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ENVIRONMENTAL DESIGN DATA FOR THE GULF OF ALASKA

(UPDATE NO. 2)

JUNE 1977

PREPARED FOR
THE UNITED STATES GEOLOGICAL SURVEY
BY
THE AEROSPACE CORPORATION

Offshore Environmental
Assessment Division
Mail Stop 644
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FOREWORD

The Aerospace Corporation was placed under contract to the U. S. Geological Survey on 1 October 1976 to characterize environmental operating conditions and develop preliminary estimates of design data applicable to offshore areas in the Gulf of Alaska, Mid-Atlantic, and Southern California. Initial attention is being given to the Gulf of Alaska and involves the assembly of environmental data, formation of a computerized data base and application of analytical techniques. This report summarizes those efforts centered in the Gulf of Alaska.

Based on past studies of the Alaskan environment, mathematical models and available industry findings, the major objective is to develop preliminary estimates of the operating conditions and to quantify parameters relative to:

- Meteorology
- Oceanographic
- Seismic
- Geologic

This report presents results from reviews and analytical efforts and is the second update of the initial material published in December 1976. Section 1.0 summarizes current efforts and Sections 2.0 through 6.0 cover details in each of the study areas with supporting material included as appendices.

The significant additions and/or changes in this report appear in the following paragraphs:

1.0	Summary Revisions
5.2.7	Normal Wind Data for the Cordova area 140°-146°W, 57°N - Coast in lieu of the adjacent Seward area 146°W - 151°W, 57°N - Coast.
5.3.5	Normal Wave Data for the Cordova area in lieu of the Seward area.
5.3.6	Updated estimates of Extreme Waves based on the latest SOWM Hindcast Data
5.3.7	Shallow Water Effects
5.4.1.1	SOWM Validation
5.4.2	Additional Wave Spectral Data
5.5	Paragraph deleted and information transferred to the summary, paragraph 1.0
6.1	Introduction Revised to reflect changes in Seismological Data
6.4	Comparison of Seismic Risk Studies
6.5	Design Basis Ground Motion Preliminary Estimate
Appendic F	Critiques of Seismic Risk Studies
Appendix G	Wave Refraction Study Results
Appendix H	Wave Height-Period Relationships

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SUMMARY

1. SUMMARY

This report presents interim results of a study to characterize environmental data relative to the Gulf of Alaska. Although the primary emphasis has centered on the northeastern sector it is believed that the oceanographic and meteorological data being generated will have application to the overall Gulf of Alaska OCS as well. Characterization of data is sought for two conditions: (1) meteorological and oceanographic conditions and (2) seismic and geologic conditions.

1.1 METEOROLOGY AND OCEANOGRAPHIC CONDITIONS

General Climatology

The primary influence on the climatology of the Gulf of Alaska is marine. The dominant physical phenomena are the Aleutian low pressure system in the winter and the North Pacific high pressure system in the summer. The coastal zone is strongly influenced in certain areas by the difference between the Arctic continental environment over Alaska and the Aleutian low. This is manifested by strong downslope winds funneling through river valleys and down along glaciers.

Visibility

In order to provide some insight into meteorological conditions affecting operations of offshore units in the Gulf of Alaska certain data on visibility, air and water temperatures and winds were abstracted both from published and unpublished data provided by the National Climatic Center (NCC), Asheville, North Carolina.

In regard to visibility, representative fog and visibility data from the northeastern Gulf area and from Middleton Island were extracted and presented in the report. These data indicate the worst visibility conditions occur in July and August and the best conditions exist in September through November. Data from the SSMO, Vol. 12 (U.S. Naval Weather Service Command, 1970), on temperature extremes indicate a relatively mild climate in the Gulf (from a temperature standpoint) compared to the mainland.

Air and Water Temperatures

There is some disagreement in the available data with regard to minimum temperatures. The Fallon et al (1973) study indicates a minimum air temperature of -6°F in the area (not stating a specific location). The Northern Gulf of Alaska Environmental Impact Statement (BLM, 1976) gives the lowest recorded air temperature on Middleton Island at 6°F. The disagreement with the SSMO could be due to location of measurement since a strong air-sea temperature gradient cannot persist long as one moves seaward. Also, extreme values in the SSMO's tend to be truncated due to data editing policies.

In spite of the disagreement it appears that structural materials will not have to operate continuously in sub-zero temperatures. On the other hand, chill factors may severely hamper some human activities during winter months. Unpublished charts being prepared for the Gulf of Alaska Climatic Atlas by NCC show that chill factors may be as low as -30°C (-22°F).

Ice Accretion

The sources for the discussions of icing conditions and floating ice are the Gulf of Alaska Operators Committee study (Fallon, et al, 1973) and the BLM-NOAA Environmental Assessment of the Alaskan Continental Shelf (BLM-NOAA, 1976).

Ice accretion may present operational problems for both aircraft and surface equipment. It must also be taken into account in calculating design loads for surface equipment.

Surface icing conditions occur at air temperature 28.4°F (-2°C) with wind velocities equal to or greater than 11 knots. Information from the NCC

unpublished Gulf of Alaska Climatic Atlas indicate that this condition could occur from 20 to 30% of the time in the month of January and for lesser periods during the remainder of the winter. Severe icing condition can occur at air temperatures $\leq 16^{\circ}F(-9^{\circ}C)$ and wind velocities ≥ 34 knots. NCC unpublished data indicates that the probability of this event is less than 0.1% in January.

Aircraft icing is a much more frequent occurrence as indicated in the Fallon et al study (1973). Icing may occur with air temperatures in the range of $25^{\circ}F$ to $40^{\circ}F$ accompanied by a substantial degree of cloud cover. These conditions will occur most frequently during the passage of weather fronts. At lower elevations icing should be a problem only during winter months, and it is expected that light icing can exist at 1500 feet elevation as much as six to seven days per month in winter, but conditions will be severe on an average of one day a month.

Floating Ice

It is pointed out in Fallon et al (1973) that floating ice is not likely to present a hazard to offshore operations in the Gulf of Alaska. The primary source of ice masses in this area is from several glaciers which front on Gulf coastal waters. Most of these glaciers "calve", breaking off large chunks which may be as large as icebergs. However, the Alaskan glaciers are currently in a period of recession and their faces are not on open Gulf water. The relatively warm air and water temperatures during the calving season (August/September) rapidly melts the ice chunks that do reach open water. Other forms of floating ice found in the Gulf consist of ice pancakes formed in rivers, lagoons and bays. This ice never achieves sufficient thickness to present any hazard and quickly melts in open water.

Near-Shore Winds

Orographic effects play an important role in the development of Gulf of Alaska coastal winds. The most common wind phenomenon is termed the "williwaw". Williwaws are downslope winds and are dangerous because

they occur suddenly and tend toward extreme gustiness. The weather patterns that cause williwaw winds can usually be predicted several days in advance. Once williwaws start, they can persist for several days with a three day period being typical. The average wind speeds are on the order of 60 knots with the maximum speeds of 80 to 100 knots. Fallon et al (1973) state that the intensity of these local winds decreases rapidly as they move away from the coast, and that the contribution of local winds to wave generation is minor. This conclusion may be open to question since at least one other source, Reynolds and Walter, in the BLM/NOAA Environmental Assessment of the Alaskan Continental Shelf (1976), state that 100 knot winds can extend out over the water for 20-25 miles. The effect of these winds on wave generation is not discussed but further investigation of the phenomena is required.

Normal and Storm Winds

Regarding normal and storm winds, the Gulf of Alaska is located at the end of the longest over-water storm tract in the Northern Hemisphere. Winds caused by the packing of the isobars along the mountain slopes are actually stronger than the winds indicated by barometric pressure gradients. Also, because of the stagnation of the cyclone systems in the Gulf of Alaska, wind duration can be prolonged up to several days during which time a second cyclonic system can move into the Gulf, reinforcing the first.

Monthly average wind speeds recorded at Middleton Island are indicative of the pronounced seasonal trends in the Northern Gulf, although the actual monthly wind speeds are somewhat lower than over water. Gale force (≥34 kt) winds may be encountered at any time during the year but are usually rare during the summer months. The Middleton Island data show that the summer months of June, July, and August are calmest. In September winds begin to increase and reach their maximum speeds by January. Wind gusts of >60 kts are likely to occur from November through January. Exposed ocean areas of the Northern Gulf are likely to experience similar, or perhaps greater, wind gusts than Middleton Island during the

same period. Sustained winds(>41)kt occur about 3-5% of the time from October through February in open ocean areas. High average wind speeds persist through February but begin to abate by March. Through the spring, wind speeds continue to decline gradually toward the summer minimum condition.

Physical Oceanography

General Circulation

General water circulation in the Gulf of Alaska is a counterclockwise gyre. The southern component of the gyre is formed by two easterly moving current systems, the west wind drift and the subarctic current. As these systems approach North America, they diverge, forming the Alaska current and the southward flowing California current.

The Alaska current flows northward initially but then turns toward the west and southwest as it follows the general contours of the coastline. The Alaska current is generally characterized as a broad, slow-moving current which transports about 10 million cubic meters per second with velocities of less than one-half knot (Fallon et al, 1973).

Currents

Although currents are generally not considered to provide a major contribution to loads, they can be an important factor in overall design of offshore structures. Currents can be an important consideration in the design of foundations and pipelines due to their scouring of sediment from the ocean floor. Currents are also important in offshore operations by affecting work-boat operations, maintenance and underwater inspection. Knowledge of current behavior is particularly important in the event of an oil spill to predict movement for planning of containment operations. Specific knowledge of currents on the continental shelf areas of the Gulf of Alaska has greatly improved as a result of recent measurement programs by the petroleum industry and by the Federal Government.

Although currents are subject to a number of site-specific variables, it is possible to describe some general set of conditions which exist in the lease areas. These conditions are discussed in Fallon et al (1973) and are the result of preliminary current models supplemented by measured current data as part of the 1967-1968 industry program. Estimates relative to extreme current conditions were computed on the basis of 20 major storms of recent years and indicate that the maximum extreme conditions at the surface are in the range of 3-4 knots, but fall to 0.5-1 - 0.125 knots on the bottom. It should also be emphasized that the extreme conditions may exceed the computed average by as much as 50%.

Sea Surface Elevation

A knowledge of sea surface elevations is necessary for offshore platform design. Rises in the water level to heights greater than mean sea level can be caused by a number of factors including waves, tsunamis, astronomical tides, storm surge, and responses to variations in atmospheric pressure. Estimates of water level rise in the northern Gulf lease area are provided by Fallon et al (1973) as a result of industry studies in the Gulf during 1967-1968. In the northeast part of the Gulf, the astronomical tides range from -3 to +15 feet relative to the mean lower low water (MLLW) tidal reference datum. Depending somewhat on location and water depth, the combined 100 year storm surge and pressure may raise the water level an additional five to six feet. The total combined 100 year effect is on the order of a 20 foot rise above MLLW.

Tsunamis

Tsunamis, often called tidal waves, are long period, progressive waves which generally result from volcanic eruptions, landslides, or earthquakes. Since the Gulf of Alaska is an area of high seismicity, earthquake induced tsunamis occasionally occur. According to Tetra Tech (1974), two destructive tsunamis have occurred in Valdez Bay within the last 70 years, and other ports which have experienced damaging tsunamis include Cordova, Whittier, Stewart, Kodiak, and Yakutat.

The damaging effects of tsunamis are primarily limited to very shallow water and coastal areas where the tsunami may be transformed to a breaking wave of great magnitude. In the open waters of the Outer Continental Shelf (OCS) lease areas however, the tsunami is felt only as a rapid rise in sea level which imparts very little horizontal force to structures it may encounter. The tsunami height is related to the magnitude of the seismic event and the distance from it. Earthquakes of Richter magnitude greater than 8, which occur occasionally in the Gulf, can be expected to produce tsunamis which exceed 30 feet in height.

Normal Wave Conditions

The Gulf of Alaska is exposed to a major portion of the Pacific Ocean and winds may act over great distances (fetch) to produce waves in the Gulf. This phenomenon as well as local meteorological effects act in concert to produce one of the most severe wave climates in the world. The Gulf is also subject to long period swells which originate in the southern hemisphere during the summer months. These occur from May through October and are the result of southern hemisphere winter storms.

Wave conditions in the Gulf of Alaska vary according to season. Since waves are wind-induced phenomena, wave conditions follow the general weather patterns of the Gulf. The seas are calmest during the summer months of July and August. In September wave heights begin to increase and maximum sea states are achieved during December. Winter conditions are somewhat less severe than fall conditions but high wave conditions generally persist through March. From April through June, wave heights gradually abate toward the summer minimum.

An annual summary of the normal wave condition in an area from 57°N to the coast and 140°- 146°W, indicates the maximum frequency of waves to be three to four feet in height although a significant number of observations occur up to 16 feet. These data reflect the generally severe normal wave climate of the northern Gulf.

Extreme Winds and Waves

Estimates of extreme winds and waves that an offshore unit is likely to encounter during its operational lifetime are required in order to evaluate structural safety. Extreme wind velocities and wave heights are usually quoted as a function of their return period, that is, the average length of time between occurrences of a wave of a given height or a wind of a given velocity. Severe events are associated with long return periods and low probabilities of occurrence. For fixed platforms the customary design practice has been to use events with 100 year return periods or longer. The choice of a return period is actually a complex problem involving an analysis of various factors including human safety, environmental risk, and economics.

This report, and appendices, reviews and evaluates recent studies which have attempted to estimate extreme winds and waves for the Gulf of Alaska. In addition an independent analysis of several historical wave data sets has been performed to supplement the results. Five of these reports have been reviewed critically. They include the results of Thom (1971, 1973a, b), the Tetra Tech study (1974), Freeman and Bujnoch (1976), Fallon et al (1973), and Quayle and Fulbright (1975).

A hindcast data base for Gulf of Alaska waves is well underway and at this point extreme waves for nine winter seasons from 1968 to 1977 have been analyzed. Extrapolation of these data indicates that extreme waves exceeding 100 ft will occur in the open ocean areas of the eastern Gulf on an average of every 25 years.

Estimates of extreme wind distribution are provided in papers by Tetra Tech (1974), Quayle and Fulbright (1975) and Fallon et al. (1973). Based on a review of these studies, it was concluded that a sustained wind speed of 108 knots is likely to occur on an average of every 100 years. The 25 year return period was estimated at 92 knots.

Seismic and Geologic Conditions

The Gulf of Alaska lies on the boundary of the North American and Pacific Plates, and is one of the most seismically active areas in the world. Due to this high seismic potential, an accurate and thorough investigation of seismic risk is essential. In this update, emphasis was placed on discussing six seismic risk studies, along with appropriate comments, criticisms, and a recommendation for further study.

The six seismic risk studies presented are: Milne and Davenport (1969), Bea (1976), the API RP 2A (1977), Page (1972), the ATC-3 (1977) and Wiggins (1975). The studies were compared on the basis of peak accelerations, velocities, displacements and free field response spectra (when available). To insure a consistent comparison, values were normalized to a 100 year return period, and an attempt was made to normalize the usage of "effective peak acceleration" to "peak acceleration". After normalization, the peak acceleration values ranged from 0.30 to 1.00 g's, while peak velocities (more important than peak accelerations for offshore platforms) ranged from 5 to 26 in/sec. In short, the six studies present a very broad range of possible seismic design parameters. If a decision had to be made at this time, the work done by Milne and Davenport (1969) appears to be the only one that is both consistent and conservative. Critiques of the six studies are presented, along with the recommendation that a more careful, detailed study be conducted, focusing on seismic source modeling, motion-attenuation relations, statistical modeling, and the usage of a complete and thorough data base.

In the section covering geology, information is provided for locating potential foundation hazards relative to proposed lease tracts. Also provided are typical soil profiles showing sedimentary layer thicknesses at various locations within the study area. Additional geologic data is required as well

as a more critical analysis of existing data before specific areas can be identified which have a high probability for slides, liquefaction, or generation of turbidity currents. Further discussion of these detailed problems will be delayed until adequate soil information is available.

Initial Estimates

Initial estimates of specific meteorological and oceanographic conditions peculiar to the subject region are summarized in Table 1-1.

Parameter	Estimated Conditions	Notes
Visibility	Minimum Values: A. 200 yds or less for periods up to 18 hr B. 1 nmi or less for periods up to 84 hr C. Minimums occur in July and August	Observations made at Middleton Island
Air and Sea Surface Temperatures	Air Temp (°F) / Sea Surface Temp (°F) A. Minimum 18 / 31 B. Mean 45 / 47 C. Maximum 71 / 66	1. Marine observations, SSMO (at 140°-146° W, 57° N to the coast) 2. Minimum of +6°F recorded on Middleton Island 3. Minimum of -6°F reported in area (Fallon et al)
Normal and Storm Winds	Station / Direction / Ave. Velocity (knots) / Max. Velocity (knots) A. Kodiak NW 8.8 99 B. Yakutat E 7.8 75 C. Middleton Island ESE 12.0 68	Annual measurements at land stations
	Marine Observations: Velocity (knots) / Annual % Frequency 0-6 20.4 7-16 45.1 17-27 23.5 28-40 9.5 41 1.6	Area: 140° - 146°W, 57°N, to the coast
Near Shore Winds	Direction / Velocity (knots) Downslope 60-100	So called "Williwaws," average duration of 3 days, effects extend 25 miles out to sea, decreasing in intensity away from shore
Extreme Winds	Velocity (knots) A. 108, gusting to 151 knots B. 92, gusting to 129 knots	100 year return period 25 year return period

Table 1-1 Initial Estimates of Environmental Design Data

Parameter	Estimated Conditions	Notes
Ice Accretion	Ships and Structures / Aircraft A. Moderate 28°F, winds at ≥ 11 knots[1] / 25-45°F w/cloud cover[3] B. Severe 16°F, winds at ≥ 34 knots[2]	1. Max frequency - (20-30%, January) 2. Max frequency - (0.1%, January) 3. Max frequency - (6-7 days/month in winter)
Floating Ice	A. Glacier ice - small chunks, 1-2 yds in diameter B. Pancake ice - near shore only[1]	1. Melts quickly in open water
Normal Waves	Significant Height (ft) / Frequency of Observation (%) <1 / 6.3 1-6 / 53.5 7-11 / 31.2 12-16 / 7.4 17-22 / 1.3 23-25 / .2 >25 / -	Area: 140° - 146°W, 57°N to the coast
Extreme Waves	Return Period (yr) / Max. Wave Height (ft) 25 / 99 50 / 105	Location: 59.2°N, 145.7°W
Sea Surface Elevation	Max Expected Elevation Change (ft) 20[1] 30[2]	1. Combined tides, storm surge, barometric pressure 2. Tsunami
Currents	Ave. Velocity (knots) / Max Expected Velocity (knots) 0.5 / Surface - 3.3 Mid-Depth - 1.9 Bottom - 1.0	

Table 1-1 Initial Estimate of Environmental Design Data (continued)

2. INTRODUCTION

This report represents the second update of Aerospace Report No. ATR-77(7626-01)-1 under contract 14-08-0001-15988. It contains a general description of environmental conditions in the Gulf of Alaska.

The report also includes initial estimates of environmental design data for use by the USGS Conservation Division until the next scheduled update. These preliminary estimates form a summary of specific environmental conditions in the area and are based on a review of prior studies by various sources and on an evaluation by Aerospace regarding their reliability. In addition, preliminary analyses were conducted of available wave and wind data to supplement these evaluations.

3. OBJECTIVES AND SCOPE

The U.S. Geological Survey has initiated efforts to develop and select environmental criteria for application to the overall exploration, development and production of energy resources from the Outer Continental Shelf in the Gulf of Alaska, and off the Mid-Atlantic and Southern California coasts. The Aerospace contribution to Task I is to assist the USGS in its basic objective of examining and quantifying, where possible, the appropriate environmental factors applicable to offshore drilling and petroleum production operations in those areas. Secondly, Aerospace will assist the USGS in developing methodology or approaches for the development and updating of information on environmental conditions and the loads they may impose on structures operating on the OCS. This effort will include identification of the data required, procedures for its acquisition and definition of steps which can be taken by the USGS to finalize environmental related specifications for offshore operations. When data does not exist, Aerospace will aid the USGS in the definition of means to gather the required field data necessary to validate existing models and/or for developing specific design information to support specification development. Effort will be made by Aerospace to identify a number of alternative means for acquiring that data which could strengthen the environmental data base.

4. APPROACH

4.1 LITERATURE REVIEW AND CONTACTS

The initial action by Aerospace was to gather and examine relevant, current environmental information and methods for predicting wind and wave behavior. A representative listing of initial reviews and contacts made to date are indicated in the reference section at the end of the report. Some principal sources of information, however, included the Northern Gulf of Alaska Environmental Impact Statement (BLM, 1976), Environmental Assessment of The Alaskan Continental Shelf (NOAA, 1976), and the Gulf of Alaska Oceanographic Environment (Fallon, et al, 1973).

4.2 CATEGORIZATION OF PERTINENT DATA

Through contacts with the USGS, private consultants and industry sources, existing data relative to environmental conditions were reviewed as well as analytical models for applicability to the objectives of this effort. These evaluations will be supplemented by analysis where possible to generate estimates of design conditions as early in the study as is practical even though the data would be quite tentative in form. The approach will be to update information as the study progresses with the latest inputs available at the time of reporting.

5. METEOROLOGICAL AND OCEANOGRAPHIC CONDITIONS

5.1 GENERAL CLIMATOLOGY

The primary influence of the climatology of the Gulf of Alaska is marine (see Figure 5-1). The dominant physical phenomena are the Aleutian low pressure system in the winter and the North Pacific high pressure system in the summer. The coastal zone is strongly influenced in certain areas by the difference between the Arctic continental environment over Alaska and the Aleutian low. This is manifested by strong downslope winds funneling through river valleys and down along glaciers.

In winter the low pressure system is constantly reinforced by new lows which move toward the Gulf from the Western Pacific. The mountains surrounding the Gulf form a barrier to the continued movement of these storm systems, causing stagnation of these storm systems and prolonging the duration of storms in the area from periods of several hours to periods of several days. The packing of the isobars up against these mountain barriers also tends to increase the intensity of these storms resulting in extremely strong local winds. The combinations of strength and duration of local winds coupled with an extremely long over water storm track result in a severe wave climate as well.

The general summer situation is that the North Pacific high pressure system moves northward into the Gulf resulting in weaker pressure gradients and reduced winds. Occasionally the high pressure system retreats southward allowing unseasonable storms to enter the area. However, these storms do not approach the intensity of winter storms.

5.2 METEOROLOGY

In order to provide some insight into meteorological conditions affecting operations of offshore units in the Gulf of Alaska certain data on visibility, air and water temperatures and winds were abstracted both from published and unpublished data provided by the National Climatic Center (NCC), Asheville, North Carolina. The published source was the Summary of Synoptic Meteorological Observations (SSMO), Vol 12. (U. S. Naval Weather Service Command, 1970). The data contained in this source are distilled from thousands of ship and shore station observations collected over a long period of time, in some cases ranging as far back as 1890. The unpublished source was the data presently being compiled by NCC for a Gulf of Alaska Climatic Atlas (Brower and Searby, in prep.). The data source for this atlas is the same historical file of observations mentioned above.

The sources for the discussion of icing conditions and floating ice given below are the Gulf of Alaska Operators Committee study, (Fallon et al, 1973) and the BLM-NOAA Environmental Assessment of the Alaskan Continental Shelf (BLM-NOAA, 1976).

5.2.1 Visibility

Tables 5-1 and 5-2 present some representative fog and visibility data from the northeastern Gulf area and from Middleton Island. Table 5-1 contains marine observations taken in the areas 140-146°W and 146°-151°W, respectively, and from 57°N to the coast. The values shown represent percentages of observations in which fog, without precipitation was observed. Table 5-2 presents persistence data for visibility measured on Middleton Island which is located in the center of the areas covered by Table 5-1. Table 5-2 presents the maximum and median durations for low visibility (due to both fog and precipipation) for four threshold distances. Under the column labeled 100%, the periods of low visibility

Table 5-1 Marine Fog Conditions
Fog Without Precipitation

	57°N to Coast 140° to 146°W		57°N to Coast 146° to 151°W	
Month	% of Obs.	No. of Obs.	% of Obs.	No. of Obs.
JAN	4.0	25	6.1	26
FEB	4.6	25	4.5	20
MAR	2.7	16	3.6	16
APR	2.9	20	2.1	13
MAY	5.6	42	5.6	44
JUN	4.1	31	9.4	60
JUL	8.4	61	12.1	84
AUG	4.7	33	12.5	85
SEP	3.3	23	6.1	36
OCT	1.2	9	1.2	6
NOV	1.1	8	0.6	3
DEC	3.5	22	1.6	8
ANNUAL	3.9	315	5.9	400

Source: Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command, 1970)

Table 5-2 Visibility on Middleton Island (59°26'N, 146°20'W)
Monthly Maximum Duration of Events in Hours

Visibility	< 200 Yds		<1/4 NM		<1/2 NM		<1 NM	
	100%	50%	100%	50%	100%	50%	100%	50%
JAN	9	3	15	3	27	3	30	3
FEB	9	1	15	1	18	2	18	3
MAR	9	4	12	3	15	2	21	3
APR	9	2	15	2	21	3	24	2
MAY	9	3	15	3	15	3	15	3
JUN	9	3	18	3	27	3	38	5
JUL	12	2	27	3	27	3	36	3
AUG	18	3	42	4	39	5	84	3
SEP	6	1	12	3	24	3	24	3
OCT	3	<1	9	1	9	3	15	3
NOV	0	0	6	1	12	2	18	3
DEC	3	<1	12	1	15	1	21	2

Source: Gulf of Alaska Climatic Atlas (Brower and Searby, in prep)

never exceeded the number of hours shown. Similarly for the next column, 50% of the periods of low visibility did not exceed the indicated number of hours. Both tables indicate that the worst visibility conditions occur in July and August. The period of best visibility in the Gulf is September through November. The Gulf of Alaska Operators Committee study (Fallon et al.,1973) also agrees with these conclusions.

5.2.2 Air and Water Temperature

Tables 5-3 and 5-4 present maximum, minimum and mean air and sea surface temperature for the same two areas designated in Table 5-1 The sources of these data are the SSMO, Vol 12 (U.S. Naval Weather Service Command, 1970). These temperatures demonstrate the relatively mild climate of the Gulf (from a temperature standpoint) compared to that of the nearby mainland.

There is some disagreement in the available data with regard to minimum temperatures. The Fallon et al (1973) study indicates a minimum air temperature of -6°F in the area (not stating a specific location). The Northern Gulf of Alaska Environmental Impact Statement (BLM, 1976) gives the lowest recorded air temperature on Middleton Island as 6°F. The disagreement with the SSMO could be due to location of measurement since a strong air-sea temperature gradient cannot persist long as one moves seaward. Also, extreme values in the SSMO's tend to be truncated due to data editing policies.

In spite of the disagreement it appears that structural materials will not have to operate continuously in sub-zero temperatures. On the other hand, chill factors may severely hamper some human activities during winter months. Unpublished charts being prepared for the Gulf of Alaska Climatic Atlas by NCC show that chill factors may be as low as -30°C (-22°F).

Table 5-3 Air and Water Temperatures

Area: 57N - Coast
140-146° W

Month	Air Temperature °F				Sea Surface Temperature °F			
	MAX	MIN	MEAN	No. of OBS	MAX	MIN	MEAN	No. of OBS
JAN	48	18	36.6	671	50	33	42.3	549
FEB	49	25	38.2	575	50	33	41.9	451
MAR	48	26	37.7	643	48	33	41.6	505
APR	53	30	40.6	764	50	35	42.3	573
MAY	60	36	45.2	776	56	37	45.1	606
JUN	63	42	50.4	758	62	39	50.8	589
JUL	64	43	54.4	769	66	45	55.2	620
AUG	69	43	56.8	776	66	45	57.7	640
SEP	70	45	53.8	722	66	47	55.7	595
OCT	60	36	47.0	772	62	43	50.7	663
NOV	55	27	41.8	734	56	41	46.9	629
DEC	50	23	38.2	639	52	37	44.4	502
ANNUAL	70	18	45.5	8599	66	33	48.3	6922

Source: Summary of Synoptic Meteorlogical Observations (U.S. Naval Weather Service Command, 1970)

Table 5-4 Air and Water Temperatures
Area: 57N - Coast
146-151°W

	Air Temperature °F				Sea Surface Temperature °F			
	MAX	MIN	MEAN	No. Of OBS	MAX	MIN	MEAN	No. of OBS
JAN	48	25	37.4	485	50	33	41.7	428
FEB	48	20	36.8	520	48	33	40.6	441
MAR	48	18	37.2	482	50	33	40.6	427
APR	54	27	39.6	679	48	31	40.9	568
MAY	61	32	44.2	827	54	35	43.1	723
JUN	63	40	49.0	672	60	39	48.0	584
JUL	69	43	53.7	805	64	41	52.8	725
AUG	71	45	55.7	737	64	43	55.1	611
SEP	67	42	52.5	622	66	45	52.9	546
OCT	58	32	45.5	553	60	39	49.0	510
NOV	52	24	41.0	528	56	37	45.2	473
DEC	50	19	37.2	534	50	35	43.0	475
ANNUAL	71	18	45.0	7444	66	31	46.6	6511

Source: Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command, 1970)

5.2.3 Ice Accretion

Ice accretion may present operational problems for both aircraft and surface equipment. It must also be taken into account in calculating design loads for surface equipment.

Surface icing conditions occur at air temperature 28.4°F (-2°C) with wind velocities equal to or greater than eleven knots. Information from the NCC unpublished Gulf of Alaska Climatic Atlas indicate that this condition could occur from 20 to 30% of the time in the month of January and for lesser periods during the remainder of the winter. Severe icing condition can occur at air temperatures $\leq$ 16°F (-9°C) and wind velocities $\geq$ 34 knots. NCC unpublished data indicates that the probability of this event is less than 0.1% in January.

Aircraft icing is a much more frequent occurrence as indicated in the Fallon et al. study (1973). Icing may occur with air temperatures in the range of 25°F to 40°F accompanied by a substantial degree of cloud cover. These conditions will occur most frequently during the passage of weather fronts. At lower elevations icing should be a problem only during winter months and it is expected that light icing can exist at 1500 feet elevation as much as 6 to 7 days per month in winter, but conditions will be severe an average of one day a month.

5.2.4 Floating Ice

It is pointed out in Fallon et al (1973) that floating ice is not likely to present a hazard to offshore operations in the Gulf of Alaska. The primary source of ice masses in this area is from several glaciers which front on Gulf coastal water. Most of these glaciers "calve", breaking off large chunks which may be as large as icebergs. However, the Alaskan glaciers are currently in a period of recession and their faces are not on open Gulf water. Rather, glacial moraines, shoals, and bars between the

face and open waters prevent the large ice masses from moving into the Gulf. According to Fallon et al. (1973) ice chunks larger than 1 to 2 yards in diameter are seldom seen in the Gulf. The relatively warm air and water temperatures during the calving season (August/September) rapidly melts the ice chunks that do reach open water. Other forms of floating ice found in the Gulf consist of ice pancakes formed in rivers, lagoons and bays. This ice quickly melts in open water.

5.2.5 Near-Shore Winds

Orographic effects play an important role in the development of Gulf of Alaska coastal winds. The most common wind phenomenon is termed the "williwaw". Williwaws are downslope winds and are dangerous because they occur suddenly and tend toward extreme gustiness. Williwaws occur when air dams up on the windward side of a range of mountains and then spills over suddenly. Local topography determines the average direction from which williwaws will come, but still they can have great variability in direction and speed. The weather patterns that cause williwaw winds can usually be predicted several days in advance. Once williwaws start, they can persist for several days with a three day period being typical. The average wind speeds are on the order of 60 knots with maximum speeds of 80 to 100 knots. It is possible to estimate the strength of the williwaws by considering the height of the blocking ridge and the steepness and shape of the valley. Temperature readings across the ridges may also serve as good indicators of coming williwaws. Fallon et al (1973) state that the intensity of these local winds decreases rapidly as they move away from the coast, and that the contribution of local winds to wave generation is minor. This conclusion may be open to question since at least one other source, Reynolds and Walter, in the BLM/NOAA Environmental Assessment of the Alaskan Continental Shelf (1976), state that 100 knot winds from the Copper River, Icy Bay and

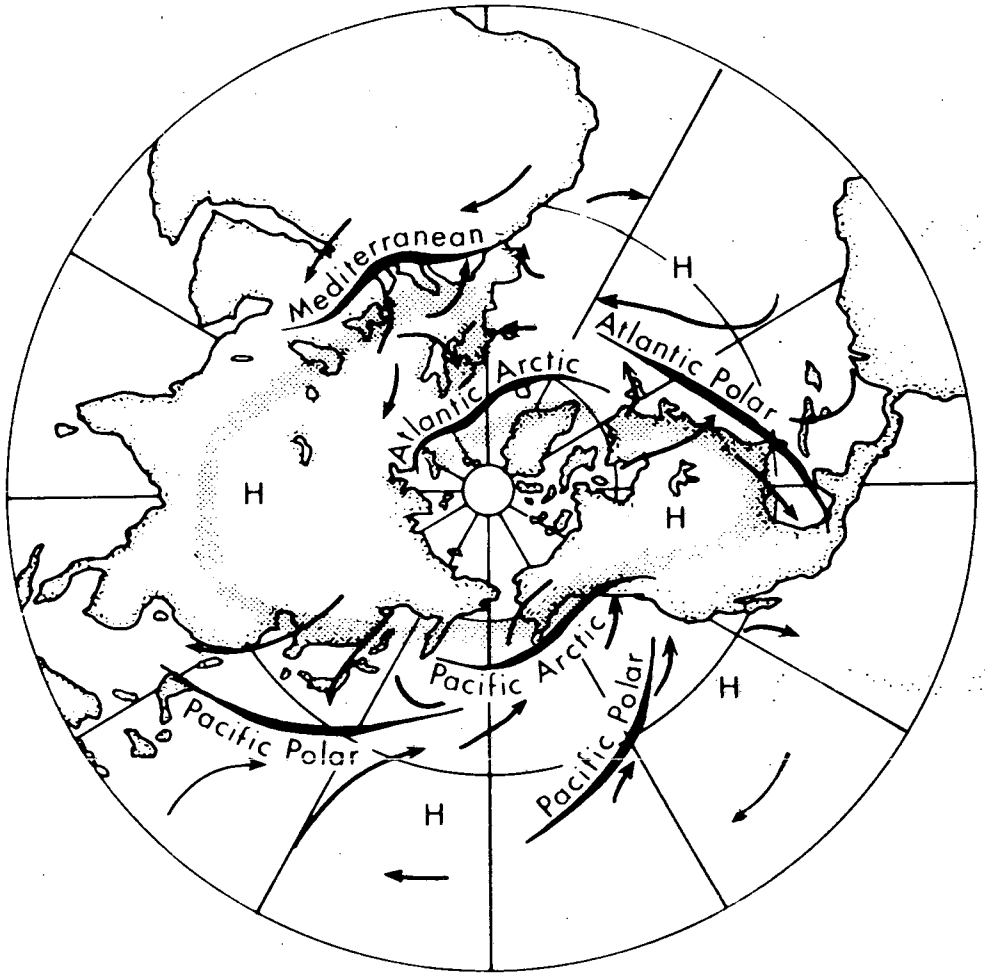
Yakutat Bays can extend out over the water for 20 - 25 miles. The effect of these winds on wave generation is not discussed but further investigation of the phenomena is required.

A secondary cause of high local winds in coastal areas is funneling or venturi effects. These can occur at any place where the pressure gradient is strengthened by the terrain or where the geography of the area is such that the winds are tunneled through a narrow channel. In the lease areas, these winds are common when there are moderate southeast winds.

5.2.6 North Pacific Weather Systems

The following discussion by Nummedal and Stephen was excerpted from the Environmental Assessment of the Alaskan Continental Shelf, Vol. 12 (BLM/NOAA, 1976).

> "The principal frontal zones of the northern hemisphere winter are shown in Figure 9 (Figure 5-1 in this report). Two Pacific polar fronts and one Pacific arctic front are generally present. Normally, the front near Asia is the stronger and generates a majority of the storms which travel into the Gulf of Alaska. Storm tracks derived from inspection of Northern Hemisphere surface synoptic charts (NOAA, National Climatic Center, 1973) illustrate this (Figure 5-2 storm track no. 13). The Pacific arctic front can also be responsible for local storm generation within the Gulf of Alaska, Figure 5-3 track nos. 7, 15, and 18. The steep temperature gradients at the Alaska and St. Elias Ranges in winter, which separate the mild maritime climate from the cold continental interior, prevent the cyclones from penetrating inland, and low pressure centers which enter the central Gulf of Alaska have a tendency to remain there until they dissipate. This combination of locally generated cyclones on the Pacific arctic front and decaying traveling cyclones arriving from the west generates in the Gulf of Alaska the highest winter cyclone frequency in the northern hemisphere (Pettersen, 1969, pg. 227; Figure 12A). Winter cyclones of the North Pacific frequently have central pressures less than 950 mb and move at speeds of between 20 and 30 knots before they encounter the mountains, causing a packing of isobars along the mountain slopes."



Source: BLM/NOAA (1976)

Figure 5-1 Principal Frontal Zones in the Northern Hemisphere in Winter

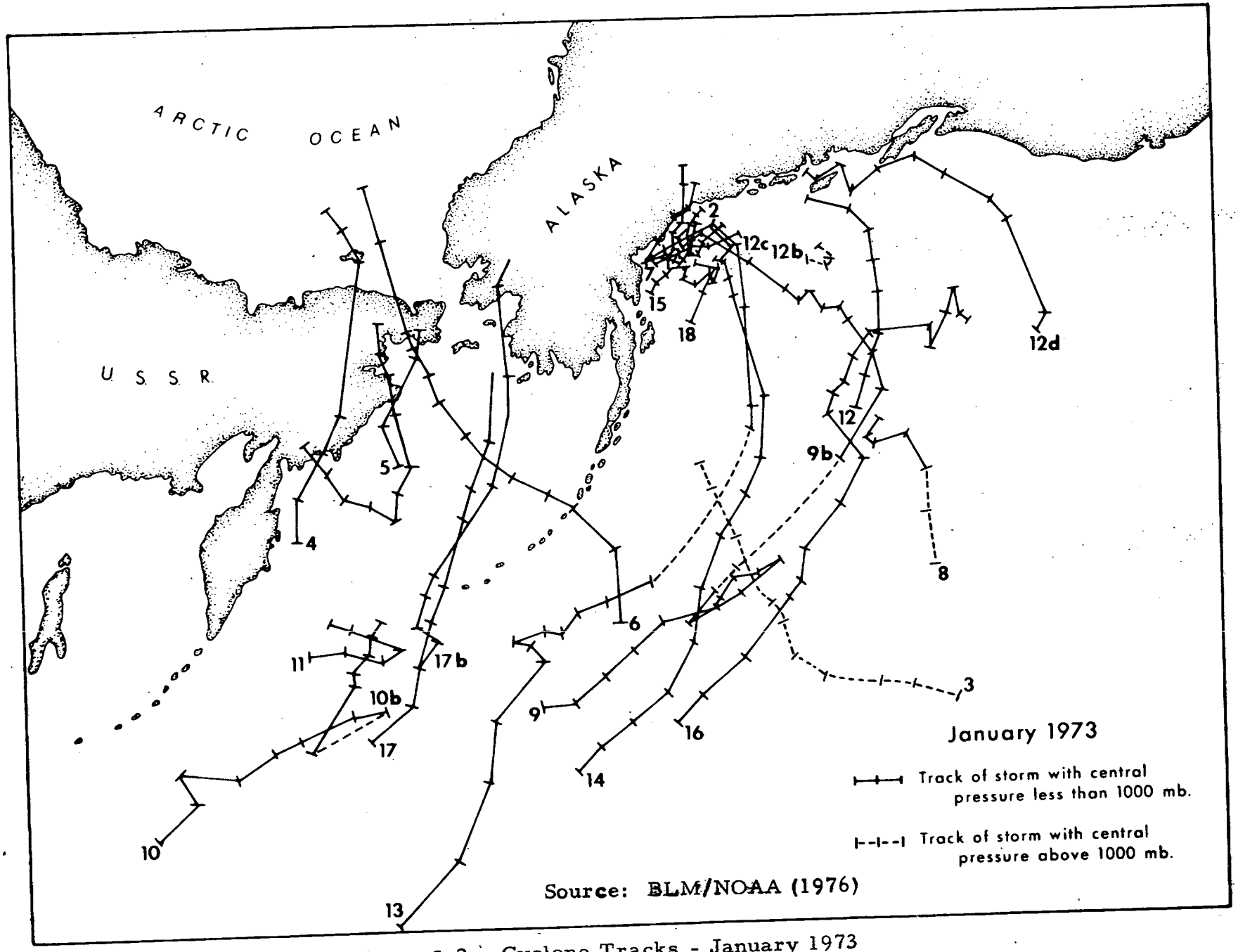


Figure 5-2 Cyclone Tracks - January 1973

"The reduction in intensity of latitudinal pressure differences in summer causes a breakdown of the zonal current with consequent decrease in frontal cyclogenic activity. The cyclones that do occur are weak, but surprisingly long lived. Typical travel patterns are shown in Figure 5-3 by storm tracks 3, 4, and 5. Most of the summer storm activity is located in the western Gulf of Alaska and to the south of the outer Aleutian Islands. Even there, the summer cyclone frequency is not any higher than many other places in the Northern Hemisphere (Pettersen, 1969, pg. 229, Figure 12B)."

5.2.7 Normal and Storm Winds

Storm track 13 in Figure 5-2 shows that the Gulf of Alaska is located at the end of the longest over-water storm track in the Northern Hemisphere. Winds caused by the packing of the isobars along the mountain slopes are actually stronger than the winds indicated by barometric pressure gradients. Also, because of the stagnation of the cyclone systems in the Gulf of Alaska, wind duration can be prolonged up to several days during which time a second cyclonic system can move into the Gulf, reinforcing the first storm. Average wind conditions for 3 land stations in the Gulf are shown in Table 5-5. The source for this information was the Northern Gulf of Alaska EIS (BLM, 1976). Tables 5-6 and 5-7 from the SSMO, Vol. 12 (U.S. Naval Weather Service Command, 1970) for the Cordova Maritime area give the distribution of wind speed vs wind direction averaged by month over the period 1934 to 1969.

Monthly average wind speeds for Middleton Island (Table 5-5), are indicative of the pronounced seasonal trends in the Northern Gulf, although the actual monthly wind speeds are somewhat lower than over water

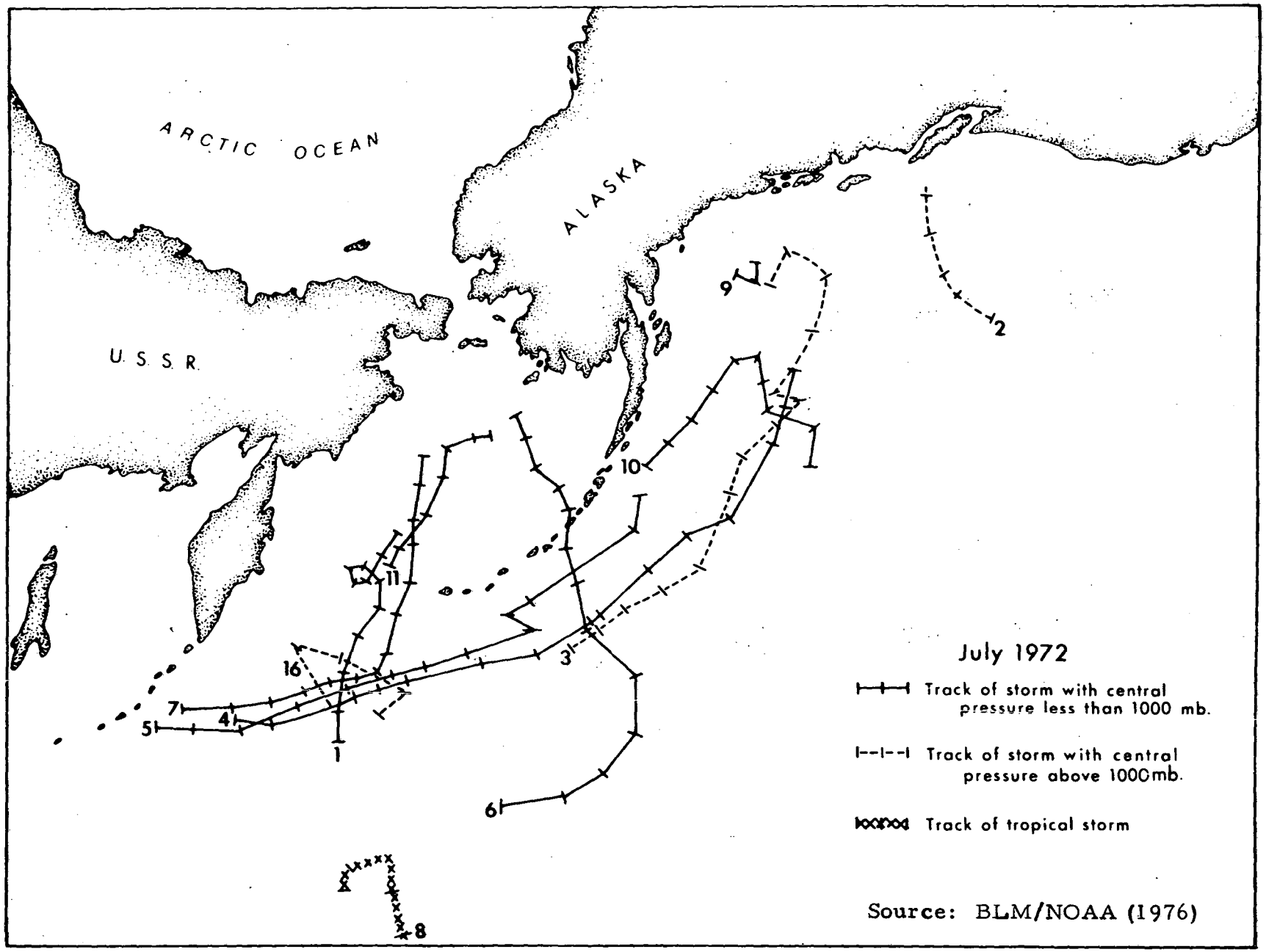


Figure 5-3 Cyclone Tracks - July 1972

(Table 5-6). The Middleton Island data show that the summer months of June, July, and August are the calmest. In September, winds begin to increase and reach their maximum speeds by January. High average wind speeds persist through February but begin to abate by March. Through the spring, wind speeds continue to decline gradually toward the summer minimum condition.

Gale force ($\geq$ 34 kt) winds may be encountered at any time during the year but are usually rare during the summer months. According to the Northern Gulf of Alaska EIS (BLM, 1976), the frequency of gales increases from a minimum of 1 percent in the summer months to 16.7 percent in December. Gale force winds occur commonly through March and then decline in frequency approaching the summer months.

Sustained winds >41kt occur about 3-5 percent of the time from October through February in open ocean areas. According to wind data from Middleton Island (Table 5-5), wind gusts of >60kts are likely to occur from November through January. Exposed ocean areas of the Northern Gulf are likely to experience similar, or perhaps greater, wind gusts than Middleton Island during the same period.

TABLE 5-5

Average Wind Conditions, Gulf of Alaska

Month	KODIAK			YAKUTAT			MIDDLETON ISLAND		
	Direction	Speed (mph)	Max. Speed (mph)	Direction	Speed (mph)	Max. Speed (mph)	Direction	Speed (mph)	Max. Speed (mph)
January	NW	10.6	99	E	8.1	63	E	15.0	68
February	NW	10.0	86	E	8.3	47	ESE	14.7	55
March	NW	10.2	73	E	7.7	41	ESE	13.4	50
April	NW	9.4	84	E	7.4	51	E	11.7	50
May	E	8.5	52	ESE	8.0	52	E	10.7	43
June	E	7.0	61	ESE	7.7	48	E	8.5	34
July	E	5.6	50	ESE	7.1	35	SW	7.3	37
August	NW	6.3	52	ESE	6.9	43	ESE	8.6	39
September	NW	7.5	63	E	7.5	56	ESE	10.5	55
October	NW	9.4	72	E	8.7	75	E	13.2	55
November	NW	10.3	74	E	8.5	63	ESE	15.2	66
December	NW	10.6	76	E	9.1	63	ESE	14.8	63
ANNUAL	NW	8.8	99	E	7.9	75	ESE	12.0	68

Source: Searby (1969) in Northern Gulf EIS (1976)

Table 5-6 Annual Percentage Frequency of Wind Direction By Speed and By Hour

AREA 0004 CORDOVA
57N-COAST 140-146W

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.4	2.5	1.0	.3	.1	453	5.2	12.6
NE	1.5	3.3	1.7	.8	.2	651	7.5	15.4
E	2.5	7.3	6.0	3.9	.8	1782	20.5	19.3
SE	1.9	7.0	4.4	1.6	.3	1321	15.2	16.6
S	2.1	6.3	2.9	.9	.1	1053	12.1	14.5
SW	2.0	6.2	2.6	.8	.1	1009	11.6	14.0
W	3.6	8.8	3.7	.9	.1	1494	17.2	13.4
NW	1.5	3.7	1.2	.4	*	596	6.9	13.0
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.8					328	3.8	.0
TOT OBS	1773	3914	2040	821	139	8687		14.9
TOT PCT	20.4	45.1	23.5	9.5	1.6		100.0	

WND DIR	HOUR (GMT) 00	03	06	09	12	15	18	21
N	4.8	8.1	4.8	19.4	5.4	.0	5.8	3.9
NE	7.0	10.8	7.6	6.5	7.7	20.6	7.4	9.4
E	21.1	5.4	20.8	6.5	20.4	8.8	20.8	14.2
SE	15.2	.0	15.2	6.5	15.7	11.8	15.3	13.4
S	12.7	18.9	12.0	3.2	12.1	8.8	11.7	12.6
SW	12.2	18.9	10.9	6.5	10.1	14.7	12.3	18.9
W	17.0	35.1	18.0	41.9	17.0	32.4	15.8	20.5
NW	6.7	2.7	6.7	9.7	7.1	2.9	7.1	7.1
VAR	.0	.0	.0	.0	.0	.0	.0	.0
CALM	3.4	.0	4.1	.0	4.4	.0	3.8	.0
TOT OBS	2436	37	1912	31	1756	34	2354	127
TOT PCT	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command, 1970)

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour

AREA 0004 CORDOVA
57N-COAST 140-146W

JANUARY

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	2.2	4.3	2.7	1.3	.1	72	10.7	15.4
NE	1.9	4.0	2.7	2.2	.1	74	11.0	17.4
E	1.8	5.8	7.9	5.9	.7	149	22.1	22.0
SE	.6	5.5	4.5	2.8	.3	92	13.6	20.1
S	1.9	4.6	4.3	1.6	.1	85	12.6	17.2
SW	1.3	4.7	1.3	.9	.0	56	8.3	14.5
W	2.8	5.2	2.8	.7	.0	78	11.6	13.1
NW	.7	3.0	1.8	1.0	.1	45	6.7	17.4
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	3.4					23	3.4	.0
TOT OBS	113	250	188	112	11	674		17.2
TOT PCT	16.8	37.1	27.9	16.6	1.6		100.0	

WND DIR	HOUR (GMT) 00	03	06	09	12	15	18	21
N	11.6	25.0	9.7	33.3	11.8	.0	9.1	11.1
NE	12.6	25.0	6.9	.0	11.0	.0	12.6	11.1
E	22.6	25.0	24.3	.0	19.1	25.0	22.3	22.2
SE	12.1	.0	14.6	.0	12.5	50.0	15.4	11.1
S	15.1	25.0	11.8	.0	11.0	.0	11.4	22.2
SW	7.0	.0	11.1	.0	7.4	.0	8.6	11.1
W	11.1	.0	13.2	.0	14.0	25.0	9.1	11.1
NW	4.5	.0	5.6	66.7	10.3	.0	6.9	.0
VAR	.0	.0	.0	.0	.0	.0	.0	.0
CALM	3.5	.0	2.8	.0	2.9	.0	4.6	.0
TOT OBS	199	4	144	3	136	4	175	9
TOT PCT	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

FEBRUARY

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD
N	1.5	3.4	1.6	.2	.0	41	6.7	12.5
NE	.8	4.1	3.1	2.0	.7	65	10.7	20.0
E	2.5	5.9	7.6	5.3	1.5	138	22.7	21.6
SE	1.5	8.0	3.8	2.8	.7	102	16.7	19.2
S	1.0	4.1	3.3	.8	.0	56	9.2	16.8
SW	1.0	2.5	2.5	2.1	.0	49	8.0	19.7
W	2.3	5.1	5.4	1.8	.2	90	14.8	17.5
NW	1.8	4.4	2.3	.7	.0	56	9.2	14.1
VAR	.0	.0	.0	.0	.0	0	.0	.0
CALM	2.0					12	2.0	.0
TOT OBS	87	229	180	95	18	609		18.1
TOT PCT	14.3	37.6	29.6	15.6	3.0		100.0	

WND DIR	HOUR (GMT) 00	03	06	09	12	15	18	21
N	4.4	40.0	7.1	25.0	9.0	.0	5.3	16.7
NE	8.2	40.0	10.2	25.0	12.0	75.0	9.9	.0
E	23.3	.0	25.2	25.0	21.8	25.0	22.2	.0
SE	18.2	.0	15.0	.0	21.8	.0	14.6	.0
S	10.7	.0	7.1	.0	9.0	.0	9.9	16.7
SW	8.8	20.0	4.7	.0	8.3	.0	9.9	.0
W	13.8	.0	15.7	25.0	8.3	.0	18.7	66.7
NW	10.7	.0	11.8	.0	7.5	.0	8.2	.0
VAR	.0	.0	.0	.0	.0	.0	.0	.0
CALM	1.9	.0	3.1	.0	2.3	.0	1.2	.0
TOT OBS	159	5	127	4	133	4	171	6
TOT PCT	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Summary of Synoptic Meteorological Observations (U.S. Naval Weather Service Command, 1970)

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour (Cont'd)

MARCH

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	1.2	4.3	.9	.3	.2	45	7.0	13.3	6.3	.0	7.5	.0	6.7	.0	7.3	14.3
NE	1.4	3.3	3.1	1.1	.0	57	8.8	16.1	6.9	.0	7.5	.0	10.4	.0	10.6	14.3
E	2.2	9.5	6.5	3.4	.3	141	21.9	18.0	19.4	.0	24.5	.0	20.7	.0	24.0	.0
SE	.6	5.6	4.7	1.7	.0	81	12.6	18.7	13.7	.0	10.2	.0	11.9	.0	14.0	14.3
S	1.7	8.5	3.3	.5	.0	90	14.0	14.0	16.6	.0	13.6	.0	16.3	.0	9.5	28.6
SW	1.9	5.0	2.3	.2	.5	63	9.8	14.8	13.1	.0	6.1	.0	9.6	.0	9.5	14.3
W	2.0	5.4	4.0	1.2	.0	82	12.7	15.6	12.0	.0	12.9	50.0	14.8	.0	11.7	.0
NW	1.2	7.3	1.9	.6	.2	72	11.2	13.8	10.3	.0	13.6	50.0	6.7	.0	12.8	14.3
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	2.2					14	2.2	.0	1.7	.0	4.1	.0	3.0	.0	.6	.0
TOT OBS	93	315	172	58	7	645		15.5	175	0	147	2	135	0	179	7
TOT PCT	14.4	48.8	26.7	9.0	1.1		100.0		100.0	.0	100.0	100.0	100.0	.0	100.0	100.0

APRIL

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	1.6	2.4	1.5	.3	.0	43	5.7	12.7	3.2	.0	6.0	57.1	8.0	.0	5.2	5.0
NE	2.4	4.1	1.3	.4	.0	62	8.2	11.1	5.6	.0	7.2	.0	8.8	44.4	8.8	25.0
E	2.8	6.5	4.0	4.9	.1	138	18.3	18.7	21.8	.0	16.9	14.3	20.4	.0	16.0	15.0
SE	2.0	5.3	5.0	1.2	.0	102	13.5	15.5	13.4	.0	15.1	.0	13.1	.0	13.9	15.0
S	2.0	4.9	2.1	.3	.0	70	9.3	12.4	6.5	50.0	10.2	.0	10.9	11.1	10.8	.0
SW	2.5	5.3	3.3	.4	.0	87	11.6	13.1	17.1	.0	10.2	.0	8.8	.0	8.8	20.0
W	5.3	8.2	4.5	1.5	.0	147	19.5	12.9	20.8	50.0	19.9	28.6	13.9	44.4	20.6	10.0
NW	1.2	4.2	2.8	.3	.0	64	8.5	14.0	8.3	.0	8.4	.0	10.2	.0	8.2	10.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	5.3					40	5.3	.0	3.2	.0	6.0	.0	5.8	.0	7.7	.0
TOT OBS	189	309	185	69	1	753		13.5	216	4	166	7	137	9	194	20
TOT PCT	25.1	41.0	24.6	9.2	.1		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour (Cont'd)

MAY

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	1.6	2.0	.1	.1	.0	31	3.9	9.3	3.0	.0	3.1	.0	4.5	.0	5.4	.0
NE	2.4	2.9	1.1	.1	.4	55	7.0	12.4	4.6	.0	6.9	.0	9.7	.0	7.4	12.5
E	3.8	9.6	6.0	1.5	.3	167	21.2	15.0	23.2	50.0	26.3	.0	14.2	100.0	20.1	25.0
SE	3.7	8.0	4.8	1.3	.3	142	18.0	14.9	15.2	.0	20.6	.0	21.0	.0	16.7	25.0
S	2.3	6.2	1.8	.3	.0	83	10.5	12.4	8.4	.0	8.8	.0	11.9	.0	13.2	12.5
SW	2.5	5.6	1.8	.1	.0	79	10.0	11.3	12.7	.0	10.0	.0	8.0	.0	9.3	.0
W	3.8	8.8	2.8	.4	.0	124	15.7	11.6	17.7	50.0	15.6	.0	16.5	.0	13.2	.0
NW	2.3	4.4	.5	.0	.0	57	7.2	9.5	11.0	.0	2.5	.0	8.0	.0	5.4	25.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	6.3					50	6.3	.0	4.2	.0	6.3	.0	6.3	.0	9.3	.0
TOT OBS	227	375	149	30	7	788		12.0	237	2	160	0	176	1	204	8
TOT PCT	28.8	47.6	18.9	3.8	.9		100.0		100.0	100.0	100.0	.0	100.0	100.0	100.0	100.0

JUNE

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	1.8	2.3	.4	.0	.0	35	4.5	8.6	4.0	.0	3.4	.0	3.2	.0	7.0	.0
NE	1.4	3.2	1.0	.6	.0	49	6.3	13.6	5.8	.0	6.7	.0	5.8	.0	6.6	20.0
E	2.8	8.9	8.1	.9	.0	161	20.7	14.9	20.0	.0	20.2	.0	21.2	.0	22.1	.0
SE	2.8	8.6	3.0	.4	.0	115	14.8	12.3	14.2	.0	18.5	.0	10.3	.0	15.5	20.0
S	2.6	5.7	1.4	.1	.0	76	9.8	11.0	11.1	.0	12.4	.0	9.6	.0	5.6	40.0
SW	2.1	6.3	1.7	.1	.0	79	10.2	11.4	11.6	.0	9.0	.0	9.0	.0	10.8	.0
W	6.2	13.0	3.2	.0	.1	175	22.5	11.0	19.6	.0	21.9	.0	30.1	.0	20.7	20.0
NW	1.9	3.7	.5	.0	.0	48	6.2	9.5	6.7	.0	6.2	.0	5.1	.0	6.6	.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	5.0					39	5.0	.0	7.1	.0	1.7	.0	5.8	.0	5.2	.0
TOT OBS	207	402	150	17	1	777		11.5	225	0	178	0	156	0	213	5
TOT PCT	26.6	51.7	19.3	2.2	.1		100.0		100.0	.0	100.0	.0	100.0	.0	100.0	100.0

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour (Cont'd)

JULY

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	2.0	.9	.5	.0	.0	27	3.4	8.4	4.8	.0	4.1	.0	4.2	.0	1.4	4.5
NE	2.5	3.2	.8	.0	.0	51	6.5	9.7	4.8	10.0	8.1	20.0	4.9	.0	7.8	4.5
E	4.1	9.0	3.8	1.1	.0	142	18.1	13.2	16.3	.0	21.5	.0	21.7	.0	15.7	27.3
SE	3.8	7.1	2.9	.5	.0	113	14.4	12.5	15.8	.0	11.0	20.0	14.0	28.6	16.6	9.1
S	4.2	6.8	3.4	.3	.0	115	14.6	11.6	15.8	30.0	10.5	.0	18.2	14.3	14.7	9.1
SW	3.2	7.6	1.9	.1	.0	101	12.9	11.3	12.4	30.0	12.8	20.0	9.8	28.6	13.8	13.6
W	5.5	12.2	3.4	.1	.0	167	21.3	11.1	20.6	30.0	25.6	40.0	16.1	28.6	20.3	27.3
NW	1.8	2.8	.6	.0	.0	41	5.2	10.0	4.8	.0	2.9	.0	8.4	.0	6.0	4.5
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	3.6					28	3.6	.0	4.8	.0	3.5	.0	2.8	.0	3.7	.0
TOT OBS	241	390	137	17	0	785		11.1	209	10	172	5	143	7	217	22
TOT PCT	30.7	49.7	17.5	2.2	.0		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

AUGUST

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	.9	2.2	.1	.0	.0	25	3.2	8.8	4.4	.0	1.1	.0	3.4	.0	4.4	.0
NE	1.2	2.1	.5	.3	.0	31	4.0	11.7	3.4	.0	4.0	.0	4.1	.0	5.4	.0
E	2.1	7.2	3.1	.9	.1	104	13.4	14.5	15.3	.0	13.0	.0	10.8	.0	16.7	.0
SE	1.8	6.8	2.6	.5	.1	92	11.8	13.7	13.8	.0	14.7	.0	12.2	.0	9.8	.0
S	3.2	8.1	2.2	.1	.0	106	13.6	11.4	15.8	.0	14.7	12.5	14.9	.0	11.3	10.5
SW	2.7	10.9	2.1	.1	.0	123	15.8	11.2	12.8	30.0	14.7	12.5	17.6	37.5	16.2	26.3
W	5.0	16.1	4.9	.3	.0	204	26.3	12.1	24.1	60.0	24.3	75.0	22.3	50.0	25.5	57.9
NW	1.7	4.5	.5	.0	.0	52	6.7	10.3	4.9	10.0	7.3	.0	7.4	12.5	7.4	5.3
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	5.1					40	5.1	.0	5.4	.0	6.2	.0	7.4	.0	3.4	.0
TOT OBS	184	450	124	17	2	777		11.5	203	10	177	8	148	8	204	19
TOT PCT	23.7	57.9	16.0	2.2	.3		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour (Cont'd)

SEPTEMBER

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	1.3	1.7	.4	.0	.0	24	3.3	9.5	3.0	.0	3.1	.0	3.9	.0	3.7	.0
NE	.8	3.6	1.1	.7	.0	45	6.3	14.9	8.4	.0	6.2	.0	4.5	.0	5.3	12.5
E	2.8	5.4	7.8	4.5	.6	151	21.0	20.1	19.3	.0	17.4	.0	25.2	.0	23.3	12.5
SE	2.6	8.1	5.0	1.5	.1	125	17.4	16.0	15.8	.0	16.8	.0	20.6	.0	17.5	12.5
S	2.2	6.4	2.9	1.0	.1	91	12.7	15.1	13.9	50.0	16.8	.0	7.1	100.0	11.6	12.5
SW	1.8	7.2	2.6	.4	.0	87	12.1	13.4	11.4	.0	11.2	.0	8.4	.0	15.9	37.5
W	3.9	10.3	2.9	1.3	.0	132	18.4	13.0	19.8	50.0	21.1	100.0	19.4	.0	13.8	.0
NW	1.8	2.4	.6	.0	.0	34	4.7	9.7	5.4	.0	1.9	.0	5.8	.0	5.3	12.5
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	4.2					30	4.2	.0	3.0	.0	5.6	.0	5.2	.0	3.7	.0
TOT OBS	154	324	168	67	6	719		14.6	202	2	161	1	155	1	189	8
TOT PCT	21.4	45.1	23.4	9.3	.8		100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

OCTOBER

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	.9	2.6	1.0	.1	.1	37	4.7	14.0	4.2	.0	4.0	.0	4.2	.0	6.2	.0
NE	.5	2.7	1.9	.6	.1	46	5.9	17.8	6.1	.0	7.5	.0	5.5	.0	4.9	.0
E	1.3	5.3	5.9	7.1	1.9	167	21.4	25.4	23.4	.0	19.1	.0	20.6	.0	22.2	.0
SE	.9	6.0	5.5	2.6	.4	120	15.4	19.7	16.4	.0	15.0	.0	17.6	.0	12.9	33.3
S	1.3	6.4	4.4	2.1	.1	111	14.2	17.8	14.5	.0	15.6	.0	11.5	.0	14.7	33.3
SW	1.7	6.4	4.7	1.4	.0	111	14.2	16.7	13.1	.0	13.9	.0	15.8	.0	14.2	33.3
W	1.7	6.9	4.1	1.8	.4	116	14.9	17.3	15.0	.0	13.9	.0	15.2	.0	15.6	.0
NW	.9	2.8	1.4	1.3	.0	50	6.4	17.3	5.6	.0	8.1	.0	5.5	.0	6.7	.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	2.8					22	2.8	.0	1.9	.0	2.9	.0	4.2	.0	2.7	.0
TOT OBS	93	305	226	132	24	780		18.8	214	0	173	0	165	0	225	3
TOT PCT	11.9	39.1	29.0	16.9	3.1		100.0		100.0	.0	100.0	.0	100.0	.0	100.0	100.0

Table 5-7 Monthly Percentage Frequency of Wind Direction by Speed and by Hour (Cont'd)

NOVEMBER

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	.7	2.3	1.2	.1	.1	33	4.4	15.1	3.7	.0	4.5	.0	2.7	.0	6.9	.0
NE	1.3	3.5	2.0	.7	.5	60	8.1	17.4	7.3	.0	12.3	.0	9.3	.0	4.9	6.7
E	1.5	6.1	6.2	6.7	2.8	173	23.3	25.2	24.7	.0	17.5	.0	26.0	.0	24.5	20.0
SE	1.2	7.1	6.9	1.8	.7	131	17.7	18.7	17.4	.0	16.2	.0	16.0	.0	19.6	26.7
S	1.3	6.2	3.6	2.4	.3	103	13.9	18.5	12.8	.0	11.7	.0	14.7	.0	16.7	6.7
SW	1.5	5.8	3.4	2.3	.1	97	13.1	17.3	13.7	.0	14.9	.0	10.0	.0	11.8	33.3
W	1.9	5.4	3.2	1.1	.0	86	11.6	14.8	12.3	.0	13.0	.0	13.3	.0	8.8	6.7
NW	1.8	2.2	.8	.5	.3	41	5.5	15.0	5.9	.0	6.5	.0	4.7	.0	5.4	.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	2.4					18	2.4	.0	2.3	.0	3.2	.0	3.3	.0	1.5	.0
TOT OBS	101	286	203	116	36	742		18.6	219	0	154	0	150	0	204	15
TOT PCT	13.6	38.5	27.4	15.6	4.9		100.0		100.0	.0	100.0	.0	100.0	.0	100.0	100.0

DECEMBER

WND DIR	WIND SPEED (KNOTS) 0-6	7-16	17-27	28-40	41+	TOTAL OBS	PCT FREQ	MEAN SPD	HOUR (GMT) 00	03	06	09	12	15	18	21
N	.9	2.8	1.6	.8	.2	40	6.3	16.7	5.6	.0	5.2	.0	4.9	.0	8.9	.0
NE	1.6	3.1	2.0	.9	1.1	56	8.8	20.0	11.8	.0	8.5	.0	8.2	.0	6.7	.0
E	2.7	7.7	6.3	5.6	1.4	151	23.7	20.9	23.6	.0	26.1	.0	24.6	.0	21.2	20.0
SE	.9	7.7	4.9	2.5	.6	106	16.6	19.2	17.4	.0	14.4	100.0	15.6	.0	17.9	20.0
S	.5	6.9	1.9	1.1	.2	67	10.5	16.0	12.4	.0	9.2	.0	9.8	.0	10.1	20.0
SW	1.9	5.6	3.0	1.4	.2	77	12.1	16.1	10.7	.0	9.8	.0	8.2	.0	17.9	20.0
W	2.0	6.9	3.8	1.4	.5	93	14.6	16.3	15.7	.0	16.3	.0	18.9	.0	9.5	.0
NW	.8	3.0	1.4	.5	.0	36	5.6	14.5	2.2	.0	7.2	.0	6.6	.0	6.7	20.0
VAR	.0	.0	.0	.0	.0	0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
CALM	1.9					12	1.9	.0	.6	.0	3.3	.0	3.3	.0	1.1	.0
TOT OBS	84	279	158	91	26	638		17.8	178	0	153	1	122	0	179	5
TOT PCT	13.2	43.7	24.8	14.3	4.1		100.0		100.0	.0	100.0	100.0	100.0	.0	100.0	100.0

5.3 PHYSICAL OCEANOGRAPHY

5.3.1 General Circulation

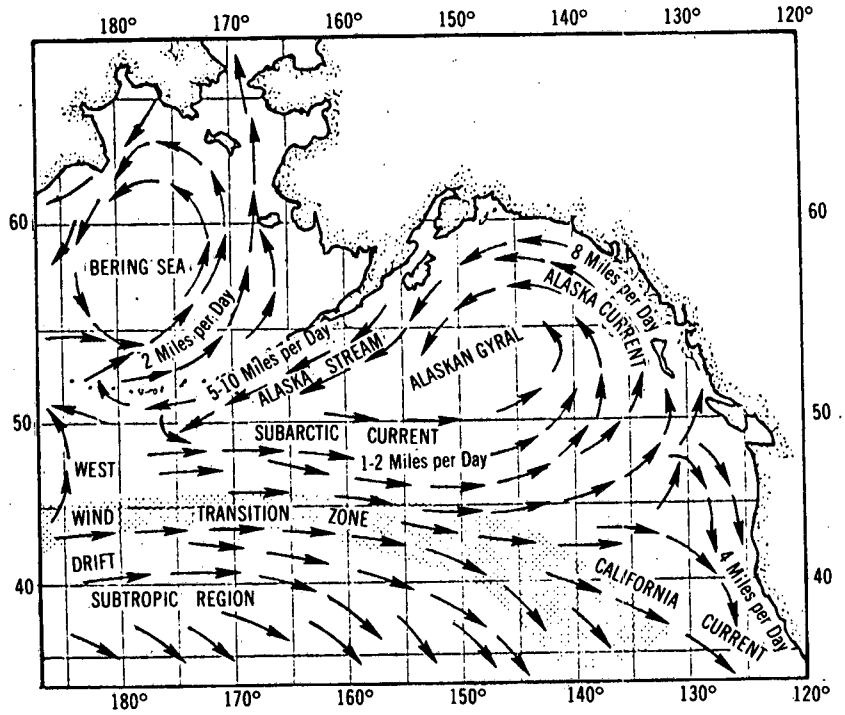
General water circulation in the Gulf of Alaska is a counterclockwise gyre (Figure 5-4). The southern component of the gyre is formed by two easterly moving current systems, the west wind drift and the subarctic current. As these systems approach North America, they diverge forming the Alaska current and the southward flowing California current.

The Alaska current flows northward initially but then turns toward the west and southwest as it follows the general contours of the coastline. South of Kodiak, the Alaska current narrows and intensifies becoming the Alaska stream which moves southwesterly along the Aleutian chain. The Alaska current is generally characterized as a broad, slow-moving current which transports about 10 million cubic meters per second with velocities of less than one-half knot (Fallon et al, 1973).

5.3.2 Currents

Depending on their magnitude currents can be an important design overload consideration for offshore structures. Currents may also effect foundation and pipeline design because of their ability to scour sediment on the ocean floor. From an operational standpoint, currents may effect such things as work boat operations, maintenance, and underwater inspection. In the event of an oil spill, a knowledge of currents is likewise important for predicting movements and containment operations.

The general state of knowledge regarding currents on the continental shelf areas of the Gulf of Alaska has improved considerably in recent years as a result of both petroleum industry studies and work by the Federal Government. The latter ongoing program is part of the Bureau of Land Management Environmental Studies Program. The petroleum industry studies have included both current measurements and current modeling studies. Unfortunately only a small portion of the industry work is available for review. The remaining



Source: BLM(1976)

Figure 5-4 General Circulation - North Pacific

part of this section examines some preliminary data from the BLM program and then discusses the non-proprietary results of the industry study.

Charnell et al (1976) have recently analyzed current meter data from a long time series station located off Icy Bay (59° 34' N and 142° 10' W) in the southeastern portion of the northern Gulf lease area. This station has been maintained since August 1974 and will continue in operation through the summer of 1977. The analysis period includes 15 months of data from August 1974 through May 1976. Data were collected at depths of 20, 50, 100 and 175 meters below the surface of the water. Water depth at the station site was 185 meters.

An extreme value statistical analysis following the technique of Gumbel (1954) was performed. Specific methodologies of this technique are discussed in Appendix A to this report. In brief, Gumbel (1959) has derived an asymptotic extremal probability law in the form of a double exponential:

$$P(S_m) = P\ S_m\ S = e^{-e^{-Y}}$$

$$\text{where } Y = \frac{S_{m-B}}{A}$$

and A and B are shape and scale factors for the distribution. S_m is the ranked current speed. Using this technique, data may be fitted to a linear function through the use of a least squares method. The resulting linear equation allows calculation of extreme values (i.e. current speed) as a function of return period or probability.

Charnell et al (1976) used data from the current meters at the 50 meter and 100 meter depths to obtain the distribution shown in Figure 5-5. These depths were selected because continuous records were available for the entire 15 month period. The data were then extrapolated to 5000 days (13.7 yrs) indicating an extreme speed of about

112 cm/sec ($\cong$ 2.2 kts) at 50 meters and
100 cm/sec ($\cong$ 1.9 kts) at 100 meters.

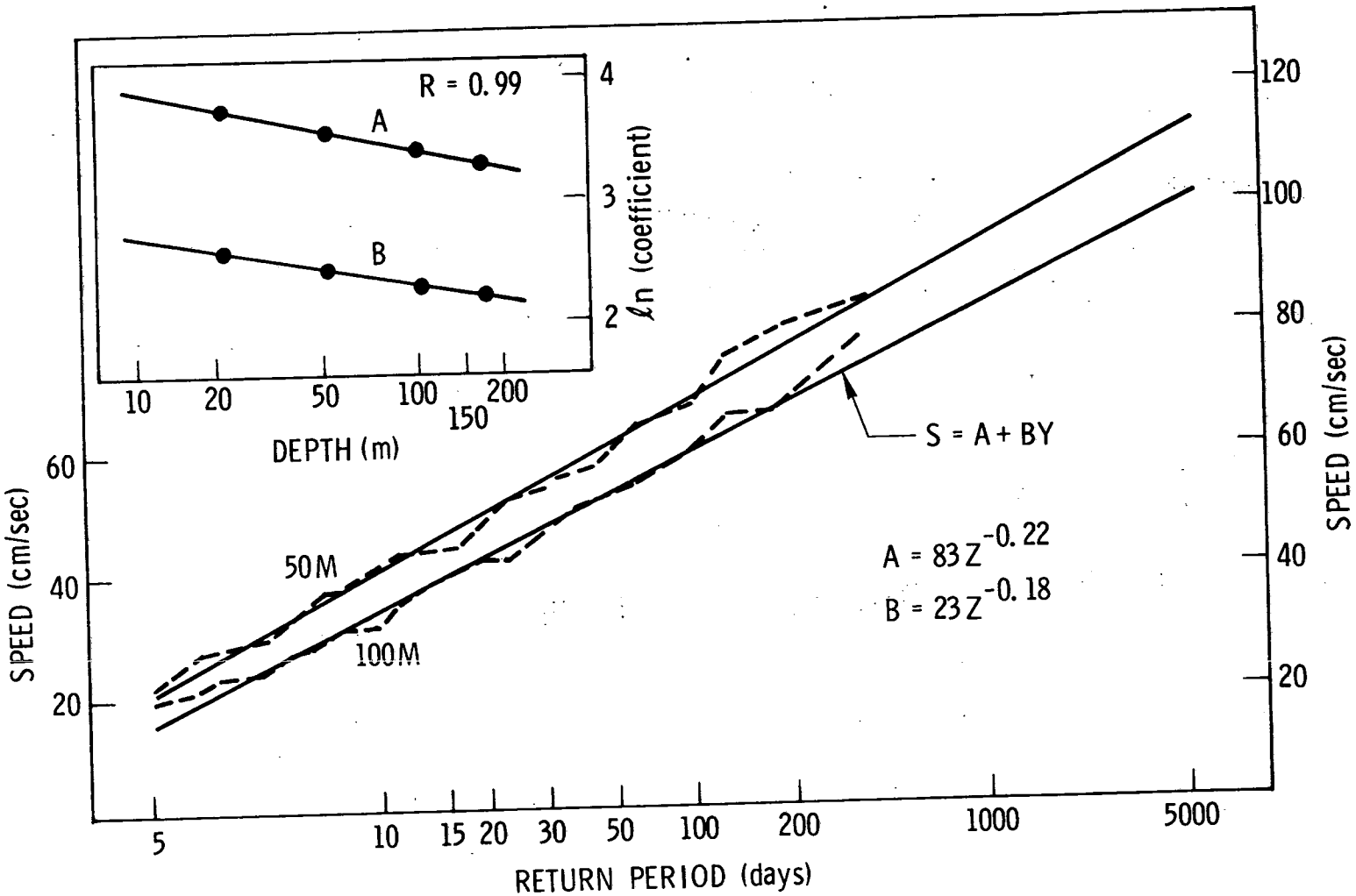


Figure 5-5 Estimated Extreme Currents Near Icy Bay, Alaska
Source: Charnell, et al (1976)

To determine the extreme current speed at other depths, Charnell et al (1976) compared data taken concurrently at the 20 and 175 meter depths with data taken at 50 and 100 meters. This allowed the development of depth coefficients for estimating current speeds at all points in the water column except very near to the surface and bottom where other physical factors begin to act. This comparison and the estimated depth coefficients are shown in Figure 5-5. The general expression for determining the current speed (S_Z) at any depth (Z) is thus:

$$S_Z = A_Z + B_Z Y$$

where A and B are the intercept and slope coefficients at depth Z and:

$$Y = - \ln (-\ln (P_S)).$$

Using this relationship, the 5000 day maximum current at 10 meters depth, for example, would be about 155 cm/sec (~3 knots).

The extreme value analysis performed by Charnell et al (1976) must be regarded as very preliminary owing to the rather short time span of the data set. Extreme value techniques are best suited to data sets covering many more years because of the necessity to obtain representative extremes.

Extrapolation of this data to 5000 days is probably a risky overextension of the technique. It has been suggested by Borgman (1975), that extreme values should not be extrapolated more than twice the data base beyond the largest observation. Nevertheless, it is an interesting yardstick by which to compare future data.

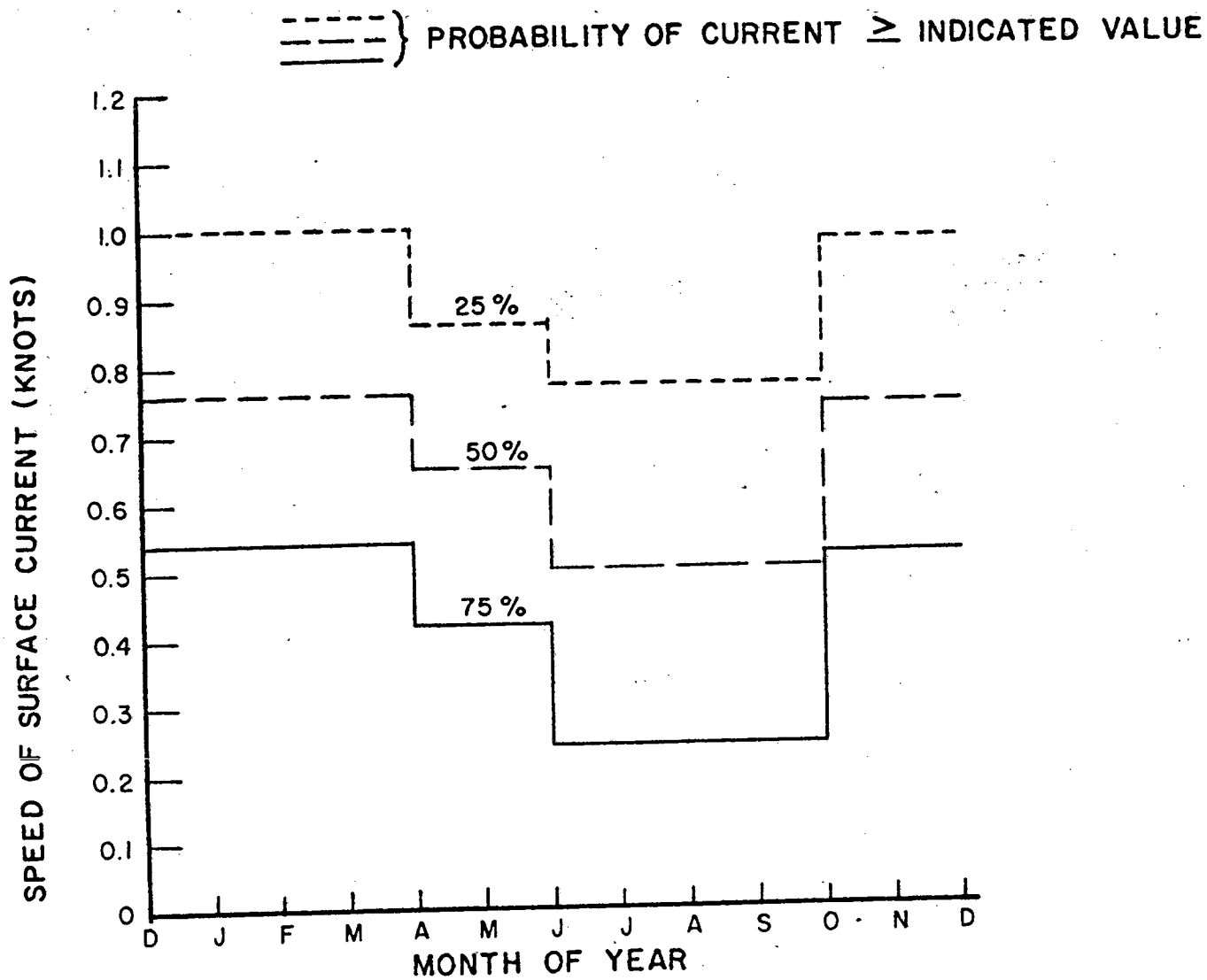
It should also be noted that current measurements at this specific location may not be representative of the northern Gulf lease area as a whole. Currents may vary as a function of: (1) depth, (2) distance offshore, (3) time, and (4) bottom topography. A site close to shore for example, may be strongly influenced by tidal currents and bottom topography.

The Petroleum Industry Study (Fallon et al, 1973) also provides insight into the general nature of Gulf of Alaska currents. It should be noted, however, that the nonproprietary data presented in the industry report is the result of analytic modeling efforts and are therefore calculated values rather than measured values. These data have received only limited validation with measured data. Furthermore, the industry report discusses the modeling technique only in very general terms such that a critical review of the methodologies is precluded.

Figure 5-6 shows the monthly distribution of normal current speeds as described by Fallon et al (1973). Currents which exceed one knot, for example, occur about 25% of the time during the winter months. The more general condition however, is that current speeds of one-half to three-quarters of a knot prevail most of the time. The corresponding direction is generally westward except at nearshore sites where a strong tidal component may mask the general circulation.

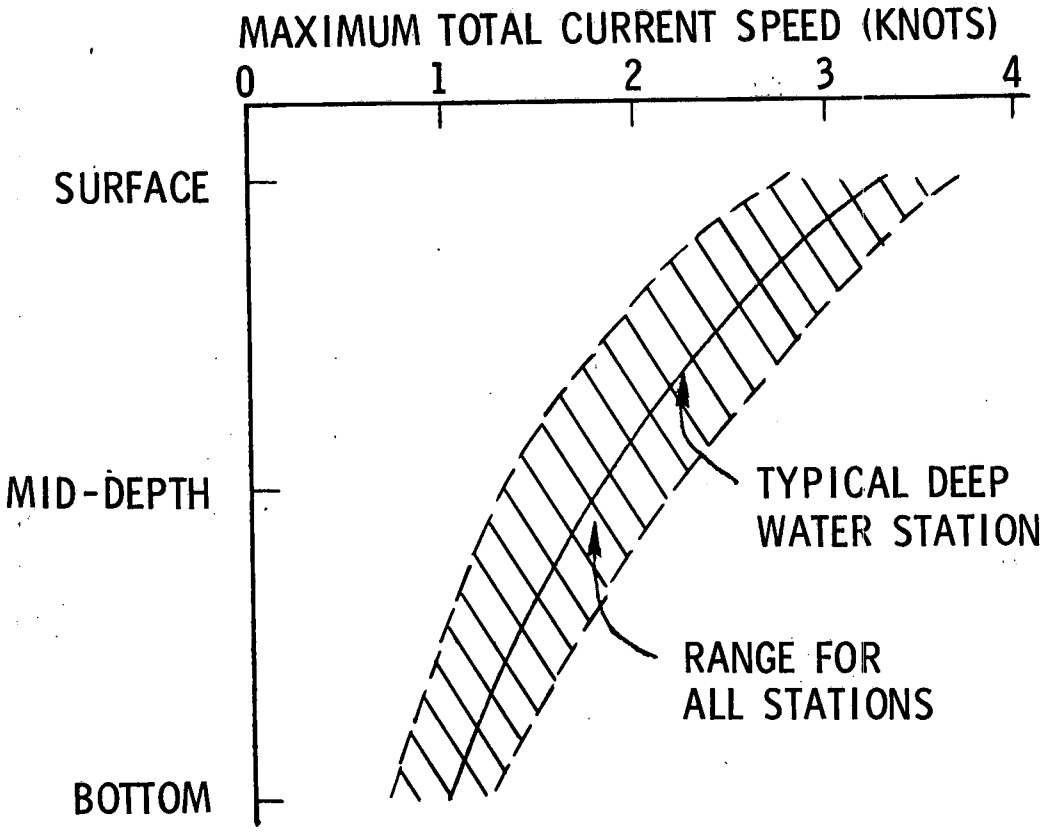
Estimated extreme current conditions are shown in Figure 5-7 (Fallon et al, 1973). These were computed on the basis of 20 major storms of recent years. Values were computed for surface, mid-depth, and bottom current velocities and represent the maximum sum of the component motion for each storm. The solid line represents a current profile for a typical deep water site (~1000 ft) in the lease area. The shaded band represents the range of values which might be expected for all sites in all of the twenty storms. Maximum extreme conditions at the surface are in the range of 3-4 knots but fall to 0.5-1.25 knots at the bottom. The current directions associated with the extreme conditions are toward the northeast-northwest quadrants but are mainly west of north.

According to Fallon et al (1973) computational analyses of the current conditions described above were done by conservative methods and should therefore, slightly overestimate actual conditions. The authors also point out that the magnitude of currents is highly variable in the Gulf of Alaska due primarily to the complex bottom topography. In general, the results



Source: Fallon et al (1973)

Figure 5-6 Seasonal Variation of Surface Current Speeds



Source: Fallon et al (1973)

Figure 5-7. Maximum Total Current Speed

are felt to be valid for most areas away from shore but should be applied with caution to nearshore shallow water locations where they may be greatly exceeded. It should also be emphasized that the extreme conditions described represent a range of values and that actual conditions may exceed the computed average by as much as 50%.

5.3.3 Sea Surface Elevation

A knowledge of sea surface elevations is necessary for offshore platform design. Rises in the water level to heights greater than mean sea level can be caused by a number of factors including waves, tsunamis, astronomical tides, storm surges, and responses to variations in atmospheric pressure. Waves and tsunamis are considered elsewhere in the report. This discussion is limited to tides, storm surges, and pressure responses. The specific application of sea surface elevation information in design is mainly for determining the platform deck height. A rise in sea surface elevation due to tides, storm surges, or pressure variations does not impose any significant loads on the structure, per se. If coupled with high wave conditions, however, an increase in water level elevation will increase the effective height of a wave above a fixed reference point, although it will not increase the wave force. High waves superimposed on a high water level may thus threaten the deck structure if improperly designed to account for this contingency. The deck height must therefore be set to accommodate: the design wave height, the maximum probable water level elevation rise, and a suitable air gap for a margin of safety.

Estimates of water level rise in the northern Gulf lease area are provided by Fallon et al (1973) as a result of industry studies in the Gulf during 1967-1968. Astronomical tide components were derived from standard Department of Commerce tide tables for the area. Storm surge, which is a piling up of water by the wind, was computed from semi-empirical equations. The source of barometric pressure responses was not mentioned but is described as being small, on the order of two feet for severe storms.

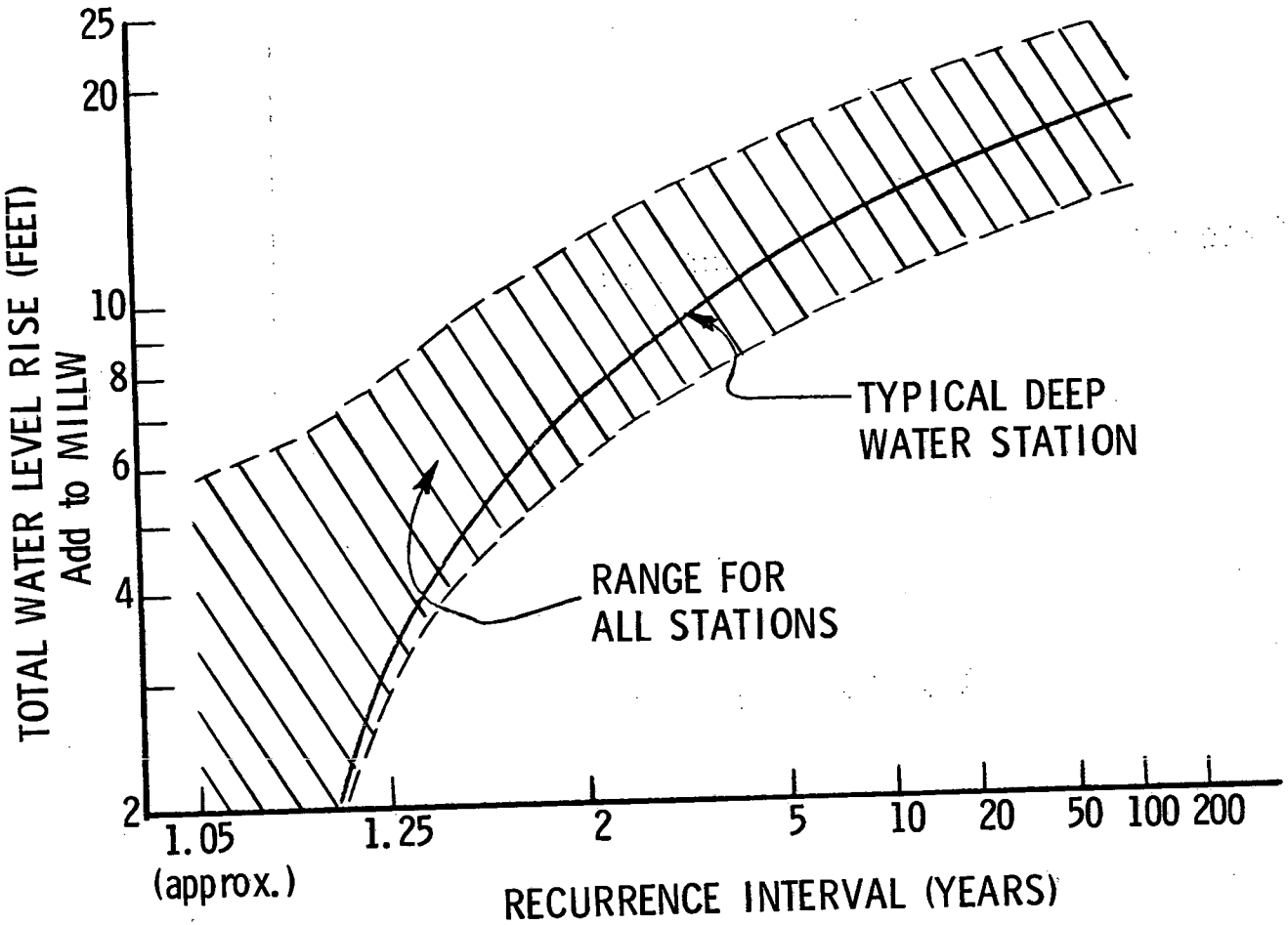
Shore based tidal observations were used to compare the predicted sea level rise and were found to have a consistent conservative bias. The results of this study are shown in Figure 5-8.

In the northeast part of the Gulf, the astronomical tides range from -3 to +15 feet relative to the mean lower low water (MLLW) tidal reference datum. Depending somewhat on location and water depth, the combined 100 year storm surge and pressure response may raise the water level an additional five to six feet. The total combined 100 year effect is on the order of a 20 foot rise above MLLW.

5.3.4 Tsunamis

Tsunamis, often called tidal waves, are long period progressive waves which generally result from volcanic eruptions, landslides, or earthquakes. Since the Gulf of Alaska is an area of high seismicity, earthquake induced tsunamis occasionally occur. According to Tetra Tech (1974), two destructive tsunamis have occurred in Valdez Bay within the last 70 years, and other ports which have experienced damaging tsunamis include Cordova, Whittier, Stewart, Kodiak and Yakutat.

The damaging effects of tsunamis are primarily limited to very shallow water and coastal areas where the tsunami may be transformed to a breaking wave of great magnitude. In the open waters of the OCS lease areas however, the tsunami is felt only as a rapid rise in sea level which imparts very little horizontal force to structures it may encounter. Since this pheonmenon is frequently misunderstood, it is useful to place it in perspective by comparing the forces generated by both a large storm wave and a tsunami. According to Horrer (1975), a large tsunami which raised the water level 30 feet in five minutes at a site where the water depth is 200 feet would produce water particle horizontal accelerations and velocity maxima of 0.15 ft/sec^2 and 7 ft/sec respectively. Similar water particle accelerations and velocities for a 90 foot high storm wave with a 16 second period in the same water depth would be 8 ft/sec^2 and 20 ft/sec at the surface and 4 ft/sec^2 and 10 ft/sec at the bottom.



Source: Fallon et al (1973)

Figure 5-8 Recurrence Interval of Total Water Level Rise

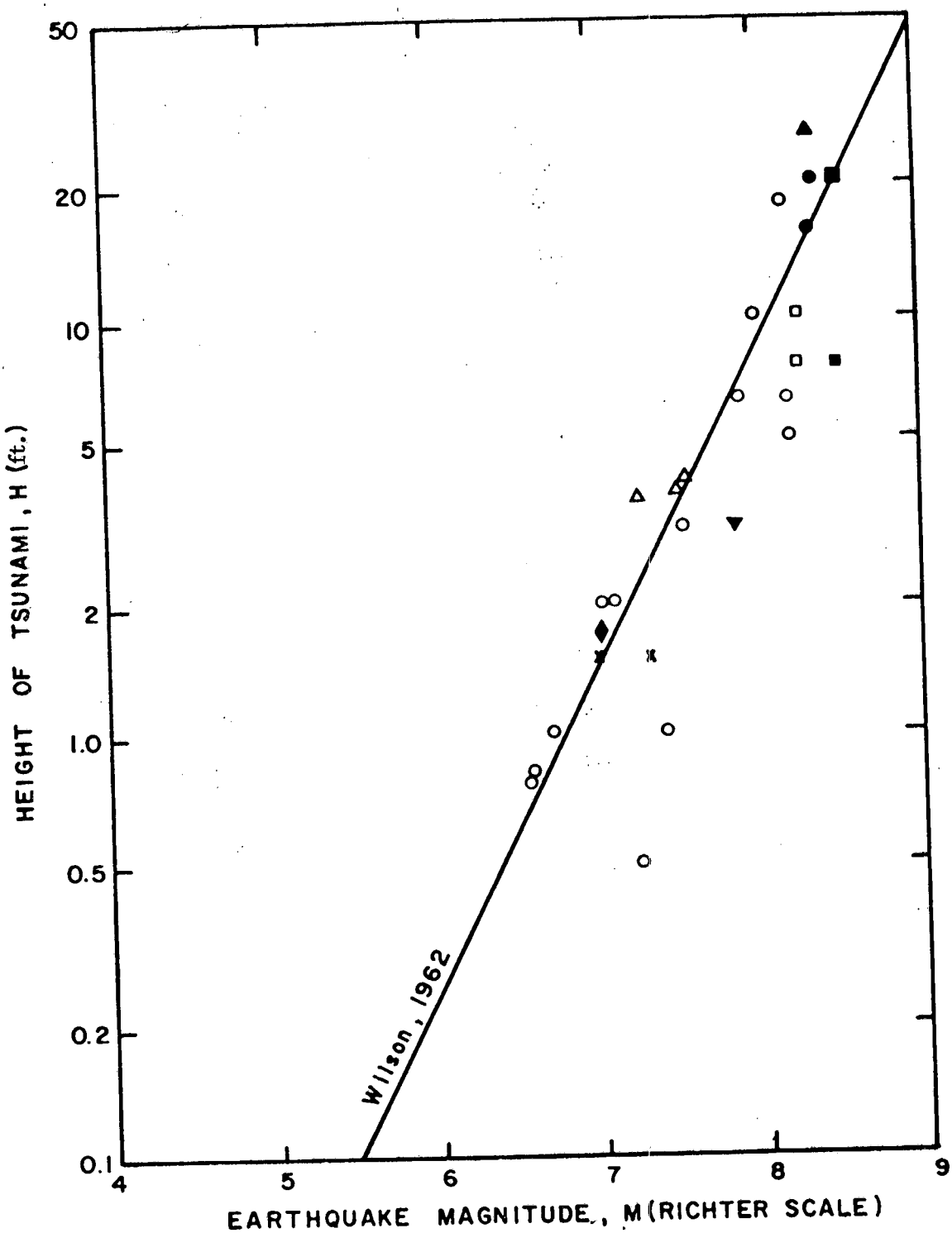
Thus from an offshore platform design standpoint, tsunamis can be treated in the same manner as a rise in water level elevation. This rise in water level has been calculated by Wilson (1972) and is presented graphically in the Tetra Tech (1974) report cited previously. This graph is reproduced in Figure 5-9. The tsunami height is related to the magnitude of the seismic event and the distance from it. Figure 5-9 is calculated for tsunami heights which are close to the source. Earthquakes of Richter magnitude greater than 8 which occur occasionally in the Gulf, can be expected to produce tsunamis which exceed 30 feet in height.

Tetra Tech (1974) has also calculated potential tsunami heights throughout the northern Gulf which is based on a vertical uplift of 30 feet at various points within the Gulf. From these calculations, a contour chart of potential tsunami heights in the northern Gulf was drawn. This chart is illustrated in Figure 5-10. Platforms in the OCS lease areas could expect tsunami heights of 30-35 feet which will increase as the tsunami propagates toward the shore. Under normal circumstances, an increase in water level elevation of 30-35 feet should pose no special problems for offshore platforms since deck elevations will probably greatly exceed this water level elevation to provide adequate clearance for high storm waves.

5.3.5 Normal Wave Conditions

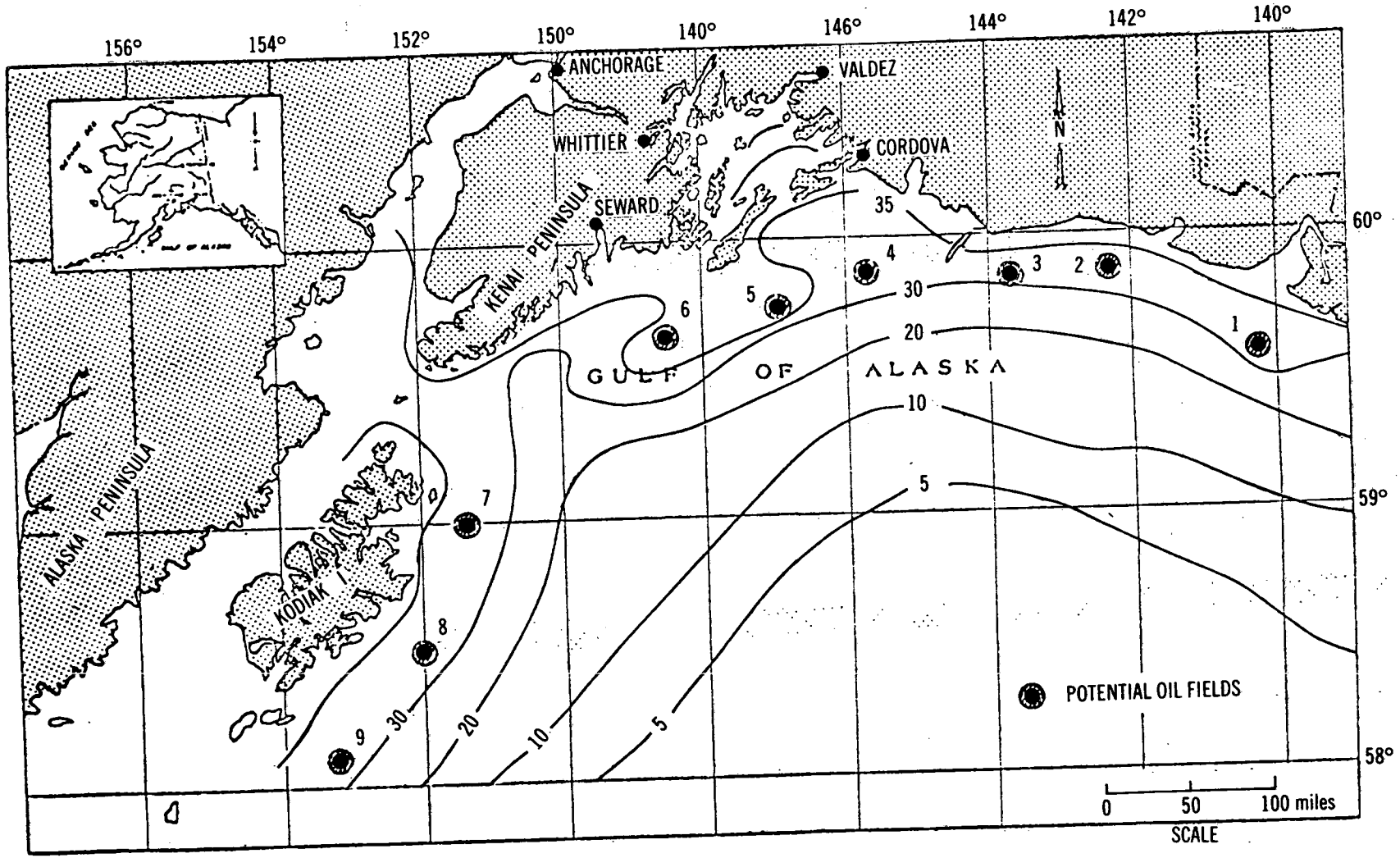
The Gulf of Alaska is exposed to a major portion of the Pacific Ocean and winds may act over great distances (fetch) to produce waves in the Gulf. This phenomenon as well as local meteorological effects act in concert to produce one of the most severe wave climates in the world. The Gulf is also subject to long period swells which originate in the southern hemisphere during the summer months. These occur from May through October and are the result of southern hemisphere winter storms.

Wave conditions in the Gulf of Alaska vary according to season. Since waves are wind induced phenomena, wave conditions follow the general weather patterns of the Gulf. The seas are calmest during the summer



Source: Tetra-Tech (1974) as adapted from Wilson (1962)

Figure 5-9 Correlation of Near Source Tsunami Height with Earthquake Magnitude



Source: Tetra-Tech (1974)

Figure 5-10 Tsunami Height Distribution in Gulf of Alaska

months of July and August. In September wave heights begin to increase and maximum sea states are achieved during December. Winter conditions are somewhat less severe than fall conditions but high wave conditions generally persist through March. From April through June, wave heights gradually abate toward the summer minimum.

Table 5-8 is an annual summary of the normal wave conditions as a function of wind speed in an area which extends from 57° north latitude to the coast and 140° - 146° west longitude. The modal number of observations occur up to the 13-16 ft range. These data reflect the generally severe normal wave climate of the Northern Gulf. Table 5-9 is a month-by-month summary of wave conditions in the same geographic area. The seasonal trends in sea states discussed previously are illustrated by the modal number of observations for each wave height category.

Tables 5-8 and 5-9 are useful for describing only the normal wave enrironment of the Northern Gulf. They should not be confused or substituted for a description of the extreme wave conditions which are required for estimating maximum structural loading conditions on offshore platforms. These extremes are discussed in the following sections.

5.3.6 Extreme Winds and Waves

Estimates of extreme winds and waves that an offshore unit is likely to encounter during its operational lifetime are required in order to evaluate structural safety. Extreme wind velocities and wave heights are usually quoted as a function of their return period, that is, the average length of time between occurrences of a wave of a given height or a wind of a given velocity. Severe events are associated with long return periods and low probabilities of occurrence. For fixed platforms the customary design practice has been to use events with 100 year return periods or longer. The choice of a return period is actually a complex problem involving an

ANNUAL

PERIOD: (PRIMARY)
(OVER-ALL) 1963-1970

AREA 0004 CORDOVA
57N-COAST 140-146W

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	5.4	6.5	.0	.0	.0	.0	360
1-2	1.2	9.7	6.1	*	.0	.0	513
3-4	.5	10.5	13.1	1.5	.0	.0	772
5-6	.1	3.6	11.0	3.8	.3	.0	566
7	.1	.7	5.2	4.0	1.0	.1	335
8-9	.1	.3	2.0	3.0	1.1	.1	197
10-11	.0	.4	1.0	1.4	.8	.0	107
12	*	*	.5	.8	.6	*	58
13-16	.0	.0	.3	1.0	1.2	.2	81
17-19	.0	.0	*	.1	.1	*	8
20-22	.0	.0	.0	.1	.1	.1	11
23-25	.0	.0	.0	*	*	.0	2
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	224	956	1183	474	158	15	3010
PCT	7.4	31.8	39.3	15.7	5.2	.5	100.0

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.4	8.4	13.5	8.7	2.9	1.6	.6	.1	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	1297	3
6-7	*	1.4	4.8	6.6	5.0	3.2	2.1	1.0	1.4	.1	.1	*	.0	.0	.0	.0	.0	.0	.0	884	6
8-9	.0	.5	2.8	3.8	4.1	2.8	1.9	1.1	1.0	.3	.3	.1	.0	.0	.0	.0	.0	.0	.0	638	7
10-11	.0	.3	.5	.9	1.7	1.1	1.4	.5	.8	.2	.1	*	.0	.0	.0	.0	.0	.0	.0	261	8
12-13	.0	*	*	.7	.6	.3	.5	.2	.3	.1	*	.0	.0	.0	.0	.0	.0	.0	.0	95	8
>13	.0	.0	.0	.0	.5	.3	.2	.3	.4	.1	.1	.1	.0	.0	.0	.0	.0	.0	.0	63	11
INDET	4.9	.2	.1	.3	.2	.1	.1	*	.1	*	*	*	.0	.0	.0	.0	.0	.0	.0	212	2
TOTAL	217	375	750	721	517	326	233	108	149	25	22	7	0	0	0	0	0	0	0	3450	5
PCT	6.3	10.9	21.7	20.9	15.0	9.4	6.8	3.1	4.3	.7	.6	.2	.0	.0	.0	.0	.0	.0	.0	100.0	

Table 5-8 Annual Normal Waves

Source: Summary of Synoptic Meteorological Observations
(U.S. Naval Weather Service Command, 1970)

PERIOD: (PRIMARY)
(OVER-ALL) 1963-1970

AREA 0004 CORDOVA
57N-COAST 140-146W

JANUARY

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	3.1	3.6	.0	.0	.0	.0	15
1-2	.0	6.7	7.6	.0	.0	.0	32
3-4	1.3	7.1	11.1	.0	.0	.0	44
5-6	.4	3.6	11.6	7.1	1.3	.0	54
7	.0	.4	2.2	5.8	.4	.0	20
8-9	.0	.4	4.0	3.1	3.6	.0	25
10-11	.0	.9	.9	3.6	2.2	.0	17
12	.0	.0	.4	.9	.4	.0	4
13-16	.0	.0	.4	1.8	2.2	.0	10
17-19	.0	.0	.0	.4	.0	.0	1
20-22	.0	.0	.0	.4	.4	.4	3
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	11	51	86	52	24	1	225
PCT	4.9	22.7	38.2	23.1	10.7	.4	100.0

FEBRUARY

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	3.4	2.3	.0	.0	.0	.0	10
1-2	1.1	5.1	2.3	.0	.0	.0	15
3-4	.0	7.4	12.5	2.3	.0	.0	39
5-6	.0	3.4	10.2	6.3	.0	.0	35
7	.0	.0	5.7	6.3	2.3	.0	25
8-9	.0	.0	2.8	5.7	2.8	.0	20
10-11	.0	.0	2.8	2.8	.0	.0	10
12	.0	.0	1.7	.0	.6	.0	4
13-16	.0	.0	.6	1.7	5.7	.6	15
17-19	.0	.0	.0	.0	.6	.0	1
20-22	.0	.0	.0	.0	1.1	.0	2
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	8	32	68	44	23	1	176
PCT	4.5	18.2	38.6	25.0	13.1	.6	100.0

MARCH

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	5.2	2.3	.0	.0	.0	.0	13
1-2	.0	5.7	2.3	.0	.0	.0	14
3-4	.6	8.6	14.4	1.1	.0	.0	43
5-6	.0	4.0	14.4	4.6	.0	.0	40
7	.6	.6	6.9	4.0	1.1	.0	23
8-9	.0	.6	4.0	5.7	2.3	.0	22
10-11	.0	.6	2.3	2.3	.6	.0	10
12	.0	.0	.6	2.9	.0	.0	6
13-16	.0	.0	.0	.6	1.1	.0	3
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	11	39	78	37	9	0	174
PCT	6.3	22.4	44.8	21.3	5.2	.0	100.0

APRIL

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	7.4	2.5	.0	.0	.0	.0	20
1-2	3.5	9.9	3.5	.0	.0	.0	34
3-4	.5	14.9	7.9	.5	.0	.0	48
5-6	.5	2.5	12.9	2.5	.0	.0	37
7	.0	2.5	9.4	4.0	.0	.0	32
8-9	.5	.5	1.0	3.0	1.0	.0	12
10-11	.0	.0	.0	2.0	1.0	.0	6
12	.0	.0	.5	2.0	1.0	.0	7
13-16	.0	.0	.5	.0	1.0	.0	3
17-19	.0	.0	.5	.0	.0	.0	1
20-22	.0	.0	.0	.0	.5	.0	1
23-25	.0	.0	.0	.0	.5	.0	1
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	25	66	73	28	10	0	202
PCT	12.4	32.7	36.1	13.9	5.0	.0	100.0

Table 5-9 Monthly Normal Waves

Source: Summary of Synoptic Meteorological Observations
(U.S. Naval Weather Service Command, 1970)

PERIOD: (PRIMARY)
(OVER-ALL) 1963-1969

AREA 0004 CORDOVA
57N-COAST 140-146W

MAY

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	10.0	10.8	.0	.0	.0	.0	52
1-2	.4	11.2	5.2	.0	.0	.0	42
3-4	.0	11.2	14.5	.4	.0	.0	65
5-6	.0	2.8	11.2	1.6	.4	.0	40
7	.0	2.0	2.0	4.0	.4	.0	21
8-9	.0	.8	1.6	1.6	.0	.0	10
10-11	.0	1.2	1.2	1.2	.0	.0	9
12	.0	.0	.4	.4	.8	.0	4
13-16	.0	.0	.8	.4	1.2	.0	6
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	26	100	92	24	7	0	249
PCT	10.4	40.2	36.9	9.6	2.8	.0	100.0

JUNE

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	6.0	16.8	.0	.0	.0	.0	57
1-2	1.2	16.8	7.2	.0	.0	.0	63
3-4	1.2	10.8	10.8	.4	.0	.0	58
5-6	.0	6.0	10.0	1.6	.0	.0	44
7	.0	.4	3.2	1.6	.0	.0	13
8-9	.0	.4	1.2	2.4	.0	.0	10
10-11	.0	.0	.4	.0	.0	.0	1
12	.0	.0	1.2	.0	.4	.0	4
13-16	.0	.0	.0	.0	.0	.0	0
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	21	128	85	15	1	0	250
PCT	8.4	51.2	34.0	6.0	.4	.0	100.0

JULY

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	4.9	7.1	.0	.0	.0	.0	32
1-2	3.4	15.4	6.4	.0	.0	.0	67
3-4	.8	18.4	15.0	.8	.0	.0	93
5-6	.4	4.9	11.3	3.4	.0	.0	53
7	.0	.4	3.0	1.5	.8	.0	15
8-9	.0	.0	.4	.4	.4	.0	3
10-11	.0	.0	.8	.4	.0	.0	3
12	.0	.0	.0	.0	.0	.0	0
13-16	.0	.0	.0	.0	.0	.0	0
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	25	123	98	17	3	0	266
PCT	9.4	46.2	36.8	6.4	1.1	.0	100.0

AUGUST

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	10.2	9.5	.0	.0	.0	.0	56
1-2	2.1	14.7	8.4	.0	.0	.0	72
3-4	.7	13.3	17.5	.4	.0	.0	91
5-6	.0	4.2	9.5	3.9	.0	.0	50
7	.0	.4	1.1	.7	.0	.0	6
8-9	.0	.0	.7	1.1	.0	.0	5
10-11	.0	.0	.0	.4	.0	.0	1
12	.0	.0	.0	.7	.4	.0	3
13-16	.0	.0	.0	.4	.0	.0	1
17-19	.0	.0	.0	.0	.0	.0	0
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	37	120	106	21	1	0	285
PCT	13.0	42.1	37.2	7.4	.4	.0	100.0

Table 5-9 Monthly Normal Waves (Cont'd)

PERIOD: (PRIMARY)
(OVER-ALL) 1963-1969

AREA 0004 CORDOVA
57N-COAST 140-146W

SEPTEMBER

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	3.3	6.6	.0	.0	.0	.0	27
1-2	1.1	10.3	4.1	.0	.0	.0	42
3-4	.4	13.3	16.2	3.7	.0	.0	91
5-6	.0	2.6	11.1	3.0	.0	.0	45
7	.0	.7	5.5	5.9	1.8	.0	38
8-9	.0	.0	.7	3.7	1.1	.0	15
10-11	.0	.0	.7	1.1	1.5	.0	9
12	.0	.0	.0	.4	.0	.0	1
13-16	.0	.0	.0	.0	.7	.0	2
17-19	.0	.0	.0	.0	.4	.0	1
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	13	91	104	48	15	0	271
PCT	4.8	33.6	38.4	17.7	5.5	.0	100.0

OCTOBER

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	5.2	4.3	.0	.0	.0	.0	33
1-2	.0	6.3	5.5	.3	.0	.0	42
3-4	.0	6.3	11.8	2.3	.0	.0	71
5-6	.3	.6	11.8	5.2	.3	.0	63
7	.0	.3	11.0	4.9	2.3	.6	66
8-9	.0	.0	3.5	2.9	1.2	.6	28
10-11	.0	.0	1.2	2.0	1.2	.0	15
12	.0	.0	.0	1.2	1.4	.3	10
13-16	.0	.0	.3	2.9	1.2	.6	17
17-19	.0	.0	.0	.0	.3	.0	1
20-22	.0	.0	.0	.0	.0	.0	0
23-25	.0	.0	.0	.3	.0	.0	1
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	19	62	156	76	27	7	347
PCT	5.5	17.9	45.0	21.9	7.8	2.0	100.0

NOVEMBER

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	4.1	4.7	.0	.0	.0	.0	30
1-2	.9	8.7	11.1	.0	.0	.0	71
3-4	.3	7.3	12.8	3.5	.0	.0	82
5-6	.0	2.6	9.6	4.1	.9	.0	59
7	.0	.6	5.2	6.1	1.5	.0	46
8-9	.0	.9	1.2	3.8	1.2	.0	24
10-11	.0	1.2	.6	.3	1.2	.0	11
12	.0	.3	.9	.6	.9	.0	9
13-16	.0	.0	.9	1.2	.3	.0	8
17-19	.0	.0	.0	.6	.0	.0	2
20-22	.0	.0	.0	.3	.0	.0	1
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	18	90	145	70	20	0	343
PCT	5.2	26.2	42.3	20.4	5.8	.0	100.0

DECEMBER

WIND SPEED (KTS) VS SEA HEIGHT (FT)

HGT	0-3	4-10	11-21	22-33	34-47	48+	TOTAL OBS
<1	1.8	5.0	.0	.0	.0	.0	15
1-2	.9	2.7	5.0	.0	.0	.0	19
3-4	.5	7.7	11.3	1.8	.0	.0	47
5-6	.0	8.1	9.9	2.7	.0	.0	46
7	.5	.5	7.7	3.6	1.4	.0	30
8-9	.5	.0	4.1	4.5	1.4	.0	23
10-11	.0	.5	2.3	1.8	2.3	.0	15
12	.5	.0	.9	.9	.5	.0	6
13-16	.0	.0	.5	2.7	2.7	1.4	16
17-19	.0	.0	.0	.0	.0	.5	1
20-22	.0	.0	.0	.9	.0	.9	4
23-25	.0	.0	.0	.0	.0	.0	0
26-32	.0	.0	.0	.0	.0	.0	0
33-40	.0	.0	.0	.0	.0	.0	0
41-48	.0	.0	.0	.0	.0	.0	0
49-60	.0	.0	.0	.0	.0	.0	0
61-70	.0	.0	.0	.0	.0	.0	0
71-86	.0	.0	.0	.0	.0	.0	0
87+	.0	.0	.0	.0	.0	.0	0
TOTAL	10	54	92	42	18	6	222
PCT	4.5	24.3	41.4	18.9	8.1	2.7	100.0

Table 5-9 Monthly Normal Waves (Cont'd)

JANUARY

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.1	6.8	8.4	10.6	3.0	2.7	3.0	.4	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	98	4
6-7	.0	.4	3.0	5.3	4.6	3.0	3.0	.8	1.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	58	7
8-9	.0	.0	2.7	1.9	4.6	4.9	2.7	.4	1.1	.8	1.5	.0	.0	.0	.0	.0	.0	.0	.0	54	8
10-11	.0	.0	.0	.4	2.7	1.5	2.3	1.1	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	22	8
12-13	.0	.0	.0	.0	1.1	.0	.4	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	8
>13	.0	.0	.0	.0	.0	.0	.4	.0	.4	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	4	16
INDET	7.2	.0	.4	.0	.4	.0	.0	.0	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	22	2
TOTAL	22	19	38	48	43	32	31	8	12	3	6	1	0	0	0	0	0	0	0	263	6
PCT	8.4	7.2	14.4	18.3	16.3	12.2	11.8	3.0	4.6	1.1	2.3	.4	.0	.0	.0	.0	.0	.0	.0	100.0	

FEBRUARY

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.5	2.4	11.4	4.3	4.3	4.3	.5	.0	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	4
6-7	.0	.5	1.4	7.1	2.8	.9	4.3	2.4	2.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	46	7
8-9	.0	.0	1.4	5.2	3.3	4.3	1.4	.9	1.4	.5	.9	.0	.0	.0	.0	.0	.0	.0	.0	41	8
10-11	.0	.0	.0	1.9	3.3	1.9	1.9	.0	2.8	1.9	.9	.0	.0	.0	.0	.0	.0	.0	.0	31	10
12-13	.0	.0	.0	.5	.9	1.4	.0	.9	.9	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	9
>13	.0	.0	.0	.0	.0	.5	.5	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	3	10
INDET	5.7	.0	.5	.9	.5	.0	.9	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	19	2
TOTAL	13	6	31	42	32	28	20	9	20	6	4	0	0	0	0	0	0	0	0	211	7
PCT	6.2	2.8	14.7	19.9	15.2	13.3	9.5	4.3	9.5	2.8	1.9	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

MARCH

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.4	2.3	12.8	11.5	1.4	4.1	1.8	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	78	4
6-7	.0	.0	4.6	1.4	4.1	4.6	3.2	1.8	1.8	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	49	7
8-9	.0	.5	1.4	3.2	6.4	5.5	3.2	.9	1.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	50	7
10-11	.0	.0	.0	.5	1.4	1.4	2.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	13	8
12-13	.0	.0	.0	.5	.5	.9	.0	.5	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6	8
>13	.0	.0	.0	.0	2.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	7
INDET	7.3	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	17	0
TOTAL	19	6	41	38	35	36	24	7	10	2	0	0	0	0	0	0	0	0	0	218	6
PCT	8.7	2.8	18.8	17.4	16.1	16.5	11.0	3.2	4.6	.9	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

APRIL

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.8	5.5	12.6	9.8	3.5	2.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	88	4
6-7	.0	.8	5.5	8.7	5.9	2.4	2.0	1.2	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	68	5
8-9	.0	.0	.4	2.4	5.5	1.6	.8	2.0	1.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	36	8
10-11	.0	.4	.0	.8	2.4	.4	.4	.0	.4	.4	.0	.4	.0	.0	.0	.0	.0	.0	.0	14	9
12-13	.0	.0	.0	1.2	.0	.4	1.2	.0	1.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	10
>13	.0	.0	.0	.0	.8	.4	.0	.0	.4	.8	.4	.0	.0	.0	.0	.0	.0	.0	.0	7	12
INDET	10.6	.4	.0	.0	.4	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	30	0
TOTAL	29	18	47	58	47	18	12	9	11	3	1	1	0	0	0	0	0	0	0	254	5
PCT	11.4	7.1	18.5	22.8	18.5	7.1	4.7	3.5	4.3	1.2	.4	.4	.0	.0	.0	.0	.0	.0	.0	100.0	

Table 5-9 Monthly Normal Waves (Cont'd)

MAY

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	4.1	10.5	16.9	10.5	3.4	.3	.7	.0	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	139	3
6-7	.3	.7	5.4	6.8	3.4	1.7	.7	.3	1.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	61	5
8-9	.0	.3	2.4	4.4	2.7	1.0	1.0	1.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	39	6
10-11	.0	.0	.3	.0	.0	1.7	1.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	8
12-13	.0	.0	.0	2.0	.0	.0	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	6
>13	.0	.0	.0	.0	.7	.3	.0	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	9
INDET	9.8	.0	.3	.3	.0	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	32	0
TOTAL	42	34	75	71	30	15	13	6	8	1	0	0	0	0	0	0	0	0	0	295	4
PCT	14.2	11.5	25.4	24.1	10.2	5.1	4.4	2.0	2.7	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

JUNE

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.9	12.1	13.9	8.8	1.5	1.5	.4	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	113	3
6-7	.0	3.3	9.9	6.6	3.7	2.9	1.5	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	78	4
8-9	.0	1.1	7.0	3.7	1.5	.7	1.5	1.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	47	5
10-11	.0	.7	1.1	.4	1.5	2.9	1.1	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	23	7
12-13	.0	.4	.0	.0	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	5
>13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	
INDET	2.6	.0	.4	.4	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	10	1
TOTAL	15	48	88	54	22	24	12	10	0	0	0	0	0	0	0	0	0	0	0	273	4
PCT	5.5	17.6	32.2	19.8	8.1	8.8	4.4	3.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

JULY

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	2.3	11.0	22.7	9.0	2.3	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	143	3
6-7	.0	2.7	5.0	6.0	4.3	.7	1.7	.7	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	64	5
8-9	.0	.7	3.3	5.0	1.3	1.7	2.0	.7	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	45	6
10-11	.0	.7	3.0	1.0	2.0	.7	.3	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	25	5
12-13	.0	.0	.0	1.7	.0	.3	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	8	6
>13	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0	
INDET	4.3	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	15	0
TOTAL	20	46	103	68	30	10	15	5	3	0	0	0	0	0	0	0	0	0	0	300	4
PCT	6.7	15.3	34.0	22.7	10.0	3.3	5.0	1.7	1.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

AUGUST

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	1.6	15.4	14.1	9.3	.3	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	129	3
6-7	.0	3.2	7.7	8.0	4.2	2.3	.0	.3	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	82	4
8-9	.0	1.6	7.1	3.2	2.6	1.9	.6	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	57	5
10-11	.0	.6	1.0	.6	.6	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	5
12-13	.0	.0	.0	.6	1.0	1.0	1.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12	7
>13	.0	.0	.0	.0	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	2	7
INDET	5.8	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	18	0
TOTAL	23	65	93	68	28	20	7	5	2	0	0	0	0	0	0	0	0	0	0	311	4
PCT	7.4	20.9	29.9	21.9	9.0	6.4	2.3	1.6	.6	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

Table 5-9 Monthly Normal Waves (Cont'd)

SEPTEMBER

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.3	9.3	9.0	7.7	2.3	1.3	.3	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	92	3
6-7	.0	2.7	6.3	7.7	5.0	5.7	2.0	.7	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	92	5
8-9	.0	.3	1.7	3.7	9.3	2.7	1.3	.3	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	60	6
10-11	.0	.0	.3	2.0	4.0	.7	3.0	.3	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	33	7
12-13	.0	.0	.0	1.3	.7	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	7	7
>13	.0	.0	.0	.0	.7	.3	.0	.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	9
INDET	2.3	.3	.0	.0	.0	.7	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	11	2
TOTAL	8	38	52	67	66	34	21	5	7	2	0	0	0	0	0	0	0	0	0	300	5
PCT	2.7	12.7	17.3	22.3	22.0	11.3	7.0	1.7	2.3	.7	.0	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

OCTOBER

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.8	9.1	12.2	6.5	4.9	.8	.0	.5	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	136	4
6-7	.0	.8	3.9	5.7	7.0	4.7	2.3	.8	3.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	109	7
8-9	.0	.8	2.1	4.9	2.6	2.6	1.8	2.1	1.6	.3	.3	.5	.0	.0	.0	.0	.0	.0	.0	75	8
10-11	.0	.5	.0	1.6	.3	.8	1.0	1.6	2.3	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	33	10
12-13	.0	.0	.0	.3	1.6	.3	.8	.3	.5	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	15	9
>13	.0	.0	.0	.0	1.0	.8	.5	.3	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	12	9
INDET	.3	.0	.0	.0	.5	.0	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	5	8
TOTAL	4	43	70	73	69	38	25	21	35	2	3	2	0	0	0	0	0	0	0	385	6
PCT	1.0	11.2	18.2	19.0	17.9	9.9	6.5	5.5	9.1	.5	.8	.5	.0	.0	.0	.0	.0	.0	.0	100.0	

NOVEMBER

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.5	9.0	17.7	8.2	4.0	1.3	.3	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	155	3
6-7	.0	.5	1.8	8.7	6.9	3.7	2.6	1.3	.5	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	100	6
8-9	.0	.0	1.8	3.7	4.0	3.2	1.8	.8	.3	.8	.3	.0	.0	.0	.0	.0	.0	.0	.0	63	7
10-11	.0	.5	.0	.8	2.1	.5	.8	.5	1.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	24	8
12-13	.0	.0	.0	.3	.8	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	6	7
>13	.0	.0	.0	.0	.3	.3	.0	.8	1.3	.0	.0	.5	.0	.0	.0	.0	.0	.0	.0	12	14
INDET	3.4	.8	.0	.3	.0	.3	.0	.0	.0	.0	.3	.0	.0	.0	.0	.0	.0	.0	.0	19	2
TOTAL	15	41	81	83	68	35	23	13	12	3	2	3	0	0	0	0	0	0	0	379	5
PCT	4.0	10.8	21.4	21.9	17.9	9.2	6.1	3.4	3.2	.8	.5	.8	.0	.0	.0	.0	.0	.0	.0	100.0	

DECEMBER

PERCENT FREQUENCY OF WAVE HEIGHT (FT) VS WAVE PERIOD (SECONDS)

PERIOD (SEC)	<1	1-2	3-4	5-6	7	8-9	10-11	12	13-16	17-19	20-22	23-25	26-32	33-40	41-48	49-60	61-70	71-86	87+	TOTAL	MEAN HGT
<6	.4	2.7	6.9	8.4	3.4	1.9	.8	.4	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	66	4
6-7	.0	1.1	2.7	6.1	6.1	4.6	2.3	1.1	4.6	.0	.8	.0	.0	.0	.0	.0	.0	.0	.0	77	8
8-9	.0	.4	1.5	3.4	6.5	5.0	5.0	.4	3.8	.8	.4	.0	.0	.0	.0	.0	.0	.0	.0	71	8
10-11	.0	.0	.0	.4	1.5	1.5	1.9	.8	1.1	.4	.4	.0	.0	.0	.0	.0	.0	.0	.0	21	10
12-13	.0	.0	.4	.0	.0	.0	.4	.0	.4	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	4	12
>13	.0	.0	.0	.0	.0	.4	.8	1.1	.4	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	8	11
INDET	2.3	.0	.4	1.1	.4	.4	.4	.0	.4	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	14	4
TOTAL	7	11	31	51	47	36	30	10	29	3	6	0	0	0	0	0	0	0	0	261	7
PCT	2.7	4.2	11.9	19.5	18.0	13.8	11.5	3.8	11.1	1.1	2.3	.0	.0	.0	.0	.0	.0	.0	.0	100.0	

Table 5-9 Monthly Normal Waves (Cont'd)

analysis of various factors including human safety, environmental risk, and economics. They should therefore, not be chosen arbitrarily. For mobile units the design return periods may be much shorter, say 15 to 25 years, since the operational periods of these units in any one location is relatively short.

The subsequent analysis reviews and evaluates recent studies which have attempted to estimate extreme winds and waves for the Gulf of Alaska. In addition, an independent analysis of ocean weather ship measurements has been performed to supplement the results. The results of these reviews and analysis are summarized in the following paragraphs. Where appropriate, more extensive critical reviews are provided in the Appendices of this report.

5.3.6.1 Review of Past Studies

Several studies have been reported in the recent past which have included estimates of extreme winds and waves for the Gulf of Alaska. Five of these reports have been reviewed critically. They include the results of Thom (1971, 1973a, b), the Tetra Tech study (1974), Freeman and Bujnoch (1976), Fallon et al (1973), and Quayle and Fulbright (1975). These reviews are summarized below. More detailed criticism is provided in the Appendices.

5.3.6.2 Extreme Wave Data

Results of extreme wave studies by Thom (1971, 1973a, b), Fallon et al (1973), Tetra Tech (1974), and Quayle and Fulbright (1975) are shown in Figure 5-11. The Freeman and Bujnoch (1976) results are shown in Table 5-10.

The Tetra Tech report credits their results to NOAA and states that they were calculated using the methods of Thom (1971, 1973a, b). The results of Quayle and Fulbright are also based on Thom's work. Therefore, an analysis of Thom's methodology for estimating extreme wind velocities and wave heights is appropriate to three of the four sets of data given in Figure 5-11 (Thom, Tetra Tech, Quayle and Fulbright).

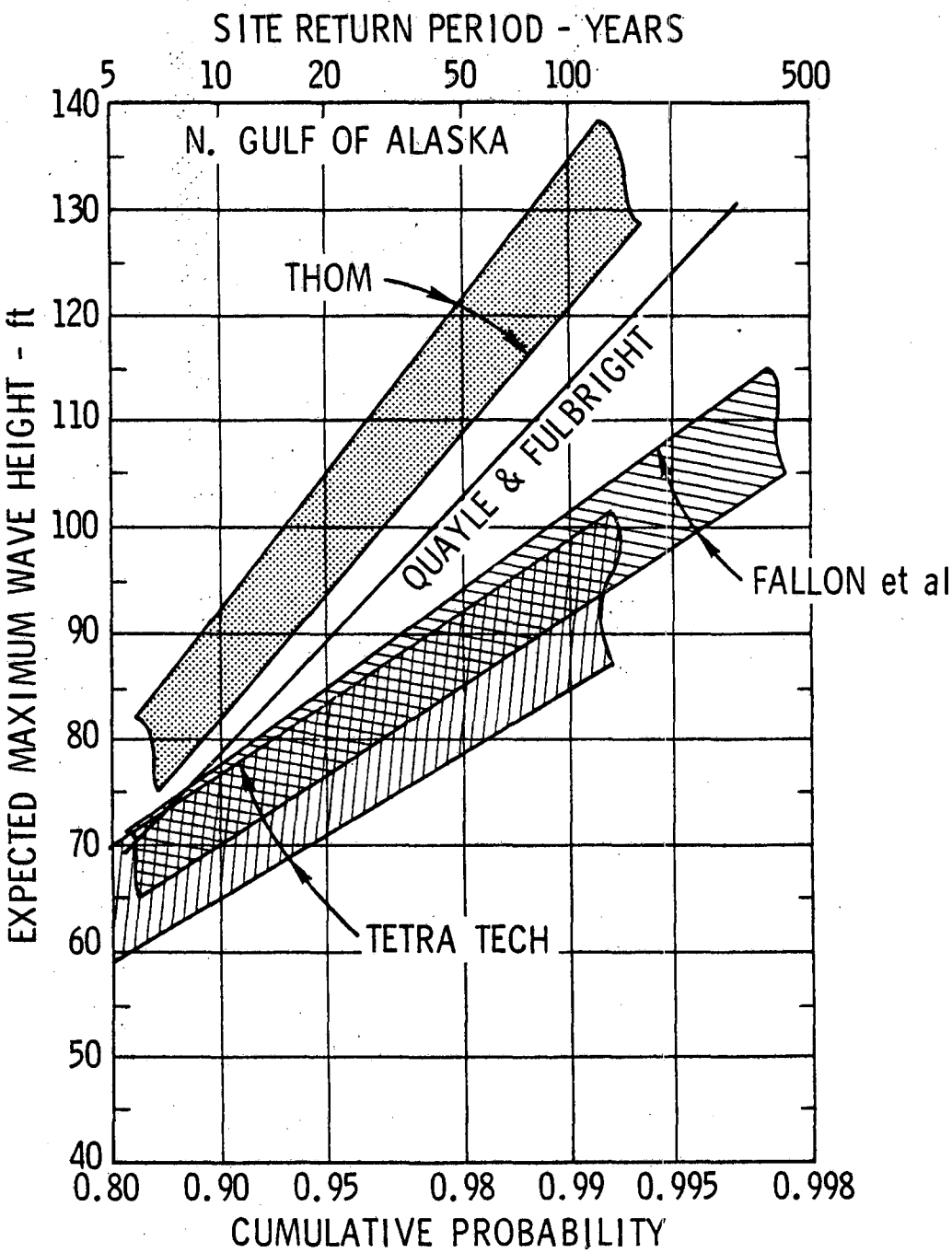


Figure 5-11 Comparison of Extreme Wave Height Studies

Table 5-10 Return Periods for Extreme Waves in the Gulf of Alaska

Source: Freeman and Bujnoch, 1976

Return Period (Years)	Significant Wave Height (ft)	Maximum Wave Height (ft)
10	73.4	136.5
25	88.6	164.8
50	97.4	181.2
100	106.5	198.1

This analysis is given in Appendix B. It is concluded that while the methods devised by Thom for estimating extreme winds are acceptable and likely to be useful, the adequacy of his methods relative to extreme wave estimation is of doubtful reliability. The basic shortcoming of this method is that it attempts to relate extreme wave distribution to extreme wind distribution through a single constant. This must be considered an oversimplification of the complex physics of wave generation, propagation and dissipation. Until Thom's methods are verified with measured over ocean wind data, their reliability must remain in serious question.

With respect to the extreme wave estimates of Quayle and Fulbright (1975) the following comments should be considered. First, their basic methodology is that of Thom, which as discussed above, is of doubtful reliability. Furthermore, the authors refer to arbitrary manipulations of the data set without providing sufficient justification. For example, the type of extreme value distribution is presupposed (i.e., Frechet) and its parameters estimated from the data. This approach is an oversimplification since an evaluation of the correct distribution is called for. In other words, the data may have been fit with various possible extreme value distributions and the best fit selected using standard statistical procedures. Also the statement "adjustments have been made to compute wave extremes when they appear inconsistent with the wave climatology of the area or adjacent areas", implies a procedure which is antithetical to extreme value analysis.

In comments submitted to the Mariners Weather Log (Unpublished), Bea finally has seriously questioned the results of Thom, Quayle and Fulbright. Bea points out that "...the authors should characterize the reliability of their wind-wave relationships with measured and observed data if their results are to have meaning and credibility." Bea demonstrates significant discrepancies when the results of these authors are compared with hindcast results of demonstrated reliability.

The work of Freeman and Bujnoch (1976) forecasting extreme wave heights for the Gulf of Alaska has generated considerable controversy in the offshore

industry and therefore deserves some critical attention. A brief review of this work appears in Appendix C. The basic thrust of these comments are as follows: (1) the hindcast method used is not documented and its applicability to the Gulf of Alaska has not been demonstrated (as have other hindcast models applied in areas such as the Gulf of Mexico); (2) the screening of severe storms through subjective evaluation could have seriously biased the results; and (3) the visual estimates of extreme wave heights (reports of crab boat and tug boat captains "seeing" 100 foot waves) have little credibility. It appears that Freeman's estimate of 198.1 ft wave with a return period of 100 yrs should be disregarded unless considerably better substantiation for its validity can be provided.

The final set of data reviewed for this report are those given in an industry report by Fallon et al (1973). While it is surmised that the results of the study have the most valid scientific basis it was not possible to do a thorough critical review because the data used to validate the hindcast program and the description of the extreme value statistical analysis are held proprietary by the consortium of offshore operators which sponsored the study. Only the final report summarizing results is in the public domain. Nevertheless, some information is available which permits a tentative conclusion to be drawn with regard to validity and usefulness of the extreme wave data reported therein. First the LOCWAV hindcast program utilized to generate the historical wave data for the extreme value analysis is described in a paper given at the Offshore Technology Conference 1970, by Baer, et al. This paper demonstrates that the program uses recognized techniques for wave growth and dissipation, and was validated with measured wave data for the North Atlantic. Second, the comments of Bea (unpublished) on these results are available. Bea had access to the wave data used to calibrate the LOCWAV program for the Gulf of Alaska and had the opportunity to analyze these data. In his opinion, the model has an unconservative bias of 10-15%. Bea (personal communication) has also stated that he compared hindcast waves of the LOCWAV model with

measured wave data from four severe storms at two locations in the North Atlantic and found the same unconservative bias of 15%. Thus Bea is satisfied that the hindcasts made with this model are consistent and are satisfactory if the unconservative bias is removed. The estimate then is that the maximum wave height with a 100 year return period of 100 feet forecast in the Fallon et al study (1973) should be increased to 115 ft.

5.3.6.3 Extreme Value Analysis of Gulf of Alaska Wave Data

The previous report in this series (March 1977) included extreme value analysis of three sets of data: 1) ship observations from the TDF-11 files maintained by the National Climatic Center in Asheville, N.C., 2) hindcast data from the Spectral Ocean Wave Model (SOWM), and 3) OSV PAPA. It was shown that analysis of the NCC data predicted values for extreme wave heights in the Gulf of Alaska which were low by about 20%, compared to hindcast results. A "fair weather bias" probably exists and it was concluded that this data source was not appropriate for extreme value analysis. Therefore these results have been deleted from this issue.

Hindcast storm wave data from nine winter seasons, 1968-1969 through 1976-1977, were available for this report. While this is still a relatively short data base, the results from extreme value analysis for three Gulf of Alaska grid points appear to be coming more and more consistent. Moreover, the hindcast results for the grid point near Ocean Station Vessel PAPA now appear to be consistent with measured wave data from Canadian weather ships at that station. As in the previous report, the locations of these grid points were 59.2°N, 145.7°W near Middleton Island, 56.8°N, 141.9°W about 150 nmi off Icy Bay and 50.9°N, 145.7°W near OSV PAPA.

The technique used in the extreme value analysis was that due to Gumbel (1954) and described in detail in Appendix A. In this analysis the maximum significant wave height for each month of the winter seasons of 1968-1969 through 1976-1977 were used. A restriction that these significant wave heights must be greater than 30 ft. was applied. This restriction, while somewhat arbitrary, is consistent with the notion of fitting an extreme value distribution to the data. The wave heights used should be extremes. Admitting lower values to the analysis would result in poorer correlation due to non-linearities and bias the slopes of the fitted curves toward higher values. The average number of events per year, λ, was about 5, corresponding to the five stormiest months per year. Maximum wave heights

were obtained by the transformation due to Longuet-Higgins (1952):

$$H_{max} = 1.86\ \bar{H}_{1/3}$$

The maximum wave height data were then plotted on probability paper corresponding to a Gumbel distribution as given by equation A-4 in Appendix A. These plots are shown in Figures 5-12 through 5-15. Straight lines were fit to the data using linear regression and the corresponding correlation coefficient, r, was computed for each plot. As evidenced by the high correlation coefficients ($r \geq .93$ in all cases), the fits appear to be quite good.

The curves have been extrapolated to 25 and 50 year return periods. This extrapolation is long considering the length of the data base but the excellent correlation and the lack of significant changes from previous extrapolations for two grid points which were based on a 3 year data base have encouraged this. Also, the results for the grid point near OSV PAPA have changed in a manner which appears to be more consistent with its location. These results are summarized in Table 5-11. Both open ocean locations show very comparable values for 25 and 50 year return periods. The third point, considerably nearer the coastline, apparently experiences some sheltering effect where extreme wave heights are approximately 10% lower.

Table 5-11. Summary of Estimated Extreme Wave Heights for the Gulf of Alaska Area

Data Source	Location	Return Period (yr)	Wave Height (ft)
SOWM, 1968-1977	59.2°N, 145.7°W *	25	99
		50	105
	56.8°N, 141.9°W	25	108
		50	113
	50.9°N, 145.7°W	25	111
		50	118
OSV PAPA (Dec 68-Dec 70)	50.0°N, 145°W	25	109

*Near shore location (Middletown)

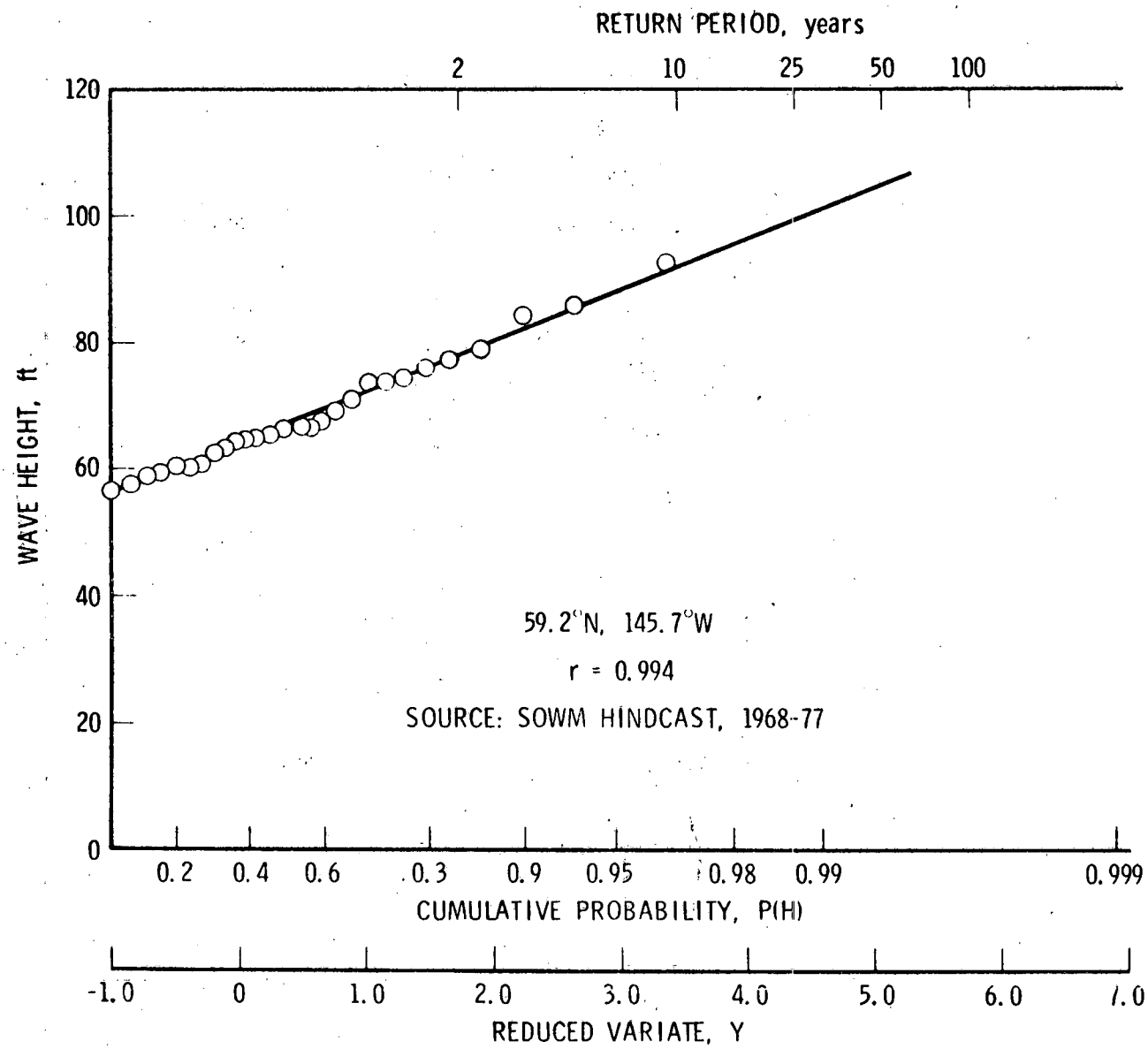


Figure 5-12. Extreme Wave Heights, 59.2°N, 145.7°W

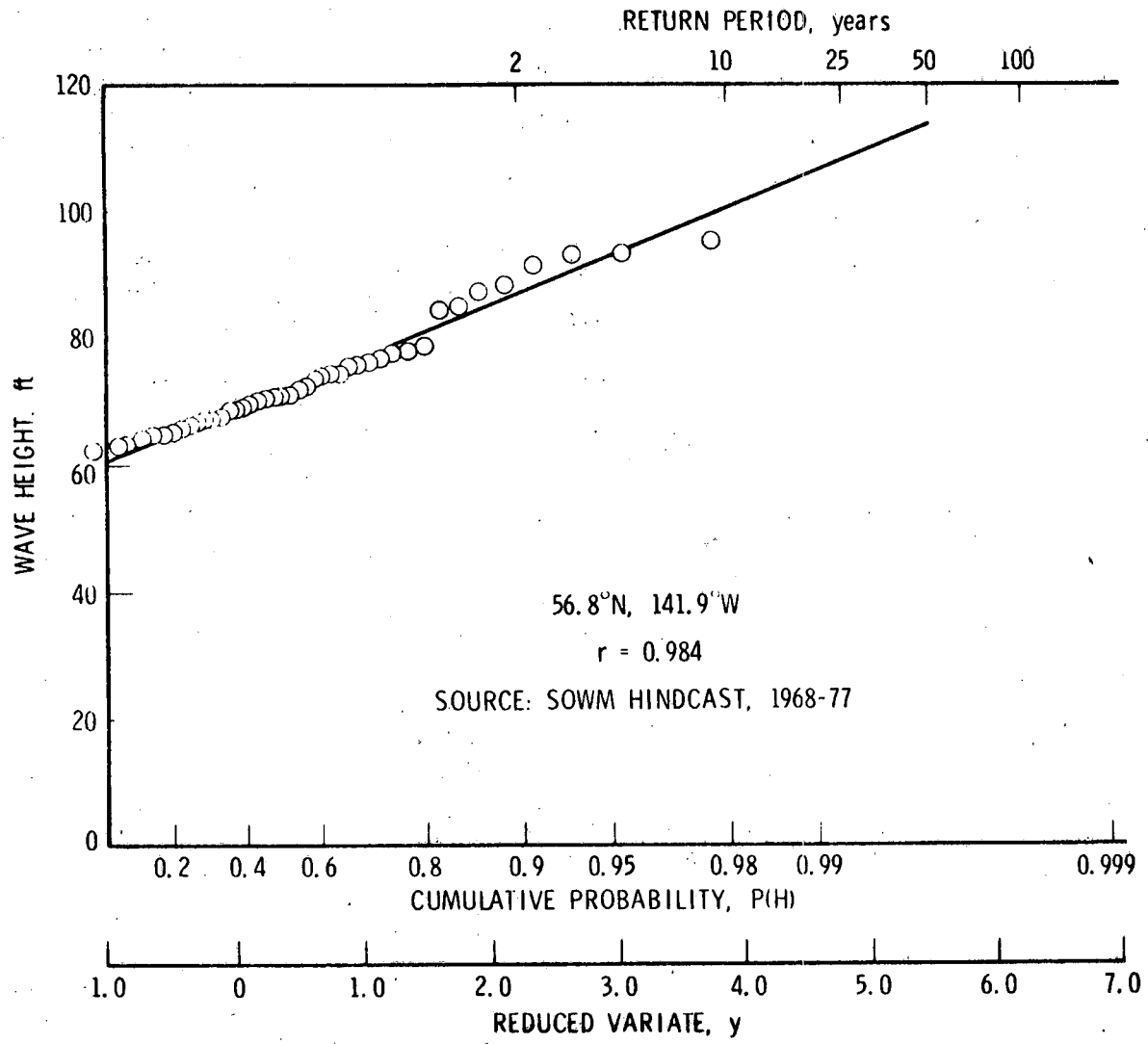


Figure 5-13. Extreme Wave Heights, 56.8°N, 141.9°W

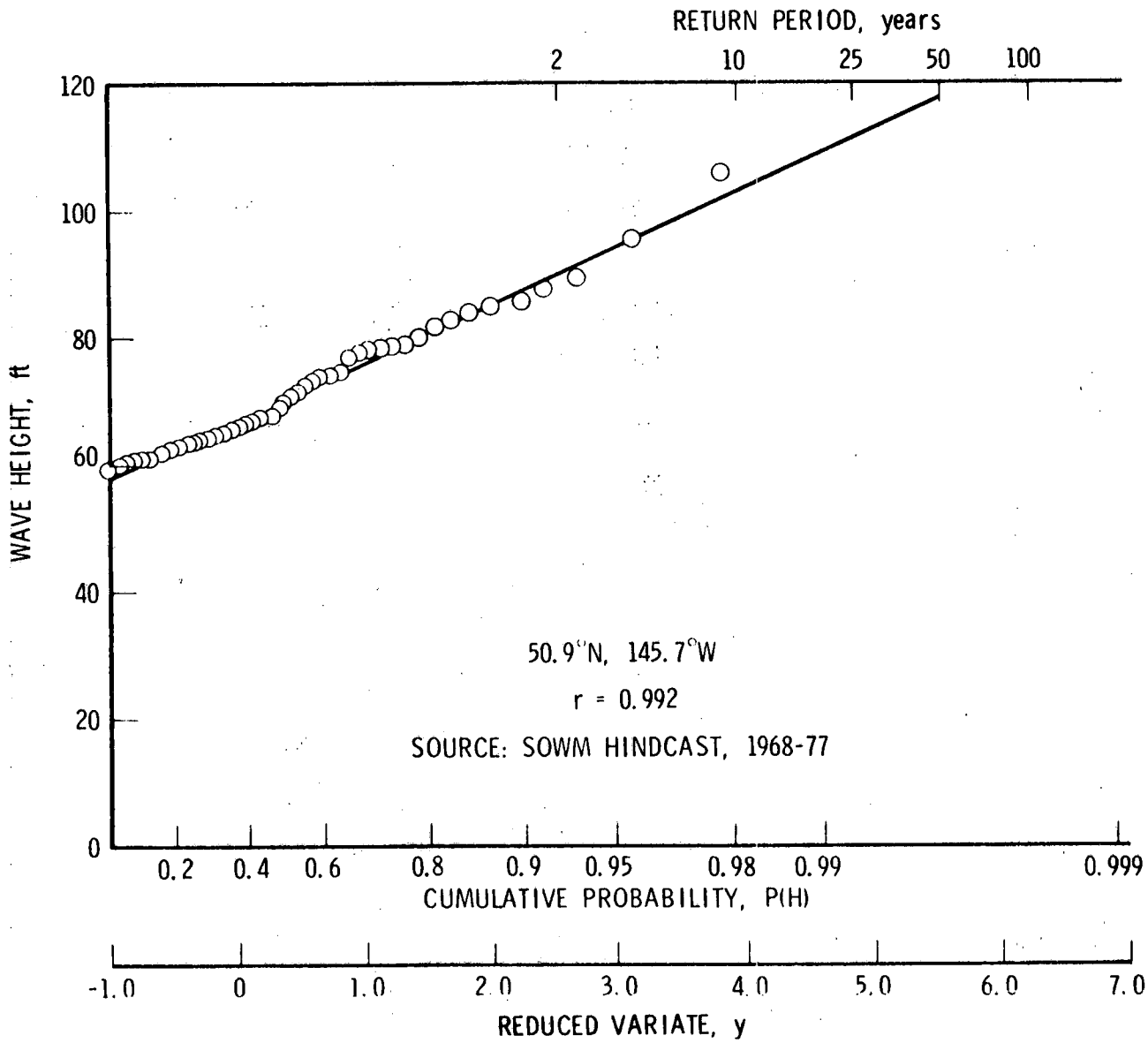


Figure 5-14. Extreme Wave Heights, 50.9°N, 145.7°W

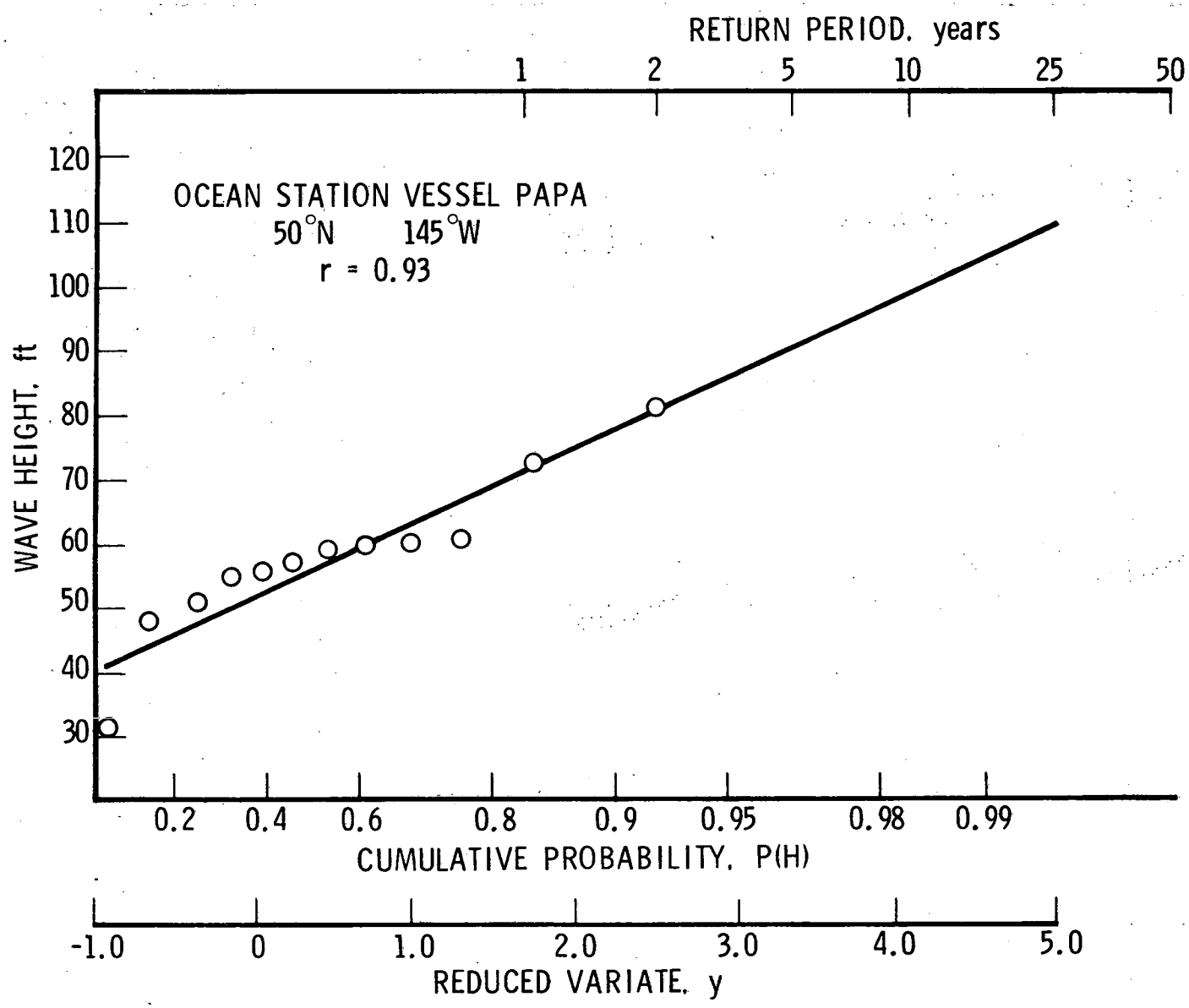


Figure 5-15 Extreme Wave Heights, OSV PAPA

5.3.6.4 Extreme Wind Data

Estimates of the extreme wind distribution for the Gulf of Alaska have been given by Tetra Tech (1974), Quayle and Fulbright (1975), and the petroleum study industry (Fallon et al, 1973). These estimates are shown in Fig. 5-16. The Tetra Tech and Quayle and Fulbright data are identical. Since the source of the Tetra Tech data was NOAA, it appears likely that they are also the work of Quayle and Fulbright. In any case, the former two estimates are straight forward applications of the wind distribution developed by Thom for long histories of measured maximum winds at stations in the United States and later found to suitably describe extratropical marine winds (Thom, 1973). The "extreme wind" fit by Thom to the Frechet distribution refers to the "fastest mile", though the fastest "minute" wind (highest one minute average) appears to be used interchangeably. Routinely available marine measurements consist of 1 minute average winds available once per hour. Thom estimates that such winds are lower than fastest mile winds by about 10 mph. Quayle and Fulbright (1975) note that peak gusts average about 1.4 times the fastest mile (minute).

As noted in the earlier discussion of Thom's work, the wind distribution should be transferrable to the measured environment, and in the absence of a long history of measured wind data, should provide a useful design wind estimate.

The distribution of extreme winds for the Fallon et al, (1973) study was derived in a hindcast study of 80 storms over a 23 year period from 1945 to 1968 from which 30 storms having the highest winds were studied in detail. For each storm, surface air pressure charts were analyzed to compute the maximum geostrophic wind ("winds aloft"). This pressure gradient derived wind is then reduced to a surface wind through the application of empirical relationships derived to yield the average wind at a height of 19.5 meters (Thomasell and Welsh, 1963 Travelers Research Center Report 2040-88). Such winds are typically representative of

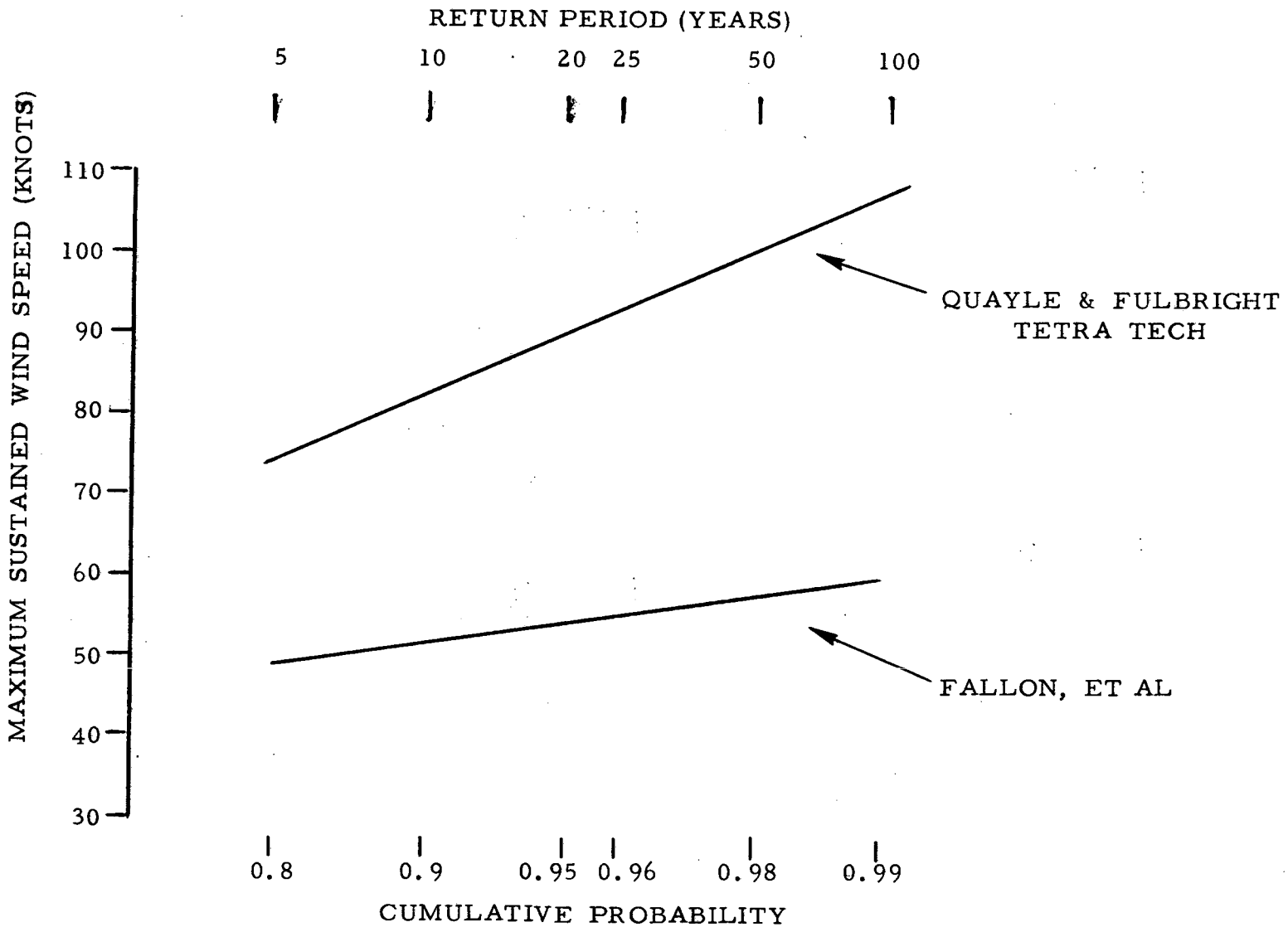


Figure 5-16. Comparison of Extreme Wind Studies

considerably longer time scales than the fastest mile or minute winds. In fact, such winds should average out nearly all turbulent scales and represent the true synoptic scale flow; that is, the wind averaged over a time scale of 1-6 hours and areas of the scale of $10^4 km^2$. Thus the distribution is <u>not</u> comparable with the distributions derived from Thom's distribution, but neither is it inconsistent.

The apparent disagreement in maximum sustained wind velocities estimated using Thom's method and the estimate given in the Fallon et al report (1973) may be explainable on the basis of averaging time. The choice of a wind velocity for purposes of estimation of a maximum quasi-static load for design purposes should probably be based on the shorter averaging time since it is apparent that such high wind velocities are possible and that one minute is considerably longer than the natural period of typical offshore structures ($\cong$3-5 seconds).

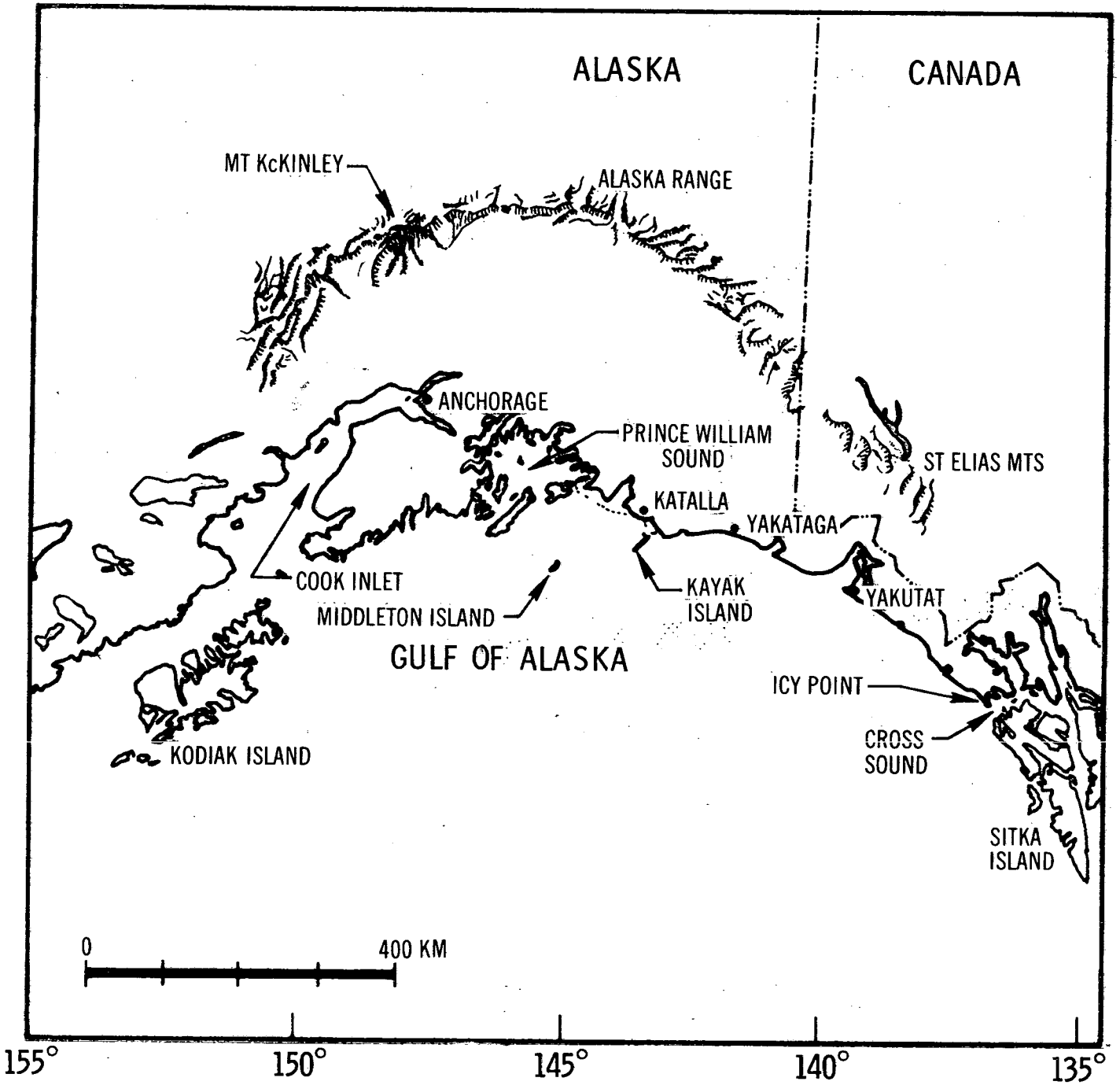


Figure 5-17. Gulf of Alaska

5.3.7 Shallow Water Wave Effects

5.3.7.1 Introduction

A numerical analysis of wave refraction was performed as part of a preliminary assessment of shallow water wave effects in the northeastern Gulf lease area. This work was undertaken in order to obtain an understanding of changes which occur in both wave height and direction as waves move from deep water into the shallower waters of the continental shelf where the lease tracts are located. The study described below includes only a consideration of the refraction and shoaling effects. Other shallow water modifications such as bottom dissipation, nonlinear effects, and wave breaking are still in the process of being analyzed. The results described herein are therefore only tentative.

The study boundaries include an area covering (roughly) from $59^{\circ}30'$ N to 60°N and from $141^{\circ}40'$ W to $144^{\circ}20'$W. Figure 5-18 is a chart of the study area which is numerically annotated to show groupings of contiguous tracts. All of the presently leased tracts in the northeastern Gulf region were included in the study. The chart also shows a rectangular zone which is denoted the "Pamplona Spur Area". This area was singled out for a more detailed analysis because of an elevated bottom feature which suggested that refraction effects might be pronounced for waves crossing the area.

5.3.7.2 Method of Analysis

The numerical refraction analysis was performed by Dr. Y.Y. Chao using two computer programs based on the methods reported in the literature (Chao, 1972 and Chao, 1971).

The first program computes wave refraction using conventional methods based on Snell's Law. It performs the calculation of all relevant parameters along an individual ray associated with a given wave period, initial direction and starting point. The equations employed in the calculation of the ray path and the energy intensity along the ray take into account

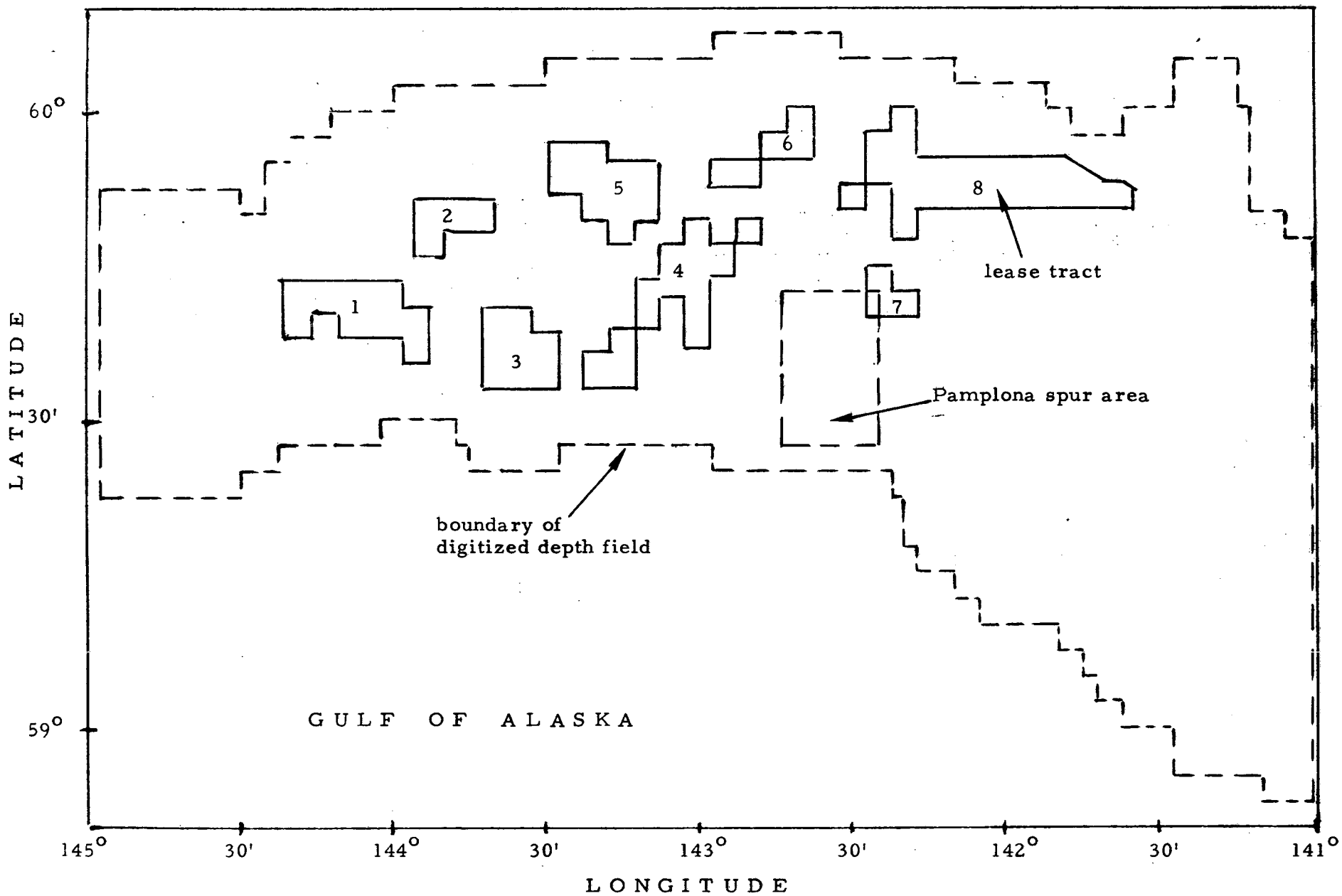


Figure 5-18. Contiguous Lease Tracts, Eastern Gulf of Alaska

the combined effects of bottom configuration and the curved earth surface and can be applied directly on the longitude and latitude coordinates as described by Chao (1972).

The second program is designed to overcome the inadequacies in conventional theory for treating refraction at caustic points, i.e. points where wave rays cross each other. This theory was developed by Chao (1971) and is a major breakthrough in refraction theory. The output of this program includes the shoaling factor, refraction coefficient, wave amplification factor, wave length, wave separation factor, phase velocity and group velocity as a function of latitude, longitude and distance along a wave ray.

The depth grid required as an input to these programs was based on the bathymetric chart NOS 1513N-10 for areas between 141°W and 144°W and a chart prepared by Molina and Carlson (1975) west of 144°W. The normal grid interval utilized in this analysis was 2.5 minutes of arc in both longitude and latitude (about 1.25 nmi in the east-west direction and 2.5 nmi in the north-south direction) the grid size was chosen based on availability of depth information given in the bathymetric charts. Because of the rapid change in depth in the Pamplona Spur Area, a grid size of 0.5 minutes of arc was chosen for this particular area.

Thirty-six cases were analyzed for this study corresponding to wave periods of 12.0, 12.9, 13.8, 15.0, 16.4, 18.0, 20.0, 22.5 and 25.7 seconds and azimuths of wave propagation of 330°, 0°, 30° and 60°. The azimuth of propagation is defined as the forward direction of propagation measured clockwise from north.

5.3.7.3 Results

Computer printouts of wave amplication factor and wave turning for all thirty-six cases are given in Appendix G. Of major concern was the identification of areas where significant wave amplification might take place and which should be taken into account in structural design. Two

such areas have been tentatively identified. Site 1 (see Figure 5-18) from its center to its west boundary will experience wave amplification of about 25 to 55% for 20 sec period waves on initial azimuths of 60°. For periods of 22.5 sec, amplification of 20 to 30% will occur near the west boundary of this area.

Site 8 is an area which will likely require precautions with regard to wave amplification. Amplification occurs for wave periods ranging from 16.4 seconds to 25.7 seconds and initial azimuths of 0, 30 and 60°. Amplification can be as high as 60 to 100% in the eastern portion of the area. A substantial increase in the wave height can also be found for the wave periods of 25.7 and 22.5 sec with an initial azimuth of 330°. For wave periods of 20 sec or less on this azimuth and initiated from areas where depth data is available, waves are not refracted enough to cause problems. Depth data further to the east and south were not available to check whether or not shorter period waves initiated further to the east and south could cause problems.

It should be emphasized that the information presented on shallow water effects is not yet complete because effects of bottom friction and particularly wave breaking, have not yet been fully analyzed. Moreover, the periods of hindcast deep water waves have not been analyzed to determine if such problem waves are likely to occur. Furthermore, it is quite possible that shallow depths may cause deep water waves with extreme heights and periods to break before they are amplified significantly. Calculation of such effects is being carried out and will be reported.

5.4 Wave Spectral Data

5.4.1 Spectral Ocean Wave Model (SOWM)

Figure 5-19 is a flow chart which depicts the major elements of input, output and operations of the SOWM. This program is being used to generate the long term wave climatology data base which is the major source of wave data for Task I of the present contract.

This program was developed through the cooperative efforts of the U.S. Naval Oceanographic Office, the U.S. Navy Fleet Numerical Weather Central (FNWC) in Monterey, California and the New York University. It is now in operation at FNWC as a global spectral wave prediction program forecasting wave conditions twice daily in the North Pacific and North Atlantic Oceans, and is also used to hindcast 20 year wave climatology for use in ship design. This 20 year hindcast is being carried out under the auspices of FNWC. The U.S. Navy Ship Research and Development Center, Carderock, Md., has contributed to the development of the 20 year wind climatology that is being used as input to SOWM. The Aerospace Corporation is participating by providing the consulting services of Mr. Sheldon Lazanoff for the operation of the program at FNWC and will apply the data generated to needs of the USGS.

The basic input to the program is surface wind fields such as those depicted schematically in Figure 5-20. These wind fields have been generated in turn from surface pressure fields such as shown in Figure 5-21. Geostrophic winds are computed from the equations of motion and corrected appropriately for effects of the planetary boundary layer. Both surface pressure data and the resulting surface wind fields are upgraded by incorporation of observed data from weather ships and other vessels in the local area. Direction is computed from the frictional velocity which is the necessary input to the basic source function for wave energy. The function is based on the theories of Miles and Phillips and is described in detail by Inoue (1967). Local wave energy growth is limited as a function of wind velocity, duration and fetch by comparison to a Pierson-Moskowitz spectrum to determine if a fully developed sea state exists. The components of wave energy for 15 frequencies and 12 directions at each grid point are based on local wind velocity. In addition to local energy generation, wave energy propagated from all other generating points is added for each element of the energy matrix.

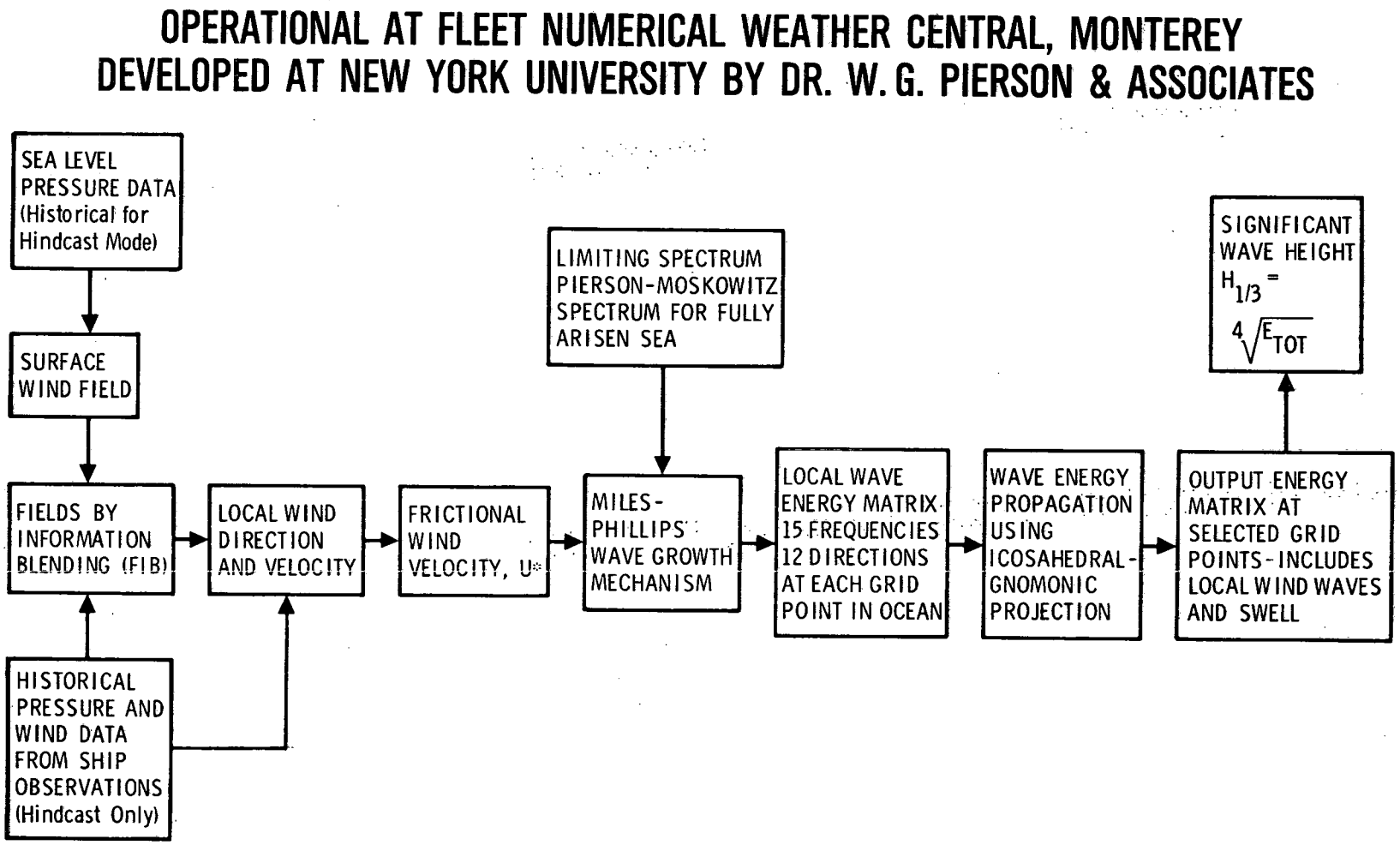


Figure 5-19 Spectral Ocean Wave Model (SOWM)

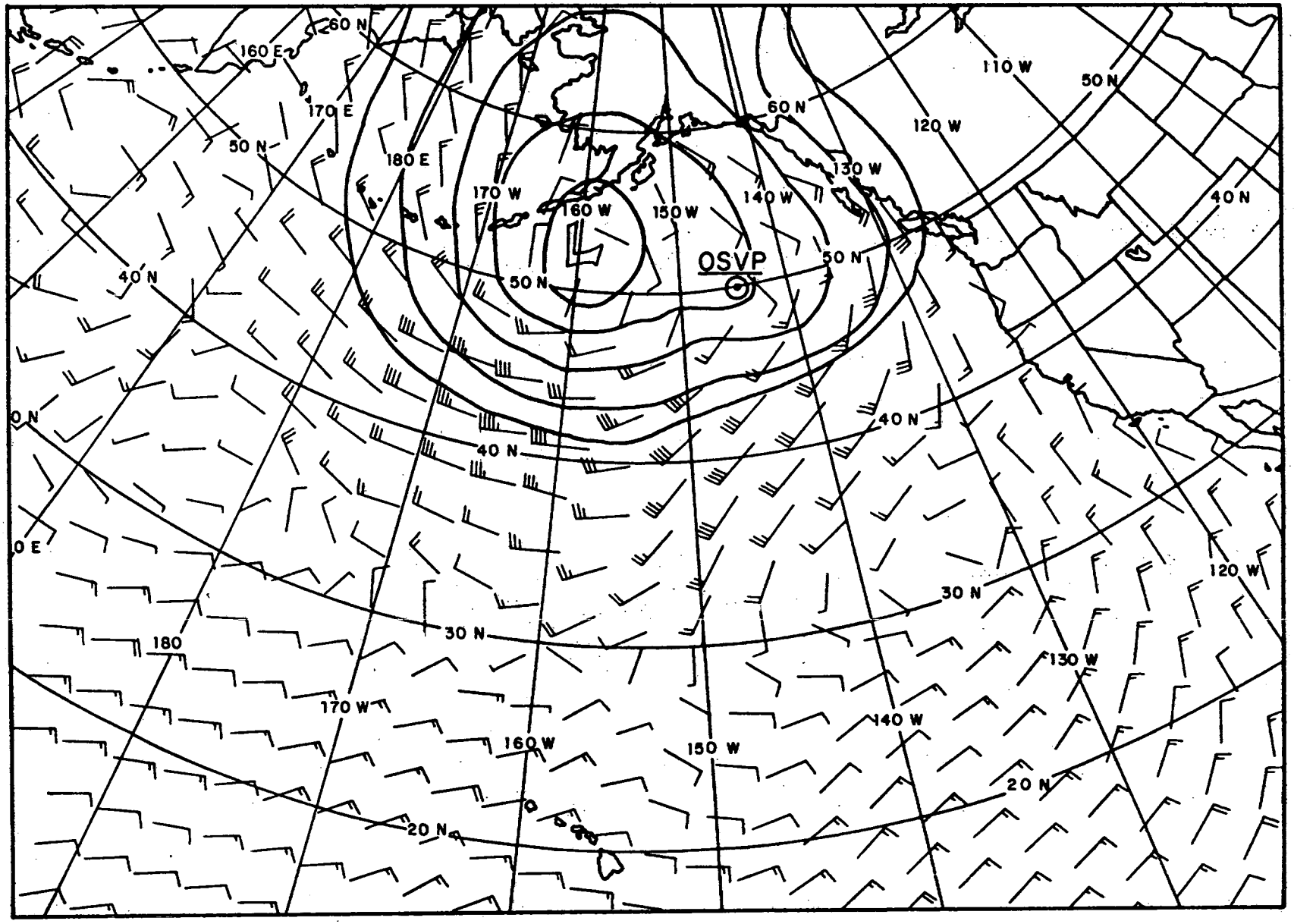


Figure 5-20 Wind Field

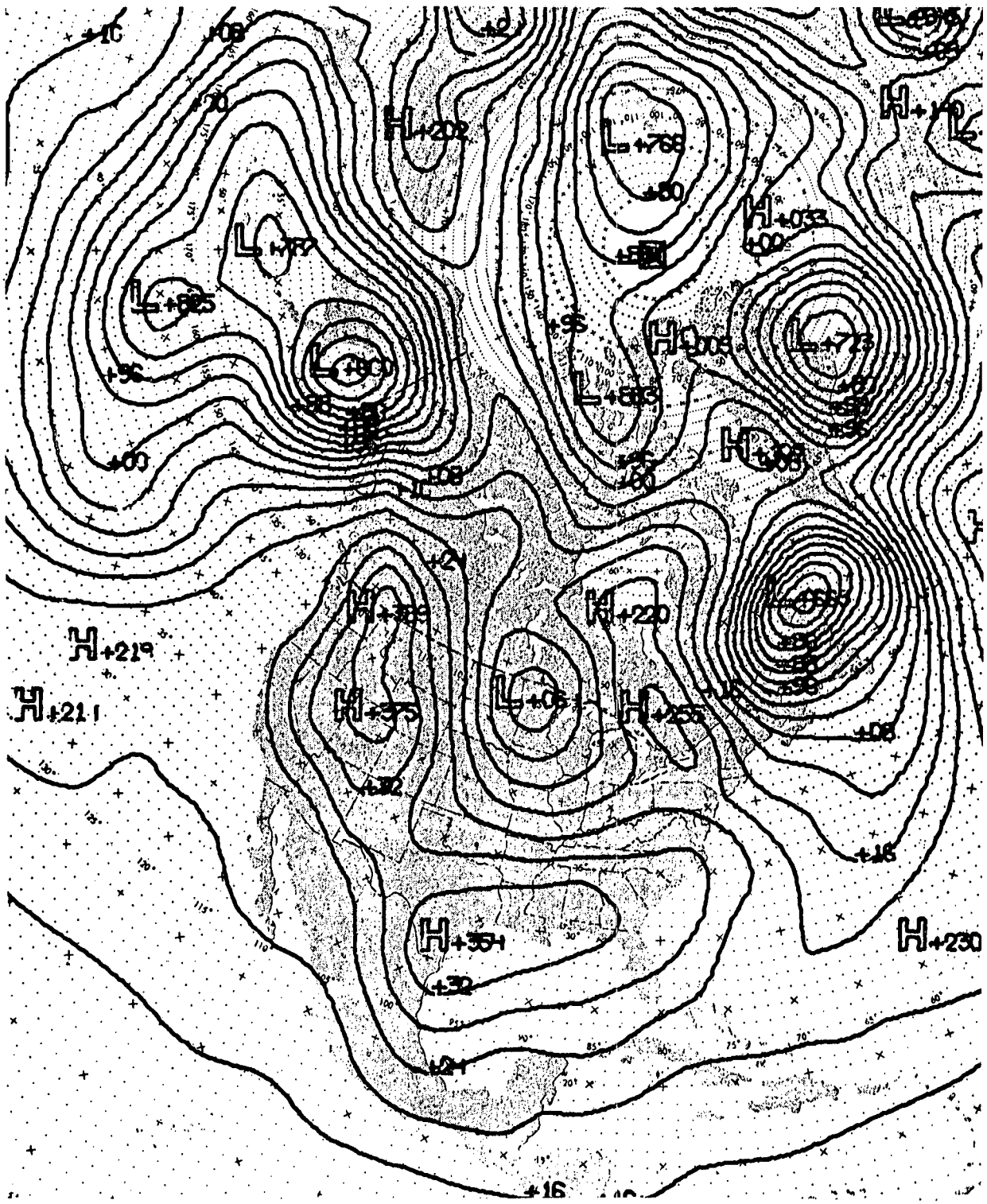


Figure 5-21 Surface Pressure Field @ 18Z, December 19, 1975

The grid system and energy propagation scheme for this program are based on an Icosahedral-Gnomonic projection designed by Adamo et al. (1968) for global numerical wave prediction. An icosahedron is a twenty sided polyhedron with equilateral triangles for its faces. Each triangle is tangent to the earth's surface at the center of the triangle. A gnomonic projection of the earth's surface on each triangle provides a chart in which great circles map as straight lines with a minimum distortion of the area. Wave energy is propagated at group velocity along great circles from grid point to grid point. The SOWM uses seven triangles for the North Pacific Ocean, six triangles for the North Atlantic and one for the Indian Ocean. Each triangle has 325 grid points with a spacing of approximately 188 n. mi at the point of tangency and 105 n. mi at the vertices (see Figure 5-22).

The energy matrix is output for real time increments of six hours. It consists of the sum of wind wave and swell energy at each grid point. Each matrix is identified by its date time group and latitude and longitude (the latter measured east from Greenwich through 360°). In addition to the energy matrix, the local wind speed, direction and frictional wind velocity are printed. Significant wave height, $\overline{H}_{1/3}$, for each wave spectrum can be obtained from the following relationship:

$$\overline{H}_{1/3} = 4\sqrt{E_{TOT}}$$

where E_{TOT} is the energy sum of the entire matrix. This value is printed in the lower right hand corner of each matrix.

Another output of SOWM is shown in Figure 5-23, a computer graphic which depicts significant wave height at each ocean point in one triangle of the icosahedron. This triangle (triangle 3) shows the Gulf of Alaska grid and the waves corresponding to the intense low pressure system in the Gulf on 19 December 1975 shown in Figure 5-21. Energy matrices and energy density as a function of frequency for two grid points on this triangle are given in paragraph 5.4.2.

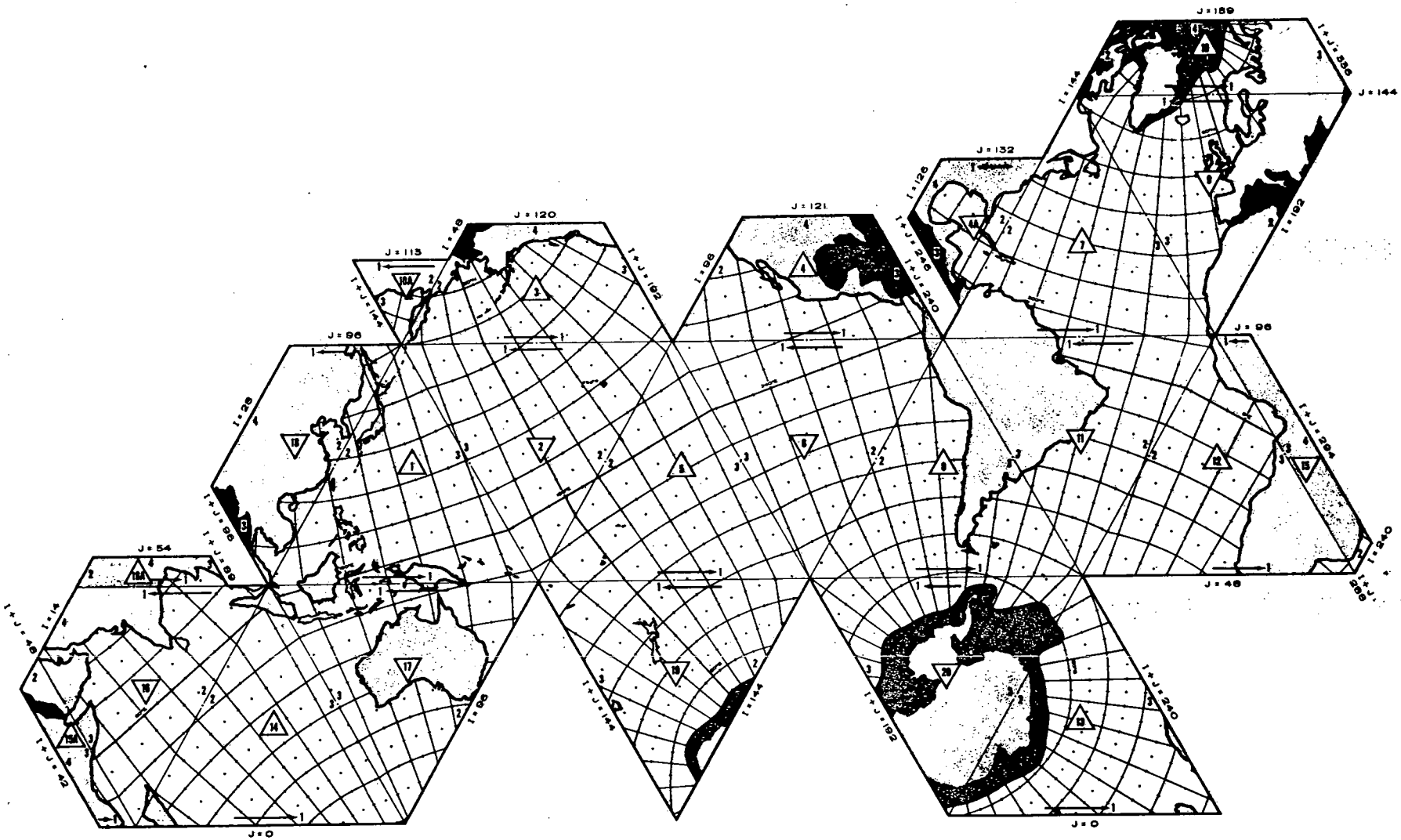


Figure 5-22. The Icosahedral-Gnomonic Projection of the earth designed for global numerical wave prediction. (Baer and Adamo, 1966)

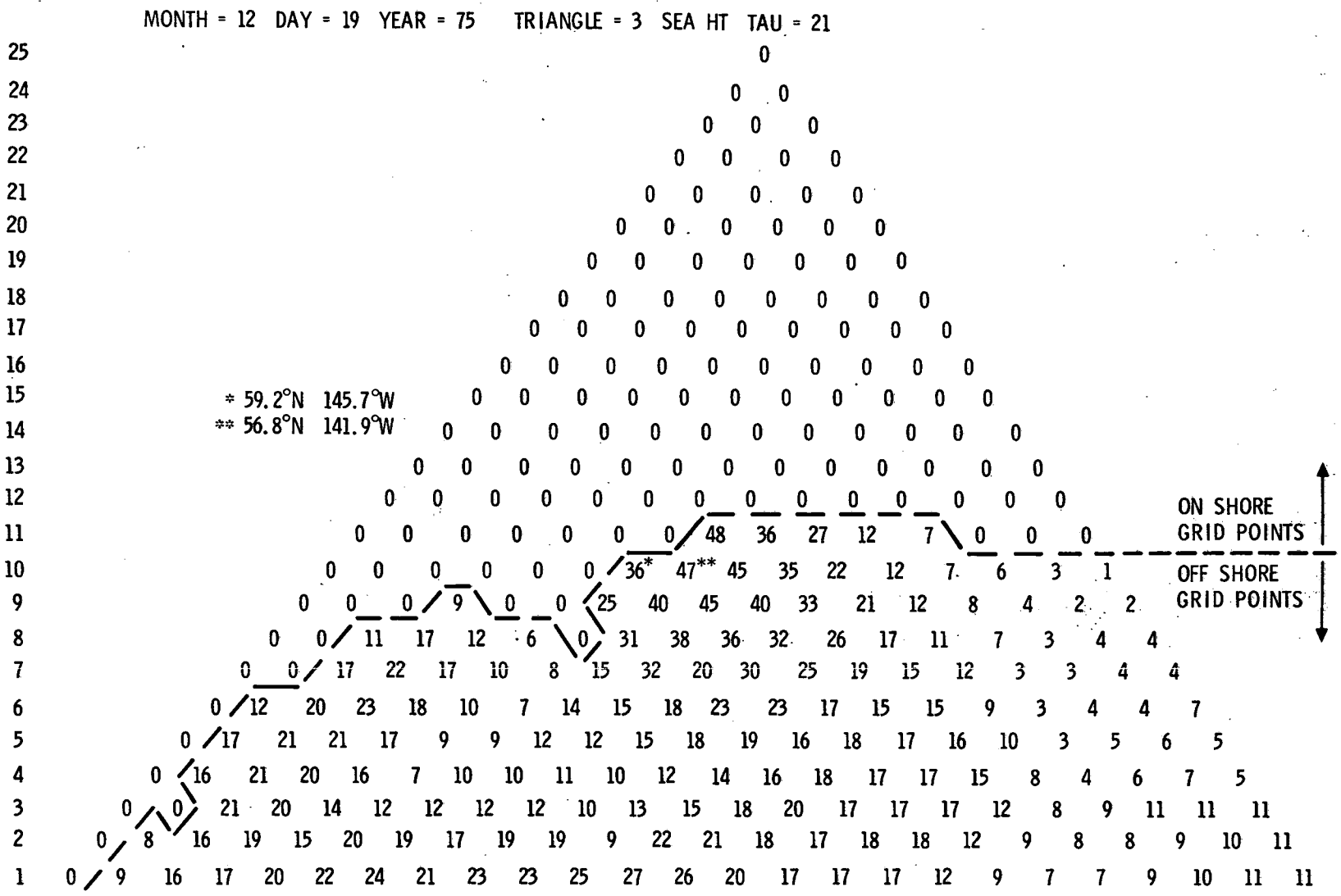


Figure 5-23. Significant Wave Heights, Gulf of Alaska, 19 Dec 1975, 2100 hrs.

5.4.1.1 Validation of the Spectral Ocean Wave Model Analysis

Introduction/Summary

Investigations to establish the validity of the Spectral Ocean Wave Model (SOWM) data for the Gulf of Alaska were begun during this reporting period. Comparisons of data measured by a Data-Well Wave Rider Buoy positioned in the northeast Gulf during the summer-fall time period were made with SOWM results. The comparisons described below, although not conclusive, revealed that SOWM errors appear to be random. This supports the assumption that the model will be adequate for analyzing long term trends in wave climatology where random error will be averaged out. On the other hand, there were discrepancies found between computed winds and those measured at the buoy indicating that there may be some local wind effects (most probably orographic) that are not being included in the input wind fields. The extent of the effect of such winds offshore is not yet determined and it seems that fetch limitation will limit their potential for wave growth. This aspect of the problem requires further investigation.

During the next reporting period, measured wave data from two deep water open ocean measurement systems will be available for validation of the model. Both sets of measurements were made close to SOWM grid points which will also facilitate validation.

Data Comparison

A set of wave spectra calculated from data measured by a Data-Well Wave Rider buoy in the northern part of the Gulf of Alaska during summer-fall conditions were obtained for comparison to SOWM wave spectral analyses. The buoy was located in a water depth of approximately 170 meters, which is deep enough to have little effect on deep water swell propagating in from other areas. The location of the buoy was such that there would be little significant wave energy propagating in from 270° through 90°, moving in a clockwise direction. The two closest SOWM grid points were selected for comparison.

One point was approximately 86 nautical miles west-southwest (WSW) of the buoy and had a similar geographical situation as the buoy. The other point was approximately 185 nautical miles south-southeast (SSE) of the buoy and was not affected by land features. Figures 5-24 and 5-25 show the comparison between significant wave heights (the average height of the highest one-third waves) calculated from the SOWM and the Data-Well Wave Rider. The numbers adjacent to the plotted points indicate the number of times each comparison occurred. Figure 5-24 (for the SOWM point closest to the buoy) had the better comparison whereas Figure 5-25 shows some bias. This may be due to the distance between the points of comparison. Several statistical computations are shown in Table 5-12. Generally speaking, the comparison is rather good, considering the distance of the grid points to the buoy and the closeness of the buoy to the land. Probably the most important point to gain from this study is that the SOWM errors tend to be random. As pointed out above, this is important in a climatological study such as this because the user is more interested in overall statistics rather than in data for a specific time.

Inspection of the SOWM model periods and the significant periods computed from the Data-Well Rider data indicate that during times of low swell energy propagation, the SOWM periods tended to be longer. This is probably due to the limited fetch in the area of the buoy. During times of significant wind wave energy growth, the periods compared better but the SOWM periods usually were longer.

Analyses of SOWM WSW Grid Point Discrepancies

Significant discrepancies in wave height occurred at three different points during the period of comparison, July to October 4. It is important to know if these discrepancies occurred because of model deficiencies. The principal driving force of the SOWM is surface wind velocity which is primarily computed from FNWC analyzed surface pressure fields. If the analyzed surface pressure fields are not computed correctly, then errors can occur in the wind velocity calculations which in turn would cause errors

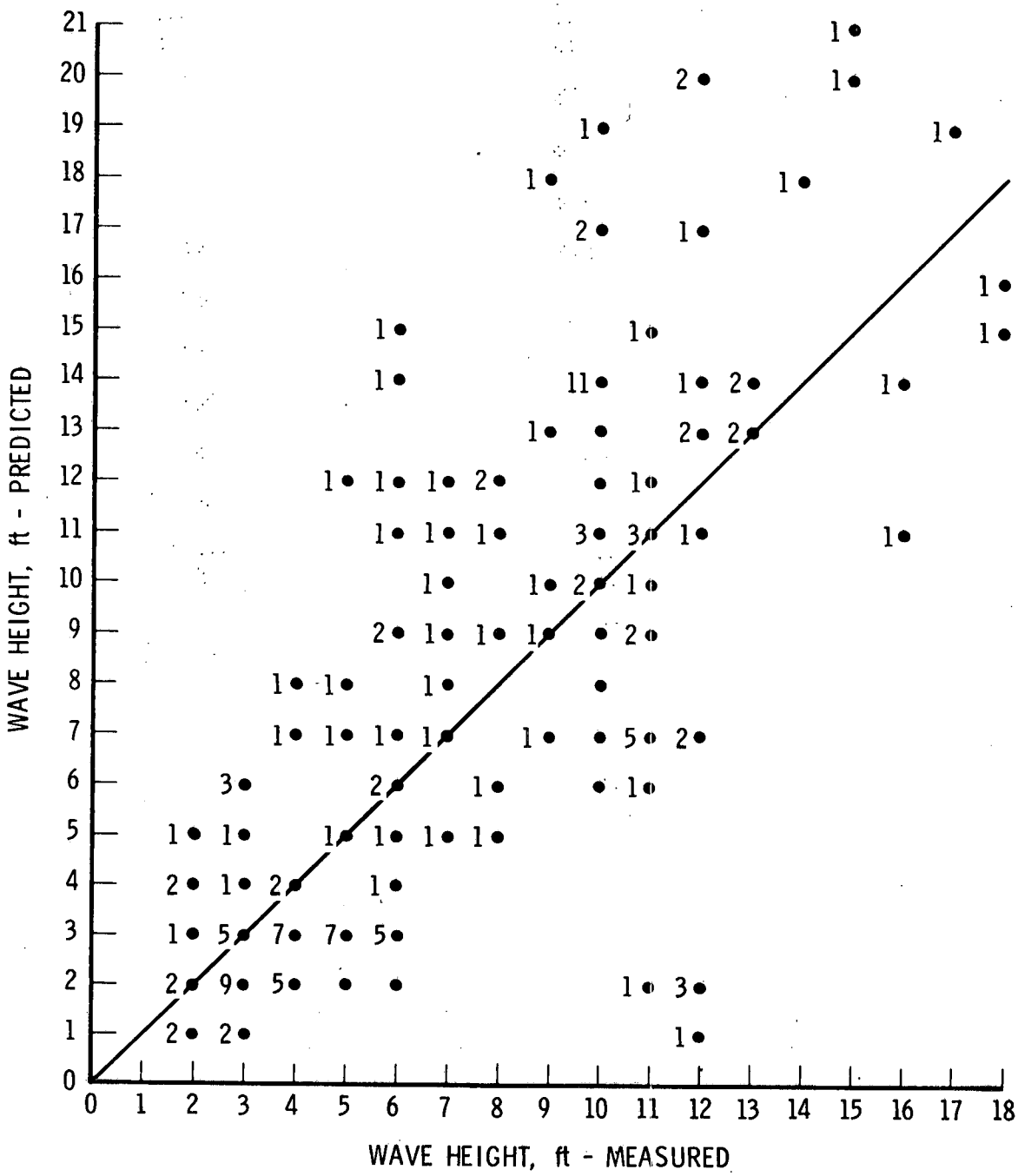


Figure 5-24. Comparison of Measured and Hindcast Wave Heights, WSW Grid Points

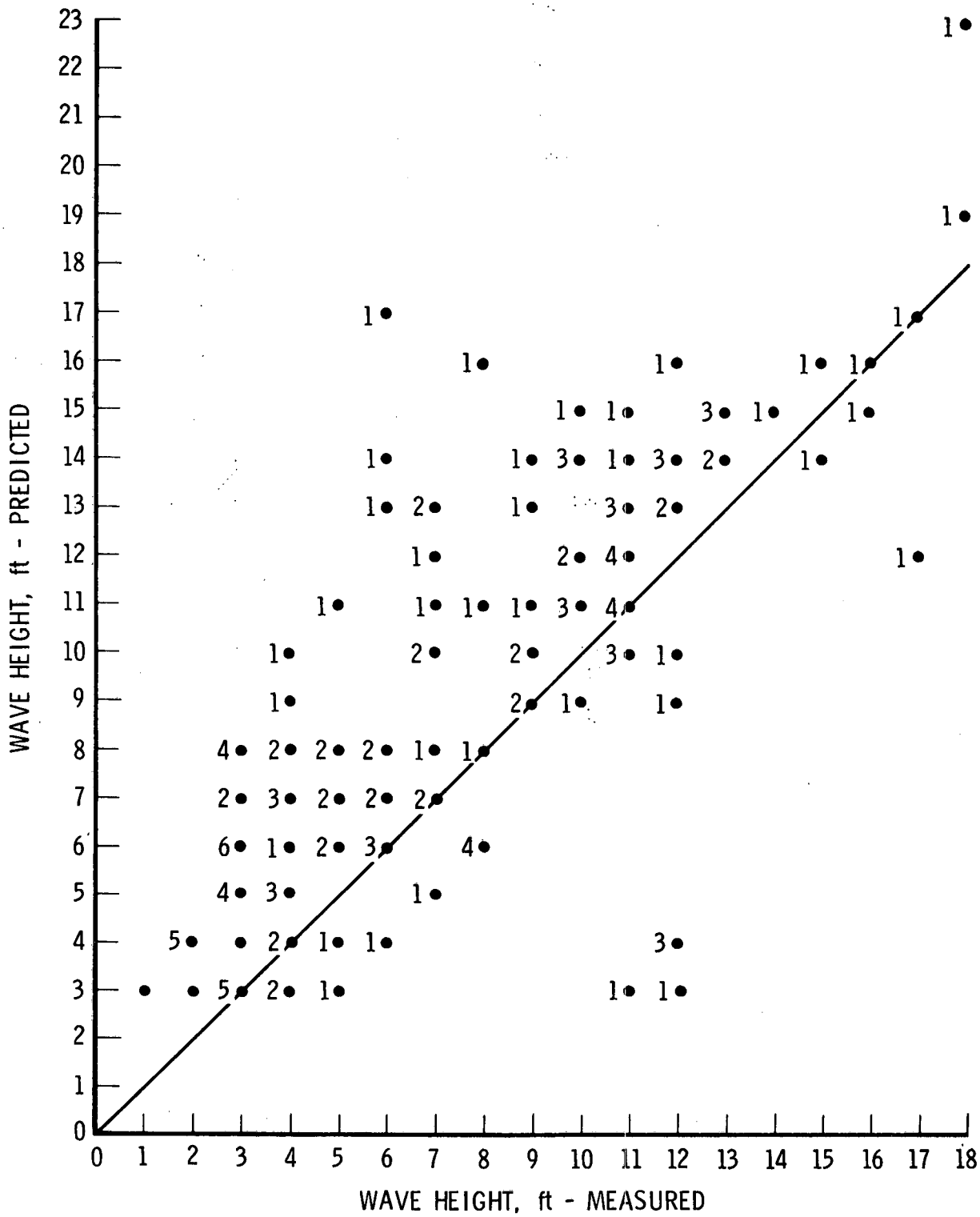


Figure 5-25. Comparison of Measured and Hindcast Wave Heights, SSE Grid Points

Table 5-12 Statistical Comparison of Significant Wave Height ($\bar{H}$ 1/3) Measured at Buoy and Predicted at Two SOWM Grid Points ("WSW" and "SSE")

	"WSW" vs Buoy	"SSE" vs Buoy
Mean Difference	0.1 ft	1.2 ft
Variance	14.3	9.4
Standard Deviation	± 3.8 ft	± 3.1 ft
Root Mean Square Error	± 3.8 ft	± 3.2 ft

in the growth and propagation of wave spectral energy. Several factors have to be investigaged when looking at surface pressure analyses - the position of the surface low center, the intensity of the low, the shape of the low and the speed and direction of the low. Figures 5-26 and 5-27 show the National Weather Service (NWS) 0600 GMT, 18 August surface pressure analysis for the North Pacific and the FNWC Northern Hemisphere surface pressure analysis, respectively. The NWS analysis has a more significant low center in the Gulf of Alaska than does the FNWC analysis. Presumably, this analysis was done locally including more reporting stations and may be more accurate. Therefore, the wind velocities calculated by the FNWC model would be expected to be lower than actually existed and, in fact, the calculation of the growth of wave energy was less than was measured.

On another occasion, 18 September, there was more SOWM wave energy than was measured even though the wind velocities compared rather well. This may be due to the limited fetch area near the buoy. The problem of orographic effects is demonstrated during the time period of 26-28 September where a comparison of measured wind velocities and computed wind velocities are shown in Table 5-13. The computed wind speeds were significantly less than the measured wind speeds. In addition, the buoy wind speeds were significantly greater than those of adjacent land stations, including one that was about 25 nautical miles from the buoy. This indicates that the wind velocity in the vicinity of the buoy was not only affected by the low pressure patterns but also were influenced by local orographic effects which are not accounted for in the input wind fields. This would require a very fine grid system, which may not be feasible with SOWM. The magnitude of these effects will probably have to be estimated in another manner.

Even though the wind speeds were on the order of 50 knots and greater during a two day period, the significant wave height at the buoy never exceeded 25 feet, indicating that wave energy growth is severely limited in the area of the buoy, again, probably due to fetch limitation.

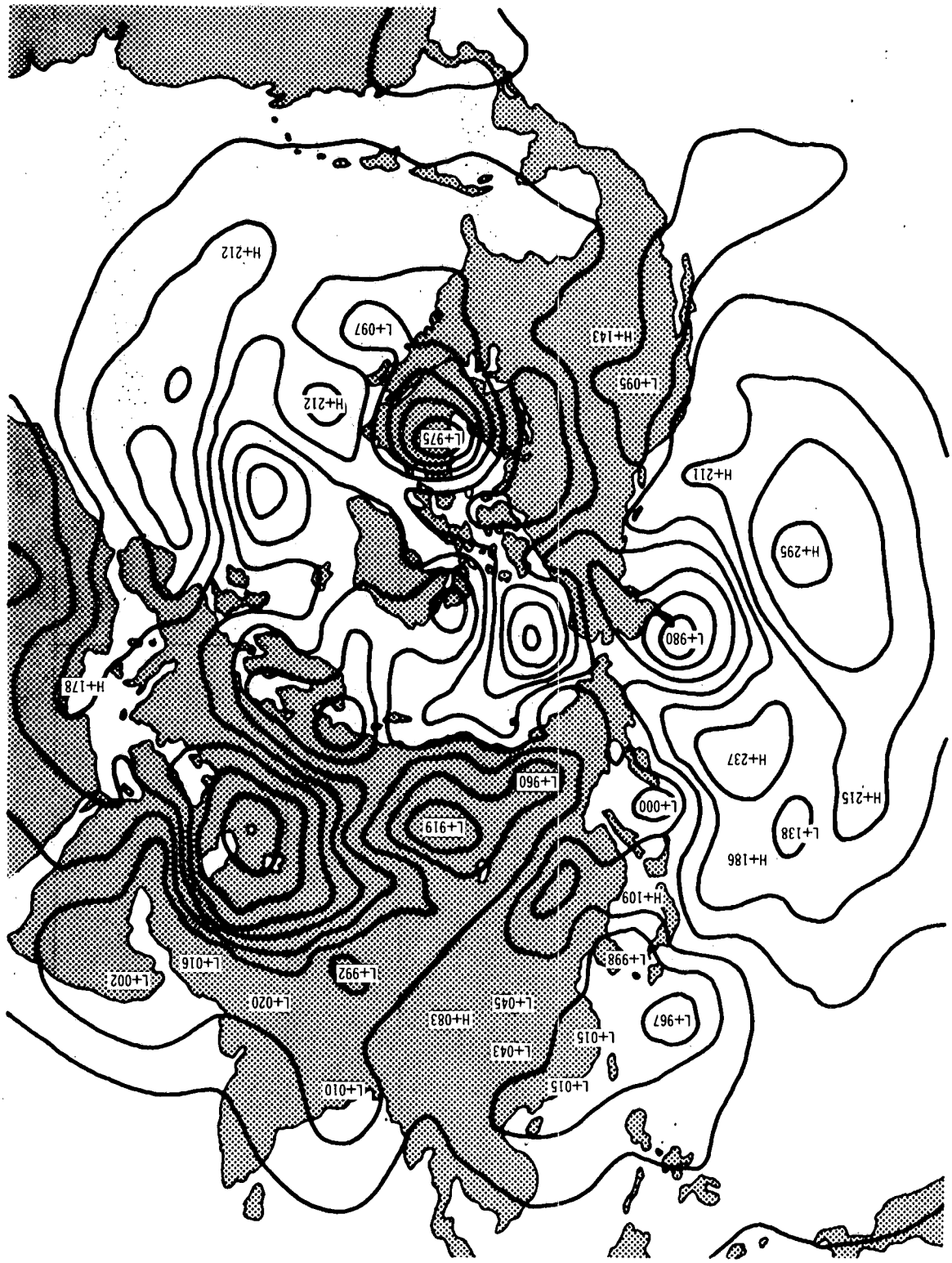


Figure 5-26. NWS 0600 GMT, 18 August Surface Pressure Analysis

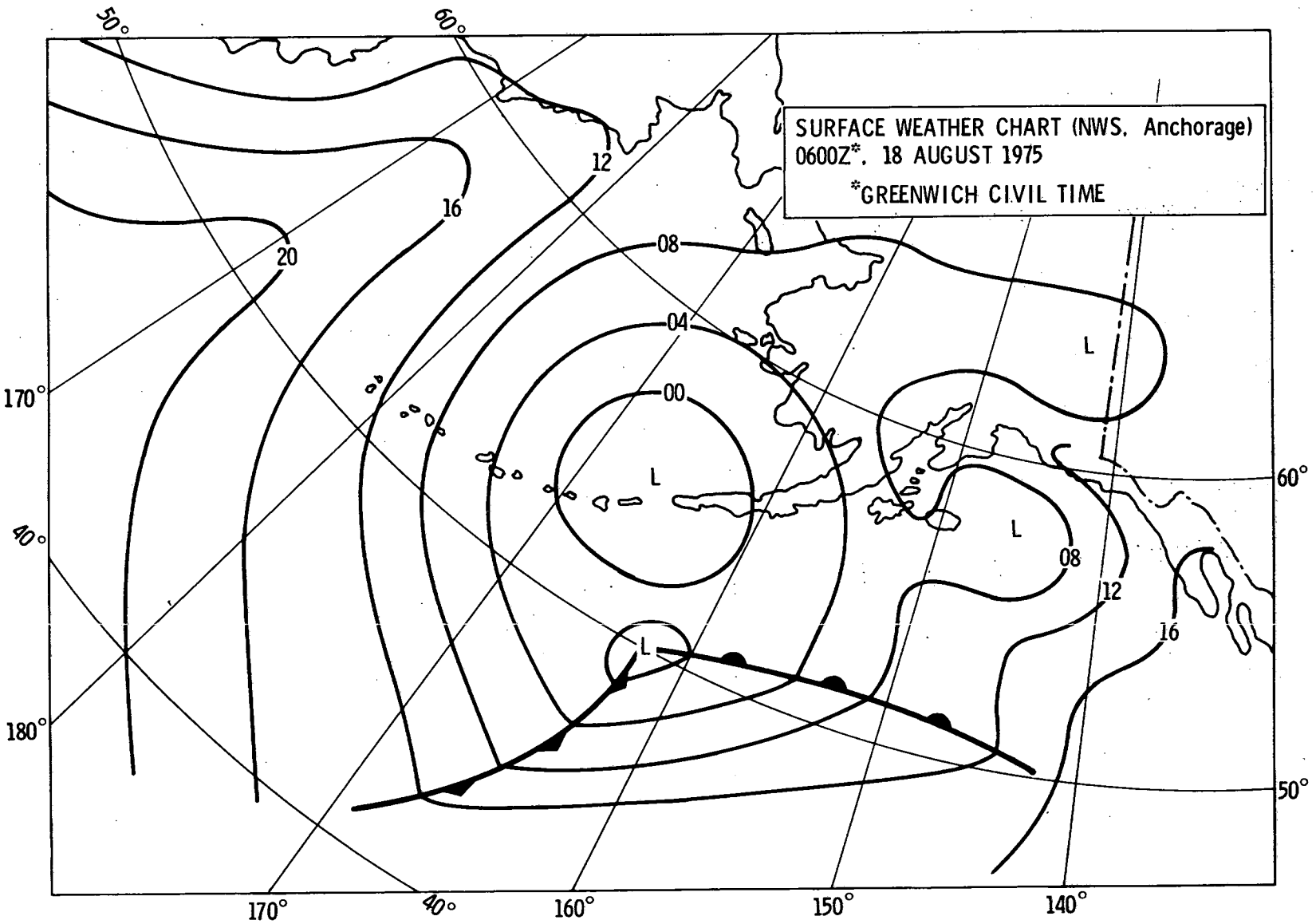


Figure 5-27. FNWS Northern Hemisphere Surface Pressure Analysis

Table 5-13. Wind Velocity Comparisons

SOWM WSW Grid Point				Measured Data							
				Buoy		Land Pt 1 (40 nm from Buoy)		Land Pt 2 (45 nm from Buoy)		Land Pt 3 (25 nm from Buoy)	
Time (GTM)	Date	Speed (kts)	Direction	Speed (kts)	Direction	Speed (kts)	Direction	Speed (kts)	Direction	Speed (kts)	Direction
0300	9/26	21	104°	49	112°						
0600				62	131°	35	ENE			35	NE
0900		29	100°	58	081°						
1200				63	121°	40	E				
1500		22	122°	58	124°						
1800				50	124°	40	ESE	23	ESE	35	E
2100		18	135°	47	124°						
0000	9/27			56	99°	35	E	11	ESE	20	E
0300		17	142°	54	106°						
0600				56	139°	50	E	11	ESE	23	E
0900		16	133°	56	111°						
1200				58	111°	23	E			2	NE
1500		13	129°	56	111°						
1800				50	114°	17	E			2	NE
2100		12	118°	43	118°						
0000	9/28			46	118°	23	ESE	2	SE	23	SE
0300		14	123°	35	125°						
0600				38	114°	11	SE	11	SE	17	SE

Conclusion

The SOWM significant wave heights compared rather well to the heights calculated from the buoy data considering the distance of the grid points to the buoy and the geographic location of the buoy. The most significant point ascertained in this comparison study is that the calculation errors tended to be random. This is extremely important when looking at large quantities of data even though individual meteorological and oceanographic conditions may not match up precisely, the overall data will be representative of the area.

5.4.2 Gulf of Alaska Spectral Data

Wave spectral information is receiving increased attention as a design tool for offshore platforms, both mobile and fixed. More traditional approaches to design have utilized the deterministic single period "design wave" method in which a single large wave is chosen to represent the maximum foreseeable stress on a platform. For fixed shallow water platforms, this approach has provided both ease of computation and relatively good accuracy.

As offshore structures have moved into harsher environments and deeper water, the suitability of the "design wave" approach has come into serious question. Newer and larger structures are typically more flexible than shallow water structures and have longer natural periods. They are thus more sensitive to the normal wave periods and factors such as dynamic response and fatigue are becoming increasingly important design considerations.

A wave spectrum is a statistical representation of the distribution of wave energy as a function of wave period. If it is known how a structure responds to waves of different periods, it is usually possible to derive the corresponding response spectrum of the structure in an irregular sea state. Using this response spectrum it is possible for the designer to predict the structure behavior in a variety of typical sea conditions as well as storm conditions. This, in turn, allows some prediction of fatigue life for individual members as well as the total structure.

Figures 5-28-5-33 show plots of wave spectra at 59.2°N, 145.7°W and 56.8°N, 141.9°W for typical severe winter storm situations between 1974 and 1977. These plots were drawn from the corresponding spectral matrix Tables 5-14-15 generated by the SOWM program. The matrix tables are divided into 15 columns representing wave frequencies and 12 rows representing directions from which wave energy is propagated. The last number in each column is the total energy (ft^2) in the frequency band whose center point is defined at the top of the column. Likewise, the next to last number in each row is the total energy for each direction band whose center point is defined in the last column. The total energy for all frequency and direction bands is the last number in the next to last column. Significant wave height ($\overline{H}_{1/3}$) is related to the total matrix energy (E_{TOT}) by the formula:

$$\overline{H}_{1/3} = 4\sqrt{E_{TOT}}$$

Other information in the spectral matrix tables includes identifier data such as date, time, and position as well as environmental conditions at the grid point.

The spectral density plots, Figures 5-28 through 5-33, were computed from the matrix by dividing out the corresponding bandwidths about the center frequencies. Spectral density is thus represented in units of ft^2-sec. Figures 5-29 and 5-33 correspond to the surface pressure analysis for 19 Dec 75 (shown in para 5.4.1.).

In addition to the individual spectra just discussed some "representative" or composite spectra for a range of wave heights are given in Figures 5-34 through 5-49. These spectra were developed under Task II, Compatibility of Mobile Units with the Gulf of Alaska Environment by Dr. Dan Hoffman, Consultant, They are based on spectral data generated by the SOWM for three grid points in the Gulf located at 56.0N°, 147.9°W, 59.2°N, 145.7°W, and 55.4°N, 153°W for a 2-1/2 year period ending in February 1977.

Figure 5-28. Wave Spectral Data at 59,225N, 145.702W on Jan. 30, 1976 1500 HRS

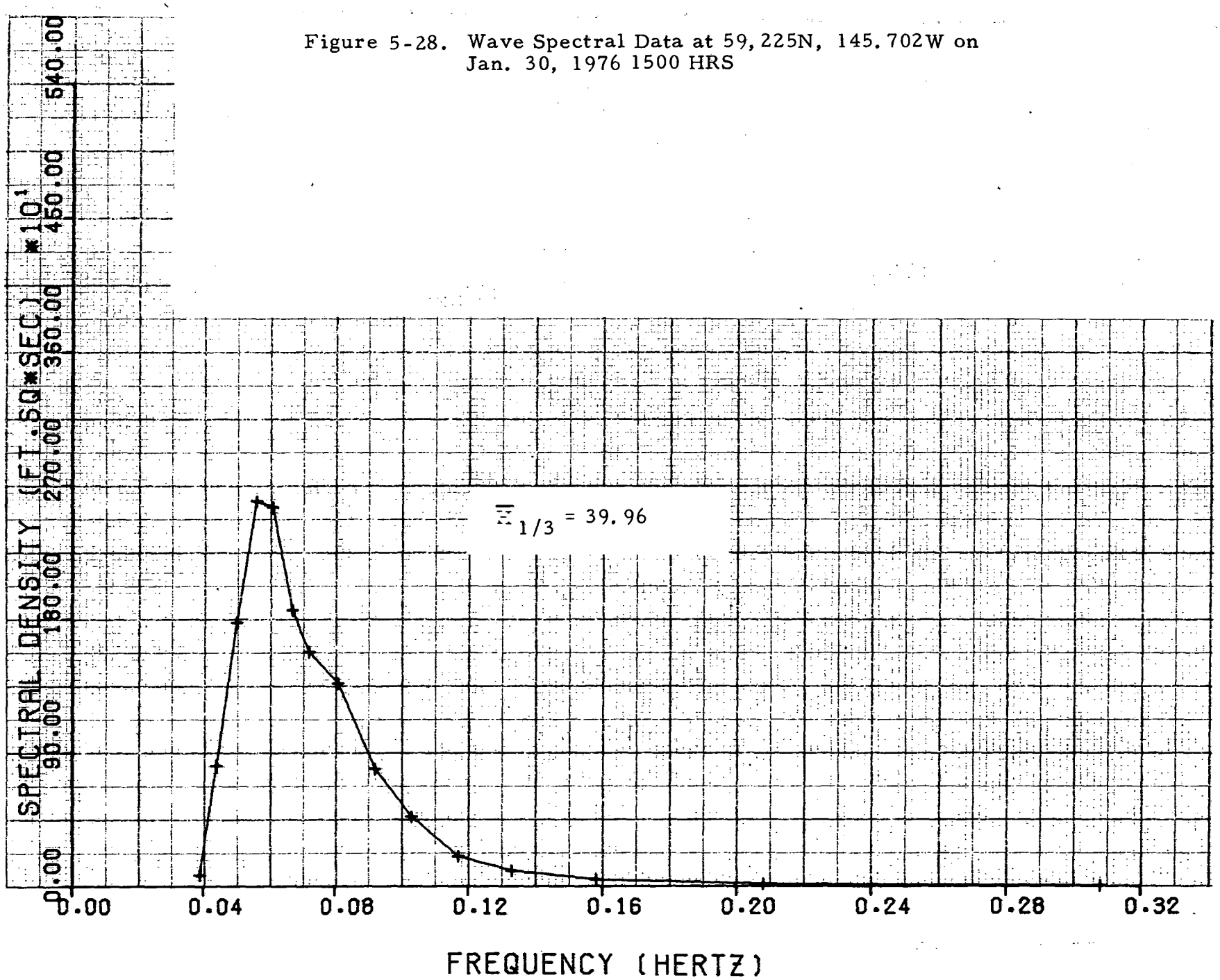


Figure 5-29. Wave Spectral Data

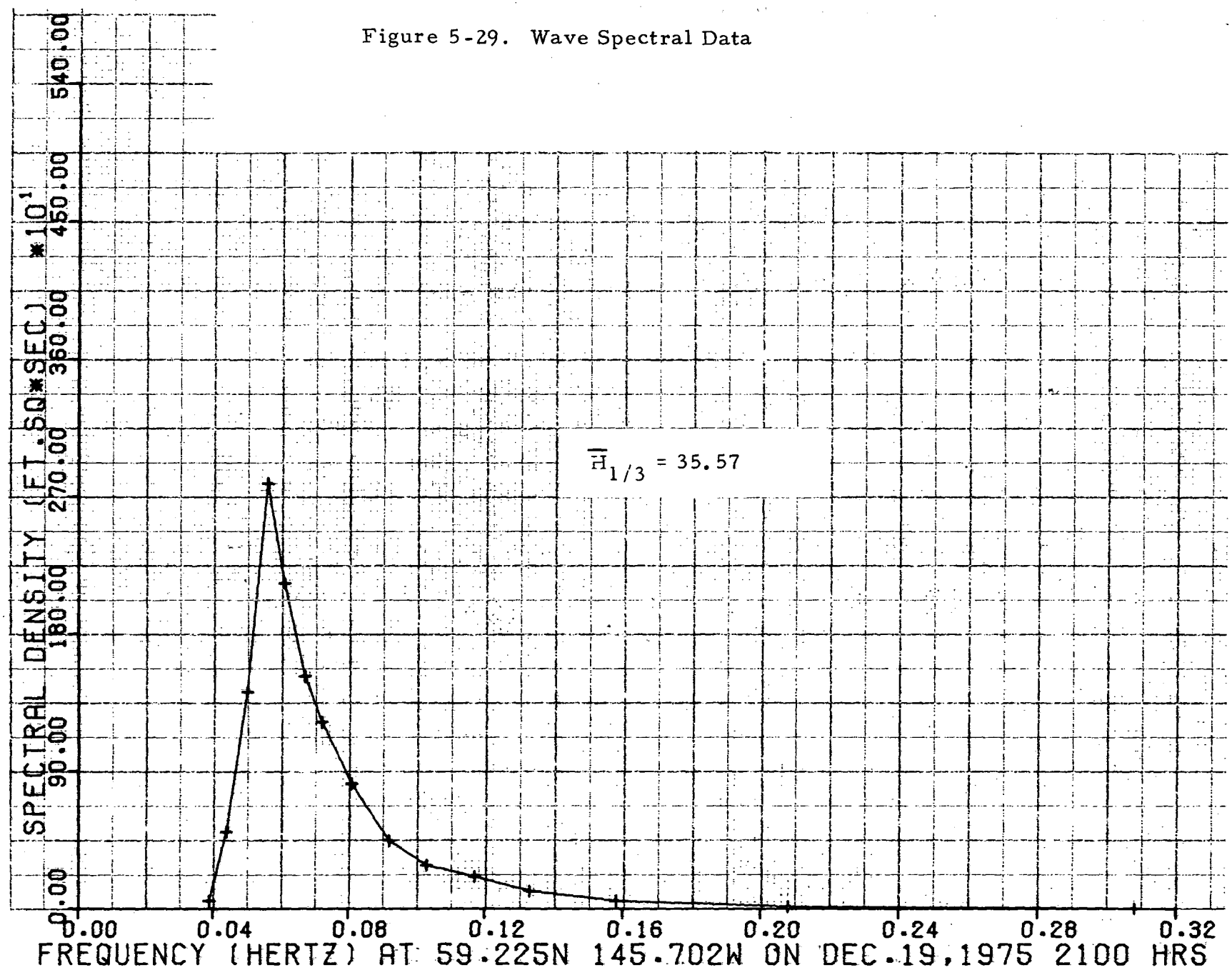


Figure 5-30. Wave Spectral Data

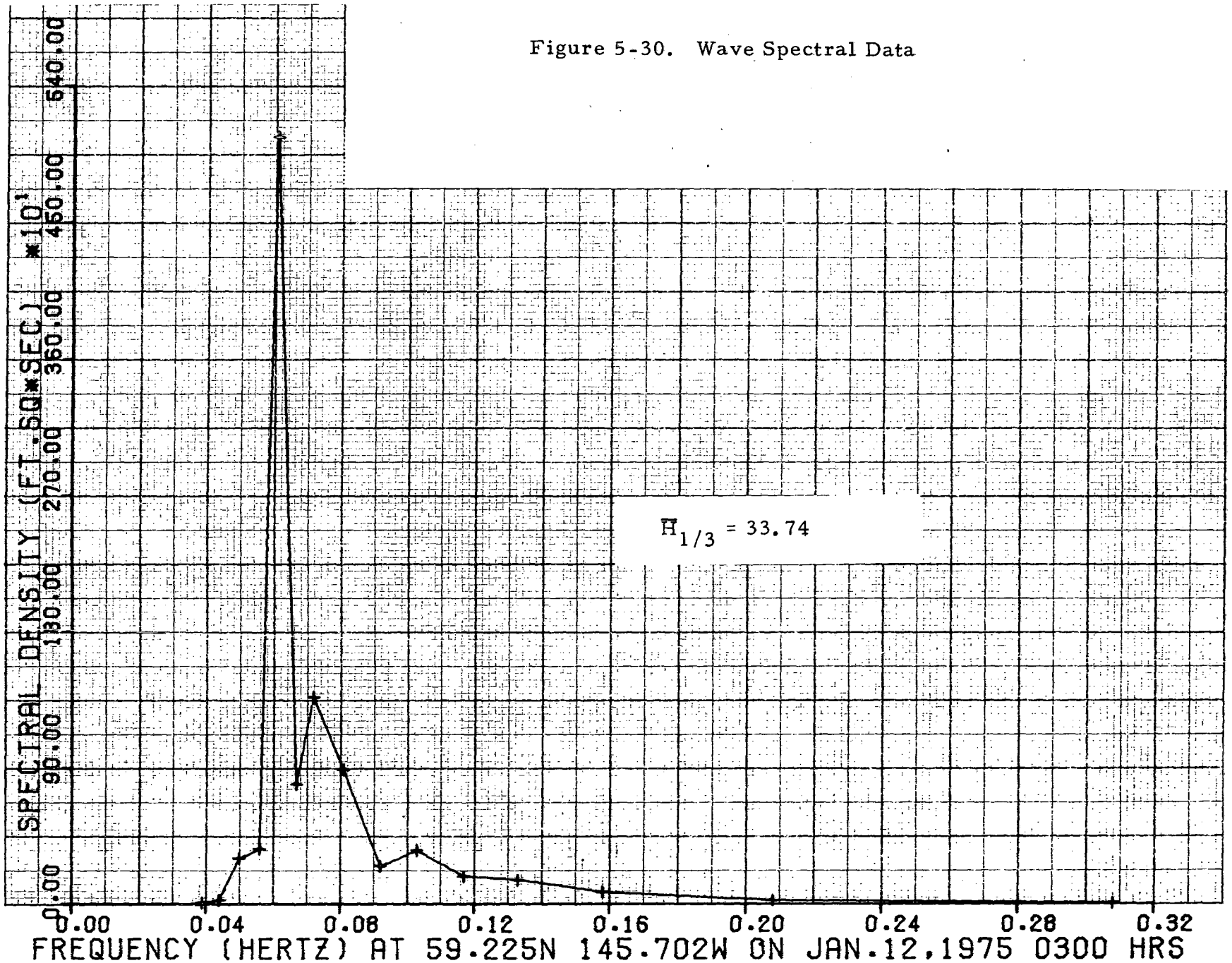


Figure 5-31. Wave Spectral Data

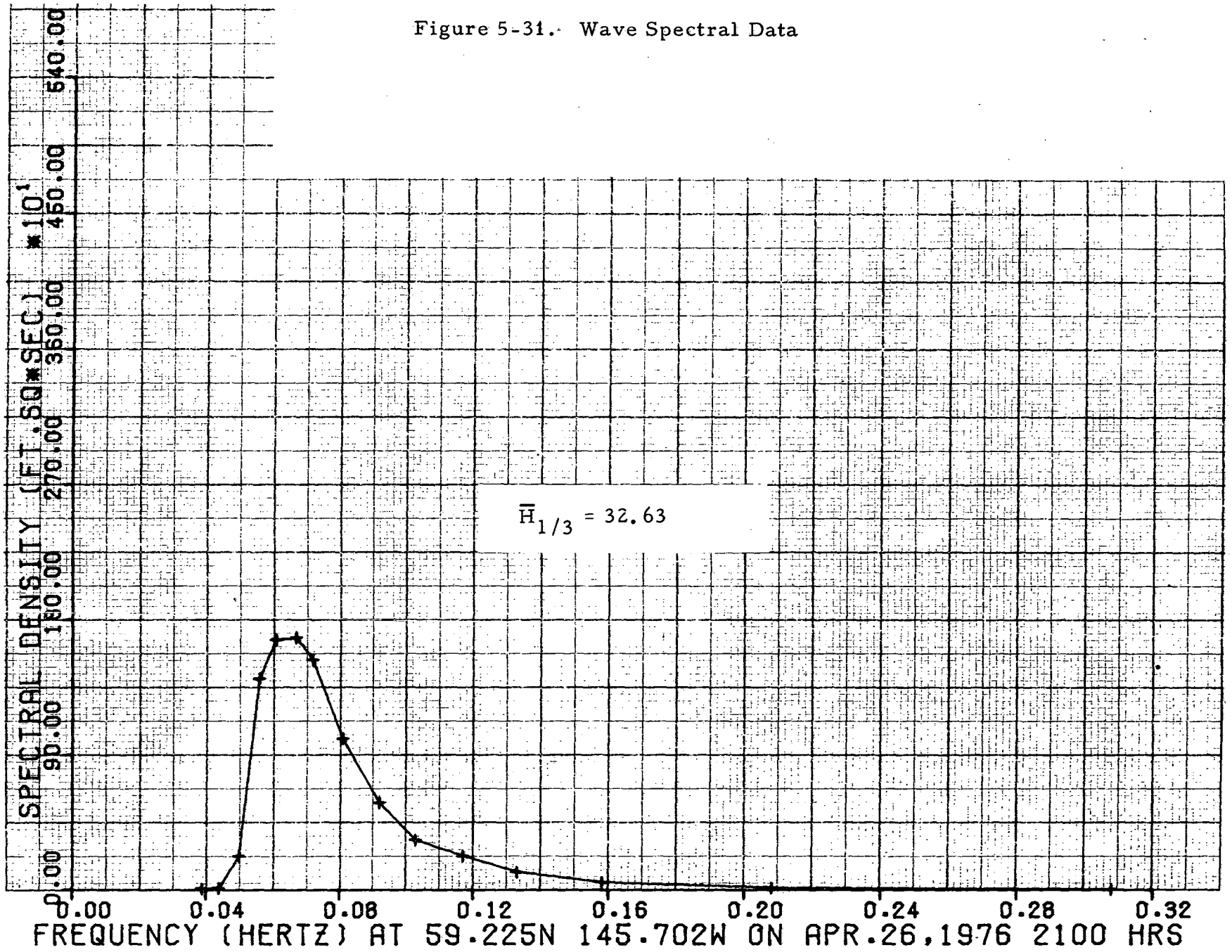


Figure 5-32. Wave Spectral Data

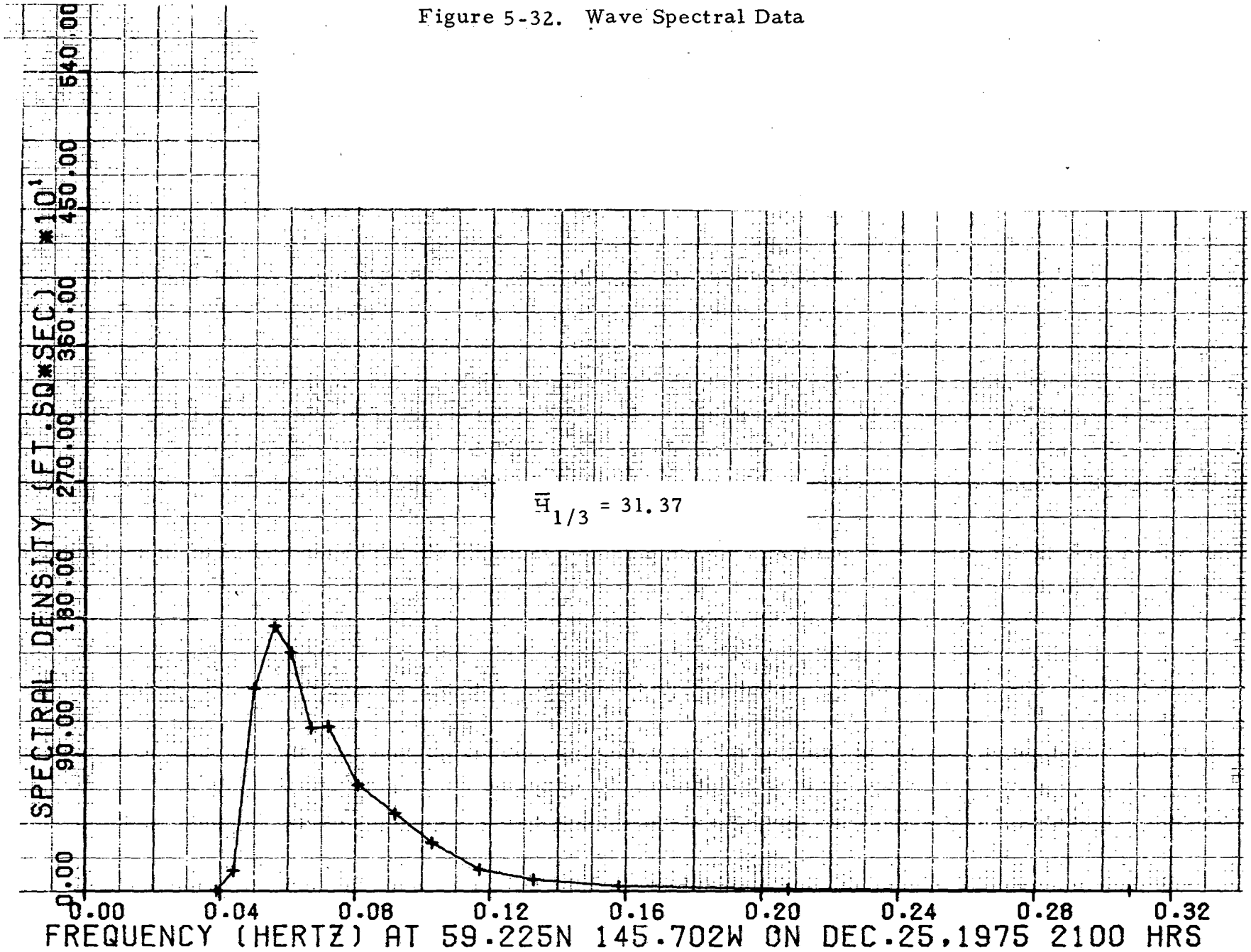


Figure 5-33. Wave Spectral Data

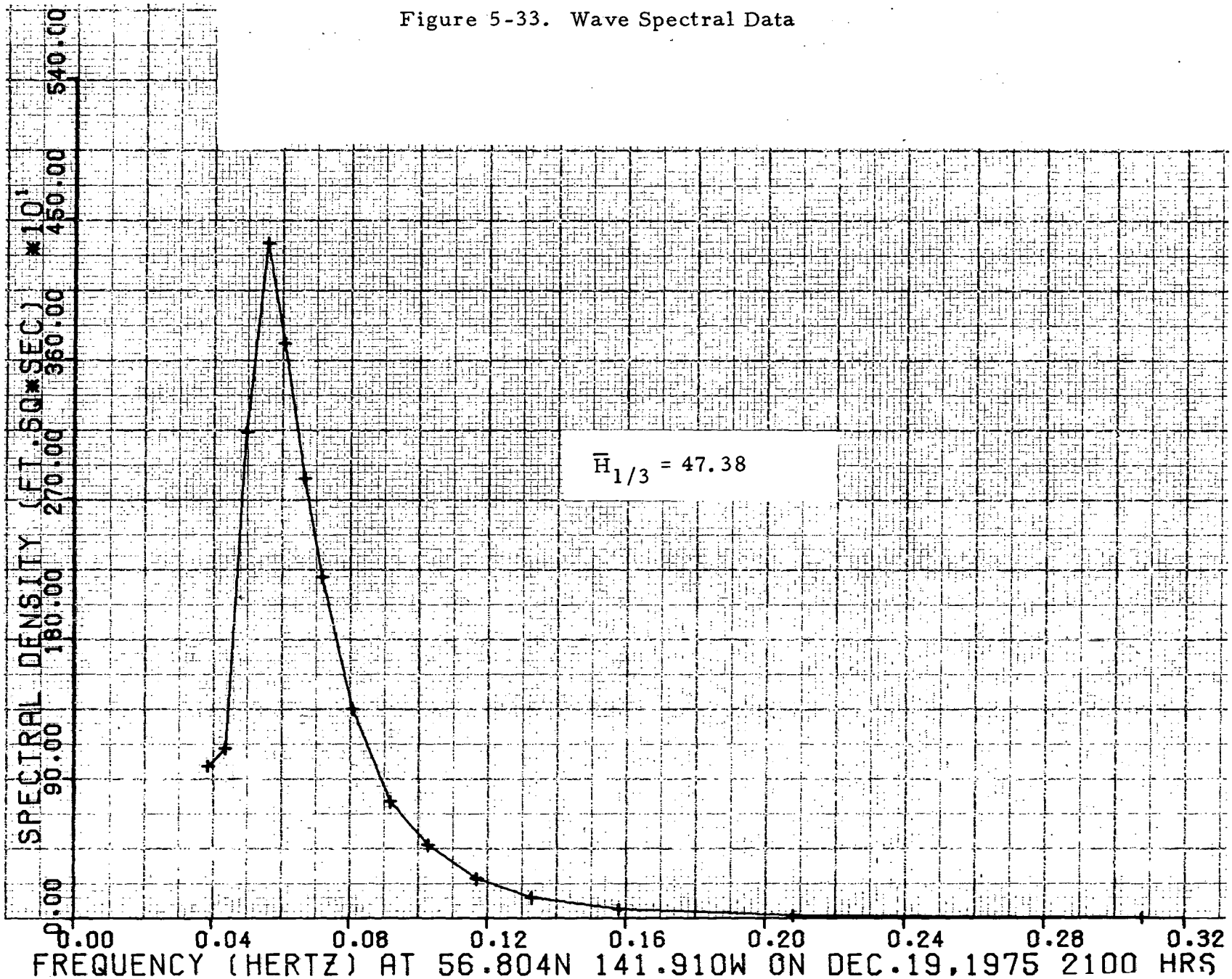


Table 5-14. Spectral Matrix Table, 56.804 N; 141.910 W

217 19 DEC 75 56.804N 141.910W

WIND DIR 200.6 WIND SPD 51.2 WHITE CPS .47 USTR 2.60

FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR(FROM)
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	322.63
	0.000	0.000	0.000	0.000	0.000	.010	0.000	.010	.390	.280	1.510	.010	.450	.230	.050	2.940	292.63
	.070	.150	.250	.290	.580	.720	.570	.500	.400	.240	.390	3.290	.740	.340	.240	8.770	262.63
	.110	.250	.390	.440	.840	1.030	1.070	2.930	1.970	2.360	1.970	4.110	2.330	1.570	.700	23.170	232.63
	.140	.300	.470	.510	.980	1.210	2.120	3.980	3.300	4.480	5.960	6.930	6.530	2.040	1.830	40.840	202.63
	.120	.290	.480	.510	.980	1.200	2.090	3.920	3.240	4.520	6.240	6.350	4.730	1.450	1.810	37.930	172.63
	.070	.210	.430	.470	.880	1.040	1.730	3.000	2.310	3.020	3.590	2.870	1.680	.420	.750	22.470	142.63
	0.000	0.000	0.000	0.000	.010	.040	.190	.610	.500	.790	.860	.540	.360	.030	.060	4.090	112.63
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.010	.030	.040	.040	.020	.010	0.000	0.000	.150	82.63
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.010	0.000	0.000	0.000	.010	52.63
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	22.63
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	352.63
	.51	1.20	2.02	2.22	4.27	5.25	8.37	14.96	12.20	15.73	20.56	24.13	17.39	6.08	5.44	140.33	

Table 5-15. Spectral Matrix Table, 59.225 N, 145.732 W

21Z 19 DEC 75 59.225N 145.732W
WIND DIR 191.5 WIND SPD 26.2 WHITE CPS 16 USTR 1.26

FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR(FROM)
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	319.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	289.54
	.040	.100	.140	.110	.140	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.530	259.54
	.060	.160	.320	.350	.620	.180	.060	.030	.140	.020	.810	2.500	.830	.650	0.000	6.730	229.54
	.090	.220	.400	.470	.850	.740	1.070	2.060	.830	.600	.520	1.720	.220	.140	.030	9.950	199.54
	.070	.210	.430	.480	.900	1.080	1.840	3.490	2.990	4.010	5.830	6.820	4.690	1.610	.150	34.600	169.54
	.050	.260	.450	.490	.940	1.160	1.950	3.520	2.830	3.830	4.680	4.430	2.140	.400	.110	27.250	139.54
	0.000	0.000	0.000	0.000	.030	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.030	109.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	79.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	49.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	349.54
	.300	.950	1.740	1.900	3.480	3.160	4.930	9.100	6.790	8.460	11.840	15.470	7.880	2.800	.290	79.090	

21Z 25 DEC 75 59.225N 145.702W
WIND DIR 140.5 WIND SPD 32.7 WHITE CPS 14 USTR 1.43

FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR(FROM)
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	319.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	289.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	259.54
	0.000	0.000	0.000	0.000	.020	.020	0.000	.020	.070	.030	.180	2.210	2.210	0.000	0.000	4.760	229.54
	.060	.110	.250	.330	.580	.740	1.440	2.700	3.050	3.620	4.230	5.400	2.710	.660	.010	25.670	199.54
	.070	.190	.390	.450	.870	1.050	1.800	2.900	2.030	1.800	3.480	1.730	2.200	.050	.010	19.020	169.54
	.080	.220	.420	.480	.900	1.060	1.550	2.160	.880	.720	.850	.380	.300	.040	0.000	10.040	139.54
	.070	.190	0.000	0.000	0.000	.680	.910	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.860	109.54
	.040	.120	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.160	79.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	49.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	349.54
	.300	.830	1.060	1.260	2.370	3.560	5.700	7.780	6.030	5.970	8.740	9.720	7.420	.750	.020	61.510	

Table 5-15. Spectral Matrix Table, 59.225 N, 145.732 W (Cont'd)

3Z 12 JAN 75 59.225N 145.702W
WIND DIR 91.5 WIND SPD 66.2 WHITE CPS 14 USTR 3.69

FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR(FROM)
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	319.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	289.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	259.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.010	.030	0.000	0.000	0.000	.040	229.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.010	.010	.050	0.000	0.000	0.000	0.000	0.000	.070	199.54
	0.000	0.000	.430	.440	.820	.940	.200	.700	.800	1.110	1.450	.470	.310	.010	0.000	7.680	169.54
	.120	.280	.400	.430	.810	.980	1.650	2.920	2.260	3.240	4.370	1.520	1.360	.120	.020	20.480	139.54
	.180	.400	.550	.540	0.000	1.160	0.000	3.590	0.000	0.000	7.280	0.000	0.000	0.000	.030	13.730	109.54
	.190	.420	.580	.570	1.010	0.000	0.000	0.000	3.210	0.000	7.770	0.000	0.000	0.000	0.000	13.750	79.54
	.140	.310	.440	.420	0.000	.860	0.000	2.600	0.000	0.000	4.900	0.000	0.000	0.000	0.000	9.670	49.54
	.080	.180	.240	.220	.390	0.000	.920	0.000	1.240	0.000	2.190	0.000	0.000	0.000	0.000	5.460	19.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.060	.070	0.000	.140	0.000	0.000	0.000	0.000	.270	349.54
	.710	1.590	2.640	2.620	3.030	3.940	2.770	9.880	7.590	4.400	28.110	2.020	1.670	.130	.050	71.150	

21Z 26 APR 76 59.225N 145.702W
WIND DIR 174.5 WIND SPD 39.8 WHITE CPS 3 USTR 1.88

FREQ	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		DIR(FROM)
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	319.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	289.54
	0.000	0.000	0.000	0.000	0.000	0.000	.020	.020	0.000	0.000	.010	0.000	0.000	0.000	0.000	.050	259.54
	.060	.140	.230	.240	.460	.370	.750	.720	.400	.110	.070	.020	.060	0.000	0.000	3.630	229.54
	.090	.220	.380	.440	.820	1.000	1.680	3.220	1.980	1.470	.510	.150	.130	.010	.010	12.110	199.54
	.100	.250	.450	.510	.980	1.200	2.060	3.660	3.240	3.810	4.160	4.990	.640	.030	.020	26.100	169.54
	.080	.200	.430	.480	.920	1.140	1.960	3.580	2.900	3.960	4.520	2.660	.420	.030	.020	23.300	139.54
	.050	.120	.260	.320	.600	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.350	109.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	79.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	49.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.54
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	349.54
	.380	.930	1.750	1.990	3.780	3.710	6.470	11.200	3.520	9.350	9.270	7.820	1.250	.070	.050	66.540	

TIME STEP 5 SUBPROJECTION 3 GRID PT 196 LAT 59.225 LONG (EAST) 214.298
WIND SPEED 42.39 WIND DIR 205.8 USTAR 2.02

FREQ / DIR	.308	.208	.158	.133	.117	.103	.092	.081	.072	.067	.061	.056	.050	.044	.039		(MET DIR)
1	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	319.54
2	0.000	0.000	0.000	0.000	0.000	.031	.072	.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.242	289.54
3	.062	.150	0.000	0.000	0.000	.632	.883	1.281	0.000	0.000	.000	0.000	0.000	0.000	0.000	3.000	259.54
4	.095	.231	.251	.302	.593	1.000	1.060	3.207	.484	.410	2.276	2.981	0.000	.115	.311	13.913	229.54
5	.166	.256	.416	.472	.908	1.180	2.005	3.408	2.007	2.287	2.165	1.281	.571	.068	.016	17.143	199.54
6	.082	.249	.440	.501	.950	1.185	2.070	3.764	3.190	4.326	5.635	6.283	5.903	3.052	.311	37.949	169.54
7	.049	.186	.430	.484	.922	1.119	1.912	3.405	2.579	3.311	4.110	3.869	3.406	1.283	.079	27.162	139.54
8	0.000	0.000	0.000	.001	.015	0.000	0.000	0.000	.513	0.000	0.000	0.000	0.000	0.000	0.000	.529	109.54
9	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	79.54
10	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	49.54
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	19.54
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	349.54
****	393	.072	1.536	1.759	3.396	5.235	8.809	15.204	8.773	10.334	14.086	14.415	9.874	4.517	.417	99.925	

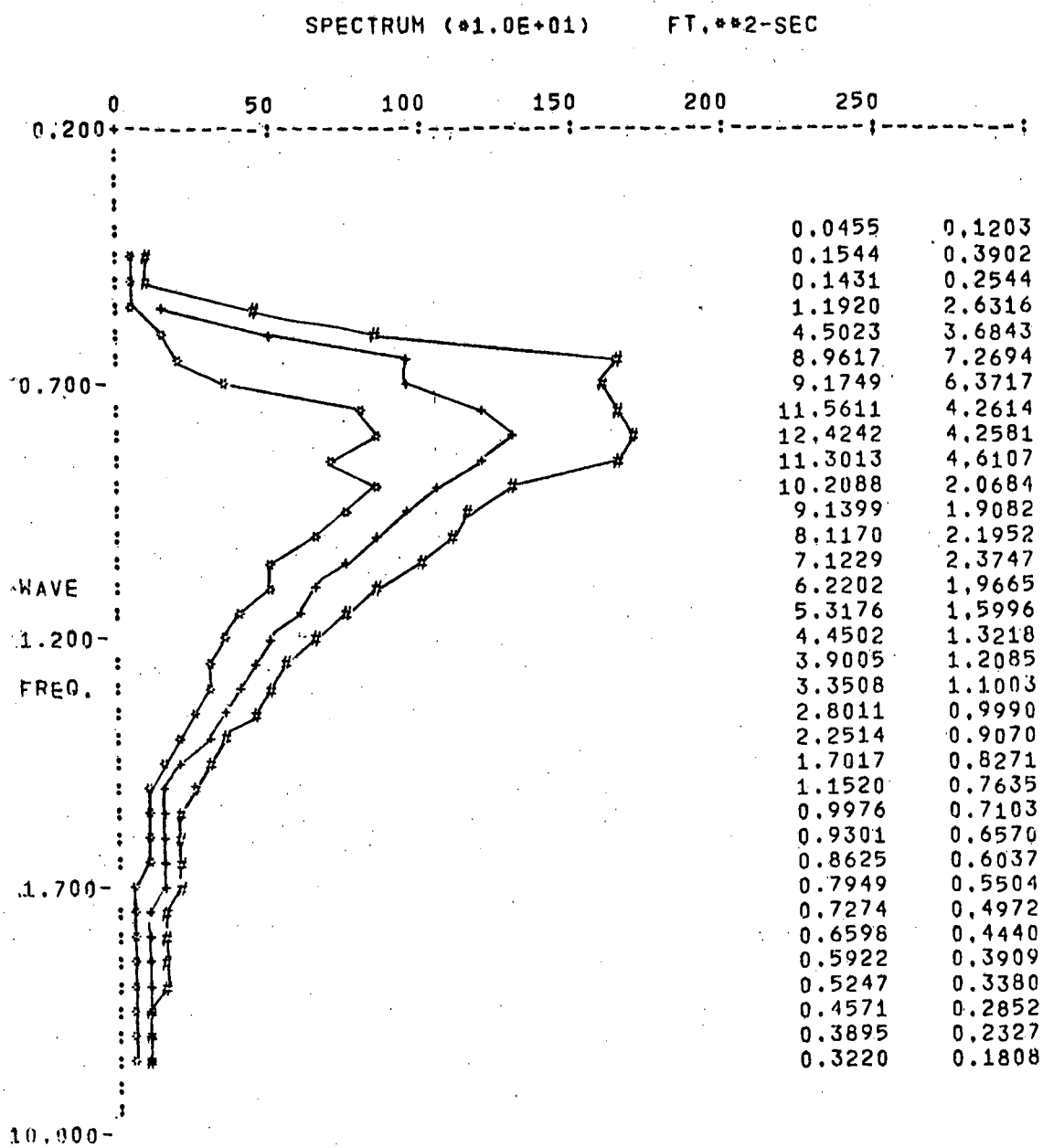


Figure 5-34. Gulf of Alaska Wave Spectra, 9'-12' Group Summer Mean ± Standard Deviation

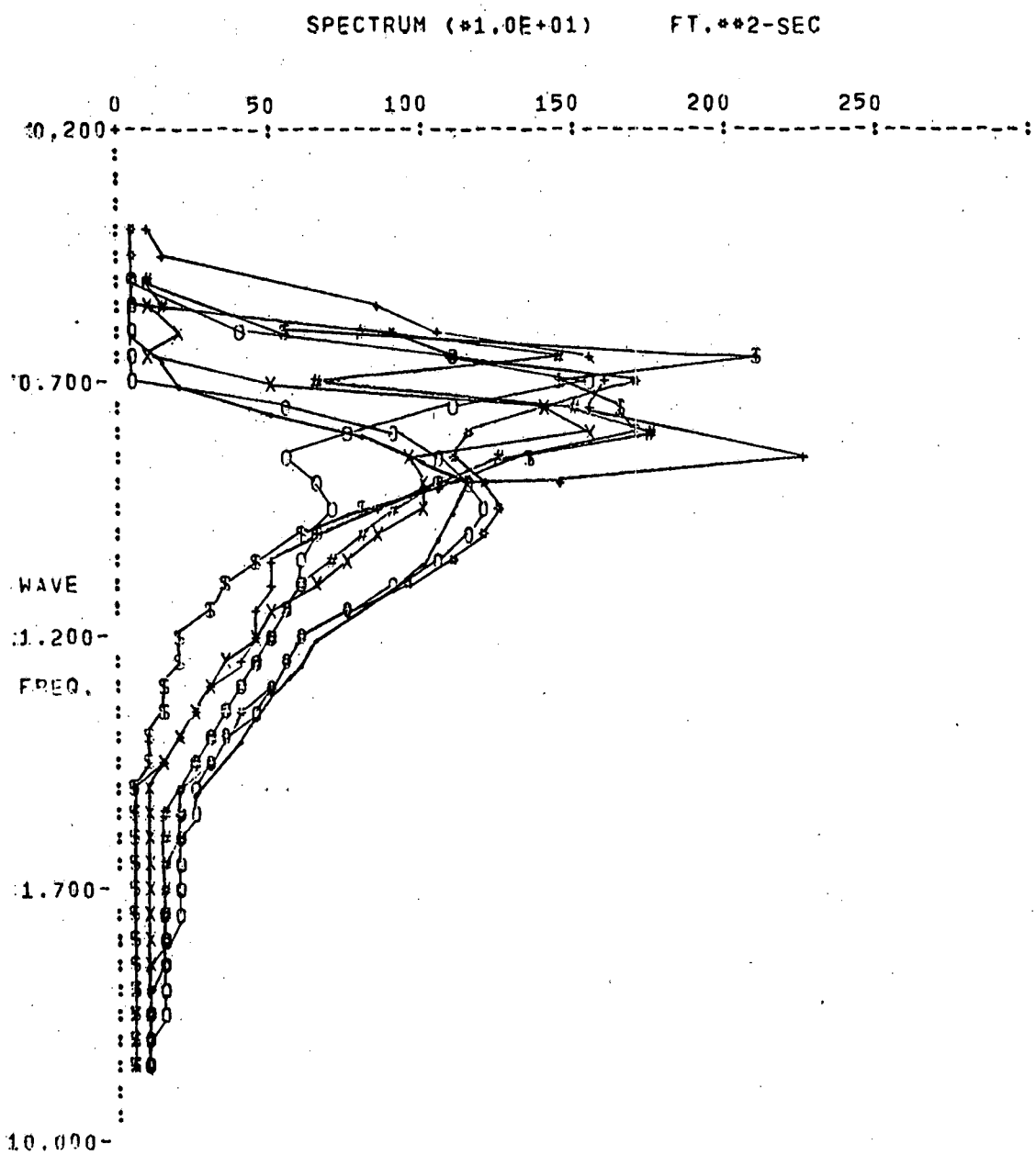


Figure 5-35. Gulf of Alaska Wave Spectra, 9'-12' Group-Summer

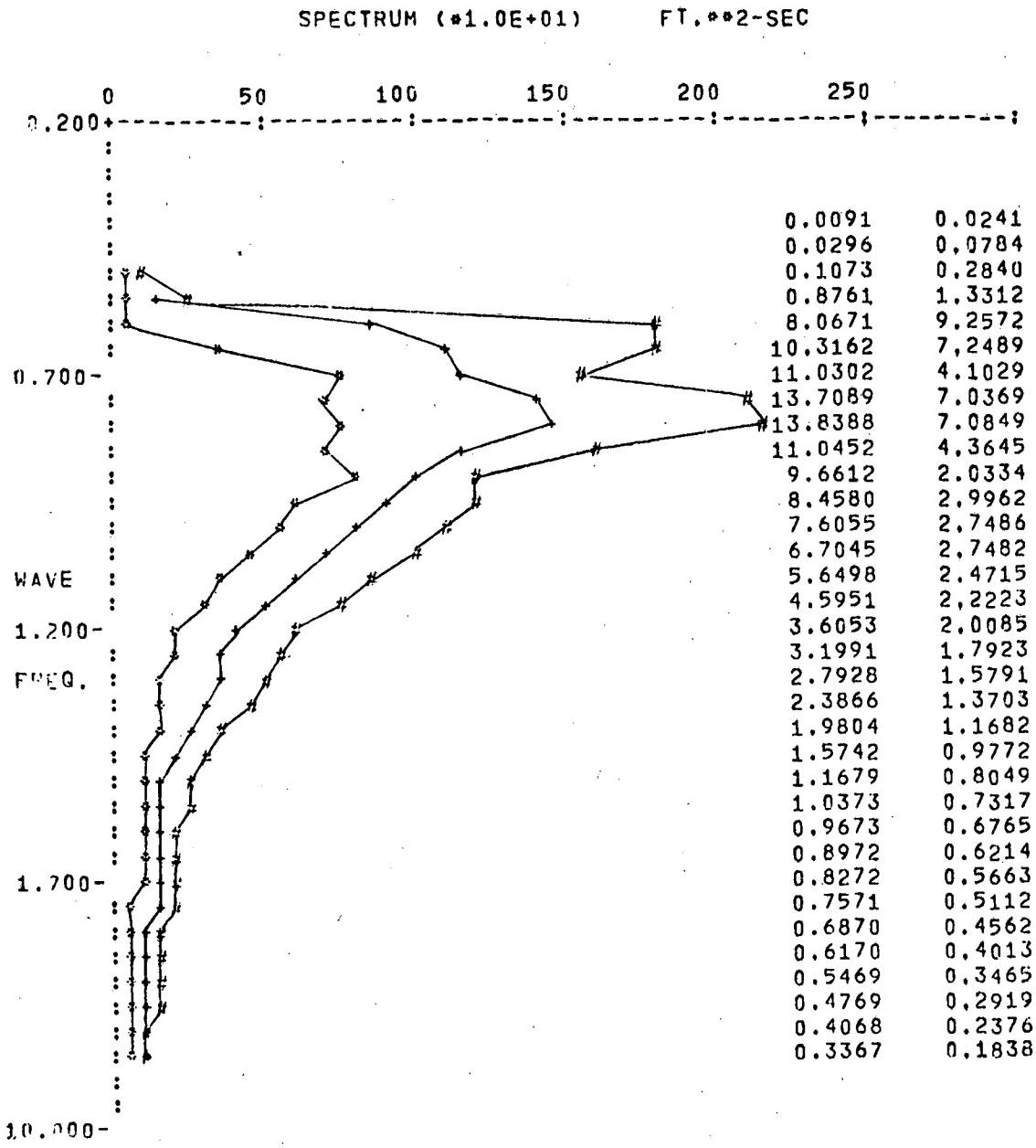


Figure 5-36. Gulf of Alaska Wave Spectra, 9'-12' Group-Winter Mean±Standard Deviation

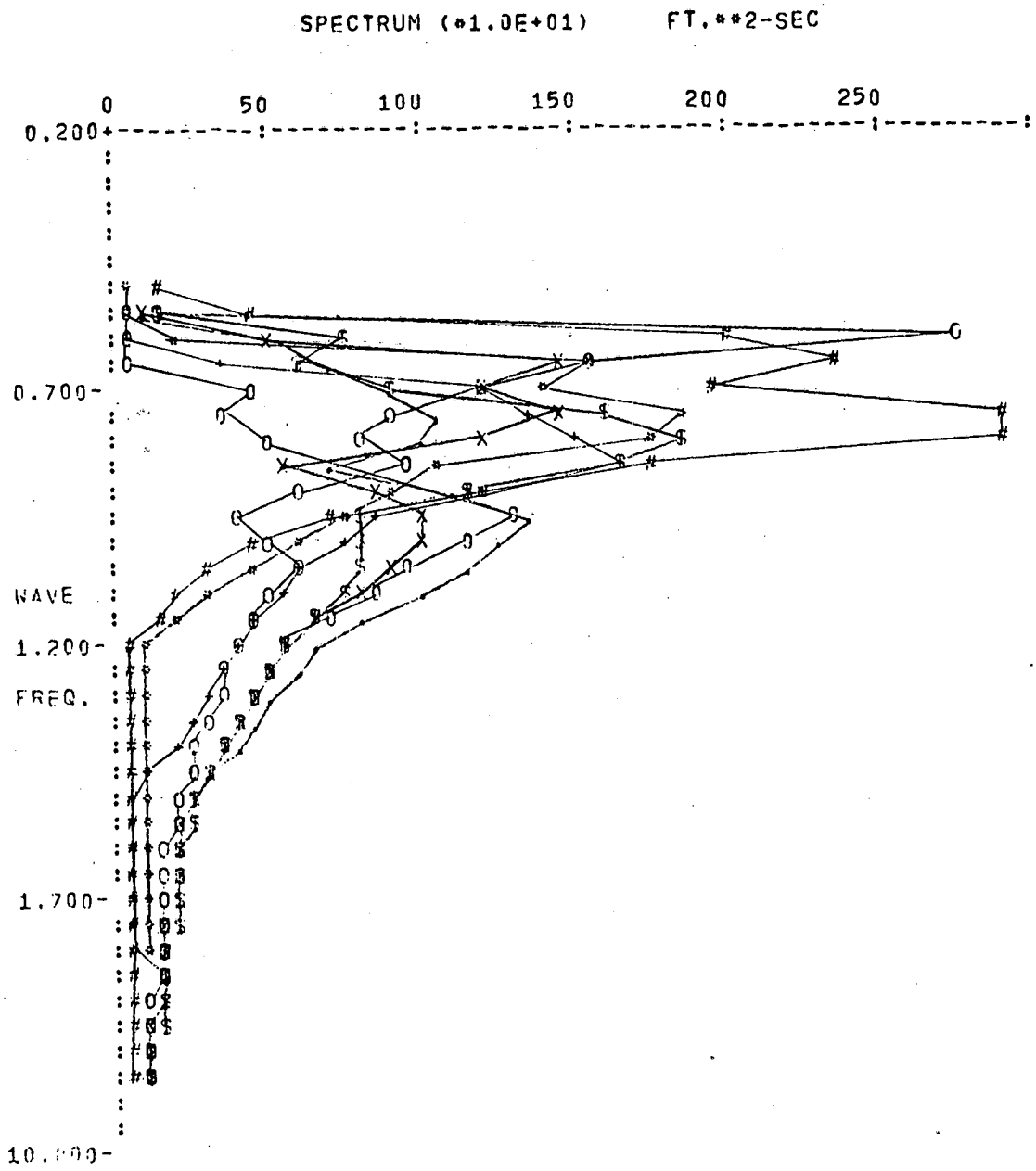
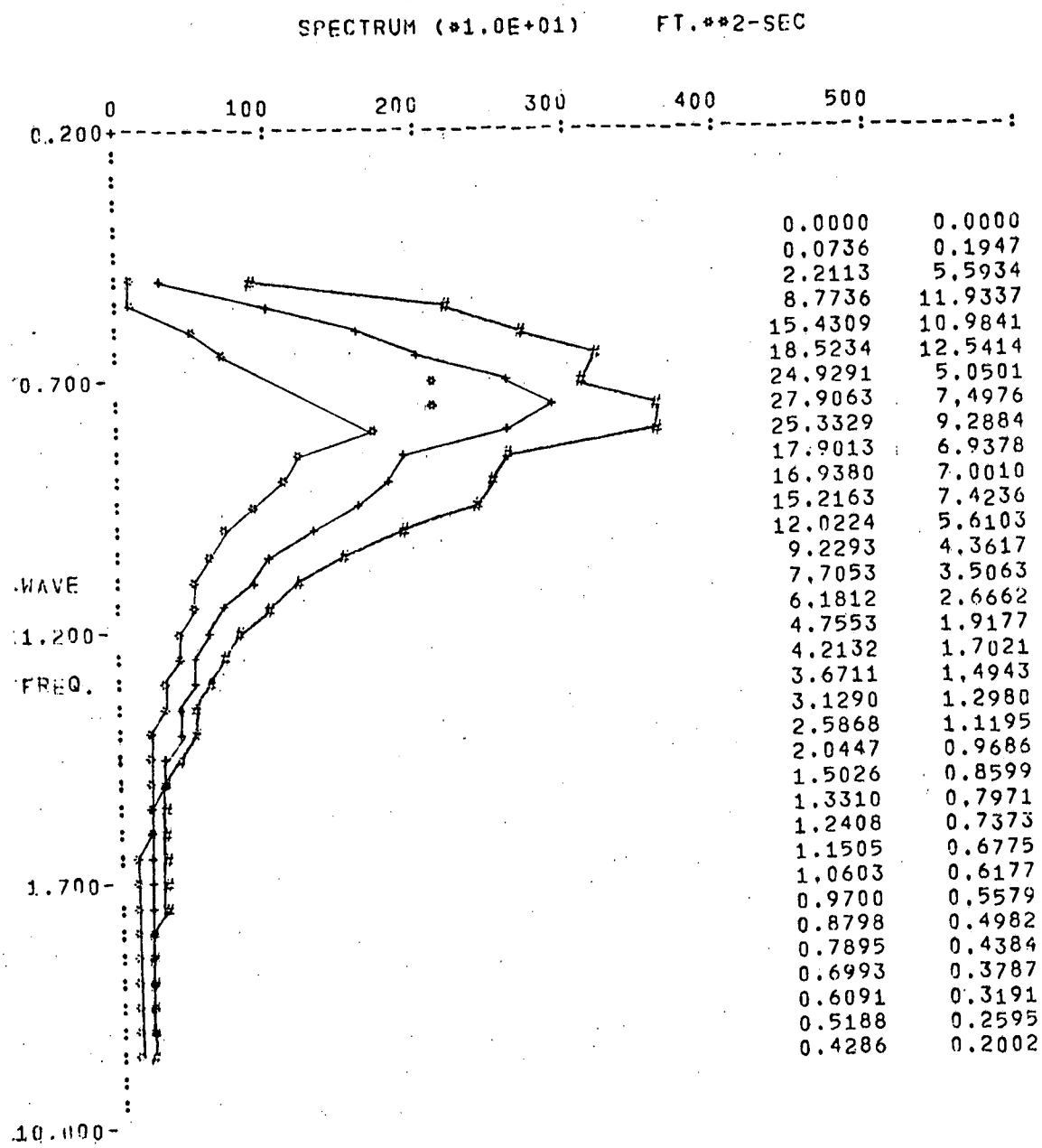


Figure 5-37. Gulf of Alaska Wave Spectra, 9'-12' Group-Winter



0.0000	0.0000
0.0736	0.1947
2.2113	5.5934
8.7736	11.9337
15.4309	10.9841
18.5234	12.5414
24.9291	5.0501
27.9063	7.4976
25.3329	9.2884
17.9013	6.9378
16.9380	7.0010
15.2163	7.4236
12.0224	5.6103
9.2293	4.3617
7.7053	3.5063
6.1812	2.6662
4.7553	1.9177
4.2132	1.7021
3.6711	1.4943
3.1290	1.2980
2.5868	1.1195
2.0447	0.9686
1.5026	0.8599
1.3310	0.7971
1.2408	0.7373
1.1505	0.6775
1.0603	0.6177
0.9700	0.5579
0.8798	0.4982
0.7895	0.4384
0.6993	0.3787
0.6091	0.3191
0.5188	0.2595
0.4286	0.2002

Figure 5-38. Gulf of Alaska Wave Spectra, 12'-16' Group-Winter Mean ± Standard Deviation

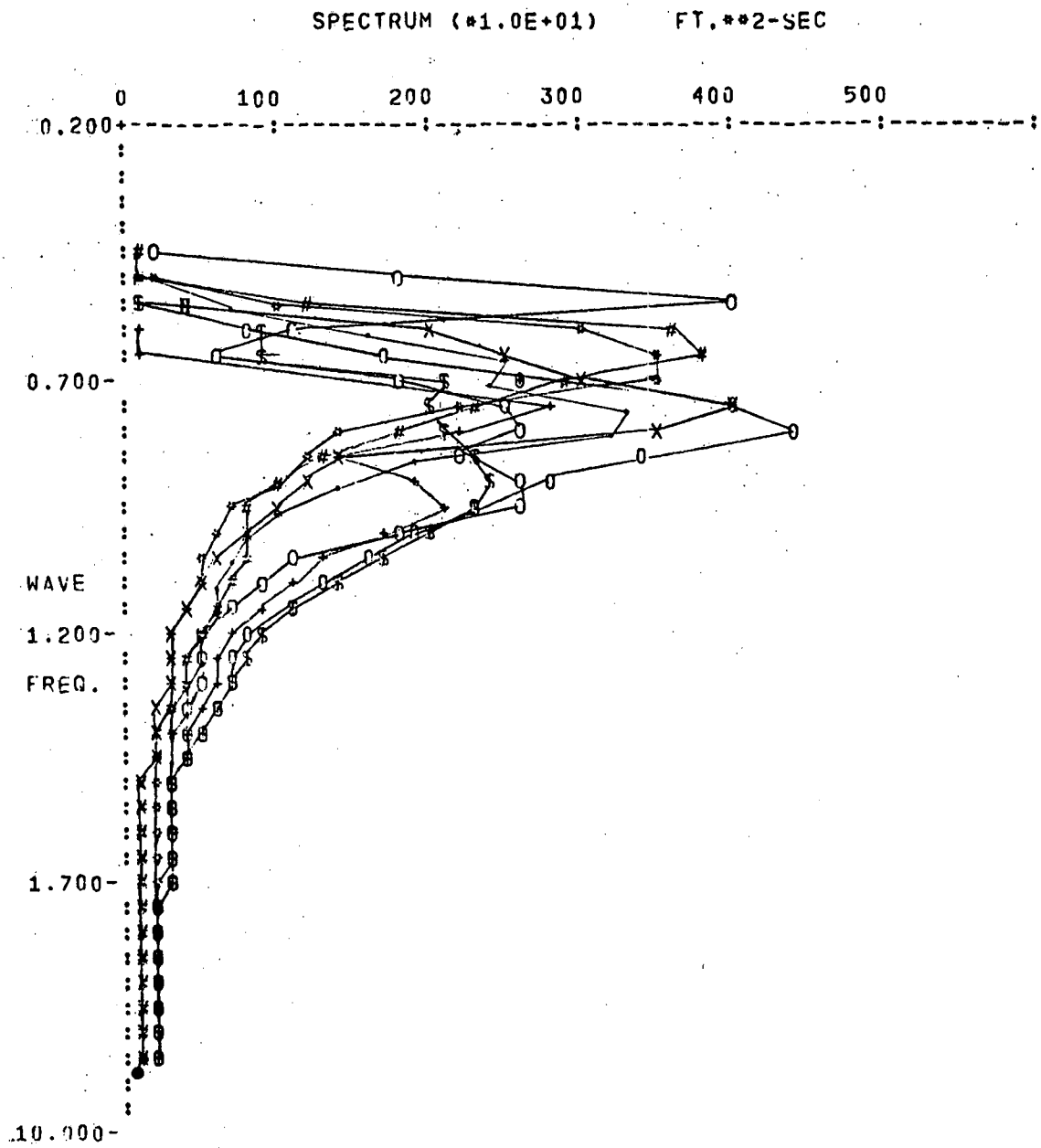


Figure 5-39. Gulf of Alaska Wave Spectra, 12'-16'Group-Winter

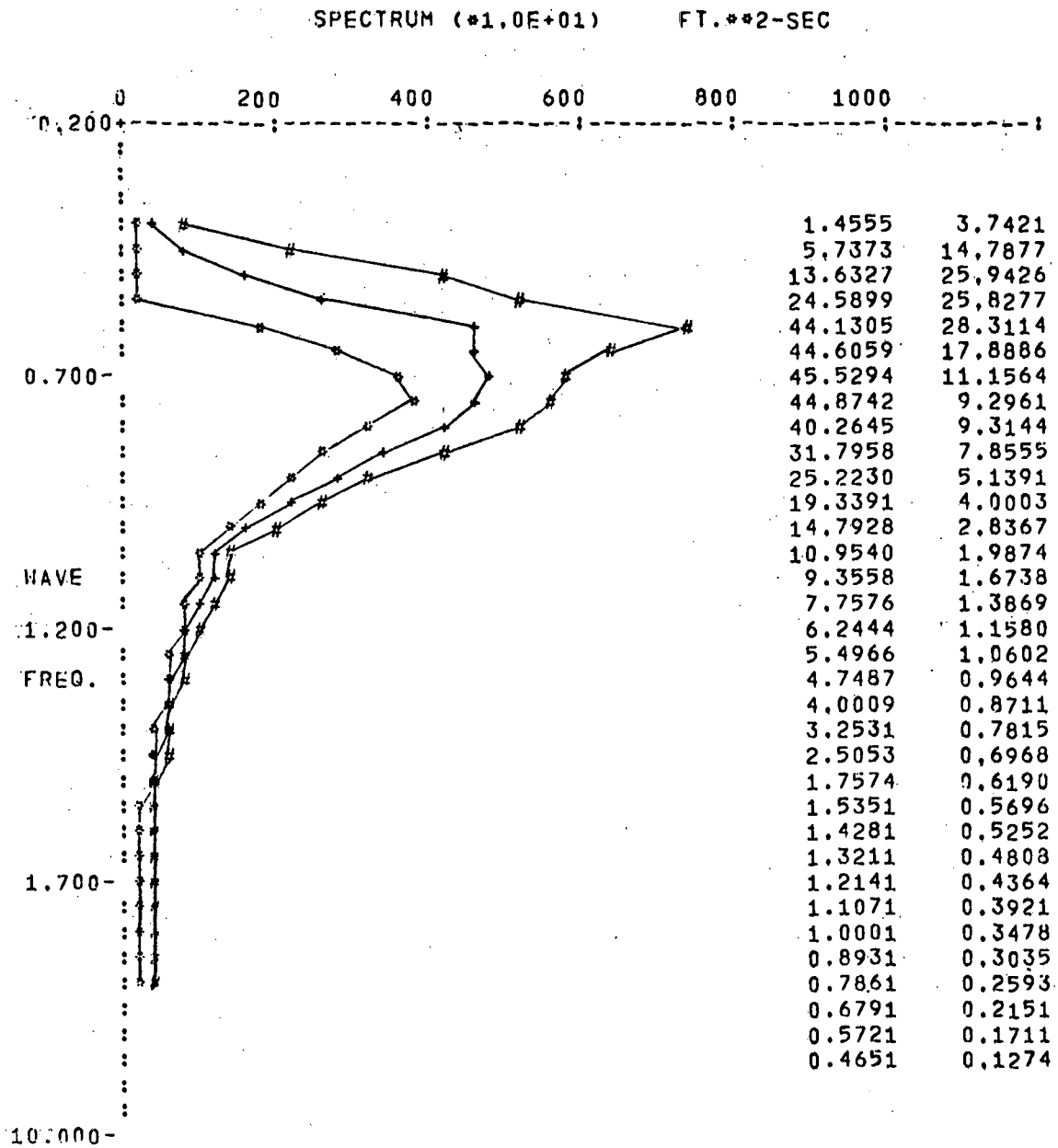


Figure 5-40. Gulf of Alaska Wave Spectra, 16'-21' Group-Winter Mean ± Standard Deviation

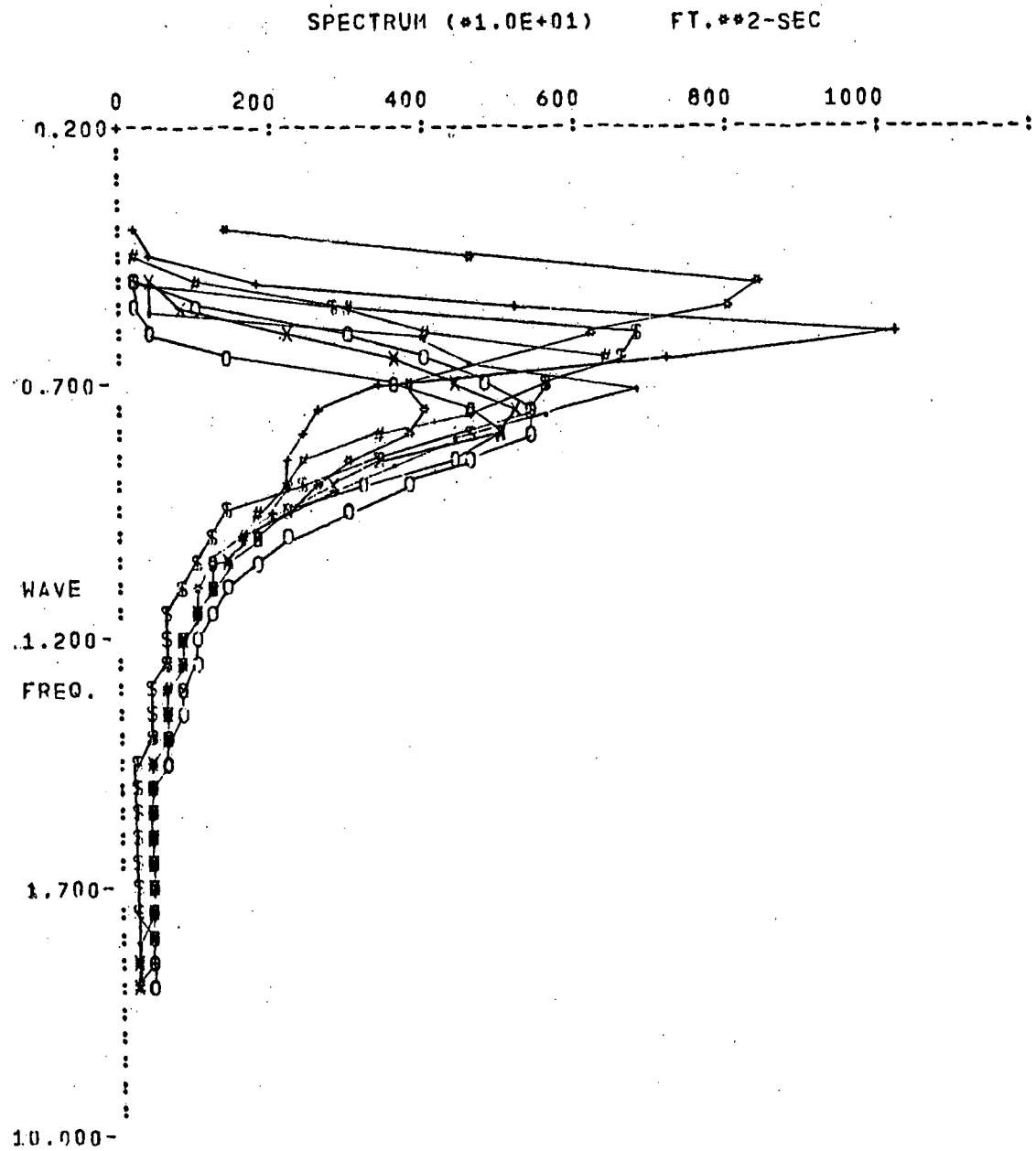


Figure 5-41. Gulf of Alaska Wave Spectra, 16'-21' Group-Winter

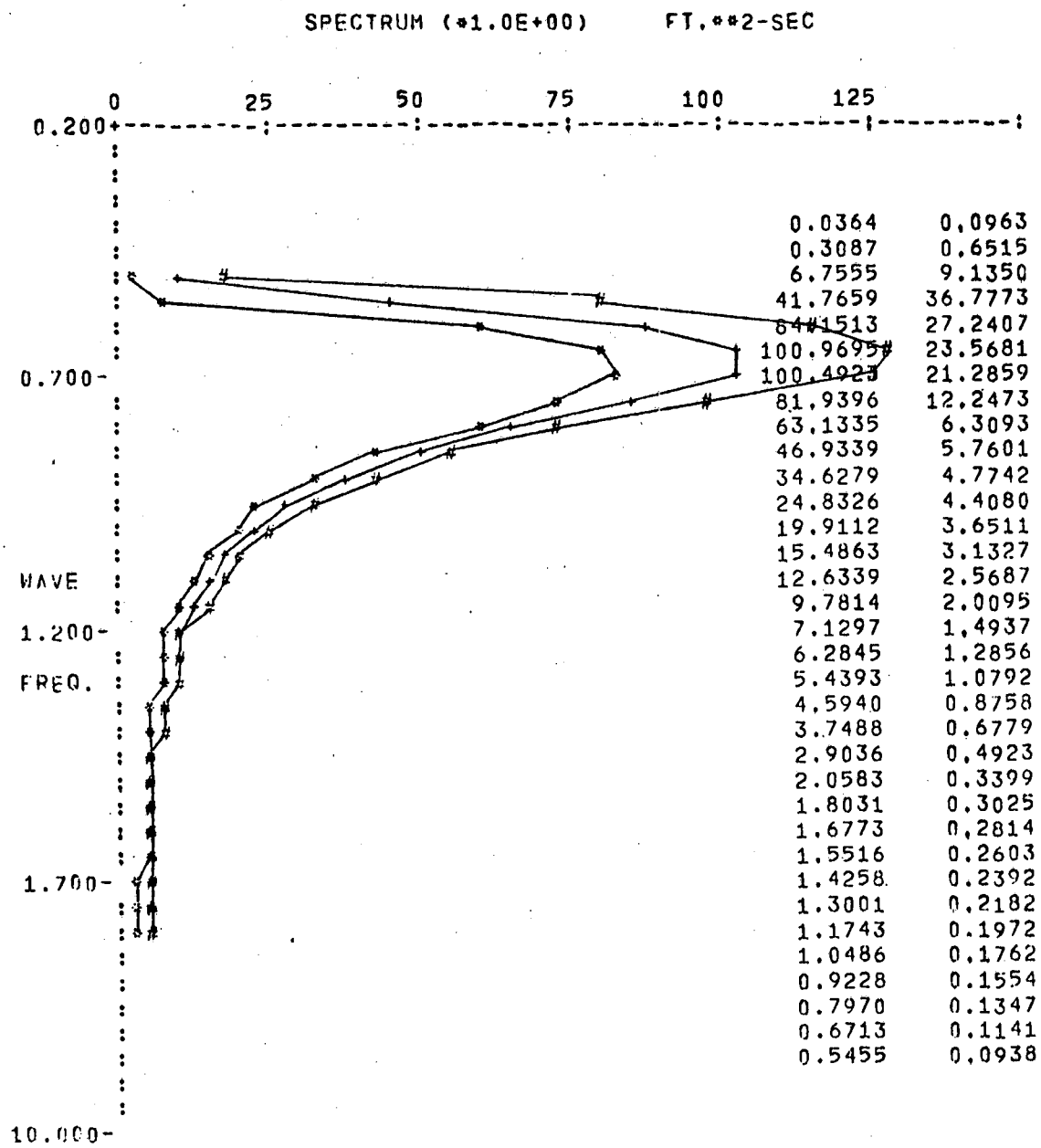


Figure 5-42. Gulf of Alaska Wave Spectra, 21'-27' Group-Summer Mean ± Standard Deviation

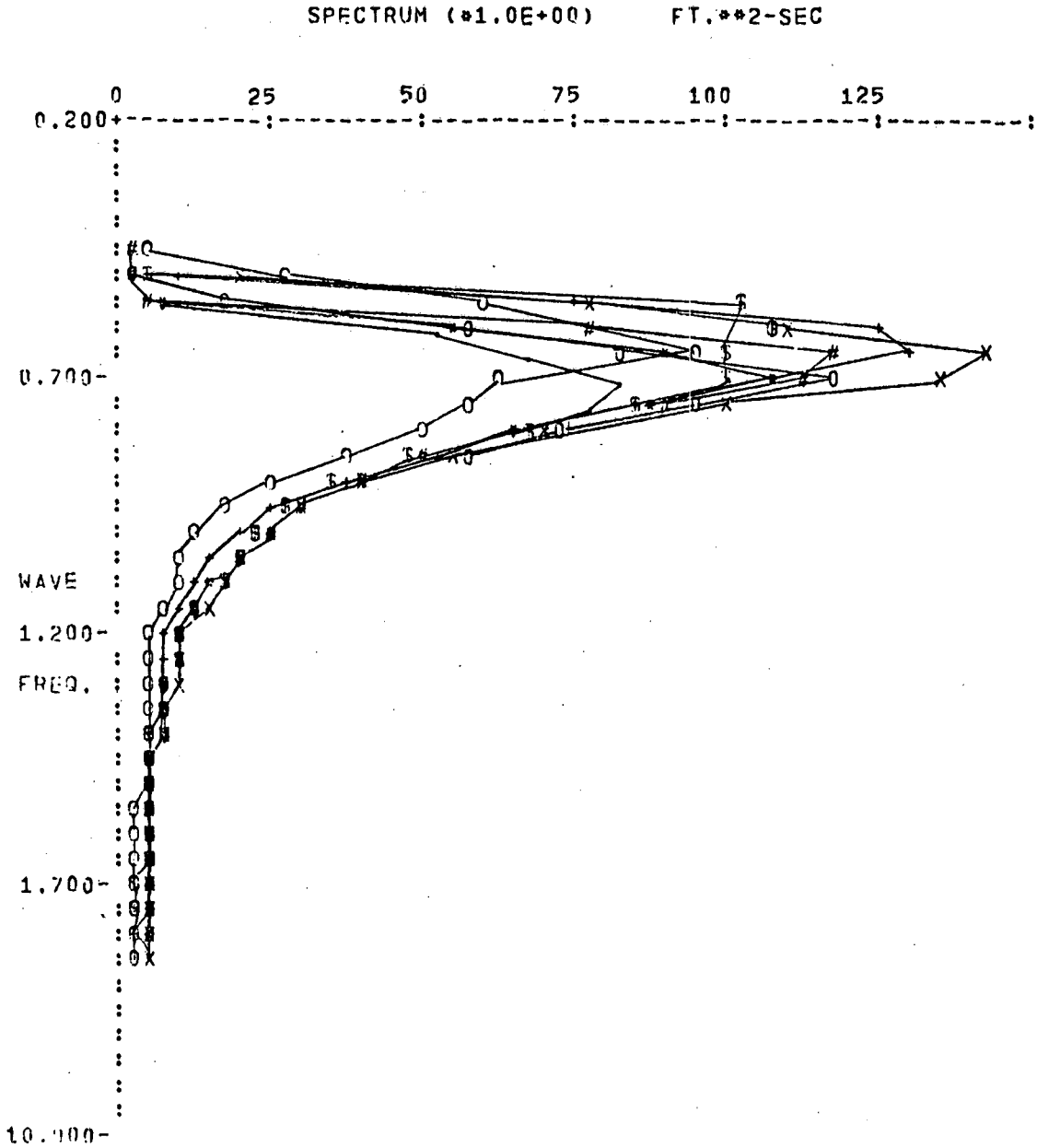


Figure 5-43. Gulf of Alaska Wave Spectra, 21'-27' Group-Summer

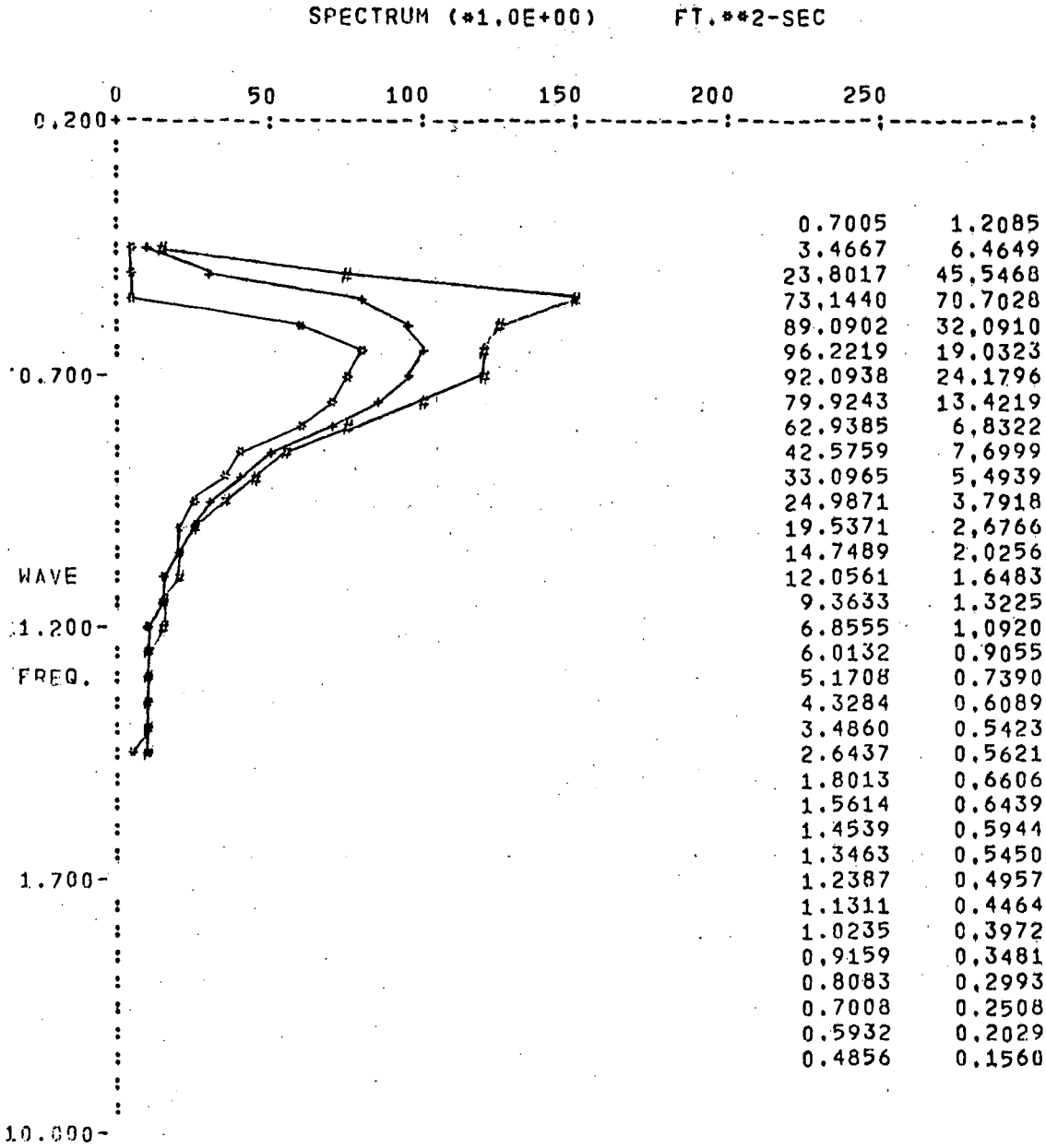


Figure 5-44. Gulf of Alaska Wave Spectra, 21'-27' Group-Winter Mean ± Standard Deviation

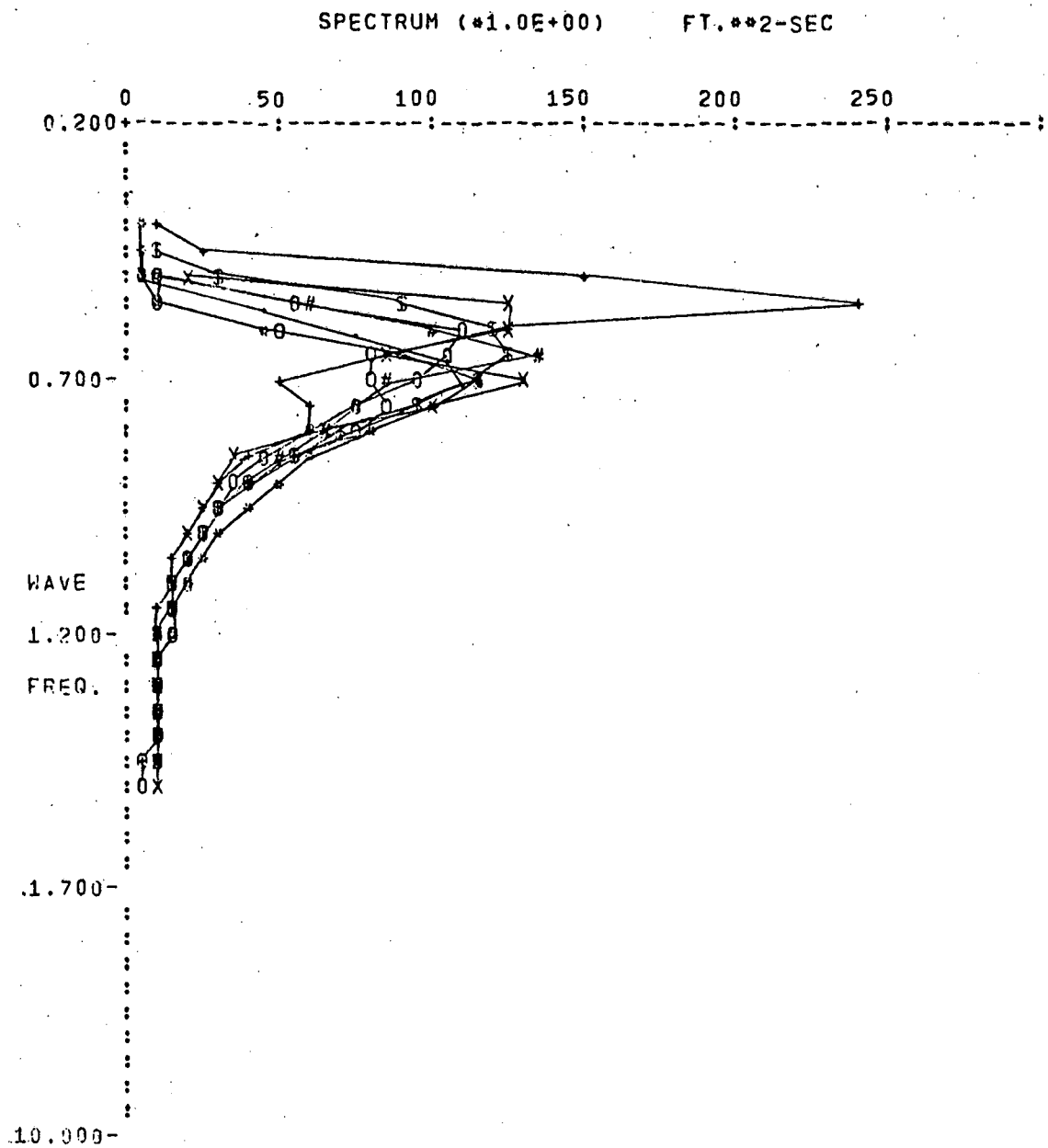


Figure 5-45. Gulf of Alaska Wave Spectra, 21'-27' Group-Winter

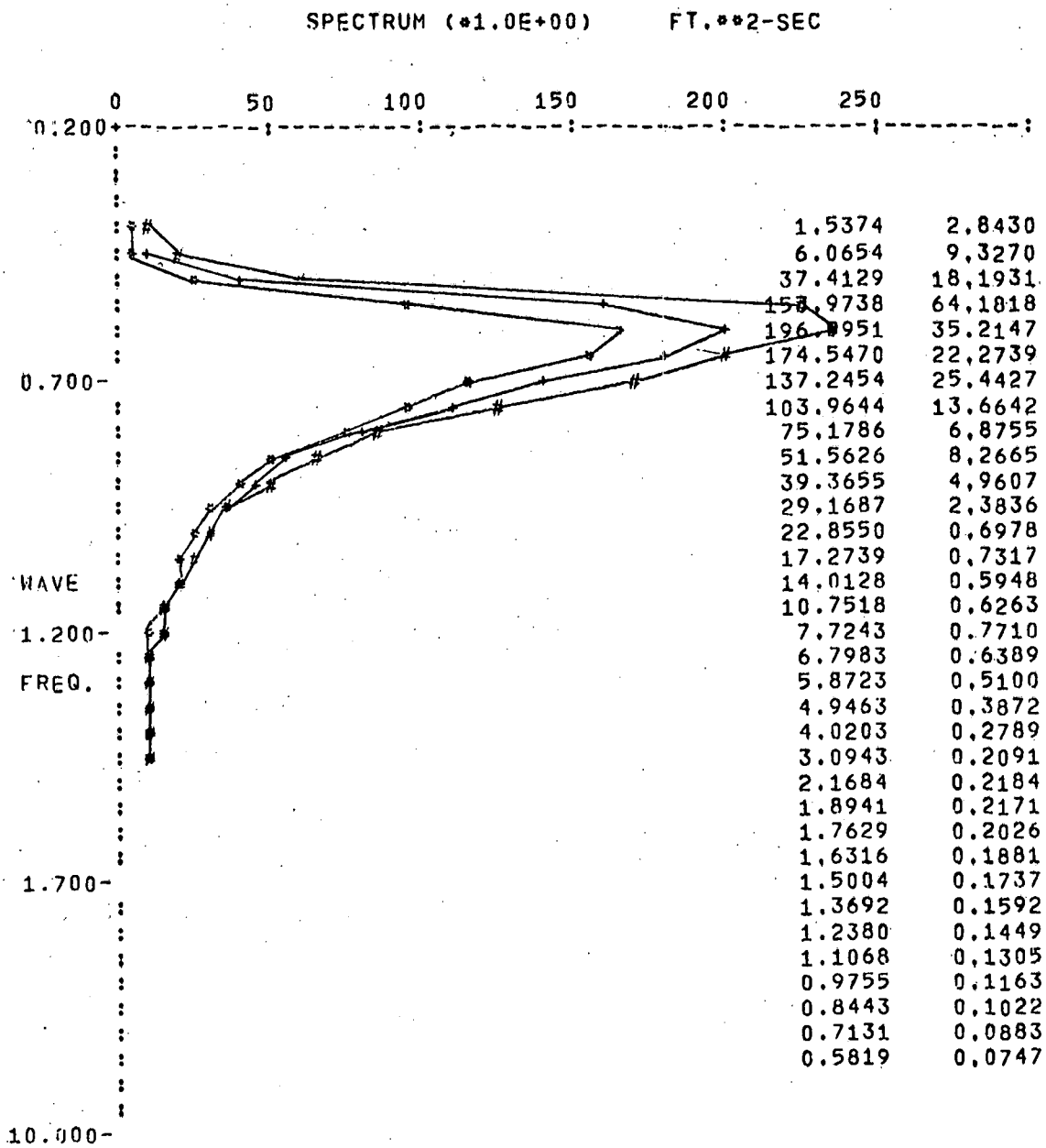


Figure 5-46. Gulf of Alaska Wave Spectra, 27'-34' Group-Winter Mean ± Standard Deviation

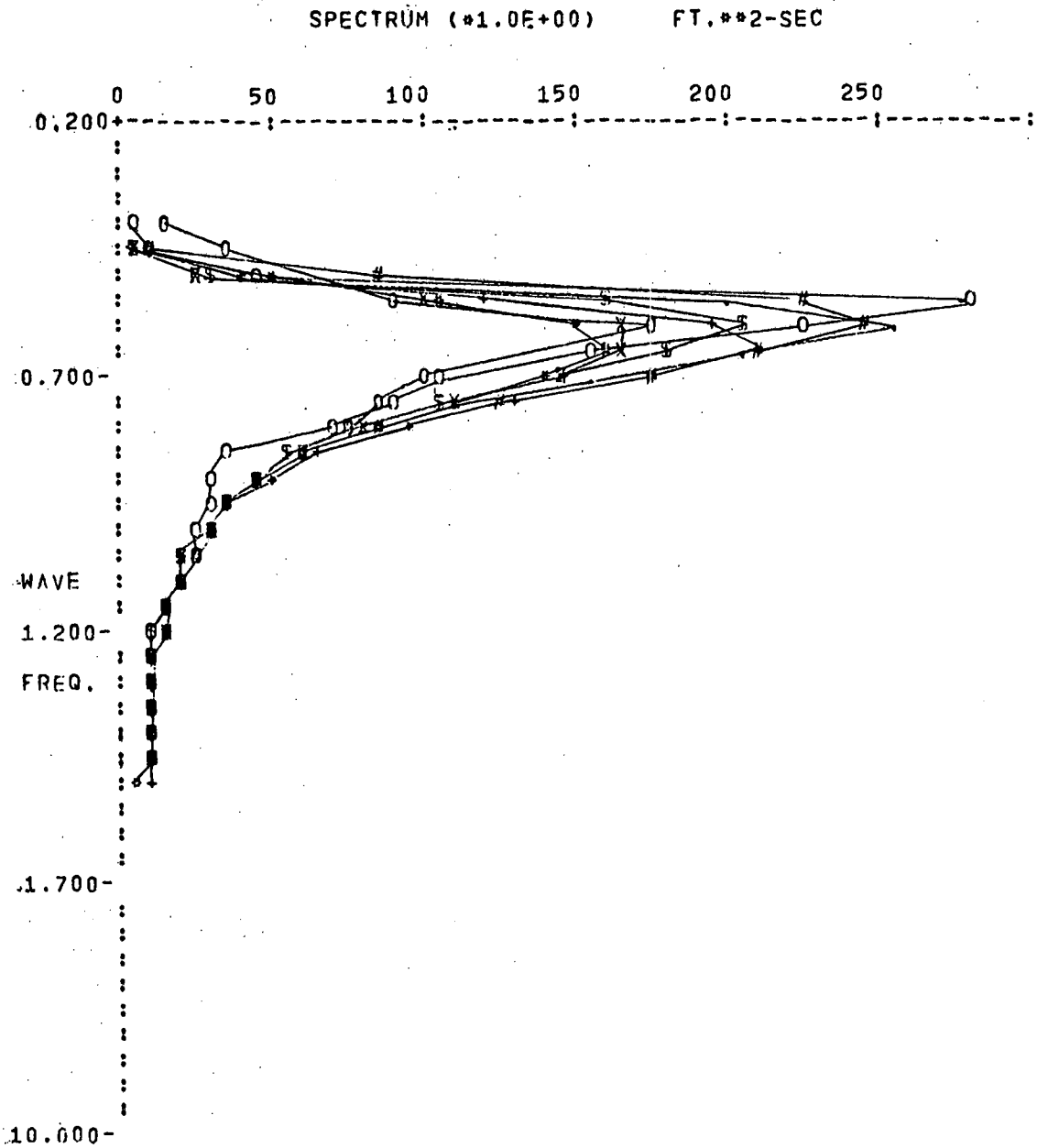


Figure 5-47. Gulf of Alaska Wave Spectra, 27'-34' Group-Winter

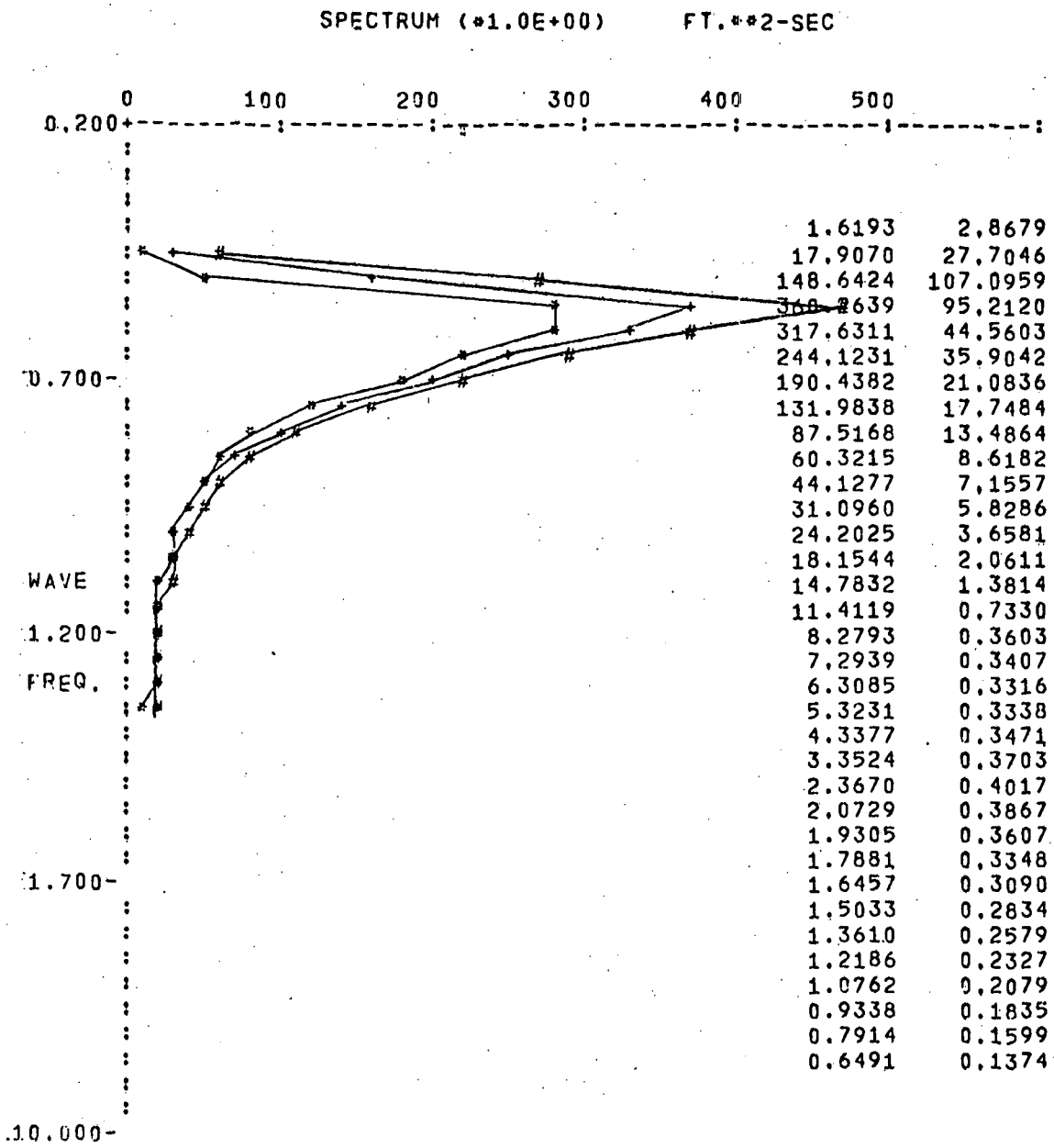


Figure 5-48. Gulf of Alaska Wave Spectra, 34'-42' Group-Winter Mean ± Standard Deviation

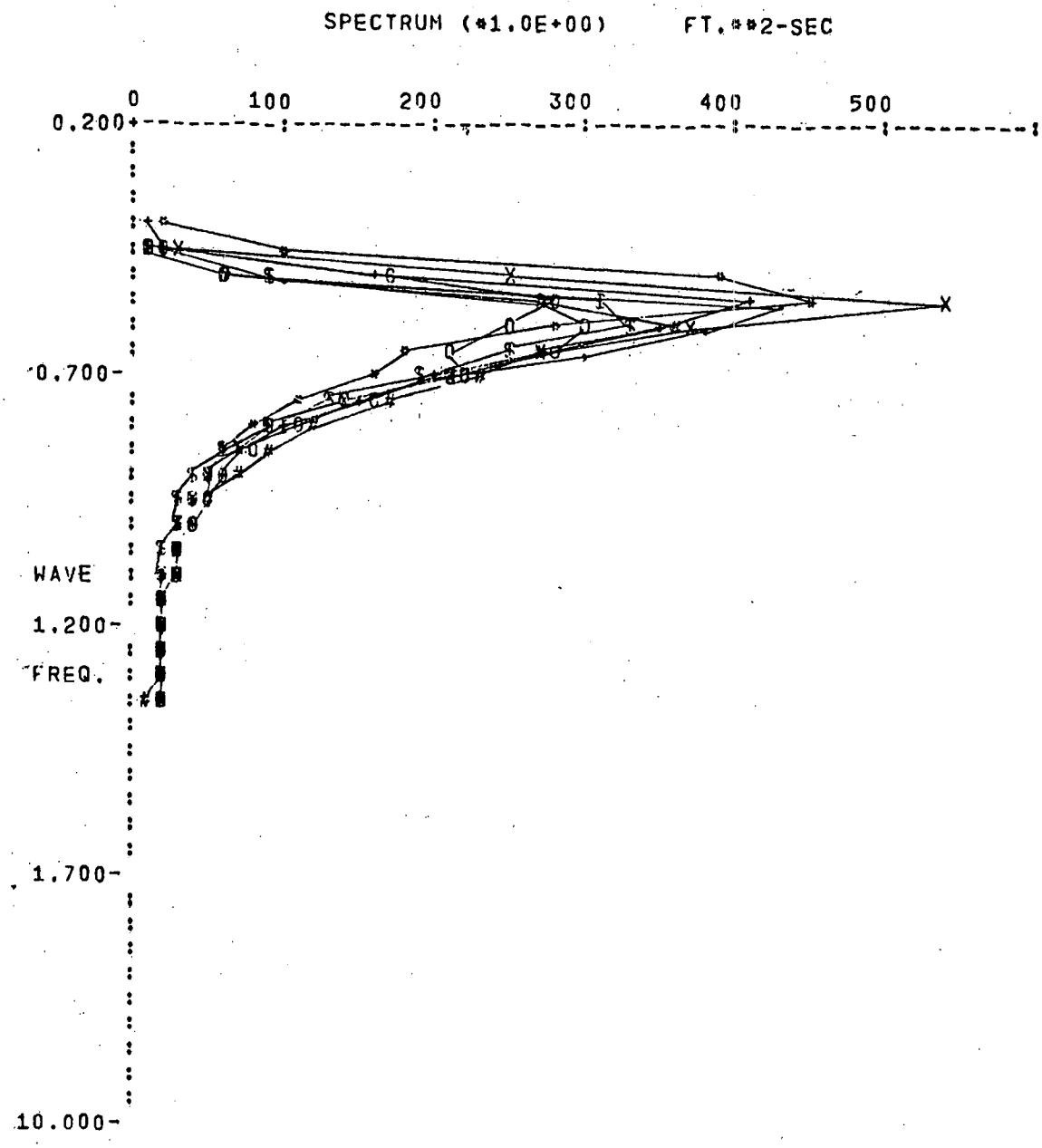


Figure 5-49. Gulf of Alaska Wave Spectra, 34'-42' Group-Winter

The spectral families depicted in the figures were developed as input for motion analysis of semi-submersibles and drill ships. Several spectral families corresponding to significant wave heights in the mid to upper end of the normal wave height range are given. In the range 9'-12' and 21'-27' spectral data for both the winter season (October-March) and the summer season (April-September) are given for comparison purposes. Table 5-16 presents certain spectral parameters comparing spectral shape for winter and summer. It is seen that there is not a significant variation in spectral shape from season to season. This was found to be generally true and, therefore, spectral data for only winter seasons are given for the remaining groups.

The selection of representative spectra for each range of significant height was based on four spectral parameters: (1) the mean significant height; (2) mean period; (3) standard deviation of the area under a spectral curve; and (4) the mean "broadness" parameter. The "broadness" parameter, ϵ, is defined in terms of the zero, second and fourth spectral moments:

$$\epsilon^2 = 1 - \frac{M_2^{\,2}}{M_o M_4}$$

From each group, sets of eight spectra were selected randomly; the same four parameters were calculated and compared to the mean parameters of the group. When a set was found for which the parameters were considered sufficiently close to the means, this set of eight spectra was then considered to be representative of that wave height range. The spectral properties obtained for several of the wave height groups are shown in Figures 5-34 through 5-49. The first figure for each group is a plot of the mean spectral density $\pm$ the standard deviation for the eight spectral curves in each group. Spectral density is plotted as a function of circular frequency, ω. The second figure in each group shows the eight spectral curves which are representative of the height group.

Table 5-16. Comparison of Spectral Parameters for Winter and Summer Wave Groups

	Winter 9' - 12'	Summer 9' - 12'
H (1/3), ft.	10.42	10.29
Mean Period, sec.	8.44	8.15
Broadness	0.653	0.628
	Winter 21' - 27'	**Summer 21' - 29'**
H (1/3), ft.	23.98	23.47
Mean Period, sec.	11.05	10.62
Broadness	0.700	0.691

6. SEISMIC AND GEOLOGIC CONDITIONS

6.1 INTRODUCTION / SUMMARY

This section of the report contains preliminary design data for the Eastern Gulf of Alaska.

Emphasis is placed on a review of important considerations relative to selecting a format for seismic design data. Considerations reviewed include the concept of risk as related to structural performance, soil structure interaction, point of motion application, attenuation of ground motion, and regional seismic source distribution. It is concluded from this review that a general form for ground motion description involving response spectra and stochastic simulation from which time histories may be generated, is necessary to satisfactorily describe the ground motion environment.

Also included are the results from reviewing three strong motion studies performed by McGuire, 1974; Seed, et al, 1976; and Mohraz, 1976. These studies were reviewed to ascertain their applicability to the Eastern Gulf of Alaska. Whereas studies reviewed previously were found to be deficient in several areas, these studies tended to overcome some of the deficiencies, particularly those related to the treatment of long period motion.

A critical evaluation was completed of six recent studies of seismic risk pertaining to the Eastern Gulf of Alaska, and the results are provided.

A composite of design basis earthquake ground motions proposed by various investigators is presented in the form of peak ground velocity as a function of return period. Also presented is a family of response spectra which have been proposed for developments in the Eastern Gulf of Alaska.

Finally, the section on geology provides information on locating potential hazards relative to proposed lease tracts. Also provided are typical soil profiles showing sedimentary layer thicknesses at various locations within the study area.

6.2 DATA FORMAT

6.2.1 General

The purpose of the current activity is to provide seismological and geological data which are pertinent to ensuring the safety and pollution control of offshore developments in frontier lease areas. More directly stated, the purpose is to provide data which will serve as a basis for design criteria for offshore structures. As such, it is necessary to study the form or format of alternatives available for criteria specification, and use the results as a guide to the collection, organization, and analysis of seismological and geological data. The goal of this effort is to provide a basis for standards which are definitive, defensible, enforceable, and rational.

It is important to recognize two basic concerns in developing a format for criteria specification. One is the limitation of our basic knowledge regarding the seismic environment. The other is the limitation of available methods for design and analysis. These factors are important in deciding where to apply the controls in the regulatory process. Specifically, the question of whether criteria should be accompanied by methods for design and in the extent to which such methods should be specified is of major importance and the subject of considerable controversy within the technical profession. Regarding these considerations, performance criteria or standards are possibly more appropriate than design/fabrication standards. The former allow innovation and flexibility in design, which is considered extremely desirable in view of the relative severity of the offshore environment, the limits of our knowledge of that environment, and the state-of-the-art in offshore structure design and analysis. Design/fabrication standards are more easily enforced than are performance standards; however, they tend to encourage the development of definitive or standard designs and discourage the development of new technology with its related economic benefits.

In selecting a format for seismic design data, it is important to recognize a number of issues which face the earthquake engineering community. These issues are possibly the best indication of the current state-of-the-art. The most recent forum for debate on these issues was the Advisory Committee on Reactor Safeguards (ARCS) Seismic Activity Subcommittee meeting sponsored by the Nuclear Regulatory Commission on 8 and 9 February 1977. This meeting was attended by approximately 200 members of the nuclear engineering community and featured a number of prominent speakers representing a cross section of seismologists, geologists, and engineers. A summary of the ARCS meeting, prepared by T. Hasselman, is included as Appendix F in an earlier issue of this report (March, 1977). The summary provides an insight into some of the more important current issues.

The following paragraphs address the important technical considerations as they relate to data evaluation and format selection.

6.2.2 Risk Preference

It is generally agreed that designs should be conservative. The question is how conservative? The current controversy concerning conservatism seems to center about whether methods of risk analysis should be used to quantify the degree of conservatism or whether other means involving experience and judgment ought to be used to establish limiting bounds. The primary objection to risk analysis seems to be borne out of suspicion that "statistics can be used to justify anything" and that in any case, we may not have enough information to arrive at statistically meaningful conclusions. Proponents of risk analysis argue that the tools of probabilistic analysis, when used properly, provide both a valid and objective basis for quantifying conservatism or risk.

With regard to the use of risk analysis as a basis of selecting seismic design data, six sources of uncertainty are recognized. They are: • Occurrence, • Magnitude, • Location, • Attenuation (of intensity from source to site),

• Spectral Shape (distribution of energy), and • Waveform (giving the distribution of energy). These and similar sources of uncertainty will be treated parametrically, to the extent practical in this study, in arriving at a description of the seismic design environment.

6.2.3 Ground Motion Characterization

The method of characterizing strong ground motion is of critical importance to offshore structure design. Both interpretation of the seismic environment, as well as the influence of this environment on platform design depend on the method of ground motion characterization. A Response spectrum, as shown in Figure 6-1, is the most commonly used description of strong ground motion for design purposes. Less widely used descriptions are normalized time histories either generated synthetically or based on adjusted actual records, Figure 6-2, and power spectral densities, Figure 6-3. These descriptions of strong ground motion are scaled using descriptors of ground motion intensity derived from studies of regional seismicity and tectonics such as peak acceleration, peak velocity, significant acceleration, and total energy. The accuracy and adequacy of ground motion prescription, considering their dependence on earthquake magnitude, distance, site conditions, etc., is a matter of considerable concern and controversy.

Information, and therefore knowledge with regard to near-field ground motion, is recognized as being very limited. Instrumental data are extremely sparse and little theoretical work has been done. This is an area of current research.

Another area of weakness is in the estimation of long-period motion. This, as with near-field ground motion, is an area of current research involving statistical analysis of strong motion data, as well as some theoretical modeling. Spectral shape, intensity, and duration are all recognized as being important parameters in the characterization of long-period motion.

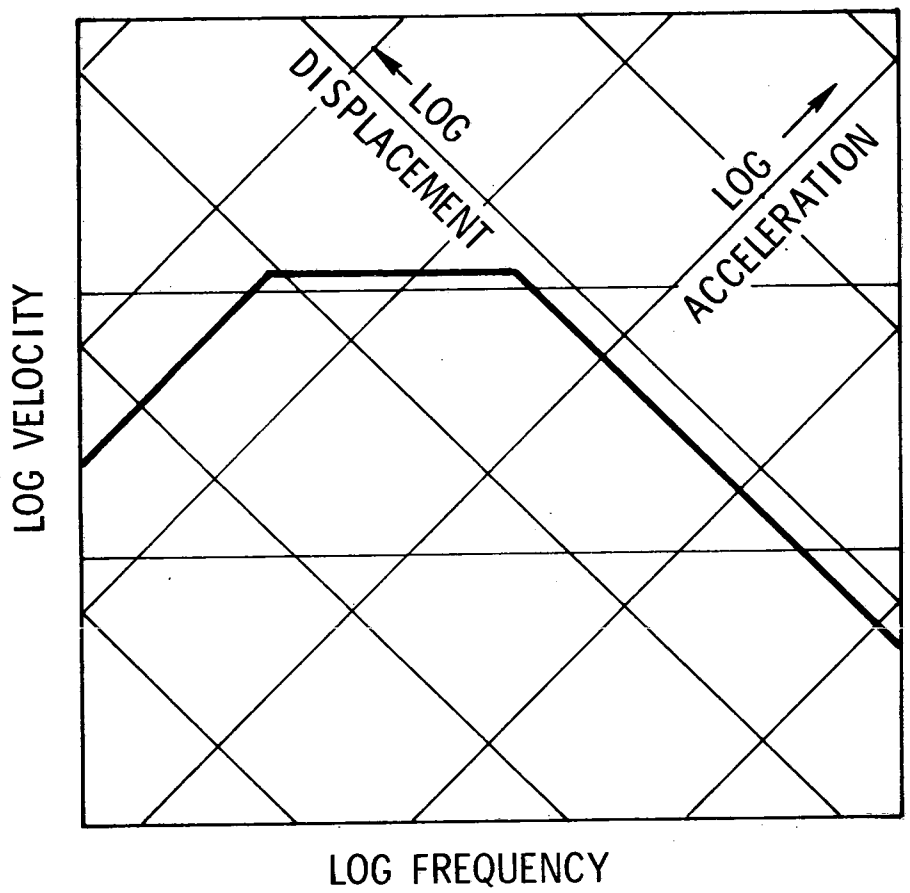


Figure 6-1 Ground Motion Response Spectrum

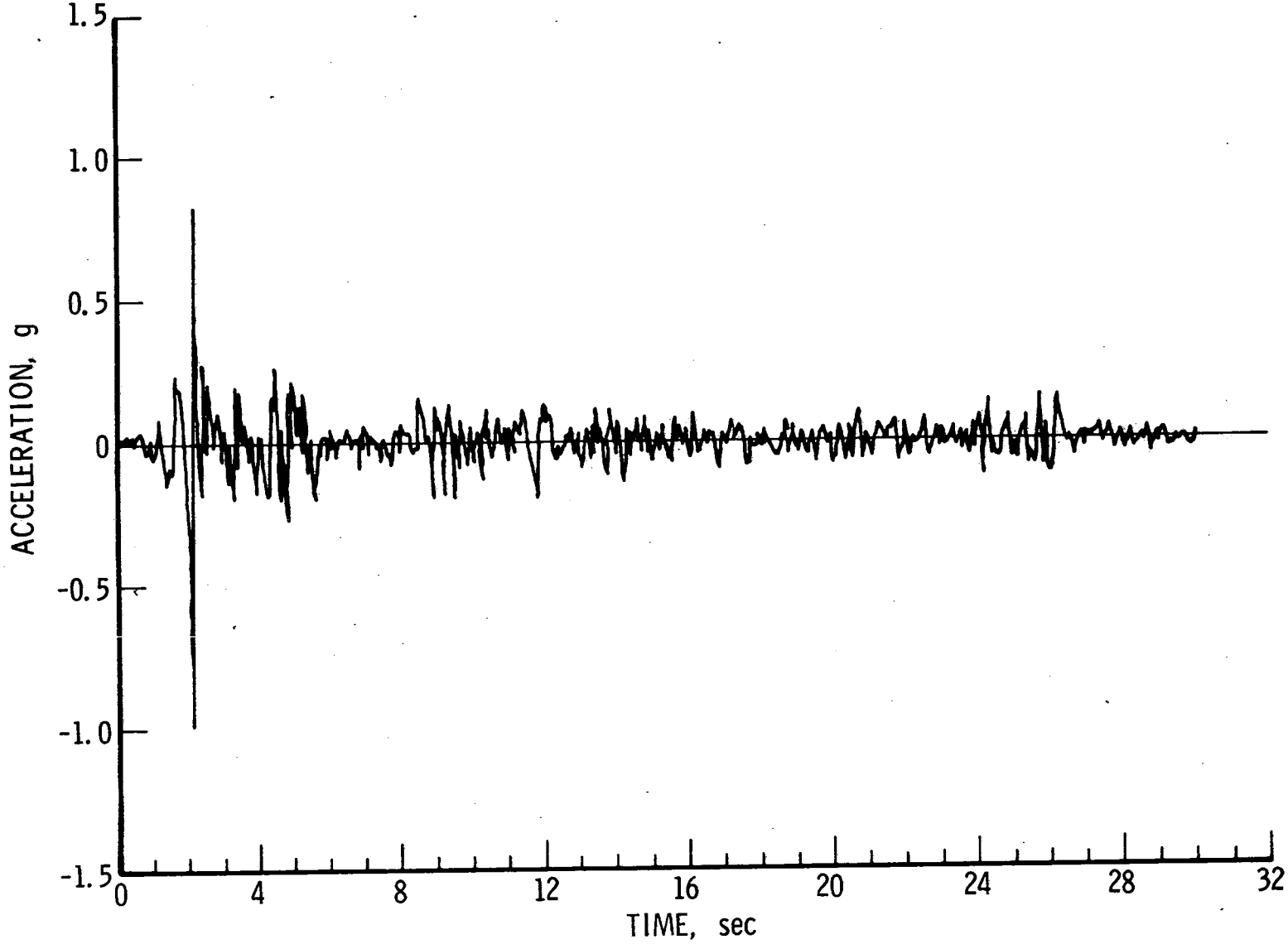


Figure 6-2 Acceleration-Time History, El Centrol, California, May 5, 1940

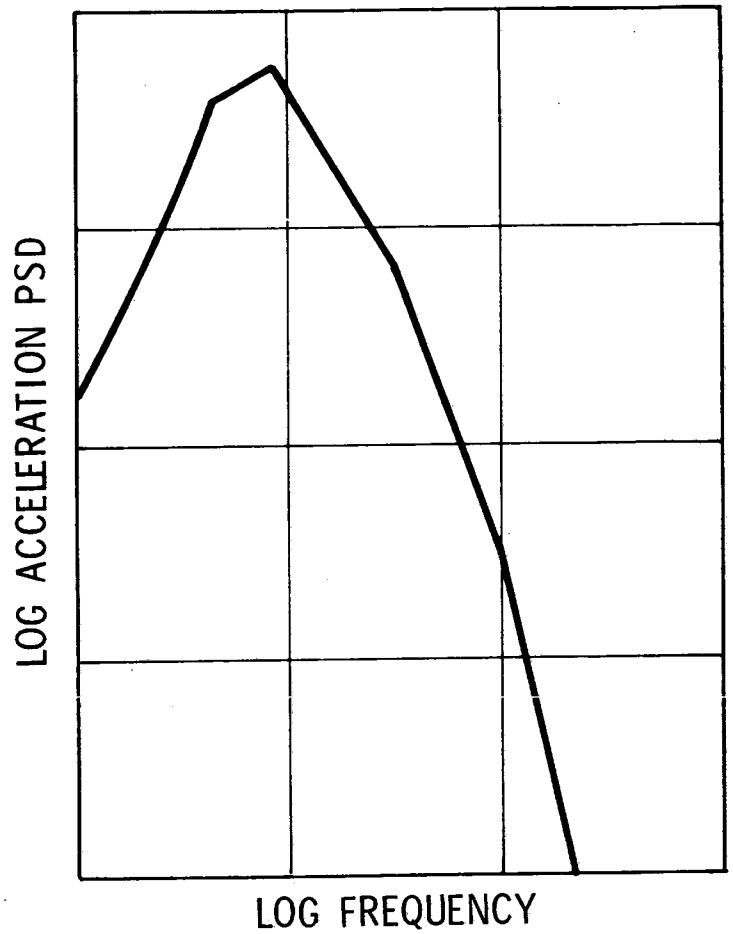


Figure 6-3 PSD Function for Seismic Ground Motion

The selected format for strong motion characterization will provide for specification of seismic ground motion in three different forms: • Response (or design) Spectra, • Time Histories, and • Stochastic Simulation. The latter will constitute a generic form for ground motion characterization based on energy distribution over frequency and time. Either response spectra or artificial time histories can be developed from this form. Since the resulting time histories and response spectra are both derived from the same source, they will be inherently consistent. Response spectra will be probabilistic in nature with spectral intensity being governed by the selected level of risk. Artifically generated time histories will represent important waveform characteristics presently recognized in real accelograms. These characteristics are: random components from body and surface waves which vary in both frequency and intensity as a function of time, and a deterministic component superimposed on the random, as illustrated in Figure 6-4.

The intent is not to produce something which practicing engineers will not understand. The familiar response spectra will provide the basis for preliminary design. However, many of the technical questions and objections now being raised are a direct result of this limited form of ground motion specification. Further, there is no completely satisfactory method for obtaining time history records which are consistent with the specified design spectra. The selection of three different methods; response spectra, time histories, and stochastic simulation for characterizing seismic strong motion is intended to answer these needs.

6.2.3.1 Point of Application

A major concern in the interpretation and use of design spectra is where the input spectra should be applied. In other words, do the design spectra represent limiting response of a bank of oscillators based at the ground surface level, the foundation level of the structure which may be some distance beneath the surface, or at some interface between rock and surficial

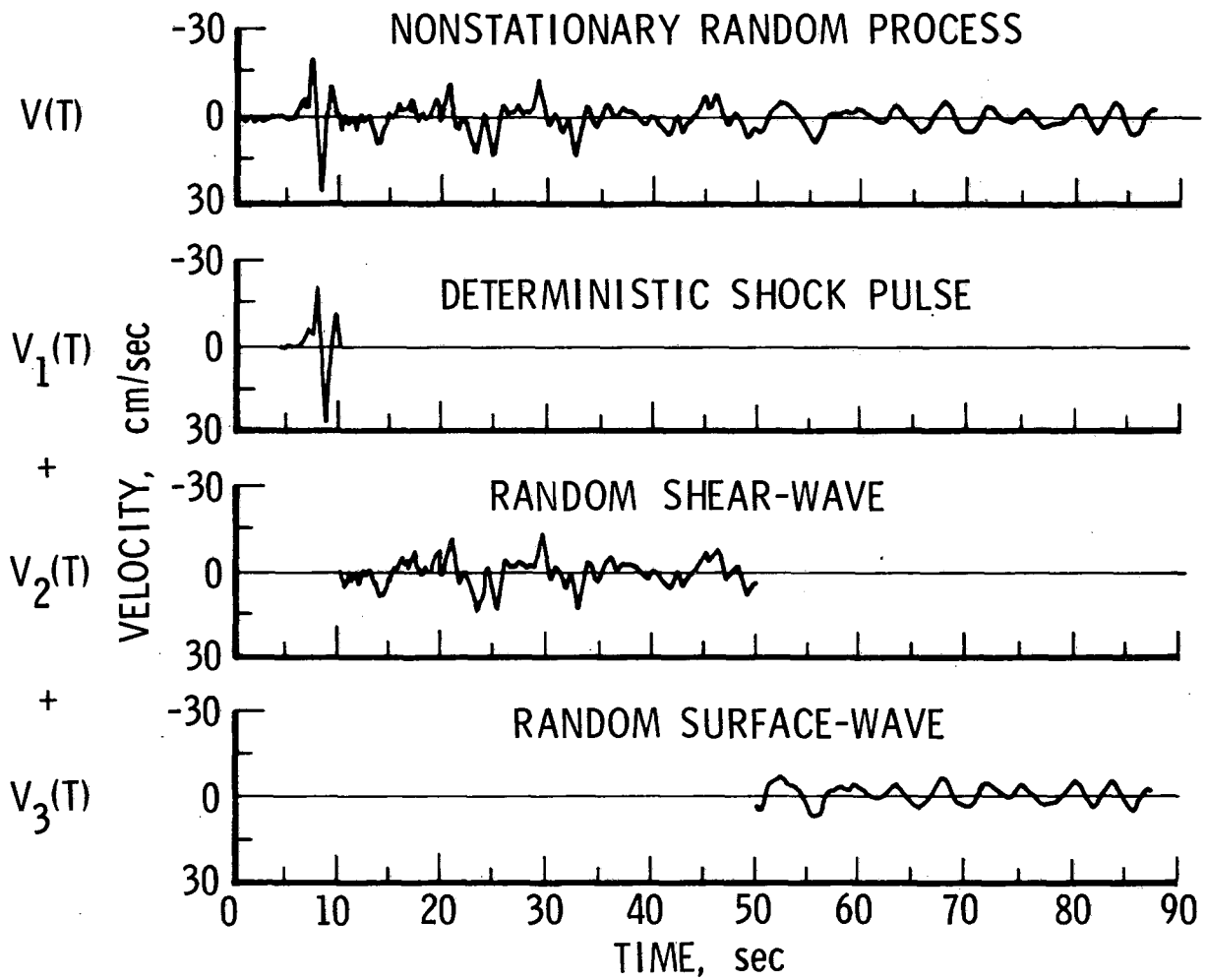


Figure 6-4 Stochastic Simulation of 1968 Borrego Mountain Earthquake

layering of softer materials? Various points of application for the design spectra motion and techniques for modeling soil structure interaction are illustrated in Figure 6-5. In Figure 6-5(A), the platform is considered to be resting on an infinitely rigid foundation with the input motions applied at its base. Figure 6-5(B) couples the platform superstructure to the media through a set of linear springs and dampers. In this illustration, the point of application is the mud line through a set of appropriately characterized springs and dampers. The model shown in Figure 6-5(C) recognizes that free field ground motions may vary appreciably over the foundation for a fixed pile-type platform. Modeling the soil-pile-structure system using the principles of continuum mechanics is illustrated in Figure 6-5(D). In this illustration the design spectrum is applied to the boundaries of a soil island containing the structure and its foundation.

From the foregoing, it is apparent that specification of design inputs which are limited to response spectra are frequently inappropriate. For example, if design spectra are specified to represent ground motion at the mud line, it may be necessary to "deconvolve" that ground motion to obtain an appropriate representation of ground motion at some depth below the mud line. Such a transformation typically results in subsurface spectra which are unrealistic in the sense that they display extreme peaks and notches which are inconsistent with the physical processes involved. Obviously, engineering judgment must be used in interpreting the results. In the absence of specific guidelines for use in such a case, the designer is free to use his own interpretation.

The suggested format for design data specification is sufficiently general to cover the anticipated needs of various site conditions, foundation configurations, and modeling and analyses techniques. It will accommodate the

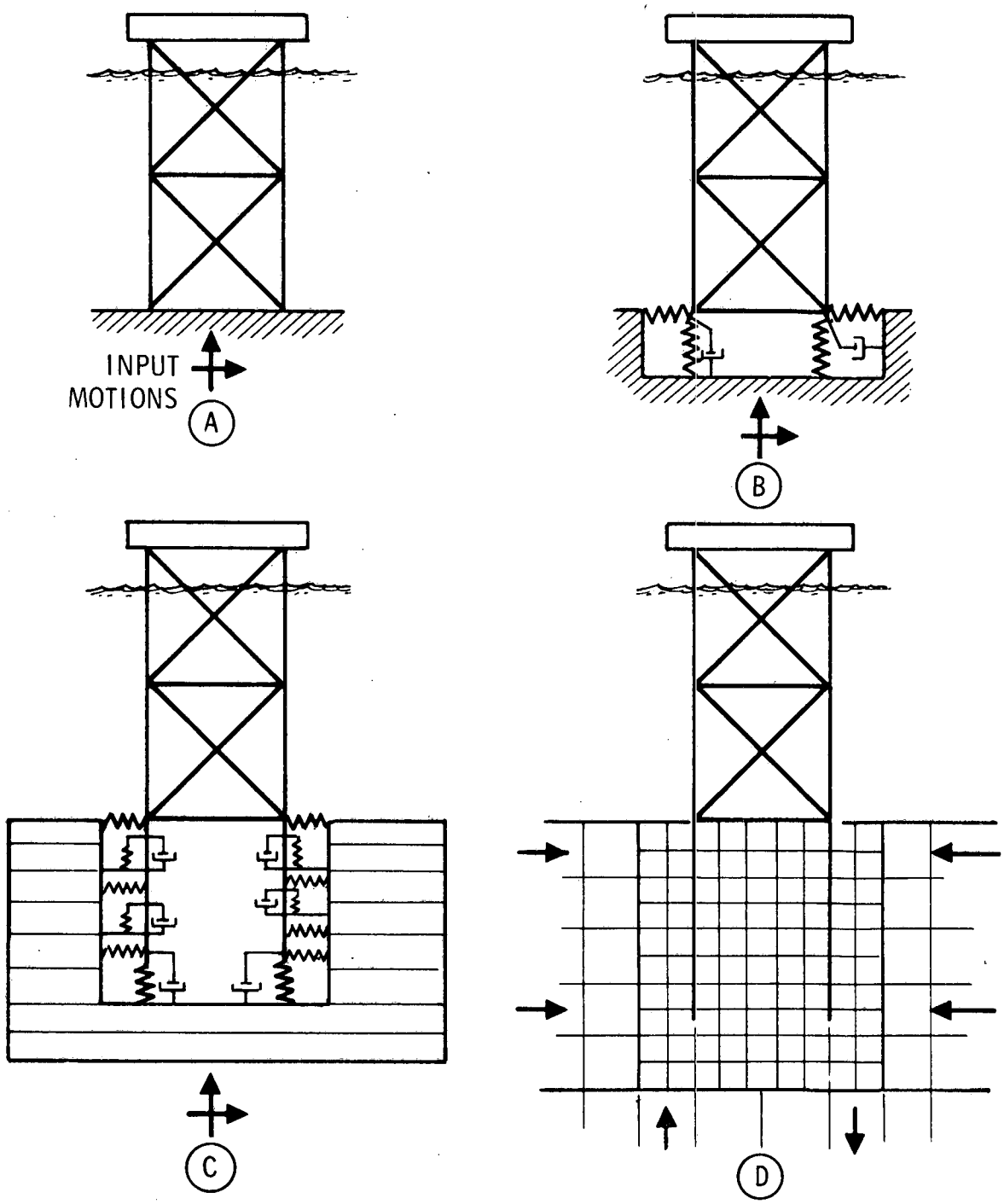


Figure 6-5 Structure-Pile-Soil Behavior Models

specification of ground motion in any or all of the three forms previously mentioned (Response Spectra, Time Histories, and Stochastic Simulation) and will provide for the specification of inputs in an energy consistent manner, either at the mud line or at depth. The energy basis for ground motion characterization is the key to maintaining consistency.

6.2.3.2 Foundation and Soil Modeling

In the previous subsection, the point of application was discussed and models were presented illustrating how the free field motion may be translated into forces acting directly on the structure. From these models, it is obvious that the mechanics of soil-structure interaction are crucial to a determination of these forces. If the seismic design data provide no guidelines for treating interaction phenomena, then the assurance of the desired structural performance is lost. The lack of guidelines in treating the soil-structure interaction problem gives the designer sufficient latitude to circumvent the specific intent of the seismic design criteria. Thus, a complete description of the seismic environment will by necessity include guidelines concerning the application of the environment to structures of interest.

From the standpoint of dynamic response analysis (as opposed to preliminary design), the problem of choosing a point of application for seismic inputs is greatly simplified by including the soil as a part of the system model. The point of application may then be associated with some point (or surface within the system) associated with free-field motion. Soil models may be spacially limited (finite element models) or unlimited (infinite or semi-infinite half space models). Different models may be suitable for different applications. For example; a half space model may be more suitable in the case of a gravity foundation where radiation damping is important. Finite element models may be more suitable in a case of pile foundations where non-linear soil-pile interaction is more important. In any case, a complete specification of the seismic design environment must embrace all of these

possibilities from a standpoint of providing guidelines for establishing different forms of seismic input. Accordingly, work is underway to develop the necessary description of the seismic environment together with guidelines for its application.

6.2.4 Motion Attenuation

The primary concerns regarding motion attenuation include: (1) selection of data for use in regression analyses, (2) parameters to be estimated by regression analyses, (3) geographical dependence of attenuation equations, (4) physical limits to regression parameters such as peak acceleration in the near field, and (5) extrapolation of the data with regard to current activity. These issues all tend to come together in one basic problem, i.e., there are practically no strong motion records available for the Eastern Gulf of Alaska or for the Mid-Atlantic Coast. While attenuation laws based on Western United States data, as summarized by Trifunac and Brady (1975) and shown on Figure 6-6 have been used in Alaska, they have not gone unchallenged. Attenuation laws for the Central and Eastern United States have been developed by Nuttli on the basis of Modified Mercalli Intensity (MMI) and teleseismic data. Special attenuation laws for Alaska could possibly be developed on a similar basis, or as an extension of the work done by Seed, et al., (1976). The latter study developed attenuation laws for acceleration and velocity based on different soil conditions. The selection of appropriate attenuation laws will be the subject of further investigation during the following quarter.

Insofar as the general format for design data is concerned, the basic need is for some form of energy transfer function relating source energy (or epicentral energy) to site energy. It is presently anticipated that attenuation laws of the conventional form (i.e., relationships expressing intensity as a function of magnitude and distance) will be used. Attenuation laws constitute one of the two key elements required to produce an isoseismal strong

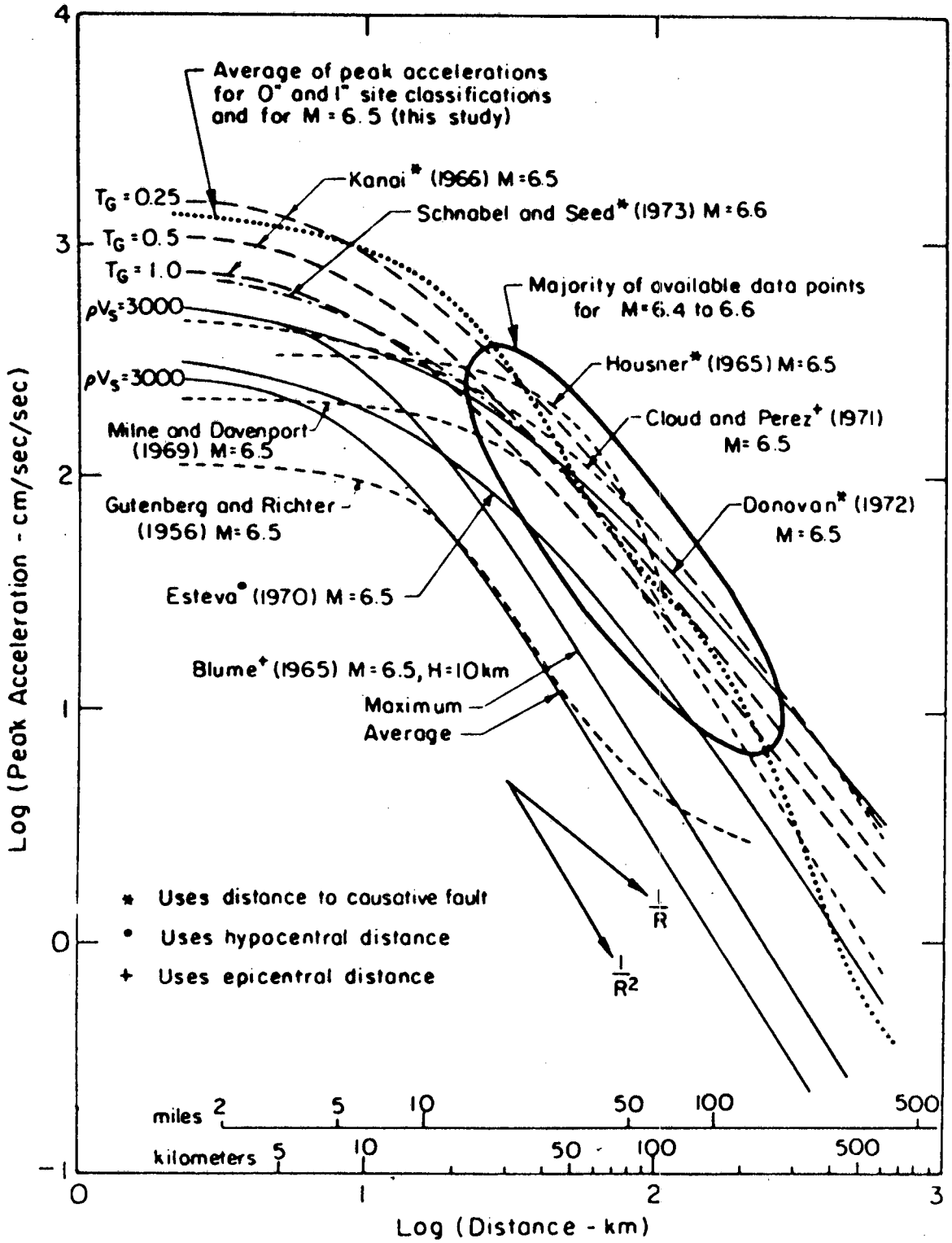


Figure 6-6 Relationships Between Peak Acceleration and Distance from Source for Magnitude 6.5 Earthquakes

motion intensity map. The other is a seismic source distribution for the particular region of interest. Issues concerning seismic source modeling and seismic mapping in general are discussed in the following subsection.

6.2.5 Seismic Source Modeling

The adequacy and stationarity of historical seismic data are key issues in seismic source modeling. Both spatial and temporal stationarity are of concern. The concern is extrapolating a relatively short and recent experience in the prediction of what may happen in a particular area over the next few decades. The paucity of historical earthquake data has given rise to growing interest in the idea of combining available geotectonic data with the historical record of earthquakes. The majority of seismic risk studies have relied on the historical earthquake data. However, some studies have combined judgmentally the historical data with geotectonic data. Statistical methods of systematically integrating the two types of data have been suggested. However, these methods are considered to be beyond the scope of the current activity.

Presently used methods for seismic mapping are compatible with the general format being considered for seismic design data. The only difference envisioned is that peak velocity or some other measure of strong motion intensity may be used in place of the more common peak acceleration. This does not represent a major deviation from current practice. In fact, the final draft of the Applied Technology Council (ATC 3) report provides isoseismal contours in terms of peak acceleration and peak velocity. The advantage of using peak velocity in place of peak acceleration, as mentioned previously, is that it correlates better with intensity, particularly in the long period range.

6.2.6 Format Development

In the preceding subsections some of the issues involved in the stipulation of seismic design criteria were examined along with the extent to which the

criteria need be supplemented by methods for design and analysis. The issues were discussed in somewhat of a reverse order beginning with the concept of risk as related to structural performance and then back through the structure, its foundation, soil conditions at the site, attenuation from source to site, and the regional seismic source distribution. The objective of this continuing review is to help formulate a suitable format for the assembly and evaluation of seismic design data.

6.3 STRONG MOTION STUDIES

The first interim report discussed the suitability of strong motion descriptions contained in reports by Blume and Associates (1973), Newmark and Associates (1973), and the Applied Technology Council, ATC-2 (1974). A common deficiency noted in all of these studies, with regard to their application to offshore structures, was their limited treatment of long period motion. More recent studies examined during the current quarter tend to overcome these deficiencies. Included in the recent studies are reports by McGuire (1974), Seed, et al., (1976), and Mohraz (1976). Whereas the earlier studies utilized strong motion accelograms, which were not corrected for baseline drift, the latter three studies all utilized the corrected accelograms published in the Cal Tech Volume II Series. Appreciable differences exist between the corrected and uncorrected accelograms in the long period range of interest.

The studies by Seed and Mohraz concentrate on differentiating among ground motion spectra for different classes of sites ranging from hard rock to deep alluvium. Seed's results are limited to the statistical analysis of response spectra for five percent damping. The study by Mohraz includes values of damping from 0 to 20 percent. Both Seed and Mohraz concentrate on the development of amplification spectra which may be applied to ground surface particle velocity spectra. Comparison of Seed's results and the results of Mohraz for five percent damping indicate reasonably good agreement.

The study by McGuire made no attempt to differentiate spectra according to various site conditions. Data for all types of sites were processed together. The most distinguishing characteristic of the McGuire study is the attempt to recognize dependency of spectral shape on earthquake magnitude and distance. Furthermore, McGuire does not attempt to develop amplification spectra; instead he performs his regression analyses directly on response spectra as a function of frequency. One advantage of this approach is that uncertainty in ground motion attenuation, as well as energy distribution is accounted for. In contrast, the studies by Seed and Mohraz normalize response spectra by some form of peak ground motion for each record (either peak acceleration, peak velocity, or peak displacement) so that variations in ground motion intensity are factored out of the analyses. Standard deviations in pseudo-velocity computed by McGuire tend to be twice as large as those computed by Mohraz resulting in higher levels of response for the mean plus one sigma case.

The one drawback to McGuire's results, with regard to general application, is that they tend to be tied more strongly to the geographical area over which his data apply. This means that they can not be applied as conveniently to the Eastern Gulf of Alaska and the Mid-Atlantic Coast regions. However, an attempt is being made to derive frequency amplification spectra by dividing response spectra by the appropriate ground particle velocity spectra. Results of this effort to date appear to hold some promise.

6.4 SEISMIC RISK STUDIES

The studies given in Table 6-1 were reviewed during the current Quarter. These are seismic risk studies for regions which include the Eastern Gulf of Alaska.

To provide an overview of the type of data provided by the individual studies, the summary of Table 6-2 was prepared. The X's denote that data of the type indicated is provided. The use of the terms "effective peak acceleration"

Table 6-1

Studies on Seismicity for Regions Which Include the Eastern Gulf of Alaska

Study No.	
1	"Distribution of Earthquake Risk in Canada." W. G. Milne and A. G. Davenport. Bulletin of the Seismological Society of America. Volume 59, Pg. 729-754. April 1969.
2	"Earthquake Criteria for Platforms in the Gulf of Alaska." R. G. Bea. Paper No. OTC 2675. 1976.
3	"API Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms." American Petroleum Institute. API RP 2A, Seventh Edition. January 1977.
4	"Ground Motion Values for Use in the Seismic Design of the Trans-Alaska Pipeline Systems." R. A. Page, et al. Geological Survey Circular No. 672. 1972.
5	"Recommended Comprehensive Seismic Design Provisions for Buildings." Applied Technology Council. ATC-3-05. January 1977.
6	"Seismic Risk Maps for the Contiguous United States, Alaska, and Hawaii." J. H. Wiggins, et al., J. H. Wiggins Co. Tech. Report No. 75-1245. 1 August 1975.

TABLE 6-2. DATA PROVIDED BY THE SEISMIC RISK STUDIES

Study Number	Descriptor	Peak Motion Values			Response Spectra		Risk Basis
		Accel.	Vel.	Disp.	Pseudo-Vel.	Accel. Ratio	
1	Milne	X					100 year return period
2	Bea	X	X	X			100 year return period and certain event
3	API RP 2A	X*			X	X	200 year return period
4	Page	X	X	X	X		200 year return period for line target
5	ATC-3	X*	X*			X	475 year return period
6	Wiggins	X	X	X	Vel. Ratio		100 year return period

* denotes effective peaks

and "effective peak velocity" follows that of the ATC-3 study in which, for example the effective peak acceleration is the response spectrum peak acceleration in a certain frequency range divided by 2.5. The response spectra provided are not derived within the study in every case, but are sometimes adopted from other works and suggested for use.

A comparison of the studies of Table 6-1 may be made on the basis of peak acceleration. However, it is necessary to put the results on an equal basis.

The first adjustment that must be made is the relationship of peak acceleration and effective peak acceleration. A detailed study was not performed or discovered on the ratio of these two quantities. However, guidance on this ratio may be inferred from a comparison of the seismic risk map of the ATC-3 study and the map by Algermissen which influenced it. From the reduction of the peak contour level of 0.6 g in California to 0.4 g, it may be inferred that this ratio is about 1.5.

The second adjustment that must be made is the presentation of all data for a common return period. The definition used herein for the return period of an acceleration of level A or greater at a site is simply the reciprocal of the average frequency of occurrence of A or greater. Milne in Study 1, correlates the data for a site as

$$N(A) = \left(\frac{A}{C_p}\right)^{\alpha_p}$$

where N (A) is the average frequency of occurrence of A or greater.

Fitting this relationship to data presented by Bea in Study 2 for the area of interest for the time period of 1940 - 1974 resulted in an exponent of

$$\alpha_p = -2.283.$$

If there exists a return period R_1 associated with an acceleration A or greater, and if we wish to determine the acceleration A_z appropriate for a return period R_2, then by manipulation of the above relationship we have

$$A_z = A_1 \left(\frac{N_2}{N_1}\right)^{1/\alpha_p} = A_1 \left(\frac{R_1}{R_2}\right)^{1/\alpha_p}$$

For example, these results

$$\left(\frac{200}{100}\right)^{1/-2.283} = 0.738$$

$$\left(\frac{475}{100}\right)^{1/-2.283} = 0.505$$

The accelerations quoted within the reports are listed in Table 6-3 and adjusted by the factor's discussed above. Study 4 was influenced heavily by the structure under consideration; a pipeline of many hundreds of miles in length. Thus, the motion given in Study 4 refers to those motions of a certain frequency of occurrence that occur anywhere within the region of, say, the southerly section of the pipeline. This is quite different from the remaining studies which give motions of a certain frequency of occurrence at a point. Thus, the high acceleration level of Study 4 is to be expected. Among the remaining five studies, there are four whose adjusted accelerations are bracketed by the range 0.3 - 0.45 g and Study 1 whose adjusted acceleration is 1 g.

In the interest of investigating possible reasons for the difference between Study 1 and the other four comparable studies, let us consider Figure 6-7. This figure indicates the correlation between peak acceleration and distance suggested by Trifunac and Brady for various site classifications for an M = 6.5 event together with data for events in the range of M = 6.4 to M = 6.6.

TABLE 6-3. ADJUSTED PEAK ACCELERATION OF SEISMIC RISK STUDIES

Study Number	Descriptor	Quoted Acceleration(g)	Adjustment for EPA	Peak Acceleration	Adjustment for Return Period	100-Year Peak Acceleration
1	Milne	1.	1.	1.	1.	1.
2	Bea	0.3	1.	0.3	1.	0.3
3	API RP 2A	0.4	1.5	0.6	0.738	0.44
4	Page	1.25	1.	1.25	0.738	0.92
5	ATC-3	0.4	1.5	0.6	0.505	0.3
6	Wiggins	0.45	1.	0.45	1.	0.45

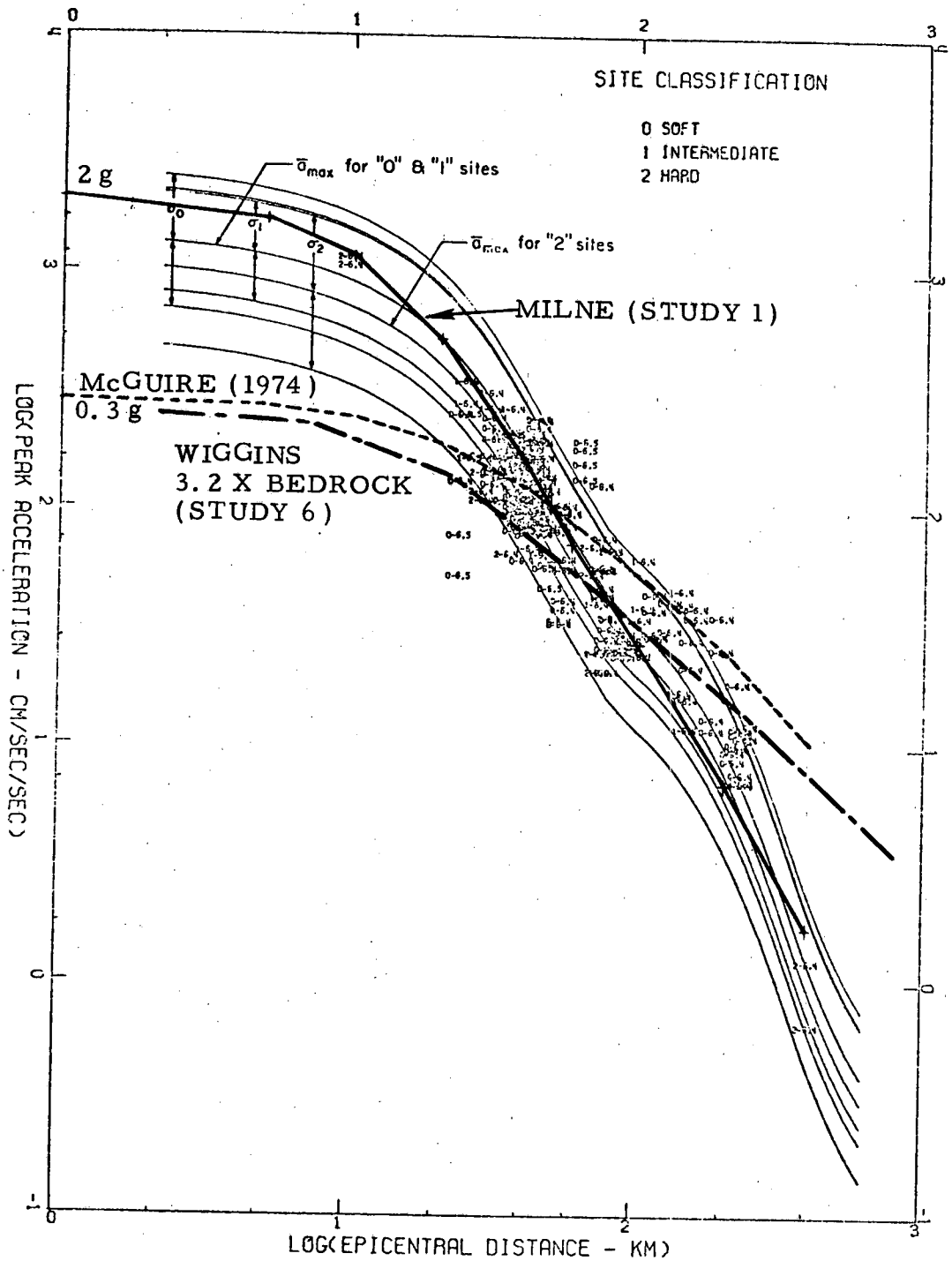


FIGURE 6-7. ATTENUATION RELATIONS OF McGUIRE, MILNE AND WIGGINS FOR M = 6.5 SUPERIMPOSED ON CORRELATION SUGGESTED BY TRIFUNAC AND BRADY FOR M = 6.5 AND DATA FOR M = 6.4 TO M = 6.6

This magnitude range includes the San Fernando Earthquake of 1971 for which much excellent data has been obtained. The attenuation relation adopted by Milne for M = 6.5 is superimposed on Figure 1. It may be seen that the Milne relation fits the data and the assumed shape very well. The Milne relation may be a bit high near the epicenter. That is, a peak of 2 g very close to the epicenter has been predicted. No acceleration larger than 1.25 g has been recorded, but on the other hand, no data has been measured near the epicenter of a large earthquake.

Also superimposed on Figure 6-1 is the attenuation relation used by J. H. Wiggins to represent attenuation of surface motion. This relation was developed in 1973 and is based on 90 strong motion records from El Centro, Hollister and Ferndale. This relation does not appear to have the correct slope relative to the data and appears low at epicentral distances less than say 40 km.

The final curve superimposed on Figure 6-1 is the correlation derived by McGuire for M = 6.5. This curve does not appear to fit the data well, even though the San Fernando data were used by McGuire. A peak acceleration of only 0.3 g is predicted near the epicenter which appears quite low. This correlation was used in Study 2 by Bea.

Detailed critiques of five of the six individual studies of Table 6-1 are included as Appendix F. These critiques were prepared by the authors noted in Table 6-4. A summary of the comments of the critiques and additional comments are provided as indicated in the table.

It appears that Study 4, with its viewpoint of a long target structure, may be set aside as not appropriate to form the basis of a seismic risk estimate for an individual site in the Eastern Gulf of Alaska. Study 1 may be conservative in the relation of an acceleration - distance - magnitude relation and the use of point earthquake sources rather than line sources along known faults. Studies 2 and 6 may be non-conservative in the relation of

TABLE 6-4. SEISMIC RISK STUDY CRITIQUES

Study Number	Study Descriptor	Critique Number	Critique Author(s)
1	Milne	1	M. R. Akky and R. G. Bea
2	Bea	2	T. K. Hasselman
3	API RP 2A	3	T. K. Hasselman
4	Page	4	M. R. Akky and R. G. Bea
5	ATC-3	5	T. L. Alley

acceleration - distance - magnitude. In addition, Study 6 appears to have mislocated the large 1899 - 1900 Yakataga events. It is difficult to comment on Studies 3 and 5 because the detailed bases of the recommendations are not given. None of the studies list the historical earthquakes considered so that the data base may be neither complete nor comparable among the studies.

In summary, it appears that all of the studies considered suffer various shortcomings. It is believed that the estimate of the seismic risk of the Eastern Gulf of Alaska could be improved by a more careful, detailed study. This study would be of the same basic form as those reviewed herein, but the elements of the model such as:

- seismic source modeling
- motion-attenuation relations
- statistical modeling
- the data base

should be refined. Because of the apparent fidelity of the attenuation relation used and the proper statistical treatment, Study 1 is the preferred study if a selection must be made at this time. This selection is conservative and is subject to revision with further study.

6.5 Design Basis Ground Motion Preliminary Estimate

6.5.1 Motion Intensity

The motion intensities that will be considered herein are the peak ground acceleration, velocity, and displacement at the upper strata of firm ground. The peak ground motion parameters should be expressed in a statistical sense; the level associated with an average 100 year return period shall be used herein.

The peak ground accelerations implied by the seismic risk studies reviewed

in Section 6.4 are noted in Table 6-3. It may be recalled that the range of peak acceleration for a 100-year return period was found to be 0.3 to 1.0 g. As formidable as is this range of acceleration, it may be noted from Table 6-5 and 6-6 that the spread of peak velocity and peak displacement is even greater. It is assumed here that the peak velocity is approximately equal to the effective peak velocity.

It may be noted that whereas the peak ground acceleration had a maximum/minimum ratio of about 3, the velocities have a ratio of about 5 and the displacements have a ratio of about 16. This greater uncertainty on velocity and displacement probably results primarily from two sources:

- acceleration is the quantity measured directly by strong motion accelerographs
- more research has been performed on accelerations resulting from earthquakes

A convenient method of presentation of the peak ground motion parameters is by means of a ground motion spectrum. The peak values are drawn on tripartite spectral paper and the lines connected to form a figure which normally appears as a hill. This has been done on Figure 6-8 with the extremes of the motion of Tables 6-3, 6-5, and 6-6. It may be seen that for natural periods less than 10 seconds the peak displacement bounds do not appear.

6.5.2 Response Spectra

As noted in Table 6-2, some of the seismic risk studies have recommended response spectral shapes for use as design spectra. The pseudo-velocity spectra may be used directly. The type of spectra labeled "acceleration ratio" is an acceleration amplification spectrum and is to be multiplied by the peak ground acceleration or the effective peak ground acceleration as appropriate. The velocity-ratio spectrum presented by J. H. Wiggins is the

TABLE 6-5 PEAK GROUND VELOCITIES FROM SEISMIC RISK STUDIES

Study Number	Descriptor	Quoted Peak Velocity	Risk Basis	Adjusted Peak Velocity (100 yr, cm/sec)
1	Bea	44 cm/sec	100 yrs	44 cm/sec
2	ATC - 3	12 in/sec	475 yrs	12.5 cm/sec
3	Wiggins	25.6 in/sec	100 yrs	65 cm/sec

TABLE 6-6 PEAK GROUND DISPLACEMENT FROM SEISMIC RISK STUDIES

Study Number	Descriptor	Risk Basis	Peak Displacement (cm)
2	Bea	100 year return	320
6	Wiggins	100 year return	20

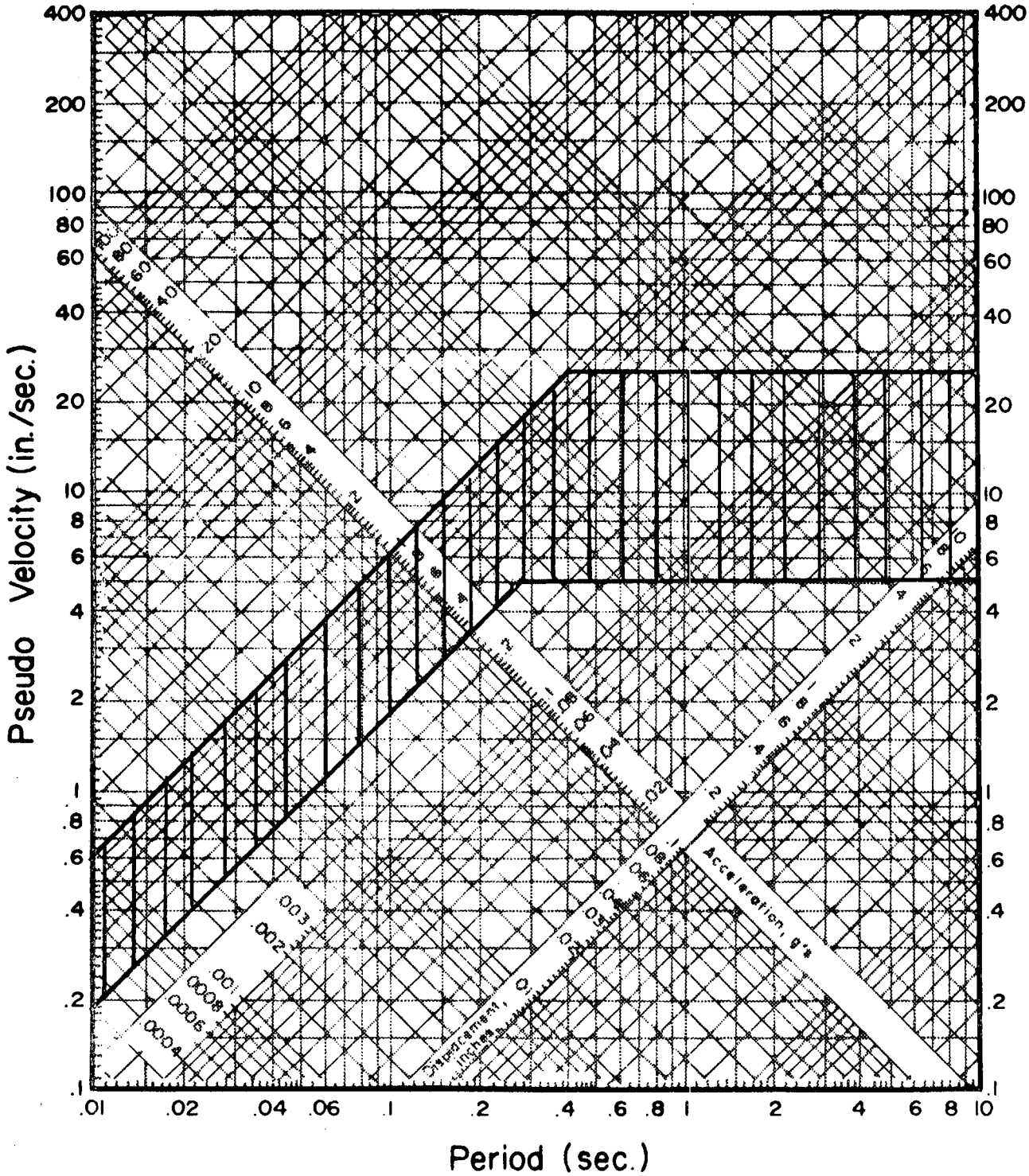


FIGURE 6-8 UNCERTAINTY BAND OF GROUND MOTION SPECTRA FOR THE EASTERN GULF OF ALASKA

zero-damped pseudo-velocity response spectrum divided by the 20 percent damped pseudo-velocity response spectrum.

The problem of specifying a design response spectrum for the Eastern Gulf of Alaska may be regarded as two separate problems:

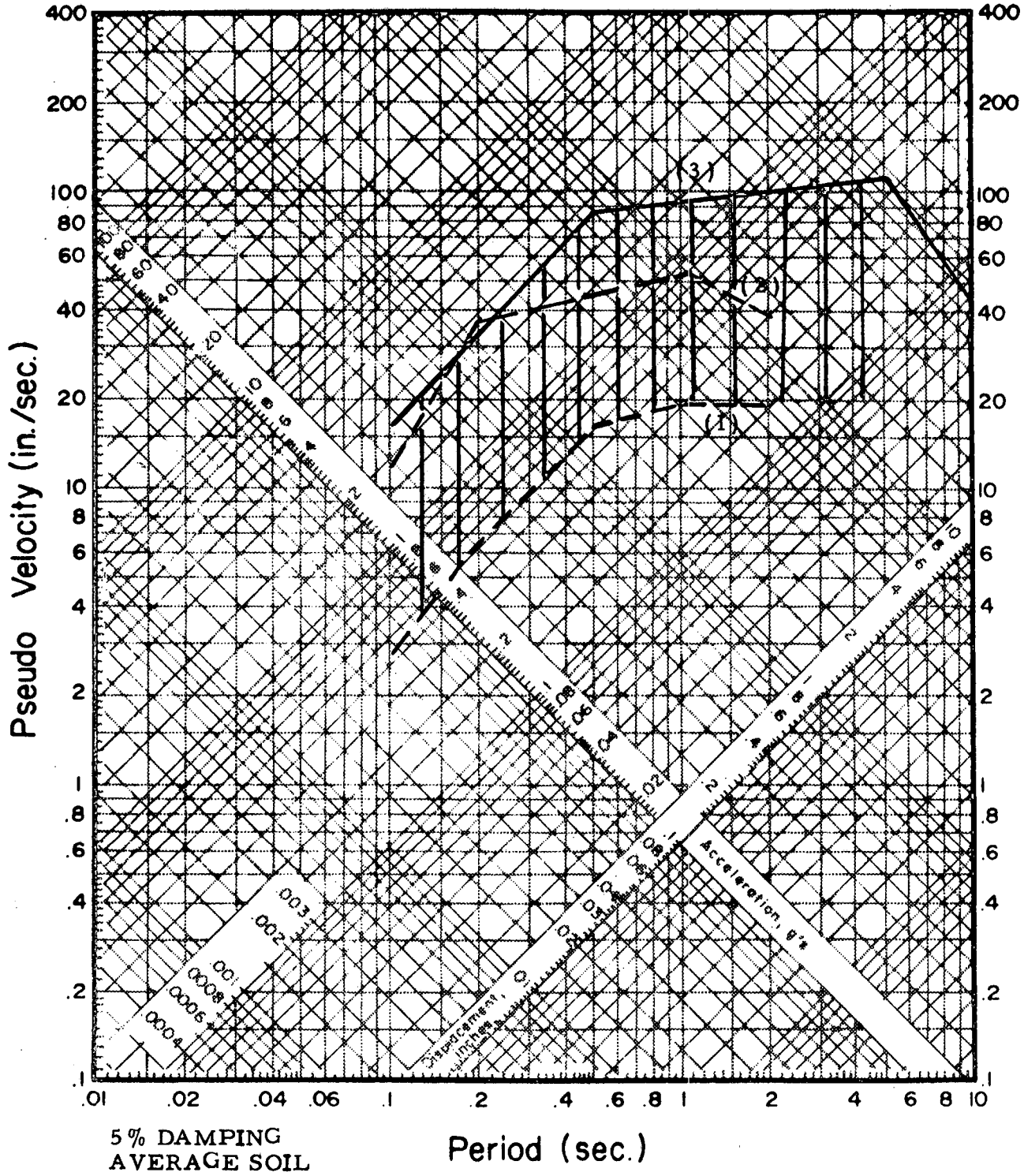
- the specification of peak ground motion parameters for the study area on a suitable risk basis
- the specification of a normalized spectral shape for an appropriate risk basis, appropriate soil conditions, and appropriate oscillator damping

A reasonable format for the spectral shape is a pseudo-velocity spectrum versus period, normalized to the peak ground velocity. This would place emphasis on specification of the peak ground velocity, a parameter more of interest to platform design than peak ground acceleration. It may be seen that the uncertainty involved in construction of the response spectrum is a combination of the uncertainties in specification of the spectral shape.

An example of the spectra that may be obtained is provided in Figure 6-3. Curve (1) was constructed by combining the ATC - 3 (Study 5) acceleration amplification spectrum with the effective peak ground acceleration therein adjusted for a 100-year return period. Curve (2) was constructed by combining the Milne (Study 1) 1g, 100-year peak acceleration with the acceleration amplification spectrum of Mohraz. Finally, Curve (3) is the NRC 1g spectrum used for the design of nuclear power plants. (NRC Reg. Guide 1.60, 1973). These examples were chosen specifically in an attempt to portray the extreme bounds of a 100-year five percent damping response spectra for the Eastern Gulf of Alaska.

Narrowing of the uncertainty bands of Figure 6-8 and 6-9 will have to await a refined seismic risk study of the Eastern Gulf of Alaska.

NOTES: (1) ATC-3 (STUDY 5) SPECTRUM WITH ACCELERATION FOR A 100-YEAR RETURN PERIOD
(2) MOHRAZ AMPLIFICATION SPECTRUM WITH MILNE 1 g ACC
(3) NRC R.G. 1.60 1g SPECTRUM



5% DAMPING
AVERAGE SOIL

FIGURE 6-9 UNCERTAINTY BAND OF RESPONSE SPECTRA FOR THE EASTERN GULF OF ALASKA

6.6 GEOLOGY

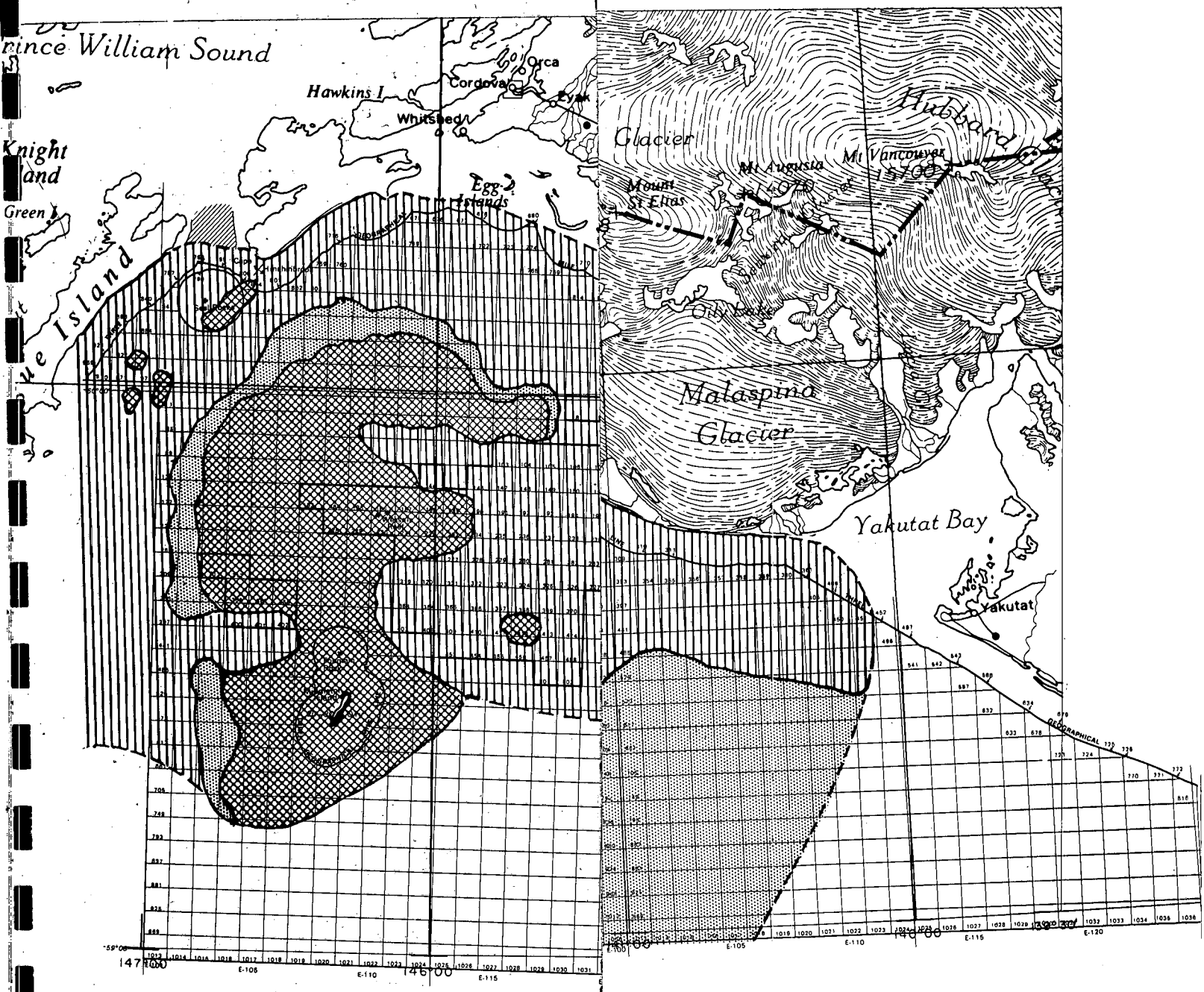
6.6.1 Introduction

The Initial Estimate Report released in January provided an overview of the geology of the Eastern Gulf of Alaska. Included in that report is a description of the sedimentary units, identification of some near surface faulting and areas of potential slope instability. Even though an attempt has been made, no additional soils data has been acquired during the last Quarter upon which an update of geological hazards data can be based. Hopefully, by the end of the coming Quarter soils information will become available to support a more definitive characterization of the foundation hazards within the Eastern Gulf of Alaska.

In the absence of additional data, attention was directed toward locating potential hazard areas relative to proposed lease tracts and toward providing additional information on the thickness of bottom sediments at selected locations.

6.6.2 Location of Potential Hazards

Slumping or sliding of bottom sediments represents a potential foundation hazard for many of the leases nominated for sale. Figure 6-10 locates the lease areas relative to different bottom sediments. Figure 6-11 delieates past or potential slide areas according to Carlson, et al., (1975). The area south of the Bering Glacier is potentially hazardous due to underconsolidation state of Holocene sedimentary deposits and Holocene moraines. These deposits are mostly clayey silt dispersed with fine sands. Seismic profiles taken by Molnia and Carlson (1975) indicate that this area is covered with thick sediments, more than 25 meters in depth, on relatively steep slopes ranging from 1° to 8°. Since these sediments are largely



OCENE

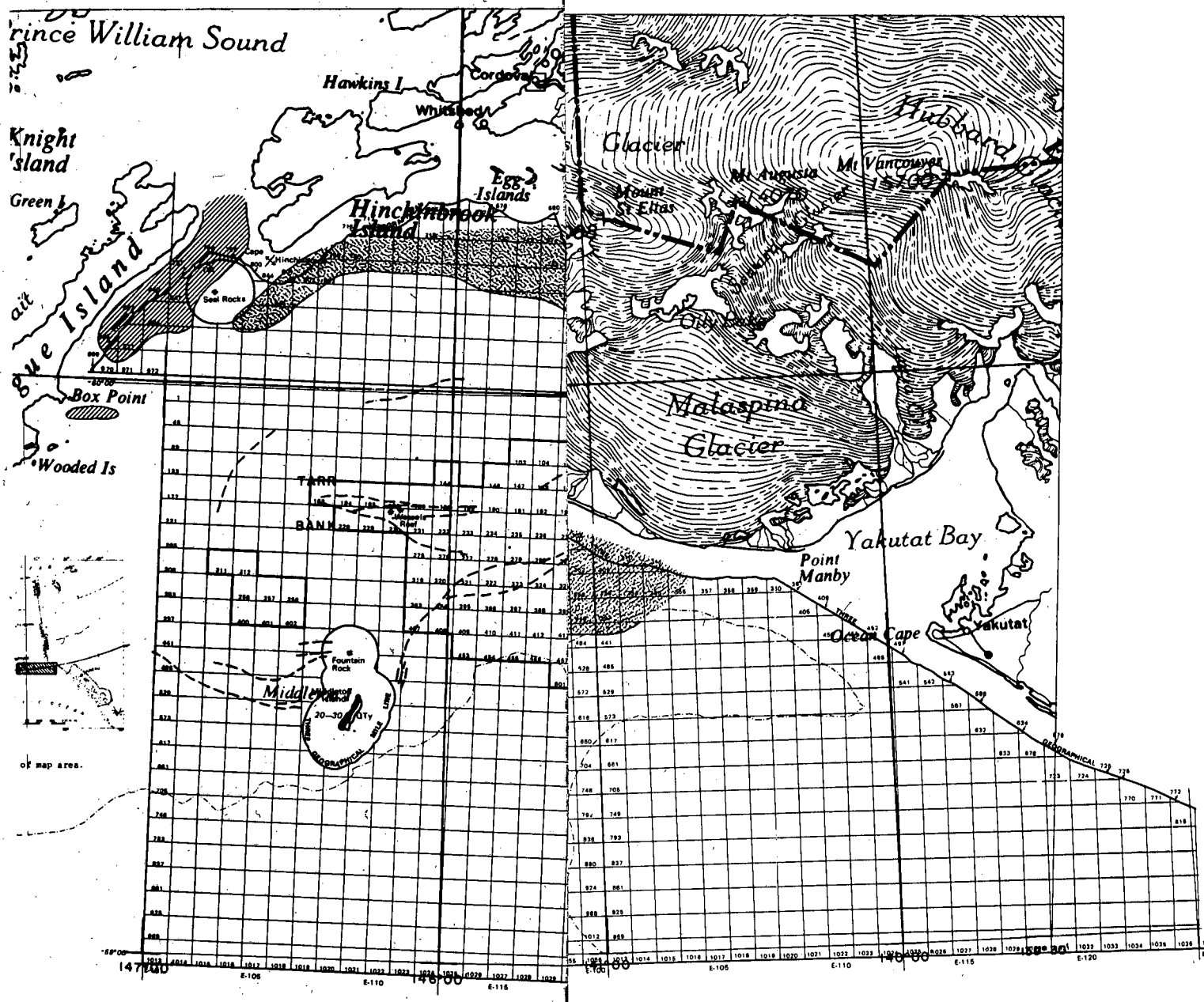
OCENE END MORAINES

RTERNARY GLACIAL MARINE

IARY AND PLEISTOCENE
RATIFIED DEPOSITS

0 50 KILOME

SCALE 1:500,000



Explanation

SLUMP OR SLIDE STRUCTURES
High resolution seismic profiles show discontinuous reflectors which are interpreted to be slump or slide related

POTENTIAL SLUMP OR SLIDE AREAS
High resolution seismic profiles show thick sediment (>25m) on relatively steep slopes (>1-8°)

NEAR SURFACE OR SURFACE FAULTS

200 METRE ISOBATH

0 — 50 K

SCALE 1:500,000

cohesionless and underconsolidated, they are subject to liquefaction. Leases nominated for sale within this area are listed in Table 6-7, Group A.

The Kayak Trough is also subject to potential slumping or sliding of thick deposits of Holocene sediments on relatively steep slopes. Leases falling within this potentially hazardous area are listed in Table 6-7, Group B. Other leases subject to potential slumping or sliding of Holocene deposits are listed in Table 6-7, Group C.

Discontinuous reflectors observed in seismic profiles have identified areas where slumping and sliding is currently taking place. Many of these areas are on current lease tracts, as listed in Table 6-7, Group D.

It should be emphasized that the areas discussed herein, as representing potential hazards, have been identified solely as a basis for focusing future investigations. Their identification is based on very limited soils data. Certainly identification of the existence and extent of unstable foundation conditions and the impact of these conditions on lease tract development must await more detailed site investigations.

6.6.3 Selected Soil Profiles

The soil profiles or stratigraphic columns, shown in Figure 6-12 identify the type and thickness of deposits found in four selected areas within the Eastern Gulf of Alaska. (Figure 6-13)

Column A, Figure 6-12, characterizes the depth and position of Holocene sediments south of the Copper River. This area, as mentioned previously, is one of rapid sedimentation and the deposits are typically loosely consolidated and saturated. The Holocene sediments here are underlain by Tertiary and Pliestocene stratified deposits which are typically competent at depth.

Column B illustrates the thick Holocene marine deposits which build to great thicknesses due to rapid sedimentation of glacial detritus carried by rivers

Table 6-7
Proposed Lease Tracts Having
Potential Foundation Hazards

Group A

15, 16, 17, 59, 60, 61, 100, 101, 104, 105, 144, 145, 149, 198, 188, 189, 233

Group B

154, 155, 156, 198, 199, 243

Group C

340, 341, 383, 384, 385, 386, 387, 432, 414, 279, 378, 422, 423, 465, 466

Group D

297, 298, 249, 205, 206, 207, 208, 209

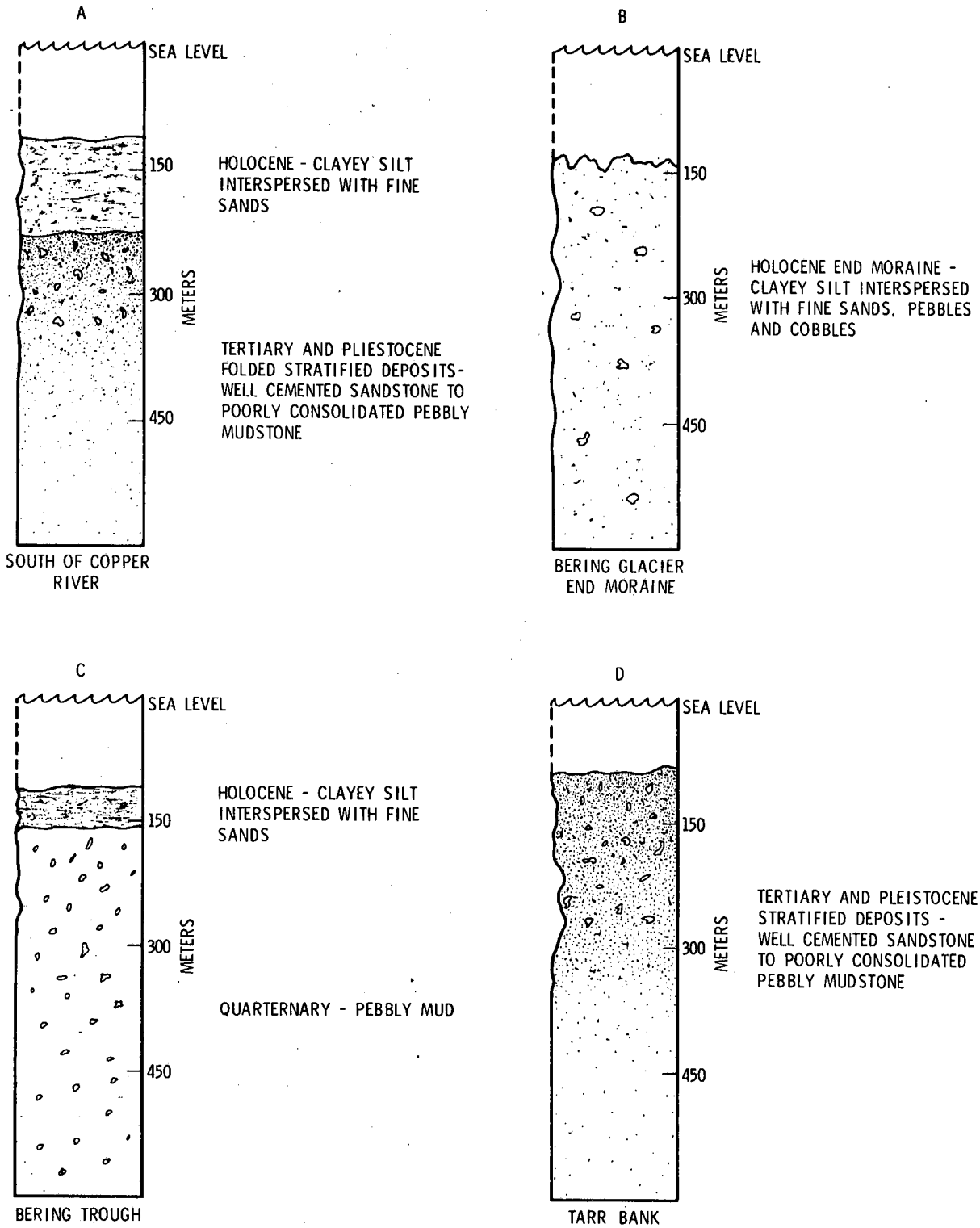


Figure 6-12 Selected Soil Profiles

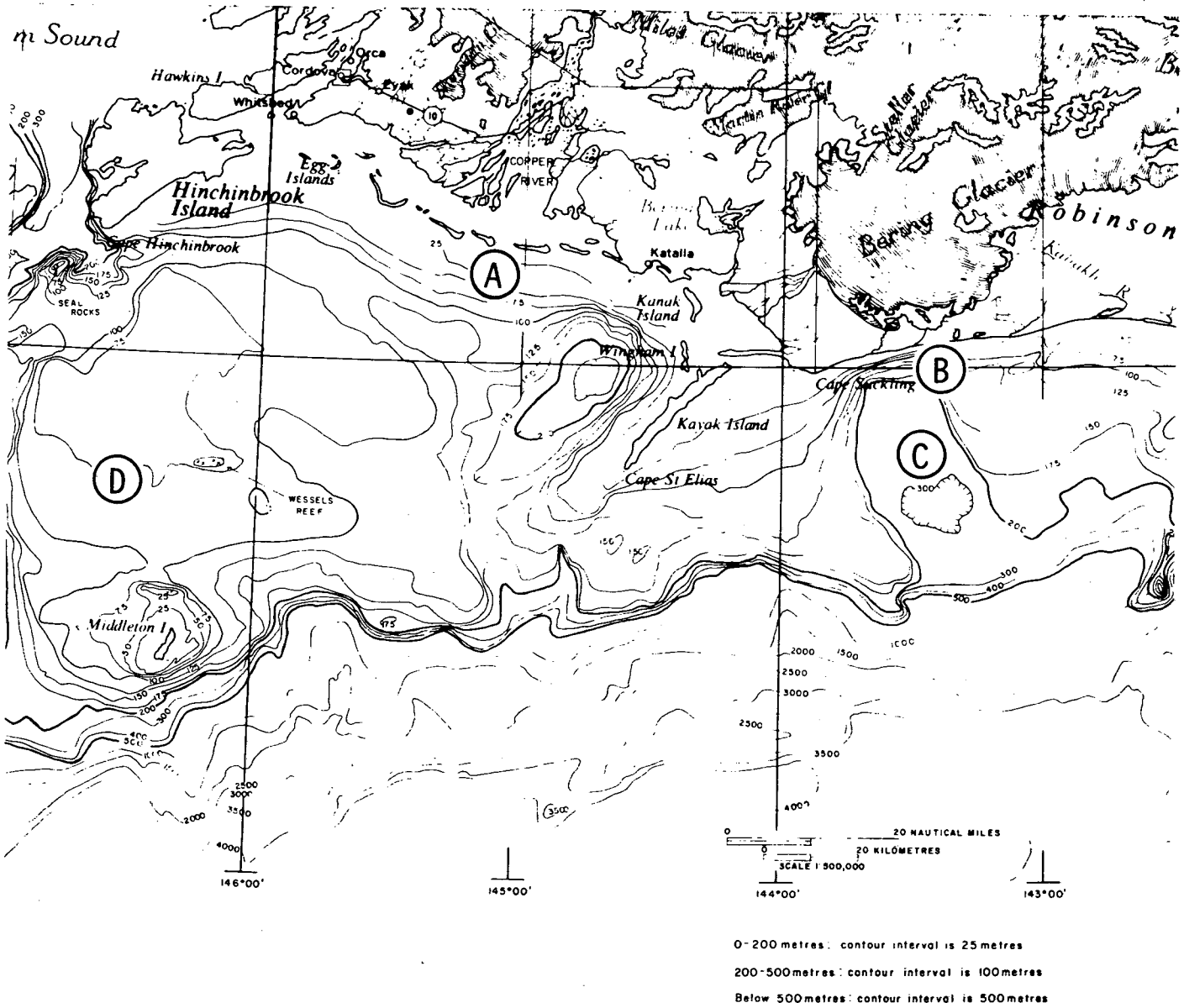


Figure 6-13 Location Chart for Stratigraphic Columns

to the area. These deposits typically vary in consolidation according to depth. They frequently present problems for drilling due to their varying composition ranging from silts to cobbles.

Column C depicts a thinner layer of Holocene sediments overlayering Quarternary material. The Quarternary units are not present in all areas and vary in thickness. These units consist of a pebbly mud which becomes well consolidated with depth.

The fourth column, Column D, is devoid of any overlaying Holocene or Quarternary deposits. This may be due to local scouring or faulting causing the Tertiary to be exposed. Well consolidated Tertiary deposits are expected to provide stable foundation material.

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Appendix A.
Estimation of Return Periods for Extreme Waves

The means used to estimate return period, R and the non-exceedance probability, P(H) of extreme wave heights in this report was the application of the methods of extreme value statistics developed by Gumbel (1954). The return period, R, is defined as the average time between occurances of a wave of a certain height, H. The non-exceedance probability P(H) is defined as the probability that the random variable H is less than or equal to h.

$$P(H) = Pr\ [H \leq h] \qquad \text{(A-1)}$$

The return period and non-exceedance probability are related by the equation.

$$R = \frac{1}{\lambda[1 - P(H)]} \qquad \text{(A-2)}$$

where λ = average number of events (storms) per unit time. This formulation is based on the assumption that the probability of n events occuring in time, t, is given by a Poisson process:

$$P_N(n) = P(N = n) = \frac{e^{-\lambda t}\lambda^n}{n!} \qquad \text{(A-3)}$$

A probability distribution which describes the probability of occurrence of rare events such as floods, storms, etc. is the Gumbel distribution (also known as the Fischer-Tippett Type I) and is given by:

$$P(H) = \exp\left\{ - \exp\ [- a\ (h-h_o)]\right\} \qquad \text{(A-4)}$$

where

h = wave height

a, h_o = Parameters which describe the distribution and are usually estimated from the sample data

If the transformation,

$$y = a(h-h_o) \tag{A-5}$$

is performed, then the probability P(H) becomes

$$P(H) = \exp \left\{ -\exp(-y) \right\} \tag{A-6}$$

Solving for y gives:

$$y = -\ln \left\{ -\ln P(H) \right\} = a(h-h_o) \tag{A-7}$$

This equation is linear in the wave height, h, and the so called reduced variate, y. This forms the basis for fitting straight lines to the extreme wave data in this report. The extreme wave heights are ranked in order of height, and assigned according to the plotting position formula given by Gumbel (1954):

$$P(H) = \frac{m}{N+1} \tag{A-8}$$

where:

m = rank order from smallest to largest

N = total number of extreme observations

These data are then plotted on probability paper with an abscissa scaled according to the relation given above for the Gumbel distribution. Straight lines were fitted to the data using a standard least squares technique. The correlation coefficients for all curves were determined from the linear regression.

With the aid of the Posisson distribution the probability of non-encounter for a wave of any return period in a given design life is:

$$P\,(\text{largest } H \leq h) = \sum_{j=o}^{\infty} P\left[H_{(n)} \leq h, \text{ given } N = j\right] \; P\left[N = j\right] \qquad \text{(A-9)}$$

$$= e^{-\lambda L\left[(1 - P(H))\right]}$$

$$= e^{-L/R} \qquad \text{(A-10)}$$

where L = design lifetime.

A plot of non-encounter probability as a function of the ratio L/R is given in Figure A-1. Using this curve in conjunction with plots of Return period, R, will yield non-encounter probability for a given wave height, H.

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APPENDIX B

COMMENTS ON THE ANALYSIS TECHNIQUES OF THOM

Prepared by V. J. Cardone

In a series of papers published between 1954 and 1973, Thom has used the Frechet distribution to fit extreme winds and waves:

$$G(v) = \exp - \left[\left(\frac{v}{\beta_2}\right) - \gamma \right] \qquad (1)$$

where G (v) is the probability of an extreme less than v, β_2 is the scale parameter and γ is the shape parameter. This is also called the Fisher-Tippett Type II distribution. The type I Fisher-Tippett distribution is given as

$$F(x) = \exp \left[- \exp \left[\frac{x - \alpha}{\beta_1} \right] \right] \qquad (2)$$

where F(x) is the probability of an extreme less than x, is the location parameter and β_1 is the scale parameter. For x = ln v, (2) is transformed to (1) with

$$\gamma = \frac{1}{\beta_1} \qquad \beta_2 = e^{\alpha} \qquad (3)$$

For annual extremes, the recurrence interval is given by

$$R = \left[\frac{1}{1 - F(x)} \right]$$

Thom has proposed that for extreme winds, $\gamma = 9$ provides a good fit for extratropical storms. The scale parameter was found to be related to the maximum monthly mean wind speed $\bar{v}_{max}$ according to the relation derived by regression analysis:

$$\beta_2 = (320.5\, \bar{v}_{max} + 248.7)^{1/2} - 15.7 \qquad (4)$$

Thom has also applied a variation of (4) with (1) to tropical storm wind extremes but with $\gamma = 4.5$. For areas affected by both tropical and extratropical storms he attempts to apply a "mixed Frechet distribution" which is not, strictly speaking, a Frechet distribution at all.

The use of mixed distribution is curious. For one would expect that in the tail of a process which is a mixture of two distributions, the component with the slower decay rate will prevail. The tail of a mixture of Frechet distributions with $\gamma = 4.5$ and $\gamma = 9$ behaves asymptotically as $x^{-4.5}$ and any pseudo γ in the range $4.5 < \gamma < 9$ is inappropriate. The prudent analysis for a mixed regime is to compute a design wind (or wave) for each process and to use the larger of the two.

Thom fits the distribution to "extreme annual wind speed" which is somewhat loosely defined as the "fastest mile" or "fastest minute" wind as would be measured at a standard anemometer height of 30 feet. The basic fits and scale relation (eqn 4) are based upon the analysis of long records of measured wind data for many land based weather stations. Comparable wind data do not exist at sea even from the Ocean Station Vessels, but Thom has applied an "adjustment" factor to OSV measured hourly one minute average winds and applied (4) and (1) with some success. To the extent that the fits apply to land stations, they should be transferable to the marine environment in the sense that imposed atmospheric pressure distributions coupled with a smoother different surface boundary will be incorporated in the $\bar{v}_{max}$. Thus except for the "mixed distribution" Thom's work seems to provide a useful design tool for winds. The relevance of this body of work to ocean waves however, needs to be established.

Thom fits (1) to extreme annual "observed" wave heights for 12 Ocean Station Vessels whose record of observations cover up to 15 years. For each station, the distribution (1) was fit actually by applying (2) to the logarithm of wave height (thereby suppressing the scatter in the data) and then transforming the scale and shape parameters of (1) from (3). The fits shown on pages 22 and 23 of Thom (1971) are less than convincing. It is interesting that the two "better" fits shown are for OSV "E" and "V" which are both located in the Subtropics while the "poorer, fits for OSV "B" and "M", are poor indeed and might reveal the failure of the distribution at higher latitudes. Also there is no tendency for γ to be constant as it ranges from 5 to about 11. Thom transforms the fits from significant (visual) to maximum wave height by a factor of 1.8 applied to β_2.

A shortcoming of Thom's work at this point is its reliance on visually estimated wave height data. A number of comparisons of visual and measured wave data exist. Table A-1 from Hogben shows the results of several comparisons for both wave height and period. In all cases measurements were made with calibrated shipboard wave recorders. Hoffman (1975) has presented comparisons from the weather ships "I" and "P" with the resulting relation:

$$\overline{H}_{1/3}(\text{measured}) = 7.0 + .775\ H\ (\text{visual})\ (\text{ft})$$

Wiegel (1975) summarized other comparisons including that of Cartwright, $\overline{H}_{1/3}$ (measured) = 1.1H (visual) obtained from 905 observations, and Paape, $\overline{H}_{1/3}$ (measured) = .8H (visual. Visual wave data from transient ships are subject to even greater biases due to their avoidance of storm areas. Most of the existing extreme wave estimates for the Gulf of Alaska, Quayle and Fulbright (1975), and Tetra-Tech (1974), are based upon Thom's (1973b) paper in which he develops a method to transform the extreme wind distribution to an extreme wave distribution. The OSV data are used to derive

$$\beta_s = \beta_v\, e^{\overline{c}} \quad \text{and} \quad \gamma = 6$$

where $\overline{e}$ is a constant and β_v is given by (4)

thus from (1) $G\,(\overline{H}_{1/3}) = \exp\ -\left(\frac{\overline{H}_{1/3}}{2}\right)^{-6}$

where $\overline{H}_{1/3}$ is extreme significant wave height. Thus according to Thom the distribution of extreme waves can be determined entirely from the maximum mean monthly wind $\overline{v}$ max. This must be considered an extremely crude estimate which can be quite misleading. For example Dattatri (1974) attempted to apply Thom's methods to the West India coast, where it gave a 91 feet maximum wave for a 50 year return. Dattatri's extrapolation from a continuous one year record of measured wave data provided a 100 year return maximum wave height of 32 feet. Bea (1976) has shown that Thom's method provides extreme wave estimates that are 30% to 40%

higher for the Gulf of Mexico than estimates from a historical hindcast study performed with an accurate calibrated hindcast model. These discrepancies are to be expected from a method that attempts to lump all of the physics of wave generation, propagation and dissipation in the factor $\bar{C}$.

In sum, Thom's method needs to be verified with measured over ocean wind and wave data before its reliability can be determined.

TABLE B-1

Correlation of Measured and Maximum Wave Height

Source: Hogben

Reference	A	B		C	ρ	σ		N
		feet	meters			feet	meters	
1	1.41	6.72	2.05	1.89		4.59 5.41	1.40 1.65	905
2*	1.41	6.46	1.97	1.70	0.86	4.17 4.43	1.27 1.35	317
3	0.83	6.26	1.91	1.42	0.73	3.25 5.03	0.99 1.53	527
4*	1.24	11.2				**		876

A. B. and C are coefficients defining best fitting Lines through the spots thus:

H_m = Maximum wave height measured from record

= $AH_v + B$ (Best straight line through spots)

= CH_v (Best straight line through origin)

H_v = Visually observed wave height

*In the case of 3 and 4, H_m has been derived from $H_m = 1.6\ H_s$

H_s = significant height, H_s was calculated in these cases from

$$H_s = 4\sqrt{m_o}$$

where m_o is the wave energy calculated from the wave records.

ρ = correlation coefficient

σ = the standard deviation

N = the total number of comparisons

**Line was fitted visually

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APPENDIX C

COMMENTS ON THE WORK OF FREEMAN

Prepared by V. J. Cardone

This appendix presents a review of the following papers:

1) "Forecasting Waves in the Gulf of Alaska", Freeman and Bujnoch, Ocean Engineering, February 15, 1976

2) "A State of Art Method of Estimating Extreme Conditions in Storms", J.C. Freeman, submitted to Petroleum Engineer, 1976

The above two articles present an attempt at what can be considered the most realistic solution to the problem of determining the distribution of extreme waves in the Gulf of Alaska - namely the use of wave-hindcasting techniques in conjunction with a long history of meteorological data that characterizes historical storms. Freeman's attempt, however, suffers from serious shortcomings that render his results inconclusive.

Primarily the hindcast model referenced is not documented, its applicability to extratropical wave specification in the Gulf of Alaska is not demonstrated, and only scant reference to its accuracy is offered. The latter is a reference to a single spectrum measured in a Gulf of Mexico hurricane which was closely matched in a hindcast by the model. However, the entire hierarchy of wave hindcast models from slide-rule parametric (Ross, 1976), significant wave (Wilson, 1961, Bea, 1974) and directional spectral (Cardone et al, 1976) have been shown, when suitably calibrated, to be capable of very accurate specifications of moderate Gulf of Mexico hurricanes. Such models, however, can produce divergent results (see e.g., Cardone et al, 1976) when applied to the broader class of hurricanes and extratropical storms. Thus the hindcasting accuracy of the model needs to be established for the Gulf of Alaska or at least a comparable region such as the northeast North Atlantic before credibility of results can be established.

Another difficulty with Freeman's implementation of the hindcast study was in the screening of storms. A total of 15 storms in 10 years were hindcast. An initial screening identified 120 possible candidates and a subjective evaluation of storm fetch, intensity, size and speed of motion were used to reduce the number to 15. A better screening procedure is to let the hindcast model itself, through the complex solution of the wave energy balance equation, identify the most significant wave producing storms. It is quite possible that Freeman's subjective procedure could have biased the sample of hindcast wave data used in the statistical extrapolation.

Finally, the supporting evidence given by Freeman consist largely of references to visual estimates of extreme wave heights - estimates will tend to have a large variance, particularly at high sea states. Thus there is little value in the quoted reports of crab boat and tug boat captains who have reported "seeing" 100 foot waves in storms in the Gulf of Alaska.

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APPENDIX D

OCEAN WAVE PREDICTION - AN UPDATE 1973 - 1977

Prepared by V. J. Cardone

Introduction

In a review prepared for the Society of Naval Architects amd Marine Engineers Seakeeping Symposium in 1973 (see Appendix E), this author considered the development of ocean surface gravity wave specification methods. Particular emphasis was placed upon those methods that provided a description of the wave spectrum. Computer based models that simulated the spectral energy balance were described in some detail and several model predictions were intercompared. The review also noted considerable work in progress.

Since that review, ocean wave prediction has continued to be a subject of considerable interest as models are developed and applied in both a hindcasting mode for climatological and design studies and in a real time mode for operational forecasting. This update should be read in combination with the 1973 review (Appendix E). It reviews work published since 1973 in the form of new models developed or the further application of models already in existence. Finally an assessment of remaining deficiencies in the current state of the art is given.

Model development

There have been a number of significant developments in wave prediction models in the past several years. The model originally described by Pierson, Tick and Baer (P-T-B) (1966) has been refined and successfully adapted on the U.S. Navy Fleet Numerical Weather Central (FNWC) system for operational forecasting. Twice daily, the model is used to prepare wave forecasts out to 72 hours on a

grid of points covering all Northern Hemisphere seas, with input wind fields computed from sea level pressure forecasts provided by the numerical weather prediction model of FNWC. Before each forecast is run, observed wind data and analysis wind fields prepared therefrom are used to update the wave spectral field via a 12 hour hindcast run. A description and preliminary evaluation of the Navy wave prediction system is given by Lazanoff and Stevenson (1975).

The P-T-B model has been applied to hurricane scale meteorological systems and validated against data collected in an oil industry sponsored measurement program known as the Ocean Data Gathering Program (Ward, 1975). That version of the model, known as the ODGP model, is described by Cardone et al (1976). The model is being applied currently in the hindcast of all significant hurricanes known to have occurred in the Gulf of Mexico. It has also been tested in a real time mode at the NOAA Atlantic Oceanographic and Meteorological Laboratory during the passage of hurricane Belle along the East Coast of the U. S. in August of 1976 (Cardone, Ross et al, 1976). That test program will continue this hurricane season and the model will be used in hindcast studies of Belle and Eloise, 1975, storms for which NOAA data buoy wave measurements are available.

The wave spectral prediction model originally described by Isozaki and Uji (1973) has also been applied to tropical cyclone wind fields by Uji (1975). The sensitivity of the wave solution to storm forward speed of the hypothetical typhoon considered was found to be large. In a later study (Isozaki et al, 1975), the hindcast model was applied to an actual typhoon with the hindcasts compared to measurements of swell observed near the Japanese coast some distance from the storm track. The models applied include a spectral growth formulation similar to that of P-T-B.

A class of spectral models formulated about the P-T-B growth scheme has been proposed in one form or another by Baer et al - (1970), Hsu (1973) and Freeman (1976). Those models attempt to avoid the computationally expensive solution of the spectral energy balance equation by finite differences for a large number of grid points when wave predictions at only a few sites are needed. For such applications, solutions are sought along ray paths projected outward from the sites. The ray model described by Freeman is documented only for stationary wind fields, but it apparently can be applied to non-steady moving wind fields in a manner described first by Wilson (1961) for a significant wave type hindcast model.

All of the models described above employ an explicit representation of the processes of wave generation and dissipation in the so called Source Function. Within the past several years there has been little progress from either a theoretical or experimental standpoint in our knowledge of the various components of the Source Function, with perhaps the exception of the JONSWAP experiment described by Hasselmann et al (1973). In that experiment, measurements of the wave spectrum were made in the North Sea at short fetch under well defined linear wind fields. It was inferred from an analysis of the evolution of the wave spectrum with fetch that for a growing wave spectrum, the dominant process responsible for the development of the spectrum was the non-linear transfer of energy across the spectrum associated with resonant wave-wave interactions. Further, it was proposed that the process was responsible for the characteristic shape of the spectrum observed in JONSWAP; that is, a narrow spectrum with a pronounced peak. It was inferred that the results of JONSWAP could be applied to all growing wind seas.

The implication of the above interpretation to the form of wave prediction models is profound, since an inclusion of a rigorous wave-wave interaction term in the Source Function is impossible

with current computer speeds. Therefore, Hasselmann, Ross, Mueller and Sell (1976) have proposed a wave prediction model based upon a parametrical representation of the spectrum. Indeed, it is proposed that one parameter, the nondimensional peak frequency $\nu = U f_m/g$ (where U is wind speed, f_m is the spectral peak frequency, g is gravity) can be used to characterize the stage of wave development and they describe a model that involves only the prediction of wind waves from a specification of the time varying wind field on a grid of points. The method is not suited to swell, which must be represented and propagated by conventional methods. The parametric approach is being incorporated into a North Sea Wave Hindcast model. Some results of that effort will be described below.

The JONSWAP analysis has been criticized recently by Pierson (1977), who demonstrated that the overall behavior of the spectrum with fetch observed in the experiment could be explained without resort to the non-dimensional parametric representative of the spectrum used and without recourse to non-linear interactions. In addition, it was shown that the procedures used to fit the spectra measured in JONSWAP could bias the values of some of the parameters, especially the so called peak enhancement factor. Also, on theoretical grounds. Longuet-Higgins (1975) and Fox (1976) have presented calculations of the non-linear transfer of energy within a narrow continuous spectrum which suggest that the effect of the non-linear interactions is to broaden initially narrow peaks in the frequency spectrum. The issue of the role of non-linear interactions in wave generation must therefore be considered to remain quite controversial.

Model intercomparison

Ocean wave prediction models continue to be tested in two ways. First, they are typically used to simulate the evolution of the wave spectrum with fetch or duration for stationary and uniform wind fields. Such tests are used frequently to reveal model sensitivity to alternate Source Function component parameterizations or to compare model predictions with fetch limited wave data. Two recent studies of this nature compared several candidate wave models. Dexter (1974) programmed the P-T-B model,

Barnett's (1968) spectral growth model, and the significant wave hindcast model of Wilson to produce time histories of significant wave height and peak frequency for simply prescribed wind input. It was concluded that the differences in the model predictions were slight and that the choice of one or another model could be made simply on the basis of computing efficiency. No comparisons were made between model predictions and actual wave data.

In more recent study, Resio (1977, unpublished) compared the behavior of Barnett's (1968) and the FNWC P-T-B spectral growth models in non-dimensional space. That is, for constant wind input of 15 m/sec and 30 m/sec, the dimensionless wave height $\bar{H} = g\sqrt{E/U^2}$ (where E is total variance) was plotted versus dimensionless fetch $\bar{F} = g\,F/U^2$ (where F is fetch) and dimensionless duration $\bar{T} = gT/U$ (where T is duration). It was shown that neither model implied a single relationship between $\bar{H}$ and $\bar{F}$ as has been proposed by Mitsuyasu (1968) and Hasselmann,et al (1976) but that Barnett's model obeyed such a law approximately. Resio proposed a modified version of Barnett's model, one that included a more accurate propagation system and a fetch dependent equilibrium range specification, which more nearly followed the similarity relationship between $\bar{H}$ and $\bar{F}$. Resio also showed that neither the FNWC nor the modified. Barnett model implied a similarity behavior between $\bar{H}$ and $\bar{T}$ and he suggests that such a law does not hold in nature and that duration limited spectra do not possess the JONSWAP shape.

Hindcast Accuracy

A most revealing test of an ocean wave prediction model is its ability to specify the directional wave spectrum for realistic wind fields that vary in space and time. This is a very difficult test to carry out properly for several reasons. First, it is very difficult to specify accurate wind fields over the open ocean and once specified it is difficult to assess quantitatively the errors in wave hindcasts attributed solely to errors in the input wind fields. Second, measurements of the wave

frequency spectrum are relatively scarce and measurements of the directional spectrum are rare indeed. Finally, where wave measurements are available, the spectral analysis of those measurements provides only an estimate of the true spectrum. Predictions of wave models are in terms of the expected value of the true spectrum and any comparison of predicted and measured spectra must consider the effects of the sampling variability that characterizes the measured (estimated) spectrum.

One of the most comprehensive sets of wave measurements in high sea states resulted from the ODGP measurement program. Measurements were made from six oil rigs with data automatically recorded over a period of nearly two years. The ODGP hindcast model was developed and validated with the data obtained in the more severe tropical cyclone events sampled including severe hurricane Camille, 1968. Since the intended application of the model was to produce design data in terms of the distribution of maximum individual wave heights in hurricanes, a useful measure of accuracy was provided by a comparison of hindcast and measured (or estimated) maximum wave heights at various locations in the Gulf of Mexico during five different hurricanes. Over a data range of 20 to 80 feet in 18 comparisons, the r. m. s. error (difference) was 4.5 feet. The model also predicted spectra in good agreement with measured spectra.

It cannot be concluded, a priori, that the ODGP model would produce comparable results in general. Gulf of Mexico hurricanes do not exercise the broad range of Source Function component parameterizations. For example, in a recent study of east coast hurricanes (Cardone, Ross et al, 1976) the model produced quite a different solution for fast moving storms of comparable intensity to slower moving Gulf of Mexico storms. Unfortunately wave measurements do not exist in such storms. However, the ODGP model has produced accurate hindcasts of very recent Gulf Mexico hurricanes for which industry and NOAA buoy wave data exist, such as in Delia, 1973, Carmen, 1974 and Eloise, 1975.

The existence of an operational spectral hindcasting and forecasting model at FNWC should allow ample opportunity for model validation, since offshore wave measurements made anywhere in the Northern Hemisphere and at any time can be compared to the model produced hindcast and forecast time histories at nearby grid points. Particularly as a result of the proliferation of NOAA data buoys equipped with wave recorders, it should be possible to accumulate a large sample of hindcast, forecast and measured frequency spectra for the FNWC model. FNWC should be encouraged to produce and publish such data and error analysis derived therefrom.

A model similar to the operational FNWC model was recently applied to the hindcast of a particularly stormy period in the North Atlantic Ocean that occurred between late December, 1973 and mid January 1974. Special wave measurements made at Ocean Stations J and K in the eastern North Atlantic were compared to the hindcasts by Salfi and Pierson (1977). They concluded that while the hindcast significant wave heights were typically within 4.5 feet of the measured heights. It was clear that the hindcasts could be improved by increasing the angular, spatial and temporal resolutions of the P-T-B model. Also, there was some evidence of a systematic error in the spectral comparisons but sampling variablity in the meaured spectra did not allow a conclusive definition of that error.

Feldhausen et al (1973) have compared eleven hindcasts of the severe North Atlantic December 1959 storm. Of the models compared, which included both spectral and significant wave types, the hindcasts made by the models of Barnett (1968) Bretschneider (1963) and P-T-B were best with correlations of 0.85 between measured and hindcast significant wave heights. However, all models had difficulty simulating the low wave heights recorded between storm events, during periods of rapidly shifting winds.

A first test of the parametric approach to wave prediction as proposed by Hasselmann et al (1976) is being conducted in Great Britain at the Hydraulics Research Station. There, a North Sea hindcast model has

been developed and validated with wave measurements made in the North Sea in about a dozen severe storms sampled since 1969. Early in the development of the model, a three parameter model was found to be necessary to track swell with fairly high frequency, spatial and angular resolution. Further, to produce realistic hindcasts, a set of rules, largely intuitively based, had to be developed that governed the sea-to-swell and swell-to-sea energy transfers that occur in the hybrid model. After considerable model parameter tuning, the r. m. s. difference between hindcast and measured significant wave height for the dependent storm sample was found to be close to 3 feet. However, there is evidence of large systematic errors in the peak frequency specification, which would imply large errors in the spectral shape. The model is currently being used to hindcast about 40 severe storms that have affected the North Sea since 1966. The hindcast wave data will subjected to standard statistical analyses to determine the long term distribution of extreme waves (Ewig, personal communication).

Summary and Conclusions

There has been little fundamentally new knowledge generated in the past decade on the basic processes of wave generation and dissipation in either deep or shallow water. The impact of field programs designed to gather wave data for basic studies, such as JONSWAP and GATE (the GARP Atlantic Tropical Experiment) remains slight. There remains a considerable lack of knowledge as to the importance of wave-wave interactions in wave growth and of the processes governing the transition of growing seas to a fully developed state. The behavior of the wave spectrum in response to a rapidly shifting wind pattern is poorly understood.

Despite those theoretical difficulties, ocean wave prediction models can be applied to yield wave data useful for design or forecasting purposes. However, since all models possess a significant amount of empiricism and parameterization of poorly understood processes, they should be applied cautiously. The level of accuracy and reliability of a model

should be determined in so far as possible in the environment of model application. For example, models developed for and tested in semi-enclosed basins (e. g. North Sea) may not work in the open sea. Models calibrated with short fetch-limited, low sea state data may fail in more general application. Models that simulate well the wave distribution in slow moving tropical cyclones (e. g. ODGP, Freeman, 1976:) may not be as accurate where applied to extratropical cyclones. To date, no single hindcast model has been tested extensively over a wide range of storm types though the P-T-B, FNWC, ODGP family of models probably comes closest to having demonstrated wide applicability.

Too often, hindcast model results have been verified against integral properties of the spectrum, such as significant wave height and average wave period. Seemingly small errors in such properties can mask large errors in the frequency and/or directional spectrum. However, significant new wave data bases in the form of spectra and some directional spectra are becoming available as a result of various government and industry sponsored measurement programs. Those programs include the NOAA NDBO program, GATE, the ODGP and its follow on the OCMP (Ocean Current Measurement Program-sponsored by Shell Development Company) and the Gulf of Alaska wave measurement program (sponsored by the Marathon Oil Company). As government data are processed and industry data reach the public domain, it should become possible to further refine and validate ocean wave prediction models.

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Appendix E

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OCEAN WAVE PREDICTION: TWO DECADES OF PROGRESS AND FUTURE PROSPECTS

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ABSTRACT

The development of theories to describe the movement of ships in random seas was accompanied, two decades ago, by the introduction of graphical procedures to specify the ocean wave spectrum from meteorological time histories. In the following decade, these techniques were adapted to the digital computer to provide limited climatological descriptions of the state of the sea for design purposes. Modern refinements of these models have capitalized on the many theoretical advances made in the last two decades in our understanding of the processes of wave generation, propagation and dissipation. These models, based on the numerical integration of the spectral energy balance equation, have been shown to be capable of providing accurate predictions of the two dimensional wave spectrum on grid systems that resolve the influence of cyclone scale disturbances on the major Northern Hemisphere oceans. Unfortunately, computer limitations have prevented extensive implementation of these models for either wave forecasting or climatological applications. Recent extensions of these models to smaller ocean basins, mesoscale meteorological disturbances and to the continental shelf are most promising and will be reviewed.

Further advances in wave prediction will require considerable improvement in our ability to specify and predict the wind field over the oceans. In addition more measurements of the wave spectrum than are currently made are required in order to refine and verify existing models. Satellite borne remote sensors that can essentially satisfy both requirements are currently under development and show great promise. These systems are likely to become operational within the next two decades. In the same time frame, advances in computer technology will make feasible the operational use of the most sophisticated wave prediction models, both for real time wave forecasting out to perhaps five days and for the calculation of wave climatologies of the world's oceans.

INTRODUCTION

The application of spectral concepts to the description of ocean surface waves by Pierson and Marks (1952) signalled the beginning of a new era in ocean wave prediction. Indeed, the so-called spectral method of wave prediction was already outlined in the paper by St. Denis and Pierson (1953) on the basis of the pioneering studies of Pierson (1952), Neumann (1952), and Longuet Higgins (1952) and Pierson, Neumann, James (1953). The former work proved that the only way in which to explain correctly ship motions is to relate them to the properties of the wave spectrum. The latter group of studies provided the hope that such properties would be available one day to the naval architect and marine engineer at least in a climatological sense for the oceans on a global scale and that they migh might be forecast for several days into the future on a routine basis for use in marine forecasting and ship routing.

Today, the goals expressed in this early work remain largely unattained. There is, however, considerable basis for the belief that they will be attained well within the next two decades, because of a combination of advances in satellite remote sensing, numerical weather prediction and computer technology. The last two decades, however, can be credited with the fundamental theoretical advances that had to be made before global scale spectral wave prediction models could hope to be applied successfully.

THE SIGNIFICANT WAVE METHOD

The serious study of wave prediction began in World War II in response to the crucial need for wave forecasts to support planning of amphibious operations. To Sverdrup and Munk fell a task all too common in the geophysical science - to produce the capability to predict a physical phenomenon before that phenomenon has been adequately observed, described or explained theoretically. As noted by Kinsman (1965), "Until 1942, the study of mathematical wave models and the behavior of actual ocean waves had very few points of contact ----nothing much was known about the mechanisms of generation, interaction or decay ----the properties of waves at sea are very difficult to measure, and little had been done with any certainty."

It is generally agreed that considering this state of affairs, Sverdrup and Munk (1947) produced an imaginative and useful wave prediction scheme, which has come to be known as the significant wave method. Their study introduced the concepts of significant wave height Hs and significant wave period Ts, as an early recognition of the fact that ocean waves had to be treated

statistically. Relationships were derived between wave steepness. $\gamma = H_s/L$ (wave height/wave length) and wave age $\beta = c/u$ (wave phase speed/wind speed) and between the non-dimensional quantities gF/u^2, gt/u, and γ and β (where g is gravity acceleration, F is wind fetch and t is wind duration). Additionally, a simple theory for wave propagation and decay yielded relationships between period and height of swell and decay distance and travel time. To apply the method, one determined wind speed, fetch and duration from analyzed or prognostic weather maps and graphically determined H_s and T_s for the forecast point of interest. Swell was forecast graphically as well.

The significant wave method is of considerably more than historical interest as it continues in wide use today. Until just several months ago, it formed the basis of all operational wave forecast programs, and it has been applied to the hindcast of climatological significant wave conditions in a wide variety of locations and for various wind field scales. The original Sverdrup-Munk relationships have been revised several times (e.g. Bretschneider 1952 and 1958) adapted to more complex wind fields (e.g. Wilson, 1955) and solved on digital computers in objective wave forecasting programs (e.g. Hubert, 1964; Pore and Richardson, 1969). The significant wave method is still the most widely used wave forecasting method, largely because of its simplicity and speed of application, and it can produce forecasts of significant wave height that agree reasonably well with observations.

It is clear, however, that the significant wave method has seen its day. It simply cannot provide an adequately detailed description of the sea surface, as required in current marine structural design problems. In addition, attempts to marry the significant wave method to the spectral method by the use of parameterized spectral forms, usually fail to predict the complexity characteristic of wave spectra observed in the open ocean. The significant wave method fundamentally fails to provide a suitable framework for self improvement. The detection of systematic errors in a given method has often led to revision of relationships and graphs, but nothing fundamentally new was learned about the processes of wave generation propagation or dissipation. It is simply based on an inadequate theory of ocean waves!

SPECTRAL METHODS

As early as 1953, the concepts of stochastic processes and spectra had already been incorporated into a practical wave forecasting method. This technique, referred to as the PNJ method (Pierson, Neumann and James, 1953 and 1955) was based on the spectrum proposed by Neumann (1953) which in turn was derived with the use of data on wave heights and periods obtained by visual observing methods. This imaginative derivation was in a sense verified when Pierson (1954) interpreted the observable properties of waves in terms of the wave spectrum.

Among the innovative aspects of the PNJ method was the recognition of directional properties of waves-fetch width as well as length were considered. The concept of moving fetch was introduced, and the "period increase" of swell was orrectly explained in terms of spectral component group velocity dispersion effects.

A series of proposed spectral forms followed the introduction of the Neumann spectrum (e.g. Darbyshire 1955 and 1959, Gelci, Gazale and Vassal 1957, Bretschneider 1959). That based on the largest sample of wave recorder data, however, was the fully developed spectral form of Pierson and Moskowitz (1964), which incorporated the similarity theory of Kitaigorodskii (1961). The Pierson-Moskowitz spectrum was consistent, at high frequencies, with the -5 frequency dependence of the equilibrium range proposed by Phillips (1958). Further, it was shown by Pierson (1964) that a consideration of the variation of wind with height in the marine boundary layer through the use of a logarithmic profile brought the results of Neumann, Pierson, Moskowitz and others into close agreement. This paper implied that failure to account properly for the wind structure in the marine atmosphere in existing wave prediction schemes was clearly to their detriment and affected wave forecasts in an uncontrollable way.

One important weakness of all wave prediction schemes in existence in the early 1950's was the subjectivity of their application. Wave hindcasting and forecasting was still an art - only practisioners with considerable experience could produce consistent results. With the development of numerical weather prediction, however, it became evident that large digital computers could be applied to the wave prediction problem. Hubert (1957), Gelci and Chavy (1961) and Baer (1962) were among the first to use a computer to make wave predictions.

Baer's work represented an early attempt to build a comprehensive and completely computerized wave prediction scheme. His model represented the North Atlantic ocean with a grid of 519 points spaced 120 nautical miles apart. At each grid point the spectrum was described by 120 numbers that represented ten frequencies and 12 directions. Wind speed and direction were supplied to the grid and updated each 6 hours, while each two hours, the 120 numbers were systematically modified to account for wave generation and propagation.

The PNJ spectral component wave growth was coupled to the angular dispersion relationship given by Project SWOP (Cote et al., 1960) and expressed in the form of a large table. At each time step, growth was allowed only for components travelling within 90° of the wind direction with the Neumann fully developed spectrum used to limit growth. No other form of implicit or explicit attenuation was assumed.

Wave propagation was approximated by the so-called jump technique - that is, spectral components were simply translated to adjacent grid points after a sufficient number of time steps had elapsed to account for the grid spacing. This technique allowed the wave energy to retain the quasi-discontinuous characteristics imparted by

moving fetches and as occur for example near meteorological fronts.

Baer tested his model by hindcasting the severe wave conditions observed in the North Atlantic in December, 1959 (see Figure 9). Despite some deficiencies, Baer's work could be credited with the establishment of the feasibility of an objective numerical wave prediction model. It demonstrated that the concepts of fetch, duration, sea, and swell were implicitly treated in such an approach and that accurate wave predictions in an ocean basin such as the North Atlantic required simulation of wave conditions for several prior days if zero spectral energy was assumed as initial condition.

The suitability of this model to further development was soon utilized. By 1964, a revised version had been used to hindcast the two dimensional wave spectrum on the 519 point grid for the year 1959. This project, sponsored by the U.S. Naval Oceanographic Office, and carried out at New York University has been summarized in detail by Bunting (1966). Briefly, the revisions included the introduction of objective wind field analysis techniques (Thomasell and Welsh, 1963), the adoption of the Pierson-Moskowitz fully developed spectrum as a limiting state and the addition of a dissipation mechanism based on gross Austausch turbulence to simulate the attenuation of swell travelling against wind generated seas.

The climatology of the wave spectrum of the North Atlantic generated as a result of this project remains the only such description available. It has and continues to be utilized in a number of design studies.

Spectral Energy Balance

The frame work of contemporary spectral wave prediction models can be traced through the work of Gelci et al. (1956), Hasselman (1960), Pierson et al. (1966) and Barnett (1968). These models are based on the numerical integration of the energy balance equation

$$\frac{\partial}{\partial t} E(f, \theta, x, t) = -C_g (f, \theta) \cdot \nabla E(f, \theta, t, x) - S \qquad (1)$$

where E is the directional wave spectrum defined as a function of frequency, f, direction, θ, position, x and time t · Cg is the deep water group velocity and S, the source function, represents all physical processes that transfer energy to or from the spectrum. In principal, if S could be specified in terms of E and the wind field, (1) could be numerically integrated, subject to appropriate initial and boundary conditions, to yield wave predictions with an accuracy limited only by errors in the wind field and in the numerical methods.

Propagation. The physical nature of wave propagation in deep water is well understood as a result of the work of Barber and Ursell (1948), Groves and Melcer (1961) and Snodgrass et al. (1966). Each component in the two dimensional spectrum travels along a great circle in its direction at the deep water group velocity appropriate to its frequency. The development of an accurate computer algo- to implement these principles, however, poses a significant problem.

Baer (1962) demonstrated that propagation by a simple first order finite difference analog

$$E_x^{t+\Delta t} = E_x^t + \mu/2\,(E_{x+\Delta x}^t - E_{x-\Delta x}^t) \qquad (2)$$

where Δt is the time step, Δx the grid spacing and $\mu = Cg \cdot \Delta t/\Delta x$, is inadequate if the quasi-discontinuous nature of the spatial distribution of wave energy is to be preserved. Such a scheme has been used by Gelic et al. (1966) and Barnett (1968).

The jump technique, as developed by Baer (1962) partially overcame this difficulty but was at best only an approximation to propagation for most spectral components and it could lead to serious errors for large propagation distances. Pierson, Tick and Baer (1966) proposed a technique that combines the finite difference and jump techniques. Their propagation algorithm attempts to keep track of discontinuities in the energy field and employs jump techniques in such regions while (2) is applied where the fields vary smoothly. Uzi and Isozaki (1972) have developed a more complicated version of the jump technique whereby lateral spreading and longitudinal dispersion associated with discrete directional spectral components are simulated.

Though the above methods are not very appealing from the standpoint of numerical analysis, they have made it possible to implement numerical wave prediction models on relatively small and slow computers. A more elegant solution to the propagation simulation problem has recently been proposed by Ewing (1971). He applied a fourth order convective difference scheme, which can be written, for the case of energy propagation in the x direction as

$$E_x^{t+\Delta t} = E_x^t + \left[\frac{1}{12}\mu/(1-\frac{1}{12}\mu)\right] \cdot \left[E_{x+2\Delta x}^t + 8\left(E_{x-2\Delta x}^{t+\frac{1}{2}\Delta t} - E_{x+\Delta x}^{t+\frac{1}{2}\Delta t}\right) - E_{x-2\Delta x}^{t+\Delta t}\right] \qquad (3)$$

The scheme, which can be extended to two dimensions, is stable and very accurate for $\mu < \frac{1}{2}$. Ewing (1971) presented a test of (3) for a 12 knot group velocity spectral component on a 120 nautical mile mesh grid (Figure 1). After 300 iterations (hours), the peak variance is reduced by only about 10%.

Most numerical models have used grid systems on conformal map projections because of their minimal distortion, small scale variation and conservation of angle. Grid paths on such projections are not, in general, great circles, though for distances less than one

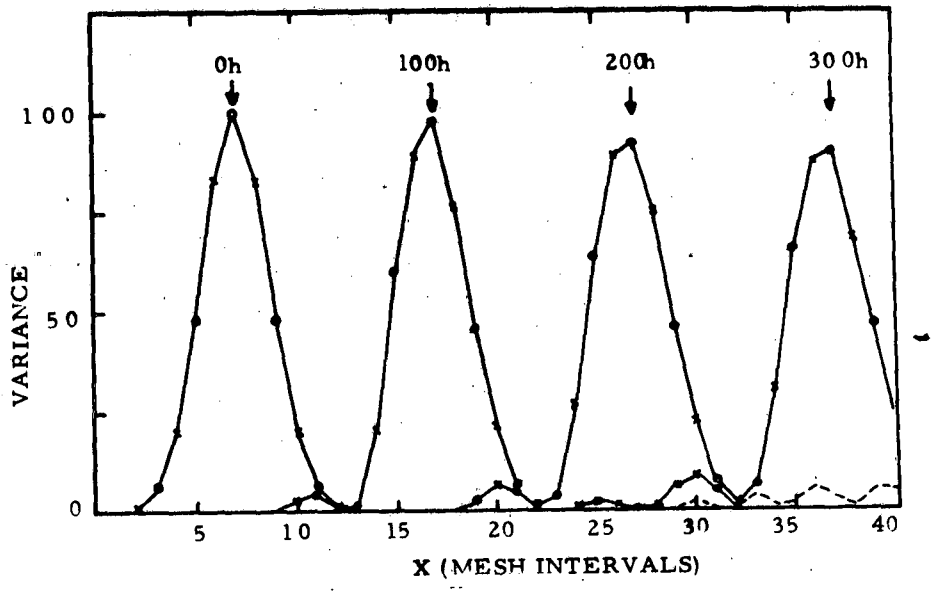

Fig. 1. Ewing's (1971) test of propagation using a 4th order difference method, for dispersion of a Gaussian profile of wave energy with group velocity 12 knots. Vertical arrows indicate theoretical distances travelled after given times.

quarter of the earth's circumference, errors are not too large. For global scale predictions, Baer and Adamo (1966) proposed a grid system based upon the gnomonic projection - on which all straight lines are great circles. A multi-projection system was devised in which the earth was mapped onto 20 faces of an icosahedron circumscribed about the earth. This "Icosahedral-Gnomonic Projection" is shown in Figure 2. Within each triangular subprojection, a hexagonal coordinate system defines a 1225 point grid of average spacing 95 nautical miles. A modified jump technique has been used on the Northern Hemisphere portion of this grid system and appears to give reasonable results.

The Source Function. The dominant processes that can transfer energy to or from a spectral component include direct transfers from the wind field, wave breaking and wave-wave non linear interactions. The wind generation part of the source function, Sw, is usually expressed as

$$Sw = A(f, x, t) + B(f, x, t) \cdot E(f, x, t) \qquad (4)$$

where A and B are also functions of the wind field. The quantity A has been given physical significance through the theory of Phillips (1957) which explains the initial generation of gravity waves on an undisturbed sea surface through a resonant excitation by incoherent atmospheric turbulent pressure fluctuations being convected by the mean wind. To this author's knowledge, the only reliable field measurements of this pressure spectrum remain those of Priestly (1965) who obtained measurements over mowed grass for a variety of wind speed and stability conditions. The limited fetch wave growth studies of Snyder and Cox (1966), Barnett and Wilkerson (1967), Schule et al. (1971) and Ross et al. (1971) have verified that the resonance mechanism is responsible for the early linear stage of wave growth. The wave prediction models of Barnett (1968), Inoue (1967) and Ewing (1971) and others all incorporate Priestly's functional form of the three dimensional pressure spectrum with a scaling factor fitted to growth rates determined in the field experiments. Figure 3, for example, shows the linear growth rates of Snyder and Cox (for f = 0.3 cps) and the forms adopted by Inoue (1967) and Barnett (1968). The implications of Priest Priestly's measurements at this frequency are also indicated. Recent hindcasting experience with the Inoue (1967) growth formulation suggests (revised curve in Figure 3) that Priestly's measurements should be taken more literally.

The quantity B in (4) has been given dynamical significance through a series of studies studies beginning with the work of Miles (1957 and 1959). In those studies Miles was the first to calculate the amplitude of the component of atmospheric pressure, induced by a prescribed free surface wave, in the air flow over the wave and in phase with wave slope. His analysis was quasi-laminar, atmospheric turbulence being neglected except in the sense that the wind profile over the waves was specified as logarithmic. Phillips (1966) was successful in extending Miles' model to include some aspects of atmospheric turbulence and showed that these effects were important in determining the energy transfer to spectral components possessing phase speeds above anemometer height wind speeds.

The important result of the Miles-Phillips instability theories is that spectral energy increases exponentially with time or fetch until dissipative effects become important. For a neutrally stratified atmosphere, they show that the dimensionless growth rate B/f can be expressed solely as a function of dimensionless friction velocity, u_*/c, where $u_* = \sqrt{\tau/\rho}$ (τ is the surface shear stress and ρ is air density). The instability theories have been verified qualitatively by direct measurement of the wave induced air velocity and pressure fields both in

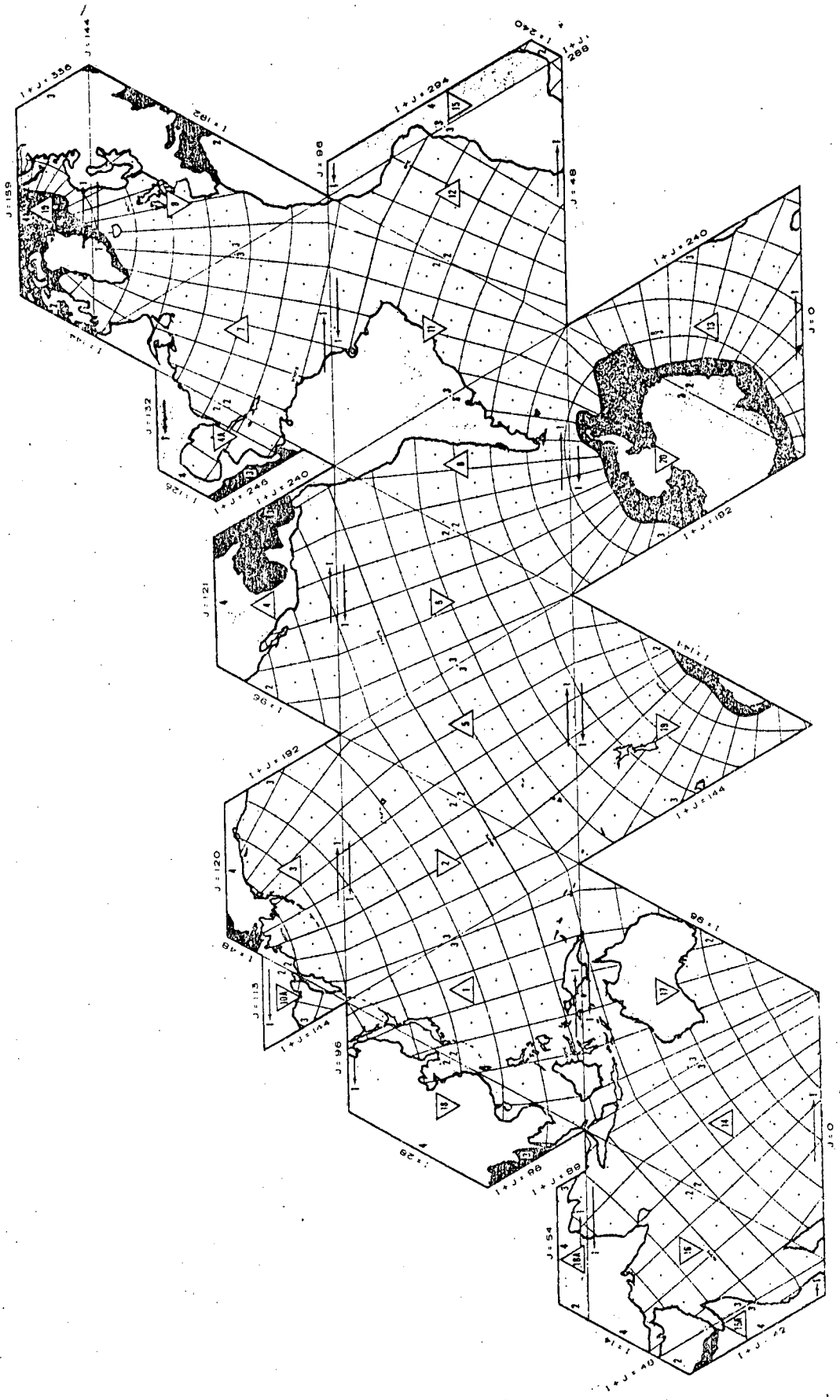

Fig. 2. The Icosahedral-Gnomonic Projection of the earth designed for global numerical wave prediction. (Ba... and Adamo, 1966).

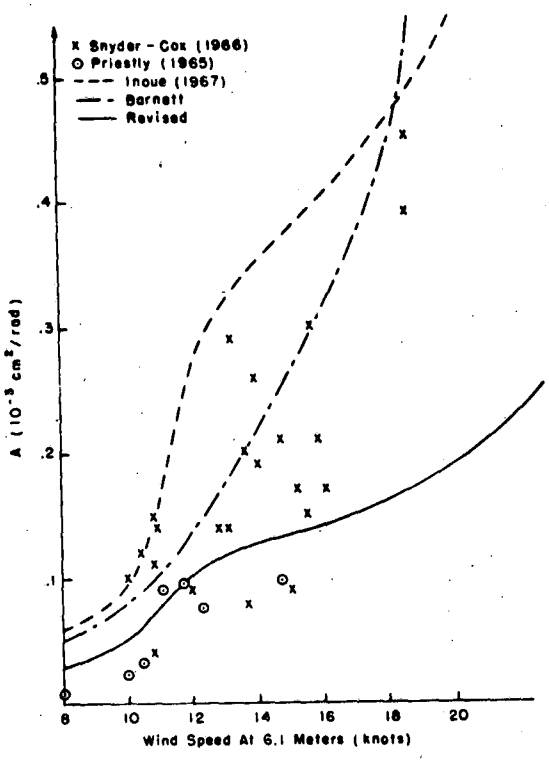

Fig. 3. The magnitude of the resonance mechanism linear growth rate for a .3 hertz spectral componenet from observations of fetch limited wave growth, atmospheric pressure spectrum measurements and various parametric forms.

the laboratory (Shemdin and Hsu, 1967) and in the field (Dobson, 1971), but the theoretical growth rates appear to underestimate those observed by about a factor of 4. A collection of available field determinations of B/f is shown in Figure 4 along with the theoretical predictions and the form adopted by Inoue (1967).

The limitation of wave growth imposed by wave breaking is generally modelled by invoking Phillips (1958) equilibrium range dependence, which is one dimensional form is given as

$$\frac{\alpha g^2}{(2\pi)^4} f^{-5}$$

A value of α near 8×10^{-3} has been verified repeatedly in the literature. However, a recent study of the behavior of the high frequency gravity and gravity-capillary region of the wave spectrum (Pierson and Stacy, 1972) has verified the existence of a range of frequencies that obeys the form originally proposed by Kitaigorodskii (1961) as

$$\left[\frac{\alpha g^2}{2\pi^4 u_{*_{min}} f_2}\right] \frac{u_*}{f^4}$$

where $u_{*_{min}}$ is a critical friction velocity and f_2 is the upper limit to which this form applies. The lower frequency limit is given as

$$f_{min} = \frac{u_{*_{min}}}{u_*} f_2$$

It follows that in this "Kitaigorodskii range" the spectrum exceeds the equilibrium value by the ratio f/f_{min}. Limited available measurements suggest $u_{*_{min}} = 12 \pm 3$ cm/sec and $f_2 = 3 \pm .5$ hz. Thus at high wind speeds ($u_* > 100$ cm/sec) this range may govern a part of the spectrum that contributes significantly to the total energy. Stacy's (1973) analysis of wave spectra obtained in hurricanes strongly confirm these results.

The significance to wave prediction of non-linear wave-wave energy transfers as originally proposed by Phillips (1960) and developed by Hasselmann (1963) remains a controversial subject as does the related question of the existence of a fully developed sea. Wave prediction models whose source function ignores non-linear energy transfers, invariably involve the concept of a fully developed spectrum to limit spectral component growth at frequencies below the equilibrium range. The Pierson-Moskowitz spectrum has been widely used in this context. An example of such a solution for the special case of infinite duration fetch limited constant wind conditions is shown in Figure 5. The variation of significant wave height implied in this spectral calculation compares favorably with prior semi-empirical results.

This kind of spectral growth model, however, has been questioned on at least two fronts. Phillips (1966) has suggested that the low frequency part of the spectrum should continue to grow toward low frequencies as long as the wind continues to blow over a long enough fetch and that fully developed spectral forms empirically express the duration and fetch limitations characteristic of real wind fields. In response, Pierson (e.g. Pierson and Stacy, 1973) notes that the trade wind seas seem to be in equilibrium with winds over vast areas and that spectral components with periods greater than about 24 seconds have never been observed.

The spectral growth model exemplified in Figure 5 also does not represent the so-called "overshoot" phenomenon. Barnett and Sutherland (1968) have compared laboratory and field fetch-limited spectral growth studies that show amplifying spectral components exceeding their ultimate equilibrium values by up to 50% before stabilization. Since that study, the overshoot effect has been observed in the fetch limited growth studies of Ross et al. (1971) and Schule et al. (1971). It has also been observed in the duration limited spectra observed at Argus Island tower (near Bermuda) as analyzed by DeLeonibus and Simpson (1972). There now seems to be little doubt that the overshoot effect is a real phenomenon that forms an integral part of the wave generation process and that is unexplainable by linear theories of wave growth.

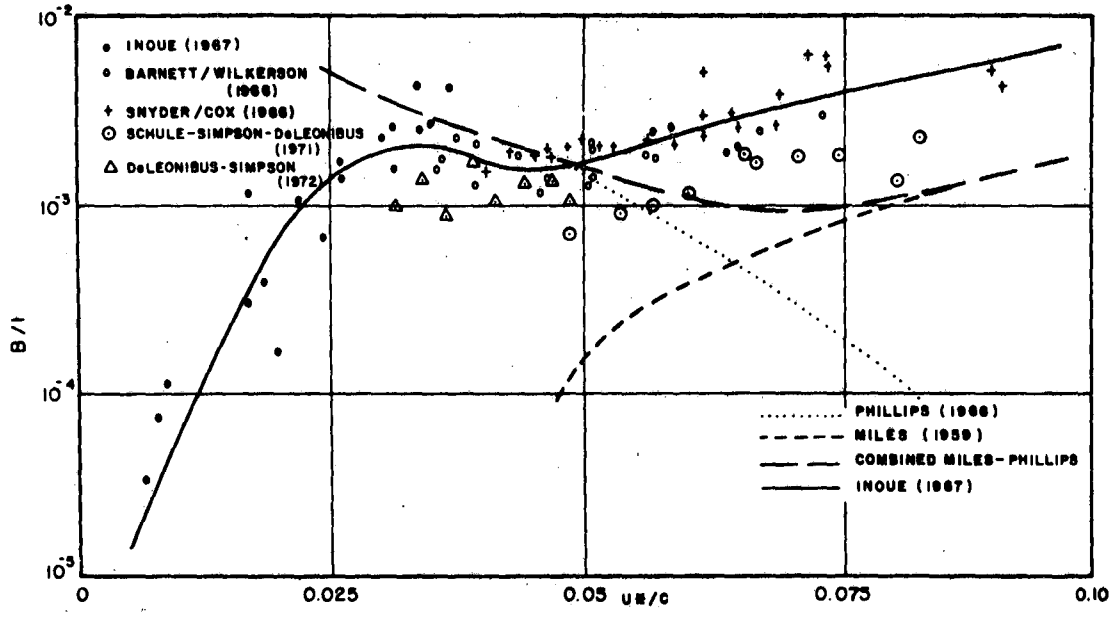

Fig. 4. The magnitude of the instability mechanism dimensionless growth rate from fetch limited measurements of wave growth (Barnett and Wilkerson, 1966; Snyder and Cox, 1966; Schule, Simpson and DeLeonibus, 1971), duration limited measurements (Inoue, 1967; DeLeonibus and Simpson, 1972); the empirical form proposed by Inoue and the theoretical predictions. (Figure from Cardone, 1969 as updated by Lazanoff, Stevenson and Cardone, 1973).

Rather convincing evidence of the importance of non-linear interactions to the development of the wave spectrum has come out of the first JONSWAP (Joint North Sea Wave Project) experiment (Hasselmann et al. 1973). Indeed, the results suggest that non-linear transfers occount for the dominant features of a growing wave spectrum. Figure 6 shows schematically the mean observed JONSWAP spectrum, the observed net source function and the non-linear transfer rate computed for the observed spectrum from Hasselmann's (1963) theoretical non-linear transfer model. According to this result, non-linear interactions largely control development of the spectrum at frequencies near and below the spectral peak, while the equilibrium range actually describes a quasi-balance between energy drain by wave breaking, energy transfer from the wind field and non-linear interactions. A second JONSWAP experiment has just been conducted and may provide additonal verification of these concepts.

The calculation of non-linear transfers involves evaluation of quadruple integrals over the directional spectrum. Even with the fastest computers available, such calculations are impractical in a wave prediction model. The wave-wave transfer rates have therefore been computed only for typical spectral shapes and applied to a given spectrum parameterized in terms of total energy, mean frequency and mean direction. The wave prediction models of Barnett (1968) and Ewing (1971) have included

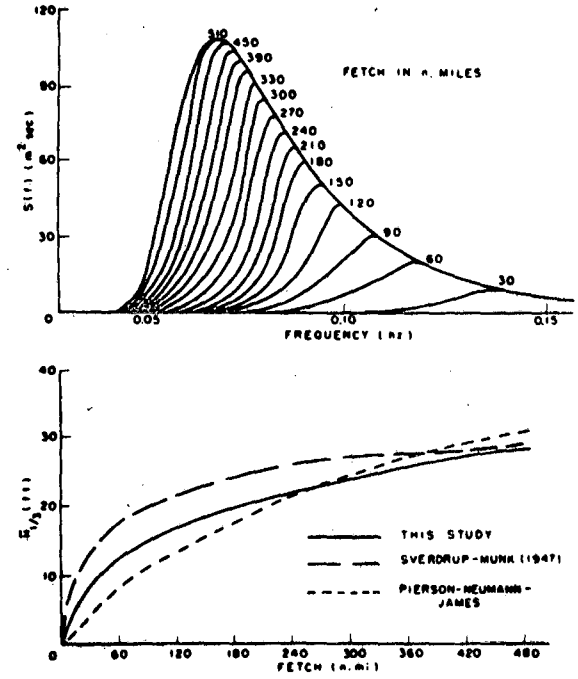

Fig. 5. Development of the spectrum and significant wave height for fetch limited 40 knot winds (at 19.5 meters), according to the spectral growth model proposed in Pierson et al. (1966).

a wave-wave interaction component in their source function through such parameterization.

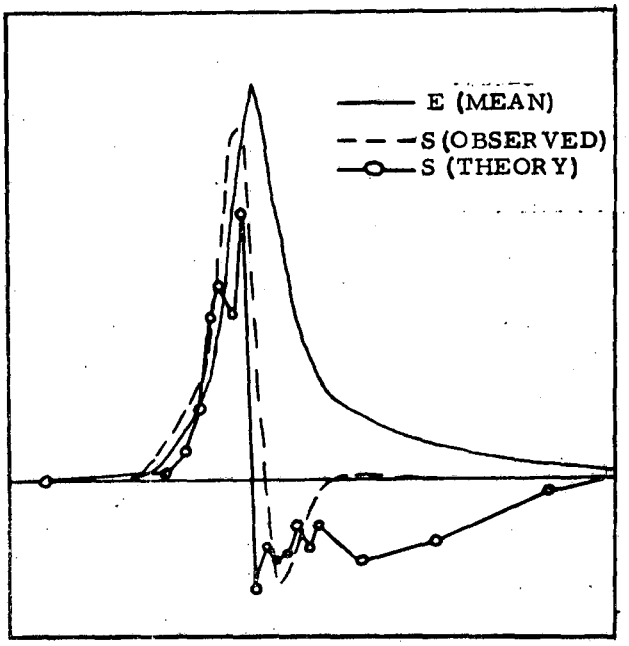

Fig. 6. Comparison of the mean observed JONSWAP spectrum, net source function, and source function computed from theoretical non-linear model (Hasselmann, 1973).

Specification of the Wind Field

Sophisticated spectral growth formulations require a rather detailed description of the wind distribution in the marine boundary layer and a specification of the effective wind stress at the sea surface. From a practical stand point, this description has had to be provided from conventional ships' weather observations for wave hindcasting purposes and from routinely available prognostic weather maps for wave forecasting purposes.

Cardone (1969) applied advances made in the last decade in planetary boundary layer theory, to the marine atmosphere and produced an objective, fully computerized wind analysis program specifically designed for wave prediction models (Figure 7). According to that study, the characteristics of the low level wind speed, stress and direction over the oceans depend significantly on the gradient wind, air-sea temperature difference, magnitude and orientation of horizontal air temperature gradients (baroclinicity) and the latitude. The analysis program uses objectively analyzed fields of these input quantities as provided, for example, by NOAA or the NAVY weather analysis and forecast centers and systematically incorporates ships' wind observations. The above approach made possible the incorporation of atmospheric stability into the Miles-Phillips type spectral growth formulation and explained the empirical evidence for the dependence of wave generation on air-sea temperature difference (Figure 8).

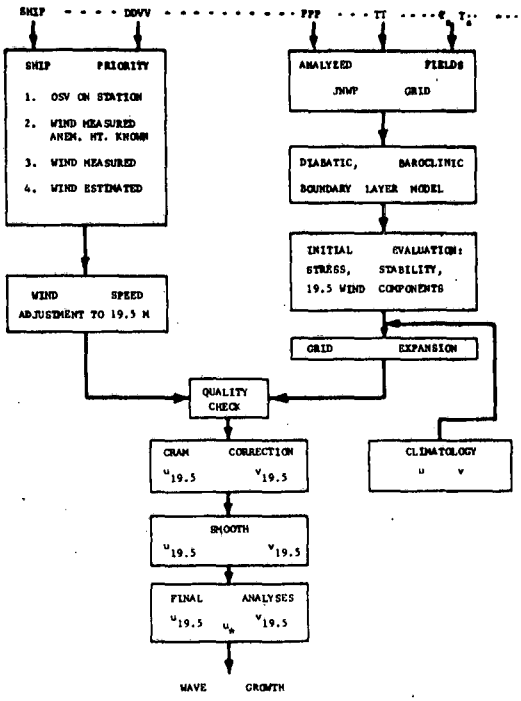

Fig. 7. Flow diagram of an objective wind specification program designed for spectral wave hindcast models. (Cardone, 1968).

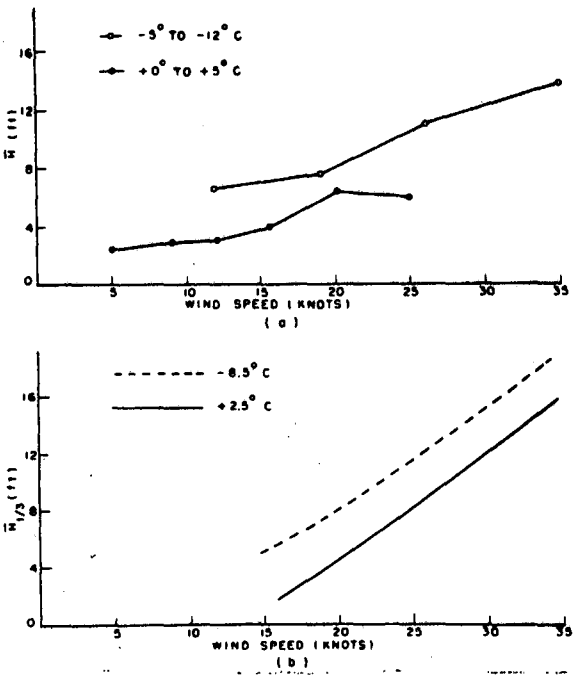

Fig. 8. Observed (a) and predicted (b) dependence of wave generation on air-sea temperature for fetch limited (270 n.m.) seas (Cardone, 1969).

When applied to the North Atlantic on North Pacific Oceans, wind field analysis techniques such as Cardone's, can provide reasonably accurate wind specifications, since these oceans are usually well observed by a combination of fixed weather ships, and transient military and commercial shipping. At

times, however, the winds can be in substantial error. Bunting (1970) has evaluated wave hindcasts and forecasts made in a real-time operational test of a North Atlantic wave prediction model developed at New York University (see e.g. Inoue, 1967). Though his evaluation established the feasibility of an operational spectral wave prediction program, it also demonstrated that significant errors in the wave hindcast could almost always be ascribed to errors in the wind field analysis while errors in wave forecasts followed closely substantial "busts" in the prognostic pressure field. This study tends to confirm the suspicion that it will be impossible to evaluate further development of spectral wave prediction models until corresponding improvements are made in our ability to specify the wind field input. Such improvements are likely to come very soon, as will be discussed in a later section.

All existing wind specifications programs used for wave prediction are uncoupled - that is, the wind field is prescribed without explicit reference to sea state. There is increasing evidence, however, that such a simplification is not always justified. Kitaigorodskii and Volkov (1965) presented measurements to support the dependence of the wind stress along the sea surface on wind speed and gross features of the wave spectrum. Their proposed formulation for the effective drag coefficient as a function of sea state and wind speed has not yet been verified by additional data. DeLeonibus and Simpson (1972) however, have confirmed, through the direct measurement of air sea momentum flux over the open ocean, that the characteristics of the wave spectrum may affect and possibly at times even reverse the direction of the flux. The incorporation of such effects when correctly formulated will require coupling of wind specification and wave prediction models so that the feedbacks can be correctly accounted for.

Model Comparisons

Spectral wave hindcast models have been usually compared on the basis of their growth or dissipation functions (e.g. Figure 4) or on their ability to simulate spectral growth under relatively stationary and homogeneous wind conditions (e.g. Figure 5). The ultimate test of a wave prediction model is, of course, of its ability to hindcast the time history of the directional wave spectrum in the open ocean, as the wind field varies in time and space in response to the typical development and movement of synoptic scale weather systems. In practice, two-dimensional spectral measurements have been too scarce for verification of such hindcasts and one-dimensional spectra are used instead. An additional difficulty arises from the sensitivity of wave predictions to the wind field - it is difficult to assess wave predictions made from different wind fields.

Several hindcasts of a severe storm in the North Atlantic, December, 1959 have been compared by Hayes (1973). The comparison is significant because each hindcast was made by a numerical spectral model applied on the same exact grid system (Baer, 1962) and driven with the same wind fields. The differences between the hindcasts therefore reflect mainly differences in the source function and propogation method. The time history of hindcast and observed significant wave height for this storm at ocean station "J" is shown in Figure 9, with the hindcast and observed one dimensional spectra at peak storm conditions shown in Figure 10. It is clear that the "second generation" spectral wave prediction models (Inoue, 1967; Barnett, 1968; Isozaki and Uji, 1973) significantly improved upon the original Baer (1962) results. The source function of Barnett's model included a non-linear interaction parameterization but its hindcasts are not significantly better than those models that do not model model non-linear transfers explicitly. Those models that include a dissipation mechanism for turbulent attenuation of spectral components propagating against locally wind generated seas (Inoue and Isozaki and Uji) appear to simulate better the decay of seas after peak storm conditions.

The observed spectrum at peak conditions (Figure 10) appears to be narrower than all hindcast spectra, and this discrepancy cannot be completely explained by sampling variability or the limited frequency resolution of the hindcast spectra. Further refinement of these hindcasts would appear to require two dimensional measurements and a further reduction of the remaining differences between the grid wind fields and the true wind distribution.

FUTURE PROSPECTS

It is relatively easy to conclude, on the basis of current research activities alone, that the next two decades will witness the development of accurate and truly global wave prediction capabilities. This optimistic view appears justified in view of the continued current intense interest in basic wave research, recent developments in satellite remote sensing techniques, reasonable projections of progress in numerical weather prediction and the scheduled introduction of larger and faster digital computers.

Basic Research

The thrust of current research appears to be in the specification of the source function and in the extension of deep water prediction models to the shallow water regions characteristic of the continental shelves and inland bodies of wat water. Large scale field experiments that employ the best directional wave observing systems available (e.g. JONSWAP II) are likely to more clearly define the individual components of the source function. It is not unrealistic to expect that all components of the source function, including wave dissipation in breaking and white-capping, may be explicitly calculated, thus eliminating the use of asymptotic spectral forms based upon fully developed or dimensional considerations. A start in this direction has already been made by Hasselmann (1973).

Numerical spectral wave prediction models have been extended recently to shallow water, by Barnett (1969) and Collins (1972). In both of these attempts, wave propagation was modi-

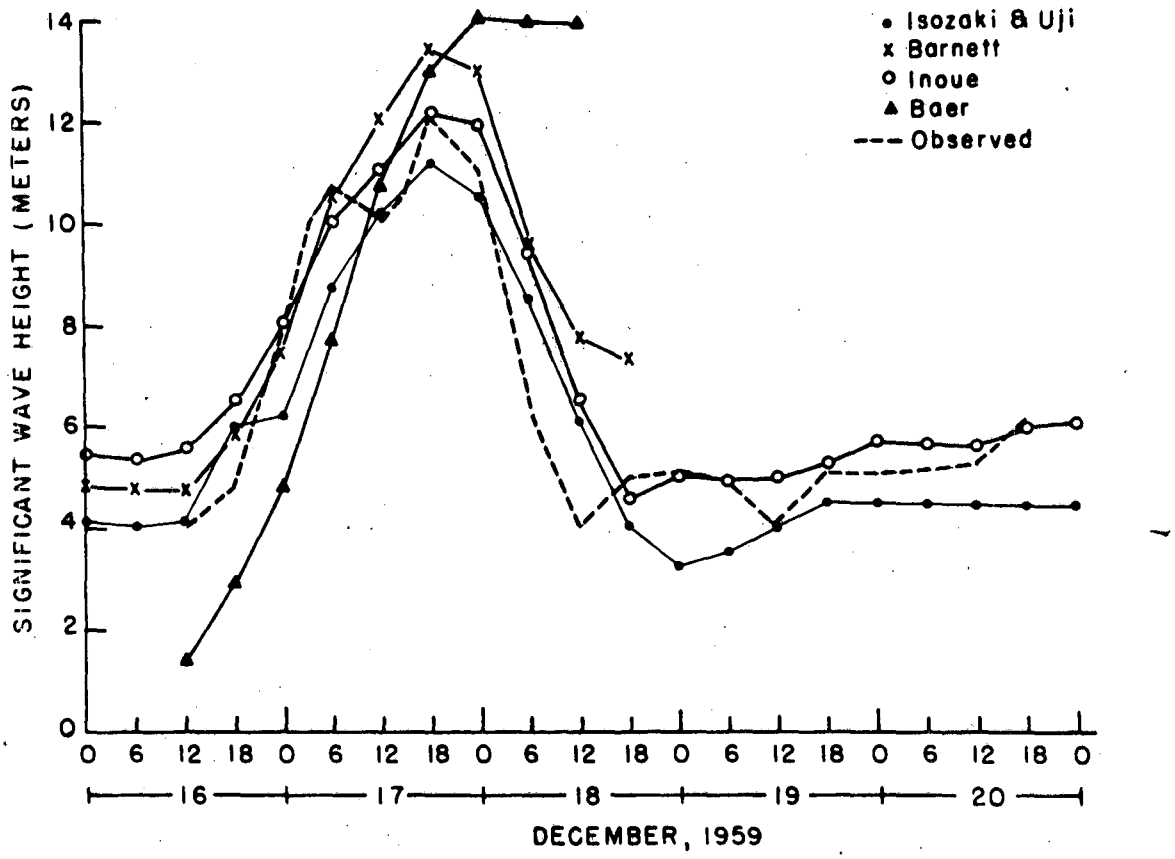

Fig. 9. A comparison of various spectral hindcast model predictions of the time history of significant wave height at the position of the Ocean Station Vessel 'J' (52°40'N, 20°W) in the eastern North Atlantic, during the severe storm of December, 1959. (Hayes, 1973).

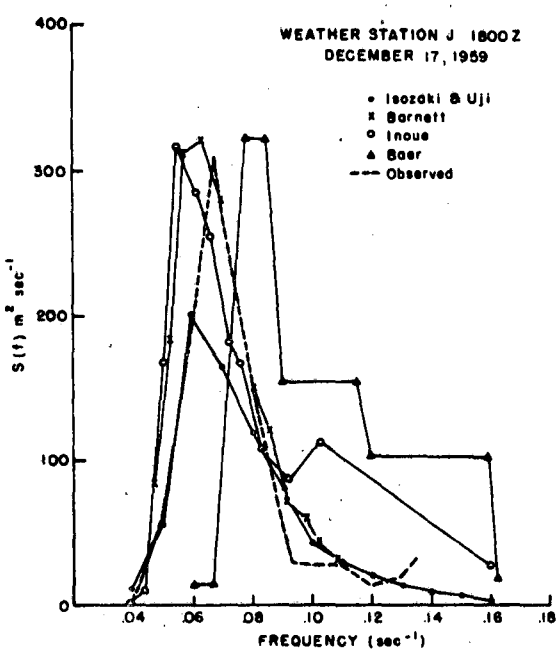

Fig. 10. Observed and hindcast spectra at station "J". (Hayes, 1973).

fied to model the effects of shoaling and refraction. In addition a non-linear bottom friction theory (Hasselmann and Collins, 1968) was incorporated with the wave predictions checked against observations of directional wave spectra. The problem of caustics has been apparently solved theoretically by Chao (1971) as experimentally verified by Chao and Pierson (1972). The theory can, where necessary, be incorporated into wave prediction schemes. Large scale refraction studies of the Gulf of Mexico and portions of the U.S. east coast are underway at the Institute of Oceanography, C.U.N.Y. and will likely be extended to other areas in the near future.

Remote Sensing and Numerical Weather Predictions.

Elsewhere in this symposium, Pierson (1973) describes progress and prospects in remote sensing as applied to observation and prediction of winds and waves. Briefly summarized here, it appears that a satellite borne atmospheric vertical temperature profiling radiometer combined with a microwave radiometer-scatterometer (as is currently being test flown by SKYLAB) will be able to provide an

accurate description of the initial state of the atmosphere over the oceans. Such a description will mean accurate surface wind fields for use in wave hindcasting and improved short-range numerical weather forecasts as required for wave forecasting.

There is evidence that accurately initialized primitive equation weather prediction models already possess useful forecasting skill to about 5 days (Shuman and Hovermale, 1968; Kesel and Winninghoff, 1972). The sea level pressure field forecasts can therefore be used to calculate wind fields for wave forecasts out to such periods for use in optimal track ship routing.

Pierson (1973) also describes instruments that may be able to measure the two dimensional wave spectrum from an orbiting satellite. Such observations could provide a powerful tool for the further refinement of global wave prediction models and provide for more observations that could ever be obtained from ground or aircraft based systems.

Model Application

Currently available digital computers have already allowed implementation of numerical spectral wave prediction models on a regional basis. Efforts underway strongly suggest that within about a year, spectral wave hindcasts and forecasts will be available for the Northern Hemisphere oceans on a daily basis.

Mediterranean Sea. Through the cooperative efforts of the U.S. Naval Oceanographic Office, the NAVY Fleet Numerical Weather Central (FNWC) in Monterey, California and New York University, a real time spectral hindcast and forecast program has been made operational on the CDC 6500 computer at FNWC. Twice a day, the wave spectrum is updated and forecast to 48 hours on a grid of points (mesh length 40 nautical miles) that represent the Mediterranean. The forecasts and hindcasts have been verified (Lazanoff, Stevenson and Cardone, 1973) against measured wave staff and laser profilometer data with good results. Shallow water effects, however, are not yet included in this model.

Gulf of Mexico. A project is nearing completion at the Institute of Oceanography of CUNY, that is sponsored by a consortium of oil companies and that deals with the development of wind field analysis and two dimensional spectral hindcasting techniques applicable to hurricanes. The research program made use of special measurements of pressure, winds and waves made in the vicinity of several recent Gulf hurricanes from oil platforms (the data are currently proprietary but will be completely released to the public by early 1975). A rather straightforward application of the most recent spectral hindcasting techniques applied to extratropical disturbances but with a considerably finer time and spatial resolution (the hindcast model employs a portion of the icosahedral gnomonic projection, Figure 2, but with the spatial resolution increased by a factor of about 5) yielded remarkably accurate wave hindcasts in severe hurricane conditions, when verified against observed one-dimensional spectra. Shallow water effects are included.

The hurricane hindcast model will be used to calculate a climatology of hurricane generated waves in the Gulf of Mexico for platform design purposes. It could, however, also be applied in real time to hindcast and forecast waves generated by tropical storms generally.

Northern Hemisphere. The proposed implementation of global hindcasting procedures in the 1960's was delayed, largely because the task required larger and faster computers than were then available. For example, to produce hindcasts for just one day for the North Pacific Ocean, with the procedures outlined in Pierson et al. (1966), required nearly 2 hours of processing time and perhaps 8 hours of clock time on a UNIVAC 1108 system. Such a program could clearly not be applied routinely for wave hindcasting and forecasting purposes.

Great progress toward the goal of global wave prediction has been made in the past year. Again, a cooperative effort between the C.U.N.Y. group, the Naval Oceanographic Office and FNWC has resulted in a global spectral wave prediction program that is operationally feasible. The model is based on the icosahedral-gnomonic grid system but with the resolution decreased by a factor of 2, such that there are 325 grid points per triangular subprojection. The wave prediction program is run twice daily at FNWC on a quasi-operational basis for the North Pacific Ocean, represented by 7 subprojections and the North Atlantic Ocean, represented by 4 subprojections. Less than 30 minutes of processing time are required on a CDC 6500 for a one day wave specification for all 11 subprojections. In addition to a twice daily 12 hour hindcast to update the spectral fields, wave forecasts are made out to 48 hours, with wind fields supplied by the FNWC primitive equation model.

Conclusion

The above discussion of current activities in this country is by no means intended to be exhaustive. There are substantial research programs underway in France, Japan, and the United Kingdom. The immediate benefits of these efforts will be improved climatological descriptions of the state of the sea, at first for smaller seas, but rather soon for the major Northern Hemisphere Oceans. Eventually, as spacecraft sources of data become routinely available, these procedures will be extended to the Southern Hemisphere. Ultimately, as weather prediction models improve in accuracy out to the limits of synoptic scale predictability (probably about 7 days) the same procedures can be applied to relatively long range wave forecasting. It is this author's opinion that this point will be reached long before two more decades will have elapsed.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the history of support that has made possible, since 1966, his involvement in research programs that deal with various aspects of the overall wave prediction problem. The author's earlier work in development of models of the extratropical marine planetary boundary and application of such models to wave prediction has been sponsored by the U.S. Naval Oceanographic Office and the Office of Navel Research. His participation in programs designed to develop remote sensors for winds and waves has been sponsored by the U.S. Naval Oceanographic Office and the National Aeronautics and Space Administration under several contracts. The author's current activities in development of wind field and wave hindcasting models applicable to hurricanes is sponsored by a contract from a consortium of oil companies under Shell Development Company (Shell Development Company, Chevron Oil Field Research Corporation, Esso Production Research Company, Mobil Research and Development Corporation, Texaco, Inc., Gulf Oil Corporation and the CAGC Group of Continental Oil Company, Atlantic Richfield Company, Getty Oil Company, and Cities Service Oil Company).

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APPENDIX F

CRITIQUES OF SEISMIC RISK STUDIES OF SECTION 6.4

The following table identifies the critiques contained in this Appendix:

Study No.	Study Description	Critique No.	Critique Authors
1	Milne	1	M. R. Akky and R. G. Bea
2	Bea	2	T. K. Hasselman
3	API RP 2A	3	T. K. Hasselman
4	Page	4	M. R. Akky and R. G. Bea
5	ATC - 3	5	T. L. Alley

CRITIQUE 1

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Woodward-Clyde Consultants

June 15, 1977

Mr. L. A. Selzer,
Manager, Design Analysis
Engineering Science Operation
The Aerospace Corporation
2350 East El Segundo Boulevard
El Segundo, California 90245

Dear Mr. Selzer:

Reference to our telephone conversation of June 3, 1977, we have reviewed the study entitled "Distribution of Earthquake Risk in Canada," by W. G. Milne and A. G. Davenport. The findings of this study were published in the Bulletin of the Seismological Society of America, Volume 59, Number 2, April, 1969.

The study consists of statistical analyses of earthquakes from the earthquake catalogues in Canada. In these analyses, the amplitudes of earthquake shock at a specific location due to any given earthquake were assumed to be represented by a simplified amplitude distance function (attenuation relationship). Then utilizing earthquake catalogues information and statistical analytical techniques, the study evaluated the seismic risk in the eastern and western Canadian regions. Two seismic risk indicies were evaluated: the return period of a specific acceleration amplitude and the acceleration amplitudes associated with specific return period. These indicies were evaluated for grid points of the eastern and western Canadian regions map and several population centers of interest.

Values of acceleration amplitudes required for the statistical analyses were obtained in a direct manner for western Canada and through intensity observations for eastern Canada. For western Canada, data from western United States (Cloud, 1963) were used to produce the empirical expression:

$$A = F(M,\Delta) = \frac{0.69e^{1.64M}}{1.1e^{1.10M} + \Delta^2}$$

where A is the acceleration amplitude due to an earthquake with a magnitude (M) at epicentral distance (Δ).

Because of the unusually low attenuation of earthquake shock in eastern Canada, a different approach has been taken to establish the required attenuation relationship. Based on published isoseismal maps for five strong earthquakes in eastern Canada, the following intensity attenuation relationship has been developed:

$$I(M,\Delta) = I_7 - 9.66 - .00370\Delta + 1.38M + .00528\Delta \cdot M$$

where $I(M,\Delta)$ is the intensity of the earthquake magnitude (M) at epicentral distance (Δ). I_7 is the intensity of a magnitude (7) earthquake at the same location.

Conversion from intensity to acceleration amplitudes were made using the following relationship:

$$\log_{10} A = \frac{I}{3} - 1.5$$

where I is the intensity.

There are two problems with the attenuation relationship used by the study for the western Canadian region. First, this relationship is based on data from western United States, and second, the acceleration amplitudes are attenuated in terms of epicentral distances. A detailed study to prove the similarity of the tectonic and geologic setting between western United States and western Canada is needed before using this data in developing the used attenuation relationship. In addition, recent studies have indicated that a better and more representative attenuation relationship would be obtained using the closest distance to the slip surface rather than the epicentral distance.

The attenuation relationship developed for eastern Canada relies on intensity isoseismal contours and an empirical relation between

intensity and acceleration amplitudes. The study did not provide compelling justification to indicate that these isoseismal contours and the associated computed acceleration amplitudes fit closely measured data in eastern Canada.

Both attenuation relationships developed by the study for eastern and western Canada assume that acceleration amplitudes are independent of local tectonic, mechanism and physical extent of the fracture, focal depth and site soil conditions. Evidence from data recorded in the United States and Japan indicate that those factors are of prime importance.

The statistical analyses in the study assume that the occurrence of large earthquakes are independent of one another and have Poisson arrival. The study then proceeds to calculate the probability of a given amplitude being the largest shock in a given year and then the probability of being exceeded in a given year. Using extreme value analysis, the study extracted the largest shock amplitude for each year of record for both eastern and western regions.

In this statistical analysis, the study assumed that the record (60 years) represents a full cycle of seismic activities. There is evidence suggesting that 60 years is a short interval to represent a full cycle. In addition, the seismic record used in the study consists of five earthquakes in the eastern region ranging in magnitude between 5.9 and 7.2 and five earthquakes in the western region between 6.5 and 8 with one earthquake only having a magnitude exceeding 7.3. Whether this statistical sample represents the full earthquake potential of existing faults in the studied regions is an open question.

In calculating the probability of non-exceedance of a given amplitude, the study assumes a point-source mechanism. This probability should be calculated taking into consideration the real physical nature of the source mechanism, that is the line-source mechanism. The probability of non-exceedance should be calculated assuming the length of rupture along any segment of the fault under consideration.

The objective of this study was to evaluate the seismic risk in eastern and western Canada. The index chosen by the study to characterize the seismic risk is the acceleration amplitude. There are serious doubts whether the acceleration amplitude, or for that matter, any single index can characterize the seismic risk of a given region. While acceleration amplitude is reasonable as an index of earthquake destructive energy in structures with short natural periods such as nuclear power plant, velocity and displacement amplitudes are more representative of such energy for structures having larger natural periods such as fixed offshore platforms.

Considerations regarding frequency contents and duration of strong motion are necessary also to describe fully the earthquake destructive potential. The study's recommended normalized spectra (Housner spectra) are based on a few southern California records. It is doubtful that this spectra represent the frequency contents of potential earthquakes in eastern and western Canada.

The Milne and Davenport study represented a pioneering effort and contributed to the state-of-the-art advancement in 1969. However, its findings need to be examined in light of presently (1977) available large body of information regarding geologic and tectonic setting effects on earthquake potential and more sophisticated analytical techniques.

Very truly yours,

M. R. Akky

M. R. Akky
Senior Project Engineer

R. G. Bea/MRA

R. G. Bea
Chief Engineer

MRA/RGB/cd

Review of OTC Paper 2675

by R. G. Bea

T. K. Hasselman

Introduction

The subject paper by Bea entitled "Earthquake Criteria for Platforms in the Gulf of Alaska" develops design criteria based on both a random and a "non-random gap filling" earthquake. Seismicity parameters for several fault systems in the GOA are presented. Comparisions of earthquake occurrence rates are made for these fault systems on the basis of data spanning different periods of time. Probabilistic ground motion parameters are computed using the methods of Cornell and Vanmarcke, with attenuation equations developed by McGuire. No response spectra are presented.

Points of Criticism

The following critical comments are made in regard to the suitability of Bea's results for use by Aerospace in the presentation of seismic data to the USGS for eventual selection of design criteria.

(1) Bea's definition of the "non-random" earthquake seems to pose a problem as to how it might be utilized within a risk oriented decisional framework. Bea does not give any indication of how this might be accomplished.

(2) It is difficult to rationalize the low b-values documented in Table 1. Bea includes earthquakes as small as M = 3.5 in his data base covering the period 1899 - 1974, but offers no explanation of how the numbers of small events were determined in the absence of actual records for much of this period.

(3) The relatively shallow slopes indicated in Figures 3 and 4 of Bea's paper appear to be inconsistent with his b-values of Table 1. Since these are "combined" b-values for the period 1899 - 1974, and the curves in Figures 4 and 5 are based on the period 1940 - 1974, the b-values actually used in the study are evidently not reported. For attenuation equations of the form

$$\log x = C_1 + C_2M - C_3\log R$$

the slope, α, of the curves in Figures 4 and 5 is given by

$$\alpha = C_2/b$$

Values of α scaled from Bea's curves suggest b-values on the order of 1.0, not 0.5. The following table compares α-slope factor attributed to Bea, Wiggins, Cornell, and Algermissen.

Comparison of α-slope values

Motion Parameter	Bea	Wiggins	Cornell	Algermissen
Accl.	.301	.482	.5	.43
Vel.	.397	.625	.675	---
Disp.	.407	.715	.750	---

These slopes are quite important in establishing relative risk levels for earthquake shaking. Bea should be asked to explain how he derived these results.

(4) Figures F-1, F-2, and F-3 compare respectively acceleration, velocity and displacement curves for the GOA as a function of return period (Bea's curves for the random earthquake are shown). The two sets of curves represent Kayak Island and Pamplona Ridge, as determined by Bea and the Wiggins GOA Study. One point of interest is that the Wiggins curves for the two sites tend to be closer together indicating less of a difference between the sites. This may be due in part to the fault line energy distribution used in the Wiggins Study. Of greatest interest, however, is the difference in ground velocity between the two studies. Bea's velocity values are significantly lower. Even when McGuire's attentuaiton equations are used with the Wiggins values of M and R, Bea's velocity values are lower. Coincidently, Wiggins velocity values for

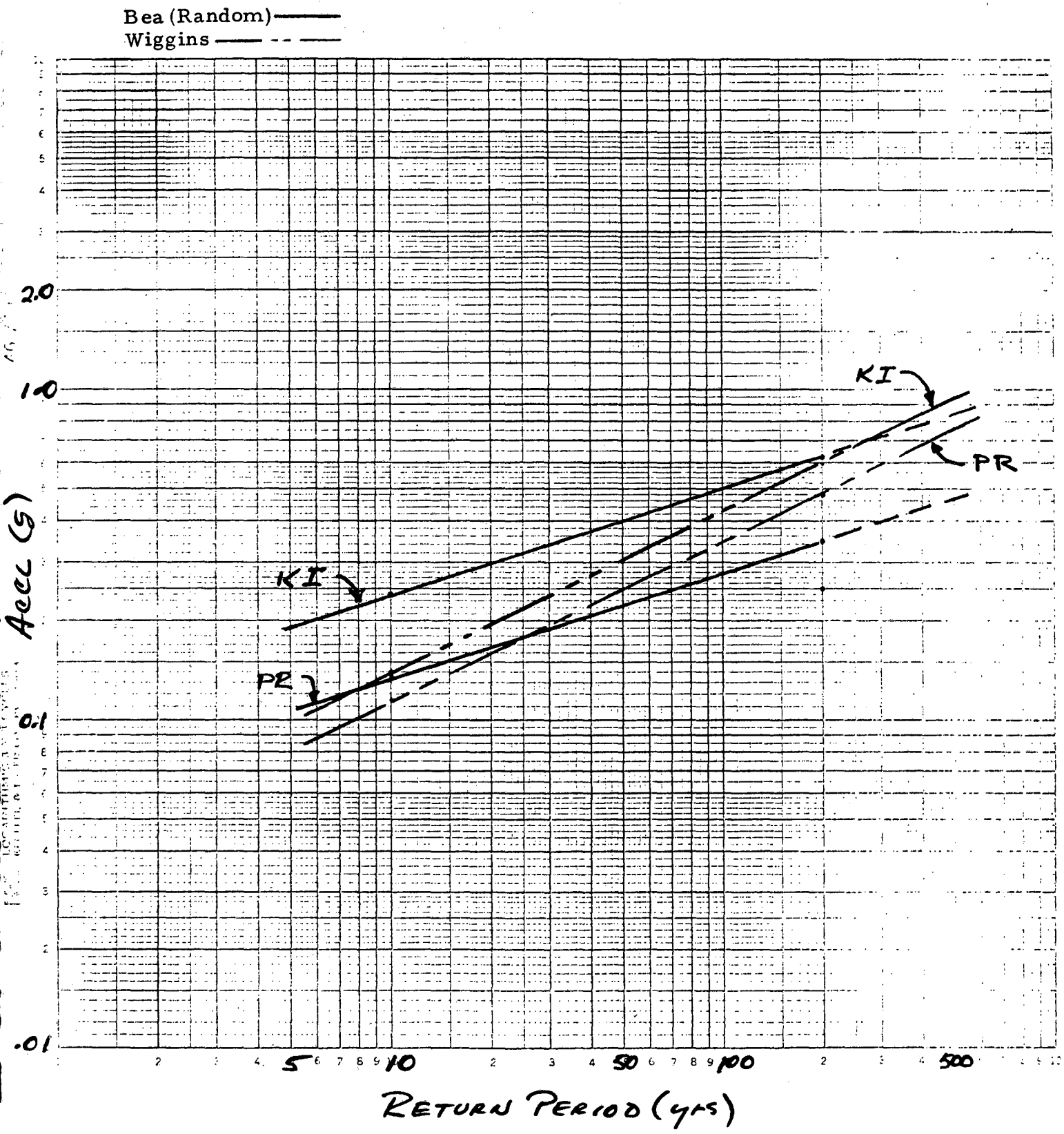

Figure F-1. Comparison of Peak Acceleration vs Return Period

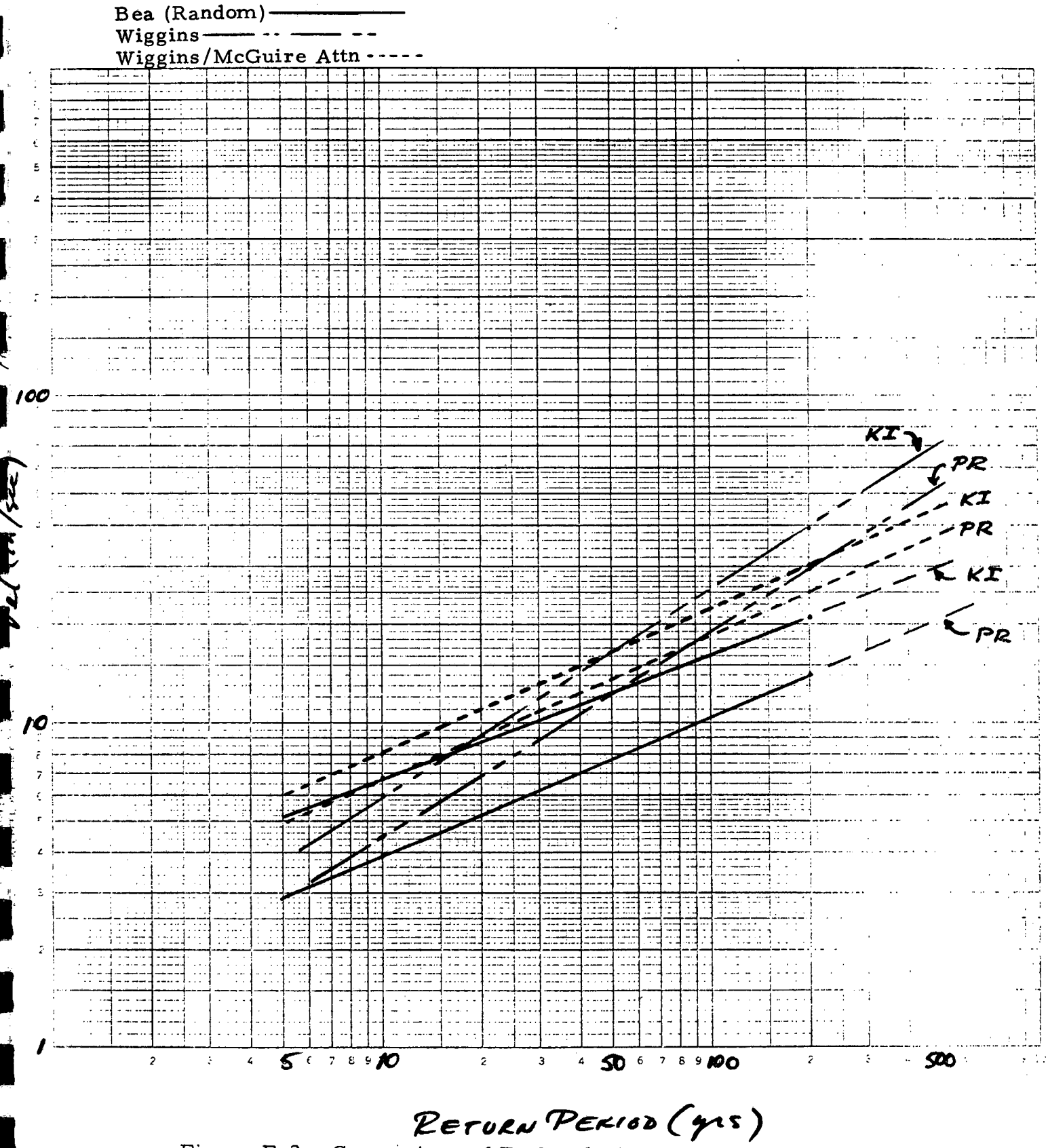

Figure F-2. Comparison of Peak Velocity vs. Return Period

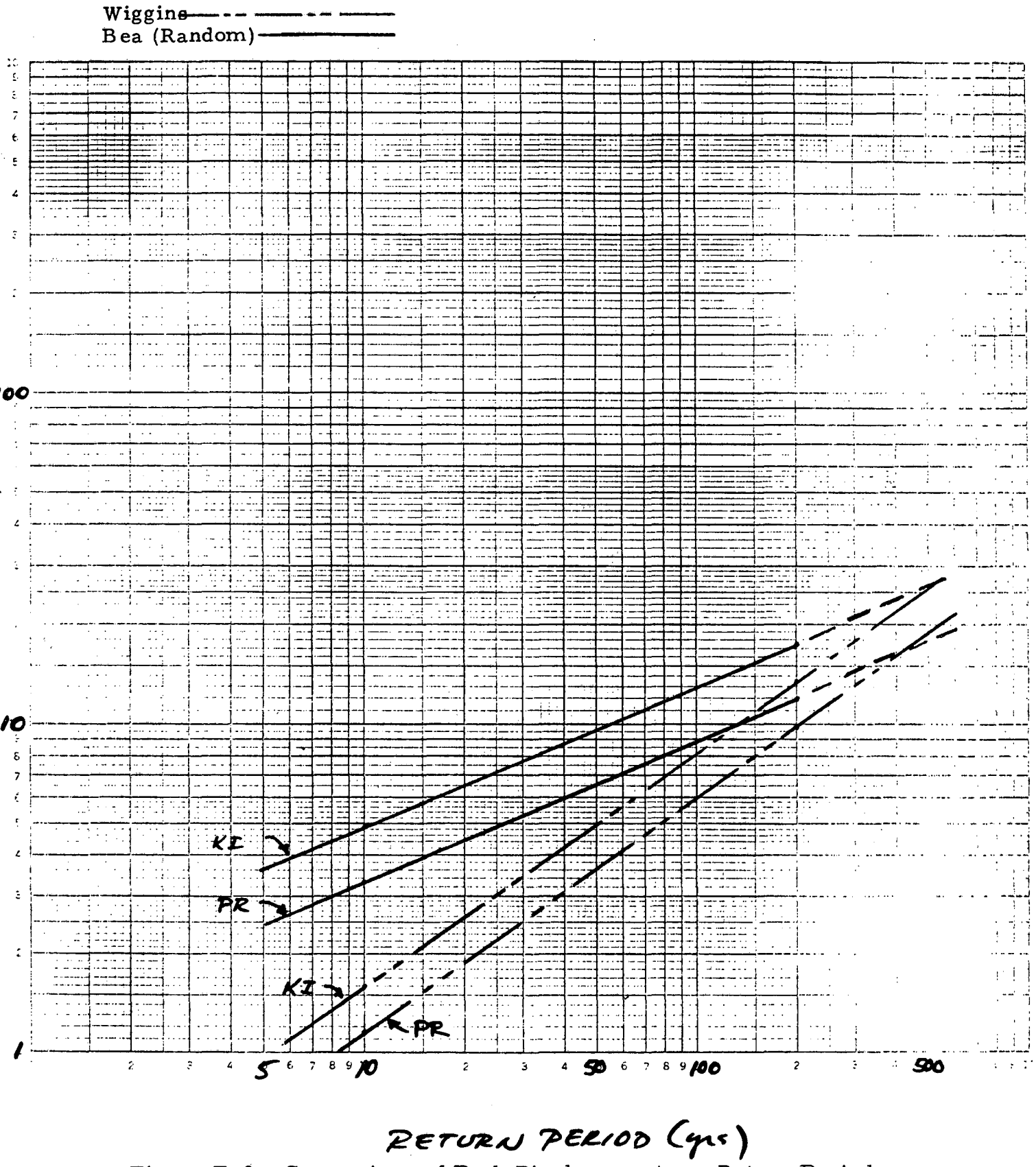

Figure F-3. Comparison of Peak Displacement vs. Return Period

a return period of 400 - 500 years seem to agree with values proposed by Page in GS Circular 672. Bea should be asked to explain these seemingly low values.

(5) In general, the documentation of Bea's work as reported in the subject paper seems to be inadequate. It would be difficult to justify recommendations on the basis of this brief paper. Complete documentation of the three year study upon which the paper is based would be desirable.

(6) Bea's results are incomplete from the standpoint of specifying response spectra. Only ground motion spectra are presented.

(7) Finally, Bea's conclusions are based upon the reliability analysis of a single platform design. As in the case of API RP-2A, Bea's approach is from the reliability point of view. He does not suggest a decisional framework which would appear to satisfy the needs of the USGS.

Points of Merit

(1) The Bea Study purports to have used the seismic risk analysis methods of Cornell and Vanmarcke. This is one of the most rigorous methods available. If implemented properly, it should provide a valuable baseline for comparison with other methods.

(2) The general discussion contained in Bea's paper provides a valuable overview of the problems and special considerations unique to seismic design in the GOA.

CRITIQUE 3

Review of API RP-2A
1977 Edition

T. K. Hasselman

Introduction

API RP-2A adopts a two level design basis. Level 1 is called the "Strength Level" and Level 2 is called the "Ductility Level". Design Criteria are based on a normalized reponse spectrum where 5% damping is assumed. "Effective ground acceleration" (EGA) is used as a scaling factor.

Seed's recent work (1974-76) provides the basis for defining a normalized response spectrum. For the GOA, the Strength Level EGA is specified to be 0.4g, evidently corresponding to a 200 year return period. The "Ductility Level" EGA is presently unknown.

According to R.G. Bea and M.R. Akky, both of whom have participated on the API mini-committee, EGA represents a "design coefficient" based upon reliability, rather than any direct measure of expected ground motion. This subtle point is of utmost importance with respect to interpretation of the API criteria.

Points of Criticism

The following comments are made in regard to the suitability of the API standards for use by Aerospace in the presentation of seismic data to the USGS for eventual selection of design criteria.

(1) No decisional basis is presented to show how the criteria were determined.

(2) Evidently, reliability is a major factor in the selection of API criteria. To the extent that reliability depends on existing platforms or specific platform designs, the concept may not be relevant to the Aerospace effort which addresses the problem of environmental specification, rather than design reliability. A direct consequence of the API approach in the use of "effective ground acceleration" rather than any direct measure of ground motion. Members of the API Mini-committee seem to recognize a profound difference between the two.

(3) The amplification spectrum adopted by the API is keyed to ground acceleration. Ground acceleration is a relatively insignificant quantity as far as long period structures are concerned. A more appropriate scaling factor would be ground velocity or Arias Intensity (total energy).

(4) Of even more concern is the apparent use of mean amplification spectra by the API. See Figure F-4 Solid lines represented the API spectra. Plotted points correspond to Seed's spectra for three soil types. The plotted x's correspond to a spectrum derived from McGuire's 1974 MIT report. It represents average soil for M-6.6, R=30 miles and a probability level of mean plus one sigma. Uncertainties in both attenuation (energy level) and waveform (spectral shape) are represented. The API spectra appear to be underconservative.

(5) The API criteria contain no explicit mention of

duration. Duration will be an important consideration in both linear and nonlinear analysis. In the former, it will have a significant effect on the response amplitudes of long period structures with light damping. In the latter it will have a significant effect on the amount of yielding beyond the elastic range.

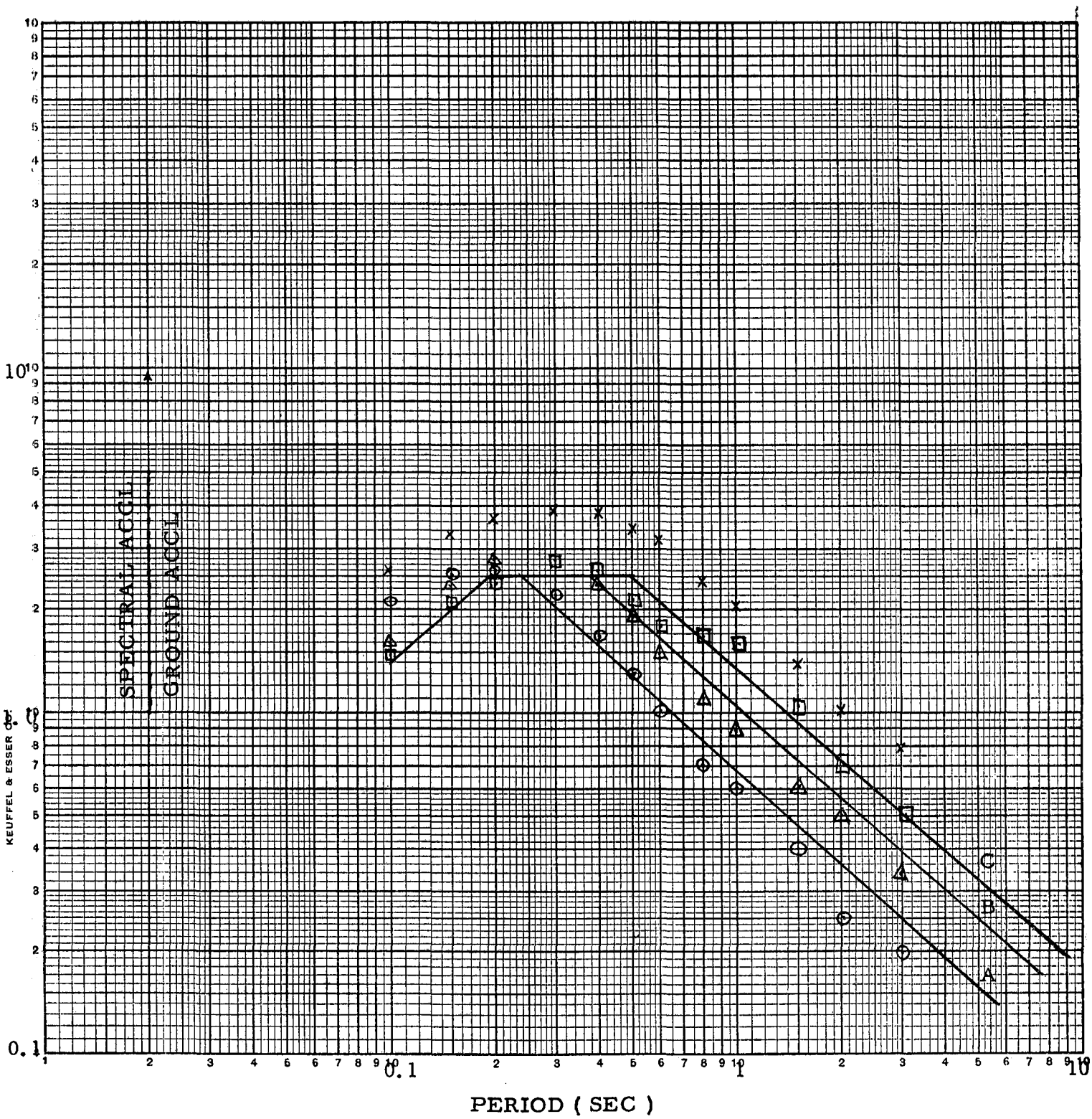

Figure F- 4. COMPARISON OF AMPLIFICATION SPECTRA

CRITIQUE 4

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Woodward-Clyde Consultants

June 14, 1977

Mr. L. A. Selzer
Manager Design Analysis
Engineering Science Operation
The Aerospace Corporation
2350 East El Segundo Boulevard
El Segundo, California 90245

Dear Mr. Selzer:

Per your request in our telephone conversation on June 3, 1977, we have reviewed the U. S. Geological Survey Circular 672 entitled, "Ground Motion Values for Use in the Seismic Design of the Trans-Alaska Pipeline System," co-authored by R. Page, D. Boore, W. B. Joyner and H. W. Coulter.

The circular presents a characterization of ground motions for design earthquakes ranging in magnitude between 5.5 and 8.5 specified in "Stipulations for Proposed Trans-Alaskan Pipeline System" (U. S. Federal Task Force on Alaskan Oil Development, 1972, Appendix, Sec. 3.4.1). This characterization is carried out in terms of peak levels of ground acceleration, velocity and displacement, and of duration of shaking, based on limited available (1972) geologic-tectonic information regarding the Alaskan region, and data and extrapolation of data from the Western United States.

This brief report presents a critical review of the USGS Circular 672 in light of the present (1977) better known seismic and tectonic environment and availability of more advanced analytical tools to characterize seismic risk in the Alaskan region.

The earthquake potential along the Trans-Alaska pipeline route is characterized by the "Stipulations" in terms of five broad seismic zones. As noted by the circular, this zonation was based on limited geologic and tectonic information, and therefore might be conservative. The predicted event for each zone is defined as the "maximum credible" in the sense that it is the largest shock that is reasonably likely to occur over an interval of a few hundred years..

Based on historic seismic records and some tectonic arguments regarding plates convergence rates and evidenced or assumed total uplift (or offset) associated with a given magnitude, the circular presents estimates of recurrence intervals for the design earthquakes as follows:

Seismic Zone	Magnitude (Richter)	Recurrence Interval (Years)
Valdez to Willow Lake	8.5	200
Willow Lake to Paxson	7.0	200
Paxson to Donnelly Dome	8.0	200
Donnelly Dome to 67° N	7.5	50
67° N to Prudhoe Bay	5.5	50

Because of the lack of detailed geologic studies, the circular assumes the design earthquake to occur anywhere within each associated zone. Specifically, the circular states, "In the absence of detailed geologic information to delineate active faults and to assess the seismic risk associated with each fault, the design of the pipeline must allow for the occurrence of the design earthquake anywhere within the seismic zone. In particular, the design must consider potential ground motion and deformation associated with earthquakes occurring at shallow depth in the immediate vicinity of the pipeline."

The circular then cites lack of near-field recorded data for similar magnitudes at different distances and extrapolates from smaller magnitudes to present estimates of horizontal peak accelerations, velocities and displacements. In addition, the circular presents levels of absolute acceleration exceeded 2, 5 and 10 times, and levels of absolute velocity exceeded 2 and 3 times. These estimated values are summarized below:

Magnitude	Accelerations (g) Peak Absolute Values 1st	2nd	5th	10th
8.5	1.25	1.15	1.00	0.75
8.0	1.20	1.10	0.95	0.70
7.5	1.15	1.00	0.85	0.65
7.0	1.05	0.90	0.75	0.55
6.5	0.90	0.75	0.60	0.45
5.5	0.45	0.30	0.20	0.15

Magnitude	Velocity (cm/sec) Peak Absolute Values 1st	2nd	3rd
8.5	150	130	110
8.0	145	125	105
7.5	135	115	100
7.0	120	100	85
6.5	100	80	70
5.5	50	40	30

Magnitude	Displacement (Cm)
8.5	100
8.0	85
7.5	70
7.0	55
6.5	40
5.5	15

The circular provides for an estimate of vertical component intensity not exceeding two-thirds of the associated horizontal component intensity.

The circular also provides for estimates of duration defined as the time interval between the first and last acceleration peaks equal to or greater than 0.05 g as follows:

Magnitude	Duration (sec)
8.5	90
8.0	60
7.5	40
7.0	25
6.5	17
5.5	10

Finally, the circular recommends using the Newmark and Hall (1969) procedure in conjunction with ground motion values presented herein to construct design response spectra.

The major problem with the design criteria presented by the circular is the philosophical framework by which the limited seismological, geological and tectonic information was synthesized. This philosophy is basically deterministic and tends to be extremely conservative.

In a way it is prudent to be conservative in the light of the lack of detailed geological and seismological information. However, the choice of a deterministic analytical framework tends to force the designer to systematically augment this conservatism along each step of the development of the criteria. This in turn would yield unrealistic and extremely severe criteria which, in most cases, have no relation with the desired objectives; safe and reliable structures in the regions of concern.

The design earthquakes associated with each zone in the circular were basically projected from the relatively short historic seismic record of the Alaskan region modified by some tectonic consideration. The underlying philosophy here is: history is likely to repeat itself. There are two areas of concern relevant to this line of thinking. First, there is evidence that long-term fluctuation of seismic activity could extend over intervals of a few centuries. Page (1975) reported that uplift marine terraces on Middleton Island show quiet intervals 500 to 1400 years long between deformational episodes producing 6 to 10m of uplift. Therefore, Page concluded that with a short historic seismic record, future earthquake activity cannot be confidently predicted by simply extrapolating from the historic seismicity. Second, this line of thinking cannot incorporate a contrasting phenomenon; the seismic gap. The seismic gaps in the Alaskan region are well documented and any design criteria have to fully address their potential effects.

The projected design earthquakes are defined as those maximum credible events that are reasonably likely to occur over an interval of a few hundred years. The probability of these earthquakes occurring over the useful life of the Trans-Alaska pipeline (much smaller than a few hundred years) is definitely less than over a few hundred years. However, the circular, because of its deterministic approach, did incorporate this smaller probability.

The most conservative aspect of the circular is the assumption that the design earthquake assigned to each zone could occur anywhere within the zone and, therefore, the associated near-field ground motion parameters have equal probability of occurrence across the zone.

The probability of the design earthquake occurring near a specific site in the associated zone is again much less than the probability of its occurrence over the whole zone. Therefore, the probabilities of occurrence of the near-field ground motion parameters as estimated by the circular, could be extremely small.

Insofar as the attenuation relationships used to extrapolate the near-field estimate of ground motion parameters, the circular relies totally on data recorded in the Western United States. Recognizing that the choice of these data may be compatible with the circular's shallow focal depth assumption of 13-21 km, we still feel that data recorded in other tectonic environments which might be more representative of the Alaskan region (such as that from Japanese and some eastern European records) should be incorporated in the analyses.

The attenuated parameters and seismic risk indicators cannot be divorced from the structure they are used to design. For example, while the Newmark and Hall procedure to construct design response spectra from peak ground parameters yield reasonable results for structures having small natural periods, it is inadequate for the design of structures with large natural periods such as fixed offshore platforms.

It is our opinion that the criteria advanced by the circular, along with the analytical method by which they were provided, are quite severe. We believe that a more sophisticated and fully pledged seismic risk analysis based on elements of local geologic, tectonic and seismic environment and statistical probabilistic analytical framework would yield the desired criteria.

Very truly yours,

M. R. Akky

M. R. Akky
Senior Project Engineer

for R. G. Bea
Chief Engineer

MRA/RGB/sw

CRITIQUE 5

Review of
ATC-3-05
Final Review Draft of Recommended Comprehensive
Seismic Design Provisions for Buildings
1977
Reviewed by T. L. Alley

This study provides seismic risk maps which include the Gulf of Alaska for effective peak ground velocity and effective peak ground acceleration. The statistical risk basis is that there is a 10 percent probability of exceedance of the stated level within a fifty year period. The study also provides site-dependent response spectral shapes in the form of acceleration amplification factors versus the period of a linear oscillator.

There are no procedures or references given for many of the elements of the specification of this document. This is particularly so for the seismic risk maps for Alaska. The results appear to have been arrived at by application of engineering judgement to a number of assorted geological and seismological studies in the area. As such, there is no basis for judging the accuracy of the final results other than by comparison of the results to those of other studies.

APPENDIX G

WAVE REFRACTION IN THE EASTERN GULF OF ALASKA

This appendix presents the results of a wave refraction study carried out for the eastern Gulf of Alaska. Thirty-six cases are given in the following Appendix G printouts, each corresponding to a certain wave period and initial azimuth. The lease areas corresponding to those identified in Figure 5-18 of the main body of this report are indicated by heavy borders. Location is indicated by longitude across the top of the figures and latitude in the left hand border. Longitude is given by five digits - thus, 14225 means $142^{\circ}25'$. Latitude is given by four digits - 6000 meaning $60^{\circ}00'$. Wave amplification factor to two decimal places is the upper of the two numbers given at each location. The lower number is the increment in wave turning from the initial azimuth and is positive to the right and negative to the left. Dummy values of 10.0 and 1000 indicate that wave rays could not be computed for that location due to the lack of bathymetric data.

PERIOD 12.00SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144	2514	4201	4415	1441	0144	05144	00143	5514	3501	4345	1434	0143	3514	3301	4325	1432	0143	1514	3101	4305	14300
6000	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	.99	.99	.99	.99	.98	.98	.97	.96	.94	.91
	1000	1000	1000	1000	1000	1000	1000	1000	1	1	1	1	1	1	1	0	0	-0
5955	10.00	10.00	10.00	10.00	.99	.99	.99	.99	.99	.99	.99	.99	.98	.98	.98	.97	.96	.95
	1000	1000	1000	1000	0	0	0	1	1	1	1	1	1	1	1	1	0	0
5950	10.00	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.98	.98	.98	.98	.98	.98
	1000	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
5945	1.00	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99
	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
5940	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
5935	1.00	1.00	1.00	1.00	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	1425	5142	5014	2451	4240	1423	5142	3014	2251	4220	1421	5142	1014	2051	4200	1415	5514	1501	4145	1401	4135	14130
6000	.89	.87	.87	.87	.88	.88	.87	.88	.93	.97	1.00	1.01	.97	.92	1.00	1.58	1.80	2.00
	-1	-2	-2	-2	-2	-3	-2	-2	-1	-2	-3	-5	-8	-10	-10	-2	0	4
5955	.93	.93	.93	.92	.92	.91	.91	.93	.96	.98	.98	.96	.93	.90	.97	1.36	1.60	1.83
	0	-0	-0	-0	-0	-0	-0	-0	-0	-1	-3	-5	-7	-9	-9	-5	-2	1
5950	.98	.97	.97	.96	.96	.95	.95	.96	.97	.96	.95	.92	.90	.90	.94	1.19	1.39	1.59
	1	1	1	0	0	0	0	0	-0	-1	-3	-4	-6	-7	-8	-6	-4	-1
5945	.99	.99	.99	.99	.98	.98	.97	.97	.96	.95	.94	.93	.91	.91	.93	1.03	1.11	1.14
	1	1	1	1	1	1	0	0	0	-0	-1	-2	-3	-4	-5	-5	-5	-4
5940	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.95	.95	.95	.95	.95	.93
	1	1	1	1	1	1	1	0	0	0	0	0	-0	-1	-1	-1	-1	-2
5935	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.94
	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	-0	-0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.98	.97	.96
	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0

PERIOD 12.90SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144	2514	4201	4415	1441	0144	0514	4001	4355	1435	0143	4514	3401	4335	1433	0143	2514	3201	4315	1431	0143	0514	300
6000	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00			.99	.98	.98	.97	.97	.96	.94	.93	.90	.88			
	1000	1000	1000	1000	1000	1000	1000	1000			0	0	0	0	0	0	0	-0	-0	-1			
5955	10.00	10.00	10.00	10.00			.99	.99	.99	.98	.98	.98	.98	.97	.97	.96	.95	.94	.93	.92			
	1000	1000	1000	1000			0	0	0	0	0	0	0	0	0	0	0	0	0	-0			
5950	10.00	.98	.98	.97	.98	.98	.98	.98	.98	.98	.98	.98	.98	.97	.97	.96	.96	.96	.96	.96			
	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
5945	.99	.99	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.99			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1			
5940	1.00	.99	.99	.98	.98	.98	.98	.98	.98	.98	.98	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00			
	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1			
5935	1.00	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00			
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

LONG / LAT	142	5514	2501	4245	1424	0142	3514	2301	4225	1422	0142	1514	2101	4205	1420	0141	5514	1501	4145	1414	0141	3514	130
6000	.85	.84	.84	.85	.85	.85	.85	.88	.98	1.06	1.10	1.11	1.06	.92	1.01	1.11	1.13	1.15					
	-2	-3	-3	-4	-4	-4	-4	-3	-2	-3	-4	-6	-8	-11	-11	-0	3	7					
5955	.91	.90	.90	.90	.90	.89	.91	.95	1.01	1.05	1.05	1.03	.97	.90	.98	1.06	1.11	1.14					
	-0	-0	-1	-1	-1	-1	-1	-0	-1	-2	-4	-6	-8	-10	-10	-4	-0	4					
5950	.96	.96	.96	.95	.94	.94	.95	.97	.99	.99	.97	.94	.91	.90	.95	1.02	1.07	1.10					
	0	0	0	0	0	0	0	0	-0	-2	-4	-5	-7	-8	-9	-6	-3	-0					
5945	.99	.99	.99	.98	.97	.97	.97	.97	.96	.95	.93	.92	.91	.91	.94	.97	.98	.97					
	1	1	1	1	1	0	0	0	-0	-1	-2	-3	-4	-5	-6	-6	-5	-4					
5940	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.95	.94	.94	.94	.94	.93	.92					
	1	1	1	1	1	1	0	0	0	0	0	-0	-1	-1	-1	-2	-2	-3					
5935	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.94	.93					
	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	-0	-0	-1					
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.98	.97	.96	.95					
	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	-0					
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99					
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0					

PERIOD 13.80SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	10.00	10.00	10.00	10.00	10.00	10.00	10.00	1.00	.99	.98	.97	.96	.95	.93	.91	.89	.86	.83
	1000	1000	1000	1000	1000	1000	1000	-0	-0	-0	-0	-0	-0	-0	-1	-1	-2	-3
5955	10.00	10.00	10.00	10.00	.99	.98	.99	.98	.98	.97	.97	.96	.95	.93	.92	.90	.89	.87
	1000	1000	1000	1000	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-1
5950	10.00	.98	.97	.96	.96	.97	.97	.97	.97	.97	.96	.95	.94	.94	.93	.93	.93	.93
	1000	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0	0	0	0
5945	.99	.98	.97	.96	.96	.96	.96	.97	.96	.96	.96	.96	.96	.96	.96	.97	.97	.98
	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	1	1
5940	.99	.98	.98	.97	.96	.96	.96	.96	.97	.97	.97	.98	.98	.99	.99	.99	.99	.99
	0	0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0	1	1	1	1
5935	.99	.99	.98	.98	.98	.97	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.79	.79	.80	.82	.83	.84	.85	.88	.94	.99	1.02	1.01	.99	.93	1.03	1.23	1.30	1.36
	-4	-4	-5	-5	-6	-5	-4	-3	-3	-3	-5	-7	-10	-12	-13	-5	-1	2
5955	.87	.87	.88	.88	.88	.89	.91	.94	.98	1.00	.99	.95	.93	.91	1.01	1.16	1.25	1.32
	-1	-1	-2	-2	-2	-2	-1	-0	-1	-3	-5	-8	-10	-11	-11	-7	-3	0
5950	.94	.94	.94	.94	.93	.93	.95	.97	.97	.97	.94	.90	.89	.91	.98	1.09	1.17	1.23
	0	0	0	0	0	0	0	-0	-1	-3	-5	-7	-8	-9	-10	-8	-6	-2
5945	.98	.98	.98	.97	.96	.96	.96	.96	.95	.93	.92	.90	.90	.92	.96	1.01	1.03	1.01
	1	1	1	1	0	0	0	-0	-1	-2	-3	-3	-5	-6	-7	-7	-6	-6
5940	.99	.99	.99	.99	.99	.99	.98	.97	.97	.96	.95	.95	.94	.95	.95	.94	.93	.92
	1	1	1	1	1	0	0	0	0	-0	-0	-0	-1	-2	-2	-2	-3	-4
5935	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.97	.96	.95	.93	.92
	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	-0	-1	-2
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.98	.97	.96	.95	.94
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-1
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98	.98	.98
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PERIOD 15.00SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144	25	144	20	144	15	144	10	144	05	144	00	143	55	143	50	143	45	143	40	143	35	143	30	143	25	143	20	143	15	143	10	143	05	143	00
6000	10.00	1000	10.00	1000	10.00	1000	10.00	1000	10.00	1000	10.00	1000	10.00	1000	1.00	-2	.98	-2	.97	-2	.96	-2	.94	-2	.91	-3	.88	-3	.85	-4	.82	-4	.76	-4	.73	-5
5955	10.00	1000	10.00	1000	10.00	1000	10.00	1000	.98	-2	.99	-2	.98	-3	.98	-3	.97	-3	.96	-3	.95	-2	.93	-2	.91	-2	.88	-3	.85	-2	.82	-2	.80	-2	.80	-2
5950	1.00	-2	.98	-2	.97	-2	.95	-2	.95	-2	.96	-2	.96	-2	.96	-2	.96	-2	.95	-2	.94	-2	.92	-2	.90	-2	.88	-1	.87	-1	.87	-0	.88	-0	.90	-0
5945	.99	-1	.97	-1	.96	-2	.95	-2	.94	-2	.94	-2	.94	-2	.94	-2	.94	-2	.93	-2	.93	-1	.92	-1	.92	-0	.92	-0	.93	0	.94	0	.95	0	.96	0
5940	.99	-1	.98	-1	.96	-1	.95	-1	.94	-1	.94	-1	.93	-1	.93	-1	.94	-1	.94	-0	.95	-0	.96	0	.97	0	.97	0	.98	0	.98	0	.98	0	.99	0
5935	.99	-0	.98	-0	.97	-0	.96	-0	.96	-0	.95	-0	.95	-0	.96	-0	.96	0	.97	0	.98	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0
5930	.99	-0	.99	-0	.98	0	.98	0	.98	0	.98	0	.98	0	.98	0	.98	0	.99	0	.99	0	.99	0	1.00	0	1.00	0	.99	0	.99	0	1.00	0	1.00	0
5925	.99	0	.99	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0

LONG / LAT	142	55	142	50	142	45	142	40	142	35	142	30	142	25	142	20	142	15	142	10	142	05	142	00	141	55	141	50	141	45	141	40	141	35	141	30
6000	.72	-5	.74	-5	.77	-6	.80	-7	.81	-7	.81	-8	.83	-6	.94	-4	1.09	-3	1.17	-3	1.21	-5	1.19	-7	1.07	-10	.92	-14	1.62	-12	2.16	-1	2.44	4	2.58	10
5955	.81	-2	.83	-2	.85	-3	.86	-3	.86	-3	.87	-3	.90	-2	.99	-1	1.09	-1	1.13	-3	1.13	-5	1.09	-8	.97	-11	.93	-12	1.38	-11	1.82	-5	2.16	0	2.44	7
5950	.91	-0	.92	-0	.92	-0	.92	-0	.91	-0	.92	-0	.94	-0	.99	-0	1.02	-2	1.03	-4	1.01	-6	.96	-8	.91	-9	.95	-10	1.21	-10	1.52	-7	1.82	-4	2.07	1
5945	.97	0	.97	0	.97	0	.96	0	.95	0	.94	-0	.94	-0	.94	-1	.94	-2	.93	-3	.92	-4	.92	-5	.93	-6	.97	-7	1.07	-7	1.19	-7	1.26	-6	1.23	-6
5940	.99	0	.99	0	.99	0	.98	0	.98	0	.97	0	.97	0	.96	0	.96	-0	.96	-0	.96	-1	.96	-1	.97	-2	.97	-3	.98	-3	.96	-3	.95	-4	.93	-6
5935	.99	0	.99	0	1.00	0	1.00	1	1.00	1	1.00	1	1.00	1	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.98	0	.97	0	.95	-0	.94	-1	.93	-2	.92	-4
5930	1.00	0	1.00	0	1.00	0	1.00	0	1.00	1	1.00	1	1.00	1	1.01	0	1.00	0	1.00	0	.99	0	.99	0	.98	0	.97	0	.96	0	.95	-0	.94	-1	.93	-2
5925	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.99	0	.98	0	.98	0	.97	0	.97	0	.98	0

PERIOD 16.40SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144	2514	4201	4415	1441	0144	05144	0014	3551	4350	1434	5143	4014	3351	4330	1432	5143	2014	3151	4310	1430	5143	00
6000	10.00	10.00	10.00	10.00	10.00	1.01	.95	.91	.88	.85	.80	.76	.73	.70	.66	.64	.63	.64					
	1000	1000	1000	1000	1000	-7	-7	-7	-7	-7	-8	-8	-9	-9	-8	-7	-7	-7					
5955	10.00	10.00	10.00	1.02	.98	.97	.94	.92	.89	.86	.82	.79	.75	.71	.69	.70	.72	.74					
	1000	1000	1000	-5	-5	-6	-7	-7	-7	-7	-7	-7	-7	-7	-6	-4	-4	-4					
5950	1.05	1.02	1.01	.99	.97	.95	.93	.91	.89	.86	.83	.80	.77	.77	.78	.81	.83	.86					
	-5	-6	-6	-5	-5	-6	-6	-7	-7	-6	-6	-5	-4	-3	-2	-1	-1	-1					
5945	1.00	1.00	.99	.97	.95	.93	.91	.89	.88	.86	.85	.85	.86	.88	.90	.92	.93	.95					
	-4	-5	-5	-5	-5	-5	-6	-5	-5	-4	-3	-2	-1	-0	-0	-0	-0	-0					
5940	.99	.98	.97	.95	.93	.91	.89	.88	.89	.90	.92	.93	.95	.96	.97	.97	.98	.98					
	-3	-4	-4	-4	-4	-4	-4	-3	-2	-1	-0	-0	-0	0	0	0	0	-0					
5935	.98	.97	.96	.95	.93	.92	.92	.93	.94	.95	.97	.98	.99	.99	.99	.98	.98	.98					
	-2	-2	-2	-2	-2	-1	-1	-0	-0	-0	-0	0	0	0	0	0	0	0					
5930	.98	.98	.97	.97	.97	.97	.97	.97	.97	.98	.98	.99	.99	.99	.99	.99	.99	.99					
	-1	-1	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0					
5925	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00				
	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				

LONG / LAT	1425	5142	5014	2451	4240	1423	5142	3014	2251	4220	1421	5142	1014	2051	4200	1415	5141	5014	1451	4140	1413	5141	30
6000	.66	.70	.73	.77	.79	.80	.83	.93	1.03	1.09	1.11	1.07	.96	.99	1.84	2.46	2.71	2.86					
	-8	-8	-9	-9	-9	-9	-7	-5	-4	-5	-6	-8	-11	-15	-13	-4	0	5					
5955	.77	.79	.82	.84	.85	.86	.89	.96	1.02	1.05	1.05	1.00	.94	1.09	1.66	2.13	2.45	2.73					
	-4	-4	-5	-5	-5	-4	-2	-2	-3	-4	-7	-9	-12	-13	-12	-7	-3	2					
5950	.89	.90	.92	.91	.90	.90	.91	.94	.97	.98	.96	.93	.97	1.16	1.51	1.84	2.11	2.30					
	-1	-1	-2	-1	-1	-1	-1	-2	-3	-5	-7	-9	-10	-11	-11	-9	-6	-3					
5945	.96	.96	.96	.94	.92	.91	.91	.91	.91	.91	.93	.96	1.05	1.18	1.34	1.46	1.47	1.34					
	-0	-0	-0	-0	-0	-1	-1	-2	-3	-4	-5	-6	-7	-8	-8	-8	-8	-8					
5940	.98	.97	.97	.97	.96	.96	.95	.95	.96	.98	1.01	1.04	1.08	1.10	1.09	1.04	1.00	.96					
	0	0	0	0	0	0	-0	-0	-0	-1	-1	-2	-3	-3	-4	-4	-6	-7					
5935	.98	.99	.99	.99	.99	.99	1.00	1.01	1.03	1.03	1.04	1.02	1.00	.98	.96	.94	.93	.93					
	0	0	0	1	1	1	1	0	0	0	0	0	-0	-0	-1	-2	-3	-5					
5930	1.00	.99	.99	.99	1.00	1.00	1.01	1.02	1.01	1.00	.99	.98	.97	.96	.96	.94	.94	.93					
	0	0	1	1	1	1	1	0	0	0	0	0	0	0	-0	-1	-2	-3					
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.98	.98	.98	.97	.96	.96	.96	.97					
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	-0					

PERIOD 18.00SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	10.00	10.00	10.00	1.15	1.13	1.00	.96	.93	.87	.74	.59	.57	.55	.53	.53	.55	.57	.59
	1000	1000	1000	-22	-29	-43	-42	-41	-37	-28	-15	-13	-12	-11	-8	-8	-10	-11
5955	10.00	10.00	1.33	1.22	1.14	1.04	.99	.94	.87	.72	.61	.60	.58	.59	.61	.63	.66	.70
	1000	1000	-16	-18	-24	-34	-34	-34	-31	-23	-13	-11	-10	-8	-6	-5	-6	-6
5950	1.20	1.19	1.23	1.20	1.14	1.08	1.01	.94	.84	.70	.66	.67	.68	.70	.73	.77	.80	.85
	-10	-11	-14	-16	-19	-24	-25	-25	-22	-16	-10	-7	-6	-4	-3	-3	-2	-3
5945	1.12	1.13	1.16	1.15	1.11	1.05	.98	.88	.78	.75	.77	.79	.82	.84	.87	.90	.94	.97
	-9	-10	-12	-13	-15	-16	-16	-15	-12	-7	-5	-3	-2	-1	-1	-1	-1	-1
5940	1.06	1.06	1.07	1.06	1.02	.95	.88	.83	.83	.85	.88	.91	.93	.95	.96	.97	.98	.98
	-7	-8	-9	-10	-10	-10	-8	-6	-4	-2	-1	-1	-0	-0	-0	-0	-1	-1
5935	1.01	1.00	.99	.96	.93	.90	.89	.89	.91	.93	.95	.97	.98	.98	.98	.97	.97	.96
	-5	-6	-6	-5	-4	-3	-2	-1	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0
5930	.98	.97	.96	.96	.96	.96	.96	.96	.96	.96	.97	.98	.98	.98	.98	.98	.98	.98
	-3	-2	-1	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0	0	0
5925	.98	.98	.98	.99	.99	.99	.99	.99	.98	.98	.98	.98	.99	.99	.99	.99	.99	1.00
	-0	-0	0	0	0	0	0	0	0	-0	-0	-0	-0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.62	.67	.72	.79	.84	.88	.90	.92	.93	.94	.93	.90	.88	1.02	1.68	2.12	2.28	2.35
	-11	-11	-11	-11	-11	-11	-10	-10	-9	-9	-9	-11	-14	-15	-9	2	8	12
5955	.74	.80	.85	.89	.91	.91	.91	.91	.91	.91	.89	.87	.95	1.17	1.58	1.92	2.12	2.24
	-6	-6	-7	-7	-7	-7	-7	-7	-7	-8	-10	-12	-14	-13	-9	-1	4	10
5950	.90	.94	.96	.97	.95	.91	.89	.87	.86	.86	.87	.92	1.07	1.26	1.51	1.74	1.90	1.97
	-3	-3	-4	-4	-4	-4	-5	-6	-7	-8	-10	-11	-12	-11	-9	-5	-0	3
5945	.99	1.00	.98	.95	.92	.88	.86	.85	.86	.90	.97	1.06	1.18	1.30	1.40	1.45	1.41	1.30
	-2	-2	-2	-2	-2	-3	-4	-5	-5	-6	-6	-7	-8	-8	-8	-7	-6	-7
5940	.98	.97	.96	.95	.94	.93	.93	.94	.98	1.04	1.11	1.17	1.20	1.19	1.13	1.06	1.02	1.00
	-1	-0	-0	-0	-0	-0	-0	-1	-1	-1	-2	-3	-4	-4	-4	-5	-7	-9
5935	.97	.98	.98	.98	.98	.98	1.00	1.03	1.07	1.09	1.10	1.08	1.03	1.00	.97	.96	.95	.96
	0	0	0	1	1	1	1	0	0	0	-0	-0	-0	-1	-2	-3	-5	-7
5930	.99	.99	.99	.99	.99	1.00	1.02	1.03	1.02	1.01	.99	.98	.97	.96	.95	.95	.94	.94
	0	0	1	1	1	1	1	1	0	0	0	0	0	-0	-1	-2	-3	-5
5925	1.00	.99	.99	.99	1.00	1.00	1.00	.99	.98	.97	.97	.97	.96	.96	.96	.95	.96	.97
	0	0	1	1	1	1	0	0	0	0	0	0	0	-0	-0	-1	-1	-2

PERIOD 20.00SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	10.00	10.00	1.73	1.39	1.35	1.31	1.26	1.03	.62	.60	.54	.45	.40	.43	.47	.51	.55	.58
	1000	1000	-39	-46	-47	-47	-47	-41	-24	-23	-20	-15	-12	-12	-11	-11	-10	-11
5955	10.00	1.97	1.72	1.51	1.46	1.41	1.33	1.01	.62	.59	.54	.49	.49	.51	.54	.59	.64	.71
	1000	-22	-35	-41	-42	-43	-42	-37	-22	-20	-17	-13	-10	-9	-9	-8	-7	-8
5950	1.46	1.71	1.68	1.58	1.53	1.47	1.32	.89	.62	.60	.59	.60	.62	.65	.69	.75	.82	.91
	-17	-20	-29	-34	-36	-36	-36	-29	-17	-15	-12	-9	-7	-6	-5	-5	-4	-5
5945	1.34	1.51	1.56	1.54	1.50	1.39	1.12	.71	.67	.69	.72	.75	.78	.82	.87	.93	.99	1.04
	-15	-18	-22	-25	-27	-27	-24	-15	-11	-9	-7	-5	-4	-3	-3	-3	-3	-4
5940	1.21	1.30	1.33	1.32	1.25	1.07	.82	.75	.78	.81	.85	.89	.92	.95	.98	1.01	1.02	1.01
	-13	-15	-17	-17	-17	-15	-10	-7	-6	-4	-3	-3	-2	-2	-2	-2	-3	-3
5935	1.08	1.09	1.08	1.02	.95	.88	.85	.86	.87	.90	.93	.96	.98	.99	.98	.97	.96	.95
	-10	-10	-10	-8	-6	-4	-3	-3	-2	-2	-2	-2	-2	-2	-2	-2	-2	-3
5930	.99	.98	.96	.95	.94	.94	.94	.94	.94	.94	.96	.97	.97	.97	.97	.96	.96	.97
	-5	-4	-3	-1	-0	-0	-0	-0	-1	-1	-1	-2	-2	-1	-1	-0	-0	0
5925	.97	.97	.97	.98	.98	.99	.98	.98	.97	.97	.97	.97	.98	.98	.98	.98	.99	.99
	-1	-0	-0	0	0	0	0	0	-0	-0	-0	-1	-0	-0	0	0	0	0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	.63	.70	.77	.84	.90	.93	.92	.91	.89	.90	.91	.89	.84	.98	1.57	2.19	2.41	2.64
	-11	-11	-13	-15	-17	-18	-16	-12	-9	-10	-12	-13	-16	-18	-14	-4	0	7
5955	.78	.85	.90	.93	.93	.92	.88	.86	.86	.87	.86	.84	.86	1.11	1.56	2.02	2.30	2.63
	-8	-8	-10	-12	-13	-13	-11	-9	-9	-11	-12	-14	-15	-16	-13	-7	-3	4
5950	.98	1.02	1.02	.99	.92	.86	.82	.81	.81	.82	.83	.85	.95	1.20	1.52	1.85	2.05	2.10
	-5	-6	-7	-8	-9	-9	-9	-9	-10	-11	-12	-12	-13	-13	-12	-9	-7	-4
5945	1.06	1.05	1.00	.93	.84	.80	.79	.80	.83	.88	.94	1.00	1.09	1.23	1.40	1.49	1.42	1.29
	-4	-5	-5	-5	-5	-6	-7	-7	-7	-7	-7	-8	-9	-9	-9	-9	-10	-11
5940	.99	.95	.93	.91	.90	.89	.89	.92	.98	1.04	1.10	1.13	1.14	1.15	1.12	1.09	1.07	1.07
	-3	-2	-1	-1	-0	-1	-1	-2	-2	-2	-3	-4	-4	-4	-5	-6	-8	-10
5935	.95	.95	.96	.96	.96	.96	.98	1.03	1.07	1.09	1.09	1.06	1.03	1.00	.99	.99	1.00	1.01
	-0	0	0	1	1	1	1	0	0	-0	-0	-0	-0	-1	-2	-4	-6	-8
5930	.98	.98	.98	.98	.98	.99	1.01	1.02	1.01	1.00	.98	.97	.97	.97	.97	.97	.97	.98
	0	0	1	1	1	2	1	1	0	0	0	0	-0	-0	-1	-3	-4	-6
5925	1.00	.99	.98	.98	.99	.99	1.00	.98	.97	.96	.96	.96	.96	.96	.96	.96	.96	.98
	0	1	1	1	1	1	0	0	0	0	0	0	-0	-0	-1	-2	-3	-4

PERIOD 22.50SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	10.00	1.26	1.15	1.12	1.10	1.06	.62	.42	.42	.42	.42	.42	.42	.43	.46	.49	.53	.58
	1000	-46	-47	-47	-47	-47	-44	-41	-41	-40	-30	-12	-13	-14	-14	-14	-13	-14
5955	1.31	1.27	1.16	1.13	1.10	1.05	.64	.45	.45	.45	.46	.47	.47	.49	.52	.56	.63	.71
	-30	-41	-43	-44	-44	-44	-42	-37	-36	-32	-22	-12	-12	-12	-11	-11	-10	-10
5950	1.32	1.29	1.20	1.16	1.11	1.02	.62	.49	.51	.53	.54	.56	.58	.61	.66	.73	.82	.89
	-26	-35	-38	-39	-40	-40	-38	-29	-26	-21	-15	-10	-10	-9	-8	-7	-7	-8
5945	1.33	1.29	1.23	1.18	1.10	.92	.58	.58	.61	.64	.67	.71	.75	.80	.86	.92	.96	.99
	-24	-28	-30	-32	-33	-32	-25	-18	-15	-12	-9	-7	-6	-5	-5	-5	-6	-7
5940	1.29	1.26	1.21	1.11	.94	.74	.68	.70	.73	.77	.81	.86	.90	.94	.96	.97	.97	.96
	-20	-22	-23	-24	-22	-17	-12	-10	-8	-7	-6	-5	-4	-4	-4	-5	-5	-6
5935	1.17	1.14	1.06	.93	.83	.81	.82	.83	.84	.87	.91	.94	.96	.96	.95	.93	.91	.90
	-15	-16	-14	-11	-7	-6	-5	-5	-4	-4	-4	-4	-5	-5	-4	-4	-4	-3
5930	1.02	.98	.95	.92	.92	.93	.92	.92	.92	.93	.94	.95	.95	.94	.94	.93	.94	.95
	-8	-6	-3	-1	-1	-1	-1	-1	-2	-3	-3	-4	-4	-3	-2	-1	-1	-0
5925	.96	.96	.97	.97	.98	.98	.98	.97	.96	.96	.96	.96	.96	.96	.97	.97	.98	.99
	-2	-1	-0	0	0	0	-0	-0	-0	-1	-2	-2	-1	-1	-0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.66	.78	.86	.95	1.00	1.02	.99	.91	.78	.77	.73	.66	.78	.92	1.35	1.47	1.59	1.61
	-14	-16	-18	-19	-20	-20	-18	-15	-13	-14	-15	-16	-18	-18	-20	-21	-22	-24
5955	.80	.87	.93	.97	1.00	1.00	.95	.87	.80	.75	.70	.73	.92	1.05	1.22	1.30	1.39	1.44
	-11	-13	-15	-16	-17	-16	-14	-13	-13	-14	-15	-16	-17	-16	-17	-18	-19	-21
5950	.93	.96	.97	.96	.95	.91	.86	.82	.77	.72	.72	.84	.99	1.06	1.13	1.18	1.22	1.27
	-9	-10	-12	-12	-13	-13	-13	-13	-14	-14	-14	-14	-14	-14	-15	-15	-16	-17
5945	.99	.97	.93	.87	.81	.78	.76	.76	.76	.79	.84	.92	.98	1.02	1.06	1.12	1.17	1.22
	-8	-9	-9	-9	-9	-10	-11	-11	-10	-9	-8	-9	-10	-11	-11	-12	-12	-14
5940	.92	.89	.87	.85	.84	.83	.83	.85	.88	.91	.92	.94	.97	1.00	1.05	1.11	1.14	1.18
	-6	-5	-3	-2	-2	-2	-2	-3	-3	-3	-4	-5	-5	-5	-6	-7	-9	-12
5935	.91	.92	.92	.92	.92	.93	.94	.97	.98	.97	.96	.97	.99	1.01	1.04	1.06	1.08	1.11
	-2	-1	0	1	1	2	1	0	-0	-0	-0	-0	-1	-2	-3	-5	-7	-10
5930	.96	.96	.95	.95	.96	.97	.99	.99	.98	.96	.96	.97	.98	.99	1.00	1.02	1.03	1.05
	-0	0	1	2	2	2	2	1	0	0	0	0	-0	-1	-2	-4	-6	-8
5925	.99	.98	.97	.97	.98	.98	.99	.96	.95	.95	.95	.96	.96	.97	.97	.97	.98	1.00
	0	1	1	2	2	1	1	0	0	0	0	-0	-0	-1	-2	-3	-5	-8

PERIOD 25.70SEC, INITIAL AZIMTH 60.00DEG

LONG / LAT	144	251	442	01	441	51	441	01	440	51	440	01	435	51	435	01	434	51	434	01	433	51	433	01	432	51	432	01	431	51	431	01	430	51	430
6000	1.06	-51	.99	-50	.96	-49	.95	-49	.93	-49	.65	-48	.37	-48	.29	-45	.29	-42	.31	-38	.37	-26	.40	-20	.44	-17	.47	-16	.51	-16	.57	-16	.69	-18	.88	-19
5955	1.06	-44	1.00	-45	.98	-45	.96	-45	.93	-45	.67	-43	.39	-41	.31	-39	.32	-37	.36	-33	.42	-24	.45	-19	.48	-16	.51	-15	.57	-14	.67	-14	.81	-14	.91	-15
5950	1.09	-38	1.04	-39	1.01	-40	.98	-40	.91	-39	.63	-35	.39	-31	.37	-31	.41	-30	.45	-26	.50	-20	.54	-16	.58	-13	.63	-12	.72	-11	.81	-11	.89	-11	.92	-12
5945	1.13	-31	1.09	-33	1.05	-34	.99	-34	.85	-32	.55	-25	.47	-22	.50	-22	.55	-20	.59	-18	.64	-14	.69	-11	.75	-9	.82	-8	.87	-8	.91	-9	.92	-9	.92	-11
5940	1.13	-26	1.10	-27	1.04	-27	.92	-26	.70	-20	.60	-16	.63	-15	.66	-14	.70	-13	.74	-11	.79	-9	.85	-8	.90	-8	.93	-8	.94	-8	.93	-8	.90	-9	.87	-10
5935	1.07	-20	1.01	-20	.92	-17	.81	-11	.77	-8	.78	-8	.79	-8	.80	-8	.82	-7	.85	-7	.89	-7	.92	-8	.94	-9	.94	-8	.91	-8	.88	-7	.85	-7	.84	-6
5930	.97	-12	.92	-8	.90	-4	.90	-2	.90	-2	.91	-2	.91	-2	.90	-3	.90	-4	.91	-5	.92	-6	.93	-7	.93	-7	.91	-6	.90	-4	.90	-3	.91	-2	.92	-2
5925	.94	-4	.94	-1	.95	-0	.96	-0	.97	-0	.97	-0	.97	-0	.96	-0	.95	-2	.94	-3	.94	-4	.94	-4	.94	-3	.94	-2	.95	-1	.96	-0	.97	-0	.97	-0

LONG / LAT	142	551	425	01	424	51	424	01	423	51	423	01	422	51	422	01	421	51	421	01	420	51	420	01	415	51	415	01	414	51	414	01	413	51	413	0
6000	.94	-19	.94	-20	.93	-20	.89	-21	.84	-22	.85	-24	.88	-24	.93	-20	.91	-18	.82	-18	.63	-15	.52	-16	.64	-18	.83	-21	.84	-25	.74	-22	.61	-20	.44	-17
5955	.93	-16	.92	-17	.88	-18	.84	-20	.82	-21	.86	-22	.91	-21	.93	-19	.88	-18	.77	-17	.61	-16	.63	-17	.84	-18	.98	-19	.95	-21	.86	-21	.68	-20	.47	-17
5950	.92	-13	.90	-15	.86	-16	.81	-18	.81	-19	.84	-19	.86	-19	.86	-18	.80	-17	.69	-16	.65	-15	.77	-15	.93	-16	1.01	-16	.99	-18	.94	-18	.87	-19	.94	-18
5945	.91	-12	.87	-13	.82	-14	.76	-15	.73	-15	.73	-16	.73	-16	.73	-15	.71	-12	.71	-10	.76	-10	.84	-10	.91	-11	.96	-11	.98	-12	1.09	-13	1.21	-14	1.34	-15
5940	.83	-10	.81	-9	.79	-7	.78	-5	.77	-4	.77	-3	.78	-3	.78	-4	.78	-4	.79	-4	.80	-5	.83	-5	.89	-5	.97	-5	1.09	-6	1.21	-8	1.29	-10	1.35	-12
5935	.85	-5	.86	-2	.86	-0	.87	0	.88	2	.89	3	.91	2	.90	0	.87	-0	.86	-0	.87	-0	.93	-0	1.00	-0	1.06	-2	1.11	-4	1.17	-6	1.21	-8	1.26	-11
5930	.93	-1	.92	0	.92	1	.93	2	.94	3	.96	3	.98	2	.96	1	.93	1	.93	1	.96	0	.98	0	1.01	-0	1.04	-1	1.07	-3	1.10	-5	1.13	-7	1.18	-12
5925	.97	0	.96	1	.96	2	.96	2	.97	2	.98	2	.98	1	.95	1	.94	1	.94	0	.96	0	.97	-0	.99	-1	1.00	-1	1.01	-3	1.01	-5	1.02	-9	1.07	-14

PERIOD 12.00SEC. INITIAL AZIMTH 30.000EG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.87	.87	.87	.87	.91	.92	.93	.94	.96	.97	.99	.99	.99	.99	.99	.99	.98	.96
	-5	-7	-7	-8	-11	-10	-8	-5	-2	-0	0	0	0	0	0	0	0	-0
5955	.90	.89	.89	.89	.91	.92	.93	.95	.97	.98	.99	.99	.99	.99	.99	.99	.99	.98
	-3	-4	-5	-5	-6	-6	-5	-3	-1	0	0	0	0	0	0	0	0	0
5950	.93	.92	.92	.92	.93	.94	.96	.97	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	.99	.99
	-1	-2	-2	-3	-3	-2	-2	-1	-0	0	0	0	0	0	0	0	0	0
5945	.96	.96	.96	.96	.96	.97	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	-0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	0
5940	.99	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5935	1.00	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.95	.94	.93	.93	.93	.95	.97	.99	.99	.99	.98	1.00	1.02	1.03	.98	.95	.96	10.00
	-0	-0	-0	-0	0	0	0	1	1	2	3	2	2	0	0	0	0	1000
5955	.97	.96	.96	.95	.95	.96	.97	.97	.95	.95	.96	.97	.98	.98	.96	1.01	1.16	1.39
	0	0	0	0	0	0	1	1	1	2	2	1	1	0	0	1	3	7
5950	.99	.99	.98	.97	.97	.97	.96	.95	.94	.94	.94	.95	.95	.94	.94	1.00	1.09	1.15
	0	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	2
5945	1.00	1.00	.99	.99	.98	.98	.97	.96	.96	.95	.95	.95	.94	.94	.94	.97	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5940	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98	.98	.98	.97	.96	.95	.95	.95	.95	.95
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0
5935	1.00	1.00	1.00	1.00	1.00	.99	.99	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.96
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PERIOD 12.90SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.85	.85	.86	.86	.85	.84	.87	.89	.92	.95	.97	.98	.98	.98	.98	.98	.97	.95
	-7	-9	-9	-9	-9	-9	-7	-5	-3	-1	0	0	0	0	0	0	-0	-0
5955	.89	.88	.88	.88	.87	.88	.90	.92	.95	.97	.98	.99	.99	.99	.99	.98	.98	.97
	-4	-6	-7	-7	-7	-6	-5	-3	-1	-0	0	0	0	0	0	0	0	0
5950	.92	.90	.90	.90	.91	.92	.94	.96	.97	.98	.99	.99	.99	.99	.99	.99	.99	.99
	-2	-3	-4	-4	-4	-3	-2	-1	-0	0	0	0	0	0	0	0	0	0
5945	.95	.94	.94	.94	.95	.96	.97	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	-1	-1	-1	-1	-1	-1	-0	-0	0	0	0	0	0	0	0	0	0	0
5940	.98	.97	.97	.97	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5935	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.94	.93	.93	.92	.92	.97	1.01	1.04	1.03	1.02	.99	1.02	1.05	1.06	1.00	.98	.99	10.00
	-0	-0	-0	-0	0	0	1	1	1	2	3	2	2	0	-0	-2	-3	1000
5955	.96	.96	.95	.94	.94	.97	.99	.99	.97	.96	.96	.98	1.00	.99	.98	1.03	1.15	1.46
	0	0	0	0	0	1	1	1	1	2	2	1	1	0	-0	-0	0	7
5950	.98	.98	.97	.96	.96	.97	.96	.94	.93	.93	.94	.95	.96	.95	.96	1.02	1.11	1.19
	0	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0	0	2
5945	1.00	.99	.99	.98	.98	.97	.95	.94	.94	.94	.94	.94	.94	.94	.94	.98	1.01	1.02
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0
5940	1.00	1.00	1.00	.99	.99	.98	.97	.97	.97	.97	.97	.96	.95	.95	.94	.95	.95	.95
	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	-0
5935	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	.98	.98	.97	.97	.96	.96	.95
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	.99	.99	.99	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98	.98	.97
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PERIOD 13.80SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.86 -9	.85 -12	.85 -12	.84 -12	.83 -12	.82 -12	.84 -10	.87 -8	.90 -5	.93 -2	.95 -0	.96 0	.97 0	.97 0	.97 0	.97 0	.95 -0	.94 -0
5955	.88 -6	.87 -9	.86 -9	.85 -9	.85 -9	.86 -9	.88 -7	.90 -5	.93 -3	.95 -1	.96 -0	.97 0	.98 0	.98 0	.98 0	.98 0	.97 0	.96 0
5950	.90 -4	.89 -5	.89 -6	.88 -6	.89 -6	.90 -5	.92 -4	.94 -2	.96 -1	.97 -0	.98 0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.98 0
5945	.93 -2	.92 -2	.92 -2	.92 -2	.93 -2	.95 -1	.96 -1	.97 -0	.98 -0	.99 0	.99 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0
5940	.96 -0	.96 -0	.96 -0	.96 -0	.97 -0	.97 -0	.98 0	.98 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	1.00 0	1.00 0	1.00 0
5935	.98 0	.98 0	.98 0	.98 0	.99 0	.99 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5930	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5925	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.93 -0	.93 -0	.93 -0	.92 -0	.91 0	1.01 0	1.08 1	1.12 1	1.13 1	1.13 2	1.08 2	1.13 2	1.17 2	1.17 0	1.02 -0	1.00 -2	1.01 -3	10.00 1000
5955	.95 0	.95 0	.94 0	.93 0	.93 1	.99 1	1.03 1	1.03 1	1.02 1	1.01 1	1.01 1	1.04 1	1.06 1	1.04 0	.99 -0	1.05 -0	1.19 0	1.52 1
5950	.98 0	.97 0	.96 0	.95 1	.96 1	.97 1	.97 1	.95 0	.93 0	.93 0	.95 0	.97 0	.98 0	.97 0	.97 0	1.04 0	1.14 0	1.23 2
5945	.99 0	.99 0	.98 0	.98 1	.97 0	.95 0	.93 0	.92 0	.92 0	.93 0	.94 0	.94 0	.94 0	.94 0	.95 0	1.00 0	1.03 -0	1.04 -0
5940	1.00 0	1.00 0	1.00 0	.99 0	.98 0	.96 0	.95 0	.96 0	.96 0	.96 0	.96 0	.95 0	.95 1	.94 1	.94 0	.95 0	.95 -0	.96 -0
5935	1.00 0	1.00 0	1.00 0	.99 0	.98 0	.97 0	.97 0	.98 0	.99 0	.99 0	.98 0	.98 0	.97 1	.96 0	.96 0	.95 0	.95 -0	.95 -0
5930	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.98 0	.98 0	.97 0	.97 0	.97 0
5925	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0

PERIOD 15.00SEC. INITIAL AZIMTH 30.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.87 -12	.85 -16	.85 -16	.82 -17	.81 -16	.83 -15	.86 -13	.88 -9	.91 -5	.92 -2	.92 -0	.93 -0	.95 0	.96 0	.97 0	.96 -0	.94 -0	.92 -1
5955	.88 -9	.86 -13	.86 -13	.84 -13	.84 -13	.86 -12	.88 -9	.90 -7	.93 -4	.93 -2	.94 -0	.95 0	.97 0	.97 0	.97 0	.96 0	.95 -0	.94 -0
5950	.90 -7	.88 -8	.87 -9	.86 -9	.87 -8	.89 -7	.92 -5	.94 -4	.95 -2	.96 -1	.97 -0	.98 0	.99 0	.99 0	.98 0	.97 0	.96 0	.96 0
5945	.92 -3	.90 -4	.90 -4	.90 -4	.91 -4	.93 -3	.95 -2	.96 -1	.97 -0	.98 -0	.99 0	1.00 0	1.00 0	.99 0	.98 0	.98 0	.98 0	.98 0
5940	.95 -1	.94 -1	.94 -1	.94 -1	.95 -1	.96 -0	.97 -0	.97 -0	.98 0	.99 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0
5935	.97 -0	.97 -0	.97 -0	.97 0	.97 0	.98 0	.98 0	.98 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0
5930	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5925	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.92 -1	.93 -0	.93 -0	.93 -0	.91 0	.93 1	.95 1	.97 1	.99 1	1.08 1	1.16 2	1.23 2	1.23 2	1.22 0	1.03 0	1.04 0	1.01 -0	.94 4
5955	.94 -0	.94 -0	.93 -0	.92 0	.91 1	.93 1	.93 1	.92 1	.93 0	1.01 1	1.06 1	1.10 1	1.10 1	1.07 0	1.01 0	1.07 1	1.19 1	1.48 6
5950	.96 0	.96 0	.95 0	.94 1	.94 1	.93 1	.91 0	.88 -0	.89 -0	.94 0	.97 0	.99 0	1.00 0	.99 0	.99 0	1.06 1	1.17 1	1.27 2
5945	.98 0	.98 0	.97 0	.97 1	.95 0	.92 0	.90 -0	.89 -0	.90 -0	.92 0	.93 0	.94 0	.94 1	.95 1	.96 1	1.02 0	1.06 -0	1.07 -0
5940	.99 0	.99 0	.99 0	.98 0	.96 0	.93 -0	.92 -0	.93 0	.95 0	.95 0	.95 1	.94 1	.94 1	.94 1	.94 0	.95 0	.96 -0	.97 -0
5935	1.00 0	1.00 0	.99 0	.98 0	.96 -0	.95 -0	.95 0	.97 0	.98 0	.98 1	.97 1	.97 1	.96 1	.95 1	.95 0	.95 0	.94 -0	.94 -0
5930	1.00 0	1.00 0	.99 0	.98 0	.98 0	.98 0	.98 0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.97 0	.97 0	.96 0	.96 0	.96 -0
5925	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.98 0	.98 0

PERIOD 16.40SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	144	2514	420	1441	5144	1014	405	1440	0143	551	435	0143	451	4340	1433	5143	3014	325	1432	0143	151	4310	1430	514300
6000	.91	.84	.83	.81	.80	.89	.90	.90	.89	.88	.87	.89	.93	.97	.98	.97	.93	.90
	-15	-16	-17	-18	-18	-18	-17	-14	-10	-5	-2	-1	-0	-0	-0	-0	-1	-2
5955	.91	.86	.84	.82	.83	.89	.91	.91	.91	.91	.90	.92	.96	.98	.98	.96	.93	.92
	-12	-13	-14	-15	-14	-14	-13	-11	-8	-4	-1	-0	0	0	-0	-0	-0	-0
5950	.91	.87	.86	.84	.86	.90	.92	.93	.93	.93	.94	.97	.99	.99	.98	.96	.94	.94
	-9	-10	-11	-11	-10	-9	-8	-6	-5	-2	-0	-0	0	0	0	0	-0	-0
5945	.91	.89	.88	.88	.89	.92	.94	.95	.95	.96	.98	1.00	1.00	.99	.97	.96	.96	.97
	-6	-6	-6	-6	-5	-4	-4	-3	-2	-1	-0	-0	0	0	0	0	0	0
5940	.93	.92	.91	.92	.93	.94	.95	.96	.97	.98	1.00	1.00	1.00	.99	.98	.98	.98	.98
	-3	-2	-2	-2	-1	-1	-1	-0	-0	-0	-0	-0	-0	0	0	0	0	0
5935	.95	.95	.95	.96	.96	.96	.96	.97	.97	.99	.99	1.00	.99	.99	.99	.99	.99	.99
	-1	-0	-0	-0	-0	-0	-0	0	0	0	-0	-0	0	0	0	0	0	0
5930	.98	.98	.98	.99	.99	.99	.98	.98	.98	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00
	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	.99	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	1425	514250	1424	514240	1423	514230	1422	514220	1421	514210	1420	514200	1415	514150	1414	514140	1413	514130
6000	.91	.93	.93	.92	.91	.96	1.00	1.03	1.07	1.18	1.31	1.32	1.32	1.32	1.03	1.05	1.06	1.00
	-1	-1	-1	-0	0	0	0	0	0	1	3	3	2	0	0	0	0	6
5955	.93	.93	.93	.91	.91	.94	.96	.98	1.01	1.11	1.15	1.16	1.15	1.11	1.02	1.10	1.25	1.56
	-0	-0	-0	0	1	1	0	0	0	1	2	2	1	0	0	1	2	7
5950	.95	.95	.93	.92	.91	.91	.91	.92	.94	1.00	1.01	1.01	1.02	1.01	1.01	1.10	1.23	1.34
	-0	-0	0	1	0	0	-0	-0	-0	1	1	1	1	1	1	1	1	2
5945	.97	.97	.96	.94	.91	.89	.88	.89	.92	.93	.93	.94	.95	.96	.98	1.05	1.10	1.11
	0	0	0	0	-0	-1	-1	-1	0	0	0	1	1	1	1	0	-0	-0
5940	.99	.99	.98	.95	.92	.89	.89	.93	.94	.94	.93	.93	.94	.94	.95	.97	.98	.99
	0	0	0	-0	-1	-2	-2	-0	0	1	1	1	1	1	1	0	-0	-1
5935	1.00	1.00	.98	.96	.94	.92	.93	.97	.97	.96	.96	.95	.95	.94	.94	.94	.95	.95
	0	0	-0	-1	-2	-2	-1	0	1	1	1	1	1	1	0	0	-0	-1
5930	1.00	1.00	.98	.98	.97	.97	.97	.99	.98	.98	.98	.97	.96	.96	.96	.95	.95	.95
	0	0	-0	-1	-1	-1	-0	0	1	1	1	1	1	0	0	0	-0	-1
5925	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	.98	.98	.98	.97	.97	.97	.97	.97	.97
	0	0	-0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	-0	-0

PERIOD 18.00SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.87	.85	.83	.82	1.07	1.11	1.09	1.04	.96	.82	.85	.87	.99	1.06	1.08	1.06	.98	.90
	-21	-22	-23	-23	-25	-25	-24	-21	-16	-9	-3	-0	-0	-0	-1	-1	-2	-3
5955	.90	.88	.85	.83	.96	1.02	1.02	1.00	.94	.85	.88	.92	1.01	1.05	1.06	1.03	.96	.91
	-17	-18	-19	-19	-20	-20	-18	-16	-13	-6	-2	-0	-0	-0	-0	-1	-1	-1
5950	.92	.90	.86	.84	.89	.94	.96	.96	.93	.89	.93	.98	1.03	1.04	1.02	.98	.94	.93
	-13	-13	-15	-14	-14	-13	-12	-10	-8	-4	-2	-0	-0	-0	-0	-0	-0	-0
5945	.92	.90	.87	.86	.88	.91	.93	.94	.94	.95	.99	1.02	1.03	1.01	.98	.94	.94	.95
	-9	-9	-9	-8	-7	-6	-6	-5	-4	-2	-1	-0	-0	-0	-0	0	0	-0
5940	.92	.90	.89	.89	.91	.92	.93	.94	.95	.98	1.01	1.02	1.01	.98	.96	.96	.97	.97
	-5	-5	-4	-3	-2	-2	-2	-1	-1	-0	-0	-1	-0	-0	0	0	0	0
5935	.93	.93	.93	.94	.95	.95	.95	.95	.96	.98	1.00	1.00	.99	.98	.97	.98	.98	.99
	-2	-2	-1	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0	0	0	0
5930	.97	.97	.98	.98	.98	.98	.98	.97	.97	.98	.98	.99	.99	.99	.99	.99	.99	1.00
	-0	-0	-0	0	0	0	0	0	0	-0	-0	-0	-0	0	0	0	0	0
5925	.99	.99	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.92	.95	.96	.94	.90	.97	1.05	1.12	1.21	1.36	1.42	1.43	1.43	1.43	1.07	1.11	1.12	1.08
	-2	-2	-1	-1	-1	-1	-0	-0	1	2	3	3	2	0	1	2	2	8
5955	.93	.94	.94	.90	.89	.95	1.01	1.06	1.14	1.22	1.23	1.24	1.23	1.17	1.07	1.17	1.31	1.64
	-1	-1	-1	-0	-0	-0	-0	0	1	2	2	2	1	1	1	2	3	8
5950	.94	.94	.92	.89	.89	.92	.95	.98	1.02	1.04	1.04	1.05	1.06	1.05	1.06	1.16	1.28	1.40
	-0	-0	-0	-0	-0	-1	-1	-0	1	1	1	1	1	1	2	2	2	2
5945	.96	.95	.94	.91	.90	.89	.90	.92	.93	.92	.93	.94	.97	.99	1.02	1.09	1.15	1.17
	-0	-0	-0	-1	-2	-2	-2	-0	0	1	1	1	2	2	2	1	-0	-1
5940	.98	.98	.98	.97	.96	.94	.93	.93	.93	.92	.92	.93	.94	.96	.97	1.00	1.02	1.04
	0	0	-1	-2	-3	-4	-2	0	1	1	2	2	2	2	1	-0	-1	-2
5935	.99	.99	1.01	1.02	1.02	1.01	.99	.96	.95	.95	.95	.95	.94	.94	.94	.95	.97	.98
	0	0	-1	-3	-4	-4	-2	1	1	2	2	2	2	1	0	-0	-1	-2
5930	1.00	1.00	1.02	1.03	1.03	1.02	1.00	.97	.97	.96	.96	.96	.95	.95	.95	.95	.95	.96
	0	0	-1	-2	-2	-2	-0	1	1	1	1	1	1	0	0	-0	-1	-2
5925	1.00	1.00	1.01	1.01	1.01	1.00	1.00	.98	.98	.97	.97	.96	.96	.96	.96	.96	.96	.96
	0	0	-0	-0	-0	-0	0	1	1	1	1	1	0	0	0	-0	-1	-2

PERIOD 20.00SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	1.05	1.00	.92	.87	.83	.83	.81	.79	.78	.77	.78	.81	.91	.94	.95	.92	.88	.90
	-24	-23	-26	-25	-26	-26	-25	-23	-19	-11	-6	-2	-1	-2	-2	-3	-3	-3
5955	1.05	1.00	.93	.87	.84	.84	.83	.82	.81	.80	.83	.88	.95	.97	.96	.91	.88	.92
	-21	-20	-22	-22	-22	-21	-21	-19	-15	-9	-5	-2	-1	-1	-2	-2	-2	-2
5950	1.02	.97	.92	.86	.86	.87	.88	.87	.86	.86	.91	.98	1.01	1.00	.96	.90	.89	.94
	-17	-17	-18	-17	-15	-15	-14	-13	-11	-6	-3	-2	-1	-1	-1	-1	-1	-1
5945	.98	.94	.90	.85	.87	.89	.90	.90	.90	.93	1.00	1.04	1.04	1.01	.95	.90	.92	.95
	-13	-12	-12	-10	-9	-8	-8	-7	-6	-4	-2	-2	-2	-1	-1	-0	-0	-1
5940	.93	.90	.88	.87	.89	.90	.91	.91	.93	.97	1.02	1.03	.01	.97	.93	.93	.95	.96
	-8	-7	-6	-5	-4	-4	-3	-3	-2	-2	-2	-2	-2	-1	-0	-0	-0	-0
5935	.92	.91	.91	.92	.93	.93	.93	.93	.95	.97	.99	.99	.98	.95	.95	.96	.97	.97
	-5	-4	-2	-1	-1	-1	-1	-0	-0	-1	-2	-2	-2	-0	-0	0	-0	-0
5930	.95	.96	.97	.97	.97	.97	.97	.96	.96	.97	.97	.97	.97	.97	.98	.99	.99	.99
	-2	-1	-0	-0	-0	-0	0	0	-0	-0	-1	-1	-0	-0	0	0	0	0
5925	.98	.99	.99	.99	.99	.99	.99	.98	.98	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00
	-0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	0	0	0	0	0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	1.01	1.05	1.07	1.05	.96	.88	.91	.95	1.02	1.34	1.57	1.60	1.60	1.62	1.12	1.23	1.25	1.27
	-3	-2	-2	-2	-1	-0	-0	0	0	3	3	3	3	2	2	3	4	7
5955	.98	1.00	1.00	.96	.89	.89	.91	.93	1.02	1.25	1.34	1.35	1.34	1.28	1.14	1.28	1.42	1.72
	-2	-2	-2	-0	-0	-0	0	0	0	3	3	2	2	2	3	3	4	7
5950	.96	.96	.94	.90	.88	.88	.89	.91	.98	1.07	1.09	1.10	1.11	1.12	1.13	1.25	1.37	1.50
	-2	-2	-1	-0	-0	-0	-1	-1	0	1	2	2	2	3	3	3	2	1
5945	.96	.95	.93	.89	.87	.86	.86	.87	.90	.92	.93	.96	1.01	1.05	1.09	1.17	1.24	1.27
	-1	-1	-0	-1	-1	-2	-2	-1	0	1	2	3	3	3	3	1	-0	-1
5940	.96	.96	.95	.92	.90	.87	.86	.88	.89	.90	.92	.94	.97	1.00	1.01	1.06	1.10	1.13
	-0	-0	-1	-2	-2	-3	-1	0	1	2	3	4	4	3	2	-0	-1	-3
5935	.98	.99	.98	.96	.95	.93	.91	.92	.92	.93	.94	.95	.96	.95	.96	.99	1.02	1.04
	0	-0	-1	-2	-3	-3	-0	1	2	3	3	3	3	2	0	-1	-2	-4
5930	.99	1.00	1.00	.99	.99	.98	.96	.95	.95	.95	.95	.95	.94	.94	.95	.96	.97	.97
	0	-0	-1	-2	-2	-1	0	1	2	3	3	2	1	0	-0	-1	-3	-5
5925	1.00	1.00	1.00	1.00	1.00	.99	.98	.97	.96	.95	.95	.95	.94	.94	.95	.96	.96	.94
	0	-0	-1	-1	-0	-0	0	1	1	2	1	1	1	0	-0	-1	-3	-5

PERIOD 22.50SEC. INITIAL AZIMTH 30.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	10.00 1000	.57 -23	.97 -27	.97 -27	1.10 -29	1.08 -31	1.03 -30	.92 -27	.83 -23	.72 -14	.76 -7	.82 -4	.93 -2	.94 -1	.94 -1	.88 -2	.84 -3	.93 -4
5955	.96 -22	.72 -21	.92 -24	.93 -24	1.02 -25	1.02 -25	1.00 -25	.92 -23	.85 -20	.76 -13	.85 -7	.94 -3	1.01 -1	1.00 -1	.97 -1	.88 -1	.85 -2	.92 -4
5950	.94 -19	.80 -18	.86 -20	.87 -19	.94 -19	.96 -19	.96 -19	.92 -17	.87 -15	.83 -10	.96 -6	1.05 -3	1.08 -2	1.06 -2	.99 -1	.87 -1	.88 -2	.93 -3
5945	.92 -15	.85 -14	.83 -14	.83 -12	.88 -12	.90 -12	.91 -11	.90 -10	.88 -9	.93 -6	1.03 -5	1.09 -4	1.09 -3	1.04 -2	.94 -1	.87 -1	.91 -2	.93 -3
5940	.91 -11	.87 -10	.84 -8	.85 -6	.87 -6	.89 -6	.89 -5	.89 -4	.91 -4	.98 -4	1.04 -4	1.05 -4	1.03 -4	.97 -3	.89 -1	.90 -1	.92 -1	.93 -2
5935	.91 -7	.90 -5	.89 -4	.90 -3	.91 -2	.92 -2	.91 -2	.91 -1	.93 -1	.97 -2	.99 -3	.99 -4	.97 -3	.93 -2	.92 -0	.94 -0	.95 -0	.95 -1
5930	.94 -3	.95 -2	.95 -1	.96 -0	.97 -0	.96 -0	.95 -0	.95 0	.95 -0	.96 -1	.96 -2	.96 -2	.96 -2	.95 -0	.96 -0	.97 -0	.98 -0	.98 0
5925	.97 -1	.98 -0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.97 0	.97 -0	.97 -1	.97 -1	.98 -0	.98 0	.99 0	.99 0	.99 0	1.00 0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	1.02 -5	1.04 -6	1.04 -6	1.01 -5	.92 -2	.90 0	.91 2	.89 1	.90 1	1.00 1	1.13 2	1.17 3	1.16 3	1.16 3	1.22 3	1.42 3	1.47 3	1.45 4
5955	.98 -4	1.00 -5	.98 -4	.94 -2	.91 0	.92 1	.91 1	.89 0	.92 0	1.01 0	1.08 2	1.11 3	1.13 3	1.20 3	1.29 4	1.45 4	1.57 4	1.79 5
5950	.95 -4	.95 -4	.93 -2	.91 -0	.91 0	.91 0	.89 -0	.88 -0	.91 -0	.96 0	.99 1	1.03 3	1.11 4	1.21 4	1.29 4	1.42 3	1.54 2	1.65 0
5945	.94 -3	.93 -3	.92 -2	.93 -0	.94 -0	.92 -0	.88 -0	.85 -0	.85 0	.88 1	.92 3	.99 5	1.09 5	1.17 5	1.23 4	1.34 1	1.41 -1	1.43 -3
5940	.94 -2	.94 -1	1.00 -0	1.08 -0	1.14 -0	1.14 0	1.06 0	.87 1	.85 2	.88 4	.93 5	.99 6	1.05 6	1.09 5	1.12 2	1.19 -0	1.22 -3	1.22 -5
5935	.96 -0	.97 -0	1.04 -0	1.12 -0	1.18 -0	1.20 0	1.14 1	.91 2	.89 4	.92 5	.95 6	.98 6	1.00 5	1.00 3	1.01 -0	1.04 -2	1.06 -4	1.07 -7
5930	.99 0	.99 -0	1.02 -1	1.04 -1	1.06 -1	1.05 -0	1.02 1	.93 3	.93 4	.94 4	.95 4	.96 4	.95 2	.95 0	.96 -1	.97 -3	.98 -6	.98 -8
5925	1.00 0	1.00 -0	1.00 -1	1.00 -1	1.00 -0	.99 -0	.97 1	.95 2	.94 3	.94 3	.94 2	.94 1	.93 1	.93 -0	.94 -1	.95 -4	.96 -6	.95 -8

PERIOD 25.70SEC, INITIAL AZIMTH 30.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.52	.90	1.30	1.34	1.33	1.25	1.15	1.05	.95	.75	.76	.78	.80	.82	.82	.82	.98	1.18
	-22	-41	-37	-37	-37	-39	-38	-37	-32	-18	-9	-6	-5	-4	-3	-3	-5	-8
5955	.98	.90	1.16	1.19	1.18	1.12	1.03	.94	.87	.78	.79	.82	.83	.83	.82	.83	.97	1.09
	-22	-32	-33	-33	-32	-33	-32	-32	-28	-17	-9	-6	-4	-3	-2	-2	-5	-7
5950	1.06	.93	1.01	1.02	1.02	1.00	.93	.87	.83	.84	.85	.87	.87	.85	.82	.85	.96	1.02
	-21	-24	-27	-26	-24	-24	-24	-23	-21	-14	-9	-6	-5	-3	-2	-2	-4	-6
5945	1.06	.96	.91	.88	.90	.91	.88	.85	.85	.91	.92	.93	.91	.87	.82	.88	.93	.96
	-18	-18	-18	-17	-15	-14	-14	-13	-12	-10	-8	-7	-6	-4	-2	-2	-4	-5
5940	.99	.93	.86	.85	.88	.88	.87	.87	.90	.95	.96	.96	.93	.86	.85	.89	.91	.93
	-15	-13	-11	-9	-8	-8	-7	-6	-6	-7	-7	-8	-7	-4	-2	-3	-3	-4
5935	.92	.90	.88	.89	.91	.91	.90	.90	.93	.95	.96	.95	.92	.87	.89	.91	.92	.93
	-10	-8	-5	-4	-4	-3	-2	-2	-2	-4	-6	-7	-6	-4	-2	-2	-2	-2
5930	.92	.93	.94	.95	.96	.95	.95	.94	.95	.95	.95	.94	.93	.93	.94	.95	.96	.97
	-5	-3	-1	-1	-1	-0	-0	0	-1	-2	-4	-4	-4	-2	-1	-1	-0	-0
5925	.96	.97	.98	.99	.99	.99	.98	.97	.97	.96	.96	.96	.96	.97	.98	.98	.99	.99
	-1	-0	-0	0	0	0	0	0	-0	-1	-2	-2	-1	-0	-0	-0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	1.22	1.23	1.19	1.07	.94	.96	.95	.86	.85	.86	.90	.91	.95	1.24	1.66	1.83	1.87	2.01
	-9	-9	-8	-5	-3	-1	-0	3	5	6	7	7	6	4	5	5	5	5
5955	1.13	1.13	1.10	.99	.96	.97	.94	.85	.80	.81	.84	.87	1.04	1.45	1.68	1.81	1.87	1.97
	-7	-7	-6	-3	-1	-0	0	2	4	5	5	5	5	5	5	5	4	3
5950	1.03	1.03	1.00	.94	.94	.91	.88	.82	.78	.78	.80	.88	1.18	1.50	1.63	1.72	1.76	1.76
	-6	-6	-4	-2	-1	-0	0	1	3	3	4	4	5	6	5	3	1	-1
5945	.97	.95	.91	.88	.84	.78	.79	.80	.80	.81	.85	1.00	1.23	1.41	1.49	1.54	1.53	1.48
	-6	-5	-4	-2	-1	-0	0	1	2	3	4	6	7	7	4	1	-2	-5
5940	.93	.91	.88	.85	.80	.75	.76	.78	.81	.86	.95	1.06	1.17	1.26	1.28	1.27	1.25	1.24
	-4	-3	-1	-0	0	2	2	2	3	5	8	9	8	7	1	-2	-6	-8
5935	.94	.93	.92	.89	.86	.83	.81	.82	.87	.92	.99	1.05	1.09	1.10	1.08	1.07	1.08	1.10
	-1	-0	-0	0	1	1	2	4	6	8	9	8	7	3	-2	-5	-8	-10
5930	.97	.97	.96	.94	.93	.91	.88	.89	.91	.94	.98	1.00	1.00	.98	.98	.99	1.00	1.01
	-0	-0	-0	-0	-0	0	2	4	6	7	7	6	4	-1	-4	-7	-10	-13
5925	.99	1.00	.99	.98	.97	.96	.94	.93	.93	.94	.95	.95	.94	.94	.95	.96	.97	.97
	0	-0	-1	-1	-0	0	2	3	5	5	4	2	1	-1	-4	-8	-11	-13

PERIOD 12.00SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.91	.93	.92	.93	.94	.94	.95	.97	.98	1.00	1.00	1.00	.99	.99	.99	.99	.98	.96
	-3	-3	-3	-3	-3	-3	-2	-1	-0	0	0	0	0	0	0	0	0	0
5955	.92	.93	.93	.94	.94	.95	.96	.98	.99	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98
	-1	-2	-2	-2	-2	-2	-1	-0	-0	0	0	0	0	0	0	0	0	0
5950	.94	.94	.94	.95	.96	.97	.97	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99
	-0	-1	-1	-1	-1	-1	-0	-0	0	0	0	0	0	0	0	0	0	0
5945	.96	.96	.96	.97	.97	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	0	0
5940	.98	.98	.98	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5935	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.95	.94	.94	.95	.96	.97	.96	.94	.92	.93	.94	.97	.98	.95	.87	.78	.73	.70
	1	2	2	3	3	3	4	5	6	9	11	12	12	10	4	0	-0	-0
5955	.97	.96	.95	.96	.96	.97	.96	.94	.92	.92	.92	.94	.95	.94	.90	.88	.86	.85
	1	1	1	2	2	2	2	3	5	7	8	10	10	9	6	4	4	5
5950	.99	.99	.98	.98	.97	.97	.96	.95	.93	.92	.92	.92	.92	.93	.92	.92	.92	.93
	0	0	1	1	1	1	1	2	3	4	5	6	7	7	6	6	6	7
5945	1.00	1.00	1.00	.99	.99	.98	.97	.97	.96	.95	.95	.94	.93	.93	.93	.93	.94	.94
	0	0	0	0	0	0	0	0	1	1	2	3	4	5	5	5	6	6
5940	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.97	.96	.95	.95	.94	.94	.94
	0	0	0	0	0	0	0	0	0	0	1	1	1	2	2	3	3	3
5935	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.97	.97	.96	.96
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.98
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PERIOD 12.90SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.91 -4	.95 -4	.93 -4	.94 -4	.94 -4	.94 -4	.95 -3	.96 -2	.98 -0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.98 0	.97 0	.95 0
5955	.92 -2	.94 -2	.93 -3	.94 -3	.94 -3	.95 -3	.95 -2	.97 -1	.98 -0	.99 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0	.98 0	.97 0
5950	.93 -1	.94 -1	.93 -1	.94 -1	.95 -2	.96 -1	.97 -1	.98 -0	.99 -0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0
5945	.95 -0	.95 -0	.95 -0	.96 -0	.97 -0	.98 -0	.98 -0	.99 -0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5940	.97 0	.97 0	.97 0	.98 0	.98 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5935	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5930	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0
5925	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.94 1	.93 2	.92 3	.95 4	.97 4	.98 4	.97 4	.96 5	.92 7	.94 10	.94 12	.99 13	1.01 13	1.01 12	.97 11	.84 19	.76 25	.67 32
5955	.96 1	.95 1	.95 2	.96 3	.97 3	.98 3	.96 3	.94 4	.91 6	.92 8	.93 10	.95 11	.96 11	.97 10	.96 10	.91 14	.87 18	.83 24
5950	.98 0	.98 0	.97 1	.98 2	.97 2	.97 2	.95 2	.94 2	.92 3	.92 5	.92 6	.92 7	.93 8	.94 8	.95 8	.94 11	.93 13	.93 15
5945	1.00 0	1.00 0	.99 0	.99 1	.98 1	.98 1	.96 1	.96 1	.95 1	.94 2	.94 3	.93 4	.93 5	.93 5	.94 6	.94 7	.95 8	.95 8
5940	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.98 0	.98 1	.97 1	.96 1	.95 2	.94 3	.94 3	.94 3	.94 4	.94 4
5935	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.98 0	.98 1	.97 1	.96 1	.96 1	.95 1	.95 1
5930	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0	.99 0	.98 0	.98 0	.98 0
5925	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	.99 0	.99 0	.99 0

PERIOD 13.80SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	144	25	144	20	144	15	144	10	144	05	144	00	143	55	143	50	143	45	143	40	143	35	143	30	143	25	143	20	143	15	143	10	143	05	143	00
6000	.92	-4	.97	-5	.95	-5	.96	-5	.95	-6	.94	-5	.94	-4	.96	-3	.98	-1	.99	-0	.99	0	.98	0	.98	0	.98	0	.97	0	.97	0	.96	0	.94	0
5955	.92	-2	.95	-3	.94	-4	.95	-4	.95	-4	.95	-4	.95	-3	.97	-2	.98	-1	.99	-0	.99	0	.98	0	.98	0	.98	0	.98	0	.98	0	.97	0	.96	0
5950	.92	-1	.94	-1	.93	-2	.95	-2	.95	-2	.96	-2	.96	-2	.98	-1	.99	-0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.99	0	.99	0	.98	0	.98	0
5945	.94	-0	.94	-0	.94	-0	.95	-0	.96	-0	.97	-0	.97	-0	.99	-0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0
5940	.96	0	.96	0	.97	0	.97	0	.97	0	.98	0	.98	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5935	.98	0	.98	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5930	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5925	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0

LONG / LAT	142	55	142	50	142	45	142	40	142	35	142	30	142	25	142	20	142	15	142	10	142	05	142	00	141	55	141	50	141	45	141	40	141	35	141	30
6000	.93	2	.92	3	.92	4	.97	5	1.00	5	1.02	5	.99	5	.98	6	.93	8	.95	11	.95	13	1.00	15	1.03	14	1.06	13	1.11	11	1.17	17	1.18	25	1.20	40
5955	.95	1	.95	2	.95	3	.98	4	1.00	4	1.00	4	.97	4	.95	5	.91	7	.92	9	.93	11	.96	12	.98	12	1.03	11	1.07	10	1.11	15	1.12	21	1.14	30
5950	.97	0	.98	1	.98	2	.99	2	.99	2	.98	2	.95	2	.93	3	.91	4	.91	5	.92	7	.93	8	.94	9	.99	9	1.02	9	1.05	13	1.07	16	1.08	20
5945	.99	0	1.00	0	1.00	1	1.00	1	.99	1	.98	1	.95	1	.95	1	.94	2	.93	2	.93	3	.92	5	.92	6	.95	6	.96	7	.99	9	.99	10	.99	10
5940	1.00	0	1.00	0	1.01	0	1.01	0	1.00	0	.99	0	.98	0	.98	0	.97	1	.97	1	.96	1	.95	2	.94	3	.94	3	.94	4	.94	4	.94	4	.94	4
5935	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.98	0	.98	1	.97	1	.96	1	.96	1	.95	1	.95	2	.94	2
5930	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.98	0	.98	0	.97	0	.97	0	.97	0
5925	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0

PERIOD 15.00SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	.93	1.04	1.00	1.01	.99	.96	.95	.97	.99	1.00	.98	.96	.96	.96	.96	.96	.95	.93
	-5	-5	-7	-7	-7	-8	-6	-4	-2	-0	0	1	1	1	1	0	0	1
5955	.92	.99	.97	.99	.98	.97	.96	.98	.99	1.00	.99	.97	.96	.97	.97	.97	.96	.95
	-3	-4	-5	-5	-6	-6	-5	-3	-2	-0	0	0	1	1	1	0	0	0
5950	.91	.95	.95	.97	.97	.97	.96	.99	1.00	1.00	1.00	.97	.97	.98	.98	.98	.98	.97
	-2	-2	-3	-3	-4	-4	-3	-2	-1	-0	0	0	0	0	0	0	0	0
5945	.92	.94	.94	.95	.96	.97	.97	.99	1.00	1.01	1.00	.99	.98	.99	.99	.99	.99	.99
	-0	-0	-1	-1	-1	-1	-1	-0	-0	-0	0	0	0	0	0	0	0	0
5940	.95	.95	.95	.96	.96	.97	.97	.99	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99
	-0	0	0	0	-0	-0	-0	0	0	0	0	0	0	0	0	0	0	0
5935	.97	.97	.98	.98	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	.91	.90	.94	.99	1.02	1.03	.99	.95	.93	.95	.97	1.01	1.05	1.08	1.14	1.29	1.37	1.45
	2	3	5	6	6	6	6	7	9	12	15	16	16	14	12	16	25	40
5955	.93	.94	1.00	1.06	1.07	1.04	.97	.93	.91	.92	.95	.98	1.00	1.06	1.11	1.20	1.27	1.34
	1	2	4	5	5	5	5	5	8	10	12	14	13	13	12	16	22	32
5950	.96	1.01	1.07	1.12	1.11	1.05	.94	.92	.90	.91	.92	.94	.96	1.02	1.06	1.13	1.18	1.23
	0	1	2	3	3	3	3	3	5	7	9	10	11	11	10	14	18	23
5945	.98	.04	1.08	1.11	1.08	1.03	.94	.94	.93	.92	.92	.92	.93	.97	.99	1.03	1.06	1.07
	0	0	1	1	1	1	1	2	2	3	5	6	7	8	8	10	11	12
5940	.99	1.02	1.04	1.05	1.04	1.02	.97	.97	.96	.96	.94	.94	.94	.94	.95	.96	.96	.96
	0	0	0	0	0	0	0	1	1	1	2	3	4	4	5	5	5	5
5935	1.00	1.01	1.02	1.02	1.01	1.01	.99	.99	.99	.98	.97	.96	.96	.95	.95	.94	.94	.94
	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2	2	2
5930	1.00	1.00	1.01	1.01	1.00	1.00	1.00	1.00	.99	.99	.98	.98	.98	.97	.97	.96	.96	.95
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	.98	.98	.98
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

PERIOD 16.40SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.95	1.12	1.13	1.12	1.07	1.03	1.02	1.05	1.07	1.07	.99	.92	.93	.95	.96	.96	.95	.93
	-6	-7	-8	-8	-10	-10	-8	-6	-4	-1	0	1	2	2	1	1	0	1
5955	.93	1.04	1.06	1.08	1.06	1.03	1.02	1.04	1.06	1.06	1.01	.93	.93	.95	.96	.96	.95	.94
	-4	-5	-6	-7	-8	-8	-7	-5	-3	-1	-0	0	1	1	1	1	0	0
5950	.91	.98	.99	1.02	1.02	1.01	1.00	1.03	1.05	1.05	1.01	.95	.95	.96	.97	.97	.97	.96
	-2	-3	-4	-4	-5	-6	-5	-3	-2	-1	-0	0	1	1	1	0	0	0
5945	.91	.94	.94	.97	.97	.97	.98	1.01	1.03	1.03	1.01	.97	.97	.98	.98	.98	.98	.97
	-1	-1	-1	-2	-2	-2	-2	-1	-1	-0	-0	-0	0	1	1	0	0	0
5940	.93	.93	.94	.95	.95	.95	.96	.99	1.01	1.01	1.00	.99	.98	.99	.99	.99	.99	.99
	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0
5935	.96	.96	.97	.97	.97	.97	.97	.98	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99
	-0	0	0	0	0	0	0	0	0	-0	-0	-0	0	0	0	0	0	0
5930	.98	.99	.99	.99	.99	.99	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.90	.88	.83	.90	.97	1.04	1.06	1.04	.94	.97	.99	1.03	1.06	1.07	1.15	1.24	1.30	1.36
	2	4	6	7	8	7	7	8	11	14	17	18	17	14	14	20	28	41
5955	.92	.88	.82	.87	.92	.97	1.00	.98	.92	.94	.96	.98	1.01	1.07	1.12	1.20	1.26	1.33
	1	3	5	6	7	6	6	7	9	12	14	15	14	13	14	19	25	33
5950	.94	.90	.85	.85	.87	.90	.93	.93	.91	.92	.93	.94	.97	1.05	1.09	1.16	1.21	1.26
	0	1	3	5	5	4	4	5	6	8	10	12	12	12	12	16	20	24
5945	.97	.94	.90	.88	.88	.89	.92	.93	.92	.92	.91	.92	.95	1.00	1.03	1.07	1.10	1.11
	0	1	1	2	2	2	2	3	4	5	6	7	9	9	10	11	12	13
5940	.99	.97	.96	.95	.95	.95	.95	.96	.95	.95	.93	.92	.94	.96	.98	.99	.99	.98
	0	0	0	0	0	1	1	1	2	3	3	4	5	5	5	6	6	6
5935	1.00	.98	.98	.98	.98	.98	.98	.98	.98	.97	.96	.95	.96	.96	.96	.96	.95	.93
	0	0	0	0	0	0	0	1	1	1	2	2	2	2	2	2	2	2
5930	1.00	.99	.99	.99	.99	.99	.99	.99	.99	.98	.97	.97	.97	.97	.97	.96	.95	.93
	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0
5925	1.00	1.00	.99	.99	.99	.99	1.00	.99	.99	.98	.98	.98	.98	.98	.98	.98	.97	.96
	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

PERIOD 18.00SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	.95	.88	.86	.94	.98	.99	1.10	1.14	1.18	1.15	1.01	.87	.89	.94	.96	.98	.96	.93
	-4	-8	-10	-11	-13	-13	-10	-8	-5	-3	0	2	3	3	2	1	0	1
5955	.92	.91	.89	.93	.95	.97	1.07	1.12	1.16	1.14	1.03	.89	.90	.94	.96	.97	.96	.94
	-3	-5	-7	-8	-10	-11	-9	-7	-5	-2	-0	1	3	2	2	1	0	0
5950	.91	.92	.91	.93	.94	.95	1.03	1.09	1.13	1.11	1.04	.91	.91	.94	.96	.97	.96	.95
	-2	-3	-4	-5	-7	-8	-6	-5	-4	-2	-1	0	2	2	2	1	0	0
5945	.90	.92	.92	.94	.94	.95	.99	1.04	1.07	1.06	1.03	.95	.94	.96	.97	.97	.97	.96
	-1	-1	-2	-2	-3	-3	-3	-3	-2	-2	-1	-0	1	1	1	0	0	0
5940	.91	.92	.93	.94	.94	.94	.95	1.00	1.02	1.02	1.01	.98	.96	.97	.98	.98	.98	.97
	-0	-0	-0	-0	-0	-0	-0	-0	-1	-1	-1	-0	0	0	1	0	0	0
5935	.94	.95	.95	.96	.95	.95	.95	.97	.98	.99	.99	.98	.98	.99	.99	.99	.99	.99
	-0	0	0	0	0	0	0	0	0	-0	-0	-0	0	0	0	0	0	0
5930	.97	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00
	-0	0	0	0	0	0	0	0	0	0	-0	-0	0	0	0	0	0	0
5925	.99	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	.90	.87	.81	.85	.91	.97	1.01	1.01	.94	1.01	1.08	1.11	1.15	1.13	1.11	1.20	1.41	1.99
	2	4	6	9	10	10	10	11	13	16	19	20	19	16	10	1	0	-1
5955	.90	.86	.79	.80	.84	.90	.94	.96	.93	.99	1.03	1.05	1.08	1.07	1.08	1.22	1.41	1.75
	2	3	5	8	9	9	9	9	12	14	16	17	17	13	9	6	6	8
5950	.92	.87	.80	.76	.77	.82	.88	.92	.93	.96	.97	.98	1.02	1.03	1.06	1.20	1.35	1.52
	0	1	4	6	7	7	7	7	9	11	12	14	14	12	9	8	8	10
5945	.95	.90	.84	.79	.78	.82	.88	.92	.94	.94	.93	.92	.99	1.01	1.05	1.13	1.20	1.22
	0	1	2	3	3	4	4	4	6	7	8	9	10	10	9	8	8	8
5940	.97	.94	.91	.89	.89	.89	.92	.95	.95	.95	.93	.92	.99	1.02	1.06	1.06	1.06	1.01
	0	0	1	1	1	1	2	3	4	4	5	6	6	6	6	5	5	5
5935	.99	.96	.95	.95	.95	.95	.96	.97	.97	.96	.94	.93	1.00	1.03	1.05	1.04	1.00	.93
	0	0	0	0	0	0	1	2	2	3	3	3	3	3	2	2	2	2
5930	1.00	.98	.97	.97	.97	.97	.98	.98	.97	.97	.95	.95	1.00	1.01	1.02	1.01	.97	.91
	0	0	0	0	0	0	1	1	2	2	2	2	1	1	0	0	-0	0
5925	1.00	.99	.99	.99	.99	.99	.99	.98	.98	.97	.96	.96	.98	.99	1.00	.99	.97	.93
	0	0	0	0	0	0	0	1	1	1	1	1	1	0	-0	-0	-0	-0

PERIOD 20.00SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	.97	1.94	1.96	1.67	1.50	1.42	1.29	1.18	1.07	.91	.84	.78	.84	.95	1.00	1.02	.99	.96
	-3	-10	-11	-12	-15	-16	-14	-11	-8	-4	-0	3	5	4	3	2	1	1
5955	.93	1.52	1.60	1.52	1.40	1.31	1.19	1.12	1.07	.98	.90	.79	.85	.94	.99	1.01	.99	.95
	-3	-7	-9	-10	-12	-14	-12	-10	-7	-4	-1	2	4	4	3	2	0	0
5950	.91	1.19	1.27	1.28	1.23	1.16	1.09	1.09	1.08	1.04	.97	.83	.86	.93	.98	.99	.98	.95
	-2	-5	-6	-7	-9	-10	-9	-8	-6	-4	-2	0	3	3	3	1	0	0
5945	.90	.98	1.02	1.04	1.03	1.00	1.00	1.04	1.07	1.06	1.01	.90	.90	.94	.97	.97	.96	.95
	-1	-2	-3	-4	-4	-5	-4	-5	-5	-4	-3	-1	1	2	2	1	0	-0
5940	.91	.91	.93	.94	.94	.93	.94	1.00	1.03	1.03	1.00	.96	.94	.95	.97	.96	.96	.96
	-1	-0	-0	-0	-0	-0	-0	-1	-2	-3	-3	-1	0	1	1	0	0	-0
5935	.93	.93	.94	.94	.94	.94	.93	.96	.98	.99	.98	.97	.96	.97	.98	.97	.97	.98
	-1	-0	0	0	0	0	1	0	-0	-1	-1	-1	-0	0	0	0	0	0
5930	.96	.97	.98	.98	.98	.97	.97	.97	.97	.97	.97	.98	.98	.99	.99	.99	.99	.99
	-0	0	0	0	0	0	1	1	0	-0	-0	-0	-0	0	0	0	0	0
5925	.99	.99	1.00	1.00	1.00	.99	.99	.98	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.92	.93	.93	.96	.96	.95	.93	.98	1.10	1.26	1.33	1.32	1.27	1.19	1.26	1.40	1.47	1.62
	2	4	5	8	12	13	14	15	19	20	22	22	21	18	15	13	12	13
5955	.91	.92	.93	.91	.89	.87	.86	.98	1.13	1.23	1.25	1.22	1.15	1.21	1.33	1.44	1.54	1.70
	1	3	4	8	12	13	14	14	17	18	19	19	18	16	15	14	14	13
5950	.91	.93	.90	.83	.78	.77	.82	.98	1.10	1.15	1.14	1.08	1.05	1.23	1.36	1.46	1.56	1.59
	0	1	3	7	10	11	11	12	13	15	15	16	15	14	14	13	13	12
5945	.93	.93	.87	.79	.74	.74	.83	.98	1.04	1.06	1.02	.95	1.03	1.22	1.36	1.45	1.51	1.31
	0	0	2	4	6	6	7	8	9	10	11	11	11	11	11	10	10	8
5940	.95	.92	.87	.83	.81	.81	.88	.97	1.00	1.00	.96	.90	1.03	1.17	1.28	1.33	1.33	1.08
	0	0	1	2	3	3	4	5	6	7	7	7	7	7	6	5	5	5
5935	.97	.93	.90	.89	.89	.89	.93	.97	.98	.98	.94	.91	1.02	1.10	1.16	1.17	1.14	.97
	0	1	1	2	1	2	2	4	5	5	5	5	3	3	2	1	1	1
5930	.99	.95	.94	.94	.94	.94	.96	.97	.97	.96	.94	.93	1.00	1.05	1.09	1.07	1.03	.91
	0	1	1	1	1	1	1	2	3	3	3	3	2	0	-0	-1	-1	-0
5925	1.00	.98	.97	.97	.97	.97	.98	.97	.96	.95	.94	.94	.99	1.02	1.04	1.02	.98	.90
	0	1	0	0	0	0	1	2	2	2	2	2	1	0	-1	-2	-2	-0

PERIOD 22.50SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	144251	144201	144151	144101	144051	144001	143551	143501	143451	143401	143351	143301	143251	143201	143151	143101	143051	143001
6000	.99 -3	1.00 -3	1.06 -6	1.11 -7	1.18 -20	1.17 -22	1.16 -23	1.10 -18	.99 -11	.83 -2	.78 -1	.74 3	.73 6	1.04 5	1.08 3	1.10 1	1.07 0	1.02 1
5955	.94 -3	.96 -2	1.01 -4	1.07 -5	1.13 -16	1.12 -20	1.11 -21	1.07 -17	.98 -11	.88 -3	.81 -1	.75 2	.75 4	1.00 5	1.05 2	1.07 1	1.04 0	.99 0
5950	.91 -3	.93 -2	.96 -2	1.02 -3	1.06 -10	1.06 -14	1.07 -16	1.06 -13	1.01 -10	.95 -5	.87 -1	.78 0	.79 3	.96 5	1.01 2	1.03 1	1.01 0	.97 -0
5945	.89 -2	.90 -1	.92 -1	.96 -1	.98 -3	.99 -6	1.03 -8	1.06 -8	1.05 -7	1.03 -6	.95 -3	.83 -0	.84 2	.93 4	.97 2	.98 0	.97 -0	.95 -1
5940	.90 -2	.89 -0	.90 0	.93 0	.93 0	.92 0	.98 -1	1.03 -2	1.05 -3	1.05 -4	.99 -3	.91 -2	.89 0	.93 2	.95 1	.95 0	.95 -0	.95 -0
5935	.93 -2	.92 -0	.92 0	.93 1	.93 1	.92 2	.94 2	.97 1	1.00 0	1.00 -1	.98 -1	.95 -2	.93 -0	.95 0	.95 0	.95 0	.96 0	.96 -0
5930	.96 -1	.96 -0	.97 0	.97 0	.97 1	.97 1	.96 2	.96 2	.96 1	.97 0	.97 -0	.97 -1	.96 -0	.97 0	.98 0	.98 0	.98 0	.98 0
5925	.98 -0	.99 0	.99 0	.99 0	.99 0	.99 0	.98 1	.98 1	.97 1	.97 0	.97 0	.98 -0	.98 0	.99 0	.99 0	.99 0	1.00 0	1.00 0

LONG / LAT	142551	142501	142451	142401	142351	142301	142251	142201	142151	142101	142051	142001	141551	141501	141451	141401	141351	141301
6000	.96 2	.92 4	.85 5	.65 9	.55 11	.63 12	.69 13	.76 13	.99 16	1.31 21	1.47 25	1.44 25	1.39 25	1.25 21	1.13 16	1.16 7	1.18 7	1.17 9
5955	.93 1	.88 2	.80 4	.62 8	.56 10	.62 11	.67 11	.81 12	1.08 16	1.30 20	1.36 23	1.31 23	1.25 23	1.15 19	1.12 15	1.15 11	1.17 11	1.17 13
5950	.91 -0	.87 1	.79 2	.63 6	.59 8	.62 9	.69 9	.92 11	1.15 15	1.25 18	1.25 20	1.18 20	1.11 20	1.08 17	1.09 13	1.12 12	1.15 12	1.16 13
5945	.91 -0	.89 -0	.82 0	.70 3	.66 6	.65 8	.75 10	.98 13	1.12 15	1.15 17	1.13 18	1.05 17	1.00 15	1.02 13	1.06 12	1.09 11	1.12 11	1.13 10
5940	.92 -0	.93 -0	.88 1	.82 4	.78 7	.74 9	.80 12	.95 14	1.04 15	1.06 15	1.04 14	.97 11	.95 9	.98 9	1.04 8	1.06 7	1.08 7	1.05 6
5935	.94 0	.95 1	.91 4	.88 6	.85 7	.83 9	.84 11	.94 11	.99 11	1.01 10	.98 8	.93 6	.96 5	1.01 4	1.06 3	1.06 3	1.05 2	.96 1
5930	.97 0	.96 2	.93 3	.92 4	.91 5	.90 6	.91 7	.95 6	.97 7	.97 6	.94 5	.92 4	.99 3	1.05 1	1.08 0	1.06 -0	1.01 -0	.88 -0
5925	.99 0	.97 1	.96 2	.96 2	.96 2	.96 2	.96 3	.96 3	.95 4	.94 4	.92 4	.92 4	.98 2	1.03 0	1.05 -0	1.03 -1	.97 -2	.85 -1

PERIOD 25.70SEC, INITIAL AZIMTH 0.00DEG

LONG / LAT	I44251	I44201	I44151	I44101	I44051	I44001	I43551	I43501	I43451	I43401	I43351	I43301	I43251	I43201	I43151	I43101	I43051	I43001
6000	1.50 -12	1.43 -18	1.39 -23	1.30 -22	1.33 -23	1.29 -23	1.24 -21	1.06 -17	.84 -12	.61 -4	.61 -0	.63 5	.71 9	.97 7	1.05 5	1.08 3	1.14 1	1.15 0
5955	1.30 -8	1.32 -13	1.31 -18	1.26 -21	1.24 -23	1.17 -23	1.13 -22	.99 -18	.82 -12	.65 -6	.64 -1	.66 3	.72 8	.94 7	1.02 5	1.04 3	1.08 0	1.07 -0
5950	1.12 -5	1.19 -8	1.21 -12	1.19 -16	1.14 -20	1.05 -22	1.01 -22	.93 -18	.83 -14	.75 -8	.72 -3	.71 0	.75 6	.90 6	.97 4	.99 2	1.02 -0	1.00 -1
5945	.97 -3	1.04 -4	1.07 -6	1.08 -8	1.03 -12	.96 -15	.93 -17	.93 -16	.92 -14	.91 -10	.87 -6	.81 -1	.80 2	.89 4	.93 3	.95 1	.97 -0	.96 -1
5940	.91 -3	.93 -2	.96 -1	.98 -1	.96 -2	.92 -4	.93 -7	1.00 -8	1.04 -9	1.05 -9	1.01 -8	.92 -4	.86 -0	.90 1	.93 1	.94 0	.94 -0	.94 -1
5935	.91 -3	.92 -1	.94 -0	.95 0	.94 0	.92 1	.92 0	1.02 -0	1.06 -3	1.06 -4	1.03 -5	.97 -4	.90 -1	.93 0	.94 0	.94 0	.94 -0	.94 -0
5930	.95 -2	.96 -0	.97 0	.97 0	.97 0	.96 1	.95 2	.98 1	1.00 0	1.00 -0	.99 -1	.96 -2	.94 -1	.96 -0	.96 0	.97 0	.97 0	.97 0
5925	.99 -0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 1	.99 1	.98 0	.98 0	.98 -0	.98 -0	.98 -0	.99 0	.99 0	.99 0	.99 0	.99 0

LONG / LAT	I42551	I42501	I42451	I42401	I42351	I42301	I42251	I42201	I42151	I42101	I42051	I42001	I41551	I41501	I41451	I41401	I41351	I41301
6000	1.13 0	1.10 1	1.03 2	.58 9	.59 15	.71 17	.78 18	.81 19	.99 21	1.52 23	1.79 25	1.87 24	1.93 22	1.82 17	1.31 4	1.23 -1	1.18 -2	1.16 -1
5955	1.03 0	.99 0	.90 2	.54 10	.55 16	.65 16	.70 17	.72 18	1.02 21	1.52 22	1.71 22	1.76 21	1.76 20	1.62 15	1.41 9	1.42 6	1.41 5	1.38 7
5950	.95 -1	.91 -0	.80 2	.53 9	.53 14	.59 15	.62 16	.66 18	1.06 20	1.42 20	1.55 19	1.57 18	1.52 17	1.49 15	1.47 12	1.51 11	1.51 10	1.48 11
5945	.92 -1	.87 -0	.76 1	.58 6	.55 11	.57 13	.58 16	.72 18	1.05 19	1.27 17	1.33 16	1.32 15	1.27 14	1.38 13	1.46 13	1.50 12	1.50 12	1.42 11
5940	.91 -1	.88 0	.81 3	.73 7	.70 11	.67 13	.66 16	.82 17	1.04 16	1.15 14	1.15 12	1.12 10	1.10 9	1.22 10	1.31 10	1.34 9	1.32 8	1.19 6
5935	.93 0	.92 2	.89 6	.86 8	.84 10	.81 11	.79 13	.89 13	1.02 13	1.06 12	1.04 9	1.00 7	1.02 5	1.08 5	1.13 5	1.14 5	1.10 4	.96 1
5930	.96 1	.96 3	.94 5	.93 6	.93 6	.91 7	.89 8	.93 9	.97 10	.99 9	.97 7	.94 5	.98 3	1.03 2	1.05 1	1.04 0	1.00 -0	.86 -1
5925	.98 1	.98 2	.97 3	.97 3	.97 3	.96 3	.94 4	.94 6	.94 7	.94 6	.93 6	.91 5	.97 2	1.01 0	1.03 -1	1.01 -2	.96 -2	.83 -2

PERIOD 12.00SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	014	415	144	101	440	514	400	143	551	435	014	345	143	401	433	514	330	143	251	432	014	315	143	101	430	514	300
6000	.93	.93	.93	.94	.95	.95	.97	.98	.99	1.00	1.00	.99	.99	.99	.99	.98	.96	.93
	0	-0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
5955	.93	.93	.94	.94	.95	.96	.97	.98	.99	1.00	1.00	1.00	1.00	1.00	1.00	.99	.98	.97
	0	0	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5950	.94	.94	.95	.95	.96	.97	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5945	.96	.96	.96	.97	.98	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5940	.98	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5935	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	142	551	425	014	245	142	401	423	514	230	142	251	422	014	215	142	101	420	514	200	141	551	415	014	145	141	401	413	514	130
6000	.91	.92	.94	.97	.96	.90	.83	.81	.79	.79	.80	10.00	10.00	10.00	10.00	10.00	10.00	10.00
	4	6	8	8	8	5	6	7	8	8	8	1000	1000	1000	1000	1000	1000	1000
5955	.94	.94	.95	.96	.95	.92	.87	.84	.83	.84	.85	.92	10.00	10.00	10.00	10.00	10.00	10.00
	2	3	4	4	4	4	4	5	6	6	6	2	1000	1000	1000	1000	1000	1000
5950	.98	.97	.97	.97	.96	.95	.92	.90	.89	.90	.91	.95	.98	.99	10.00	10.00	10.00	10.00
	0	1	1	2	2	2	2	3	3	3	3	1	0	0	1000	1000	1000	1000
5945	1.00	.99	.99	.98	.98	.97	.96	.95	.95	.95	.96	.97	.98	.99	.99	10.00	10.00	10.00
	0	0	0	0	0	0	0	1	1	1	1	0	0	0	-0	1000	1000	1000
5940	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.98	.98	.98	.99	.99	.99	1.00	1.00	10.00	10.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	-0	1000	1000
5935	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	1.00	1.00	1.00	1.00	1.00	10.00
	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	-0	-0	-0	-0	-0	1000
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	-0	-0	-0	-0	-0	-0	-0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	0	0	0	0

PERIOD 12.90SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	01	441	51	441	01	440	51	440	01	435	51	435	01	434	51	434	01	433	51	433	01	432	51	432	01	431	51	431	01	430	51	430	0
6000	.93	0	.94	-0	.95	-0	.95	0	.95	0	.95	0	.96	0	.97	0	.98	-0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.98	1	.95	1	.91	2
5955	.93	1	.94	0	.94	0	.95	-0	.95	-0	.95	-0	.96	0	.97	0	.99	0	.99	0	1.00	0	.99	0	.99	0	1.00	0	1.00	0	.99	0	.98	0	.96	1
5950	.94	1	.94	0	.94	0	.95	0	.96	-0	.96	-0	.97	-0	.98	-0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0
5945	.95	1	.95	0	.95	0	.96	0	.97	0	.98	-0	.99	-0	.99	-0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5940	.97	0	.97	0	.97	0	.98	0	.98	0	.99	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.01	0
5935	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5930	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0
5925	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0

LONG / LAT	142	551	425	01	424	51	424	01	423	51	423	01	422	51	422	01	421	51	421	01	420	51	420	01	415	51	415	01	414	51	414	01	413	51	413	0
6000	.87	5	.91	8	.94	10	.98	10	.98	10	.92	8	.79	9	.76	11	.74	12	.74	14	.77	13	.85	7	1.00	1000	1.00	1000	1.00	1000	1.00	1000	1.00	1000	1.00	1000
5955	.92	2	.92	4	.94	6	.96	6	.95	6	.91	6	.84	6	.81	8	.79	9	.79	10	.81	10	.87	5	1.00	1000	1.00	1000	1.00	1000	1.00	1000	1.00	1000	1.00	1000
5950	.97	0	.96	1	.96	2	.96	3	.95	3	.93	3	.89	3	.87	4	.86	5	.86	5	.87	5	.91	3	.95	1	.97	0	1.00	1000	1.00	1000	1.00	1000	1.00	1000
5945	1.00	0	.99	0	.98	0	.98	1	.97	1	.96	1	.95	1	.93	1	.93	2	.92	2	.93	2	.95	1	.97	0	.98	0	.99	0	1.00	1000	1.00	1000	1.00	1000
5940	1.01	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.98	0	.97	0	.97	0	.97	0	.97	0	.98	0	.99	0	.99	0	.99	-0	1.00	1000	1.00	1000
5935	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	0	.99	-0	.99	-0	1.00	1000	1.00	1000
5930	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	.99	0	.99	-0	1.00	-0	1.00	-0	1.00	0	1.00	0
5925	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0	1.00	0

PERIOD 13.80SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	01	441	51	441	01	440	51	440	01	435	51	435	01	434	51	434	01	433	51	433	01	432	51	432	01	431	51	431	01	430	51	430
6000	.93	.98	.99	.97	.95	.94	.94	.96	.98	.99	.99	.99	.99	1.00	1.00	.99	.95	.90																	
	2	0	-0	0	-0	-0	-0	-0	-0	0	1	1	1	1	1	1	2	3																	
5955	.93	.95	.97	.96	.96	.95	.95	.96	.98	.99	.99	.99	.99	1.00	1.01	1.00	.99	.95																	
	2	1	0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0	0	1	1																	
5950	.93	.94	.95	.96	.96	.96	.97	.97	.98	.99	.99	.99	.99	1.00	1.00	1.01	1.01	1.00																	
	1	1	0	-0	-0	-0	-0	-0	-0	0	0	0	0	0	0	0	0	0																	
5945	.94	.94	.95	.96	.97	.98	.98	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.01	1.01	1.01																	
	1	1	0	0	-0	-0	-0	-0	-0	0	0	0	0	0	0	0	0	0																	
5940	.96	.96	.96	.97	.98	.98	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01	1.01																	
	1	0	0	0	0	0	0	-0	-0	0	0	0	0	0	0	0	0	0																	
5935	.98	.98	.98	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.01																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
5930	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	

LONG / LAT	142	55	142	50	142	45	142	40	142	35	142	30	142	25	142	20	142	15	142	10	142	05	142	00	141	55	141	50	141	45	141	40	141	35	141
6000	.84	.85	.88	.92	.93	.89	.78	.75	.73	.74	.75	.81	10.00	10.00	10.00	10.00	10.00	10.00																	
	7	10	11	12	11	9	11	12	14	15	18	12	1000	1000	1000	1000	1000	1000																	
5955	.91	.89	.91	.93	.93	.90	.83	.79	.77	.78	.78	.83	10.00	10.00	10.00	10.00	10.00	10.00																	
	3	6	7	8	8	7	8	10	11	12	14	9	1000	1000	1000	1000	1000	1000																	
5950	.97	.95	.94	.94	.94	.92	.88	.84	.83	.83	.84	.87	.93	.95	10.00	10.00	10.00	10.00																	
	1	2	3	4	4	4	5	6	7	8	8	6	2	1	1000	1000	1000	1000																	
5945	1.01	.99	.98	.96	.96	.95	.94	.92	.90	.90	.90	.92	.95	.96	.97	10.00	10.00	10.00																	
	0	0	1	1	1	2	2	3	3	4	4	3	1	0	0	1000	1000	1000																	
5940	1.01	1.01	1.00	.99	.99	.98	.98	.97	.96	.95	.95	.96	.96	.97	.98	.98	10.00	10.00																	
	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	-0	1000	1000																	
5935	1.01	1.01	1.01	1.00	1.00	1.00	.99	.99	.99	.98	.98	.98	.98	.98	.98	.99	.99	10.00																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	1000																	
5930	1.01	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	.99	.99																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	0																	
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99																	
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0																	

PERIOD 15.00SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	014	415	144	101	440	514	400	143	551	435	014	345	143	401	433	514	330	143	251	432	014	315	143	101	430	514	300
6000	.96	1.07	1.10	1.05	1.00	.95	.93	.94	.96	.98	.99	.99	.98	1.04	1.07	1.06	1.01	.93
	2	0	-0	-0	-1	-1	-0	-0	-0	1	2	2	2	2	1	2	3	4
5955	.94	1.00	1.04	1.04	1.01	.98	.95	.94	.96	.98	.99	.99	.99	1.03	1.06	1.07	1.05	.99
	2	1	0	-0	-1	-1	-1	-0	-0	0	1	1	1	1	1	1	1	2
5950	.93	.95	.99	1.01	1.01	.99	.97	.96	.97	.98	.99	.99	.99	1.00	1.03	1.06	1.06	1.04
	2	1	0	-0	-1	-1	-1	-1	-0	0	0	1	1	0	0	0	0	0
5945	.93	.94	.95	.97	.99	1.00	1.00	.99	.98	.99	.99	.99	.99	.99	1.00	1.03	1.05	1.05
	2	1	1	0	-0	-0	-1	-1	-0	-0	0	0	0	0	0	0	0	0
5940	.95	.95	.95	.96	.97	.98	.99	1.00	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.02	1.03
	1	1	1	1	0	0	-0	-0	-0	-0	0	0	0	0	0	0	0	0
5935	.97	.97	.97	.97	.98	.98	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.01
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5930	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	142	551	425	014	245	142	401	423	514	230	142	251	422	014	215	142	101	420	514	200	141	551	415	014	145	141	401	413	514	130
6000	.81	.84	.90	.96	.98	.96	.79	.73	.71	.71	.74	.77	10.00	10.00	10.00	10.00	10.00	10.00
	8	12	14	14	14	12	13	16	19	21	25	27	1000	1000	1000	1000	1000	1000
5955	.90	.87	.91	.94	.96	.93	.83	.76	.74	.74	.76	.78	.84	10.00	10.00	10.00	10.00	10.00
	4	8	10	10	10	10	10	13	16	18	20	22	7	1000	1000	1000	1000	1000
5950	.99	.93	.92	.93	.93	.92	.87	.82	.80	.79	.80	.82	.87	.90	10.00	10.00	10.00	10.00
	1	3	5	6	6	6	7	9	11	12	13	13	5	2	1000	1000	1000	1000
5945	1.03	1.00	.97	.95	.94	.94	.92	.90	.88	.86	.86	.87	.90	.92	.93	10.00	10.00	10.00
	0	1	2	2	3	3	3	4	5	6	6	6	3	1	0	1000	1000	1000
5940	1.03	1.02	1.01	.99	.98	.97	.97	.96	.95	.93	.92	.92	.93	.94	.95	.95	10.00	10.00
	0	0	0	0	0	1	1	1	2	2	2	2	2	1	0	-0	1000	1000
5935	1.02	1.02	1.01	1.00	1.00	.99	.99	.99	.98	.97	.97	.96	.96	.96	.96	.96	10.00	
	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	-0	-0	1000
5930	1.01	1.01	1.01	1.00	1.00	.99	.99	.99	.99	.99	.99	.98	.97	.97	.97	.97	.97	.97
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.98	.98	.98	.98	.98
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-0	-0	-0	0

PERIOD 16.40SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	1.00	1.25	1.29	1.20	1.10	.99	.90	.91	.93	.98	1.00	1.00	.99	1.02	1.04	1.04	1.01	.93
	3	1	-1	-2	-2	-2	-2	-1	-0	3	4	4	4	3	2	3	4	6
5955	.97	1.10	1.19	1.20	1.15	1.07	.96	.92	.94	.97	.99	1.00	.99	1.01	1.05	1.07	1.07	1.02
	3	2	-0	-1	-2	-3	-2	-1	-0	2	3	3	3	2	2	2	2	3
5950	.95	1.00	1.09	1.14	1.15	1.11	1.04	.97	.95	.97	.98	.99	.99	.99	1.04	1.08	1.10	1.09
	3	2	0	-0	-2	-3	-3	-2	-0	0	1	2	2	1	1	1	1	1
5945	.93	.94	.98	1.04	1.08	1.09	1.06	1.02	.98	.97	.98	.99	.99	.99	1.01	1.05	1.09	1.10
	3	2	1	0	-0	-2	-2	-2	-1	-0	0	1	1	1	0	0	0	0
5940	.93	.94	.94	.96	.99	1.02	1.03	1.02	1.00	.99	.98	.99	.99	.99	.99	1.00	1.03	1.06
	2	2	1	1	0	0	-0	-1	-1	-0	-0	0	0	0	0	0	0	0
5935	.96	.96	.96	.96	.96	.98	.99	.99	.99	.99	.99	.99	1.00	.99	.99	.99	1.00	1.03
	1	1	1	1	1	1	0	0	-0	-0	-0	0	0	0	0	0	0	0
5930	.98	.99	.99	.99	.99	.98	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.01
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5925	1.00	1.00	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.79	.78	.88	.94	.98	.98	.86	.75	.72	.72	.76	.77	10.00	10.00	10.00	10.00	10.00	10.00
	12	16	18	17	16	14	15	20	24	28	31	33	1000	1000	1000	1000	1000	1000
5955	.91	.82	.88	.93	.96	.95	.87	.78	.74	.74	.76	.77	.76	10.00	10.00	10.00	10.00	10.00
	6	11	13	13	13	12	12	17	20	23	26	28	10	1000	1000	1000	1000	1000
5950	1.02	.92	.89	.90	.92	.92	.89	.83	.79	.77	.77	.78	.79	.82	10.00	10.00	10.00	10.00
	2	5	8	9	9	9	9	12	14	16	18	19	8	4	1000	1000	1000	1000
5945	1.08	1.02	.96	.92	.92	.93	.92	.90	.87	.83	.82	.82	.83	.85	.86	10.00	10.00	10.00
	0	1	3	4	5	5	5	6	8	9	9	9	6	3	1	1000	1000	1000
5940	1.07	1.05	1.02	.99	.96	.96	.96	.96	.94	.91	.89	.87	.87	.88	.89	.88	10.00	10.00
	0	0	0	1	1	2	2	3	3	4	4	4	3	2	0	-0	1000	1000
5935	1.05	1.04	1.03	1.01	.99	.97	.98	.98	.98	.97	.95	.92	.91	.91	.91	.90	.90	10.00
	0	0	0	0	0	0	1	1	1	2	2	1	1	1	0	-0	-0	1000
5930	1.03	1.02	1.01	1.00	.99	.98	.98	.98	.99	.99	.98	.96	.94	.93	.93	.92	.92	.92
	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	-0	-0	0
5925	1.01	1.01	1.00	1.00	1.00	.99	.99	.98	.98	.98	.99	.98	.97	.95	.94	.94	.93	.94
	0	0	0	0	0	0	0	0	1	1	0	0	0	0	-0	-0	-0	0

PERIOD 18.00SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	014	415	144	101	440	514	400	143	551	435	014	345	143	401	433	514	330	143	251	432	014	315	143	101	430	514	300
6000	1.08	1.17	1.18	1.14	1.05	.94	.86	.87	.89	1.04	1.11	1.11	1.09	1.06	1.00	.98	.96	.90
	0	-4	-5	-6	-6	-5	-3	-1	-0	5	7	7	6	5	4	4	5	6
5955	1.02	1.09	1.11	1.10	1.06	.98	.89	.88	.90	.97	1.05	1.07	1.05	1.04	1.00	.99	.98	.96
	3	-1	-3	-5	-6	-6	-4	-2	-0	2	5	6	5	4	3	3	3	4
5950	.98	1.01	1.04	1.06	1.05	1.02	.96	.92	.92	.94	.99	1.02	1.01	1.01	1.00	.99	1.00	.99
	4	1	-0	-3	-5	-6	-5	-3	-1	0	3	4	4	3	2	1	1	1
5945	.93	.94	.96	.99	1.02	1.03	1.02	.99	.95	.95	.97	.99	.99	.99	.98	.99	1.00	1.02
	4	3	1	-0	-2	-4	-4	-3	-2	-0	1	2	2	2	1	1	0	0
5940	.92	.92	.92	.94	.96	.99	1.01	1.00	.99	.97	.97	.98	.99	.98	.98	.98	.99	1.02
	3	3	2	1	0	-0	-1	-2	-2	-1	-0	0	1	1	1	0	0	0
5935	.94	.95	.95	.95	.95	.96	.97	.98	.98	.98	.98	.98	.99	.99	.98	.98	.99	1.01
	1	1	1	1	1	1	1	0	-0	-0	-0	-0	0	0	0	0	0	0
5930	.97	.98	.98	.98	.98	.98	.98	.98	.98	.98	.98	.99	.99	.99	.99	.99	.99	1.00
	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0
5925	.99	1.00	1.00	1.00	1.00	.99	.99	.99	.99	.99	.99	.99	1.00	1.00	1.00	1.00	1.00	1.00
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

LONG / LAT	142	551	425	014	245	142	401	423	514	230	142	251	422	014	215	142	101	420	514	200	141	551	415	014	145	141	401	413	514	130
6000	.78	.75	.84	.99	1.07	1.13	1.14	1.08	.72	.69	.71	.74	.67	10.00	10.00	10.00	10.00	10.00
	15	23	24	22	21	18	18	20	24	29	32	35	35	1000	1000	1000	1000	1000
5955	.87	.80	.84	.95	1.03	1.08	1.08	1.02	.78	.70	.70	.72	.65	10.00	10.00	10.00	10.00	10.00
	8	16	19	19	18	16	16	18	21	25	28	30	30	1000	1000	1000	1000	1000
5950	.96	.90	.85	.89	.98	1.03	1.04	1.00	.86	.73	.71	.71	.65	.66	10.00	10.00	10.00	10.00
	3	7	13	15	14	13	13	14	16	19	20	22	21	6	1000	1000	1000	1000
5945	1.01	.98	.93	.90	.93	.99	1.02	1.01	.95	.84	.75	.73	.70	.71	.70	10.00	10.00	10.00
	1	2	5	7	9	9	9	9	10	11	12	12	11	5	2	1000	1000	1000
5940	1.04	1.03	1.00	.97	.94	.96	1.00	1.02	1.01	.95	.86	.80	.77	.76	.74	.75	10.00	10.00
	0	0	1	1	3	4	5	5	6	6	6	6	5	3	1	-0	1000	1000
5935	1.04	1.04	1.02	1.00	.97	.94	.97	1.01	1.02	1.01	.96	.88	.83	.81	.79	.79	.78	10.00
	0	0	0	0	0	1	3	3	3	3	3	2	2	1	0	-0	-1	1000
5930	1.03	1.02	1.01	1.00	.98	.96	.96	.98	1.00	1.01	1.00	.95	.90	.86	.84	.82	.82	.82
	0	0	0	0	0	0	1	2	2	2	2	1	0	0	-0	-0	-0	0
5925	1.01	1.01	1.00	.99	.99	.98	.97	.96	.97	.99	.99	.98	.95	.91	.88	.86	.85	.85
	0	0	0	0	0	0	0	1	2	2	1	1	0	-0	-0	-0	-0	0

PERIOD 20.00SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	14425	14420	14415	14410	14405	14400	14355	14350	14345	14340	14335	14330	14325	14320	14315	14310	14305	14300
6000	1.12 1	1.11 -4	1.10 -5	1.09 -4	1.02 -4	.93 -3	.86 -1	.83 -0	.82 -0	.80 5	.91 8	.95 8	.96 7	.91 6	.84 5	.75 5	.72 5	.70 6
5955	1.13 3	1.17 -1	1.16 -3	1.14 -5	1.09 -6	1.00 -5	.90 -3	.84 -1	.84 -0	.84 2	.91 6	.97 7	.99 6	.95 5	.88 4	.80 4	.76 4	.74 4
5950	1.06 5	1.15 1	1.17 -1	1.17 -4	1.14 -6	1.08 -6	1.00 -5	.91 -3	.88 -1	.88 0	.91 3	.98 5	1.00 5	.99 4	.94 3	.87 3	.82 2	.81 2
5945	.96 5	1.04 4	1.09 1	1.11 -1	1.12 -4	1.11 -5	1.07 -5	1.02 -5	.96 -3	.92 -1	.92 0	.97 3	.99 4	.99 3	.97 3	.93 2	.90 1	.90 1
5940	.91 4	.93 4	.95 3	.98 2	1.02 0	1.05 -1	1.07 -2	1.05 -3	1.02 -3	.97 -2	.95 -1	.96 1	.98 2	.98 2	.97 1	.95 1	.94 1	.96 1
5935	.93 1	.93 2	.94 2	.93 2	.94 2	.97 2	.99 1	1.00 0	1.00 -0	.98 -1	.96 -1	.97 -0	.97 0	.98 1	.97 1	.97 0	.97 0	.99 0
5930	.96 0	.97 0	.97 1	.97 1	.97 1	.97 1	.97 2	.97 1	.97 1	.97 0	.97 -0	.98 -0	.98 0	.99 0	.99 0	.99 0	.99 0	.99 0
5925	.99 0	.99 0	.99 0	.99 0	.99 0	.99 0	.99 1	.98 1	.98 1	.98 0	.98 0	.99 0	.99 0	.99 0	1.00 0	1.00 0	1.00 0	1.00 0

LONG / LAT	14255	14250	14245	14240	14235	14230	14225	14220	14215	14210	14205	14200	14155	14150	14145	14140	14135	14130
6000	.66 6	1.09 16	1.16 26	1.13 25	1.11 25	1.09 24	1.04 24	1.05 24	1.01 25	.76 30	.69 35	.73 38	.68 38	.34 37	10.00 1000	10.00 1000	10.00 1000	10.00 1000
5955	.72 4	.96 10	1.11 24	1.09 25	1.07 23	1.06 22	1.01 21	1.02 21	.98 23	.80 27	.66 31	.67 34	.62 34	.34 34	10.00 1000	10.00 1000	10.00 1000	10.00 1000
5950	.81 2	.88 4	1.02 17	1.03 21	1.01 21	1.02 19	.99 18	1.00 17	.97 18	.86 21	.65 25	.61 27	.57 27	.34 27	.38 8	10.00 1000	10.00 1000	10.00 1000
5945	.90 1	.92 1	.96 6	.96 11	.94 14	.97 14	.99 14	1.01 13	1.01 14	.94 14	.76 15	.62 17	.55 18	.39 17	.41 6	10.00 1000	10.00 1000	10.00 1000
5940	1.00 1	1.00 0	1.00 1	.97 2	.93 4	.91 8	.99 10	1.04 9	1.07 9	1.04 9	.95 9	.75 9	.61 9	.52 8	.47 4	.48 1	.52 -0	10.00 1000
5935	1.05 1	1.04 0	1.01 0	.99 0	.95 0	.89 2	.94 6	1.05 7	1.09 7	1.10 6	1.06 5	.93 4	.73 3	.64 3	.58 2	.55 0	.56 -0	.64 1
5930	1.04 1	1.03 0	1.01 0	.98 0	.96 0	.92 0	.91 3	.98 5	1.05 5	1.08 5	1.07 4	1.01 2	.87 1	.75 0	.68 0	.64 0	.63 0	.69 2
5925	1.01 1	1.01 0	1.00 0	.98 0	.97 0	.96 0	.94 1	.93 3	.96 4	1.00 4	1.02 3	1.01 2	.96 1	.87 0	.78 -0	.74 -0	.71 0	.72 2

PERIOD 22.50SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	01	441	51	441	01	440	51	440	01	435	51	435	01	434	51	434	01	433	51	433	01	432	51	432	01	431	51	431	01	430	51	430
6000	1.13	1.05	1.00	.93	.87	.81	.77	.76	.76	.75	1.22	1.25	1.21	1.12	.94	.63	.54	.51
	0	-4	-1	-1	-2	-3	-3	-2	0	2	12	13	12	10	9	7	9	11
5955	1.09	1.04	.99	.95	.91	.86	.82	.78	.78	.77	1.12	1.20	1.19	1.11	.96	.70	.59	.56
	1	-2	-2	-2	-3	-3	-3	-3	-0	1	10	11	11	9	8	5	7	8
5950	1.04	1.01	.98	.96	.94	.92	.90	.87	.83	.81	.97	1.09	1.12	1.08	.98	.81	.68	.63
	3	-0	-2	-3	-4	-4	-4	-4	-1	0	5	9	9	8	6	4	4	5
5945	.96	.96	.95	.94	.96	.99	1.01	1.01	.95	.88	.89	.98	1.02	1.01	.97	.89	.79	.74
	5	2	-0	-2	-4	-5	-5	-5	-3	-1	1	5	6	6	5	3	2	3
5940	.90	.91	.91	.91	.96	1.02	1.06	1.07	1.04	.96	.91	.93	.96	.97	.96	.93	.88	.87
	5	5	3	1	-1	-3	-4	-4	-4	-3	-1	1	3	3	3	2	1	1
5935	.91	.92	.92	.92	.93	.97	1.01	1.03	1.02	.99	.95	.94	.95	.96	.95	.95	.94	.95
	2	3	3	3	2	1	0	-0	-1	-2	-2	-0	1	1	1	1	1	1
5930	.95	.96	.97	.96	.96	.96	.97	.97	.97	.97	.96	.96	.97	.97	.97	.98	.98	.98
	0	1	1	1	1	2	2	2	1	0	-0	-0	0	0	0	0	0	0
5925	.98	.99	.99	.99	.99	.98	.98	.97	.97	.97	.97	.98	.98	.99	.99	.99	.99	.99
	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0

LONG / LAT	142	551	425	01	424	51	424	01	423	51	423	01	422	51	422	01	421	51	421	01	420	51	420	01	415	51	415	01	414	51	414	01	413	51	413
6000	.47	.40	.67	.97	1.51	1.51	1.47	1.38	1.19	.81	.86	.94	.90	1.04	1.04	1.04	1.04	1.04
	13	15	19	25	26	27	28	31	33	36	40	43	44	34	34	34	34	34
5955	.53	.47	.69	.93	1.41	1.42	1.35	1.24	1.08	.80	.83	.90	.82	1.19	1.18	1.18	1.17	1.17
	10	11	17	23	25	25	26	28	31	33	36	39	40	36	36	36	36	36
5950	.61	.58	.68	.88	1.23	1.26	1.18	1.08	.98	.81	.81	.84	.67	1.29	1.29	1.28	1.27	1.26
	6	7	12	19	22	22	22	24	26	27	29	31	29	37	37	37	37	37
5945	.74	.74	.76	.86	1.02	1.10	1.05	.99	.92	.85	.81	.81	.64	1.30	1.33	1.33	1.32	1.32
	3	4	5	10	15	18	18	19	19	20	20	20	16	32	34	34	35	36
5940	.91	.93	.92	.92	.91	.94	.97	.97	.93	.91	.88	.86	.71	1.03	1.15	1.16	1.16	1.12
	2	2	2	3	6	8	14	15	14	14	13	12	8	21	27	28	28	28
5935	1.02	1.02	.99	.95	.91	.83	.88	.95	.96	.95	.95	.92	.82	.73	.81	.84	.84	.79
	2	2	1	1	2	4	8	11	11	10	9	7	4	8	16	21	22	21
5930	1.03	1.03	1.00	.96	.93	.87	.86	.89	.94	.96	.96	.95	.90	.75	.65	.64	.64	.62
	2	2	1	1	1	1	5	9	9	8	7	5	3	2	5	11	15	16
5925	1.01	1.01	.99	.97	.95	.93	.91	.88	.88	.92	.95	.95	.93	.86	.72	.64	.60	.58
	1	1	1	0	0	1	2	5	7	7	6	5	3	1	1	3	7	9

PERIOD 25.70SEC, INITIAL AZIMTH 330.00DEG

LONG / LAT	144	251	442	01	441	51	440	10	440	51	440	01	435	51	435	01	434	51	434	01	433	51	433	01	432	51	432	01	431	51	431	01	430	51	430
6000	1.08	1.08	1.07	1.02	.98	.86	.74	.71	.71	.65	1.01	1.06	1.05	.97	.84	.71	.77	.89																	
	-0	-3	-3	-4	-5	-7	-5	-3	-0	8	16	15	14	12	10	9	12	14																	
5955	1.01	1.02	1.02	.98	.95	.86	.77	.73	.73	.69	.92	1.04	1.06	1.00	.88	.71	.67	.75																	
	-1	-3	-3	-4	-5	-7	-6	-4	-1	4	12	14	13	11	9	7	8	10																	
5950	.97	.97	.97	.94	.92	.88	.84	.81	.79	.75	.81	.99	1.04	1.01	.93	.79	.66	.68																	
	-1	-3	-4	-5	-6	-7	-6	-4	-2	1	6	11	12	10	8	5	5	6																	
5945	.92	.92	.91	.89	.90	.92	.94	.95	.92	.85	.81	.92	.98	.99	.95	.86	.73	.69																	
	0	-1	-3	-5	-7	-7	-6	-5	-3	-1	1	7	9	8	7	5	2	3																	
5940	.89	.90	.89	.87	.89	.95	1.01	1.04	1.03	.97	.88	.89	.93	.95	.94	.90	.83	.78																	
	3	2	0	-2	-4	-5	-5	-4	-4	-3	-2	2	5	5	4	3	2	2																	
5935	.90	.91	.91	.90	.89	.94	1.01	1.04	1.04	1.01	.94	.91	.92	.93	.93	.93	.90	.88																	
	2	3	4	3	1	1	0	-0	-1	-2	-2	-0	1	2	2	2	1	1																	
5930	.94	.95	.96	.96	.95	.95	.97	.98	.98	.98	.96	.94	.95	.95	.95	.96	.96	.95																	
	0	1	2	2	2	3	3	3	2	0	-0	-0	0	1	1	1	0	1																	
5925	.98	.98	.99	.99	.98	.98	.97	.97	.97	.96	.96	.96	.97	.98	.98	.98	.99	.98																	
	0	0	0	0	1	1	2	2	2	1	0	0	0	0	0	0	0	0																	

LONG / LAT	142	551	425	01	424	51	424	01	423	51	423	01	422	51	422	01	421	51	421	01	420	51	420	01	415	51	415	01	414	51	414	01	413	51	413
6000	1.01	1.11	.76	1.00	1.76	1.78	1.76	1.68	1.50	.73	.73	.75	.84	.95	10.00	1.61	1.61	1.61																	
	17	19	19	30	30	31	31	32	36	41	45	49	47	43	1000	81	81	81																	
5955	.85	.97	.89	.91	1.55	1.60	1.56	1.44	1.26	.77	.76	.81	.90	.96	.87	1.02	1.03	1.05																	
	13	15	17	29	29	29	29	31	34	38	41	45	43	42	43	56	57	58																	
5950	.74	.82	.89	.80	1.23	1.33	1.29	1.19	1.06	.83	.81	.87	.96	.99	.82	.88	.89	.91																	
	8	10	12	26	27	26	26	28	30	33	36	38	38	39	41	48	49	50																	
5945	.73	.79	.86	.82	.95	1.08	1.07	1.01	.94	.87	.85	.91	.99	1.07	.75	.73	.74	.75																	
	5	6	7	15	23	24	24	25	25	27	28	30	31	34	40	41	41	42																	
5940	.86	.90	.94	.93	.92	.90	.95	.93	.89	.88	.90	.93	1.00	1.14	.66	.60	.59	.59																	
	3	4	4	6	11	21	22	21	21	21	21	21	23	23	37	35	34	34																	
5935	.98	1.00	1.00	.98	.95	.83	.87	.88	.87	.89	.92	.94	.98	1.03	.61	.52	.51	.49																	
	4	4	3	3	4	10	19	19	17	16	14	14	14	14	27	30	29	28																	
5930	1.02	1.02	1.00	.97	.95	.87	.85	.85	.85	.89	.91	.93	.94	.91	.68	.52	.48	.47																	
	4	3	2	2	2	3	10	16	15	12	11	10	9	9	14	23	25	23																	
5925	1.01	1.00	.98	.96	.94	.91	.89	.85	.83	.85	.89	.92	.93	.90	.79	.58	.51	.48																	
	2	2	1	1	1	1	5	11	12	11	10	9	7	6	6	10	16	18																	

APPENDIX H

Wave Height - Period Relationships

A pilot analysis of wave height-period relationships has been performed using SSMO data for two areas in the Gulf of Alaska. The boundaries of these areas are 58°N - land, 140°W - 145°W and 55° N - 58°N, 147°W - 152°W.

The method of analysis invoked no initial assumptions regarding physical or theoretical relationships and without regard to the form of joint distributions. The basic approach was to attempt to estimate one parameter when given the value of the other. If such an estimator exists with some useful degree of confidence, an inference may be made about the relationship. If the relationship is linear, the inference is that correlation exists; if the relationship is non-linear yet well behaved, regression methodology may be applied. The method of orthogonal polynomials was used to estimate relationships. Successively, higher order coefficients were eliminated to reach a "good" fit at a second order level. Regression of wave height on period and period on wave height were performed. In case of the former regression, wave height appeared to have a non-zero lower limit. In the latter case wave period appears to be asymptotic to some limiting value. This latter case seems more consistent with the physical situation and therefore in all cases the regression of period on height is presented. This relationship was computed and plotted for data available for each month of the year and the results are presented in Figure H-1 through H-12. The data for these plots is comprised of approximately 25,000 samples over 25 years which are considered to be pseudo-random and independent.

There is a definite trend during the summer months for wave period to become asymptotic to some upper limit. This limit is significantly lower than during the winter, as would be expected. During the winter months the curves still definitely show a non-linear trend but the asymptotic limit has

not been reached within the range of the data. This may possibly be due to the "fair weather" bias of ship observations, i.e., the avoidance of severe weather conditions. The month of May appears to be anomalous, showing a trend toward higher limits in both wave height and period than the previous months of March and April. This anomaly remains unexplained.

The lower portion of these curves formed by the 95% confidence limits are graphical extrapolations and may not be strictly valid with respect to their intersections with the wave height and wave period axis. Care must be taken with the interpretation of these limits.

Further analysis of wave height-period relationships is required but in the meantime the results given in this appendix may be used as a basis for estimating design values for wave period.

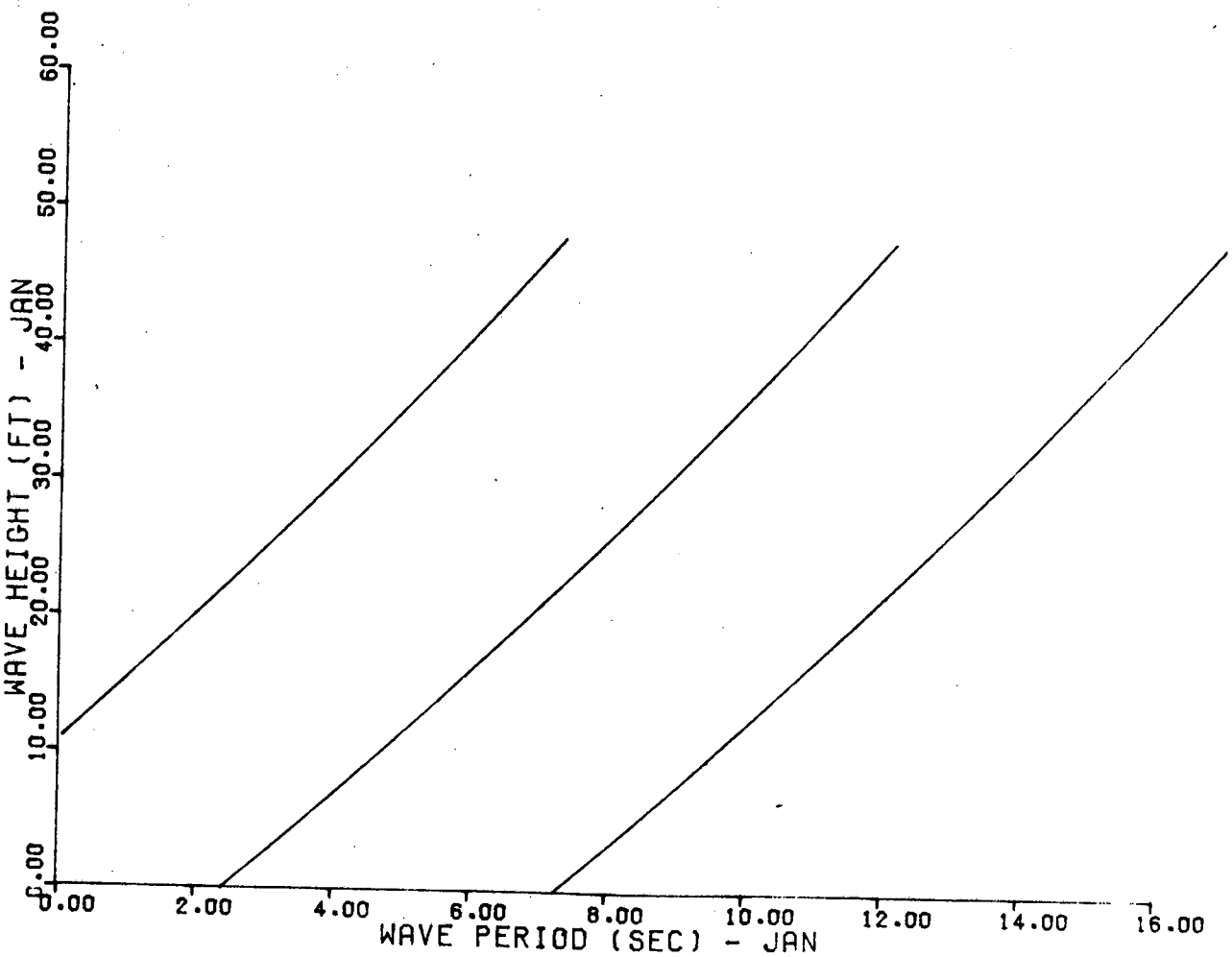

Figure H-1. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

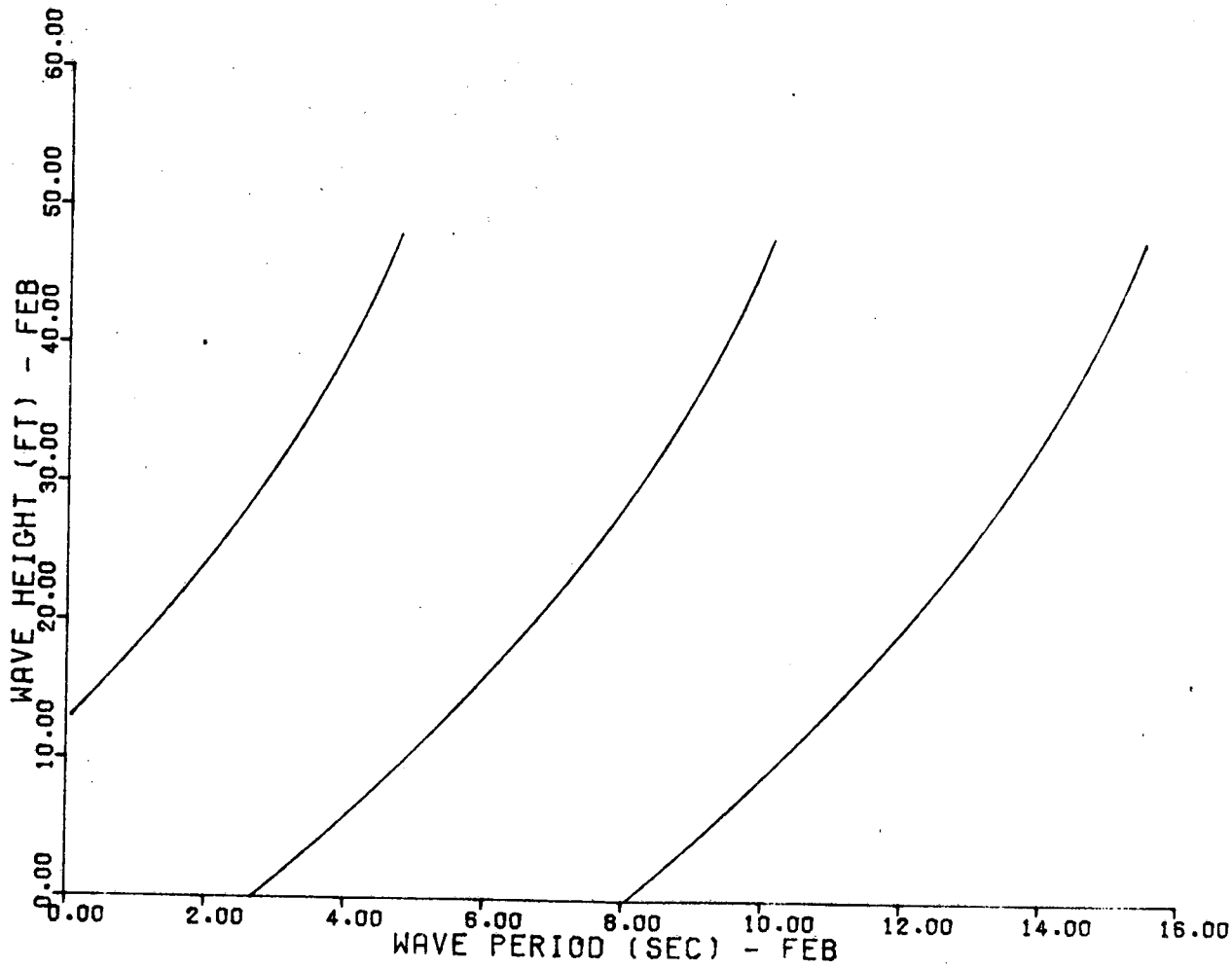

Figure H-2. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

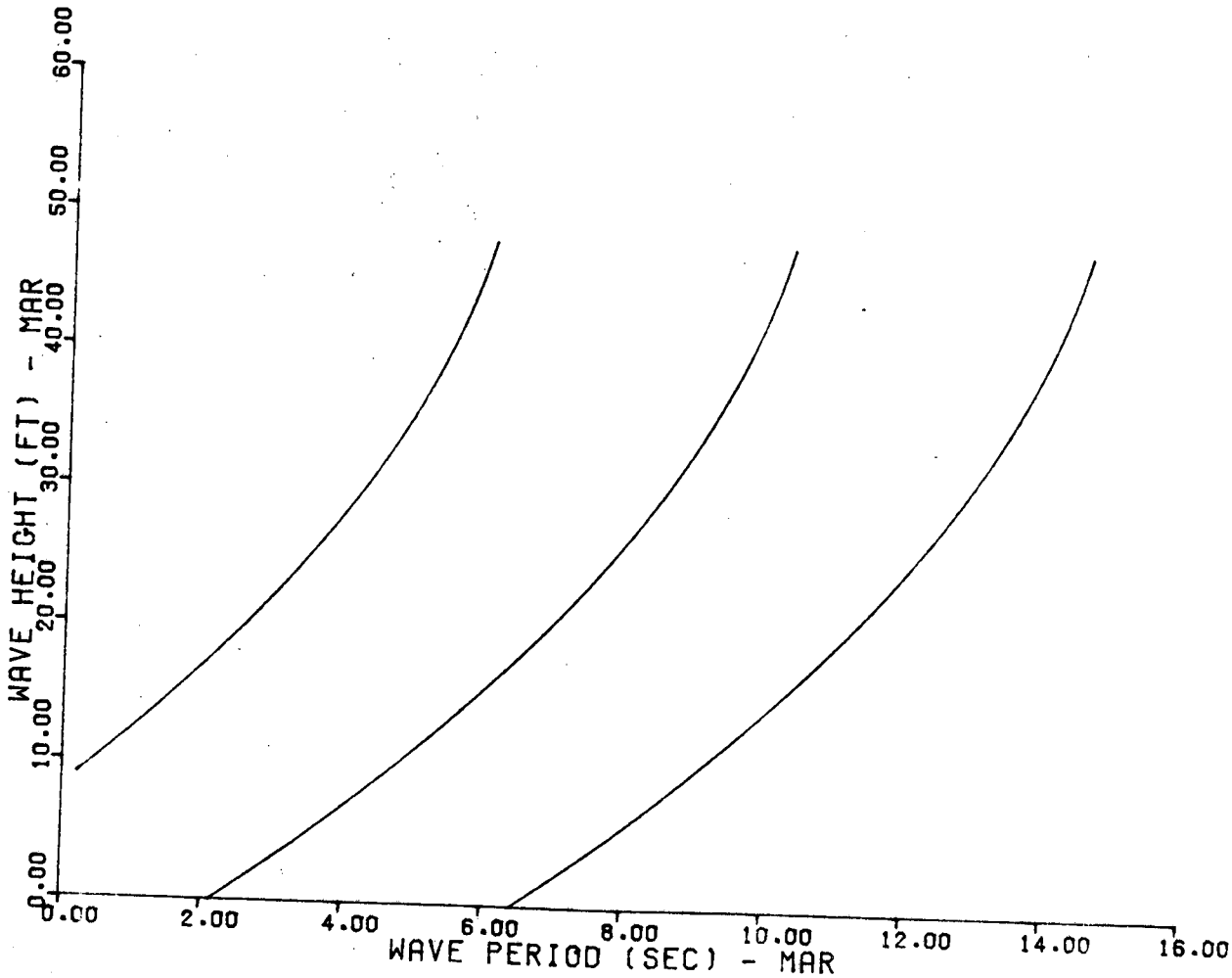

Figure H-3. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

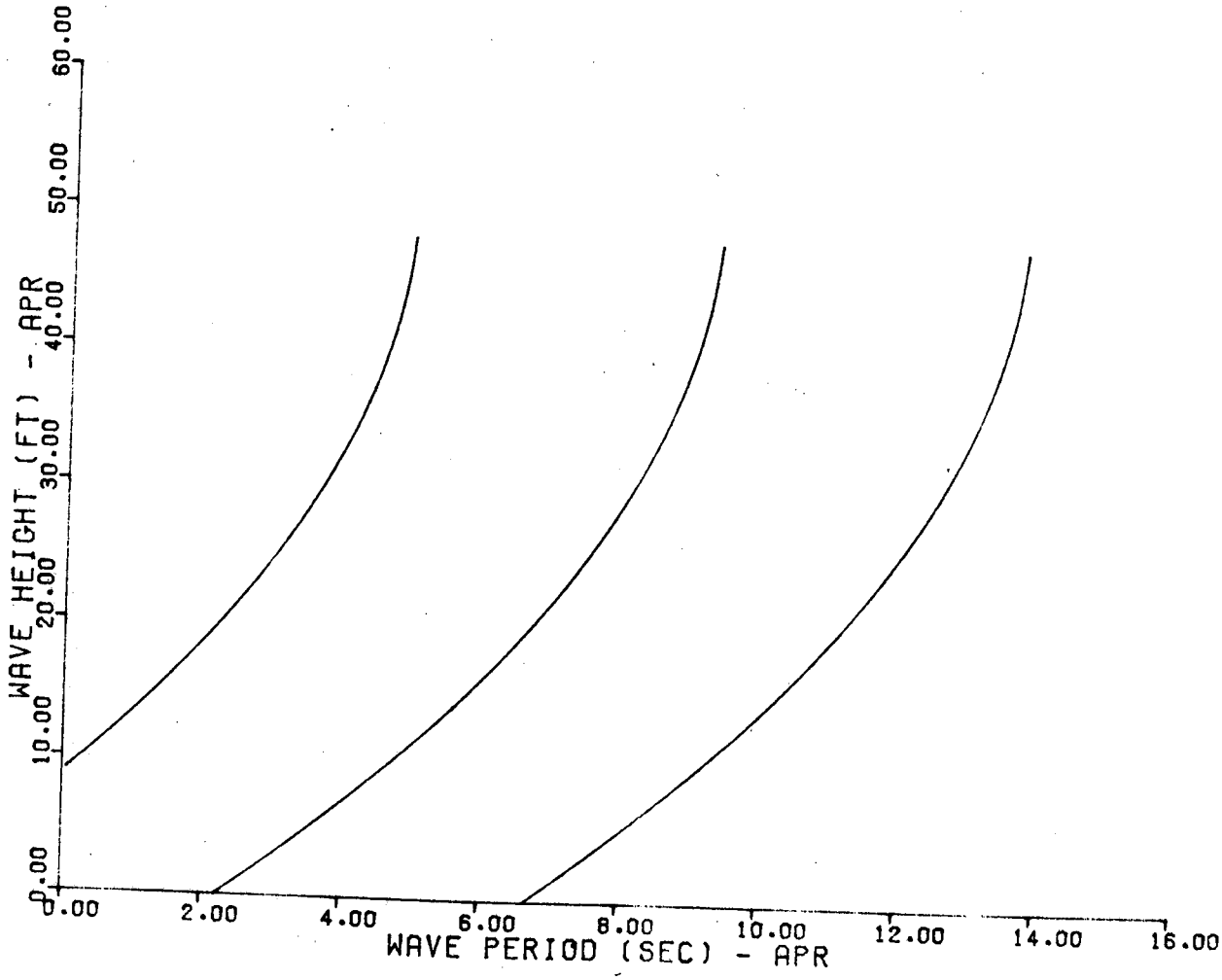

Figure H-4. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

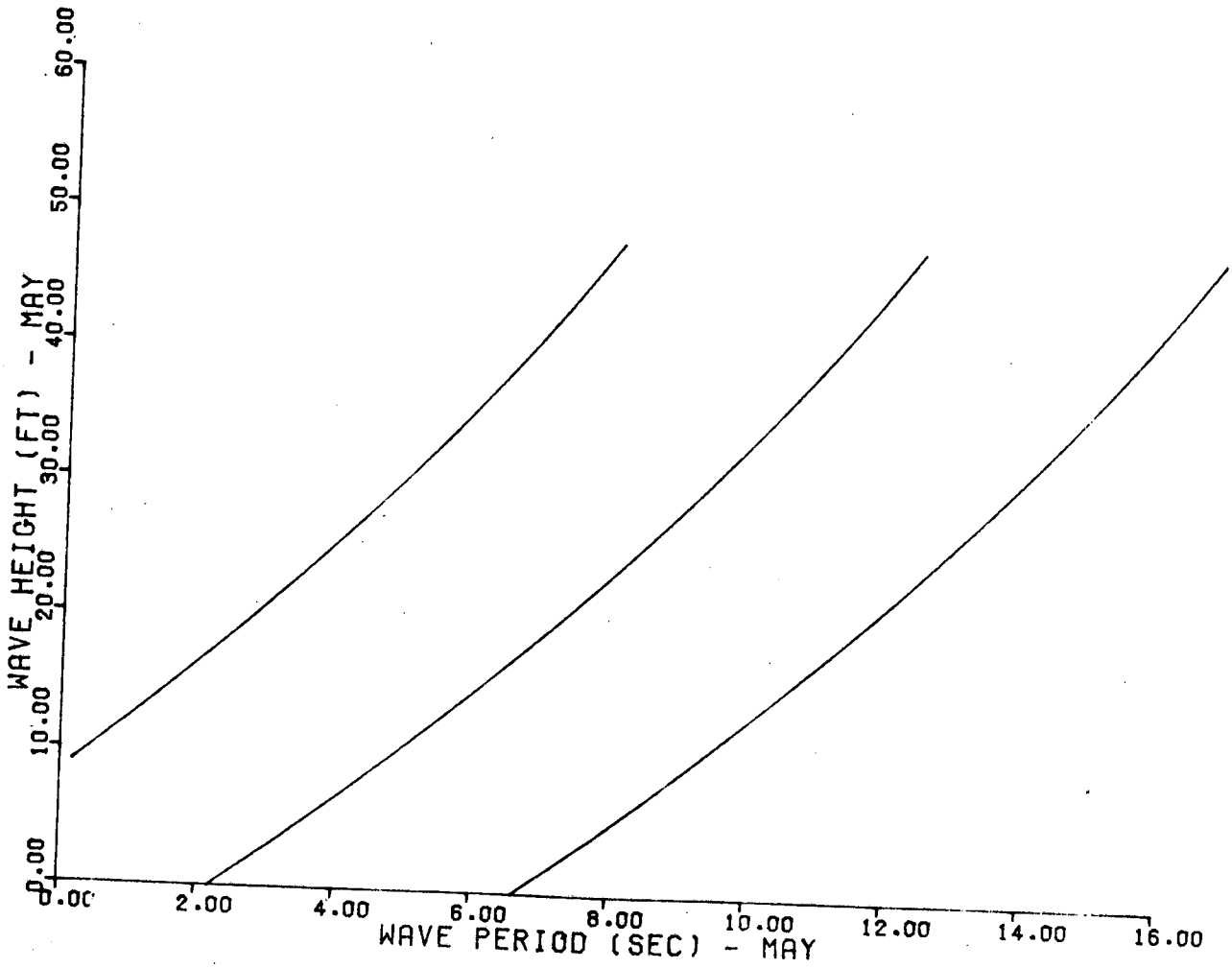

Figure H-5. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

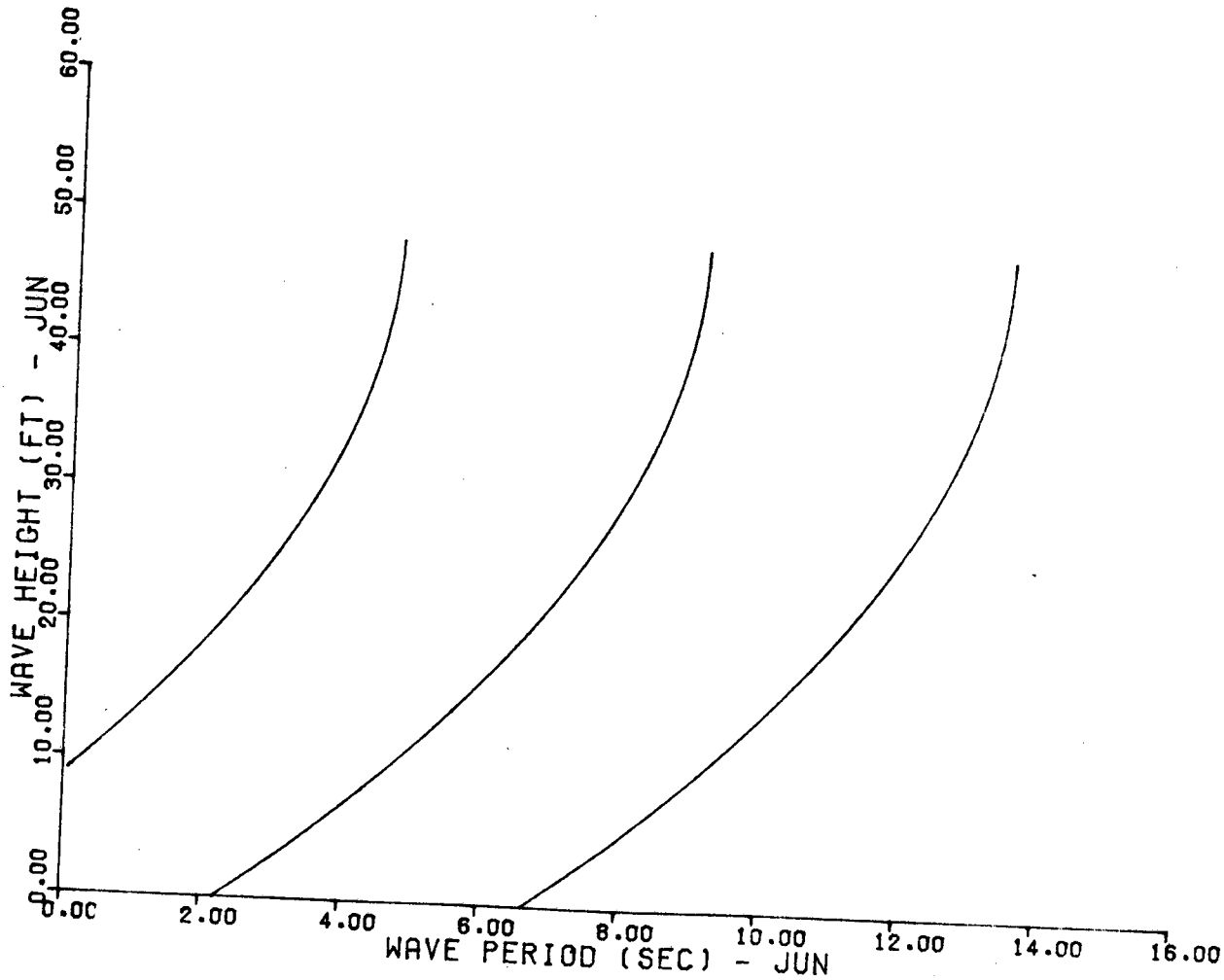

Figure H-6. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

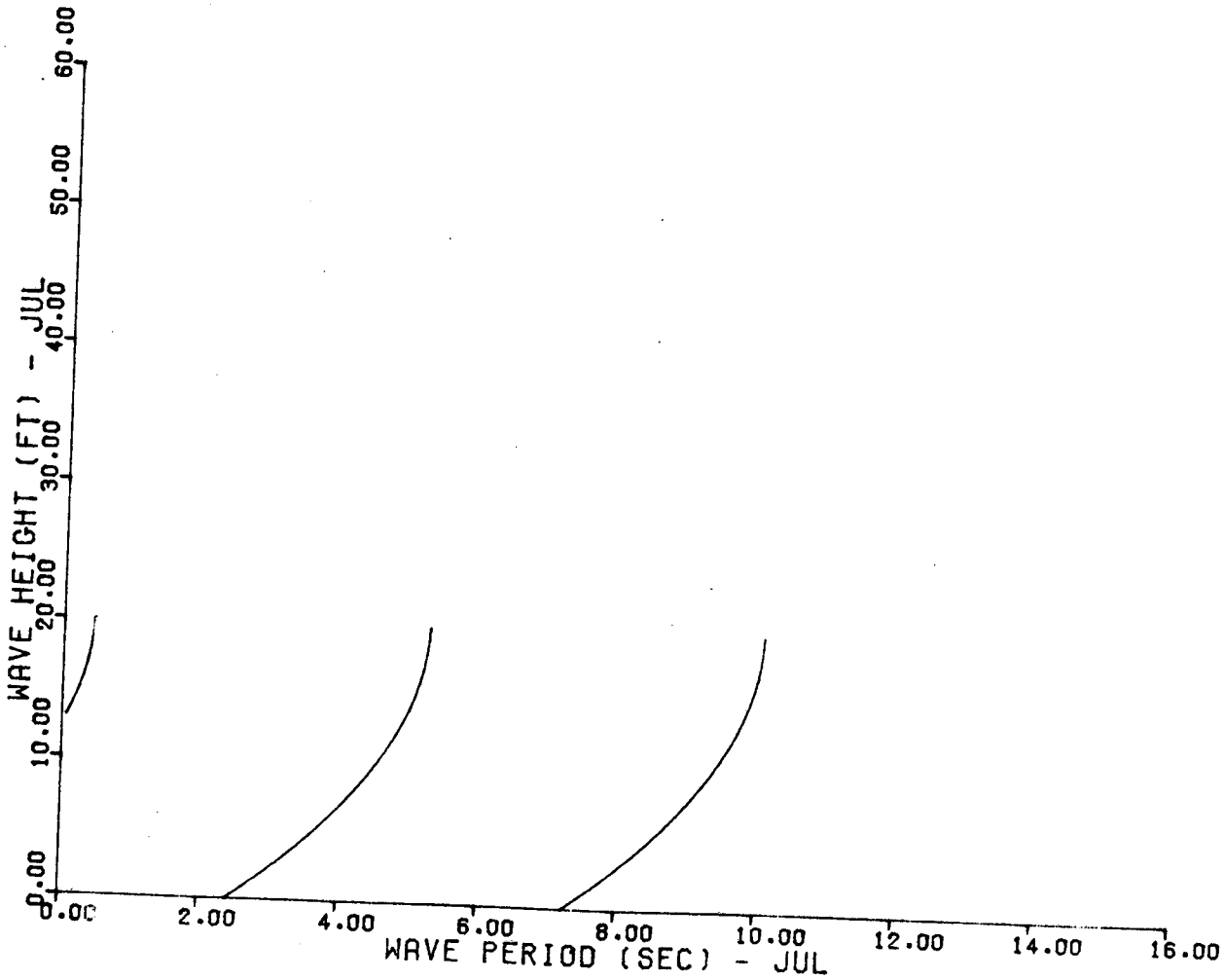

Figure H-7. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

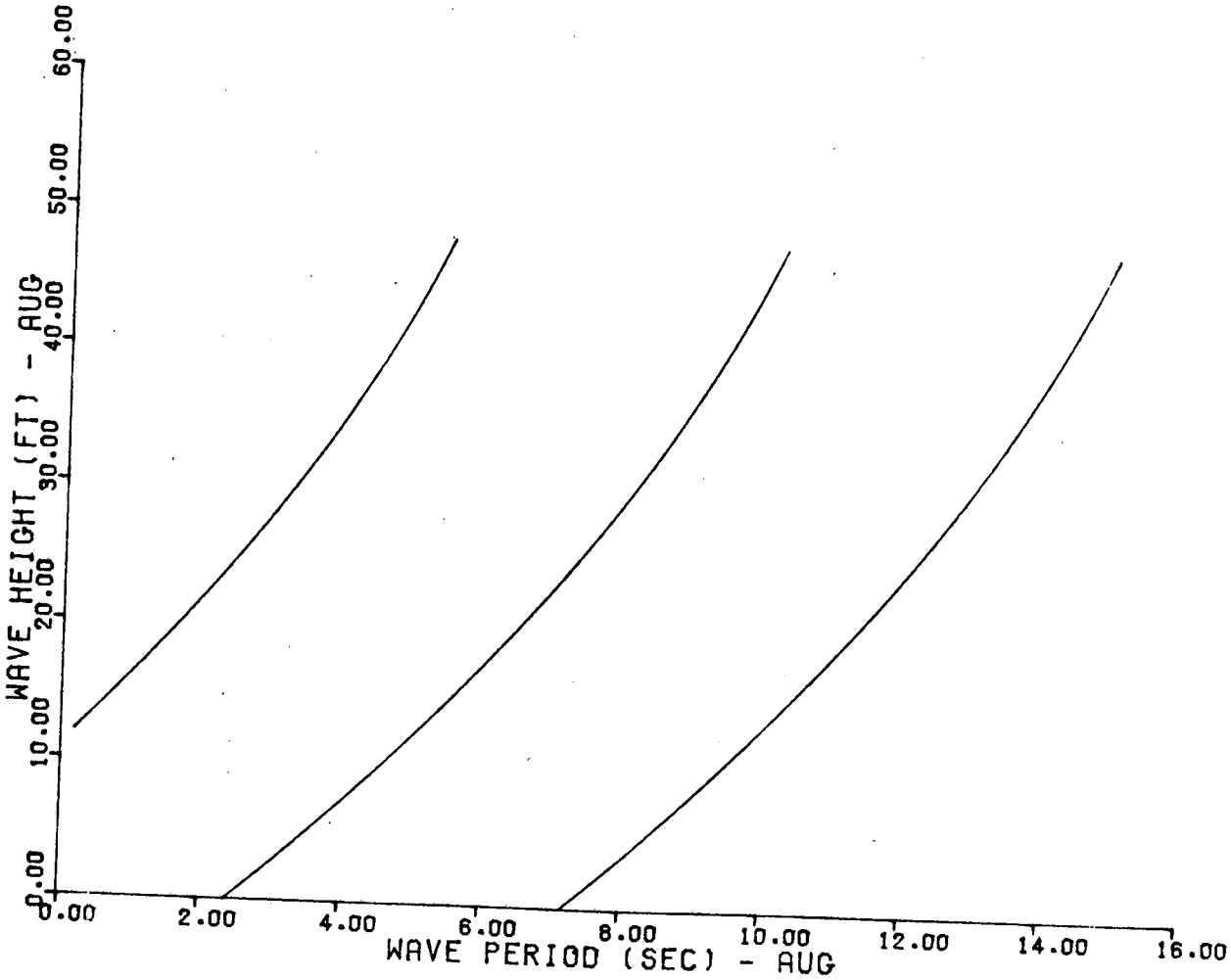

Figure H-8. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

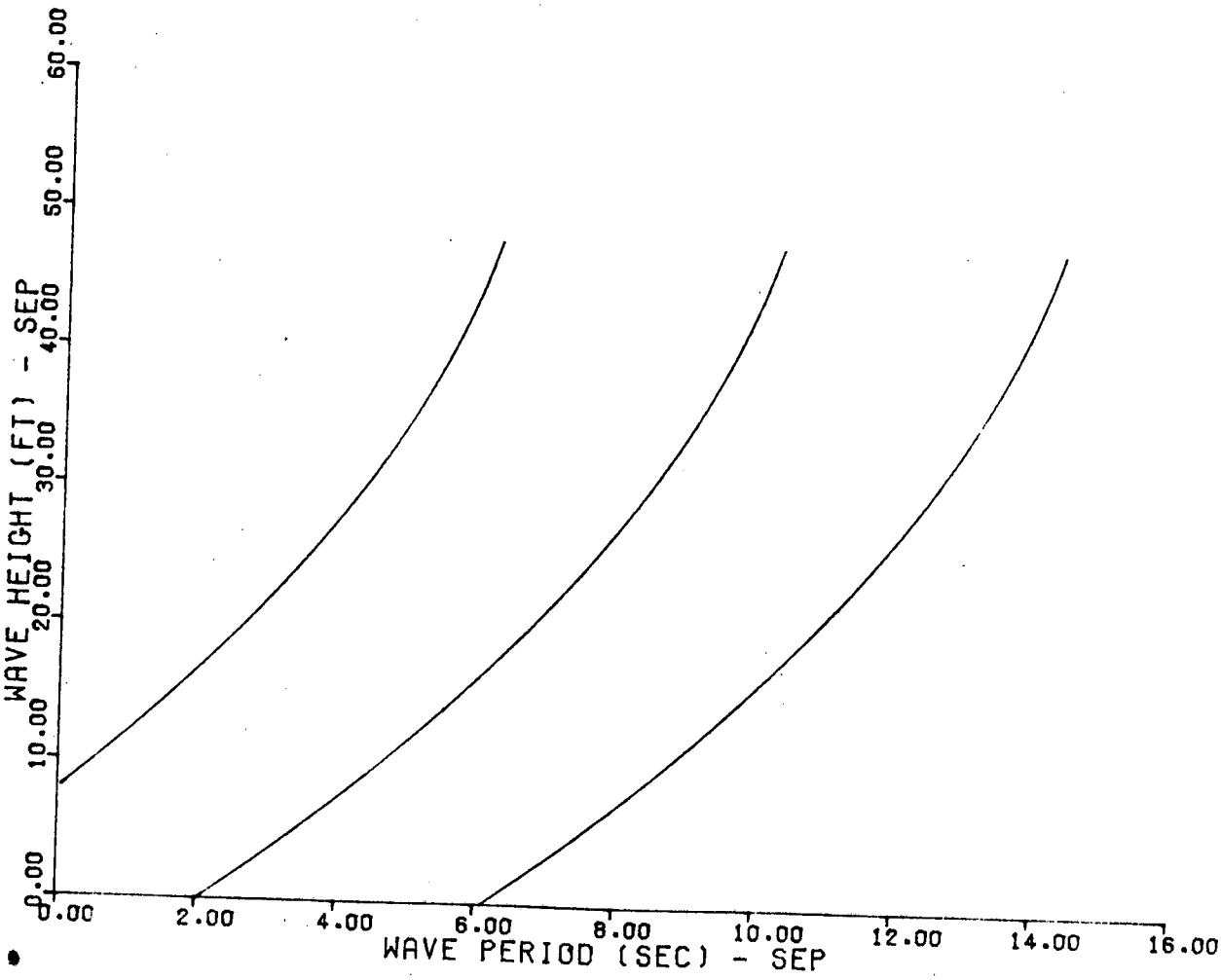

Figure H-9. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

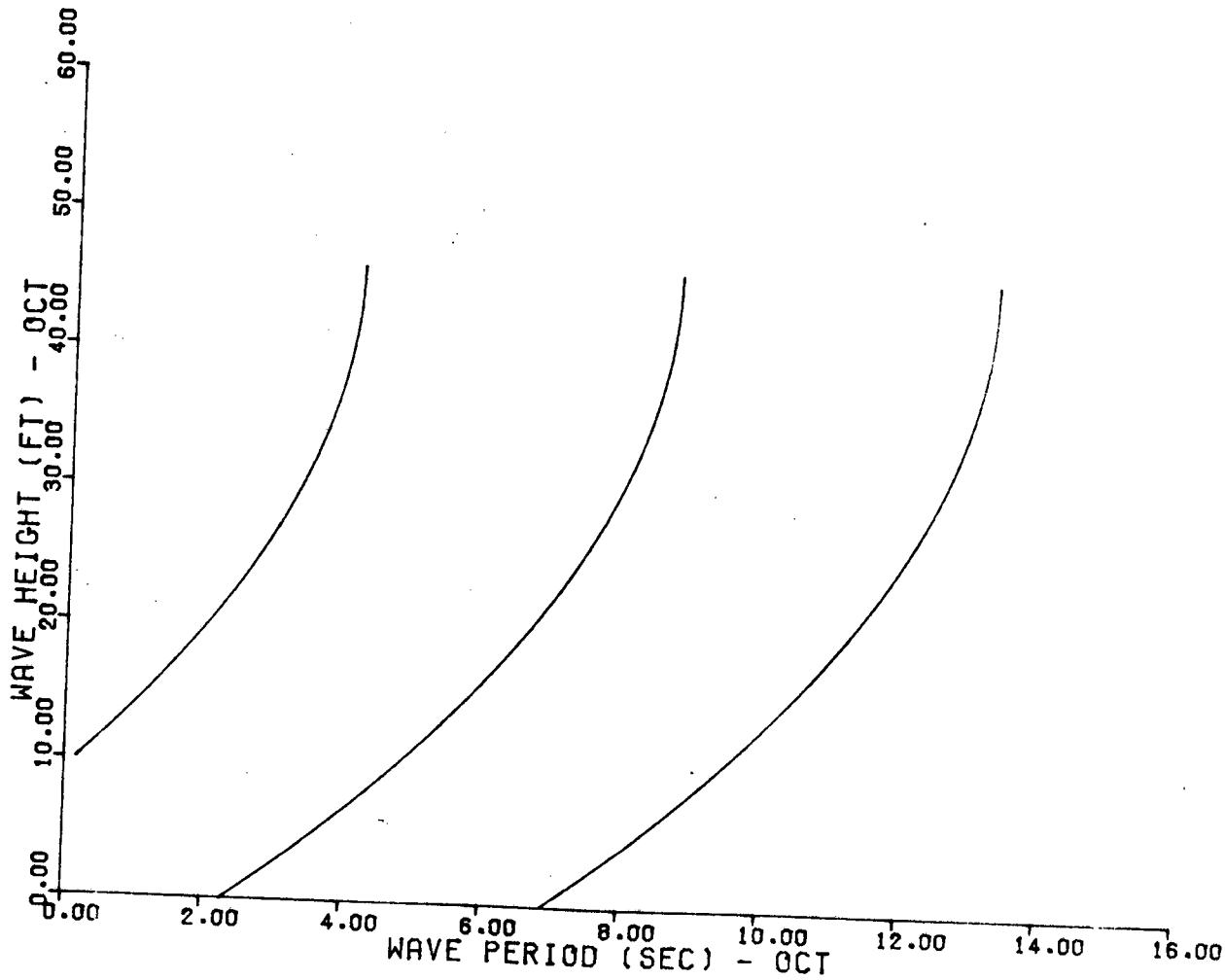

Figure H-10. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

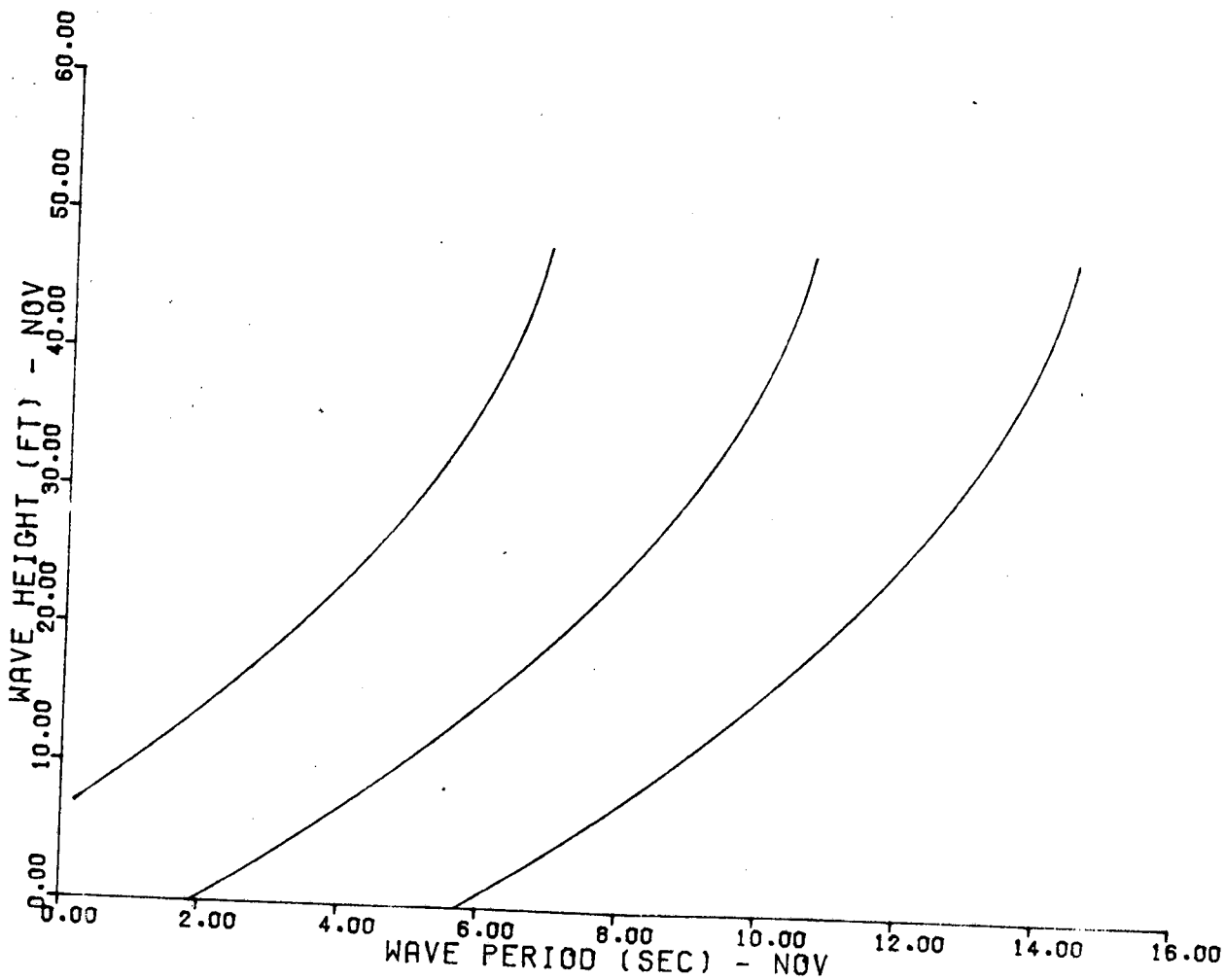

Figure H-11. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska

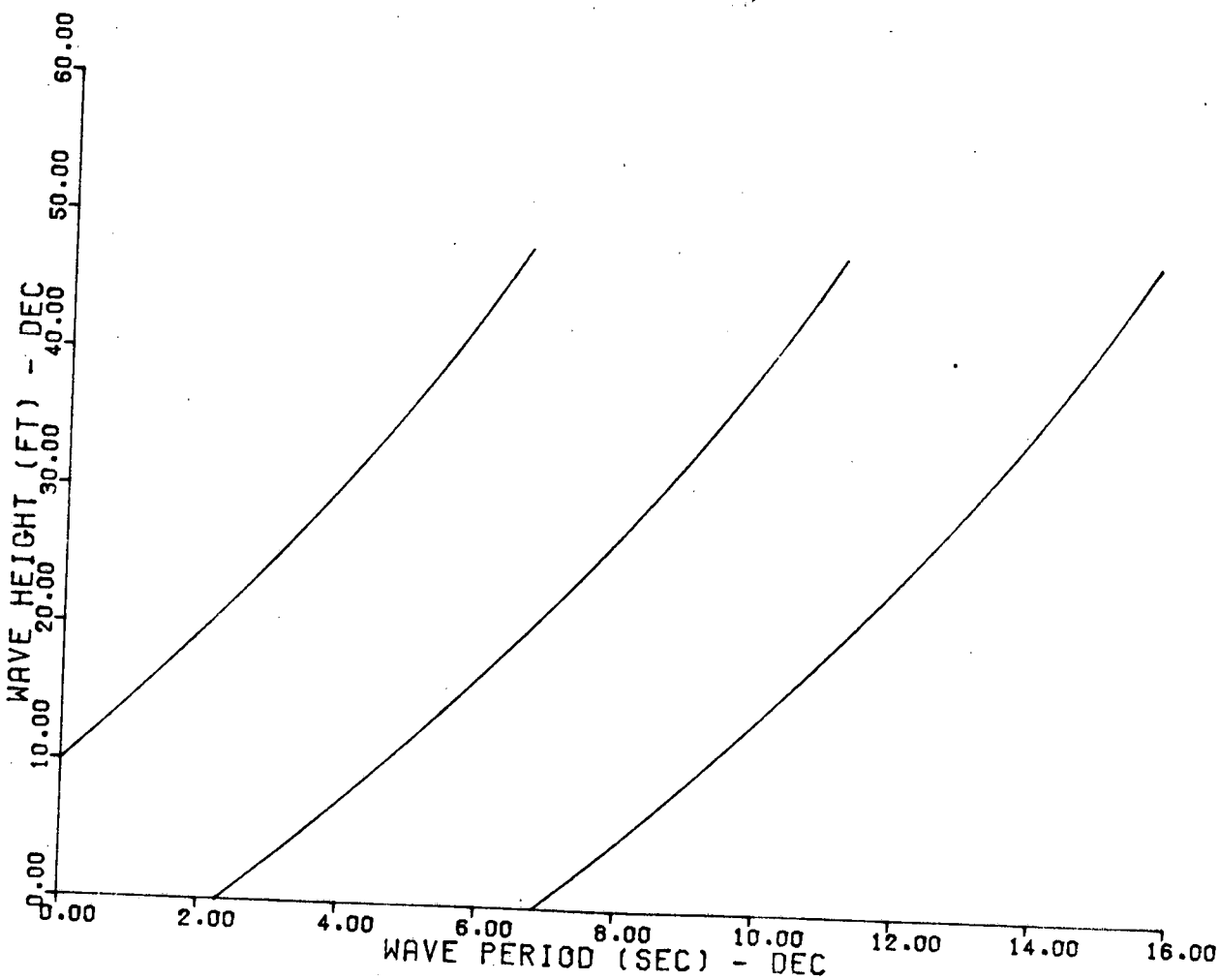

Figure H-12. Wave Height - Period Mean Distribution with 95% Confidence Bands for Gulf of Alaska