1	0.5	0.01	0.60	0.28	0.56	0.41	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.43	0.41	0.40
20	100	0.1	0.5	0.10	0.60	0.28	0.56	0.41	0.48	0.65	0.64	0.67	0.13	0.12	0.08	0.13	0.41	0.35	0.43	0.40	0.40
20	100	0.1	0.5	1.00	0.60	0.28	0.56	0.41	0.48	0.65	0.64	0.67	0.09	0.04	0.08	0.04	0.39	0.32	0.43	0.37	0.38
20	100	0.1	1.0	0.0	0.60	0.28	0.56	0.41	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.40	0.34	0.41	0.40	0.39
20	100	0.1	1.0	0.01	0.60	0.28	0.56	0.41	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.40	0.34	0.41	0.40	0.39
20	100	0.1	1.0	0.10	0.60	0.28	0.56	0.41	0.47	0.62	0.60	0.64	0.13	0.12	0.08	0.13	0.40	0.34	0.41	0.39	0.39
20	100	0.1	1.0	1.00	0.60	0.28	0.56	0.41	0.47	0.62	0.60	0.64	0.09	0.04	0.08	0.04	0.39	0.31	0.41	0.36	0.37
20	100	0.5	0.0	0.0	0.61	0.26	0.54	0.35	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.42	0.36	0.43	0.40	0.40
20	100	0.5	0.0	0.01	0.61	0.26	0.54	0.35	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.42	0.36	0.43	0.40	0.40
20	100	0.5	0.0	0.10	0.61	0.26	0.54	0.35	0.50	0.68	0.68	0.70	0.13	0.12	0.08	0.13	0.41	0.36	0.43	0.39	0.40
20	100	0.5	0.0	1.00	0.61	0.26	0.54	0.35	0.50	0.68	0.68	0.70	0.09	0.04	0.08	0.04	0.40	0.33	0.43	0.36	0.38
20	100	0.5	0.1	0.0	0.61	0.26	0.54	0.35	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.43	0.40	0.40
20	100	0.5	0.1	0.01	0.61	0.26	0.54	0.35	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.41	0.36	0.43	0.40	0.40
20	100	0.5	0.1	0.10	0.61	0.26	0.54	0.35	0.50	0.67	0.67	0.69	0.13	0.12	0.08	0.13	0.41	0.35	0.43	0.39	0.40
20	100	0.5	0.1	1.00	0.61	0.26	0.54	0.35	0.50	0.67	0.67	0.69	0.09	0.04	0.08	0.04	0.40	0.33	0.43	0.36	0.38
20	100	0.5	0.5	0.0	0.61	0.26	0.54	0.35	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.42	0.39	0.39
20	100	0.5	0.5	0.01	0.61	0.26	0.54	0.35	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.41	0.35	0.42	0.39	0.39
20	100	0.5	0.5	0.10	0.61	0.26	0.54	0.35	0.48	0.65	0.64	0.67	0.13	0.12	0.08	0.13	0.41	0.35	0.42	0.38	0.39
20	100	0.5	0.5	1.00	0.61	0.26	0.54	0.35	0.48	0.65	0.64	0.67	0.09	0.04	0.08	0.04	0.40	0.32	0.42	0.35	0.37
20	100	0.5	1.0	0.0	0.61	0.26	0.54	0.35	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.41	0.34	0.41	0.38	0.38
20	100	0.5	1.0	0.01	0.61	0.26	0.54	0.35	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.41	0.34	0.41	0.38	0.38
20	100	0.5	1.0	0.10	0.61	0.26	0.54	0.35	0.47	0.62	0.60	0.64	0.13	0.12	0.08	0.13	0.40	0.34	0.41	0.37	0.38
20	100	0.5	1.0	1.00	0.61	0.26	0.54	0.35	0.47	0.62	0.60	0.64	0.09	0.04	0.08	0.04	0.39	0.31	0.41	0.34	0.36
20	100	1.0	0.0	0.0	0.63	0.25	0.52	0.28	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.42	0.35	0.43	0.37	0.40
20	100	1.0	0.0	0.01	0.63	0.25	0.52	0.28	0.50	0.68	0.68	0.70	0.13	0.13	0.08	0.14	0.42	0.35	0.43	0.37	0.40
20	100	1.0	0.0	0.10	0.63	0.25	0.52	0.29	0.50	0.68	0.68	0.70	0.13	0.12	0.08	0.13	0.42	0.35	0.43	0.37	0.39
20	100	1.0	0.0	1.00	0.63	0.25	0.52	0.28	0.50	0.68	0.68	0.70	0.09	0.04	0.08	0.04	0.41	0.32	0.43	0.34	0.38
20	100	1.0	0.1	0.0	0.63	0.25	0.52	0.28	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.42	0.35	0.42	0.37	0.39
20	100	1.0	0.1	0.01	0.63	0.25	0.52	0.28	0.50	0.67	0.67	0.69	0.13	0.13	0.08	0.14	0.42	0.35	0.42	0.37	0.39
20	100	1.0	0.1	0.10	0.63	0.25	0.52	0.28	0.50	0.67	0.67	0.69	0.13	0.12	0.08	0.13	0.42	0.35	0.42	0.37	0.39
20	100	1.0	0.1	1.00	0.63	0.25	0.52	0.28	0.50	0.67	0.67	0.69	0.09	0.04	0.08	0.04	0.41	0.32	0.42	0.34	0.37
20	100	1.0	0.5	0.0	0.63	0.25	0.52	0.28	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.42	0.34	0.41	0.36	0.39
20	100	1.0	0.5	0.01	0.63	0.25	0.52	0.28	0.48	0.65	0.64	0.67	0.13	0.13	0.08	0.14	0.42	0.34	0.41	0.36	0.39
20	100	1.0	0.5	0.10	0.63	0.25	0.52	0.28	0.48	0.65	0.64	0.67	0.13	0.12	0.08	0.13	0.41	0.34	0.41	0.36	0.38
20	100	1.0	0.5	1.00	0.63	0.25	0.52	0.28	0.48	0.65	0.64	0.67	0.09	0.04	0.08	0.04	0.40	0.31	0.41	0.33	0.37
20	100	1.0	1.0	0.0	0.63	0.25	0.52	0.28	0.47	0.62	0.60	0.64	0.13	0.13	0.08	0.14	0.41	0.33	0.40	0.35	0.38
20	100	1.0	1.0	0.01	0.63	0.25	0.52	0.29	0.47	0.62	0.60	0.64	0.13	0.13	0.09	0.14	0.41	0.33	0.40	0.35	0.38
20	100	1.0	1.0	0.10	0.63	0.25	0.52	0.28	0.47	0.62	0.60	0.64	0.13	0.12	0.09	0.13	0.41	0.33	0.40	0.35	0.37
20	100	1.0	1.0	1.00	0.63	0.25	0.52	0.28	0.47	0.62	0.60	0.64	0.09	0.04	0.09	0.04	0.40	0.30	0.40	0.32	0.36

Buoys per Area	Relia-bility (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
20	80	0.0	0.0	0.0	0.55	0.25	0.48	0.35	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	60	0.0	0.0	0.01	0.55	0.25	0.48	0.35	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	80	0.0	0.0	0.10	0.55	0.25	0.48	0.35	0.44	0.64	0.61	0.66	0.10	0.06	0.07	0.10	0.37	0.32	0.39	0.37	0.36
20	80	0.0	0.0	1.00	0.55	0.25	0.48	0.35	0.44	0.64	0.61	0.66	0.06	0.03	0.05	0.05	0.35	0.31	0.38	0.35	0.35
20	80	0.0	0.1	0.0	0.55	0.25	0.48	0.35	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	80	0.0	0.1	0.01	0.55	0.25	0.48	0.35	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	80	0.0	0.1	0.10	0.55	0.25	0.48	0.35	0.44	0.63	0.60	0.66	0.10	0.06	0.07	0.10	0.37	0.31	0.39	0.37	0.36
20	80	0.0	0.1	1.00	0.55	0.25	0.48	0.35	0.44	0.63	0.60	0.66	0.06	0.03	0.05	0.05	0.35	0.31	0.38	0.35	0.35
20	80	0.0	0.5	0.0	0.55	0.25	0.48	0.35	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.31	0.38	0.37	0.36
20	80	0.0	0.5	0.01	0.55	0.25	0.48	0.35	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.31	0.38	0.37	0.36
20	80	0.0	0.5	0.10	0.55	0.25	0.48	0.35	0.43	0.61	0.58	0.64	0.10	0.06	0.07	0.10	0.36	0.31	0.38	0.37	0.360
20	80	0.0	0.5	1.00	0.55	0.25	0.48	0.35	0.43	0.61	0.58	0.64	0.06	0.03	0.05	0.05	0.35	0.30	0.37	0.35	0.34
20	80	0.0	1.0	0.0	0.55	0.25	0.48	0.35	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.36	0.35
20	80	0.0	1.0	0.01	0.55	0.25	0.48	0.35	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.36	0.35
20	80	0.0	1.0	0.10	0.55	0.25	0.48	0.35	0.43	0.59	0.56	0.63	0.10	0.06	0.07	0.10	0.36	0.30	0.37	0.36	0.35
20	80	0.0	1.0	1.00	0.55	0.25	0.48	0.35	0.43	0.59	0.56	0.63	0.06	0.03	0.05	0.05	0.35	0.29	0.36	0.34	0.34
20	80	0.1	0.0	0.0	0.55	0.25	0.48	0.34	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	80	0.1	0.0	0.01	0.55	0.25	0.48	0.34	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.32	0.39	0.37	0.36
20	80	0.1	0.0	0.10	0.55	0.25	0.48	0.34	0.44	0.64	0.61	0.66	0.10	0.06	0.07	0.10	0.37	0.32	0.39	0.37	0.36
20	80	0.1	0.0	1.00	0.55	0.25	0.48	0.34	0.44	0.64	0.61	0.66	0.06	0.03	0.05	0.05	0.35	0.31	0.38	0.35	0.35
20	80	0.1	0.1	0.0	0.55	0.25	0.48	0.34	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.37	0.36
20	80	0.1	0.1	0.01	0.55	0.25	0.48	0.34	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.37	0.36
20	80	0.1	0.1	0.10	0.55	0.25	0.48	0.34	0.44	0.63	0.60	0.66	0.10	0.06	0.07	0.10	0.37	0.31	0.39	0.37	0.36
20	80	0.1	0.1	1.00	0.55	0.25	0.48	0.34	0.44	0.63	0.60	0.66	0.06	0.03	0.05	0.05	0.35	0.30	0.38	0.35	0.35
20	80	0.1	0.5	0.0	0.55	0.25	0.48	0.34	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.31	0.38	0.37	0.36
20	80	0.1	0.5	0.01	0.55	0.25	0.48	0.34	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.31	0.38	0.37	0.36
20	80	0.1	0.5	0.10	0.55	0.25	0.48	0.34	0.43	0.61	0.58	0.64	0.10	0.06	0.07	0.10	0.36	0.31	0.38	0.36	0.35
20	80	0.1	0.5	1.00	0.55	0.25	0.48	0.34	0.43	0.61	0.58	0.64	0.06	0.03	0.05	0.05	0.35	0.30	0.37	0.35	0.34
20	80	0.1	1.0	0.0	0.55	0.25	0.48	0.34	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.36	0.35
20	80	0.1	1.0	0.01	0.55	0.25	0.48	0.34	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.36	0.35
20	80	0.1	1.0	0.10	0.55	0.25	0.48	0.34	0.43	0.59	0.56	0.63	0.10	0.06	0.07	0.10	0.36	0.30	0.37	0.36	0.35
20	80	0.1	1.0	1.00	0.55	0.25	0.48	0.34	0.43	0.59	0.56	0.63	0.06	0.03	0.05	0.05	0.35	0.29	0.36	0.34	0.34
20	80	0.5	0.0	0.0	0.55	0.23	0.48	0.30	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.36	0.36
20	80	0.5	0.0	0.01	0.55	0.23	0.48	0.30	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.36	0.36
20	80	0.5	0.0	0.10	0.55	0.23	0.48	0.30	0.44	0.64	0.61	0.66	0.10	0.06	0.07	0.10	0.37	0.31	0.39	0.36	0.36
20	80	0.5	0.0	1.00	0.55	0.23	0.48	0.30	0.44	0.64	0.61	0.66	0.06	0.03	0.05	0.05	0.35	0.30	0.38	0.34	0.34
20	80	0.5	0.1	0.0	0.55	0.23	0.48	0.30	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.36	0.36
20	80	0.5	0.1	0.01	0.55	0.23	0.48	0.30	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.36	0.36
20	80	0.5	0.1	0.10	0.55	0.23	0.48	0.30	0.44	0.63	0.60	0.66	0.10	0.06	0.07	0.10	0.37	0.31	0.39	0.35	0.35
20	80	0.5	0.1	1.00	0.55	0.23	0.48	0.30	0.44	0.63	0.60	0.66	0.06	0.03	0.05	0.05	0.35	0.30	0.38	0.34	0.34
20	80	0.5	0.5	0.0	0.55	0.23	0.48	0.30	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.30	0.38	0.35	0.35
20	80	0.5	0.5	0.01	0.55	0.23	0.48	0.30	0.43	0.61	0.58	0.64	0.11	0.06	0.07	0.11	0.37	0.30	0.38	0.35	0.35
20	80	0.5	0.5	0.10	0.55	0.23	0.48	0.30	0.43	0.61	0.58	0.64	0.10	0.06	0.07	0.10	0.36	0.30	0.38	0.35	0.35
20	80	0.5	0.5	1.00	0.55	0.23	0.48	0.30	0.43	0.61	0.58	0.64	0.06	0.03	0.05	0.05	0.35	0.29	0.37	0.33	0.34
20	80	0.5	1.0	0.0	0.55	0.23	0.48	0.30	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.35	0.35
20	80	0.5	1.0	0.01	0.55	0.23	0.48	0.30	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.30	0.37	0.35	0.35
20	80	0.5	1.0	0.10	0.55	0.23	0.48	0.30	0.43	0.59	0.56	0.63	0.10	0.06	0.07	0.10	0.36	0.29	0.37	0.35	0.34
20	80	0.5	1.0	1.00	0.55	0.23	0.48	0.30	0.43	0.59	0.56	0.63	0.06	0.03	0.05	0.05	0.35	0.29	0.36	0.33	0.33
20	80	1.0	0.0	0.0	0.55	0.22	0.48	0.25	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.34	0.350
20	80	1.0	0.0	0.01	0.55	0.22	0.48	0.25	0.44	0.64	0.61	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.34	0.35
20	80	1.0	0.0	0.10	0.55	0.22	0.48	0.25	0.44	0.64	0.61	0.66	0.10	0.06	0.07	0.10	0.37	0.31	0.39	0.34	0.35
20	80	1.0	0.0	1.00	0.55	0.22	0.48	0.25	0.44	0.64	0.61	0.66	0.06	0.03	0.05	0.05	0.35	0.30	0.38	0.32	0.340
20	80	1.0	0.1	0.0	0.55	0.22	0.48	0.25	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.34	0.35
20	80	1.0	0.1	0.01	0.55	0.22	0.48	0.25	0.44	0.63	0.60	0.66	0.11	0.06	0.07	0.11	0.37	0.31	0.39	0.34	0.35
20	80	1.0	0.1	0.10	0.55	0.22	0.48	0.25	0.44	0.63	0.60	0.66	0.10	0.06	0.07	0.10	0.37	0.30	0.39	0.34	0.35
20	80	1.0	0.1	1.00	0.55	0.22	0.48	0.25	0.44	0.63	0.60	0.66	0.06	0.03	0.05	0.05	0.35	0.30	0.38	0.32	0.34
20	80	1.0	0.5	0.0	0.55	0.22	0.48	0.25	0.43	0.61	0.58	0.640	0.11	0.06	0.07	0.11	0.37	0.30	0.38	0.34	0.35
20	80	1.0	0.5	0.01	0.55	0.22	0.48	0.25	0.43	0.61	0.59	0.64	0.11	0.06	0.07	0.11	0.37	0.30	0.38	0.34	0.350
20	80	1.0	0.5	0.10	0.55	0.22	0.48	0.25	0.43	0.61	0.58	0.64	0.10	0.06	0.07	0.10	0.36	0.30	0.38	0.33	0.34
20	80	1.0	0.5	1.00	0.55	0.22	0.48	0.25	0.43	0.61	0.58	0.64	0.06	0.03	0.05	0.05	0.35	0.29	0.37	0.32	0.33
20	80	1.0	1.0	0.0	0.55	0.220	0.48	0.25	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.29	0.37	0.33	0.34
20	80	1.0	1.0	0.01	0.55	0.22	0.48	0.25	0.43	0.59	0.56	0.63	0.11	0.06	0.07	0.11	0.36	0.29	0.37	0.33	0.34
20	80	1.0	1.0	0.10	0.55	0.22	0.48	0.25	0.43	0.59	0.56	0.63	0.10	0.06	0.07	0.10	0.36	0.29	0.37	0.33	0.34
20	80	1.0	1.0	1.00	0.55	0.22	0.48	0.25	0.43	0.59	0.56	0.63	0.06	0.03	0.05	0.05	0.35	0.28	0.36	0.31	0.33

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
20	50	0.0	0.0	0.0	0.48	0.20	0.37	0.27	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.0	0.01	0.48	0.20	0.37	0.27	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.0	0.10	0.48	0.20	0.37	0.27	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.0	1.00	0.48	0.20	0.37	0.27	0.39	0.61	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.28	0.32	0.30	0.30
20	50	0.0	0.1	0.0	0.48	0.20	0.37	0.27	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.1	0.01	0.48	0.20	0.37	0.27	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.1	0.10	0.48	0.20	0.37	0.27	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.1	1.00	0.48	0.20	0.37	0.27	0.39	0.60	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.28	0.32	0.30	0.30
20	50	0.0	0.5	0.0	0.48	0.20	0.37	0.27	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.5	0.01	0.48	0.20	0.37	0.27	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.5	0.10	0.48	0.20	0.37	0.27	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.32	0.31
20	50	0.0	0.5	1.00	0.48	0.20	0.37	0.27	0.38	0.58	0.53	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.31	0.30	0.30
20	50	0.0	1.0	0.0	0.48	0.20	0.37	0.27	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.32	0.30
20	50	0.0	1.0	0.01	0.48	0.20	0.37	0.27	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.32	0.30
20	50	0.0	1.0	0.10	0.48	0.20	0.37	0.27	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.08	0.31	0.27	0.32	0.32	0.30
20	50	0.0	1.0	1.00	0.48	0.20	0.37	0.27	0.37	0.56	0.52	0.59	0.04	0.02	0.04	0.04	0.30	0.26	0.31	0.30	0.29
20	50	0.1	0.0	0.0	0.48	0.20	0.37	0.26	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.0	0.01	0.48	0.20	0.37	0.26	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.0	0.10	0.48	0.20	0.37	0.26	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.31	0.31
20	50	0.1	0.0	1.00	0.48	0.20	0.37	0.26	0.39	0.61	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.28	0.32	0.30	0.30
20	50	0.1	0.1	0.0	0.48	0.20	0.37	0.26	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.1	0.01	0.48	0.20	0.37	0.26	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.1	0.10	0.48	0.20	0.37	0.26	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.31	0.31
20	50	0.1	0.1	1.00	0.48	0.20	0.37	0.26	0.39	0.60	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.28	0.32	0.30	0.30
20	50	0.1	0.5	0.0	0.48	0.20	0.37	0.26	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.5	0.01	0.48	0.20	0.37	0.26	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.32	0.31
20	50	0.1	0.5	0.10	0.48	0.20	0.37	0.26	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.08	0.31	0.27	0.32	0.31	0.31
20	50	0.1	0.5	1.00	0.48	0.20	0.37	0.26	0.38	0.58	0.53	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.31	0.30	0.30
20	50	0.1	1.0	0.0	0.48	0.20	0.37	0.26	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.32	0.30
20	50	0.1	1.0	0.01	0.48	0.20	0.37	0.26	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.32	0.30
20	50	0.1	1.0	0.10	0.48	0.20	0.37	0.26	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.08	0.31	0.27	0.32	0.31	0.30
20	50	0.1	1.0	1.00	0.48	0.20	0.37	0.26	0.37	0.56	0.52	0.59	0.04	0.02	0.04	0.04	0.30	0.26	0.31	0.30	0.29
20	50	0.5	0.0	0.0	0.47	0.19	0.36	0.24	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.0	0.01	0.47	0.19	0.36	0.24	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.0	0.10	0.47	0.19	0.36	0.24	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.0	1.00	0.47	0.19	0.36	0.24	0.39	0.61	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.32	0.29	0.30
20	50	0.5	0.1	0.0	0.47	0.19	0.36	0.24	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.1	0.01	0.47	0.19	0.36	0.24	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.1	0.10	0.47	0.19	0.36	0.24	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.31	0.31
20	50	0.5	0.1	1.00	0.47	0.19	0.36	0.24	0.39	0.60	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.32	0.29	0.30
20	50	0.5	0.5	0.0	0.47	0.19	0.36	0.24	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.31	0.30
20	50	0.5	0.5	0.01	0.47	0.19	0.36	0.24	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.31	0.30
20	50	0.5	0.5	0.10	0.47	0.19	0.36	0.24	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.08	0.31	0.27	0.32	0.31	0.30
20	50	0.5	0.5	1.00	0.47	0.19	0.36	0.24	0.38	0.58	0.53	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.31	0.29	0.29
20	50	0.5	1.0	0.0	0.47	0.19	0.36	0.24	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.26	0.32	0.31	0.30
20	50	0.5	1.0	0.01	0.47	0.19	0.36	0.24	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.31	0.26	0.32	0.31	0.30
20	50	0.5	1.0	0.10	0.47	0.19	0.36	0.24	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.08	0.30	0.26	0.32	0.31	0.30
20	50	0.5	1.0	1.00	0.47	0.19	0.36	0.24	0.37	0.56	0.52	0.59	0.04	0.02	0.04	0.04	0.30	0.26	0.31	0.29	0.29
20	50	1.0	0.0	0.0	0.47	0.18	0.36	0.22	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.0	0.01	0.47	0.18	0.36	0.22	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.0	0.10	0.47	0.18	0.36	0.22	0.39	0.61	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.0	1.00	0.47	0.18	0.36	0.22	0.39	0.61	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.31	0.28	0.29
20	50	1.0	0.1	0.0	0.47	0.18	0.36	0.22	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.1	0.01	0.47	0.18	0.36	0.22	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.09	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.1	0.10	0.47	0.18	0.36	0.22	0.39	0.60	0.54	0.59	0.07	0.04	0.06	0.08	0.31	0.28	0.32	0.30	0.30
20	50	1.0	0.1	1.00	0.47	0.18	0.36	0.22	0.39	0.60	0.54	0.59	0.04	0.02	0.04	0.04	0.30	0.27	0.31	0.28	0.29
20	50	1.0	0.5	0.0	0.47	0.18	0.36	0.22	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.30	0.30
20	50	1.0	0.5	0.01	0.47	0.18	0.36	0.22	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.09	0.31	0.27	0.32	0.30	0.30
20	50	1.0	0.5	0.10	0.47	0.18	0.36	0.22	0.38	0.58	0.53	0.59	0.07	0.04	0.06	0.08	0.31	0.27	0.32	0.30	0.30
20	50	1.0	0.5	1.00	0.47	0.18	0.36	0.22	0.38	0.58	0.53	0.59	0.04	0.02	0.04	0.04	0.30	0.26	0.31	0.28	0.29
20	50	1.0	1.0	0.0	0.47	0.18	0.36	0.22	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.30	0.26	0.31	0.30	0.30
20	50	1.0	1.0	0.01	0.47	0.18	0.36	0.22	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.30	0.26	0.31	0.30	0.30
20	50	1.0	1.0	0.10	0.47	0.18	0.36	0.22	0.37	0.56	0.52	0.59	0.07	0.04	0.06	0.09	0.30	0.26	0.31	0.30	0.30
20	50	1.0	1.0	1.00	0.47	0.19	0.36	0.22	0.37	0.56	0.52	0.59	0.04	0.02	0.04	0.04	0.29	0.25	0.31	0.28	0.29

Buoys per Area	Reliability (%)	Standard Deviation of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
30	100	0.0	0.0	0.0	0.72	0.41	0.63	0.52	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.44	0.50	0.48	0.49
30	100	0.0	0.0	0.01	0.72	0.41	0.63	0.52	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.44	0.50	0.48	0.49
30	100	0.0	0.0	0.10	0.72	0.41	0.63	0.52	0.65	0.73	0.74	0.73	0.22	0.18	0.12	0.19	0.53	0.44	0.50	0.48	0.49
30	100	0.0	0.0	1.00	0.72	0.41	0.63	0.52	0.65	0.73	0.74	0.73	0.14	0.10	0.10	0.07	0.50	0.41	0.49	0.44	0.46
30	100	0.0	0.1	0.0	0.72	0.41	0.63	0.52	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.44	0.49	0.48	0.49
30	100	0.0	0.1	0.01	0.72	0.41	0.63	0.52	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.44	0.49	0.48	0.49
30	100	0.0	0.1	0.10	0.72	0.41	0.63	0.52	0.64	0.72	0.73	0.72	0.22	0.18	0.12	0.19	0.53	0.44	0.49	0.48	0.49
30	100	0.0	0.1	1.00	0.72	0.41	0.63	0.52	0.64	0.72	0.73	0.72	0.14	0.10	0.10	0.07	0.50	0.41	0.49	0.44	0.46
30	100	0.0	0.5	0.0	0.72	0.41	0.63	0.52	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.43	0.48	0.47	0.48
30	100	0.0	0.5	0.01	0.72	0.41	0.63	0.52	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.43	0.48	0.47	0.48
30	100	0.0	0.5	0.10	0.72	0.41	0.63	0.52	0.61	0.69	0.69	0.69	0.22	0.18	0.12	0.19	0.52	0.43	0.48	0.47	0.48
30	100	0.0	0.5	1.00	0.72	0.41	0.63	0.52	0.61	0.69	0.69	0.69	0.14	0.10	0.10	0.07	0.49	0.40	0.47	0.43	0.45
30	100	0.0	1.0	0.0	0.72	0.41	0.63	0.52	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.42	0.46	0.46	0.46
30	100	0.0	1.0	0.01	0.72	0.41	0.63	0.52	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.42	0.46	0.46	0.46
30	100	0.0	1.0	0.10	0.72	0.41	0.63	0.52	0.58	0.65	0.64	0.66	0.22	0.18	0.12	0.19	0.51	0.41	0.46	0.46	0.46
30	100	0.0	1.0	1.00	0.72	0.41	0.63	0.52	0.58	0.65	0.64	0.66	0.14	0.10	0.10	0.07	0.48	0.39	0.46	0.42	0.44
30	100	0.1	0.0	0.0	0.72	0.40	0.63	0.51	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.44	0.50	0.48	0.49
30	100	0.1	0.0	0.01	0.72	0.40	0.63	0.51	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.44	0.50	0.48	0.49
30	100	0.1	0.0	0.10	0.72	0.40	0.63	0.51	0.65	0.73	0.74	0.73	0.22	0.18	0.12	0.19	0.53	0.44	0.50	0.48	0.49
30	100	0.1	0.0	1.00	0.72	0.40	0.63	0.51	0.65	0.73	0.74	0.73	0.14	0.10	0.10	0.07	0.50	0.41	0.49	0.44	0.46
30	100	0.1	0.1	0.0	0.72	0.40	0.63	0.51	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.44	0.49	0.48	0.49
30	100	0.1	0.1	0.01	0.72	0.40	0.63	0.51	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.44	0.49	0.48	0.49
30	100	0.1	0.1	0.10	0.72	0.40	0.63	0.51	0.64	0.72	0.73	0.72	0.22	0.18	0.12	0.19	0.53	0.44	0.49	0.47	0.48
30	100	0.1	0.1	1.00	0.72	0.40	0.63	0.51	0.64	0.72	0.73	0.72	0.14	0.10	0.10	0.07	0.50	0.41	0.49	0.43	0.46
30	100	0.1	0.5	0.0	0.72	0.40	0.63	0.51	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.43	0.48	0.47	0.48
30	100	0.1	0.5	0.01	0.72	0.40	0.63	0.51	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.43	0.48	0.47	0.48
30	100	0.1	0.5	0.10	0.72	0.40	0.63	0.51	0.61	0.69	0.69	0.69	0.22	0.18	0.12	0.19	0.52	0.43	0.48	0.46	0.47
30	100	0.1	0.5	1.00	0.72	0.40	0.63	0.51	0.61	0.69	0.69	0.69	0.14	0.10	0.10	0.07	0.49	0.40	0.47	0.42	0.45
30	100	0.1	1.0	0.0	0.72	0.40	0.63	0.51	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.42	0.46	0.46	0.46
30	100	0.1	1.0	0.01	0.72	0.40	0.63	0.51	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.42	0.46	0.46	0.46
30	100	0.1	1.0	0.10	0.72	0.40	0.63	0.51	0.58	0.65	0.64	0.66	0.22	0.18	0.12	0.19	0.51	0.41	0.46	0.45	0.46
30	100	0.1	1.0	1.00	0.72	0.40	0.63	0.51	0.58	0.65	0.64	0.66	0.14	0.10	0.10	0.07	0.48	0.39	0.46	0.41	0.43
30	100	0.5	0.0	0.0	0.71	0.37	0.62	0.45	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.43	0.49	0.46	0.48
30	100	0.5	0.0	0.01	0.71	0.37	0.62	0.45	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.43	0.49	0.46	0.48
30	100	0.5	0.0	0.10	0.71	0.37	0.62	0.45	0.65	0.73	0.74	0.73	0.22	0.18	0.12	0.19	0.53	0.43	0.49	0.46	0.48
30	100	0.5	0.0	1.00	0.71	0.37	0.62	0.45	0.65	0.73	0.74	0.73	0.14	0.10	0.10	0.07	0.50	0.40	0.49	0.42	0.45
30	100	0.5	0.1	0.0	0.71	0.37	0.62	0.45	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.43	0.49	0.46	0.48
30	100	0.5	0.1	0.01	0.71	0.37	0.62	0.45	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.43	0.49	0.46	0.48
30	100	0.5	0.1	0.10	0.71	0.37	0.62	0.45	0.64	0.72	0.73	0.72	0.22	0.18	0.12	0.19	0.53	0.43	0.49	0.45	0.48
30	100	0.5	0.1	1.00	0.71	0.37	0.62	0.45	0.64	0.72	0.73	0.72	0.14	0.10	0.10	0.07	0.50	0.40	0.48	0.42	0.45
30	100	0.5	0.5	0.0	0.71	0.37	0.62	0.45	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.42	0.48	0.45	0.47
30	100	0.5	0.5	0.01	0.71	0.37	0.62	0.45	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.42	0.48	0.45	0.47
30	100	0.5	0.5	0.10	0.71	0.37	0.62	0.45	0.61	0.69	0.69	0.69	0.22	0.18	0.12	0.19	0.52	0.42	0.48	0.44	0.47
30	100	0.5	0.5	1.00	0.71	0.37	0.62	0.45	0.61	0.69	0.69	0.69	0.14	0.10	0.10	0.07	0.49	0.39	0.47	0.41	0.44
30	100	0.5	1.0	0.0	0.71	0.37	0.62	0.45	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.41	0.46	0.44	0.45
30	100	0.5	1.0	0.01	0.71	0.37	0.62	0.45	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.41	0.46	0.44	0.45
30	100	0.5	1.0	0.10	0.71	0.37	0.62	0.45	0.58	0.65	0.64	0.66	0.22	0.18	0.12	0.19	0.51	0.40	0.46	0.43	0.45
30	100	0.5	1.0	1.00	0.71	0.37	0.62	0.45	0.58	0.65	0.64	0.66	0.14	0.10	0.10	0.07	0.48	0.38	0.45	0.39	0.43
30	100	1.0	0.0	0.0	0.71	0.34	0.61	0.38	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.42	0.49	0.44	0.47
30	100	1.0	0.0	0.01	0.71	0.34	0.61	0.38	0.65	0.73	0.74	0.73	0.23	0.19	0.12	0.20	0.53	0.42	0.49	0.44	0.47
30	100	1.0	0.0	0.10	0.71	0.34	0.61	0.38	0.65	0.73	0.74	0.73	0.22	0.18	0.12	0.19	0.53	0.42	0.49	0.43	0.47
30	100	1.0	0.0	1.00	0.71	0.34	0.61	0.39	0.65	0.73	0.74	0.73	0.14	0.10	0.10	0.07	0.50	0.39	0.48	0.39	0.44
30	100	1.0	0.1	0.0	0.71	0.34	0.61	0.39	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.42	0.49	0.44	0.47
30	100	1.0	0.1	0.01	0.71	0.34	0.61	0.38	0.64	0.72	0.73	0.72	0.23	0.19	0.12	0.20	0.53	0.42	0.49	0.43	0.47
30	100	1.0	0.1	0.10	0.71	0.34	0.61	0.38	0.64	0.72	0.73	0.72	0.22	0.18	0.12	0.19	0.53	0.42	0.49	0.43	0.47
30	100	1.0	0.1	1.00	0.71	0.34	0.61	0.39	0.64	0.72	0.73	0.72	0.14	0.10	0.10	0.07	0.50	0.39	0.48	0.39	0.44
30	100	1.0	0.5	0.0	0.71	0.34	0.61	0.38	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.41	0.47	0.43	0.46
30	100	1.0	0.5	0.01	0.71	0.34	0.61	0.39	0.61	0.69	0.69	0.69	0.23	0.19	0.12	0.20	0.52	0.41	0.47	0.43	0.46
30	100	1.0	0.5	0.10	0.71	0.34	0.61	0.38	0.61	0.69	0.69	0.69	0.22	0.18	0.12	0.19	0.52	0.40	0.47	0.42	0.46
30	100	1.0	0.5	1.00	0.71	0.34	0.61	0.38	0.61	0.69	0.69	0.69	0.14	0.10	0.10	0.07	0.49	0.38	0.47	0.38	0.43
30	100	1.0	1.0	0.0	0.71	0.34	0.61	0.38	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.39	0.46	0.41	0.44
30	100	1.0	1.0	0.01	0.71	0.34	0.61	0.38	0.58	0.65	0.64	0.66	0.23	0.19	0.12	0.20	0.51	0.39	0.46	0.41	0.44
30	100	1.0	1.0	0.10	0.71	0.34	0.61	0.38	0.58	0.65	0.64	0.66	0.22	0.18	0.12	0.19	0.50	0.39	0.46	0.41	0.44
30	100	1.0	1.0	1.00	0.71	0.34	0.61	0.38	0.58	0.65	0.64	0.66	0.14	0.10	0.10	0.07	0.43	0.36	0.45	0.37	0.42

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
		σ_{SLP}	σ_{SAT}	σ_{SST}	Pacific HiVar	Pacific LoVar	Atlantic HiVar	Atlantic LoVar	Pacific HiVar	Pacific LoVar	Atlantic HiVar	Atlantic LoVar	Pacific HiVar	Pacific LoVar	Atlantic HiVar	Atlantic LoVar	Pacific HiVar	Pacific LoVar	Atlantic HiVar	Atlantic LoVar	
30	80	0.0	0.0	0.0	0.65	0.37	0.55	0.45	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.0	0.0	0.01	0.65	0.37	0.55	0.45	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.0	0.0	0.10	0.65	0.37	0.55	0.45	0.58	0.70	0.67	0.68	0.17	0.13	0.10	0.16	0.47	0.40	0.44	0.43	0.44
30	80	0.0	0.0	1.00	0.65	0.37	0.55	0.45	0.58	0.70	0.67	0.68	0.10	0.07	0.07	0.06	0.44	0.38	0.43	0.40	0.41
30	80	0.0	0.1	0.0	0.65	0.37	0.55	0.45	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.0	0.1	0.01	0.65	0.37	0.55	0.45	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.0	0.1	0.10	0.65	0.37	0.55	0.45	0.58	0.69	0.66	0.67	0.17	0.13	0.10	0.16	0.47	0.40	0.44	0.43	0.43
30	80	0.0	0.1	1.00	0.65	0.37	0.55	0.45	0.58	0.69	0.66	0.67	0.10	0.07	0.07	0.06	0.44	0.38	0.43	0.40	0.41
30	80	0.0	0.5	0.0	0.65	0.37	0.55	0.45	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.47	0.39	0.43	0.43	0.43
30	80	0.0	0.5	0.01	0.65	0.37	0.55	0.45	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.47	0.39	0.43	0.43	0.43
30	80	0.0	0.5	0.10	0.65	0.37	0.55	0.45	0.56	0.66	0.63	0.65	0.17	0.13	0.10	0.16	0.46	0.39	0.43	0.42	0.43
30	80	0.0	0.5	1.00	0.65	0.37	0.55	0.45	0.56	0.66	0.63	0.65	0.10	0.07	0.07	0.06	0.44	0.37	0.42	0.39	0.41
30	80	0.0	1.0	0.0	0.65	0.37	0.55	0.45	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.46	0.38	0.42	0.42	0.42
30	80	0.0	1.0	0.01	0.65	0.37	0.55	0.45	0.55	0.63	0.60	0.63	0.18	0.140	0.10	0.17	0.46	0.38	0.42	0.42	0.42
30	80	0.0	1.0	0.10	0.65	0.37	0.55	0.45	0.55	0.63	0.60	0.63	0.17	0.13	0.10	0.16	0.46	0.38	0.42	0.41	0.42
30	80	0.0	1.0	1.00	0.65	0.37	0.55	0.45	0.55	0.63	0.60	0.63	0.10	0.07	0.07	0.06	0.43	0.36	0.41	0.38	0.40
30	80	0.1	0.0	0.0	0.65	0.36	0.55	0.44	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.1	0.0	0.01	0.65	0.36	0.55	0.44	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.1	0.0	0.10	0.65	0.36	0.55	0.44	0.58	0.70	0.67	0.68	0.17	0.13	0.10	0.16	0.47	0.40	0.44	0.43	0.43
30	80	0.1	0.0	1.00	0.65	0.36	0.55	0.44	0.58	0.70	0.67	0.68	0.10	0.07	0.07	0.06	0.44	0.380	0.43	0.39	0.41
30	80	0.1	0.1	0.0	0.65	0.36	0.55	0.44	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.44
30	80	0.1	0.1	0.01	0.65	0.36	0.55	0.44	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.40	0.44	0.43	0.43
30	80	0.1	0.1	0.10	0.65	0.36	0.55	0.44	0.58	0.69	0.66	0.67	0.17	0.13	0.10	0.16	0.47	0.40	0.44	0.42	0.43
30	80	0.1	0.1	1.00	0.65	0.36	0.55	0.44	0.58	0.69	0.66	0.67	0.10	0.07	0.07	0.06	0.44	0.38	0.43	0.39	0.41
30	80	0.1	0.5	0.0	0.65	0.36	0.55	0.44	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.47	0.39	0.43	0.42	0.43
30	80	0.1	0.5	0.01	0.65	0.36	0.55	0.44	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.47	0.39	0.43	0.42	0.43
30	80	0.1	0.5	0.10	0.65	0.36	0.55	0.44	0.56	0.66	0.63	0.65	0.17	0.13	0.10	0.16	0.46	0.39	0.43	0.42	0.43
30	80	0.1	0.5	1.00	0.65	0.36	0.55	0.44	0.56	0.66	0.63	0.65	0.10	0.07	0.07	0.06	0.44	0.37	0.42	0.39	0.40
30	80	0.1	1.0	0.0	0.65	0.36	0.55	0.44	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.46	0.38	0.42	0.41	0.42
30	80	0.1	1.0	0.01	0.65	0.36	0.55	0.44	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.46	0.38	0.42	0.41	0.42
30	80	0.1	1.0	0.10	0.65	0.36	0.55	0.44	0.55	0.63	0.60	0.63	0.17	0.13	0.10	0.16	0.46	0.38	0.42	0.41	0.42
30	80	0.1	1.0	1.00	0.65	0.36	0.55	0.44	0.55	0.63	0.60	0.63	0.10	0.07	0.07	0.06	0.43	0.36	0.41	0.38	0.39
30	80	0.5	0.0	0.0	0.64	0.33	0.55	0.39	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.39	0.44	0.41	0.43
30	80	0.5	0.0	0.01	0.64	0.33	0.55	0.39	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.47	0.39	0.44	0.41	0.43
30	80	0.5	0.0	0.10	0.64	0.33	0.55	0.39	0.58	0.70	0.67	0.68	0.17	0.13	0.10	0.16	0.46	0.39	0.44	0.41	0.43
30	80	0.5	0.0	1.00	0.64	0.33	0.55	0.39	0.58	0.70	0.67	0.68	0.10	0.07	0.07	0.06	0.44	0.37	0.43	0.38	0.41
30	80	0.5	0.1	0.0	0.64	0.33	0.55	0.39	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.39	0.44	0.41	0.43
30	80	0.5	0.1	0.01	0.64	0.33	0.55	0.39	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.47	0.39	0.44	0.41	0.43
30	80	0.5	0.1	0.10	0.64	0.33	0.55	0.39	0.58	0.69	0.66	0.67	0.17	0.13	0.10	0.16	0.46	0.39	0.44	0.41	0.43
30	80	0.5	0.1	1.00	0.64	0.33	0.55	0.39	0.58	0.69	0.66	0.67	0.10	0.07	0.07	0.06	0.44	0.37	0.43	0.38	0.40
30	80	0.5	0.5	0.0	0.64	0.33	0.55	0.39	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.46	0.38	0.43	0.41	0.42
30	80	0.5	0.5	0.01	0.64	0.33	0.55	0.39	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.46	0.38	0.43	0.41	0.42
30	80	0.5	0.5	0.10	0.64	0.33	0.55	0.39	0.56	0.66	0.63	0.65	0.17	0.13	0.10	0.16	0.46	0.38	0.43	0.40	0.42
30	80	0.5	0.5	1.00	0.64	0.33	0.55	0.39	0.56	0.66	0.63	0.65	0.10	0.07	0.07	0.06	0.44	0.36	0.42	0.37	0.40
30	80	0.5	1.0	0.0	0.64	0.33	0.55	0.39	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.46	0.37	0.42	0.40	0.41
30	80	0.5	1.0	0.01	0.64	0.33	0.55	0.39	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.46	0.37	0.42	0.40	0.41
30	80	0.5	1.0	0.10	0.64	0.33	0.55	0.39	0.55	0.63	0.60	0.63	0.17	0.13	0.10	0.16	0.45	0.37	0.42	0.39	0.41
30	80	0.5	1.0	1.00	0.64	0.33	0.55	0.39	0.55	0.63	0.60	0.63	0.10	0.07	0.07	0.06	0.43	0.35	0.41	0.36	0.39
30	80	1.0	0.0	0.0	0.63	0.30	0.55	0.33	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.0	0.01	0.63	0.30	0.55	0.33	0.58	0.70	0.67	0.68	0.18	0.14	0.10	0.17	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.0	0.10	0.63	0.30	0.55	0.33	0.58	0.70	0.67	0.68	0.17	0.13	0.10	0.16	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.0	1.00	0.63	0.30	0.55	0.33	0.58	0.70	0.67	0.68	0.10	0.07	0.07	0.06	0.44	0.36	0.43	0.36	0.40
30	80	1.0	0.1	0.0	0.63	0.30	0.55	0.33	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.1	0.01	0.63	0.30	0.55	0.33	0.58	0.69	0.66	0.67	0.18	0.14	0.10	0.17	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.1	0.10	0.63	0.30	0.55	0.33	0.58	0.69	0.66	0.67	0.17	0.13	0.10	0.16	0.46	0.38	0.44	0.39	0.42
30	80	1.0	0.1	1.00	0.63	0.30	0.55	0.33	0.58	0.69	0.66	0.67	0.10	0.07	0.07	0.06	0.44	0.36	0.43	0.36	0.40
30	80	1.0	0.5	0.0	0.63	0.30	0.55	0.33	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.46	0.37	0.43	0.39	0.41
30	80	1.0	0.5	0.01	0.63	0.30	0.55	0.33	0.56	0.66	0.63	0.65	0.18	0.14	0.10	0.17	0.46	0.37	0.43	0.39	0.41
30	80	1.0	0.5	0.10	0.63	0.30	0.55	0.33	0.56	0.66	0.63	0.65	0.18	0.13	0.10	0.16	0.46	0.37	0.43	0.38	0.41
30	80	1.0	0.5	1.00	0.63	0.30	0.55	0.33	0.56	0.66	0.63	0.65	0.10	0.07	0.07	0.06	0.43	0.35	0.42	0.350	0.39
30	80	1.0	1.0	0.0	0.63	0.30	0.55	0.33	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.45	0.36	0.42	0.38	0.40
30	80	1.0	1.0	0.01	0.63	0.30	0.55	0.33	0.55	0.63	0.60	0.63	0.18	0.14	0.10	0.17	0.45	0.36	0.42	0.38	0.40
30	80	1.0	1.0	0.10	0.63	0.30	0.55	0.33	0.55	0.63	0.60	0.63	0.17	0.13	0.10	0.16	0.45	0.36	0.42	0.37	0.40
30	80	1.0	1.0	1.00	0.63	0.30	0.55	0.33	0.55	0.63	0.60	0.63	0.10	0.07	0.07	0.06	0.43	0.33	0.41	0.34	0.38

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
30	50	0.0	0.0	0.0	0.57	0.29	0.45	0.36	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.37	0.38
30	50	0.0	0.0	0.01	0.57	0.29	0.45	0.36	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.37	0.38
30	50	0.0	0.0	0.10	0.57	0.29	0.45	0.36	0.51	0.67	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.36	0.37	0.37	0.38
30	50	0.0	0.0	1.00	0.57	0.29	0.45	0.36	0.51	0.67	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.35	0.36
30	50	0.0	0.1	0.0	0.57	0.29	0.45	0.36	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.37	0.38
30	50	0.0	0.1	0.01	0.57	0.29	0.45	0.36	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.37	0.380
30	50	0.0	0.1	0.10	0.57	0.29	0.45	0.36	0.51	0.66	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.36	0.37	0.36	0.37
30	50	0.0	0.1	1.00	0.57	0.29	0.45	0.36	0.51	0.66	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.35	0.36
30	50	0.0	0.5	0.0	0.57	0.29	0.45	0.36	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.35	0.37	0.36	0.37
30	50	0.0	0.5	0.01	0.57	0.29	0.45	0.36	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.35	0.37	0.36	0.37
30	50	0.0	0.5	0.10	0.57	0.29	0.45	0.36	0.49	0.64	0.58	0.62	0.11	0.11	0.07	0.10	0.39	0.35	0.37	0.36	0.37
30	50	0.0	0.5	1.00	0.57	0.29	0.45	0.36	0.49	0.64	0.58	0.62	0.07	0.04	0.04	0.05	0.38	0.32	0.36	0.34	0.35
30	50	0.0	1.0	0.0	0.57	0.29	0.45	0.36	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.36	0.36
30	50	0.0	1.0	0.01	0.57	0.29	0.45	0.36	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.36	0.36
30	50	0.0	1.0	0.10	0.57	0.29	0.45	0.36	0.47	0.61	0.57	0.61	0.11	0.11	0.07	0.10	0.39	0.34	0.36	0.36	0.36
30	50	0.0	1.0	1.00	0.57	0.29	0.45	0.36	0.47	0.61	0.57	0.61	0.07	0.04	0.04	0.05	0.37	0.31	0.35	0.34	0.35
30	50	0.1	0.0	0.0	0.57	0.29	0.45	0.35	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.36	0.38
30	50	0.1	0.0	0.01	0.57	0.29	0.45	0.35	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.36	0.38
30	50	0.1	0.0	0.10	0.57	0.29	0.45	0.35	0.51	0.67	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.36	0.37	0.36	0.37
30	50	0.1	0.0	1.00	0.57	0.29	0.45	0.35	0.51	0.67	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.34	0.360
30	50	0.1	0.1	0.0	0.57	0.29	0.45	0.35	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.36	0.37
30	50	0.1	0.1	0.01	0.57	0.29	0.45	0.35	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.36	0.37	0.36	0.37
30	50	0.1	0.1	0.10	0.57	0.29	0.45	0.35	0.51	0.66	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.35	0.37	0.36	0.370
30	50	0.1	0.1	1.00	0.57	0.29	0.45	0.35	0.51	0.66	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.34	0.36
30	50	0.1	0.5	0.0	0.57	0.29	0.45	0.35	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.35	0.37	0.36	0.37
30	50	0.1	0.5	0.01	0.57	0.29	0.45	0.35	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.35	0.37	0.36	0.37
30	50	0.1	0.5	0.10	0.57	0.29	0.45	0.35	0.49	0.64	0.58	0.62	0.11	0.11	0.07	0.10	0.39	0.35	0.37	0.36	0.370
30	50	0.1	0.5	1.00	0.57	0.29	0.45	0.35	0.49	0.64	0.58	0.62	0.07	0.04	0.04	0.05	0.38	0.32	0.36	0.34	0.35
30	50	0.1	1.0	0.0	0.57	0.29	0.45	0.35	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.36	0.360
30	50	0.1	1.0	0.01	0.57	0.29	0.45	0.35	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.36	0.36
30	50	0.1	1.0	0.10	0.57	0.29	0.45	0.35	0.47	0.61	0.57	0.61	0.11	0.11	0.07	0.10	0.39	0.34	0.36	0.36	0.36
30	50	0.1	1.0	1.00	0.57	0.29	0.45	0.35	0.47	0.61	0.57	0.61	0.07	0.04	0.04	0.05	0.37	0.31	0.35	0.34	0.34
30	50	0.5	0.0	0.0	0.57	0.27	0.44	0.31	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.0	0.01	0.57	0.27	0.44	0.31	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.0	0.10	0.57	0.27	0.44	0.31	0.51	0.67	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.0	1.00	0.57	0.27	0.44	0.31	0.51	0.67	0.60	0.630	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.33	0.35
30	50	0.5	0.1	0.0	0.57	0.27	0.44	0.31	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.1	0.01	0.57	0.27	0.44	0.31	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.1	0.10	0.57	0.27	0.44	0.31	0.51	0.66	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.35	0.37	0.35	0.37
30	50	0.5	0.1	1.00	0.57	0.27	0.44	0.31	0.51	0.66	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.33	0.36	0.33	0.35
30	50	0.5	0.5	0.0	0.57	0.27	0.44	0.31	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.34	0.37	0.35	0.36
30	50	0.5	0.5	0.01	0.57	0.27	0.44	0.31	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.34	0.37	0.35	0.36
30	50	0.5	0.5	0.10	0.57	0.27	0.44	0.31	0.49	0.64	0.58	0.62	0.11	0.11	0.07	0.10	0.39	0.34	0.36	0.35	0.36
30	50	0.5	0.5	1.00	0.57	0.27	0.44	0.31	0.49	0.64	0.58	0.62	0.07	0.04	0.04	0.05	0.38	0.32	0.36	0.33	0.35
30	50	0.5	1.0	0.0	0.57	0.27	0.44	0.31	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.33	0.36	0.34	0.36
30	50	0.5	1.0	0.01	0.57	0.27	0.44	0.31	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.33	0.36	0.34	0.36
30	50	0.5	1.0	0.10	0.57	0.27	0.44	0.31	0.47	0.61	0.57	0.61	0.11	0.11	0.07	0.10	0.39	0.33	0.36	0.34	0.36
30	50	0.5	1.0	1.00	0.57	0.27	0.44	0.31	0.47	0.61	0.57	0.61	0.07	0.04	0.04	0.05	0.37	0.31	0.35	0.32	0.34
30	50	1.0	0.0	0.0	0.57	0.25	0.43	0.26	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.33	0.36
30	50	1.0	0.0	0.01	0.57	0.25	0.43	0.26	0.51	0.67	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.33	0.36
30	50	1.0	0.0	0.10	0.57	0.25	0.43	0.26	0.51	0.67	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.34	0.37	0.33	0.36
30	50	1.0	0.0	1.00	0.57	0.25	0.43	0.26	0.51	0.67	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.32	0.36	0.31	0.35
30	50	1.0	0.1	0.0	0.57	0.25	0.43	0.26	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.33	0.36
30	50	1.0	0.1	0.01	0.57	0.25	0.43	0.26	0.51	0.66	0.60	0.63	0.12	0.12	0.07	0.11	0.40	0.35	0.37	0.33	0.36
30	50	1.0	0.1	0.10	0.57	0.25	0.43	0.26	0.51	0.66	0.60	0.63	0.11	0.11	0.07	0.10	0.40	0.34	0.37	0.33	0.36
30	50	1.0	0.1	1.00	0.57	0.25	0.43	0.26	0.51	0.66	0.60	0.63	0.07	0.04	0.04	0.05	0.38	0.32	0.36	0.31	0.34
30	50	1.0	0.5	0.0	0.57	0.25	0.43	0.26	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.33	0.360
30	50	1.0	0.5	0.01	0.57	0.25	0.43	0.26	0.49	0.64	0.58	0.62	0.12	0.12	0.07	0.11	0.39	0.34	0.36	0.33	0.36
30	50	1.0	0.5	0.10	0.57	0.25	0.43	0.26	0.49	0.64	0.58	0.62	0.11	0.11	0.07	0.10	0.39	0.33	0.36	0.33	0.36
30	50	1.0	0.5	1.00	0.57	0.25	0.43	0.26	0.49	0.64	0.58	0.62	0.07	0.04	0.04	0.05	0.38	0.31	0.35	0.31	0.340
30	50	1.0	1.0	0.0	0.57	0.25	0.43	0.26	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.33	0.36	0.33	0.350
30	50	1.0	1.0	0.01	0.57	0.25	0.43	0.26	0.47	0.61	0.57	0.61	0.12	0.12	0.07	0.11	0.39	0.33	0.36	0.33	0.35
30	50	1.0	1.0	0.10	0.57	0.25	0.43	0.26	0.47	0.61	0.57	0.61	0.11	0.11	0.07	0.10	0.39	0.32	0.36	0.33	0.35
30	50	1.0	1.0	1.00	0.57	0.25	0.43	0.26	0.47	0.61	0.57	0.61	0.07	0.04	0.04	0.05	0.37	0.30	0.35	0.31	0.33

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
50	100	0.0	0.0	0.0	0.81	0.54	0.73	0.62	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.53	0.58	0.56	0.59
50	100	0.0	0.0	0.01	0.81	0.54	0.73	0.62	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.53	0.58	0.56	0.59
50	100	0.0	0.0	0.10	0.81	0.54	0.73	0.62	0.82	0.78	0.82	0.77	0.46	0.26	0.17	0.26	0.70	0.53	0.58	0.55	0.59
50	100	0.0	0.0	1000	0.81	0.54	0.73	0.62	0.82	0.78	0.82	0.77	0.31	0.13	0.13	0.07	0.65	0.48	0.56	0.49	0.55
50	100	0.0	0.1	0.0	0.81	0.54	0.73	0.62	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.70	0.53	0.57	0.55	0.59
50	100	0.0	0.1	0.01	0.81	0.54	0.73	0.62	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.70	0.53	0.57	0.55	0.59
50	100	0.0	0.1	0.10	0.81	0.54	0.73	0.62	0.81	0.77	0.81	0.76	0.46	0.26	0.17	0.26	0.69	0.52	0.57	0.55	0.59
50	100	0.0	0.1	1000	0.81	0.54	0.73	0.62	0.81	0.77	0.81	0.76	0.31	0.13	0.13	0.07	0.64	0.48	0.56	0.48	0.54
50	100	0.0	0.5	0.0	0.81	0.54	0.73	0.62	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.51	0.56	0.54	0.57
50	100	0.0	0.5	0.01	0.81	0.54	0.73	0.62	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.51	0.56	0.54	0.57
50	100	0.0	0.5	0.10	0.81	0.54	0.73	0.62	0.75	0.72	0.77	0.72	0.46	0.26	0.17	0.26	0.68	0.51	0.56	0.53	0.57
50	100	0.0	0.5	1.00	0.81	0.54	0.73	0.62	0.75	0.72	0.77	0.72	0.31	0.13	0.13	0.07	0.63	0.46	0.54	0.47	0.53
50	100	0.0	1.0	0.0	0.81	0.54	0.73	0.62	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.66	0.49	0.54	0.52	0.56
50	100	0.0	1.0	0.01	0.81	0.54	0.73	0.62	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.66	0.49	0.54	0.52	0.56
50	100	0.0	1.0	0.10	0.81	0.54	0.73	0.62	0.69	0.66	0.72	0.67	0.46	0.26	0.17	0.26	0.66	0.49	0.54	0.52	0.55
50	100	0.0	1.0	1.00	0.81	0.54	0.73	0.62	0.69	0.66	0.72	0.67	0.31	0.13	0.13	0.07	0.60	0.44	0.53	0.45	0.51
50	100	0.1	0.0	0.0	0.81	0.52	0.72	0.60	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.53	0.58	0.55	0.59
50	100	0.1	0.0	0.01	0.81	0.52	0.72	0.60	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.53	0.58	0.55	0.59
50	100	0.1	0.0	0.10	0.81	0.52	0.72	0.60	0.82	0.78	0.82	0.77	0.46	0.26	0.17	0.26	0.70	0.52	0.57	0.55	0.59
50	100	0.1	0.0	1.00	0.81	0.52	0.72	0.60	0.82	0.78	0.82	0.77	0.31	0.13	0.13	0.07	0.65	0.48	0.56	0.48	0.54
50	100	0.1	0.1	0.0	0.81	0.52	0.72	0.60	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.70	0.52	0.57	0.55	0.59
50	100	0.1	0.1	0.01	0.81	0.52	0.72	0.60	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.70	0.52	0.57	0.55	0.59
50	100	0.1	0.1	0.10	0.81	0.52	0.72	0.60	0.81	0.77	0.81	0.76	0.46	0.26	0.17	0.26	0.69	0.52	0.57	0.54	0.58
50	100	0.1	0.1	1.00	0.81	0.52	0.72	0.60	0.81	0.77	0.81	0.76	0.31	0.13	0.13	0.07	0.64	0.48	0.56	0.48	0.54
50	100	0.1	0.5	0.0	0.81	0.52	0.72	0.60	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.51	0.56	0.54	0.57
50	100	0.1	0.5	0.01	0.81	0.52	0.72	0.60	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.51	0.56	0.54	0.57
50	100	0.1	0.5	0.10	0.81	0.52	0.72	0.60	0.75	0.72	0.77	0.72	0.46	0.26	0.17	0.26	0.68	0.50	0.56	0.53	0.57
50	100	0.1	0.5	1.00	0.81	0.52	0.72	0.60	0.75	0.72	0.77	0.72	0.31	0.13	0.13	0.07	0.62	0.46	0.54	0.47	0.52
50	100	0.1	1.0	0.0	0.81	0.52	0.72	0.60	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.66	0.49	0.54	0.52	0.55
50	100	0.1	1.0	0.01	0.81	0.52	0.72	0.60	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.66	0.49	0.54	0.52	0.55
50	100	0.1	1.0	0.10	0.81	0.52	0.72	0.60	0.69	0.66	0.72	0.67	0.46	0.26	0.17	0.26	0.65	0.48	0.54	0.51	0.55
50	100	0.1	1.0	1.00	0.81	0.52	0.72	0.60	0.69	0.66	0.72	0.67	0.31	0.13	0.13	0.07	0.60	0.44	0.53	0.45	0.51
50	100	0.5	0.0	0.0	0.79	0.46	0.70	0.54	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.51	0.57	0.53	0.58
50	100	0.5	0.0	0.01	0.79	0.46	0.70	0.54	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.70	0.51	0.57	0.53	0.58
50	100	0.5	0.0	0.10	0.79	0.46	0.70	0.54	0.82	0.78	0.82	0.77	0.46	0.26	0.17	0.26	0.69	0.50	0.57	0.53	0.57
50	100	0.5	0.0	1.00	0.79	0.46	0.70	0.54	0.82	0.78	0.82	0.77	0.31	0.13	0.13	0.07	0.64	0.46	0.55	0.46	0.53
50	100	0.5	0.1	0.0	0.79	0.46	0.70	0.54	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.69	0.50	0.57	0.53	0.57
50	100	0.5	0.1	0.01	0.79	0.46	0.70	0.54	0.81	0.77	0.81	0.76	0.48	0.27	0.180	0.28	0.69	0.50	0.57	0.53	0.57
50	100	0.5	0.1	0.10	0.79	0.46	0.70	0.54	0.81	0.77	0.81	0.76	0.46	0.26	0.17	0.26	0.69	0.50	0.56	0.52	0.57
50	100	0.5	0.1	1.00	0.79	0.46	0.70	0.54	0.81	0.77	0.81	0.76	0.31	0.13	0.13	0.07	0.64	0.46	0.55	0.46	0.53
50	100	0.5	0.5	0.0	0.79	0.46	0.70	0.54	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.49	0.55	0.52	0.56
50	100	0.5	0.5	0.01	0.79	0.46	0.70	0.54	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.68	0.49	0.55	0.52	0.560
50	100	0.5	0.5	0.10	0.79	0.46	0.70	0.54	0.75	0.72	0.77	0.72	0.46	0.26	0.17	0.26	0.67	0.48	0.55	0.51	0.55
50	100	0.5	0.5	1.00	0.79	0.46	0.70	0.54	0.75	0.72	0.77	0.72	0.31	0.13	0.13	0.07	0.62	0.44	0.54	0.45	0.51
50	100	0.5	1.0	0.0	0.79	0.46	0.70	0.54	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.65	0.47	0.54	0.50	0.54
50	100	0.5	1.0	0.01	0.79	0.46	0.70	0.54	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.65	0.47	0.54	0.50	0.54
50	100	0.5	1.0	0.10	0.79	0.46	0.70	0.54	0.69	0.66	0.72	0.67	0.46	0.26	0.17	0.26	0.65	0.46	0.53	0.49	0.54
50	100	0.5	1.0	1.00	0.79	0.46	0.70	0.54	0.69	0.66	0.72	0.67	0.31	0.13	0.13	0.07	0.60	0.42	0.52	0.43	0.49
50	100	1.0	0.0	0.0	0.77	0.39	0.68	0.47	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.69	0.48	0.56	0.51	0.56
50	100	1.0	0.0	0.01	0.77	0.39	0.68	0.47	0.82	0.78	0.82	0.77	0.48	0.27	0.18	0.28	0.69	0.48	0.56	0.51	0.56
50	100	1.0	0.0	0.10	0.77	0.39	0.68	0.47	0.82	0.78	0.82	0.77	0.46	0.26	0.17	0.26	0.69	0.48	0.56	0.50	0.56
50	100	1.0	0.0	1.00	0.77	0.39	0.68	0.47	0.82	0.78	0.82	0.77	0.31	0.13	0.13	0.07	0.63	0.43	0.54	0.44	0.51
50	100	1.0	0.1	0.0	0.77	0.39	0.68	0.47	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.69	0.48	0.56	0.50	0.56
50	100	1.0	0.1	0.01	0.77	0.39	0.68	0.47	0.81	0.77	0.81	0.76	0.48	0.27	0.18	0.28	0.69	0.48	0.56	0.50	0.56
50	100	1.0	0.1	0.10	0.77	0.39	0.68	0.47	0.81	0.77	0.81	0.76	0.46	0.26	0.17	0.26	0.68	0.47	0.56	0.50	0.55
50	100	1.0	0.1	1.00	0.77	0.39	0.68	0.47	0.81	0.77	0.81	0.76	0.31	0.13	0.13	0.07	0.63	0.43	0.54	0.43	0.51
50	100	1.0	0.5	0.0	0.77	0.39	0.68	0.47	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.67	0.46	0.54	0.49	0.54
50	100	1.0	0.5	0.01	0.77	0.39	0.68	0.47	0.75	0.72	0.77	0.72	0.48	0.27	0.18	0.28	0.67	0.46	0.54	0.49	0.54
50	100	1.0	0.5	0.10	0.77	0.39	0.68	0.47	0.75	0.72	0.77	0.72	0.46	0.26	0.17	0.26	0.66	0.46	0.54	0.48	0.54
50	100	1.0	0.5	1.00	0.77	0.39	0.68	0.47	0.75	0.72	0.77	0.72	0.31	0.13	0.13	0.07	0.61	0.41	0.53	0.42	0.49
50	100	1.0	1.0	0.0	0.77	0.39	0.68	0.47	0.69	0.66	0.72	0.67	0.48	0.27	0.18	0.28	0.65	0.44	0.53	0.47	0.52
50	100	1.0	1.0	0.01	0.77	0.39	0.68	0.47	0.690	0.66	0072	0.67	0.48	0.27	0.18	0.28	0.65	0.44	0.53	0.47	0.52
50	100	1.0	1.0	0.10	0.77	0.39	0.68	0.47	0.69	0.66	0.72	0.67	0.45	0.26	0.17	0.26	0.64	0.44	0.53	0.47	0.52
50	100	1.0	100	1.00	0.77	0.39	0.68	0.47	0.69	0.66	0.72	0.67	0.31	0.13	0.13	0.07	0.59	0.39	0.51	0.40	0.48

Buoys per Area	Reliability (%)	σ_{SLP}	σ_{SAT}	σ_{SST}	SLP Effectiveness Pacific HiVar	SLP Pacific LoVar	SLP Atlantic HiVar	SLP Atlantic LoVar	SAT Effectiveness Pacific HiVar	SAT Pacific LoVar	SAT Atlantic HiVar	SAT Atlantic LoVar	SST Effectiveness Pacific HiVar	SST Pacific LoVar	SST Atlantic HiVar	SST Atlantic LoVar	Effectiveness Pacific HiVar	Effectiveness Pacific LoVar	Effectiveness Atlantic HiVar	Effectiveness Atlantic LoVar	Avg. Total Effect.
50	80	0.0	0.0	0.0	0.73	0.50	0.66	0.58	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.0	0.0	0.01	0.73	0.50	0.66	0.58	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.0	0.0	0.10	0.73	0.50	0.66	0.58	0.73	0.74	0.74	0.73	0.36	0.19	0.14	0.19	0.61	0.48	0.51	0.50	0.53
50	80	0.0	0.0	1.00	0.73	0.50	0.66	0.58	0.73	0.74	0.74	0.73	0.23	0.11	0.12	0.06	0.56	0.45	0.51	0.46	0.50
50	80	0.0	0.1	0.0	0.73	0.50	0.66	0.58	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.0	0.1	0.01	0.73	0.50	0.66	0.58	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.0	0.1	0.10	0.73	0.50	0.66	0.58	0.72	0.73	0.73	0.72	0.36	0.19	0.14	0.19	0.61	0.47	0.51	0.50	0.52
50	80	0.0	0.1	1.00	0.73	0.50	0.66	0.58	0.72	0.73	0.73	0.72	0.23	0.11	0.12	0.06	0.56	0.45	0.51	0.45	0.49
50	80	0.0	0.5	0.0	0.73	0.50	0.66	0.58	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.46	0.50	0.49	0.52
50	80	0.0	0.5	0.01	0.73	0.50	0.66	0.58	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.46	0.50	0.49	0.52
50	80	0.0	0.5	0.10	0.73	0.50	0.66	0.58	0.69	0.69	0.70	0.69	0.36	0.19	0.14	0.19	0.60	0.46	0.50	0.49	0.51
50	80	0.0	0.5	1.00	0.73	0.50	0.66	0.58	0.69	0.69	0.70	0.69	0.23	0.11	0.12	0.06	0.55	0.43	0.50	0.44	0.48
50	80	0.0	1.0	0.0	0.73	0.50	0.66	0.58	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.45	0.49	0.48	0.50
50	80	0.0	1.0	0.01	0.73	0.50	0.66	0.58	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.45	0.49	0.48	0.50
50	80	0.0	1.0	0.10	0.73	0.50	0.66	0.58	0.66	0.64	0.67	0.65	0.36	0.19	0.14	0.19	0.59	0.44	0.49	0.47	0.50
50	80	0.0	1.0	1.00	0.73	0.50	0.66	0.58	0.66	0.64	0.67	0.65	0.23	0.11	0.12	0.06	0.54	0.42	0.48	0.43	0.47
50	80	0.1	0.0	0.0	0.73	0.48	0.66	0.56	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.1	0.0	0.01	0.73	0.48	0.66	0.56	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.48	0.51	0.50	0.53
50	80	0.1	0.0	0.10	0.73	0.48	0.66	0.55	0.73	0.74	0.74	0.73	0.36	0.19	0.14	0.19	0.61	0.47	0.51	0.49	0.52
50	80	0.1	0.0	1.00	0.73	0.48	0.66	0.56	0.73	0.74	0.74	0.73	0.23	0.11	0.12	0.06	0.56	0.45	0.51	0.45	0.49
50	80	0.1	0.1	0.0	0.73	0.48	0.66	0.56	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.47	0.51	0.49	0.52
50	80	0.1	0.1	0.01	0.73	0.48	0.66	0.56	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.47	0.51	0.49	0.52
50	80	0.1	0.1	0.10	0.73	0.48	0.66	0.56	0.72	0.73	0.73	0.72	0.36	0.19	0.14	0.19	0.61	0.47	0.51	0.49	0.52
50	80	0.1	0.1	1.00	0.73	0.48	0.66	0.56	0.72	0.73	0.73	0.72	0.23	0.11	0.12	0.06	0.56	0.44	0.50	0.45	0.49
50	80	0.1	0.5	0.0	0.73	0.48	0.66	0.56	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.46	0.50	0.48	0.51
50	80	0.1	0.5	0.01	0.73	0.48	0.66	0.56	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.46	0.50	0.48	0.51
50	80	0.1	0.5	0.10	0.73	0.48	0.66	0.56	0.69	0.69	0.70	0.69	0.36	0.19	0.14	0.19	0.60	0.46	0.50	0.48	0.51
50	80	0.1	0.5	1.00	0.73	0.48	0.66	0.56	0.69	0.69	0.70	0.69	0.23	0.11	0.12	0.06	0.55	0.43	0.49	0.44	0.48
50	80	0.1	1.0	0.0	0.73	0.48	0.66	0.56	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.44	0.49	0.47	0.50
50	80	0.1	1.0	0.01	0.73	0.48	0.66	0.56	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.44	0.49	0.47	0.50
50	80	0.1	1.0	0.10	0.73	0.48	0.66	0.55	0.66	0.64	0.67	0.65	0.36	0.19	0.14	0.19	0.58	0.44	0.49	0.47	0.50
50	80	0.1	1.0	1.00	0.73	0.48	0.66	0.56	0.66	0.64	0.67	0.65	0.23	0.11	0.12	0.06	0.54	0.41	0.48	0.42	0.47
50	80	0.5	0.0	0.0	0.71	0.43	0.64	0.47	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.46	0.51	0.47	0.51
50	80	0.5	0.0	0.01	0.71	0.43	0.64	0.47	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.61	0.46	0.51	0.47	0.51
50	80	0.5	0.0	0.10	0.71	0.43	0.64	0.47	0.73	0.74	0.74	0.73	0.36	0.19	0.14	0.19	0.60	0.45	0.51	0.46	0.51
50	80	0.5	0.0	1.00	0.71	0.43	0.64	0.47	0.73	0.74	0.74	0.73	0.23	0.11	0.12	0.06	0.56	0.43	0.50	0.42	0.48
50	80	0.5	0.1	0.0	0.71	0.43	0.64	0.47	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.45	0.51	0.47	0.51
50	80	0.5	0.1	0.01	0.71	0.43	0.64	0.47	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.61	0.45	0.51	0.47	0.51
50	80	0.5	0.1	0.10	0.71	0.43	0.64	0.47	0.72	0.73	0.73	0.72	0.36	0.19	0.14	0.19	0.60	0.45	0.51	0.46	0.51
50	80	0.5	0.1	1.00	0.71	0.43	0.64	0.47	0.72	0.73	0.73	0.72	0.23	0.11	0.12	0.06	0.56	0.42	0.50	0.42	0.48
50	80	0.5	0.5	0.0	0.71	0.43	0.64	0.47	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.44	0.50	0.46	0.50
50	80	0.5	0.5	0.01	0.71	0.43	0.64	0.47	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.60	0.44	0.50	0.46	0.50
50	80	0.5	0.5	0.10	0.71	0.43	0.64	0.47	0.69	0.69	0.70	0.69	0.36	0.19	0.14	0.19	0.59	0.44	0.50	0.45	0.50
50	80	0.5	0.5	1.00	0.71	0.43	0.64	0.47	0.69	0.69	0.70	0.69	0.23	0.11	0.12	0.06	0.55	0.41	0.49	0.41	0.47
50	80	0.5	1.0	0.0	0.71	0.43	0.64	0.47	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.42	0.49	0.44	0.49
50	80	0.5	1.0	0.01	0.71	0.43	0.64	0.47	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.59	0.42	0.49	0.44	0.48
50	80	0.5	1.0	0.10	0.71	0.43	0.64	0.47	0.66	0.64	0.67	0.65	0.36	0.19	0.14	0.19	0.58	0.42	0.49	0.44	0.48
50	80	0.5	1.0	1.00	0.71	0.43	0.64	0.47	0.66	0.64	0.67	0.65	0.23	0.11	0.12	0.06	0.54	0.39	0.48	0.40	0.45
50	80	1.0	0.0	0.0	0.70	0.35	0.63	0.37	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.60	0.43	0.50	0.43	0.49
50	80	1.0	0.0	0.01	0.70	0.35	0.63	0.37	0.73	0.74	0.74	0.73	0.38	0.20	0.14	0.20	0.60	0.43	0.50	0.43	0.49
50	80	1.0	0.0	0.10	0.70	0.35	0.63	0.37	0.73	0.74	0.74	0.73	0.36	0.19	0.14	0.19	0.60	0.43	0.50	0.43	0.49
50	80	1.0	0.0	1.00	0.70	0.35	0.63	0.37	0.73	0.74	0.74	0.73	0.23	0.11	0.12	0.06	0.55	0.40	0.50	0.39	0.46
50	80	1.0	0.1	0.0	0.70	0.35	0.63	0.37	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.60	0.43	0.50	0.43	0.49
50	80	1.0	0.1	0.01	0.70	0.35	0.63	0.37	0.72	0.73	0.73	0.72	0.38	0.20	0.14	0.20	0.60	0.43	0.50	0.43	0.49
50	80	1.0	0.1	0.10	0.70	0.35	0.63	0.37	0.72	0.73	0.73	0.72	0.36	0.19	0.14	0.19	0.60	0.42	0.50	0.43	0.49
50	80	1.0	0.1	1.00	0.70	0.35	0.63	0.37	0.72	0.73	0.73	0.72	0.23	0.11	0.12	0.06	0.55	0.40	0.50	0.38	0.46
50	80	1.0	0.5	0.0	0.70	0.35	0.63	0.37	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.59	0.41	0.49	0.42	0.48
50	80	1.0	0.5	0.01	0.70	0.35	0.63	0.37	0.69	0.69	0.70	0.69	0.38	0.20	0.14	0.20	0.59	0.41	0.49	0.42	0.48
50	80	1.0	0.5	0.10	0.70	0.35	0.63	0.37	0.69	0.69	0.70	0.69	0.36	0.19	0.14	0.19	0.59	0.41	0.49	0.42	0.48
50	80	1.0	0.5	1.00	0.70	0.35	0.63	0.37	0.69	0.69	0.70	0.69	0.23	0.11	0.12	0.06	0.54	0.38	0.49	0.37	0.45
50	80	1.0	1.0	0.0	0.70	0.35	0.63	0.37	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.58	0.40	0.48	0.41	0.47
50	80	1.0	1.0	0.01	0.70	0.35	0.63	0.37	0.66	0.64	0.67	0.65	0.38	0.20	0.14	0.20	0.58	0.40	0.48	0.41	0.47
50	80	1.0	1.0	0.10	0.70	0.35	0.63	0.37	0.66	0.64	0.67	0.65	0.36	0.19	0.14	0.19	0.58	0.39	0.48	0.40	0.46
50	80	1.0	1.0	1.00	0.70	0.35	0.63	0.37	0.66	0.64	0.67	0.65	0.23	0.11	0.12	0.06	0.53	0.37	0.47	0.36	0.43

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
50	50	0.0	0.0	0.0	0.65	0.39	0.56	0.48	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.46
50	50	0.0	0.0	0.01	0.65	0.39	0.56	0.48	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.46
50	50	0.0	0.0	0.10	0.65	0.39	0.56	0.48	0.66	0.71	0.67	0.69	0.24	0.16	0.10	0.12	0.52	0.42	0.44	0.43	0.45
50	50	0.0	0.0	1.00	0.65	0.39	0.56	0.48	0.66	0.71	0.67	0.69	0.17	0.08	0.09	0.05	0.49	0.39	0.44	0.41	0.44
50	50	0.0	0.1	0.0	0.65	0.39	0.56	0.48	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.0	0.1	0.01	0.65	0.39	0.56	0.48	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.0	0.1	0.10	0.65	0.39	0.56	0.48	0.65	0.70	0.66	0.68	0.24	0.16	0.10	0.12	0.52	0.42	0.44	0.43	0.45
50	50	0.0	0.1	1.00	0.65	0.39	0.56	0.48	0.65	0.70	0.66	0.68	0.17	0.08	0.09	0.05	0.49	0.39	0.44	0.41	0.43
50	50	0.0	0.5	0.0	0.65	0.39	0.56	0.48	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.41	0.44	0.42	0.45
50	50	0.0	0.5	0.01	0.65	0.39	0.56	0.48	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.41	0.44	0.42	0.45
50	50	0.0	0.5	0.10	0.65	0.39	0.56	0.48	0.62	0.66	0.64	0.66	0.24	0.16	0.10	0.12	0.51	0.41	0.44	0.42	0.44
50	50	0.0	0.5	1.00	0.65	0.39	0.56	0.48	0.62	0.66	0.64	0.66	0.17	0.08	0.09	0.05	0.48	0.38	0.43	0.40	0.42
50	50	0.0	1.0	0.0	0.65	0.39	0.56	0.48	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.50	0.39	0.43	0.41	0.43
50	50	0.0	1.0	0.01	0.65	0.39	0.56	0.48	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.50	0.39	0.43	0.41	0.43
50	50	0.0	1.0	0.10	0.65	0.39	0.56	0.48	0.59	0.62	0.62	0.63	0.24	0.16	0.10	0.12	0.49	0.39	0.43	0.41	0.43
50	50	0.0	1.0	1.00	0.65	0.39	0.56	0.48	0.59	0.62	0.62	0.63	0.17	0.08	0.09	0.05	0.47	0.36	0.42	0.39	0.41
50	50	0.1	0.0	0.0	0.65	0.38	0.56	0.46	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.1	0.0	0.01	0.65	0.38	0.56	0.46	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.1	0.0	0.10	0.65	0.38	0.56	0.46	0.66	0.71	0.67	0.69	0.24	0.16	0.10	0.12	0.52	0.42	0.44	0.43	0.45
50	50	0.1	0.0	1.00	0.65	0.38	0.56	0.46	0.66	0.71	0.67	0.69	0.17	0.08	0.09	0.05	0.49	0.39	0.44	0.40	0.43
50	50	0.1	0.1	0.0	0.65	0.38	0.56	0.46	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.1	0.1	0.01	0.65	0.38	0.56	0.46	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.42	0.44	0.43	0.45
50	50	0.1	0.1	0.10	0.65	0.38	0.56	0.46	0.65	0.70	0.66	0.68	0.24	0.16	0.10	0.12	0.52	0.42	0.44	0.42	0.45
50	50	0.1	0.1	1.00	0.65	0.38	0.56	0.46	0.65	0.70	0.66	0.68	0.17	0.08	0.09	0.05	0.49	0.39	0.44	0.40	0.43
50	50	0.1	0.5	0.0	0.65	0.38	0.56	0.46	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.41	0.43	0.42	0.44
50	50	0.1	0.5	0.01	0.65	0.38	0.56	0.46	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.41	0.43	0.42	0.44
50	50	0.1	0.5	0.10	0.65	0.38	0.56	0.46	0.62	0.66	0.64	0.66	0.24	0.16	0.10	0.12	0.51	0.40	0.43	0.42	0.44
50	50	0.1	0.5	1.00	0.65	0.38	0.56	0.46	0.62	0.66	0.64	0.66	0.17	0.08	0.09	0.05	0.48	0.38	0.43	0.39	0.42
50	50	0.1	1.0	0.0	0.65	0.38	0.56	0.46	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.50	0.39	0.43	0.41	0.43
50	50	0.1	1.0	0.01	0.65	0.38	0.56	0.46	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.50	0.39	0.43	0.41	0.43
50	50	0.1	1.0	0.10	0.65	0.38	0.56	0.46	0.59	0.62	0.62	0.63	0.24	0.16	0.10	0.12	0.49	0.39	0.43	0.41	0.43
50	50	0.1	1.0	1.00	0.65	0.38	0.56	0.46	0.59	0.62	0.62	0.63	0.17	0.08	0.09	0.05	0.47	0.36	0.42	0.38	0.41
50	50	0.5	0.0	0.0	0.64	0.35	0.54	0.40	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.41	0.44	0.41	0.44
50	50	0.5	0.0	0.01	0.64	0.35	0.54	0.40	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.52	0.41	0.44	0.41	0.44
50	50	0.5	0.0	0.10	0.64	0.35	0.54	0.40	0.66	0.71	0.67	0.69	0.24	0.16	0.10	0.12	0.51	0.41	0.44	0.40	0.44
50	50	0.5	0.0	1.00	0.64	0.35	0.54	0.40	0.66	0.71	0.67	0.69	0.17	0.08	0.09	0.05	0.49	0.38	0.44	0.38	0.42
50	50	0.5	0.1	0.0	0.64	0.35	0.54	0.40	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.41	0.44	0.41	0.44
50	50	0.5	0.1	0.01	0.64	0.35	0.54	0.40	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.52	0.41	0.44	0.41	0.44
50	50	0.5	0.1	0.10	0.64	0.35	0.54	0.40	0.65	0.70	0.66	0.68	0.24	0.16	0.10	0.12	0.51	0.40	0.44	0.40	0.44
50	50	0.5	0.1	1.00	0.64	0.35	0.54	0.40	0.65	0.70	0.66	0.68	0.17	0.08	0.09	0.05	0.49	0.38	0.43	0.38	0.42
50	50	0.5	0.5	0.0	0.64	0.35	0.54	0.40	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.40	0.43	0.40	0.43
50	50	0.5	0.5	0.01	0.64	0.35	0.54	0.40	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.51	0.40	0.43	0.40	0.43
50	50	0.5	0.5	0.10	0.64	0.35	0.54	0.40	0.62	0.66	0.64	0.66	0.24	0.16	0.10	0.12	0.50	0.39	0.43	0.39	0.43
50	50	0.5	0.5	1.00	0.64	0.35	0.54	0.40	0.62	0.66	0.64	0.66	0.17	0.08	0.09	0.05	0.48	0.37	0.43	0.37	0.41
50	50	0.5	1.0	0.0	0.64	0.35	0.54	0.40	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.49	0.38	0.42	0.39	0.42
50	50	0.5	1.0	0.01	0.64	0.35	0.54	0.40	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.49	0.38	0.42	0.39	0.42
50	50	0.5	1.0	0.10	0.64	0.35	0.54	0.40	0.59	0.62	0.62	0.63	0.24	0.16	0.10	0.12	0.49	0.38	0.42	0.38	0.42
50	50	0.5	1.0	1.00	0.64	0.35	0.54	0.40	0.59	0.62	0.62	0.63	0.17	0.08	0.09	0.05	0.47	0.35	0.42	0.36	0.40
50	50	1.0	0.0	0.0	0.63	0.31	0.53	0.32	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.51	0.40	0.43	0.38	0.43
50	50	1.0	0.0	0.01	0.63	0.31	0.53	0.32	0.66	0.71	0.67	0.69	0.25	0.17	0.10	0.13	0.51	0.40	0.43	0.38	0.43
50	50	1.0	0.0	0.10	0.63	0.31	0.53	0.32	0.66	0.71	0.67	0.69	0.24	0.16	0.10	0.12	0.51	0.39	0.43	0.38	0.43
50	50	1.0	0.0	1.00	0.63	0.31	0.53	0.32	0.66	0.71	0.67	0.69	0.17	0.08	0.09	0.05	0.49	0.37	0.43	0.35	0.41
50	50	1.0	0.1	0.0	0.63	0.31	0.53	0.32	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.51	0.39	0.43	0.38	0.43
50	50	1.0	0.1	0.01	0.63	0.31	0.53	0.32	0.65	0.70	0.66	0.68	0.25	0.17	0.10	0.13	0.51	0.39	0.43	0.38	0.43
50	50	1.0	0.1	0.10	0.63	0.31	0.53	0.32	0.65	0.70	0.66	0.68	0.24	0.16	0.10	0.12	0.51	0.39	0.43	0.38	0.43
50	50	1.0	0.1	1.00	0.63	0.31	0.53	0.32	0.65	0.70	0.66	0.68	0.17	0.08	0.09	0.05	0.49	0.36	0.43	0.35	0.41
50	50	1.0	0.5	0.0	0.63	0.31	0.53	0.32	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.50	0.38	0.43	0.37	0.42
50	50	1.0	0.5	0.01	0.63	0.31	0.53	0.32	0.62	0.66	0.64	0.66	0.25	0.17	0.10	0.13	0.50	0.38	0.43	0.37	0.42
50	50	1.0	0.5	0.10	0.63	0.31	0.53	0.32	0.62	0.66	0.64	0.66	0.24	0.16	0.10	0.12	0.50	0.38	0.43	0.37	0.42
50	50	1.0	0.5	1.00	0.63	0.31	0.53	0.32	0.62	0.66	0.64	0.66	0.17	0.08	0.09	0.05	0.48	0.35	0.42	0.34	0.40
50	50	1.0	1.0	0.0	0.63	0.31	0.53	0.32	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.49	0.37	0.42	0.36	0.41
50	50	1.0	1.0	0.01	0.63	0.31	0.53	0.32	0.59	0.62	0.62	0.63	0.25	0.17	0.10	0.13	0.49	0.37	0.42	0.36	0.41
50	50	1.0	1.0	0.10	0.63	0.31	0.53	0.32	0.59	0.62	0.62	0.63	0.24	0.16	0.10	0.12	0.47	0.36	0.42	0.36	0.41
50	50	1.0	1.0	1.00	0.63	0.31	0.53	0.32	0.59	0.62	0.62	0.63	0.17	0.08	0.09	0.05	0.45	0.34	0.41	0.33	0.39

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
100	100	0.0	0.0	0.0	0.89	0.67	0.83	0.74	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.82	0.63	0.73	0.67	0.71
100	100	0.0	0.0	0.01	0.89	0.67	0.83	0.74	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.82	0.63	0.73	0.67	0.71
100	100	0.0	0.0	0.10	0.89	0.67	0.83	0.74	0.90	0.84	0.92	0.86	0.64	0.36	0.42	0.39	0.81	0.62	0.72	0.66	0.71
100	100	0.0	0.0	1.00	0.89	0.67	0.83	0.74	0.90	0.84	0.92	0.86	0.50	0.17	0.35	0.13	0.76	0.56	0.70	0.58	0.65
100	100	0.0	0.1	0.0	0.89	0.67	0.83	0.74	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.81	0.62	0.72	0.67	0.71
100	100	0.0	0.1	0.01	0.89	0.67	0.83	0.74	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.81	0.62	0.72	0.67	0.71
100	100	0.0	0.1	0.10	0.89	0.67	0.83	0.74	0.88	0.82	0.91	0.84	0.64	0.36	0.42	0.39	0.81	0.62	0.72	0.66	0.70
100	100	0.0	0.1	1.00	0.89	0.67	0.83	0.74	0.88	0.82	0.91	0.84	0.50	0.17	0.35	0.13	0.76	0.55	0.70	0.57	0.65
100	100	0.0	0.5	0.0	0.89	0.67	0.83	0.74	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.79	0.60	0.71	0.64	0.69
100	100	0.0	0.5	0.01	0.89	0.67	0.83	0.74	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.79	0.60	0.71	0.64	0.69
100	100	0.0	0.5	0.10	0.89	0.67	0.83	0.74	0.81	0.75	0.88	0.76	0.64	0.36	0.42	0.39	0.78	0.59	0.71	0.63	0.68
100	100	0.0	0.5	1.00	0.89	0.67	0.83	0.74	0.81	0.75	0.88	0.76	0.50	0.17	0.35	0.13	0.73	0.53	0.69	0.55	0.63
100	100	0.0	1.0	0.0	0.89	0.67	0.83	0.74	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.76	0.57	0.70	0.61	0.66
100	100	0.0	1.0	0.01	0.89	0.67	0.83	0.74	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.76	0.57	0.70	0.61	0.66
100	100	0.0	1.0	0.10	0.89	0.67	0.83	0.74	0.72	0.66	0.84	0.67	0.64	0.36	0.42	0.39	0.75	0.56	0.70	0.60	0.65
100	100	0.0	1.0	1.00	0.89	0.67	0.83	0.74	0.72	0.66	0.84	0.67	0.50	0.17	0.35	0.13	0.70	0.50	0.67	0.51	0.60
100	100	0.1	0.0	0.0	0.88	0.63	0.83	0.70	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.82	0.62	0.73	0.66	0.71
100	100	0.1	0.0	0.01	0.88	0.63	0.83	0.70	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.82	0.62	0.73	0.66	0.71
100	100	0.1	0.0	0.10	0.88	0.63	0.83	0.70	0.90	0.84	0.92	0.86	0.64	0.36	0.42	0.39	0.81	0.61	0.72	0.65	0.70
100	100	0.1	0.0	1.00	0.88	0.63	0.83	0.70	0.90	0.84	0.92	0.86	0.50	0.17	0.35	0.13	0.76	0.55	0.70	0.56	0.64
100	100	0.1	0.1	0.0	0.88	0.63	0.83	0.70	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.81	0.61	0.72	0.65	0.70
100	100	0.1	0.1	0.01	0.88	0.63	0.83	0.70	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.81	0.61	0.72	0.65	0.70
100	100	0.1	0.1	0.10	0.88	0.63	0.83	0.70	0.88	0.82	0.91	0.84	0.64	0.36	0.42	0.39	0.80	0.61	0.72	0.64	0.70
100	100	0.1	0.1	1.00	0.88	0.63	0.83	0.70	0.88	0.82	0.91	0.84	0.50	0.17	0.35	0.13	0.76	0.54	0.70	0.56	0.64
100	100	0.1	0.5	0.0	0.88	0.63	0.83	0.70	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.79	0.59	0.71	0.63	0.68
100	100	0.1	0.5	0.01	0.88	0.63	0.83	0.70	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.79	0.59	0.71	0.63	0.68
100	100	0.1	0.5	0.10	0.88	0.63	0.83	0.70	0.81	0.75	0.88	0.76	0.64	0.36	0.42	0.39	0.78	0.58	0.71	0.62	0.67
100	100	0.1	0.5	1.00	0.88	0.63	0.83	0.70	0.81	0.75	0.88	0.76	0.50	0.17	0.35	0.13	0.73	0.52	0.69	0.53	0.62
100	100	0.1	1.0	0.0	0.88	0.63	0.83	0.70	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.76	0.56	0.70	0.60	0.65
100	100	0.1	1.0	0.01	0.88	0.63	0.83	0.70	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.76	0.56	0.70	0.60	0.65
100	100	0.1	1.0	0.10	0.88	0.63	0.83	0.70	0.72	0.66	0.84	0.67	0.64	0.36	0.42	0.39	0.75	0.55	0.70	0.59	0.65
100	100	0.1	1.0	1.00	0.88	0.63	0.83	0.70	0.72	0.66	0.84	0.67	0.50	0.17	0.35	0.13	0.70	0.49	0.67	0.50	0.59
100	100	0.5	0.0	0.0	0.86	0.50	0.81	0.53	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.81	0.57	0.72	0.61	0.68
100	100	0.5	0.0	0.01	0.86	0.50	0.81	0.53	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.81	0.57	0.72	0.61	0.68
100	100	0.5	0.0	0.10	0.86	0.50	0.81	0.53	0.90	0.84	0.92	0.86	0.64	0.36	0.42	0.39	0.80	0.57	0.72	0.60	0.67
100	100	0.5	0.0	1.00	0.86	0.50	0.81	0.53	0.90	0.84	0.92	0.86	0.50	0.17	0.35	0.13	0.76	0.50	0.70	0.51	0.62
100	100	0.5	0.1	0.0	0.86	0.50	0.81	0.53	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.80	0.57	0.72	0.60	0.67
100	100	0.5	0.1	0.01	0.86	0.50	0.81	0.53	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.80	0.57	0.72	0.60	0.67
100	100	0.5	0.1	0.10	0.86	0.50	0.81	0.53	0.88	0.82	0.91	0.84	0.64	0.36	0.42	0.39	0.80	0.56	0.72	0.59	0.67
100	100	0.5	0.1	1.00	0.86	0.50	0.81	0.53	0.88	0.82	0.91	0.84	0.50	0.17	0.35	0.13	0.75	0.50	0.69	0.50	0.61
100	100	0.5	0.5	0.0	0.86	0.50	0.81	0.53	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.78	0.54	0.71	0.57	0.65
100	100	0.5	0.5	0.01	0.86	0.50	0.81	0.53	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.78	0.54	0.71	0.57	0.65
100	100	0.5	0.5	0.10	0.86	0.50	0.81	0.53	0.81	0.75	0.88	0.76	0.64	0.36	0.42	0.39	0.77	0.54	0.71	0.56	0.65
100	100	0.5	0.5	1.00	0.86	0.50	0.81	0.53	0.81	0.75	0.88	0.76	0.50	0.17	0.35	0.13	0.73	0.47	0.68	0.48	0.59
100	100	0.5	1.0	0.0	0.86	0.50	0.81	0.53	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.75	0.51	0.70	0.54	0.63
100	100	0.5	1.0	0.01	0.86	0.50	0.81	0.53	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.75	0.51	0.70	0.54	0.63
100	100	0.5	1.0	0.10	0.86	0.50	0.81	0.53	0.72	0.66	0.84	0.67	0.64	0.36	0.42	0.39	0.74	0.51	0.69	0.53	0.62
100	100	0.5	1.0	1.00	0.86	0.50	0.81	0.53	0.72	0.66	0.84	0.67	0.50	0.17	0.35	0.13	0.70	0.44	0.67	0.45	0.56
100	100	1.0	0.0	0.0	0.84	0.32	0.80	0.33	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.80	0.51	0.72	0.54	0.64
100	100	1.0	0.0	0.01	0.84	0.32	0.80	0.33	0.90	0.84	0.92	0.86	0.66	0.38	0.43	0.42	0.80	0.51	0.72	0.54	0.64
100	100	1.0	0.0	0.10	0.84	0.32	0.80	0.33	0.90	0.84	0.92	0.86	0.64	0.36	0.42	0.39	0.80	0.51	0.71	0.53	0.64
100	100	1.0	0.0	1.00	0.84	0.32	0.80	0.33	0.90	0.84	0.92	0.86	0.50	0.17	0.35	0.13	0.75	0.44	0.69	0.44	0.58
100	100	1.0	0.1	0.0	0.84	0.32	0.80	0.33	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.79	0.51	0.71	0.53	0.64
100	100	1.0	0.1	0.01	0.84	0.32	0.80	0.33	0.88	0.82	0.91	0.84	0.66	0.38	0.43	0.42	0.79	0.51	0.71	0.53	0.64
100	100	1.0	0.1	0.10	0.84	0.32	0.80	0.33	0.88	0.82	0.91	0.84	0.64	0.36	0.42	0.39	0.79	0.50	0.71	0.52	0.63
100	100	1.0	0.1	1.00	0.84	0.32	0.80	0.33	0.88	0.82	0.91	0.84	0.50	0.17	0.35	0.13	0.74	0.44	0.69	0.43	0.58
100	100	1.0	0.5	0.0	0.84	0.32	0.80	0.33	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.77	0.48	0.70	0.51	0.62
100	100	1.0	0.5	0.01	0.84	0.32	0.80	0.33	0.81	0.75	0.88	0.76	0.66	0.38	0.43	0.42	0.77	0.48	0.70	0.51	0.62
100	100	1.0	0.5	0.10	0.84	0.32	0.80	0.33	0.81	0.75	0.88	0.76	0.64	0.36	0.42	0.39	0.77	0.48	0.70	0.50	0.61
100	100	1.0	0.5	1.00	0.84	0.32	0.80	0.33	0.81	0.75	0.88	0.76	0.50	0.17	0.35	0.13	0.72	0.41	0.68	0.41	0.56
100	100	1.0	1.0	0.0	0.84	0.32	0.80	0.33	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.74	0.45	0.69	0.47	0.59
100	100	1.0	1.0	0.01	0.84	0.32	0.80	0.33	0.72	0.66	0.84	0.67	0.66	0.38	0.43	0.42	0.74	0.45	0.69	0.47	0.59
100	100	1.0	1.0	0.10	0.84	0.32	0.80	0.33	0.72	0.66	0.84	0.67	0.64	0.36	0.42	0.39	0.74	0.45	0.69	0.46	0.58
100	100	1.0	1.0	1.00	0.84	0.32	0.80	0.33	0.72	0.66	0.84	0.67	0.50	0.17	0.35	0.13	0.69	0.38	0.66	0.38	0.53

Buoys per Area	Relia-bility (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
100	80	0.0	0.0	0.0	0.80	0.61	0.76	0.71	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.58	0.67	0.62	0.65
100	80	0.0	0.0	0.01	0.80	0.61	0.76	0.71	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.58	0.67	0.62	0.65
100	80	0.0	0.0	0.10	0.80	0.61	0.76	0.71	0.82	0.81	0.86	0.81	0.55	0.29	0.37	0.31	0.73	0.57	0.67	0.61	0.64
100	80	0.0	0.0	1.00	0.80	0.61	0.76	0.71	0.82	0.81	0.86	0.81	0.42	0.13	0.32	0.09	0.68	0.52	0.65	0.54	0.60
100	80	0.0	0.1	0.0	0.80	0.61	0.76	0.71	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.73	0.57	0.66	0.62	0.65
100	80	0.0	0.1	0.01	0.80	0.61	0.76	0.71	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.73	0.57	0.66	0.61	0.65
100	80	0.0	0.1	0.10	0.80	0.61	0.76	0.71	0.81	0.79	0.85	0.79	0.55	0.29	0.37	0.31	0.72	0.57	0.66	0.61	0.64
100	80	0.0	0.1	1.00	0.80	0.61	0.76	0.71	0.81	0.79	0.85	0.79	0.42	0.13	0.32	0.09	0.68	0.51	0.64	0.53	0.59
100	80	0.0	0.5	0.0	0.80	0.61	0.76	0.71	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.71	0.55	0.65	0.59	0.63
100	80	0.0	0.5	0.01	0.80	0.61	0.76	0.71	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.71	0.55	0.65	0.59	0.63
100	80	0.0	0.5	0.10	0.80	0.61	0.76	0.71	0.75	0.72	0.81	0.73	0.55	0.29	0.37	0.31	0.70	0.54	0.65	0.59	0.62
100	80	0.0	0.5	1.00	0.80	0.61	0.76	0.71	0.75	0.72	0.81	0.73	0.42	0.13	0.32	0.09	0.66	0.49	0.63	0.51	0.57
100	80	0.0	1.0	0.0	0.80	0.61	0.76	0.71	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.69	0.52	0.64	0.57	0.60
100	80	0.0	1.0	0.01	0.80	0.61	0.76	0.71	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.69	0.52	0.64	0.57	0.60
100	80	0.0	1.0	0.10	0.80	0.61	0.76	0.71	0.69	0.64	0.77	0.65	0.55	0.29	0.37	0.31	0.68	0.51	0.64	0.56	0.60
100	80	0.0	1.0	1.00	0.80	0.61	0.76	0.71	0.69	0.64	0.77	0.65	0.42	0.13	0.32	0.09	0.64	0.46	0.62	0.48	0.55
100	80	0.1	0.0	0.0	0.80	0.58	0.76	0.67	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.57	0.67	0.61	0.64
100	80	0.1	0.0	0.01	0.80	0.58	0.76	0.67	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.57	0.67	0.61	0.64
100	80	0.1	0.0	0.10	0.80	0.58	0.76	0.67	0.82	0.81	0.86	0.81	0.55	0.29	0.37	0.31	0.72	0.56	0.66	0.60	0.64
100	80	0.1	0.0	1.00	0.80	0.58	0.76	0.67	0.82	0.81	0.86	0.81	0.42	0.13	0.32	0.09	0.68	0.51	0.65	0.53	0.59
100	80	0.1	0.1	0.0	0.80	0.58	0.76	0.67	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.73	0.56	0.66	0.60	0.64
100	80	0.1	0.1	0.01	0.80	0.58	0.76	0.67	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.73	0.56	0.66	0.60	0.64
100	80	0.1	0.1	0.10	0.80	0.58	0.76	0.67	0.81	0.79	0.85	0.79	0.55	0.29	0.37	0.31	0.72	0.56	0.66	0.60	0.63
100	80	0.1	0.1	1.00	0.80	0.58	0.76	0.67	0.81	0.79	0.85	0.79	0.42	0.13	0.32	0.09	0.68	0.50	0.64	0.52	0.59
100	80	0.1	0.5	0.0	0.80	0.58	0.76	0.67	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.71	0.54	0.65	0.58	0.62
100	80	0.1	0.5	0.01	0.80	0.58	0.76	0.67	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.71	0.54	0.65	0.58	0.62
100	80	0.1	0.5	0.10	0.80	0.58	0.76	0.67	0.75	0.72	0.81	0.73	0.55	0.29	0.37	0.31	0.70	0.53	0.65	0.57	0.62
100	80	0.1	0.5	1.00	0.80	0.58	0.76	0.67	0.75	0.72	0.81	0.73	0.42	0.13	0.32	0.09	0.66	0.48	0.63	0.50	0.57
100	80	0.1	1.0	0.0	0.80	0.58	0.76	0.67	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.69	0.51	0.64	0.56	0.60
100	80	0.1	1.0	0.01	0.80	0.58	0.76	0.67	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.69	0.51	0.64	0.56	0.60
100	80	0.1	1.0	0.10	0.80	0.58	0.76	0.67	0.69	0.64	0.77	0.65	0.55	0.29	0.37	0.31	0.68	0.51	0.63	0.55	0.59
100	80	0.1	1.0	1.00	0.80	0.58	0.76	0.67	0.69	0.64	0.77	0.65	0.42	0.13	0.32	0.09	0.64	0.45	0.62	0.47	0.55
100	80	0.5	0.0	0.0	0.78	0.47	0.75	0.53	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.53	0.66	0.56	0.62
100	80	0.5	0.0	0.01	0.78	0.47	0.75	0.53	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.73	0.53	0.66	0.56	0.62
100	80	0.5	0.0	0.10	0.78	0.47	0.75	0.53	0.82	0.81	0.86	0.81	0.55	0.29	0.37	0.31	0.72	0.53	0.66	0.55	0.62
100	80	0.5	0.0	1.00	0.78	0.47	0.75	0.53	0.82	0.81	0.86	0.81	0.42	0.13	0.32	0.09	0.68	0.47	0.64	0.48	0.57
100	80	0.5	0.1	0.0	0.78	0.47	0.75	0.53	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.72	0.53	0.66	0.56	0.62
100	80	0.5	0.1	0.01	0.78	0.47	0.75	0.53	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.72	0.53	0.66	0.56	0.62
100	80	0.5	0.1	0.10	0.78	0.47	0.75	0.53	0.81	0.79	0.85	0.79	0.55	0.29	0.37	0.31	0.72	0.52	0.66	0.55	0.61
100	80	0.5	0.1	1.00	0.78	0.47	0.75	0.53	0.81	0.79	0.85	0.79	0.42	0.13	0.32	0.09	0.67	0.47	0.64	0.47	0.56
100	80	0.5	0.5	0.0	0.78	0.47	0.75	0.53	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.70	0.50	0.65	0.54	0.60
100	80	0.5	0.5	0.01	0.78	0.47	0.75	0.53	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.70	0.50	0.65	0.54	0.60
100	80	0.5	0.5	0.10	0.78	0.47	0.75	0.53	0.75	0.72	0.81	0.73	0.55	0.29	0.37	0.31	0.70	0.50	0.65	0.53	0.59
100	80	0.5	0.5	1.00	0.78	0.47	0.75	0.53	0.75	0.72	0.81	0.73	0.42	0.13	0.32	0.09	0.65	0.44	0.63	0.45	0.55
100	80	0.5	1.0	0.0	0.78	0.47	0.75	0.53	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.68	0.48	0.63	0.51	0.58
100	80	0.5	1.0	0.01	0.78	0.47	0.75	0.53	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.68	0.48	0.63	0.51	0.58
100	80	0.5	1.0	0.10	0.78	0.47	0.75	0.53	0.69	0.64	0.77	0.65	0.55	0.29	0.37	0.31	0.68	0.47	0.63	0.50	0.57
100	80	0.5	1.0	1.00	0.78	0.47	0.75	0.53	0.69	0.64	0.77	0.65	0.42	0.13	0.32	0.09	0.63	0.42	0.61	0.43	0.52
100	80	1.0	0.0	0.0	0.77	0.34	0.74	0.36	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.72	0.49	0.66	0.50	0.59
100	80	1.0	0.0	0.01	0.77	0.34	0.74	0.36	0.82	0.81	0.86	0.81	0.57	0.31	0.38	0.34	0.72	0.49	0.66	0.50	0.59
100	80	1.0	0.0	0.10	0.77	0.34	0.74	0.36	0.82	0.81	0.86	0.81	0.55	0.29	0.37	0.31	0.72	0.48	0.66	0.50	0.59
100	80	1.0	0.0	1.00	0.77	0.34	0.74	0.36	0.82	0.81	0.86	0.81	0.42	0.13	0.32	0.09	0.67	0.43	0.64	0.42	0.54
100	80	1.0	0.1	0.0	0.77	0.34	0.74	0.36	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.72	0.48	0.66	0.50	0.59
100	80	1.0	0.1	0.01	0.77	0.34	0.74	0.36	0.81	0.79	0.85	0.79	0.57	0.31	0.38	0.34	0.72	0.48	0.66	0.50	0.59
100	80	1.0	0.1	0.10	0.77	0.34	0.74	0.36	0.81	0.79	0.85	0.79	0.55	0.29	0.37	0.31	0.71	0.48	0.66	0.49	0.58
100	80	1.0	0.1	1.00	0.77	0.34	0.74	0.36	0.81	0.79	0.85	0.79	0.42	0.13	0.32	0.09	0.67	0.42	0.64	0.42	0.54
100	80	1.0	0.5	0.0	0.77	0.34	0.74	0.36	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.70	0.46	0.65	0.48	0.57
100	80	1.0	0.5	0.01	0.77	0.34	0.74	0.36	0.75	0.72	0.81	0.73	0.57	0.31	0.38	0.34	0.70	0.46	0.65	0.48	0.57
100	80	1.0	0.5	0.10	0.77	0.34	0.74	0.36	0.75	0.72	0.81	0.73	0.55	0.29	0.37	0.31	0.69	0.45	0.64	0.47	0.57
100	80	1.0	0.5	1.00	0.77	0.34	0.74	0.36	0.75	0.72	0.81	0.73	0.42	0.13	0.32	0.09	0.65	0.40	0.63	0.39	0.52
100	80	1.0	1.0	0.0	0.77	0.34	0.74	0.36	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.68	0.43	0.63	0.45	0.55
100	80	1.0	1.0	0.01	0.77	0.34	0.74	0.36	0.69	0.64	0.77	0.65	0.57	0.31	0.38	0.34	0.68	0.43	0.63	0.45	0.55
100	80	1.0	1.0	0.10	0.77	0.34	0.74	0.36	0.69	0.64	0.77	0.65	0.55	0.29	0.37	0.31	0.67	0.42	0.63	0.44	0.54
100	80	1.0	1.0	1.00	0.77	0.34	0.74	0.36	0.69	0.64	0.77	0.65	0.42	0.13	0.32	0.09	0.63	0.37	0.61	0.37	0.53

Buoys per Area	Reliability (%)	Standard Deviations of Sys. Data Errors			SLP Effectiveness				SAT Effectiveness				SST Effectiveness				Effectiveness				Avg. Total Effect.
					Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		Pacific		Atlantic		
		σ_{SLP}	σ_{SAT}	σ_{SST}	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	HiVar	LoVar	
100	50	0.0	0.0	0.0	0.72	0.50	0.67	0.63	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.64	0.50	0.59	0.55	0.57
100	50	0.0	0.0	0.01	0.72	0.50	0.67	0.63	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.64	0.50	0.59	0.55	0.57
100	50	0.0	0.0	0.10	0.72	0.50	0.67	0.63	0.75	0.76	0.78	0.77	0.42	0.23	0.31	0.24	0.63	0.50	0.59	0.55	0.57
100	50	0.0	0.0	1.00	0.72	0.50	0.67	0.63	0.75	0.76	0.78	0.77	0.29	0.10	0.27	0.06	0.59	0.45	0.57	0.49	0.53
100	50	0.0	0.1	0.0	0.72	0.50	0.67	0.63	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.50	0.59	0.55	0.57
100	50	0.0	0.1	0.01	0.72	0.50	0.67	0.63	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.50	0.59	0.55	0.57
100	50	0.0	0.1	0.10	0.72	0.50	0.67	0.63	0.74	0.75	0.77	0.76	0.42	0.23	0.31	0.24	0.63	0.49	0.59	0.54	0.56
100	50	0.0	0.1	1.00	0.72	0.50	0.67	0.63	0.74	0.75	0.77	0.76	0.29	0.10	0.27	0.06	0.58	0.45	0.57	0.48	0.52
100	50	0.0	0.5	0.0	0.72	0.50	0.67	0.63	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.48	0.58	0.53	0.55
100	50	0.0	0.5	0.01	0.72	0.50	0.67	0.63	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.48	0.58	0.53	0.55
100	50	0.0	0.5	0.10	0.72	0.50	0.67	0.63	0.69	0.69	0.74	0.70	0.42	0.23	0.31	0.24	0.61	0.48	0.58	0.52	0.55
100	50	0.0	0.5	1.00	0.72	0.50	0.67	0.63	0.69	0.69	0.74	0.70	0.29	0.10	0.27	0.06	0.57	0.43	0.55	0.46	0.51
100	50	0.0	1.0	0.0	0.72	0.50	0.67	0.63	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.46	0.56	0.51	0.53
100	50	0.0	1.0	0.01	0.72	0.50	0.67	0.63	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.46	0.56	0.51	0.53
100	50	0.0	1.0	0.10	0.72	0.50	0.67	0.63	0.64	0.62	0.70	0.63	0.42	0.23	0.31	0.24	0.60	0.45	0.56	0.50	0.53
100	50	0.0	1.0	1.00	0.72	0.50	0.67	0.63	0.64	0.62	0.70	0.63	0.29	0.10	0.27	0.06	0.55	0.41	0.55	0.44	0.49
100	50	0.1	0.0	0.0	0.72	0.48	0.67	0.60	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.64	0.50	0.59	0.55	0.57
100	50	0.1	0.0	0.01	0.72	0.48	0.67	0.60	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.64	0.50	0.59	0.55	0.57
100	50	0.1	0.0	0.10	0.72	0.48	0.67	0.60	0.75	0.76	0.78	0.77	0.42	0.23	0.31	0.24	0.63	0.49	0.59	0.54	0.56
100	50	0.1	0.0	1.00	0.72	0.48	0.67	0.60	0.75	0.76	0.78	0.77	0.29	0.10	0.27	0.06	0.59	0.45	0.57	0.48	0.52
100	50	0.1	0.1	0.0	0.72	0.48	0.67	0.60	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.49	0.59	0.54	0.56
100	50	0.1	0.1	0.01	0.72	0.48	0.67	0.60	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.49	0.59	0.54	0.56
100	50	0.1	0.1	0.10	0.72	0.48	0.67	0.60	0.74	0.75	0.77	0.76	0.42	0.23	0.31	0.24	0.63	0.49	0.59	0.53	0.56
100	50	0.1	0.1	1.00	0.72	0.48	0.67	0.60	0.74	0.75	0.77	0.76	0.29	0.10	0.27	0.06	0.58	0.44	0.57	0.47	0.52
100	50	0.1	0.5	0.0	0.72	0.48	0.67	0.60	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.48	0.58	0.52	0.55
100	50	0.1	0.5	0.01	0.72	0.48	0.67	0.60	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.47	0.58	0.52	0.55
100	50	0.1	0.5	0.10	0.72	0.48	0.67	0.60	0.69	0.69	0.74	0.70	0.42	0.23	0.31	0.24	0.61	0.47	0.57	0.52	0.54
100	50	0.1	0.5	1.00	0.72	0.48	0.67	0.60	0.69	0.69	0.74	0.70	0.29	0.10	0.27	0.06	0.57	0.43	0.56	0.46	0.50
100	50	0.1	1.0	0.0	0.72	0.48	0.67	0.60	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.45	0.56	0.50	0.53
100	50	0.1	1.0	0.01	0.72	0.48	0.67	0.60	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.45	0.56	0.50	0.53
100	50	0.1	1.0	0.10	0.72	0.48	0.67	0.60	0.64	0.62	0.70	0.63	0.42	0.23	0.31	0.24	0.60	0.45	0.56	0.49	0.53
100	50	0.1	1.0	1.00	0.72	0.48	0.67	0.60	0.64	0.62	0.70	0.63	0.29	0.10	0.27	0.06	0.55	0.40	0.55	0.43	0.48
100	50	0.5	0.0	0.0	0.71	0.42	0.65	0.50	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.63	0.48	0.59	0.51	0.55
100	50	0.5	0.0	0.01	0.71	0.42	0.65	0.50	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.63	0.48	0.59	0.51	0.55
100	50	0.5	0.0	0.10	0.71	0.42	0.65	0.50	0.75	0.76	0.78	0.77	0.42	0.23	0.31	0.24	0.63	0.47	0.58	0.51	0.55
100	50	0.5	0.0	1.00	0.71	0.42	0.65	0.50	0.75	0.76	0.78	0.77	0.29	0.10	0.27	0.06	0.58	0.43	0.57	0.45	0.51
100	50	0.5	0.1	0.0	0.71	0.42	0.65	0.50	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.47	0.58	0.51	0.55
100	50	0.5	0.1	0.01	0.71	0.42	0.65	0.50	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.47	0.58	0.51	0.55
100	50	0.5	0.1	0.10	0.71	0.42	0.65	0.50	0.74	0.75	0.77	0.76	0.42	0.23	0.31	0.24	0.63	0.47	0.58	0.50	0.54
100	50	0.5	0.1	1.00	0.71	0.42	0.65	0.50	0.74	0.75	0.77	0.76	0.29	0.10	0.27	0.06	0.58	0.42	0.57	0.44	0.50
100	50	0.5	0.5	0.0	0.71	0.42	0.65	0.50	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.45	0.57	0.49	0.53
100	50	0.5	0.5	0.01	0.71	0.42	0.65	0.50	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.62	0.45	0.57	0.49	0.53
100	50	0.5	0.5	0.10	0.71	0.42	0.65	0.50	0.69	0.69	0.74	0.70	0.42	0.23	0.31	0.24	0.61	0.45	0.57	0.48	0.53
100	50	0.5	0.5	1.00	0.71	0.42	0.65	0.50	0.69	0.69	0.74	0.70	0.29	0.10	0.27	0.06	0.57	0.40	0.56	0.42	0.49
100	50	0.5	1.0	0.0	0.71	0.42	0.65	0.50	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.43	0.56	0.47	0.51
100	50	0.5	1.0	0.01	0.71	0.42	0.65	0.50	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.60	0.43	0.56	0.47	0.51
100	50	0.5	1.0	0.10	0.71	0.42	0.65	0.50	0.64	0.62	0.70	0.63	0.42	0.23	0.31	0.24	0.59	0.42	0.56	0.46	0.51
100	50	0.5	1.0	1.00	0.71	0.42	0.65	0.50	0.64	0.62	0.70	0.63	0.29	0.10	0.27	0.06	0.55	0.38	0.54	0.40	0.47
100	50	1.0	0.0	0.0	0.70	0.33	0.64	0.38	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.63	0.45	0.58	0.47	0.53
100	50	1.0	0.0	0.01	0.70	0.33	0.64	0.38	0.75	0.76	0.78	0.77	0.44	0.25	0.32	0.26	0.63	0.45	0.58	0.47	0.53
100	50	1.0	0.0	0.10	0.70	0.33	0.64	0.38	0.75	0.76	0.78	0.77	0.42	0.23	0.31	0.24	0.63	0.44	0.58	0.46	0.53
100	50	1.0	0.0	1.00	0.70	0.33	0.64	0.38	0.75	0.76	0.78	0.77	0.29	0.10	0.27	0.06	0.58	0.40	0.56	0.40	0.49
100	50	1.0	0.1	0.0	0.70	0.33	0.64	0.38	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.44	0.58	0.47	0.53
100	50	1.0	0.1	0.01	0.70	0.33	0.64	0.38	0.74	0.75	0.77	0.76	0.44	0.25	0.32	0.26	0.63	0.44	0.58	0.47	0.53
100	50	1.0	0.1	0.10	0.70	0.33	0.64	0.38	0.74	0.75	0.77	0.76	0.42	0.23	0.31	0.24	0.62	0.44	0.58	0.46	0.53
100	50	1.0	0.1	1.00	0.70	0.33	0.64	0.38	0.74	0.75	0.77	0.76	0.29	0.10	0.27	0.06	0.58	0.39	0.56	0.40	0.48
100	50	1.0	0.5	0.0	0.70	0.33	0.64	0.38	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.61	0.42	0.57	0.45	0.51
100	50	1.0	0.5	0.01	0.70	0.33	0.64	0.38	0.69	0.69	0.74	0.70	0.44	0.25	0.32	0.26	0.61	0.42	0.57	0.45	0.51
100	50	1.0	0.5	0.10	0.70	0.33	0.64	0.33	0.69	0.69	0.74	0.70	0.42	0.23	0.31	0.24	0.61	0.42	0.57	0.44	0.51
100	50	1.0	0.5	1.00	0.70	0.33	0.64	0.38	0.69	0.69	0.74	0.70	0.29	0.10	0.27	0.06	0.56	0.37	0.55	0.38	0.47
100	50	1.0	1.0	0.0	0.70	0.33	0.64	0.38	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.59	0.40	0.55	0.42	0.49
100	50	1.0	1.0	0.01	0.70	0.33	0.64	0.38	0.64	0.62	0.70	0.63	0.44	0.25	0.32	0.26	0.59	0.40	0.55	0.42	0.49
100	50	1.0	1.0	0.10	0.70	0.33	0.64	0.38	0.64	0.62	0.70	0.63	0.42	0.23	0.31	0.24	0.59	0.40	0.55	0.42	0.49
100	50	1.0	1.0	1.00	0.70	0.33	0.64	0.38	0.64	0.62	0.70	0.63	0.29	0.10	0.27	0.06	0.54	0.35	0.54	0.36	0.45