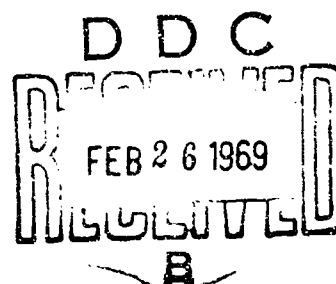


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**CHARACTERISTICS OF
NATIONAL DATA BUOY SYSTEMS:
THEIR IMPACT ON DATA USE AND
MEASUREMENT OF NATURAL PHENOMENA**

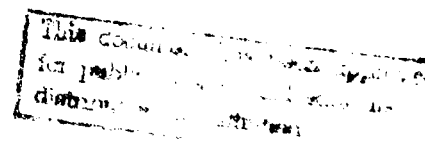
by

**Clifford A. Jacobs
Project Scientist**

and

**Joseph P. Pandolfo
E. J. Aubert**

December 1968



**TBC Report 7493-334
Prepared for the U. S. Coast Guard
Under Contract No. DOT-CG-82504-A**

**E. J. Aubert
G. M. Northrop
Principal Investigators**

THE TRAVELERS RESEARCH CENTER, INC.

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Views or conclusions contained in this study report should not be interpreted as official opinion or policy of the Federal Government.

FOREWORD

Contract Number DOT-CG-82504-A between the U.S. Coast Guard and The Travelers Research Center, Inc. (TRC) consists of five parallel activities. The five final reports stemming from these activities are entitled:

- 1) Applicability of National Data Buoy Systems to Refined National Requirements for Marine Meteorological and Oceanographic Data
- 2) Characteristics of National Data Buoy Systems: Their Impact on Data Use and Measurement of Natural Phenomena
- 3) Cost Effectiveness Sensitivity of National Data Buoy Systems: An Essay
- 4) Computer Programs for National Data Buoy Systems Simulation and Cost Models
- 5) An Analysis of Cruise Strategies and Costs for Deployment of National Data Buoy Systems

Each of these five reports is complete in itself, but it must be recognized that in all instances the other four activities both influenced and contributed to the results presented in each individual report.

The present USCG/TRC contract is an outgrowth of a study of the feasibility of National Data Buoy Systems performed by TRC and Alpine Geophysical Associates for the USCG during 1967. Need was evident for investigation, research, and analysis in greater depth in several areas to support the concept formulation and deployment planning efforts of the newly-formed U.S. Coast Guard National Data Buoy System Designated Project Office (NDBS DPO). This report and the other four cited above satisfy some of those needs.

All five TRC reports have benefited from the close cooperation and guidance afforded by the USCG NDBS DPO. Contributions have been made by Capt. J. Hodgman (Project Manager), Cmdrs. V. Rinehart, J. Wesler, E. Parker, and P. Morrill, and Lt. Cmdr. W. Merlin (Contract Monitor). Acknowledgment is also given to the following individuals for significant contributions to this report: Dr. Ferris Webster, Woods Hole Oceanographic Institution.

SUMMARY

The ultimate goals of this study are twofold: (1) to provide sufficient information to National Data Buoy Systems (NDBS) designers to assist in making decisions pertinent to the design of the operational system; and (2) to provide a "users' manual" to inform data users of the properties of data that might be provided by the NDBS. At this time, these goals cannot be completely attained because of lack of basic information and understanding related to three problem elements; viz., system characteristics, natural variability, data use techniques. It is recognized, however, that successively better approximate solutions to satisfy these goals can be made available to the NDBS DPO in an evolutionary, iterative fashion. A structured approach and an initial effort to attain the goals is presented in this report. It is not suggested that the concepts applied, the method of application, or the method of presentation developed in this report are definitive. But the framework developed herein for comparing NDBS characteristics, natural variability, and data use techniques is believed to be adequate for its purpose within our present state of knowledge of the marine environment.

The fundamental objective of the NDBS is to collect systematic measurements of the marine environment and to retrieve from these measurements information that will be useful for a variety of national purposes. As a "window through which the natural marine environment can be observed, the National Data Buoy System must be designed with care. It is not feasible to attempt to observe all the natural processes occurring in the marine environment through the NDBS window. Rather, economic factors dictate that a carefully selected set of phenomena be chosen for observation. It is important that the NDBS be designed to match the national marine data requirements to the natural environment. It is important, too, that users of this system be clearly aware of its limitations.

The proposed NDBS will route the data collected from the ocean and atmosphere to many different users. For example, from the buoy system, the data will go to government agencies, industrial organizations, scientific institutions and to the general public. In some cases the dissemination of data will be direct; in others an important intermediate role will be played by data processing centers. At these

centers, state-of-the-art data use techniques will be employed to convert the information into a form for maximum utility to the ultimate users.

An important function of the data processors will be their feedback to the design and operation of the NDBS. Feedback from the ultimate users to the data processing centers will likely lead to a sharper definition of the data buoy system requirements.

The NDBS will collect measurements over a three-dimensional spatial array of points in the ocean at regular intervals in time. At each array point, a time series of discrete values of a set of oceanic parameters will be obtained. These parameters might be, for example, temperature, salinity, water velocity, surface wind velocity, etc. The time series for each parameter will represent the combined influence of a broad spectrum of physical processes typically, such processes might be tides, waves, hurricanes, diurnal heating, etc. The purpose of the NDBS must be to provide information about selected processes that is required by a set of users.

As has been mentioned, economic considerations dictate that the NDBS can only return information on a selected class of processes in the marine environment. To attempt to monitor all oceanic processes in the wide sense cannot be economically justified. It is therefore necessary to develop criteria by which the information-collecting ability of the NDBS can be evaluated. These criteria must be clearly understood by both the system designers and by the data users.

The concept used in this report to describe the NDBS system resolution is that of the spectrum. Any time series can be decomposed into a set of spectral components, each contributing to the variability of the parameter being measured. This decomposition can be a powerful tool for resolving physical processes which are superposed in the data record. The design of a buoy data-collecting system can be conveniently formulated in terms of matching the spectral content of the natural environment as seen through the spectral "window" of the buoy system to the spectral content required by the set of data users.

The quantities used to classify oceanic and atmospheric processes in the spectral sense are frequency (for time variability) and wave number (for space variability). By specifying both frequency and wave number, it is possible to uniquely categorize all marine processes. This categorization is referred to here as an f - k representation, following the usual abbreviations for frequency (f) and wave number (k). Graphs

with frequency as one ordinate and wave number as the other are used heavily in this study. You will find in this report, therefore, sets of f-k graphs representing classes of natural phenomena in the ocean and atmosphere, and the window characteristics of various buoy system designs.

The f-k graphs of Section 3.0 show the natural processes affecting the variability of specific parameters. A presentation in graphical and tabular form of known major oceanic and atmospheric phenomena which could be sensed by the NDBS has been undertaken. For each of a certain class of parameters to be measured by the NDBS, a f-k graph has been prepared showing the natural phenomena affecting that parameter. Also shown on each f-k graph are the windows implied by hypothetical sets of buoy system characteristics.

Some of the system characteristics under control of the NDBS designer have been studied with regard to the data requirements of the user and the natural variability of the environment. This study has considered alternatives for NDBS design; these have been illustrated by example applications.

Unfortunately, knowledge and theory of processes in the marine environment are not yet sufficient to permit definitive design criteria to be established. The embryonic NDBS will be a vital instrument in the collection of knowledge that will aid its own evolutionary growth. Until further critical knowledge is obtained, there must be a degree of arbitrariness in the choice of some system design factors.

Guidelines have been provided in this report for the feedback of data use techniques to the data requirements. Somewhat greater detail is provided an illustrative example where a particular data user - the Public Weather Service - is discussed. There is a potentially large number of data users each of whose needs and modes of operation should be investigated in detail, if maximum benefits are to be derived from the NDBS and the output of the data use techniques are to have the most favorable possible performance cost characteristics. This problem is broader than (but not independent of) NDBS design.

The following are recommendations for further study and experimentation:

- (1) It is recommended that the NDBS DPO sponsor a continuing study of the interface between the needs of data users and the design and operation of the

NDBS. This study should establish priorities for parameters to be measured and the design requirements of the system.

(2) The NDBS DPO should support the early deployment of single buoys and small networks to obtain more information about natural variability. Requirements and priorities should be defined by a scientific organization that will also be responsible for analysis of the data, thus assuring continuity throughout the entire scope of the investigation.

(3) Similar experimental programs should be conducted in both natural and laboratory test environments to determine the performance and effectiveness of various hardware combinations being considered for use in the NDBS.

(4) The present study should be extended to examine the effects of instrument sensitivity on system design. This study should also consider the data quality requirements of NDBS users.

(5) The present study should be extended to examine the system design requirements in the vertical dimension. Such a study can only be effective in conjunction with additional studies of natural variability.

(6) A survey of available information in terms of specific regional and seasonal segments of the marine environment should be compiled into an easily used form, such as a handbook.

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1.0 INTRODUCTION

1.1 Background of the Problem

The specific area of interest in this study is the attainment of a suitable balance among certain characteristics of National Data Buoy Systems (NDBS), the time and space variability of the geophysical parameters to be monitored by this observing system, and the techniques likely to be applied in the derivation of environmental information products from the data provided by the NDBS. A general description of the NDBS as one component in the larger setting of an environmental prediction system identified this problem area prior to the undertaking of the work reported here. [1]

This study of marine data use analysis is being performed by The Travelers Research Center, Inc. (TRC) in the context of a contractual effort intended to provide on a broad basis, information and assistance to the U. S. Coast Guard National Data Buoy Systems Designated Project Office (NDBS DPO) which has been assigned the lead agency responsibility for planning and management of the development phases of National Data Buoy Systems. The concept of National Data Buoy Systems imposes on the Designated Project Office a more complex task than normally has been faced by the scientific coordinator of a conventional observational expedition, in which the data users are more sharply defined. The national system context necessarily shaped the study objectives selected from the broad range of possible goals implied in the problem area identified above. The initial objectives chosen by TRC in coordination with the NDBS DPO may be ideally defined:

(1) To provide sufficient information to the system designer to allow him, within practical constraints, to rationally decide, at each of many branch points in the development, what course will result in a system best structured to measure the portions of the spectrum of natural variability of interest to the manifold direct users of the data.

(2) To prepare a "Users' Manual" in which these users are fully informed of the properties of the potential data to be collected by the NDBS in such a manner that they can evaluate the impact of the data collection procedures on

the quality and utility of the environmental information products they expect to derive from the collected data.

In the real world, of course, these objectives cannot be fully achieved immediately. Lack of definitive scientific and operational knowledge with respect to all three problem elements (viz., system characteristics, natural variability, data use techniques) precludes this. Many indications of this knowledge gap in the scientific literature will be noted in the remainder of this report. However, it is evident from previous studies that sufficient benefit could be obtained from the NDBS to justify its development and implementation in the near future. Thus, while it is useful to identify idealized ultimate objectives to properly set the direction of the study, it is necessary to recognize that only successively better approximate fulfillment of these objectives can be made available to the NDBS DPO in an evolutionary, iterative fashion.

Thus, the context in which this study has been carried out shapes not only the objectives selected, but also the approach adopted to complete the first iterative step in achieving the full objectives.

1.2 Approach

The approach adopted for the 1968 TRC study of Data Use Analysis was to first develop a framework in which tentative National Data Buoy System characteristics and measures of the natural variability could be easily related and compared. Section 2.0 of this report describes the first version of such a framework. As noted above, it is not suggested that the concepts applied, the method of application, or the method of presentation are definitive, but it is believed that the framework is adequate for its purpose within our present state of knowledge of the marine environment.

The next step was to make a general classification of probable data use techniques in categories relevant to this framework; this is also outlined in Section 2.0.

Third, a first application of the framework and classification method is presented in Section 3.0. For this first approximation, hypothetical system characteristics were derived from the preliminary design considerations developed during the 1967 TRC feasibility study [2] with cognizance of the parallel TRC 1968 marine data requirements refinement effort. These were used in conjunction with the known facts and informed estimates of natural variability derived from the pooled knowledge and

experience of meteorologists and oceanographers within TRC and serving as consultants. To say that the result is definitive, particularly with regard to oceanic variability, would be to deny the existence of some of the most urgent data collection needs which the projected NDBS is to satisfy. Finally, the general classification of foreseen data use techniques was applied in Section 3.0 to indicate matches of possible data use techniques and hypothetical system characteristics deemed most suitable at this stage of investigation.

In Section 4.0, those NDBS characteristics that are under the control of the system designer are identified and the alternatives available to the designer broadly specified. Examples of hypothetical regional deployments are used to illustrate an application of the framework to two parameters: ocean current and air pressure. Specific scales of interest are identified based on our present (deficient) state of knowledge of the natural variability in these two regions.

In Section 5.0, the framework is applied from the viewpoint of a typical potential NDBS data user: the Public Weather Service. In this perspective, the procedure of application is to first identify the phenomena producing parameter value variations of particular interest to this user. These are then either translatable into specific requirements in terms of future NDBS system design characteristics, or matched against a prescribed set of characteristics to determine which data use techniques (data processing and analysis procedures, prediction models) are likely to produce the most effective product available from the given system.

Sections 4.0 and 5.0 show that the accomplishments of this study comprise only the first steps toward achievement of the idealized objectives defined at the beginning of this introduction. Some areas of further study are identified in Section 6.0.

2.0 PRINCIPLES FOR ANALYZING NDBS CHARACTERISTICS, NATURAL PHENOMENA AND DATA USE TECHNIQUES

2.1 NDBS Characteristics

The National Data Buoy System is one cost-effective means with which to sample a portion of the natural environment. That portion of the environment that can be best sampled by buoys is the oceans and the lower part of the atmosphere. [2]

Agencies, organizations, and individuals who are potential recipients of data from the NDBS have submitted requirements for parameters to be measured in terms of necessary and desirable characteristics of measurements. From the combined requirements statements submitted to TRC emerges a general picture of required time and space scale characteristics. In simple terms, the NDBS will consist of an array of sensors, placed in the ocean and the bottom layer of the atmosphere as shown in Fig. 2-1. This array is on a spatial grid with some specified constant or space variable grid spacing and total extent. In general, for each transmitted report, measurements are obtained over short time intervals (i.e., the duration of observation) at a synchronized time at all horizontal and vertical sensing points (see Fig. 2-2). These synchronized measurements are normally interrupted by long periods of inactivity when compared to the averaging period.

Two special extreme cases may be considered as extensions of this scheduling procedure. At one extreme the duration of observation may be extended to provide continuous measurements. At the other extreme, the duration of observation may be decreased to produce a series of instantaneous measurements. Throughout the remainder of this report most of the discussions and illustrations apply to cases between these two extremes.

Alternative procedures may also be applied over the short time period of measurement. In one case, it is assumed that measurements made over the duration of observation will frequently be integrated to obtain a single average, in which case "duration of observation" becomes synonymous with "averaging period". Alternatively, other statistics of the measurements or the complete continuous measurement over the short time period may be provided in its purest state. We will consider the first procedure as the normal case throughout the remainder of this report.

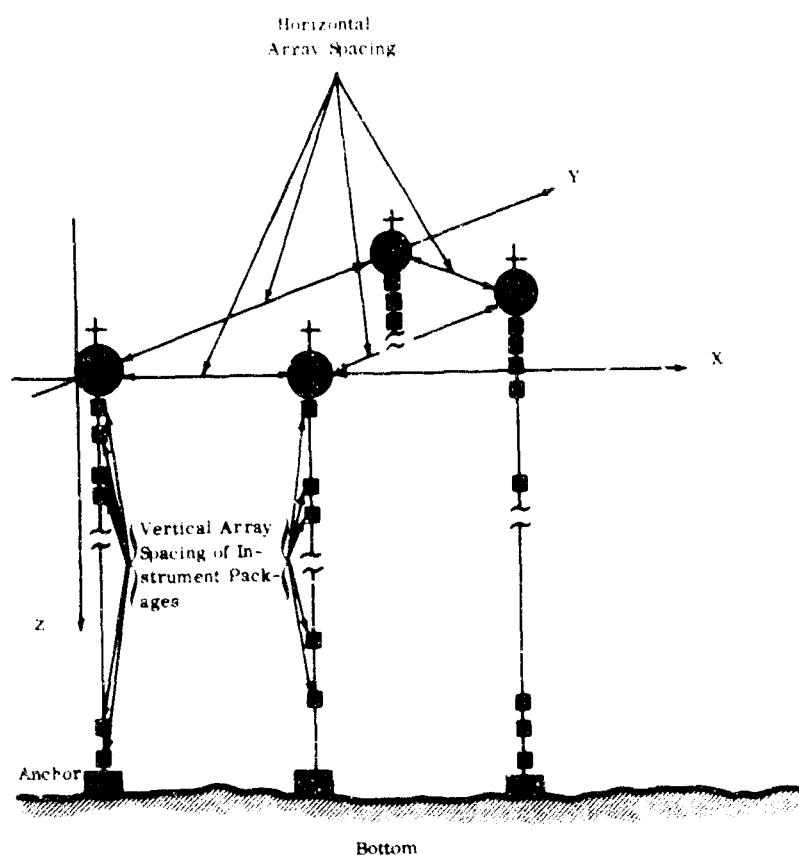


Fig. 2-1. System Characteristics in Space

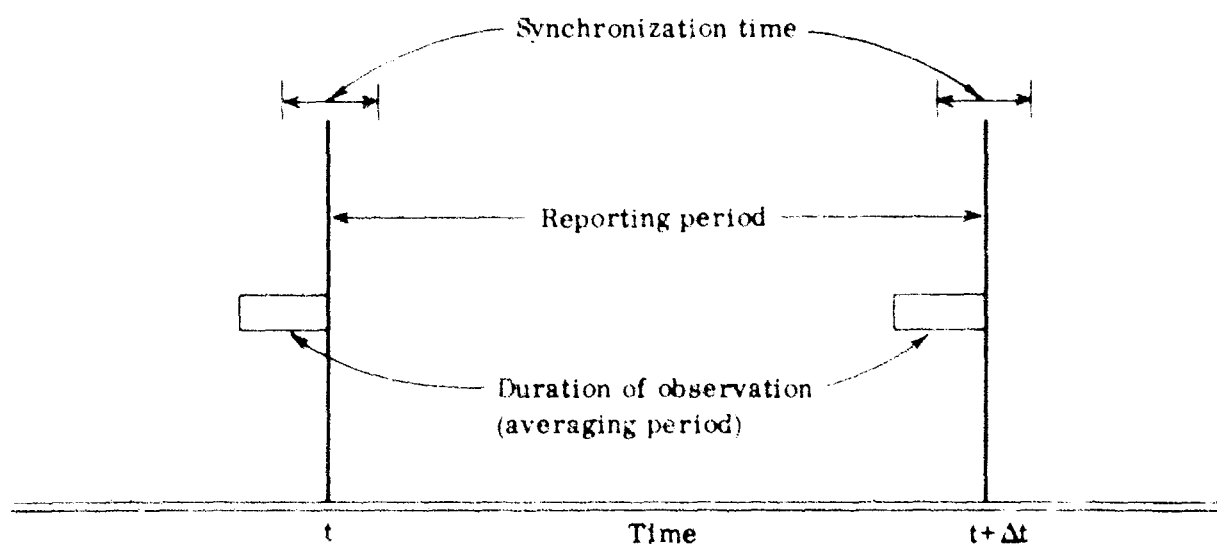


Fig. 2-2. Temporal Definitions

Finally, a full range of spatial analogues to the time scheduling procedures outlined above is possible in principle. However, it is generally physically impractical to collect instantaneous measurements over a spatial region about a nominal array location. The usual procedure is to collect measurements only at the array points. The resulting set of measurements is spatially analogous to the instantaneous measurements in time described above as a limiting case. There is however, a class of measuring techniques which can average spatially. Indirect measurements of ocean currents through pressure or electric field observations are integrating techniques, as are acoustic anemometry or thermometry. The use of concurrent weather radar observations in conjunction with an ocean buoy system raises the possibility of combining extensive continuous observations over the sea surface with an array of point measurements. In this report, the spatial observations will be assumed to be point measurements.

The physical construction of any sensor imposes a limit on time and space scales to which it can respond. That is, any sensor will be unable to respond to the variability of a physical parameter having a time scale less, or a spatial scale smaller, than some specific value. This value depends on the construction of the sensor, and is referred to here as the response time or response distance.

A final basic system design factor is sensitivity, the accuracy with which parameter values are recorded and transmitted. Sensitivity considerations must be carefully taken into account in good systems design, but a detailed consideration of instrumental sensitivity is not critical at this stage of planning for the NDBS and is not discussed extensively in this report.

2.2 Data Flow

In this report we will consider "users" to denote an intermediate group (i. e., each user may have its own ultimate recipients of environmental information products). The recipients of these products will be referred to as the "ultimate users", when necessary. An example of the distinction arises in the case of the Weather Bureau, which would be the "user" in our terms. The general public would be the "ultimate users" as the recipients of weather forecasts.

The NDBS will gather data from the natural environment and Fig. 2-3 shows a possible representation of data flow. From the buoy system, the data is routed to

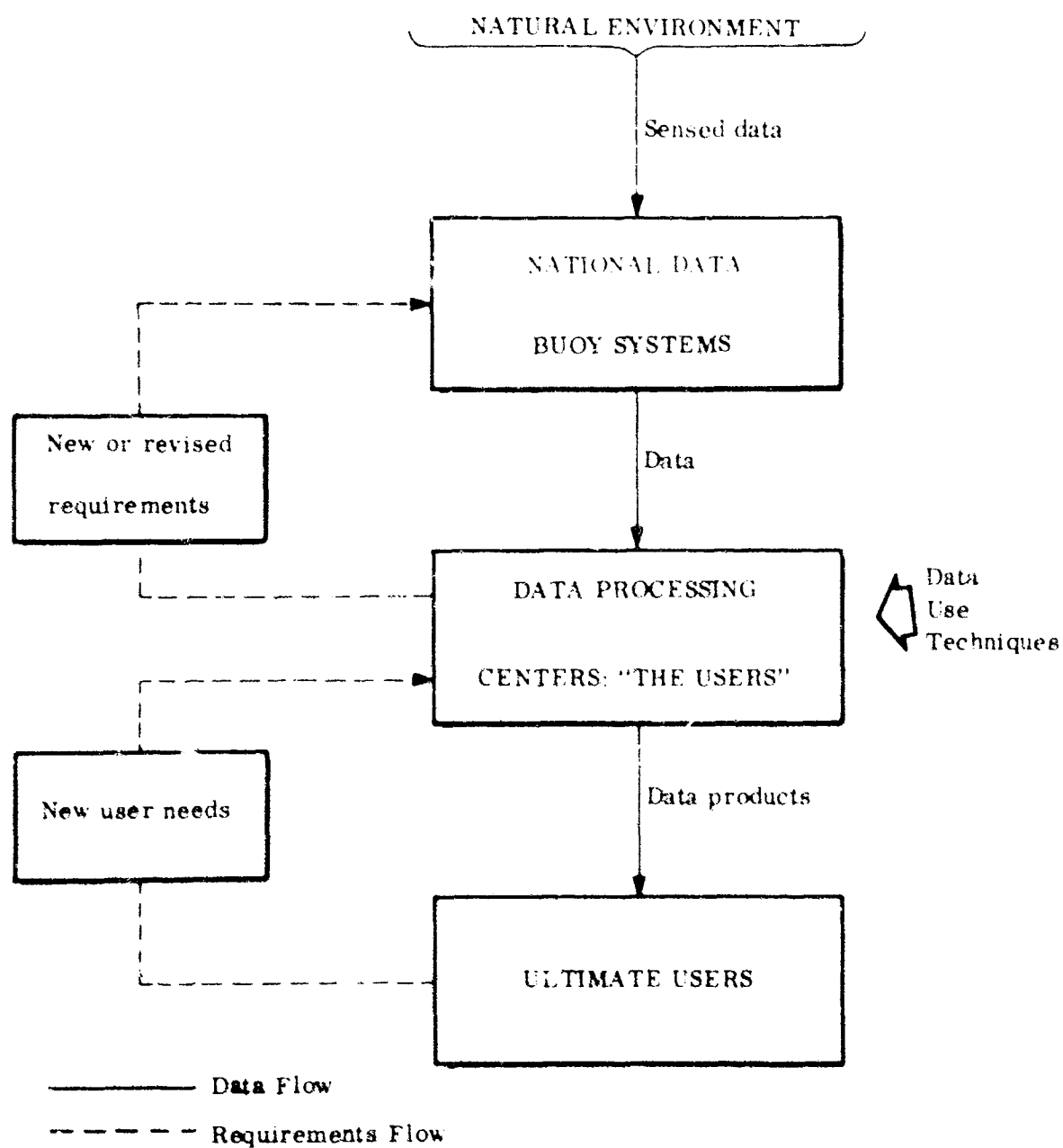


Fig. 2-3. Data Flow

the data processing centers where state-of-the-art data use techniques will be employed (i.e., Fourier methods, etc.). This is a critical link in the data flow chain. The incoming data must be matched to the particular data processing techniques that are being employed by the users at the time the NDBS becomes operational.

As more information is gained about the environment, the data processors will undoubtedly revise their requirements. These revisions will be fed through appropriate feedback channels to the operators of the NDBS.

The data centers will provide their data products to the ultimate users. A feedback channel from the ultimate users to the data processing centers will likely result in still further revisions of requirements.

2.3 Data Use - General Considerations

Data output from the NDBS might appear in a form such as seen in Fig. 2-4 and could have a variety of uses ranging from archiving to complex processing in an automated physical prediction model. We propose that the most demanding use of the gathered data to be considered in this study is to produce estimates of the values of the required parameters at times and places at which no measurements are available. This use of the data does not restrict the applicability of our considerations as much as it might appear at first glance, since in most cases such an objective will be a necessary intermediate step, even if the information product ultimately desired goes beyond this. If the time at which the data is desired is of little interest, one might fill the gap by placing a sensor at the point desired and thereby solve the problem. However, if the data value is desired at some future time, a large range of practical problems arise which cannot be solved so easily. These comprise in total the environmental prediction problem.

A much more comprehensive discussion of these problems than is possible here is given in Ref. 1.

Historically, there have been three general approaches used in the environmental prediction problem. In a gross sense, these may be labelled statistical, empirical, and physical.

(1) The statistical approach is based on the availability of a large representative sample of past data representative of the location of interest and, in general, a set of similar observations at an initial time.

(2) The empirical approach applies some simplified physical principle, generally with a more limited past data sample that is sufficient to show that the simplification is valid. A set of similar observations is required at some initial time prior to the time for which the prediction is made.

(3) The physical approach applies more detailed physical laws to a set of initial data obtained from recent observations prior to the time at which prediction is required.

In principle, fullest application of the physical approach to the environmental prediction problem would require that the physical state at initial time be described over the full spectrum of scales of variability in the atmosphere and ocean. This would be true even if the prediction were only desired for a limited portion of the spectrum, because of the possibility for significant energy transfers between widely different scales of variation. Thus, a purist would deny the validity of the physical approach to the prediction of global atmospheric or oceanic circulations, unless it includes explicit consideration of physical processes down to the scale of cloud or ocean spray droplets. However, experience has shown that useful, physically based prediction models can be developed with the effects of smaller scale physical processes either omitted or included in gross approximate ways. Therefore, distinction between these three approaches is somewhat overstated here, for the purposes of highlighting a few of the different ways in which the NDBS data recipient might use the data to extract only one class of environmental information (viz., prediction of the marine environment).

It is expected that data gathered from the NDBS will have significance insofar as it reduces uncertainty in the marine meteorological and oceanographic information, e. g., insofar as the differences between forecast values of a parameter at a future time and the actual values observed at that future time are reduced in some statistical sense with NDBS data from those obtained without NDBS data. We assume that as uncertainty is reduced, the prediction has increasing significance and value to an increasing number of users. This underlying assumption is quite difficult to confirm in detail, as anyone who has struggled with the problem of estimating benefits obtainable from environmental information services can confirm. [3] Still, it forms the justification for many of our present operating environmental information systems.

2.4 Data Analysis: Spectral Representation

A series of measurements of an oceanic parameter will usually show complex variations with time. An example is the time series of ocean current shown in Fig. 2-4. [4] In the general case, this variability will have a random (or noise-like) character. It probably cannot be described by any explicit mathematical relationship because each set of observations of the parameter will be unique. Often, meaningful representations of such signals can be obtained by using the spectral method to obtain a description of the variance of the parameter as a function of frequency. Such a representation of the time series (Fig. 2-4) is shown by the spectrum in Fig. 2-5. [4] This method can be applied with generality to any time series, and does not require (or imply) that the series be composed of regular oscillations. For geophysical processes, most of which produce variability with random properties, spectral techniques provide a powerful framework for describing the basic characteristics of the geophysical system.

Observations collected over the array points of a data buoy system at any point in time can be treated as space series in complete analogy with the time series collected over time at any point in space. The result of spectral methods will provide a description of the variability in space in terms of the variance of the parameter as a function of wave number. (Just as frequency can be thought of as equivalent to the number of cycles of variation in a unit time, so wave number is equivalent to the number of cycles of variation in a unit distance.) As with time variability, the space variability produced by most geophysical processes has a random character.

Nearly every physical process will have a spectral representation in the horizontal space dimension different from that in the vertical. A few will have one spectral representation in the north-south (y) dimension and another in the east-west (x). However, for the purposes of this report, a generalized horizontal wave number is used. This will adequately describe most atmospheric and oceanic processes. The variability in the vertical does not play a critical role at this stage of planning for the NDBS. Vertical variability must be considered carefully in planning a complete NDBS, but this factor has not been considered within the scope of the present report.

Using both the frequency (f) and the horizontal wave number (k), natural processes in the marine environment can be separated and categorized. This method

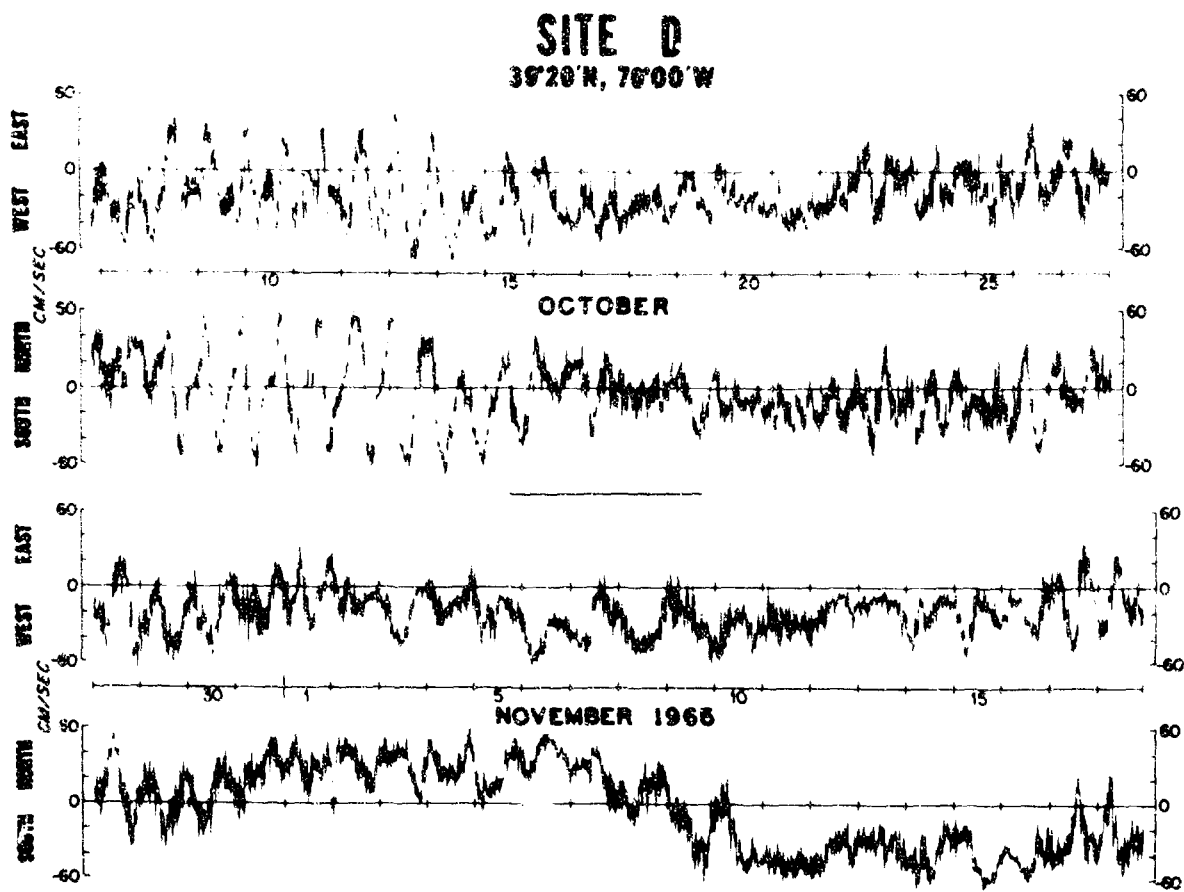


Fig. 2-4. An Example of an Observed Series of Ocean Current Measurements (after Webster [4])

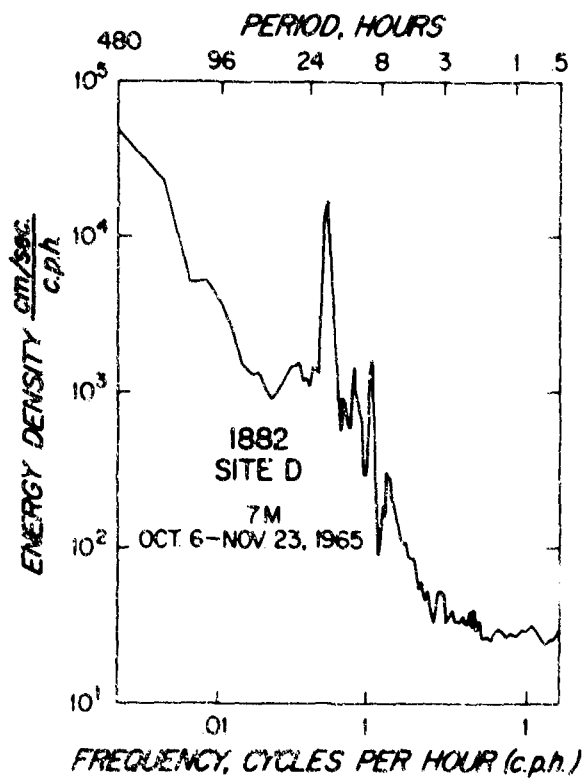


Fig. 2-5. The Spectral Representation of Fig. 2-4 (after Webster [4])

will be used extensively in this report to examine design alternatives for National Data Buoy Systems. Any system that is finally implemented will necessarily impose limitations on our ability to monitor, understand, and predict the marine environment. By describing the system in the frequency-wave number domain, those limitations can be outlined most clearly.

2.5 Representation of Processes in the Marine Environment

Natural processes in the atmosphere and ocean can be categorized by the frequency and wave number of the variability which they produce in various physical parameters. An example of this categorization is shown in Fig. 2-6, where the spectrum of variability of sea level is shown. [5] In this spectrum where the axes of period and wave length have been used in preference to frequency and wave number, energy peaks corresponding to concentrations of variability can be seen. These peaks (or perhaps 'mounds' might be a better description for this figure) can be related to physical processes. Thus, for example, it can be seen that tidal effects have associated energy concentrations with periods of nearly a day and with wave lengths of from 1 to 10,000 km.

Graphs similar to Fig. 2-6 are used throughout this report to classify natural phenomena and to examine the implications of systems design alternatives. Because the abscissa used is frequency (f) and the ordinate is wave number (k), such diagrams will be referred to hereafter as f - k graphs (see for example Figs. 3-1 through 3-17).

The basic units of the f - k graphs are:

- (1) Frequency in cycles per year
- (2) Wave number in cycles per earth's circumference, i.e., cycles/25,000 miles or cycles/40,000 km.

For convenience in interpretation, the f - k graphs have also been labelled with corresponding period and wavelength equivalents.

The f - k graphs of natural phenomena have been compiled from the best information currently available. This information is not sufficient to produce a definitive set of f - k graphs. The frequency and wave number properties of many marine processes are barely understood yet. However, estimates for the properties are given here in order to provide some guidance in buoy system design. It should be clearly recognized

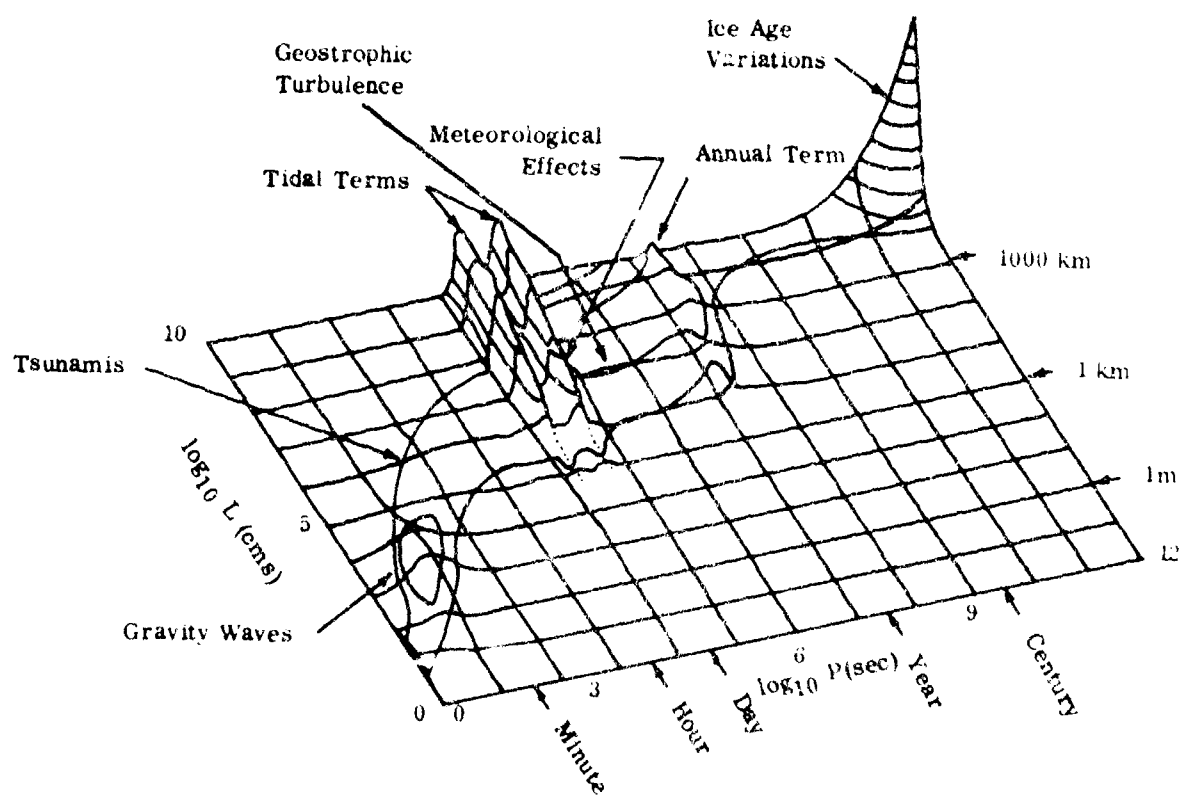


Fig. 2-6. Schematic Diagram of the Spectral Distribution of Sea Level
(After Stormel [5])

that a high priority objective of any data buoy system should be the acquisition of more complete knowledge about the natural variability of the environment.

In Section 3.0 a separate f-k graph is presented for each of various parameters which the NDBs might observe. On each graph, regions have been enclosed showing the limits of various oceanic processes which affect that parameter. The limits of these regions depend on the physical properties of the natural processes in the marine environment. They do not depend on the sensitivity or accuracy of any data collection system. In fact, the amplitude of variability in the third dimension of the f-k graph (as shown, for example, in Fig. 2-6) is unrelated to choice of sensor accuracy or level of detection. Such choices, while of great importance to system design, have not been considered within the scope of this report.

2.6 Representation of Data Buoy System Characteristics

The spectral range of natural phenomena of national interest in the marine environment is extremely broad. Even the limited spectrum of Fig. 2-6 covers 10 decades in wave length (or wave number) and 12 decades in period (or frequency). Any national data buoy system will only be able to respond to natural processes within some limited area of this frequency-wave number domain. Unless this area is clearly known and carefully chosen, there is the possibility that a buoy system will fail to collect the data needed for specific national purposes.

The region of the f-k domain within which a data collection system can respond is known as the system "window". A central issue discussed in this report is the matching of systems windows to the natural environment which is to be monitored.

There are a number of choices which can be made in systems design. Their influence on the spectral window of the system is briefly summarized here. (In the following discussion, the word "frequency" should be interpreted in the general sense, referring to either frequency or wave number.)

(1) Sampling rate. The sampling rate in either space (x, y, z) or time (t) must be carefully matched to the smallest space or time scales at which the system can respond to significant variance in the parameter being measured. If the frequency corresponding to the sampling rate is less than the frequency of significant variance in the parameter, the high-frequency variability will be folded into the system window

and will appear "aliased" as low-frequency variation. Countless observational programs have been ruined by careless regard for aliasing problems.

(2) Duration of individual observations. (Cutoff frequency.) By averaging over a period in time, the highest frequency to which the system can respond can be lowered. By this means, high-frequency "noise" can be prevented from contaminating the system through aliasing. The highest frequency to which the system can respond is called the "cutoff" frequency. The cutoff frequency can be controlled either by sensor design (time constant, spatial dimensions) or by sampling procedures.

(3) Duration of a set of observations. The longer a set of observations is extended in space or time, the more accurately can the spectrum of variability be estimated. This is not true if the spectrum of the processes changes in time or space (nonstationary or inhomogeneous processes).

(4) Accuracy of observations. Accuracy of observation (sometimes called sensitivity or threshold) is not critical to the estimation of spectral properties. As accuracy is decreased, the only result is an increase in the uncertainty of the estimated value of the spectrum. This is not to say that accuracy is unimportant, but that it does not play a critical role in the spectral formulation. (See Section 6.0 for further comments on accuracy.)

(5) Position and timing accuracy. (Synchronization.) Inaccuracies in position and timing will increase the uncertainty of the estimated value of the spectrum. Synchronization of a set of measurements over an array is not critical to the spectrum if sampling rates have been properly chosen.

Fig. 2-7 shows diagrammatically how design choices are related to the system window. Definitions of the numbered boundary lines are as follows. Boundaries ① and ②: Cutoff wave number and frequency (k_C and f_C). Any variability with wave number or frequency greater than these values cannot be detected by the system. By the nature of their definition, cutoff frequencies and wave numbers are not sharply defined. Boundaries ③ and ④: Folding wave number and frequency (k_N and f_N , where N stands for Nyquist*). Any variability with wave number or frequency greater

*The nyquist frequency is defined as the lowest frequency coinciding with one of its aliases: it is the reciprocal of twice the time interval between sampled values.

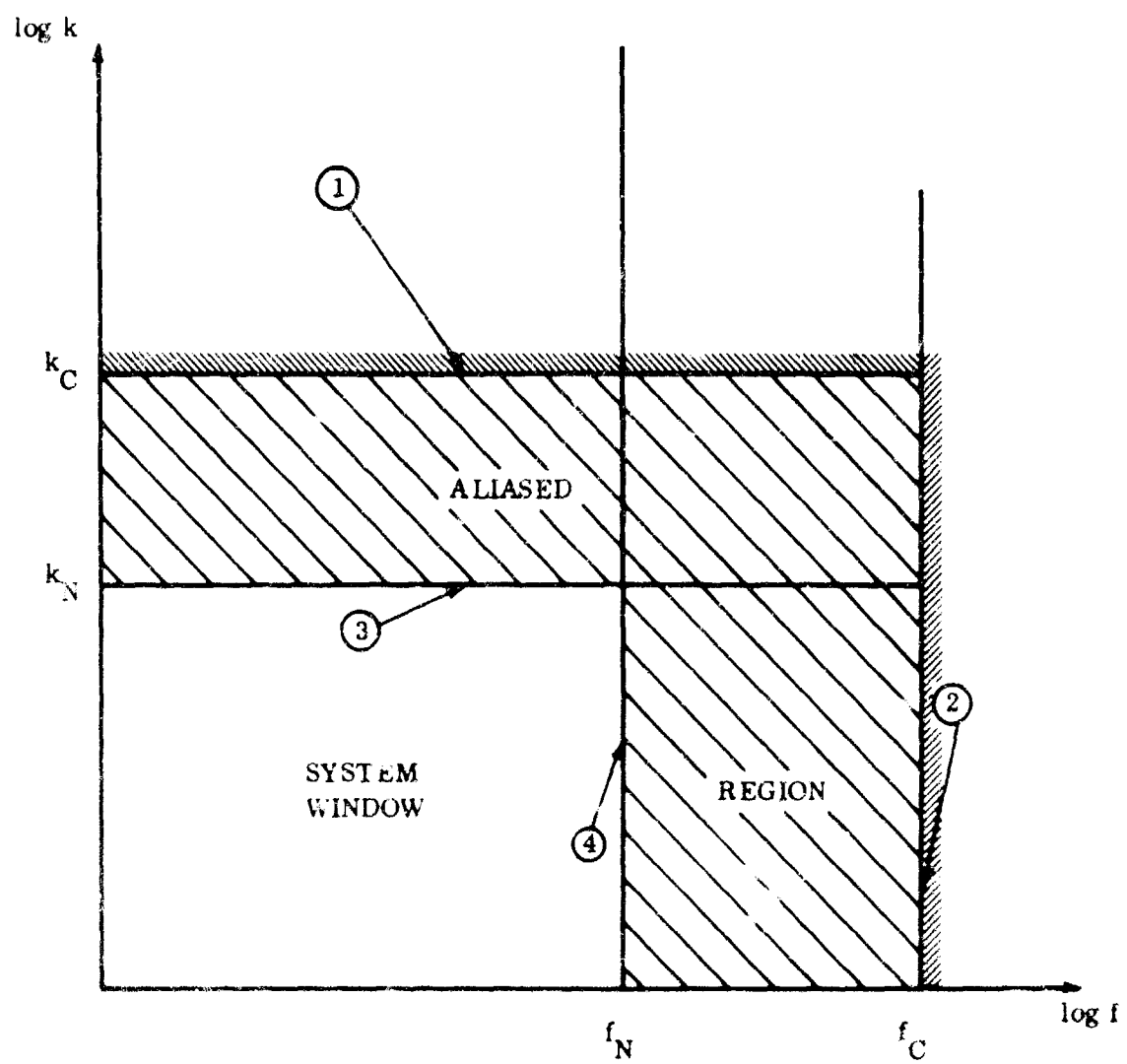


Figure 2-7. Relation of Design Choices to System Window

than f_N or k_N that can be detected by the system will be folded into the system window. This folding process will "alias" high-frequency processes into low-frequency images and can degrade the system effectiveness. It is therefore important in system design to guard against any large amplitude variability in the "aliased region" of Fig. 2-7. Aliasing can be prevented either by increasing f_N and k_N by sampling more intensely or by decreasing f_C and k_C by increased filtering at the sensor. [6]

The folding wave number and frequency are sharply defined by the sampling rate. If a sample is collected every Δs units (of time or space), then f_N or $k_N = 1/(2 \Delta s)$.

Fig. 2.3 shows how system design choices can effect the response to natural processes. Possible physical processes are labelled P_1 , P_2 , P_3 and P_4 . Discussions of these processes are given below.

Process P_1 (e.g., large-scale atmospheric disturbances) is wholly within the system window, and can be adequately monitored with the chosen system design.

Process P_2 (e.g., tides) is wholly within the system frequency window, but is aliased with respect to wave number. Such a design may be fully adequate if only time variability is of interest.

Process P_3 (e.g., wind generated waves) is within the aliased region. It is folded into the system window represented by regions P'_3 , and may corrupt the quality of the information of interest. In this example, both k_C and f_C should be lowered by systems design changes.

Process P_4 is beyond the system response. It cannot be detected.

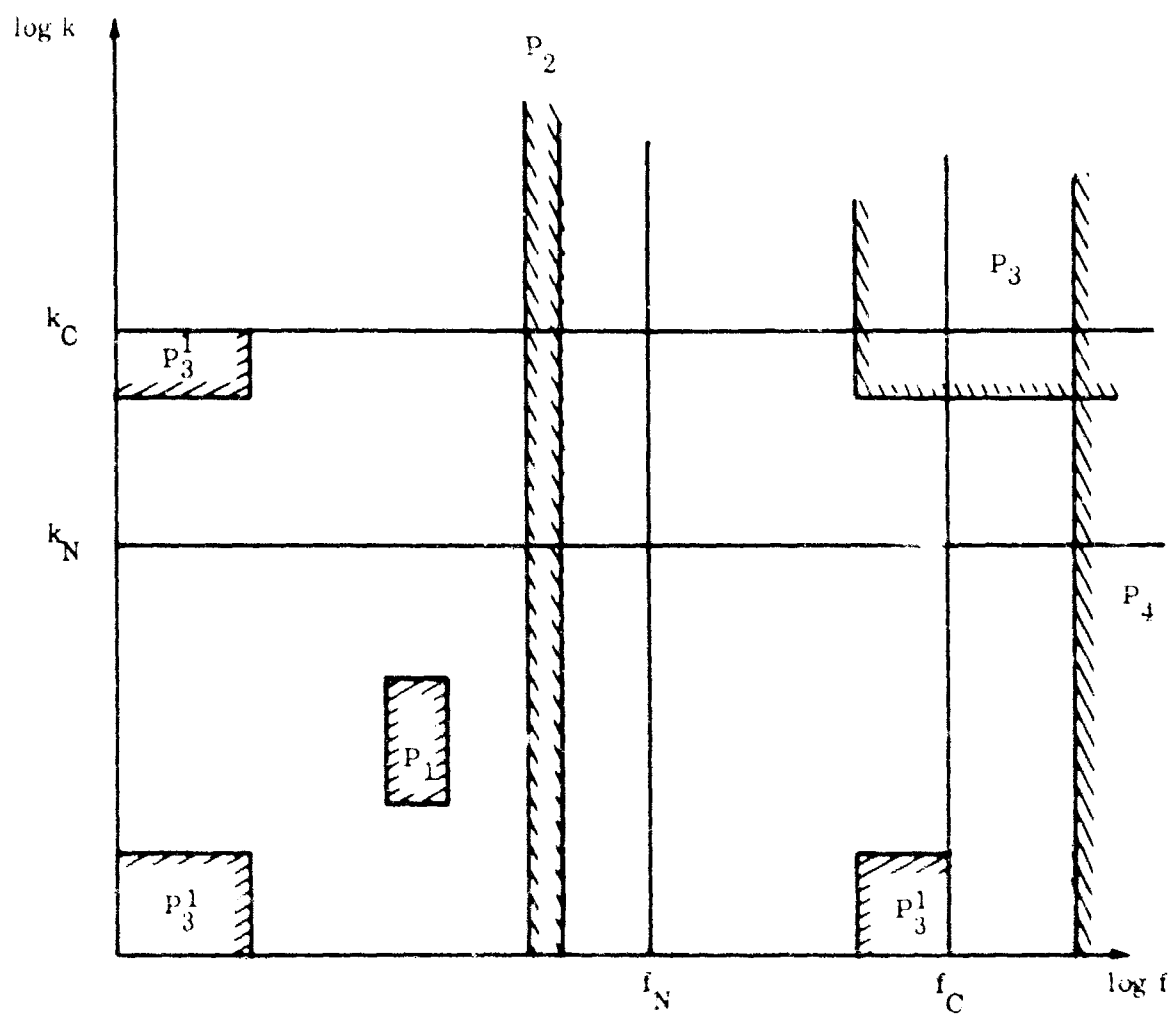


Fig. 2-8. Response of System to Natural Processes

3.0 COMPARISON OF NDBS CHARACTERISTICS, NATURAL PHENOMENA, AND DATA USE TECHNIQUES

3.1 Background

In Section 2.0, a somewhat abstract framework was developed upon which a first comparison of NDBS characteristics, natural phenomena and data use techniques can be easily made. In this section, the f - k graphical approach is applied within this framework to compare several different sets of NDBS characteristics with the time and space variability of atmospheric and oceanic phenomena, as presently understood. The comparison is presented graphically on an f - k diagram and is followed by interpretation with respect to data use techniques (prediction models).

A refinement of the treatment of the system characteristics illustrated in Fig. 2-7 is offered in many of the following f - k graphs. The refinement graphically illustrates the potential information gained by not averaging over the duration of an observation. Perhaps this is best illustrated by example. Suppose the wind is sampled every 3 hours over a duration of observation of 15 minute with a sensor response time of 10 seconds (Fig. 3-11). The data received during the observation in its unprocessed form allows another window to be opened in the aliased region between the 10 second cutoff frequency and about the 15 minute duration of observation (see Fig. 3-11). On the other hand, if the data is averaged over the 15 minute period this second window is lost and variability in this window is not detected. Thus, the cutoff frequency becomes the 15 minute line, and the width of the aliased region is reduced.

It should be noted that the limits of the window in Fig. 2-7 and all the similar windows in the following f - k graphs represent a somewhat ideal case. In reality, in the presence of noise the limits of the windows might not extend to as high a frequency and/or wave number as the Nyquist frequency.

There are two important underlying simplifications in the presentation of the natural variability of phenomena on f - k graphs. First, the variability of natural phenomena as indicated on these graphs in this section are representative only of horizontal space scales. A separate set of graphs would be necessary for the vertical scales of variability in the ocean and atmosphere. The work required for this second set was outside the practical scope of the present study. Second, the k axis on the f - k graphs is assumed to be a scalar magnitude

independent of horizontal direction. At this point in our knowledge of the environment and within the unrefined framework that has been set forth in Section 2.0, this is a useful simplification. For example, the representation of directional characteristics of Gulf Stream meanders (i. e., along and across the main axis of the stream) would unnecessarily complicate the resulting graphs. Under this simplification the position of k_N (line γ in Fig. 2-7) on the f-k graphs is determined by a uniformly spaced grid. The framework developed in Section 2 (in particular the f-k graphs) is a very general approach to a complicated problem, but it can serve as a "first approximation."

The scales of natural variability depicted in the following graphs (Figs. 3-1 through 3-17) are based on some observation, a good deal of inference, and some theoretically calculated limits. The scales are indeed a "first guess" and indicate the pressing need for the development of the NDBS in order to develop greater understanding of the phenomena.

3.2 Major Oceanographic Phenomena

There are a variety of oceanic physical variables ranging from bathymetry to surface waves. This report is only concerned with the phenomena that affect the parameters to be measured by the NDBS. In this section the discussion is devoted to the oceanographic parameters: viz., current, salinity, water temperature, sound speed, ambient noise, ambient light, and transparency.* Thus, we are concerned with the motion, the thermohaline state, and some of the biological matter in the ocean.

Ocean currents are particularly important because of their ability to transport all physical properties and suspended material in the oceans. Some of the most important of these properties are heat, mass, momentum, salt, and dissolved oxygen. Therefore, a presentation of the pertinent oceanic phenomena must include most forms

*The projected NDBS will probably measure at least 20 parameters, three of which are concerned with wave measurements (e. g. height, period, and direction), for which f-k graphical analysis are not presented. The windows required for these measurements are well-known, and do not coincide with the windows of concern for the rest of the parameters. Surface gravity waves with periods between 1 and 30 seconds are indicated in some of the tables and f-k graphs for the purposes of demonstrating possible sources of noise and aliasing. Four of the parameters--current direction and speed and wind direction and speed--have been collapsed into two parameters: current and wind vectors. This was done for convenience of representation.

of ocean currents. The currents are modified by astronomical, thermal, and geographic factors which act and interact in the ocean.

Another influential factor causing variation in several of the ocean parameters is biological matter. Parameters influenced by biological matter include transparency, ambient light, and ambient noise.

Ocean phenomena display a wide spectrum of time and space variability (variations in frequency, f , and wave number, k , see Fig. 3-1) as well as variations in their relative frequency and location of occurrence.* In Table 3-1 are summarized the characteristic space, time, and amplitude scales and the characteristic-geographical location and occurrence of oceanic phenomena affecting the NDBS sensors. The graphical representation of these phenomena is found in Fig. 3-1. Table 3-1 and Fig. 3-1 represent an attempt to summarize our fragmentary information about ocean variability. The use of the "phenomena" concept represents a convenience for communication and summary purposes at our present state of knowledge.

Some of the points worth noting in Table 3-1 and Fig. 3-1 are as follows. Large-scale wind-driven gyres and thermohaline gyres (Item 1 and 2 in Table 3-1) are theoretically two distinct phenomena (e. g., they have two distinct driving forces). In reality, they may not be distinguishable, because of their common space and time scales. The characteristic time scales of Item 1 and 2 are estimates based on some theoretical limits and a few observations. There is only ambiguous evidence for the postulate that the thermohaline gyres have smaller speeds than large-scale wind-driven gyres.

Philosophically, Items 3 (probably a part of Item 12), 4 (also probably a part of Item 12), 7, 8, 9, 10 and 12 (Table 3-1) all might be considered as wave motions, and all have the same characteristic locations, occurrence, and (probably) speed amplitudes. As more is learned about ocean currents, we will likely recognize that many of the phenomena are really manifestations of a few fundamental processes.

The Deep Scattering Layer (Item 13) and plankton and/or algae bloom (Item 14) are included because they could cause variations in several of the parameters (i. e., sound speed, ambient light, noise, and transparency).

*Most of the ocean phenomena that appear in Fig. 3-1 occur in all oceans although certain types appear to be more common in some locations. The frequency of occurrence is based on the likelihood of a phenomena occurring at any one buoy.

- | | |
|---|------------------------------------|
| 1 - Large-Scale Wind Driven Gyres | 10 - Small-Scale Convective Eddies |
| 3 - Surface Current Meanders | 11 - Surface Gravity Waves |
| 4 - Internal Current Meanders | 12 - Rossby Waves |
| 5 - Surface Topographic Eddies | 13 - Deep Scattering Layer |
| 6 - Submarine Topographic Eddies | 14 - Plankton and/or Algae Bloom |
| 7 - Semi-Diurnal, Diurnal, Semi-Annual Tides (As indicated on Fig. 3-1) | 15 - Thermocline |
| 8 - Inertial Currents | 16 - Turbidity |
| 9 - Internal Waves | 17 - Surges |
| | 18 - Tsunami |

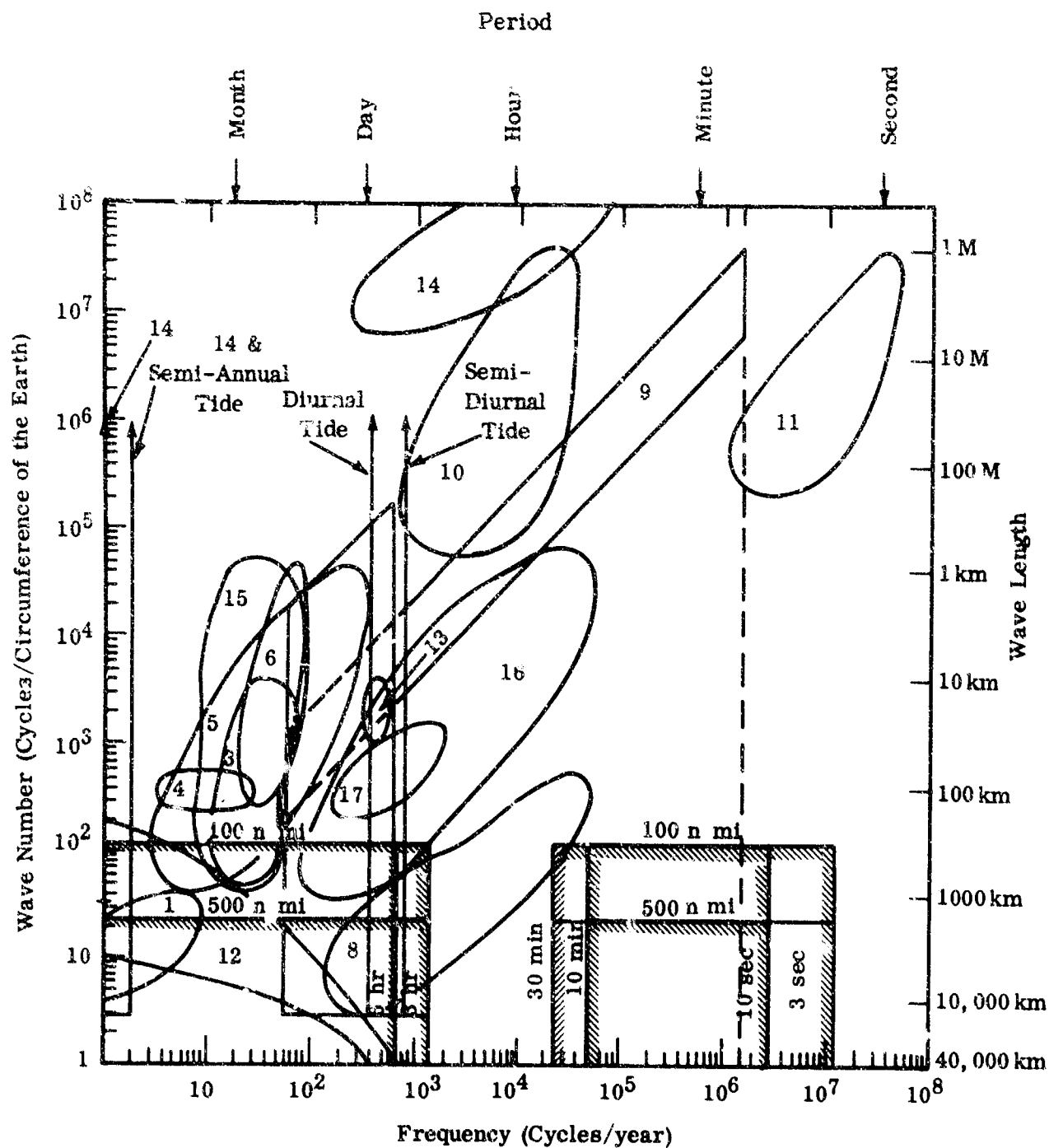


Fig. 3-1. Major Oceanic Phenomena

TABLE 3-1
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA

Phenomenon	Characteristic Space Scale	Characteristic Time Scale	Characteristic Location	Characteristic Occurrence	Characteristic Amplitudes ⁽¹⁾
1. Large-scale wind-driven gyres	$10^3 - 10^4$ km	1 mo - 10 yr	All oceans	Continuous	50 cm/sec - 250 cm/sec (1 kt - 5 kt)
2. Thermohaline gyres (not shown on graph)	$10^3 - 10^4$ km	1 - 10^2 yr	All oceans	Continuous	1 cm/sec - 10 cm/sec (.02 kt - .20 kt)
3. Surface current meanders	$10 - 10^3$ km	10 days	All oceans but especially western portion	Continuous	50 cm/sec - 200 cm/sec (1 kt - 4 kt)
4. Internal current meanders	10^2 km	10 - 10^2 dy	All oceans	Continuous	3 cm/sec - 20 cm/sec (.06 kt - .40 kt) ⁽²⁾
5. Surface topographic eddies	$1 - 10^3$ km	1 - 10^2 dy	Coasts and convergence regions	Continuous	~ 2.5 cm/sec or less (0.05 kt)
6. Submarine topographic eddies	$1 - 10^4$ km	10 days	All ocean	Continuous	~ 2 cm/sec (0.04 kt)
7. Tidal currents	? - 1.5×10^4 km ⁽³⁾	.5 - 182 dy	All, but especially coasts	diurnal, semi-diurnal, or semi-annual (solar tide)	~ 50.0 cm/sec ⁽⁴⁾ (1.0 kt)

TABLE 3-1
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA (Continued)

Phenomenon	Characteristic Space Scale	Characteristic Time Scale	Characteristic Location	Characteristic Occurrence	Characteristic Amplitudes ⁽¹⁾
8. Inertial currents	.2 - 1.5 x 10 ⁴ km	13 - 137 hr ⁽⁵⁾	All oceans	Frequent	50 cm/sec (1 kt)
9. Internal waves	10 m - 1 km	2 - 10 ³ min ⁽⁶⁾	All oceans	Frequent	5 cm/sec - 25 cm/sec ⁽⁷⁾ (.1 kt - .5 kt)
10. Small-scale convective eddies	10 m - 1 km	10 - 10 ³ min	All oceans	Frequent	25 cm/sec (max) (.5 kt)
11. Surface gravity waves	1 m - .25 km	1 - 30 sec	All oceans	Continuous	100 cm/sec (max) ⁽⁸⁾ (2 kt)
12. Rossby waves ⁽³⁾	200 - 40,000 km	4 dy - 1 yr	Theoretically in all oceans	Occasional	2.5 cm/sec - 500 cm/sec (.05 kt - 10 kt)
13. Deep scattering layer	10 - 10 ² km	1 day	Most oceans	Frequent	10 ² m
14. Plankton and/or Algae Bloom	10 cm - 10 km	10 min. - 10 days	Mostly coastal regions	Rare	30,000 per c.c.
	? - 10,000 km	1/2 yr.	Mid & sub-tropical latitudes	Continuous	15,000 per c.c.
	? - 3000 km	1 yr.	High arctic seas & tropic	Continuous	10,000 per c.c.

TABLE 3-1
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA (Continued)

Phenomenon	Characteristic Space Scale	Characteristic Time Scale	Characteristic Location	Characteristic Occurrence	Characteristic Amplitudes ^①
15. Thermocline	1 - 10 ³ km	10 - 200 days (seasonal) 1 - 10 yr. (permanent)	All oceans	Continuous	10 m - 500 m
16. Turbidity currents	1 - 10 ³ km	10 min - 10 days	All oceans	Occasional to rare	25 cm/sec - 25 m/sec ^⑩ (.5 kts - 50 kts)
17. Surges	20 - 200 km	5 hrs - 3 days	Coastal regions of all oceans	Occasional	1 - 5 m (in coastal regions)
18. Tsunami ↙ Individual wave ↘ Field	80-400 km 80 - 1.5 x 10 ⁴ km	15-60 min 2 hrs - 3 days	All oceans	Rare	5-20 m (in island or coastal region)

① Amplitudes given are for a single "key" parameter.

② In one instance, current velocities of 43 cm/sec were measured at 4000 m.

③ The distance of 15,000 km was arbitrarily chosen in the extent of the largest ocean basin. There is some doubt as to the extent to which the tidal effect influences the smaller scales. In theory, at least, the tidal force should effect the entire water mass.

④ Tidal currents in channels or other narrow passage ways may reach upwards of 10 knots.

TABLE 3-1
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA (Continued)

- ⑤ The two time scales correspond to the inertial periods at 5° latitude (~137 hrs) and 60° latitude (~13 hrs), respectively. For determination of the upper limits of the spatial scales of inertial oscillations, see the Appendix A.
- ⑥ The time scales for internal waves at a particular latitude must lie somewhere between the inertial frequency at that latitude and the Brunt-Väisälä frequency (see Appendix A). Very often internal waves will display a semi-diurnal (12 hrs 25 min) tidal period.
- ⑦ Speeds of 3 to 4 knots have been observed at the density discontinuity interface (largest orbital velocities for internal waves are found at this interface) under certain density stratification conditions and with the passage of a fast moving atmospheric storm.
- ⑧ The maximum orbital velocity of a 12 foot wave of 10 second period in deep water is 115 cm/sec.
- ⑨ The Rossby waves were considered to have a sinusoidal form, and propagate in an ideal (frictionless) homogeneous medium which is in purely horizontal motion. The equations for calculation of the Rossby waves along with the restrictions on zonal velocities are given in the Appendix A.
- ⑩ The lower characteristic speed is pure speculation based on a heuristic consideration of the dynamic properties of turbidity currents. The upper characteristic speed is taken from the calculations of B. C. Heezen and M. Ewing (1952) which are based on time sequence of breaks in the transatlantic cable south of the Grand Banks after the earthquake of November 18, 1929.

Appearing in Fig. 3-1 are several hypothetical NDBS sampling schemes (i. e., grid spacing of 100 and 500 n mi, reporting periods of 3 and 6 hours., etc.), intended to give the reader an understanding of the effects of various NDBS sampling designs on the windows (defined in Section 2.6).

Possible matches of different NDBS sampling schemes and data use techniques (prediction models) are listed in Table 3-2.

In Table 3-2, the emphasis is on prediction of phenomena (i. e., most of the phenomena that appear in Table 3-1). At the bottom of each phenomenon column is a list of the parameters that might be used in the prediction of the phenomenon. The basis of Table 3-2 is the classification of prediction models outlined in Section 2.3. In some cases no prediction model is applicable, and in other cases no single prediction model class is uniquely applicable. In the second case the most applicable class is listed first. The principles upon which a choice of the most applicable prediction techniques was made are stated in Section 2.6. There are many cases of potential aliasing (see Section 2.6, 4.0) of phenomena in Fig. 3-1. For the construction of Table 3-2, potentially aliased phenomena are treated as if they will be discriminable from one another. In addition noise arising from platform motions were considered to be non-existent in this table.

A tentative conclusion that might be drawn from Table 3-2 is that the 24-hour reporting period, is for most phenomena, just as applicable for prediction purposes as the 1 hour reporting period. However, future data on the scales of variability of many of the phenomena could reposition them on the f-k graph and lead to drastic changes in the contents of Table 3-2. Still, for designers who must make decisions in the very near future, Table 3-2 should be helpful in early design decisions.

3.3 Major Atmospheric Phenomena

This section is similar to Section 3.2, as it is concerned only with those phenomena that affect the atmospheric parameters to be measured. These parameters include wind, air temperature, atmospheric pressure, dew point, insulation, precipitation and atmospheric electricity. Thus, in this section we are concerned with the motion and energetic state of the atmosphere.

In the atmosphere, various forms of instability are responsible for many of the phenomena that are of interest in this report. These instabilities are produced by

TABLE 3-2
POSSIBLE PREDICTION MODELS APPLICABLE FOR VARIOUS
SAMPLING SCHEMES*

		Phenomena																	
Grid Spacing (m)	Sampling Times	Large-Scale Wind-Driven Gyres	Thermohaline Gyres	Surface Current Meanders	Internal Current Meanders	Surface Topographic Eddies	Submarine Topographic Eddies	Tidal Currents	Inertial Currents	Internal Waves	Small-Scale Convective Eddies	Rough Waves	Deep Scattering Layer	Plankton and/or Algae Bloom	Thermocline	Turbidity Currents	Surges	Tsunami Waves	
		P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
1000	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
500	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
100	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
50	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
10	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
25	24 hr.	P-E	P-F	F	E	E	E	E	P-E	N/A	S	P-E	S	S	E	S	S	S	
	12 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	6 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	3 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
	1 hr.	P-E	P-F	F	E	E	E	E	P-E	P	S	P-E	S	S	E	S	S	P-E	
Parameters Required for Prediction Models		Current	Salinity	Temperature	Water Pressure	Ambient Light & Noise	Transparency	Water Pressure											

Parameters Required for Prediction Models: Current, Salinity, Temperature, Water Pressure, Ambient Light & Noise, Transparency, Water, Pressure.

All Parameter Required as a Function of Depth

Key to Symbols Used in Table

- P = Physical Prediction Model
- E = Empirical Prediction Model
- S = Statistical Prediction Model
- P-E = Physical or Empirical Prediction Model (Most Probably Physical)
- E-S = Empirical or Statistical Prediction Model (Most Probably Empirical)

*The reader should refer to section 2.6 for a general description of the criteria used in determining a choice of applicable prediction model. This table is of a very tentative nature.

**The duration of observation and instrument response time are assumed to have been chosen to yield a representative average of the parameters being measured.

processes such as energy absorption from the sun, radiation into space, conduction, convection, condensation, and evaporation.

A summary of the time and space scales of variability of atmospheric phenomena is presented in graphical and tabular form in Fig. 3-2 and Table 3-3. Again, the estimates of phenomena scales in Fig. 3-2 and Table 3-3 are tentative, but do carry a higher degree of confidence than those of Section 3.2, because of the relatively better understanding of the atmosphere.

Interpreting the variability scales associated with particular atmospheric phenomena should be cross-referenced in using Fig. 3-2 and Table 3-3.

Table 3-4 is similar to Table 3-2 in Section 3.2. It explores the possible prediction models that might be applicable for various NDBS sampling schemes. The emphasis is on prediction of the phenomena appearing in Table 3-3. For the purposes of constructing Table 3-4, any problems arising from an inability to discriminate between phenomena (i. e., aliasing; see Sections 2.6 and 4.2) or platform motions are ignored.

One comparative observation that may be drawn from Table 3-4 is that for the range of reporting periods considered, prediction techniques for atmospheric phenomena are much more sensitive to a change in reporting period than were the oceanic prediction techniques. Other implications of Table 3-4 for the early decision stages in the design of the NDBS are treated in Section 4.0.

3.4 The Parameters to be Measured: A Discussion and Graphical Analysis

A brief discussion and graphical analysis is offered for each of a set of 15 parameters (see first footnote in Section 3.2). The discussion and analyses are concerned with the processes and/or phenomena which influence parameter variability, and any special noise problems due to combined sensor platform motions or natural high frequency oscillations in parametric values. A more detailed discussion of platform mooring motions is given in Appendix B. The effect of these motions on the sensor output are discussed in this section.

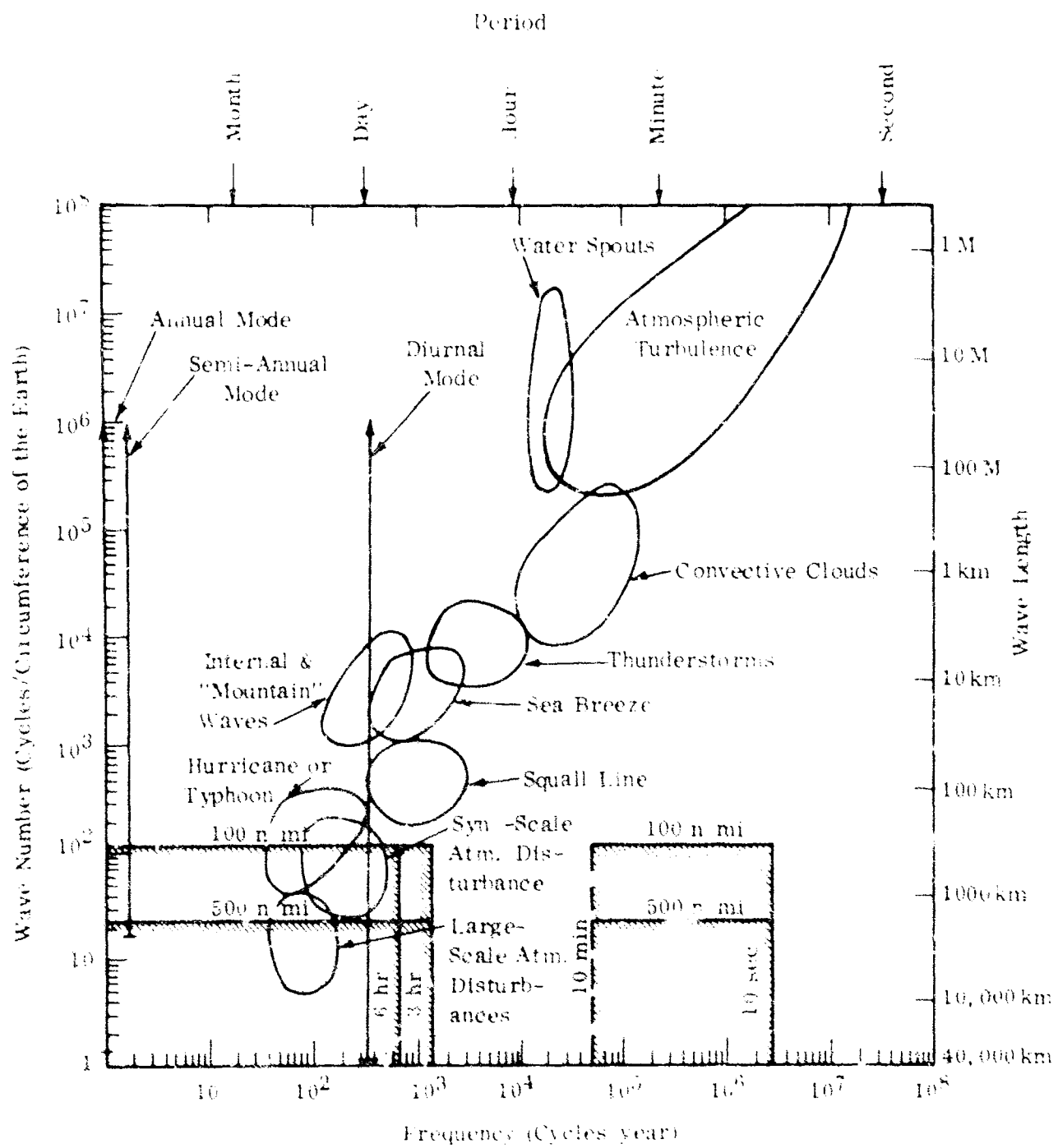


Fig. 3-2 Major Atmospheric Phenomena

TABLE 3-3
CHARACTERISTICS OF IDENTIFIABLE ATMOSPHERIC PHENOMENA

Phenomena	Characteristic Space Scales	Characteristic Time Scales	Characteristic Location	Characteristic Occurrence	Characteristic Wind Speed Amp.
1. Large-scale atm. disturbances	1000-8000 km	2-10 days	All oceans	Continuous	10-20 m/sec
2. Syn.-scale atm. disturbances	200-1500 km	18 hrs.-5 days	All oceans	Frequent	20-30 m/sec
3. Particulars of typhoons	100-1000 km	1-10 days	Tropical (some times migrate to mid-lat.)	Occasional	50 m/sec or greater
4. Squall line	40-200 km	3-24 hrs	All oceans	Occasional	20-50 m/sec
5. Baromet. and "mountain" waves	4-40 km	10 hr.-3-5 days	Coastal or island regions	Rare	20-30 m/sec
6. Sea breeze	5-40 km	3-24 hr.	Coastal or island regions	Frequent	10 m/sec
7. Thunderstorms	2-12 km	45 min.-6 hr	All oceans	Occasional	20-50 m/sec
8. Convective clouds	200 m-5 km	5 min.-1 hr.	All oceans	Occasional	1-10 m/sec
9. Water spouts	2-500 m	15 min.-45 min.	All oceans	Rare	> 100 m/sec
10. Atm. turbulence	1 cm-80 m	1 sec-30 min.	All oceans	Frequent	> 1 m/sec
11. Diurnal mode	2-40,000 km	1 day	All oceans	Continuous	> 1 m/sec
12. Semi-annual (tropical) mode	2-3000 km	1/2 yr.	Tropics	Continuous	> 1 m/sec
13. Annual mode	-40,000 m	1 yr.	All oceans	Continuous	> 1 m/sec

TABLE 3-4
POSSIBLE PREDICTION MODELS APPLICABLE FOR VARIOUS SAMPLING SCHEMES*

Grid Spacing	Sampling	Phenomenon									
		Large-Scale Atm. Disturbances	Small-Scale Atm. Disturbances	Hurricanes Typhoons	Squall Line	Internal and "Mountain" Waves	Sea Breeze	Thunderstorms	Convective Clouds	Water Sprouts	Atm. Turbulence
1000 N.M.	24 hr. **	Phys. - Emp.	Stat.	Emp.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.
	12 hr.		Emp.	Phys. - Emp.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.
	6 hr.										
	3 hr.										
	1 hr.										
500 N.M.	24 hr.	Phys. - Emp.	Stat.	Emp.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.
	12 hr.		Emp.	Phys. - Emp.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.
	6 hr.	Phys.									
	3 hr.										
	1 hr.										
100 N.M.	24 hr.	Phys. - Emp.	Emp.	Phys. - Emp.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.
	12 hr.	Phys.	Phys. - Emp.		Emp.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.
	6 hr.										
	3 hr.										
	1 hr.										
50 N.M.	24 hr.	Phys. - Emp.	Phys.	Phys.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.
	12 hr.	Phys.	Phys.		Stat.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.
	6 hr.				Emp.		Emp.	Emp.	Emp.	Emp.	Emp.
	3 hr.										
	1 hr.										
25 N.M.	24 hr.	Phys. - Emp.	Phys. - Emp.	Phys. - Emp.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.	Stat.
	12 hr.	Phys.	Phys.		Stat.	Emp.	Emp.	Emp.	Emp.	Emp.	Emp.
	6 hr.				Phys. - Emp.						
	3 hr.										
	1 hr.										
Parameters Required Wind Vector											
for Prediction Models Air Temp.											
Atm. Pressure											
Dew Point Precipitation Rate Insolation											

All Parameters Required as a Function of Height

*The reader should refer to Section 2.6 for a general description of the criteria used in determining a choice of applicable prediction model. This table is of a tentative nature.

**The duration of observation and instrument response time are assumed to have been chosen to yield a representative average of the parameters being measured.

3.4.1 Current

The only major oceanic phenomena (see Fig. 3-1) which do not influence the current are the Deep Scattering Layer, plankton and/or algae bloom. Figure 3-3 presents on an f-k graph the phenomena and processes affecting the variability of current. There is, of course, a marked similarity between Fig. 3-1 and Fig. 3-3. Oceanic motions basically occur continuously in all oceans (see Table 3-1) and generally have their highest speeds at the surface (maxima of more than 5 kts are found) and decrease downward to speeds estimated to be several centimeters per second. A possible exception to this are the turbidity currents* which have been calculated (although never observed) to have speeds as high as 50 kts. These currents, if they exist, could pose a serious problem to anchored buoys in certain oceanic and coastal regions. When the time comes to deploy the buoys, the little information available about these currents (i. e., suspected areas of occurrence, etc.) should be taken into consideration in selecting buoy deployment locations.

The current is probably the most susceptible parameter to noise due to sensor-platform motions. Serious distortion (noise) may be introduced into a time series current record in many ways due to the motions induced by the platform and/or mooring (see Appendix B), as well as by the imperfect response of the sensor to the noise and platform transients and to the real transients which appear to exist in the sea. There are basically two types of errors that can occur when measuring currents from a fixed or moored platform. First, there are those errors that can occur without any motion of the supporting platform or mooring, such as distortion of the near-surface flow past the platform and the dynamic error of the current meter itself; second, there are possible errors due to mooring motions (platform-mooring system) in company with sluggish response of the meter, when exposed to a sudden change in the current. The second type of error is the most serious and could possibly lead to phase shifts and attenuation of certain parts of a time series speed record (see Fig. B-2 in Appendix B). The slack and elasticity of the suspension element also can lead

*A turbidity current originates on sloping bottoms. It is a gravity current resulting from a density increase by suspended material. It also is called suspension current and density current.

- | | |
|---|------------------------------------|
| 1 - Large-Scale Wind Driven Gyres | 10 - Small-Scale Convective Eddies |
| 3 - Surface Current Meanders | 11 - Surface Gravity Waves |
| 4 - Internal Current Meanders | 12 - Rossby Waves |
| 5 - Surface Topographic Eddies | 13 - Deep Scattering Layer |
| 6 - Submarine Topographic Eddies | 14 - Plankton and or Algae Bloom |
| 7 - Semi-Diurnal, Diurnal, Semi-Annual Tides (As indicated on Fig. 3-1) | 15 - Thermocline |
| 8 - Inertial Currents | 16 - Turbidity |
| 9 - Internal Waves | 17 - Surges |
| | 18 - Tsunami |

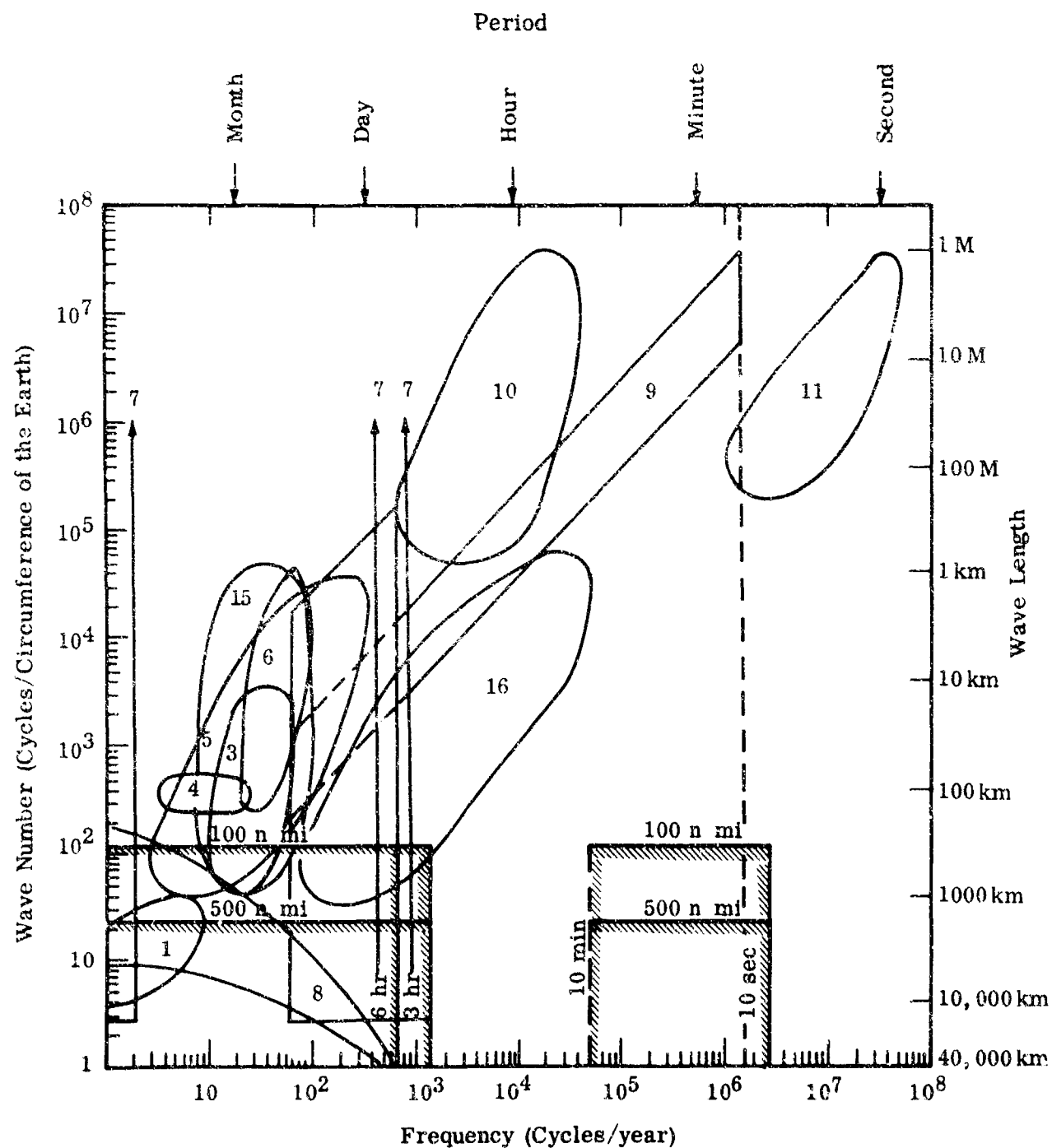


Fig. 3-3. Phenomena and Processes Affecting the Variability of Current

to system time constants larger than those of the sensor in both direction and speed response depending on the type of buoy and mooring used. These time constants can be of the order of 1000 seconds.

Vertical motion of the current meter (heaving of the platform transmitted to the meter) can also cause distortion in the speed record of a current meter. Some current meters also tend to tilt from the horizontal when encountering strong currents or moderate to heavy heaving.

The best available solution to many of these problems appears to be found in a Savonius rotor meter with built-in OESE (Oceanic Environmental Sensing Equipment)*, on a taut moor. The current meter must have rapid response in both direction and speed and be able to operate accurately over a wide range of speeds (the NDBS requirements are 0.05 to 10 kt). In addition, the current meter should be insensitive to vertical motions and able to integrate accurately to zero all the undesired cyclic motions that occur from mooring-sensor-platform combinations. The meter must also sample at a sufficiently high rate or have a large enough cutoff frequency to minimize aliasing problems.

The occurrence of distorted records from current meters could introduce noise into spectrum bands in both frequency and wave number. Noise may appear across the entire band or at only a few discrete frequencies or wave numbers. The noise band in frequency spans all wave numbers (although its intensity might vary with wave number) and similarly, the band of noise in wave numbers span all frequencies, thus creating areas in which increased difficulty arises in resolving phenomena. Unfortunately, there are too many variables involved to be able to arrive at exact limits for the bands of noise as they would appear on the current f - k graph. However, a graphical display of the possible noise from platform motion is given in Fig. B-5 in Appendix B. The approximate limits of these bands would be 10^4 to 10^6 in wave number and 10^4 to 10^9 in frequency. The upper limit was suggested by Toth and Vochon. [7]

An important consequence of slow response often associated with mooring motions, is that the corresponding time constant of the mooring system may far exceed the

*The OESE is capable of measuring linear accelerations, angular rotations, and the forces in the three coordinate directions.

duration of observation. Thus a time constant larger than many physically significant periods of natural variation might result. Therefore, a 10 minute duration of observation could possibly present sampling problems. Again, this may be avoided by the use of the Savonius rotor current meter with OESE instrumentation and a taut moor.

3.4.2 Salinity

The processes affecting the variability of salinity are advection in the presence of a salinity gradient, evaporation, precipitation, melting and freezing, and run off. Evaporation is influenced by atmospheric humidity, wind speed, and air-sea temperature differences. Precipitation is influenced by that general class of phenomena identified as atmospheric disturbances (see Fig. 3-2).

It is obvious that the f-k graph of phenomena and processes affecting salinity*, Fig. 3-4, should contain many of the phenomena of Fig. 3-1 and Fig. 3-2.

Instead of indicating all influencing phenomena on the salinity f-k graph (Fig. 3-4), several summarized estimates, based on Fig. 3-1 and Fig. 3-2, of the scales on which these processes act are indicated on Fig. 3-4. The estimate of the scales of advection processes takes into account those phenomena which generally have a moderate to strong salinity gradients associated with them. These are the large-scale wind-driven gyres, thermohaline gyres (not shown on graph), surface and internal current meanders, surface and submarine topographic eddies, inertial currents, internal waves, and small scale convective eddies. Also indicated is the thermocline, which is the result of many of the aforementioned processes. The general estimate of evaporation minus precipitation (E-P) is based on all the phenomena in Fig. 3-2 and some advection phenomena. The runoff estimate roughly takes into account time scales of atmospheric disturbances with associated precipitation and the time and space scales of river out-flow; the effects of run-off were considered to be neglectable when more than 100 km from a coast.

Noise in salinity data can occur in three ways. First, errors could occur in the collection of conductivity measurements due to the motions of the combined sensor

*The processes of melting and freezing are not considered in this report as affecting salinity because the proposed system is to be placed in relatively ice free areas.

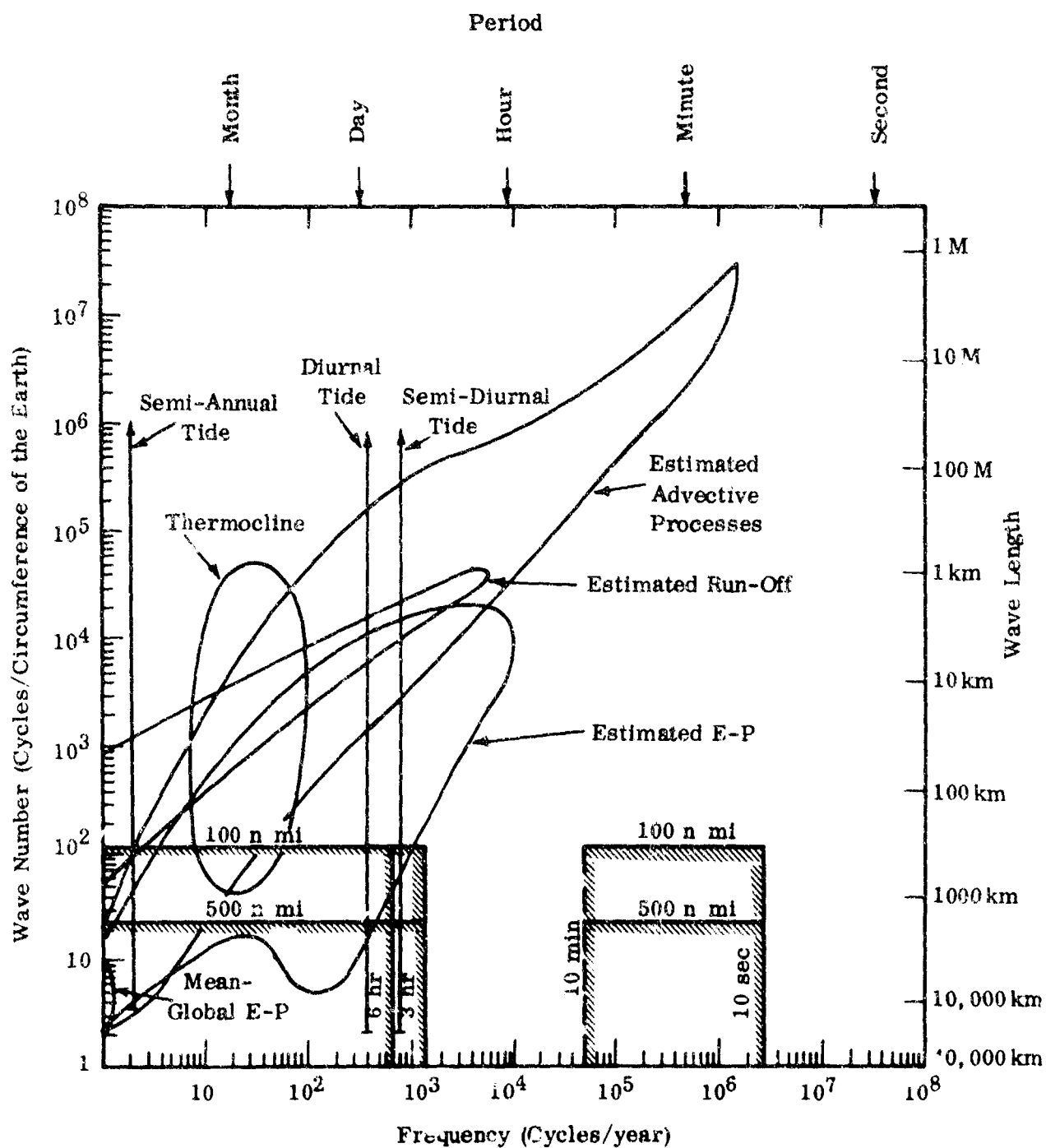


Fig. 3-4. Phenomena and Processes Affecting the Variability of Salinity

suspension system (moving) through a salinity gradient. Second, erroneous results can possibly occur because of the inaccuracies in the empirical relationships linking conductivity, chlorinity, salinity, and density. The determination of the important density parameter becomes increasingly difficult when changes in density occur without changes in chlorinity. Third, errors may develop due to failure of the constancy of composition hypothesis. Errors are most likely to occur from this type of noise in coastal waters where runoff is present.

These problems can be partially resolved by having a low response conductivity meter (10 or more seconds) on a taut-moor buoy and by adoption of the recommendations of the 1962 UNESCO Joint Panel on the Equations of State of Sea Water which will establish universal empirical relationships linking conductivity, chlorinity, salinity, index of refraction, and density.

There are two bands of noise that possibly can occur in salinity: one in wave number and the other in frequency. These bands are primarily caused by the platform sensor motions and might span a range from 10^4 - 10^6 in wave number and 10^4 - 10^6 in frequency depending on the response of the conductivity sensor. An additional problem is that the time constant of the buoy system can become sufficiently large to mask some physically significant periods of natural variability.

3.4.3 Temperature (Surface to Bottom)

Temperature has been the most intensively measured physical parameter in the ocean. The temperature structure of the vast majority of the ocean is fairly uniform. Only a small fraction of the ocean is warmer than 6°C and almost half is cooler than 2°C. These statistics can be deceiving since the small portion of ocean water above 6°C is exposed to the atmosphere and the thermal interactions which take place at the air-sea interface modify temperatures of both air and sea.

There are several quasi-periodic modes effecting the temperature variability. These modes are annual, semi-annual, and diurnal in time and in space have wave lengths from 40,000 km (circumference of the earth at the equator) to 20,000 km (circumference of the earth at 60°N or S). Estimates of the time and space scales of the above processes and phenomena and the resultant of many of their interactions, the thermocline, are found graphically displayed in Fig. 3-5.

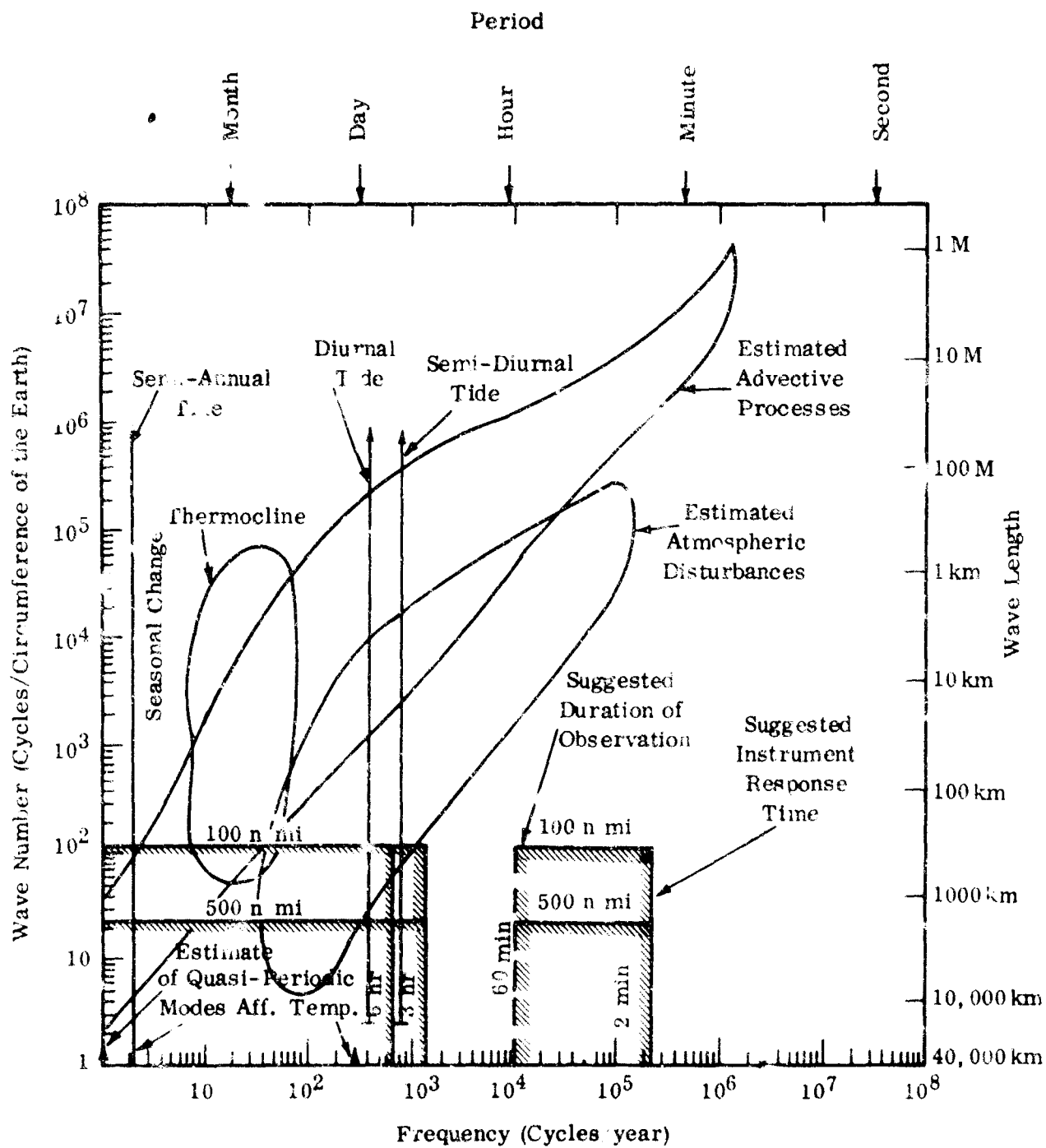


Fig. 3-5. Phenomena and Processes Affecting the Variability of Oceanic Temperature (sfc. to bottom)

The noise problem in measuring temperature from a platform arises from two sources: (1) natural "noise" (unwanted fluctuations) found in the environment, and (2) platform induced noise associated with the free movements of the platform-mooring sensor system.

The first problem is apparent from several detailed studies of the temperature structure appearing in the literature. The Hecht and White report [8] is a fairly representative study. They report frequencies of temperature oscillation ranging from 0.05 cycles/hr to at least 43 cycles/min ($T = 20$ hr = 1.4 sec, respectively). With rapid response sensors, it becomes increasingly difficult to separate the platform suspension motions and natural oscillations. Spatial scales of temperature could be as small as 10 cm [9] with a mean size defined as 60 cm.

Therefore it may be concluded that some temperature fluctuations are small scale and/or high frequency (with these characteristics not necessarily occurring together) and of large enough amplitude to be significant. Baer and Hamm have suggested an approach to this problem which seems adequate for the surface layers through the permanent thermocline. [10] Their approach to a system to observe the hourly and longer fluctuations is based on a relatively inexpensive thermistor (or other sensor) that had an error of one standard deviation equal to 0.03°C^* . The average of 30 samples which are taken at specified times from 30 min before the observation time to 30 min after it would then be recorded. The sensor should have a time constant of several minutes (see Fig. 3-5). The sampling rate would be non-uniformly distributed to give more readings near the center of the interval than near the extremes. An estimate of the standard deviation of average errors obtained by this procedure is less than 0.0055°C , which is adequate for synoptic purposes. Sampling schemes such as this are designed to allow a low pass filter to be imposed on the environmental data. Such filters can be shaped by selection of sampling intervals within the 60 minute duration of observation, thus allowing for selection of the filter

*The NDBS requirements indicate a required accuracy of 0.01°C . This seems to be too stringent in the upper layers of the ocean due to the large dynamic range of this portion of the ocean.

shape which would provide the best match for local variability. Small scale temperature fluctuations, that would be particularly enhanced by the free movement of the platform and sensors, would also be spatially averaged out by this type of filter. The procedure is described here as merely one of many possible solutions to some foreseeable problems. Ultimately, the averaging period or the characteristics of the filter should be determined for the geographical locations and depth of the sensor. Measurements taken by the first buoys deployed might well confirm that temperatures in the deeper layers of the ocean (below the permanent thermocline) are fairly constant in space and time and have a small dynamic range. There, a greater accuracy of the sensor would be required, if the high frequency noise problem is negligible or can be overcome.

3.4.4 Water Pressure (Depth)

Water pressure is a parameter that will be used primarily for determining the depth of the sensor package. It will also be influenced by several oceanic phenomena. Among the phenomena which will be most easily detectable are surges (sometimes referred to as "storm tides") and tsunamis. Both of these phenomena have been identifiable from the time series record of a bottom-mounted pressure sensor.

Tsunamis could present a detection problem in an observation schedule which samples at discrete intervals in time. The frequency of occurrence of these waves is rare and the duration of the phenomena could be as little as several hours* as shown in Fig. 3-6. In some cases the probability of detecting these waves is quite small, especially for a short duration of observation (tsunamis can travel in excess of 350 kts).

Other long-wave phenomena, such as tides, will also be detectable from bottom mounted sensors. These waves could have periods ranging from 2 minutes, to semi-annual, or perhaps longer. Most of these waves occur continuously or at least frequently and there should be no problems arising from non-continuous sampling.

*Tsunamis usually occur in series, gradually increasing in height until a maximum is reached between about the third and eighth wave. Following the maximum, they again become smaller. Waves may continue to form for several hours or even days. Tsunami waves in the deep oceans are often imperceptible to the casual observer. It is only near shore that the scales of wave height become extreme.

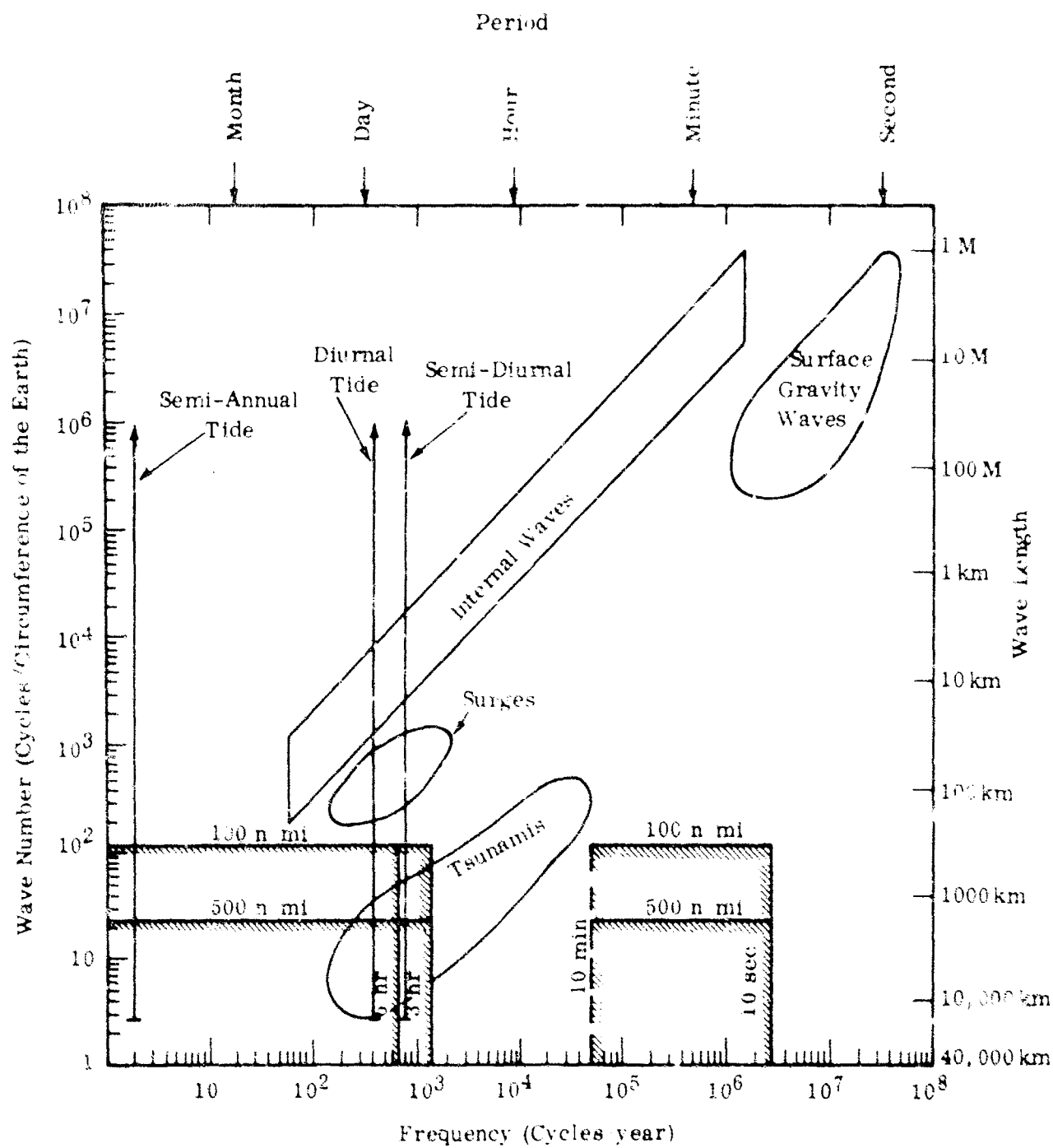


Fig. 3-6. Phenomena and Processes Affecting the Variability of Water Pressure (depth)

The pressure sensors which are not bottom mounted will be subject to horizontal and vertical movement. This movement will show up as "noise" when attempting to detect a long period wave phenomena, but will be "signal" for determining the depth of the sensor package.

Platform-sensor motions can be detected by the pressure sensor since there will be some indication of the depth of the sensor package as a function of time during the duration of observation. A pressure sensor could conceivably respond to high frequency oscillations of the platform-mooring system. These oscillations could occur at frequency between 10^4 - 10^9 (see Appendix B) although the higher frequencies are unlikely to be present in the pressure record, unless an extremely sensitive and rapid response sensor is used. Drifting of the platform and mooring could also present some changes in pressure at some of the sensors, but most of these changes would probably be within the accuracy of measurement.

3.4.5 Sound Speed

In nearly all the oceans and adjacent seas sound speed is governed by temperature, salinity, and pressure (e.g., the density of sea water.*). Therefore, it is assumed all the processes and phenomena which appeared in the temperature, salinity and pressure f-k graphs should appear on the sound speed f-k graph in Fig. 3-7. The exceptions to this assumption are surges, tsunamis and surface gravity waves which appear on the pressure f-k graph (see Fig. 3-6). This is because sound speed is least sensitive to pressure change and the pressure changes which are associated with these phenomena result in smaller variations in sound speed than the range of accuracy (± 1 fps). Tidal forces do not significantly effect the sound speed through pressure changes but through such temperature and salinity changes as are generated by tidal currents.

Noise in sound speed measurement is also associated with the frequency and wave number bands due to platform sensor motions. Although oscillations in moorings have been reported with frequencies as high as 60 cps (10^9 on f-k graph), it is

*In areas where the constancy of composition hypothesis is seriously in error because of an abundance of one or more chemicals in solution the sound speed could have an additional dependence on these chemicals.

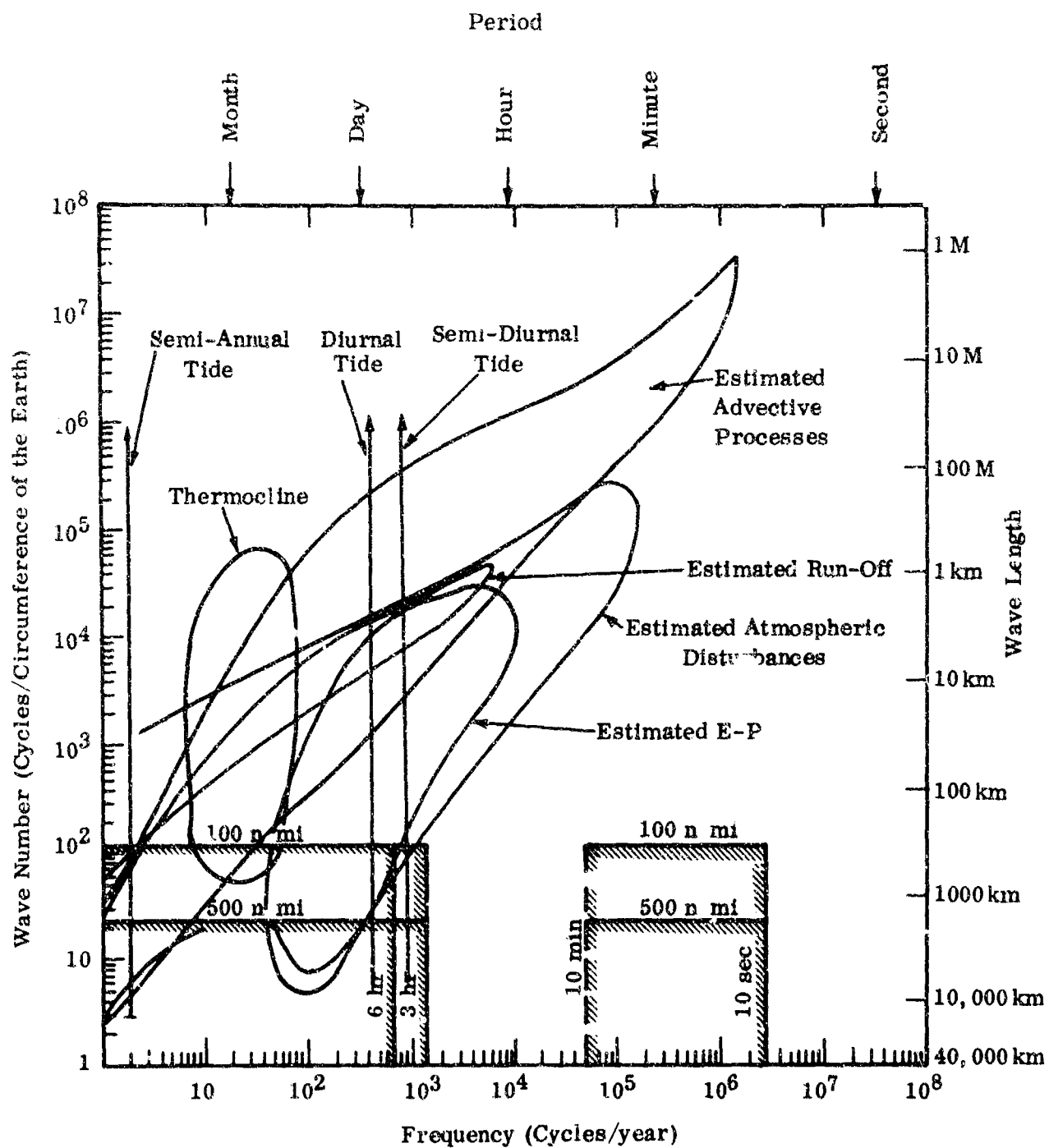


Fig. 3-7. Phenomena and Processes Affecting the Variability of Sound Speed

unlikely that these oscillations occur with enough spatial amplitude to effect the sound speed data. A more realistic estimate of possible frequencies of noise due to buoy motions, would be in the range of frequencies from 10^4 - 10^6 . Noise generated by platform-sensor motions only take on significant amplitudes in the presence of strong temperature and/or salinity gradients. Strong horizontal gradients would give rise to noise in the wave number band between 10^4 - 10^6 .

3.4.6 Ambient Noise

The variability of ambient noise is influenced by a number of phenomena. Its primary source appears to be wind and wave action on the surface which results in noise propagating downward. In addition there is noise from ships, especially in the major shipping routes, and submarines. This type of noise can reach very high levels and carries for many miles. A third type of noise is probably more sporadic and is biological in nature. Among some of these biological noises are shrimp crackling and low frequency whale noise (~ 20 cps).

A mode of variability for ambient noise is probably diurnal, as indicated on Fig. 3-8. The deep scattering layer and plankton and/or algae bloom have also been entered on the f-k graph for ambient noise. Plankton or algae blooms will probably not contribute to ambient noise directly but it is speculated that increased feeding activity of other biological species on the plankton or algae may lead to a substantial increase in noise. On the other hand a bloom such as the "red tide"* would result in a decrease in feeding activity due to the death of large numbers of fish.

Scales of atmospheric disturbances and surface gravity waves are also indicated on Fig. 3-8 because of the primary source identified above; viz, wind and wave action on the surface.

The problem of sensor-platform motions will probably be acute for ambient noise. There are probably three sources of platform-sensor noise: the noise of the platform interacting with the wind and waves; noise of mooring vibrations and

*"Red tide" is the name given to a growth of Dinoflagellatis (single celled plant-like animals) in surface waters in such quantities as to color the sea red and kill fish.

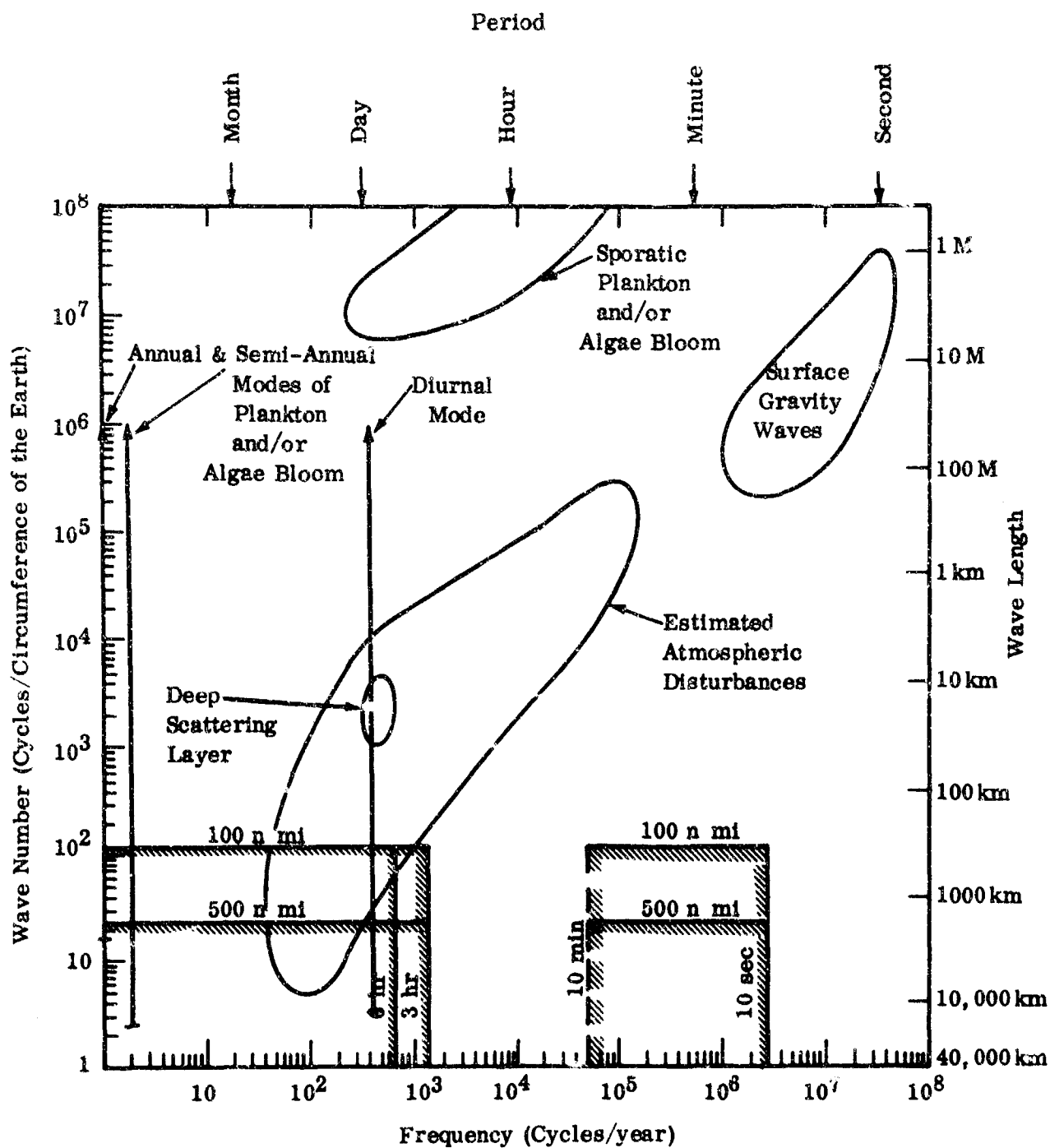


Fig. 3-8. Phenomena and Processes Affecting the Variability of Ambient Noise

oscillations; and noise of flow past the sensor. The latter two types of noise become particularly pronounced in regions of strong currents. One possible solution to these noise problems is to perform a spectral analysis on the aforementioned noise and filter the output of the ambient noise sensor with filters designed from the results of the analysis. Of course, these filters could remove wanted signal with the noise. At this time the platform-mooring effects on the sensor can only be grossly estimated.

3.4.7 Ambient Light

Ambient light is the visible radiation (about 0.4 to 0.7 microns in wave length) in terms of its luminous efficiency in sea water at a given depth undisturbed and unaffected by the platform or detection equipment. The primary source of this light is solar radiation, but some consideration might be given to bioluminescence. Light will suffer a decrease in intensity on passing through sea water because of absorption of energy by the sea water; absorption of energy by suspended material including organisms in the water; scattering by the sea water; and scattering by suspended particles. The ambient light may also be reduced by cloud cover.

The variability of ambient light displays strong diurnal and annual modes due to daily and seasonal changes of the sun's position in the sky and is affected by the biological activity, e. g., deep scattering layer and plankton and/or algae bloom* (see Fig. 3-9). In coastal regions the water may be clouded by run-off, which carries small sedimentary particles in suspension, and strong wind mixing, which in shallow regions may stir up the bottom sediments. Most of the atmospheric phenomena which appear in Fig. 3-2 effect the variability of ambient light. Some of these phenomena possess strong enough winds for deep mixing in shallow areas. In Fig. 3-9 (the f-k graph for ambient light) appear the estimates of scales of atmospheric disturbances, run-off; diurnal and annual modes, the deep scattering layer, and plankton and algae blooms.

Platform-sensor effects in relation to ambient light could possibly arise from the platform or mooring casting a shadow on the sensors. The motions of the

*See Table 3 for the characteristic space and time scales of plankton and/or algae bloom.

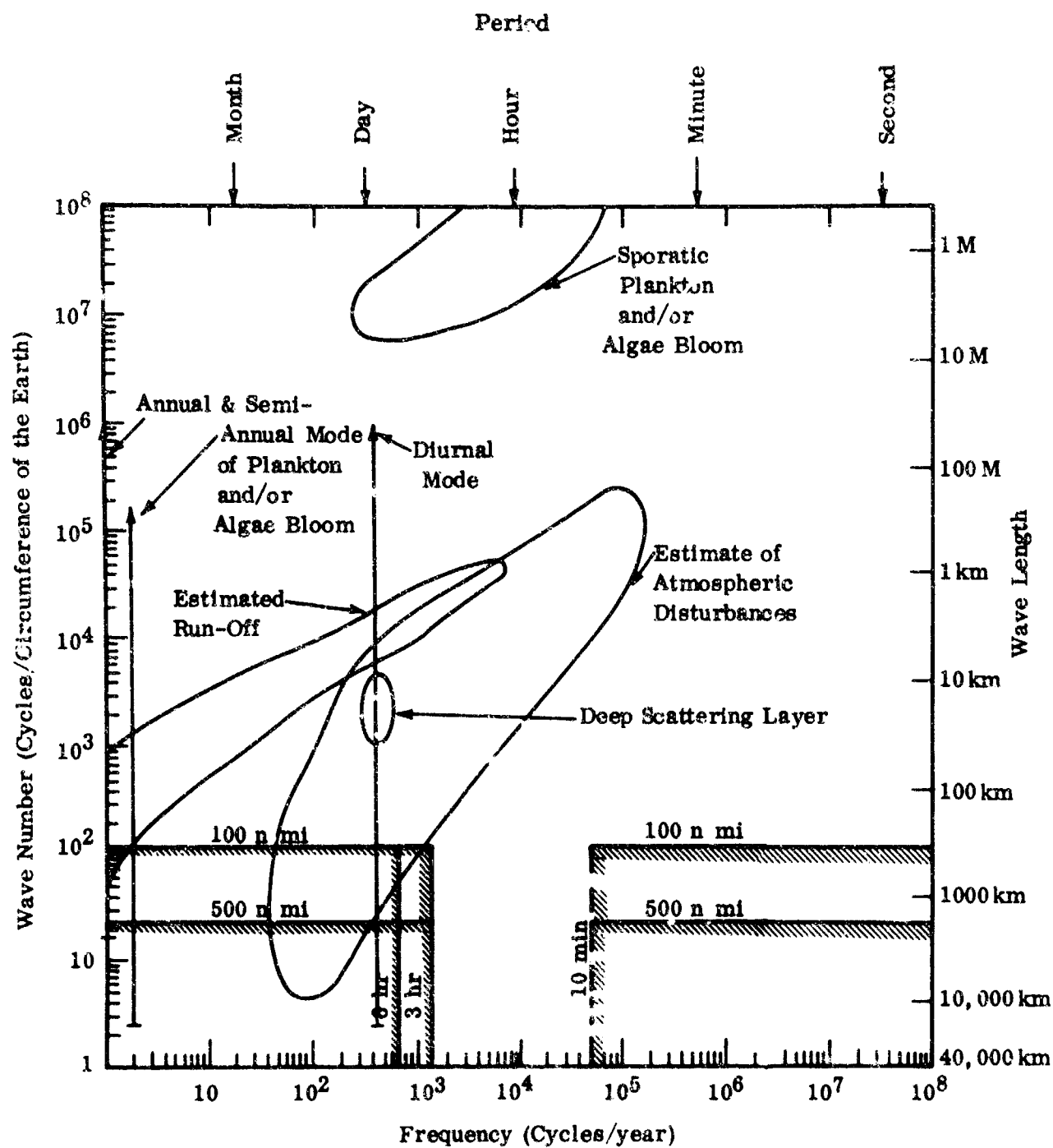


Fig. 3-9. Phenomena and Processes Affecting the Variability of Ambient Light

platform probably will not effect the measurements. The instrument response time is taken as nearly instantaneous. The duration of observation time was taken as 10 minutes to allow a decreased cutoff frequency through averaging and to minimize the effects of the shadows cast on the sensor by infrequent small passing clouds.

3.4.8 Transparency

Transparency is a measure of the ability of water to transmit light of different wave lengths. Thus, ambient light is dependent on the transparency of the water. The variability of transparency is also effected by many of the phenomena and processes that ambient light is effected by, but it is not dependent on variable amounts of solar radiant energy reaching the surface of the ocean. Therefore, the processes affecting transparency are the absorption and scattering of light by the sea water and by suspended material in the water, including organisms. The phenomena and processes effecting transparency as indicated in Fig. 3- are sporadic, annual, and semi-annual plankton and/or algae bloom, the deep scattering layer and run-off. Atmospheric phenomena with associated strong winds (e. g., synoptic-scale disturbances, hurricanes or typhoons, squall lines, internal and mountain waves, thunderstorms, and water spouts) could effect transparency in shallow coastal regions where winds might be strong enough to stir up bottom sediments. These phenomena are also indicated on Fig. 3-10.

There are no foreseeable problems in collecting transparency data from platform-sensor motions. The instrument response time is nearly instantaneous and the duration of observation is taken to be 10 seconds.

3.4.9 Wind

The wind in the atmosphere is affected by every major atmospheric phenomenon (Fig. 3-2 and Table 3-3). In Fig. 3-11 these atmospheric phenomena are graphically represented on an f-k graph that also shows three pronounced modes of wind variability. The diurnal mode is associated with daily solar heating and cooling which is an influencing factor in many of the atmospheric phenomena indicated in Fig. 3-11 (i. e., convective clouds, thunderstorms, and sea breeze). The semi-annual mode is found in the tropics where six month seasonal cycles take place. The annual seasonal changes of global scale account for the last mode of variability.

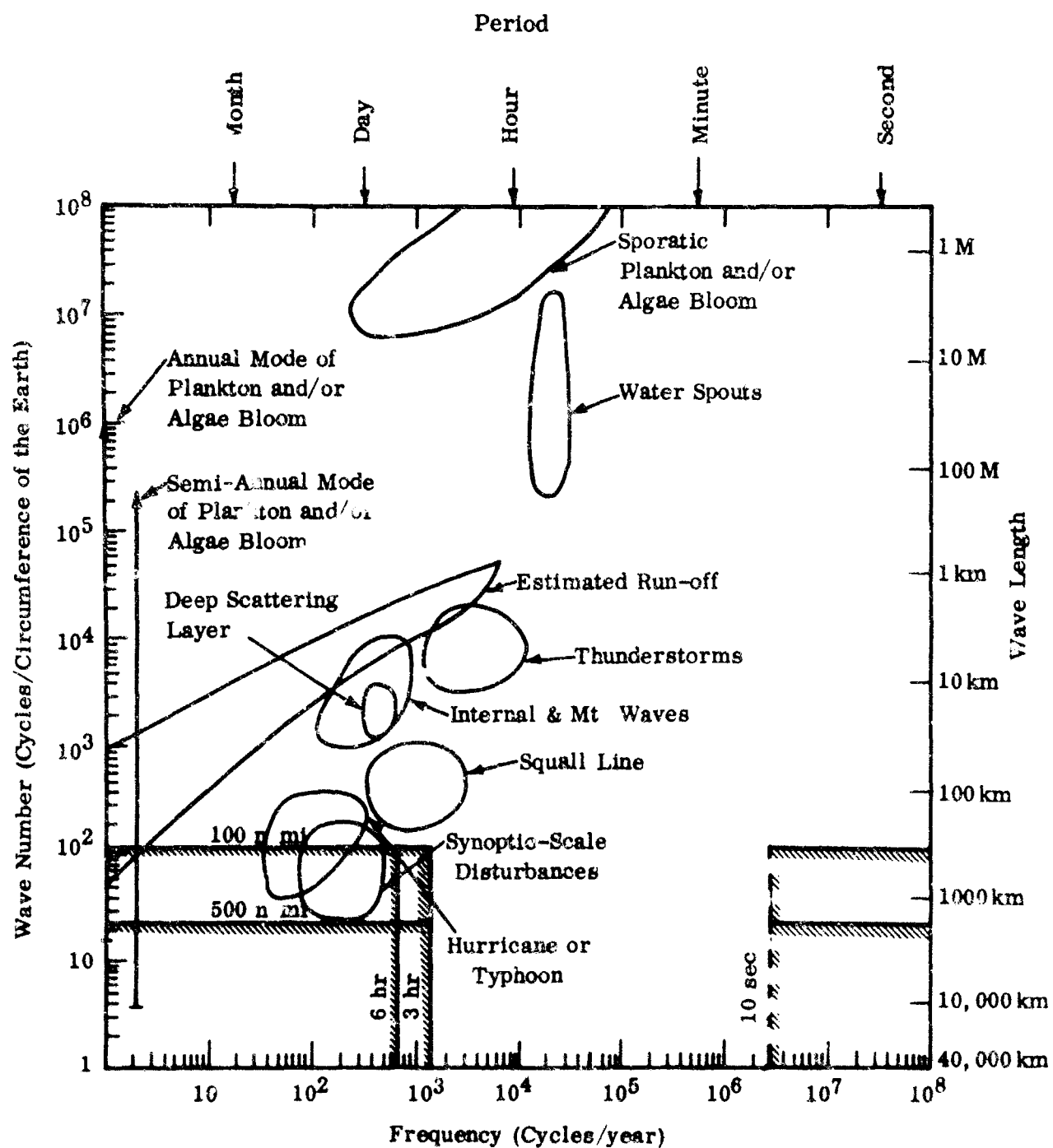


Fig. 5-10. Phenomena and Processes Affecting the Variability of Transparency

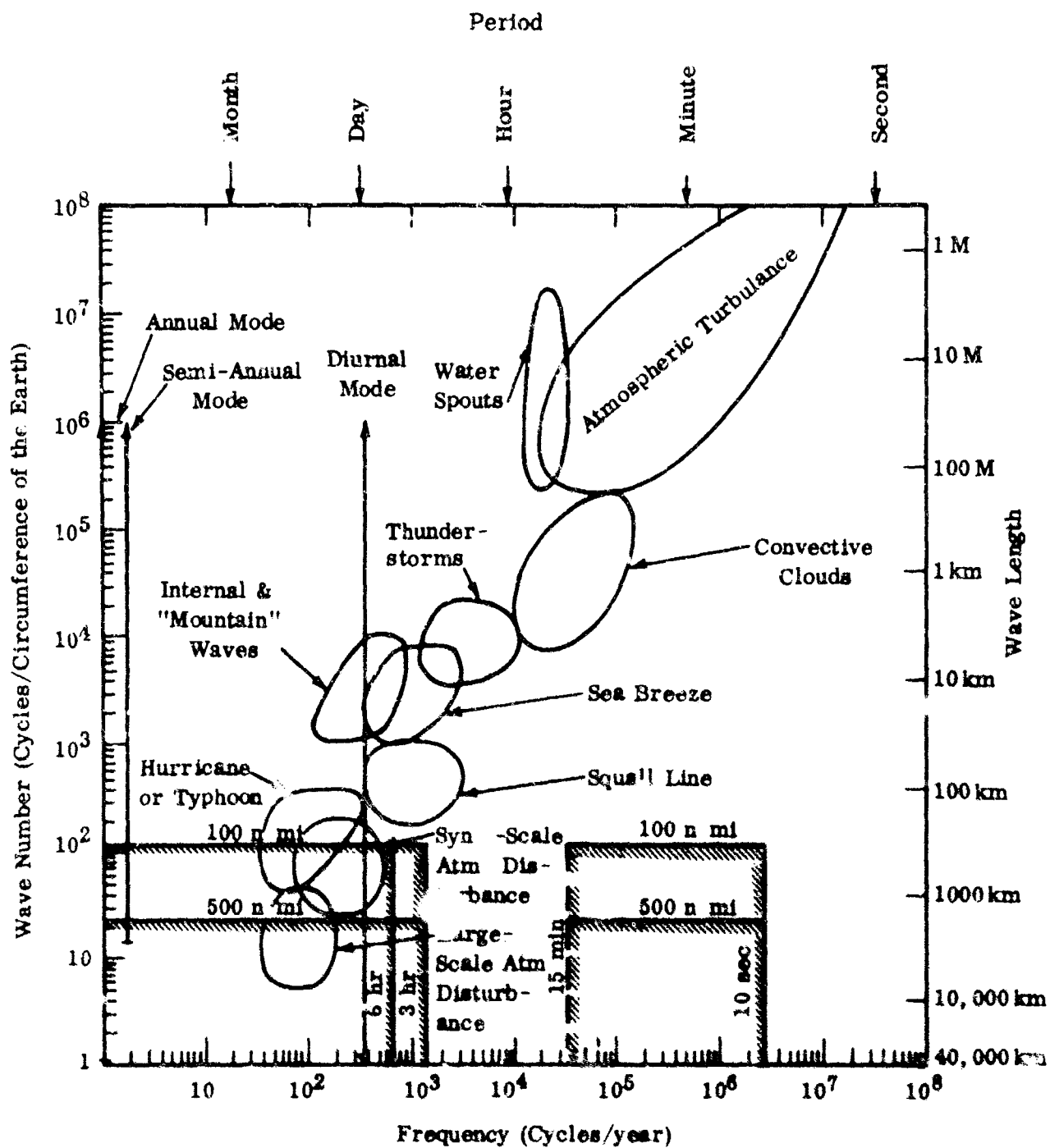


Fig. 3-11. Phenomena and Processes Affecting the Variability of Wind

General wind speed is a fairly good indicator of the intensity of an atmospheric phenomena (see Table 3-3) and is an essential parameter for prediction purposes.

Since this parameter is a vector quantity, there is a greater chance for noise to be introduced into the time series record by platform-sensor motions. It takes little imagination to picture the gyrations an anemometer goes through fixed to a surface-following buoy on the top of a 10 m mast in heavy seas. These gyrations lead to erroneous results, since the horizontal wind vector is the parameter which is supposed to be measured. In theory the anemometer should be fixed (in an x, y, z sense) and remain in the horizontal plane at all times. The motions of the platform do not easily allow these ideal conditions to be realized. Certain types of platforms ride low in the water (i.e., a spar buoy, non-surface following) and minimize the vertical motion (heave) to near zero and horizontal motions (pitch and roll) to angles smaller than 10° - 20° . In this case effects of platform motions may be fairly small. Pond points out that in the above situation with rapid response anemometers (hot-wire) the error arising from the correlation between the turbulent velocity components and the components produced by the buoy motions is probably 10-20% [11]. He also shows that it is extremely important to keep the mean tilt very small. A surface following buoy will tend to have considerably more heave, pitch and roll. This increased motion must be compensated for by a much slower response anemometer that will not respond to any significant extent to vertical motions. This type of anemometer is available today and some rough calculations based on time series records of wind speed, heave, roll and pitch of an ONR 40-ft discus buoy anchored in the Gulf Stream during Hurricane Betsy [12] have revealed the errors in wind speed due to buoy motions were rarely larger than $\pm 5\%$, with an average of about $\pm 3\%$, of the recorded wind speed. No calculations were made of error in wind direction, although no serious errors are expected. It may be concluded, until further data is taken (i.e., simultaneous data from a fixed and floating platform with identical anemometers), that a well designed platform-anemometer combination will keep error within the prescribed limits.*

*The requirements state a maximum allowable error in wind speed of 0.5 kt or 3% whichever is larger.

The optimum averaging period or duration of observation for the wind vector appears to be about 15 min (c. f., Ref. 13). Samples during this period should be taken continuously or very rapidly (e. g., every 20 seconds). An instrument response time of 10 seconds seems to be desirable and practical considering the buoy motions and the mechanical limitations of the type of anemometer needed.

3.4.10 Air Temperature

Air temperature is a very sensitive indicator of the presence of atmospheric phenomena. Thus, Fig. 3-12 is a replica of Fig. 3-2 (the major atmospheric phenomena). There is also the strong diurnal mode associated with solar radiation, the semi-annual mode of the tropics, and annual mode of the global seasonal cycle.

An important influencing factor in the variability of air temperature is the air-sea temperature differences. This difference influences air temperature directly through sensible heat transfer (eddy conduction) and indirectly through its effects on such processes as evaporation and back radiation. The effect of the sea surface temperature (and thus air temperature) on the formation of many of the phenomena on Fig. 3-12 is probably considerable.

There are probably enough high frequency fluctuations in air temperature over the water to warrant a slow response (of the order of 10 seconds) temperature probe. The duration of observation was taken as 10 minutes to provide a decrease in cutoff frequency through averaging if any additional filtering of high frequency ($\sim 10^5 - 10^6$) fluctuations is desired.

There are no platform sensor problems anticipated for air temperature.

3.4.11 Air Pressure

With normal sensors, air pressure is not as sensitive a parameter to atmospheric phenomena as air temperature, see Fig. 3-13. Phenomena such as the sea breeze, internal and mountain waves, and convective clouds should not contribute to detectable variability of the air pressure. These atmospheric phenomena have associated pressure variations which are probably smaller than the allowable error of 0.1 mb.

The three modes of variation arise from the same sources as these modes for air temperature (e. g., solar heating, semi-annual seasonal changes in the tropics, and annual seasonal cycles).

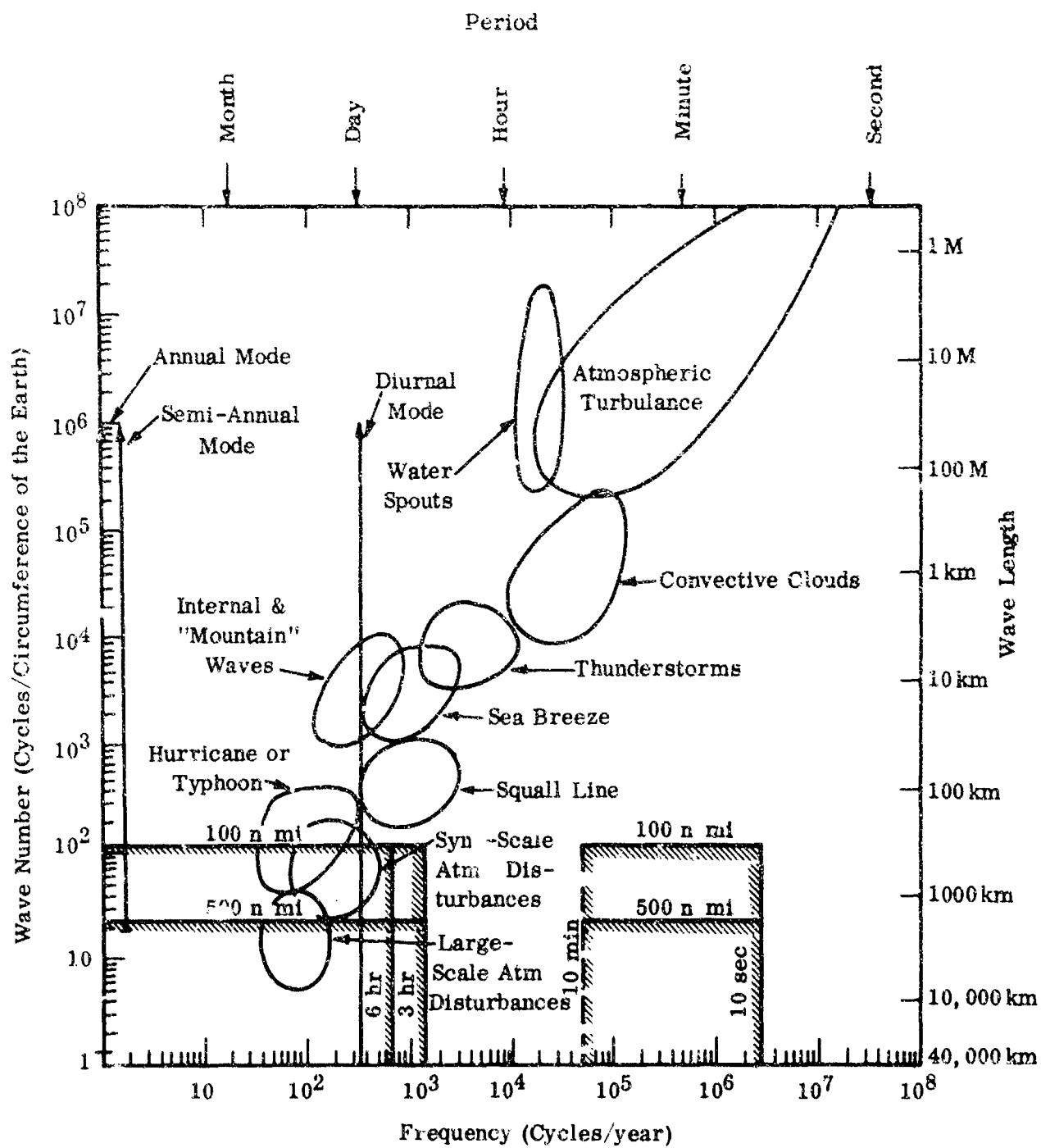


Fig. 3-12. Phenomena and Processes Affecting the Variability of Air Temperature

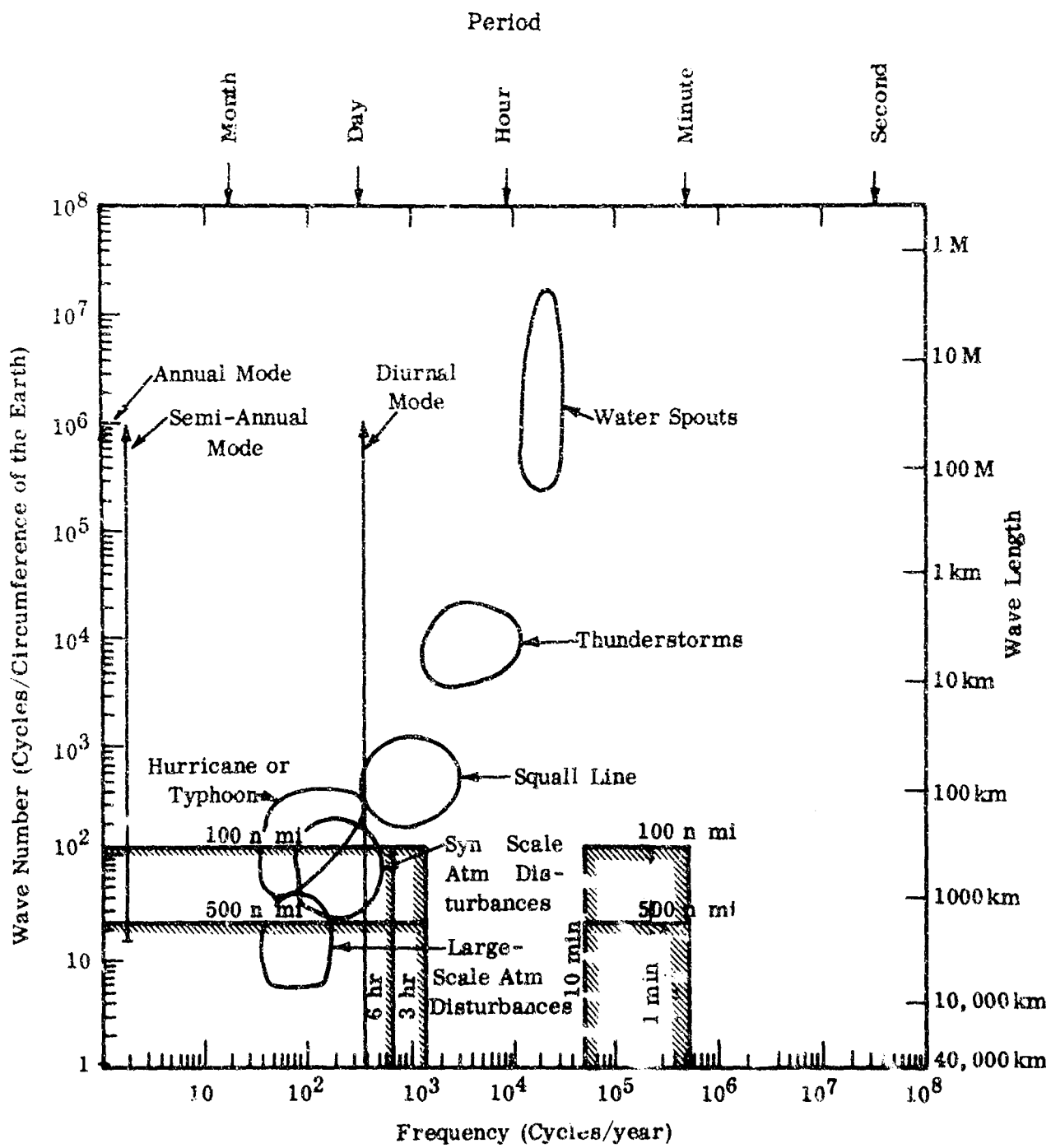


Fig. 3-13. Phenomena and Processes Affecting the Variability of Air Pressure

There appears to be no need for a rapid response barometer. A response time of about one minute would be sufficient to obtain the needed data and be well within the practical range of a durable barometer. A duration for the observation of 10 minutes is estimated to be adequate for the retrieval of desired data.

3.4.12 Dew Point

Dew point is the temperature to which a given parcel of air must be cooled at a constant pressure and constant water vapor content in order for saturation to occur. The three modes of variation in dew point remain the same as in air temperature, pressure, etc., as shown in Fig. 3-14. The diurnal mode of dew point is indirectly related to solar heating. Solar heating over the ocean through various processes usually increases or decreases the water vapor of the lower atmosphere.

The duration of observation and instrument response time as shown in the figure were both chosen because they will fulfill the needs for gathering accurate data and are practical from the standpoint of instrumentation.

There are no problems expected from platform sensor motions.

3.4.13 Insolation

Insolation is affected only by the atmospheric phenomena which have associated clouds. Therefore, all atmospheric phenomena in Fig. 3-2 have clouds associated with them and are indicated in Fig. 3-15.

The source of the diurnal mode of variation is obvious, and the annual mode is associated with seasonal cloud changes and the changes in the declination angle of the sun. The semi-annual mode is again due to seasonal changes of the tropics.

The duration of observation is taken as 10 minutes to minimize any effects of passing clouds casting shadows on the sensor. Also a 10-minute averaging period will compensate for any platform sensor effects which might arise from the departures of the sensor from the horizontal plane due to pitch and roll. Existing instrument response time of 30 seconds is estimated to be adequate.

3.4.14 Precipitation

The phenomena with associated clouds capable of producing precipitation are indicated on Fig. 3-16. The sea breeze, and internal and mountain waves, rarely

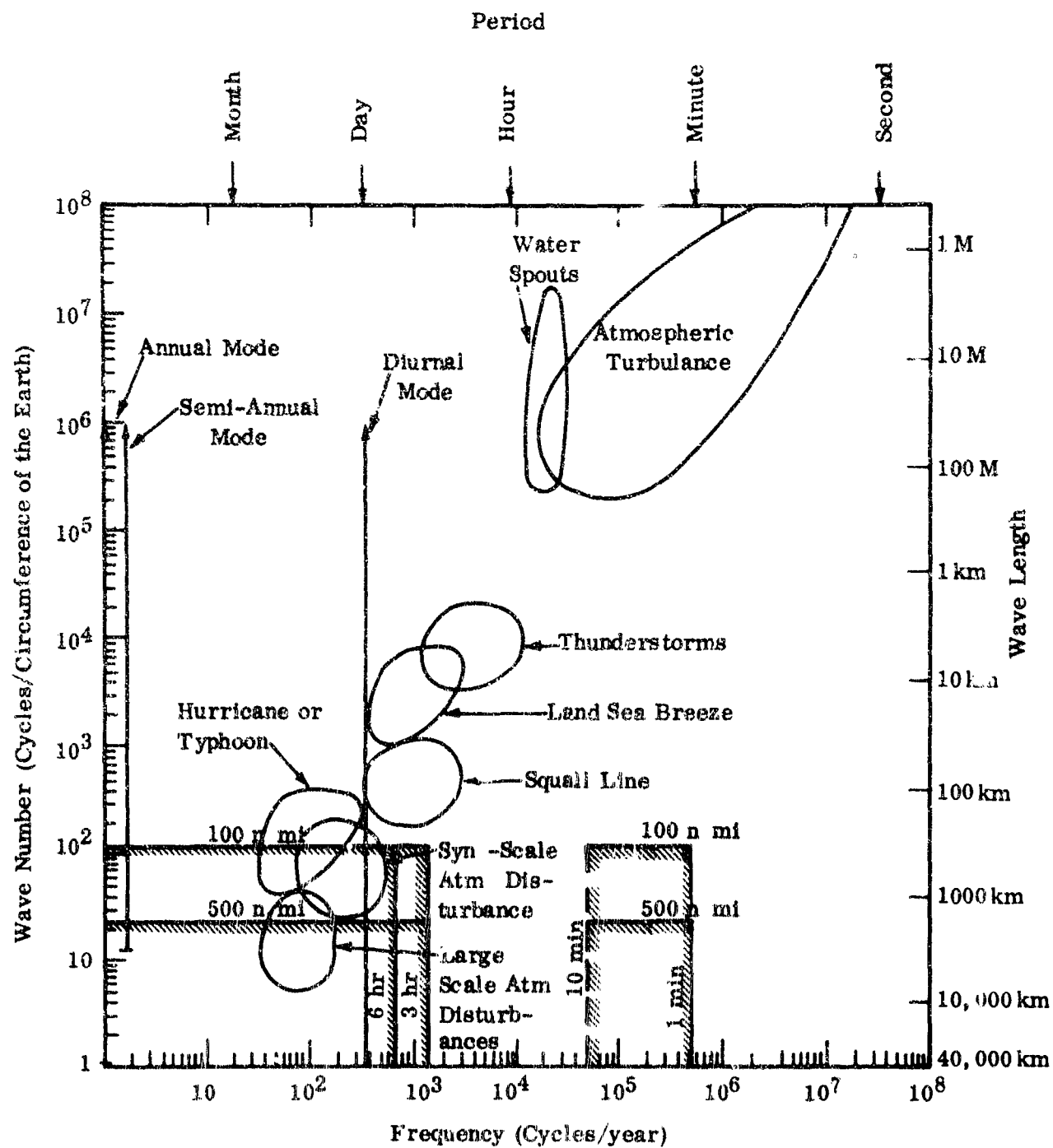


Fig. 3-14. Phenomena and Processes Affecting the Variability of Dew Point

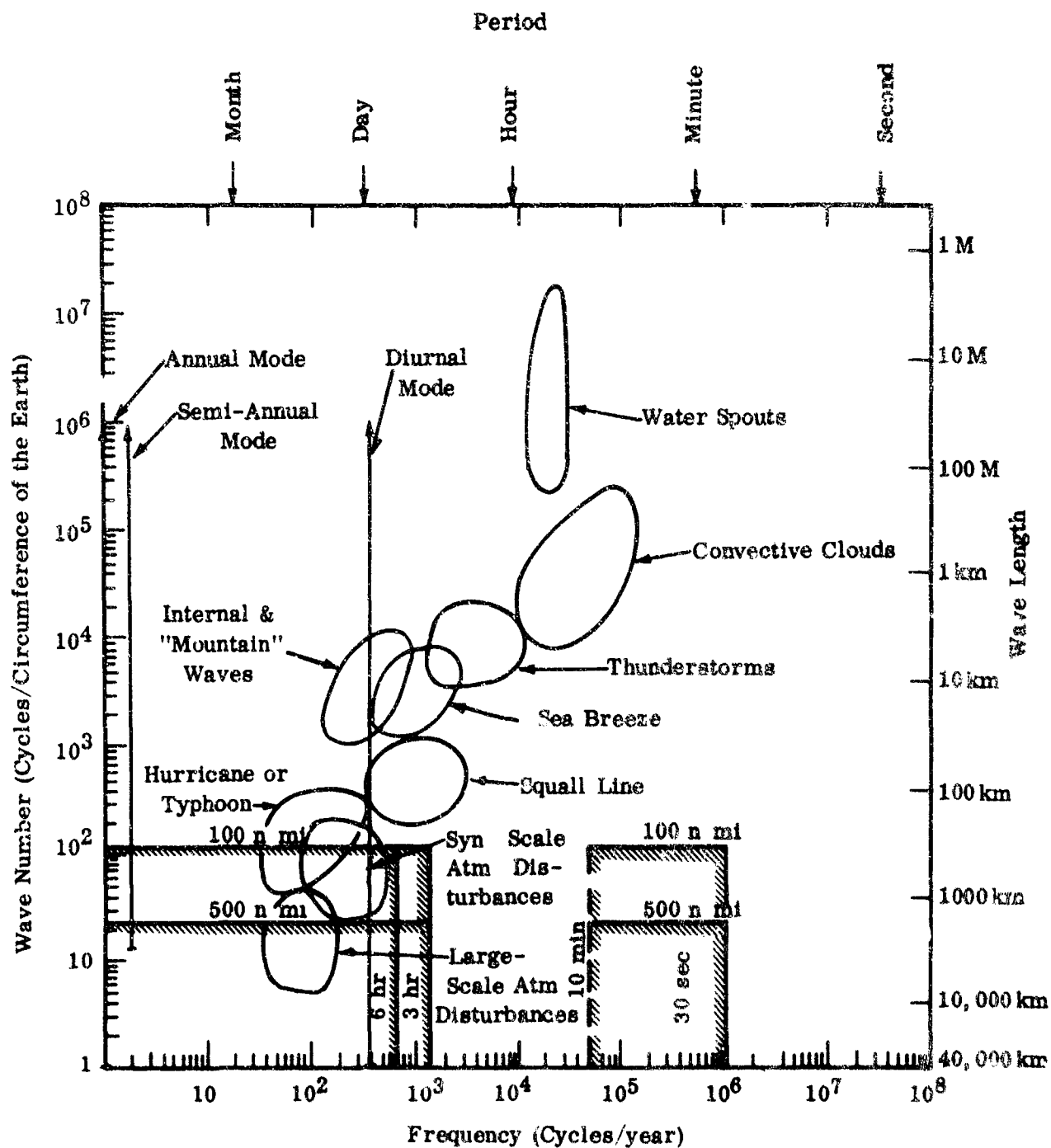


Fig. 3-15. Phenomena and Processes Affecting the Variability of Insolation

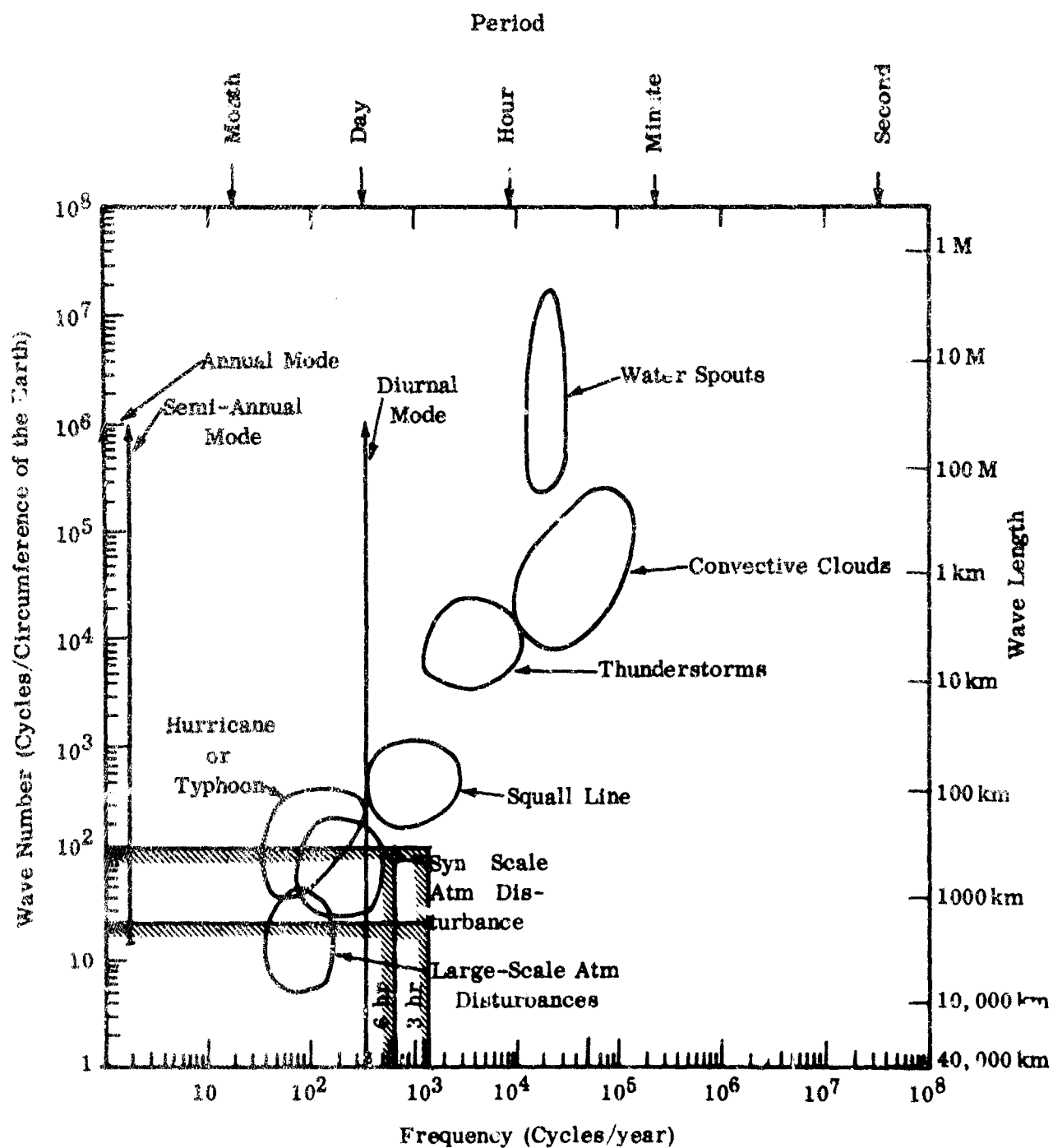


Fig. 3-16. Phenomena and Processes Affecting the Variability of Precipitation Rate

have precipitation associated with them and consequently should contribute little to the precipitation variability.

The annual, semi-annual and diurnal modes of variability have the same characteristics as similar modes in the previous parameters.

This parameter is of a different character from the others discussed. The precipitation measurement defined in the requirements represents an integral over a given number of hours; for example, the total amount of rain that has fallen in the past three hours is recorded. In terms of the windows indicated on the f-k graph this means that all the lines which imply the boundaries of the windows in time fall at one frequency, the reporting frequency (see Fig. 3-16). In other words, the duration of observation (averaging period) and the instrument response time are equal to the reporting period. This type of sampling eliminates any chance of aliasing the data, with a corresponding loss of detailed high frequency information.

3.4.15 Atmospheric Electricity

The variability of this parameter is associated with several atmospheric phenomena and also possesses a diurnal and an annual mode. Very often, atmospheric electricity is associated with various types of clouds found in the phenomena indicated in Fig. 3-17. At times the electrical content of these clouds reach such levels that rapid discharges occur in the form of lightning.

More than 50 years of data on the atmospheric charge has revealed that it has remained basically constant over that period of time. It is also known that the atmosphere is continually losing its charge at a rate that would deplete the atmosphere within 30 minutes. It is inferred that 90% of the recharging is done by thunderstorms and the remaining 10% by the ocean. Only synoptic measurements of this parameter will reveal if there are any correlations between it and other global atmospheric phenomena.

Data on atmospheric electricity has shown a diurnal and annual mode of variation. The exact cause of this variation is not fully understood.

The duration of observation (10 min) and instrument response time (10 sec) have been chosen so that representative data may be collected within the state-of-art on variations in the parameter.

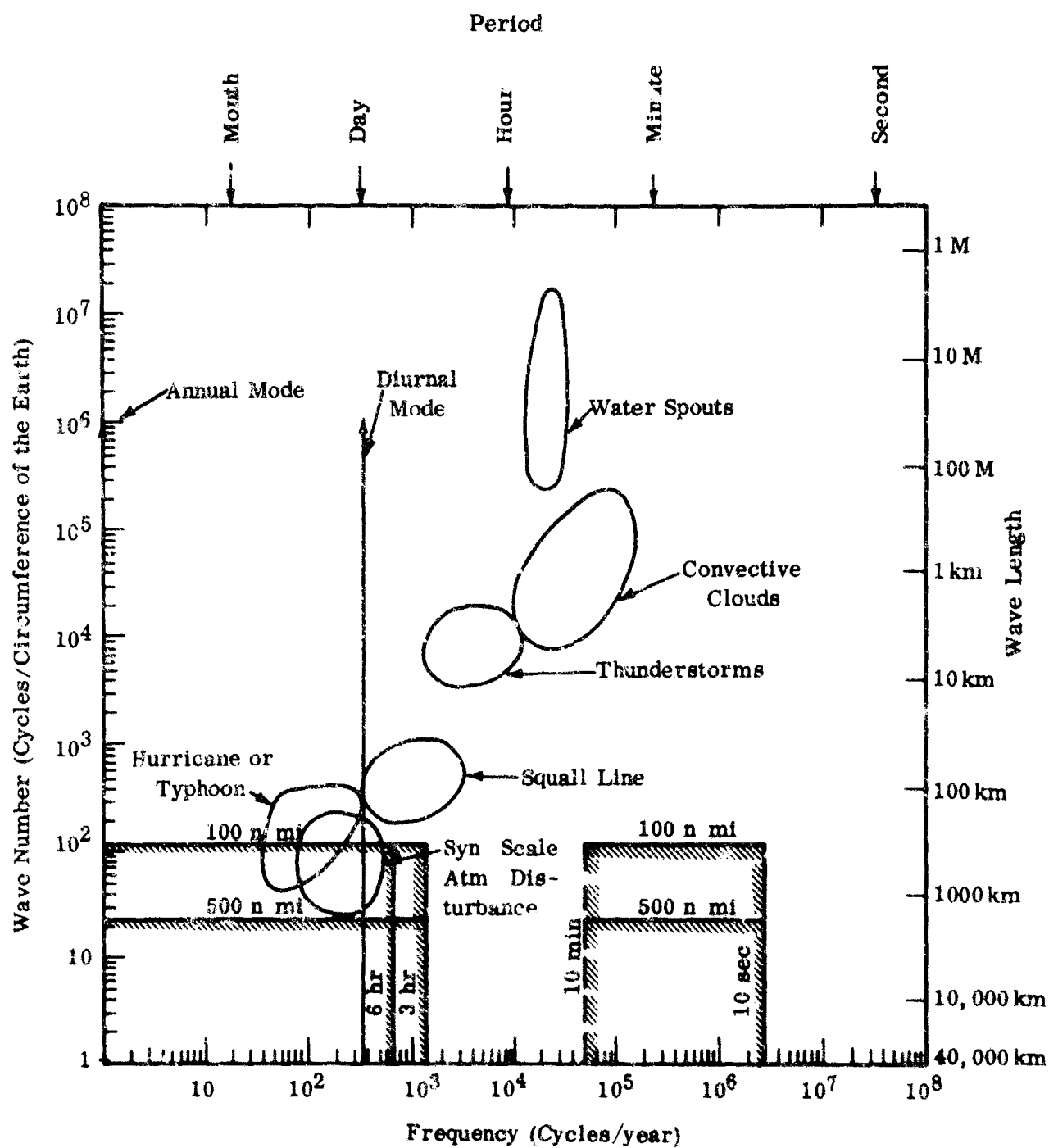


Fig. 3-17. Phenomena and Processes Affecting the Variability of Atmospheric Electricity

4.0 IMPLICATIONS FOR NDBS DESIGN

4.1 Background

The NDBS DPO has the task of designing a marine observing system with suitable system characteristics to yield observational data with characteristics that meet user requirements within budget, technical and cost effectiveness limitations. Distinction must be made among:

- (1) System characteristics.
- (2) Observational data characteristics.
- (3) Characteristics of data requirements.

System characteristics are relevant to system design and pertain to the system components, subsystems, or systems. Some flexibility in selecting system characteristics is available to the NDBS designer for matching observational data characteristics (output of the NDBS) to the data requirements as shown in Fig. 4-1 within the feasibility constraints. Relevant system design characteristics (Table 4-1) include sampling intensity and interval, location accuracy and synchronization, parameter range and accuracy, transmission time, and filtering. These may vary as functions of location and time.

The marine environment is influenced by a variety of phenomena and processes that are associated with natural variability and occur over characteristic space and time scales. The choice of system characteristics influences the resulting observational data characteristics; that is, the natural variability in certain scales may be faithfully reproduced, while in other scales the variability may be decreased and in certain other scales the variability may be aliased. In addition to the above, the choice of system characteristics influences the system costs. Trade-offs that effect the selection of certain system characteristics are of importance to the NDBS designer. The range of suitable system characteristics available to the designer to match the NDBS output to the requirements is dependent upon the amplitude of natural variability which itself varies with wave number, frequency, space and time as shown in Fig. 4-2. Knowledge of natural variability is, therefore, of importance to the NDBS designer. Further discussion of system characteristic alternatives available to the NDBS designer will be given in Section 4.2.

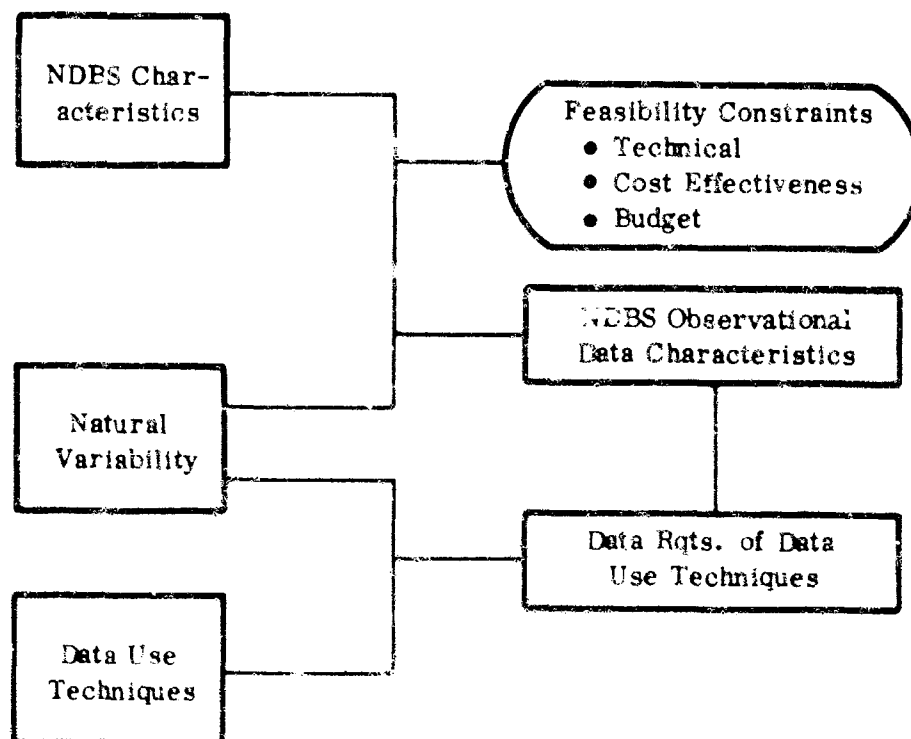


Fig. 4-1. Conceptual Relationship Between System Characteristics and User Data Requirements

TABLE 4-1
RELEVANT SYSTEM DESIGN CHARACTERISTICS

System Design Characteristics
Sampling intensity
Location accuracy
Synchronization
Transmission time
Parameter accuracy
Parameter range
Filtering

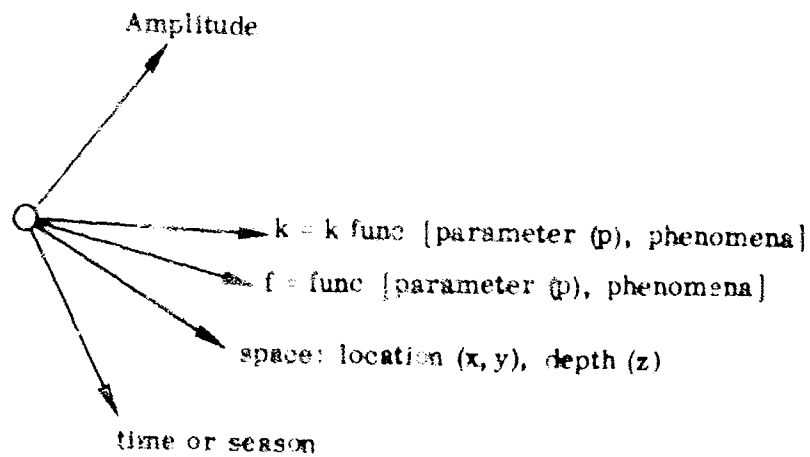


Fig. 4-2. Dimensions of Natural Variability

The 1967 TRC NDBS Feasibility Study made clear that data requirements exist that are not to be beyond the anticipated scope of available funding. Horizontal spacing buoys, levels measured in the vertical, frequency of reporting, and number of parameters measured all impact on buoy system costs. Needed is a logical design rationale that relates data requirements, data uses, and system and data characteristics in a cost-effective fashion that maximizes benefits. Unfortunately, knowledge and theory of marine environmental processes are not yet at the stage where all the details of logical system design can be handled in a perfunctory manner. In fact, the embryonic NDBS will contribute considerably to the knowledge that will aid its evolutionary growth.

This section organizes information on natural variability to assist the system designer in the determination of the observational data characteristics that will result from the system design characteristics. Which observational scales will be faithfully reproduced? Which scales will be aliased by the system design and may require that filtering techniques be included in the design? Several additional questions are relevant to this objective:

- (1) What are the design relationships between "representative" observations in the marine environment and the intended data use?
- (2) What is the signal-to-noise ratio in the natural environment?
- (3) What filter characteristics are required to eliminate unwanted scales or noise from the observed data?
- (4) What sensor response times are desirable and what range of sensor response times are acceptable?
- (5) What observation duration is desirable?
- (6) What scales of natural variability are faithfully measured by the system design? What scales are not resolved? What aliasing might result unless proper filtering is provided?
- (7) What unwanted signals may result from sensor package motion effects and how can these be handled?
- (8) What is the spatial correlation of the data collected?

While complete answers to the above eight questions are beyond present understanding of the marine environment and answers to several of these questions are at this time fragmentary at best, an organization of existing information can be performed in order to make rational preliminary design decisions and to build a base of understanding that can be augmented in the future (see recommendations Section 6.2).

In the next section we will discuss general considerations believed to be relevant to the NDBS design. Sections 4.3 and 4.4 will present examples of the use of graphical and tabular information contained in this report and their relevance to NDBS design in the Deep Ocean (DO) and Coastal North America (CNA) regions. Section 4.5 will summarize the major consequences of this information for NDBS design. *

4.2 General Considerations of System Design

It is relevant to ask the question, "What marine environmental information is required by developers or designers of the NDBS?" While answers to this question are at present only preliminary, this report contains relevant background information and presents a structure for handling this problem. The answer to the question may be addressed both from the ideal point of view of information that would be most useful to the designer or from the practical point of view of what information is available. Let us first discuss the answer to this question from the ideal point of view. Ideally, one would like all relevant information on natural variability for the dimensions shown in Fig. 4-2. This pertains to each parameter which is observed by the NDBS and also those parameters that influence the performance of the NDBS. Information is considered relevant if it has influence on the design of a buoy component, subsystem or system to meet the observational requirements of the data user. Ideally, the system designer may desire the variability of each parameter presented in terms of a probability frequency distribution or typical distributions in space (x, y, and z) and time and the accuracy that is significant for the expected data use (see Ref. 14 and recommendations Section 6.2).

*Deep Ocean data buoy networks are defined to be those more than 400 n mi from the shores of Coastal North America. CNA data buoy networks are those within 400 n mi of the North American shore.

The natural variability of a parameter is dependent upon the scale of natural phenomena, i. e. , a wave number (k) in the horizontal, a wave number (n) in the vertical and a frequency (f) in time. No information on the vertical wave number has been assembled for this study. The variability of a parameter also is a function of space (i. e. , x , y , and z locations on the earth) as well as time of the year or season. A data buoy observing system such as the NDBS must be designed to observe relevant information about particular parameters for particular locations and times of the year. Of particular importance to the designer is the fact that natural phenomena occur over very broad ranges of scale and due to cost limitations the natural variability in all scales cannot be observed. The designer must, therefore, select NDBS characteristics that measure information only as it is relevant to the data requirements and the intended data use techniques. The selected NDBS characteristics should eliminate unwanted scales from the observational data characteristics to the extent feasible.

How does one design an observing system to make "representative" observations? This will be discussed with reference to Fig. 4-3. System characteristics such as sampling intensity (f_N and k_N), observation duration (f_{C1}), instrument response time (f_{C2}), path length (k_{C1} , the spatial analogue of duration time), and instrument characteristic length (k_{C2} , the spatial analogue of response time), delineate "windows" in the frequency, wave number space within which the natural variability may be fully resolved (i. e. , in time and space) by the observing system. For certain bands of scales the natural variability is only partly resolved (i. e. , in time only or space only). The significance of the partially resolved information is dependent upon:

- (1) The intended data use techniques.
- (2) The variability amplitude in relation to the amplitude of the variability for resolved scales.
- (3) The accuracy requirements for data use.

Likewise, the variability may be aliased from some wave bands which are only partially resolved.

One is concerned, therefore, with suitable filtering of information in time and space (x , y and z).

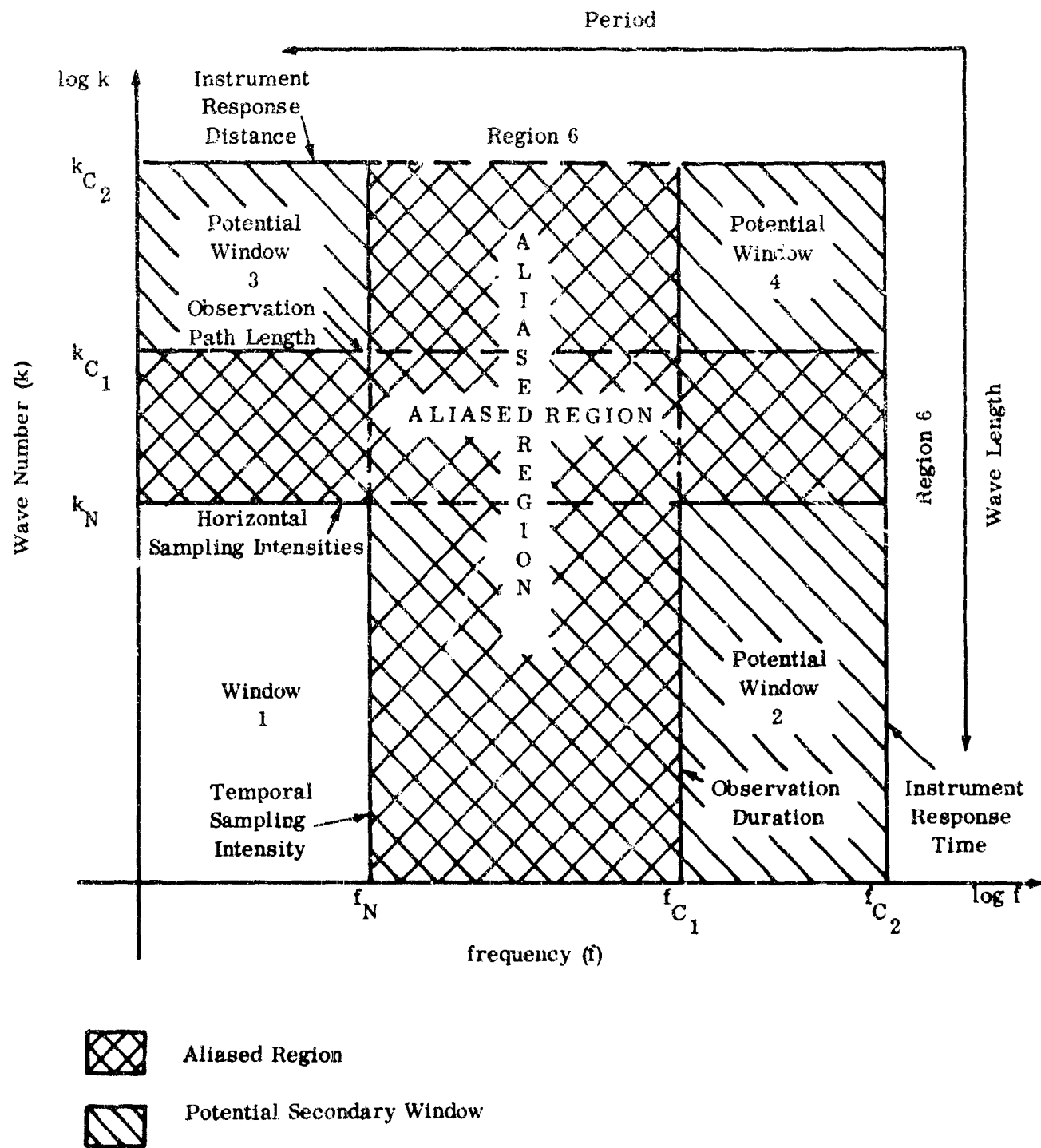


Fig. 4-3. Resolution of Natural Variability by System Characteristics

Let us now continue this discussion with reference to Fig. 4. The six pertinent system characteristics f_N , f_{C1} , f_{C2} , and k_N , k_{C1} , and k_{C2} delineate six regions on this figure within which something can be said about the resolution capabilities of the NDBS. Ideally f_N is greater than f_{C1} and k_N is greater than k_{C1} . The amplitude of the natural variability for each parameter, as shown in Fig. 4-2, is of importance to the NDBS with respect to identifying phenomena.

The discussion of these six regions of Fig. 4-3 will be made with cross-reference to Table 4-2. In Window 1, covering the low frequency and small wave number region, natural variability is completely resolved by the NDBS. Within this window, however, variability may exist in parameter observations due to natural variability in the aliased region which will not be discriminable from natural variability in window 1. Aliasing from Potential Windows 2, 3, 4 can be eliminated by suitable filters.

In the aliased region, the NDBS would not resolve the natural variability for a parameter. Likewise, the natural variability in frequency or wave number which occurs in this region can be an alias of variability in Window 1 and/or Potential Windows 2 or 3. In the aliased region, however, the natural variability can be partially resolved provided it is known beforehand that the variability in the aliased region occurs with scales which are not aliases of scales with significant variability in Windows 1, 2 and 3. *

The natural variability in Potential Window 2 can be fully resolved by making use of the continuous analog record over the period of observation; the average of the analog record filters out the natural variability occurring in potential Window 3. The natural variability in frequency in this window, however, may be aliased into Window 1 unless a low pass filter (e. g., averaging) over the duration of observation is applied. Time filtering may be desirable, if the time variability amplitude in either window cannot be neglected relative to the natural variability in the other, and the scales of only one of these windows are of interest to the user.

*The exception to this is the region in the center of the aliased region (entirely enclosed by dotted lines) from which no discernable information can be obtained about natural variability.

TABLE 4-2
RESOLUTION OF NATURAL VARIABILITY BY SYSTEM CHARACTERISTICS

Window/ Region	Range of Scales	Remarks
Window 1	$f < f_N$ and $k < k_N$	- Natural variability in this Window completely resolved; - Aliasing possible for natural variability of scales $f_N < f < f_{C_2}$ and/or in all other $k_N < k < k_{C_2}$, except region 6
Potential Window 2	$f_{C_1} < f < f_{C_2}$ and $k < k_N$	- Natural variability in this Potential Window is resolved if no temporal averaging is applied - Natural variability in frequency in the Potential Window may be aliased into window 1 above unless low pass filter is applied in time
Potential Window 3	$f < f_N$ and $k_{C_1} < k < k_{C_2}$	- Natural variability in this Potential Window is resolved if no spatial averaging is applied - Natural variability in wave number in this Potential Window may be aliased into Window 1 above unless low pass filter in space is applied.
Potential Window 4	$f_{C_1} < f < f_{C_2}$ and $k_{C_1} < k < k_{C_2}$	- Natural variability in this Potential Window is resolved if no Temporal and spatial averaging is applied - Natural variability in frequency and wave number in this Potential Window may be aliased into Window 1 above unless low pass filters are applied in time and space - Natural variability in frequency may be aliased into Potential Window 3 - Natural variability in wave number may be aliased into Potential Window 2
Aliased Region	$f_N < f < f_{C_1}$ or $k_N < k < k_{C_1}$	- Natural variability not resolved in center box of aliased region. Possibly partially resolved within aliased region - Natural variability in frequency or wave number within this region may be an aliased of variability in Window 1, 2 or 3
6	$f > f_{C_2}$ or $k > k_{C_2}$	Natural variability unresolved, undetected

In Potential Window 3, the natural variability is fully resolved if the continuous single observation is not spatially averaged over the observation distance. The natural variability in wave number in this window, however, may be aliased into Window 1 unless a low pass (e.g., spatial averaging) over the observation distance is applied. Space filtering may be desirable, if the space variability amplitude in either window cannot be neglected relative to the natural variability in the other, and the scales of only one of these windows are of interest to the user. More representative buoy deployments may reduce the amplitude of space variability in Window 3.

In Window 4, where wave numbers and frequencies are high, the natural variability is resolved if no spatial or temporal averaging is applied. The high frequency-wave number variability in this window, however, may be aliased into Windows 1 and/or 2 and 3 unless a low pass spatial and temporal filter is applied to both the space and time observations.

In Region 5, (i.e., $f > f_{C2}$ or $k > k_{C2}$) the natural variability is undetected.

The importance of the aliasing is dependent upon the relative amplitudes of the variabilities within the respective windows and the accuracy desired in the particular parameter by the user. From presently available observational data, the importance of aliasing to the NDBS and the need for filtering can only be surmised. Extensive data from test buoy deployments will be required to provide further information in this regard* (see recommendations in section 6.2).

The system design problem is one of obtaining the best (cost effective) design that is feasible. At high cost, a simple solution that would yield complete scale resolution for the NDBS would be to set $f_N = f_{C1} = f_{C2}$ and $k_N = k_{C1} = k_{C2}$ and measure all of the scales of natural variability explicitly. This is analogous to expanding the size of Window 1 to span all relevant frequencies and wave numbers. This high resolution is obtained, however, only at exceedingly great cost that is well in excess of budget feasibility. This simple design solution, therefore, must be ruled out as unacceptable. The NDBS designer is, therefore, confronted with the task of determining the most suitable values for f_N , f_{C1} , and f_{C2} and k_N , and k_{C1} , and k_{C2} .

*Note that practical problems arise from unresolved high frequencies and wave numbers being aliased into observations corresponding to windows at lower frequencies and/or wave numbers.

within reasonable cost limitations. The system designer must concern himself with the amplitudes of the natural variability in the frequency-wave number space as well as the marine environmental space (location, depth) and season. It is perhaps of importance to repeat that at this stage of the NDBS system design, the parameter k_{C_1} has been taken equal to k_{C_2} for most parameters and instrument packages under consideration.

The system designer should attempt to match the observational data characteristics to the user requirements as closely as possible within feasibility constraints. Alternatives in the matching process that are available to the NDBS system designer and will influence the observational data characteristics and costs of the NDBS are shown in Table 4-3. As is indicated in Section 5.0, the user data requirements should also be delineated. Application of a common framework by both user and designer is desirable. This information will assist in the identification of the system characteristics and filtering that are desired in the design; these also depend upon the space and time characteristics of the selected deployment configuration and the natural variability of the desired parameter as a function of wave number and frequency.

4.3 Considerations Relative to Deep Ocean Design

To make this discussion more meaningful, let us consider as an example a possible set of Deep Ocean NDBS characteristics in the frequency-wave number space and the variability of the current parameter. The values selected from these Deep Ocean NDBS characteristics result from the hypothetical deployment shown in Fig. 4-4, for the North Atlantic Ocean. As in this deployment, it is likely that preferred values of system characteristics will not be constants, but will vary in space (x, y and z).

Preliminary values, based on our present knowledge of natural variability in the North Atlantic, indicate that greater horizontal resolution would be desirable in delineating surface weather parameter patterns in the oceanic region covering the hurricane and tropical storm approaches to the continental U. S. (region HA in Fig. 4-4), whereas coarser detail will suffice over most of the remainder of the ocean. The system space characteristics approximately corresponding to those shown in Fig. 4-4 for Region HA are labelled HA in Figs. 4-5 and 4-6. Those corresponding

TABLE 4-3
SYSTEM CHARACTERISTIC ALTERNATIVES AVAILABLE
TO NDBS DESIGNER

- | | |
|-----------------|--|
| (1) Frequency | - increase f_N
vary f_{C1}
vary f_{C2}
filter part or all natural variability for $f_{C1} < f < f_{C2}$ |
| (2) Wave Number | - vary k_N
vary k_{C1}
vary k_{C2}
filter part or all natural variability for $k_{C1} < k < k_{C2}$ |

to the remainder of the deployment region are labelled OC. Preferred values will be determined by further trade-off studies and by extensive interaction between the NDBS designer and the data user. Final preferred values of system characteristics must await observational data from an initial NDBS.

Fig. 4-5 contains the preliminary Deep Ocean NDBS characteristics and also identifies the scales of the phenomena that influence current velocity in frequency-wave number space. As was indicated in Fig. 4-2, there are three additional dimensions of importance to the variability of a parameter that are not presented on this diagram for current; they are the magnitude of the variability, the variation of variability in depth (z) and the variability with season or time. The variation of variability in horizontal (x, y) is grossly represented by the division into the two regions HA and OC. A brief summary of the state of knowledge on the variability of the current with space and time as collected in this study is given in Table 4-4*. In Fig. 4-5, three system characteristics are identified relative to the frequency axis: the 6-hour temporal sampling interval, a 10-minute duration of observation, and instrument response times of 50 and 10 seconds. (As noted above, these values are considered representative and not necessarily preferred values.)

*It is recognized that the state of knowledge of the natural variability of the current parameter as a function of wave number, frequency, space and time is incomplete. The operational NDBS will itself add to the state of knowledge of natural variability in the marine environment. See also recommendations of section 6.2.

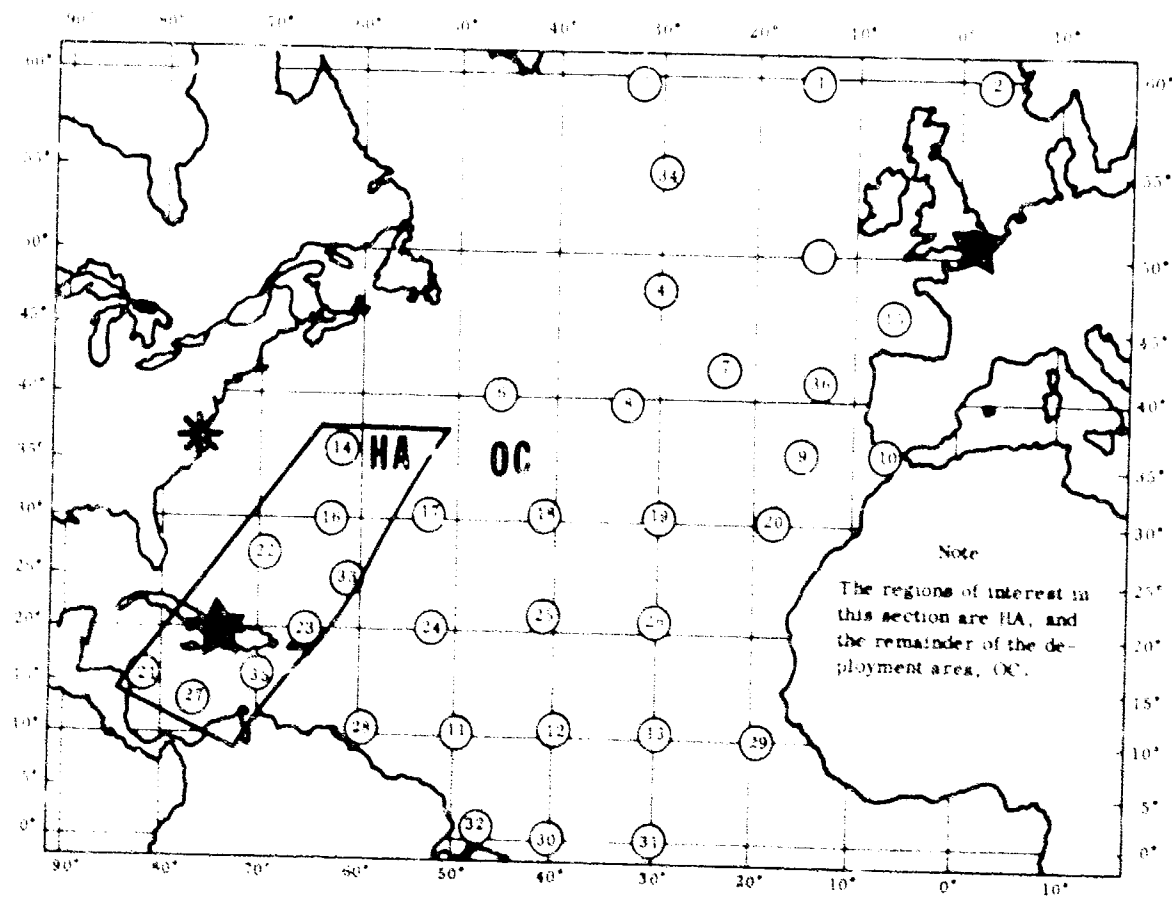


Fig. 4-4. Hypothetical Deep Ocean Buoy Deployment for the North Atlantic Ocean

- | | |
|---|------------------------------------|
| 1 - Large-Scale Wind Driven Gyres | 10 - Small-Scale Convective Eddies |
| 3 - Surface Current Meanders | 11 - Surface Gravity Waves |
| 4 - Internal Current Meanders | 12 - Rossby Waves |
| 5 - Surface Topographic Eddies | 13 - Deep Scattering Layer |
| 6 - Submarine Topographic Eddies | 14 - Plankton and or Algae Bloom |
| 7 - Semi-Diurnal, Diurnal, Semi-Annual Tides (As indicated on Fig. 3-1) | 15 - Thermocline |
| 8 - Inertial Currents | 16 - Turbidity |
| 9 - Internal Waves | 17 - Surges |
| | 18 - Tsunami |

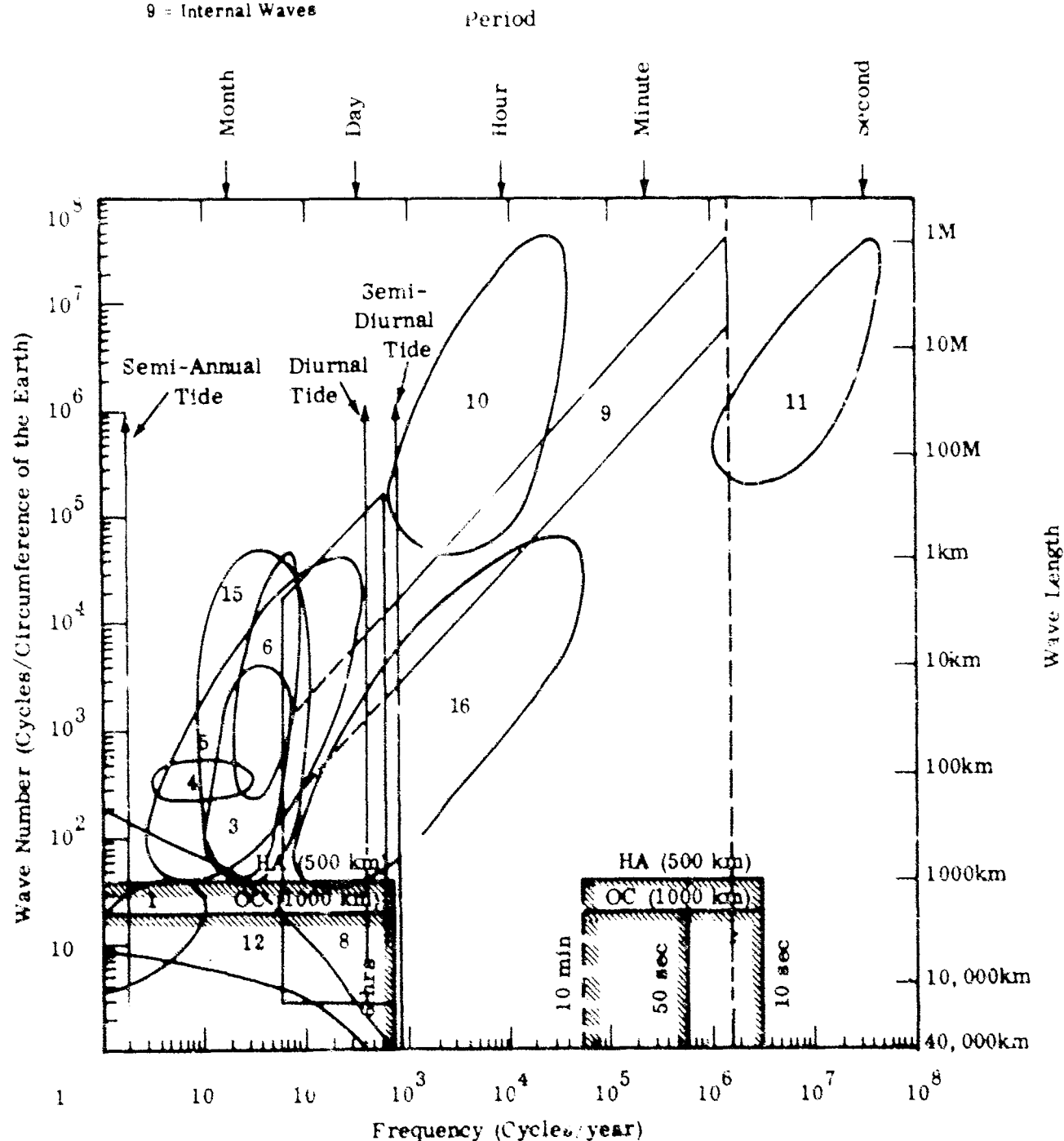


Fig. 4-5. Natural Variability of Current and Preliminary Deep Ocean System Characteristics for the Two Regions of the North Atlantic Ocean Shown in Figure 4-4.

Let us now interpret the effect of these selected system characteristics on the resulting observations. The surface gravity waves depicted on Fig. 4-5 were defined as those surface waves with periods between 1 and 30 seconds. As noted previously, these phenomena are indicated on some of the graphs solely for the purposes of demonstrating possible sources of noise and aliasing. The gravity waves with periods of less than 10 seconds will not be detected at all by the 10-second sensor response. The longer period waves (10-30 seconds), however, will be folded (aliased) into Window 1 (see Fig. 4-3), if the observation is not averaged and if the amplitude of the variability in surface gravity waves for the space-time deployment is significant (over a long period of time) relative to the variability of the current. Reference to Table 4-4 for sea surface gravity waves indicates characteristic speed as high as 2 kt. This will occur over all oceans, with the greatest amplitude found near the ocean surface. Due to this large amplitude in the upper ocean layers, filtering must be considered for current measuring instrument to be employed near the surface. This could be accomplished by utilizing the 50-second instrument response time. Here the lack of precision or completeness of the data in Table 4-4 becomes apparent, since the considerable spatial (x, y and z) variation of current variability due to surface gravity waves is only handled in a gross fashion. (A collection of detailed information concerning surface gravity waves was considered beyond the scope of this study, see Section 6.2).

Returning to Fig. 4-5, the indicated 10-minute observation duration will allow filtering of all frequency variability for periods less than 3 minutes and will, therefore, allow surface gravity waves to be filtered numerically, if desired, in the resulting observational data. It should be mentioned that some versions of the Savonius Rotor current meter provide a 50-second averaging in the instrument package, by counting. This instrument filters the gravity waves without further numerical filtering.

The 6-hour temporal sampling intensity will resolve temporal variability in the current velocity for phenomena with periods greater than 12 hours. Unresolved will be the natural variability associated with such phenomena as small scale convective eddies and convective eddies with periods greater than 10 minutes. In Table 4-4, internal waves and small scale convective eddies indicate a characteristic speed

TABLE 4-4
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA

Phenomenon	Characteristic Space Scale	Characteristic Time Scale	Characteristic Location	Characteristic Occurrence	Characteristic Amplitudes ⁽¹⁾
1. Large-scale wind-driven gyres	$10^3 - 10^4$ km	1 mo - 10 yr	All oceans	Continuous	50 cm/sec - 250 cm/sec (1 kt - 5 kt)
2. Thermohaline gyres (not shown on graph)	$10^3 - 10^4$ km	1 - 10^2 yr	All oceans	Continuous	1 cm/sec - 10 cm/sec? (.02 kt - .20 kt)
3. Surface current meanders	$10 - 10^3$ km	10 days	All oceans but especially western portion	Continuous	50 cm/sec - 200 cm/sec (1 kt - 4 kt)
4. Internal current meanders	10^2 km	$10 - 10^2$ dy	All oceans	Continuous	3 cm/sec - 20 cm/sec (.06 kt - .40 kt) ⁽²⁾
5. Surface topographic eddies	$1 - 10^3$ km	$1 - 10^2$ dy	Coasts and convergence regions	Continuous	~2.5 cm/sec or less (0.05 kt)
6. Submarine topographic eddies	$1 - 10^2$ km	10 days	All ocean	Continuous	~2 cm/sec (0.04 kt)
7. Tidal currents	$2 - 1.5 \times 10^4$ km ⁽³⁾	.5 - 182 dy	All, but especially coasts	Diurnal, semi-diurnal, or semi-annual (solar tide)	~50 cm/sec ⁽⁴⁾ (1.0 kt)

TABLE 4-4
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA (Continued)

Phenomenon	Characteristic Space Scale	Characteristic Time Scale	Characteristic Location	Characteristic Occurrence	Characteristic Amplitudes ⁽¹⁾
8. Inertial current	.2 - 1.5 x 10 ⁴ km	13 - 137 hr ⁽⁵⁾	All oceans	Frequent	~50 cm/sec (1 kt)
9. Internal wave	10 m - 1 km	2 - 10 ⁵ min ⁽⁶⁾	All oceans	Frequent	5 cm/sec-25 cm/sec ⁽⁷⁾ (.1 kt - .5 kt)
10. Small-scale convective eddies	10 m - 1 km	10 - 10 ³ min	All oceans	Frequent	25 cm/sec (max) (.5 kt)
11. Surface Gravity Wave	1 m - .25 km	1 - 30 sec	All oceans	Continuous	100 cm/sec (max) ⁽⁸⁾ (2 kt)
12. Rossby waves ⁽⁹⁾	200 - 40,000 km	4 dy - 1 yr	Theoretically in all oceans	Occasional	2.5 cm/sec-500 cm/sec (.05 kt - 10 kt)
15. Thermocline	1 - 10 ³ km	10-200 days (seasonal) 1-10 yr (permanent)	All oceans	Continuous	10m - 500 m
16. Turbidity currents	1 - 10 ³ km	10 min - 10 dy	All oceans	Occasional to rare?	25 cm/sec-25 m/sec ¹⁰ (.5 kt - 50 kt)

TABLE 4-4
CHARACTERISTICS OF IDENTIFIABLE OCEANIC PHENOMENA (Continued)

- ① The amplitude is for a "key" parameter.
- ② In one instance, current velocities of 43 cm/sec were measured at 4000 m.
- ③ The distance of 15,000 km was arbitrarily chosen in the extent of the largest ocean basin. There is some doubt as to the extent to which the tidal effect influences the smaller scales. In theory, at least, the tidal force should effect the entire water mass.
- ④ Tidal currents in channels or other narrow passage ways may reach upwards of 10 knots.
- ⑤ The two time scales correspond to the inertial periods at 5° latitude (~137 hrs) and 60° latitude (~13 hrs), respectively. For determination of the upper limits of the spatial scales of inertial oscillations, see the Appendix A.
- ⑥ The time scales for internal waves at a particular latitude must lie somewhere between the inertial frequency at that latitude and the Brunt-Valsala frequency (see Appendix A). Very often internal waves will display a semi-diurnal (12 hrs 25 min) tidal period.
- ⑦ Speeds of 3 to 4 knots have been observed at the density discontinuity interface (largest orbital velocities for internal waves are found at this interface) under certain density stratification conditions and with the passage of a fast moving atmospheric storm.
- ⑧ The maximum orbital velocity of a 12 foot wave of 10 second period in deep water is 115 cm/sec.
- ⑨ The Rossby waves were considered to have a sinusoidal form, and propagate in an ideal (frictionless) homogeneous medium which is in purely horizontal motion. The equations for calculation of the Rossby waves along with the restrictions on zonal velocities are given in the Appendix A.
- ⑩ The lower characteristic speed is pure speculation based on a heuristic consideration of the dynamic properties of turbidity currents. The upper characteristic speed is taken from the calculations of B.C. Heezen and M. Ewing (1952) which are based on time sequence of breaks in the transatlantic cable south of the Grand Banks after the earthquake of Nov. 18, 1929.

amplitude of 25 centimeters/second. This would indicate that some aliasing in the associated Window 1 (lower left hand corner of Fig. 4-5) is possible.

The high wave number phenomena surface current meanders and internal current meanders, surface topographic eddies and marine topographic eddies will not be resolved by the grid spacing characteristic of this deployment area. The aliasing possibilities of these phenomena in the resolvable window can be handled by judicious selection of deployment locations in the Deep Ocean. Deployment locations should be selected which are unlikely to be influenced by small scale phenomena. In practice, this may have to be determined by trial and error; e.g., by surveying prospective sites and installing temporary buoy networks.

Fig. 4-6 contains the preliminary Deep Ocean NDBS characteristics and also identifies the scales of the phenomena that influence surface air pressure in frequency wave-number space.

The preliminary characteristics shown will not fully resolve the particular phenomenon of interest in Region HA during certain seasons of the year, viz., the hurricane. This phenomenon falls in the aliased region (see Fig. 4-3). However, it can be partially resolved, since the lower wave number scales which are its aliases, and which lie in the same frequency band (i.e., those contained by synoptic scale and large scale atmospheric disturbances) contribute little natural variability in Region HA during the hurricane season in that Region. Partial resolution of the hurricane scales (i.e., estimation of its variability in the time or frequency domain) by the NDBS can provide invaluable supplementary information to that gained from other observing systems and/or theoretical models.

The phenomena in Fig. 4-6 containing higher frequencies that also fall in the aliased region can produce serious aliasing problems since they occur in conjunction with the hurricane, and can produce significant natural variability in the parameter of concern, viz., air pressure. Therefore, it would be preferable to eliminate the presence of the center box in the aliased region (see Fig. 4-3 and the second footnote in Section 4.2) thus, allowing time filtering to be applied. This could be done quite simply by extending the duration of observation to obtain a continuous time record of air pressure in Region HA during the hurricane seasons.

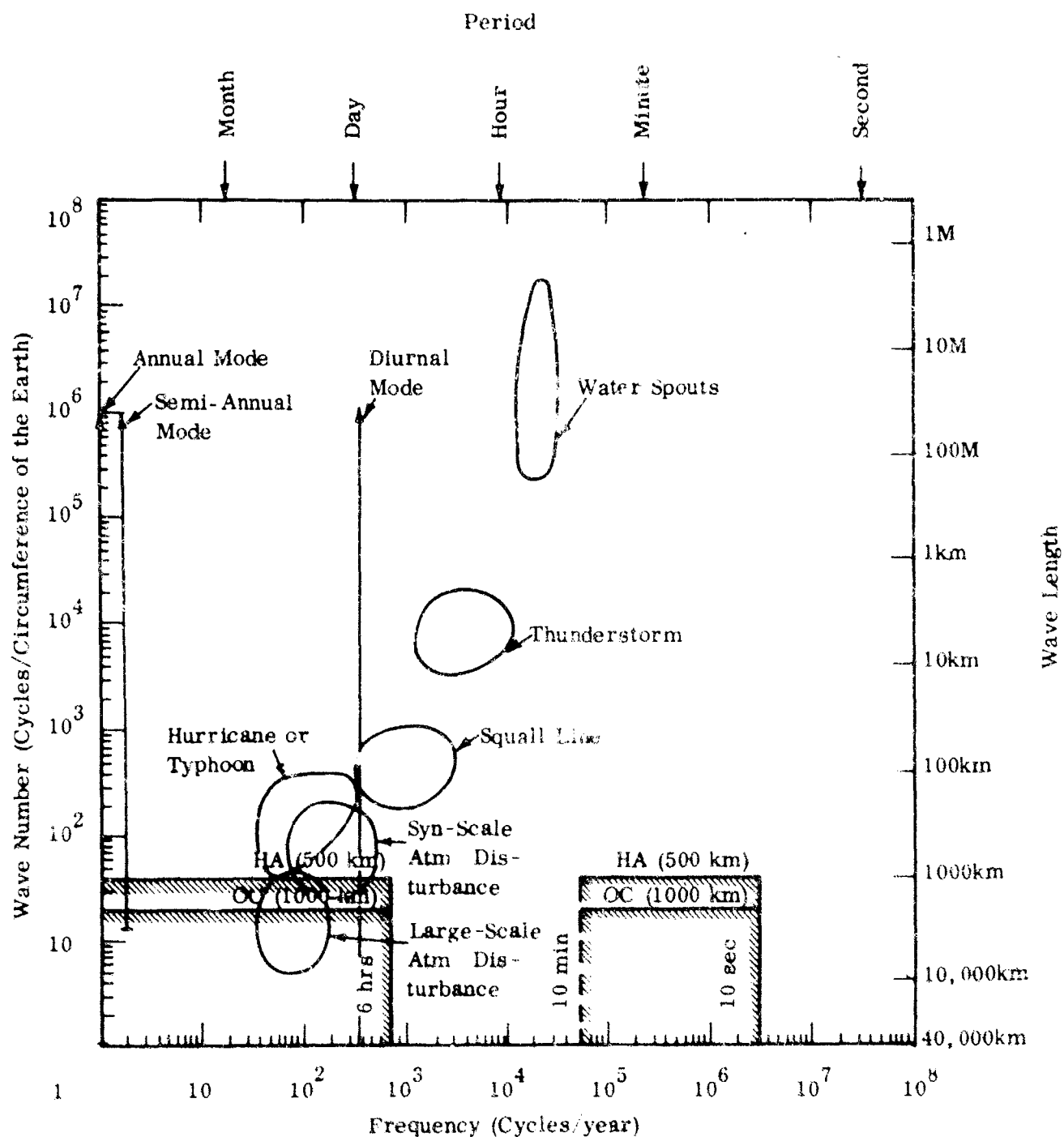


Fig. 4-6. Natural Variability of Surface Air Pressure and Preliminary Deep Ocean System Characteristics for the Two Regions of the North Atlantic Ocean Shown in Figure 4-4.

4.4 Considerations Relative to Coastal North American Design

Let us now consider an example of a possible set of Coastal North American characteristics in the frequency wave number space, and the variability of the same two parameters discussed in Section 4.3. The values selected for these characteristics result from the hypothetical deployment shown in Fig. 4-7, for the Gulf of Mexico and adjacent waters.

Again it is likely that preferred values of system space (x, y, and z) characteristics will themselves vary in space. Preliminary values based on our present knowledge of natural variability in these waters suggest that greater horizontal resolution is desirable in the Yucatan and Florida straits (Regions S in Fig. 4-7), with coarser resolution in the vicinity of the mid-Gulf current eddy (Region E in Fig. 4-7), and still coarser resolution elsewhere (Region G) in Fig. 4-7. System Space characteristics corresponding approximately to the spacings shown in Fig. 4-7, have corresponding labels in Fig. 4-8 and Fig. 4-9.

The increased detail in the horizontal obtained by the finer Gulf mesh now brings some of the larger scale surface meanders and topographic eddies within full resolution capability as shown in Fig. 4-8. Fig. 4-9 shows that mature hurricanes can also be fully resolved in the eastern and central Gulf regions, as can the larger extratropical pressure disturbances found in this area during the winter season.

NOTE: The Regions of Interest are:
S, E and G. G is all of the region not
in the three boxes.

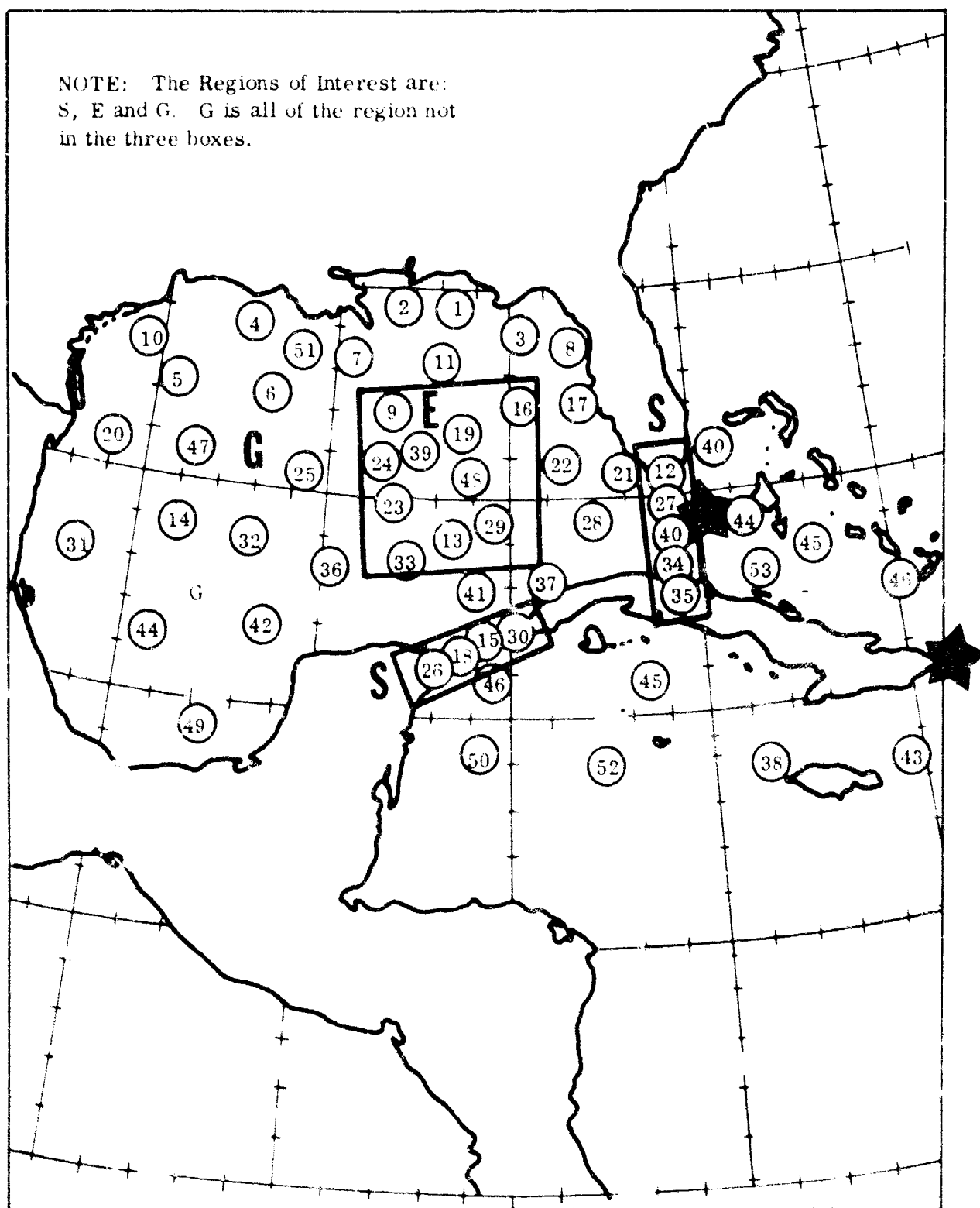


Fig. 4-7. Hypothetical Coastal North American Buoy Deployment for the Gulf of Mexico and Adjacent Waters.

- | | |
|---|----------------------------------|
| 1 Large-Scale Wind Driven Gyres | 10 Small-Scale Convective Eddies |
| 3 Surface Current Meanders | 11 Surface Gravity Waves |
| 4 Internal Current Meanders | 12 Rossby Waves |
| 5 Surface Topographic Eddies | 13 Deep Scattering Layer |
| 6 Submarine Topographic Eddies | 14 Plankton and/or Algae Bloom |
| 7 Semi-Diurnal, Diurnal, Semi-Annual Tides (As indicated on Fig. 3-1) | 15 Thermocline |
| 8 Inertial Currents | 16 Turbidity |
| 9 Internal Waves | 17 Surges |
| | 18 Tsunami |

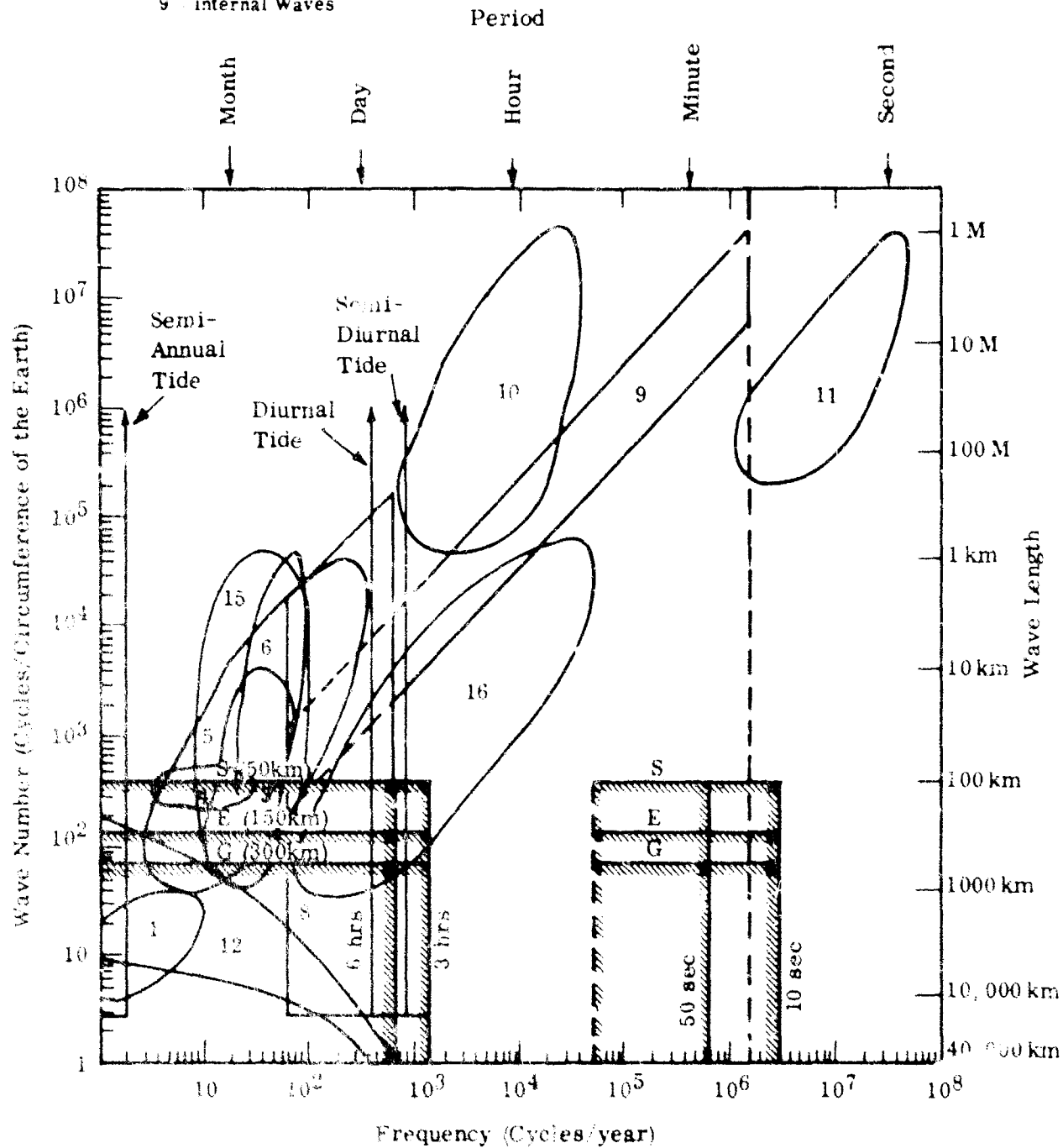


Fig. 4-8. Natural Variability of Current and Preliminary Coastal North American System Characteristics for Three Regions of the Gulf of Mexico as Identified in Fig. 4-7.

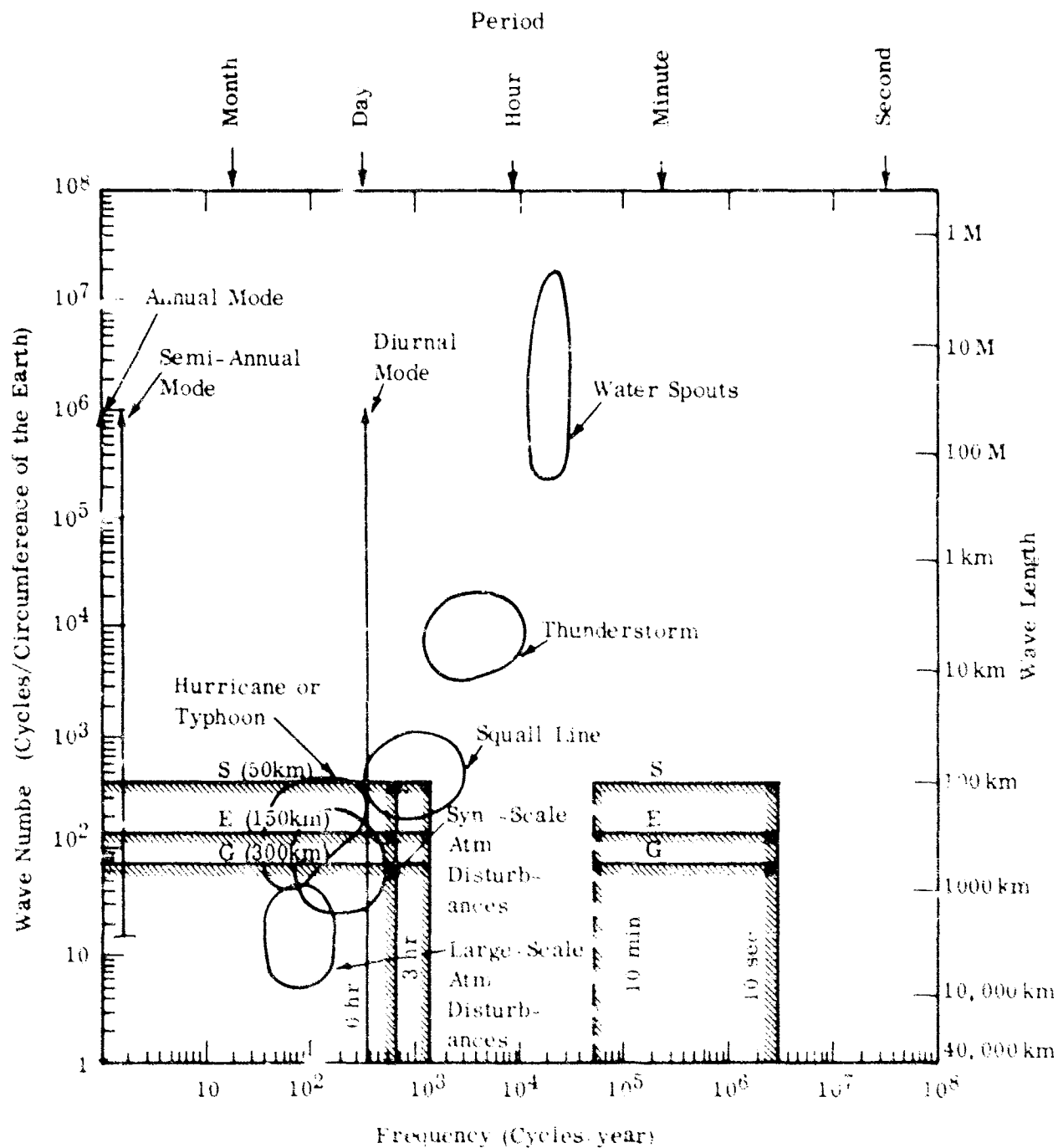


Fig. 4-9. Natural Variability of Air Pressure and Preliminary Coastal North American System Characteristics for Three Regions off the Gulf of Mexico Identified in Fig. 4-7

5.0 IMPLICATIONS FOR THE NDBS DATA USER

5.1 Background

Who is the NDBS data user? We have identified two classes of NDBS data users in Section 2.0. One class of NDBS data users is located at the data processing centers as shown in Fig. 5-1. The observational data from the NDBS are input to the data use techniques at the processing centers. The products output from the data processing centers are intended to satisfy the second general class of users - the ultimate user. There may be several classes of processing centers; for example, some processing centers may be concerned with archival and retrieval, others with analysis, prediction and interpretation. Likewise, some processing centers may be automated, others may be manual and some a combination of men and machines. Some processing centers may be operated by government agencies, others by private organizations. Some processing centers may be operationally oriented, others may be research oriented. Table 5-1 indicates a partial list of government users of NDBS data. Some of these government users are ultimate users, some participate in the processing function, and some government users fall in both classes. Table 5-2 indicates a partial list of ultimate users having operations that are environmentally sensitive. Most of these users are industrial organizations that have economic performance measures (profit).

In this section of the report we are primarily concerned with the data processing user of the observations collected by the NDBS. We are concerned primarily with the problem of how the data processing user should ascertain the data requirements of the data use techniques that are to be satisfied by the observing system (here, the NDBS). We will also develop a common language to facilitate the interactions necessary between the data user and the NDBS system designer.

As background to this discussion, let us consider the problem of the data user with reference to Fig. 7-2. The primary problem of the data user is the development and operation of data use techniques. Here, we will consider the data use as prediction, although archival and retrieval, and research have also been listed earlier as potential uses.

As was implied in Section 2, the prediction use will probably place the most stringent and comprehensive demands on the operating system. Thus, its early

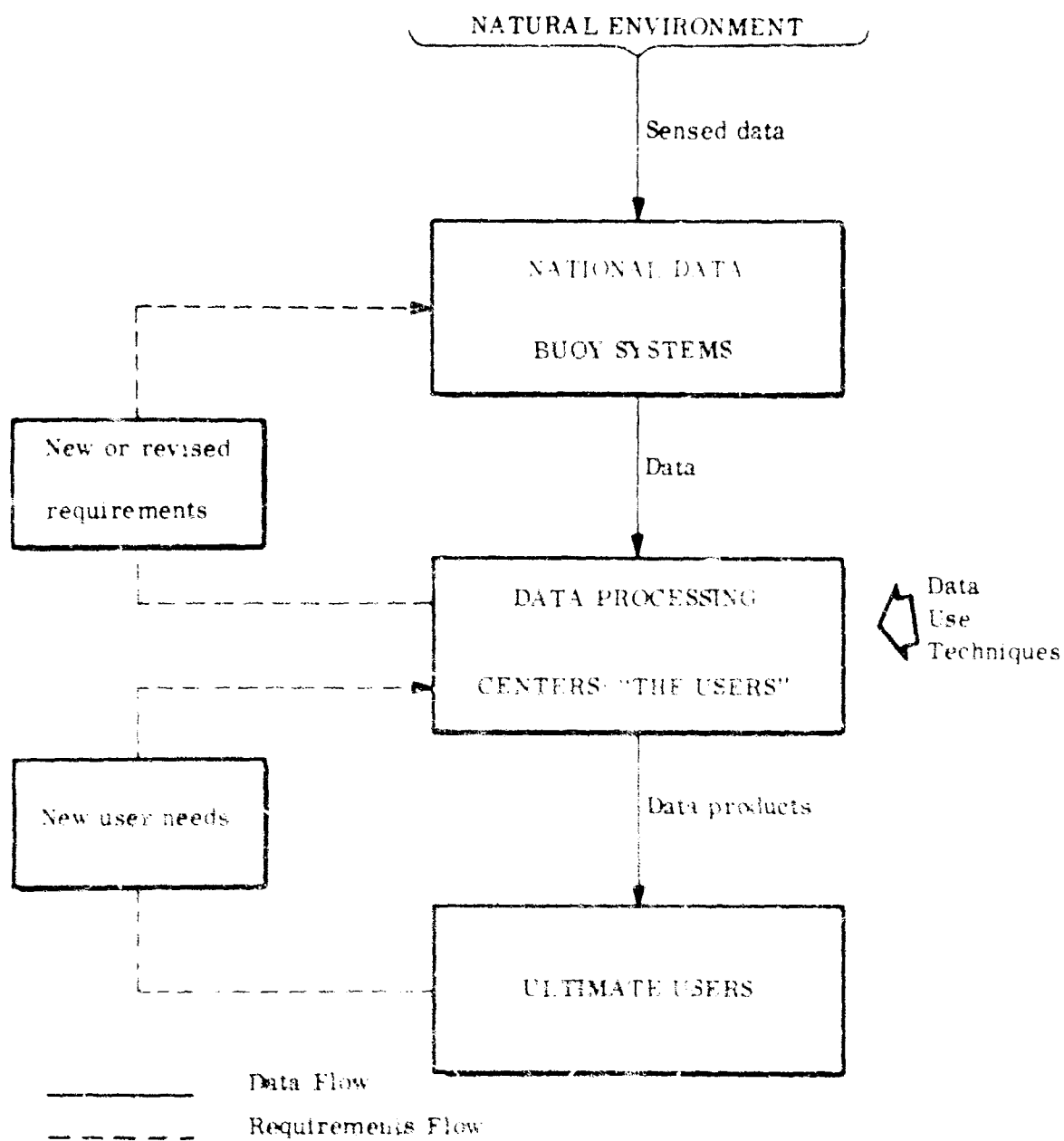


Fig. 5-1. Relationship Between Data Users and NDBS

TABLE 5-1
A PARTIAL LIST OF GOVERNMENT USERS OF NDBS

Air Weather Service	Health, Education and Welfare
Coastal Engineering Research Center USA	Maritime Administration
Lake Survey, USA	NASA
Atomic Energy Commission	National Oceanographic Data Center
Bureau of Commercial Fisheries	Chief of Naval Operations
Bureau of Mines	Naval Electronics Laboratory
Bureau of Sports Fisheries	Naval Mine Defense Laboratory
U. S. Coast Guard	Naval Air System Command
Coast & Geodetic Survey, ESSA	Naval Underwater Sound Laboratory
ESSA Research Laboratories	Naval Oceanographic Office
U. S. Weather Bureau	Naval Oceanographic Instrumentation Center
National Weather Records Center, ESSA	Naval Weather Service
Federal Aviation Agency	Office of Naval Research
Federal Water Pollution Control Administration	Pacific Missile Range
Geological Survey	National Science Foundation

consideration will probably uncover at an early stage more technical problems in matching system characteristics, natural variability, and data use techniques, that are common to many uses. This is not meant to depreciate the benefits obtainable from other uses, or the necessity for special consideration of their more exclusive demands on the system characteristics in the near future.

There are several classes of prediction data use techniques. We have already outlined a categorization into empirical, physical and statistical techniques. Some of

TABLE 5-2
A PARTIAL LIST OF ECONOMIC USERS

Construction Industry	Heat, Light and Power
Offshore Oil and Gas	Insurance
Transportation Industry (sub-surface ship, surface ship, land, aviation)	Public Works
Agriculture	Mining
Commercial Fishing	Air Resource Management
General Public	Water Resource Management

these techniques are objective and may require use of electronic computers, other techniques are subjective. The data user is concerned with the desired output from the data use techniques that is intended to reduce the environmental uncertainty for an ultimate user with environmentally sensitive operations. Fig. 5-2 is arranged in what might normally be considered reverse order. Our discussion will trace the analysis sequence to define the data requirements of data use techniques. In operations, the NDBS observational data are input to data use techniques. The uncertainty which exists in the data products provided to the ultimate user is due to our restricted ability to explain the natural variability in space and time by the observational data and the data use techniques. The data use technique developer should obtain a suitable balance between the natural variability, the data use technique and the observational data input in order to reduce the unexplained (and therefore, unexpected) natural variability which is significant to the ultimate user in a benefit-cost sense. In a broad sense, the data use technique developer is confronted with a trade-off problem. It is necessary for him to ascertain a measure of performance, significant to the ultimate user, and to perform a trade-off analysis of alternative observation, analysis, and prediction systems using the ultimate user's performance measure vs. cost. The multi-dimensions of concern to the data use developer are presented in Fig. 5-3.

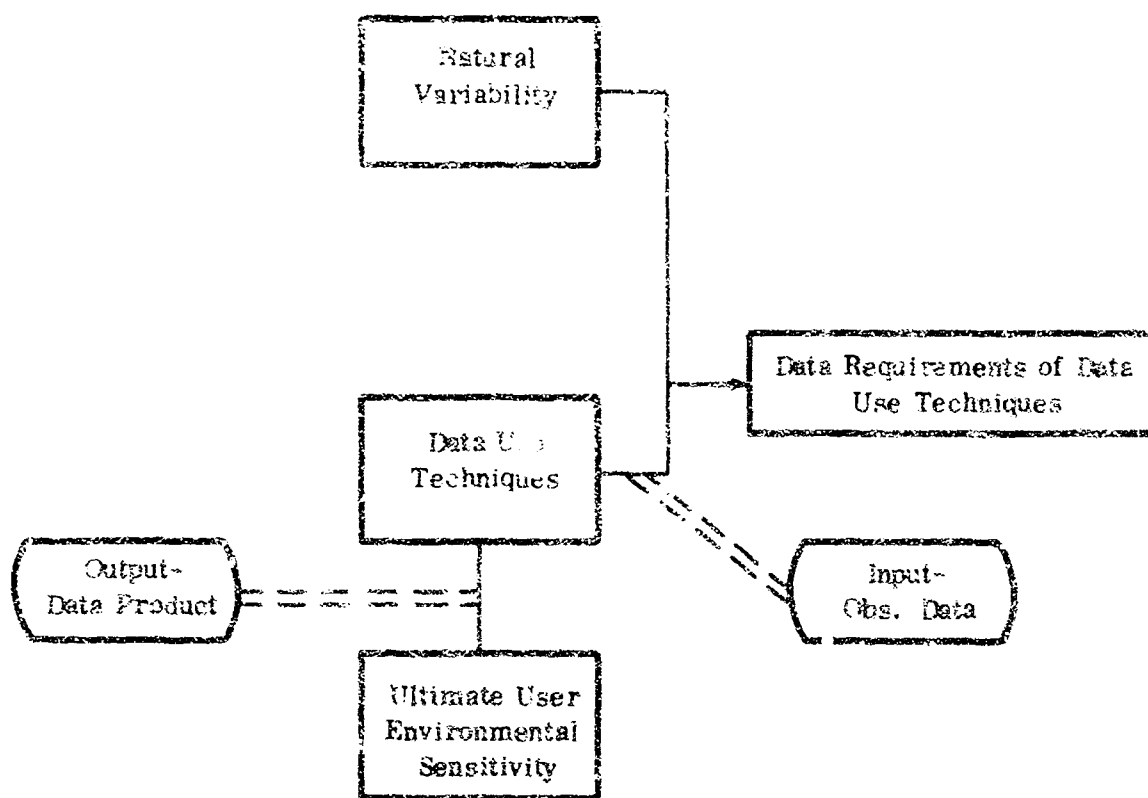


Fig. 5-2. Data Requirements of Data Use Techniques

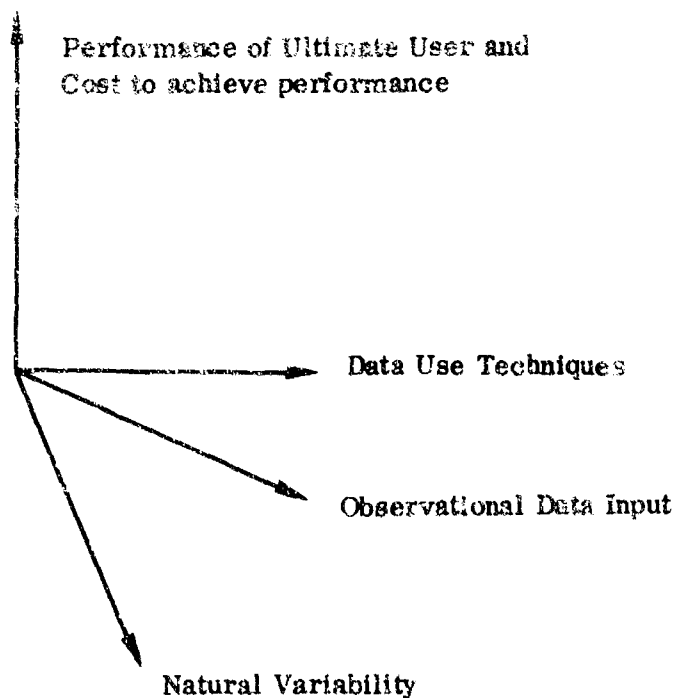


Fig. 5-3. Problem Dimensions of Data Use Technique Developer

The problems of the data use developer are not independent of those which concern the NDBS designer. Figure 5-4 results from overlapping Fig. 5-2 and Fig. 4-1 and indicates an interface between the NDBS designer and the data use developer. The data user must specify the data requirements of the data use techniques. The NDBS designer will attempt to match the NDBS observational data characteristics to these data requirements within the feasibility constraints of the NDBS. In this section, we are concerned with how the data user should ascertain his data requirements and how these should be specified.

5.2 General Considerations of Data User

The data requirements of data use techniques should be specified in terms of the parameters required as well as pertinent parameter characteristics. This specification may be made in more than one way due to the interrelationship of the quantities to be discussed below. One method of specifying the relative data requirements for data use techniques is given in Table 5-3. In addition to the pertinent parameters, we are concerned with the specification of what is frequently referred to as a representative observation. The scales (x, y, z, t) are specified for which the natural variability needs to be resolved by the observing system. Since the natural variability varies as a function of space (location and depth) and in time or season as well as with frequency and wave number, accuracy requirements are necessary to define the natural variability in these four dimensions. The accuracy requirements statement should be made as the least stringent precision required to be satisfactory to the data user. In addition to the scales which are to be resolved, a statement should be made of the scales which should be filtered from the data and any parameterization or environmental event identification within these scales. Several data use system constraints are also pertinent. These include transmission time, observation time(s), observation interval (usually continuous for an operational user) and space in the marine environment that is to be observed.

The NDBS system designer is undertaking trade-off studies in terms of an NDBS performance measure and cost which allow a relative ranking of the match between the NDBS observational data characteristics and the data requirements of data use

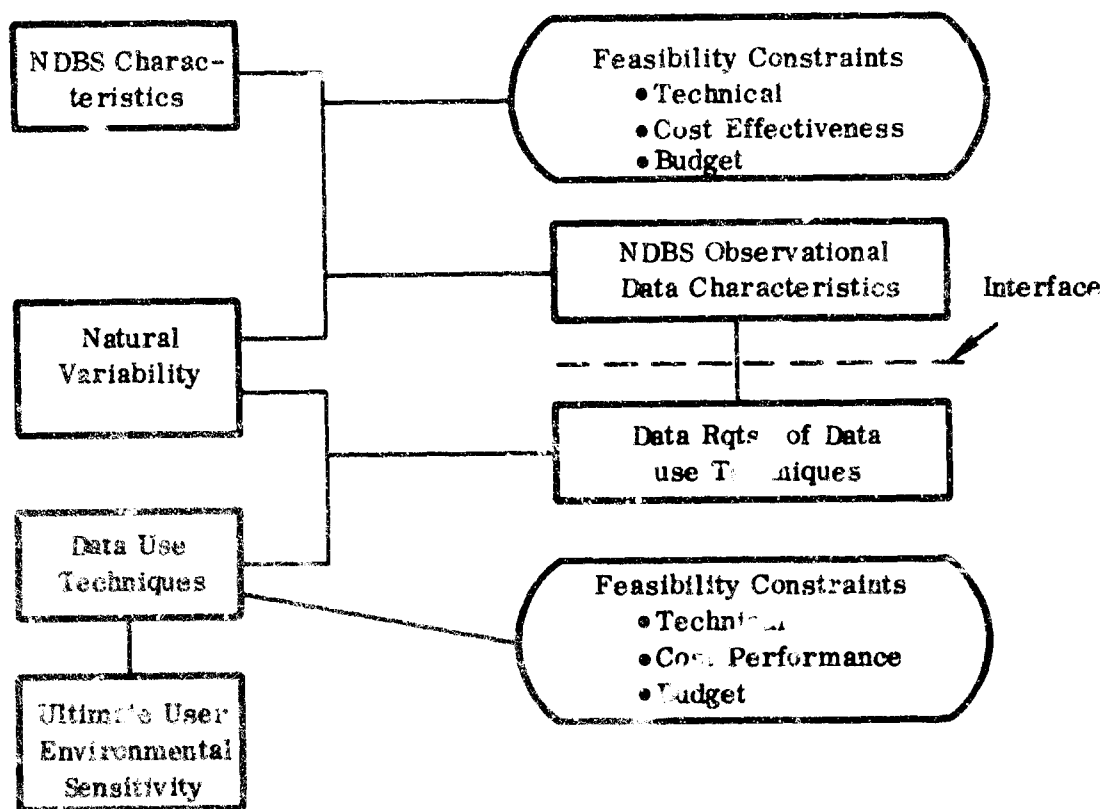


Fig. 5-4. Interface Between NDBS Designer and Data Use System Developer

TABLE 5-3
RELEVANT DATA REQUIREMENTS FOR DATA USE TECHNIQUES

Parameter(s)
Scales (x, y, z, t) to resolve Natural Variability
• Accuracy required [- t(space:location (x, y), depth(z); time or season)] • Range
Scales (x, y, z, t) to filter - parameterization of events
Data Use system constraints
• Transmission time • Observation time • Observation interval (if not continuous) • Volume of Marine Environment to be observed

techniques (see Fig. 5-4). The data user is also undertaking trade-off studies in his performance-cost environment. Therefore, it is necessary that a close interaction exist between the NDBS designer and the data use developer (see Recommendations, section 6. 2).

Let us consider the problems of the data user first from an ideal point of view and then from a practical point of view with reference to Fig. 5-4. Ideally, the data user knows the sensitivity of the ultimate user's operation, a pertinent performance measure, and the pertinent environmental factors. The environmental factors include the parameters which are output from the data use techniques. The sensitivity of the ultimate user's operations to environmental factors indicates the precision necessary in the output of the data use techniques. Ideally, information is available to bound the problem. This information would describe the ultimate user's performance with no environmental support, with "perfect" environmental support and with environmental support with the precision of climatological variability.

Ideally, the data user would also have at his disposal a trade-off analysis of alternative data use techniques measured in terms of ultimate system performance, as determined above, and cost to provide the environmental information. This would require that he have available a state-of-knowledge on the precision of each of the

data use techniques as a function of input data requirements for given levels of natural variability. He would then be able to, ideally, make a selection of the most desirable data use technique (in a cost performance sense) and would be in a position to specify the data requirements of a particular data use technique in a form consistent with Table 5-3.

Practically, his state-of-knowledge falls far short of that ideally required. The data user may not have a clear picture of his ultimate user in terms of the information required, forms, environmental factors, sensitivity and relevant performance measures. Our state-of-knowledge on the precision of the output of data use techniques as a function of the input data is fragmentary. Our present operational data use techniques are shaped by the existing available observational input data which is very primitive from the marine environment. In a practical sense, budget constraints are of equal importance to technical feasibility constraints. The practical solution is to choose from among alternative technique development sequences which build upon the present operational state-of-the-art, to formulate improved data use models, develop the associated techniques, and proceed through a test and evaluation stage which may result in a feedback to a "revised model" formulation stage. The practical approach is to take small steps to reduce relevant uncertainty, i.e., unexplained natural variability that is pertinent to the ultimate user, starting with the present operational system.

These general concepts can perhaps be better understood with reference to a particular example which will be addressed in the next section.

5.3 A Meteorological Data Use - The Public Weather Service

In this example of meteorological data use by a Public Weather Service, we will discuss, in order, the three major considerations indicated on Fig. 5-5 to arrive at the NDBS data requirements:

- Weather sensitivity of the general public ultimate user,
- Natural variability as a function of f , k , space and time, and
- Applicable data use techniques.

It should be mentioned that this section (5.3) is to be interpreted strictly as an example of procedure. The data provided do not represent the result of an exhaustive study but rather the state of information readily available to the authors.*

5.3.1 Weather Sensitivity of the General Public User

The activities of the general public are diverse and vary between sections of the United States as well as between cities, urban and rural areas. Only a broad overview can be considered here, although we are considering an area of the United States within which the potential observational data from the NDBS is important input to the data use techniques as indicated in Fig. 5-1. Such an area is the megalopolis extending from Washington, D.C. to Boston, Massachusetts. Table 5-4 contains some typical activities of the general public which are weather sensitive. In the upper group of activities, criteria which measure satisfactory performance include: satisfactory accomplishment of activity, human comfort, and enjoyment. In the lower group, criteria include dollar loss to property as well as death and injury. The environmental factors causing this sensitivity are related to the parameters and/or phenomena identified. The phenomena identified have a specific meaning to the general public and represent a mode of information "parameterization" for communicating combinations of parameters to the general public, e.g., a hurricane signifies high wind speed (in excess of 75 mph), strong surf, storm tides and heavy rain.

Most of the general public operational decision options require short lead times of 0 to 2 hours. Forecast information is useful, however, for planning operations for 0 to 36 hours. The forecast frequency should be such to provide information with greatest precision at the time required by the general public for decision and planning. General public decisions are most frequently made in the early morning and evening.

5.3.2 Natural Variability

We are concerned with the natural variability of the particular parameters and phenomena indicated in Table 5-4. The important parameters include precipitation, temperature, wind, dew point and sunshine. The phenomena indicated include extreme values of these same parameters. Fig. 5-6 portrays the frequency-wave number scales of major atmospheric phenomena. Separate diagrams for the wind

*It should be noted that TRC operates a commercial weather forecasting service, The Travelers Weather Service, covering the Hartford, Connecticut area.

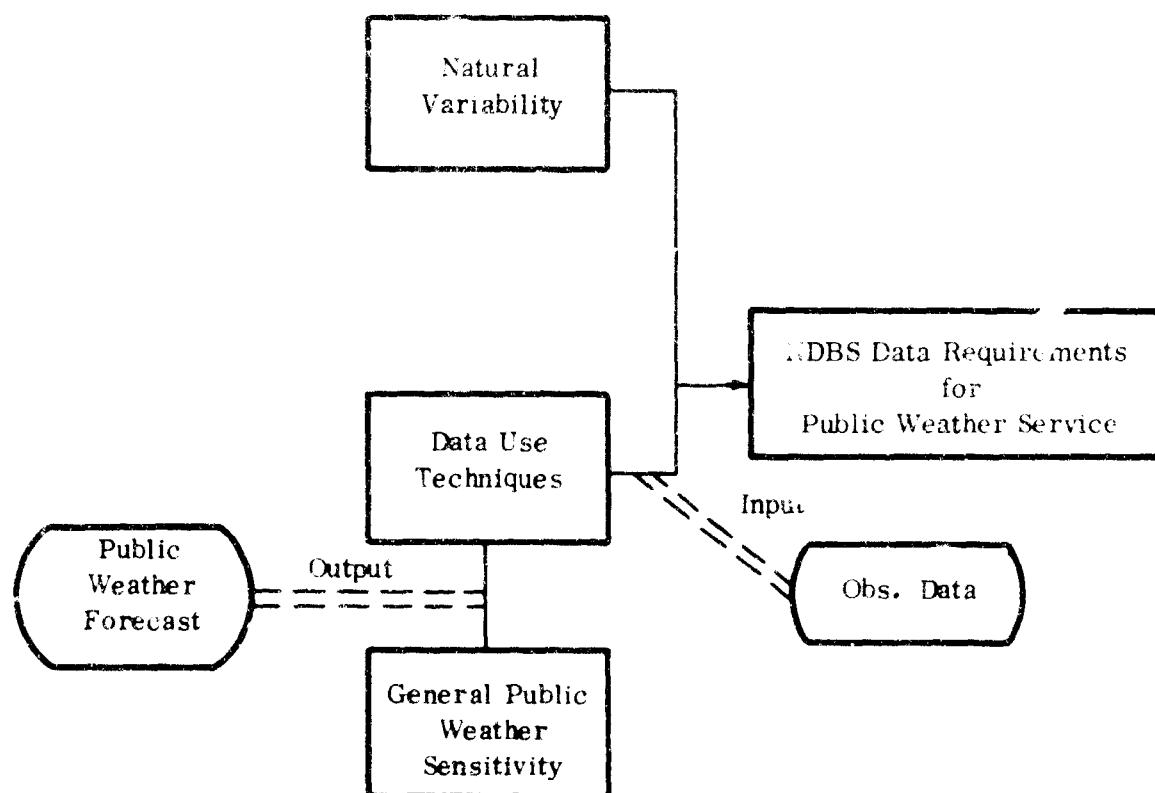


Fig. 5-5. Public Weather Service - Data Use Analysis

TABLE 5-4
ENVIRONMENTAL FACTORS FOR PUBLIC WEATHER SERVICE

Activity	Meteorological Parameters or Phenomena
Work Outdoors	precip, sunshine, T, $\checkmark$, T_d
Dry Clothes	precip, sunshine, T, $\checkmark$, T_d
Grounds Maintenance & Home Repairs	precip, sunshine, T, $\checkmark$
Auto Transportation	precip, T
Outdoor Recreation	precip, sunshine, T, $\checkmark$
Damage to Property	precip, T, $\checkmark$, hurricane, tornado, thunderstorm, cold wave, heavy snow, freezing rain, storm tide
Damage to Life & Limb	precip, T, $\checkmark$, hurricane, tornado, thunderstorm, cold wave, heavy snow, freezing rain, storm tide

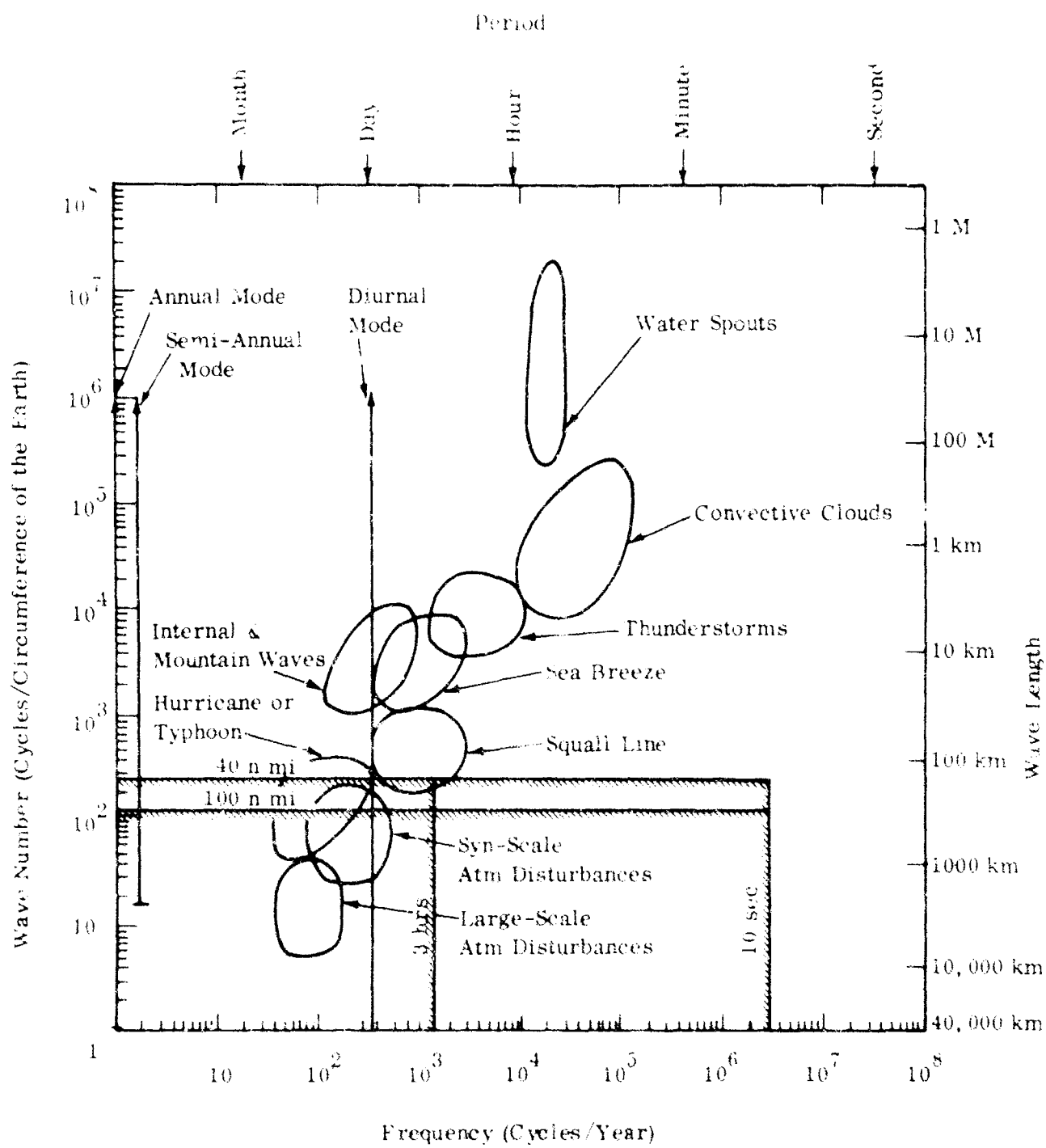


Fig. 5-6. Major Atmospheric Phenomena

velocity, temperature, dew point, precipitation and pressure are included in Fig. 5-7 through Fig. 5-11. Information on the amplitude of variability of these parameters is not provided in detail since such data collection was beyond the scope of this investigation (see Recommendations, Section 6.2).

5.3.3 Data Use Techniques for Public Weather Service

The present state-of-the-art of data use techniques to support the public weather service are combinations of subjective and objective methods. The major phenomena which influence the important parameters range downward in frequency and wave number from the thunderstorm, as shown in Fig. 5-6. The presently operational objective numerical weather predictions techniques of the U.S. Weather Bureau are designed to support each of the operating services such as the public weather service. These analysis and prediction techniques are designed to predict the synoptic scale and large-scale atmospheric disturbances. Data intensity over land areas are adequate to support these techniques. Over ocean areas, however, the horizontal observation intensity is only adequate for the large-scale atmospheric disturbances. The general public, however, is sensitive to scales of atmospheric variability which are not predictable by present operational numerical weather predictions. The public weather service utilizes data use techniques of analysis and prediction which are suitable to support the general public on the scales of concern and within the observational limitations. The state-of-the-art allows for subjective and objective analysis methods. For forecasting, subjective, kinematic, statistical and limited physical-numerical techniques are available. There is no unique technique and the design and development of improved analysis and prediction techniques is a continual process. A conservative approach is to expect little evolution from the present operational data use techniques.

5.3.4 NDBS Data Requirements for Public Weather Service

The data required as input to the data use techniques for the public weather service depends upon which techniques are to be utilized; particularly, what scales will be observed and analyzed and predicted explicitly (in detail), and which scales will be "parameterized" or forecast in a statistical sense. The assumption made here is that initially we should specify the data requirements with no more

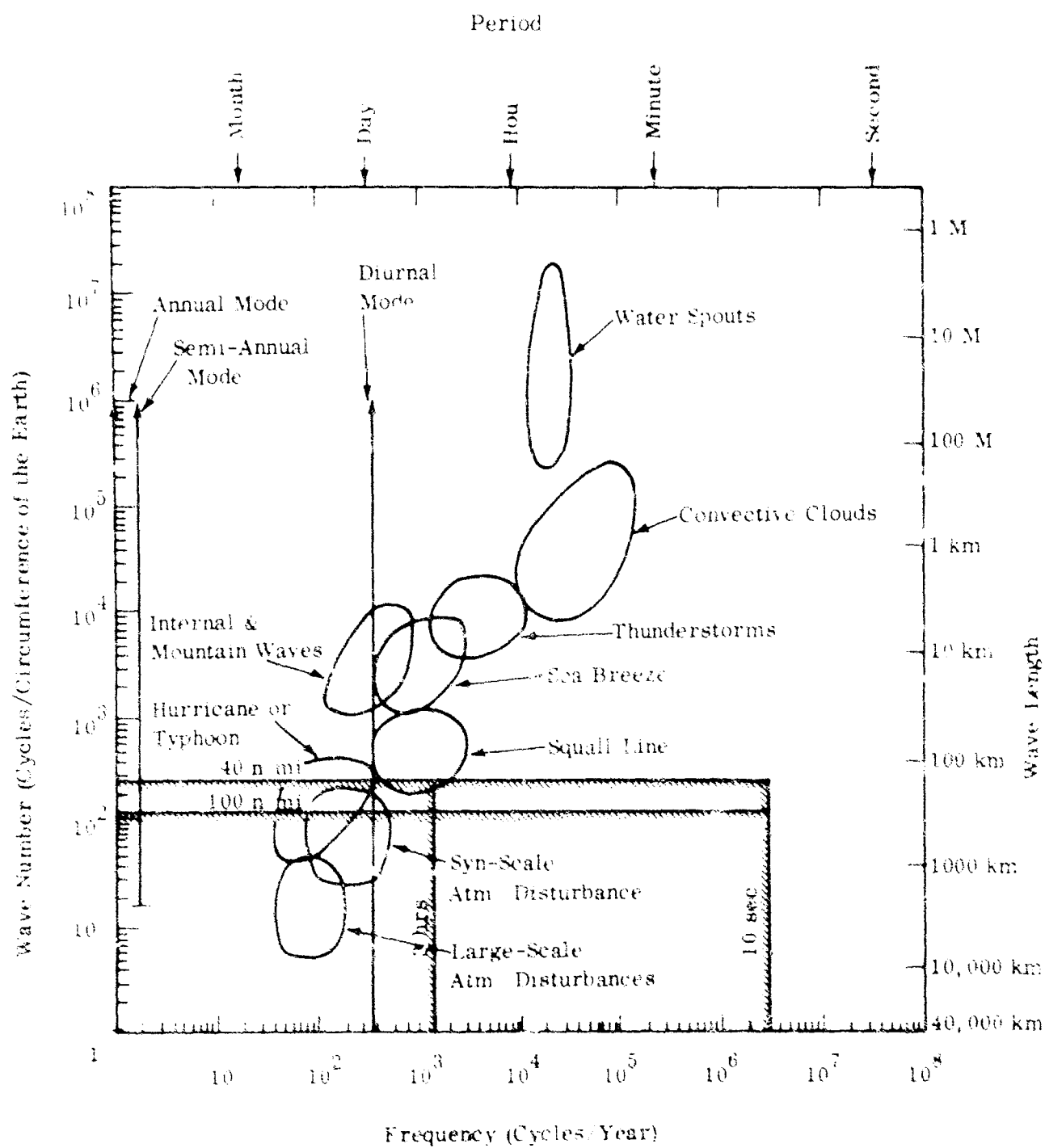


Fig. 5-7. Phenomena and Processes Affecting the Variability of the Wind Velocity

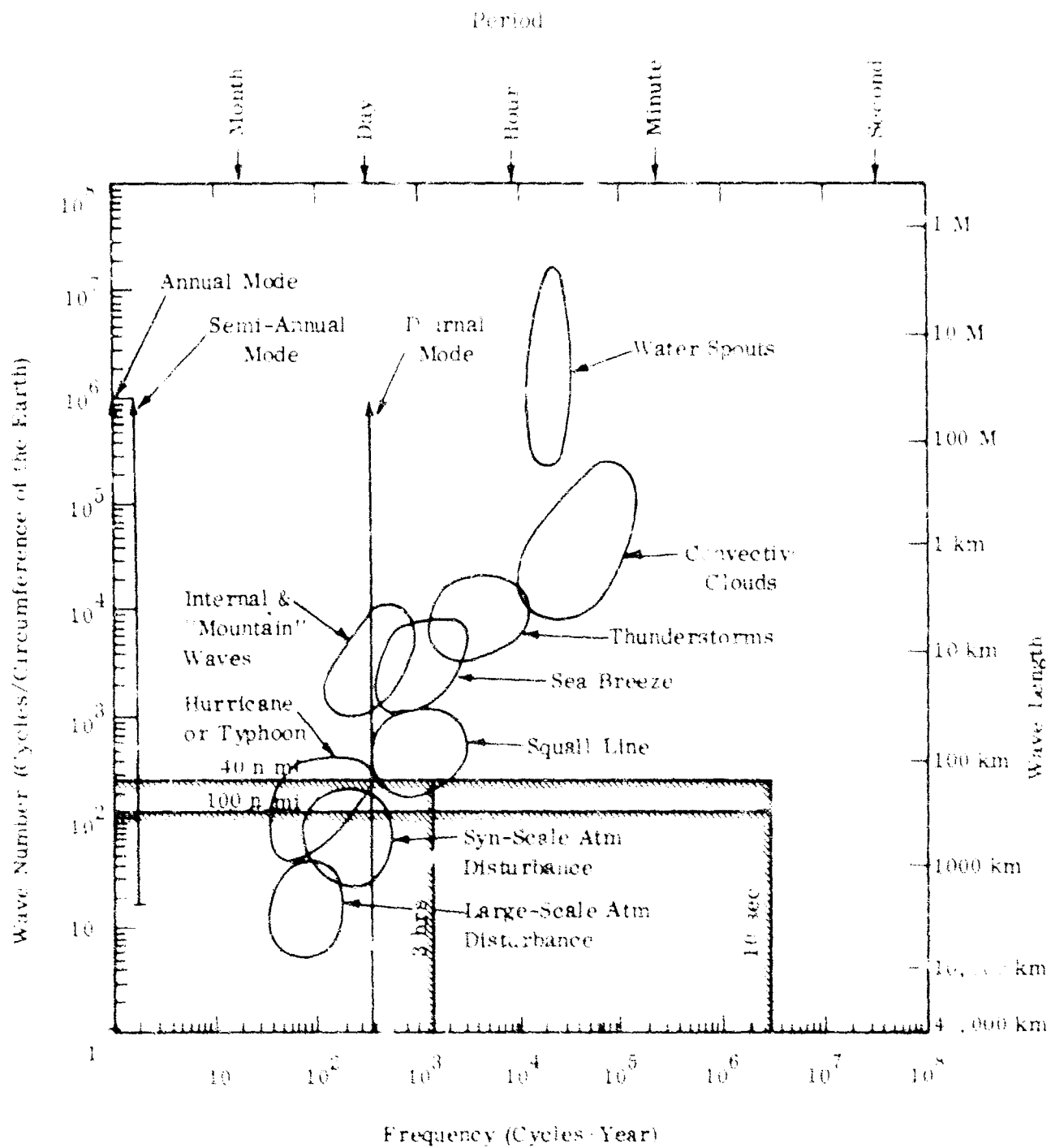


Fig. 5-8. Phenomena and Processes Affecting the Variability of Air Temperature

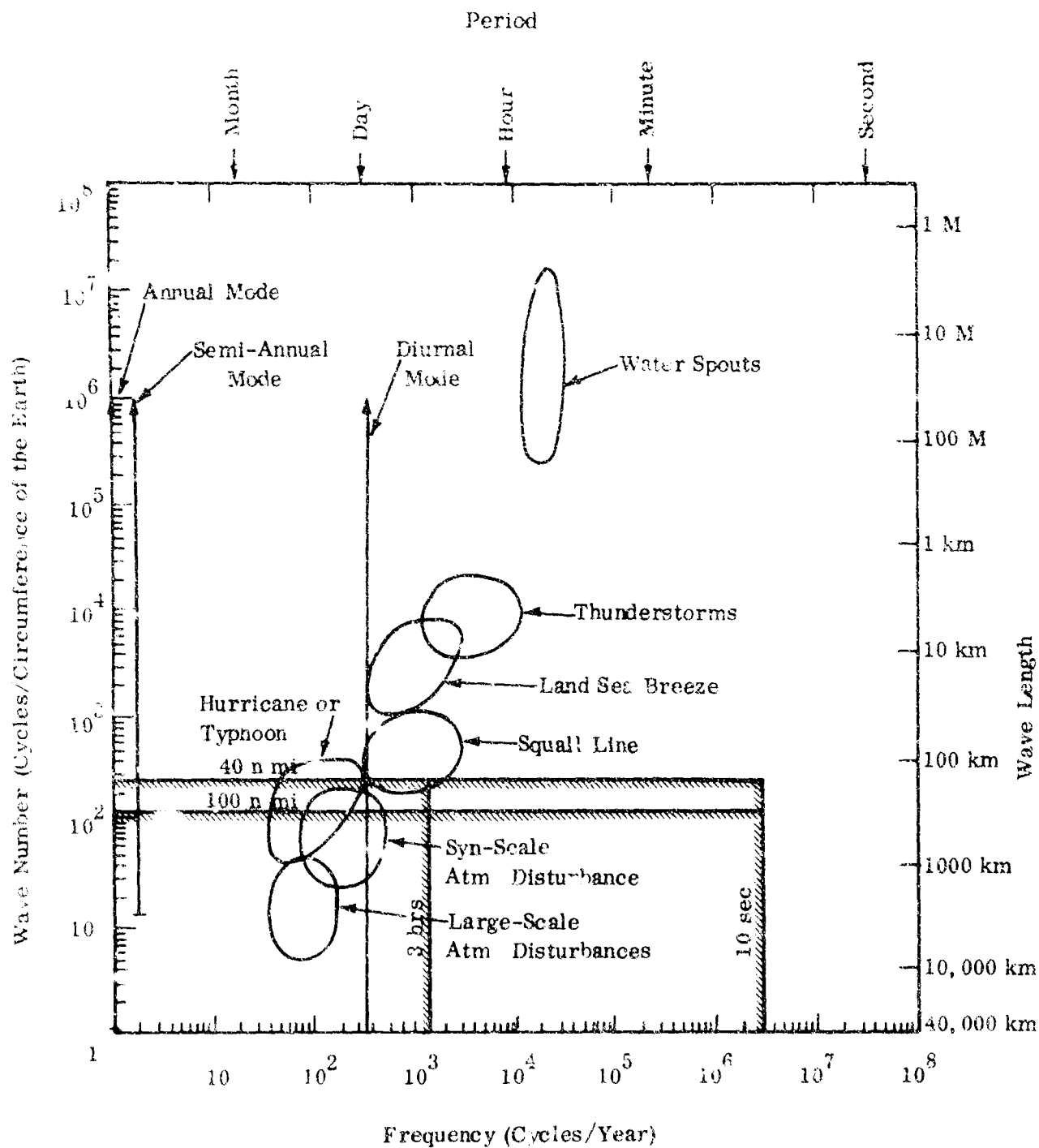


Fig. 5-9. Phenomena and Processes Affecting the Variability of Dew Point

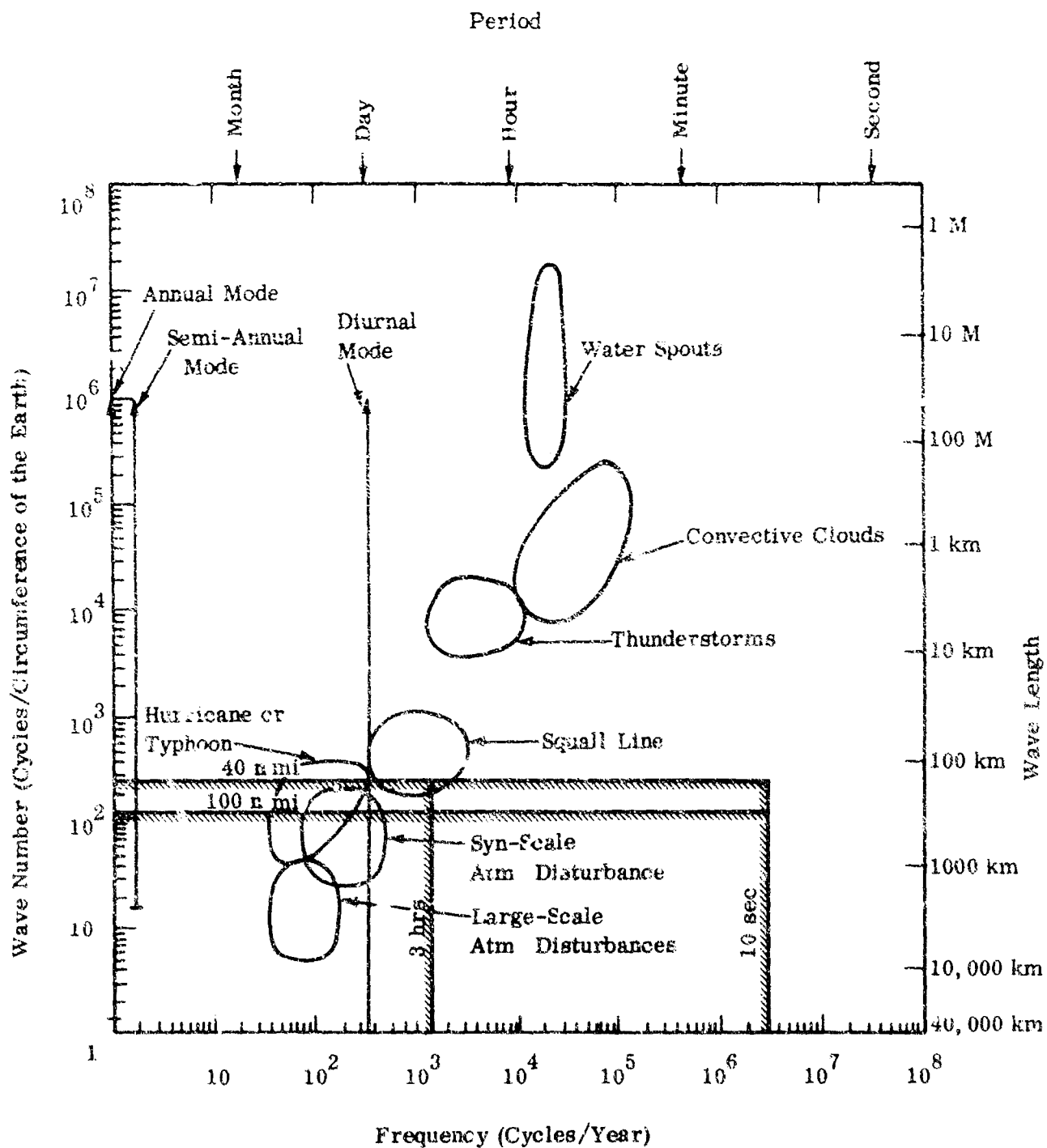


Fig. 5-10. Phenomena and Processes Affecting the Variability of Precipitation

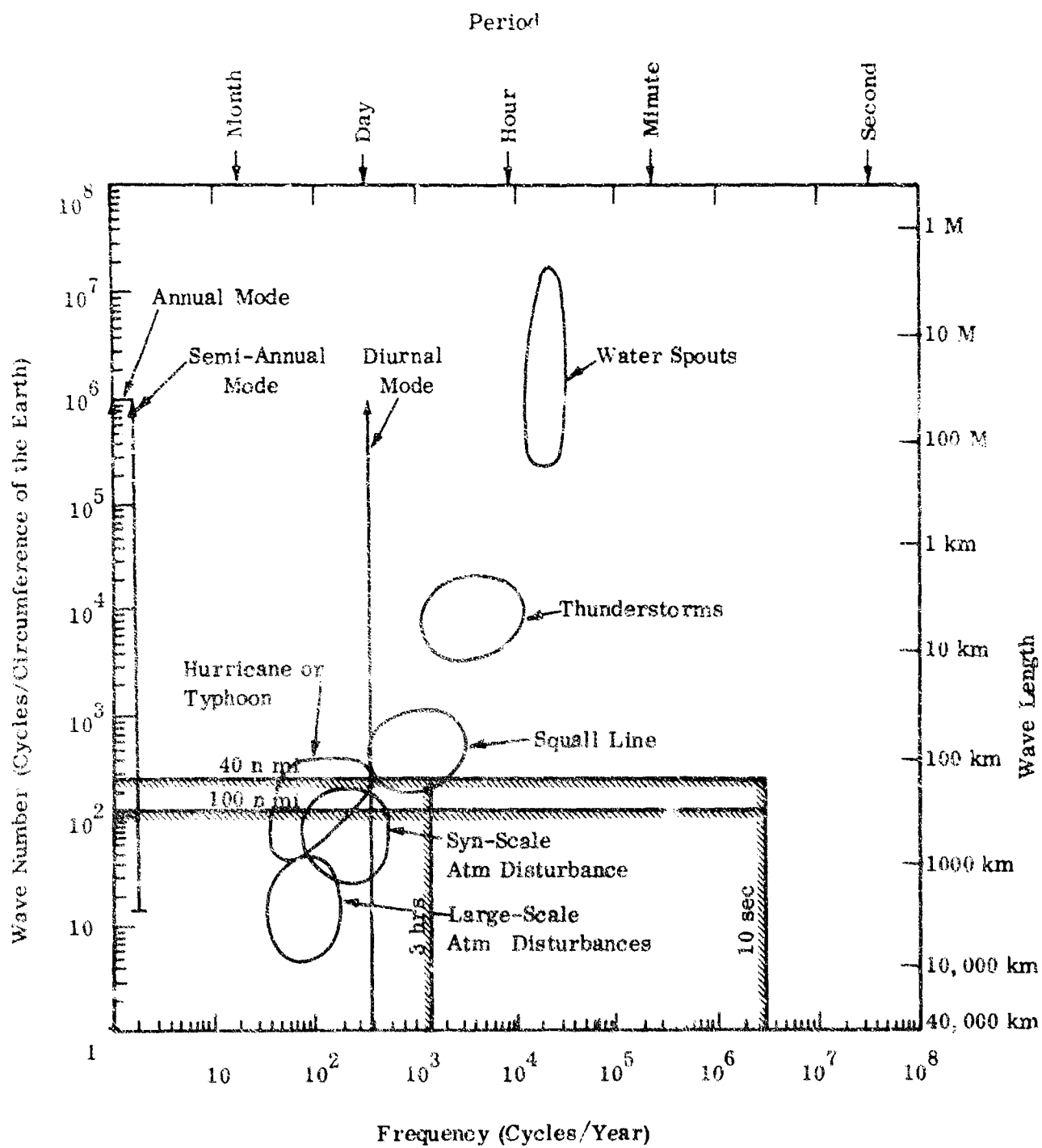


Fig. 5-11. Phenomena and Processes Affecting the Variability of Air Pressure

stringency than is necessary for the data use techniques being presently used or definitely planned for use in the near future. Since the public weather service of a Megalopolis (Washington, D.C. to Boston, Mass.) is adjacent to the coast, the NDBS meteorological data complements the meteorological data over the land as input to the data use techniques. The parameters required include temperature, wind, dew point, precipitation and sunshine as well as pressure. Pressure is a parameter required by the data use techniques even though the public is not sensitive to pressure. The available information on natural variability has been summarized on f-k graphs for parameters measurable by the NDBS. Figures 5-6 through Fig. 5-11 indicate scales which should be resolved, parameterized and filtered.

A somewhat higher wave number resolution is required adjacent to the coast (40 n mi) and lower wave number resolution (100 n mi) would be suitable at approximately 300 n mi from the coast. Along the U.S. east coast, this would resolve the synoptic scale and most hurricane disturbances. The 3-hour temporal sampling intensity would be suitable. The requirements call for a parameterizing and filtering of all scales of frequency greater than $\sim 10^3$ and wave length less than 150 or 370 km. For parameterization, we require information on the occurrence (or not) of non-resolved phenomena as they yield a characteristic signature on the parameter time series, e.g., squall line, thunderstorm. Short period parameter intensities pertinent to design climatology should also be acquired.

6.0 CONCLUDING REMARKS AND RECOMMENDATIONS FOR FURTHER STUDY AND EXPERIMENTATION

6.1 Concluding Remarks

- A framework has been constructed relating the National Data Buoy System characteristics to the natural variability of the marine environment to assist the NDBS system designer in specifying observational data characteristics that are to be matched with the requirements of data use techniques. This framework is usable by the NDBS designer in trade-offs between cost and effectiveness (or utility) of the NDBS observational data characteristics needed to satisfy the data requirements.

- A structure has been established relating:
 - Marine environmental data requirements
 - Data use techniques
 - Natural variability of phenomena
 - Needs of ultimate data users relative to mission environmental sensitivity

This structure has been devised to assist data users in documenting and revising data requirements commensurate with intended data use techniques (prediction models).

- A compendium has been made of the scales of natural variability of meteorological and oceanographic parameters to be measured by the NDBS. Natural phenomena have been "parameterized," to make possible broad analyses of the ability of various buoy networks to resolve these phenomena. It is clear that existing information describing the amplitude of the natural variability and its variation in space and time (season) is inadequate. Field experiments in the marine environment will be needed to overcome this lack of information.

6.2 Recommendations for Further Study and Experimentation

The results of the present study are limited by gaps in our present knowledge of the natural marine environment.

Certain of these identified knowledge gaps may be candidates for observational and theoretical studies in the near future. The results of these investigations will likely influence the deployment of instrumented buoys in the first phases of the NDBS program. Preliminary investigations should focus on specific parameters and regions of the ocean that are of high-priority concern to NDBS development. It is recommended that the NDBS DPO sponsor a continuing study of the interface between the needs of data users and the design and operation of the NDBS. The advice and cooperation of major operational data users having presently-defined techniques and procedures for data use would be solicited to establish initial priorities for collection of data. It is suggested that the results and future plans for the continuing DATA Users/NDBS Interface Study be periodically reviewed by an appropriate Data Users Advisory Group, reporting to the NDBS DPO.

As a first step toward initiation of the recommended Interface Study, a general framework for observational and theoretical study should be developed from results of several present marine data collection programs involving buoys. Among these programs are the WHOI - ONR moored buoy studies in the Atlantic, the SIO-ONR Northern Pacific (NORPAC) experiment, and the ESSA-coordinated BOMEX experiment in the Caribbean. Briefs outlining the impact of these experiments on NDBS development and implementation should be prepared for the NDBS DPO. These briefs would be based upon scientific analyses of the experimental results. The briefs and scientific analyses would be available for review and use by a selected Scientific Advisory Group, reporting to the NDBS DPO.

To augment present scientific investigations, it is recommended that NDBS DPO support observational studies directed to obtaining better definition of natural variability having specific application to high-priority NDBS design requirements. To obtain this better definition, NDBS DPO support should include the early deployment of single buoys and small networks of buoys with observational characteristics defined by a scientific organization that will also be responsible for analysis of the data, thus assuring continuity throughout the entire scope of the scientific investigation.

Similar experimental programs should be conducted in a test environment to determine the performance and effectiveness of various hardware combinations under consideration for use in the NDBS. The object of these experiments is to anticipate

problems and seek feasible solutions. For example, problems may result from mismatching system characteristics with the natural environment.* Possible solutions for such problems might be achieved by some type of filtering of the signal, by changes in some system component properties, or by replacement of the entire system. The design of these studies should include planning for "benchmark" standards (e.g., simultaneous measurements from fixed platforms), and for the inclusion of a wide range of environmental conditions.

The present study has necessarily been restricted in its scope to those critical design problems of immediate concern to the initial formulation of a data buoy system. Therefore, there has been little or no consideration of other system design problems which are less pressing but which must be carefully considered in reaching the final operational system. The present study should thus be extended to include a consideration of such factors as:

(1) Instrument sensitivity. What accuracy or threshold should be chosen for measurement of each of the natural parameters to be observed?

(2) Data quality. The design of the sensor and hardware system will interact with the data use techniques to affect the quality of the data. The effect of system design alternatives on quality should be explored.

(3) Data extent. The duration of data collection in both space and time will affect the usefulness of data obtained. This design characteristic can enter trade-off considerations with instrument sensitivity in some situations.

(4) Vertical variability. Little is known of the natural variability in the vertical dimension. Studies, possibly in combination with additional observational programs should be undertaken to define design requirements in the vertical.

*An extreme example to illustrate this point, a current meter with inertial characteristics mounted on a high-profile buoy, moored in shallow water with an elastic, large-scope mooring in a region of mild currents and strong winds would most likely produce highly erroneous current data.

A survey of available information in terms of specific regional and seasonal segments of the marine environment should be compiled into an easily used form, such as a handbook, such as Ref. 14. This readily accessible present-state-of knowledge handbook would be of considerable use to designers of the NDBS, and to designers of other marine data collection systems and the developers of techniques for the use of marine data. An important by-product of such a survey effort would be the identification of gaps in our present state-of-knowledge which must ultimately be filled by experimental research.

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APPENDIX A
DETERMINATION OF PHENOMENA SCALES

I. INERTIAL OSCILLATIONS

Pure inertial motion occurs when centripetal acceleration due to the deflecting force of the earth's rotation is balanced by centrifugal force of the path of curvature

$$(2\Omega \sin\phi)c = \frac{c^2}{R} \quad (1)$$

where Ω is the angular velocity of the earth's rotation, ϕ is the latitude and c is the velocity of a water parcel relative to the earth.

The period of the inertial oscillation is given by

$$T = \frac{\pi}{\Omega \sin\phi} \quad (2)$$

and is therefore dependent only on the latitude. Oscillations of this period may also occur in combination with other flow components. In very low latitudes the inertial period becomes large and therefore 5° latitude was arbitrarily chosen as the upper limit (longest period) to be represented in Fig. 3-1. The lower limit (shortest period) that appears in Figure 3-1 was dictated by restriction of buoy placement above 60° latitude due to ice problems.

The radius of a pure oscillation is given by

$$R = \frac{c}{2\Omega \sin\phi} \quad (3)$$

and is dependent of the velocity and the location of the oscillation. Although R constitutes the radius of the trajectory of an individual particle in the oscillation, it is possible for entire oceans to be subject to such an inertial oscillation. Therefore, the limit for the lower wave numbers (long wave lengths) should be dictated by the physical limits of the ocean basin. The limits on the upper wave numbers (short wave lengths) are prescribed by the minimum dimensions of an individual particle trajectory at a particular latitude with a particular particle speed as can be seen from Equation (3). The limits for the latitude have already been identified; the lower limit

on the speed was identified as the stated accuracy of measurement in the users requirements which was 0.05 knot (2.5 cm/sec).

II. INTERNAL WAVES

Internal waves can only exist in a non-homogeneous medium such as the sea. They form between subsurface water layers of varying density. The limiting frequencies (angular frequency) of internal waves are

$$\Omega < |\omega| < N_m \quad (4)$$

where Ω is the inertial frequency equal to fardi the angular velocity of the earth times the sine of the latitude and N_m is the maximum value of $N(z)$ which is Brunt-Vaisala's frequency defined as

$$N(z) = - \left(\frac{g}{\rho} \frac{dp}{dz} - \frac{g^2}{c^2} \right)^{1/2} \quad (5)$$

here g is the gravity, ρ is the density and c is velocity of sound. The Brunt-Vaisala frequency is a measure of the stability of the oceanic stratification.

Observed values of N_m in the ocean are of the order 10^{-2} radian/sec while $\Omega < 1.5 \times 10^{-4}$ radian/sec. Internal waves have been observed to have speeds of 0.11 to 0.60 knots. With observed values, and the relationship $c = f/k$, limiting wave numbers are obtained at a particular frequency.

III. ROSSBY WAVES

Consider the very simplest case of an ideal (non-viscous) homogeneous, incompressible ocean in purely horizontal motion in which there exists a simple sinusoidal disturbance of wave length L . The relationship between the phase velocity, c , the zonal velocity, U , and the change in the Coriolis parameter ($2\Omega \sin \phi$) with respect to latitude, β , may be expressed as

$$L = \pm 2\pi \frac{U - c}{\beta} \quad (6)$$

The value of β is determined by the latitude and here again the limits of 60° to 5° were chosen for reasons stated above. The range of zonal speeds was chosen to correspond to the range specified in the users requirements; viz., 0.05 to 10 knots. The phase velocity was given an unrealistically large range for 0 to 40,000 cm/sec, for the purpose of exploring the area which is bounded in Fig. 3-1 by the results of Equation (6). The relationship to relate frequency and phase velocity is $c = f/\kappa$.

APPENDIX B

MOORING AND PLATFORM MOTIONS

This appendix is intended to generally describe the possible motions that a single moor platform (surface and/or subsurface) can undergo under oceanic environmental conditions. These motions can affect the data collecting capabilities of many of the sensors on or suspended from the platform. At times, serious distortion may be introduced into the time series record obtained from these sensors. This distortion, generally termed "noise", may be induced in many ways by the motions of the platform and/or mooring, as well as by the imperfect response of the sensor to the resulting transients and to the real transients which appear to exist in the sea. The sensors to be used by the NDBS will be affected to varying degrees by platform and mooring motions. The current meter is the most susceptible to these platform-mooring effects.

The term mooring motions generally refers to the mooring and float (surface or subsurface) as one system which oscillates at various modes. A surface platform (float), particularly of the surface following type, undergoes many gyrations due to surface waves. These modes of oscillation differ from mooring motions which arise primarily from currents. The reader is referred to the Proceedings of the Buoy Technology Symposiums (1963 and 1967); (Marine Technology Society) for more detailed information about platform motions due to sea surface waves.

Mooring motion is the change in the equilibrium position of a moored platform in response to a change in the direction and speed of the current flowing past the mooring and platform. The maximum amplitude of these motions occurs near the surface and decreases to zero at the bottom. These motions become acute with respect to current measurements which are made relative to the mooring so that mooring motion is present as an extraneous signal in the measurement. Other NDBS sensors are sensitive to these motions only in the presence of gradients of the parameter values.

In the presence of a rotary current (e. g., the inertial current) the motion is particularly pronounced if the amplitude of the rotary components exceeds the mean current. The mooring is swept through an irregular orbit with the frequency of the rotary component at speeds that may attain a significant fraction of the measured speeds. The amplitude of the rotary components can be considerably attenuated in the relative flow passed the mooring and platform tend to move with the current. For example, a simple model may be derived [15] to demonstrate that in the presence of a 100 cm/sec rotary inertial current of 17.5 hour period, the float or

platform speed would be a steady 10 cm/sec for a given practical mooring compliance. The speed of the mooring cable would decrease approximately linearly with depth. Therefore, the measured currents at depth can be contaminated with spurious indications of rotary flow by the motion. At mid-depth (2000-3000 meters), the speed of the moor in the previous example would still be 5 cm/sec which is comparable to the speeds expected in deep water. The displacement of the mooring is approximately proportional to the horizontal drag (a non-linear function of speed) and as a result harmonics and inter-modulation frequencies are generated in the recorded velocities.

Several oscillatory modes have been detected or calculated from simple mooring motion models and observations. [15, 16, 17] The first mode acts like an inverted pendulum and is an oscillation of the entire mooring-platform system. For moorings such as being used by WHOI (taut wire moor) the oscillation periods is of the order of 100 seconds. There is a second mode (type) of oscillation which occurs between the float and anchor (see Fig. B-1). Its characteristic period is shorter than the first mode.

The first mode will always be highly over damped and it is unlikely that it will appear as an oscillatory motion unless the flow contains coherent fluctuations at a resonant frequency. Although the first mode will probably not appear as an oscillation there will be some distortion of the speed record. This distortion can be estimated from the Fofonoff and Garrett simple theoretical model. [17] Figure B-2 displays the response of a mooring to a step function change in current where K is the mooring compliance or "softness", u_0 is the current speed, and u_r is the relative speed measured by a current meter.

The second mode (or type) of oscillation can be executed under certain conditions and has been detected in current meter records. In May, 1964, a subsurface taut-wire mooring (#161, WHOI) was set southeast of Bermuda in a depth of about 2500 meters. Record #1612 (depth 494 meters) contained a persistent rotary oscillation of the instrument case for speeds above 22-24 cm/sec. The oscillations started and stopped abruptly. Fluctuations of the vane and compass readings become coherent with a period of about 4 seconds at 40 cm/sec and increased in period to 9 seconds, then ceased abruptly at 18 cm/sec. The pressure case had an external fin rigidly attached to it, so the oscillation converted a rotary motion to the case with peak-to-peak

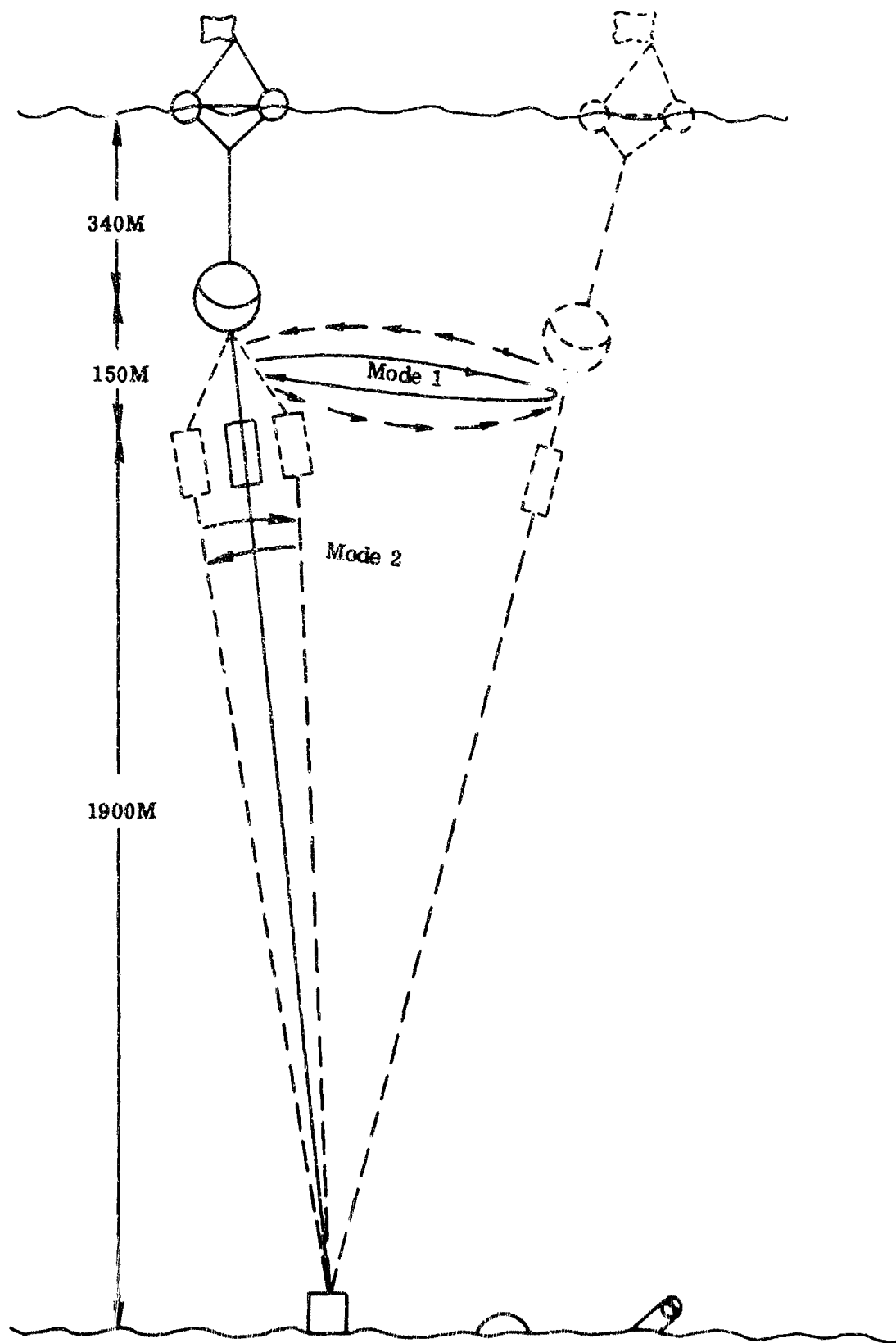


Fig. B-1. (After Fofonoff [16]) Modes of Oscillation for a Platform-Mooring System

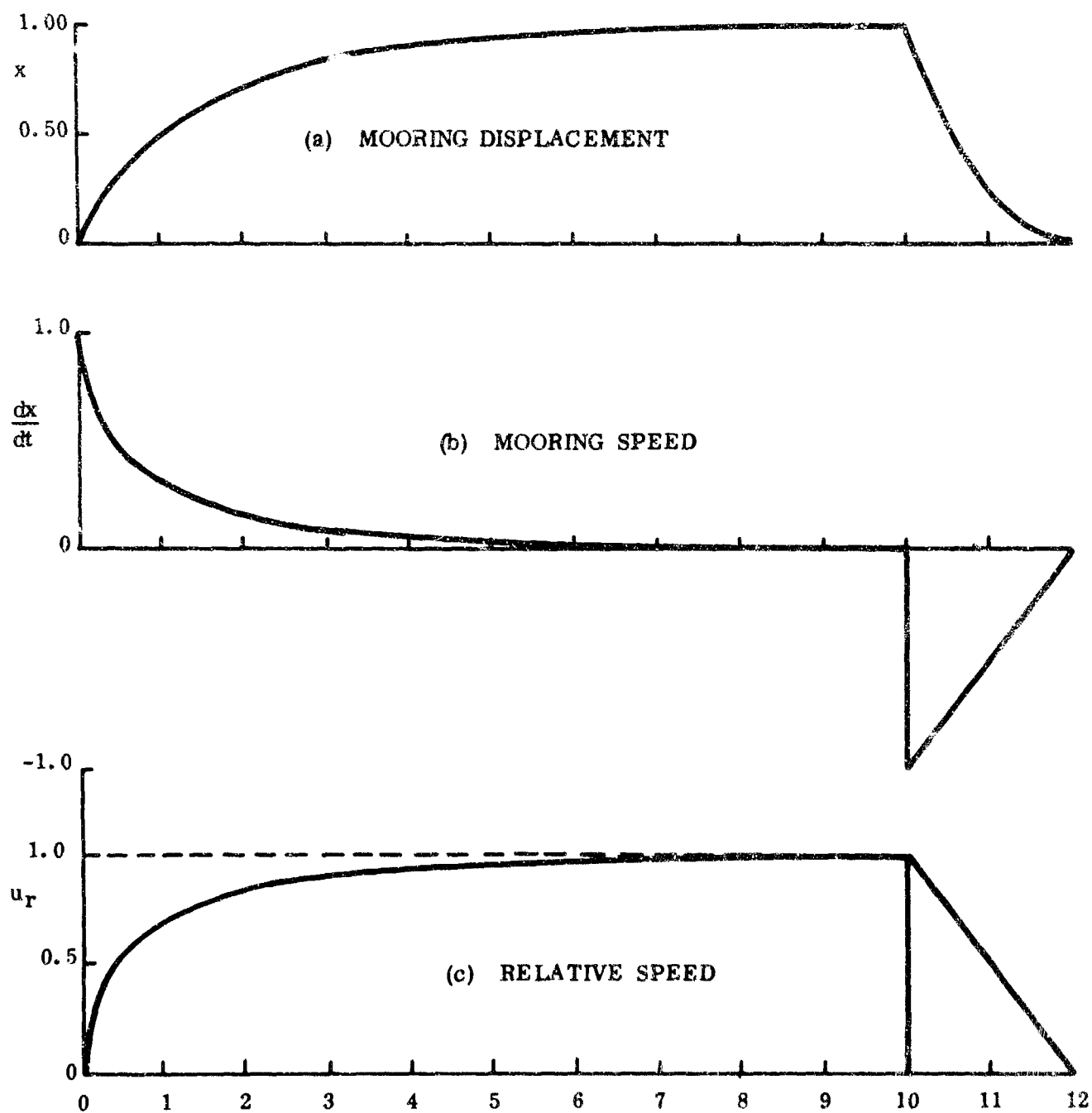


Fig. B-2. (After Fofonoff and Garrett, [17]) Response of a Mooring to a Step Function Current. The displacement unit is Ku_0^2 (where K = mooring compliance or "softness" and u = current speed) and the time unit Ku_0 . The displacement (a) is shown for a current applied at $t = 0$ and removed at $t = 10$ units. The mooring speed (b) scaled by u_0 is subtracted from the current to yield the relative speed (c) that would be sensed by a current meter on the mooring.

amplitude of 30-40°. The suggested exciting mechanisms for the oscillations is vortex shedding. This type of oscillation probably occurs frequently in taut-wire moorings, but is usually not recognized at lower sampling rates and in the absence of a fin to transfer the motion to the instrument case. There is a possibility that the vortex shedding frequencies become locked to the mooring oscillations mode (mode 2) and is "pulled" towards the resonant frequency. There were no comparable oscillations at deeper levels (#1614, 1494 meters) where the currents were much weaker.

To avoid complacency in accepting plausible explanations, spectra of kinetic energy density from two half-hour segments of the current record were prepared. The first spectra was taken just before the outbreak of rotary oscillation and the second just after. There is a strong 8 second peak in the second spectrum which is the rotary oscillation. However, a relatively strong peak in energy density occurs in both spectra at 12 seconds. It represents an irregular speed fluctuation in the currents record with no corresponding direction fluctuation. Fofonoff [16] has referred to this peak as a "surging" mode. The f-k graph, Fig. 3-1, of major oceanic phenomena does not show any surge mode with periods of the order of 12 seconds, which should point up further the tentativeness of this graph on others appearing in this report.

Mooring-platform motion degrades the quality of the measured currents and possibly many of the other parameters being measured in a region of gradients. The magnitude of this motion has to be estimated to determine the conditions under which it is not negligible. The effects in measured currents or other parameters can be minimized by techniques provided through a knowledge of the mechanics of the mooring-platform motions. It is possible to construct models of mooring motions and estimate numerically the motion for a given mooring configuration and current profile. However, the difficulty of specifying a profile continuously in time from measurements at discrete depths and the uncertainty of drag calculations make it desirable to obtain an independent measure of the motion to evaluate the numerical model. In May, 1964, WHOI conducted mooring-platform motion experiments at sea off the Coast of Bermuda. Two anchored buoys, Station 158 in 2670 meters of water and Station 160 in 2157 meters of water, were visually tracked by two tracking azimuth telescopes on a three-mile base line. The telescopes were located 200 feet above sea level and could locate the 7-foot toroidal surface float up to 17 miles away under the best conditions.

Unfortunately, the floats were not always visible, especially during daylight hours when the flashing beacons on the floats could not be seen. Some of the results of this experiment are seen in Figs. B-3 and B-4. The spatial excursion of Station 158 are of the order of 1 km. Station 160 has a smaller scope*, 90% as compared to 100% of Station 158, and thus underwent excursions of the order of 0.5 km.

In addition to all these modes of oscillation there are various forms of motions associated with surface platforms. Some platform designs have managed to eliminate much of these motions by riding low in the water (placing the center of gravity of the platform well below the sea surface). The surface following buoys (e.g., the discus or boat hull) undergo a series of oscillations excited by surface waves, wind, currents and mooring tension. These oscillations can take the form of yaw, swing, roll, pitch, riding, and heave, depending on the buoy configuration and the orientation of the buoy hull to the accelerating forces. Certain buoys eliminate some of these oscillations, but most of the surface platforms undergo riding (a fore-and-aft movement due to cyclic tightening and relaxing of the anchor cable) and heaving. These two types of motion can be transmitted down the mooring line and therefore might possibly be detected in the near surface sensors on the mooring, as well as the platform mounted sensors. In theory, the oscillation of the surface platform and near-surface moor associated with surface waves should integrate to zero or at least possess distinguishable periodicities.

These excursions and oscillations can be graphically represented on an $f-k$ graph (Fig. B-5) as bands of noise in frequency and wave number. These bands are meant to represent the limits of possible noise (distortion introduced into sensor records) for a variety of buoy configurations and moorings. It is not suggested that noise will occur at all the frequencies and wave numbers in these bands, but it will probably occur at several discrete intervals within these bands. The band in wave number is estimated to extend from 10^4 to an upper wave number determined by the sensor dimensions, $\sim 10^8$. The band in frequency is estimated to be from 10^4 to 10^9 . The upper limit (10^9) on this band was chosen because of the findings of Toth and Vachon [7] who found "vibrational energy due to variations in cable tension and vortex shedding are grouped in discrete frequency intervals, the highest of which does not exceed 60 cycles

*Scope is the ratio of mooring line length to depth. It can also be expressed as a percentage.

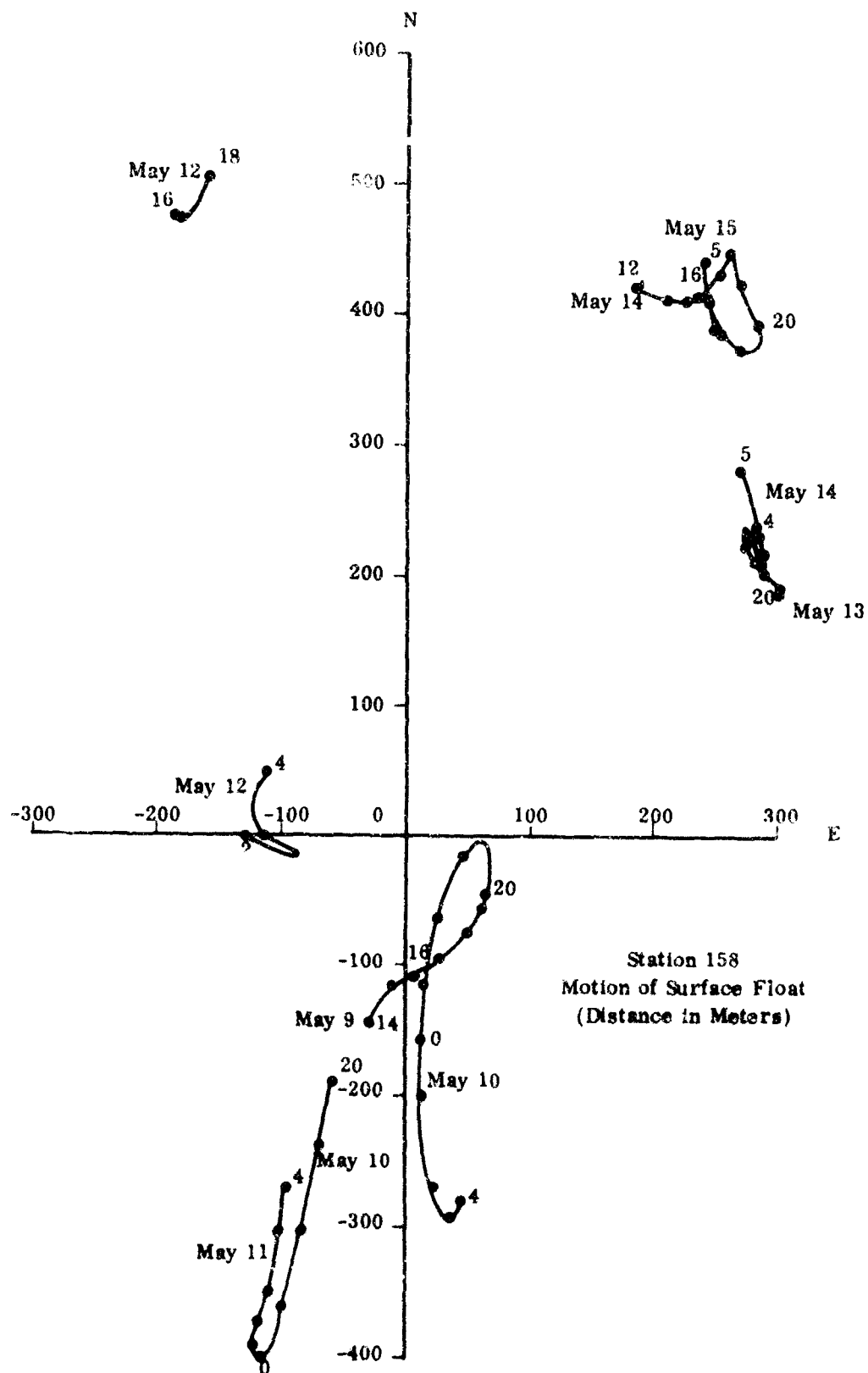


Fig. B-3. (After Fofonoff and Garrett [17]) Excursions of Mooring 158 During Tracking. Mooring Depth: 2670 Meters with Scope of 100 Percent (1:1)

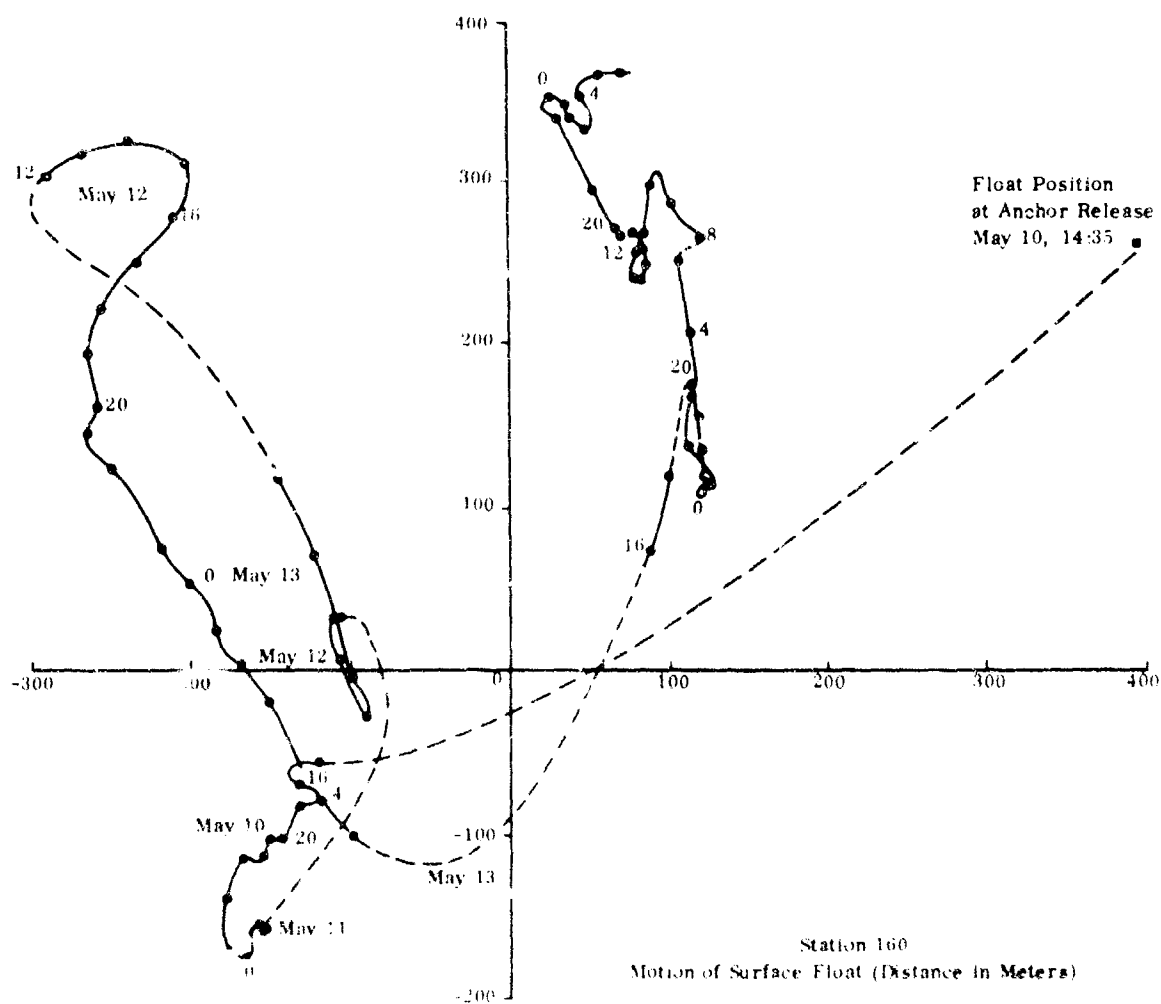


Fig. B-4. (After Fofonoff and Garrett, [17]) Excursions of Mooring of 160 During Tracking. Mooring Depth: 2157 meters with Scope of 90 Percent (1:0.9)

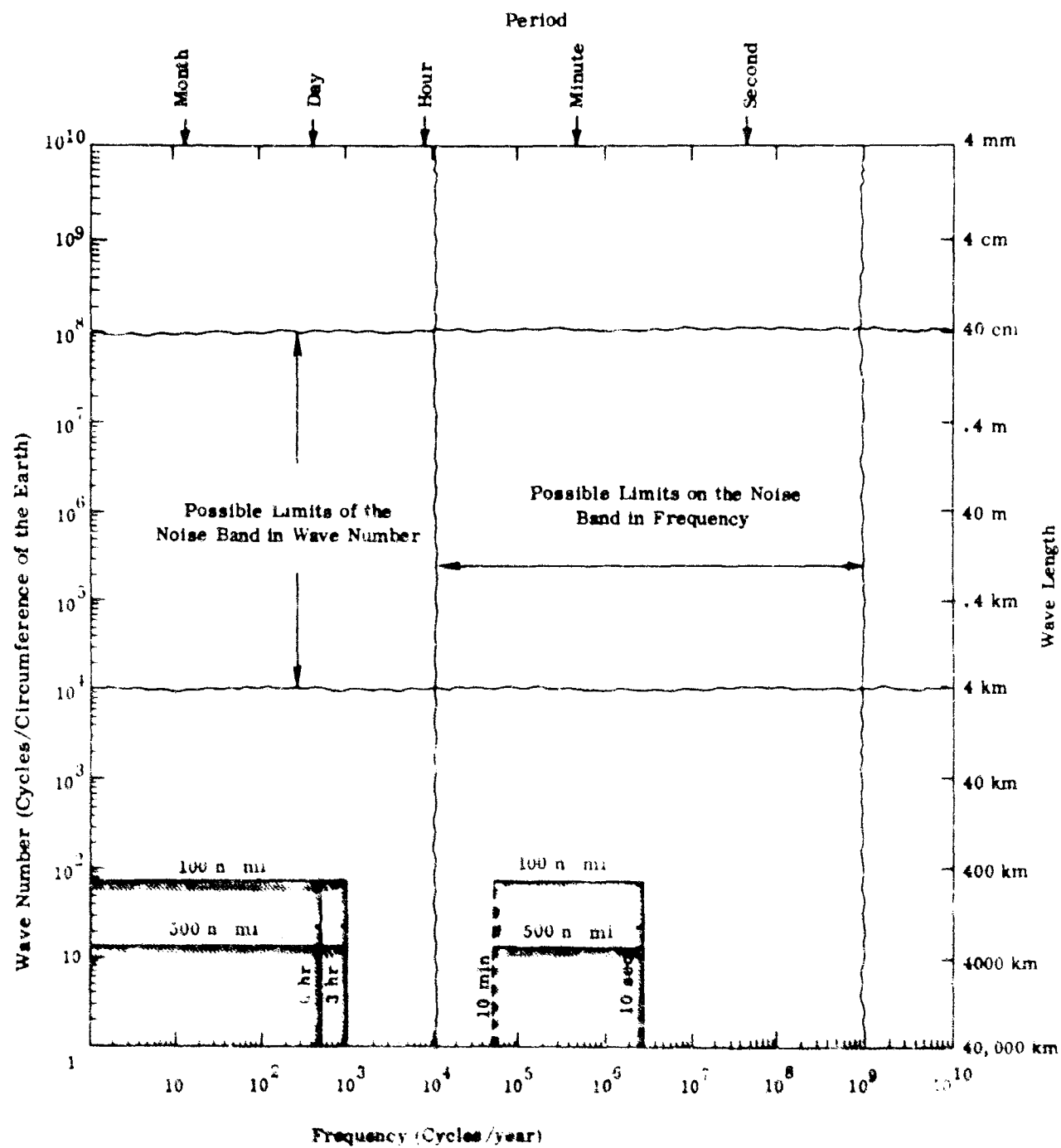


Fig. B-5. Possible Limits of the Noise Bands in Frequency and Wave Number

per second. " Once buoy and mooring combinations have been selected, extensive sea test will have to be performed to determine the effect of mooring motions on sensor records.

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13. ABSTRACT This report presents a framework by which the characteristics of National Data Buoy Systems, the variability of natural phenomena in the oceans and atmosphere, and data use techniques, may be compared to better define what marine environmental phenomena National Data Buoy Systems can measure most effectively. This framework is based on the utilization of hypothetical buoy system characteristics which would collect measurements over a three dimensional array of points in the ocean at regular intervals in time superimposed over wave spectral analysis of natural environmental phenomena, using frequency for time variability and wave number for space variability. By matching the spectral content of the natural environment with the characteristics of buoy systems, spectral windows describing what is measureable, may be analyzed against their ability to meet the spectral content required by users of marine environmental information.		