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GEOS-C GROUND TRUTH

PROGRAM DESCRIPTION

NASA WALLOPS FLIGHT CENTER

WALLOPS ISLAND, VA 23337

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FOREWORD

This document consolidates into a single publication, a description of the extensive efforts put forth by NASA, including inputs from both NOAA and DOD, to develop the various models and plans for in-situ measurements required to calibrate and evaluate the altitude and sea state measurement capabilities of the GEOS-C Radar Altimeter.

The stated objective of this document is to provide a broad, in-depth description of the planned GEOS-C Ground Truth Program Plan developed for the purpose of calibration and evaluation of the Radar Altimeter.

It is readily apparent upon examination of the document that coverage in some areas is much more extensive and detailed than in other areas. The merits of the publication, however, should be judged on a qualitative basis, rather than on the sheer bulk of material found in some sections as opposed to the limited amount of information in other sections.

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1.0 INTRODUCTION

The term "ground truth" originated in the field of aerial photography, and if applied strictly, means direct "in situ" data taken for verification of remote measurements. For satellite applications, the definition has been extended to encompass all reference data (including remote sensing by aircraft and, in some cases, even other statellites). With regard to Geodynamics Experimental Ocean Satellite (GEOS-C) ground truth, this will include all ocean surface features and atmospheric parameters which must be addressed to both calibrate the altitude measurements and to verify the sea state measurement capability of the Radar Altimeter. These features include the marine geoid, pelagic tides, solid earth tides, geostrophic heights of ocean currents, atmospheric loading, sea water density variation, tropospheric refraction, combined sea state, and synoptic weather. Some of these features can be mathematically modeled in advance, while others require measurements to be taken at the same time and the same geographic position as the satellite altimeter measurements.

1.1 PHILOSOPHY OF EFFORT.

The Ground Truth Effort for GEOS-C is directed towards: (a) providing the Altimeter Experiment Manager with a Ground Truth Calibration Data Package (CDP); and (b) providing the various Principal Investigators with a Ground Truth Investigator Package (IDP). It is also the intent of this effort to provide a Data Source Catalog (DSC) to describe, and serve as a contact point for, other ground truth data not necessarily contained in the CDP and/or IDP which may be of interest to GEOS-C Principal Investigators.

The primary purpose of the Calibration Data Package (CDP) is to compile all Ground Truth data considered to be necessary for the calibration of the Radar Altimeter. The basic intent, therefore, is to consolidate, into a single comprehensive data package, all of the information to be used in calibrating the sea state measuring capability of the altimeter as well as measuring potential range bias caused by sea state. More detailed information regarding the CDP is contained in Section 4 of this document.

The IDP makes available to the Principal Investigators all Ground Truth data collected and processed during the Phase B calibration effort as well as any secondary information of possible interest which may have been gathered during the course of these operations or that has been received from other data sources. It is emphasized that the GEOS-C project is not obligated to process all collected data nor is it committed to making further investigative efforts on behalf of the Principal Investigators to obtain data not presently available, or which may still not be available after the completion of the calibration efforts.

The Data Source Catalog (DSC) is intended to give a description of the various data sources for other ground truth information, not necessarily included in the CDP or IDP, which may be of interest to GEOS-C Principal Investigators. Since the GEOS-C project itself cannot adequately judge all scientific fields associated with GEOS-C, it was decided that the inclusion of a Data Source Catalog would perhaps at least give an investigator a head start in researching allied and related information germane to the Ground Truth effort or his own particular area of concern.

The ground truth effort will consist of both initial calibration and continuing spot check calibration. The initial calibration will be accomplished within the scheduled Phase B operational period following stabilization. During this time period a concentrated effort will be made to obtain the complete spectrum of sea states up to 30 feet ($H_{1/3}$). The spot check calibration is presently planned to be once per month for the following nine months and will be supported with ground truth missions.

The overall ground truth effort is being directed towards two broad categories of sea surface topography - short wavelength features and long wavelength features. The long wavelength features include the geoid, pelagic tides, solid earth tides, atmospheric loading effects, sea water density variations, and geostrophic heights associated with ocean currents. The short wavelength features include sea and swell and are usually referred to as combined sea state.

Real-time ground truth for GEOS-C will concentrate on short wave length features and synoptic weather data since most of the long wave length features involve mathematical modeling efforts and thus do not require real-time monitoring.

Figure 1-1 presents a top-level flow diagram of the entire Ground Truth Data Handling system used at NASA's Wallops Flight Center facilities.

1.2 SCOPE.

This document consolidates, under one cover, the various planning information, including inputs from both DOD and NOAA, needed to verify the altitude and sea state measurements taken by the GEOS-C program radar altimeter. Methods, procedures, and forms for gathering and evaluating the various types of required ground truth data acquired from diverse sources such as aircraft, environmental buoys, Coast Guard stations, Ocean station vessels, etc. are provided in this document. Voluminous descriptive material, thoroughly supported by back-up data supplied by tabular material, charts, diagrams, maps, overlays, computer printouts, etc., has been provided for this purpose in Sections 2 through 8, Appendices A through D, and the remainder of this section.

In addition to the introductory statements and the Ground Truth data flow diagram presented in Figure 1-1, Section 1 gives a complete description and top-level breakdown of the project organization as well as the responsibilities of key personnel within the project; organizational structure is broken down both by agency and by personnel positions.

Section 2.1 introduces the GEOS-C program and provides the reader with a brief synopsis of its structure and planned functions. The GEOS-C Mission Profile is described in some detail, including each of its four operational phases (for the purposes of this document, primary emphasis is placed on Phase B).* Section 2.2 furnishes details on the scheduling effort entailed for the GEOS-C altimeter calibration mission. This section also briefly delineates the sets of data (e.g., altimeter, SSE, C-band radar, laser, doppler, ground

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* Experimental Systems Calibration and Evaluation.

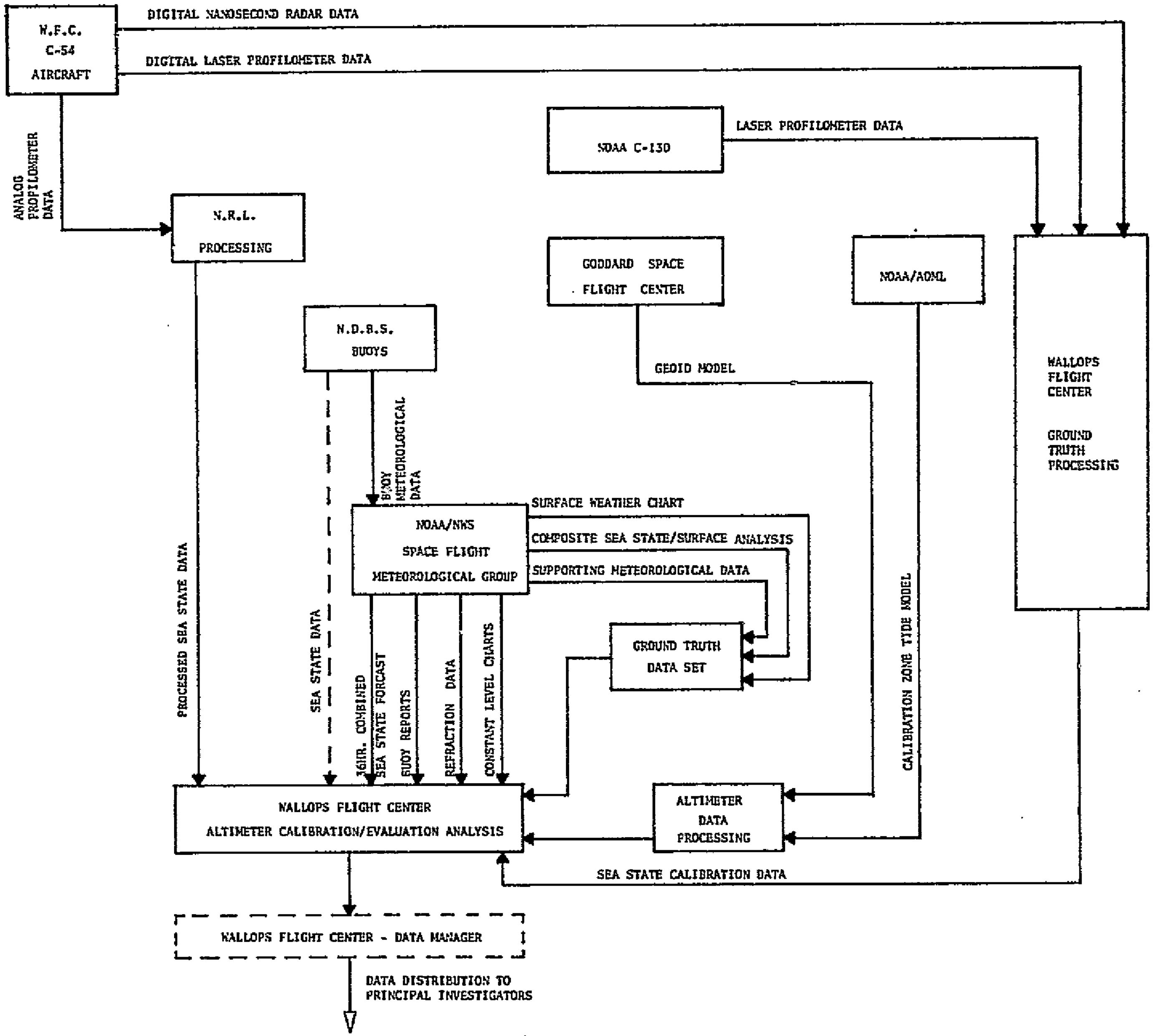

Figure 1-1. Ground Truth Data Flow Diagram

truth, etc.) to be collected during the 10-revolution calibration effort, and the procedures to be followed after collection of these data. Much of the information contained in this section was extracted from the GEOS-C Mission Plan, prepared by the GEOS-C project group at Wallops Flight Center in May 1974; it is suggested, therefore, that the reader familiarize himself with that document since it provides a much more detailed and comprehensive description of the overall program.

Ground truth parameters applicable to GEOS-C altimetry are presented in Section 3. For purposes of this document, the parameters were divided into the following major categories:

a. Long Wavelength Features (e.g., geoid, pelagic tides, solid earth tides, atmospheric pressure loading, ocean current geostrophic heights, etc.)

b. Short Wavelength Features (combined sea state)

c. Synoptic Weather Data Applicable to Tropospheric Refraction Corrections (atmospheric pressure, temperature, relative humidity)

d. Other Weather Data (cloud cover, wind fields, precipitation, etc.).

A brief description of each parameter is provided (e.g., parameter definition, program use, applicable mathematical models, etc.).

Section 4 supplies detailed information pertaining to the Calibration Data Package (CDP), which is a compilation of Ground Truth Data considered necessary for the calibration of the Radar Altimeter. Other supporting and miscellaneous data provided include: several mathematical models used in calculating certain long wavelength data parameters (e.g., geoid, palagic tides, etc.); an explanation of Satellite Meteorological Group (SMG) calibration products; samples of a typical SMG ground truth data set (e.g., related meteorological charts and analyses, satellite photographs, etc.); and descriptive material describing the contents and purpose of the CDP.

Section 5 contains general information pertaining to the Investigator Data Package (IDP) including its purpose and its contents. A listing is provided of the various types of information (e.g., unprocessed Nanosecond Radar and Laser Profilometer data and elements of the Calibration Data Package) available to the Principal Investigators within the package.

Ground truth operations are covered principally in Section 6, which includes discussions on the various operations involved in gathering and measuring observable data for the calibration effort. Prime emphasis is placed on aircraft operations since aircraft are considered to be the most feasible means for collecting Ground Truth data for the calibration effort. A brief description of three general flight profiles is included plus a top level delineation of specific inflight instrumentation requirements (e.g., Nanosecond Radar, Laser Profilometer Inertial Navigation System).

Section 7 provides short functional briefs, supported by functional diagrams, of C-54 instrumentation to be used in Ground Truth data acquisition for the GEOS-C Radar Altimeter calibration program. The discussion covers the prime sensors (i.e., Nanosecond Radar and Laser Profilometer) plus other assorted instrumentation such as the Inertial Navigation System, radiometers, refractometer, and the like.

Section 8 contains the Data Source Catalog which describes the various data sources for Ground Truth information not necessarily included in either the CDP or IDP. Included in this section are the following:

- A comprehensive list of data sources for various data products which may be of benefit to Principal Investigators.

- A description of the content and availability of specific data products included in the Data Source List.

- A bibliography which lists all reference material used in the compilation of this document or which is related to the subject matter presented herein.

This section also presents samples of various satellite products (e.g., satellite photographs) as well as examples of analogous activities/experiments (e.g., NOAA Fleet Sailing Schedules and major oceanographic experiments conducted on a world-wide basis).

Appendices A through D contain supporting and supplemental data necessary to gain a complete understanding of the material contained in Sections 2 through 8 plus any other documentation deemed to be of interest to the reader and which may not be included in the basic document. Following is a brief highlight of each appendix.

Appendix A - Appendix A is a "personal correspondence" technical note prepared by Dr. Davidson Chen which explains the theory and equations involved in geostrophic height calculations as well as typical expected heights calculated from nominal Gulf Stream data.

Appendix B - Appendix B contains excerpts from the refraction studies performed at Wallops Flight Center. Included are comparisons of various mathematical refraction correction models as well as an analysis of the magnitude of the errors which can be introduced by utilizing monthly surface meteorological data as inputs.

Appendix C - Operational and performance data pertaining to the C-54G aircraft assigned to Wallops are contained in this appendix. While not all of this information may be completely relevant (except as general background material), certain portions are of very much interest to the data gatherer - in particular the endurance of the aircraft, its speed and cruising range (e.g., coverage area radius), location and type of instrumentation carried, amount of available working space, etc.

Appendix D - Appendix D presents samples and coding requirements for the following synoptic weather observation forms: (a) NOAA Form 72-1, Ship's Weather Observations; (b) NOAA Form 72-5a, Marine Coastal Weather Log - Ship Station; and (c) NOAA Form 72-5b, Marine Coastal Weather Log - Coastal Station.

1.3 ORGANIZATION AND RESPONSIBILITY.

1.3.1 GENERAL. The GEOS-C spacecraft is intended to service principal investigators and scientific observers around the world. To accomplish this the organization of participants must form a cooperative balance between observers, investigators, and the operational, functional servicing of the spacecraft. Management responsibilities and procedures are in accordance with NMI 7120.1 dated 4 May 1970, entitled "Approval and Implementation of Office of Space Science and Applications Research and Development Projects".

1.3.2 ORGANIZATION RESPONSIBILITIES.

a. NASA Headquarters - The Associate Administrator of the Office of Applications is responsible for the overall direction and evaluation of the GEOS-C Program. The Special Programs Directorate is responsible for fulfilling this obligation.

b. Wallops Flight Center - Wallops Flight Center is responsible for directly managing the GEOS-C Project. Additionally, Wallops Flight Center has systems responsibility for the spacecraft and subsystems responsibility for the Radar Altimeter and C-Band experiments.

c. Goddard Space Flight Center - GSFC is responsible for the systems management of the Mission Operations and Launch Vehicle System and subsystem management of the S-Band and Laser experiments. Additionally, GSFC is responsible for supplying technical consultation for the Laser Retroreflectors and provision of the S-Band Transponder.

d. The Applied Physics Laboratory (APL), Johns Hopkins University - The APL is responsible for: spacecraft design, fabrication, and assembly; provision of the Doppler, Laser Retroreflector, and Altimeter experiment subsystems, integration of all experiments and spacecraft instrumentation; testing on spacecraft/launch vehicle interfaces; preparation of the spacecraft for launch;

systems functional evaluation during the launch and engineering evaluation phase; and for consultation services during the remainder of the mission.

e. The Naval Weapons Laboratory (NWL) - The NWL is responsible for the subsystem management of the Doppler System.

1.3.3 PROJECT PERSONNEL AND RESPONSIBILITIES.

Program Manager - Mr. Dick S. Diller of the Office of Applications Special Programs Directorate, NASA Headquarters, is responsible for the overall direction to Wallops Flight Center as it pertains to GEOS-C.

Program Scientist - Mr. James P. Murphy of the Office of Applications Special Programs Directorate, NASA Headquarters, is responsible to the Program Manager for all scientific aspects of the mission. This responsibility includes (a) overseeing the definition and accomplishment of project science objectives and mission requirements, (b) evaluating proposals for data analysis, (c) developing data management plans, (d) the overall coordination between the GEOS-C program and the scientific community, and (e) assisting in the assembly and publication of scientific results in the project report.

Project Manager - Mr. Laurence C. Rossi of the Operations Directorate, Wallops Flight Center, is responsible for ensuring that the project is properly planned and executed so as to meet mission objectives with proper regard to cost and schedule. He is the focal point of all activity in support of the project and is responsible for its organization and direction. He reviews actions which interface with other centers and organizations. His specific duties are to ensure adequate project planning and evaluation for the systems engineering, systems integration, and scheduling efforts; to establish adequate budget and fiscal planning; and to ensure adequate project reporting.

Project Scientist - Mr. H. Ray Stanley of the Applied Science Directorate, Wallops Flight Center, is responsible for assuring coordination between and satisfactory accomplishment of the scientific objectives of the mission and its individual experiments. He reviews experiment operations plans and data acquisition and processing requirements to ensure that the total mission plan is consistent with the overall scientific objectives. He provides leadership in assuring that experiment data are effectively collected, distributed, and utilized and that scientific results of the mission are expeditiously produced. He evaluates all scientific requirements placed on the project and provides scientific guidance to the Project Manager and other project participants.

Remote Sensing Aircraft Manager - Mr. Roger L. Navarro of the Operations Directorate, Wallops Flight Center, is responsible for implementing the GEOS-C Project Radar Altimeter calibration area aircraft ground truth requirements as defined in the Aircraft Flight Support Plan for this effort.

Ground Truth Support Manager - LCDR Lowell R. Goodman of the NOAA Corps, on loan to Wallops Flight Center, is responsible for coordination of all GEOS-C ground truth project efforts. He will coordinate the ground truth efforts of NASA, DOD, and NOAA to produce the data required by the Project Scientist for Radar Altimeter calibration/evaluation.

GEOS-C Project Engineer - Mr. Dempsey B. Bruton, Jr., is responsible for implementing the aircraft support necessary for the ground truth activities described. He will also be responsible for disseminating raw and preprocessed ground truth data acquired by the WFC aircraft in response to direction from the Ground Truth Support Manager as defined in the GEOS-C Project Range Operations Directive.

GEOS-C Ground Truth Aircraft Instrumentation Manager - Mr. Robert A. Mennella of the Advanced Space Sensing Applications Branch, Naval Research Laboratory, is responsible for the installation and calibration of all Ground Truth Aircraft Instrumentation. He is also responsible for coordinating the operation of the instrumentation during the various flight profiles.

Experiment Managers - The activity associated with each of the experiments flown aboard the GEOS-C spacecraft is under the responsiblity of Experiment Managers from NASA, Wallops Flight Center; NASA, Goddard Space Flight Center;

and the DOD, Naval Weapons Laboratory. These individuals are actively involved in the day-to-day activities necessary to support the hardware and software aspects of the GEOS-C experiments, both prior to launch and throughout the GEOS-C Mission lifetime. In this regard, therefore, they are responsible for assuring that their respective experiment hardware meets the performance parameters necessary to support mission objectives; maintaining a compatible interface with the spacecraft bus during the design, development, and test phases; scheduling experiment conduct during the mission; and collecting, preprocessing, and distributing data to the approved investigators. Each Experiment Manager will be assisted by the necessary technical and analytical personnel required in order for him to accomplish the above responsibilities.

NASA/WFC has Project responsibility for both the Radar Altimeter and C-Band experiment aboard the GEOS-C spacecraft. Cognizant personnel are identified below.

Radar Altimeter Experiment Manager - Mr. Craig L. Purdy of the Engineering Directorate, Wallops Flight Center, is responsible for all activities associated with the GEOS-C Radar Altimeter Experiment. This will include: (a) the development of the altimeter hardware specifications; (b) technical direction of the Applied Physics Laboratory in their efforts to contractually obtain the Radar Altimeter; (c) the development of operational experiment schedules in accordance with approved principal investigator data needs; (d) data collection; (e) data preprocessing; (f) Radar Altimeter calibration; (g) data distribution; and (h) status reporting.

Assisting Mr. Purdy in accomplishing the above tasks will be the following individuals:

Altimeter Hardware Technical Consultant - Mr. W. F. Townsend of the Applied Science Directorate, Wallops Flight Center.

Altimeter Data Manager - Mr. C. D. Leitao of the Information Processing and Analysis Branch, Wallops Flight Center.

C-Band Experiment Manager - Mr. E. B. Jackson of the Operations Directorate, Wallops Flight Center; he is responsible for the overall direction of the C-Band Experiment.

Assisting Mr. Jackson will be the following individuals:

C-Band Hardware Technical Consultant - Mr. A. R. Selser of the Engineering Directorate, Wallops Flight Center.

C-Band Data Manager - Mr. W. B. Krabill of the Applied Science Directorate, Wallops Flight Center.

Others - All of the other GEOS-C project personnel, including the principal investigators, are identified in the GEOS-C Mission Plan, Section II, entitled, "Organization and Directory".

2.0 GEODYNAMICS EXPERIMENTAL OCEAN SATELLITE (GEOS-C)

2.1 GEOS-C MISSION PROFILE.

The GEOS-C Mission is divided into two distinct phases: Phase I, covering all activities from launch through one year of Experiment data collection; and Phase II, covering those activities after Phase I through the remainder of the Mission lifetime. Phase II activities cannot be detailed at this time and will not be described further.

The GEOS-C Mission - Phase I can be subdivided into several sub-phases according to the extent of experiment data collection, the type of data being collected, and various other operational and physical constraints. These sub-phases along with the dominant activity are as follows:

SUB-PHASES	TIME PERIOD (Days after Launch)	DOMINANT ACTIVITY
Phase A	0-15	Launch and Operational Assessment
Phase B	16-71	Experiment Systems Calibration and Evaluation
Phase C	72-112	Global Activities
Phase D	113- *	Unique Experiments and Localized Grid Activity

Many activities associated with the overall GEOS-C Mission cannot be divided into these distinct time periods; i.e. they extend over the entire Phase I time

* Presently under study. Planned mission lifetime is one year minimum. However, considerations such as the rephasing of activities and extended DOD requirements may necessitate extending the mission lifetime as much as three to four months.

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period. However, the extent of intensity of many activities will be modulated according to the various sub-phases and many dominant activities can be identified. Therefore, the following sections will attempt to discuss in detail all of the activities associated with each of the sub-phases as well as provide some estimate of the level of these activities and describe the criteria controlling the transition between phases.

2.1.1 PHASE A - LAUNCH AND OPERATIONS ASSESSMENT. This sub-phase begins with launch and extends over a period of approximately 15 days in which the following activities occur:

a. Launch
b. Orbit injection
c. Early orbit determination and refinement
d. Gravity gradient capture and damping
e. Momentum wheel turn on
f. Yaw capture and stabilization damping
g. Spacecraft functional and electrical checkout
h. Operational Assessment of experiment systems

It is not planned to distribute any radar altimeter data collected during Phase A to Principal Investigators.

2.1.2 PHASE B - EXPERIMENT SYSTEMS CALIBRATION AND EVALUATION. It is expected that Phase B will begin about 15 days after launch and continue for about two months. It is expected that the bulk of the data collected during this period will be useful for investigation purposes. However, data distribution during this period will be slower than normal due to the more detailed analyses required to calibrate all experiment systems and to validate all data processes.

Major activities associated with this phase include the following:

a. Altimeter Experiment Systems Calibration activities (including ground truth) in the North Atlantic Calibration area on a schedule of 3 days on, 2 days off, 3 days on, one day off for a total of 40 attempts during Phase B.

b. Satellite-to-satellite experiment (SSE) systems calibration activities in the North Atlantic Calibration area on the same schedule as for the altimeter calibration activity for a total of 26 attempts.

c. Altimeter experiment systems operation globally (within the real-time ground telemetering (TM) station coverage areas) on those days not utilized for altimeter calibration activities.

d. Ground tracking system (laser, C-Band, and doppler) data collection activities on a global basis to the maximum extent possible commensurate with power budget, other systems calibration activities, and investigator needs.

Further details concerning the calibration activities are given below.

The area of calibration operation will be primarily in the North Atlantic with emphasis on the area bounded by the quadrangle of tracking station location at Wallops Island, Bermuda, Grand Turk, and Merritt Island. Each of these reference stations (except Merritt Island which will have no laser) will have ground station tracking capability consisting of at least one C-Band radar, a laser and a geoceiver doppler instrumentation. A typical day of calibration data acquisition will consist of the following:

a. Altimetry Data. Altimetry data will be scheduled over those portions of ten consecutive orbits that cross the North Atlantic Ocean. The key orbits are the third and ninth. The ten orbit set will be selected in which the third orbit intersects the Wallops Island to Bermuda baseline in a north-south going direction (see Figure 2-1). Orbit 9, then, will cross orbit 3 within or near the quadrangle of stations.

b. SSE Data. SSE data will typically be scheduled on orbits 3 and 2 or 4 and orbits 9 and 8 or 10 of the ten orbits described above.

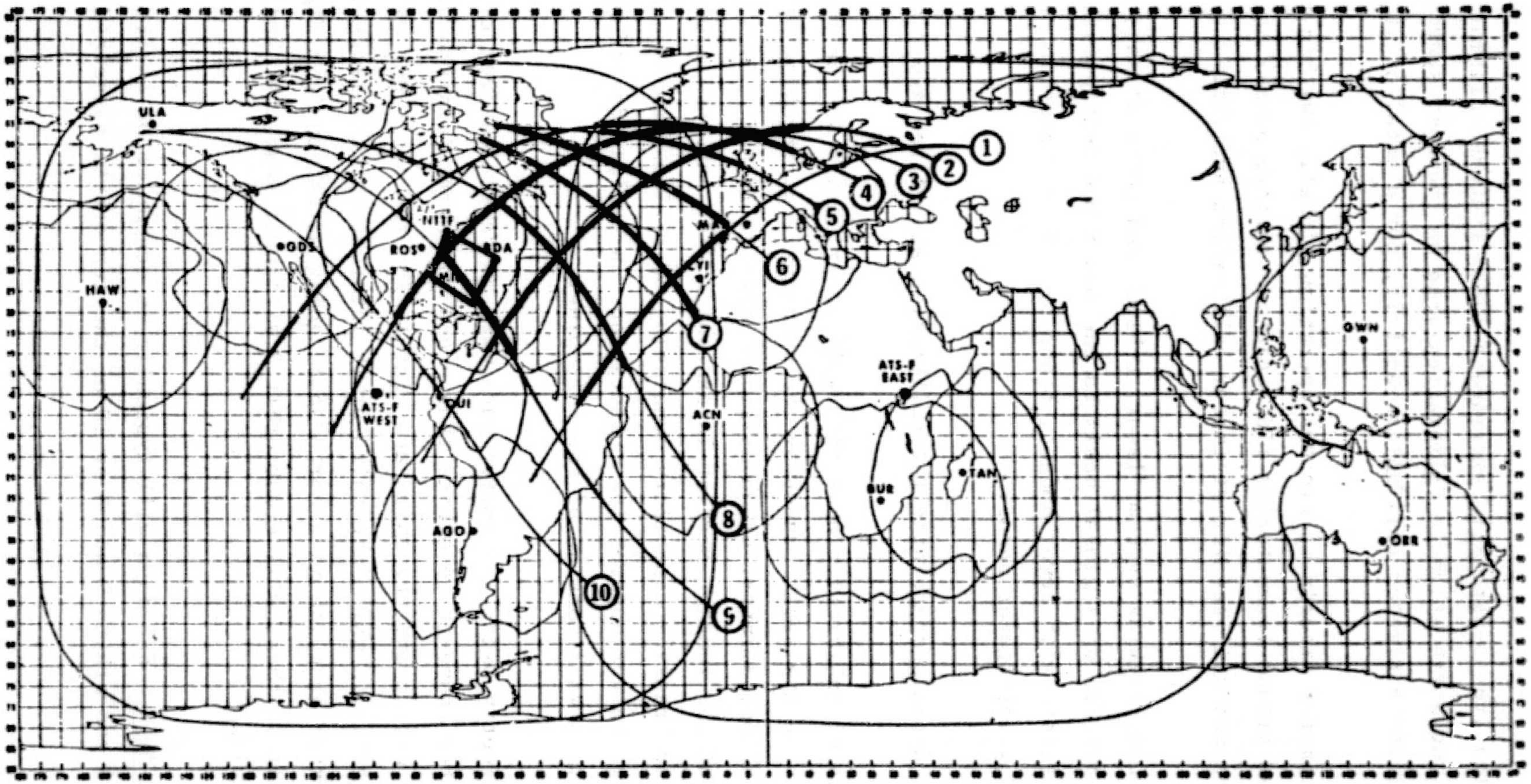

Figure 2-1. Typical Systems Calibration Arcs

SSE data will be scheduled not only over the North Atlantic but for the entire duration of mutual visibility between the ATS-F and GEOS-C satellites for the four orbits selected.

c. C-Band, Doppler, Laser Data. These data will be scheduled on a global basis to provide precise orbit determination capability for the aforementioned ten orbits. Data spans over the North Atlantic will be emphasized with particular emphasis on tracking at the four stations of the quadrangle.

d. Ground Truth Data. Ground truth data will be collected to support definition of sea conditions primarily within the area bounded by the four-station quadrangle. Data, supplied from a Spaceflight Meteorology Group (SMG) overlay, are collected from sources such as aircraft (Nanosecond Radar, Laser Profilometer, etc.), environmental buoys, ocean station vessels, lighthouses, etc. Sea condition measurements are made (e.g., wave and swell height and period) by coastal stations, ocean station vessels, etc., within the prime calibration area and its periphery.

2.1.3 PHASE C - GLOBAL ACTIVITIES. Phase C activities will be conducted during the time in which the ATS-F is being maneuvered from the Western to the Eastern Hemisphere, and will require only very limited Ground Truth support.

2.1.4 PHASE D - UNIQUE EXPERIMENTS AND LOCALIZED GRID ACTIVITIES. Phase D activities will begin at the time when activities associated with the ATS-F have been completed, and will continue through the remainder of the Mission lifetime. During the latter part of this phase, the S-Band ground tracking network stations should all be modified compatible with GEOS-C instrumentation and will assume a more active role. A typical day during this time period will consist of:

a. Ground Tracking Systems (laser, C-Band and doppler) data collection activities to the maximum extent possible on a global basis commensurate with power budget, altimeter experiment operations, and Principal Investigator needs.

b. Altimeter experiment data collection activities commensurate with power budget, investigator needs, and within the constraints of the Ground TM Station coverage areas.

In addition to Phase D activities, intermittent calibration and evaluation activities will be conducted at a nominal rate of once per month; i.e., the "typical day of calibration data acquisition" described in Phase B will be conducted at the rate of one day per month.

2.2 RADAR ALTIMETER CALIBRATION.

2.2.1 CALIBRATION SCHEDULE. The schedule for performance of GEOS-C altimeter calibration missions is based upon the expected need for calibration, and available opportunities for calibration. Broadly, an opportunity for calibration may be considered as a satellite pass with the ground track over any portion of the calibration area. Based on the planned orbital elements, such passes may normally be expected to occur for three successive days, followed by 1 or 2 days of no passes. During the three days, passes such as those shown in Figure 2-2 will occur. This network of passes will repeat during other three-day periods, with some shifting of the network in longitude.

It can be noted, in Figure 2-2, that there are a number of crossing points among the arcs. In particular, each North-South pass is crossed approximately 10 hours later by a South-North pass at a latitude of approximately 32.5°N. Each South-North pass is also crossed approximately 14 hours later by a North-South pass at approximately 29°N latitude. Other crossings occur at other latitudes and at different separations in time. If geoid height errors in the calibration area are considered to be significant at the time of the altimeter calibration, these crossing points can be used as a part of altimeter stability verification.

In addition to crossing arcs, Figure 2-2 also shows one pass which should meet the criteria for a high elevation pass for both Bermuda and Grand Turk. There is only one such pass in the three-day set and, in general, no more than

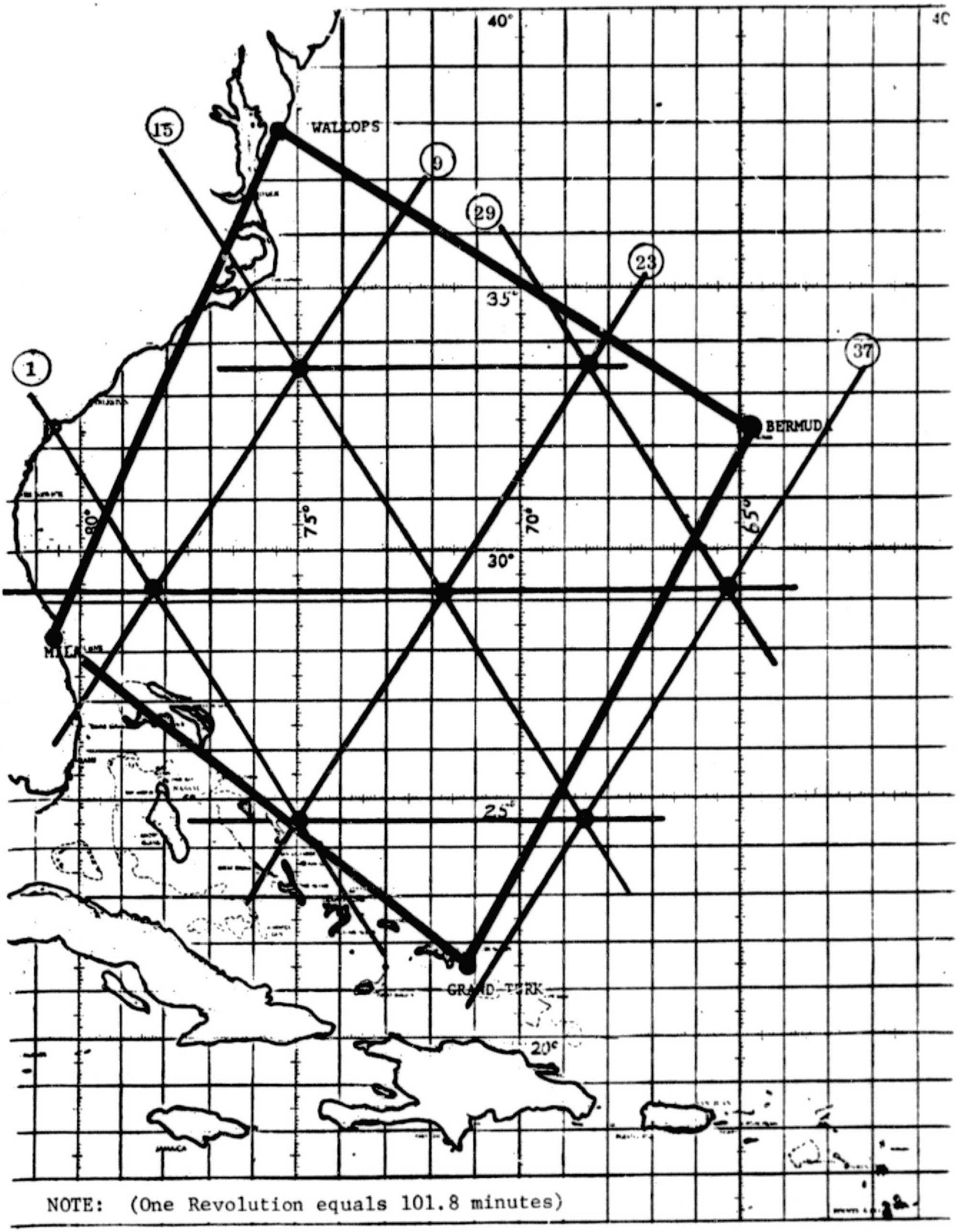

Figure 2-2. Typical Set of Calibration Area Passes

one high elevation pass per three days is expected for an island station. However, any high elevation North-South pass over Bermuda will also be a high elevation pass over Grand Turk and, depending upon the exact orbital period achieved, any South-North high elevation pass over Bermuda may be preceded two days earlier by a high elevation pass over Grand Turk.

Based on the expected need for calibration, the altimeter calibration will be divided into two phases. There are the intensive calibration phase (Phase B) at the beginning of the mission, and the calibration/verification phase (Phase D) which will be needed to identify long period changes in altimeter characteristics. Both the intensive calibration efforts and the calibration/verification efforts require extensive Ground Truth support. These calibration activities are discussed further in the following paragraphs.

2.2.1.1 Intensive Altimeter Calibration (Phase B). The calibrations performed during this sub-phase will begin approximately 15 days after launch, and will be a part of the overall GEOS-C system's calibration and evaluation. Initially, an altimeter calibration is planned for each passage of the satellite through the calibration area. This means at least six calibrations each 5 days. Depending upon the pass geometry, three different modes of data reduction are planned. These are as follows:

a. Multi-Station Calibration - For a general pass through (for example, the middle of the calibration area), tracking data from the four primary calibration sites will be processed, along with the altimeter data during this period, to determine a best value of the altimeter range bias for this pass.

b. High Elevation Pass Calibration - For those passes which have a high maximum elevation (>80°) for one (or more) of the island stations, data from this single tracking station will be reduced using the same data reduction and bias estimation procedure as for the Multi-Station calibration. Assuming a well calibrated tracking instrument (such as a C-Band radar calibrated by a collocated laser) on the island, this procedure should produce an accuracy close to that of the altimeter range accuracy, and should be superior to the Multi-Station calibration due to the reduced effects of geoid height error.

c. Stability Verification - As noted above, there are crossing arcs during a three-day calibration period at latitudes of approximately 32.5°N and 29°N, separated in time by approximately 10 hours and 14 hours, respectively. Very short arc bias estimations using the two segments of data around a crossing arc point should produce bias estimates which are affected almost exactly the same by various systematic errors, including geoid height error, station position errors, and ground tracker biases. Comparison of altimeter bias estimates obtained in this way should be a more sensitive test of altimeter stability than comparisons of absolute bias as estimated by Methods a and b above. This sensitivity is, of course, strongly dependent on the stability of systematic errors in the ground trackers used. At the beginning of the calibration period, stability verifications for the 32.5°N crossing arc points are planned for each set within the calibration area, with selected verifications also for the 29°N crossing points. This set of stability tests will continue throughout the entire Phase B period, and intermittently for as long thereafter as the results warrant.

2.2.1.2 Operational Altimeter Calibration (Phase D). Plans are to continue the intensive altimeter calibration portion of Phase D until the operational characteristics of the altimeter have been determined. It is expected that the instrument will prove sufficiently accurate and stable such that the use of the pre- and post-mission on-board calibration data, along with the absolute calibrations from the Phase B calibrations, will result in the altimeter height measurement accuracy at least as good as a new calibration using any of the above methods. That is, assuming altimeter performance as expected, the best calibration of the altimeter height measurement is obtained from the set of calibration missions previously performed.

After the Phase B calibrations, and with expected altimeter performance, the number of calibrations will be rapidly reduced to a level of approximately two (one crossing arc pair) per month in order to monitor any long period changes in the altimeter characteristics.

2.2.2 CALIBRATION/EVALUATION DATA SET. The set of data to be collected during the ten-revolution calibration operations should be as follows:

a. Altimeter data during the Atlantic Ocean portion of all ten revolutions as shown in Figure 2-3.

b. SSE data on the Atlantic Ocean portion of Revolutions 2-3 and 8-9 as shown in Figure 2-3. (The SSE data will be especially useful during Revolutions 3 and 9 which pass through the calibration area. Revolutions 2 and 8 are included to strengthen the orbital solution since successive tracks for the SSE appear to produce maximum results.)

c. C-Band radar data on each revolution visible from all supporting stations in the calibration region as well as (for certain periods of time) C-Band radar data from the VANGUARD ship stationed at the crossing point of Revolutions 3 and 9.

d. Laser data on each revolution visible from all stations in the calibration region.

e. Doppler, USB, C-Band radar, and laser data to the maximum extent possible during all portions of all revolutions (1 through 10 as shown in Figure 2-3).

f. Extensive Ground Truth information (primarily for the Calibration Data Package) taken by the NASA WFC C-54 aircraft as well as information from ships and other aircraft of opportunity anywhere within the

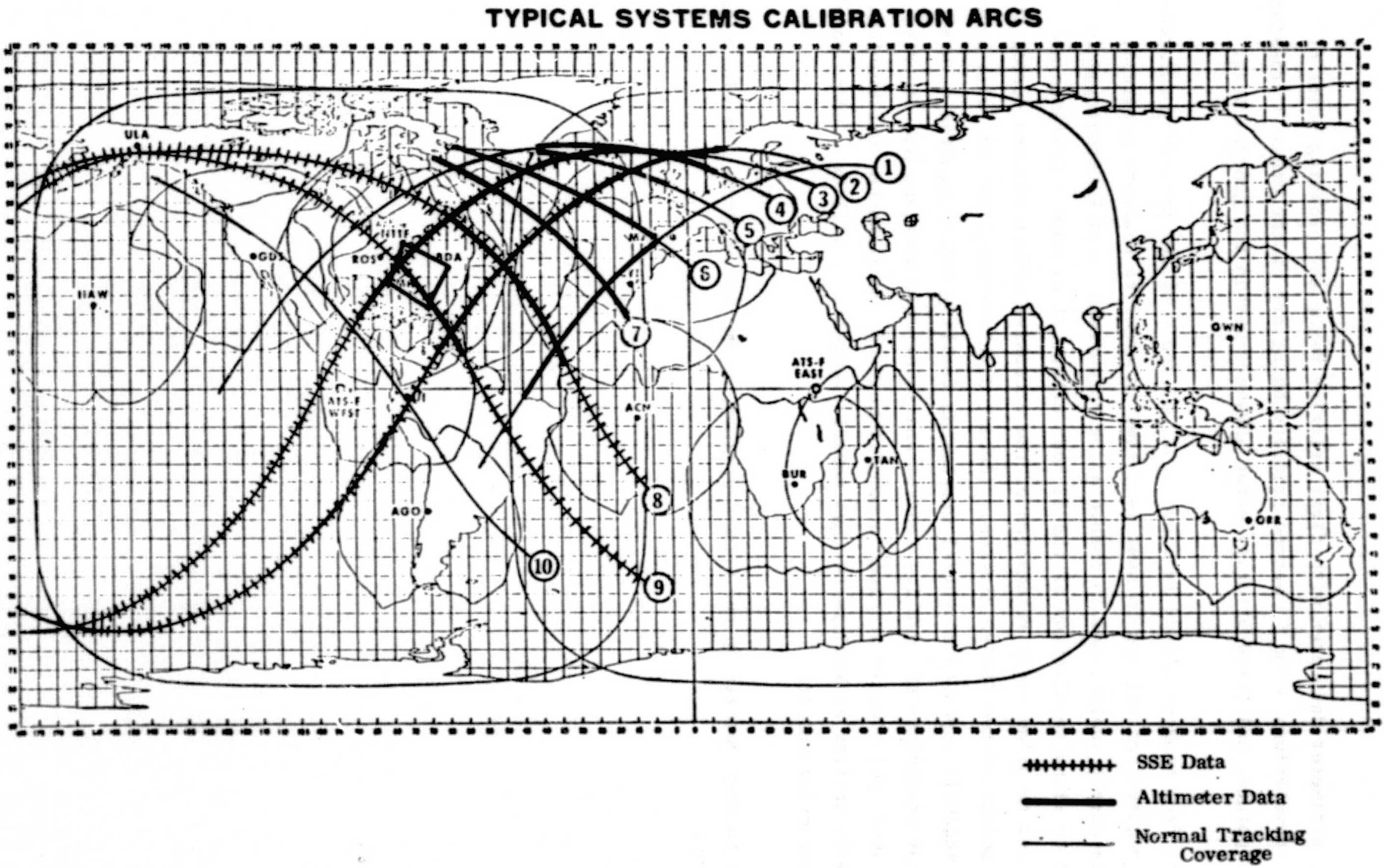

Figure 2-3. Radar Altimeter Sub-Satellite Tracks

altimeter data area with first priority being the crossing point of Revolutions 3 and 9, second priority being any of the other 3 crossing points, and third priority being anywhere within the general area.

Data from sources listed in items a, c, d, and f of the preceding paragraph will be required at Wallops in near real time in order to evaluate progress, check spacecraft health, and to enable quick turnaround. Quick turnaround is required to allow termination of the 12-hour effort if minimum conditions are not met and to allow early relaxation of the extensive effort planned during the initial months of the GEOS-C Mission. (Normal data retrieval methods will be by mailing magnetic tapes to a central processing facility which requires several months for preprocessing, quality control analysis, reformatting, and distribution to users which would preclude accomplishment of the altimeter calibration.) As new data arrives at Wallops through normal channels, it will be used to check and refine prior results.

For further details on the GEOS-C program, refer to the GEOS-C Mission Plan, TK 6340-001.

3.0 GROUND TRUTH PARAMETERS APPLICABLE TO GEOS-C ALTIMETRY

3.1 GENERAL.

All ground truth parameters considered applicable to the calibration/evaluation of the GEOS-C Radar Altimeter are presented in this section. These parameters are divided into the following major categories:

a. Long Wavelength Features - The geoid, pelagic tides, solid earth tides, ocean current geostrophic heights, atmospheric pressure loading, sea water density effects, etc.

b. Short Wavelength Features - Combined sea state (sea and swell)

c. Synoptic Weather Data Applicable to Tropospheric Refraction Corrections - Atmospheric pressure, temperature, and relative humidity

d. Other Weather Data - Cloud cover, wind fields, precipitation, etc.

3.2 LONG WAVELENGTH FEATURES.

3.2.1 GEOID. The geoid is defined to be that equipotential of attraction and rotation which most nearly corresponds to mean sea level. Mean sea level will differ from the geoid by a few meters due to dynamic ocean effects related to currents, etc. Additionally, instantaneous sea level will differ from mean sea level due to time variable factors such as tides, barometric pressure variations, etc. Information exists, as indicated elsewhere in this document, to provide first order estimates of the effects of currents, tides, pressure variations, etc. Thus, in the calibration area, a geoid, as modified by the oceanographic effects, gives an estimate of the instantaneous sea level geometry for comparison with the altimeter output. This comparison will provide a means of evaluating the accuracy of the altimeter in measuring the geometry of the ocean surface.

At present, the ocean geoid can only be derived by computations using observed gravity data. The best available gravity geoids are, at present, computed by combining available surface gravity data to define the shorter wavelength (0.1° to 10° wavelength) geoid undulation variations and satellite gravity data in order to define the longer wavelength geoid variations. In principle, gravimetric geoids can be absolute geoids; i.e., the geoid heights in conjunction with the geometry of the reference ellipsoid can provide true values of geocentric radial distance to the geoid. However, at present, some parameters are uncertain so that, in addition to random errors, gravimetric geoids can contain a constant error. In order to identify and remove this constant error, geocentric station positions derived from satellite tracking are used.

The geoids to be provided in the ground truth package will be computed using the best available surface and satellite gravity data and will be adjusted to remove constant error using high accuracy geocentric tracking station positions computed in the calibration area.

3.2.2 PELAGIC TIDES. Deep Ocean Tides are being handled with mathematical models for altimeter purposes. The Hendershott model is being used in A/OMEGA II (the global altimeter data reduction program). The NOAA/Mofjeld model is incorporated in the data reduction program for the calibration zone. (Detailed descriptions of both models follow in Section 4.)

3.2.3 SOLID EARTH TIDES. Calculations indicate that earth tides could also be and error source for the range measurements. Due to their relatively small contributions in relation to other potential errors, no model has been developed for the altimeter data reduction programs. However, space is provided in the programs for a height correction for earth tides.

3.2.4 OCEAN CURRENTS. The only major current system within the prime calibration zone is the Gulf Stream. It is planned, therefore, to calibrate the radar altimeter using data collected outside the area affected by the Stream in order to avoid potential errors caused by geostrophic heights associated with current flow.* The Stream will be avoided for calibration by utilizing routinely available data on Gulf Stream meanderings such as the NOAA publication "Gulf Stream" 16872-GS and the U.S. Coast Guard Oceanographic Unit Airborne Radiation Thermometer Analysis.**

This should not be construed to mean that altimeter data will not be taken over the Stream - but simply that it is considered an error source and is being avoided for calibration.

3.2.5 ATMOSPHERIC PRESSURE LOADING EFFECTS. Residuals from the reduction of recent deep sea tide gage data have indicated that the effect of atmospheric pressure loading could be on the order of 10 centimeters. Since this phenomena has not been adequately modeled to date, no corrections for these effects will be applied to the altimeter data. However, space has been provided in the data reduction program format for a height correction for atmospheric loading in the event of more data becoming available.

3.2.6 SEAWATER DENSITY VARIATIONS. Variations in sea water density, caused by changes in water temperature and salinity, will cause a change in the equilibrium sea surface height proportional to the integral of the density variation over the water column. Estimates indicate that a seasonal variation of up to 20 centimeters is plausible. Since the rate of change is considered to be slow (seasonal), no effort will be made to correct for these effects during calibration. Again, however, space is provided in the program for potential future corrections.

3.3 SHORT WAVE LENGTH FEATURES.

The effects of ocean surface roughness in altimeter measurement capability are to: (a) spread the leading edge of the return signal; (b) alter the

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* Included as Appendix A is a personal correspondence technical note by Dr. Davidson Chen which explains the theory and equations involved in geostrophic height calculations as well as typical expected heights calculated from nominal Gulf Stream data.

** See Section 8.0, Figure 8-1.

automated gain control (AGC); (c) introduce systematic errors, or biases, into the measurement process; and (d) increase tracking time-jitter due to concomitant changes in signal level and effective lengths of the received pulse.

Altimetric bias errors, which are a function of ocean surface roughness, may be grouped into two categories. In the first category, a wave height-dependent bias error occurs even if the radar-sensed wave height probability density function (PDF) is strictly Gaussian. This bias arises due to the small changes of the plateau gate signal level with variations in surface roughness and antenna pointing. This effect is considered to be quite small; calculated values are shown in Figure 3-1 for the tracking gate configuration used in the GEOS-C system. In order to develop models for these effects, it will be necessary to collect detailed information on ocean surface conditions. Thus, a family of sea state calibration curves must be created for calibration of the Intensive Mode sea state measuring capability as well as for calibration of any potential range bias resulting form sea state.

3.3.1 DATA COLLECTION. Initially, the data for these curves were to be derived only from aircraft (nanosecond radar and laser profilometer) data. However, considering the range of sea states to be calibrated (up to 10 meters $H_{1/3}$), the limited aircraft time available (approximately 300 hours), and the probabilities of obtaining the high sea states within range of the aircraft, it was decided to add to the sea state calibration data set by incorporating sea state information derived from meteorological analysis of data from buoys, ship reports, and wind field structure (hereafter referred to as hindcast sea state data).

All available sea state data, therefore, will be combined statistically (based on their relative accuracies) to obtain the family of curves necessary to evaluate the sea state measuring performance of the altimeter as well as any potential range bias resulting from sea state.

As an example of this procedure for a 10-foot sea, assume the hindcast data to be accurate to within 25 percent. Given that the aircraft (laser

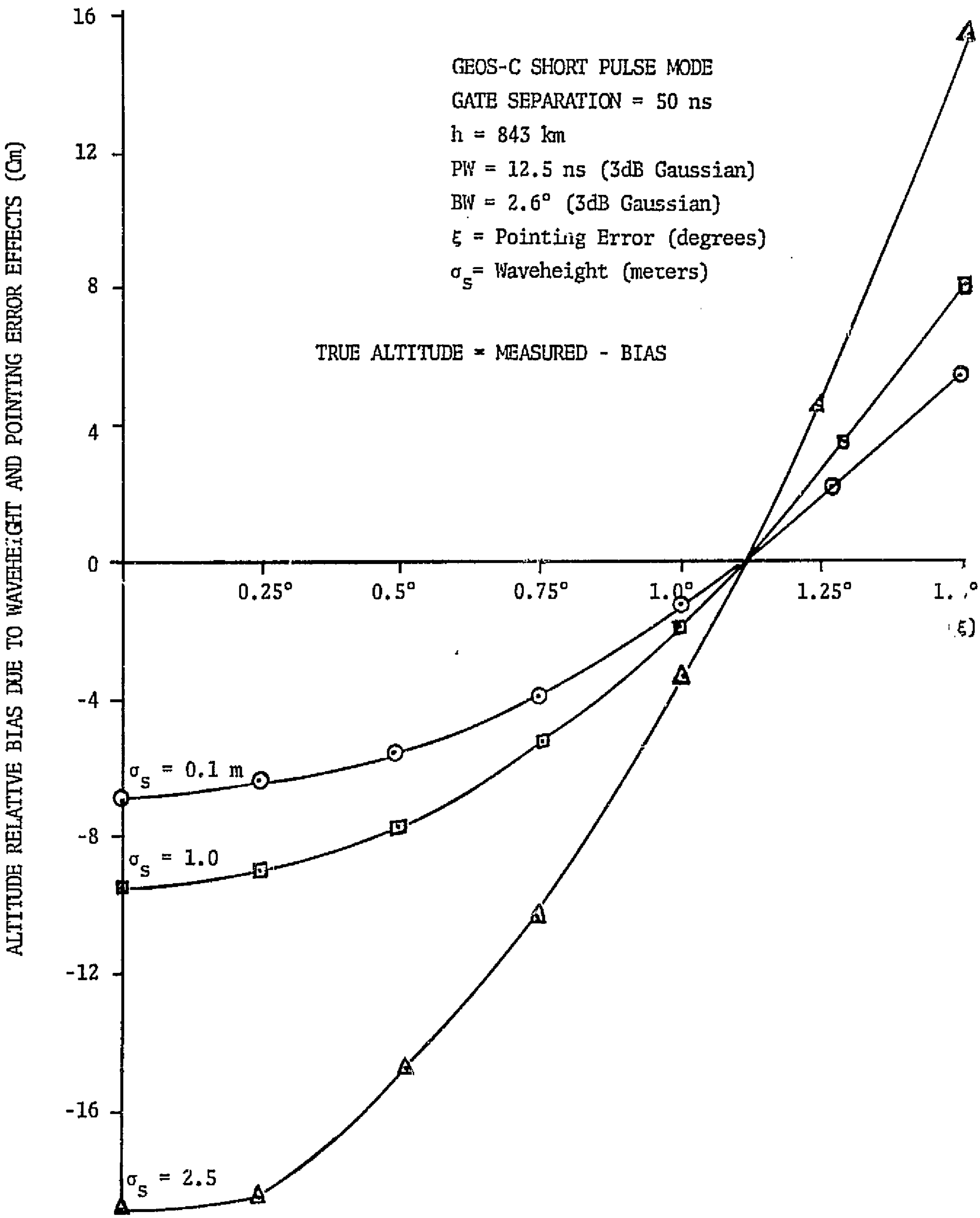

Figure 3-1. GEOS-C Altitude Bias Error Due to Wave Height and Pointing Error Effects for a Gate Separation of 50 ns

profilometer or nanosecond radar) data has a standard deviation of one foot, the 25 percent figure for hindcast data would yield a 2.5-foot standard deviation for that measurement. Statistically, this means that roughly seven data points from hindcast data for 10-foot seas would be equivalent to one data point from the aircraft instrumentation.

3.4 SYNOPTIC WEATHER DATA APPLICABLE TO REFRACTION CORRECTIONS.

Tropospheric refraction errors affect the calibration/evaluation of GEOS-C both in terms of tracking data for orbit determination and the actual altimeter measurements themselves.

The results of a refraction study completed at Wallops* has indicated, however, that refraction corrections can be handled by using a mathematical model with inputs of surface data only. These surface parameters are atmospheric pressure, temperature, and relative humidity. Consequently, tropospheric refraction corrections for the altimeter will be derived using those surface data incorporated in a mathematical model (see Section 4 for details). When actual surface data are not available, mean monthly pressure, temperature, and relative humidity for the latitude in question will be used as inputs for the model. In all cases the actual refraction correction applied will be printed on the data tape.

3.5 OTHER SYNOPTIC WEATHER DATA.

Other synoptic weather data besides the pressure, temperature, and relative humidity required for tropospheric refraction corrections are applicable to the calibration effort. The following is a list of these other weather parameters and their potential contributions.

- Atmospheric pressure - Atmospheric loading and refraction
- Cloud cover - Signal attenuation
- Precipitation - Signal attenuation
- Wind field - Sea state

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* Refer to Contractor Report No. 008-74, Effects of Tropospheric and Ionospheric Refraction Errors in the Utilization of GEOS-C Altimeter Data, dated October 1974.

4.0 CALIBRATION DATA PACKAGE (CDP)

4.1 PURPOSE.

The Calibration Data Package is a compilation of processed ground truth data considered necessary for the calibration of the Radar Altimeter. It includes all processed data to calibrate the sea state measuring capability as well as potential range bias caused by sea state. Information on both long wavelength features and short wavelength features is available for the prime calibration area for use in range measurement verification. The Calibration Data Package (CDP) also includes a description of the various mathematical models used in calculating long wavelength features, e.g., geoid, tides, etc.

Processed data on short wavelength features will include those measurements taken by the aircraft - e.g., nanosecond radar, laser profilometer etc. - and the Satellite Meteorological Group (SMG) data set. The SMG Ground Truth Data Set provides a sea state evaluation derived from an analysis of both wind fields and ship reports of observed heights and periods. This data set will also provide related meteorological charts and analyses, satellite photographs, and supporting data. Processed data from aircraft instrumentation and the SMG Ground Truth Data Set will be used to build a family of curves to calibrate the sea state measuring capability of the altimeter.

4.2 GEOID MODELS.

Several geoid models will be utilized for evaluation of the altimeter data. For evaluations outside of the calibration area, a combination geoid computed by J. Marsh of NASA/GSFC and S. Vincent of Wolf Research Corporation will be utilized. For evaluations within the calibration area, several high precision regional geoid models will be used. All the geoid models are described below.

4.2.1 GLOBAL GEOID MODEL. The Marsh/Vincent global geoid model is a gravimetric geoid computed using the GEM6 set of satellite-derived spherical harmonic coefficients in conjunction with a set of 1°x1° mean free air gravity

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anomalies. The computational procedure is well described in Strange, et al, 1972. Because the quantity and quality of available surface gravity data is highly variable, the accuracy of the derived geoid is variable. The Marsh/Vincent geoid is most accurate in areas of best surface data such as the northwest Atlantic and is least accurate in areas of little or no surface gravity such as the southern Pacific Ocean. The derived geoid heights are considered as referred to an ellipsoid with a semi-major axis of 6378.142 km and a flattening of 1/298.255. Because of uncertainties in the various input parameters, a possible systematic bias of about ±5 to 10 meters could exist in these geoid heights.

The Marsh/Vincent geoid heights were computed at intervals of one degree in latitude and one degree in longitude. This 1°x1° grid of values is available on magnetic tape and in the form of a plotted contour map. The magnetic tape is a compilation of latitude, longitude, and geoid height at 1°x1° intervals. The Marsh/Vincent geoid model has been incorporated into the ARC data reduction program discussed elsewhere in this section. A copy of the plotted contour map and/or the magnetic tape are available as part of the CDP.

4.2.2 CALIBRATION AREA GEOID MODELS. For the altimeter area, a more detailed geoid model was felt to be required. Methods of computation for this detailed geoid will not differ substantially from that used to compute the global geoid model. However, geoid heights will be computed on a 10'x10' grid rather than a 1°x1° grid using surface gravity in the form of 10'x10' mean free air anomalies rather than 1°x1° mean free air anomalies. Several calibration area geoids are being computed using differing estimates of the surface free air gravity anomalies introduced into the computations. Prior to launch, a calibration area geoid model will be selected based on comparison of the gravimetric geoids with the geoid heights derived from high accuracy geocentric positions computed for C-band radar, laser, and Doppler tracking stations in the calibration area. The selected detailed calibration area geoid will be made available on magnetic tape as a set of latitudes, longitudes, and geoid heights at 10'x10' intervals and in the form of a detailed contour map. It will be incorporated into the A/OMEGA II computer program.

In support of the readjustment of the North American horizontal datum, the National Geodetic Survey (NGS) is in the process of computing a detailed geoid for the United States and adjacent areas. In undertaking this computation a critical evaluation is being made of surface gravity data within, and adjacent to, the North American continent. The detailed geoid to be computed by NGS, which is scheduled for completion soon after the launch of GEOS-C, will extend over a substantial portion of the altimeter calibration area. The NGS results for the calibration will be made available to the project in the form of a magnetic tape containing latitude, longitude, and geoid height at approximately 10'x10' intervals and in the form of a set of coefficients of a power series polynomial expansion in latitude and longitude. When available, this geoid height data will be made available to investigators upon request.

4.3 TIDE MODELS.

The Mofjeld/NOAA tide model will be used for all evaluations within the calibration area. The Hendershott tide model will be used for all evaluations outside the area. Both models are described in subsequent paragraphs.

4.3.1 MOFJELD/NOAA TIDE MODEL. The Mofjeld tide model was developed under NASA Contract No. 369-07-01-17-53 and is designed to provide sea surface displacement information for tides in the GEOS-C calibration area.

The model description presented herein is proprietary information and has been incorporated into this document with the permission of the author. The presentation format has been altered slightly to make it consistent with the format of this document. The technical content is unchanged from its original form.

4.3.1.1 General Description. The model is a set of computer subroutines that compute the tidal displacement from mean sea level, given the coordinates of the desired location and the desired date and time. It can be used to generate a time series at a given location, the geographical distribution of tidal height at a given instant, and/or the tidal height under the GEOS-C satellite as it passes over the calibration area.

The tidal displacement is computed from a set of harmonic constants, which have been obtained by interpolation of harmonic constants at three reference stations. The latter constants were found through analysis of actual pressure or sea level observations. Figure 4-1 shows the calibration area in the Western Atlantic, the reference and test stations, and a cross-hatched area indicating where the model is applicable. Table 4-1 lists the locations of the reference stations, the periods over which the observations were made, the analysis method, literature references, and harmonic constants.

The accuracy of the model depends on several factors: (a) how accurately the harmonic constants have been determined at the reference stations; and (b) how well the interpolation scheme follows the actual distribution of harmonic constants used in the model adequately describe the tides.

The goal of the model is to provide tidal displacements above mean sea level within ±5 cm in the area shown in Figure 4-1. Eight harmonic constants have been selected for the model: four daily constituents, K_1, O_1, P_1, Q_1, and four semi-daily constituents - M_2, N_2, S_2, K_2. These eight constituents contain almost all the energy in the daily and semi-daily tidal frequency bands. Lower frequency, minor daily, and semi-daily, and higher frequency constituents are not included in the model. A discussion of the excluded constituents and their behavior in the Western Atlantic can be found in Zetler et al. (1975) and Brown et al. (1975).

The observations of the reference stations are measurements of the thickness of the water column from the bottom to the sea surface. Such measurements do not include displacements of the sea surface due to the vertical motion of the bottom; the model, therefore, does not contain earth tides.

A comparison of tidal heights as obtained from observations at the MODE/AOML-1 station with predictions of the model is shown in Figure 4-2. The standard deviation of model from the observations for the period shown is 3.4 centimeters. The observations have been filtered to remove fluctuations at lower frequencies than the tidal bands.

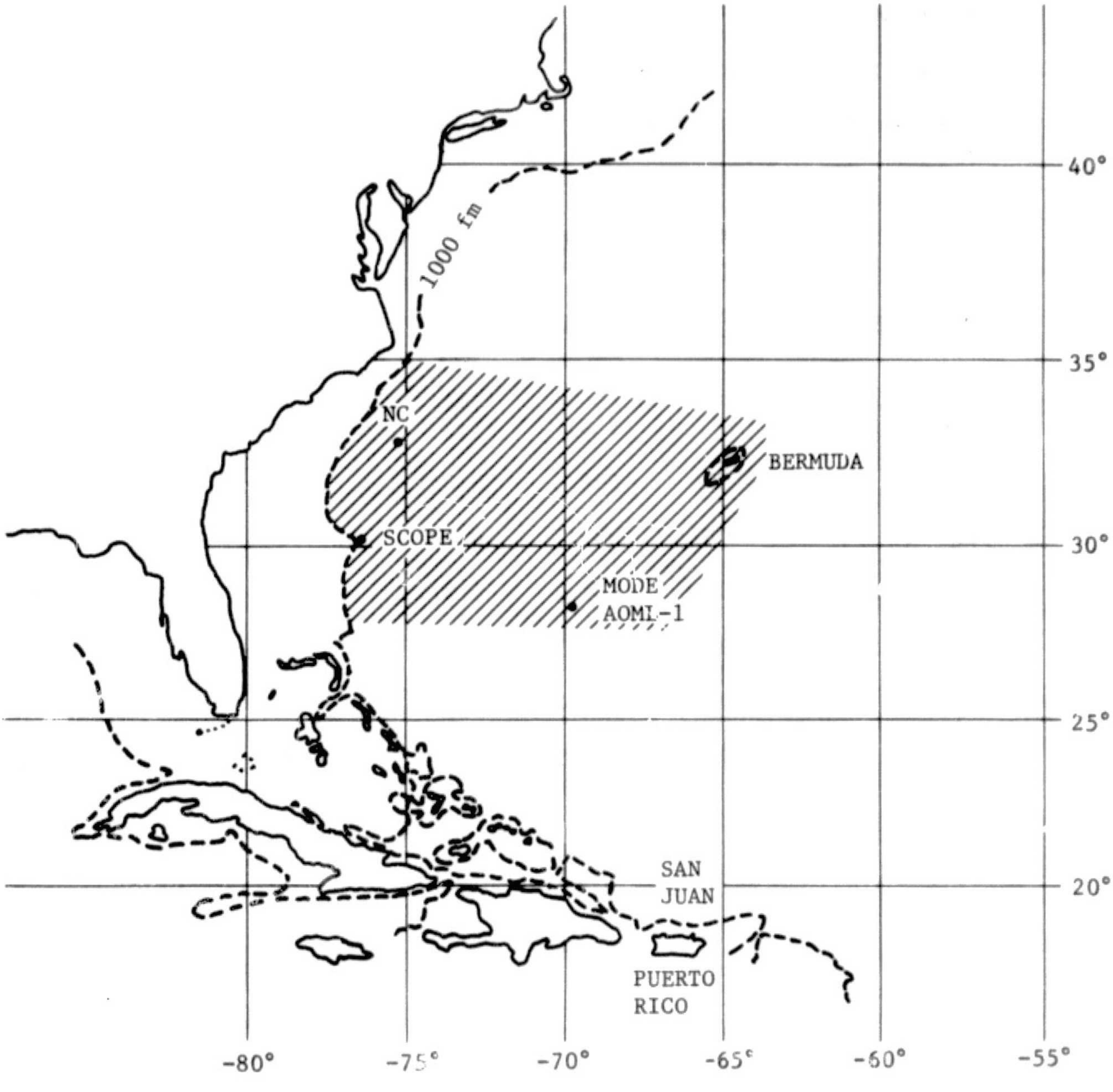

Figure 4-1. Calibration Areas in Northwest Atlantic

TABLE 4-1. REFERENCE STATIONS

Location	Bermuda 32°24N, - 64°42E		MODE/AOML-1 28°08N, - 69°45E		SCOPE 30°26N, - 76°25E	
Gage Type	Shore Gage		Bottom Pressure Gage		Bottom Pressure Gage	
Observation Period	1950-1951, 1953-1954, 1956-1957		11Mar73- 29Jun73		18Sept73- 20Mar74	
Type of Analysis	Response Method		Response Method		Response Method	
Reference	Zetler *et al.* (1975)		Zetler *et al.* (1975)		Pearson (1975)	
Constituents	Amplitude (m)	Phase (°G)	Amplitude (m)	Phase (°G)	Amplitude (m)	Phase (°G)
M_2	0.356	358.3	0.345	0.6	0.434	357.6
N_2	0.082	337.7	0.080	339.8	0.011	335.7
S_2	0.081	24.2	0.071	30.8	0.082	23.1
K_2	0.021	22.7	0.019	29.9	0.018	(21.6)
K_1	0.066	187.0	0.077	194.7	0.096	189.8
O_1	0.053	192.1	0.061	197.6	0.073	194.3
P_1	0.020	187.8	0.024	195.2	0.032	189.8
Q_1	0.011	186.6	0.013	193.3	0.014	183.8

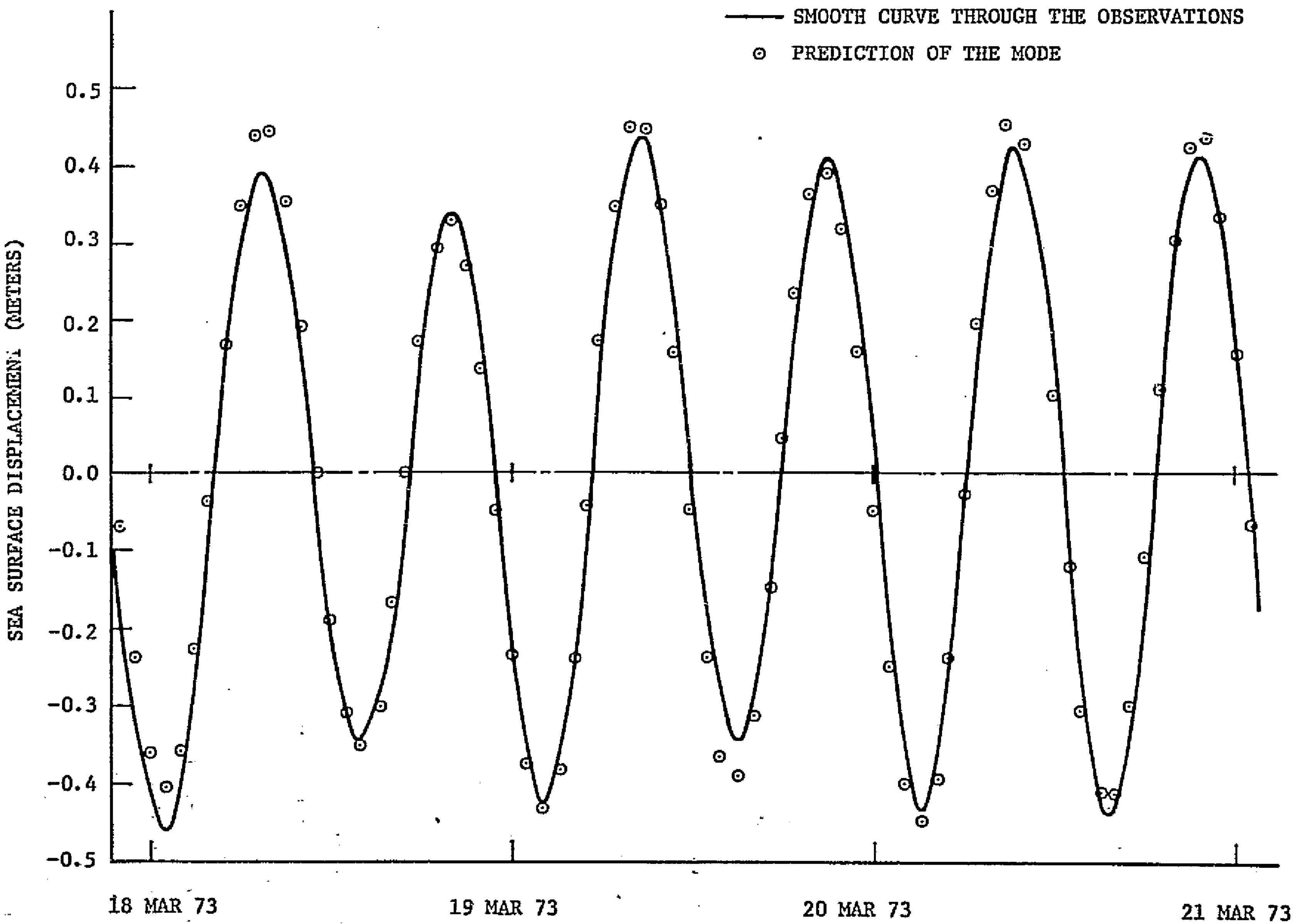

Figure 4-2. Sea Surface Displacement (Meters)

The area within which the model should meet the ±5 centimeters accuracy criterion was obtained through a study of the tidal distributions for the Atlantic Ocean as given by Dietrich (1967), and through a comparison of harmonic stations at tide stations other than the reference stations. Further checks on the model will be made as data become available from additional stations.

A comparison of observed harmonic constants with results of the model is given in Table 4-2. There is good agreement at the NC (North Carolina) station; the model should be accurate as far north as 35°N, near the continental shelf. The discrepancy at the San Juan, Puerto Rico, station is due to the tidal regime in the Equatorial Atlantic differing from the reference stations, and to a more localized influence of the passes between the islands of the Antilles and of the tidal regime in the Caribbean Sea. The southern limit of the model lies northward of these effects.

Through studies such as Redfield (1958), it is clear that on the continental shelves, tidal amplitudes and phases change over distances which are short compared with the distances over which amplitudes and phases vary in the open ocean. The GEOS-C tide model is based on harmonic constants from the open ocean and is applicable only where the tidal amplitude and phase variations have oceanic rather than shelf spatial scales. The model should be used seaward of the 2000-meter depth contour. If extrapolated into shallower water, the model will underestimate the tidal amplitudes. The discrepancy increases rapidly shoreward of the 200-meter depth contour.

While it is traditional in tidal prediction calculations to fix the node factors at a single set of values for time series up to 1 year in duration, the model computes the instantaneous node factors for each time. The more accurate procedure is used for two reasons: first, the operational period of the GEOS-C satellite coincides with a period in which the node factors are changing rapidly, and hence the fixed factors are likely to differ significantly from the correct values; second, variable node factors allow direct comparisons between results of the model and observations obtained several years before the launch date of the satellite. The additional computer time required to compute the node factors is not significant.

TABLE 4-2. COMPARISON OF MODEL WITH TEST STATIONS

Location	North Carolina Station 1 32°41.5N, -75°37.5E				San Juan, Puerto Rico Station 18°29N, -66°07E			
Gage Type	Bottom Pressure Gage				Shore Gage			
Observation Period	9 July 72 - 6 Aug 72				1899; 191 - 1/2 days duration			
Type of Analysis	Harmonic Analysis		Model		Harmonic Analysis		Model	
Reference	Mofjeld, 1972				C&GS Tidal Harmonic Constants, TH-1, 1942			
	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase	Amplitude	Phase
Constituents	(m)	(°G)	(m)	(°G)	(m)	(°G)	(m)	(°G)
M_2	.481	356	.4574	356	.149	18	.2021	16
N_2	.093	339	.1123	334	.034	4	.0409	2
S_2	.072	27	.0891	20	.021	39	.0518	65
K_2	(.020)	(27)	.0193	17	(.006)	(38)	.0187	54
K_1	.101	185	.0955	186	.082	228	.0680	216
O_1	.077	192	.0721	192	.073	227	.0551	211
P_1	(.033)	(185)	.0320	187	.027	228	.0191	220
Q_1	(.015)	(185)	.0135	179	.015	227	.0154	213

Because of assumptions used in establishing the time base of the model and because of assumptions made about the functional dependence of the node factors on time, the model is attuned for predictions for the time period 1973-1978. Extending this period will require modification of the model.

In the open ocean, the sea surface is fluctuating about a time-independent mean because of several processes of which ocean tides produce some of the largest displacements. In the GEOS-C calibration area, tidal displacements amount to about to about ±0.5 meter. Other processes such as time-dependent currents (atmospherically induced), low frequency waves, and earth tides may produce displacements of perhaps ±0.1 meter. If the altimeter of the GEOS-C is found to have sufficient resolution, these processes must be included in any analysis scheme to remove and/or study time-dependent sea surface fluctuations in the altimetry data. The region of the Gulf Stream in the calibration area is subject to meanders of the current which can produce sea surface fluctuations as large as 1 meter. The Gulf Stream is an important feature in the calibration area and must be treated carefully in order to obtain a complete picture of the sea surface's behavior in the calibration area; other investigators are considering this problem.

4.3.1.2 Fundamental Formulas. The sea surface displacement at a given time location is computed using the expression

$$h = \sum_{i=1}^{8} f_i \, A_i \cos(\sigma_1 \, t - \zeta_i) \quad , \qquad (1)$$

where f_i, A_i, σ_i, ζ_i are the node factor, amplitude, frequency, and phase lag of the i^{th} tidal constituent and t is the time relative to 0000GMT 1 March 75. The frequencies of the eight principal constituents are obtained from Schureman (1941); all other quantities are computed by the model.

The node factors f_i are computed from cubic polynomials derived from Stirling's interpolation formula applied to values for the middle of each year 1973-1977, as found in Schureman (1941)

$$f_i = a_i + b_i\, u + c_i\, u^2 + d_i\, u^3 \qquad (2)$$

where a_i, b_i, c_i, and d_i are coefficients and $u = t-t_o$, t_o being the same lag in hours from the start time of the model to 0000GMT 1 July 75.

The amplitudes A_i and phase lags ζ_i are computed from the complex harmonic constants $H_i = (H_i', H_i'')$

$$A_i = \left[(H_i')^2 + (H_i'')^2 \right]^{1/2} \qquad (3)$$

and

$$\zeta_i = \arctan\, (H_i'' \,/\, H_i') \quad . \qquad (4)$$

The complex harmonic constants are computed at a given location by the linear polynomial

$$H_i = \left(H_{i,1}\right) x + \left(H_{i,2}\right) y + H_{i,3} \quad , \qquad (5)$$

where $H_{i,1}$, $H_{i,2}$, and $H_{i,3}$ are coefficients and x and y are the zonal and meridianal Mercator coordinates corresponding to the latitude θ and east longitude λ of the location, i.e.,

$$x = \pi\, \lambda \qquad (6)$$

and

$$y = \ln\left\{\tan\,(45° + \theta/2)\,\left[\frac{1-\varepsilon\,\sin\,\theta}{1+\varepsilon\,\sin\,\theta}\right]^{\frac{\varepsilon}{2}}\right\}; \qquad (7)$$

ε(= 0.08181949) is the earth's eccentricity as given by the SAO II spheroid.

The coefficients $H_{i,j}$ are found by fitting equation (5) to complex harmonic constants (Greenwich phases adjusted to 0000GMT 1 March 75) at three reference stations, using their Mercator coordinates.

4.3.1.3 Computer Subroutines and Functions. Following are descriptions of the subroutines and functions that comprise the GEOS-C tide model.

4.3.1.3.1 Subroutine Time (Year, Month, Day, Hour, Minute, Second, T). Given the date in YEAR, MONTH (floating point variable), and DAY and the time in HOUR, MINUTE (floating point variable), and SECOND in Greenwich Mean Time, TIME computes the time elapsed in hours, T, since 0000GMT 1 March 75. This subroutine accounts only for one leap year, 1976, and is valid only for the period 1 March 1972-29 February 1980. Example: CALL TIME (1975.0, 3.0, 1.0, 0.0, 0.0, 0.000, T)

4.3.1.3.2 Subroutine Tide (Theta, Lambda, T, Height). As input data, the user provides TIDE with the latitude THETA and east longitude LAMBDA (floating point variable), both in degrees, and the elapsed time T in hours since 0000GMT 1 March 75 as obtained from TIME. TIDE then returns the sea surface displacement from the time mean in meters at that location and time.
Example: CALL TIDE (28.00, -69.40, T, HEIGHT)

4.3.1.3.3 Entry Tide 1 (T, Height). This entry point in TIDE is used to produce time series at a given location whose harmonic constants need not be recomputed at each time step. TIDE must be called at least once to establish the harmonic constants after which TIDE 1 may be used.

Example: CALL TIDE 1 (TO+FLØAT (IT), HEIGHT)
where IT is the index of a DØ loop and TO is the initial start time of the series.

4.3.1.3.4 Subroutine Cønst (H). CØNST contains the harmonic constants at the reference stations and equilibrium phase information relative to 0000GMT 1 March 75. When called by TIDE, CØNST returns a complex array H(I, J) of a linear polynomial which is used in subroutine AMPL to compute the harmonic constants at a given location. CØNST need be called only once.
Example: CALL CØNST (H)

4.3.1.3.5 Subroutine Løcate (Theta, Lambda, X, Y). Using the latitude THETA in degrees and the east longitude LAMBDA (floating point) in degrees, LØCATE returns the zonal and meridianal Mercator coordinates X and Y, respectively, where the origin is assumed to be 0°N 0°E. This subroutine uses the earth's eccentricity as obtained from the SAO II spheroid in the computations of Y.
Example: CALL LØCATE (28.00, -69.40, X, Y)

4.3.1.3.6 Subroutine Ampl (X, Y, H, A, Z). From the Mercator coordinates X and Y, obtained from LØCATE, and the coefficient array H, obtained from CØNST, AMPL uses a linear interpolation scheme to compute the amplitudes (A) and phases (Z) relative to 0000GMT 1 March 75, of the eight tidal constituents M_2, N_2, S_2, K_2, K_1, O_1, P_1, and Q_1.
Example: CALL AMPL (X, Y, H, A, Z)

4.3.1.3.7 Subroutine Node (T, F). Given the time T, NØDE returns an array F (1) of node factors which adjust the amplitudes of the harmonic constants for their 8.7 and 19 year cycles.
Example: CALL NØDE (-2000.0, F)

4.3.1.3.8 Function Sum (F, A, Z, T). Using the node factors F, the amplitudes A and phases Z of the eight principal tidal constituents, and the time T, SUM computes the sea surface displacements due to water tides in meters.
Example: HEIGHT = SUM (F, A, Z, T)

4.3.1.4 Use of the Model. A straightforward application of the model would be to first call TIME to obtain the time T from the date and time in Greenwich Mean Time, and then call TIDE with T and the latitude THETA and longitude LAMBDA to obtain the sea surface displacement at that time and place. By repeating the TIDE call at different locations but using the same time T, the spatial distribution of the sea surface displacement at that instant can be obtained for the calibration area. For a satellite passing over the calibration area in a time period which is short compared with the tidal period, the displacement under the satellite may be obtained by fixing T and computing the displacements at a series of locations under the trajectory. Time series can be obtained using the entry point TIDE 1 in subroutine TIDE. TIDE must be called once to establish the harmonic constants at the desired location after which TIDE 1 may be called in a DØ loop to generate the time series.

4.3.2 WALLOPS INPUT CARD FORMAT FOR MOFJELD NOAA TIDE MODEL. The Mofjeld/NOAA tide model program, as implemented on the Wallops Honeywell 625 computer, accepts card input in the following format:

CARD COLUMN	DESCRIPTION
1-6	YYMMDD (Date--year, month, day)
7-16	HHMMSS.SSS (Time--hours, minutes seconds) GMT
21-30	±DD.DDDDDD (Latitude in Degrees)
35-44	DDD.DDDDDD (East Longitude in Degrees)

For each card input, the Program prints out all the input variables (with the appropriate titles) and the computed sea surface displacement, in meters, for that time and geographic location. The Modified/NOAA tide model is incorporated in the A/OMEGA II computer program.

4.3.3 HENDERSHOTT TIDE MODEL. The Hendershott ocean tide model will be used in the ARC program for global ocean tide calculations outside of the calibration area.

4.3.3.1 General Description. The Hendershott tide model represents the astronomical tide generating potential by the dominant second order term, U_2, in the spherical harmonic expansion. The effects of yielding of the solid earth to the astronomical tidal force are included, but the ocean self-attraction and the ocean loading effect is neglected (Hendershott, 1973). The solution only represents the dominant lunar semi-diurnal tide..(M_2) with lunar declination terms neglected. Table 4-3 presents the spherical harmonic coefficients of the M_2 global tide.

4.3.3.2 Hendershott Tide Model Subroutine. Table 4-4 is the Hendershott tide model subroutine derived from the above information at the Wallops Island station, and is included in the ARC program.

4.4 REFRACTION CORRECTION MODEL.

Studies indicate that refraction corrections for both the altimeter and tracking data can be handled as a mathematical model. (See Appendix B.) It is planned to use the modified Hopfield model in the data reduction program. Inputs to this model are surface pressure, temperature, and relative humidity. Arrangements are being made with the NOAA Space Flight Meteorological Group to obtain these surface meteorological parameters for a major portion of the Northern Hemisphere. The parameters will be derived from the NWS computerized Spectral Global Analysis Program.

Where actual data are not available, the data reduction program will use mean monthly values tabulated as a function of latitude for both the Northern and Southern Hemisphere, Table 4-5. Values in Table 4-5 are in 5° increments from 65°S to 65°N at a longitude of 50°W.

4.5 SEA STATE DATA ACQUISITION/PROCESSING.

As stated in Ground Truth Parameters, Section 3, sea state processing data inputs will include magnetic tapes from the Nanosecond Radar and Laser Profilometer NASA C-54 aircraft observations. The data package from the aircraft will

TABLE 4-3. SPHERICAL HARMONIC COEFFICIENTS OF THE M_2 GLOBAL TIDE

n	m	α_{nm}		β_{nm}	
0	0	-5.26	-12.52		
1	0	-0.36	6.81		
1	1	10.71	3.89	10.97	35.80
2	0	4.47	1.65	0.00	0.00
2	1	-14.35	5.20	-13.04	-27.18
2	2	-32.69	44.86	11.38	23.68
3	0	2.93	-11.30	0.00	0.00
3	1	-5.25	-30.30	9.02	-9.59
3	2	16.37	-21.01	-20.87	25.82
3	3	30.62	38.45	30.81	-0.75
4	0	-3.33	-0.49	0.00	0.00
4	1	6.90	-15.36	7.63	18.49
4	2	11.85	-4.60	-19.92	-39.37
4	3	-30.74	-34.54	-11.94	-29.16
4	4	-13.04	-8.03	16.10	29.84
5	0	-4.43	4.18	0.00	0.00
5	1	15.58	32.22	-12.35	-24.71
5	2	-22.62	3.85	27.26	-26.93
5	3	-0.59	3.78	-1.66	20.90
5	4	13.85	22.57	1.00	-28.94
5	5	-1.16	-3.28	14.59	16.91
6	0	6.10	1.61	0.00	0.00
6	1	-0.66	9.79	-5.91	-2.65
6	2	-1.78	12.04	12.75	9.94
6	3	-3.68	19.94	3.21	12.08
6	4	3.98	9.32	0.35	-11.65
6	5	-2.78	18.76	-17.50	19.23
6	6	0.91	22.92	-5.82	-34.50
7	0	5.31	6.66	0.00	0.00
7	1	-10.45	-1.95	9.69	11.96
7	2	10.92	-8.19	-3.00	19.13
7	3	-9.72	1.06	2.22	2.13
7	4	3.86	-0.82	8.54	-5.37
7	5	0.50	-15.31	2.82	-18.55
7	6	2.85	0.92	0.44	-3.42
7	7	12.37	11.25	-12.86	-18.77
8	0	-3.49	2.26	0.00	0.00
8	1	-7.70	6.81	4.30	8.12
8	2	0.03	-11.78	-5.16	10.23
8	3	7.85	-5.03	5.93	-1.56
8	4	-7.62	6.90	5.59	-10.60
8	5	-6.21	-7.68	-3.30	-10.16
8	6	-5.87	-6.59	1.30	0.00
8	7	-14.70	-6.11	-4.94	14.78
8	8	4.81	-2.03	-1.70	9.10
9	0	-5.06	-3.65	0.00	0.00
9	1	-5.90	-5.94	-3.35	3.53
9	2	-0.59	1.29	-6.27	-5.04
9	3	3.08	0.48	2.26	4.37
9	4	2.67	3.61	7.71	-3.84
9	5	1.45	-2.31	7.15	0.64
9	6	8.05	2.45	4.30	-7.89
9	7	2.48	-7.74	-1.62	-1.19
9	8	-4.59	-7.09	-5.32	3.03
9	9	4.15	7.99	7.08	6.92

TABLE 4-4. HENDERSHOTT TIDE HEIGHT MODEL SUBROUTINE

```
51812 01   02-15-75    08,405          THE HENDERSHOTT TIDE HEIGHT MODEL                              LABEL TIDE
                                                                                                       GE00295
      CTIDE                 THE HENDERSHOTT TIDE HEIGHT MODEL                                          TID0005
            SUBROUTINE TIDE (TMJD,XMINS,RLAT,DLON,HEIGHT)                                              TID0015
      C...PROGRAMMED BY JIM MCMILLAN  -  WOLF RESEARCH AND DEVELOPMENT CORP.                           TID0020
      C...PURPOSE-  TO COMPUTE THE TIDE HEIGHT.                                                        TID0025
      C...METHOD-   THE HENDERSHOTT TIDE MODEL.                                                        TID0030
      C...INPUT VARIABLES-                                                                             TID0035
      C       TMJD       THE MODIFIED JULIAN DATE                                                      TID0040
      C       XMINS      THE NUMBER OF ELLAPSED MINUTES SINCE MIDNIGHT                                 TID0045
      C       DLAT       THE GEOCENTRIC LATITUDE IN DEGREES                                            TID0050
      C       DLON       THE GEOCENTRIC LONGITUDE IN DEGREES                                           TID0055
      C...OUTPUT VARIABLES-                                                                            TID0060
      C       HEIGHT     THE TIDE HEIGHT IN METERS                                                     TID0070
            INTEGER                   ZERO                                                             TID0075
            DIMENSION                 P(10,9)                                                          TID0080
            DOUBLE PRECISION          TMJD,          T1900,          T1974                             TID0085
            COMMON /BUFF02/           AAA(11),       A(10,10),       B(10,10),                         TID0090
           1                          G(10,10),      D(10,9),        VMAX                              TID0095
            COMMON /JUNK/             I,             J,              M,                                TID0100
           1                          N,             RLAT,           RLON,                             TID0105
           2                          COSMLA(10),    SINMLA(10),     SINLAM,                           TID0110
           3                          COSLAM,        SINPHI,         COSPHI,                           TID0115
           4                          DAY1,          EPSM,           DELT,                             TID0120
           5                          THETOG,        T1,             T2,                               TID0125
           6                          ORES,          RAMOON,         OMEGAT,                           TID0130
           7                          SINOMT,        COSOMT,         FN1,                              TID0135
           8                          F2N1,          F2N1CS,         PP(12)                            TID0140
            EQUIVALENCE               (PP(3),P(1,1))                                                   TID0150
            DATA                      ZERO /0/,      RAD /57.2957795/                                  TID0160
      C...POLYNOMIAL COEFFICIENTS FOR MEAN OBLIQUITY (REF-  AMERICAN EPHEMERIS                         TID0165
      C...AND NAUTICAL ALMANAC, 1971, PAGE 490) DIVIDED BY 36525**N.                                   TID0170
            DATA EP0,EP1 /4.0933975E-01,6.2179594E-09/                                                 TID0185
            DATA T1900 /-14980.0D+00/ ,  T1974 /12048.0D+00/                                           TID0200
      C...SET PRELIMINARY CONSTANTS                                                                    TID0205
            RLAT = DLAT / RAD                                                                          TID0210
            RLON = DLON / RAD                                                                          TID0215
            SINLAM = SIN(RLON)                                                                         TID0220
            COSLAM = COS(RLON)                                                                         TID0225
            SINPHI = SIN(RLAT)                                                                         TID0230
            COSPHI = COS(RLAT)                                                                         TID0235
            COSMLA(1) = COSLAM                                                                         TID0240
            SINMLA(1) = SINLAM                                                                         TID0250
            DO 2 I=1,12                                                                                TID0255
            PP(I) = 0.0                                                                                TID0260
          2 CONTINUE                                                                                   TID0265
            DO 5 I=1,10                                                                                TID0271
            DO 5 J=1,9
```

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TABLE 4-4. HENDERSHOTT TIDE HEIGHT MODEL SUBROUTINE (Cont'd)

```
          P(I,J) = 0.0
    5 CONTINUE
      P(ZERO,ZERO) = 1.0
      P(1   ,ZERO) = SINPHI
      P(1   ,1   ) = COSPHI
      HEIGHT = 0.0
C...COMPUTE THE NUMBER OF DAYS SINCE THE REFERENCE DAY (1900 JAN 0D 12H)
      DAY1 = SNGL(TMJD-T1900)
      DAY1 = TMJD - T1900
C...COMPUTE THE MEAN OBLIQUITY.
      EPSM = EP0 - EP1*DAY1
C...COMPUTE THE GREENWICH HOUR ANGLE.
      THETOG = (99.2745542 + SNGL(TMJD-T1974)*0.98564734
     1         + XMINS*0.25068448)  / RAD
C...COMPUTE THE ELLAPSED JULIAN CENTURIES SINCE 1900 JAN 0D 12H.
      T1 = DAY1 / 36525.0
      T2 = T1 * T1
C...COMPUTE THE LONGITUDE OF THE MOON.
      CRES = 270.434358 + 13.1763965268*DAY1 - 1.133E-03*T2
      CRES = AMOD(CRES,360.0) / RAD
C...COMPUTE THE RIGHT ASCENSION OF THE MOON.
      RAMOON = ATAN(COS(EPSM) * SIN(CRES)/COS(CRES))
      OMEGAT = 2.0 * (THETOG - RAMOON)
      COSOMT = COS(OMEGAT)
      SINOMT = SIN(OMEGAT)
      DO 10 M=2,NMAX
      COSMLA(M) = COSLAM*COSMLA(M-1) - SINLAM*SINMLA(M-1)
      SINMLA(M) = SINLAM*COSMLA(M-1) + COSLAM*SINMLA(M-1)
   10 CONTINUE
      FN1  = 0.0
      F2N1 = 1.0
      DO 30 N=2,NMAX
      FN1  = FN1  + 1.0
      F2N1 = F2N1 + 2.0
      P(N,ZERO) = (F2N1*SINPHI*P(N-1,ZERO) - FN1*P(N-2,ZERO)) / FLOAT(N)
      F2N1CS = F2N1 * COSPHI
      DO 30 M=1,N
      P(N,M) = P(N-2,M) + F2N1CS*P(N-1,M-1)
   30 CONTINUE
C...COMPUTE THE TIDE HEIGHT.
      DO 50 N=ZERO,NMAX
      HEIGHT = HEIGHT + (A(N,ZERO)*COSOMT + C(N,ZERO)*SINOMT)*P(N,ZERO)
      DO 50 M=1,N
      HEIGHT = HEIGHT + ((A(N,M)*COSOMT+C(N,M)*SINOMT)*COSMLA(M)
     1             + (B(N,M)*COSOMT+D(N,M)*SINOMT)*SINMLA(M))*P(N,M)
   50 CONTINUE
      HEIGHT = -HEIGHT
      RETURN
      END
```

TABLE 4-5. REFRACTION CORRECTION MEAN MONTHLY SURFACE METEOROLOGICAL DATA

PRESSURE (millibars)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°N	1004.0	1004.0	1008.0	1012.0	1015.0	1011.0	1009.0	1009.0	1007.0	1002.0	1002.0	1000.0
60°N	997.5	998.0	1002.0	1007.0	1013.0	1010.0	1011.0	1010.0	1006.0	998.0	1001.0	998.0
55°N	1002.0	1004.0	1001.0	1008.0	1013.0	1011.0	1014.0	1012.0	1010.0	1006.0	1006.5	1002.0
50°N	1007.0	1009.0	1003.0	1011.0	1014.0	1015.0	1018.0	1015.0	1014.0	1012.0	1011.0	1009.0
45°N	1012.0	1011.5	1007.0	1014.0	1016.0	1018.0	1022.0	1018.0	1018.0	1016.0	1016.5	1014.0
40°N	1016.0	1015.0	1013.0	1017.5	1021.0	1022.0	1025.0	1022.0	1020.0	1019.0	1019.0	1018.0
35°N	1019.0	1018.0	1017.5	1022.0	1022.0	1025.0	1027.0	1026.0	1023.0	1021.0	1022.0	1021.0
30°N	1022.0	1021.0	1021.0	1023.0	1023.0	1026.0	1025.0	1023.0	1021.6	1022.0	1022.0	1021.0
25°N	1022.0	1022.0	1022.0	1022.0	1022.0	1024.0	1022.0	1020.0	1019.8	1020.0	1022.0	1021.0
20°N	1021.0	1019.5	1020.0	1019.0	1019.0	1021.0	1019.0	1017.5	1017.0	1019.0	1019.0	1020.0
15°N	1017.5	1017.0	10.7.0	1015.5	1016.0	1018.0	1017.0	1014.0	1015.0	1015.5	1017.0	1017.0
10°N	1015.0	1015.0	1013.5	1013.0	1013.0	1015.0	1014.0	1014.0	1013.3	1013.0	1013.0	1014.0
5°N	1012.0	1013.0	1016.0	1010.0	1010.0	1013.0	1013.0	1013.0	1013.0	1013.0	1011.0	1011.5
0°N	1010.3	1011.2	1010.4	1010.7	1011.3	1013.1	1013.3	1013.5	1012.9	1012.2	1010.9	1011.1
- 5°N	1010.7	1011.4	1010.9	1011.3	1012.1	1014.1	1014.6	1014.8	1013.9	1012.6	1011.3	1011.5
-10°N	1012.2	1012.3	1012.1	1012.7	1013.8	1016.0	1016.8	1016.9	5.8	1013.9	1012.5	1012.3
-15°N	1013.3	1013.3	1013.2	1014.2	1016.0	1017.9	1019.1	1018.9	1017.6	1015.5	1013.6	1013.0
-20°N	1014.1	1014.2	1014.1	1015.8	1018.1	1019.6	1020.7	1020.6	1018.9	1016.6	1014.5	1013.5
-25°N	1015.0	1014.6	1015.0	1017.1	1019.2	1020.6	1021.4	1021.4	1019.6	1017.1	1015.0	1013.9
-30°N	1015.6	1015.0	1015.6	1017.8	1018.9	1020.7	1021.1	1020.9	1019.1	1017.2	1015.0	1014.2
-35°N	1015.1	1015.3	1015.3	1016.9	1017.2	1019.4	1019.0	1018.7	1017.9	1016.8	1014.4	1014.1
-40°N	1012.1	1013.4	1013.1	1014.1	1014.2	1016.0	1014.7	1015.2	1016.2	1015.3	1012.2	1012.5
-45°N	1006.3	1008.3	1008.6	1009.2	1009.0	1010.2	1009.0	1010.2	1012.6	1012.0	1007.1	1008.6
-50°N	998.7	1001.2	1002.2	1002.2	1002.1	1003.2	1003.1	1004.1	1006.4	1006.2	1000.0	1000.7
-55°N	992.2	994.1	995.1	994.6	995.3	996.9	997.5	997.5	999.0	999.0	992.6	993.3
-60°N	988.5	988.1	989.0	987.9	990.1	992.0	992.7	992.0	991.5	991.5	985.8	988.5
-65°N	987.5	984.9	985.3	984.0	987.5	989.0	989.2	988.3	985.1	984.0	981.3	986.9

TABLE 4-5. REFRACTION CORRECTION MEAN MONTHLY SURFACE METEOROLOGICAL DATA (Cont'd)

TEMPERATURE (°C)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°N	- 4.0	- 4.0	0.0	- 1.0	4.0	6.0	6.0	7.0	6.0	2.0	0.0	- 2.0
60°N	2.5	2.0	4.0	3.0	6.0	8.0	9.0	10.0	9.0	6.0	5.0	5.0
55°N	5.0	5.0	6.0	6.0	7.0	10.0	11.0	13.0	12.0	9.0	7.0	6.0
50°N	8.0	7.0	8.0	9.5	10.0	13.5	15.0	16.0	15.0	13.0	11.0	9.0
45°N	11.0	11.0	12.0	13.0	13.5	17.0	19.0	20.0	18.0	17.0	14.0	13.0
40°N	14.0	13.5	14.0	14.5	16.5	19.0	21.0	23.0	21.5	19.0	17.5	15.0
35°N	16.0	16.0	17.0	17.0	18.5	21.0	23.0	24.7	24.0	21.5	20.0	18.0
30°N	18.5	18.0	18.5	19.8	20.5	22.0	24.2	25.0	25.0	23.0	21.5	19.0
25°N	21.0	20.5	20.5	21.0	21.5	23.0	24.5	25.6	25.3	25.0	23.0	22.0
20°N	22.0	21.5	21.5	22.0	22.5	24.4	25.0	25.6	25.6	25.6	25.0	23.0
15°N	23.0	23.0	23.0	23.0	23.5	25.0	26.0	26.0	26.1	26.7	25.6	25.0
10°N	24.5	23.0	25.0	25.0	25.0	26.0	26.0	25.6	27.2	26.9	26.1	25.6
5°N	26.0	26.0	26.0	26.0	26.0	27.0	27.0	26.0	27.2	26.7	26.1	26.1
0°N	26.7	26.5	26.5	25.8	26.6	26.5	26.0	25.9	26.4	25.7	25.5	26.5
- 5°N	27.6	27.7	27.4	27.2	26.3	25.6	25.5	25.2	26.0	26.6	26.9	27.3
-10°N	27.2	27.7	27.1	26.7	26.1	24.9	24.4	24.6	25.1	25.9	26.5	26.8
-15°N	26.6	27.6	27.2	26.6	25.6	25.0	24.3	24.1	24.7	25.2	26.0	20.9
-20°N	26.4	26.6	26.8	26.2	24.5	24.0	23.0	22.7	22.9	23.5	24.4	25.3
-25°N	25.5	26.0	26.1	24.8	22.9	22.2	21.0	20.0	20.7	21.4	22.5	24.0
-30°N	23.5	24.6	24.0	22.6	20.3	19.3	18.3	18.0	18.2	18.7	20.3	21.8
-35°N	20.1	21.2	20.4	18.8	16.6	16.0	14.6	14.6	14.3	15.0	16.6	18.4
-40°N	16.1	16.5	16.0	14.8	12.9	12.3	11.2	10.7	10.7	11.5	13.0	14.6
-45°N	12.0	12.5	12.0	11.0	9.3	8.6	7.5	7.0	7.3	8.5	9.5	10.7
-50°N	7.5	8.2	7.9	5.9	4.7	3.9	3.3	3.1	3.2	4.4	5.4	6.3
[illegible]	3.5	3.8	3.2	1.3	- 0.1	- 1.7	- 2.0	- 2.4	- 1.8	0.0	1.1	2.5
-60°N	0.2	0.8	- 0.1	- 3.1	- 5.3	- 8.0	-10.0	- 9.0	- 6.6	- 3.8	- 1.8	- 0.4
-65°N	- 1.2	- 1.3	- 5.1	- 9.0	-12.0	-12.9	-15.0	-16.3	-13.0	- 8.8	- 4.7	- 1.7

TABLE 4-5. REFRACTION CORRECTION MEAN MONTHLY SURFACE METEOROLOGICAL DATA (Cont'd)

RELATIVE HUMIDITY (%)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
65°N	73	73	54	80	76	82	82	76	82	93	74	74
60°N	78	87	76	81	82	79	88	88	80	88	82	61
55°N	82	82	74	82	88	83	88	80	78	82	82	76
50°N	82	88	77	80	82	80	83	83	83	78	75	80
45°N	88	77	73	78	78	79	79	80	81	79	78	78
40°N	81	78	73	81	76	79	81	75	77	84	76	78
35°N	83	79	74	81	76	79	84	72	75	79	79	79
30°N	79	76	76	79	79	79	80	79	79	79	79	89
25°N	77	72	78	79	81	82	80	79	83	79	79	79
20°N	77	74	79	81	82	82	79	81	86	81	79	79
15°N	79	75	77	82	83	84	78	84	84	70	81	79
10°N	82	79	77	79	79	84	81	86	79	80	84	79
5°N	84	79	79	79	79	80	80	84	79	81	84	79
0°N	82	83	81	85	83	81	79	81	76	80	84	80
- 5°N	73	76	77	80	82	82	76	73	72	75	76	74
-10°N	75	74	78	82	84	88	80	77	75	81	79	76
-15°N	81	77	77	81	83	84	79	81	77	79	79	77
-20°N	81	81	79	79	78	79	77	87	77	79	80	83
-25°N	79	80	80	77	77	78	77	81	78	76	79	77
-30°N	73	75	84	74	78	78	75	76	75	76	73	75
-35°N	76	79	82	76	77	77	79	78	80	80	77	80
-40°N	78	86	84	77	77	76	76	80	82	80	80	81
-45°N	79	80	78	77	76	74	74	77	82	76	80	81
-50°N	81	84	77	82	80	74	72	76	82	76	80	81
-55°N	85	87	83	85	78	74	69	77	87	82	85	81
-60°N	89	79	87	87	79	82	85	87	86	86	82	85
-65°N	78	69	92	91	86	86	80	89	92	83	84	82

include all pertinent flight information - e.g., logs, plots, etc., - and data from supporting instrumentation. After being processed, the data will be merged with the SMG Ground Truth Data Set to produce a family of curves for calibrating the sea state measuring capability of the radar altimeter. Subsequent paragraphs describe NASA C-54 aircraft observed input and data processing products.

4.5.1 NANOSECOND RADAR. The CDP will contain processed data derived through the aircraft ground truth operations delineated in Section 6.

4.5.1.1 Nanosecond Radar Data Processing. Nanosecond radar data will be processed to provide for the following:

a. Significant Wave Height (H1/3) estimate, 4 times the surface height standard deviation.

b. Aircraft Vertical Motion

c. Normalized Radar Return Power

d. Derivative of Radar Received Power

In the process of summing a number of pulse returns to reduce the Rayleigh fluctuations and obtain the average pulse return shape, it is necessary to align the pulse returns, removing any changes in range which occurred among them due to aircraft vertical motion. This alignment process is performed with a threshold tracker. Assuming that the aircraft vertical motion effects a range change of less than the 0.625 ns range quantization in the 0.18 second it takes to record 16 pulses (aircraft vertical rate less than 0.528 m/s); then is is not possible to obtain any better alignment of the pulse returns than already exists within that group. The standard deviation on the C-54 aircraft vertical motion has been measured to be 0.26 m/s so that 16-pulse groups can be averaged and aligned as units without any degradation. The threshold crossings are recorded for each of 100 consecutive 16-pulse groups. A 17-point walking quadratic filter is applied to the thresholds to determine the aircraft vertical motion which is then quantized and the 100 16-pulse groups are aligned accordingly.

4.5.1.2 Output Products. Figure 4-3, Aircraft Vertical Motion, depicts this information graphically and is an example of a data product that will be in the package. The horizontal scale is time and the vertical scale is radar range in meters. The Xs indicate the positions of the thresholds for the 16-pulse averages, and the solid line is the aircraft vertical motion as obtained from the 17-point quadratic filter. If the range change exceeds 1.4m in one step, then that 16-pulse group is excluded as being questionable. That group does not count in the tally and, instead of an X, a D appears on the plot to indicate that the data was deleted.

The 1600 aligned pulse returns are divided into two groups and maximum likelihood estimates of SWH and the plateau decay coefficient are made for the 800-pulse averages. Figure 4-4, Nanosecond Radar Received Power and Derivative of the Received Power, presents an example of the radar data points (squares) the maximum likelihood fit to the data (solid line) for the average return, and the derivative of the average return for 800 pulse returns. Two CALCOMP plots, such as in Figure 4-4, will be in the data package, one for each 800-pulse average.

4.5.2 LASER PROFILOMETER. The CDP will contain processed Laser Profilometer data products derived from aircraft ground truth operations (see Section 6). These products are:

a. Significant Wave Height ($H_{1/3}$)
b. Wave Height Spectrum
c. Wave Height Probability Density Function

The pulse rate, spot size, etc. of the laser is such that it (the Laser Profilometer) simply profiles the ocean surface roughness under the aircraft.

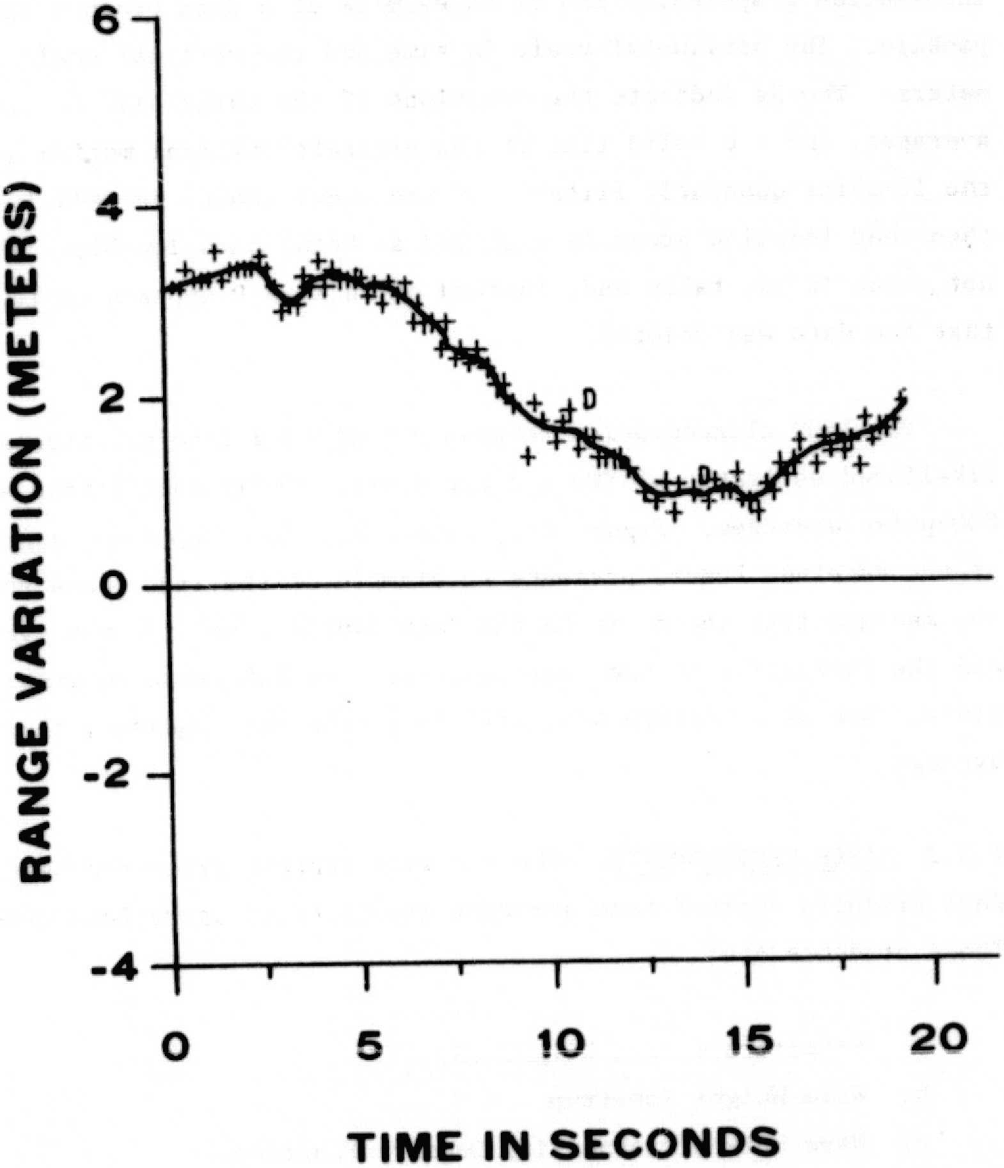


Figure 4-3. Aircraft Vertical Motion

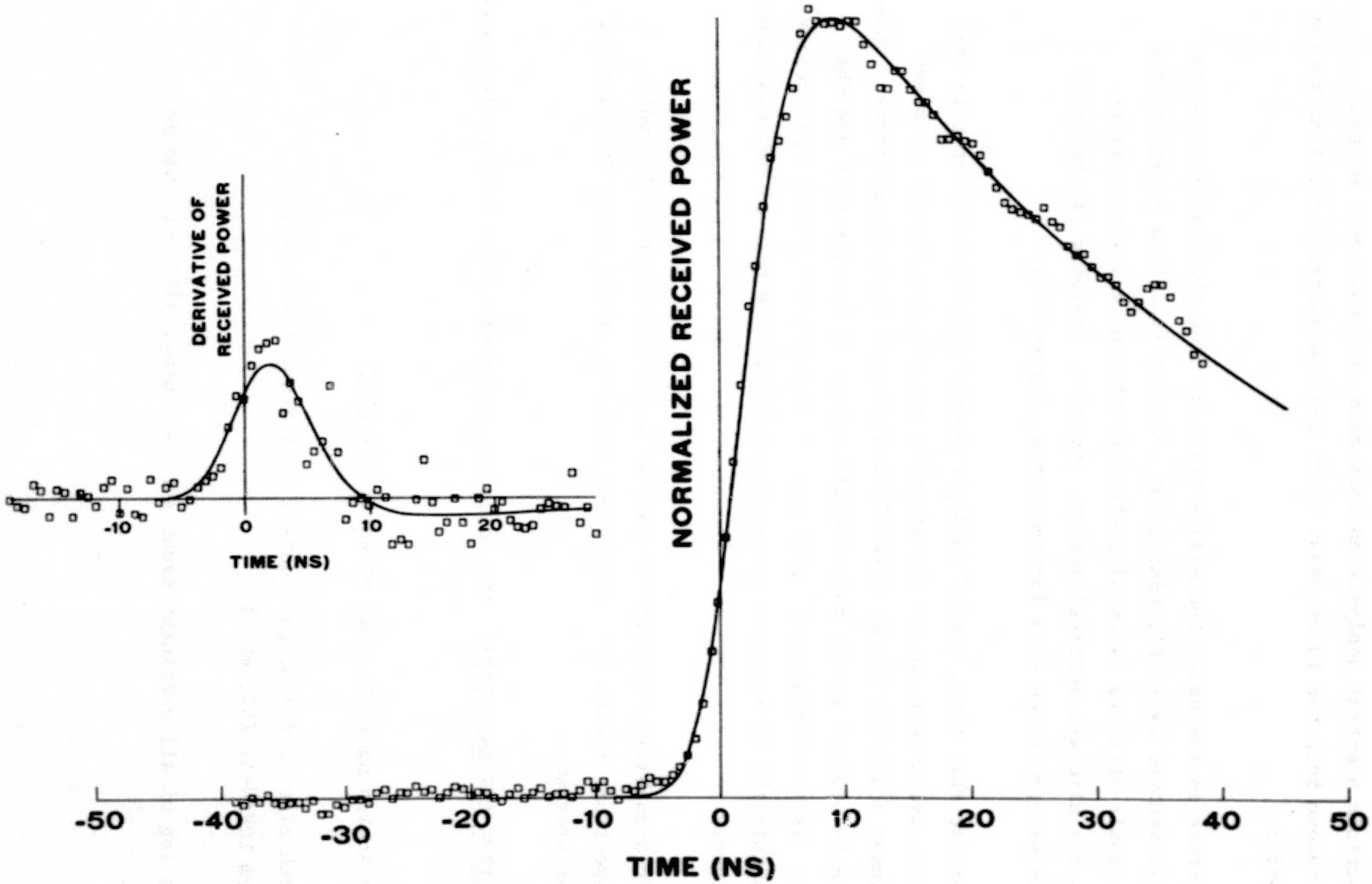


Figure 4-4. Normalized Mean Nanosecond Radar Return

In order to perform spectral analysis on this data, the data must be pre-processed to remove both the laser phase shift and the aircraft vertical motion. (See Figure 4-5.)

The top trace is raw data; the middle trace has the phase shift removed. (Phase shift is removed by simply taking out the step functions.) The bottom trace is the result obtained by running the data through a low pass filter which removes the aircraft vertical motion. Spectral analysis is then performed on this pre-processed data (bottom trace, Figure 4-5).

Note that, at this time, the LP data processing program does not take into account the relative directions of the aircraft and the sea itself; in other words, it assumes a unidirectional wave field with infinitely long crests. This correction can be applied if the relative directions of the aircraft and the sea are known. This information is difficult to obtain, but proper corrections can be made within the LP data processing program with the help of the wind-wave interaction theory.

The laser probability function (Figure 4-6) and the Laser Profilometer wave height spectrum (Figure 4-7) are output products of the Laser Profilometer data reduction program.

4.5.3 <u>SUPPORTING AIRCRAFT DATA</u>. The following supporting data will be furnished by the C-54:

a. Dead Reckoning (D.R. plot of entire flight)

b. Smooth plot of flight path during data acquisition periods (from LORAN-A, INS, etc.)

c. Time log of all pertinent event such as turns, altitude changes, etc.

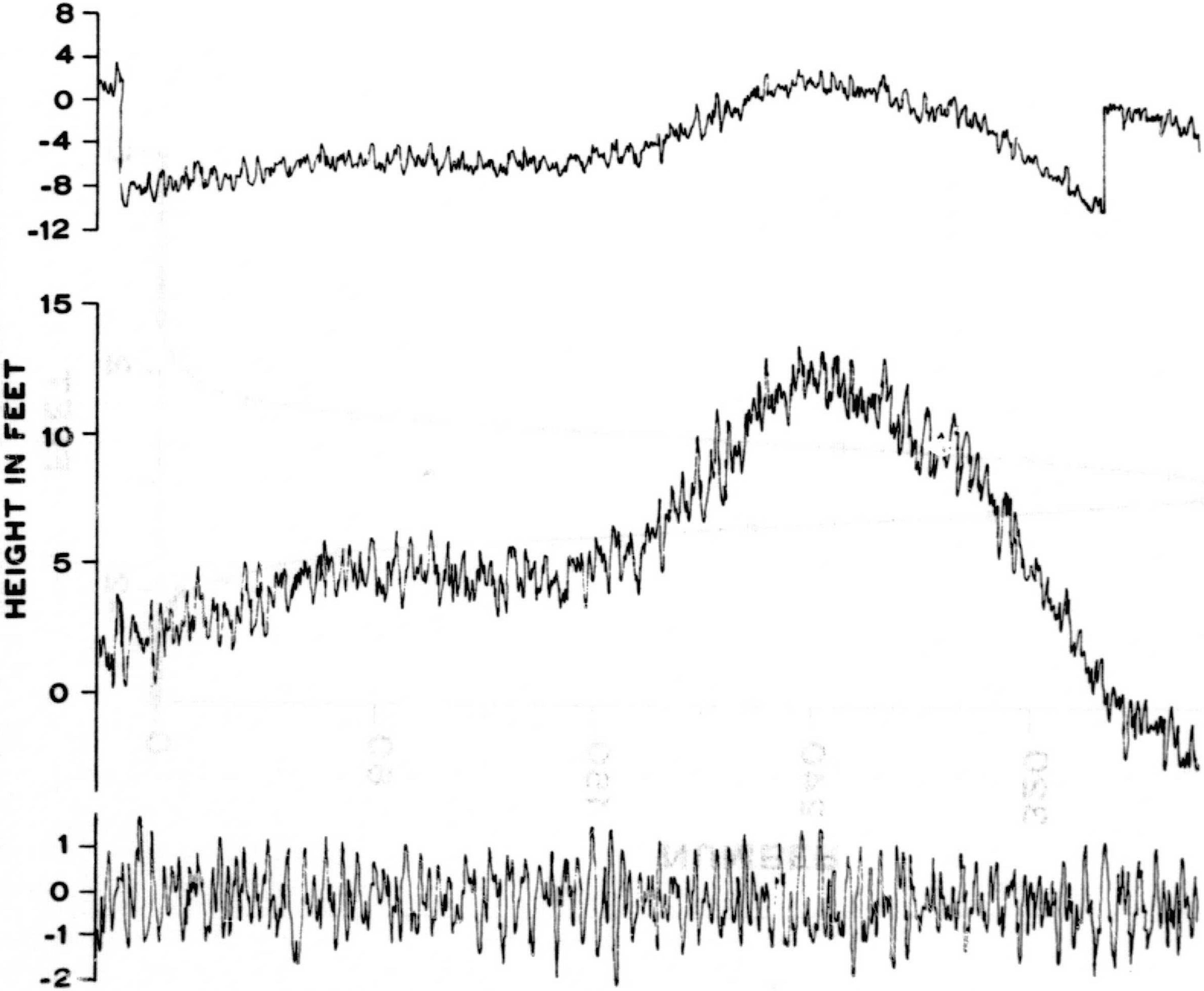


Figure 4-5. Unprocessed Laser Profilometer Data (Height vs Time)

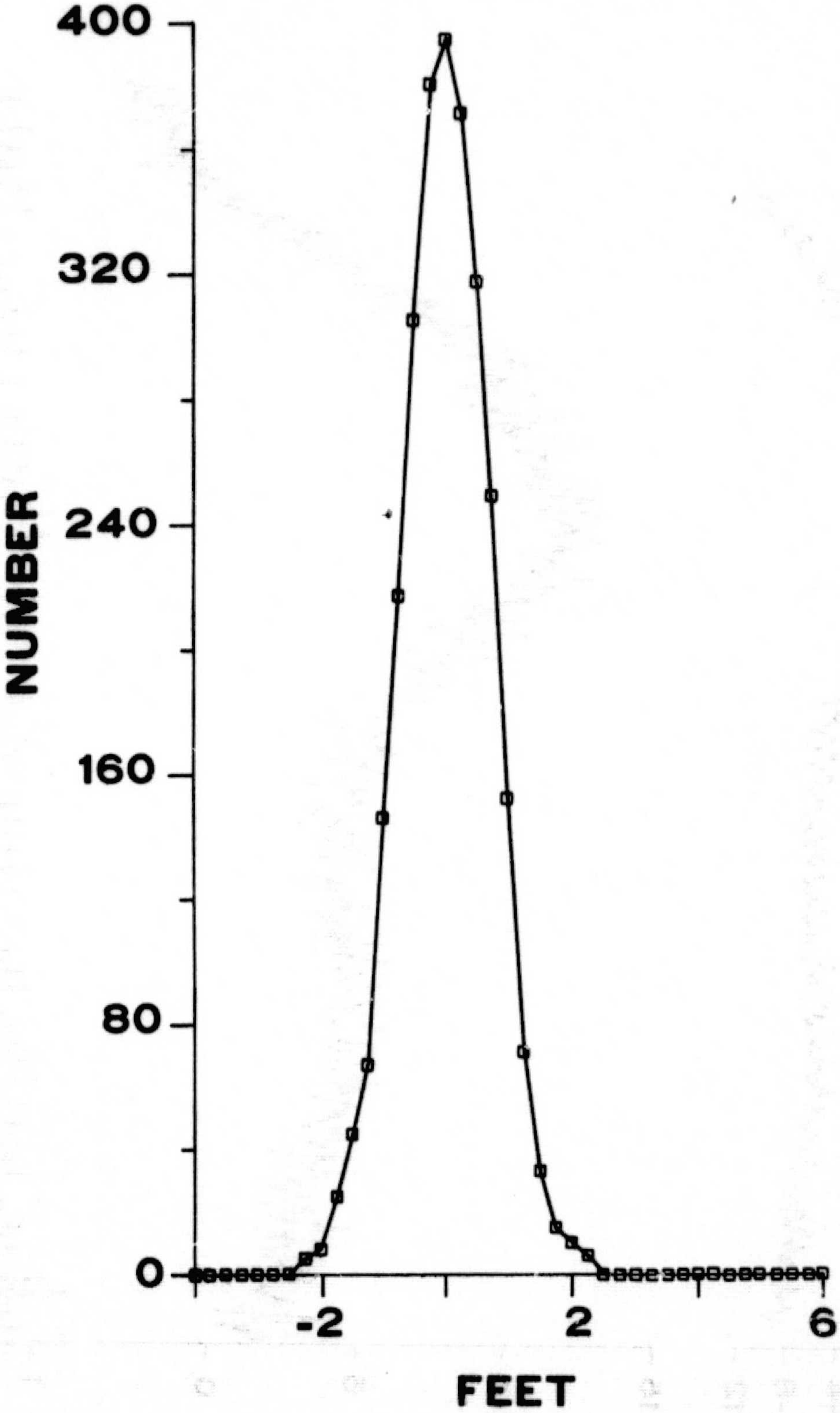


Figure 4-6. Laser Profilometer Probability Density Function

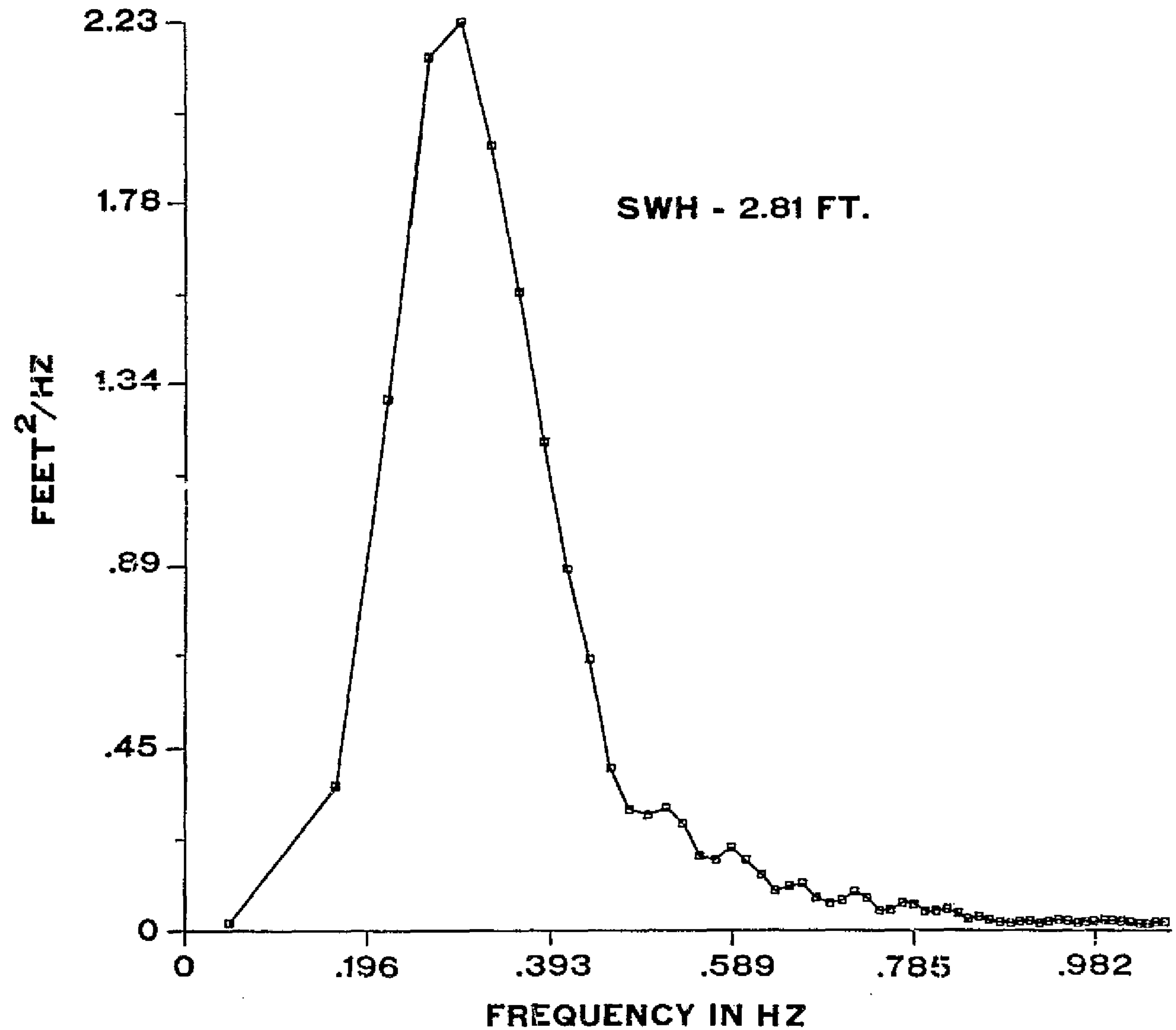


Figure 4-7. Laser Profilometer Wave Height Spectrum

4.6 SPACEFLIGHT METEOROLOGICAL GROUP (SMG) CALIBRATION PRODUCTS.

The Washington Section of the Spaceflight Meteorological Group (SMG) of the National Weather Service (NWS) has joined the GEOS-C project funded by NASA to provide meteorological support for the radar altimeter experiment with emphasis being placed on hindcast sea state. The SMG will provide the project with a Ground Truth Data Set, and has participated in the development of the Data Source Catalog.

4.6.1 SCOPE.

SMG calibration products include the SMG Ground Truth Data Set, which is directed primarily towards providing hindcast sea state ground truth for the CDP, and other meteorological and related products required for the calibration effort.

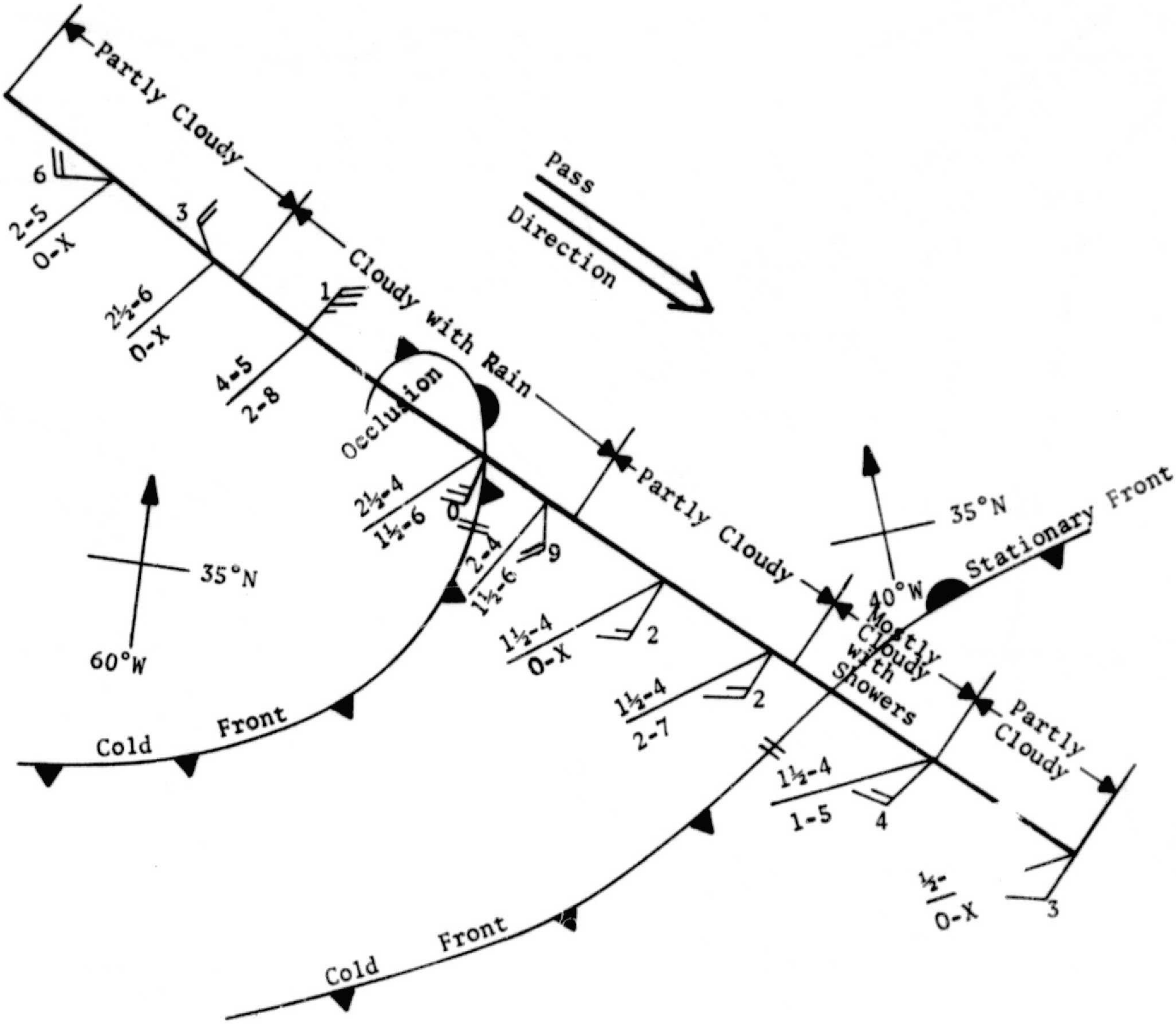
The following topics are presented in this section:

a. Sample of a typical SMG Ground Truth Data Set
b. Description of SMG Ground Truth Data Set
c. Sample of other meteorological calibration products
d. Description of other SMG calibration products.
e. Sea state analysis
f. Problems of sea state observations
g. Glossary of applicable definitions; i.e. definition of basic sea state terms

4.6.2 SAMPLE SMG GROUND TRUTH DATA SET.

A typical SMG Ground Truth Data Set will include the following information, presented in graphical form:

- Figure 4-8 Ground Track Meteorological Analysis and Overlay
- Figure 4-9 Surface Weather Analysis (with ground track annotated)
- Figure 4-10 SMS-1, Infrared 4 nm Resolution (Satellite Photograph)
- Figure 4-11 NOAA-4, Northern Hemisphere, Visual and Infrared 2 nm Resolution (Satellite Photograph)



KEY

4 - 5	Significant wave height (meters) - Wave period (seconds)
2 - 8	Significant swell ht. (meters) - Swell period (seconds)

Figure 4-8. Ground Track Meteorological Analysis and Overlay

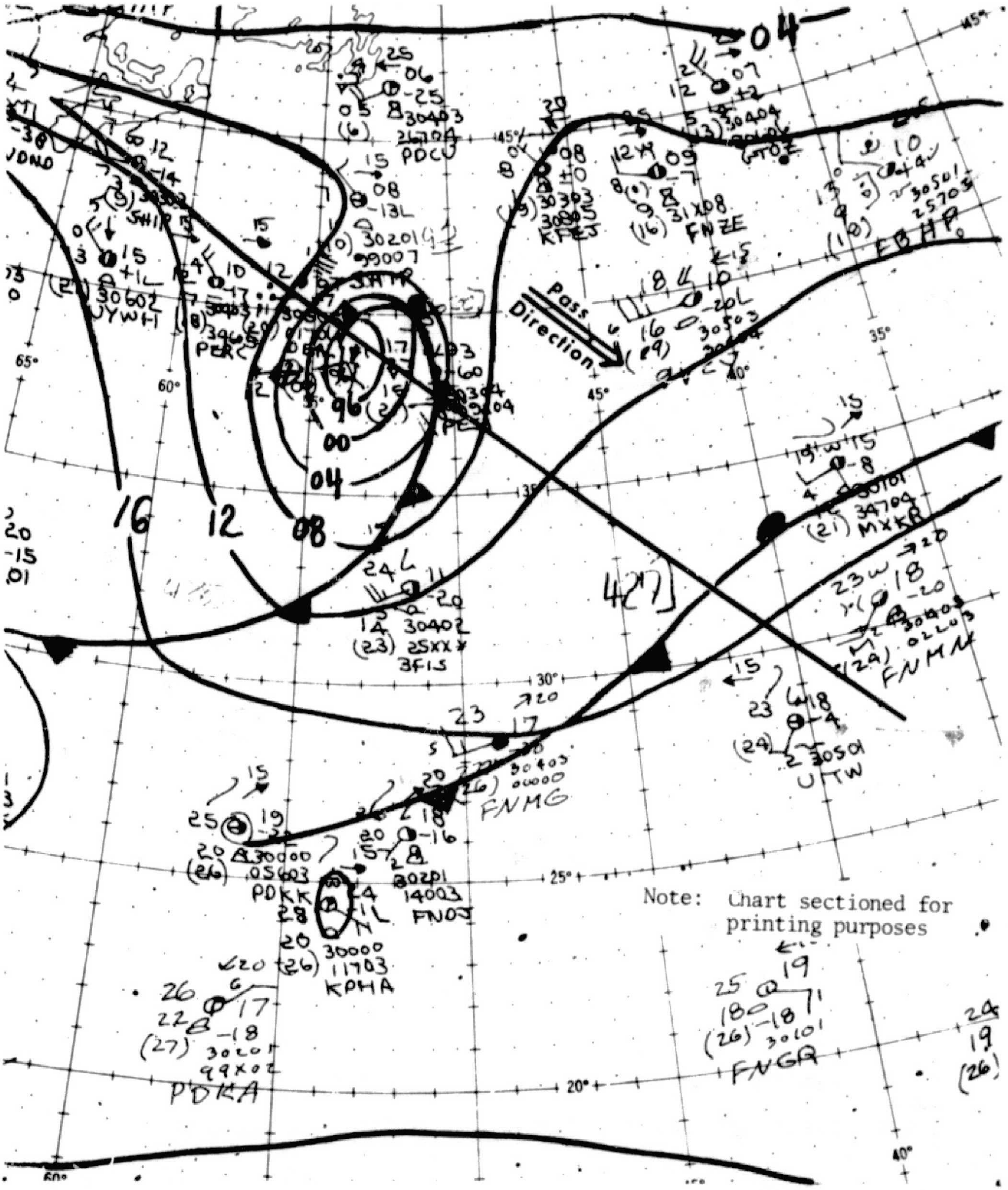


Figure 4-9. Surface Weather Analysis (1800 GMT 18 Nov 1974), with Ground Track Annotated

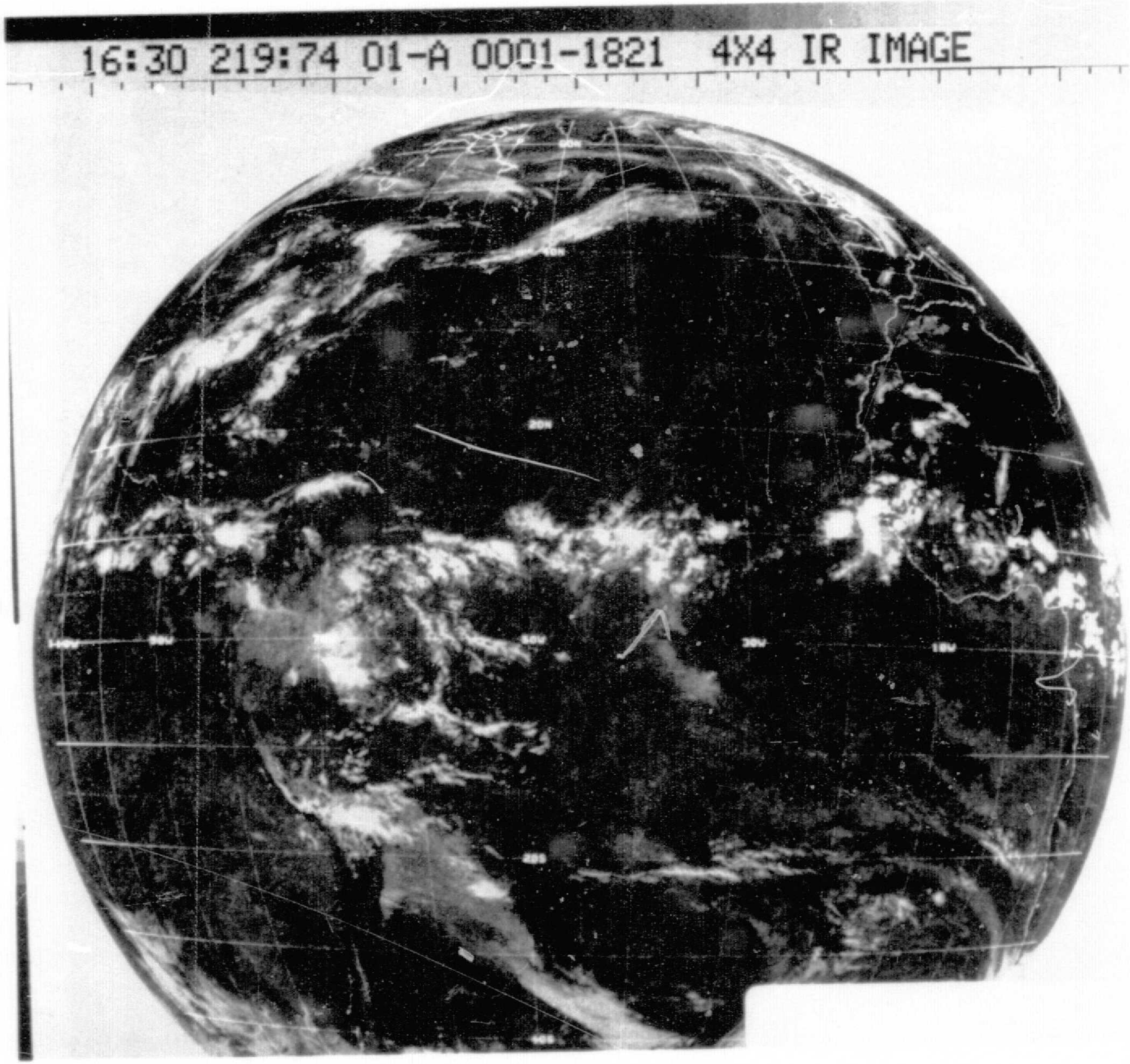


Figure 4-10. SMS-1 Infrared 4 nm Resolution

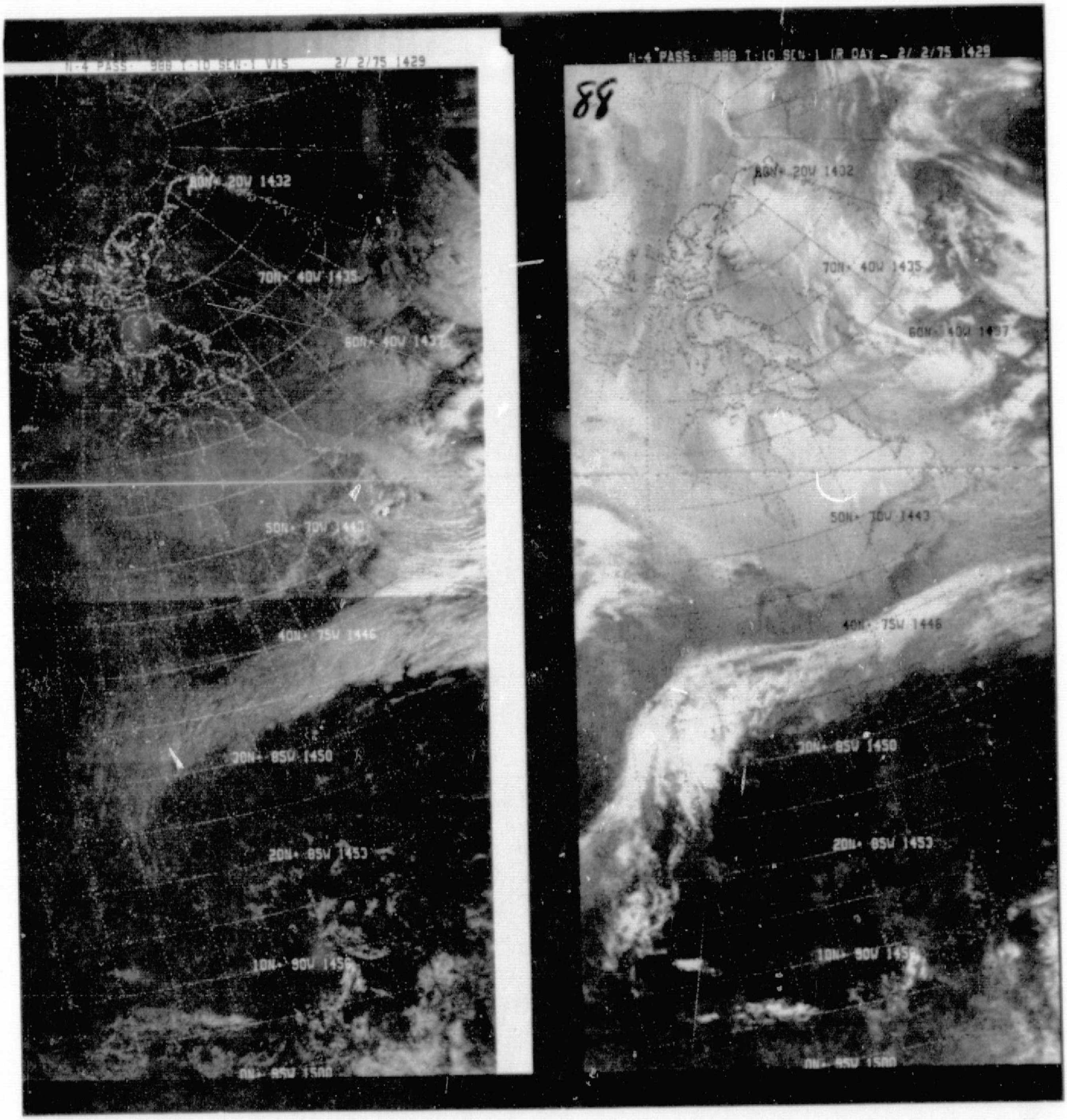


Figure 4-11. NOAA-4 Northern Hemisphere Visual and Infrared 2 nm Resolution

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4.6.3 DESCRIPTION OF SMG GROUND TRUTH DATA SET. Subsequent paragraphs present a description of the SMG Ground Truth Data Set.

4.6.3.1 Ground Track Meteorological Analysis and Overlay. An analysis (see example, Figure 4-8) of sub-satellite sea state data for the calibration area will be provided for the North Atlantic. The sea state information, contained in the overlay, will be derived from all available meteorological data such as sea state (and/or wind) reports from ships and wind fields derived from the surface atmospheric pressure gradients. Sea and swell estimates, surface wind, cloud cover, and areas of precipitation along the track will be annotated. Frontal systems affecting the track will be also depicted on the overlay (shown in Figure 4-8).

4.6.3.2 Surface Weather Analysis. The surface weather analysis will be provided for use with the ground track meteorological analysis and overlay. This chart, a 1:2,000,000 polar sterographic projection, will include a plot of all applicable synoptic weather reports (ships, land stations, and buoys) and a meteorological analysis of the area. Surface wind field patterns are delineated in the analysis by isobaric contours. Figure 4-12 is an example of a plotted ship's weather report as found on the surface weather map with the information included. Figure 4-13 gives examples and an explanation of other symbology generally appearing on the surface weather analysis chart.

Appendix D contains the information contained on the ship code card showing the weather code in symbolic form with the tables used to encode the various parts of the report. Surface weather analysis charts are produced by the National Meteorological Center (NMC) for 0000, 0600, 1200, and 1800 GMT daily. Figure 4-9 (part of Sample SMG Data Set) is an example of the portion of the Surface Weather Analysis provided in the data set.

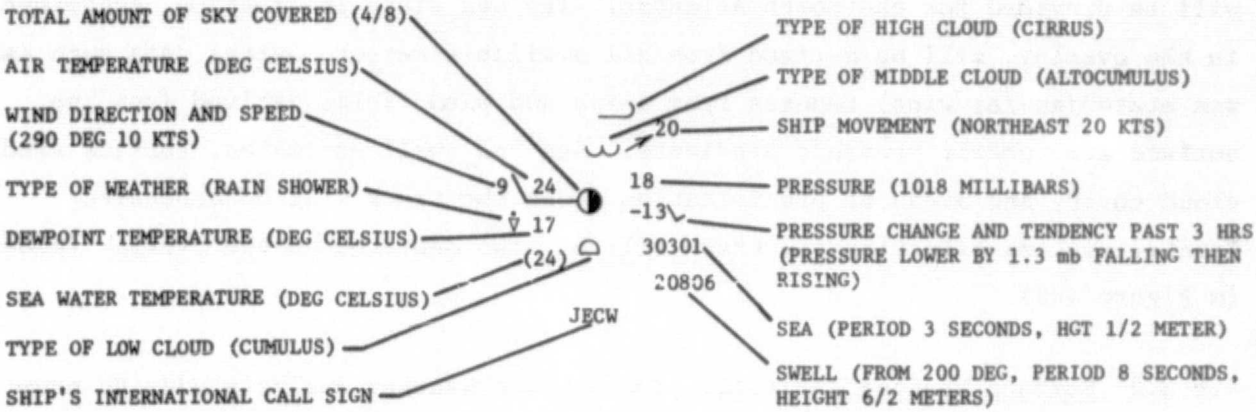


Figure 4-12. Ship Weather Plotting Model

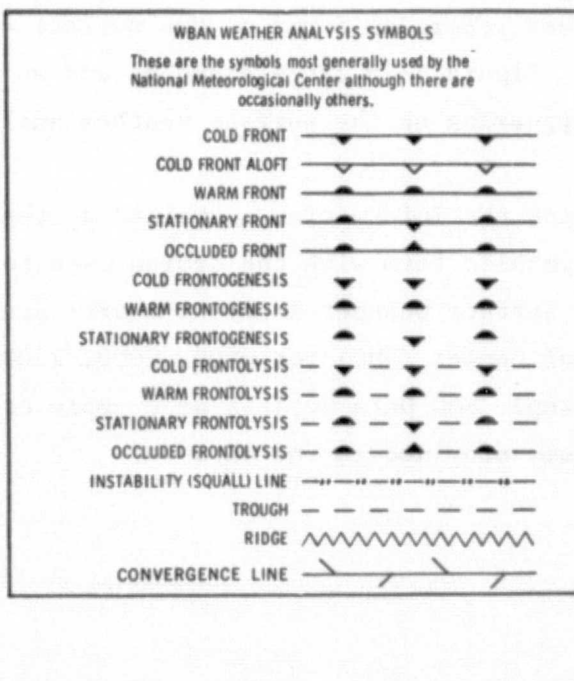


Figure 4-13. Weather Analysis Symbology

4.6.3.3 Satellite Photographs. Weather satellite photographs depict the integrated effects of all atmospheric processes, and are particularly useful in making cloud cover determinations as well as inferring areas of precipitation. Low level cloud movement routinely analyzed from satellite pictures is helpful in estimating sea-level winds over the calibration area and other areas of interest. These photographs are taken by the NOAA Synchronous Meteorological Satellites (SMS) and the Polar Orbiting Meteorological Satellites and will be included routinely in the SMG Ground Truth Data Set. (Examples of other related satellite photographs are included in the Data Source Catalog, Section 8.)

4.6.3.3.1 Synchronous Meteorological Satellites (SMS). The SMS-1 and SMS-2 are located approximately 22,000 nautical miles over their sub-points on the equator 75 degrees and 115 degrees west longitude, respectively. At this altitude, the orbital period is 24 hours and the satellites remain stationary with respect to the earth's surface. At present, available products include:

a. Visual - full-disc 4 nm, 2 nm and sectors of 1 nm resolution. Resolution of 1/2 nm is only available when requested in advance.
b. Infrared - full disc 4 nm resolution.

4.6.3.3.2 Polar Orbiting Meteorological Satellites. At the time of this writing, NOAA-4 is the operational polar orbiting meteorological satellite. It crosses the equator from north to south at approximately 0930 Eastern Standard Time and makes 12 revolutions per day. Pictures are stored on tape until the satellite comes within range of one of three readout stations. Storage capacity for the Very High Resolution Radiometer (VHRR) is limited to 9 minutes. However, most of the U.S. can be covered by direct readout. Photographic products include:

a. Visual - day visible 2 nm resolution. VHRR visible photographs are only available when requested in advance.

b. Infrared - day and night 4 nm resolution. IR 1/2 nm resolutions are only available when requested in advance.

4.6.4 SAMPLES OF OTHER SMG CALIBRATION PRODUCTS. This section contains samples of typical meteorological and other related products provided by the SMG to the calibration effort. These products, supplied in both graphical and tabular form, will include the following:

- Figure 4-14 36 Hour Wind Wave Forecast
- Figure 4-15 Northern Hemisphere Average Snow and Ice Boundaries
- Figure 4-16 Weekly Data Buoy Status Report

4.6.5 DESCRIPTION OF OTHER SMG CALIBRATION PRODUCTS. Subsequent paragraphs in this section present a brief description of other products being provided by SMG for the calibration.

4.6.5.1 Computer-Produced Meteorological Products. The following computer-produced meteorological products will be made available routinely by the Satellite Meteorological Group to the NASA Wallops Station. The Wind Wave and Combined Sea State Forecasts and Constant Pressure Charts have been mathematically modeled and programmed for operational use.

4.6.5.1.1 Combined Sea State and Wind Wave Forecasts. Combined Sea State Forecasts and Wind Wave Forecast, Figure 4-14, are computed by utilizing wind field inputs obtained from surface weather charts over a broad ocean area, and by considering as a function of time, the sea state can be estimated. Wind observations and observed sea state data from surface ships can be entered to reinforce the mathematical solution. The output is a series of charts of sea state (in terms of significant wave height) contours over the area at discrete time increments (usually 12 hours).

4.6.5.1.2 Wind Wave Analysis. The Wind Wave Analysis is a basic analysis derived from pressure fields. It is used as a "first guess" in the preparation of the 36-Hour Wind Wave Forecast.

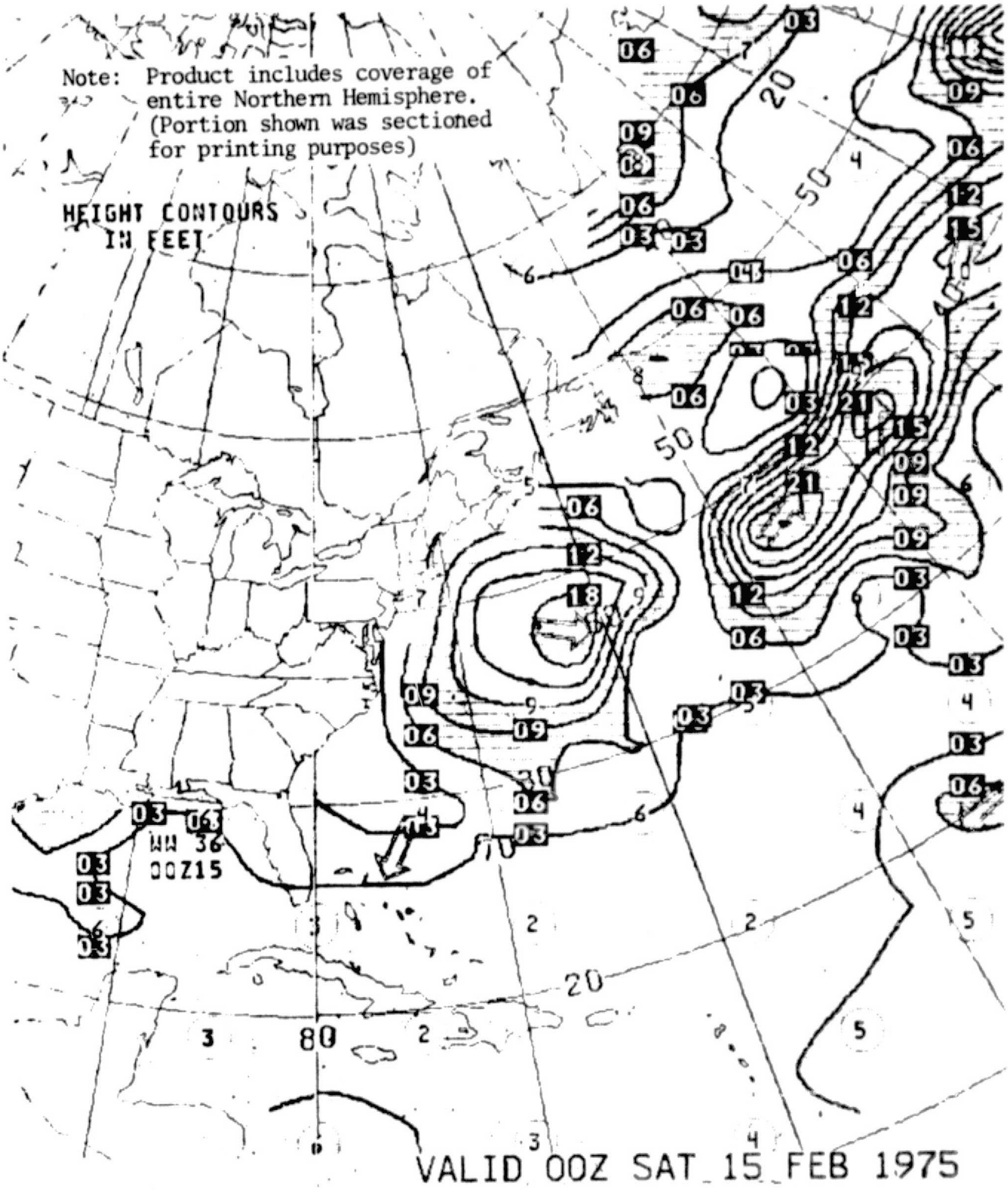


Figure 4-14. 36-Hour Wind Wave Forecast

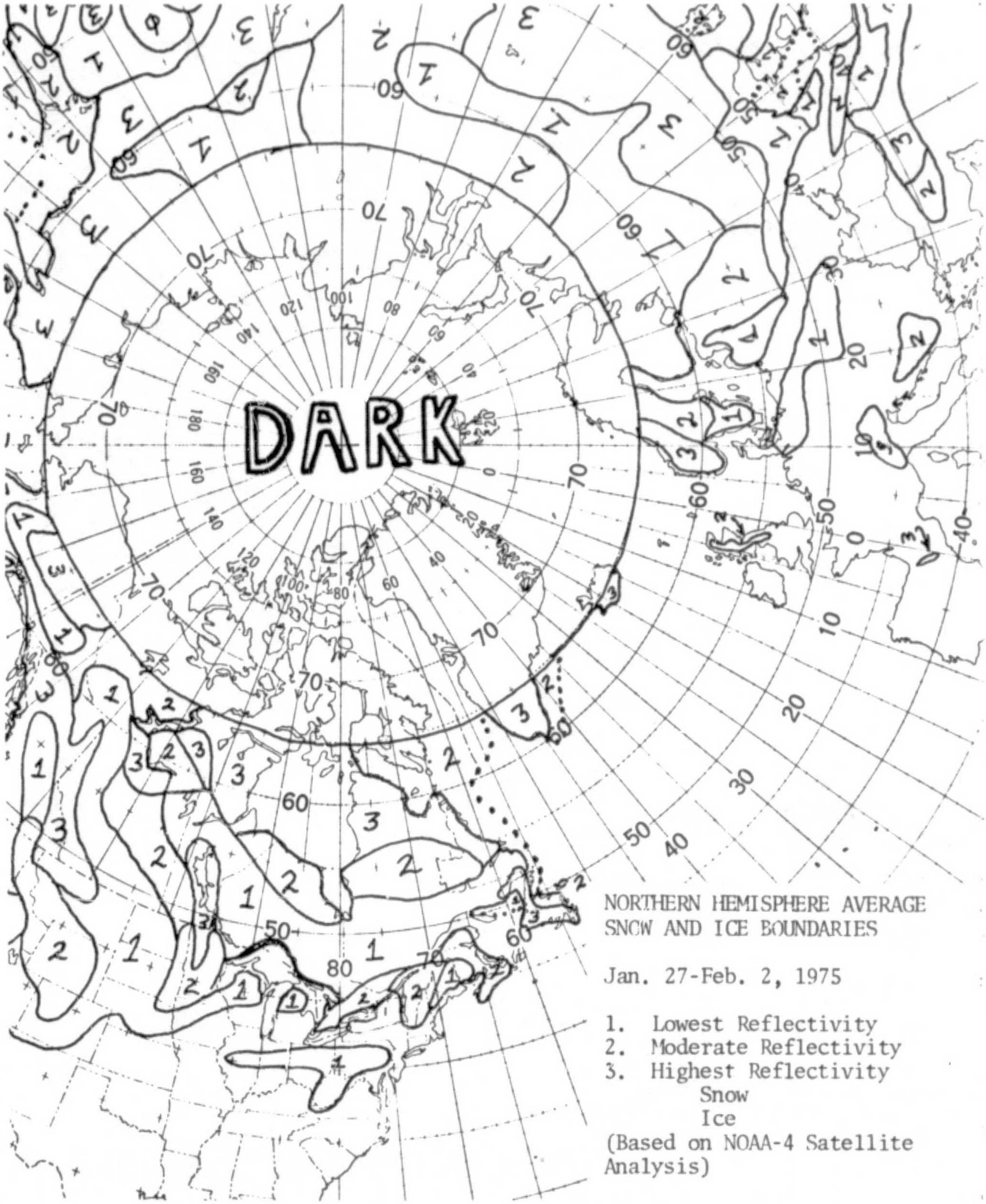


Figure 4-15. Northern Hemisphere Average Snow and Ice Boundaries

For Period: November 22, 1974 18Z to November 29, 1974 12Z

Buoy	Location	Operational Status	Synoptic Buoy Reports Received				
			Not Transmitted	Transmitted		Total	% Rec'd of Total Req'd
				Late	On Time		
EB01[1]	36°30.0'N 73°30.0'W	Out-in-Port	Deployment is scheduled for December 3 or 4.				
EB02[1]	47°00.0'N 131°00.0'W	Out-in-Port	The buoy is at Seattle, Washington; it was extensively damaged and may be unrepairable.				
EB03[1]	56°00.0'N 148°00.0'W	In	Buoy is in position but not yet moored. It should begin reporting later this week.				
EB12[1]	26°00.0'N 94°00.0'W	In			56	56	100%
EB13[1]	32°18.6'N 75°14.5'W	In			56	56	100%
EB32[2]	27°18.6'N 84°00.3'W	In	Pressures deleted.		22	28	79%
EB33[2]	58°36.0'N 141°00.0'W	In			52	56	93%
EB61[2]	25°36.0'N 84°24.0'W	In			1	28	4%
EB62[2]	29°00.0'N 85°36.0'W	In			28	28	100%
ALPHA	35°00.0'N 155°00.0'W	In	No reports received as yet.				

1 High Capability Buoy

2 Limited Capability Buoy

Figure 4-16. Weekly Data Buoy Status Report

4.6.5.1.3 Constant Pressure Charts. The 850 mb, 700 mb, 500 mb, 300 mb, and 200 mb Constant Pressure Charts will be included as meteorological calibration products applicable to the refraction error effort.

4.6.5.2 Northern Hemisphere Average Snow and Ice Boundaries. Figure 4-15, an analysis of average snow and ice boundaries, will be included in the SMG Data Set.

4.6.5.3 Data Buoy Status Report. An operational status report of deployed environmental data buoys, Figure 4-16, will be supplied each week as an SMG calibration product.

4.6.5.4 Other Data Sources. Other data may be obtained months after the fact from the NOAA Environmental Data Service at Asheville, North Carolina and other sources listed in Section 8.0, Data Source Catalog.

4.6.6 SEA STATE ANALYSIS. A sea state evaluation is derived from an analysis of both wind field and ship reports of observed sea heights and periods as found on standard meteorological surface weather maps. The sea state and swell evaluation procedures described in subsequent paragraphs of this section are the techniques h will be used in the SMG sea state analysis. They have been derived from H. . Publication No. 604 "Techniques for Forecasting Wind Waves and Swells".

4.6.6.1 Sea State Evaluation. Weather charts for the past 24 to 36 hours, and longer when necessary, are examined, keeping in mind the basic relationships regarding the effect of wind action on the water surface. For each of a number of points along the ground track, the effective wind, duration, and fetch are estimated. These values are used to obtain specific sea heights and periods. In the case of a fully arisen sea, Table 4-6 may be used. Figures 4-17 and 4-18 are utilized where a non-fully developed sea has occurred or is expected. Where wave height development is limited by the length of the fetch, as for

TABLE 4-6. REVISED WIND AND SEA SCALE FOR FULLY ARISEN SEA**

WIND							SEA					
DESCRIPTION	BEAUFORT	RANGE (KNOTS)	WIND VELOCITY (KNOTS)	WAVE HEIGHT (FEET) AVERAGE	WAVE HEIGHT (FEET) SIGNIFICANT	WAVE HEIGHT (FEET) AVERAGE 1/10 HIGHEST	SIGNIFICANT RANGE OF PERIODS (SECONDS)	T_{max} (PERIOD OF MAXIMUM ENERGY OF SPECTRUM)	$\bar{T}$ (AVERAGE "PERIOD")	$\bar{L}$ (AVERAGE "WAVE LENGTH") (FEET)	MINIMUM FETCH (NAUTICAL MILES)	MINIMUM DURATION (HOURS)
CALM	0	0-1	0.0	0.0	0.0	0.0	--	--	--	--	--	--
LIGHT AIR	1	1-3	2.0	0.04	0.07	0.09	Up to 1.2	0.75	0.5	0.83	5.0	0.3
LIGHT BREEZE	2	4-6	5.0	0.30	0.50	0.60	0.4-2.8	1.90	1.3	6.7	8.0	0.65
GENTLE BREEZE	3	7-10	8.5	0.8	1.3	1.6	0.8-5.0	3.2	2.3	20.0	9.8	1.7
			10.0	1.1	1.8	2.3	1.0-6.0	3.8	2.7	27.0	10.0	2.4
MODERATE BREEZE	4	11-16	12.0	1.6	2.6	3.3	1.0-7.0	4.5	3.2	40.0	18.0	3.8
			13.5	2.1	3.3	4.2	1.4-7.6	5.1	3.6	52.0	24.0	4.8
			14.0	2.3	3.6	4.6	1.5-7.8	5.3	3.8	59.0	28.0	5.2
			16.0	2.9	4.7	6.0	2.0-8.8	6.0	4.3	71.0	40.0	6.6
FRESH BREEZE	5	17-21	18.0	3.7	5.9	7.5	2.5-10.0	6.8	4.8	90.0	55.0	8.3
			19.0	4.1	6.6	8.4	2.8-10.6	7.2	5.1	99.0	65.0	9.2
			20.0	4.6	7.3	9.3	3.0-11.1	7.5	5.4	111.0	75.0	10.0
STRONG BREEZE	6	22-27	22.0	5.5	8.8	11.2	3.4-12.2	8.3	5.9	134.0	100.0	12.0
			24.0	6.6	10.5	13.3	3.7-13.5	9.0	6.4	160.0	130.0	14.0
			24.5	6.8	10.9	13.8	3.8-13.6	9.2	6.6	164.0	140.0	15.0
			26.0	7.7	12.3	15.6	4.0-14.5	9.8	7.0	188.0	180.0	17.0
MODERATE GALE	7	28-33	28.0	8.9	14.3	18.2	4.5-15.5	10.6	7.5	212.0	230.0	20.0
			30.0	10.3	16.4	20.8	4.7-16.7	11.3	8.0	250.0	280.0	23.0
			30.5	10.6	16.9	21.5	4.8-17.0	11.5	8.2	258.0	290.0	24.0
			32.0	11.6	18.6	23.6	5.0-17.5	12.1	8.6	285.0	340.0	27.0
FRESH GALE	8	34-40	34.0	13.1	21.0	26.7	5.5-18.5	12.8	9.1	322.0	420.0	30.0
			36.0	14.8	23.6	30.0	5.8-19.7	13.6	9.6	363.0	500.0	34.0
			37.0	15.6	24.9	31.6	6.0-20.5	13.9	9.9	376.0	530.0	37.0
			38.0	16.4	26.3	33.4	6.2-20.8	14.3	10.2	392.0	600.0	38.0
			40.0	18.2	29.1	37.0	6.5-21.7	15.1	10.7	444.0	710.0	42.0
STRONG GALE	9	41-47	42.0	20.1	32.1	40.8	7.0-23.0	15.8	11.3	492.0	830.0	47.0
			44.0	22.0	35.2	44.7	7.0-24.2	16.6	11.8	534.0	960.0	52.0
			46.0	24.1	38.5	48.9	7.0-25.0	17.3	12.3	590.0	1110.0	57.0
WHOLE GALE*	10	48-55	48.0	26.2	41.9	53.2	7.5-26.0	18.1	12.9	650.0	1250.0	63.0
			50.0	28.4	45.5	57.8	7.5-27.0	18.8	13.4	700.0	1420.0	69.0
			51.5	30.2	48.3	61.3	8.0-28.2	19.4	13.8	736.0	1560.0	73.0
			52.0	30.8	49.2	62.5	8.0-28.5	19.6	13.9	750.0	1610.0	75.0
			54.0	33.2	53.1	67.4	8.0-29.5	20.4	14.5	810.0	1800.0	81.0
STORM*	11	56-63	56.0	35.7	57.1	72.5	8.5-31.0	21.1	15.0	910.0	2100.0	98.0
			59.5	40.3	64.4	81.8	10.0-32.0	22.4	15.9	965.0	2500.0	101.0
HURRICANE*	12	>64	>64.0	>46.6	>74.5	>94.6	10.0-(35)	(24.1)	(17.2)	∞	∞	∞

* FOR HURRICANE WINDS (AND OFTEN WHOLE GALE AND STORM WINDS) REQUIRED DURATIONS AND FETCHES ARE RARELY ATTAINED. SEAS ARE THEREFORE NOT FULLY ARISEN.

** REVISED DECEMBER 1964 by L. Moskowitz, and W. Pierson.

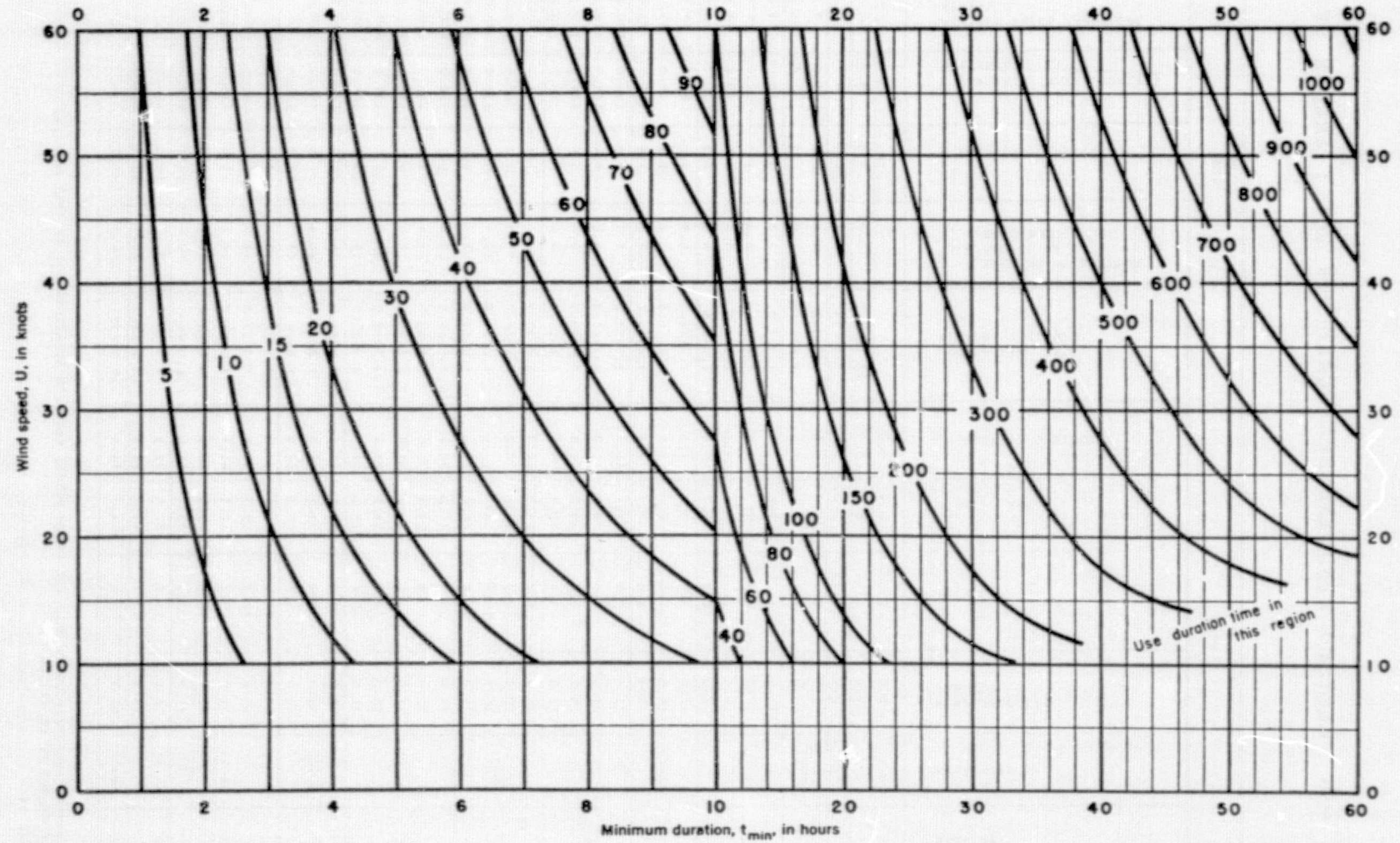


Figure 4-17. Fetch in Nautical Miles as a Function of Minimum Duration and Wind Speed

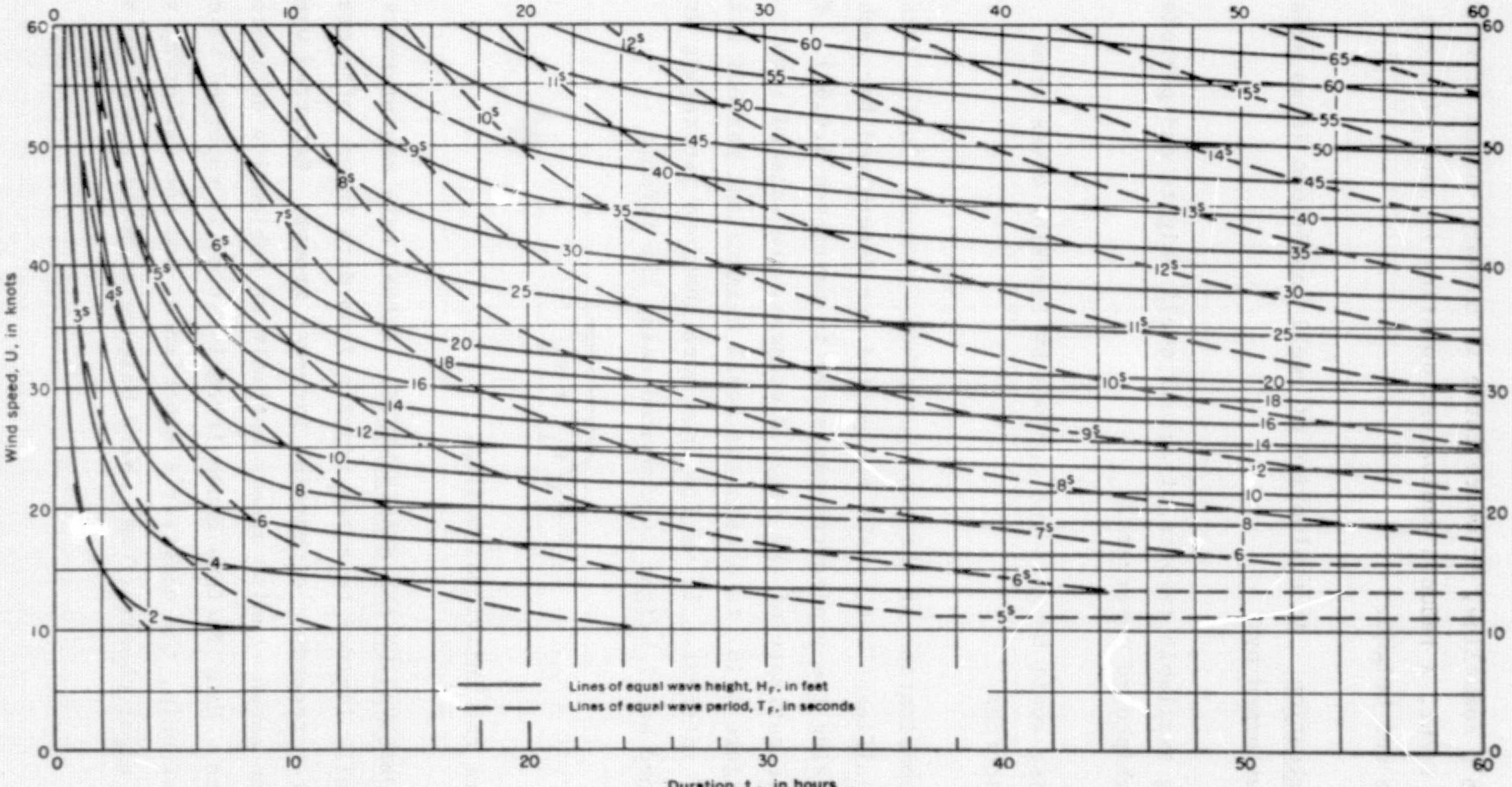


Figure 4-18. Wave Height and Wave Period as Functions of Duration of Wind and Wind Speed

winds blowing from a coastline, or where there is a sharp change of wind direction at a weather front, a reduced equivalent duration is used with the effective wind to obtain the sea height.

4.6.6.2 Swell Evaluation. An evaluation of swell conditions in an area of interest can be performed by:

a. Analyzing available reports of actual swell heights and periods made by shipboard observers.

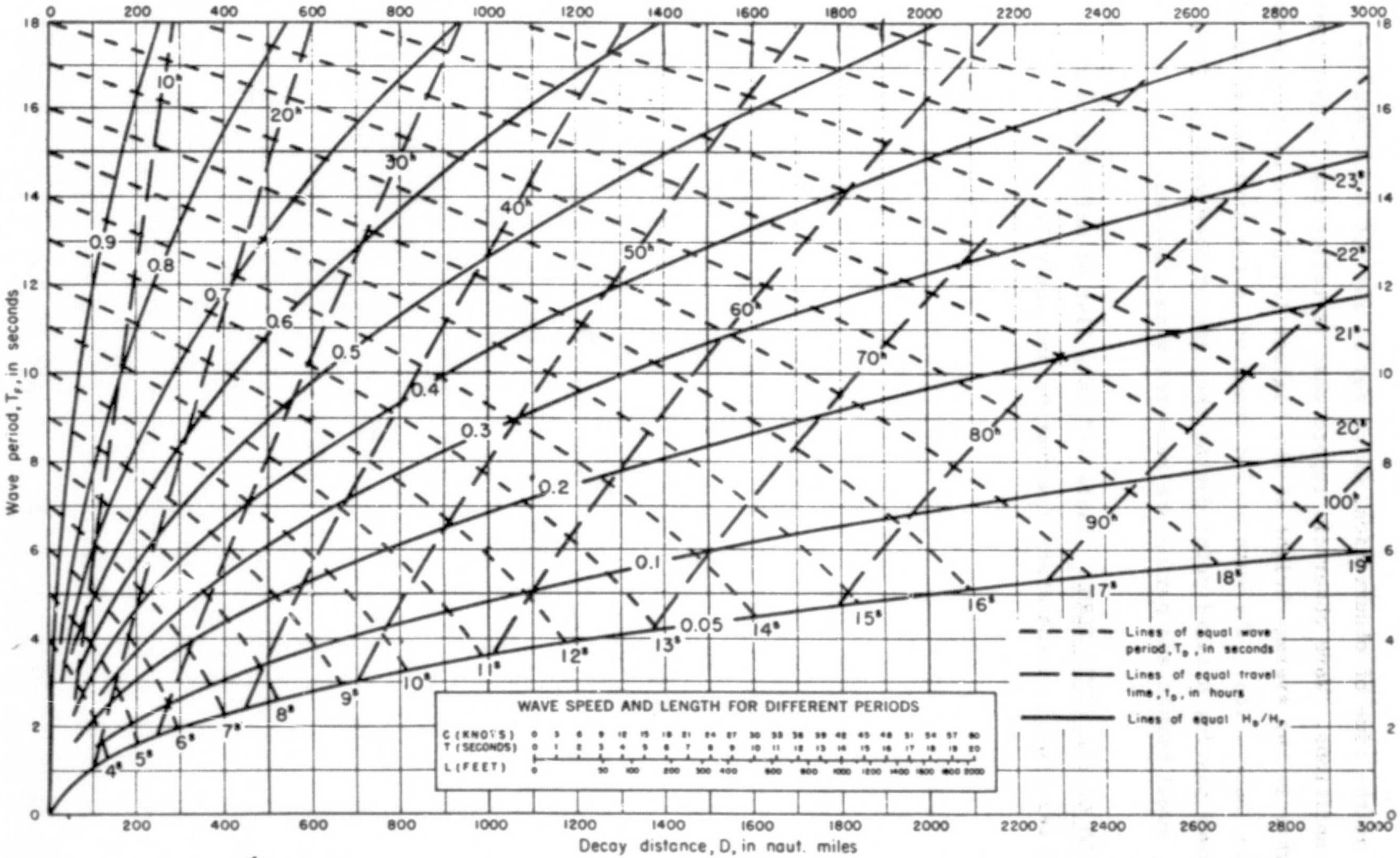
b. Calculating swell heights and periods by tracking waves from distant sources.

In most cases, a combination of the two approaches is used. In the latter technique, the significant sea height and period are determined for each of the generating areas using the procedures explained in paragraph 4.6.6.1. These parameters, with an estimate of the decay distances, are entered into the nomograph (shown in Figure 4-19) to obtain the swell heights and periods which may affect the area of interest. If swells from more than one generating area are active, the combined swell height is computed using the formula

$$S = \sqrt{s_1^2 + s_2^2}$$

where s_1 and s_2 are the individual swells.

4.6.7 SEA STATE OBSERVATION AND MEASUREMENTS. Actual wave measurements are rare, and are usually limited to a few reports from data buoys, offshore oil rigs, and deep-water recorders of special interest groups. Reported wave heights over the vast ocean areas consist almost entirely of subjective estimates made by shipboard observers. Many factors cause irregularities in reported wave heights, such as the size of ship, the observer's experience, and the differing visibilities for day and night observations. Wave heights at night are often based on



* WAVE PERIOD AT END OF DECAY DISTANCE, TRAVEL TIME, AND RATIO BETWEEN WAVE HEIGHT AT END OF DECAY DISTANCE AND AT END OF FETCH AS FUNCTIONS OF DECAY DISTANCE AND WAVE PERIOD AT END OF FETCH

Figure 4-19. Sea State Parameters as Functions of Decay Distance and Wave Period at End of Fetch* the wind speed at the time of observation, which may or may not be representative of wave conditions. Wave observers report what is called the "significant wave height"; this is the average height of the highest 1/3 of the waves observed while taking the observation. The wave period reported is the average period of the waves observed passing a fixed point during the time of observation. In a similar manner, swell height and period are reported when observed.

4.6.8 DEFINITION OF SEA STATE TERMS. Table 4-7 is a list of definitions of basic technical terms used in sea state observation and analysis.

TABLE 4-7. BASIC SEA STATE DEFINITIONS

1. Combined Sea Height/ - Combined Sea State -	The combined effects of both sea and swell (the results of the interaction of both sea and swell at any given point).
2. Decay Distance -	The distance a wave travels as swell after leaving the fetch or generating area to the point of interest.
3. Duration -	The length of time the wind blows in essentially the same direction over the fetch.
4. Fetch -	An area of the sea surface over which seas are generated by a wind having a constant direction and speed.
5. Fetch Length -	The horizontal distance (in the direction of the wind) over which a wind having a constant direction and speed, generates a sea.
6. Fully Developed (arisen) -	The fully developed (arisen) state of the sea is the state which the sea reaches when the wind has imparted maximum energy to the waves.
7. Non-Fully Developed - State of the Sea	The non-fully developed state of the sea is the state of the sea reached when the fetch or duration has limited the amount of energy imparted to the waves by the wind.
8. Sea -/Sea State -/ State of the Sea -	A numerical or written description of ocean surface roughness. It is a description of the wind driven wave over the generating area. For precise usage, sea state may be defined as the average height of the highest one third (1/3 H) of the waves observed in a wave train, refined to a numerical code see HwHw in ship's weather observation code, Appendix D.
9. Significant Wave Height -	The average height of the one-third highest waves observed at a fixed point during the time of observation.
10. Significant Wave Period -	An arbitrary period taken as the average period of the one-third highest waves that pass a fixed point during the time of observation.
11. Swell -	Ocean waves which have traveled out of their generating area. Swells characteristically exhibit a more regular and longer period and have flatter crests than waves within their fetch.
12. Travel Time -	The time necessary for waves to travel as swell a given distance from the generating sea to the point of interest.
13. Wave Height -	The vertical distance between a wave crest and the preceding trough, reported in half meter increments.
14. Wave Length -	The "distance-between-crests-of-two-successive-periodic-wave" measurements in the direction of propagation in meters (not reported in observation).
15. Wave Period -	The time, in seconds, required for two successive wave crests to pass a fixed point.
16. Wave Train -	A series of waves moving in the same direction.
17. Wave Trough -	The lowest point on the water surface between successive wave crests.
18. Wind Speed -	The scalar quantity of the wind, expressed in knots.

5.0 INVESTIGATOR DATA PACKAGE

5.1 GENERAL.

The Investigator Data Package (IDP) will contain all available ground truth data gathered as a result of the Phase B calibration effort. Additionally, the package will very likely contain information that differs from that of the CDP. Ground Truth data collected by the Nanosecond Radar, Laser Profilometer, and other aircraft instrumentation will be made available upon request to the Principal Investigators. Not all of this data may be in processed form, however.

5.2 PURPOSE OF IDP.

The basic purpose of the IDP is to make available to the Principal Investigators all Ground Truth data collected and processed during the Phase B calibration effort as well as any secondary information of possible interest which may have been gathered during the course of these operations or that has been received from other data sources. It is again emphasized that the GEOS-C program is not obligated to completely process all collected data nor is it committed to making further investigative efforts on behalf of the Principal Investigators to obtain data not presently available, or which may still not be available after the completion of the calibration efforts.

5.3 CONTENTS OF IDP.

The IDP is basically a compilation of raw (unprocessed) data taken during the Phase B calibration. In addition, elements of the CDP are available for inclusion in the IDP. Ground Truth information contained in the IDP can be briefly summarized as follows:

- Unprocessed Data
  - Nanosecond Radar (NR)
  - Laser Profilometer (LP)*

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* C-130 aircraft will be flying for NOAA/AOML in support of NOAA investigators. NOAA will make collected in LP data available to Wallops upon request.

- Refraction Data Magnetic Tape
- Miscellaneous Weather Charts
- Other Aircraft Instrumentation*

• CDP Elements

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* Some of the instruments will be used for specific NRL experiments and thus are not considered a true part of the Ground Truth IDP. (See list of aircraft instrumentation in Section 7.)

6.0 GROUND TRUTH OPERATIONS

6.1 INTRODUCTION.

The Ground Truth Effort for GEOS-C is aimed at providing the Altimeter Experiment Manager with a Calibration Activity Ground Truth Data Package. The ground truth effort will be conducted during initial altimeter calibration and during continuing spot check calibration of the altimeter. Initial calibration will be accomplished within the scheduled Phase B period. During this period, a concentrated effort will be made to obtain the complete spectrum of sea states up to 10 meters ($H_{1/3}$) as well as to assimilate other related data. The spot check calibration is planned for once-per-month intervals for the remaining mission lifetime.

When possible, in-situ measurements will be performed by buoys or ships and used as reference or calibration check-points for comparisons with simultaneous remote measurements made from aircraft. Such simultaneous measurements would be most desirable if made on the satellite subtrack; however, even nearby simultaneous (aircraft in-situ) measurements are preferred to having no comparison measurements at all.

The scope of the ground truth effort is extensive and is not limited to the NASA aircraft. As previously mentioned, the Ground Truth effort will involve NOAA and DOD as well as NASA. A Wallops Flight Center project engineer assigned to this activity will work in close coordination with the Ground Truth Operations Manager to ensure ground truth data acquisition and dissemination in compliance with GEOS-C Project requirements.

The Wallops C-54 has been scheduled to provide 300 hours of support, approximately 200 hours of which will be utilized during the Phase B calibration effort, with the remaining 100 hours to be used for monthly spot check calibration. For every 100 hours of flight time accumulated, it is planned to schedule 5 days down-time for routine maintenance.

Computer programs are available which generate satellite position information in latitude/longitude versus time. These predicts will be available at least two weeks in advance of mission support. In addition, sufficient lead time will be allowed for filing flight plans and for preparing the crew, aircraft, and instrumentation systems.

As stated previously, it is desired to obtain ground truth data on the complete spectrum of sea states up to 10 meters. In order to obtain data on the higher sea states, it may be necessary to travel to Newfoundland, for example, and operate several days from this "home base".

Generally, certain conditions must prevail to create various sea states. Figures 6-1 and 6-2 show the probabilities of occurrence of various sea states for a point in the calibration area and a point in the North Atlantic. These curves show that a good portion of the sea states should be obtainable by flying out of Wallops or Bermuda; however, it is expected that at least two five-day missions to the North Atlantic will be required. These missions will most likely be flown out of St. Johns, Newfoundland or other points in the North Atlantic, if necessary.

The Program will depend heavily upon SMG weather forecasting information for guidance in avoiding severe atmospheric conditions which might result in mission abortion or otherwise hinder flight operations (particularly for the North Atlantic missions); thus needless expenditure of fuel, funds, and other resources can thereby be prevented. The availability of such forecast data will also, in many cases, permit long-range determination of the potential for development of the higher sea state conditions.

6.2 GROUND TRUTH SAMPLING CONSIDERATIONS.

Since in-situ data for ground truthing sea state and other parameters for GEOS-C are required, a question was raised concerning area size for correlation with altimeter data. The primary concern here was to determine the number of times the GEOS-C ground track passes through a given size area.

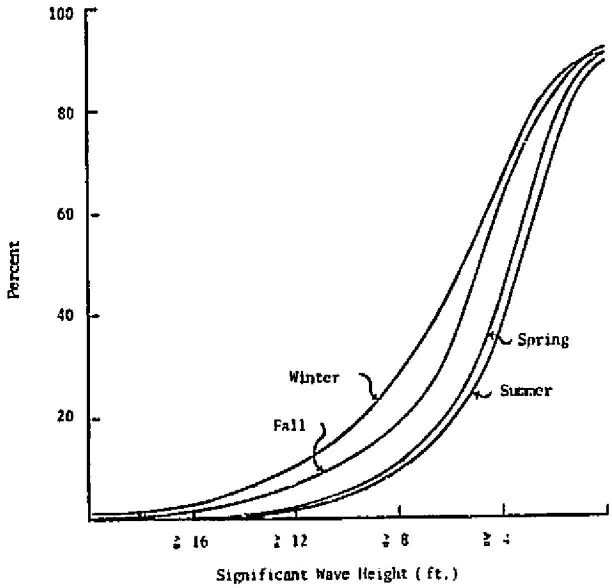

Figure 6-1. Sea State Probabilities (32.5°N; 67.5°W) (Calibration Zone)

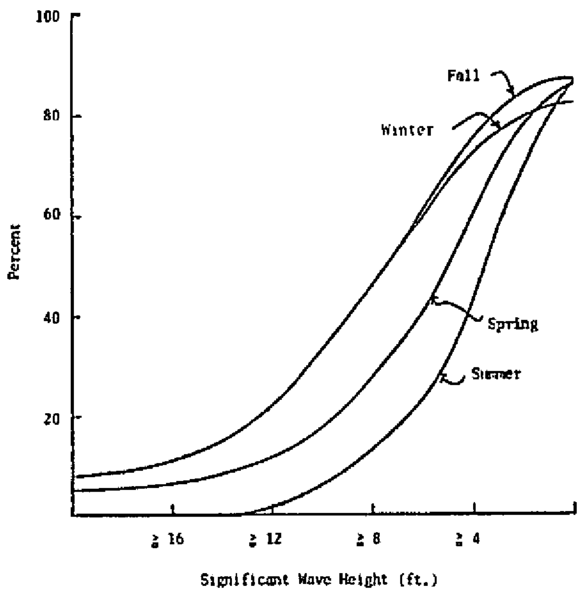

Figure 6-2. Sea State Probabilities (North Atlantic; 47.5°N, 42.5°W)

The WASP (Wallops Altimeter Scheduling Program) was utilized for the purpose of determining the number of GEOS-C passes that could be observed over specified periods of time from simulated stations at seven different latitudes and from seven different coverage area sizes at each of these latitudes. The latitudes of observation were 0, 20, 30, 40, 50, 60 and 65 degrees. The diameters of the coverage areas at each of the latitudes were 25, 50, 100, 200, 500, 1000 and 2000 kilometers.

WASP was set-up to generate the GEOS-C orbital ephemeris at a rate of one second. An elevation angle cutoff constraint was input to WASP to control the cross-sectional area of the cone through which GEOS-C would have to pass to correspond with the desired ground area. See Figure 6-3. Whenever GEOS-C was computed to pass through this cone of observation, the time and station ID were written onto a save-tape. Figure 6-3 depicts the geometry of a single-station situation with d being the diameter of the coverage area, β is the minimum elevation angle, and h is the satellite height above the spheroid.

A FORTRAN program was written which accepts as an input the WASP save tape, and puts out a count of the number of GEOS-C passes through the observation cone.

The 49 areas covered (7 diameters, 7 latitudes) were tabulated by the program for five twenty-four periods (5 days), one twelve hour period at the end of the five twenty-four hour periods for an accumulated period of 5.5 days, then for eight additional twenty-four hour periods for a total of 13.5 days.

A graphical presentation of the number of passovers at each of the latitudes over the period of 13.5 days is depicted in Figure 6-4. It may be observed that at latitudes less than 50 degrees, the minimum diameter area which should be considered for ground-truth is 200 kilometers.

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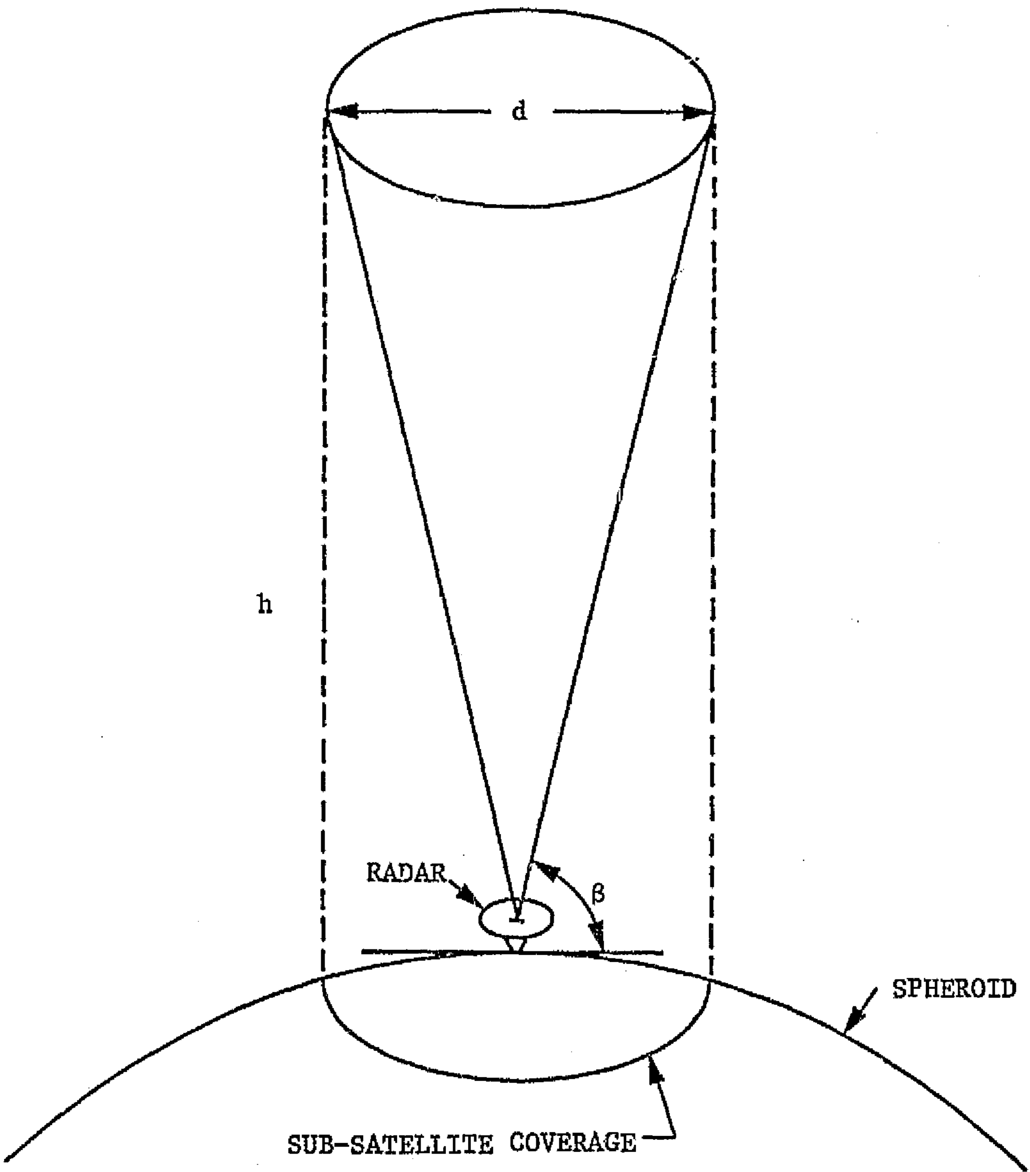


Figure 6-3. Single Station Sub-Satellite Coverage

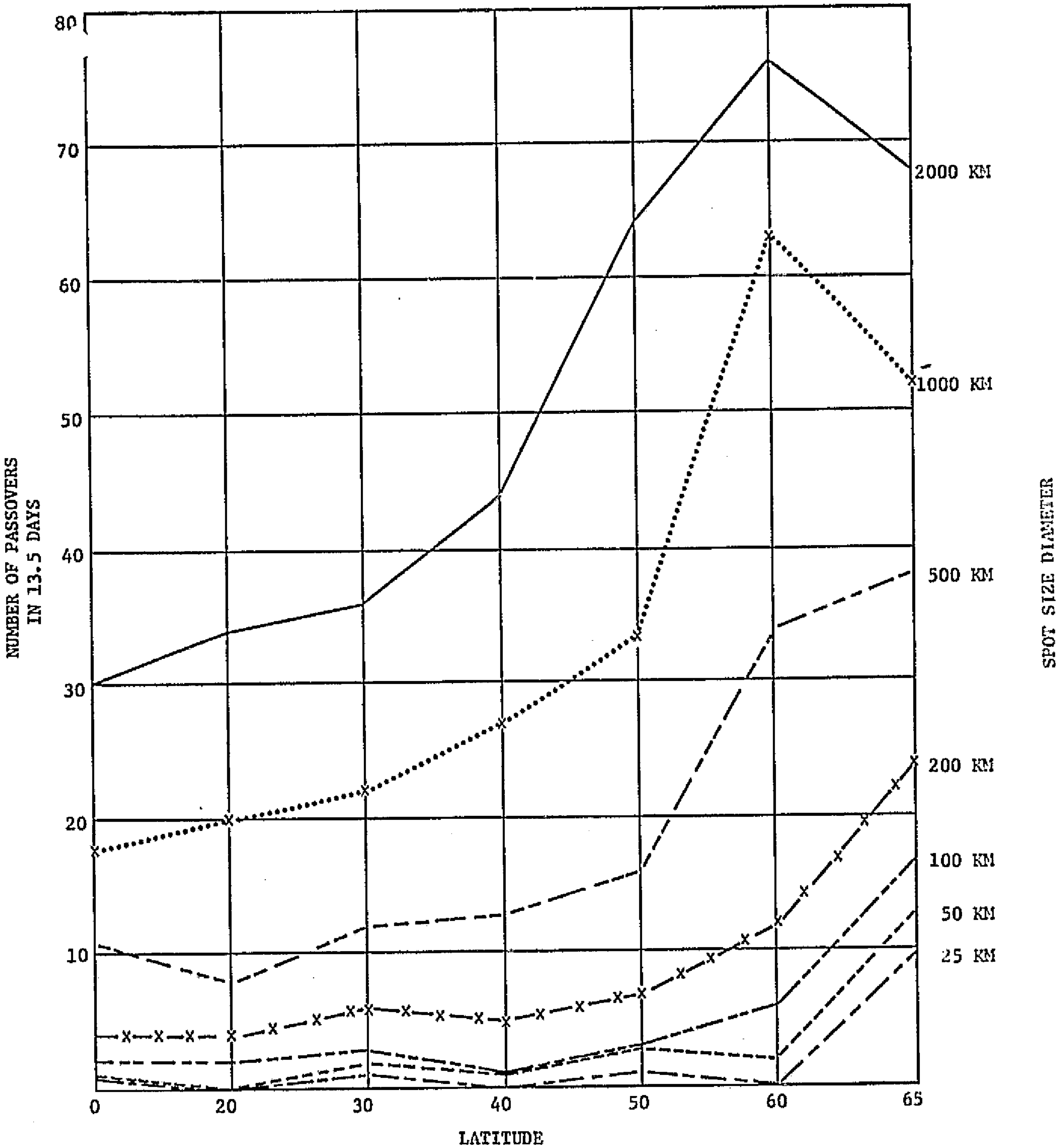


Figure 6-4. Number of Passovers vs Latitude

The GEOS-C ground track very nearly repeats itself every 4.5 days. The accumulative results shown in Figure 6-4 may be extrapolated for longer periods of times; e.g., twice as many passovers will occur in 27 days.

6.3 AIRCRAFT GROUND TRUTH OPERATIONS.

This section provides the reader with a general description of aircraft operations anticipated for ground truth data acquisition. An exact and detailed "supplement" will be issued for each aircraft flight in sufficient time prior to the flight to provide adequate preparation. These supplements will contain such detailed information as arrival times at points of interest, flight headings, data acquisition time periods, instrumentation usage, etc.

Only one C-54 aircraft from the Wallops Flight Center is being considered for ground truth support; i.e., the aircraft which has both the Laser Profilometer and the Nanosecond Radar, has a cruising speed of 150 knots and has fuel capacity which allows up to 12 hours continuous flying time. Missions will be planned to require a maximum of six hours flying time to preclude the need for two crews, if at all possible.

Aircraft support for the GEOS-C Mission is presently planned to include three general flight profiles (I, II, III) to obtain the desired spectrum of sea states. Modification of these profiles will include flight paths oriented to obtain data aligned with, and transverse to, surface winds (upwind, downwind, crosswind) and flight paths designed for data collection to accomodate special requirements. These profiles are described in the following three paragraphs.

6.3.1 CLASS I PROFILE. Figure 6-5 typifies a Class I flight operation. Flights of this type will originate and terminate at the same home base (either Wallops Island, Bermuda, or the North Atlantic base station). The aircraft will fly from "home base" to a given position and then fly a subsatellite track beginning and ending at given positions before returning to home base. A special case of this is presented in the discussion of passovers contained in Section 6.2.

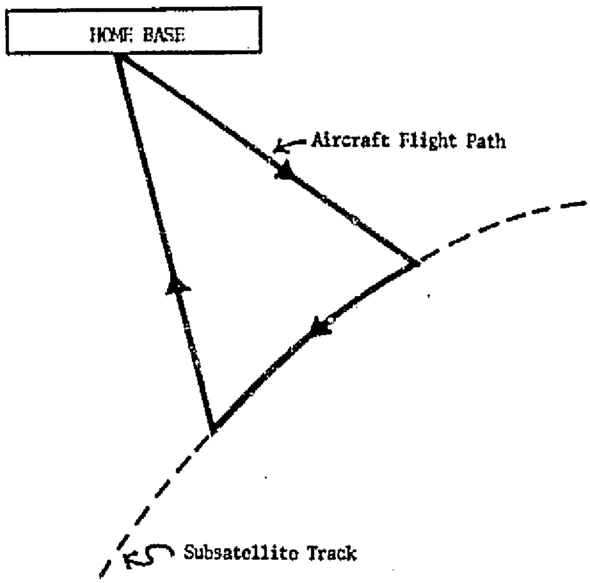


Figure 6-5. Class I Profile

6.3.2 CLASS II PROFILE. A Class II Flight Profile is shown in Figure 6-6. The difference here is that the aircraft does not return to the same home base. Between bases, the aircraft will fly a sub-satellite track with beginning and ending positions. An operation of this type could occur between any two of the home bases. It is expected that most Class II operations, however, will occur between Wallops Island and Bermuda.

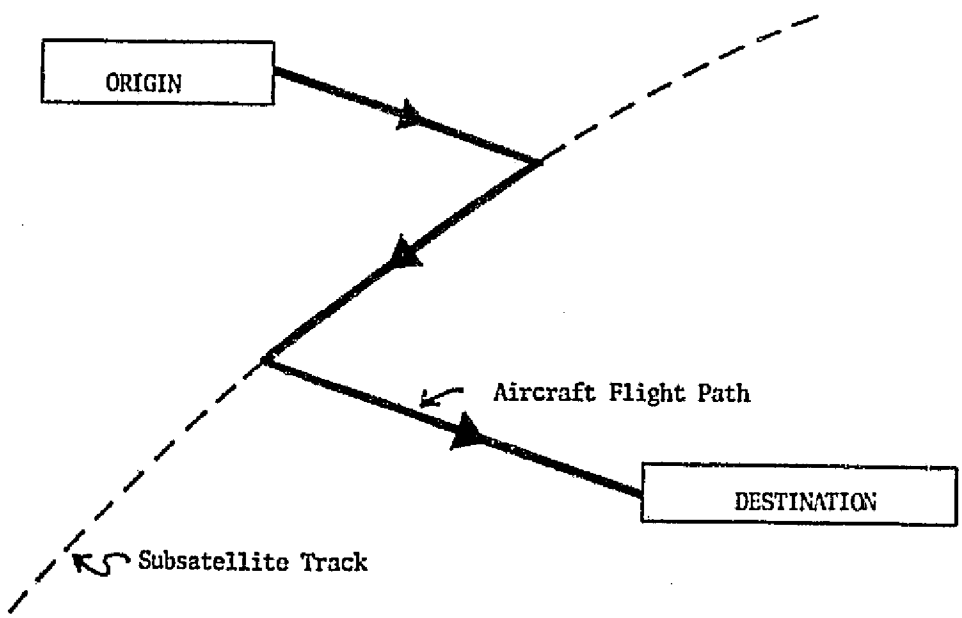


Figure 6-6. Class II Profile

6.3.3 CLASS III PROFILE. A typical Class III profile is shown in Figure 6-7. The major constraint here is that two flights will occur (both out of the same home base) in order to obtain data at the North/South and South/North subsatellite crossing points. In the case in which the home base is either Wallops or Bermuda, the two flights will occur approximately 10 hours apart. If the home base is moved further North, the time separating the two flights decreases to only 100 minutes at a latitude of near 65°.

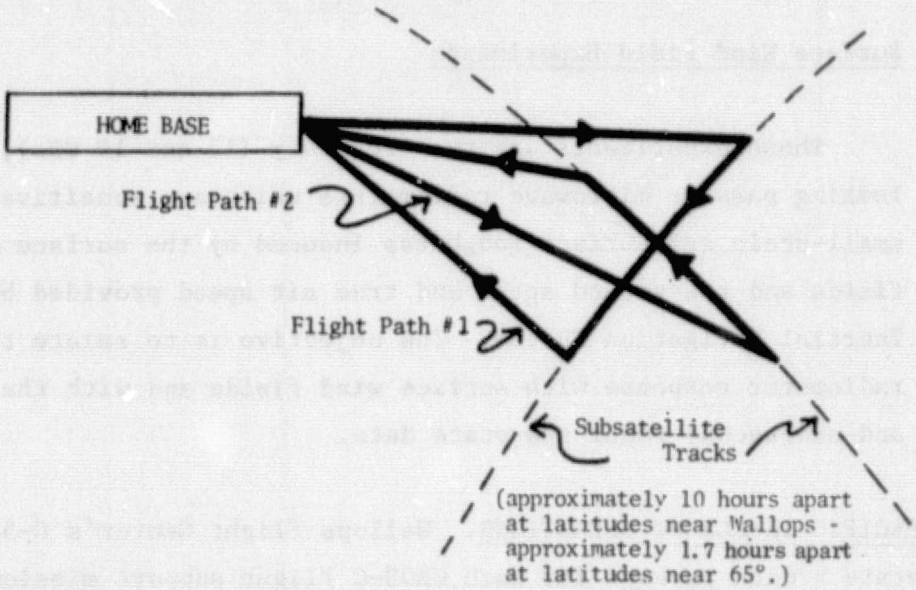


Figure 6-7. Class III Profile

6.3.4 GEOS-C PRE-LAUNCH ACTIVITIES. Prior to the launch of GEOS-C, three basic experiments are being undertaken by NRL to further solidify relevant Ground Truth measurement techniques and principles and to demonstrate operational readiness.

a. Atmospheric Range Correction Experiments

This experiment involves the upward-looking passive microwave radiometers at 22 GHz and 31 GHz; a microwave refractometer; and aircraft measurements of temperature, pressure, and water vapor content.

b. Range Bias Experiments (Sea State)

These experiments involve collecting nanosecond radar and laser data over a variety of sea states to (1) quantify the relationship between ocean-wave height, the radar pulse rise time, and the range tracker bias; (2) establish the spatial filtering effects due to the finite sizes of the beam spots of the radar and laser.

c. Surface Wind Field Experiments

These experiments use two-frequency (13 and 19 GHz), nadir-looking passive microwave radiometers which are sensitive to the small-scale sea surface roughness induced by the surface wind fields and the ground speed and true air speed provided by the Inertial Navigation System. The objective is to relate the radiometer response with surface wind fields and with the laser and nanosecond radar sea-state data.

6.3.5 SPECIFIC IN-FLIGHT OPERATIONS. Wallops Flight Center's C-54 aircraft will generate a data package for each GEOS-C flight support mission. Upon return to the Wallops Flight Center, all data will be off-loaded and given to the Wallops Flight Center Project Engineer who will be responsible for data pre-processing and raw data as well as pre-processed data distribution. Magnetic tapes will be copied and disseminated with the originals being maintained in the Wallops Flight Center Archives.

6.3.5.1 Nanosecond Radar (NR). It is planned to take seven files of data with the nanosecond radar at an altitude of approximately 3200 meters (10,000 feet) during a mission. The nanosecond radar is configured such that each time it is turned on it takes one file (approximately 91 seconds) of data. Seven files fill one magnetic tape and thus require about

10-1/2 minutes. The first and seventh NR data files will be instrument calibration data sets. The five files in between will contain measurements of sea state. The first data file, which is a calibration file, will be taken at 3200 meters just prior to coming into position over the satellite ground track. Immediately following, five continuous sea state data files will be taken along track in the direction of the pass. After the sixth file, the plane can begin its descent to 500 feet for the laser profilometer work. During the descent, the seventh (last calibration file) nanosecond radar data set is taken.

A second mode of operation is possible with the nanosecond radar. In this second mode of operation, the nanosecond radar can be used as a pulse-length-limited wave profilometer. To do this, it is required that the aircraft altitude be as low as practicable. For an altitude of approximately 150 meters (500 feet), the spot-size is approximately 7 meters. Because of the totally different character of data available in each mode of operation, present plans are to utilize both flight geometries. Thus, NR data will also be taken simultaneously with the LP data at 150 meters.

6.3.5.2 <u>Laser Profilometer (LP)</u>. Following the descent to 150 meters (500 feet), the aircraft will turn around and fly back along the track (against the direction of the satellite pass) while the laser profilometer is being set up. When the LP is ready, the aircraft will fly four minutes directly upwind and four minutes directly downwind while taking continuous LP data. During turns, maneuvers, etc., the LP recorder (see Figure 7-2) will be turned off in order to avoid possible contamination of data. On selected flights, 4 minutes of crosswind and/or along-track data will also be taken.

6.3.5.3 <u>Measurement Cells</u>. In terms of surface wind fields and ocean surface roughness, the ocean surface is to be considered the same or homogeneous over a "measurement cell". A measurement cell for GEOS-C purposes is being defined as a circle on the surface having a 50 nm diameter. It is desired to collect at least one measurement cell of data on each side of the cross-over point along the sub-satellite track. In this manner, variations in measured quantities can be qualified in terms of changes or uniformity in sea surface condition. However, flight operational problem exists if one attempts to not only cover several measurement cells but attempts to obtain off-track data for either microwave or wind speed determination studies as well. Such flights would be too time consuming. To preclude this constraint, nanosecond radar data will be collected in several measurement cells on the way out to the sub-satellite path and on the return flight to home base to satisfy the data requirements of both NASA and DOD.

6.3.5.4 Magnetic Tape Requirements. From a typical flight, one complete digitized magnetic tape of NR data at 3200 meters will be produced. Also, one digitized tape at 150 meters altitude will contain multiplexed NR and LP data (the LP data is recorded on track 4). When certain missions require crosswind LP data as well as upwind/downwind data, a third tape will be required. During other special missions a fourth tape with NR data could also be produced at 3200 meters due to the requirements explained in the previous paragraph.

6.3.5.5 Inertial Navigation System (INS). This instrument can be used operationally to determine the starting and ending points, ground track, etc., for the data runs. For ground truth data, it is planned to combine the INS with air speed sensors to obtain data for removing true airspeed error from wind data. These data will be taken simultaneously with LP data.

Other supporting aircraft information will include the following:

a. The dead reckoning plot of the entire flight;

b. Smooth plot of the flight path over the sub-satellite track as generated from such navigation instrumentation as LORAN-A, etc.;

c. Time log of all pertinent events such as turns, altitude changes, equipment operation, etc.

6.3.6 TYPICAL AIRCRAFT FLIGHT SCHEDULE. A schedule indicating typical flight activity in support of GEOS-C Altimeter Calibration/Evaluation activity appears in Table 6-1. The pattern of satellite passes through the Calibration Area closely repeats each 9-day period. It can be seen that it is possible to schedule two flights per day with sufficient regularity to achieve forty Altimeter Calibration attempts during the first two-month period.

TABLE 6-1. TYPICAL FLIGHT SUPPORT SCHEDULE

Day	Home Base	Depart. Time	ACS	Return Time	Total Time	Class	Aircraft Time
1	BDA	22:00	00:00	03:00	5.0 hr.	3	5.0 hr.
1	BDA	08:00	09:45	12:00	4.0 hr.	3	9.0 hr.
2	BDA	23:30	23:50	01:00	1.5 hr.	3	10.5 hr.
2	BDA	09:00	09:30	11:00	2.0 hr.	3	12.5 hr.
3	No Flight						
4	WFC	00:00	01:00	02:30	2.5 hr.	3	15.0 hr.
4	WFC	07:30	10:30	13:30	6.0 hr.	3	21.0 hr.
5	WFC	22:00	00:30	03:30	5.5 hr.	3	26.5 hr.
5	WFC	08:00	10:30	13:30	5.5 hr.	3	32.0 hr.
6	WFC	20:00	00:30	02:00	6.0 hr.	2	38.0 hr.
6	BDA	09:00	10:00	12:00	3.0 hr.	1	41.0 hr.
7	No Flight						
8	No Flight		Return to WFC		5.0 hr.		46.0 hr.
9	WFC	23:30	01:30	04:30	5.0 hr.	3	51.0 hr.
9	WFC	08:30	11:00	13:30	5.0 hr.	3	56.0 hr.
10	WFC	21:30	01:00	03:30	6.0 hr.	2	62.0 hr.
11	BDA	00:30	01:00	02:30	2.0 hr.	3	64.0 hr.
11	BDA	09:30	10:30	12:00	2.5 hr.	3	66.5 hr.

TABLE 6-1. TYPICAL FLIGHT SUPPORT SCHEDULE (Cont'd)

Day	Home Base	Depart. Time	ACS	Return Time	Total Time	Class	Aircraft Time
12	No Flight		Return to WFC		5.0 hr.		71.5 hr.
13	WFC	00:00	02:00	05:00	5.0 hr.	3	76.5 hr.
13	WFC	09:30	11:30	14:30	5.0 hr.	3	81.5 hr.
14	WFC	23:45	01:45	05:15	5.5 hr.	2	87.0 hr.
15	BDA	00:00	01:30	03:00	3.0 hr.	3	90.0 hr.
15	BDA	09:30	11:00	01:30	4.0 hr.	3	94.0 hr.
16	No Flight		Return to WFC for Overhaul		6.0 hr.		100.0 hr.
17	No Flight						
18-21	Aircraft Maintenance						

7.0 AIRCRAFT INSTRUMENTATION

The Laser Profilometer and Nanosecond Radar will be the prime calibration data sources. Ground truth experience gained from the Skylab altimeter program has demonstrated the firm requirement for wide-area data collection. In a number of passes, significant ground truth variations were encountered over distances of 100 kilometers. For this reason, aircraft overflight is felt to be the only feasible approach to acquisition of the needed calibration data.

In a strict sense, however, the aircraft instruments are themselves remote sensors, and periodic cross-comparisons with an in situ sensor will be made where possible. When possible, these in-situ measurements will be obtained from a NOAA environmental buoy located off the east coast of the United States. For further information regarding these buoys, refer to Section 8.0 of this document.

7.1 NANOSECOND RADAR.

The Nanosecond Radar used in the Wallops C-54 aircraft is an X-band radar designed and built by the Naval Research Laboratory. Figure 7-1 shows a simplified block diagram of the radar system.

The pulse generator drives an LSA transmitter which emits a 50 watt peak, 2 ns wide, gaussian-envelope pulse. The 24 dB transmitter and receiver horns (8.7° beamwidth) are mounted side by side and look at nadir through a port cut in the bottom of the fuselage of the aircraft. The received signal is amplified at RF and fed directly into a diode detector with a very fast response time. The detector output is displayed on the sampling scope (Channel B) whose storage also permits analog-to-digital (A/D) conversion for recording on digital magnetic tape. Part of the transmitted pulse is coupled out, detected, and fed into channel A of the sampling scope to be monitored. The control unit programs all the control signals and synchronization of the RF signals.

The transmitter operates at 10 GHz with a PRF of 90 kHz. Because of the sampling scope technique, the output display rate is 90 Hz. At the beginning

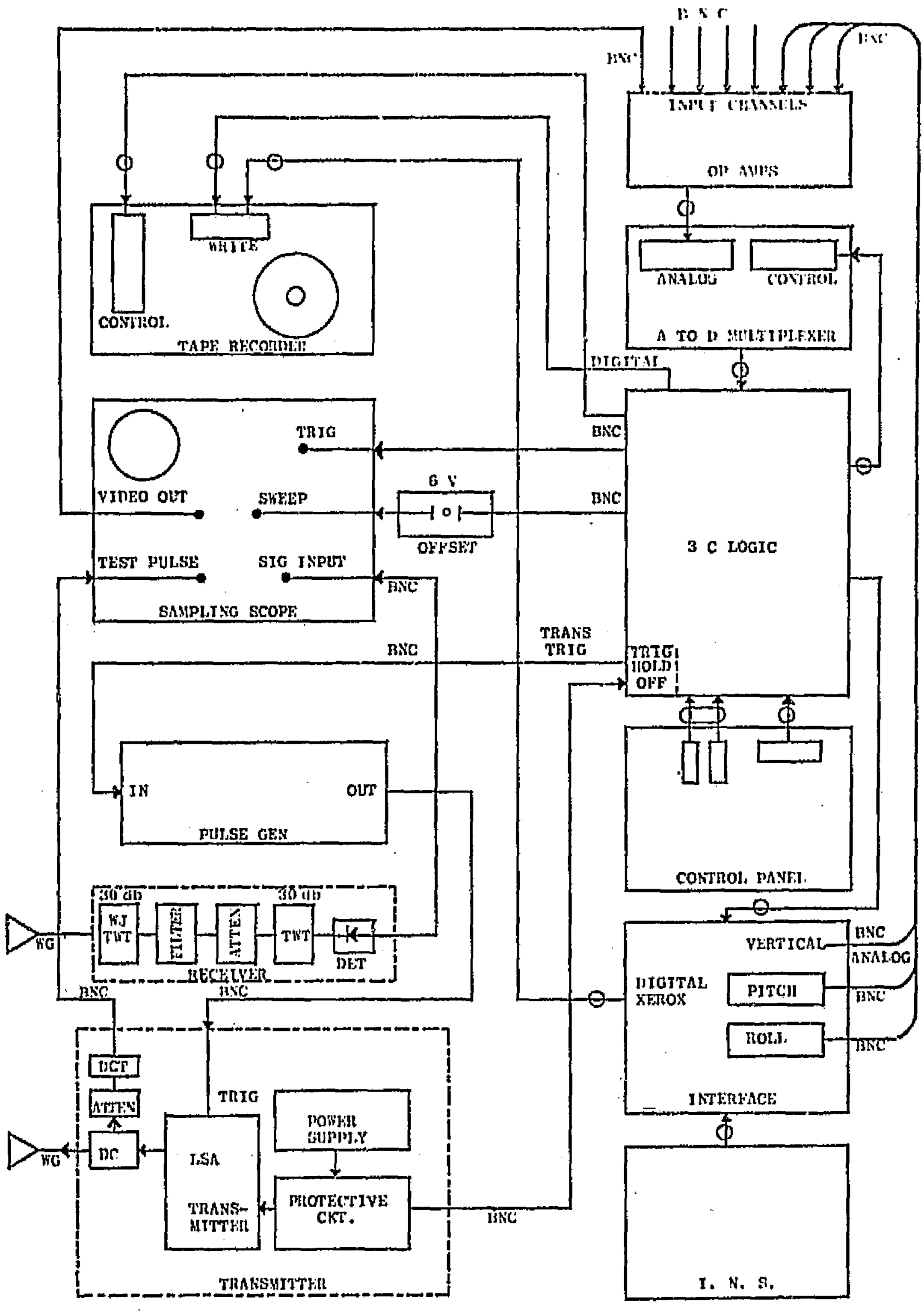


Figure 7-1. C-54 Aircraft Nanosecond Radar, Simplified Block Diagram

of each data sweep, seven external channels are sampled followed by 160 data points from the sampling scope. In a typical display, the 160 sample points would cover a 100 ns time interval for a radar range window of 15 meters and a range quantization of 9.37 cm (or 0.625 ns).

The A/D converter is triggered at a 15 kHz rate, one sixth the transmitter PRF. Each output waveform is a composite formed from the returns of a large number of transmitted pulses. This distinction generally will not be made and the output waveforms will be referred to as "pulse returns" with the transmitter being thought of as having an effective PRF of 90 Hz.

7.2 LASER PROFILOMETER.

The Laser Profilometer used in the Wallops C-54 Aircraft is a commercial unit built by Spectra-Physics to operate with passive targets. The system can be installed in the aircraft in about one-half day. The light source is a Helium-neon CW gas laser using 24 milliwatts of power. The beam divergence is less than one-tenth milliradian, resulting in a spot diameter reflecting telescope, which collects part of the reflected signal. The received signal is converted to an electrical signal which is amplified and phased compared at the modulation frequency to the transmitted signal. The measured phase delay provides a very accurate determination of the distance to the target. The static accuracy of the laser profilometer system is 3 cm. Experience with the laser profilometer indicates that an aircraft operating altitude of 1,000 feet or less is required for reliable data acquisition.

The spatial resolution achievable with a laser profilometer is dependent on the system optics in the plane transverse to the ground track and on the system response-time and aircraft speed in the along-track plane. If a profilometer with an assumed response time of 100 milliseconds is flown at a velocity over a stationary corrugated surface, the minimum wave length detectable, λ_m, is given by $\lambda_m = v \times 0.01$ sec or 0.83 meters for an aircraft speed of 300 km/hr (162 knots).

7.3 ADDITIONAL INSTRUMENTATION.

As indicated previously, the Nanosecond Radar and Laser Profilometer will be the prime instrumentation to be used by NASA Wallops and the DOD (NRL) for aircraft data collection; however, other instruments will be used on various missions to provide supporting data. These are:

- Inertial Navigation System (LTN-51, with True Air Speed Unit)
- Precision Radiation Thermometer (Barnes PRT-5)
- Multi-frequency Passive Microwave Radiometers (NRL)
- Dew Point Hygrometer (Cambridge)
- Outside Air Temperature Indicator (YSI)
- Microwave Refractometer (Electromagnetic Research Corp.)
- 35 mm Strip Film Camera
- Downward-Looking Passive Microwave Radiometers (NRL)

Appendix C of this document shows the location of both prime and secondary instrumentation aboard the C-54. The following paragraphs describe the above instrumentation for which information was available at the time of this publication.

7.3.1 INERTIAL NAVIGATION SYSTEM (LTN-51). The Inertial Navigation System (INS) uses aircraft acceleration measurements to continuously compute aircraft velocity and change in present position. These measurements are made by precision inertial devices, mounted on a three-axis stable element which is part of a four-gimbal structure. Using four gimbals, the unit has 360 degrees of freedom about the three axes. Two gyros are used primarily to maintain the stable element level with the earth's surface and aligned to true North to measure pitch and roll attitude. With a gyro-stabilized platform, it is possible to accurately detect the desired components of motion and distance in any direction using precision accelerometers, integrators, and analog computers. Three accelerometers mounted on the stable element supply output signals proportional to total accelerations experienced along computers to furnish velocity and distance information for use in providing horizontal and vertical velocity and change in present position.

The INS has a magnetic tape recorder with inputs for Latitude and Longitude. Data are recorded every 1 second. Analog voltages are available for pitch, roll, and vertical acceleration. These can be recorded directly or digitized and recorded on the magnetic tape. Correlation with time is accomplished by input to the magnetic tape unit from the time code generator. Data such as crosstrack error, ground speed, heading, etc., are displayed on the INS Control and may be recorded by the operation, if desired.

7.3.2 PRECISION RADIATION THERMOMETER (BARNS PRT-5). This instrument measures apparent radiation in the 8 to 14 micron range. It consists of two units: a power supply/control unit/indicator mounted on the operator's console, and an optical unit mounted in the sensor bay. The PRT-5 has a field of view of 2° and a response time of 5 milliseconds. Incoming radiated energy is continuously compared to an internal reference and converted to a voltage which is directly related to the energy difference between the target and the reference. This voltage is displayed on the indicator as equivalent black body temperature, to an accuracy of 0.5°C. Output voltage is amplified to 0 to 5 VDC for each of the three scales (-20°C to +15°C, +10°C to +45°C, +40°C to +75°C) and then multiplexed with the total air temperature and the Dew Point Hygrometer for one track magnetic recording.

The instrument will operate within an environmental temperature range of -20° to +40°C. However, the reference cavity within the optical unit must be heated to 55°C before operation. DURING EXTREMELY COLD GROUND CONDITIONS, THE TIME NEEDED TO RAISE CAVITY TEMPERATURE MAY BE DETERIMENTAL TO FLIGHT SCHEDULING, SINCE PREFLIGHT CALIBRATION CANNOT PROCEED UNTIL CONDITIONS ARE CORRECT.

Preflight procedures consist of allowing sufficient warm-up time, followed by a calibration using two constant temperature black body sources. In flight, the operator monitors the indicator and changes scales as necessary. Scale selections and output temperature are recorded in the Flight Logs.

7.3.3 MULTI-FREQUENCY PASSIVE MICROWAVE RADIOMETERS (NRL). The NASA C-54 aircraft has four radiometers installed; two upward looking and two nadir looking, to measure environmental microwave energy. The upward looking radiometers measure water vapor content and moisture content (cloud coverage) of the atmosphere. The nadir viewing radiometers measure turbulence of the sea water and wind speed. Radiometer data is digitized and recorded on a magnetic tape. A single magnetic tape recorder handles all four radiometers.

7.3.4 DEW POINT HYGROMETER (CAMBRIDGE). The Dew Point Hygrometer measures the ambient dew point temperature. Relative humidity is then calculated by combining dew point and outside air temperatures. The device consists of two units: a control box/power supply in the operator's console, and a TAT probe located in the aircraft's airstream. A 0 to 5 VDC output is provided for recording purposes. During missions the system is energized, balanced, and operated continuously. The operator monitors and records displayed values in his flight log.

Specifications

Dew Point Range:	-50°C to +50°C
Rate of Change Sensitivity:	3°C per second
Accuracy:	±0.5°C above 0°C

NOTE: At temperature below 0°C, the frost point rather than the point is sensed.

7.3.5 OUTSIDE AIR TEMPERATURE INDICATOR (YSI). The outside air temperature is mounted in the NASA 427 next to the dew point hygrometer in the forward, right observer's bubble just behind the pilot's compartment. The device used is the YSI 705 Air Temperature Probe. The probe is used with the 743-5 V YSI Thermivolt Thermometer for an accuracy of ±0.35°C or better. The probe is a stainless steel unit with a 0.6 sec time constant; its dimensions are approximately 1/2 inch in diameter by 1.85 inches long. Corrections for aircraft altitude and aircraft speed are made by the computer during reduction of the data to obtain true outside air temperature.

7.3.6 MICROWAVE REFRACTOMETER (ELECTROMAGNETIC RESEARCH CORP.). This instrument uses a pair of Klystron cavity oscillators to measure the collective density of all foreign materials, including water vapor, present in the air flow being sampled. Air passed through the cavity affects its tuning, hence frequency, according to the density of additives it contains. This change of frequency is compared with a standard reference frequency generated in the second oscillator which has a vacuumed cavity. Readout is digital, directly in N units. In addition, an analog output of 0 to 10 VDC is available for recording.

7.3.7 35 MM STRIP FILM CAMERA. A magazine adapter permits the use of bulk strip film in a motorized 35 mm camera. Capacity is 250 exposures. It may be operated hand held or by remote control. Remote control includes an intervalometer and exposure counter, as well as selective exposure by the operator.

7.4 AIRCRAFT EQUIPMENT INSTALLATION AND DATA RECORDING SYSTEM.

The NASA Wallops Flight Center C-54 aircraft will be the remote sensing aircraft supporting GEOS-C pre-mission experiments and GEOS-C underflight support and the related instrumentation. For the pre-mission activities and the GEOS-C underflights, the same recording scheme as presented in Figure 7-2 will be used. There will be essentially two slow-rate data collection systems and one high-rate data system.

A one or two sample-per-second data rate is sufficiently adequate for all the passive microwave data and for the environmental data. Therefore, the slow-rate data system will record all the environmental data - including latitude, longitude, airspeed, and ground speed - as well as all the passive microwave data. Time from the common Datametrics SP-100 Time Code Generator (synchronized with WWV) will also be recorded on the slow-rate system. For continuous recording of the eighteen parameters, the slow data rate system will permit continuous recording for more than 10 hours on a single reel (10-inch diameter; 2400 feet) of magnetic tape. Shorter (600-foot) rolls may be used to contain a single day only for easier data separation.

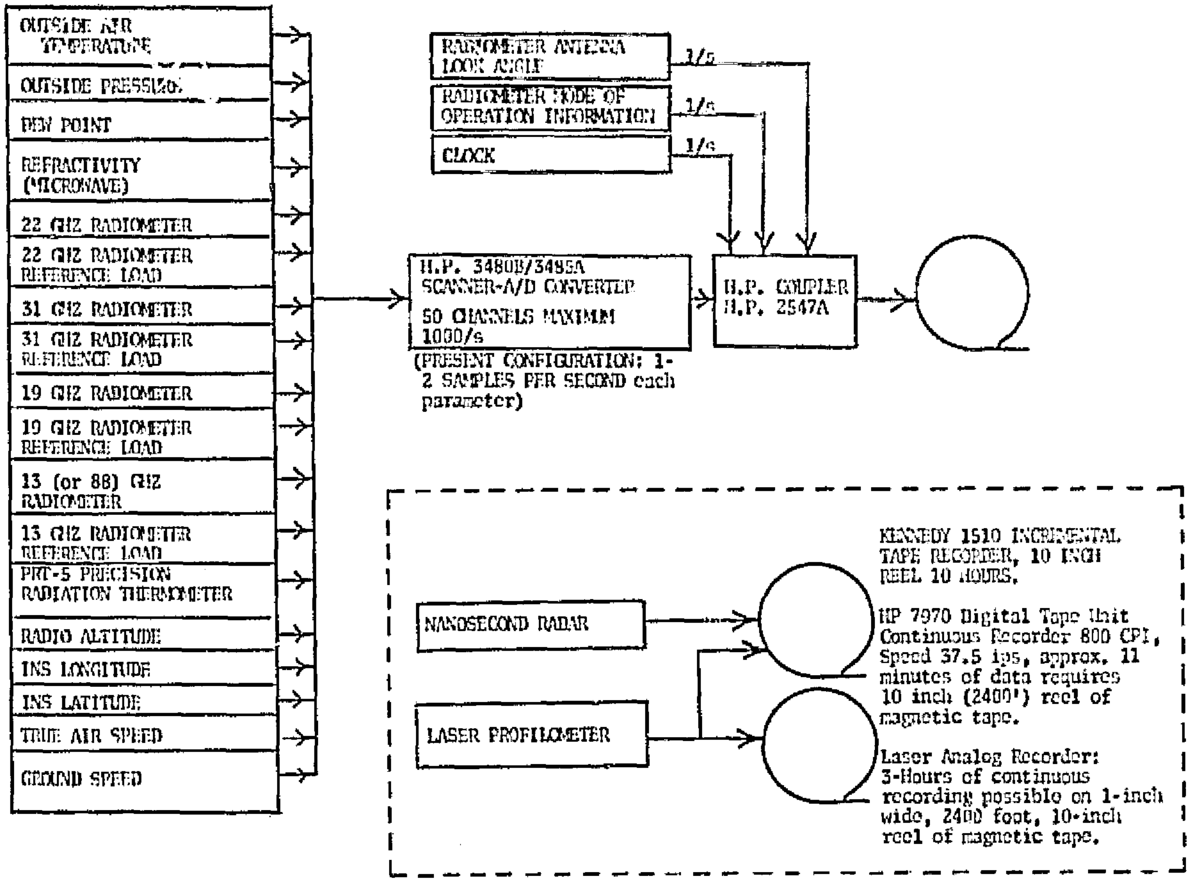


Figure 7-2. Pre-Mission and Underflight Recording Configuration

As shown in Figure 7-2, the Nanosecond Radar requires a high-speed recording system and records for approximately eleven minutes on a 10-inch reel of magnetic tape. Rewinding of the tape and loading of a new reel requires approximately three minutes. The Laser Profilometer has an independent data collection and recording system and records on a 1-inch wide, 10-inch reel of analog tape. The laser can record continuously for three hours on a single-reel of magnetic tape. The data can also be multiplexed simultaneously with the NR data onto the HP 7970 digital tape recorder.

8.0 DATA SOURCE CATALOG (DSC)

The Data Source Catalog (DSC) is intended to give a description of the various data sources for other ground truth information, not necessarily included in the CDP or IDP, which may be of interest to GEOS-C Principal Investigators.

8.1 CONTENTS OF CATALOG.

The Data Source Catalog (DSC) contains a comprehensive list of data sources for various data products which may be of use to Principal Investigators. A more detailed description of the content and the availability of specific data products included in the Data Source List is further provided in this section. The bibliography contains a list of all reference material used in the compilation of this document that is related to the subject matter presented herein. Major oceanographic experiments, conducted worldwide, and NOAA Fleet Sailing schedules are included as analogous activities/experiments.

8.2 DATA SOURCE LIST.

The Data Source List, Table 8-1, is a list of the various products available. Available samples of these products are included at the end of this section. Information provided in the Data Source List includes a contact point, office identification, phone number, and address from which information on the product can be obtained.

This is not to imply that these people are committed to supply any and all such products requested by the Principal Investigators. It does mean, however, that these people have been contacted and are aware that some interest in their products has been shown. Arrangements for any of these products requested over and above the Calibration Data Package or Investigator Data Package are not the responsibility of the GEOS-C project or SMG/NWS.

8.3 DATA SOURCES.

A brief description of various data sources is presented in subsequent paragraphs.

TABLE 8-1. DATA SOURCE LIST

Product	Mode of Presentation	Producer	Comments	Point of Contact/Availability
Surface weather maps	Northern Hemisphere Polar Stereographic Chart 1:20,000,000 Tropical Strip Mercator Chart 30°N-50°S 1:40,000,000	National Meteorological Center	Prepared every 6 hours. A portion of the surface weather map is included in the SMG Data Set, Figure 4-9. Prepared every 12 hours.	Chief Technical Support W337 Forecast Division National Meteorological Center Washington, D.C. 20233 Phone 301-763-8076 For maps more than two months old: Chief, Information Service Division D54 Environmental Data Service Asheville, N.C. 28801 Phone 754-254-0249
Ship surface weather reports not available on weather maps	Computer printout for area and time(s) desired	National Environmental Data Service	Available by special request. Detail explanation of parameter observed is presented in Appendix D.	Chief, Information Services Division D54 Environmental Data Service Asheville, N.C. 28801 Phone 754-254-0249
Environmental Data Buoy Weather Reports	Computer printout for Buoy(s) and time(s) desired	National Environmental Data Service	Description of Data Buoy program, location of buoys and parameter observed are included in Section 8.3.2	Available three months after date of observations required.
Ocean Station Vessels (OSV)	Computer printout for OSV(s) and time(s) desired	National Environmental Data Service	OSV program, location, and scope of observations are included in Section 8.3.3	
Lighthouse and other Coast Guard stations	Computer printout for Marine reporting station(s) and time(s) desired	National Environmental Data Service	Locations of Marine reporting stations, types and time of observation are included in Section 8.3.4	
Satellite photographs Synchronous Meteorological Satellites (SMS) Visual and IR (geostationary) NOAA Polar Orbiting Satellites Visual and IR	Gridded full disc and sectors Gridded individual passes	National Environmental Satellite Service	SMS photographs taken every half hour NOAA-4 global visual coverage once per day, Infrared twice per day. Figures 8-9 through 8-14 are examples of various satellite photographs available and not included in the sample SMG Ground Truth Data Set (Figures 4-10 and 4-11).	Chief, Documentation Section S11132 Environmental Data Service World Weather Building Room 606 Washington, D.C. 20233 Phone 301-763-8111

TABLE 8-1. DATA SOURCE LIST (Cont'd)

Product	Mode of Presentation	Producer	Comments	Point of Contact/Availability
Wind Wave Forecasts, 00, 24, 36 and 48 Hr Swell Forecasts, 24 and 36 Hr Combined Sea State Forecast, 24 and 36 Hr	Chart Polar Stereographic Northern Hemisphere 1:20,000,000	National Meteorological Center	Available twice daily. Computer products 00 Hr Wind Wave Forecast is analysis. Figure 4-14 is a sample of 36 Hr Combined Sea State Forecast.	Chief, Technical Support, Group W337 Forecast Division National Meteorological Center Washington, D.C. 20233 Phone 301-763-8076 For maps more than two months old: Chief, Information Service Division D54 Environmental Data Service Asheville, N.C. 28801 Phone 754-254-0249
Combined Sea Height, 36 Hr Forecast Wind Wave Forecasts, 00, 24 and 36 Hr	Chart Polar Stereographic Northern Hemisphere 1:60,000,000	U.S. Navy	Available twice daily. Computer product.	Commanding Officer U.S. Navy Fleet Numerical Weather Central Monterey, California 93940 Phone 408-646-2141
Combined Sea Height Forecasts (regional)	Chart Polar Stereographic Northern Hemisphere 1:7,000,000	U.S. Navy	Available twice daily. No samples of this product are available.	Department of the Navy Chief of Naval Operations (OP-33M) Washington, D.C. 20350
Airborne Radiation Thermometer (ART) Chart	Chart	Department of Transportation U.S. Coast Guard Airborne Radiation Thermometer (ART) Program	Available monthly per flight schedule. Figure 8-1 is a sample of this product.	Department of Transportation U.S. Coast Guard Oceanographic Unit Building 159-E Washington Navy Yard Washington, D.C. 20390
Gulf Stream Monthly Summary	Scientific Journal of the Gulf Stream and surrounding waters	National Weather Service	Published document available monthly. Presents northern edge of Gulf Stream, associated temperatures, and temperature anomalies for the western North Atlantic.	Chief, Oceanographic Service Branch W161 National Weather Service 8060 13th Street Silver Spring, Md. 20910

TABLE 8-1. DATA SOURCE LIST (Cont'd)

Product	Mode of Presentation	Producer	Comments	Point of Contact/Availability
Major Currents in the North and South Atlantic Oceans between 64°N and 60°S, W. E. Boisvert, September 1967	Technical Report TR-193	Naval Oceanographic Office	Published documents. Description of currents within specific boundaries which exhibit a definite permanent or seasonal flow.	Non-Government Agencies Commander, Naval Oceanographic Office Washington, D.C. 20390 Attn: Code 40
Currents along the East Coast of Africa, W. E. Boisvert, December 1967	Informal Report IR-No. 67-93	Naval Oceanographic Office	Description of the East Africa coastal current and Agulhas current	Government Agencies Distribution Control Department Code 4420
Ocean Currents in the Arabian Sea and Northwest Indian Ocean, W. E. Boisvert, August 1966	Special Report SP-92	Naval Oceanographic Office	Currents, winds, tidal currents in the Indian Ocean	Naval Oceanographic Office Washington, D.C. 20390
Atlas of surface currents Northwestern Pacific Ocean	H.O. Pub. No. 569	Naval Oceanographic Office	Monthly surface current roses and isotherms	
Sea Temperature Analysis	Polar Stereographic Northern Hemisphere Chart 1:60,000,000	U.S. Navy	Available twice daily.	Commanding Officer U.S. Navy Fleet Numerical Weather Central Monterey, California 93940 Phone 408-646-2141
Regional Sea Temperature Analysis	Polar Stereographic Northern Hemisphere Chart 1:7,000,000	U.S. Navy	Available daily. No samples of this product are available	Department of the Navy Chief of Naval Operations (OP-33M) Washington, D.C. 20350
Mean Sea Temperature and Salinity data for oceans/area and month	Computer printouts and magnetic tape	National Oceanographic Data Center	Available by special request. Data retrieved from NODC data bank by area and season/month	U.S. Department of Commerce National Oceanic and Atmospheric Administration National Oceanographic Data Center Rockville, Md. 20852
Average Snow and Ice Boundary Chart	Polar Stereographic Northern Hemisphere Chart	National Environmental Satellite Service	Figure 4-15 is a sample of this chart. Available weekly	Chief, Analysis and Evaluation Branch S1111 National Environmental Satellite Service World Weather Building Room 510 Washington, D.C. 20233 Phone 301-763-8401

TABLE 8-1. DATA SOURCE LIST (Cont'd)

Product	Mode of Presentation	Producer	Comments	Point of Contact/Availability
Sea Ice Limits	Polar Stereographic 1:10,000,000 Northern Hemisphere Chart 1:20,000,000 Southern Hemisphere Chart	U.S. Navy	Available weekly	Commanding Officer U.S. Navy Fleet Weather Facility Suitland Washington, D.C. 20373 Phone 301-763-5972
Archival Meteorological Data	Magnetic Tape	National Meteorological Center	Available by special request Meteorological Synoptic Data, Analysis and Prognosis for both Surface and Upper Air. Contained in NMC Archives at Asheville, N.C.	National Meteorological Center Automat Division World Weather Building Washington, D.C. 20233
NOAA Marine Climatic Guide	Atlas	Space Flight, Meteorology Group, ESSA-Weather Bureau	Published Document. Broad-scale view of weather elements over all water covered areas of the world. Description of contents in Section 8.3.5. Figures 8-5, 8-6 and 8-7 are sample charts.	Limited distribution. Available in most NASA offices.
Oceanographic Atlas of the North Atlantic Ocean	Pub. 700: Volume I* Volume II* Volume IV* Volume V*	U.S. Navy	Description of Tides and Current. Description of Physical Properties Description of Seas and Levels Description of Marine geology	Non-Government Agencies Commander, Naval Oceanographic Office Washington, D.C. 20390 Attn: Code 40 Government Agencies Distribution Control Department, Code 442 Naval Oceanographic Office Washington, D.C. 20390
U.S. Navy Marine Climatic Atlas of the World	NAVAIR 50-IC-528, Vol I NAVAIR 50-IC-529, Vol II NAVAIR 50-IC-530, Vol III NAVAIR 50-IC-531, Vol IV NAVAIR 50-IC-532, Vol V NAVAIR 50-IC-533, Vol VI NAVAIR 50-IC-50, Vol VII NAVAIR 50-IC-54, Vol VIII	U.S. Navy	Published Documents. Volumes I through VII are each prepared for specific geographic areas. Volume VIII presents a summary of Volumes I through VII	Commander Naval Weather Services Command Washington Navy Yard Washington, D.C. 20390

* Published Documents.

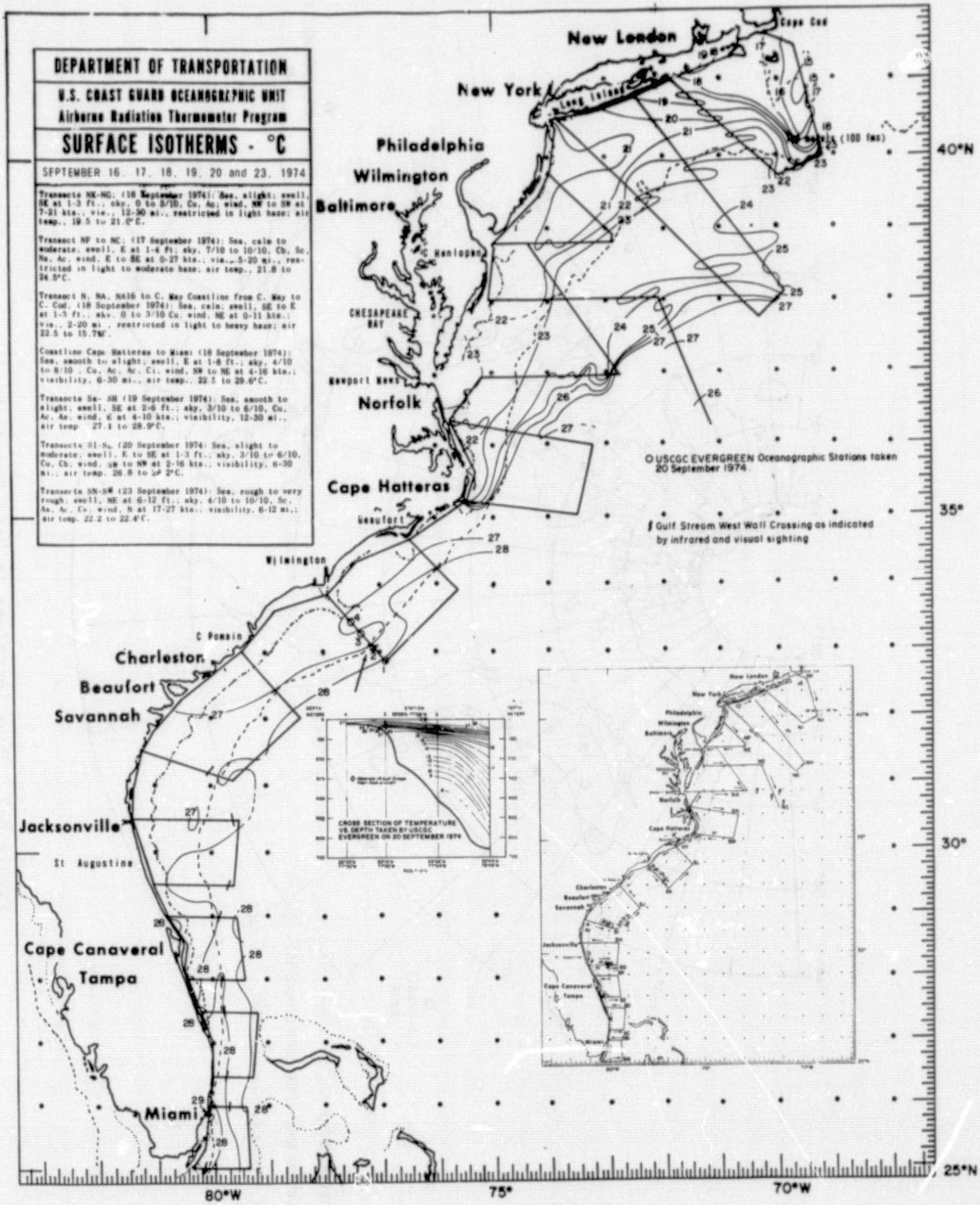
8.3.1 AIRBORNE RADIATION THERMOMETER (ART) CHARTS. Airborne Radiation Thermometer (ART) Charts, Figure 8-1, are available two weeks following the completion of that month's flight schedule. The surface isotherms on this chart are prepared from sea surface temperature data collected by a remote sensing infrared thermometer, on board Coast Guard aircraft. Additional surface temperature data are obtained from ships and Coast Guard Light Structures whenever possible and used in the preparation of the chart.

Data collection on tracklines is continuous. The point at which the contour line crosses trackline is the point at which temperature indicated was actually first observed. Isotherms are in degrees Celsius and boldface numbers. Information concerning the data, (date, sea, and weather conditions, and transects flown) is listed in the lower right hand corner.

Notes are used when a phenomenon or conditions are encountered which may influence the data. Occasionally, photographs or drawings accompany these notes to help illustrate the event.

8.3.2 ENVIRONMENTAL DATA BUOYS. NOAA's National Data Buoy System (NDBS) Program operates a group of buoys around the territorial United States. Presently, 10 buoys are deployed. Their locations and selected locations for future additional deployments are annotated on Figure 8-2. Approximately 20 more buoys are scheduled to be deployed in the Pacific and Atlantic oceans, Gulf of Mexico, and the Great Lakes within the next 5 years. Two of the presently deployed buoys - EB01 and EB13 (large capability buoys) - are in the prime calibration area. Operational status of deployed buoys is available weekly and will be available in the CDP.

The deployed buoys are of various capabilities. (See Table 8-2.) Each of the buoys measure wind direction and speed, air pressure, air temperature, and water temperature. The large capability buoys observe these parameters at 5 and 10 meters above sea level; in addition, they measure precipitation, global infrared and visual radiation above 10 meters, and specific oceanographic



September 16, 17, 18, 19, 20 and 23, 1974

Figure 8-1. Airborne Radiation Thermometer (ART) Chart

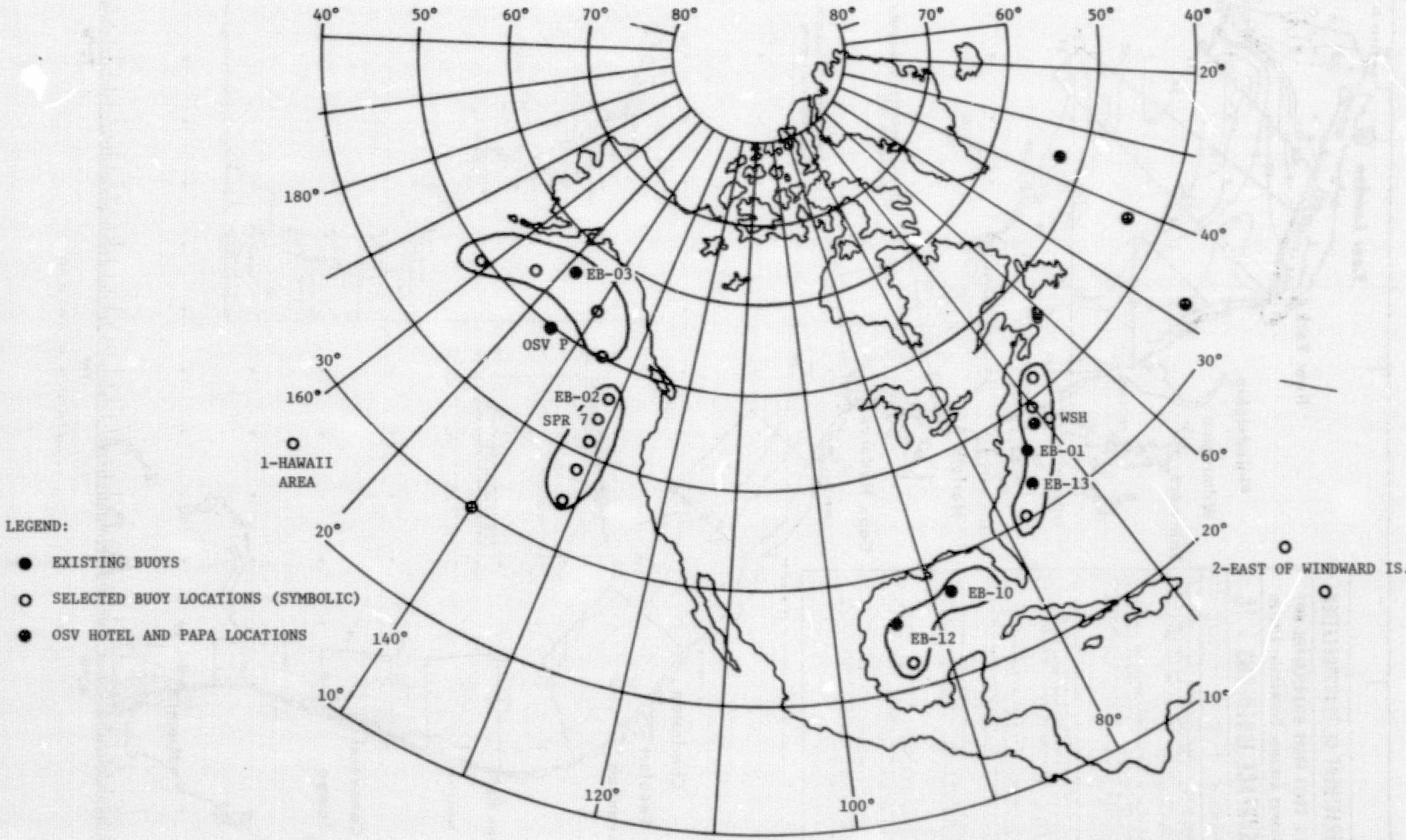


Figure 8-2. Buoy Locations in Data Sparse Areas

TABLE 8-2. NDBO BUOY MEASUREMENT CAPABILITIES SENSORS/TRANSDUCERS AND SENSOR LEVELS (Entries = Manufacturer-Sensor Type/Level[s])

15 August 1973

	SEVERE ENVIRONMENT BUOYS						MODERATE ENVIRONMENT BUOYS									
BUOY NUMBER:	EB-01	EB-02	EB-03	EB-10	EB-12	EB-13	EB-31	EB-32	EB-36	EB-37	EB-38	EB-51	EB-52	EB-53	EB-61	EB-62
CONTRACTOR:	GD	LMSC	GD	GD	GD	GD	GE	GE	LMSC	LMSC	LMSC	MAG	MAG	MAG	GE	GE
METEOROLOGICAL MEASUREMENTS																
1. Wind Direction	W-VS/*	W-VS/10	W-VS/* GD-AE/5	W-VS/*	W-VS/*	W-VS/*	EG-FCC/2	EG-GFC/2	WM-IG/2	WM-IG/2	WM-IG/2	J-VS/2	J-VS/2	J-VS/2	EG-FCC/2	EG-FCC/2
2. Wind Speed	W-VS/*	W-VS/10	W-VS/* GD-AE/5	W-VS/*	W-VS/*	W-VS/*	EG-FCC/2	EG-FGC/2	WM/IG/2	WM-IG/2	WM-IG/2	J-VS/2	J-VS/2	J-VS/2	EG-FCC/2	EG-FCC/2
3. Air Pressure	W-CD/*	W-CD/10	W-CD/* GD-AP/5	W-CD/*	W-CD/*	W-CD/*	S-AP/2	S-AP/2	G-DT/2	G-DT/2	G-DT/2	R-CD/2	R-CD/2	R-CD/2	S-AP/2	S-AP/2
4. Air Temperature	W-PTR/*	W-PTR/10	W-PTR/* GD-PTM/5	W-PTR/*	W-PTR/*	W-PTR/*	Y-T/2	Y-T/2	F-T/2	F-T/2	F-T/2	Y-T/2	Y-T/2	Y-T/2	Y-T/2	Y-T/2
5. Dewpoint Temperature	W-SC/*	W-SC/10	W-SC/* GD-TCM/5	W-SC/*	W-SC/*	W-SC/*										
6. Precipitation	W-D/15	W-D/10	W-D/10	W-D/10	W-D/10	W-D/10										
7. Global Radiation (IR)	W-T/8		W-T/10	W-T/10	W-T/10	W-T/10										
8. Global Radiation (Visual)	W-T/10		W-T/10	W-T/10	W-T/10	W-T/10										
OCEANOGRAPHIC MEASUREMENTS																
1. Wave Height	K-A/H**	L-TS/H	HU- *** A(SD)/H	HU-A/H**	HU-A/H**	SH- *** A(SD)/H										
2. Water Temperature	GD-PTM/H	W-PTR/+	W-PTR/H		W-PTR/++	W-PTR/@	Y-T/#	Y-T/#	F-T/##	F-T/##	F-T/##	Y-T/H	Y-T/H	Y-T/H	Y-T/H	Y-T/H
3. Current Direction	GD-V/H	W-V/+	W-V/H		W-V/++	W-V/@										
4. Current Speed	GD-SR/H															
5. Conductivity =		W-ICT/+	W-ICT/H		W-ICT/++	W-ICT/@										
6. Water Pressure		W-SG/+	W-SG/H		W-SG/++	W-SG/@	EG-SG/200	EG-SG/200	CEC-SG/200	CEC-SG/200	CEC-SG/200					

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TABLE 8-2. NDBO BUOY MEASUREMENT CAPABILITIES SENSORS/TRANSDUCERS AND SENSOR LEVELS (Cont'd)

* 5, 10 meters above sea level.

** Buoy Acceleration Measurement System Only.

*** Wave Period is Derived

= Salinity is Derived

LEGEND FOR SEVERE ENVIRONMENT BUOYS

MANUFACTURER

GD: General Dynamics
HU: Humphrey
K: Kistler Accelerometer
L: Lockheed
SH: Schaevitz Accelerometer
W: Westinghouse

TYPE

A: Accelerometer (SD): Strapped Down
AE: Aerovane (Bendix) with flux gate compass (Humphrey)
AP: Aneroid Potentiometer (Sostman)
CD: Variable Capacitance Diaphragm (Rosemount)
D: Volumetric Dumping (Westinghouse)
ICT: Inductively Coupled Transformer (Plessey)
PTM: Platinum Resistance Thermometer (MIL-STD)
PTR: Platinum Resistance Thermometer (Rosemount)
SC: Sapphire Crystal (Transonics)
SG: Bonded Strain Gauge - Standard Control
SR: Savonius Rotor
T: Thermopile
TCM: Thermoelectrically Cooled Mirror (EG&G)
TS: Tucker System-Accelerometer and Pressure Transducer
V: Vane
VS: Vortex Shedding (J-TEC) Anemometer with Magnavox Flux Gate Compass

LEGEND FOR MODERATE ENVIRONMENT BUOYS

MANUFACTURER/TYPE

CEC-SG: Consolidated Electrodynamics Corp./Strain Gauge, Standard Control
EG-FGC: EG&G/3-Cup Anemometer with Bar Magnet Compass
F-T: Fenwall/Thermistor
G-DT: Gulton/Linear Variable Differential Transformer
J-VS: J-TEC/Vortex Shedding Anemometer with Flux Gate Compass (Magnavox)
R-CD: Rosemount/Variable Capacitance Diaphragm
S-AP: Sostman/Aneroid Potentiometer
WM-IG: Weather Measure/Impeller Generator, Bar Magnet (Humphrey)
Y-T: Yellow Springs/Thermistor

LEVELS (DEPTHS IN METERS)

H: In or on Buoy Hull
+: H, 50, 100
++: H, 50, 100, 150, 250, 500
@: H, 30, 50, 100, 150, 200, 300
#: H, 10, 20, 50, 100, 200
##: 2, 10, 20, 50, 100, 200

parameters. This oceanographic data includes wave height (period is derived), current direction, and conductivity. Table 8-2 further delineates all observed parameters for each deployed buoy.

The data from these buoys are observed every hour. Large capability buoys are interrogated every 3 hours and small capability buoys every 6 hours. These data are then re-transmitted by the interrogation station in standard ship synoptic code to the National Weather Service (NWS) at the National Meteorological Center (NMC), Suitland, Maryland. NMC then retransmits these data over regular weather networks.

Figure 8-3 is a flow chart depicting buoy data flow. Buoy data, both meteorological and oceanographic, is reformatted to the NODC format and sent to NODC at 30-day intervals. All meteorological data is also similarly formatted in the TDF format and sent to the National Climatic Center (NCC).

8.3.3 OCEAN STATIONS. There are two ship ocean stations, PAPA and HOTEL, and five manned lighthouse stations (Frying Pan Shoals, Diamond Shoals, Chesapeake, Ambrose, and Buzzards Bay) that will furnish visual sea state data in the calibration area. Details on location, observations, and availability of data for world-wide Ocean Station Vessels are presented in subsequent paragraphs, and United States manned lighthouses and other Coast Guard Stations are contained in Paragraph 8.3.4.

8.3.3.1 Ocean Station Vessels (OSV). There are ten OSV stations listed by the World Meteorological Organization. Their locations are presented in Table 8-3. Station HOTEL is operated by the U.S.; all others are manned by foreign countries. The Keifamaru and Tango stations operate only during the typhoon season.

8.3.3.2 OSV Synoptic Weather Observations. All items in the full ship code (Appendix D) are reported. Table 8-3 lists the latitude and longitude of each OSV and also the frequency of surface and upper air observations. Sea and swell heights and periods are visual observations.

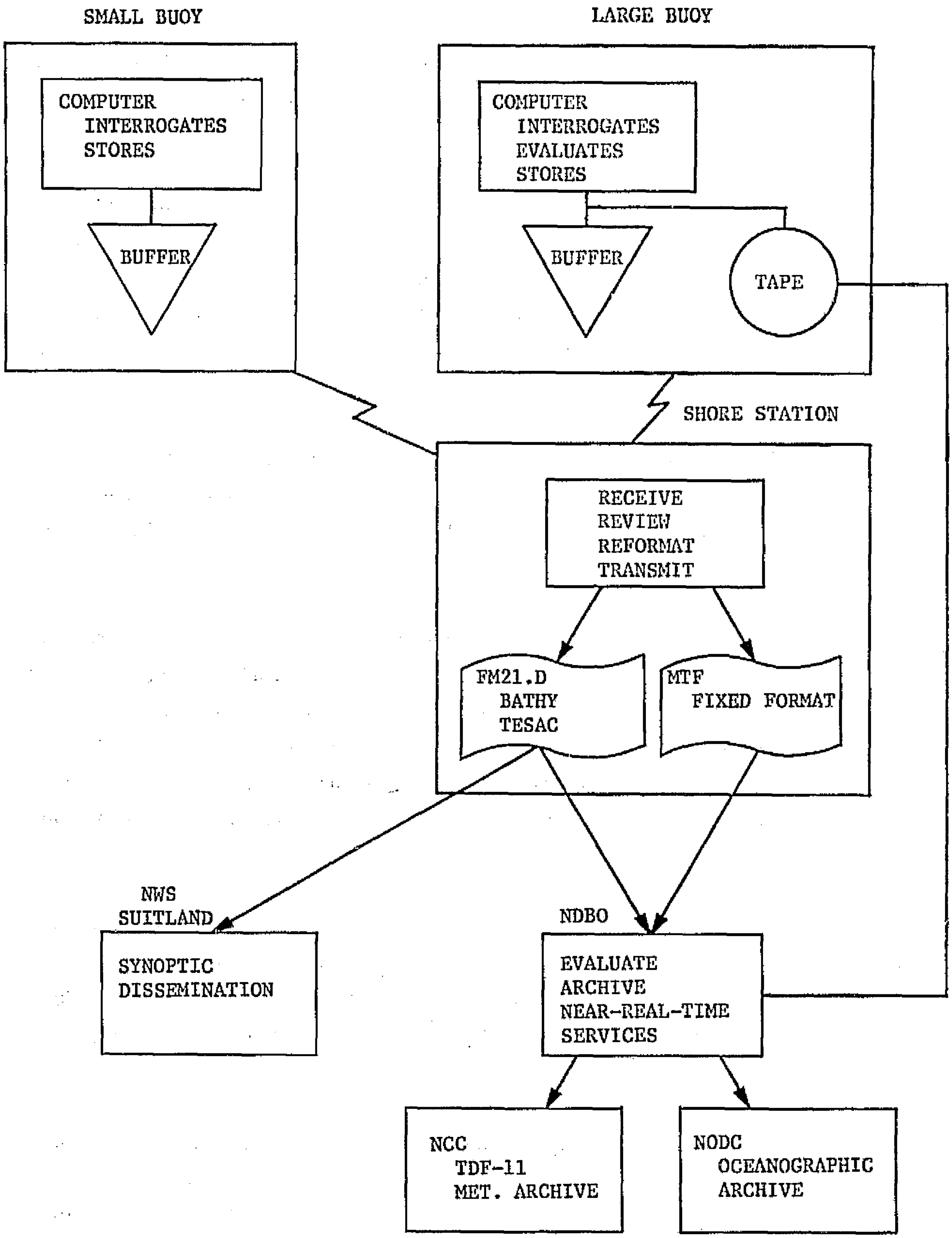

Figure 8-3. Buoy Data Flow

TABLE 8-3. OCEAN STATION VESSELS

Ocean Station Vessels	Position	3 Hourly Surface Obs.	Hourly Surface Obs.	Upper-Air Observations 00	06	12	18	Remarks
Alpha	62 00 N 33 00 W	x	x	RW	W	RW	W	Climat (CT)
Hotel	38 00 N 71 00 W	x	x	RW	W	RW	W	Climat (CT)
India	59 00 N 19 00 W	x	x	RW	W	RW	W	Climat (CT)
Juliet	52 00 N 20 00 W	x	x	RW	W	RW	W	Climat (CT)
Keifumaru	20 00 N 130 00 E	x	x	RW	No	RW	No	Operated irregularly during the typhoon season Aug-Sept
Kilo	45 00 N 16 00 W	x	x	RW	W	RW	W	Climat (CT)
Mike	66 00 N 02 00 E	x	x	RW	W	RW	W	Climat (CT)
Papa	50 00 N 145 00 W	x	No	RW	RW	RW	W	Climat (CT)
South African Weather Ship	40 00 S 10 00 E	x	No	R	No	No	No	
Tango	29 00 N	x	x	PR	P	PR	P	Climat (T) Operated during typhoon season only

R - Radiosonde; upper-air pressure, temperature and humidity observations obtained by electronic means.
W - Radiowind; upper-wind observations obtained through electronic means.
P - Pilot-balloon; upper-wind observations obtained through electronic means.
Climat (T) monthly climatological means of upper-air elements are transmitted.
Climat (CT) monthly climatological means of both surface and upper-air elements are transmitted.

The three hourly surface observation reports and upper air observations are transmitted routinely. Those received by the National Weather Service are collected with other ship reports and are available through NCC Asheville, N.C. Hourly reports are not usually transmitted but are kept in the ship's weather log (Appendix D). These logs are retained by the weather service of the particular country that supports the station ship. This is also true of any continuous observations, such as the barometric-pressure trace. Copies of these can be obtained through NCC Asheville. Three hourly observations are punched on cards by the supporting country and exchanged with other supporting nations. However, this program may lag behind the real-time reports by a few months to several years. A request through the NCC for data for a specific time period and station may possibly expedite the availability of data.

Oceanographic Data for OSVs is limited to Nanson casts which give salinity and temperature versus depth. Data for OSV HOTEL (U.S.) is received with-within about 2 months, foreign ship data from a few months to a few years. A request through the National Ocean Data Center (NODC) for specific data could possibly bring faster results.

8.3.4 <u>LIGHTHOUSE AND OTHER COAST GUARD STATIONS</u>. U.S. Coast Guard Lighthouses are scattered along all of the United States. As these stations are automated, personnel are removed. The National Weather Service is gradually installing automated weather observatories, at the automated lighthouses, to continue weather observations. Automated Weather observatories do not take sea and swell observations. The manned lighthouses and most other Coast Guard stations take weather observations. All manned lighthouses and those Coast Guard stations within sight of the oceans report visual sea and swell height and period and surf conditions.

Marine reporting stations, lighthouse and other Coast Guard stations, are depicted in Figure 8-4. Table 8-4 identifies these stations by name, latitude and longitude, gives the amount of observations taken daily, and the NWS monitor. Manned and automated weather observatories are not delineated in Table 8-4.

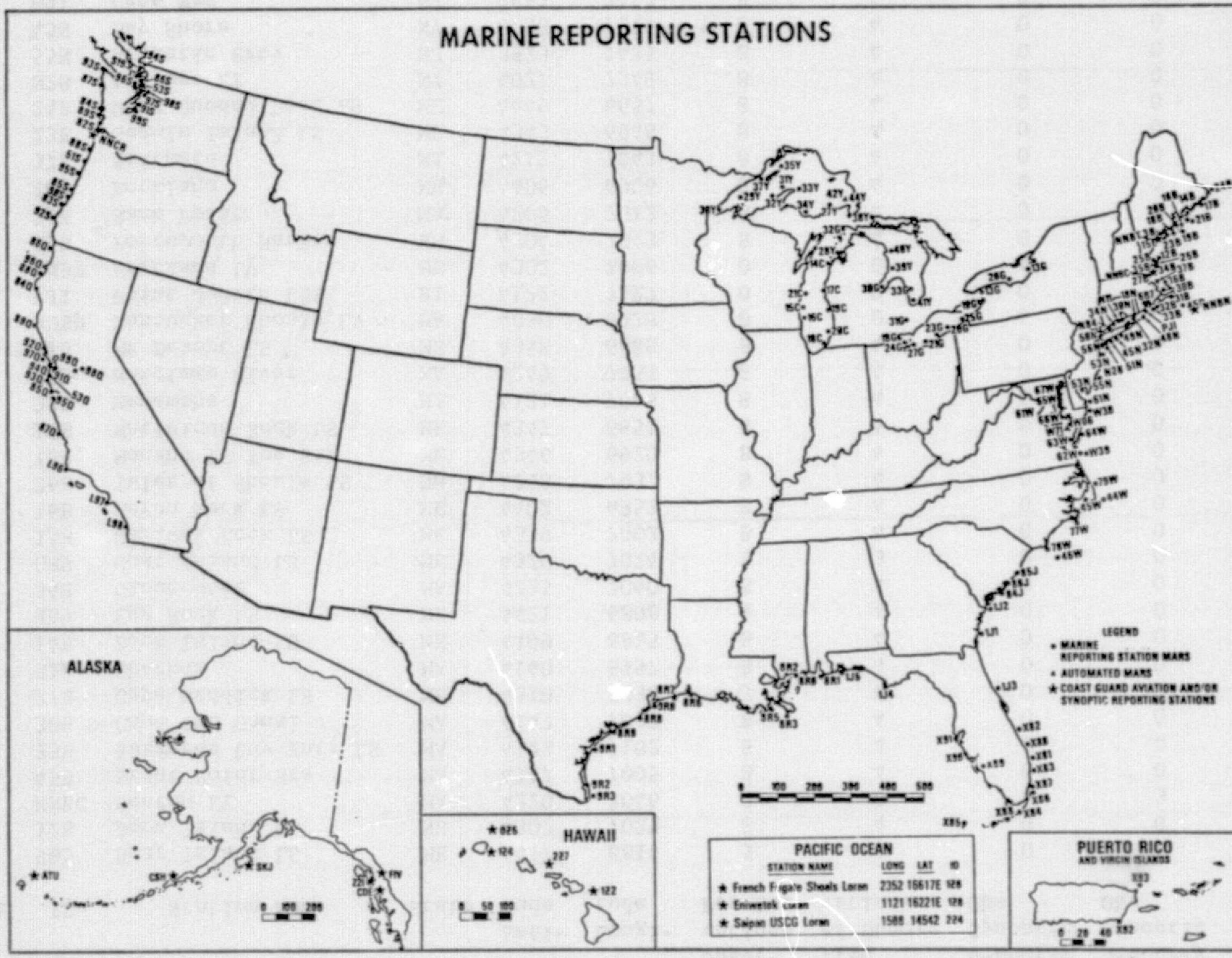

Figure 8-4. Marine Reporting Stations

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
1	9B5	Bear Island LS	ME	4417	6816	5	4	0	0	PWM
1	12B	Boon Island LS	NH	4307	7029	8	4	0	0	PWM
1	HNBC	Boston LY	MA	4220	7046	0	0	4	3	BOS
1	45B	Brant Point Sta	MA	4117	7005	8	4	0	0	BOS
1	33B	Buzzards Bay Entr LS	MA	4123	7102	8	4	0	0	BOS
1	30B	Cape Cod Canal	MA	4147	7030	8	4	0	0	BOS
1	27B	Cape Neddick LS	ME	4310	7036	5	4	0	0	PWM
1	31B	Chatham	MA	4140	6957	8	4	0	0	BOS
1	14B	Duck Island LS	ME	4409	6815	8	4	0	0	PWM
1	8B9	Egg Rock LS	ME	4421	6808	8	4	0	0	PWM
1	34B	Gloucester	MA	4235	7040	8	4	0	0	BOS
1	0B9	Goat Island LS	ME	4320	7024	5	3	0	0	PWM
1	15B	Halfway Rock LS	ME	4339	7002	8	4	0	0	PWM
1	16B	Heron Neck LS	ME	4402	6852	8	4	0	0	PWM
1	26B	Isles of Shoals LS	NH	4258	7037	8	4	0	0	PWM
1	18B	Manana IS Fog Sig	ME	4346	6920	8	4	0	0	PWM
1	19B	Matinicus Rock LS	ME	4347	6851	8	4	0	0	PWM
1	32B	Menemsha	MA	4121	7046	8	4	0	0	BOS
1	35B	Merrimac River	MA	4249	7052	8	4	0	0	BOS
1	21B	Mt Desert LS	ME	4358	6808	8	4	0	0	PWM
1	HNBN	Nantucket Shoals LV	MA	4030	6928	0	0	4	0	BOS
1	PJI	Point Judith LBS	RI	4122	7129	0	0	0	0	PVD
1	HNBT	Portland LV	ME	4332	7006	0	0	4	3	PWM
1	25B	Portsmouth Harbor	NH	4304	7043	8	4	0	0	PWM
1	36B	Race Point	MA	4205	7012	8	4	0	0	BOS
1	20B	Rockland	ME	4406	6906	8	4	0	0	PWM
1	37B	Scituate	MA	4212	7043	8	4	0	0	BOS
1	23B	Seguin Island LS	ME	4343	6946	8	4	0	0	PWM
1	24B	West Quoddy Head LS	ME	4449	6657	8	4	0	0	PWM
3	N28	Ambrose LT	NY	4027	7349	8	4	0	0	NYC
3	55N	Atlantic City	NJ	3923	7425	8	4	0	0	ACY
3	45N	Bay Shore	NY	4038	7316	8	4	0	0	NYC
3	H91	Cape May	NJ	3857	7453	8	4	0	0	ACY

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
3	34N	Eatons Neck	NY	4057	7324	8	4	0	0	NYC
3	N84	Execution Rocks LS	NY	4053	7344	0	0	4	4	NYC
3	30N	Falkners Island LS	CT	4113	7240	8	4	0	0	BDR
3	61N	Indian River	DE	3837	7504	8	4	0	0	ILG
3	32N	Little Gull IS LS	CT	4112	7206	8	4	0	0	BDR
3	54N	Manasquan Inlet	NJ	4006	7401	0	0	0	0	NYC
3	48N	Montauk Point LS	NY	4104	7156	8	4	0	0	NYC
3	49N	Moriches LS	NY	4047	7245	8	4	0	0	NYC
3	N11	New Haven	CT	4116	7254	0	0	4	4	BDR
3	18N	New London Ledge LS	CT	4118	7205	0	0	4	4	BDR
3	50N	Rockaway	NY	4034	7353	8	4	0	0	NYC
3	56N	Sandy Hook	NJ	4028	7401	8	4	0	0	NYC
3	51N	Short Beach	NY	4035	7333	8	4	0	0	NYC
5	61W	Annapolis	MD	3855	7628	8	4	0	0	BAL
5	62W	Cape Henry	VA	3656	7600	8	4	0	0	ORF
5	77W	Cape Lookout	NC	3436	7632	8	4	0	0	ILM
5	W39	Chesapeake LS	VA	3654	7543	8	4	0	0	ORF
5	66W	Cove Point LS	MD	3823	7623	8	4	0	0	BAL
5	W06	Crisfield LS	MD	3759	7552	3	4	0	0	BAL
5	44W	Diamond Shoals LS	NC	3509	7518	8	4	0	0	ORF
5	46W	Frying Pan Shoals LS	NC	3329	7735	8	4	0	0	ORF
5	63W	Milford Haven	VA	3729	7619	8	4	0	0	ORF
5	78W	Oak Island	NC	3353	7801	8	4	0	0	ILM
5	W30	Ocean City LS	MD	3820	7505	8	4	0	0	BAL
5	45W	Ocracoke	NC	3507	7559	8	4	0	0	HAT
5	79W	Oregon Inlet LS	NC	3546	7531	4	2	0	0	HAT
5	64W	Parramore Beach LS	VA	3732	7537	8	4	0	0	ORF
5	67W	Stillpond	MD	3920	7606	8	4	0	0	BAL
5	65W	Thomas Point LS	MD	3854	7626	8	4	0	0	BAL
5	1W9	Wrightsville Beach	NC	3411	7749	25	0	0	0	ILM
7	X93	Cape San Juan LBS	PR	1823	6537	8	4	0	0	MJSJ
7	86J	Charleston	SC	3246	7951	5	4	0	0	CHS
7	X85	Dry Tortugas	FL	2438	8255	8	4	0	0	EYW

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
7	X91	Egmont Key LS	FL	2736	8246	8	4	0	0	TPA
7	84J	Folly Beach Loran	SC	3241	7953	4	4	0	0	CHS
7	X89	Ft Meyers Beach	FL	2627	8157	8	4	0	0	FMY
7	X82	Ft Pierce	FL	2728	8018	8	4	0	0	PBI
7	85J	Georgetown LS	SC	3313	7911	5	4	0	0	CHS
7	X84	Islamorada Sta	FL	2455	8035	8	4	0	0	MIAC
7	X81	Lake Worth Inlet	FL	2646	8003	8	4	0	0	PBI
7	X88	Marathon	FL	2443	8107	8	4	0	0	EYW
7	X87	Miami Beach Base	FL	2547	8010	8	4	0	0	MIAC
7	X92	Point Tuna	PR	1759	6553	4	4	0	0	MJSJ
7	1J3	Ponce De Leon Inlet	FL	2904	8055	8	4	0	0	DAB
7		Port Ponce	PR	1758	6637	3	4	0	0	MJSJ
7	1J1	St Simon Island	GA	3108	8122	8	4	0	0	SAV
7		St Thomas (LAS)	VI	1821	6456	3	4	0	0	MJSJ
7	1J2	Tybee	GA	3201	8051	8	4	0	0	SAV
7	X90	Venice Loran	FL	2705	8227	8	4	0	0	TPA
8	8R6	Calcasieu RBS	LA	2947	9321	8	4	0	0	LCH
8	1J4	Cape San Blas	FL	2941	8522	8	4	0	0	AQQ
8	8R8	Freeport	TX	2857	9518	8	4	0	0	GLS
8	8R5	Grand Isle	LA	2916	8957	8	4	0	0	MSYC
8	8R1	Mobile Point	AL	3014	8802	4	9	0	0	MOB
8	8R0	Pascagoula	MS	3022	8834	8	4	0	0	MOB
8	9R1	Port Aransas	TX	2750	9704	8	4	0	0	CRP
8	9R3	Port Isabel	Tx	2604	9710	8	4	0	0	BRO
8	8R9	Port O'Connor	TX	2826	9626	8	4	0	0	GLS
8	8R7	Sabine (PSS)	TX	2944	9352	8	4	0	0	BPT
8	1J5	Santa Rosa IS LBS	FL	3019	8715	8	4	0	0	PNS
8	8R3	Southwest Pass	LA	2855	8926	8	4	0	0	MSYC
9	20G	Ashtabula LS	OH	4155	8048	12	3	0	0	CLE
9	31G	Belle Isle LS	MI	4220	8258	12	3	0	0	DTW
9	19G	Buffalo	NY	4253	7853	12	3	0	0	BUF
9	23G	Cleveland Harbor	OH	4130	8143	12	3	0	0	CLE
9	18G	Detroit River LS	MI	4200	8309	12	3	0	0	DTW

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
9	29Y	Devils IS LS	WI	4705	9044	8	4	0	0	DLH
9	30Y	Duluth Harbor Sta	MN	4646	9205	8	4	0	0	DLH
9	31Y	Eagle Harbor LS	MI	4728	8810	4	0	0	0	MQT
9	25G	Erie Harbor LBS	PA	4207	8005	24	1	0	0	ERI
9	14C	Frankfort	MI	4438	8615	8	4	0	0	MKG
9	27Y	Grand Marais	MI	4641	8559	8	0	0	0	MQT
9	16C	Kenosha	WI	4235	8745	8	4	0	0	MKE
9	32G	Lansing Shoal Light	MI	4554	8534	8	0	0	0	SSM
9	27G	Lorain	OH	4128	8211	12	8	0	0	CLE
9	17C	Ludington LS	MI	4357	8628	8	4	0	0	MKG
9	33Y	Manitou Island LS	MI	4725	8735	4	0	0	0	MQT
9	21G	Marblehead LS	OH	4133	8244	12	3	0	0	CLE
9	34Y	Marquette LS	MI	4633	8723	4	0	0	0	MQT
9	18C	Michigan City	IN	4143	8654	4	0	0	0	CHI
9	15C	Milwaukee LS	WI	4301	8757	8	0	0	0	MKE
9	19C	Muskegon LS	MI	4314	8620	8	4	0	0	MKG
9	13G	Niagara	NY	4316	7904	12	3	0	0	BUF
9	28Y	North Manitou Shoals	MI	4501	8557	8	0	0	0	MKG
9	28G	Oswego	NY	4328	7631	12	4	0	0	SYR
9	35Y	Passage Island LS	MI	4813	8822	4	0	0	0	MQT
9	36Y	Point Betsie	MI	4442	8615	3	4	0	0	MKG
9	33G	Port Huron	MI	4300	8225	12	3	0	0	DTW
9	32Y	Portage LBS	MI	4714	8838	4	0	0	0	MQT
9	26G	Rochester LS	NY	4315	7736	8	4	0	0	ROC
9	37Y	Rock of Ages LS	MI	4752	8919	4	0	0	0	MQT
9	30G	Saginaw RS	MI	4338	8351	12	3	0	0	DTW
9	44Y	Sault Ste Marie	MI	4630	8420	8	0	0	0	SSM
9	21C	Sheboygan	WI	4345	8742	8	4	0	0	MKE
9	41Y	St Clair Shores	MI	4228	8253	12	3	0	0	DTW
9	38Y	St Ignace	MI	4551	8443	8	0	0	0	SSM
9	20C	St Joseph LBS	MI	4207	8629	4	0	0	0	GRR
9	39Y	Tawas Point LS	MI	4415	8326	8	4	0	0	APN

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
9	40Y	Thunder Bay IS LS	MI	4502	8312	8	4	0	0	APN
9	24G	Toledo	OH	4142	8327	25	9	0	0	TOL
11	L97	Long Beach	CA	3245	11825	8	4	0	0	LAX
11	L96	Pt Arguello	CA	3434	12040	8	4	0	0	SMX
11	L98	San Mateo	CA	3323	11735	8	4	0	0	LAX
12	84Q	Blunts Reef	CA	4026	12430	8	4	0	0	EKA
12	92Q	Bodega Bay LS	CA	3319	12303	8	4	0	0	SFO
12	99Q	Concord	CA	3803	12201	4	9	0	0	SFO
12	88Q	Humboldt Bay	CA	4046	12414	8	4	0	0	EKA
12	89Q	Point Arena LS	CA	3857	12344	8	4	0	0	EKA
12	91Q	Point Blunt	CA	3751	12225	4	9	0	0	SFO
12	94Q	Point Bonita LS	CA	3749	12232	8	4	0	0	SFO
12	95Q	Point Pinos LS	CA	3638	12156	8	4	0	0	SFO
12	87Q	Pt Piedras Blancas	CA	3540	12117	4	4	0	0	SMX
12	98Q	Rio Vista	CA	3809	12142	4	4	0	0	SFO
12	86Q	St George Reef LS	CA	4150	12423	5	9	0	0	EKA
12	Q67	Tahoe City	CA	3911	12007	25	0	0	0	RNO
13	91S	Alki Point LS	WA	4731	12225	25	0	0	0	SEA
13	92S	Cape Blanco LS	OR	4250	12434	4	4	0	0	MFR
13	82S	Cape Disappointment	WA	4617	12403	4	9	0	0	PDX
13	93S	Cape Flattery	WA	4823	12444	7	4	0	0	UIL
13	HNCR	Columbia River LV	OR	4611	12411	0	0	4	4	SEA
13	83S	Coos Bay	OR	4321	12420	4	4	0	0	PDX
13	84S	Grays Harbor	WA	4655	12406	7	4	0	0	SEA
13	98S	Mukilted	WA	4757	12218	6	4	0	0	
13	97S	Point No Point	WA	4755	12232	6	4	0	0	
13	99S	Point Robinson LS	WA	4723	12222	6	4	0	0	SEA
13	53S	Point Wilson LS	WA	4809	12245	8	4	0	0	SEA
13	NOW	Port Angeles	WA	4808	12324	6	4	0	0	UIL
13	87S	Quillayute River	WA	4754	12438	4	4	0	0	SEA
13	85S	Siuslaw River	OR	4400	12407	4	4	0	0	PDX
13	86S	Smith Island LS	WA	4819	12251	7	9	0	0	SEA

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
13	88S	Tillamook Bay	OR	4534	12355	5	4	0	0	PDX
13	90S	Umpqua River	OR	4341	12410	5	4	0	0	PDX
13	43S	West Point LS	WA	4740	12226	6	4	0	0	
13	89S	Willapa Bay LS	WA	4642	12358	7	4	0	0	SEA
14	1Z8	Eniwetok	PAC	1121	16221	0	0	4	0	PKWA
14	1Z6	FR Frigate Shoals	HI	2352	16617	0	0	4	0	PRH
14	0Z5	Kilauea Point	HI	2214	15924	3	9	0	0	LIH
14	1Z4	Makahuena Point	HI	2152	15927	4	5	0	0	LIH
14	2Z4	Saipan USCG Loran	PAC	1508	14542	0	0	4	0	PGAC
14	1Z2	Upolu Point USCG LOR	HI	2015	15553	4	5	0	0	PHTO
17	ATU	ATTU	AK	5250	17311	8	4	0	0	ARH
17	Z21	Biorka Island	AK	5651	13533	8	4	0	0	ARH
17	CSH	Cape Sarichef	AK	5436	16456	8	2	0	0	ARH
17	FIV	Five Finger LS	AK	5716	13337	10	2	0	0	ARH
17	KPC	Port Clarence	AK	6515	16652	8	2	0	0	ARH
17	SKJ	Sitkinak	AK	5633	15408	8	4	0	0	ARH
20	08S	Bailey's Landing	MT	4804	11413	2	9	0	0	FCA
20	20S	Bonneville Dam	OR	4538	12157	25	0	0	0	PDX
20	L14	Cabrillo Beach	CA	3343	11817	2	9	0	0	LAX
20	DUK	Chicago Dunne Crib	IL	4147	8732	3	6	0	0	MDW
20	52Q	Davis Point	CA	3803	12216	25	0	0	0	SFO
20	Z56	Dolly Vard. Platform	AK	6048	15138	2	9	0	0	ARH
20	50Q	Farallon IS	CA	3742	12300	3	9	0	0	SFO
20	37S	Fort Peck Marina	MT	4759	10628	25	0	0	0	GGW
20	S19	Friday Harbor	WA	4830	12300	25	0	0	0	SEA
20	OW4	Kentmorr Marina	MD	3855	7622	0	0	2	3	BAL
20	54Q	Moss Landing	CA	3648	12148	6	4	0	0	SFO
20	L79	Oxnard (Channel IS)	CA	3410	11913	3	6	0	0	LAX
20	NIX	Pacific Beach	WA	4713	12412	25	0	0	0	SEA
20	51S	Pacific City	OR	4512	12358	0	0	0	0	PDX
20	Z69	Phillips Platform	AK	6104	15057	2	9	0	0	ARH
20	53Q	Pillar Point	CA	3730	12230	8	4	0	0	SFO

TABLE 8-4. COAST GUARD AND MARINE REPORTING STATION (Cont'd)

CG Dist	ID	Station Name	State	Latitude	Longitude	Observations Per Day	Freq of Observations	6-Hourly Synoptic Obs	3-Hourly Synoptic Obs	Supervising Station
20	Z72	Platform Dillon	AK	6044	15131	2	9	0	0	ARH
20	L13	Point Loma	CA	3240	11729	3	4	0	0	SAN
20	Q63	Pyramid Lake	NV	3957	11937	2	9	0	0	RNO
20	51Q	San Francisco (PBS)	CA	3745	12241	8	4	0	0	SFO
20	85Q	Santa Cruz	CA	3658	12200	3	4	0	0	SFO
20		Wildwood	NJ	3900	7449	25	9	0	0	ACY

Table 8-5. lists the National Weather Service station responsible for monitoring the marine stations.

All reporting stations take observation of current weather, visibility, wind speed and direction, and pressure. Manned marine reporting stations use NOAA Form 72-5a, depicted in Appendix D, to log their observations. A code card for this form is also included in Appendix D. Some of the Marine station observations are transmitted as part of the regular land-station reporting network of weather observations. All of the marine Coastal Station Log sheets are sent to NCC Asheville, N.C.

8.3.5 NOAA MARINE CLIMATIC GUIDE. In support of NASA manned space flight programs, the Spaceflight Meteorology Group prepared a rather detailed and complete statistical analysis of recorded wind and sea conditions for those water-covered areas of the world lying between latitudes 40° North and 40° South. The charts presented in this guide have been constructed using the most recent information contained in the U.S. Navy Atlases available at the time of preparation of this document.

Charts in the Marine Climatic Guide are arranged so that all charts depicting air temperature are in one group and follow in chronological sequence, i.e., January, February, March, ... etc. The charts showing sea temperature, surface wind speed, and visibility are in groups that follow and they too are shown on a monthly basis. Sea state (waves generated on the ocean by local winds blowing over the water) is shown for periods of 3 months so that February is said to be representative of January, February, and March; and May is representative of April, May, and June, etc.

Figures 8-5, 8-6, and 8-7 are representative of the content of the Marine Climatic Guide. Figure 8-5 depicts mean surface temperatures for the month of June: Figure 8-6, the occurrence of seas ≥ 8 feet for the month of August ; and Figure 8-7, percent occurrence of surface wind speed ≥ 18 knots for the month of December.

TABLE 8-5. NWS MONITORING STATIONS

NWS Monitor	Station	NWS Monitor	Station
ACY	Atlantic City, New Jersey	MFR	Medford, Oregon
APH	Alpena, Mich.	MIAC	Miami, Florida
AQQ	Apalachicola, Florida	MJSJ	San Juan, Puerto Rico
ARH	Alaska Region Headquarters	MKE	Milwaukee, Wisconsin
BAL	Baltimore, Maryland	MKG	Muskegon, Mich.
BDR	Bridgeport, Conn.	MOB	Mobile, Alabama
BOS	Boston, Mass.	MQT	Marquette, Mich.
BPT	Port Arthur, Texas	MSY	New Orleans, Louisiana
BRO	Brownsville, Texas	NYCF	New York, New York
BUF	Buffalo, New York	ORF	Norfolk, Virginia
CHI	Chicago, Illinois	PBI	West Palm Beach, Florida
CHS	Charleston, South Carolina	PDX	Portland, Oregon
CLE	Cleveland, Ohio	PGAC	Guam Marina Island, Pacific
CRP	Corpus Christi, Texas	PHLI	Lihue, Hawaii
DAB	Daytona Beach, Florida	PHTO	Hilo, Hawaii
DLH	Duluth, Minn.	PKWA	Kwajalsin, Pacific
DTN	Shreveport, Louisiana	PNS	Pensacola, Florida
DTW	Detroit, Mich.	PRH	Pacific Region Headquarters
EKA	Eureka, California	PVD	Providence, Rhode Island
ERI	Erie, Penn.	PWMF	Portland, Maine
EYW	Key West, Florida	RHO	Reno, Nevada
FCA	Kalispell, Mich.	ROC	Rochester, New York
FMY	Fort Myers, Florida	SAN	San Diego, Calif.
GGW	Glasgow, Mich.	SAV	Savannah, Georgia
GLS	Galveston, Texas	SEA	Seattle - Tacoma
GRR	Grand Rapids, Mich.	SFO	San Francisco, Calif.
HAT	Cape Hatteras, North Carolina	SMX	Santa Maria, Calif.
ILG	Wilmington, Delaware	SSM	Saulte Ste Marie, Mich.
ILM	Wilmington, North Carolina	TOL	Toledo, Ohio
LAX	Los Angeles, Calif.	TPA	Tampa, Florida
LAXF	Los Angeles, Calif.	UIL	Quillayute, Washington
LCH	Lake Charles, Louisiana		

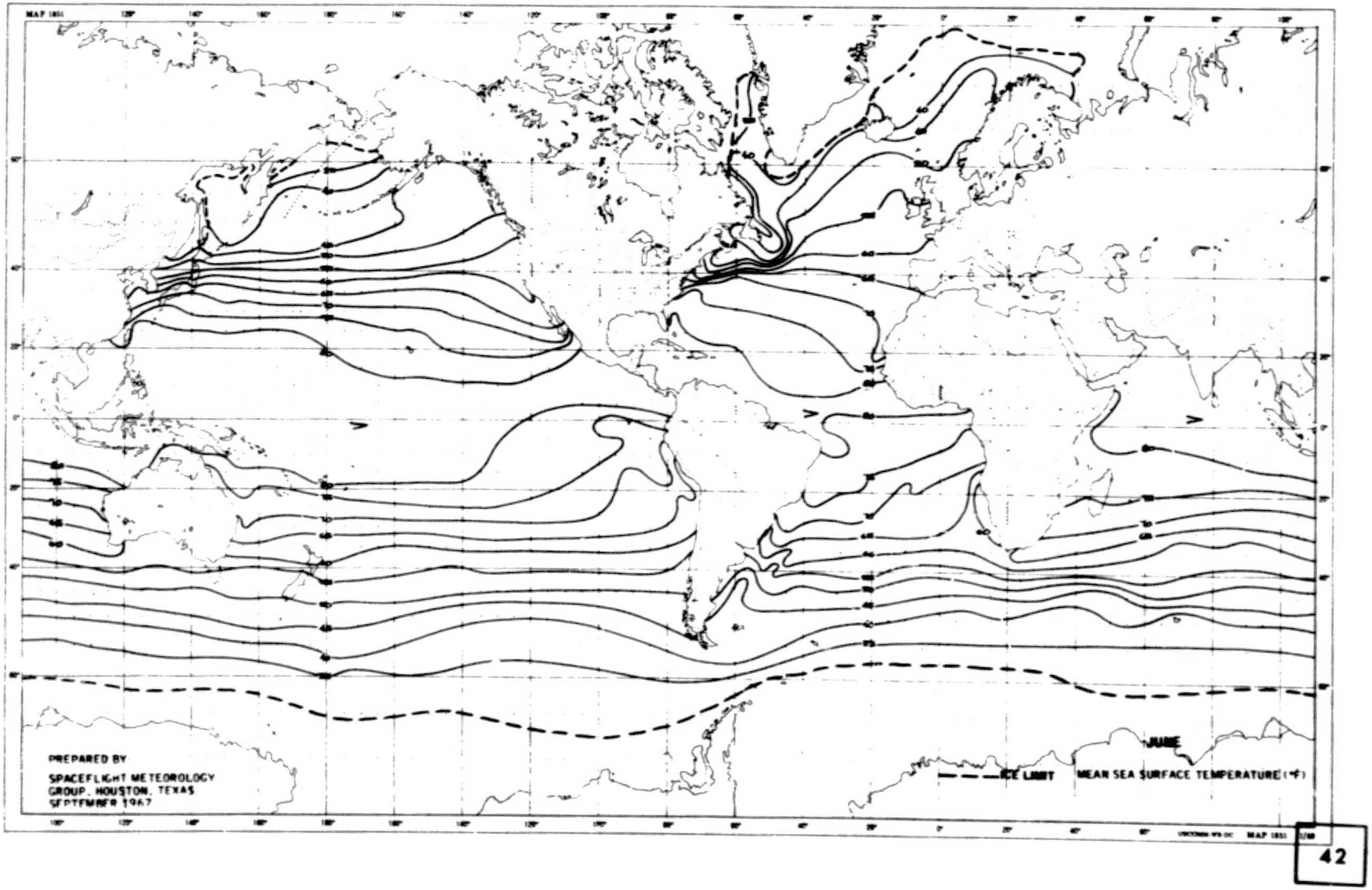

Figure 8-5. Mean Surface Temperature (°F) for the Month of June

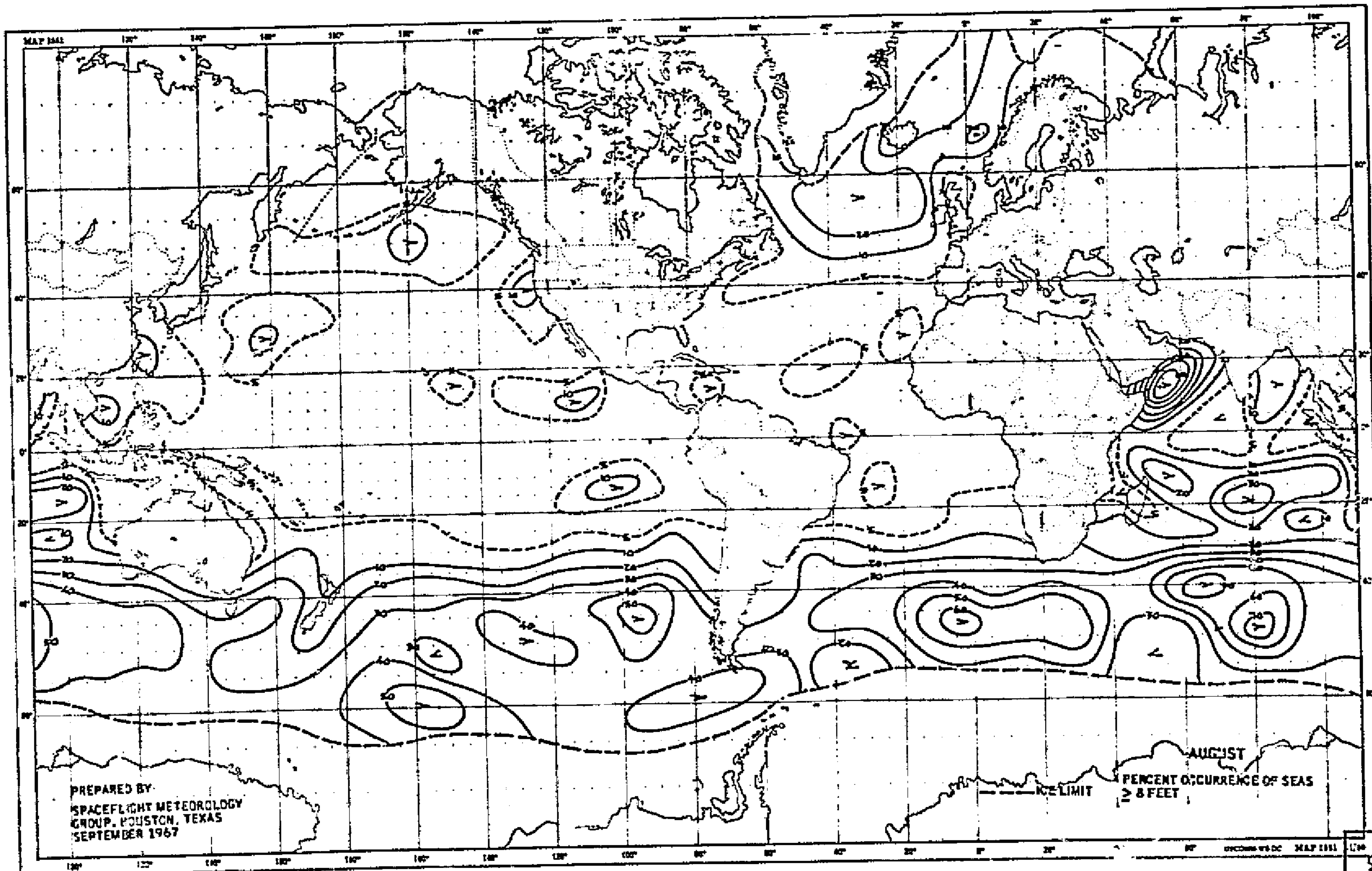

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Figure 8-6. Occurrence of Seas ≥8 Feet for the Month of August

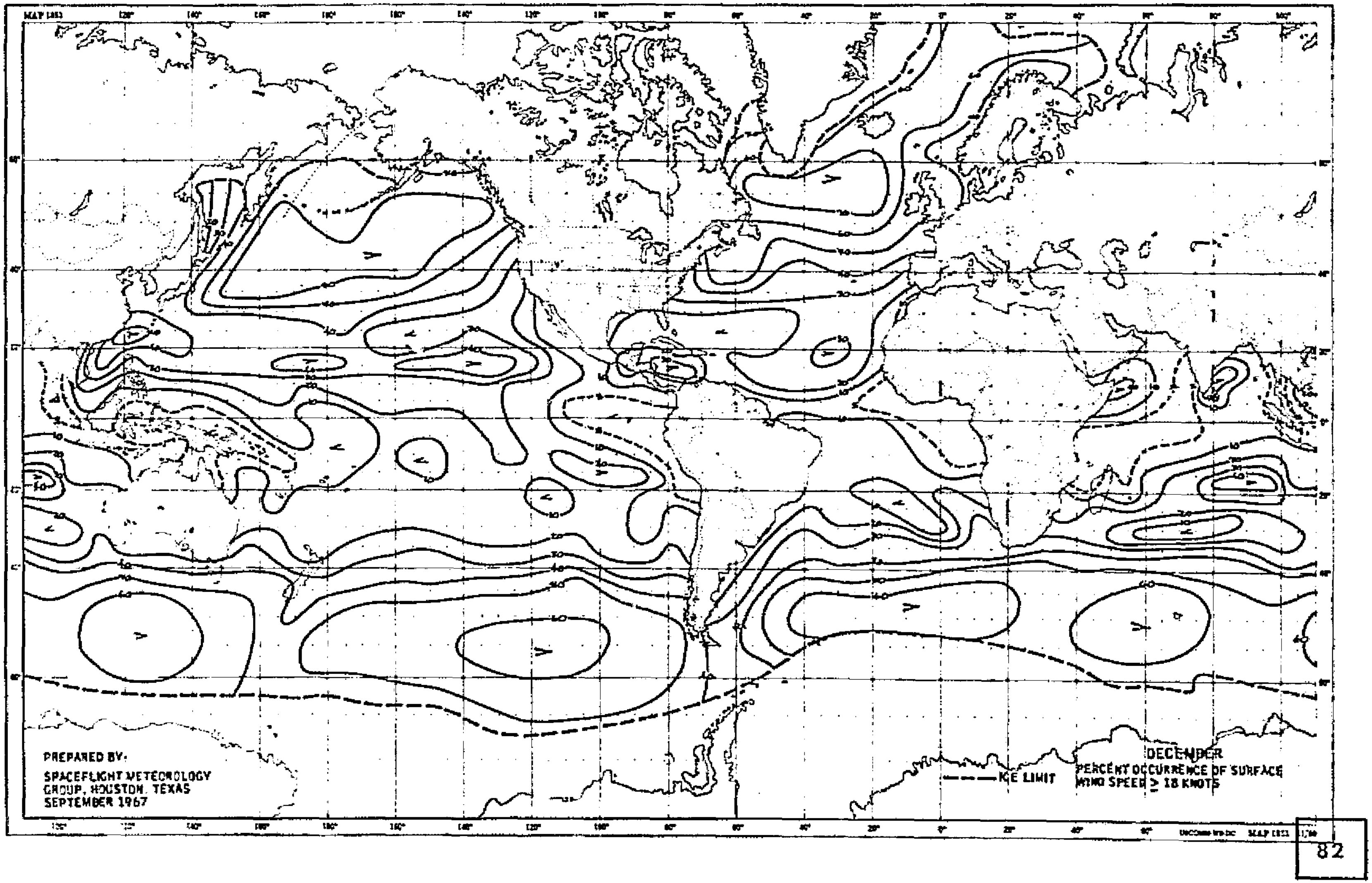

Figure 8-7. Percent Occurrence of Surface Wind Speed ≥18 Knots for the Month of December

8.3.6 ANALOGOUS ACTIVITIES/EXPERIMENT. Major oceanographic experiments planned for the period 1972-1984 are shown in Table 8-6. This table states the location of the experiment, the proposing country, the time period, and the objective of the experiment.

The Fleet Sailing Schedule for ships under NOAA cognizance are presented in Figure 8-8. Deployment schedules of ships of other organizations and activities will be given to Principal Investigators when made available to the GEOS-C Project office.

8.4 MISCELLANEOUS SATELLITE PHOTOGRAPHS.

This section contains additional satellite photographs (Figures 8-9 through 8-14) available in the SMG Calibration Package. Included are SMS-1 visual, Very High Resolution Radiometer (VHRR), and NOAA-4 nighttime infrared and visual views plus NOAA visual and infrared photographs of the Southern Hemisphere.

8.5 BIBLIOGRAPHY.

Table 8-7 is a bibliography of reference material used in the preparation of this document. It also contains references to the related subject matter presented herein. Reference material is presented in alphabetical order without categorizing as to subject matter.

TABLE 8-6. MAJOR OCEANOGRAPHIC EXPERIMENTS PLANNED FOR THE PERIOD 1972-1984

Experiment	Location	Proposer	Time Period	Objective
GARP Atlantic Tropical Experiment (GATE)	Off NW Coast of Africa	International	1974	To understand mesoscale interactions in the tropics and their effect on the global general circulation.
Air Mass Transformation Experiments (AMTEX)	East China Sea and SW Japanese Islands	Japan	1974-75	To clarify the transfer processes by which energy and momentum are supplied from the sea surface to the air and transported to the free atmosphere through the planetary boundary layer.
Joint Air-Sea Interaction (JASIN)	Northeast Atlantic Ocean	U.K.	Prelim: 1972 Main: 1975	To study the interaction of atmospheric and oceanic boundary layers with larger scale motions of the sea and the atmosphere.
Mid-Ocean Dynamics Experiments (MODE)	North Atlantic Ocean	U.K.	MODE 1: 1973	To investigate the role of medium-scale geostrophic eddies in the general circulation of the oceans.
Coastal Upwelling Experiment (CUE)	Oregon Coast: CUE I and II. NW Africa, Peru and California Coasts: Future CUEs	U.S.	CUE I: 1962 CUE II: 1973	To understand the time and space scales of coastal upwelling and to develop prognostic techniques.
North Pacific Experiment (NORPAX)	Mid-Latitudes North Pacific	U.S.	1972-82	To study the major physical processes for the large-scale oceanic and atmospheric fluctuations in the North Pacific Ocean.
Antarctic Current Experiment (ACE)	Southern Hemisphere	U.S.	Prelim: 1974/75 During FGGE: 1977	To observe, describe and study oceanic and atmospher'c parameters in the high Southern Hemisphere latitudes and provide observing platforms in this area during FGGE.
Joint North Sea Wave Atmosphere Program (JONSWAP)	North Sea	F.R.G.	JONSWAP II: 1973 JONSWAP III: 1974	To study air-sea interactions in the North Sea.
Monsoon Experiment (MONEX)	Arabian Sea	India	During FGGE: 1977	To study the air-mass transformation in the Arabian Sea during the Southwest Monsoon.
Polar Experiment (POLEX)	Polar Regions	U.S.S.R	1971-76 During FGGE: 1977	To understand the gross heat budget of the Polar Regions, the mechanisms affecting polar heat sink and the response of the atmosphere to anomalous heating.
Arctic Ice Dynamics Joint Experiment (AIDJEX)	Arctic	U.S./Canada	1975 Being Studied to Become Part of POLEX	To understand how the atmosphere and the ocean influence the movement, growth and decay of Arctic ice.
First GARP Global Experiment (FGGE)	World-Wide	International	1977-78	To provide data necessary to examine fully the general circulation of the atmosphere over a year's period for adequate testing of numerical models of the atmosphere.
International Southern Ocean Study (ISOS)	Southern Hemisphere	U.S.	1974-84	Similar to ACE, which will probably be incorporated under this study.
Storm Fury (SF)	Atlantic-Caribbean East Pacific	U.S.	1975 1977-78	Data and verification phase. Attempt cloud seeding of hurricanes to reduce energy of hurricane, thus reduce wind speed and destruction
Winter Storm (WISEX)	East Coast U.S.	U.S.	1975	To study fetch limited wave buildup.

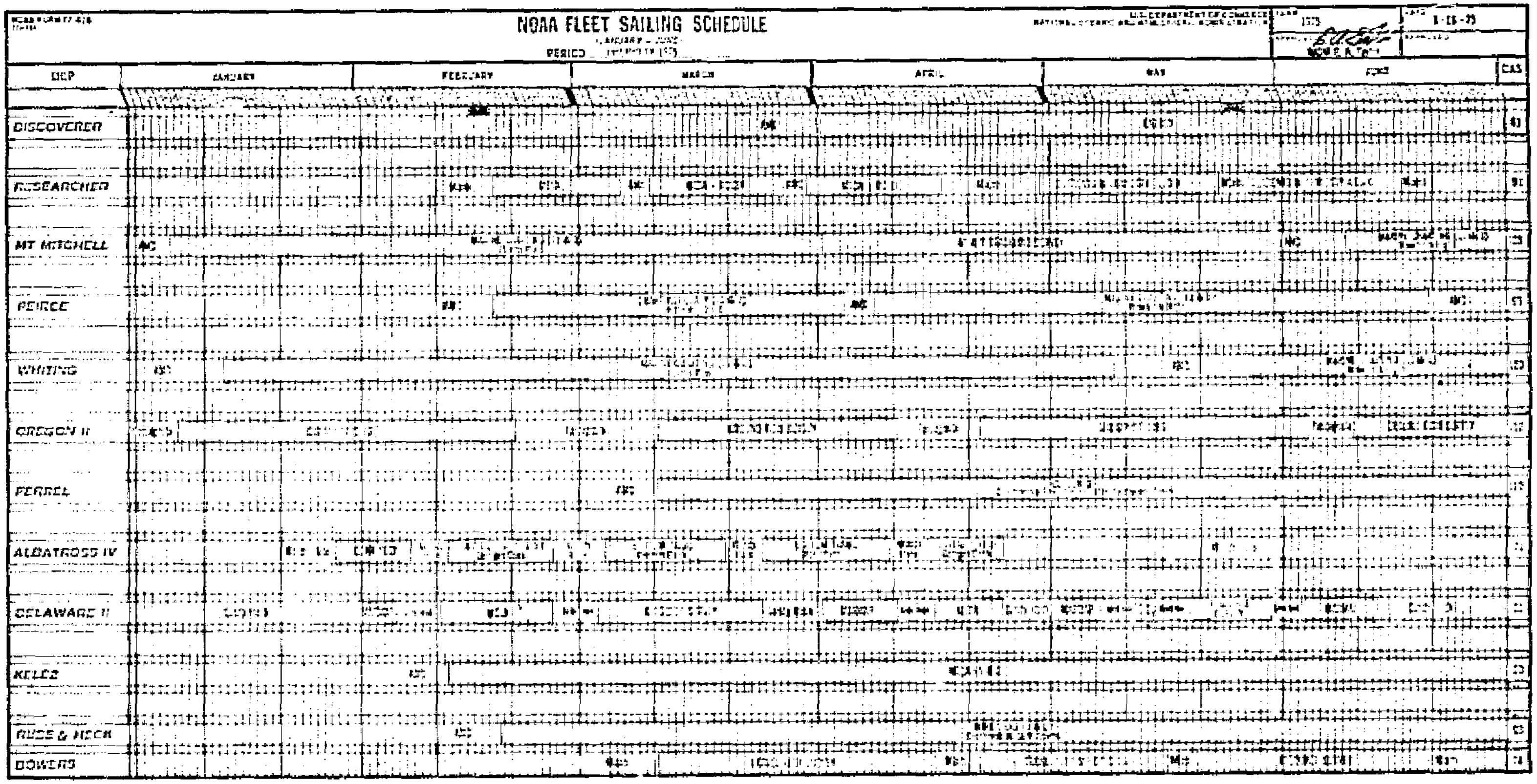

Figure 8-8. NOAA Fleet Sailing Schedule

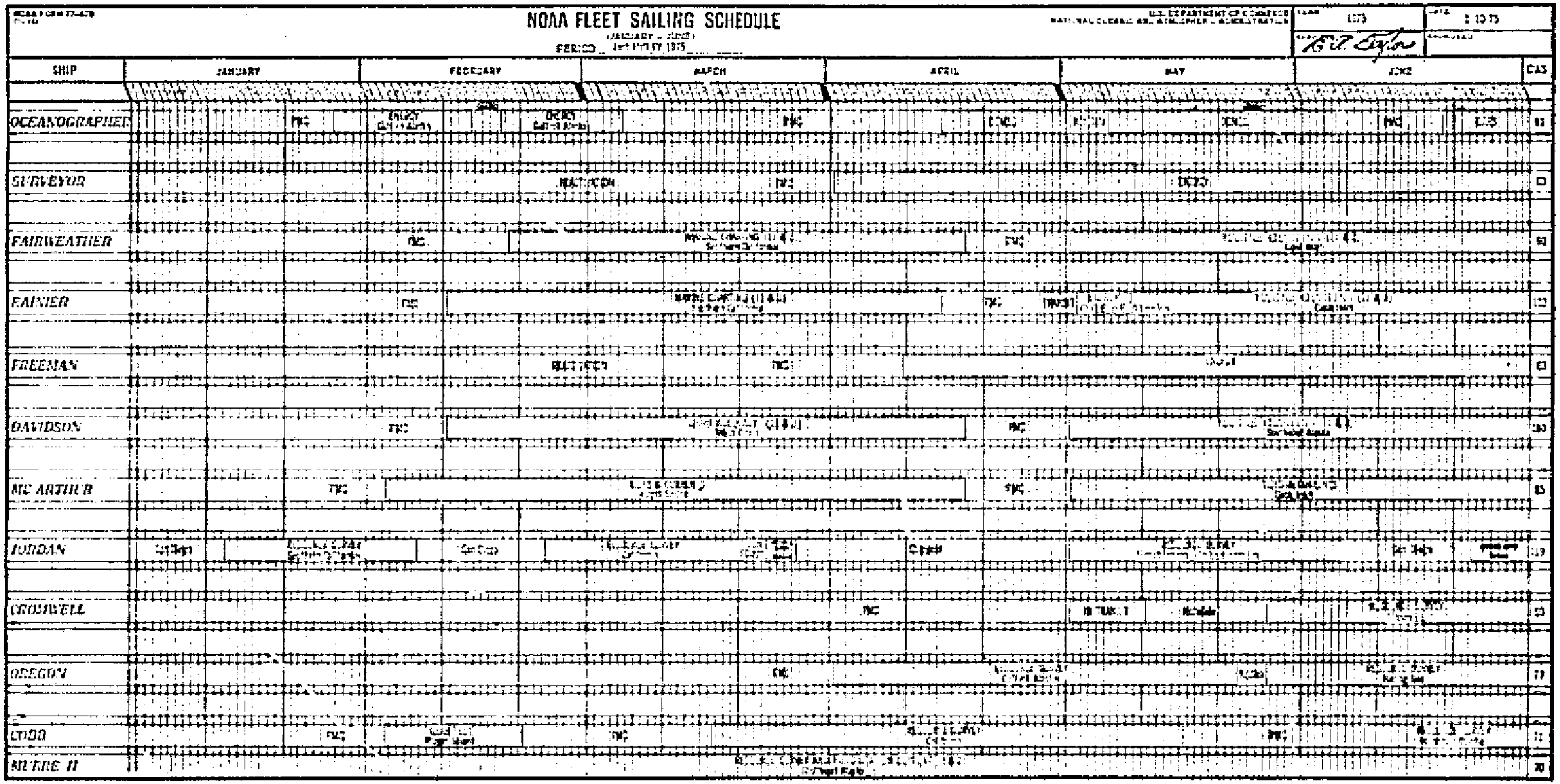

Figure 8-8. NOAA Fleet Sailing Schedule (Cont'd)

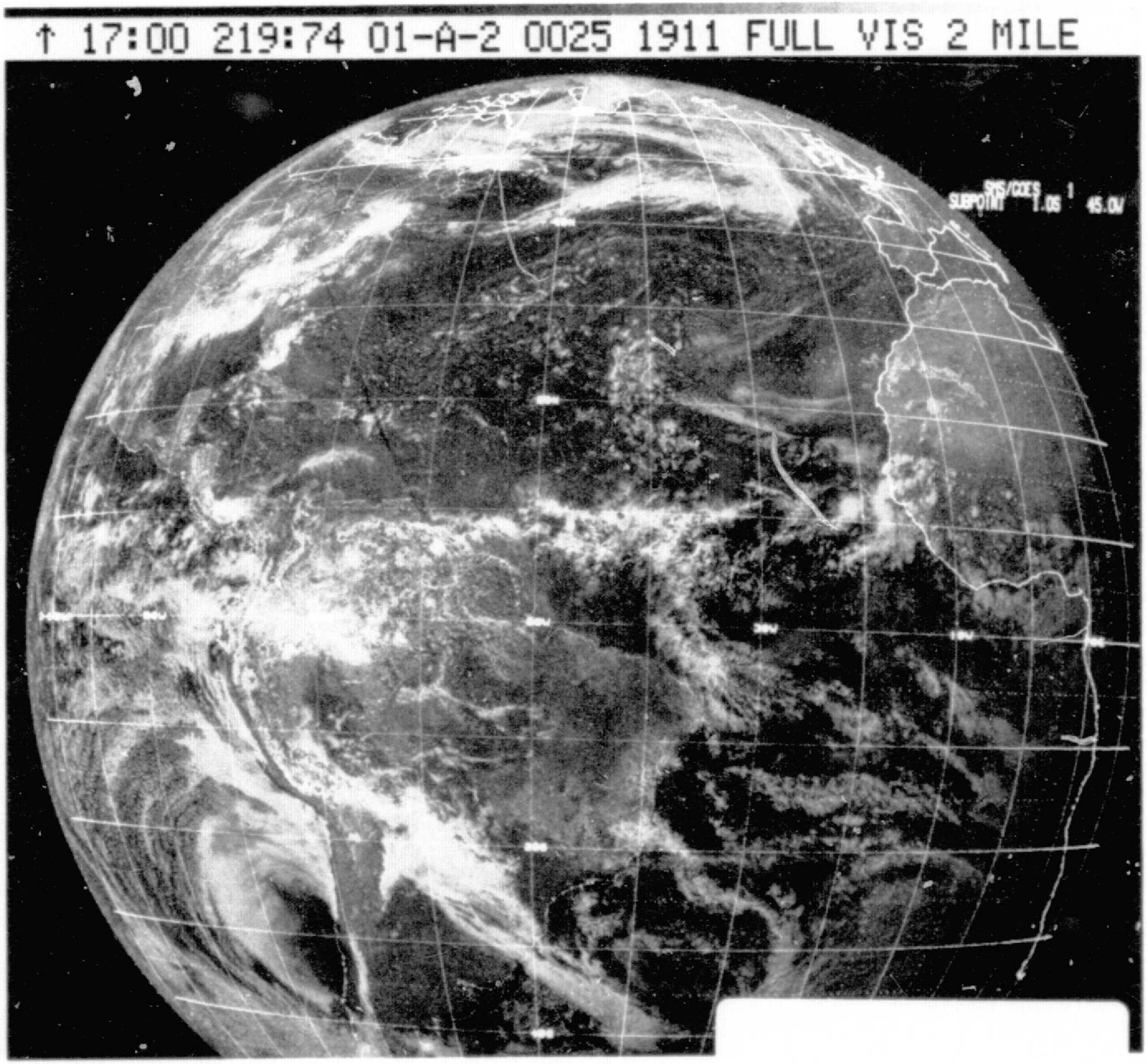

Figure 8-9. SMS-1, Visual 2 nm Resolution Photograph

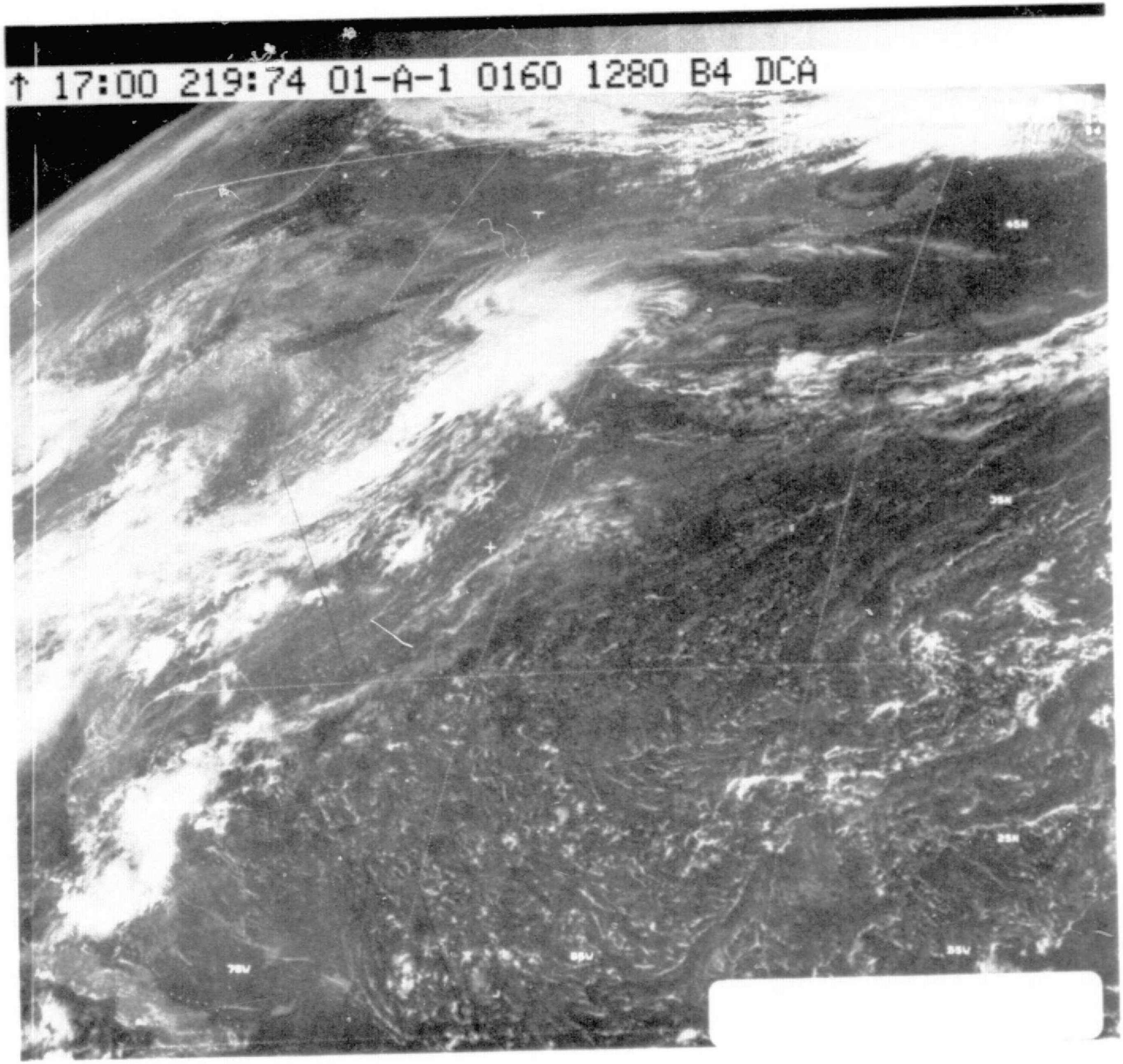

Figure 8-10. SMS-1, Visual 1 nm Resolution Photograph

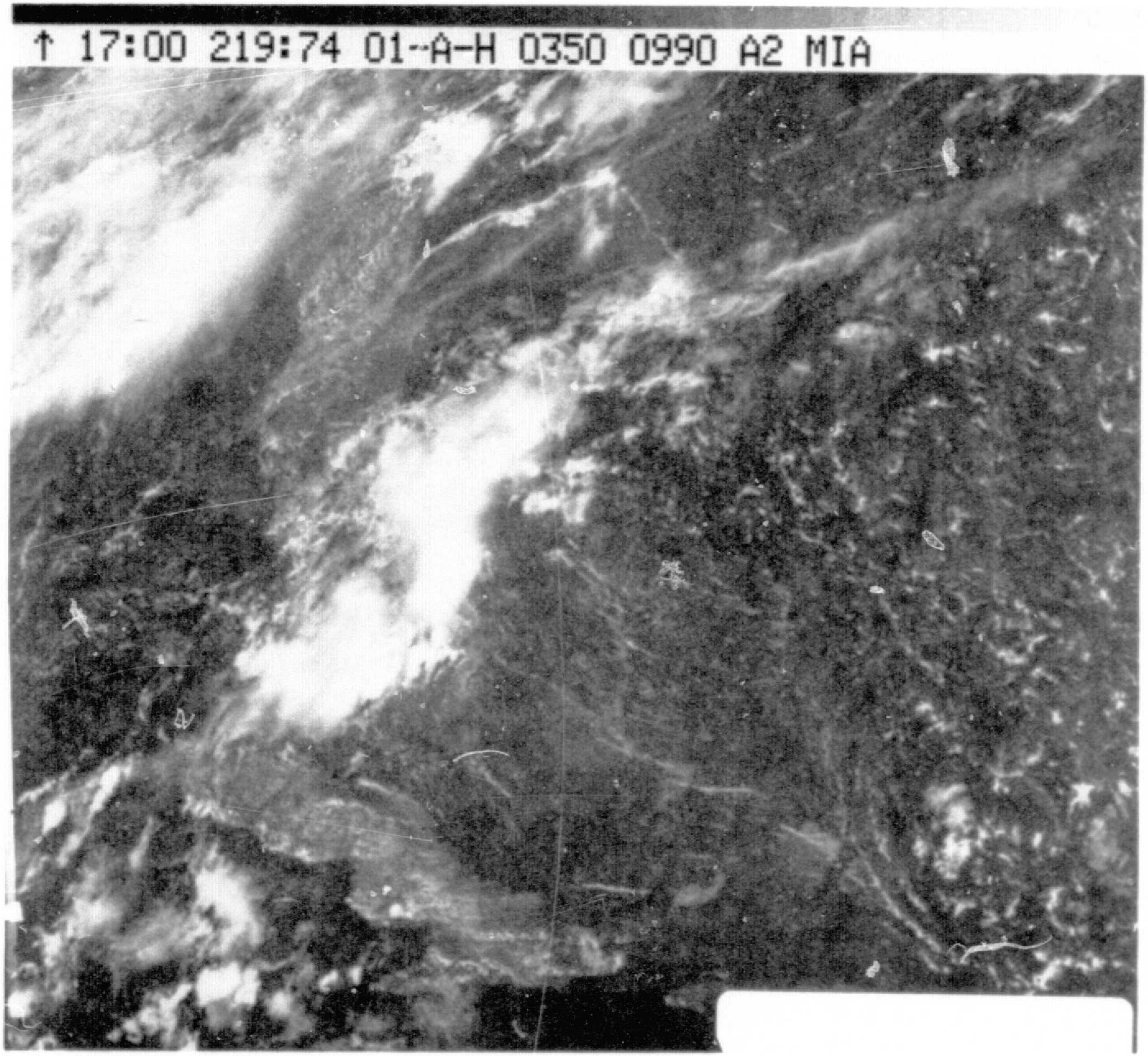

Figure 8-11. SMS-1, Visual 1/2 nm Resolution Photograph

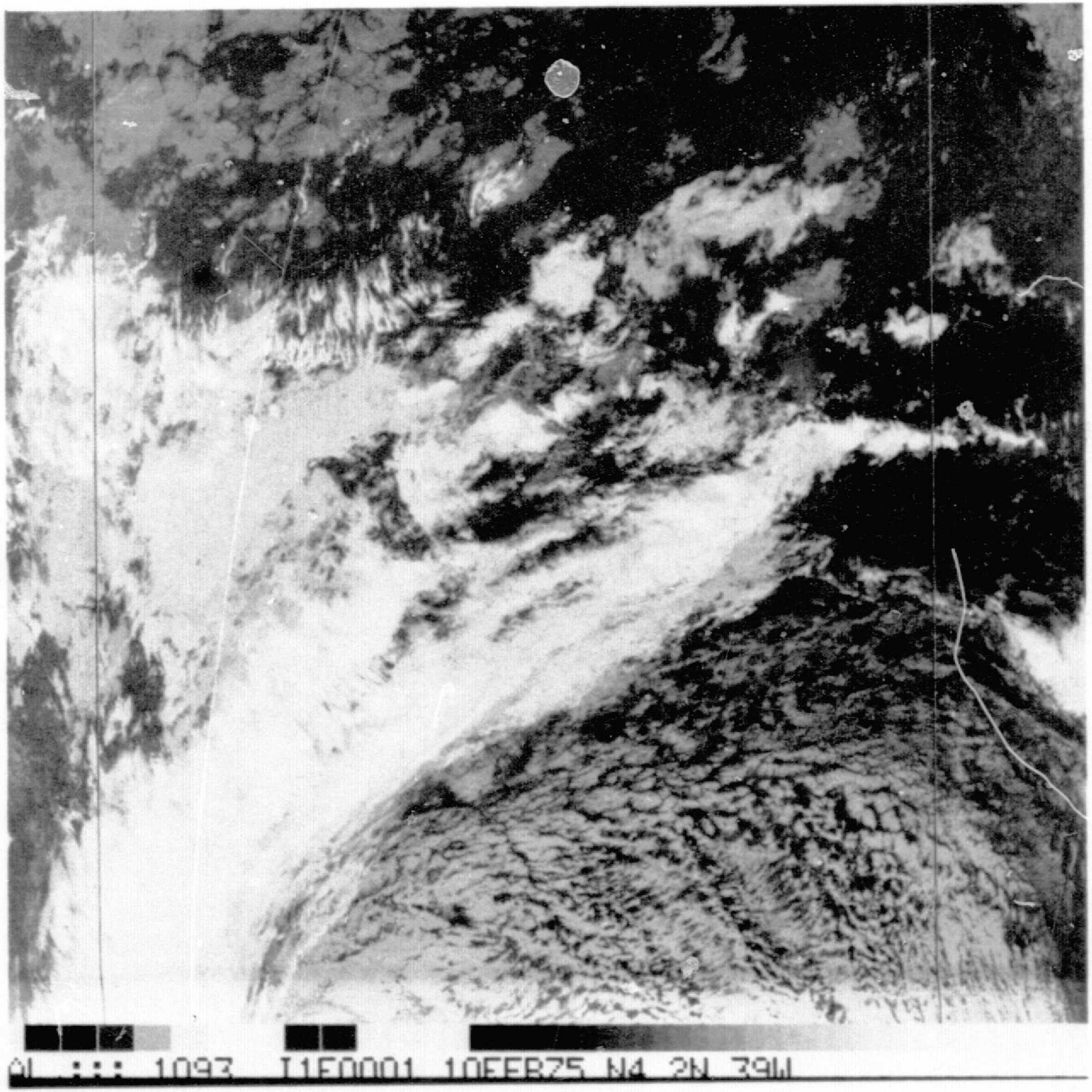

Figure 8-12, SMS-1 Very High Resolution Radiometer (VHRR) Photograph

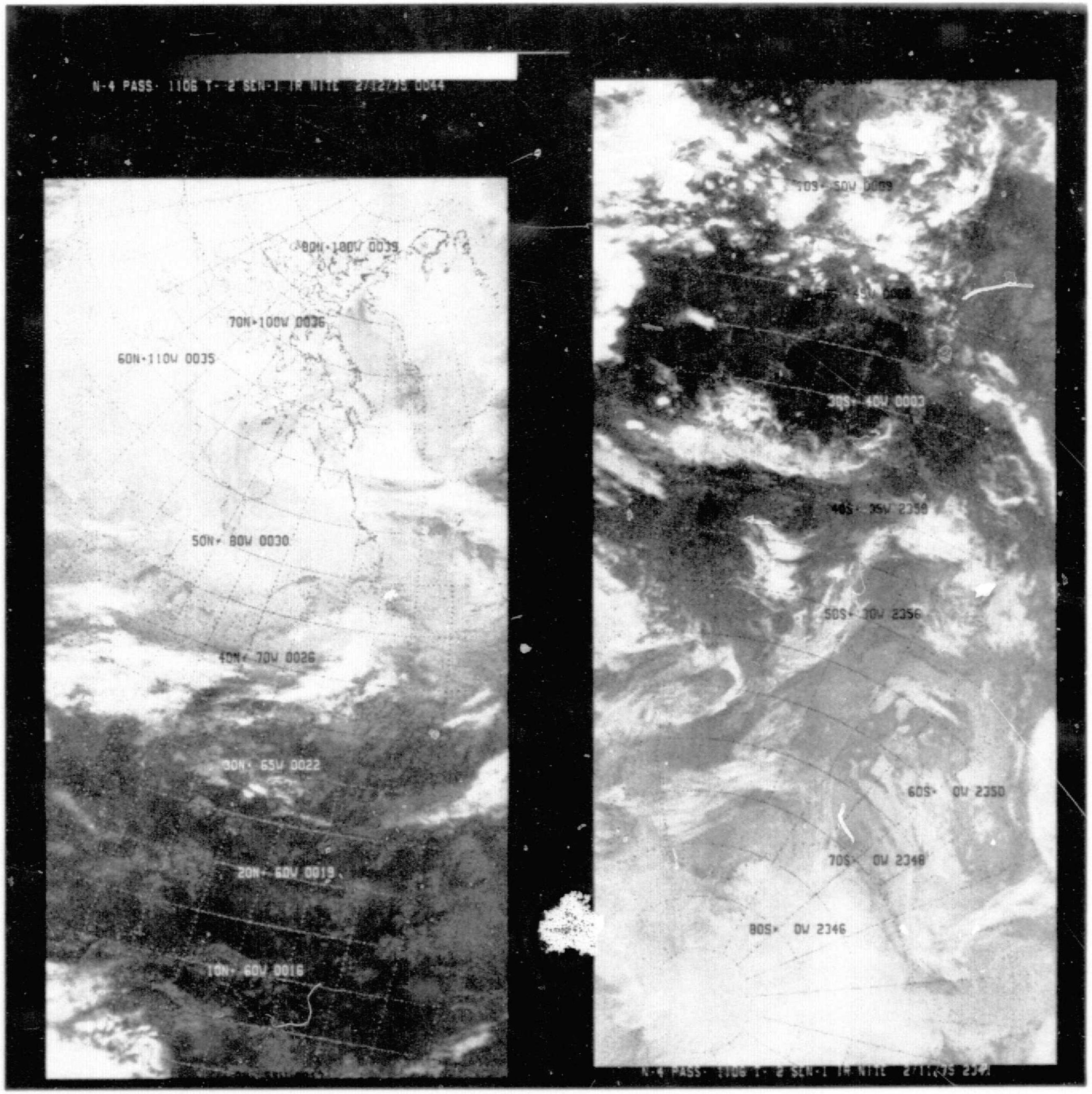

Figure 8-13. NOAA-4 Nighttime Infrared Photograph

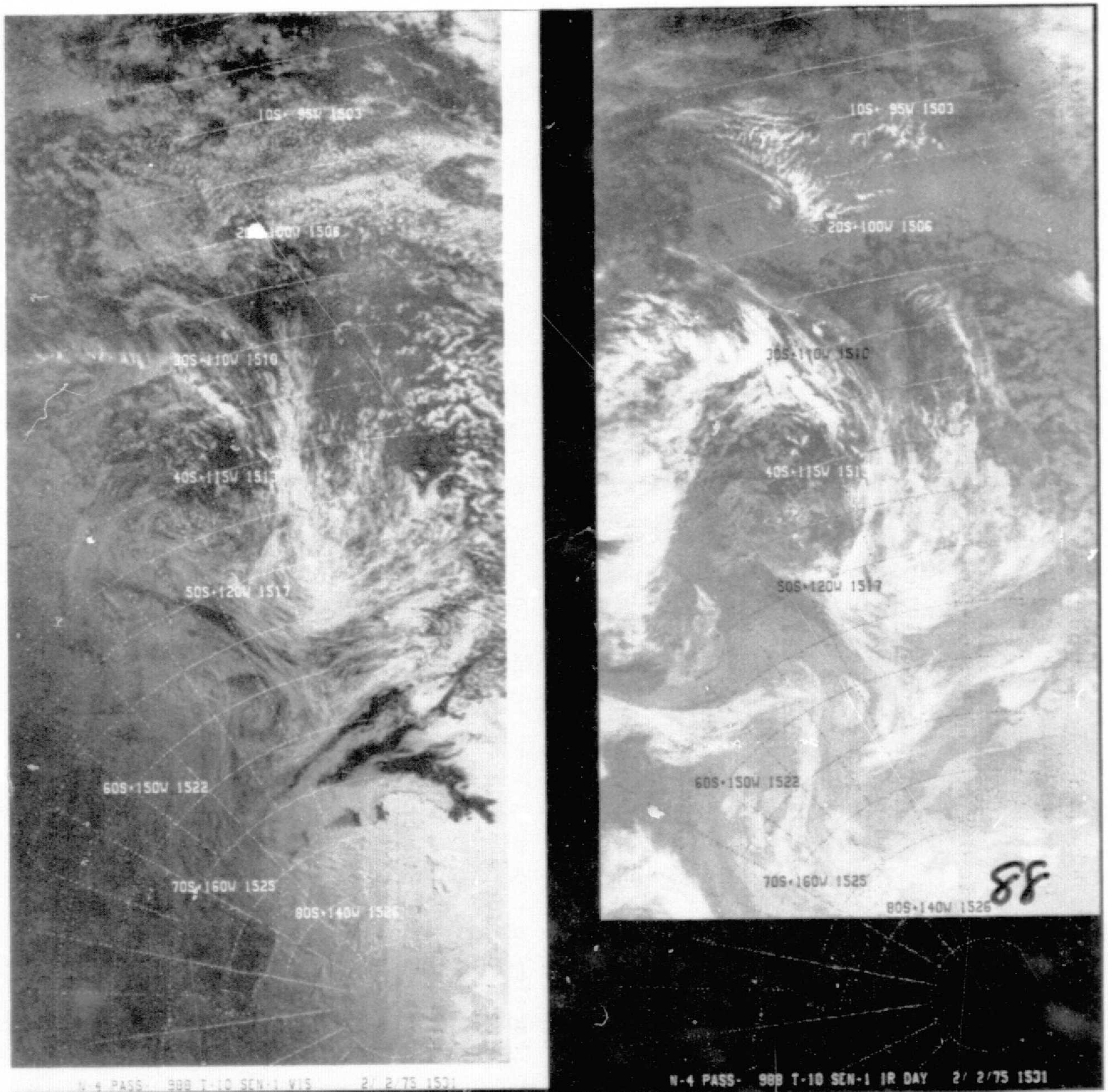

Figure 8-14. NOAA-4, Southern Hemisphere, Visual and Infrared 2 nm Resolution Photographs

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APPENDIX A

DETERMINATION OF GULF STREAM GEOSTROPHIC HEIGHT

By the geostrophic assumption, ocean current and the density structure can be related (Fomin, 1964). Furthermore, if barotropic motion is assumed, the ocean current can be related directly to the mean sea level slope (Stommel, 1965)

Let Rectangular Cartesian Coordinates be used in the ocean in which the X-axis is directed toward the east, the Y-axis is directed toward the north, and the Z-axis is directed vertically upward. The equations of motion for geostrophic current are

$$2_{\omega} \sin\psi \; u_y = \frac{1}{\rho} \frac{\partial p}{\partial y} \qquad (1)$$

$$2_{\omega} \cos\psi \; u_x = \frac{1}{\rho} \frac{\partial p}{\partial y} \qquad (2)$$

and

$$-g\rho = \frac{\partial p}{\partial z} \qquad (3)$$

where p is the pressure, g is the gravitational acceleration, ρ is the density of the ocean water, ω is the rotational speed of the earth, ψ is the latitude, and u_x and u_y are the x and the y components of ocean of current velocity $\vec{u}$.

Equation (3) is the hydrostatic balance equation which should be substituted into Equations (1) and (2) for p. In the case of a very small variation of p along the direction of Y-axis, Equation (2) can be neglected.

The angle between the subtrack and the direction of the current velocity $\vec{u}$ is Θ. By using an active microwave sensor such as lidar, one would be able to detect mean sea levels h(A, 0) and h(A + L, 0), referring to an arbitrary datum, at x = A and x + A + L respectively. Thus, Equation (L) can be rewritten in terms of the discrete space interval as shown in Figure A-1 as

$$2_{\omega} \sin\psi \left(\left| \vec{u}(A,0) \right| \cos\Theta - \left| \vec{u}\,(A + L,0) \right| \cos\Theta \right)$$

$$= g \frac{(h(A + L,0) - h(A,0))}{L} \tag{4}$$

in which the speeds $|\vec{u}(A,0)| \cos\Theta$ and $|\vec{u}(A + L,0)| \cos\Theta$ are perpendicular to the subtrack and yet they are separated by a distance L along the x-direction. Nevertheless, if Equation (4) is rearranged as

$$\frac{2\omega}{g} \sin\psi \left(\psi \left(\left| \vec{u}(A,0) \right| - \left| \vec{u}(A + L,0) \right| \right) = \frac{(h(A + L,0) - h(A,0))}{L \cos\Theta} \tag{5}$$

or $$\frac{2\omega}{g} \sin\psi \left(\Delta \left| \vec{u} \right|\right) = \frac{\Delta h}{L\cos\Theta}$$

in which $|\vec{u}(A,0)| - |\vec{u}(A + L,0)|$, or $\Delta|\vec{u}|$, is the desirable result where h(A + L,0) - h(A,0), or Δh, and L are measured. Since ω, g, and ψ are given, Equation (5) is uniquely solvable if Θ can be provided. Notice, however, that unless there is thermal boundary detected by the thermal mapping device, the value of Θ cannot be evaluated by single measurement. In order to attack this problem, it is necessary to have another measurement, whose subtrack has an angle of ζ with that of the first measurement, within the vicinity of the first subtrack. Let M be the distance, along the subtrack of the second measurement, which separates the positions where $\vec{u}(A,0)$ and $\vec{u}(A,0)$ and $\vec{u}(A + L,0)$ are located (as a matter of fact, this is quite tricky). In any event, it is justifiable to say that the measured Δh is the same as that of the first measurement and $\Delta|\vec{u}|$ inferred should be the same in both measurements. Thus, the constraint provides that

$$1 \cos\Theta = M \cos(\zeta - \Theta) \tag{6}$$

With known L, M, and ζ one should be able to solve Θ by iterative scheme. Consequently $\Delta|\vec{u}|$ in Equation (5) will be known.

In the case of the Gulf Stream, by using the nominal values derived from reference documentation,[1] one can calculate Δh's (the geostrophic heights) for several typical cross sections as listed in Table A-1.

TABLE A-1.

Latitude	Geostrophic Heights, Δh^{cm}
25°N	48
30°N	86
35°N	29
40°N	36

where $\omega = 7.3 \times 10^{-4}$ rad/sec

NOTE: $\vec{u}(A,O)$ and $\vec{u}(A + L,O)$ are not necessarily parallel.

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[1] Technical Report: Major Currents in the North and South Atlantic Oceans Between 64°N and 60°S; National Oceanographic Office, pp 56-64, September 1967.

Let x-direction be the subtrack of the measurement as shown in Figure A-1 in which the inferred velocities $\vec{u}(A,0)$ and $\vec{u}(A + L, 0)$ are separated by L cosθ where A is an arbitrary distance and L is the separation between $\vec{u}(A, 0)$ and $\vec{u}(A, 0)$ and $\vec{u}(A + L, 0)$ along the subtrack.

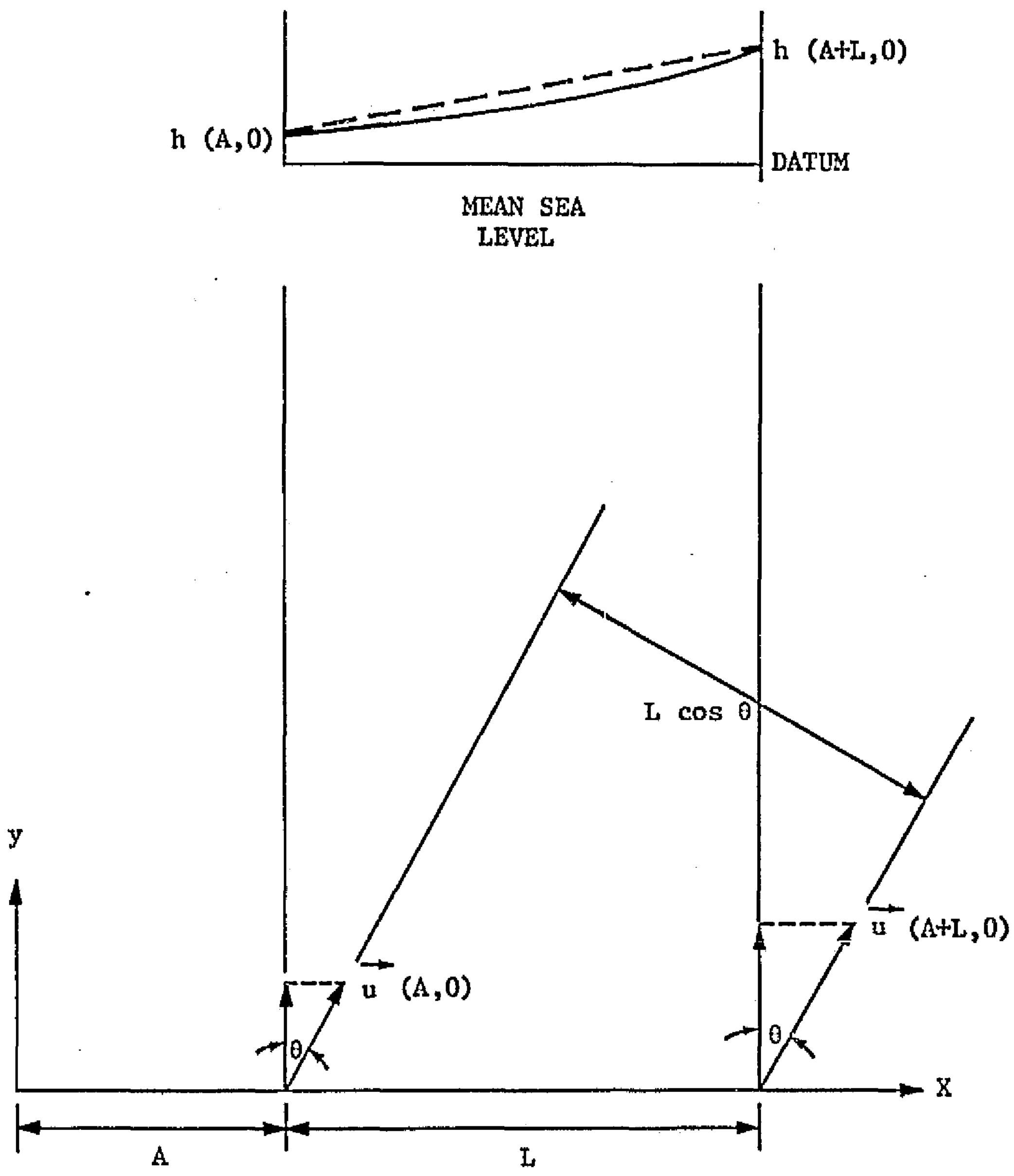


Figure A-1.

B.0 EXCERPTS FROM REFRACTION STUDIES

B.1 INTRODUCTION

Four models, each of which use only surface data as inputs for tropospheric propagation corrections, were compared with ray tracings which were based on radiosonde data. Comparisons were made for approximately a twelve-month period, utilizing data taken at Wallops Island, Virginia; the objective of this comparison was to determine the best procedure, and its associated accuracy, for correcting GEOS-C data. Models tested were: (a) the model used operationally in GEODYN for the past several years; (b) a model developed by Saastamoinen; (c) a modification of Saastamoinen's model by Marini; and (d) Hopfield's model. (See References, Appendix C.5) Study results indicate that above 20°, the Saastamoinen/Marini and Hopfield models are better, and that below 5°, the Hopfield model is superior. The tables included in this Appendix are excerpts from these studies; these tables indicate the magnitude of the refraction problem and the potential errors introduced by utilizing surface-data-only type mathematical models.

B.2 MODEL COMPARISONS

Tables B-1 through B-4 show the range correction differences for various elevation angles between the various models and the ray tracing results which are based on 15 data sets spread over 12 months.

B.3 ZENITH RANGE CORRECTION ANALYSIS

Zenith range corrections are computed using the Saastamoinen model. Temperature is varied between -10°C. and 40°C. intervals. Pressure is varied between 900 mb and 1050 mb at 25 mb intervals; relative humidity is varied between 1% and 100% at 10% intervals. This was done to determine the relative effects of the three surface parameter inputs. The results are shown in Table B-5.

TABLE B-1. AVERAGE RANGE CORRECTION

Elevation Angle (Degree)	GEODYN Model (m)	Saastamoinen Model (m)	Saastamoinen/ Marini Model (m)	Hopfield Model (m)	Average Correction (m)
90.0	.293	.034	.040	.031	2.40
45.0	.384	.054	.063	.050	3.30
30.0	.478	.085	.092	.074	4.78
20.0	.565	.154	.139	.112	6.95
10.0	.509	.604	.291	.235	13.34
7.5	.325	1.173	.384	.316	17.34
5.0	-.083	3.091	.496	.486	24.52
2.0	-.197	22.051	- 2.402	1.058	45.61
0.0	18.094	--	-54.383	1.767	88.28

TABLE B-2. RMS RANGE CORRECTION

Elevation Angle (Degree)	GEODYN Model (m)	Saastamoinen Model (m)	Saastamoinen/ Marini Model (m)	Hopfield Model (m)
90.0	.341	.047	.051	.045
45.0	.455	.068	.076	.065
30.0	.489	.107	.112	.097
20.0	.746	.180	.168	.145
10.0	1.020	.634	.349	.295
7.5	1.162	1.200	.461	.388
5.0	1.525	3.118	.637	.583
2.0	2.735	22.087	2.580	1.230
0.0	18.943	-	54.416	2.097

TABLE B-3. AVERAGE PERCENT DIFFERENCE

Elevation Angle (Degrees)	GEODYN Model (m)	Saastamoinen Model (m)	Saastamoinen/ Marini Model (m)	Hopfield Model (m)
90.0	12.2	1.4	1.7	1.3
45.0	11.3	1.6	1.9	1.5
30.0	10.0	1.8	1.9	1.5
20.0	8.1	2.2	2.0	1.6
10.0	3.8	4.5	2.2	1.8
7.5	1.9	6.8	2.2	1.8
5.0	- .3	12.6	2.0	2.0
2.0	- .4	48.3	- 5.3	2.3
0.0	20.5	--	-61.6	2.0

TABLE B-4. RMS PERCENT DIFFERENCE

Elevation Angle (Degree)	GEODYN Model (m)	Saastamoinen Model (m)	Saastamoinen/ Marini Model (m)	Hopfield Model (m)
90.0	14.20	2.0	2.1	1.9
45.0	13.40	2.0	2.2	1.9
30.0	12.30	2.2	2.3	2.0
20.0	10.70	2.6	2.4	2.1
10.0	7.65	4.8	2.6	2.2
7.5	6.70	6.9	2.7	2.2
5.0	6.20	12.7	2.6	2.4
2.0	6.0	48.4	5.7	2.7
0.0	21.5	--	61.6	2.4

TABLE B-5. RANGE CORRECTIONS (meters)

Relative Humidity 1.0%

Pressure (MB) / Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.05	2.11	2.17	2.22	2.28	2.34	2.39
- 5	2.05	2.11	2.17	2.22	2.28	2.34	2.39
0	2.05	2.11	2.17	2.22	2.28	2.34	2.39
5	2.05	2.11	2.17	2.22	2.28	2.34	2.39
10	2.05	2.11	2.17	2.22	2.28	2.34	2.39
15	2.05	2.11	2.17	2.22	2.28	2.34	2.40
20	2.05	2.11	2.17	2.23	2.28	2.34	2.40
25	2.06	2.11	2.17	2.23	2.28	2.34	2.40
30	2.06	2.11	2.17	2.23	2.28	2.34	2.40
35	2.06	2.11	2.17	2.23	2.28	2.34	2.40
40	2.06	2.12	2.17	2.23	2.29	2.34	2.40

Relative Humidity 10.0%

-10	2.06	2.11	2.17	2.23	2.28	2.34	2.40
- 5	2.06	2.11	2.17	2.23	2.28	2.34	2.40
0	2.06	2.12	2.17	2.23	2.29	2.34	2.40
5	2.06	2.12	2.17	2.23	2.29	2.35	2.40
10	2.06	2.12	2.18	2.24	2.29	2.35	2.40
15	2.07	2.13	2.18	2.24	2.30	2.36	2.41
20	2.08	2.13	2.19	2.25	2.30	2.36	2.41
25	2.08	2.14	2.20	2.25	2.31	2.37	2.42
30	2.09	2.15	2.21	2.26	2.32	2.38	2.43
35	2.10	2.16	2.22	2.28	2.33	2.39	2.45
40	2.12	2.18	2.23	2.29	2.35	2.40	2.46

TABLE B-5. (Continued)

Relative Humidity 20.0%

Pressure (MB) Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.06	2.12	2.17	2.23	2.29	2.34	2.40
- 5	2.06	2.12	2.17	2.23	2.29	2.35	2.40
0	2.06	2.12	2.18	2.24	2.29	2.35	2.41
5	2.07	2.13	2.18	2.24	2.30	2.35	2.41
10	2.07	2.13	2.19	2.25	2.30	2.36	2.42
15	2.09	2.14	2.20	2.26	2.31	2.37	2.43
20	2.09	2.16	2.21	2.27	2.32	2.38	2.44
25	2.11	2.17	2.23	2.28	2.34	2.40	2.45
30	2.13	2.19	2.25	2.30	2.36	2.42	2.47
35	2.16	2.21	2.27	2.33	2.39	2.44	2.50
40	2.19	2.25	2.30	2.36	2.42	2.47	2.53

Relative Humidity 30.0%

-10	2.06	2.12	2.18	2.23	2.29	2.35	2.40
- 5	2.07	2.12	2.18	2.24	2.29	2.35	2.41
0	2.07	2.13	2.19	2.24	2.30	2.36	2.41
5	2.08	2.14	2.19	2.25	2.31	2.36	2.42
10	2.09	2.15	2.24	2.26	2.32	2.37	2.43
15	2.10	2.16	2.22	2.27	2.33	2.39	2.44
20	2.12	2.18	2.23	2.29	2.35	2.41	2.46
25	2.14	2.20	2.26	2.31	2.37	2.43	2.49
30	2.17	2.23	2.29	2.34	2.40	2.46	2.51
35	2.21	2.27	2.32	2.38	2.44	2.49	2.55
40	2.26	2.31	2.37	2.43	2.48	2.54	2.60

TABLE B-5. (Continued)

Relative Humidity 40.0%

Pressure (MB) / Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.06	2.12	2.18	2.24	2.29	2.35	2.41
- 5	2.07	2.13	2.18	2.24	2.30	2.35	2.41
0	2.08	2.13	2.19	2.25	2.31	2.36	2.42
5	2.09	2.15	2.20	2.26	2.32	2.37	2.43
10	2.10	2.16	2.22	2.27	2.33	2.39	2.44
15	2.12	2.18	2.23	2.29	2.35	2.41	2.46
20	2.14	2.20	2.26	2.31	2.37	2.43	2.49
25	2.17	2.23	2.29	2.35	2.40	2.46	2.52
30	2.21	2.27	2.33	2.38	2.44	2.50	2.56
35	2.26	2.32	2.38	2.43	2.49	2.55	2.60
40	2.32	2.39	2.44	2.50	2.55	2.61	2.67

Relative Humidity 50.0%

-10	2.07	2.12	2.18	2.24	2.30	2.35	2.41
- 5	2.07	2.13	2.19	2.25	2.30	2.36	2.42
0	2.08	2.14	2.20	2.26	2.31	2.37	2.43
5	2.09	2.15	2.21	2.27	2.32	2.38	2.44
10	2.11	2.17	2.23	2.29	2.34	2.40	2.46
15	2.14	2.19	2.25	2.31	2.37	2.42	2.48
20	2.17	2.22	2.28	2.34	2.39	2.45	2.51
25	2.21	2.26	2.32	2.38	2.43	2.49	2.55
30	2.25	2.31	2.37	2.43	2.48	2.54	2.60
35	2.32	2.37	2.43	2.49	2.54	2.60	2.66
40	2.39	2.45	2.51	2.56	2.62	2.68	2.73

TABLE B-5. (Continued)

Relative Humidity 60.0%

Pressure (MB) / Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.07	2.13	2.18	2.24	2.30	2.36	2.41
- 5	2.08	2.14	2.19	2.25	2.31	2.36	2.42
0	2.09	2.15	2.20	2.26	2.32	2.38	2.43
5	2.11	2.16	2.22	2.28	2.33	2.39	2.45
10	2.13	2.19	2.24	2.30	2.35	2.41	2.47
15	2.15	2.21	2.27	2.33	2.38	2.44	2.50
20	2.19	2.25	2.30	2.36	2.42	2.47	2.53
25	2.24	2.29	2.35	2.41	2.46	2.52	2.58
30	2.29	2.35	2.45	2.47	2.52	2.58	2.64
35	2.37	2.43	2.48	2.54	2.60	2.65	2.71
40	2.47	2.52	2.57	2.63	2.69	2.75	2.80

Relative Humidity 70.0%

-10	2.07	2.13	2.19	2.24	2.30	2.36	2.42
- 5	2.08	2.14	2.20	2.25	2.31	2.37	2.43
0	2.10	2.15	2.21	2.27	2.32	2.37	2.44
5	2.12	2.18	2.23	2.29	2.34	2.40	2.46
10	2.14	2.20	2.25	2.32	2.37	2.42	2.48
15	2.17	2.23	2.29	2.34	2.40	2.46	2.51
20	2.21	2.27	2.33	2.38	2.44	2.50	2.55
25	2.27	2.32	2.38	2.44	2.49	2.55	2.61
30	2.34	2.39	2.45	2.51	2.56	2.62	2.68
35	2.42	2.48	2.54	2.59	2.65	2.71	2.76
40	2.53	2.59	2.64	2.70	2.76	2.81	2.87

TABLE B-5. (Continued)

Relative Humidity 80.0%

Pressure (MB) Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.08	2.13	2.19	2.25	2.30	2.36	2.42
- 5	2.09	2.15	2.20	2.26	2.32	2.37	2.43
0	2.10	2.16	2.22	2.27	2.33	2.39	2.45
5	2.12	2.18	2.24	2.30	2.35	2.41	2.47
10	2.16	2.21	2.27	2.32	2.38	2.44	2.49
15	2.19	2.25	2.30	2.36	2.42	2.47	2.53
20	2.24	2.29	2.35	2.41	2.46	2.52	2.58
25	2.30	2.35	2.41	2.47	2.53	2.58	2.69
30	2.38	2.43	2.49	2.55	2.60	2.66	2.72
35	2.47	2.53	2.59	2.65	2.70	2.76	2.82
40	2.60	2.65	2.71	2.77	2.82	2.88	2.94

Relative Humidity 90.0%

-10	2.08	2.14	2.19	2.25	2.31	2.36	2.42
- 5	2.09	2.15	2.25	2.26	2.32	2.38	2.43
0	2.11	2.17	2.22	2.28	2.34	2.39	2.45
5	2.13	2.19	2.25	2.30	2.36	2.42	2.48
10	2.16	2.22	2.28	2.34	2.40	2.45	2.51
15	2.21	2.26	2.32	2.38	2.43	2.49	2.55
20	2.26	2.32	2.38	2.43	2.49	2.54	2.60
25	2.33	2.39	2.44	2.50	2.56	2.61	2.67
30	2.42	2.47	2.53	2.59	2.64	2.70	2.76
35	2.53	2.58	2.64	2.70	2.75	2.31	2.87
40	2.67	2.72	2.78	2.84	2.89	2.95	3.01

TABLE B-5. (Continued)

Relative Humidity 100.0%

Pressure (MB) / Temp. (C)	900	925	950	975	1000	1025	1050
-10	2.03	2.15	2.20	2.25	2.31	2.37	2.42
- 5	2.10	2.15	2.21	2.27	2.33	2.38	2.44
0	2.12	2.17	2.23	2.29	2.34	2.40	2.46
5	2.14	2.20	2.26	2.31	2.37	2.43	2.48
10	2.18	2.23	2.29	2.35	2.40	2.46	2.52
15	2.22	2.28	2.34	2.39	2.45	2.51	2.57
20	2.28	2.34	2.40	2.45	2.51	2.57	2.62
25	2.36	2.42	2.47	2.53	2.59	2.64	2.70
30	2.46	2.51	2.57	2.63	2.68	2.74	2.80
35	2.58	2.64	2.69	2.75	2.81	2.86	2.92
40	2.73	2.79	2.85	2.90	2.96	3.02	3.08

B.4 WORST CASE MODELING ERRORS

The planned procedure for correcting altimeter data for tropospheric effects is to use the Hopfield model with the required input of surface meteorological parameters of pressure, temperature and humidity. For data inputs, it is planned to use monthly mean values of temperature, pressure, and relative humidity as a function of latitude. To assess the errors in this procedure, range corrections were calculated using the mean, minimum, and maximum values of these parameters for the three selected areas listed in Table B-6. The data, taken from Reference 1, are based on records over a period of approximately 100 years. The "mean" values of pressure and air temperature listed are actually median values, based on 95 percentile numbers.

The tropospheric refraction corrections corresponding to these meteorological conditions are listed in Table B-7. The values are tabulated using the tables contained listed in Table B-5, and correspond to the minimum and maximum data of Table B-7; they may, however, be somewhat pessimistic since, e.g., maximum relative humidity is assumed to occur for maximum temperature which would not normally be expected. As indicated in Table B-7, the expected maximum error from the use of average monthly meteorological conditions would be on the order of 10 cm., or about 4% of the correction itself.

TABLE B-6. MONTHLY AVERAGE ATMOSPHERIC CONDITIONS AT THE OCEAN SURFACE FOR 3 SELECTED AREAS

Area 392 Location: 45° - 46°N, 58° - 59°W

	JANUARY			APRIL			JULY			OCTOBER		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Pressure (mb)	984.8	1009.3	1027.4	992.9	1014.5	1029.1	1004.7	1015.3	1024.0	996.3	1015.4	1028.0
Temperature (°C)	-7.2	1.1	5.5	-2.1	1.7	5.5	10.0	14.4	18.3	5.9	10.6	15.0
Relative Humidity (%)	62.0	87.0	97.0	70.0	86.0	98.0	71.0	92.0	98.0	63.0	83.0	97.0

Area 451 Location: 36° - 37°N, 64° - 65°W

	JANUARY			APRIL			JULY			OCTOBER		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Pressure (mb)	997.5	1016.4	1030.5	1000.6	1015.9	1028.2	1012.1	1020.0	1026.8	1006.3	1017.3	1026.0
Temperature (°C)	9.7	15.6	20.0	11.6	17.2	21.1	23.2	25.6	28.3	19.0	22.8	26.1
Relative Humidity (%)	53.0	77.0	95.0	53.0	80.0	94.0	65.0	81.0	97.0	55.0	75.0	95.0

Area 521 Location: 23° - 24°N, 70° - 71°W

	JANUARY			APRIL			JULY			OCTOBER		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Pressure (mb)	1012.5	1018.6	1022.5	1012.6	1017.6	1022.4	1016.3	1019.1	1022.5	1003.6	1014.3	1017.7
Temperature (°C)	21.1	23.8	26.1	22.0	24.1	27.3	26.1	27.8	29.4	23.0	27.3	29.7
Relative Humidity (%)	56.0	77.0	95.0	58.0	77.0	95.0	68.0	81.0	94.0	64.0	80.0	95.0

TABLE C-/. ALTIMETER TROPOSPHERIC REFRACTION CORRECTIONS ERRORS BASED ON MONTHLY MEANS

MONTH	AREA	RANGE CORRECTION (m) Max/Min	Mean	ERROR Meters	Percent
January	392	2.42/2.27	2.36	-.06/.09	-2.5/3.8
April	392	2.43/2.30	2.38	-.05/.08	-2.1/3.4
July	392	2.54/2.38	2.47	-.07/.09	-2.8/3.6
October	392	2.51/2.34	2.42	-.09/.12	-3.7/5.0
January	451	2.56/2.34	2.45	-.11/.11	-4.5/4.5
April	451	2.56/2.35	2.47	-.09/.12	-3.6/4.9
July	451	2.69/2.49	2.58	-.11/.09	-4.3/3.5
October	451	2.64/2.41	2.52	-.12/.11	-4.8/4.4
January	592	2.64/2.45	2.54	-.10/.09	-3.9/3.5
April	592	2.66/2.45	2.55	-.11/.10	-4.3/3.9
July	592	2.71/2.53	2.62	-.09/.09	-3.4/3.4
October	592	2.72/2.49	2.59	-.13/.10	5.0/3.9
					RSS = 3.9

B.5 REFERENCES

1. "Environmental Conditions Within Specified Geographical Regions, Offshore East and West Coasts of the United States and in the Gulf of Mexico," U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, April 1973.

2. Saastamoinen, J., "Atmospheric Correction for the Troposphere Stratosphere in Radio Ranging of Satellites," in The Use of Artificial Satellites for Geodesy, Geophysical Monograph #15, American Geophysical Union, Washington, D.C., William Byrd Press, Richmond, VA., 1972: based on Third International Symposium on the Use of Artificial Satellites for Geodesy, April 15-19, 1971, Washington, D.C.

3. Marini, J.W. and C.W. Murray, Jr., Correction of Radio Range Tracking Data for Atmospheric Refraction at Elevations Above 10 Degrees, Unpublished Memo, February 2, 1974.

4. Hopfield, H.S., Two Quartic Tropospheric Refractivity Profile for Correcting Satellite Data, Journal of Geophysical Research, Vol. 74, NO. 18, 4487-4499, August 20, 1969.

5. Hopfield, H.S., Tropospheric Range Error Parameters: Further Studies APL/JHU, CP015, June 1972.

6. Hopfield, H.S., Tropospheric Effect on Electromagnetically Measured Range: Prediction from Surface Weather Data, RADIO SCIENCE, Volume 6, Number 3, pages 357-367, March 1971.

APPENDIX C

OPERATIONAL AND PERFORMANCE

DATA

ON

WALLOPS AIRCRAFT C-54G

C.0 WALLOPS AIRCRAFT DATA

C.1 C-54G (DOUGLAS DC-4).

There are three C-54G aircraft assigned to the Wallops Flight Center. All possess the same flight characteristics. The C-54G is a four-engine, low-wing monoplane with fully retractable tricycle landing gear. It is powered by four, 14-cylinder, twin-row, air-cooled Pratt & Whitney R-2000 engines. Each engine incorporates an integral single-stage, two-speed super-charger, a Bendix-Stromberg pressure-injection carburetor, and a direct-cranking starter.

The aircraft was designed as a long-range cargo, troop, or personnel transport. All three aircraft have been variously modified from the basic aircraft by the addition of special equipment necessary for specialized missions. The C-54G has a standard fuel capacity of 3,540 gallons (21,240 pounds).

C.1.1 ELECTRICAL POWER. The primary power source for each C-54 aircraft is four 28-volt DC generators. Each generator has an output capacity of 300 amperes for a total output capacity of 1,200 amperes. All instrumentation power is derived from the primary generators as shown in block diagram form Figure C-1. Twenty-eight (28) volt DC power is supplied to the instrumentation racks through the 28-volt distribution panel shown in Figure C-2.

AC instrumentation power is supplied by two 60 Hz and two 400 Hz inverters. (See Figure C-1). Each 60 Hz inverter provides single phase, 115-volt AC power at 3.0 KVA. Each 400 Hz inverter provides three phase or single phase, 115-volt AC power at 2.5 KVA.

C.1.2 PERFORMANCE. The C-54G at its maximum fuel load of 21,240 pounds can carry a cargo of approximately 12,000 pounds. With a fuel load of 3,500 pounds, its cargo carrying capacity is increased to 30,000 pounds. The maximum gross weight under any circumstances, of the C-54G, is 73,000 pounds. In any mission, range and fuel consumption directly determine the fuel which must be carried, and indirectly the cargo which can be transported. With the necessary fuel for the mission established, cargo loading is variable within the limits established

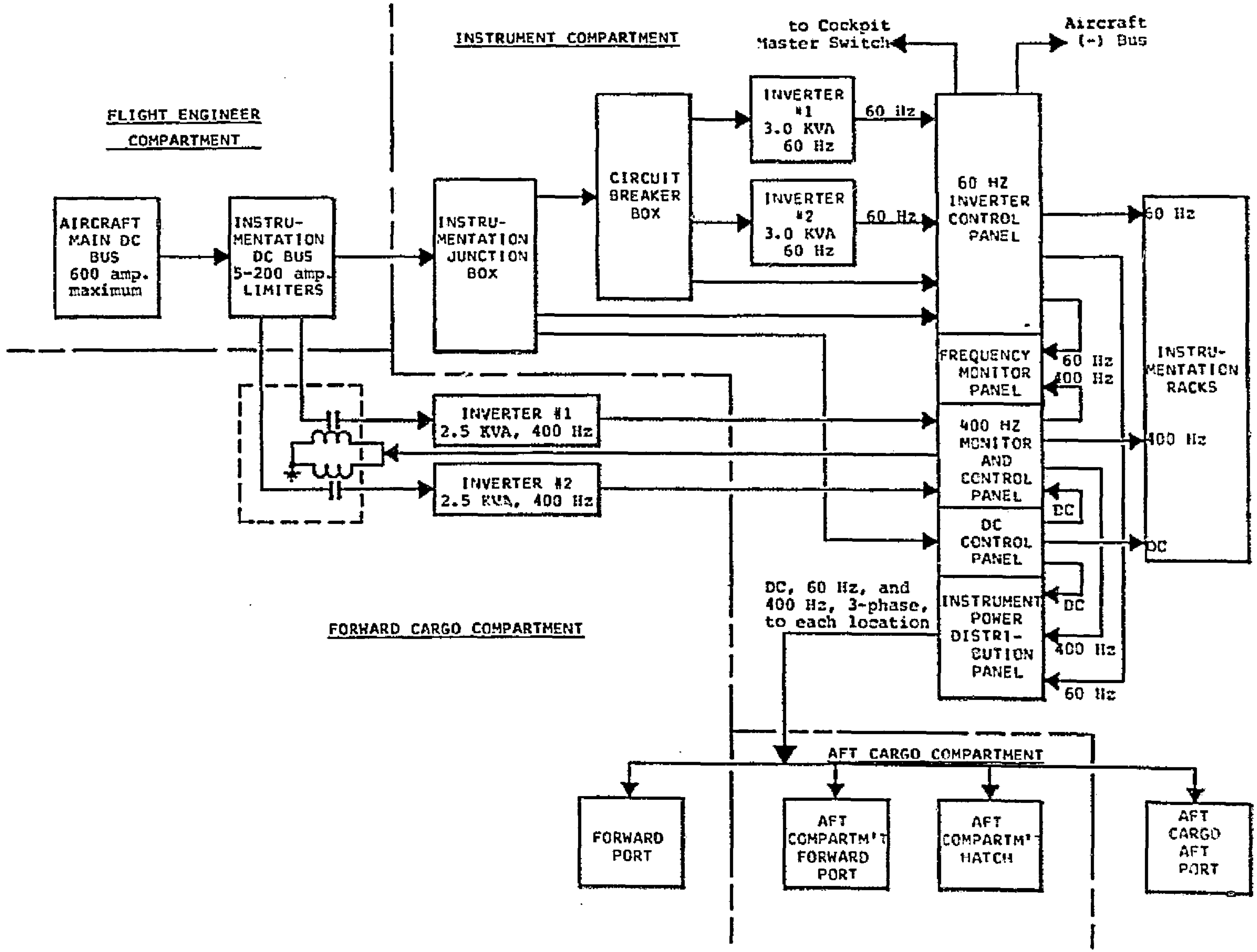
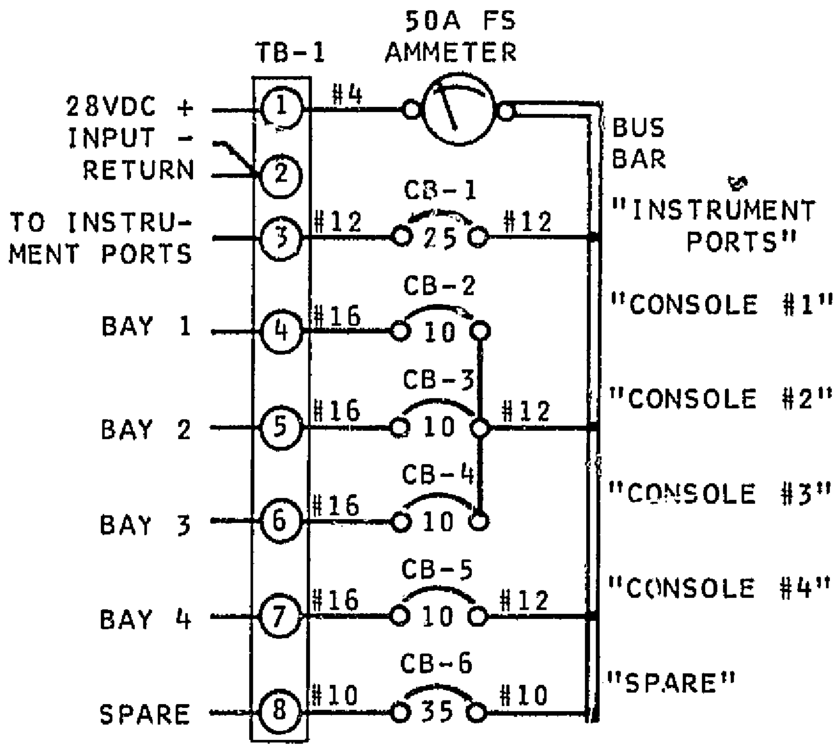
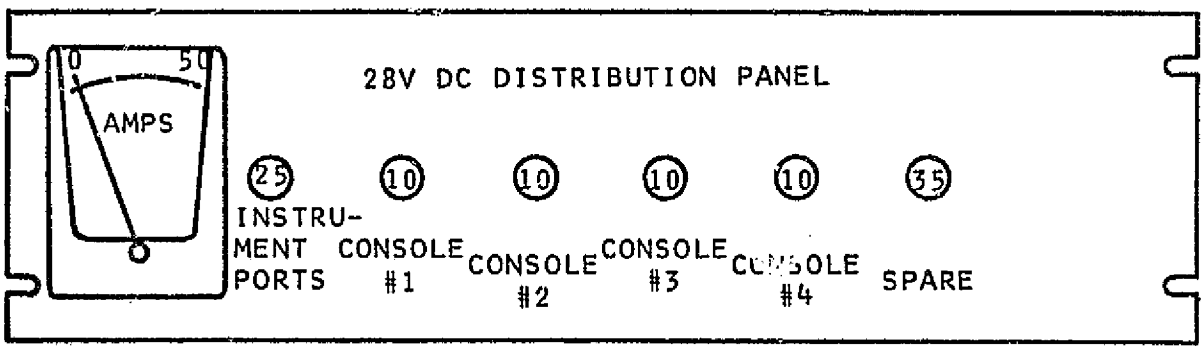


Figure C-1. Intrumentation Power System Block Diagram



SCHEMATIC DIAGRAM



FRONT PANEL LAYOUT

Figure C-2. 28-Volt DC Distribution Panel.

by the strength and performance of the aircraft. See Figure C-3, Weight Limitations Chart, for the maximum cargo weight and usable wing fuel weight.

As an example, take the case where a range user has 15,000 pounds of equipment to go aboard the plane. Add to this 4,000 pounds of NASA equipment already aboard, then enter the chart with 19,000 pounds (Point A), go across to the maximum gross weight line (Point B), then down to Point C which shows 13,700 pounds of usable wing fuel that can be loaded. Thirteen thousand, seven hundred pounds (13,700) of fuel at 1,200 pounds per hour gives approximately 11 hours of flying time. This is, of course, only an approximate figure. The actual base weight of the aircraft should be obtained from Flight Operations, Wallops Flight Center. See Appendix C.1.5 (Other Data) for additional specifications.

C.1.3 USES. Two of the C-54s (432 and 438) are equipped with Airborne Search Radar Model 9437 and are used mostly for range surveillance while the third (427) has been modified to carry active and passive sensor equipment with their control, power, and data collecting systems.

C.1.4 SPACE AVAILABLE/INSTRUMENTATION LOCATIONS. Because the three C-54s have various amounts of Wallops equipment aboard, the space available varies. Figure C-4 shows the Wallops equipment aboard N427NA for a particular mission. Eventually, with the exception of radar, all the C-54s will be instrumented similar to N427NA. See Section 7.0 of this document for a functional description of some of the individual items of Wallops instrumentation that will be used aboard the aircraft.

C.1.5 OTHER DATA.

C.1.5.1 Operational Weight Limitations. Weight, more than any other single factor, will determine the capability and performance of this aircraft. If this limitation is exceeded, a loss in the performance of the aircraft is inevitable and structural failure is quite probable. When the aircraft is loaded beyond the established limits, ceiling and range are decreased, control forces and stalling speeds become higher, and the rate of climb falls off rapidly as

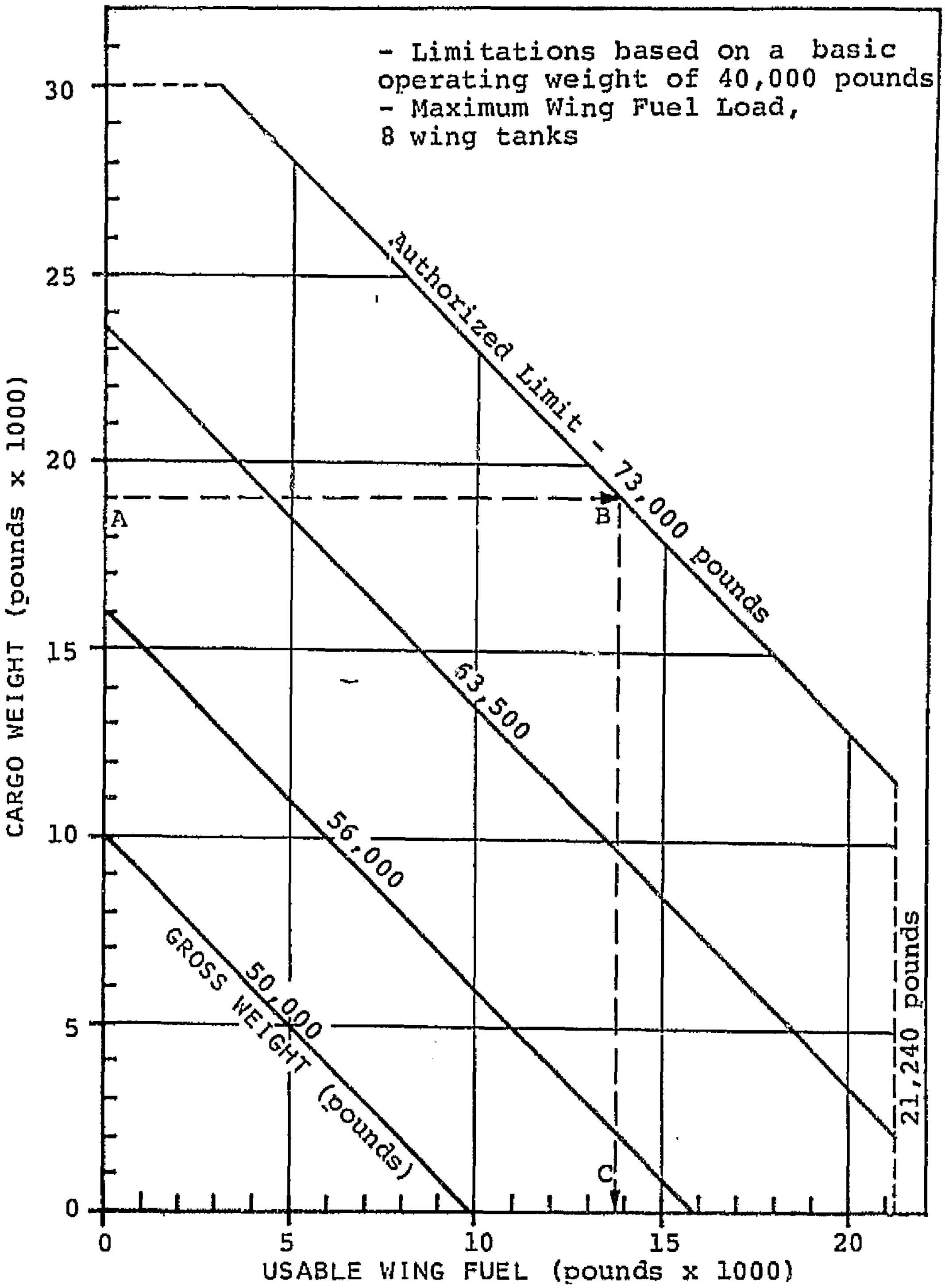


Figure C-3. C-54G Weight Limitations Chart

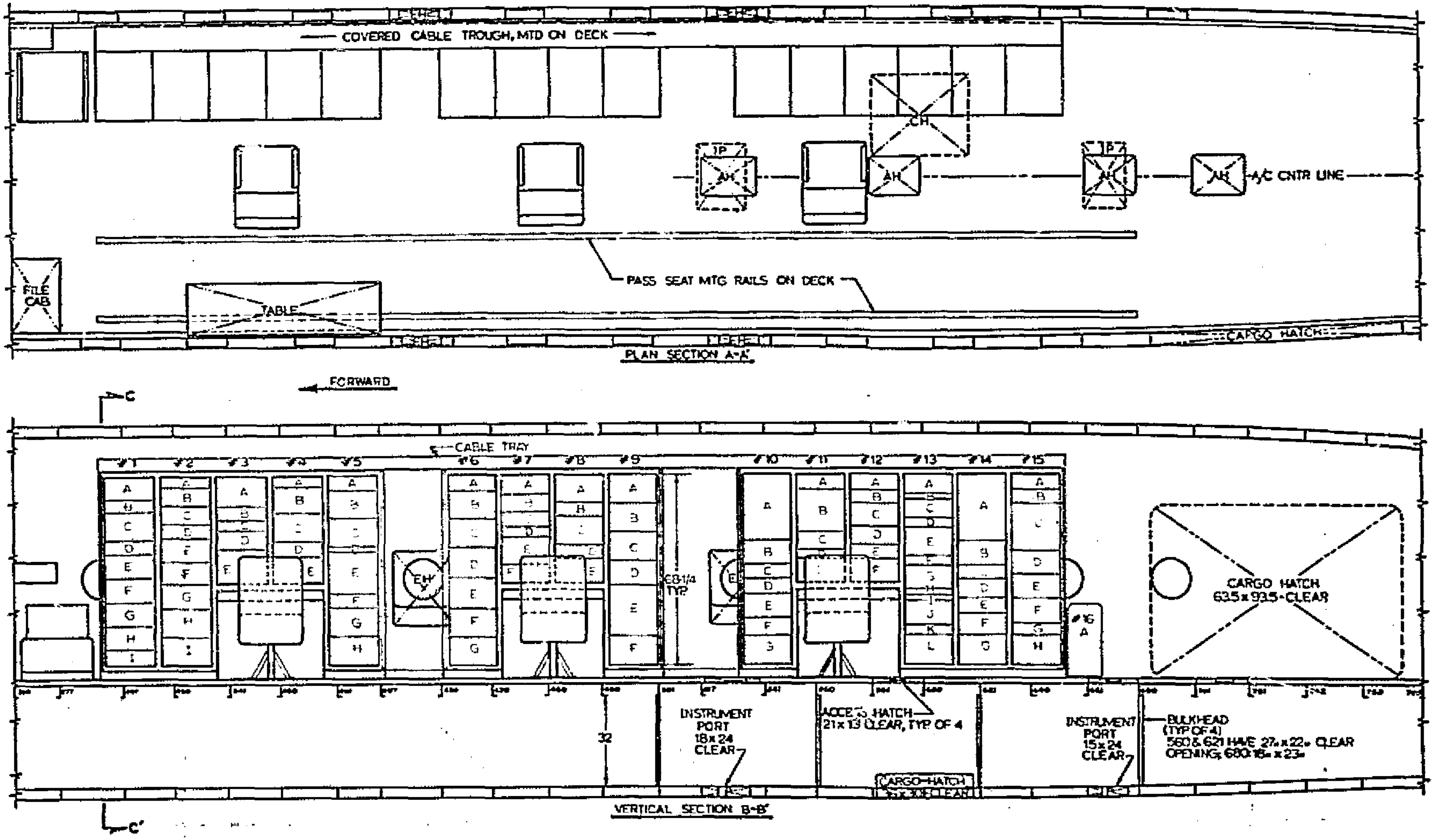


Figure C-4. Wallops Instrumentation on Aircraft N427NA (Sheet 1 of 2).

RACK NO. 1

A Inverter Control (for Topaz units)

B Inverter Frequency Monitor

C 400 Hz Inverter Control/Monitor

D 28 VDC Distribution Panel

E Instrument Power Distribution Control

F Topaz Static Inverter Model 3000GW (master)

G Topaz Static Inverter Model 3000GW (slave)

H Topaz Static Inverter Model 3000GW (slave)

RACK NO. 2

A Specific Products Model SR7 WWV Receiver

B Electronic Engineering Co. Model 812 Time Code Generator

C Tektronix Type RM 503 Oscilloscope

D Mclean Engineering Filter Model 2E300C

E Topaz Static Inverter Model 3000GW (master)

F Topaz Static Inverter Model 3000GW (slave)

G Topaz Static Inverter Model 3000GW (slave)

H Mclean Engineering Filter Model 2EB506C

I Bendix Power/Blower

RACK NO. 3

C ERTS Down Converter

D ERTS Receiver and Power Supply (custom)

RACK NO. 4

C Cohu Electronics Inc. Model RLC 14 Camera Control

D Control Panel, TV Camera Cohu 3900

E Control Panel for RF-7 Infrared Scanner

RACK NO. 5

A Airspeed, Clock, and Altitude Indicators

D Brush Instruments Power Supply

E Brush Instruments Mark 200 Chart Recorder

F Brush Instruments Preamplifiers

G Brush Instruments Drive Amplifiers

H Bendix Power/Blower

RACK NO. 6

D Custom Control for AAD-2 Infrared Scanner

G Bendix Power/Blower

RACK NO. 7

A Hewlett Packard Model 200CDR Wide Range Oscillator

B Hewlett Packard Model 400DR VTVM

C Hewlett Packard 5245L Electronic Counter

E Camera Station Control

F Tektronix RM 561A Oscilloscope

RACK NO. 8

C Conrac RLC-14 Video Monitor

D Control Panel for Stabilized Vertical Mounts (not used)

RACK NO. 9

D Bendix Intercom (modified)

F Bendix Power/Blower

RACK NO. 13

A Custom Intercom

RACK NO. 14

A Kennedy Model 1510 Recorder

RACK NO. 15

H Bendix Power/Blower

A Ampex FR-1300 Recorder (floor mounted)

NOTE: Letters not called out are range users equipment.

Figure C-4. Wallops Instrumentation on Aircraft N427NA (Sheet 2 of 2).

the maximum gross weight is exceeded. The take-off and landing rolls increase appreciably with an increase in gross weight. Likewise, the brakes may become insufficient to slow the forward momentum of the aircraft, and the wings will become more vulnerable to airloads during maneuvers or flight through turbulent air.

In order that cargo of various sizes may be accommodated, the cargo hold is of such proportions that space is not a restrictive factor; consequently, overloading is entirely possible.

The maximum recommended structural gross weight limitations for normal operation are as follows:

Take-off:	73,000 pounds
Landing:	63,500 pounds
Zero Wing Fuel (eight tank fuel system):	60,700 pounds

C.1.5.2 Dimensions. The principal dimensions of the aircraft are:

Span:	117 feet 6 inches
Length:	93 feet 6 inches
Length with Radome Nose:	94 feet 6 inches
Height:	27 feet 10 inches
Stabilizer Span:	39 feet 6 inches
Door Dimensions:	
Main Cabin and Cargo Doors:	
Both Doors Open:	95-3/4 x 67 inches
Passenger Door:	48 x 33-1/2 inches
Crew Entrance Door	28-3/4 x 57-1/4 inches
Forward Lower Cargo Door:	29-3/4 x 36 inches
Aft Lower Cargo Door:	29-3/4 x 36 inches
Accessories Compartment Door:	23 x 17 inches

C.1.5.3 Airspeed Limitations. The major airspeed limitations of the aircraft are:

Maximum Level Flight:	217 knots
Maximum Dive:	290 knots
Maximum Gear Down:	125 knots

APPENDIX D

SYNOPTIC CODES AND REPORTING FORMATS

Appendix D contains examples of various synoptic weather codes applicable to the Calibration Data Package. Coding instructions explaining the format and encoding requirements for meteorological parameters observed, as well as a sample of the logs used for entry of this data, are provided for the following synoptic weather codes:

a. Ship's Weather Observations (NOAA FORM 72-1)

b. Marine Coastal Weather Log - Coastal Station (NOAA FORM 72-5a)

c. Marine Coastal Weather Log - Ship Station (NOAA FORM 72-5b)

NOAA FORM 72-1

SHIP'S WEATHER OBSERVATIONS

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

INTERNATIONAL SHIP WEATHER CODE

$99L_aL_aL_a$ $Q_cL_oL_oL_oL_o$ $YYGGi_w$ $Nddff$ $VVwwW$ $PPPTT$ $N_hC_LhC_MC_H$ D_sv_sapp $0T_sT_sT_dT_d$ $1T_wT_wT_wt_T$ $(2I_sE_sE_sR_s)$ $3P_wP_wH_wH_w$ $d_wd_wP_wH_wH_w$ (ICE followed by plain language or C_2KD_ire)

How to use the information below.

All necessary tables and explanations are included on this cover. The column numbers from the forms inside match the aid numbers printed below. Cloud identification photos are printed on the last three pages of this pad.

Q_c — AID NO. 3 QUADRANT OF GLOBE

Code Figure	Location of Ship	
1	NORTH Latitude,	EAST Longitude
3	SOUTH Latitude,	EAST Longitude
5	SOUTH Latitude,	WEST Longitude
7	NORTH Latitude,	WEST Longitude
Choose one 1 or 7	NORTH Latitude,	0° or 180° Longitude
Choose one 3 or 5	SOUTH Latitude,	0° or 180° Longitude
Choose one 1 or 3	EQUATOR,	EAST Longitude
Choose one 5 or 7	EQUATOR,	WEST Longitude

i_w — AID NO. 7 WIND INDICATOR

Code Figure	Type of wind reported	
0	Estimated	METERS PER SECOND
1	Measured by anemometer	METERS PER SECOND
3	Estimated	KNOTS
4	Measured by anemometer	KNOTS

Note: U. S. Synoptic reports (Ship and Land) use knots - Code figures 3 and 4.

N — AID NO. 8 TOTAL CLOUD AMOUNT

Code Figure	Cloud Amt. Eighths	Cloud Amt. Tenths	Code Figure	Cloud Amount Eighths	Cloud Amount Tenths
0	0	0	5	5	6
1	1 or less	1 or less	6	6	7 and 8
2	2	2-3	7	7 or more not 8	9 or more not 10
3	3	4	8	8	10
4	4	5	9	Celestial dome obscured or cloud amount cannot be estimated.	

NOTE: Use "7" for "overcast with openings"

dd or d_wd_w — AID NOS. 9 AND 37 WIND OR SWELL DIRECTION

Wind or swell wave direction is reported to 36 points of the compass. "00" is used only for "calm", "36" is used for true North. Since the code calls for two figures in Cols. 9 and 37, prefix a "0" to 9 points or less. Use the figure "99" for d_wd_w when the direction of swell is not reported for any reason. Some examples follow.

True direction Nearest degree	36 point Code figure
355	36
354	35
4	36
5	01
90	09
Calm	00

NOTE: When the wind speed ("ff" below) exceeds 99 knots, add 50 to direction.

ff — AID NO. 10 WIND SPEED IN KNOTS

Report wind speed to whole knots using two figures. If speed is over 99 knots, add 50 to "dd" (Col. 9) and report excess over 100 knots. "00" is used for "calm" (or 100 knots if "dd" is coded 51 to 86). Prefix 1 to 9 kts with a zero.

VV — AID NO. 11 PREVAILING VISIBILITY

Code Figure	Visibility Range Nautical miles	Code Figure	Visibility Range Nautical miles
90	Less than 50 yds.	95	1 to less than 2
91	50 yds. to 199 yds.	96	2 to less than 5
92	200 yds. to 1/4 n.mi.	97	5 to less than 10
93	1/4 n.mi. to less than 1/2	98	10 to less than 25
94	1/2 n.mi. to less than 1	99	25 or more

ww — AID NO. 12 PRESENT WEATHER

Code Figures 00 - 49 No precipitation at ship now
Code Figures 50 - 99 Precipitation now

Use highest code figure applicable except that 17 has preference over 20 to 49.

00 - 03 CHANGE OF SKY DURING PAST HOUR

Code Figure	
00	Cloud development not observable
01	Clouds dissolving or becoming less developed
02	No important change in sky condition
03	Clouds generally forming or developing

04 - 09 SPRAY, SMOKE, HAZE, SAND OR DUST

04	Visibility reduced by smoke (not ship's smoke)
05	Dry haze
06	Widespread dust suspended in air
07	Blowing spray at the station
08	Dust whirls in past hour
09	Dust or sand storm in sight past hour

10 - 12 LIGHT FOG (SEE 40 - 49 FOR OTHER FOG)

10 Light fog, visibility more than 1/2 mile.

IN PATCHES ⟵⟶ CONTINUOUS

11 Fog less than 33 ft. deep 12

Apparent visibility within the fog 1/2 mile or less. (Prevailing visibility must be more than 1/2 mile.)

WW Continued from above

Code Figure	
13 - 16 PHENOMENA NOT AT SHIP	
13	Lightning visible, no thunder
14	Precipitation in sight, not reaching sea
15	Precipitation in sight, 3 or more miles away
16	Precipitation in sight, within 3 miles
17 - 19 THUNDER, SQUALLS, FUNNEL CLOUDS	
17	Thunder, but no precipitation
18	Squalls (no precipitation) in past hour or now
19	Funnel cloud, waterspout, past hour or now
20 - 29 PHENOMENA IN PAST HOUR BUT NOT NOW	
20	Drizzle (not freezing) or snow grains
21	Rain (not freezing) — Not falling as showers
22	Snow — Not falling as showers
23	Mixed rain and snow, or sleet — Not falling as showers
24	Freezing drizzle or rain — Not falling as showers
25	Rain — Falling as showers
26	Snow or rain and snow mixed — Falling as showers
27	Hail or rain and hail mixed — Falling as showers
28	Fog, visibility was 1/2 mile or less
29	Thunder, with or without precipitation

30 - 89 and 95 - 99; PHENOMENA OCCURRING AT SHIP NOW

30 - 39 LAND STATION FIGURES FOR DUST AND SAND STORMS, DRIFTING AND BLOWING SNOW

40 - 49 FOG, NOW, VISIBILITY 1/2 MILE OR LESS

Sky Visible		Sky Invisible
40	← Fog bank* / Fog in patches →	41
42	Fog, has become thinner past hour	43
44	Fog, no change past hour	45
46	Fog began or thickened past hour	47
48	Fog depositing rime	49

*Note: Apparent visibility within the fog bank estimated to be 1/2 mile or less but prevailing visibility at the ship may be any value.

WW Continued from left

50 - 59 DRIZZLE, NOW (SEE ALSO 68 AND 69)

Intermittent		Continuous
50	Slight drizzle	51
52	Moderate drizzle	53
54	Heavy drizzle	55
Slight		**Moderate or Heavy**
56	Freezing drizzle	57
58	Drizzle with rain	59

60 - 69 RAIN, NOW (SEE 80 - 89 FOR SHOWERS)

Intermittent		Continuous
60	Slight rain	61
62	Moderate rain	63
64	Heavy rain	65
Slight		**Moderate or Heavy**
66	Freezing rain	67
68	Rain or drizzle with snow	69

70 - 79 SOLID (FROZEN) PRECIPITATION, NOW

Intermittent		Continuous
70	Slight snow in flakes	71
72	Moderate snow in flakes	73
74	Heavy snow in flakes	75
76	← Ice needles / Snow grains →	77
78	Isolated starlike snow crystals	
79	Ice pellets (including sleet)	

80 - 90 SHOWERS (LIQUID OR SOLID)

Slight		Moderate or Heavy
80	Rain shower	81
	82 Violent rain shower(s)	
83	Shower of rain and snow	84
85	Snow shower	86
87	Shower of snow (or ice) pellets	88
89	Hail shower, no thunder	90

WW Continued from left

91 - 94 THUNDER ENDED PAST HOUR PRECIPITATION NOW

Note: Use 29 if there is no precipitation now.

Slight		Moderate or Heavy
91	Rain or rain shower	92
93	Snow, hail, or mixed rain and snow	94
95	Slight or moderate thunderstorm with precipitation but no hail	
96	Same as 95 but with hail	
97	Heavy thunderstorm with precipitation but no hail	
98	Thunderstorm with dust- or sandstorm	
99	Heavy thunderstorm with hail	

W

AID NO. 13
PAST WEATHER

Use the figure below which best describes

1. The weather from the last scheduled 6-hourly observation up to the time present weather (ww) began.

2. Use the highest code figure applicable except avoid, if possible, reporting the same weather types for "ww" and "W".

Code Figure	PAST WEATHER DESCRIPTION
0	Cloud cover 1/2 or less throughout period
1	Changing cloud cover from more to less than 1/2 of sky or vice versa during period
2	Cloud cover more than 1/2 throughout period
3	Sandstorm, duststorm or blowing snow
4	Fog or thick haze (visibility 1/2 mile or less)
5	Drizzle
6	Rain
7	Snow or rain and snow
8	Shower(s)
9	Thunder

PPP AID NOS. 14 AND 15 - PRESSURE, INCHES TO MILLIBARS

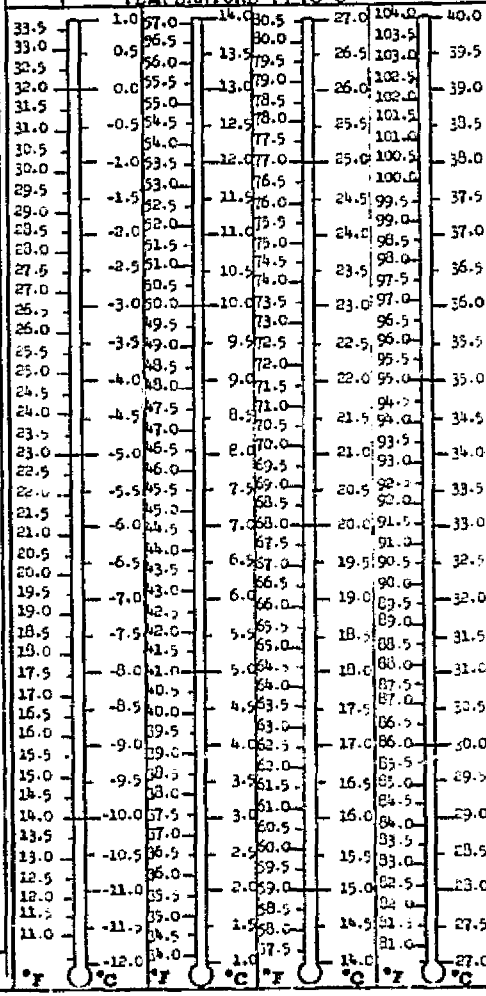
For values not here, multiply pressure in inches by 33.86 to get millibars.

in.	mb. cols. 14 15	in.	mb. cols. 14 15	in.	mb. cols. 14 15	in.	mb. cols. 14 15	in.	mb. cols. 14 15
28.50	9 651	29.00	9 821	29.50	9 990	30.00	10 159	30.50	10 329
28.51	9 655	29.01	9 824	29.51	9 993	30.01	10 163	30.51	10 332
28.52	9 658	29.02	9 827	29.52	9 997	30.02	10 166	30.52	10 335
28.53	9 661	29.03	9 831	29.53	10 000	30.03	10 169	30.53	10 339
28.54	9 665	29.04	9 834	29.54	10 003	30.04	10 173	30.54	10 342
28.55	9 668	29.05	9 837	29.55	10 007	30.05	10 176	30.55	10 345
28.56	9 672	29.06	9 841	29.56	10 010	30.06	10 179	30.56	10 349
28.57	9 675	29.07	9 844	29.57	10 014	30.07	10 183	30.57	10 352
28.58	9 678	29.08	9 848	29.58	10 017	30.08	10 186	30.58	10 356
28.59	9 682	29.09	9 851	29.59	10 020	30.09	10 190	30.59	10 359
28.60	9 685	29.10	9 854	29.60	10 024	30.10	10 193	30.60	10 362
28.61	9 688	29.11	9 858	29.61	10 027	30.11	10 196	30.61	10 366
28.62	9 692	29.12	9 861	29.62	10 030	30.12	10 200	30.62	10 369
28.63	9 695	29.13	9 865	29.63	10 034	30.13	10 203	30.63	10 373
28.64	9 699	29.14	9 868	29.64	10 037	30.14	10 207	30.64	10 376
28.65	9 702	29.15	9 871	29.65	10 041	30.15	10 210	30.65	10 379
28.66	9 705	29.16	9 875	29.66	10 044	30.16	10 213	30.66	10 383
28.67	9 709	29.17	9 878	29.67	10 047	30.17	10 217	30.67	10 386
28.68	9 712	29.18	9 881	29.68	10 051	30.18	10 220	30.68	10 389
28.69	9 716	29.19	9 885	29.69	10 054	30.19	10 224	30.69	10 393
28.70	9 719	29.20	9 888	29.70	10 058	30.20	10 227	30.70	10 396
28.71	9 722	29.21	9 892	29.71	10 061	30.21	10 230	30.71	10 400
28.72	9 726	29.22	9 895	29.72	10 064	30.22	10 234	30.72	10 403
28.73	9 729	29.23	9 898	29.73	10 068	30.23	10 237	30.73	10 406
28.74	9 732	29.24	9 902	29.74	10 071	30.24	10 240	30.74	10 410
28.75	9 736	29.25	9 905	29.75	10 075	30.25	10 244	30.75	10 413
28.76	9 739	29.26	9 909	29.76	10 078	30.26	10 247	30.76	10 417
28.77	9 743	29.27	9 912	29.77	10 081	30.27	10 251	30.77	10 420
28.78	9 746	29.28	9 915	29.78	10 085	30.28	10 254	30.78	10 423
28.79	9 749	29.29	9 919	29.79	10 088	30.29	10 257	30.79	10 427
28.80	9 753	29.30	9 922	29.80	10 091	30.30	10 261	30.80	10 430
28.81	9 756	29.31	9 926	29.81	10 095	30.31	10 264	30.81	10 433
28.82	9 760	29.32	9 929	29.82	10 098	30.32	10 268	30.82	10 437
28.83	9 763	29.33	9 932	29.83	10 102	30.33	10 271	30.83	10 440
28.84	9 766	29.34	9 936	29.84	10 105	30.34	10 274	30.84	10 444
28.85	9 770	29.35	9 939	29.85	10 108	30.35	10 278	30.85	10 447
28.86	9 773	29.36	9 942	29.86	10 112	30.36	10 281	30.86	10 450
28.87	9 777	29.37	9 946	29.87	10 115	30.37	10 284	30.87	10 454
28.88	9 780	29.38	9 949	29.88	10 119	30.38	10 288	30.88	10 457
28.89	9 783	29.39	9 953	29.89	10 122	30.39	10 291	30.89	10 461
28.90	9 787	29.40	9 956	29.90	10 125	30.40	10 295	30.90	10 464
28.91	9 790	29.41	9 959	29.91	10 129	30.41	10 298	30.91	10 467
28.92	9 793	29.42	9 963	29.92	10 132	30.42	10 301	30.92	10 471
28.93	9 797	29.43	9 966	29.93	10 135	30.43	10 305	30.93	10 474
28.94	9 800	29.44	9 970	29.94	10 139	30.44	10 308	30.94	10 477
28.95	9 804	29.45	9 973	29.95	10 142	30.45	10 312	30.95	10 481
28.96	9 807	29.46	9 976	29.96	10 146	30.46	10 315	30.96	10 484
28.97	9 810	29.47	9 980	29.97	10 149	30.47	10 318	30.97	10 488
28.98	9 814	29.48	9 983	29.98	10 152	30.48	10 322	30.98	10 491
28.99	9 817	29.49	9 986	29.99	10 156	30.49	10 325	30.99	10 494

Millibars in this table are to tenths, decimal omitted

TT AID NOS. 16, 17 AND 32

TEMPERATURE °F. TO °C



Nh AID NO. 19 - SEE AID NO. 8

AMOUNT OF ALL C_L (OR IF NONE, ALL C_M) CLOUDS

N_h is coded as "0" if only high (C_H) clouds are present

CL CM CH AID NOS. 20, 22 AND 23

SEE PHOTOS, LAST 3 PAGES OF THIS PAD FOR CLOUD IDENTIFICATION AND CODE FIGURES. ALSO SEE "INTERNATIONAL CLOUD ATLAS"

h AID NO. 21 - HEIGHT OF LOWEST CLOUD SEEN

Code Figure	Height in feet	Code Figure	Height in feet
0	0 to 149	6	3300 to 5000
1	150 to 299	7	5000 to 6500
2	300 to 599	8	6500 to 8000
3	600 to 999	9	8000 or higher or no clouds
4	1000 to 1999	/	Height cannot be estimated
5	2000 to 3300		

Note: Use "0" for height when sky is obscured

Ds AID NO. 24 SHIP'S TRUE COURSE MADE GOOD OVER PAST 3 HOURS (TO 8 POINTS OF COMPASS)

Code Figure	True Dir.	Code Figure	True Dir.
0	Ship hove to	5	SW
1	NE	6	W
2	E	7	NW
3	SE	8	N
4	S	9	No info.

Vs AID NO. 25 SHIP'S AVG. SPEED MADE GOOD OVER PAST 3 HOURS

Code Figure	Speed (Kts.)	Code Figure	Speed (Kts.)
0	Ship stopped	5	21 to 25
1	1 to 5	6	26 to 30
2	6 to 10	7	31 to 35
3	11 to 15	8	36 to 40
4	16 to 20	9	Over 40

a AID NO. 26

CHARACTER OF PRESSURE CHANGE OVER PAST 3 HOURS

Code Figure	Character	Net Pressure Change
0	Rising, then falling	Higher or no change
1	Rising, then steady or rising slowly	Higher
2	Rising steadily or unsteadily	Higher
3	Falling, steady or rising slowly, then rising more rapidly	Higher
4	Steady	No change
5	Falling, then rising	Lower or no change
6	Falling, then steady or falling slowly	Lower
7	Falling steadily or unsteadily	Lower
8	Steady, rising or falling slowly, then falling more rapidly	Lower

PP — AID NO. 27 - NET 3-HOUR PRESSURE CHANGE

Expressed in millibars and tenths. For example, a 3-hour pressure change of .8 is entered "08" in Column 27. Pressure changes of 9.9 mb or more require special groups. See observer's handbook, Chapter 6, last paragraph for details.

t_T — AID NO. 33 - TENTHS OF AIR TEMPERATURE

Copy in Column 33 the value entered in Column 17.

P_wP_w — AID NO. 35 - PERIOD OF WIND WAVES

Enter the average wave period in seconds using two figures. "00" is used for calm sea; 99 is used when the sea is confused and wave period cannot be estimated; two slants (//) are used for "missing".

H_wH_w — AID NOS. 36 AND 39
WAVE OR SWELL HEIGHTS IN HALF-METERS

Use Code Figure 00 for a calm sea. When the wave height is not reported for any reason use two slants (//) for H_wH_w.

Half-Meters Code Figure	Feet	Half-Meters Code Figure	Feet	Half-Meters Code Figure	Feet	Half-Meters Code Figure	Feet
01	2	21	34	41	67	61	100
02	3	22	36	42	69	62	102
03	5	23	38	43	71	63	103
04	7	24	39	44	72	64	105
05	8	25	41	45	74	65	107
06	10	26	43	46	76	66	108
07	12	27	44	47	77	67	110
08	13	28	46	48	79	68	112
09	15	29	48	49	80	69	113
10	16	30	49	50	82	70	115
11	18	31	51	51	84	71	117
12	20	32	52	52	85	72	118
13	21	33	54	53	87	73	120
14	23	34	56	54	89	74	121
15	25	35	57	55	90	75	123
16	26	36	59	56	92	76	125
17	28	37	61	57	94	77	126
18	30	38	62	58	95	78	128
19	31	39	64	59	97	79	130
20	33	40	66	60	98	80	131

P_w — AID NO. 38 - SWELL PERIOD

Code Figure	Average Period in sec	Code Figure	Average Period in sec.
5	5 or less	0	10
6	6	1	11
7	7	2	12
8	8	4	14 or more
9	9	/	Calm or not determined

T_dT_d — AID NO. 30 - DEW POINT ENCODED

Subtract wet-bulb temperature from dry-bulb temperature to get "wet-bulb depression." Locate nearest depression across top of table and nearest wet-bulb temperature down the side. Read encoded dew point at intersection of wet-bulb temperature row and depression column. More extensive tables are in the observers handbook.

Wet-bulb Temp (°C)	Wet-bulb Depression °C																						
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0
-5	56	57	[illegible]	59	61	63	64	67	69	72	77	88											
-4	55	56	57	58	59	61	62	64	66	69	72	76	83										
-3	53	54	55	57	58	59	61	62	64	66	69	72	76	83	97								
-2	52	53	54	55	56	57	59	60	62	64	66	68	71	75	80	91							
-1	51	52	53	54	55	56	57	58	60	61	63	65	67	70	73	78	86						
0	00	51	52	52	53	54	55	57	58	59	60	62	64	66	69	72	76	82					
+1	01	00	51	51	52	53	54	55	56	57	59	60	62	63	65	68	70	74	79	89			
2	02	01	01	50	51	52	53	54	55	56	57	58	59	61	62	64	67	69	72	77	84		
3	03	02	02	01	00	51	51	52	53	54	55	56	57	59	60	62	63	65	68	71	74	80	00
4	04	03	03	02	02	01	00	51	52	52	53	54	55	57	58	59	61	62	64	66	69	72	76
5	05	04	04	03	03	02	01	01	50	51	52	53	54	55	56	57	58	59	61	63	65	67	69
6	06	06	05	04	04	03	03	02	01	01	50	51	52	53	54	55	56	57	58	60	61	63	65
7	07	07	06	06	05	04	04	03	03	02	01	01	50	51	52	53	54	55	56	57	58	60	61
8	08	08	07	07	06	05	05	04	04	03	03	02	01	01	50	51	52	53	54	55	56	57	58
9	09	09	08	08	07	07	06	06	05	05	04	03	03	02	01	01	50	51	52	53	54	55	56
10	10	10	09	09	08	08	07	07	06	06	05	05	04	04	03	02	02	01	00	51	51	52	53
11	11	11	10	10	09	09	09	08	08	07	07	06	06	05	04	04	03	03	02	01	00	50	51
12	12	12	11	11	11	10	10	09	09	08	08	07	07	06	06	05	05	04	04	03	02	02	01
13	13	13	12	12	12	11	11	10	10	10	09	09	08	08	07	07	06	06	05	05	04	04	03
14	14	14	13	13	13	12	12	12	11	11	10	10	10	09	09	08	08	07	07	06	06	05	05
15	15	15	14	14	14	13	13	13	12	12	12	11	11	10	10	10	09	09	08	08	07	07	06
16	16	16	15	15	15	15	14	14	14	13	13	13	12	12	11	11	11	10	10	09	09	08	08
17	17	17	16	16	16	16	15	15	15	14	14	14	13	13	13	12	12	12	11	11	10	10	10
18	18	18	18	17	17	17	16	16	16	16	15	15	15	14	14	14	13	13	13	12	12	11	11
19	19	19	19	18	18	18	17	17	17	17	16	16	16	15	15	15	15	14	14	14	13	13	13
20	20	20	20	19	19	19	19	18	18	18	18	17	17	17	16	16	16	16	15	15	15	14	14
21	21	21	21	20	20	20	20	19	19	19	19	18	18	18	18	17	17	17	17	16	16	16	15
22	22	22	22	21	21	21	21	21	20	20	20	20	19	19	19	19	18	18	18	18	17	17	17
23	23	23	23	22	22	22	22	22	21	21	21	21	20	20	20	20	20	19	19	19	19	18	18
24	24	24	24	23	23	23	23	23	22	22	22	22	22	21	21	21	21	20	20	20	20	20	19
25	25	25	25	24	24	24	24	24	24	23	23	23	23	23	22	22	22	22	21	21	21	21	21
26	26	26	26	26	25	25	25	25	25	24	24	24	24	24	23	23	23	23	23	22	22	22	22
27	27	27	27	27	26	26	26	26	26	26	25	25	25	25	25	24	24	24	24	24	23	23	23
28	28	28	28	28	27	27	27	27	27	27	26	26	26	26	26	26	25	25	25	25	25	24	24
29	29	29	29	29	28	28	28	28	28	28	28	27	27	27	27	27	27	26	26	26	26	26	25
30	30	30	30	30	29	29	29	29	29	29	29	29	28	28	28	28	28	27	27	27	27	27	27
31	31	31	31	31	31	30	30	30	30	30	30	30	29	29	29	29	29	29	28	28	28	28	28
32	32	32	32	32	32	31	31	31	31	31	31	31	30	30	30	30	30	30	30	29	29	29	29
33	33	33	33	33	33	32	32	32	32	32	32	32	32	31	31	31	31	31	31	31	30	30	30
34	34	34	34	34	34	33	33	33	33	33	33	33	33	32	32	32	32	32	32	32	32	31	31
35	35	35	35	35	35	34	34	34	34	34	34	34	34	34	33	33	33	33	33	33	33	33	32

OBSERVING PROCEDURE

The following routine is suggested in taking a weather observation. Start the observation from 15 to 30 minutes before 0000, 0600, 1200 and 1800 GMT. Read the pressure as near to the scheduled time as possible, leaving only enough time to deliver the report to the radio officer a few minutes before the hour. Routine steps.

1. Indoors. Encode and enter columns [illegible] and 47.
2. Before going outdoors, wet the wick of the psychrometer and get pencil and note pad for jotting down outdoor elements.
3. Outdoors.
   a. Decide on visibility, present weather, total sky cover and cloud types.
   b. Aspirate the psychrometer while determining wave height, direction and period. (You may wish to observe wind waves and swell before starting the observation and simply check to see that they haven't changed at this time.)
   c. Read and record the dry-bulb (air temp.) and wet-bulb temperatures.
   d. Determine height of lowest cloud and eighths of lowest cloud layer if low or middle clouds are present.
   e. Determine wind direction and velocity from sea (or apparent wind from ship rigging and smoke).
4. Come indoors with data noted in step 3. Encode and record data for:
   a. Wind direction and speed. (Convert apparent wind to true wind.)
   b. Sky condition (Cols. [illegible]).
   c. Visibility and present weather (check by looking out to see if they have changed).
   d. Air temperature, wet-bulb and dew point (Cols. [illegible]).
   e. Wind waves and swell, using as many swell groups as necessary to describe the sea condition.
5. Copy the observation code on the Radiogram form (except for the pressure).
6. Read pressure (convert to millibars, if necessary) and enter it in Columns 14 and 15 and on the radiogram form.
7. Deliver the coded report to the radio officer.
8. Check the upper half of Column 41 when the message is sent ashore and enter your initials in the lower half of Column 41.

ORIGINAL PAGE IS OF POOR QUALITY

Form Approved: Budget Bureau No. 41-R1258

SHIP'S NAME S S M V	MONTH AND YEAR 19 ____	BAROMETER NUMBER	NOAA FORM 72-1 (10-71) U.S. DEPARTMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION NATIONAL WEATHER SERVICE
CALL SIGN	VOYAGE: FROM	DATE LAST CHECKED	SHIP'S WEATHER OBSERVATIONS
COUNTRY OF REGISTRY	TO	CORRECTION	

GENERAL INSTRUCTIONS
(See observing handbook for more details)

1. Fill in all blanks on upper left-hand side of this form.
2. Check appropriate box in column 32.
3. Before entering, convert:
   a. all temperatures to °C.
   b. all pressures to millibars.
   c. if conversion tables not available, enter values as observed, followed by letters or abbreviations for the first entry on each form, ("77.5°F", "29.905 in.", etc.)
4. Begin a new sheet each month, voyage, ocean and quadrant.
5. Transmit data in 5-figure groups from unshaded columns and remarks. See observing handbook, section 1-04 for handling missing data.

IND.	LATITUDE (Degrees and tenths, 3 figures)	QUADRANT OF GLOBE	LONGITUDE (Degrees and tenths, 4 figures)	DAY OF MONTH GMT (2 figures)	TIME GMT (2 figures)	WIND INDICATOR (Coded)	TOTAL CLOUD AMT.	WIND: DIRECTION ((True) tens of degrees (00 - calm))	WIND: SPEED (True knots)	VISIBILITY (Coded 90 - 99)	PRESENT WEATHER (Coded 00 - 99)	PAST WEATHER (0 - 9)	SEA LEVEL PRESSURE (Millibars and tenths. Last 3 figures in Col. 15 and first "9" or "10" in Col. 14)		AIR-TEMP. DATA °C: DRY BULB (Degrees in Col. 16, tenths in Col. 17 & 33)	WET BULB (Degrees and tenths)		AMOUNT OF LOWEST CLOUDS	TYPE OF LOW CLOUD	HEIGHT OF LOWEST CLOUDS	TYPE OF MIDDLE CLOUD	TYPE OF HIGH CLOUD	COURSE OF SHIP (Coded 0 - 9)	SPEED OF SHIP (Coded 0 - 9)	3-HOUR PRESS. CHANGE: CHARACTER OF CHANGE	3-HOUR PRESS. CHANGE: AMOUNT OF CHANGE (Mb and tenths)	INDICATOR	AIR-SEA TEMP. DIFFERENCE (Coded)	DEW POINT FROM TABLE 30	INDICATOR	SEA TEMPERATURE °C (Degrees and tenths 3 figures) CHECK ONE: BUCKET / INTAKE	TENTHS OF AIR TEMP.	INDICATOR	WAVES (Make as many groups as patterns observed): WIND WAVES: PERIOD (A-g seconds 2 figures)	WIND WAVES: HEIGHT (Coded)	SWELL: DIRECTION (tens of degrees)	SWELL: PERIOD (Coded)	SWELL: HEIGHT (Coded)	ADDITIONAL MESSAGE GROUPS AND REMARKS (More swell groups, 2 IsEsEsRs, ICE C2KDire, Wind Shifts, beginning and ending of precip., freak waves, etc.)	CHECK IF SENT BY RADIO / OBSERVERS INITIALS
1	2	3	4	5	6	7	8	9	10	11	12	13		15	16			19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
99	$L_aL_aL_a$	Q_c	$L_oL_oL_oL_o$	YY	GG	i_w	N	dd	ff	VV	ww	W		PPP	TT			N_h	C_L	h	C_M	C_H	D_s	v_s	a	pp	0	T_sT_s	T_dT_d	1	$T_wT_wT_w$	t_T	1	P_wP_w	H_wH_w	d_wd_w	P_w	H_wH_w	—	—
99					00																						0	//		1			3							
99					06																						0	//		1			3							
99					12																						0	//		1			3							
99					18																						0	//		1			3							
99					00																						0	//		1			3							
99					06																						0	//		1			3							
99					12																						0	//		1			3							
99					18																						0	//		1			3							
99					00																						0	//		1			3							
99					06																						0	//		1			3							
99					00																						0	//		1			3							
99					18																						0	//		1			3							
99					00																						0	//		1			3							
99					06																						0	//		1			3							
99					12																						0	//		1			3							
99					18																						0	//		1			3							
99	$L_aL_aL_a$	Q_c	$L_oL_oL_oL_o$	YY	GG	i_w	N	dd	ff	VV	ww	W		PPP	TT	—	—	N_h	C_L	h	C_M	C_H	D_s	v_s	a	pp	0	T_sT_s	T_dT_d	1	$T_wT_wT_w$	t_T	1	P_wP_w	H_wH_w	d_wd_w	P_w	H_wH_w		

NOAA FORM 72-1

MARINE COASTAL WEATHER LOG - COASTAL STATION

These instructions apply when taking observations at Coast Guard and other coastal or offshore fixed observation sites. Since not all of the entries required in columns 6 through 9 of the weather log may be observed at each station, a representative of the National Oceanic and Atmospheric Administration (NOAA) will assist in determining which elements each station should record. He will also advise each station how and where to transmit its weather messages and how to dispose of completed observation forms and how to obtain new observing supplies. Each station should begin a new series of weather logs at the beginning of each month.

FORM HEADING ENTRIES

Enter the (1) Station Name, (2) Station Location (latitude and longitude), and (3) Date (month and year) the form is initially prepared in the blocks provided in the heading.

COLUMN ENTRIES

Column 1. DATE - Enter the calendar day of month (local standard time).

Column 2. TIME - Enter time followed by time zone indicator in space provided using the Local Standard Time, i.e., EST, EDT, CST, CDT, etc. Enter time to the nearest whole hour using the 24-hour clock system, e.g., 1:55 p.m. EST would be entered 1400 EST, 5:15 p.m. PST as 1700 PST, etc. Except for certain U.S. Coast Guard coastal stations there is no prescribed time of day for making observations. However, cooperating stations are encouraged to make and report once a day at a convenient time, or whenever changes in existing wind and weather conditions become extreme or differ significantly from forecast conditions. Regular reporting U.S. Coast Guard stations usually take 3-hourly observations at times that correspond to the Greenwich Mean Times of 0000, 0300, 0600, . . . 2100.

Column 3. PRESENT WEATHER - Record and transmit the most prevalent weather element or elements (up to two) that best describes local conditions at observation time. The reportable elements and acceptable abbreviations for teletype transmissions are listed in Table 1 in the order of reporting preference. When two weather elements are observed concurrently, report one closest to the top of the list first.

TABLE 1. PRESENT WEATHER IN ORDER OF REPORTING PREFERENCE

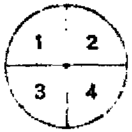
	Teletype Abbreviation		Teletype Abbreviation
1. WATER SPOUT	WATER SPOUT	9. HAIL OR SNOW PELLETS	SP
2. SQUALL*	SQUALL*	10. SNOW	S
3. THUNDERSTORM	TSTM	11. RAIN	R
4. FREEZING RAIN	ZR	12. DRIZZLE	L
5. FREEZING DRIZZLE	ZL	13. HAZE	H
6. FOG	F	14. CLOUDY	CL
7. SNOW SHOWER	SW	15. PARTLY CLOUDY	PC
8. RAIN SHOWER	RW	16. CLEAR	C

*SQUALL (a severe local storm) - defined as when there is a sudden increase in wind and an abrupt lowering of clouds with or without showers or heavy sea conditions.

Column 4. VISIBILITY - Report visibility to the nearest whole nautical mile where it is one mile or more. Below one mile, visibility should be reported to the nearest quarter mile. Visibility denotes the greatest distance from an observer that an object of known characteristics can be seen and identified. Whenever possible, estimate visibility by using objects whose distance is known.

When visibility is not the same in all directions from the observer, the highest value common to one-half or more of the horizon circle should be selected as the prevailing visibility. By this definition, the prevailing visibility to report for the conditions shown in Figure 1 would be three miles.

FIGURE 1. DETERMINATION OF PREVAILING VISIBILITY



(prevailing visibility 3 miles)

Column 5. WIND DIRECTION AND SPEED - Wind direction will be reported in tens of degrees or to 16 points of the compass (N, NNE, NE, ENE, etc.). Enter the true, not magnetic, direction from which the wind is blowing. Report calm wind as CALM.

Wind speed will be reported in knots. If the wind is estimated, Table 2 - DETERMINATION OF WIND SPEED BY OBSERVED EFFECTS AND/OR SEA CONDITIONS, may be used to estimate the wind. However, caution should be used for the values included in the table do not always reflect wind and wave relationships in immediate coastal areas.

TABLE 2. DETERMINATION OF WIND SPEED BY OBSERVED EFFECTS AND/OR SEA CONDITIONS

Descriptive	WIND Knots	WIND Mph	Effects Observed at Sea	Effects Observed on Land	Probable Wave Ht. Feet
Calm	Under 1	Under 1	Sea like mirror.	Calm; smoke rises vertically.	0
Light Air	1-3	1-3	Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.	¼
Light Breeze	4-6	4-7	Small wavelets; crests of glassy appearance, not breaking.	Wind felt on faces; leaves rustle; vanes begin to move.	½
Gentle Breeze	7-10	8-12	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.	2
Moderate Breeze	11-16	13-18	Small waves, becoming longer; numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move.	4
Fresh Breeze	17-21	19-24	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.	6
Strong Breeze	22-27	25-31	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion; whistling heard in wires.	10
Near Gale	28-33	32-38	Sea heaps up; white foam from breaking waves begins to be blown in streaks.	Whole trees in motion; resistance felt in walking against wind.	14
Gale	34-40	39-46	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well marked streaks.	Twigs and small branches broken off trees; progress generally impeded.	18
Strong Gale	41-47	47-54	High waves; sea begins to roll; dense streaks of foam; spray may reduce visibility.	Slight structural damage occurs.	23
Storm	48-55	55-63	Very high waves with overhanging crests; sea takes white appearance as foam is blown in very dense streaks; rolling is heavy and visibility is reduced.	Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.	29
Violent Storm	56-63	64-72	Exceptionally high waves; sea covered with white foam patches; visibility still more reduced.		37
Hurricane	64-71	73-82	Air filled with foam.	Very rarely experienced on land.	45

Column 6. STATE OF SEA - The state of the sea should be reported by the height of the existing wind waves (in feet) and if observed, the direction (to eight points of the compass) and height (in feet) of the swell at observation time. When reporting the STATE OF SEA always precede it by the indicator SEA followed by wind wave height and swell direction and height if observed. Examples: (1) No wind waves swell NE 5FT would be reported SEA NONE NE 5FT, (2) wind waves 12FT no swell would be reported SEA 12FT.

WAVE HEIGHT - The height of the wind waves should be the estimated height (in feet) between the troughs and crests of the well formed waves that are observed. When the sea is calm enter and report ZERO for the wind waves. When there are no wind waves but swell is observed, the wave height should be entered and reported as NONE followed by swell direction and height.

SWELL DIRECTION AND HEIGHT - Whenever a distinct swell - long, rolling waves that move independently of the locally observed wind - can be identified include the direction from which the swell is traveling to eight points of the compass and the height of the swell (in feet) from trough to crest.

OPTIONAL COLUMN ENTRIES

Column 7. SEA WATER TEMPERATURE - Those stations instructed to make sea water temperature readings should record them in whole degrees Fahrenheit or Celsius. Indicate whether temperature is in Celsius (C) by entering a "C" after the temperature. The sea water temperature transmitted should always be preceded by S and followed by the temperature scale indicator if in centigrade. Example: 28°C is reported as S28C.

Column 8. AIR TEMPERATURE - If required, enter the air temperature in whole degrees Fahrenheit or Celsius. Indicate whether temperature is in Celsius (C) by entering a "C" after the temperature. The air temperature transmitted should always be preceded by A and followed by the temperature scale indicator if in Centigrade. Example: 20°C is reported as A20C.

Column 9. PRESSURE - Pressure observations should be entered to the nearest whole millibar or tenth of an inch. For example, a pressure reading of 1012.6 mbs would be reported as 1013 while a reading of 30.14 would be reported as 301.

Column 10. REMARKS - Use this column to record any additional data that the observer thinks significant and wishes to report. Remarks in plain language could describe ice conditions, unusual tides or swell conditions, heavy rainfall, unusually squally or stormy conditions, etc.

☆U.S. GOVERNMENT PRINTING OFFICE: 1972 - 760-789

C-W

NOAA FORM 72-5a
(4-72)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

FORM APPROVED
O.M.B. NO. 41-R2427

MARINE COASTAL WEATHER LOG——COASTAL STATION

STATION NAME	LOCATION	DATE (month and year)

(1) DATE	(2) TIME	LOCAL STANDARD TIME	(3) PRESENT WEATHER	(4) VISIBILITY	(5) WIND DIR.	(5) WIND SPEED (KTS)	(6) STATE OF SEA WAVE HEIGHT	(6) STATE OF SEA SWELL DIR.	(6) STATE OF SEA SWELL HEIGHT	(7) SEA WATER TEMP.	INDICATOR	(8) AIR TEMP.	INDICATOR	(9) PRESSURE	(10) REMARKS (icing, etc.)
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			
				MI			SEA FT		FT	S		A			

NOAA FORM 72-5 A (4-72)

MARINE COASTAL WEATHER LOG

SHIP STATION

INSTRUCTIONS – NOAA FORM 72-5b

Instructions for Entries on Marine Coastal Weather Log - Ship Station: These instructions apply when making observations aboard vessels plying the U.S. coastal waters. All ships are requested to record and report the information required in columns 1 through 7 of the Weather Log. Entries in columns 8 through 11 are optional. All messages should be identified by Ship Name and Radio Call Sign. If required, mail the completed MARINE COASTAL WEATHER LOG in the envelopes provided to the office which supplies you with observation materials and forms.

FORM HEADING ENTRIES

Enter the (1) Ship Name, (2) Radio Call Sign, and (3) Date (Month, and year the form is initially prepared) in blocks provided in the heading of each sheet.

COLUMN ENTRIES

Column 1. DATE - Day of month (Greenwich Mean Time).

Column 2. TIME - Enter the time to the nearest whole hour using the 24-hour clock system, e.g., 1:55 p.m. would be entered 14, 5:15 p.m. as 17, etc. NOTE - There is no prescribed time of day for making observations. However, ships are urged to make and report at least once a day at a time convenient to the observer or whenever changes in existing wind, weather, or sea conditions are significantly different from current forecasts. Remember, always include the time of observation in all radio reports.

Column 3. POSITION - Vessels making observations have the option of reporting their position to either latitude and longitude or distance and bearing from an established landmark. If your ship is to report in distance and bearing from a landmark, the NOAA representative will either provide you with a list or suggest which navigation charts to use in determining the landmarks to use in your reports. Record latitude and longitude to the nearest tens of a degree (49.2, 38.7, etc.).

Column 4. PRESENT WEATHER - Enter the most prevalent weather element(s) from Table 1 that best describes local conditions. It is not necessary to report more than two weather elements.

TABLE 1. PRESENT WEATHER IN ORDER OF REPORTING PREFERENCE

Weather Element	Weather Element	Weather Element
1. Hurricane	7. Fog	13. Rain
2. Water Spout	8. Snow Shower	14. Drizzle
3. Squall	9. Rain Shower	15. Haze or Smoke
4. Thunderstorm	10. Hail	16. Cloudy
5. Freezing Rain	11. Snow Pellets	17. Partly Cloudy
6. Freezing Drizzle	12. Snow	18. Clear

Column 5. VISIBILITY - Report visibility to the nearest whole nautical mile where it is one mile or more. Below one mile, visibility should be reported to the nearest quarter mile. Visibility denotes the greatest distance from an observer that an object of known characteristics can be seen and identified. Where there are no identification objects, visibility may be obtained by estimating the distance to the horizon according to Table 2.

TABLE 2. DISTANCE TO HORIZON AT SEA (NAUTICAL MILES)

Height of Observation Platform (Ft.)	Distance to Horizon (n.mi.)	Height of Observation Platform (Ft.)	Distance to Horizon (n.mi.)
10	3.8	25	6.0
15	4.6	30	6.6
20	5.4	35	7.1

The information in Table 2 shows that the horizon from an observation platform aboard ship of 10 feet appears at a distance of approximately 4 nautical miles. NOTE: If the horizon is well defined with little or no blurring, the visibility is greater than the observers distance to the horizon; however, if it is blurred and indistinct, the visibility is about equal to horizon distance.

The estimation of visibility at night, especially at sea, is extremely difficult. However, if there is no obvious change in meteorological conditions, the visibility after dark will be the same as that determined shortly before dark. The development of a haze around a vessel's navigational lights is frequently a guide to deteriorating visibility.

Column 6. WIND DIRECTION AND SPEED - Wind direction will be reported in tens of degrees or to 16 points of the compass (N, NNE, NE, ENE, etc.). Enter the true, not magnetic, direction from which the wind is blowing. Report calm wind as CALM.

Wind speed will be reported in knots. If the wind is estimated, Table 3 - DETERMINATION OF WIND SPEED BY OBSERVED EFFECTS AND/OR SEA CONDITIONS, may be used to estimate the wind. However, caution should be used, for the values included in the table do not always reflect wind and wave relationships in immediate coastal areas.

TABLE 3. DETERMINATION OF WIND SPEED BY OBSERVED EFFECTS AND/OR SEA CONDITIONS

Descriptive	WIND Knots	WIND Mph	Effects Observed at Sea	Effects Observed on Land	Probable Wave Ht. -Feet-
Calm	Under 1	Under 1	Sea like mirror.	Calm; smoke rises vertically.	0
Light Air	1-3	1-3	Ripples with appearance of scales; no foam crests.	Smoke drift indicates wind direction; vanes do not move.	¼
Light Breeze	4-6	4-7	Small wavelets; crests of glassy appearance, not breaking.	Wind felt on faces, leaves rustle, vanes begin to move.	½
Gentle Breeze	7-10	8-12	Large wavelets; crests begin to break; scattered whitecaps.	Leaves, small twigs in constant motion; light flags extended.	2
Moderate Breeze	11-16	13-18	Small waves, becoming longer, numerous whitecaps.	Dust, leaves, and loose paper raised up; small branches move.	4
Fresh Breeze	17-21	19-24	Moderate waves, taking longer form; many whitecaps; some spray.	Small trees in leaf begin to sway.	6
Strong Breeze	22-27	25-31	Larger waves forming; whitecaps everywhere; more spray.	Larger branches of trees in motion, whistling heard in wires.	10
Near Gale	28-33	32-38	Sea heaps up; white foam from breaking waves begins to be blown in streaks.	Whole trees in motion; resistance felt in walking against wind.	14
Gale	34-40	39-46	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam is blown in well-marked streaks.	Twigs and small branches broken off trees; progress generally impeded.	18
Strong Gale	41-47	47-54	High waves; sea begins to roll; dense streaks of foam; spray may reduce visibility.	Slight structural damage occurs.	23
Storm	48-55	55-63	Very high waves with overhanging crests; sea takes white appearance as foam is blown in very dense streaks; rolling is heavy and visibility is reduced.	Seldom experienced on land; trees broken or uprooted; considerable structural damage occurs.	29
Violent Storm	56-63	64-72	Exceptionally high waves; sea covered with white foam patches; visibility still more reduced.		37
Hurricane	64-71	73-82	Air filled with foam.	Very rarely experienced on land.	45

If a speed indicator is used aboard ship for determining wind direction and speed, remember that the direct reading of the indicator gives apparent wind speed, not true wind speed. Therefore, the speed and course of the ship must be eliminated from apparent wind to obtain true wind. Some rules to remember when converting from apparent to true wind are: (1) True wind direction is always on the same side as, but farther from the bow than the apparent wind direction. (2) When the apparent direction is aft of the beam, the true speed is greater than apparent speed. (3) When the apparent direction is forward of the beam, the true wind is less than apparent speed.

Column 7. STATE OF SEA - All that is required from the observer is an estimate of the average height of wind waves and if observed the direction and height of swells. Wave and Swell heights should be reported to the nearest whole foot.

The following definitions are used in explaining wave parts:

Crest - High point of wave	Wave Height - Vertical distance from trough to crest
Trough - Low point of wave	Wave Period - Time between passage of successive wave crests

Waves in the same system usually occur in a sequence of a few large, well formed waves followed by an interval in which only small and poorly formed waves occur, then another series of well formed waves, etc. Observers should determine height using only well formed and discounting poorly formed waves.

When the sea is calm, enter and report only CALM for wind waves. When there are no wind waves but swell is observed, enter and report only the swell direction (8 points of compass) and height (feet).

WAVE HEIGHT - The height of waves should be the estimated height (in feet) between troughs and ridges of well formed waves.

SWELL DIRECTION AND HEIGHT - Whenever a distinct swell - long, rolling waves that move independently of the locally observed wind - can be identified the direction from which the swell is traveling to eight points of the compass and the height of the swell (in feet) from trough to crest.

Examples of reporting STATE OF SEA (column 7):

1. Wind wave height 2 feet and swell NE and height 5 feet would be entered 2 ft., NE 5 ft. and reported SEA 2 ft SWELL NE 5 ft.
2. No wind wave swell NW 8 ft. would be entered in SWELL column and reported SWELL NW 8.

OPTIONAL ENTRIES

Column 8. SEA WATER TEMPERATURE - Observers instructed to report sea water temperature should record and report it in whole degrees Fahrenheit or Celsius. Check box at the top of column to indicate C (Celsius) or F (Fahrenheit). Negative temperatures should include a minus sign preceding temperature.

Column 9. AIR TEMPERATURE - Observers instructed to report air temperature should record and report it in whole degrees Fahrenheit or Celsius. Check box at the top of column to indicate C (Celsius) or F (Fahrenheit). Negative temperature should include a minus sign.

Column 10. PRESSURE - Pressure observations should be reported to the nearest whole millibar or hundreth of inch. For example, a reading of 1016.2 millibars becomes 101[illegible] 142 becomes 30.14 inches.

Column 11. REMARKS - Use this column to record any additional data that the observer thinks significant and wishes to record. Remarks in plain language could describe ice conditions, unusual swell conditions, tides, heavy rainfall, unusually squally or stormy conditions, etc.

☆ U. S Government Printing Office: 1974—667-004

NOAA FORM 72-5b
(4-74)

U. S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

FORM APPROVED
O.M.B. No. 41-R2734

MARINE COASTAL WEATHER LOG——SHIP STATION

SHIP NAME	RADIO CALL SIGN	DATE *(month and year)*

(1) DATE	(2) TIME *(GMT)*	(3) POSITION	(4) PRESENT WEATHER	(5) VISI-BILITY *(MI)*	(6) WIND DIR. *(16 pts)*	(6) WIND SPEED *(Kts)*	(7) STATE OF SEA — WAVE HEIGHT *(Ft)*	(7) STATE OF SEA — SWELL DIRECTION *(8 Pts)*	(7) STATE OF SEA — SWELL HEIGHT *(Ft)*	(8) SEA WATER TEMP. ☐C ☐F	(9) AIR TEMP. ☐C ☐F	(10) PRES-SURE	(11) REMARKS *(icing, etc.)*

NOAA FORM 72-5B (4-74)

SUPERSEDES PREVIOUS EDITION.