CHAPTER 6

SEA SURFACE FORECASTING

The task of forecasting various elements of the sea surface is the responsibility of senior Aerographer's Mates filling a variety of billets.

Aboard carriers, sea condition forecasts for flight operations, refueling, or underway replenishment must be provided on a routine basis. Staffs of larger facilities will generally provide surf forecasts for amphibious operations, while at air stations that support search and rescue (SAR) units, you maybe called upon to provide forecasts of sea conditions and surface currents. Therefore, it is important that you be familiar with these elements and be able to provide forecasts as necessary.

In this chapter, we will discuss sea surface characteristics and the forecasting of sea waves, swell waves, surf, and surface currents. Now let's consider sea surface characteristics.

SEA SURFACE CHARACTERISTICS

LEARNING OBJECTIVES: Describe the basic principles of ocean waves. List and describe the properties that all waves have in common. Define additional terms used in sea surface forecasting. Explain wave spectrum in terms of wave frequency, energy, and wind speed.

To accurately forecast sea conditions it is necessary to understand the process of wave development, the action that takes place as the energy moves, and to have an understanding of the various properties of waves.

In this section, we will discuss this background information and the terminology used. A complete understanding of these terms is necessary to produce the most usable and accurate sea condition forecast.

BASIC PRINCIPLES OF OCEAN WAVES

Ocean waves are advancing crests and troughs of water propagated by the force of the wind. When winds start to blow, the frictional effect of the wind on the water creates ripples that form more or less regular arcs of long radii. As the wind continues to blow, the ripples increase in height and become waves.

A wave is visible evidence of energy moving in an undulating motion through a medium, such as water. As the energy moves through the water, there is little mass motion of the water in the direction of travel of the wave. This can best be illustrated by tying one end of a rope to a pole or other stationary object. When the free end of the rope is whipped up and down, a series of waves moves along the rope toward the stationary end. There is no mass motion of the rope toward the stationary end, only the energy traveling through the medium, in this case the rope.

A *sine wave* is a true rhythmic progression. The curve along the centerline can be inverted and superimposed upon the curve below the centerline. The amplitude of the crest is equal to the amplitude of the trough, and the height is twice that of the amplitude. Sine waves are a theoretical concept seldom observed in reality. They are used primarily in theoretical groundwork so that other properties of sine waves may be applied to other types of waves such as ocean waves. Principles of other types of waves are modified according to the extent of deviation of their properties from those of sine waves.

Waves that have been created by the local wind are known as *sea waves.* These waves are still under the influence of the local wind and are still in the generating area. They are composed of an infinite number of sine waves superimposed on each other, and for this reason they have a large spectrum, or range of frequencies.

Sea waves are very irregular in appearance. This irregularity applies to almost all their properties. The reason for this is twofold: first, the wind in the generating area (fetch) is irregular both in direction and speed; second, the many different frequencies of waves generated have different speeds. Figure 6-1 is a typical illustration of sea waves. The waves found in this aerial photograph are irregular in direction, wave length, and speed.

As the waves leave the generating area (fetch) and no longer come under the influence of the generating winds they become *swell waves.* Because swell waves are no longer receiving energy from the wind, their spectrum of frequencies is smaller than that of sea waves. Swell waves are also smoother and more regular

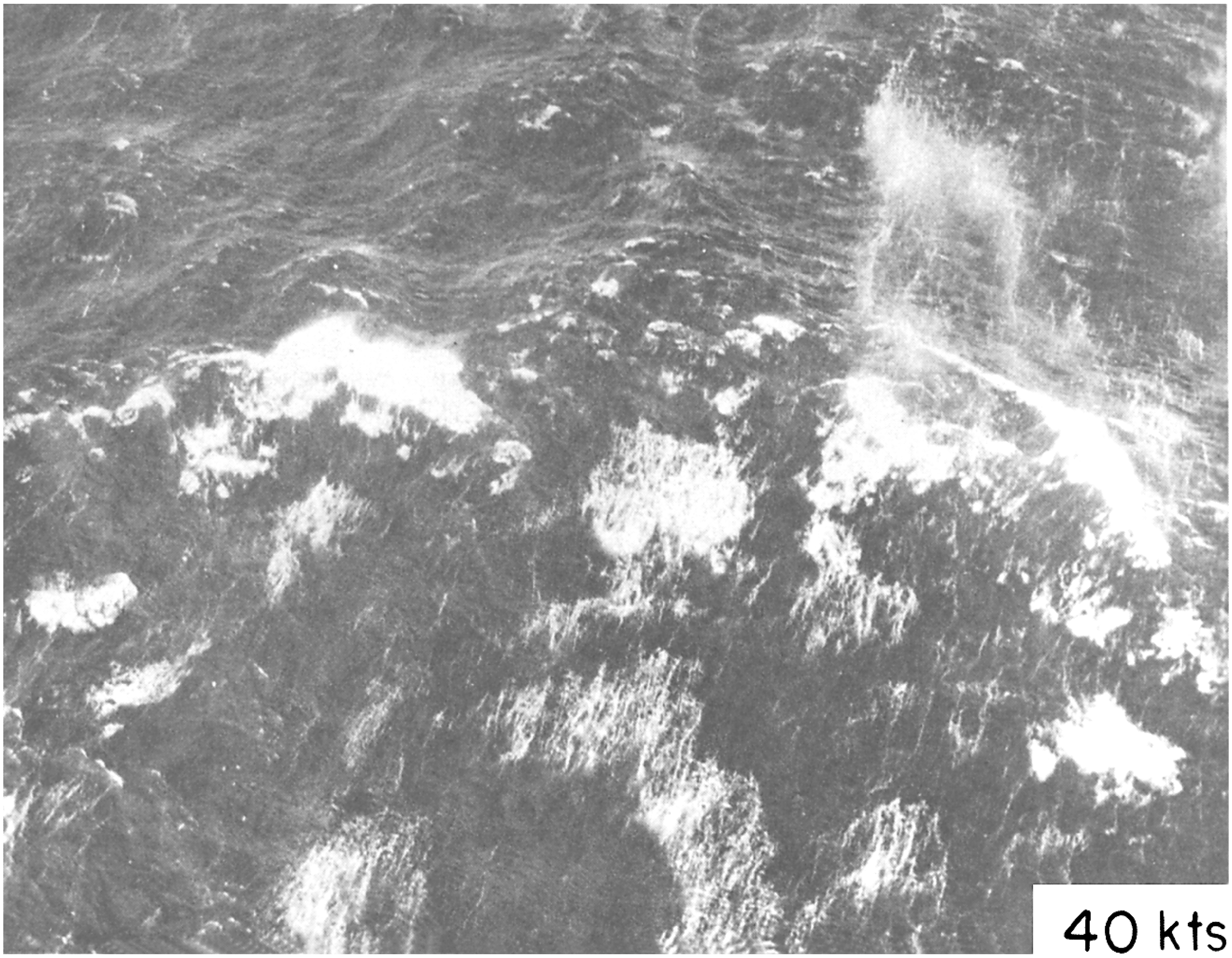

Figure 6-1.-Aerial photo of sea waves.

in appearance than sea waves. Figure 6-2 illustrates typical swell wave conditions.

PROPERTIES OF WAVES

All waves have the following properties in common:

- Amplitude. The amplitude of a wave is the maximum vertical displacement of a particle of the wave from its rest position. In the case of ocean waves, the rest position is sea level.

- Wave Height (H). Wave height is the vertical distance from the top of the crest to the bottom of the trough. Wave height is measured in feet. Four values for wave height are determined and forecast. They are:

  1. H_{avg} (the average height of the waves). This average includes all the waves from the smallest ripple to the largest wave.
  2. H_{sig} or $H_{1/3}$ (the average height of the highest one-third of all waves). This significant height of waves seems to represent the wave heights better than the other values, and this value will be used most often for this reason
  3. $H_{1/10}$ (the average height of the highest one-tenth of all waves). $H_{1/10}$ is used to indicate the extreme roughness of the sea.
  4. H_{max} - high wave.

- Period (T). The period of a wave is the time interval between successive wave crests, and it is measured in seconds.

- Frequency (f). The frequency of waves is the number of waves passing a given point during 1 second. It is the reciprocal of the period. In general, the lower the frequency, the longer the wave period; the larger the frequency, the shorter the wave period.

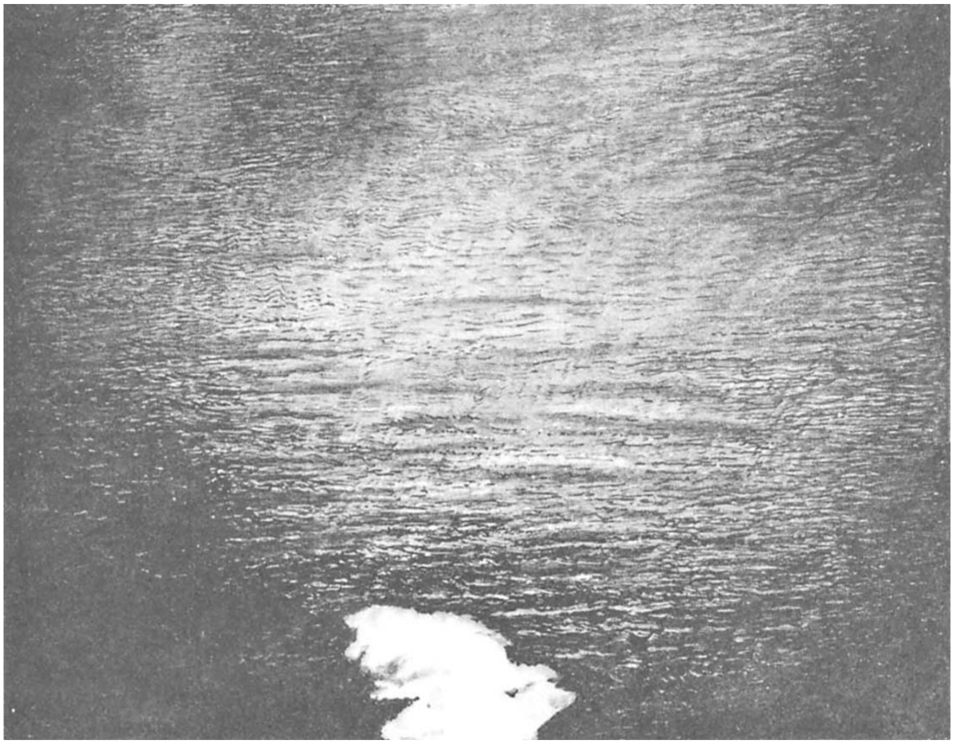

Figure 6-2.-Swell waves.

- Wave Length (L). The wave length is the horizontal distance between two successive crests or from a point on one wave to the corresponding point on the succeeding wave. Wave length is measured in feet, and it is found by the formula: $L = 5.12\ T^2$.

- Wave Speed (C). The wave speed is the rate that a particular phase of motion moves along through the medium. It is the rate that a wave crest moves through the water. There are two speeds used in ocean wave forecasting: group speed and individual speed. The group speed of waves is approximately one-half that of the individual speed The individual wave speed in knots is found by the formula $C = 3.03\ T$. The group wave speed is found by the formula $C = 1.515\ T$.

Definitions of Other Terms

Other definitions that the Aerographer's Mate should be familiar are as follows:

- Deep water. Water that is greater in depth than one-half the wave length.

Shallow water. Water that is less in depth than one-half the wave length.

- Fetch (F). An area of the sea surface over which a wind with a constant direction and speed is blowing, and generating sea waves. The fetch length is measured in nautical miles and has definite boundaries.

- Duration time (t). The time that the wind has been in contact with the waves within a fetch.

- Fully developed state of the sea. The state the sea reaches when the wind has imparted the maximum energy to the waves.

- Nonfully developed state of the sea. The state of the sea reached when the fetch or duration time has limited the amount of energy imparted to the waves by the wind.

- Steady state. The state reached when the fetch length has limited the growth of the waves. Once a steady state has been reached, the frequency range produced will not change regardless of the wind.

- Wind field. A term that refers to the fetch dimensions, wind duration, and wind speed, collectively.

- Effective duration time. The duration time that has been modified to account for the waves already present in the fetch or to account for waves generated by a rapidly changing wind.

- E value. E is equal to the sum of the squares of the individual amplitudes of the individual sine waves that make up the actual waves. Since it is proportional to the total energy accumulated in these waves, it is used to describe the energy present in them and in several formulas involving wave energy.

- Co-cumulative spectra. The co-cumulative spectra are graphs in which the total accumulated energy is plotted against frequency for a given wind speed. The co-cumulative spectra have been devised for two situations: a fetch limited wind and a duration time limited wind.

- Upper limit of frequencies (f_u). The upper limit of frequencies represents the lowest valued frequencies produced by a fetch or that are present at a forecast point. This term gets its name from the fact that the period associated with this frequency is the period with the highest value. The waves associated with this frequency are the largest waves.

- Lower limit of frequencies (f_L). The lower limit of frequencies represents the highest value frequencies produced by a fetch or that are present at a forecast point. This term gets its name from the fact that the period associated with this frequency is the period with the lowest value. The waves associated with this frequency are the smallest waves.

- Filter area. That area between the fetch and the forecast point through which swell waves propagate. This area is so termed because it filters the frequencies and permits only certain ones to arrive at a forecast point at a forecast time.

- Significant frequency range. The significant frequency range is the range of frequencies between the upper limit of frequencies and the lower limit of frequencies. The term significant range is used because those low-valued frequencies whose E values are less than 5 percent of the total E value and those high-valued frequencies whose E values are less than 3 percent of the total E value are eliminated because of insignificance. The significant range of frequencies is used to determine the range of periods present at the forecast point.

- Propagation. Propagation as applied to ocean waves refers to the movement of the swell through the area between the fetch and the forecast point.

- Dispersion. The spreading out effect caused by the different group speeds of the spectral frequencies in the original disturbance at the source. Dispersion can be understood by thinking of the different speeds of the different frequencies. The faster wave groups will get ahead of the slower ones; the total area covered is thereby extended. The effect applies to swell only.

- Angular spreading. Angular spreading results from waves traveling radially outward from the generating area rather than in straight lines or banks because of different wind direction in the fetch. Although all waves are subject to angular spreading, the effect of such spreading is compensated for only with swell waves because the spreading effect is negligible for sea waves still in the generating area. Angular spreading dissipates energy.

Wave Spectrum

The wave spectrum is the term that describes mathematically the distribution of wave energy with frequency and direction. The wave spectrum consists of a range of frequencies.

Remember that ocean waves are composed of a multitude of *sine waves,* each having a different frequency. For purposes of explanation, these frequencies are arranged in ascending order from left to right, ranging from the low-valued frequencies on the left to the high-valued frequencies on the right, as illustrated in figure 6-3.

A particular range of frequencies, for instance, from 0.05 to 0.10 does not, however, represent only six different frequencies of sine waves, but an infinite number of sine waves whose frequencies range between 0.05 and 0.10. Each sine wave contains a certain amount of energy, and the energy of all the sine waves added together is equal to the total energy present in the ocean waves. The total energy present in the ocean waves is not distributed equally throughout the range of frequencies; instead, in every spectrum, the energy is concentrated around a particular frequency (f_{max}), that corresponds to a certain wind speed. For instance, for a wind speed of 10 knots (kt) f_{max} is 0.248; for 20 kt, 0.124; for 30 kt, 0.0825; for 40 kt, 0.0619. For more

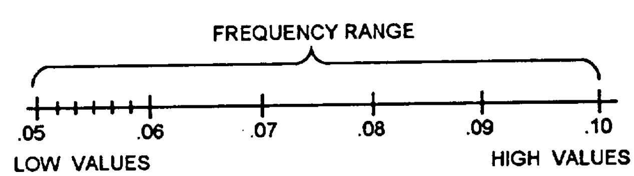

Figure 6-3.-A typical frequency range of a wave spectrum.

information refer to the publication *Practical Methods for Observing and Forecasting Ocean Waves* (H.O. Publication 603), which gives the complete range of f_{max} values and the corresponding periods for wind speeds, starting from 10 kt, at 2-kt intervals, Notice that the frequency decreases as the wind speed increases, This suggests that the higher wind speeds produce higher ocean waves. The table mentioned above can be graphed for each wind speed, An example of such a graph can also be found in H.O. publication 603.

It is difficult to work with actual energy values of these sine waves; for this reason the square of the wave amplitude has been substituted for energy. This value is proportional to wave energy.

The square of the wave amplitude plotted against frequency for a single value of wind speed constitutes the spectrum of waves. Thus, a graph of the spectrum is needed for each wind speed, and the energy associated with each sine wave can be determined from these graphs. Each wind speed produces a particular spectrum; and the higher the wind speed, the larger the spectrum.

FORECASTING SEA WAVES

LEARNING OBJECTIVES: Describe the generation and growth of sea waves. Explain the formation of fully developed seas. Recognize the factors associated with nonfully developed seas, and determine and analyze features associated with sea waves. Define sea wave terms and describe an objective method of forecasting sea waves.

Since sea waves are in the generating area, forecasting of them will be most important when units are deployed in areas close to storm centers.

Problems encountered in providing these forecasts will include accurately predicting the storm track and the intensity of the winds that develop the sea waves. Now let's look at the generation and growth of sea waves.

GENERATION AND GROWTH

When the wind starts to blow over a relatively calm stretch of water, the sea surface becomes covered with tiny ripples. These ripples increase in height and decrease in frequency value as long as the wind continues to blow or until a maximum of energy has been imparted to the water for that particular wind speed. These tiny waves are being formed over the entire length and breadth of the fetch. The waves formed near the windward edge of the fetch move through the entire fetch and continue to grow in height and period, so that the waves formed at the leeward edge of the fetch are superimposed on the waves that have come from the windward edge and middle of the fetch. This description illustrates that at the windward edge of the fetch the wave spectrum is small; at the leeward edge of the fetch the spectrum is large.

These waves are generated and grow because of the energy transfer from the wind to the wave. The energy is transferred to the waves by the pushing and dragging forces of the wind. Since the speed of the generated waves is continually increasing, these waves will eventually be traveling at nearly the speed of the wind. When this happens the energy transfer from the wind to the wave ceases, When waves begin to travel faster than the wind, they meet with resistance and lose energy because they are then doing work against the wind. This then explains the limitation of wave height and frequency that a particular wind speed may create.

Fully Developed Sea

When the wind has imparted its maximum energy to the waves, the sea is said to be fully developed. The maximum frequency range for that wind will have been produced by the fetch, and this maximum frequency range will be present at the leeward edge of the fetch. Once the sea is fully developed, no frequency is produced with a value lower than that of the minimum frequency value for the wind speed in question, no matter how long the wind blows. In brief, the waves cannot grow any higher than the maximum value for that wind speed.

When the sea is fully developed, the area near the windward edge is said to be in a steady state, because the frequency range does not increase any more. If the wind continues to blow at the same speed and from the same direction for a considerable period of time, the major portion of the fetch reaches the steady state.

Nonfully Developed Sea

When the wind is unable to impart its maximum energy to the waves, the sea is said to be nonfully developed. This can happen under two circumstances. First, when the distance over which the wind is blowing is limited or when the fetch is limited. Second, when the wind has not been in contact with the sea for a sufficient length of time, or when the duration time is limited. Now let's look at each situation.

FETCH LIMITED SEA.— When the fetch length is too short, the wind is not in contact with the waves over a distance sufficient to impart the maximum energy to the waves. The ranges of frequencies and wave heights are therefore limited, and the wave heights are less than those of a fully developed sea. The process of wave generation is cut off before the maximum energy has been imparted to the waves and the fetch is in a steady state. This leads to the conclusion that for every wind speed, a minimum fetch distance is required for the waves to become fully developed, and that if this minimum fetch requirement is not met, the sea is fetch limited.

DURATION TIME LIMITED SEA.— When the wind has not been in contact with the waves long enough, it has had insufficient time to impart the maximum energy to the waves, and the growth of the frequency range and wave heights ceases before the fully developed state of the sea has commenced. Such a situation is known as a duration time limited sea. This leads to the conclusion that for every wind speed, a minimum duration time is required for the waves to become fully developed; and that if this minimum duration time requirement is not met, the sea is duration time limited. The state of the sea, then, is one of three conditions: fully developed, fetch limited, or duration time limited.

Table 6-1 shows the various wind speeds, fetch lengths and minimum wind duration times needed to generate a fully developed state of the sea. When conditions do not meet these minimum requirements, the properties of the waves must be determined by means of graphs and formulas.

DETERMINING THE WIND FIELD

As we have discussed, wind is the cause of waves. It therefore stands to reason that in order to accurately predict sea conditions, it is necessary to determine wind properties as accurately as possible. Miscalculation of fetch, wind speed, or duration will lead to inaccuracies in predicted wave conditions.

In this section, we present methods of determining the wind properties as accurately as possible with the available data.

Table 6-1.-Minimum Wind Speed (V), Minimum Fetch Length (F), and Minimum Duration Time (t) Needed to Generate a Fully Developed Sea

V WIND SPEED (KT)	F FETCH LENGTH (NMI)	t DURATION (HR)
10	10	2.4
12	18	3.8
14	28	5.2
16	40	6.6
18	55	8.3
20	75	10
22	100	12
24	130	14
26	180	17
28	230	20
30	280	23
32	340	27
34	420	30
36	500	34
38	600	38
40	710	42
42	830	47
4	960	52
46	1,100	57
48	1,250	63
50	1,420	69
52	1,610	75
54	1,800	81
56	2,100	88

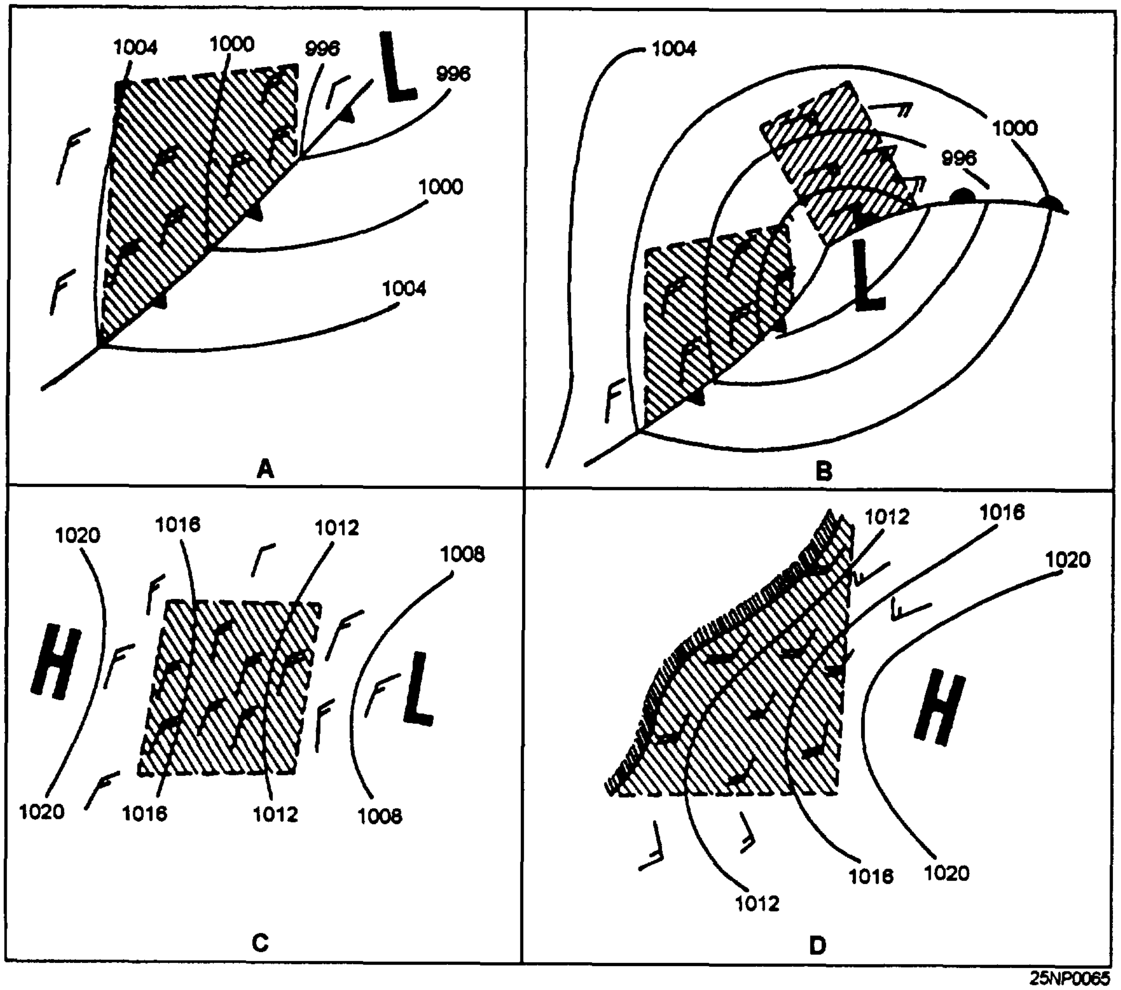

Figure 6-4.-Typical fetch areas.

Location of Fetch

In all cases, the first step toward a wave forecast is locating a fetch. A fetch is an area of the sea surface over which a wind with a constant direction and speed is blowing. Figure 6-4 shows some typical fetch areas. The ideal fetch over an open ocean is rectangular shaped, with winds that are constant in both speed and direction. As shown in figure 6-4, most fetch areas are bounded by coastlines, frontal zones or a change in isobars. In cases where the curvature of the isobars is large, it is a good practice to use more than one fetch area, as shown in figure 6-4(B).

Although some semipermanent pressure systems have stationary fetch areas, and some storms may move in such a manner that the fetch is practically stationary, there are also many moving fetch areas. Figure 6-5

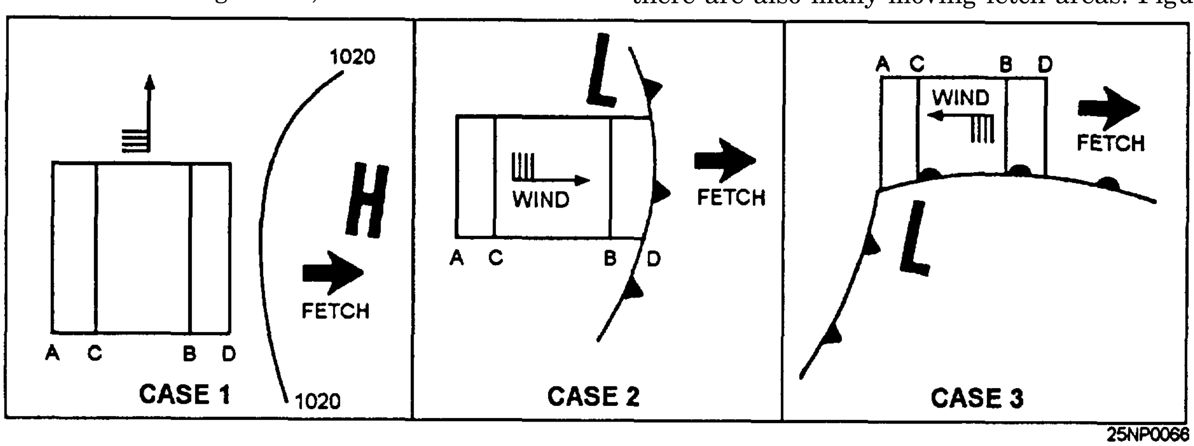

Figure 6-5.-Examples of moving fetches.

shows three cases where a fetch AB has moved to the position CD on the next map 6 hours later. The problem is determining what part of the moving fetch area to consider as the average fetch for the 6-hour period.

In figure 6-5, Case 1, the fetch moves perpendicular to the wind field. The best approximation is fetch CB. Therefore, in a forecast involving this type of fetch, use only the part of the fetch that appears on two consecutive maps. The remaining fetch does contain waves, but they are lower than those in the overlap area.

In figure 6-5, Case 2, the fetch moves to leeward (in the same direction as the wind), Since waves are moving forward through the fetch area, the area to be used in this case is fetch CD.

Case 3, figure 6-5, depicts the fetch moving windward (against the wind). Since the waves move toward A, the region AC will have higher waves than the area BD. Experience has shown that in this case AB is the most accurate choice for a fetch,

Determining Accurate Wind Speed

The most obvious and accurate way to determine wind speed over a fetch is to average the reported values from ships. This method has the advantage of not requiring a connection for gradients or stability. But often there are only a few ship reports available, and ship reports are subject to error in observation, encoding, or transmission.

A second way to determine wind speed is to measure the geostrophic wind from the isobaric spacing and then correct it for curvature and stability. At first it would seem this would be less desirable due to the extra time necessary for corrections. However, barometric pressure is probably the most reliable of the parameters reported by ships, and a reasonably accurate isobaric analysis can be made from a minimum number of reports. For these reasons the corrected geostrophic wind is considered to be the best measure of wind speed over the fetch, except of course in cases where there is a dense network of ship reports where wind direction and speed are in good agreement.

The reason for correction to geostrophic wind is that the isobars must be straight for a correct measure of the wind. When the isobars curve, other forces enter into the computations. The wind increases or decreases depending on whether the system is cyclonic or anticyclonic in nature. The stability correction is a measure of turbulence in the layer above the water. Cold air over warmer water is unstable and highly turbulent, making the surface wind more nearly equal to the geostrophic wind. Conversely, warm air over colder water produces a stable air mass and results in the surface wind being much smaller than the geostrophic wind.

Three rules for an approximation of the curvature correction are as follows:

1. For moderately curved to straight isobars-no connection is applied.

2. For great anticyclonic curvature-add 10 percent to the geostrophic wind speed.

3. For great cyclonic curvature-subtract 10 percent ffom the geostrophic wind speed.

In the majority of cases the curvature correction can be neglected since isobars over a fetch area are relatively straight. The gradient wind can always be computed if more refined computations are desired.

In order to correct for air mass stability, the sea air temperature difference must be computed. This can be done from ship reports in or near the fetch area aided by climatic charts of average monthly sea surface temperatures when data is too scarce. The correction to be applied is given in table 6-2. The symbol Ts stands for the temperature of the sea surface, and Ta for the air temperature.

Determination of Wind Duration

Once a fetch has been determined and the wind speed has been found, the next step is to determine the duration of that wind over the fetch. It is highly unlikely that the wind will begin and end at one of the 6-hour map times. Therefore an accurate value must be interpolated. Inmost cases a simple interpolation of the successive maps will be sufficient to locate the bounds of the wind field in space and time.

Table 6-2.-Air-Sea Temperature Difference Correction

(T_s - T_a) Algebraically Subtracted	Percent of Geostrophic Wind
0 or negative	60
0 to 10	65
10 to 20	75
20 or above	90

Determining how long the wind has blown is relatively simple when the wind speed has bee n constant for the entire duration. If this does not occur, a representative duration must be selected.

SLOWLY VARYING WIND.— Suppose the wind has been blowing for 24 hours, with velocities of 10 knots for 6 hours, 15 knots for 12 hours, and 20 knots for 6 hours. The duration is 24 hours but the speed value is in question. The most consistent solution is to use three durations with the corresponding wind speeds and work up three successive states.

MORE RAPID VARIATIONS.— Suppose the wind blows for 12 hours and during that time it increases in velocity from 10 to 20 knots. Studies and experience have shown that in cases of variable winds a single value may be assigned for wind speed if the change has been relatively small. The following rules can be applied under these conditions:

- Average the speeds when the change is gradual or increasing or decreasing. Apply the average to the entire duration.

- Use the last wind speed when the speed changes in the first few hours, then remains constant. Apply that speed to the entire duration.

OBJECTIVE METHODS FOR FORECASTING SEA WAVES

There are a number of different methods for forecasting sea waves. Some of the methods are too technical or time consuming to be of practical use of Aerographer's Mates.

A relationship between wave velocity (c), wave length (L), and period (T) maybe indicated using the equation $C = 3.03\ T$. The length in feet of a deep-water wave (L) may be computed using the equation $L = 5.12\ T$. The period of a wave in seconds (T) may be calculated using the equation $T = 0.33\ C$, where (C) is the wave velocity.

Sea state forecasts are divided into four categories: significant wave height ($H_{1/3}$), average wave height (H_{AVG}), one-tenth average wave height ($H_{1/10}$), and high wave (H_{MAX}).

For more information, refer to the practical training publication *Sea and Swell Forecasting,* NAVEDTRA 40560, published by the Naval Oceanographic Office. This publication presents a method for forecasting sea waves, and a brief summary follows.

In order to prepare an accurate sea state forecast one must frost determine wind speed over the fetch (U), length of the fetch (F), and the length of time the wind speed (u) has remained unchanged within the fetch (t_d).

These parameters are determined using current and/or previous surface charts. Using these parameters and the tables in NAVEDTRA 40560, an accurate sea state forecast may be obtained.

FORECASTING SWELL WAVES

LEARNING OBJECTIVES: Explain swell wave generation and recognize the two fundamental modifications that sea waves undergo as they leave the fetch area. Define the terms associated with swell waves, and explain the five rules used to determine how much of the swell will reach the forecast point. Prepare an objective swell wave forecast.

In the preceding portion of this chapter, we have discussed the principles of sea waves and methods of forecasting them. With sea wave forecasting we are considering the point that we are forecasting to be within the generating area, with the wind still blowing. This, however, will not be the problem in the majority of the forecasts that will be required. Normally the forecast point will be outside the fetch area; therefore, it will be necessary to determine what effect the distance traveled is going to have on the waves. In this section we will discuss the basic principles of swell waves as well as an objective method of determining what changes will take place in the spectrum of waves as they traverse from the generating area to the forecast point.

GENERATION OF SWELL WAVES

After a sea state has been generated in a fetch, there are many different wave trains present with different periods, and most of them are moving out of the fetch in slightly different directions. Because of these different periods and slight differences in direction, the propagation of swell waves follows two fundamental processes. These processes are dispersion and angular spreading.

Dispersion

An accepted fact about wave travel is that the waves with longer periods move faster than waves with shorter periods. The actual formula for the speed of the wave train is

$$C = 1.515T$$

where C is the speed of the wave train and T is the wave period in the wave train.

All of the different wave trains (series of waves all having the same period and direction of movement) in the fetch can be compared to a group of long distance runners at a track and field meet. At first all of the runners start out at the starting line at the same time. As they continue on, however, the faster runners move ahead and the slower runners begin to fall behind. Thus the field of runners begins to string out along the direction of travel. The wave trains leaving a fetch do the same thing. The stringing out of the various groups of waves is called dispersion.

In a swell forecast problem it is necessary to determine what wave trains have already passed the forecast point and which have not yet arrived. After this has been determined, the wave trains that are left are the ones that are at the forecast point at the time of observation.

Angular Spreading

As the wave trains leave the fetch, they may leave at an angle to the main direction of the wind in the fetch. Thus, swell waves may arrive at a forecast point though it may lie to one side of the mainline of direction of the wind. This process of angular spreading is depicted in figure 6-6.

The problem in swell forecasting is to determine how much of the swell will reach the forecast point after the waves have spread out at angles. This is accomplished by measuring the angles from the leeward edge of the fetch to the forecast point. These angles must be measured as accurately as possible, figure 6-7, and are determined by the following five rules:

1. Draw the rectangular fetch.

Frequency	Period	Distance Traveled in Nautical Miles	Length of Disturbance in Nautical Miles
.050	20	1960	300
.067	15	1470	225
.083	12	1180	180
.100	10	980	150
.167	6	590	90

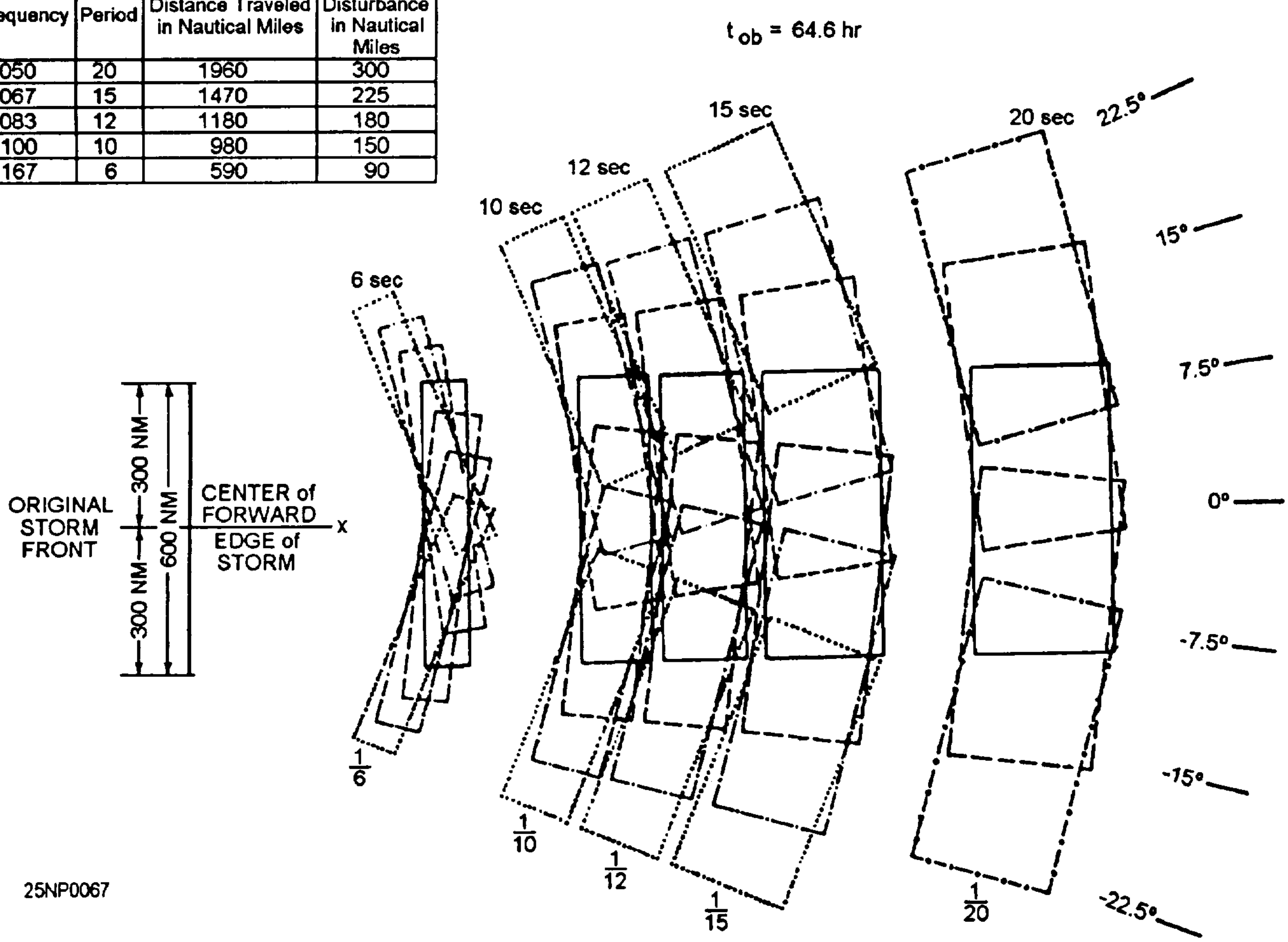

Figure 6-6.-Angular spreading.

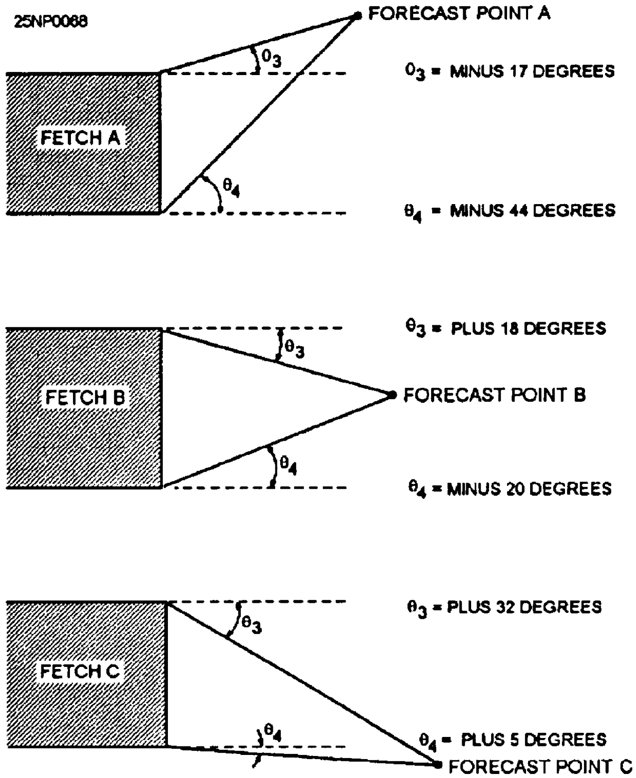

Figure 6-7.-Measuremeuts of angles for angular spreading.

2. Extend the top and bottom edge of the fetch outward parallel to the main direction of the wind. This is shown as dashed lines in figure 6-7.

3. Draw lines from the top and bottom edges of the fetch to the forecast point.

4. The angles to the forecast point are designated Theta 3 (θ3) and Theta 4 (θ4). Theta 3 is measured from the top edge of the fetch and Theta 4 from the bottom edge.

5. Any angle that lies above the dashed line is negative while any angle that lies below the dashed line is positive.

After the angles Theta 3 and 4 have been measured they are converted to percentages of the swell that will reach the forecast point. This conversion is made by entering sea and swell graph 7, figure 6-8, with the positive or negative angles and reading the corresponding percentages directly. The percentages are then subtracted ignoring the plus or minus to find the angular spreading.

OBJECTIVE METHOD FOR FORECASTING SWELL WAVES

A number of terms used in dealing with forecasting sea waves will be used again in this process; however, a number of new terms will be introduced. Table 6-3 lists most of these terms with their associated symbol and definition.

As with objective forecasting of sea waves there are a number of different methods for forecasting swell waves. Some of the methods are too technical or time consuming to be of practical use.

When ship operations are conducted outside a fetch area it becomes necessary to forecast swell conditions at that location. Prior to computing swell conditions the height and period of the significant waves departing the fetch area must be determined. For more details refer to *Sea and Swell Forecasting,* NAVEDTRA 40560.

FORECASTING SURF

LEARNING OBJECTIVES: Explain the generation of surf and describe the two changes that occur upon entering intermediate water. Recognize the characteristics of the three types of breakers. Define the terms associated with surf. Describe an objective method for surf forecasting and the calculations of the modified surf index.

Thus far we have discussed the generation of sea waves, their transformation to swell waves, some of the changes that occur as they move, and objective methods of forecasting both waves.

The Navy is greatly involved in amphibious operations, which requires the forecasting of another sea surface phenomena: surf. Senior Aerographer's Mates will occasionally be called upon to provide forecasts for amphibious operations, and accurate and timely forecasts can greatly decrease the chance of personnel injury or equipment damage. Therefore, it is important that forecasters have a thorough understanding of the characteristics of surf and a knowledge of surf forecasting techniques.

GENERATION OF SURF

The breaking of waves in either single or multiple lines along the beach or over some submerged bank or reef is referred to as surf.

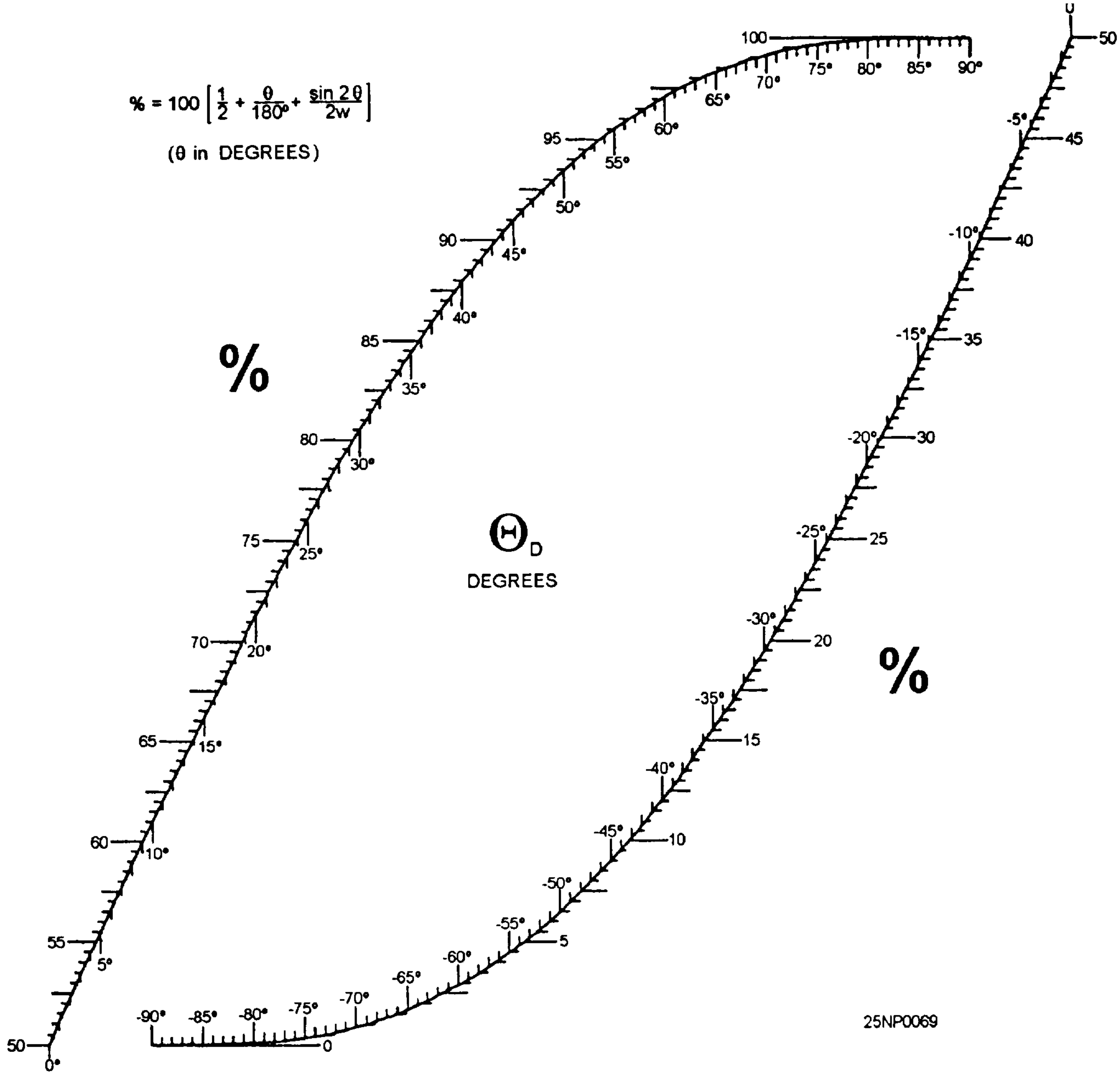

Figure 6-8.-Sea and swell graph 7.

Table 6-3.-Sea Wave Terminology

NAME	SYMBOL AND DIMENSION	DEFINITION
Decay distance	(D) Miles	Distance from point of forecast to the leeward (downwind) edge of the fetch.
Decay index	(H_o/H_f)	Ratio of deep water wave height to fetch wave height.
Deep water wave height	(H_o) Feet	Height of waves after leaving the generating fetch but before reaching shallow water to become surf. (Swell height).
Travel time	(t_o) Hours	Length of time necessary for waves to travel decay distance (D).

The energy that is being expended in producing this phenomenon is the energy that was given to the sea surface when the wind developed the sea waves. This energy is diminished as the swell waves move from the fetch area to the area of occurrence of the surf.

The surf zone is the extent from the water up-rush on the shore to the most seaward breaker. It will be within this area that the forecast will be prepared.

When waves enter an area where the depth of the bottom reaches half their wave length, the waves are said to "feel bottom." This means that the wave is no longer traveling through the water unaltered, but is entering intermediate water where changes in wave length, speed, direction, and energy will occur. There will be no change in period. These changes are known as shoaling and refraction. Shoaling affects the height of the waves, but not direction, while refraction effects both. Both shoaling and refraction result from a change in wave speed in shallow water. Now let's look at shoaling and refraction in more detail.

Shoaling

The shoaling effect is caused by two factors. The first is a result of the shortening of the wave length. Wave length is shortened as the wave slows down and the crests move closer together. Since the energy between crests remains constant the wave height must increase if this energy is to be carried in a shorter length of water surface. Thus, waves become higher near shore than they were in deep water. This is particularly true with swell since it has along wavelength in deep water and travels fast. As the swell speed decreases when approaching shore, the wave length shortens, and along swell that was barely perceptible in deep water may reach a height of several feet in shallow water.

The second factor in shoaling has an opposite effect (decreasing wave height) and is due to the slowing down of the wave velocity until it reaches the group velocity. AS the group velocity represents the speed that the energy of the wave is moving, the height of the individual wave will decrease with its decreasing speed until the wave and group velocity are equal. The second factor predominates when the wave first feels bottom, decreasing the wave height to about 90 percent of its deep water height by the time the depth is one-sixth of the wave length. Beyond that point, the effect of the decreased distance between crests dominates so that the wave height increases to quite large values close to shore.

Refraction

When waves arrive from a direction that is perpendicular to a straight beach, the wave crests will parallel the beach. If the waves are arriving from a direction other than perpendicular or the beach is not straight, the waves will bend, trying to conform to the bottom contours. This bending of the waves is known as refraction and results from the inshore portion of the wave having a slower speed than the portion still in deep water. This refraction will cause a change in both height and direction in shallow water.

Surf Development

When a wave enters water that is shallower than half its wave length, the motion of the water near the bottom is retarded by friction. This causes the bottom of the wave to slow down. As the water becomes more shallow the wave speed decreases, the wave length becomes shorter, and the wave crest increases in height. This continues until the crest of the wave becomes too high and is moving too fast. At this point the crest of the wave becomes unstable and crashes down into the preceding wave trough; when this happens the wave is said to be breaking. The type of breaker (that is, whether spilling, plunging, or surging) is determined by the steepness of the wave in deep water and the slope of the beach. Figure 6-9 depicts the general characteristics of the three types of breakers.

SPILLING BREAKER.— Spilling breakers occur with shallow beach slopes. The water at the crest of a wave may create foam as it spills down the face of the wave. Spilling breakers also occur more frequently when deepwater sea waves approach the beach. This is because the shorter wavelength of a sea wave means that the wave is steeper in the deep water and that the water spills from the crest as the waves begin to feel bottom. Because the water constantly spills from the crest in shorter wavelength (shorter period) waves, the height of spilling waves rarely increases as dramatically when the wave feels bottom, as do the longer period waves forming at the crest and expanding down the face of the breaker.

PLUNGING BREAKER.— Plunging breakers occur with a moderately steep bottom. In this type of breaker, a large quantity of water at the crest of a wave curls out ahead of the wave crest, temporarily forming a tube of water on the wave face before the water plunges down the face of the wave in a violent tumbling action. Plunging breakers are characterized by a loud, explosive sound made when the air trapped in the curl

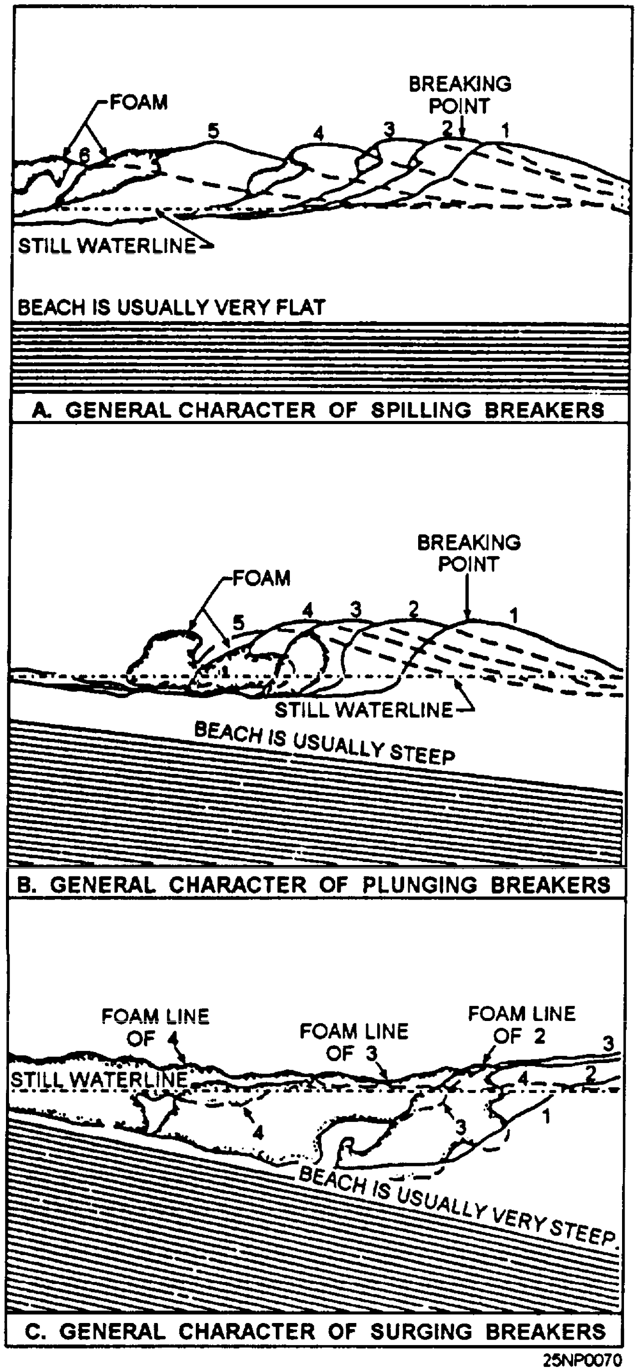

Figure 6-9.-General characteristics of spilling, plunging, and surging breakers.

is released Plunging breakers are more commonly associated with swell waves that approach the beach with much longer wavelengths. The shortening of the wavelength as the wave feels bottom causes a great mass of water to build up in the crest in a short time. Longer period swell waves may double in height when feeling bottom.

SURGING BREAKER.— Surging breakers are normally seen only with a very steep beach slope. This type of breaker is often described as creating the appearance that the water level at the beach is suddenly rising and falling. The entire face of the wave usually displays churning water and produces foam, but an actual curl never develops.

Littoral Current

Remember that refraction occurs when a wave train strikes a beach at an angle, and this action causes a mass transport of water parallel to the beach in the same direction as the wave train. This mass transports called the longshore current or littoral current.

Many of the craft used in amphibious operations are small and, because they are designed to land upon the beach are not sea-worthy. Owing to the size of landing craft, significant breaker height, maximum breaker height, breaker period, breaker type, the angle of breakers to the beach, the longshore (littoral) current speed and the number of lines of surf can have a dramatic effect on amphibious operations and are of vital importance.

Definition of Terms

The following are some terms that will be used extensively in surf discussions and should be understood by the forecaster:

- Breaker height - the vertical distance in feet between the crest of the breaker and the level of the trough ahead of the breaker.
- Breaker wave length - the horizontal distance in feet between successive breakers.
- Breaker period - the time in seconds between successive breakers. This is always the same as the deepwater wave period.
- Depth of breaking - the depth of the water in feet at the point of breaking.
- Surf zone - the horizontal distance in yards between the outermost breakers and the limit of wave uprush on the beach.
- Number of lines of surf - the number of lines of breakers in the surf zone.
- Deep water wave angle - the angle between the bottom contours and the deep water swell wave crests.
- Breaker angle - the angle between the beach and the lines of breakers. It is always less than the deep water wave angle.

- Wave steepness index - ratio of the deep water wave height to deep water wave period squared

- Breaker height index - ratio of breaker height to deep water wave height.

- Breaker type - classification of breaker as to spilling, plunging, or surging.

- Breaker depth index - ratio of depth of breaking to deep water wave height.

- Width of surf zone - horizontal distance in yards between the outermost breakers and the limit of wave uprush on the beach.

- Refraction index - ratio of depth of breaking to the deep water wave length.

- Coefficient of refraction - percent of breaker height that will actually be seen on the beach after refraction occurs.

- Longshore current - current parallel to beach due to breaker angle, height, period, and beach slope.

OBJECTIVE TECHNIQUE FOR FORECASTING SURF

Figure 6-10 provides an example of the surf worksheet that may be used in a surf forecasting procedure. The steps in the method conform to steps on the worksheet.

Equipped with an understanding of the terms discussed above, the surf forecast worksheet, figure 6-10, and the step-by-step procedures listed in *Surf Forecasting,* NAVEDTRA 40570, the Aerographer's Mate can prepare accurate surf forecasts.

The presentation to the user can be made in any manner that is agreed upon; however, figure 6-11 illustrates one of the most commonly used methods.

FORECASTING THE MODIFIED SURF INDEX

The Modified Surf Index is a dimensionless number that provides a measure of likely conditions to be encountered in the surf zone. The Modified Surf Index provides a guide for judging the feasibility of landing operations for various types of landing craft.

The Modified Surf Index Calculation Sheet, breaker, period, and wave angle modification tables are listed in the *Joint Suff Manual,* COMNAVSURFPAC/COMNAVSURFLANTINST 3840.1. By following the listed procedures on the Modified Surf Index Calculation Sheet the Aerographer's mate obtains an objective tool to be used by on-scene commanders.

The *Joint Surf Manual* also lists modified surf limits for various propeller driven landing craft. The modified surf index is not applicable for the Landing Craft Air Cushion (LCAC). LCAC operations use the significant breaker height.

For more information on amphibious operations, see *Environmental Effects on Weapon's Systems and Naval Warfare (U),* (S)RP1.

FORECASTING SURFACE CURRENTS

LEARNING OBJECTIVES: Distinguish between tidal and nontidal currents. Define the terms associated with currents. Classify currents as wind driven, coastal, or tidal. Identify publications available to obtain tidal and current information.

Although the forecasting of surface currents has been performed by aerographers for a number of years, the prominence of such forecasting became more evident when a number of incidents involving large sea-going oil tankers occurred. Collisions and grounding involving tankers caused great amounts of pollutants, mainly oil, to be spilled on the water surface. The movement, both direction and speed, of such contaminants is directly controlled by the surface currents in the affected area. More concerned emphasis has now been placed on the ability of forecasters to predict the movement of such contaminated areas.

In the past, NAVMETOC units have provided forecasts to assist in the location of personnel or boats adrift in the open sea as well as forecasts used in estimating ice flow.

With the growing concern about pollution and contamination of ocean waters, it is anticipated that more requests for current and drift forecasts will be directed to NAVMETOC units.

In this section, we will discuss the general characteristics of currents, how they form, and the different types of currents. There are presently no hard and fast rules or techniques that are universally

SURF FORECAST WORKSHEET

BEACH NAME ______________ BEACH SLOPE ______________ ETA SURF ______________

FROM OBSERVED OR FORECAST SWELL

1. Deep water wave height H_o = ________ ft
2. Deep water wave period T_o = ________ sec
3. Angle between deep water waves and depth contours a_o = ________ deg

SURF CALCULATIONS			
Step	Enter SWELL GRAPH	With	And Read
4	1	H_o from step 1 and T_o from step 2	H_o/T_o^2
5	2	H_o/T_o^2 from step 4	H_b/H_o
6	3	H_o from step 1 and H_b/H_o from step 5	H_b ft
7	4	H_o/T_o^2 from step 4 and Beach Slope from heading	Breaker Type
8	5	H_o/T_o^2 from step 4. If H_o/T_o^2 <.01 go to next step	d_b/H_o
9	6	H_o from step 1 and d_b/H_o from step 8 or use $d_b = 1.3\ H_o$ if H_o/T_o^2 <.01	d_b ft
10	7	d_b from step 9 and Beach Slope from heading	Width of Surf Zone yd
11	8	d_b from step 9 and T_o from step 2	L_b ft
12	9	L_b from step 11 and Width of Surf Zone from step 10	No. Lines of Surf
13	10	d_b from step 9 and T_o from step 2.	d_b/L_o
14	11	a_o from step 3 and d_b/L_o from step 13	a_b deg K_d
15	12	H_b from step 6 and K_d from step 14	H_b corrected for refraction cor H_b ft
16	13	a_b from step 14 and Beach Slope from heading. H_b from step 15 and T_o from step 2	Longshore Current kt

Figure 6-10.-Sample surf worksheet.

SURFCST (Beach)______ (Time)______	
ALPHA______ BRAVO______ CHARLIE______	
DELTA______ ECHO______ FOXTROT______	
GOLF______ HOTEL______	
ALPHA	= Significant Breaker Height (ft)
BRAVO	= Maximum Breaker Height (ft)
CHARLIE	= Period of Breakers (sec)
DELTA	= Type of Breakers
ECHO	= Angle Breakers Make with Beach (deg)
FOXTROT	= Longshore Current (kt)
GOLF	= Number of Lines of Surf, Width of Surf Zone (yd)
HOTEL	= Remarks

Figure 6-11.-Example of final forecast form.

followed. Most units involved in surface current forecasts have their own innovations and methods.

CURRENTS

Aerographer's Mates have a knowledge of the major ocean currents and the meteorological results of the interaction of sea and air. Oceanic circulation (currents) plays a major role in the production and distribution of weather phenomena. Principal surface current information such as direction, speed, and temperature distribution is relatively well known.

Tidal and Nontidal currents

Currents in the sea are generally produced by wind, tide, differences in density between water masses, sea level differences, or runoff from the land. They maybe roughly classed as tidal or nontidal currents. Tidal currents are usually significant in shallow water only, where they often become the strong or dominant flow. Nontidal currents include the permanent currents in the general circulatory systems of the oceans; geopotential currents, those associated with density difference in water masses; and temporary currents, such as wind-driven currents that are developed from meteorological conditions. The system of currents in the oceans of the world keeps the water continually circulating. The positions shift only slightly with the seasons except in the Southeast Asia area where monsoonal effects actually reverse the direction of flow from summer to winter. Currents appear on most charts as continuous streams defined by clear boundaries and with gradually changing directions. These presentations usually are smoothed patterns that were derived from averages of many observations.

Drift

The speed of a current is known as its drift. Drift is normally measured in knots. The term velocity is often interchanged with the term speed in dealing with currents although there is a difference in actual meaning. Set, the direction that the current acts or proceeds, is measured according to compass points or degrees. Observations of currents are made directly by mechanical devices that record speed and direction, or indirectly by water density computations, drift bottles, or visually using slicks and watercolor differences.

Ocean currents are usually strongest near the surface and sometimes attain considerable speed, such as 5 knots or more reached by the Florida Current, In the middle latitudes, however, the strongest surface currents rarely reach speeds above 2 knots.

Eddies

Eddies, which vary in size from a few miles or more in diameter to 75 miles or more in diameter, branch from the major currents. Large eddies are common on both sides of the Gulf Stream from Cape Hatteras to the Grand Banks. How long such eddies persist and retain their characteristics near the surface is not well known, but large eddies near the Gulf Stream are known to persist longer than a month. The surface speeds of currents within these eddies, when first formed, may reach 2 knots. Smaller eddies have much less momentum and soon die down or lose their surface characteristics through wind stirring.

WIND DRIVEN CURRENTS

Wind driven currents are, as the name implies, currents that are created by the force of the wind exerting stress on the sea surface. This stress causes the surface water to move and this movement is transmitted to the underlying water to a depth that is dependent mainly on the strength and persistence of the wind. Most ocean currents are the result of winds that tend to blow in a given direction over considerable amounts of time. Likewise, local currents, those peculiar to an area, will arise when the wind blows in one direction for some time. In many cases the strength of the wind may be used as a rule of thumb for determining the speed of the local current; the speed is figured as 2 percent of the wind's force. Therefore, if a wind blows 3 or 4 days in a given direction at about 20 knots, it maybe expected that a local current of nearly 0.4 knot is being experienced.

A wind-driven current does not flow in exactly the same direction as the wind, but is deflected by Earth's rotation. The deflecting force (Coriolis force) is greater at high latitudes and more effective in deep water. It is to the right of the wind direction in the Northern Hemisphere and to the left in the Southern Hemisphere. At latitudes between 10N and 10S the current usually sets downwind. In general the angular difference in direction between the wind and the surface current varies from about 10 degrees in shallow coastal areas to as much as 45 degrees in some open ocean areas. Each layer of moving water sets the layer below in motion. And the layer below is then deflected by the Coriolis effect, causing the below layer to move to the right of the overlying layer. Deeper layers move more slowly because energy is lost in each transfer between layers.

We can plot movements of each layer using arrows whose length represents the speed of movement and whose direction corresponds to the direction of the layer's movements. The idealized pattern for a surface current set in motion by the wind in the Northern Hemisphere is called the EKMAN SPIRAL. Each layer is deflected to the right of the overlying layer, so the direction of water movement shifts with increasing depth. The angle increases with the depth of the current, and at certain depths the current may flow in the opposite direction to that of the surface.

Some major wind-driven currents are the West Wind Drift in the Antarctic, the North and South Equatorial Currents that lie in the trade wind belts of the ocean, and the seasonal monsoon currents of the Western Pacific.

Chapters 6 and 7 of *Oceanography, Sixth Edition,* by M. Grant Gross, contain additional information on the subjects of waves, tides, coasts, and the coastal oceans.

COASTAL AND TIDAL CURRENTS

Coastal currents are caused mainly by river discharge, tide, and wind. However, they may in part be produced by the circulation in the open ocean areas. Because of tides or local topography, coastal currents are generally irregular.

Tidal currents, a factor of little importance in general deepwater circulation, are of great influence in coastal waters. The tides furnish energy through tidal currents, which keep coastal waters relatively well stirred. Tidal currents are most pronounced in the entrances to large tidal basins that have restricted openings to the sea. This fact often accounts for steerage problems experienced by vessels.

WIND DRIVEN CURRENT PREDICTION

Attempts at current prediction in the past have only been moderately successful. There has been a tendency to consider ocean currents in much the same manner as wind currents in the atmosphere, when in actuality it appears that ocean currents are affected by an even greater number of factors. It therefore requires different techniques to be used.

In order to predict current information, it must be understood that currents are typically unsteady in direction and speed. This has been well documented in a number of studies. The reasons for this variability have been attributed to the other forces, besides wind and tides, that affect the currents.

Climatological surface charts have been constructed for nearly all the oceans of the world using data from ship's drifts. However, this data has been shown to have limitations and should be used as a rough estimate only.

Synoptic Analysis and Forecasting of Surface Currents, NWRF 36-0667-127, provides a composite method of arriving at current forecasts. This method uses portions of other methods that have been used. Forecasters should make themselves aware of the information contained in this publication.

COASTAL AND TIDAL CURRENT PREDICTION

Prediction of tidal currents must be based on specific information for the locality in question. Such information is contained in various forms in many navigational publications.

Tidal Current Tables, issued annually, list daily predictions of the times and strengths of flood and ebb currents and the time of intervening slacks. Due to lack of observational data, coverage is considerably more limited than for tides. The Tidal Current Tables do include supplemental tidal data that can be determined for many places in addition to those for where daily predictions are given.

SUMMARY

In this chapter, we discussed the basic principles and properties of ocean waves, associated terms, and wave spectrum. Next we considered forecasting of sea waves, generation and growth, and the characteristics of fully and nonfully developed seas. Wind field and fetch areas were also covered followed by an objective method of forecasting sea waves. We also covered the generation, dispersion and angular spreading of swell waves, as well as an objective method for forecasting swell waves. The generation of surf and associated characteristics, the three breaker types, definition of terms, and an objective technique for forecasting surf were also considered, followed by an explanation of the modified surf index. Finally, we looked at forecasting surface currents, wind driven currents, coastal and tidal currents.