WEATHER BUREAU
Office of Systems Development
Techniques Development Laboratory
Silver Spring, Md.

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# Second Interim Report on Sea and Swell Forecasting

Technical Memorandum WBTM TDL 17

U.S. DEPARTMENT OF COMMERCE / ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION

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U. S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Weather Bureau

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# SECOND INTERIM REPORT ON SEA AND SWELL FORECASTING

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OFFICE OF SYSTEMS DEVELOPMENT
TECHNIQUES DEVELOPMENT LABORATORY

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| 551.46 | **Physical oceanography** |
| 551.466 | **Ocean waves and tides** |
| 551.466.33 | **Forecasting of sea and swell waves** |

# CONTENTS

# SECOND INTERIM REPORT ON SEA AND SWELL FORECASTING

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## ABSTRACT

Work on sea and swell forecasting in the Techniques Development Laboratory from December 1967 to the time the method was put into operational use (October 1968) is described. Low level atmospheric stability was found ineffective in improving the wave forecast method. Constants of the relationship for wind-wave height forecasting have been slightly modified to forecast lower, more realistic values in the maximum wave areas. Wave height charts for operational use are described.

## INTRODUCTION

Work within the Techniques Development Laboratory (TDL) up to November of 1967 on adapting a wind-wave and swell forecasting method was described in an earlier Technical Memorandum [4]. That report gave some historical background on computer-produced forecasts of sea conditions by the singular method. Brief descriptions of the wind-wave and swell programs as modified from those of Fleet Numerical Weather Facility (FNWF) were presented.

It was determined feasible to use wind forecasts from the Primitive Equation (PE) Model [5] of the National Meteorological Center (NMC) at six-hour intervals as input to the wind-wave program. The report ended with a statement of our plans to make a series of forecasts during the winter (1967 - 68) months. The plans were to use these forecasts along with observations as the basis for making slight adjustments in the method. The present report describes our work beginning at that point and covers the period to the beginning of operational use of the method (October 1968).

## CONSIDERATION OF LOW-LEVEL ATMOSPHERIC STABILITY

The ratio of surface wind speed to geostrophic wind speed depends upon the difference between sea and air temperatures. This ratio is shown in Technical Report No. 4 of The Coastal Engineering Research Center [6] to vary from about 0.56 to 0.77 for sea-air temperature differences ranging from about -13°F. to +15°F.

A study by Brown [1] showed sea-air temperature difference to have a significant effect on mean wave height. Brown used data from Ocean Station Vessels I and J for the period January 1946 to December 1951. The observations were divided into three stability classes depending on the sea-air temperature difference. Mean wave heights for each wind force were determined. The means were considerably different for the three classes of stability, with the higher mean wave heights occurring with the more unstable condition.

Brown also compared the observations of wind speeds of Beaufort Force 4, 5, and 6 to means of the wave height observations. These were examined at intervals of 1°F. in sea-air temperature difference. Wave heights increased as expected with increasing instability for differences in sea-air temperature difference greater than zero. However, mean wave heights also increased with increasing stability for differences in sea-air temperature less than zero. No explanation for the unexpected increase of mean wave height with increasing stability was given.

The method of wave forecasting used by the Fleet Numerical Weather Facility [2] considers the sea-air temperature difference in determination of wind speed. The surface wind is taken to be from about 55% to 80% of the geostrophic wind depending upon the difference of sea and air temperatures.

We have searched for an effect of stability on the winds we are obtaining from the Primitive Equation Model, but without success. Using the Ocean Station Vessel observations for the period October 22 - December 5, 1967, we compared the air-sea temperature difference to the ratio of observed wind to 1000-mb. PE wind for +00 hours. This comparison is shown in Figure 1 where the air-sea temperature difference appears to have no effect on the wind ratio. If an effect similar to that found on geostrophic winds was evident on the PE winds, we would see a trend in these points about a regression line with negative slope.

Another way of looking for the stability effect is to compare the observed wave heights at the Ocean Station Vessels to the observed wind speeds for different classes of air-sea temperature difference. The observations for October 22 - December 5, 1967 were divided into three classes depending on air-sea temperature difference. These classes were:

1. Air temperature minus sea temperature greater than -2°F.;

2. Air temperature minus sea temperature from -2°F. to -5°F.;

3. Air temperature minus sea temperature less than -5°F.

Only the cases for wind duration of twelve hours, as indicated by the PE winds not changing direction by more than 22° in twelve hours, were included. The plot of the comparison is shown in Figure 2. There appears to be no distinct separation of the points in each of these three classes of air-sea temperature difference.

Our conclusion reached from consideration of the data described above is that we should not attempt to modify the Primitive Equation wind forecasts on the basis of air-sea temperature difference.

## ADJUSTMENT TO PRIMITIVE EQUATION 1000-MB. WIND FORECASTS

The 1000-mb. PE wind velocity calculations for +00 hour forecast times were compared to observed winds reported by the Ocean Station Vessels (OSV) during the period October 22 thru December 5, 1967. These data were used as the basis for deciding how to adjust the PE wind forecasts in the wave forecast program. The PE wind at the nearest grid point to the assigned position of each OSV was compared to the reported surface wind at that ship. Anemometer heights are about eighty feet on most of these vessels. There were 770 sets of observations and calculations available for comparison. It was decided not to consider those cases in which the observed wind and the calculated PE wind were vastly different, either in direction or speed. Such differences can be caused in several ways including: erroneous observations; errors in the transmission of the observed report; and under some weather conditions, differences in wind conditions at the OSV location and the nearest grid point.

Figure 3 shows the frequency of occurrence of differences in directions of the observed wind and the calculated PE wind. The difference between the observed wind direction and the PE wind direction in tens of degrees is shown on the abscissa. Negative values indicate a shift of the observed winds toward low pressure away from the PE winds. Conversely, positive differences indicate shifts of the observed wind towards high pressure away from the PE wind. The mode of the distribution is -20°, with 126 of the 770 cases having this value. It was subjectively decided to discard the cases with differences greater than 70° from the modal value of -20°. These cutoff points are indicated in Figure 3. Less than 10% of the cases were rejected by using these cutoff points.

The 698 cases which were not rejected because of excessive wind direction differences were combined with a few more reports which had missing wind directions. The resulting 711 sets of observed and PE wind reports were then examined for differences of observed wind speed and PE wind speed. The frequency distribution of these differences is shown in Figure 4. On the basis of this distribution it was arbitrarily decided to eliminate the cases with differences (observed wind minus PE wind) greater than 13 knots and less than -22 knots. The 649 cases which were not eliminated made up about 92% of the data examined. The mean ratio of observed wind speed to PE wind speed of these 649 cases is 0.86.

We decided, by this comparison of wind velocity between the OSV observations and the 1000-mb. PE calculations, to use the PE wind with the following modifications:

1. Shift direction 20° toward low pressure,

2. Use 86% of the PE wind speed.

## MODIFICATION OF CONSTANTS IN THE WAVE-HEIGHT FORECAST EQUATION

Subjective examination of the wave height forecasts in areas of maximum waves indicated that our forecasts, based on the combination of adjusted PE winds and the FNWF wave-height relationship, were too high. Therefore, a re-examination was made of several wave forecasting techniques.

Figure 5 shows wave height plotted against wind speed for a duration of 18 hours for four wave forecasting techniques. The FNWF curve is the 1966 version of the relationship, $H = AV^2D + B$, where V is wind speed, D is duration, and A and B are constants. The Sverdrup-Munk curve (SM) is from data obtained from forecast curves in H. O. 604 [7]. The Pierson-Neuman-James (PNJ) curve was obtained from graphs in H. O. 603 [3]. The Sverdrup-Munk-Bretschneider (SMB) curve was obtained from a forecast graph in Technical Report No. 4 of the U. S. Army Coastal Engineering Research Center [6].

Our computer program is designed to use the FNWF type of forecast equation, $H = AV^2D + B$. The constants A and B were modified to put our wave forecasts in the region of the three lower curves of Figure 5.

Our wave height forecast equation being used operationally is:

$$H = 0.0176\ V^2D + 0.5$$

where H is in feet, V is in meters per second, and D is the duration in six-hour increments. This relationship is shown graphically in Figure 6.

The statistical verification of wave forecasts may be risky because of imprecise ship observations, all of which are visual estimates. However, wind-wave forecasts for the period March 20 through April 30, 1968, were verified against available ship observations in the areas of forecast highest waves in both the North Atlantic and North Pacific Oceans.

Twenty-four and thirty-six hour forecasts were verified. Verification statistics are tabulated below:

| Forecast Time Interval | 24-hr. | 36-hr. |
|---|---|---|
| Forecast Mean Height | 17.2 ft. | 20.8 ft. |
| Standard Deviation (forecast) | 6.4 ft. | 6.2 ft. |
| Observed Mean Height | 14.4 ft. | 15.2 ft. |
| Standard Deviation (observed) | 6.3 ft. | 6.2 ft. |
| Correlation Coefficient | .56 | .41 |
| Root Mean Square Error | 6.6 ft. | 8.7 ft. |
| No. of Observations | 117 | 126 |

The mean of the forecast heights is greater than the mean of the observed heights because highest actual heights are rarely observed.

## WAVE HEIGHT FORECAST CHARTS

The program became operational on October 1, 1968. Output charts prepared for facsimile transmission consist of 24 and 48 hour contoured charts of wind-wave height, swell height, and combined-wave height. These are drawn by the NMC curve follower (Electronic Associates, Inc.) on a 1:30,000,000 polar stereographic map base for the area of the NMC octagonal grid. A sample chart is shown in Figure 7.

Sections of these hemispheric charts are extracted for facsimile transmission. Figure 8 is a sample Atlantic area chart for the East Coast WB-NESC circuit. Figure 9 shows the area included for the West Coast WB-NESC circuit and the Suitland-Honolulu-SW Pacific circuit. The combined-wave prognoses for a portion of the North Pacific as shown in Figure 10 are included in the Alaskan prog package on the National Weather Facsimile Circuit.

This wave and swell forecasting system is for deep-water wave conditions on the high seas. At this point we feel that the wave conditions in offshore waters of moderate depth may be adequately forecast. A comparison of observations at Light Vessels and Light Towers off the U. S. Northeast coast will be made to determine if this is true. Certainly, breaker and surf forecasts are not to be implied from these high seas forecasts. Wave and swell heights are depicted by contours drawn at 3-foot intervals with maximum values printed at the centers. The discontinuous nature of waves at coastlines raises a problem in contouring of wave heights close to shore. A fictitious height gradient will result from the contouring program which must interpolate between zero wave heights of the inland grid points closest to the coast and appreciable forecast wave heights at the adjacent offshore grid points. In such cases, the higher wave heights in the coastal area should be considered as extending closer to shore than indicated by the height contours.

Although the significant wave height (defined as the average height of the one-third highest waves) is the variable which is forecast, other properties of wave height distribution are of value. Statistical analyses and theoretical investigations [6] show the following relationships:

a. Mean wave height = 0.6 x significant wave height,

b. Mean height of highest 10% of waves = 1.3 x significant wave height,

c. Maximum wave height = 1.9 x significant wave height.

These relationships indicate possible wave heights, for any given forecast, to be almost double the significant wave height. Further discussion of the uses of wave forecasts from an operational viewpoint is contained in reference [6].

Little confidence can be placed in the wave forecasts in the vicinity of tropical storms. The spacing of NMC grid points precludes adequate depiction of wave conditions in these areas unless the storm is large enough to affect values of parameters at grid points at initial and forecast times.

## FUTURE PLANS

A forecast verification program is being implemented. We will compare the forecast heights of wind-waves and swell to the observations of the Ocean Weather Vessels and other ships with Weather Bureau observers on board.

Further adjustments in the wave forecast model which we may consider include the following:

1. Changes in the method of modifying the PE wind forecasts;
2. Changes in the constants of the wave and swell forecast equations;
3. Addition of the effects of following and opposing winds on swell propagation;
4. Retention of two or more swells at the grid points.

## ACKNOWLEDGMENTS

The authors express their appreciation to the many persons of: the Data Automation Division and the Analysis and Forecast Division of the National Meteorological Center; the Weather Analysis and Prediction Division of the Office of Meteorological Operations; the Operations Branch of the Computer Division; and the Computer Systems Branch of Techniques Development Laboratory, who have helped us put this wave forecasting method into routine operation.

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1. Brown, P. R., "Wave Data for the Eastern North Atlantic," The Marine Observer, Vol. XXIII, No. 160, April 1953, pp. 94 - 98.

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3. Pierson, W. J., G. Neumann, and R. W. James, Practical Methods for Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics, Publication No. 603, U. S. Navy Hydrographic Office, Washington, D. C., 1955, 284 pp.

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6. U. S. Army Coastal Engineering Research Center, "Shore Protection, Planning and Design," Technical Report No. 4, Third Edition, June 1966.

7. U. S. Navy Hydrographic Office, "Techniques for Forecasting Wind Waves and Swell," H. O. Pub. 604, Washington, D. C., 1951, 37 pp.

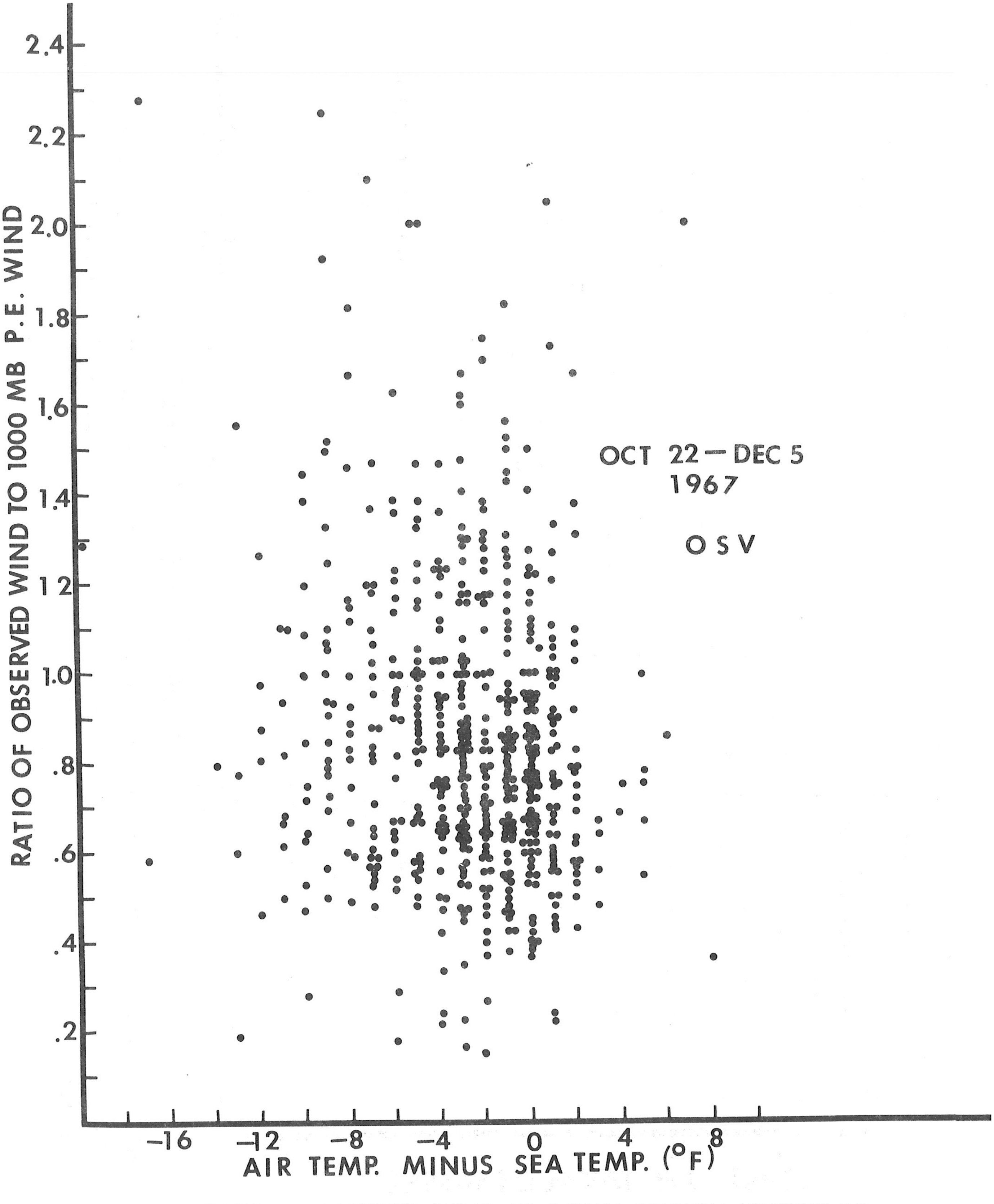

FIGURE 1. RATIO OF OBSERVED WIND AT OCEAN STATION VESSELS TO THE 1000 MB. PE +00 HOUR WIND VERSUS THE AIR-SEA TEMPERATURE DIFFERENCE.

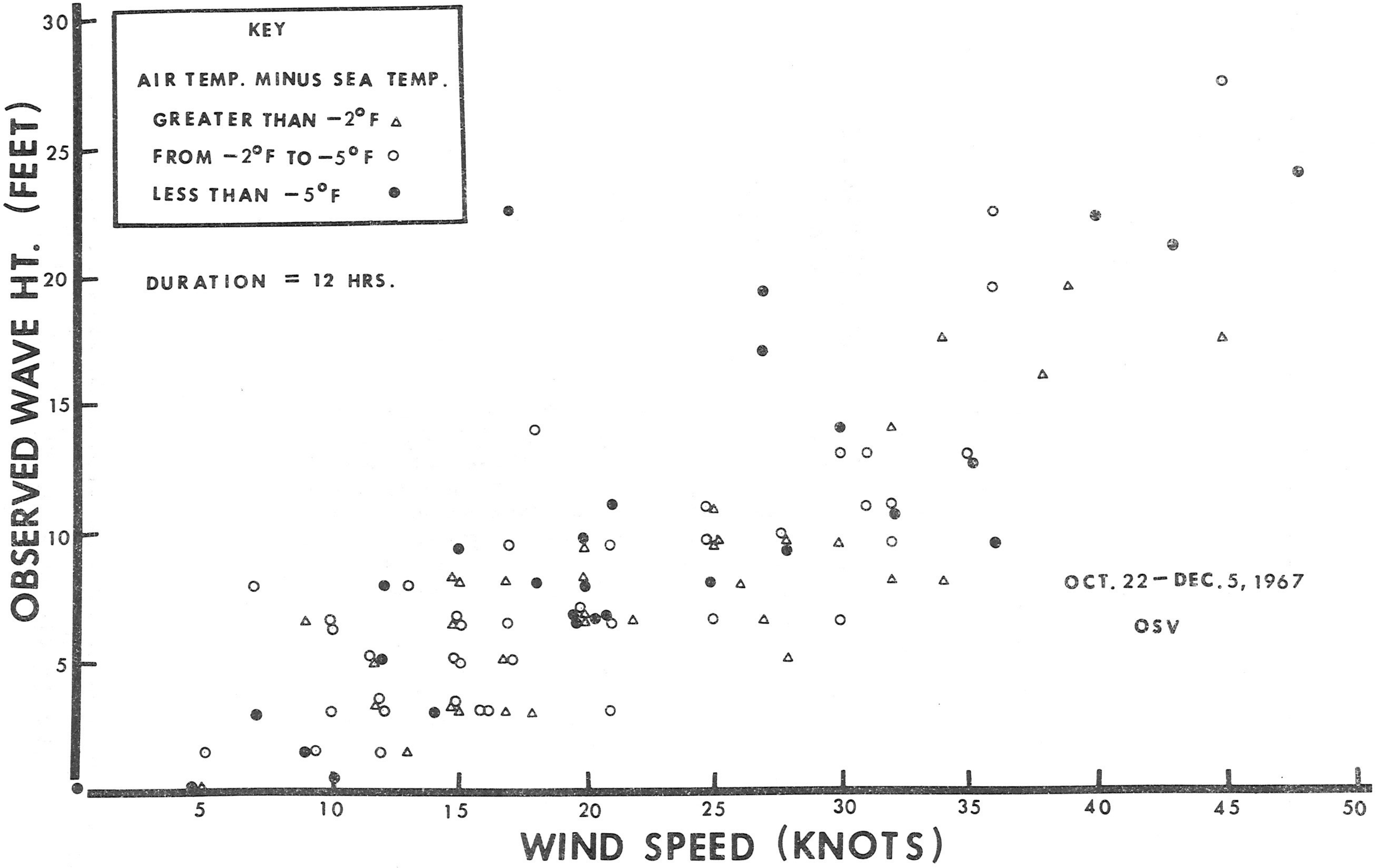

FIGURE 2. OBSERVED WAVE HEIGHT VERSUS OBSERVED WIND SPEED AT THE OCEAN STATION VESSELS. THE DATA ARE DIVIDED INTO THREE CLASSES OF ATMOSPHERIC STABILITY BASED UPON THE AIR-SEA TEMPERATURE DIFFERENCE.

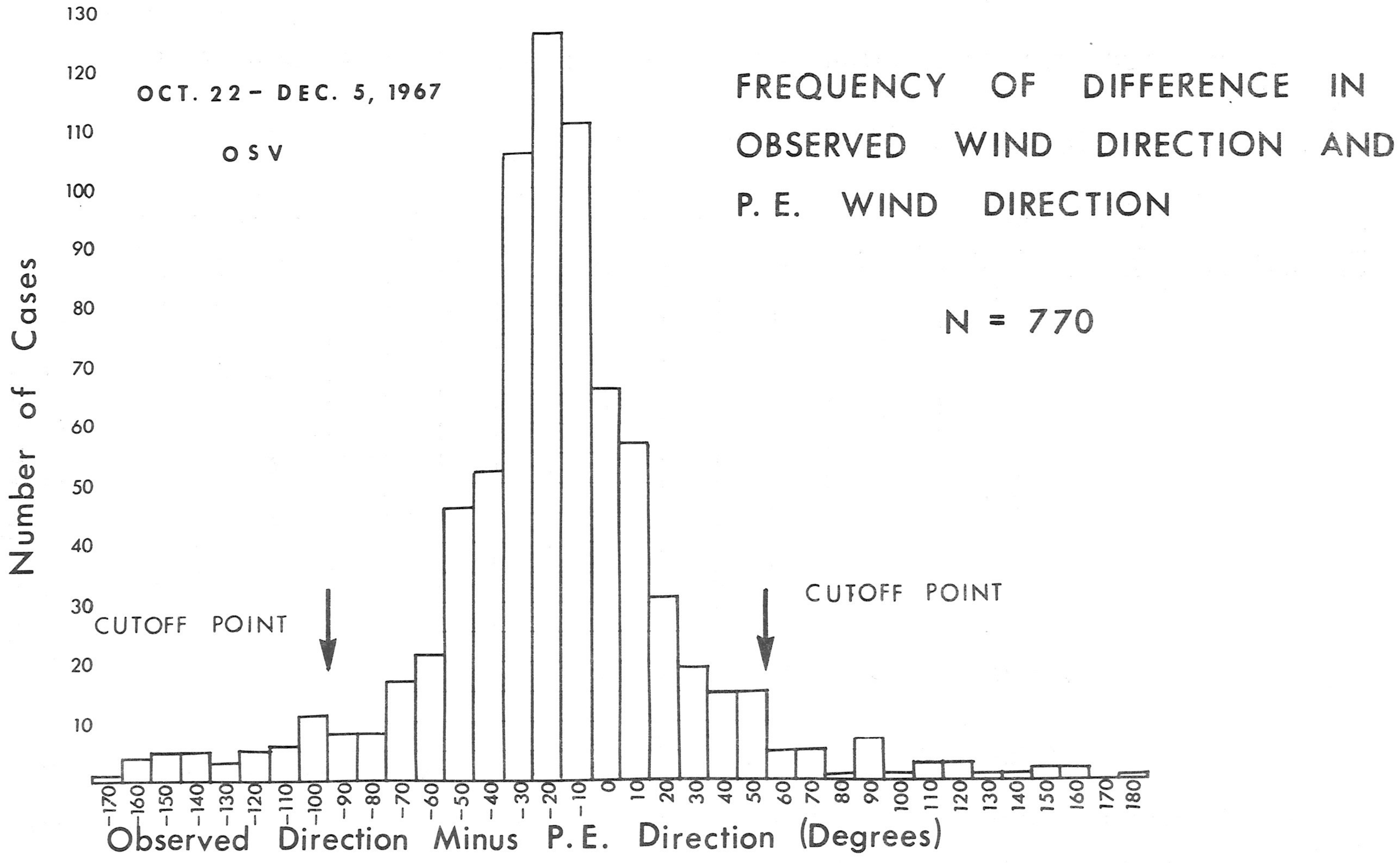

FIGURE 3. FREQUENCY OF DIFFERENCE IN OBSERVED WIND DIRECTION AND PE WIND DIRECTION FOR +00 HOURS.

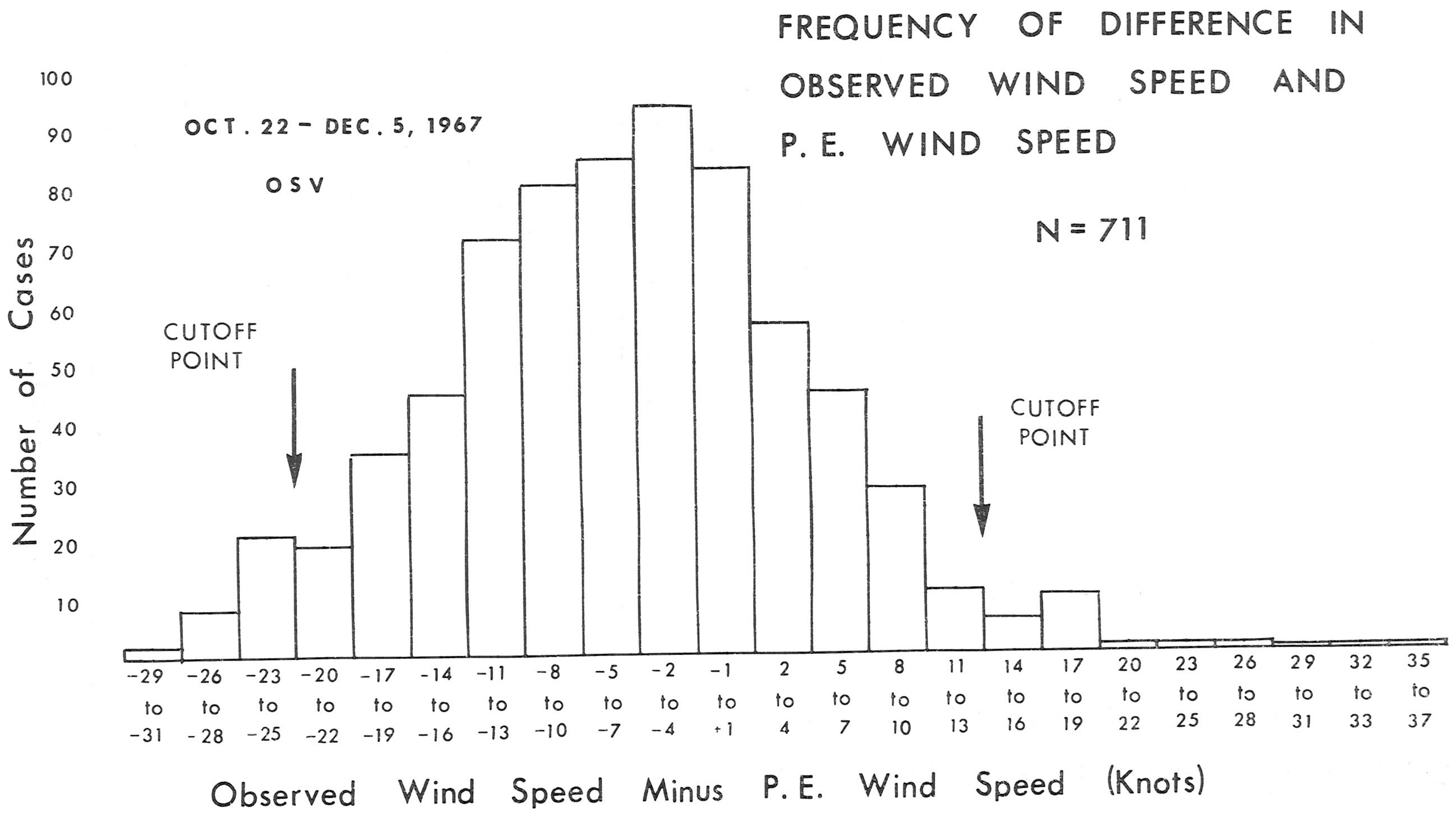

FIGURE 4. FREQUENCY OF DIFFERENCE IN OBSERVED WIND SPEED AND 1000 MB. PE WIND SPEED FOR +00 HOURS.

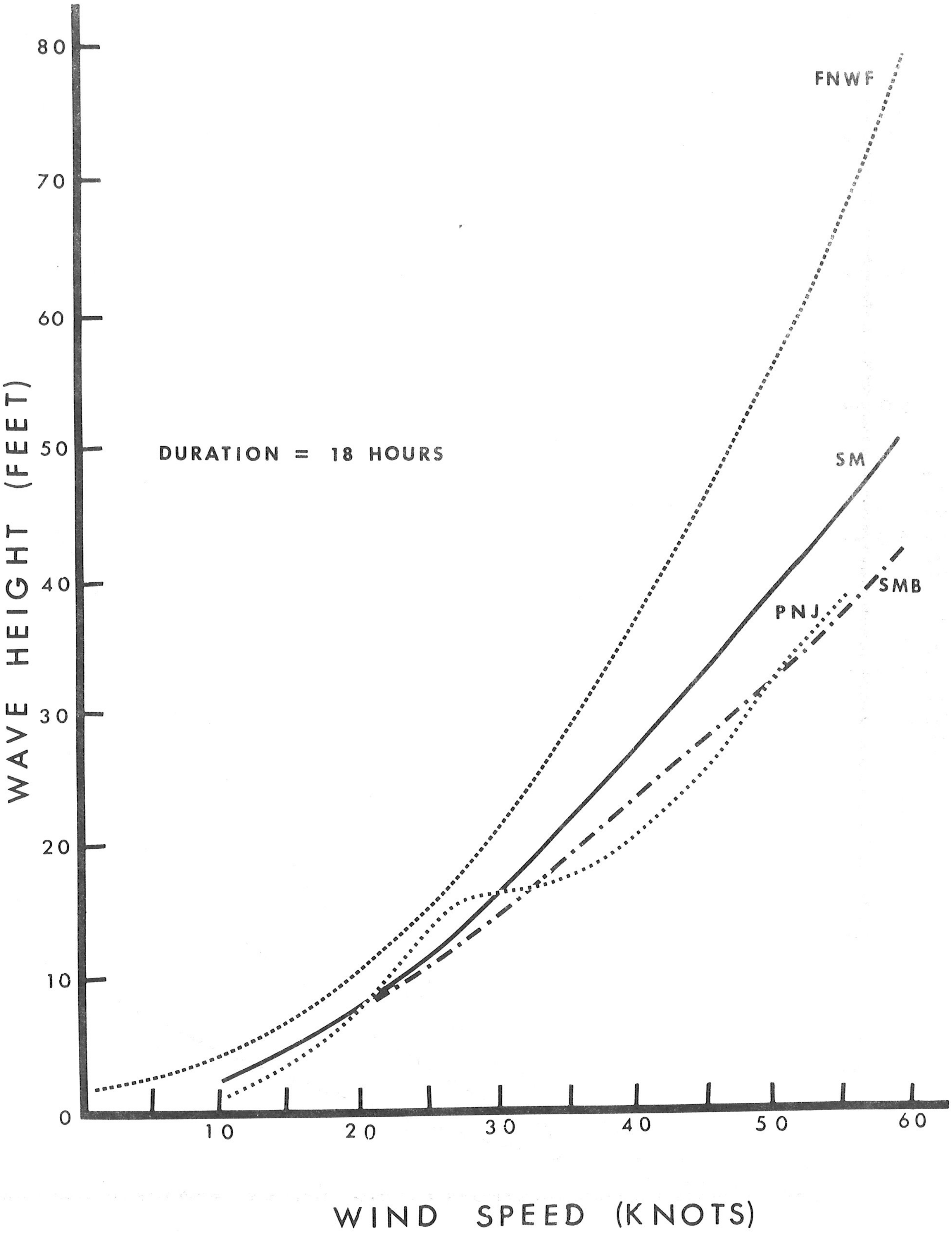

FIGURE 5. WAVE HEIGHT FORECAST CURVES FOR FOUR TECHNIQUES. ABBREVIATIONS USED ARE: FNWF FOR FLEET NUMERICAL WEATHER FACILITY; SM FOR SVERDRUP-MUNK; SMB FOR SVERDRUP-MUNK-BRETSCHNEIDER; AND PNJ FOR PIERSON-NEUMANN-JAMES.

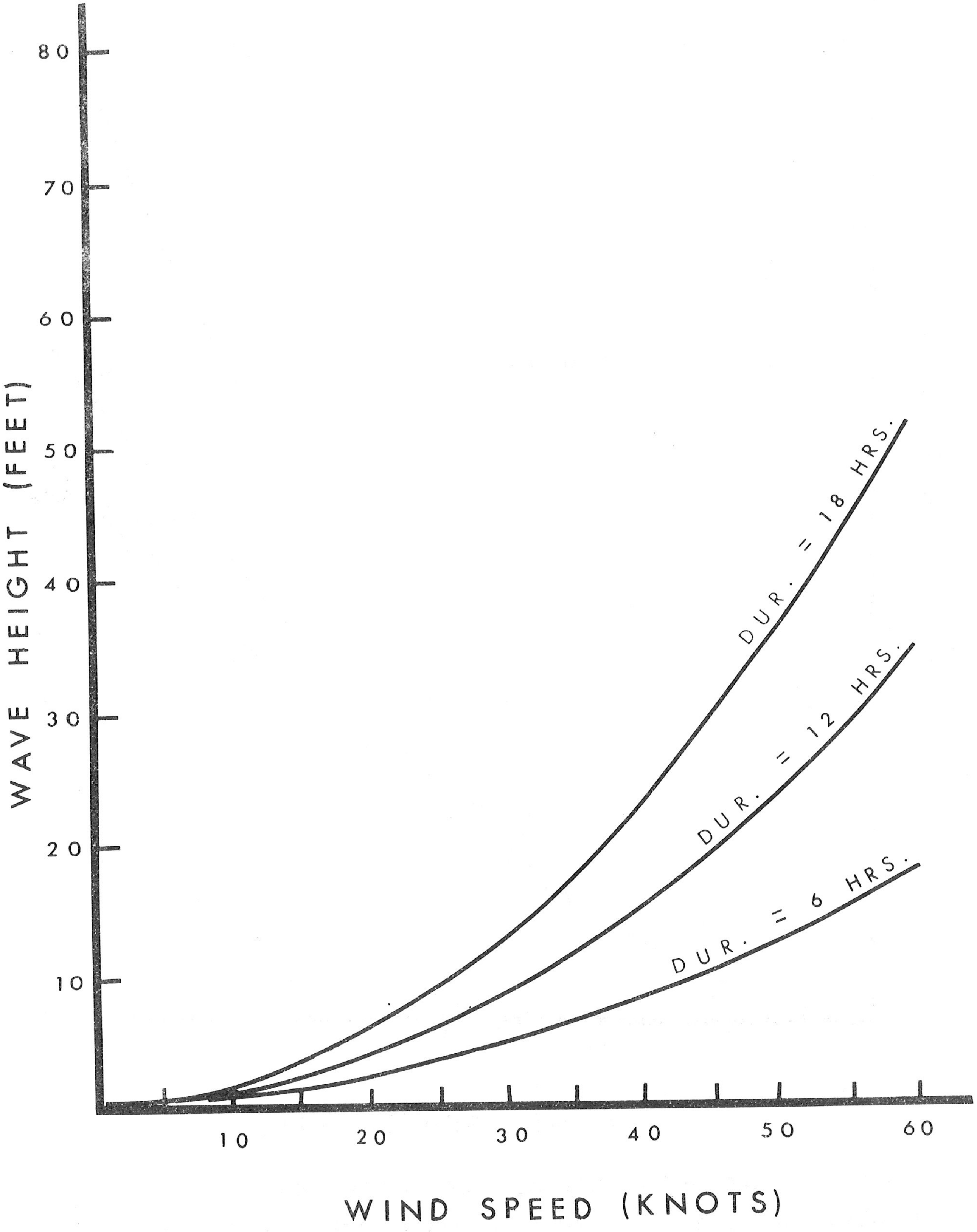

FIGURE 6. WAVE HEIGHT FORECAST CURVES BEING USED WITH THE ADJUSTED 1000 MB. PE WIND FORECASTS.

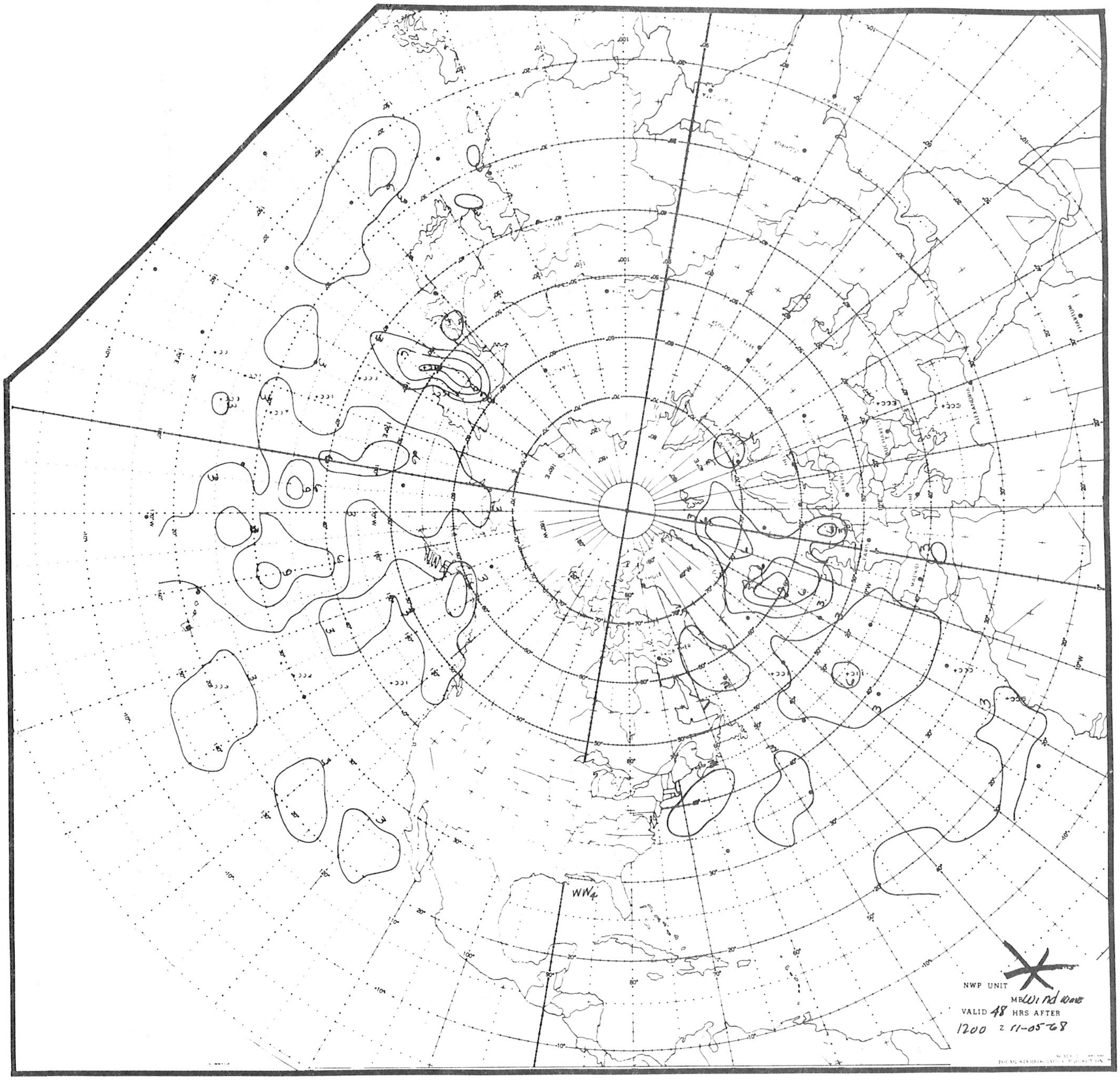

FIGURE 7. SAMPLE WIND-WAVE HEIGHT FORECAST CHART AS PREPARED BY THE NMC CURVE FOLLOWER. CONTOURS ARE DRAWN AT INTERVALS OF THREE FEET.

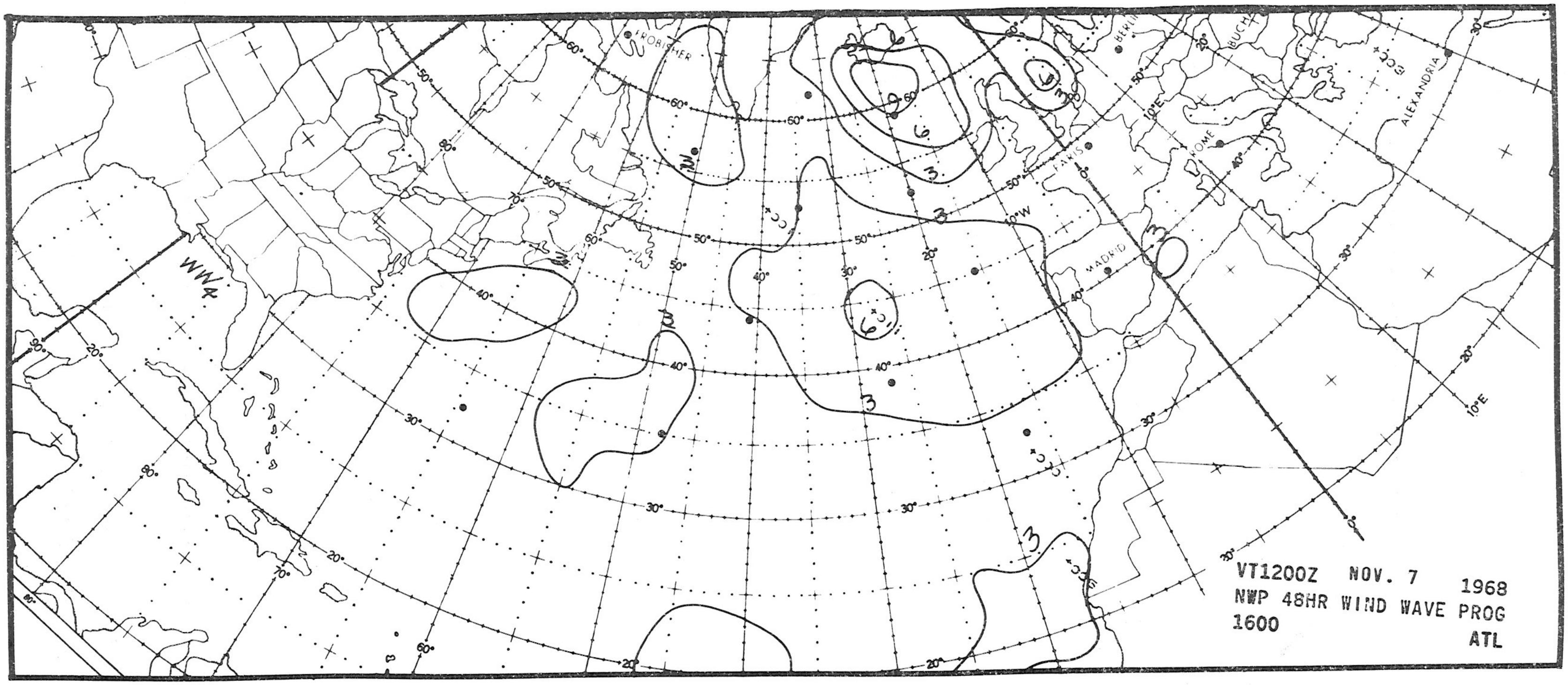

FIGURE 8. SAMPLE WIND-WAVE HEIGHT FORECAST CHART FOR EAST COAST WB-NESC FACSIMILE CIRCUIT. CONTOUR INTERVAL IS THREE FEET.

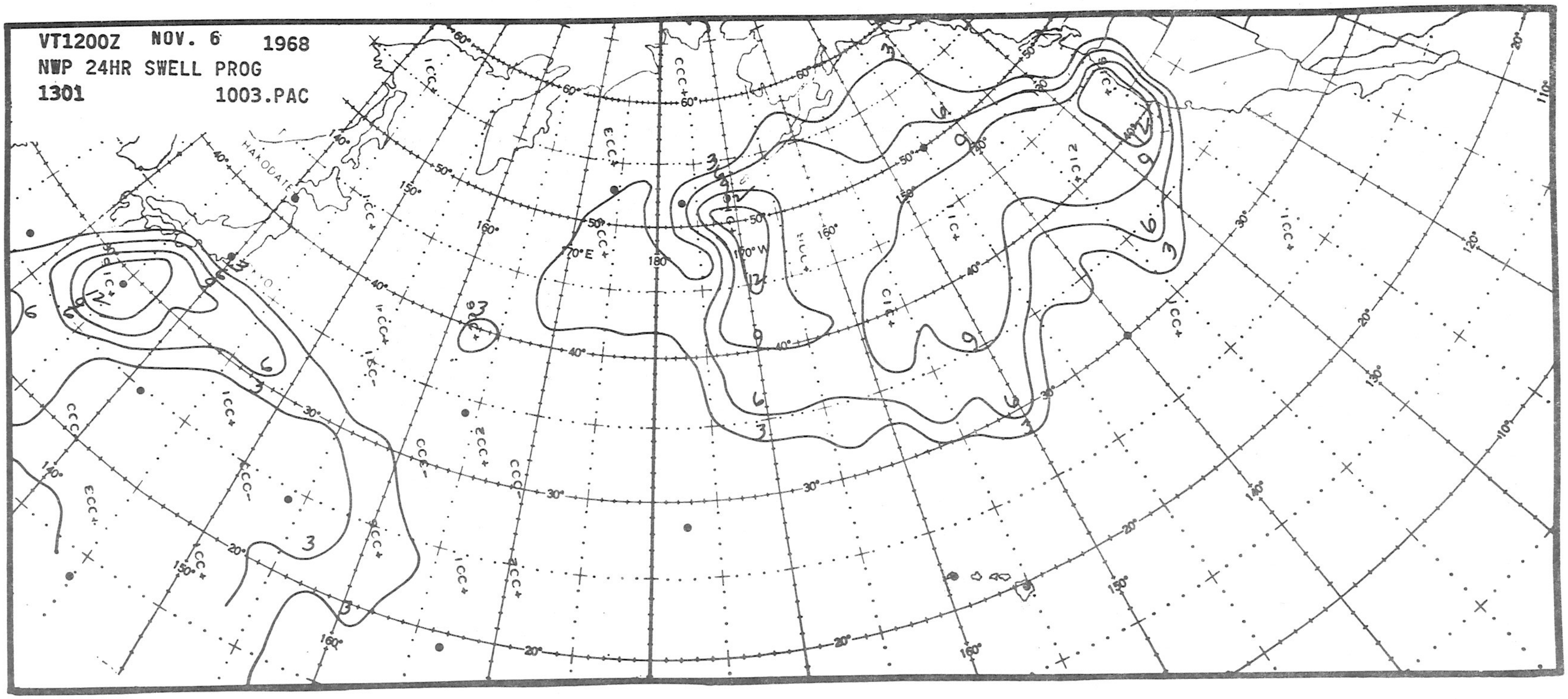

FIGURE 9. SAMPLE SWELL HEIGHT FORECAST CHART FOR WEST COAST WB-NESC AND THE SUITLAND-HONO-SOUTHWEST PACIFIC FACSIMILE CIRCUITS. CONTOUR INTERVAL IS THREE FEET.

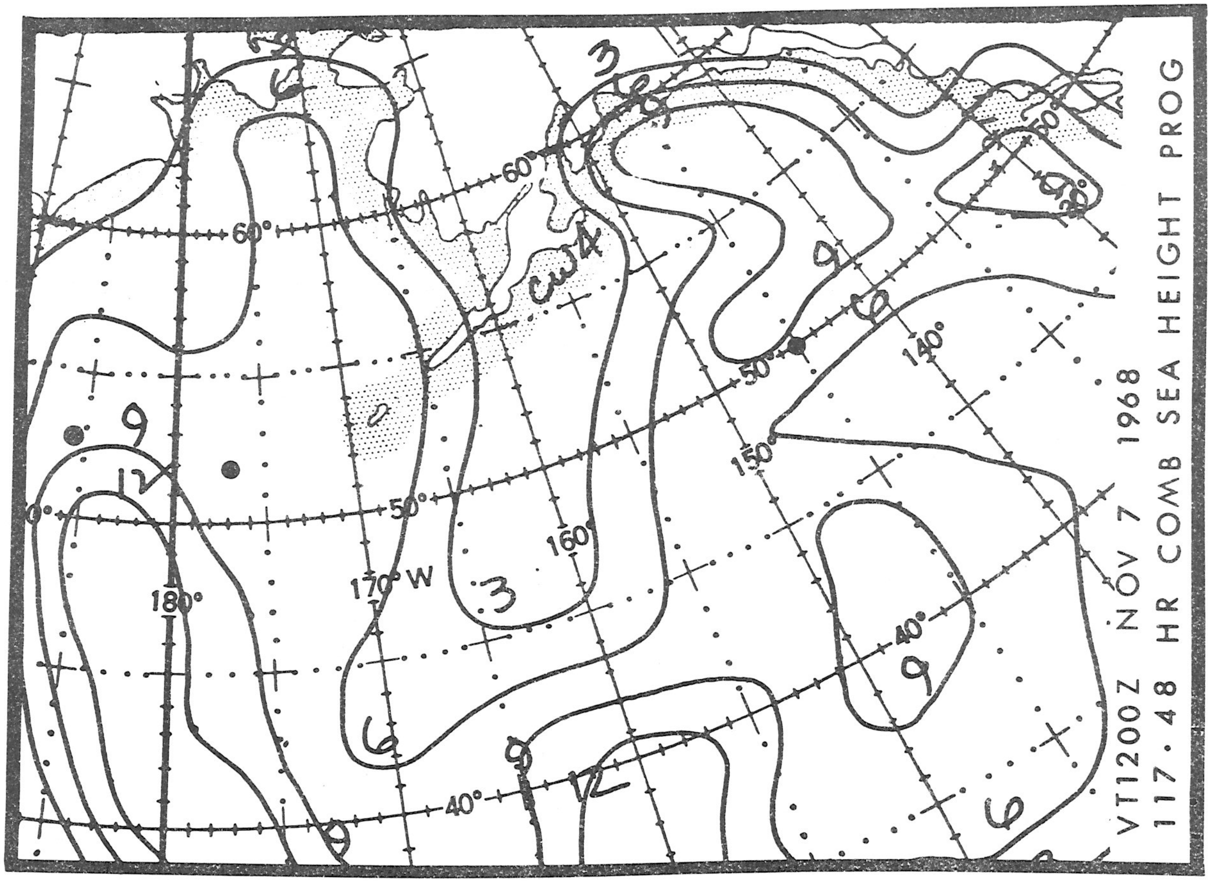

FIGURE 10. SAMPLE COMBINED-WAVE HEIGHT FORECAST CHART WHICH IS INCLUDED IN THE ALASKAN PROG PACKAGE ON THE NATIONAL WEATHER FACSIMILE CIRCUIT. CONTOUR INTERVAL IS THREE FEET.