CHAPTER 40

WEATHER OBSERVATIONS

BASIC WEATHER OBSERVATIONS

4000. Introduction

Weather forecasts are based upon information acquired by observations made at a large number of stations. Ashore, these stations are located so as to provide adequate coverage of the area of interest. Observations at sea are made by mariners, buoys, and satellites. Since the number of observations at sea is small compared to the number ashore, marine observations are of great importance. Data recorded by designated vessels are sent by radio or satellite to national meteorological centers ashore, where they are calculated into computer forecast models for the development of synoptic charts. These models are then used to prepare local and global forecasts. The complete set of weather data gathered at sea is then sent to the appropriate meteorological services for use in the preparation of weather atlases and in marine climatological studies.

Weather observations are normally taken on the major synoptic hours (0000, 0600, 1200, and 1800 UTC). However, three-hourly intermediate observations are necessary on the Great Lakes, within 200 nautical miles from the United States or Canadian coastline, or within 300 nautical miles of a named tropical cyclone. Even with satellite imagery, actual reports are needed to confirm developing patterns and provide accurate temperature, pressure, and other measurements. Forecasts can be no better than the data received.

4001. Atmospheric Pressure

The sea of air surrounding the Earth exerts a pressure of about 14.7 pounds per square inch on the surface of the Earth. This **atmospheric pressure**, sometimes called **barometric pressure**, varies from place to place, and at the same place it varies over time.

Atmospheric pressure is one of the most basic elements of a meteorological observation. When the pressure at each station is plotted on a synoptic chart, lines of equal atmospheric pressure, called **isobars**, indicate the areas of high and low pressure. These are useful in making weather predictions because certain types of weather are characteristic of each type of area, and wind patterns over large areas can be deduced from the isobars.

Atmospheric pressure is measured with a **barometer**. The earliest known barometer was the **mercurial barometer,** invented by Evangelista Torricelli in 1643. In its simplest form, it consists of a glass tube a little more than 30 inches in length and of uniform internal diameter. With one end closed, the tube is filled with mercury, and inverted into a cup of mercury. The mercury in the tube falls until the column is just supported by the pressure of the atmosphere on the open cup, leaving a vacuum at the upper end of the tube. The height of the column indicates atmospheric pressure, with greater pressures supporting higher columns of mercury.

The **aneroid barometer** has a partly evacuated, thin metal cell which is compressed by atmospheric pressure. Slight changes in air pressure cause the cell to expand or contract, while a system of levers magnifies and converts this motion to a reading on a gauge or recorder.

Early mercurial barometers were calibrated to indicate the height, usually in inches or millimeters, of the column of mercury needed to balance the column of air above the point of measurement. While units of inches and millimeters are still widely used, many modern barometers are calibrated to indicate the centimeter-gram-second unit of pressure, the hectopascal (hPa), formerly known as the millibar. The hectopascal is equal to 1,000 dynes per square centimeter. A dyne is the force required to accelerate a mass of one gram at the rate of one centimeter per second per second. 1,000 hPa = 100,000 Pascal = 14.50 pounds per square inch = 750.0 mm Hg = 0.9869 atmosphere. A reading in any of the three units of measurement can be converted to the equivalent reading in any of the other units by using the Conversion Table for hecto-Pascals (millibars), Inches of Mercury, and Millimeters of Mercury (Table 34) or the conversion factors. However, the pressure reading should always be reported in hPa.

4002. The Aneroid Barometer

The **aneroid barometer** (Figure 4002a) measures the force exerted by atmospheric pressure on a partly evacuated, thin metal element called a **sylphon cell** or aneroid capsule. A small spring is used, either internally or externally, to partly counteract the tendency of the atmospheric pressure to crush the cell. Atmospheric pressure is indicated directly by a scale and a pointer connected to the cell by a combination of levers. The linkage provides considerable magnification of the slight motion of the cell, to permit readings to higher precision than could be obtained without it. An aneroid barometer should be mounted permanently.

Figure 4002a. An aneroid barometer.

Prior to installation, the barometer should be carefully set. U.S. ships of the **Voluntary Observation Ship (VOS)** program are set to sea level pressure. Other vessels may be set to station pressure and corrected for height as necessary. An adjustment screw is provided for this purpose. The error of this instrument is determined by comparison with a mercurial barometer, Digiquartz barometer, or a standard precision aneroid barometer. If a qualified meteorologist is not available to make this adjustment, adjust by first removing only one half the apparent error. Then tap the case gently to assist the linkage to adjust itself, and repeat the adjustment. If the remaining error is not more than half a hPa (0.015 inch), no attempt should be made to remove it by further adjustment. Instead, a correction should be applied to the readings. The accuracy of this correction should be checked from time to time.

More information regarding the Voluntary Observation Ship (VOS) program can be accessed via the link provided in Figure 4002b.

Figure 4002b. Voluntary Observation Ship (VOS) Program. http://www.vos.noaa.gov/

4003. The Barograph

The **barograph** (Figure 4003) is a recording barometer. In principle it is the same as a non-recording aneroid barometer except that the pointer carries a pen at its outer end, and a slowly rotating cylinder around which a chart is wrapped replaces the scale. A clock mechanism inside the cylinder rotates it so that a continuous line is traced on the chart to indicate the pressure at any time. The barograph is usually mounted on a shelf or desk in a room open to the atmosphere and in a location which minimizes the effect of the ship's vibration. Shock absorbing material such as sponge rubber may be placed under the instrument to minimize vibration. The pen should be checked each time the chart is changed.

A **marine microbarograph** is a precision barograph using greater magnification and an expanded chart. It is designed to maintain its precision through the conditions encountered aboard ship. Two sylphon cells are used, one mounted over the other, in tandem. Minor fluctuations due to shocks or vibrations are eliminated by damping. Since oil

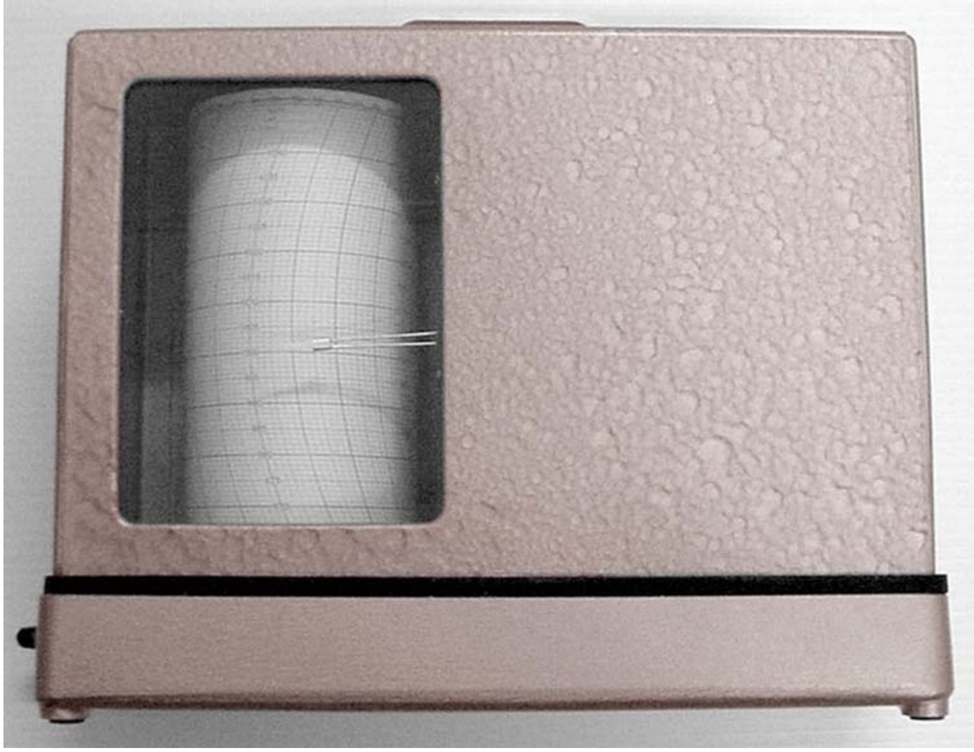


Figure 4003. A marine barograph.

filled dashpots are used for this purpose, the instrument should never be inverted. The dashpots of the marine microbarograph should be kept filled with dashpot oil to within three-eighths inch of the top. The marine microbarograph is fitted with a valve so it can be vented to the outside for more accurate pressure readings.

Ship motions are compensated by damping and spring loading which make it possible for the microbarograph to be tilted up to 22° without varying more than 0.3 hPa from the true reading. Microbarographs have been almost entirely replaced by standard barographs.

Both instruments require checking from time to time to insure correct indication of pressure. The position of the pen is adjusted by a small knob provided for this purpose. The adjustment should be made in stages, eliminating half the apparent error, tapping the case to insure linkage adjustment to the new setting, and then repeating the process.

4004. Adjusting Barometer Readings

Atmospheric pressure as indicated by a barometer or barograph may be subject to several errors.

Instrument error: Inaccuracy due to imperfection or incorrect adjustment can be determined by comparison with a standard precision instrument. The National Weather Service provides a comparison service. In major U.S. ports, a **Port Meteorological Officer (PMO)** carries a portable precision aneroid barometer or a digital barometer for barometer comparisons on board ships which participate in the VOS program. The portable barometer is compared with station barometers before and after a ship visit. If a barometer is taken to a National Weather Service shore station, the comparison can be made there. The correct sea level pressure can also be obtained by telephone. The shipboard barometer should be corrected for height, as explained below, before comparison with this value. If there is reason to believe that the barometer is in error, it should be compared with a standard, and if an error is found, the barometer should be adjusted to the correct reading, or a correction applied to all readings. More information regarding PMOs is available via the link provided in Figure 4004.

Figure 4004. *Link to Port Meteorological Officers website.*
http://www.vos.noaa.gov/met_officers.shtml

Height error: The atmospheric pressure reading at the height of the barometer is called the **station pressure** and is subject to a height correction in order to correct it to sea level. Isobars adequately reflect wind conditions and geographic distribution of pressure only when they are drawn for pressure at constant height (or the varying height at which a constant pressure exists). On synoptic charts it is customary to show the equivalent pressure at sea level, called **sea level pressure**. This is found by applying a correction to station pressure. The correction depends upon the height of the barometer and the average temperature of the air between this height and the surface. The outside air temperature taken aboard ship is sufficiently accurate for this purpose and is an important correction that should be applied to all readings of any type of barometer. See the Correction of Barometer Reading for Height Above Sea Level (Table 31) for this correction. Of special note on the Great Lakes, each Lake is at a different height above sea level, so an additional correction is needed.

Temperature error: Barometers are calibrated at a standard temperature of 32°F. Modern aneroid barometers compensate for temperature changes by using different metals having unequal coefficients of linear expansion.

4005. Temperature

Temperature is a measure of heat energy, measured in degrees. Several different temperature scales are in use.

On the **Fahrenheit (F)** scale, pure water freezes at 32° and boils at 212°.

On the **Celsius (C)** scale, commonly used with the metric system, the freezing point of pure water is 0° and the boiling point is 100°. This scale has been known by various names in different countries. In the United States it was formerly called the centigrade scale. The Ninth General Conference of Weights and Measures, held in France in 1948, adopted the name Celsius to be consistent with the naming of other temperature scales after their inventors, and to avoid the use of different names in different countries. On the original Celsius scale, invented in 1742 by a Swedish astronomer named Anders Celsius, numbering was the reverse of the modern scale, 0° representing the boiling point of water, and 100° its freezing point.

Temperature of one scale can be easily converted to another because of the linear mathematical relationship between them. Note that the sequence of calculation is slightly different; algebraic rules must be followed.

$$C = \frac{5}{9}(F - 32), \text{ or } \qquad C = \frac{F - 32}{1.8}$$

$$F = \frac{9}{5}C + 32, \text{ or } \qquad F = 1.8C + 32$$

$$K \text{ (Kelvin)} = C + 273.15$$

$$R \text{ (Rankine)} = F + 459.69$$

A temperature of –40° is the same by either the Celsius or Fahrenheit scale. Similar formulas can be made for conversion of other temperature scale readings. The Conversion Table for Thermometer Scales (Table 29) gives the equivalent values of Fahrenheit, Celsius, and Kelvin temperatures.

The intensity or degree of heat (temperature) should not be confused with the amount of heat. If the temperature of air or some other substance is to be increased by a given number of degrees, the amount of heat that must be added depends on the mass of the substance. Also, because of differences in their specific heat, equal amounts of different substances require the addition of unequal amounts of heat to raise their temperatures by equal amounts. The units used for measurement of heat are the **British thermal unit (BTU),** the amount of heat needed to raise the temperature of 1 pound of water 1° Fahrenheit, and the **calorie**, the amount of heat needed to raise the temperature of 1 gram of water 1° Celsius.

4006. Temperature Measurement

Temperature is measured with a **thermometer**. Most thermometers are based upon the principle that materials expand with an increase of temperature, and contract as temperature decreases. In its most common form, a thermometer consists of a bulb filled with mercury or a glycol based fluid, which is connected to a tube of very small cross sectional area. The fluid only partly fills the tube. In the remainder is a vacuum. Air is driven out by boiling the fluid, and the top of the tube is then sealed. As the fluid expands or contracts with changing temperature, the length of the fluid column in the tube changes.

Sea surface temperature observations are used in the forecasting of fog and furnish important information about the development and movement of tropical cyclones. Commercial fishermen are interested in the sea surface temperature as an aid in locating certain species of fish. There are several methods of determining seawater temperature. These include engine room intake readings, condenser intake readings, thermistor probes attached to the hull, and readings from buckets recovered from over the side. Although the condenser intake method is not a true measure of surface water temperature, the error is generally small.

If the surface temperature is desired, a sample should be obtained by bucket, preferably made of canvas, from a forward position well clear of any discharge lines. The sample should be taken immediately to a place where it is sheltered from wind and Sun. The water should then be stirred with the thermometer, keeping the bulb submerged, until a constant reading is obtained.

A considerable variation in sea surface temperature can be experienced in a relatively short distance of travel. This is especially true when crossing major ocean currents such as the Gulf Stream and the Kuroshio Current. Significant variations also occur where large quantities of fresh water are discharged from rivers or bays. A clever navigator will note these changes as an indication of when to allow for set and drift in dead reckoning.

4007. Humidity

Humidity is a measure of the atmosphere's water vapor content. **Relative humidity** is the ratio, stated as a percentage, of the pressure of water vapor present in the atmosphere to the saturation vapor pressure at the same temperature.

As air temperature decreases, the relative humidity increases, as long as the wet-bulb temperature remains the same or decreases at a slower rate than air temperature. At some point, saturation takes place, and any further cooling results in condensation of some of the moisture. The temperature at which this occurs is called the dew point, and the moisture deposited upon objects is called dew if it forms in the liquid state, or frost if it forms as ice crystals.

The same process causes moisture to form on the outside of a container of cold liquid, the liquid cooling the air in the immediate vicinity of the container until it reaches the dew point. When moisture is deposited on man-made objects, it is sometimes called **sweat**. It occurs whenever the temperature of a surface is lower than the dew point of air in contact with it. It is of particular concern to the mariner because of its effect upon instruments, and possible damage to ship or cargo. Lenses of optical instruments may sweat, usually with such small droplets that the surface has a "frosted" appearance. When this occurs, the instrument is said to "fog" or "fog up," and is useless until the moisture is removed. Damage is often caused by corrosion or direct water damage when pipes or inner shell plates of a vessel sweat and drip. Cargo may also sweat if it is cooler than the dew point of the air.

Clouds and fog form from the condensation of water on minute particles of dust, salt, and other material in the air. Each particle forms a nucleus around which a droplet of water forms. If air is completely free from solid particles on which water vapor may condense, the extra moisture remains vaporized, and the air is said to be **supersaturated**.

Relative humidity and dew point are measured with a **hygrometer**. The most common type, called a **psychrometer**, consists of two thermometers mounted together on a single strip of material. One of the thermometers is mounted a little lower than the other, and has its bulb covered with muslin. When the muslin covering is thoroughly moistened and the thermometer well ventilated, evaporation cools the bulb of the thermometer, causing it to indicate a lower reading than the other. A **sling psychrometer** is ventilated by whirling the thermometers. The difference between the dry-bulb and wet-bulb temperatures is used to enter **psychrometric tables** (Relative Humidity and Dew Point Tables) (Table 35 and Table 36) to find the relative humidity and dew point. If the wet-bulb temperature is above freezing, reasonably accurate results can be obtained by a psychrometer consisting of dry- and wet-bulb thermometers mounted so that air can circulate freely around them without special ventilation. This type of installation is common aboard ship.

Example: *The dry-bulb temperature is 65°F, and the wet-bulb temperature is 61°F.*

Required: *(1) Relative humidity, (2) dew point.*

Solution: *The difference between readings is 4°. Entering the Relative Humidity Table (Table 35) with this value, and a dry-bulb temperature of 65°, the relative humidity is found to be 80%. From the Dew Point Table (Table 36) the dew point is 58°.*

Answers: *(1) Relative humidity 80 percent, (2) dew point 58°.*

Also in use aboard many ships is the **electric psychrometer**. This is a hand held, battery operated instrument with two mercury thermometers for obtaining dry- and wet-bulb temperature readings. It consists of a plastic housing that holds the thermometers, batteries, motor, and fan.

4008. Wind Measurement

Wind measurement consists of determination of the direction and speed of the wind. Direction is measured by a **wind vane**, and speed by an **anemometer**. Several types of wind speed and direction sensors are available, using vanes to indicate wind direction (where the wind is coming from) and rotating cups or propellers for speed sensing. Many ships have reliable wind instruments installed, and inexpensive wind instruments are available for even the smallest yacht. If no anemometer is available, wind speed can be estimated by its effect upon the sea and nearby objects. The direction can be computed accurately, even on a fast moving vessel, by maneuvering board or using the Direction and Speed of True Wind in Units of Ship's Speed (Table 30).

4009. True and Apparent Wind

An observer aboard a vessel proceeding through still air experiences an apparent wind which is from dead ahead and has an apparent speed equal to the speed of the vessel. Thus, if the actual or true wind is zero and the speed of the vessel is 10 knots, the apparent wind is from dead ahead at 10 knots. If the true wind is from dead ahead at 15 knots, and the speed of the vessel is 10 knots, the apparent wind is 15 + 10 = 25 knots from dead ahead. If the vessel reverses course, the apparent wind is 15 – 10 = 5 knots, from dead astern.

The **apparent wind** is the vector sum of the true wind and the *reciprocal* of the vessel's course and speed vector. Since wind vanes and anemometers measure apparent wind, the usual problem aboard a vessel equipped with an anemometer is to convert apparent wind to true wind. There are several ways of doing this. Perhaps the simplest is by the graphical solution illustrated in the following example:

Example 1: *A ship is proceeding on course 240° at a speed of 18 knots. The apparent wind is from 040° relative at 30 knots.*

Required: *The direction and speed of the true wind.*

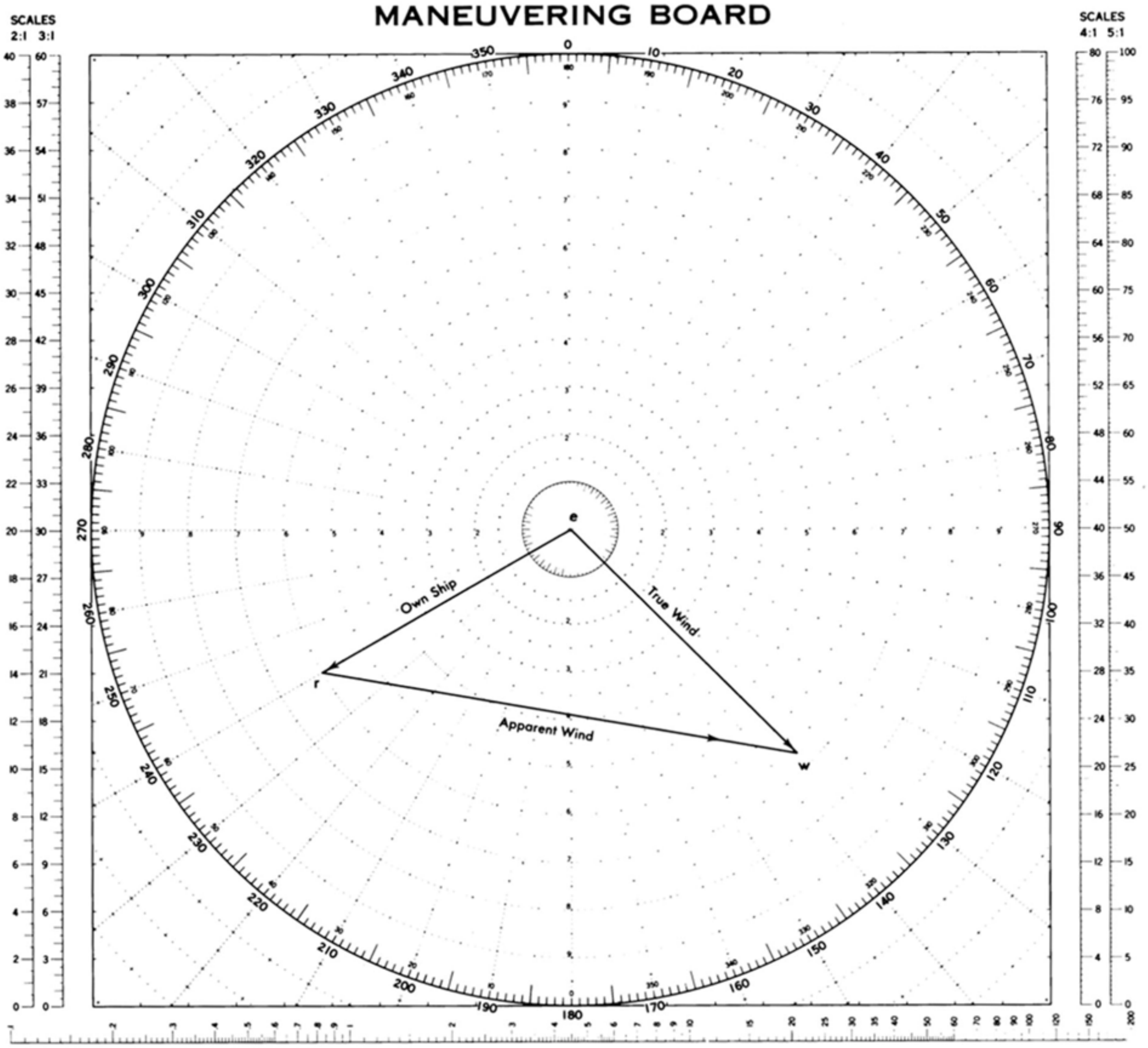


Figure 4009a. Finding true wind by Maneuvering Board.

Solution: *(Figure 4009a) First starting from the center of a maneuvering board, plot the ship's vector "er," at 240°, length 18 knots (using the 3–1 scale). Next plot the relative wind's vector from r, in a direction of 100° (the reciprocal of 280°) length 30 knots. The true wind is from the center to the end of this vector or line "ew."*

Alternatively, you can plot the ship's vector from the center, then plot the relative wind's vector toward the center, and see the true wind's vector from the end of this line to the end of the ship's vector. Use parallel rulers to transfer the wind vector to the center for an accurate reading.

Answer: *True wind is from 315° at 20 knots.*

On a moving ship, the direction of the true wind is always on the same side and aft of the direction of the apparent wind. The faster the ship moves, the more the apparent wind draws ahead of the true wind.

A solution can also be made in the following manner without plotting: On a maneuvering board, label the circles 5, 10, 15, 20, etc., from the center, and draw vertical lines tangent to these circles. Cut out the 5:1 scale and discard that part having graduations greater than the maximum speed of the vessel. Keep this sheet for all solutions. (For durability, the two parts can be mounted on cardboard or other suitable material.) To find true wind, spot in point 1 by eye. Place the zero of the 5:1 scale on this point and align the scale (inverted) using the vertical lines. Locate point 2 at the speed of the vessel as indicated on the 5:1 scale. It is always vertically below point 1. Read the relative direction and the speed of the true wind, using eye interpolation if needed.

A tabular solution can be made using the Direction and Speed of True Wind in Units of Ship's Speed table (Table 30). The entering values for this table are the apparent wind speed in units of ship's speed, and the difference between the heading and the apparent wind direction. The values taken from the table are the relative direction (right or left) of the true wind, and the speed of the true wind in units of ship's speed. If a vessel is proceeding at 12 knots, 6 knots constitutes one-half (0.5) unit, 12 knots one unit, 18 knots 1.5 units, 24 knots two units, etc.

Example 2: *A ship is proceeding on course 270° at a speed of 10 knots. The apparent wind is from 10° off the port bow, speed 30 knots.*

Required: *The relative direction, true direction, and speed of the true wind by table.*

Solution: *The apparent wind speed is*

$$\frac{30}{10} = 3.0\ ships\ speed\ units$$

Enter the Direction and Speed of True Wind in Units of Ship's Speed (Table 30) with 3.0 and 10° and find the relative direction of the true wind to be 15° off the port bow (345° relative), and the speed to be 2.02 times the ship's speed, or 20 knots, approximately. The true direction is 345°+ 270°(-360) = 255°.

Answers: *True wind from 345° relative = 255° true, at 20 knots.*

Figure 4009b. Link to Pub 1310, The Radar Navigation and Maneuvering Board Manual. https://msi.nga.mil/NGAPortal/MSI.portal?_nfpb=true&_st=&_pageLabel=msi_portal_page_62&pubCode=0008

One can also find apparent wind from the true wind, course or speed required to produce an apparent wind from a given direction or speed, or course and speed to produce an apparent wind of a given speed from a given direction. Such problems often arise in aircraft carrier operations and in some rescue situations. Printable maneuvering board files are available through the link provided in Figure 4009b.

When wind speed and direction are determined by the appearance of the sea, the result is true speed and direction. Waves move in the same direction as the generating wind, and are not deflected by Earth's rotation. If a wind vane is used, the direction of the apparent wind thus determined can be used with the speed of the true wind to determine the direction of the true wind by vector diagram.

WIND AND WAVES

4010. Effects of Wind on the Sea

There is a direct relationship between the speed of the wind and the state of the sea. This is useful in predicting the sea conditions to be anticipated when future wind speed forecasts are available. It can also be used to estimate the speed of the wind, which may be necessary when an anemometer is not available.

Wind speeds are usually grouped in accordance with the ***Beaufort Scale of Wind Force***, devised in 1806 by English Admiral Sir Francis Beaufort (1774-1857). As adopted in 1838, Beaufort numbers ranged from 0 (calm) to 12 (hurricane). The Beaufort wind scale and sea state photographs at the end of this chapter can be used to estimate wind speed (also see Table 4012). With the exception of Force 12, contributed by John Thomson of Ponteland, Northumberland, England, these pictures (courtesy of the Meteorological Service of Canada) represent the results of a project carried out on board the Canadian Ocean Weather Ships VANCOUVER and QUADRA at Ocean Weather Station PAPA (50°N, 145°W), between April 1976 and May 1981. The aim of the project was to collect color photographs of the sea surface as it appears under the influence of the various ranges of wind speed, as defined by The Beaufort Scale. The photographs represent as closely as possible steady state sea conditions over many hours for each Beaufort wind force. They were taken from heights ranging from 12-17 meters above the sea surface; anemometer height was 28 meters.

4011. Estimating the Wind at Sea

When there is not a functioning anemometer, observers on board ships will usually determine the speed of the wind by estimating Beaufort force. Through experience, ships' officers have developed various methods of estimating this force. The effect of the wind on the observer, the ship's rigging, flags, etc., is used as a guide, but estimates based on these indications give the relative wind which must be corrected for the motion of the ship before an estimate of the true wind speed can be obtained.

The most common method involves the appearance of the sea surface. The state of the sea disturbance, i.e. the dimensions of the waves, the presence of white caps, foam, or spray, depends principally on three factors:

1. **The wind speed**. The higher the speed of the wind, the greater is the sea disturbance.
2. **The wind's duration**. At any point on the sea, the disturbance will increase the longer the wind blows at a given speed, until a maximum state of disturbance is reached.

3. **The fetch**. This is the length of the stretch of water over which the wind acts on the sea surface from the same direction.

For a given wind speed and duration, the longer the fetch, the greater is the sea disturbance. If the fetch is short, such as a few miles, the disturbance will be relatively small no matter how great the wind speed is or how long it has been blowing.

Swell waves are not considered when estimating wind speed and direction. Only those waves raised by the wind blowing at the time are of any significance.

A wind of a given Beaufort force will, therefore, produce a characteristic appearance of the sea surface provided that it has been blowing for a sufficient length of time, and over a sufficiently long fetch.

In practice, the mariner observes the sea surface, noting the size of the waves, the white caps, spindrift, etc., and then finds the criterion which best describes the sea surface as observed. This criterion is associated with a Beaufort number, for which a corresponding mean wind speed and range in knots are given. Since meteorological reports require that wind speeds be reported in knots, the mean speed for the Beaufort number may be reported, or an experienced observer may judge that the sea disturbance is such that a higher or lower speed within the range for the force is more accurate.

This method should be used with caution. The sea conditions described for each Beaufort force are "steady-state" conditions; i.e. the conditions which result when the wind has been blowing for a relatively long time, and over a great stretch of water. However, at any particular time at sea the duration of the wind or the fetch, or both, may not have been great enough to produce these "steady-state" conditions. When a high wind springs up suddenly after previously calm or near calm conditions, it will require some hours, depending on the strength of the wind, to generate waves of maximum height. The height of the waves increases rapidly in the first few hours after the commencement of the blow, but increases at a much slower rate later on.

Beaufort force of wind.	Theoretical maximum wave height (ft) unlimited duration and fetch.	Duration of winds (hours), with unlimited fetch, to produce percent of maximum wave height indicated.			Fetch (nautical miles), with unlimited duration of blow, to produce percent of maximum wave height indicated.		
		50%	75%	90%	50%	75%	90%
3	2	1.5	5	8	3	13	25
5	8	3.5	8	12	10	30	60
7	20	5.5	12	21	22	75	150
9	40	7	16	25	55	150	280
11	70	9	19	32	85	200	450

Table 4011. Duration of winds and length of fetches required for various wind forces.

At the beginning of the fetch (such as at a coastline when the wind is offshore) after the wind has been blowing for a long time, the waves are quite small near shore, and increase in height rapidly over the first 50 miles or so of the fetch. Farther offshore, the rate of increase in height with distance slows down, and after 500 miles or so from the beginning of the fetch, there is little or no increase in height.

Table 4011 illustrates the duration of winds and the length of fetches required for various wind forces to build seas to 50 percent, 75 percent, and 90 percent of their theoretical maximum heights.

The theoretical maximum wave heights represent the average heights of the highest third of the waves, as these waves are most significant.

It is clear that winds of force 5 or less can build seas to 90 percent of their maximum height in less than 12 hours, provided the fetch is long enough. Higher winds require a much greater time, force 11 winds requiring 32 hours to build waves to 90 percent of their maximum height. The times given in Table 4011 represent those required to build waves starting from initially calm sea conditions. If waves are already present at the onset of the blow, the times would be somewhat less, depending on the initial wave heights and their direction relative to the direction of the wind which has sprung up.

The first consideration when using the sea criterion to estimate wind speed, therefore, is to decide whether the wind has been blowing long enough from the same direction to produce a steady state sea condition. If not, then it is possible that the wind speed may be underestimated.

Experience has shown that the appearance of white-caps, foam, spindrift, etc. reaches a steady state condition before the height of the waves attain their maximum value. It is a safe assumption that the appearance of the sea (such as white-caps, etc.) will reach a steady state in the time required to build the waves to 50-75 percent of their maximum height. Thus, from Table 4011 it is seen that a force 5 wind could require 8 hours at most to produce a characteristic appearance of the sea surface.

A second consideration when using the sea criteria is the amount of the fetch over which the wind has been blowing to produce the present state of the sea. On the open sea, unless the mariner has the latest synoptic weather map available, the length of the fetch will not be known. It will be seen from Table 4011 though, that only relatively short fetches are required for the lower wind forces to generate their characteristic seas. On the open sea, the fetches associated with most storms and other weather systems are usually long enough so that even winds up to force 9 can build seas up to 90 percent or more of their maximum height, providing the wind blows from the same direction long enough.

When navigating close to a coast or in restricted waters, however, it may be necessary to make allowances for the shorter stretches of water over which the wind blows. For example, referring to Table 4011, if the ship is 22 miles from a coast, and an offshore wind with an actual speed of force 7 is blowing, the waves at the ship will never attain more than 50 percent of their maximum height for this speed no matter how long the wind blows. Hence, if the sea criteria were used under these conditions without consideration of the short fetch, the wind speed would be underestimated. With an offshore wind, the sea criteria may be used with confidence if the distance to the coast is greater than the values given in the extreme right-hand column of Table 4011, provided that the wind has been blowing offshore for a sufficient length of time.

4012. Wind Speed Calculating Factors

Tidal and Other Currents: A wind blowing against the tide or a strong non-tidal current causes higher, steeper waves having a shorter period than normal, which may result in an overestimate of the wind speed if the estimation is made by wave height alone. On the other hand, a wind blowing in the same direction as a tide or strong current causes less sea disturbance than normal, with longer period waves, which may result in underestimating the wind speed.

Shallow Water: Waves running from deep water into shallow water increase in steepness, hence their tendency to break. Therefore, with an onshore wind there will naturally be more whitecaps over shallow waters than over the deeper water farther offshore. It is only over relatively deep water that the sea criteria can be used with confidence.

Swell: Swell is the name given to waves, generally of considerable length, which were raised in some distant area and which have moved into the vicinity of the ship, or to waves raised nearby that continue after the wind has abated or changed direction. The direction of swell waves is usually different from the direction of the wind and the sea waves. Swell waves are not considered when estimating wind speed and direction. Only those waves raised by the wind blowing at the time are used for estimation. The wind-driven waves show a greater tendency to break when superimposed on the crests of swell, and hence, more whitecaps may be formed than if the swell were absent. Under these conditions, the use of the sea criteria may result in a slight overestimate of the wind speed.

Precipitation: Heavy rain has a damping or smoothing effect on the sea surface that is mechanical in character. Since the sea surface will therefore appear less disturbed than would be the case without the rain, the wind speed may be underestimated unless the smoothing effect is taken into account.

Ice: Even small concentrations of ice floating on the sea surface will dampen waves considerably, and concentrations averaging greater than about seven-tenths will eliminate waves altogether. Young sea ice, which in the early stages of formation has a thick soupy consistency and later takes on a rubbery appearance, is very effective in dampening waves. Consequently, the sea criteria cannot be used with any degree of confidence when sea ice is present. In higher latitudes, the presence of an ice field some distance to windward of the ship may be suspected if, when the ship is not close to any coast, the wind is relatively strong but the seas abnormally underdeveloped. The edge of the ice field acts like a coastline, and the short fetch between the ice and the ship is not sufficient for the wind to fully develop the seas.

Wind Shifts: Following a rapid change in the direction of the wind, as occurs at the passage of a cold front, the new wind will flatten out to a great extent the waves which were present before the wind shift. This happens because the direction of the wind after the shift may differ by 90° or more from the direction of the waves, which does not change. Hence, the wind may oppose the progress of the waves and quickly dampen them out. At the same time, the new wind begins to generate its own waves on top of this dissipating swell, and it is not long before the cross pattern of waves gives the sea a “choppy” or confused appearance. It is during the first few hours following the wind shift that the appearance of the sea surface may not provide a reliable indication of wind speed. The wind is normally stronger than the sea would indicate, as old waves are being flattened out, and the new wave pattern develops.

Night Observations: On a dark night, when it is impossible to see the sea clearly, the observer may estimate the apparent wind from its effect on the ship’s rigging, flags, etc., or simply the “feel” of the wind.

Wind Scales and Sea Codes: Table 4012 contains descriptions for the Beaufort wind scale and corresponding sea state codes.

Beaufort Wind Scale with Corresponding Sea Codes						
Beaufort Number	**Wind Velocity (knots)**	**Wind Velocity (mph)**	**Wind Description**	**Sea State Description**	**Sea State**	
					Term and Height of Waves (feet)	**Condition Number**
0	< 1	< 1	Calm	Sea surface smooth and mirror-like	Calm, glassy 0	0
1	1-3	1-3	Light Air	Scaly ripples, no foam crests		
2	4-6	4-7	Light Breeze	Small wavelets, crests glassy, no breaking	Calm, rippled 0 - 0.3	1
3	7-10	8-12	Gentle Breeze	Large wavelets, crests begin to break, scattered whitecaps	Smooth, wavelets 0.3 - 1	2
4	11-16	13-18	Moderate Breeze	Small waves, becoming longer, numerous whitecaps	Slight 1- 4	3
5	17-21	19-24	Fresh Breeze	Moderate waves, taking longer form, many whitecaps, some spray	Moderate 4 - 8	4
6	22-27	25-31	Strong Breeze	Larger waves, whitecaps common, more spray	Rough 8 - 13	5
7	28-33	32-38	Near Gale	Sea heaps up, white foam steaks off breakers	Very rough 13 - 20	6
8	34-40	39-46	Gale	Moderately high, waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks		
9	41-47	47-54	Strong Gale	High waves, sea begins to roll, dense streaks of foam, spray may reduce visibility		
10	48-55	55-63	Storm	Very high waves, with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility	High 20 - 30	7
11	59-63	64-72	Violent Storm	Exceptionally high waves, foam patches cover sea, visibility more reduced	Very high 30 - 45	8
12	64 and over	73 and over	Hurricane	Air filled with foam, sea completely white with driving spray, visibility greatly reduced	Phenomenal 45 and over	9

Table 4012. Beaufort wind scale with corresponding sea codes.

CLOUDS

4013. Cloud Formation

Clouds are continually changing and appear in a variety of forms. Clouds consist of innumerable tiny droplets of water, or ice crystals, formed by condensation of water vapor around microscopic particles in the air. **Fog** is a cloud in contact with the surface of the Earth.

The shape, size, height, thickness, and nature of a cloud all depend upon the conditions under which it is formed. Therefore, clouds are indicators of various processes occurring in the atmosphere. The ability to recognize different types, and a knowledge of the conditions associated with them, are useful in predicting future weather (see Figure 4013b).

Although the variety of clouds is virtually endless, they may be classified by type. Clouds are grouped into three families according to common characteristics and the altitude of their bases. The families are High, Middle, and Low clouds. As shown in Table 4013a, the altitudes of the cloud bases vary depending on the latitude in which they are located. Large temperature changes cause most of this latitudinal variation.

Cloud Group	Tropical Regions	Temperate Regions	Polar Regions
High	6,000 to 18,000m (20,000 to 60,000ft)	5,000 to 13,000m (16,000 to 43,000ft)	3,000 to 8,000m (10,000 to 26,000ft)

Table 4013a. Approximate height of cloud bases above the surface for various locations.

Cloud Group	Tropical Regions	Temperate Regions	Polar Regions
Middle	2,000 to 8,000m (6,500 to 26,000ft)	2,000 to 7,000m (6,500 to 23,000ft)	2,000 to 4,000m (6,500 to 13,000ft)
Low	surface to 2,000m (0 to 6,500ft)	surface to 2,000m (0 to 6,500ft)	surface to 2,000m (0 to 6,500ft)

Table 4013a. Approximate height of cloud bases above the surface for various locations.

High clouds are composed principally of ice crystals. As shown in Table 4013a, the air temperatures in the tropic regions that are low enough to freeze all liquid water usually occur above 6000 meters, but in the polar regions these temperatures are found at altitudes as low as 3000 meters. **Middle clouds** are composed largely of water droplets, although higher ones have a tendency toward ice particles. **Low clouds** are composed entirely of water droplets.

Clouds types cannot be sufficiently distinguished just by their base altitudes, so within these 3 families are 10 principal cloud types. The names of these are composed of various combinations and forms of the following basic words, all from Latin:

Cirrus, meaning “curl, lock, or tuft of hair.”
Alto, meaning “high, upper air.”
Stratus, meaning “spread out, flatten, cover with a layer.”
Cumulus, meaning “heap, a pile, an accumulation.”
Nimbus, meaning “rainy cloud.”

Individual cloud types recognize certain characteristics, variations, or combinations of these. The following are images and definitions of the 10 principal cloud types and their commonly used symbols.

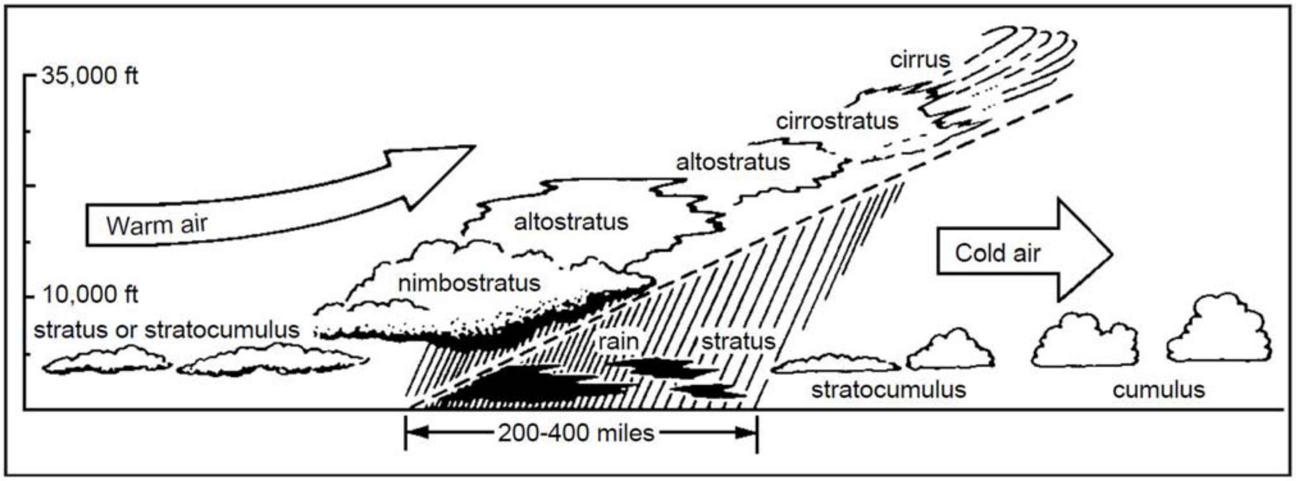


Figure 4013b. Vertical section of clouds ahead of a low. If a warm front is present, it will lie along the dashed lines.

4014. High Clouds

Cirrus (Ci) (Figure 4014a through Figure 4014e) are detached high clouds of delicate and fibrous appearance, without shading, generally white in color, often of a silky appearance. Their fibrous and feathery appearance is caused by their composition of ice crystals. Cirrus appear in varied forms, such as isolated tufts; long, thin lines across the sky; branching, feather-like plumes; curved wisps which may end in tufts, and other shapes. These clouds may be arranged in parallel bands which cross the sky in great circles, and appear to converge toward a point on the horizon. This may indicate the general direction of a low pressure area. Cirrus may be brilliantly colored at sunrise and sunset. Because of their height, they become illuminated before other clouds in the morning, and remain lighted after others at sunset. Cirrus are generally associated with fair weather, but if they are followed by lower and thicker clouds, they are often the forerunner of rain or snow.

Cirrostratus (Cs) (Figure 4014g through Figure 4014m) are thin, whitish, high clouds sometimes covering the sky completely and giving it a milky appearance and at other times presenting, more or less distinctly, a formation like a tangled web. The thin veil is not sufficiently dense to blur the outline of the Sun or Moon. However, the ice crystals of which the cloud is composed refract the light passing through to form halos with the Sun or Moon at the center. As cirrus begins to thicken, it will change into cirrostratus. In this form it is popularly known as “mares’ tails.” If it continues to thicken and lower, with the ice crystals melting to form water droplets, the cloud formation is known as altostratus. When this occurs, rain may normally be expected within 24 hours. The more brush-like the cirrus when the sky appears, the stronger the wind at the level of the cloud.

Cirrocumulus (Cc) Figure 4014n depicts high clouds composed of small white flakes or scales, or of very small globular masses, usually without shadows and arranged in groups of lines, or more often in ripples resembling sand on the seashore. One form of cirrocumulus is popularly known as “mackerel sky” because the pattern resembles the scales on the back of a mackerel. Like cirrus, cirrocumulus are composed of ice crystals and are generally associated with fair weather, but may precede a storm if they thicken and lower. They may turn gray and appear hard before thickening.

Figure 4014a. Dense Cirrus in patches or sheaves, not increasing, or Cirrus like cumuliform tufts.

Figure 4014b. Cirrus filaments, strands, hooks, not expanding.

Figure 4014c. Dense Cirrus in patches or sheaves, not increasing, or Cirrus like cumuliform tufts.

Figure 4014d. Dense Cirrus, often the anvil remaining from Cumulonimbus.

Figure 4014e. Dense Cirrus, often the anvil remaining from Cumulonimbus.

Figure 4014f. Cirrus hooks or filaments, increasing and becoming denser.

Figure 4014g. Cirrus bands and/or Cirrostratus, increasing, growing denser, veil below 45.

Figure 4014h. Cirrus bands and/or Cirrostratus, increasing, growing denser, veil below 45.

Figure 4014i. Cirrus bands and/or Cirrostratus, increasing, growing denser, veil below 45.

Figure 4014j. Cirrus bands and/or Cirrostratus, increasing, growing denser, veil below 45.

4015. Middle Level Clouds

Altostratus (As) (Figure 4015a through Figure 4015c) are middle level clouds having the appearance of a grayish or bluish, fibrous veil or sheet. The Sun or Moon, when seen through these clouds, appears as if it were shining through ground glass with a corona around it. Halos are not formed. If these clouds thicken and lower, or if low, ragged "scud" or rain clouds (nimbostratus) form below them, continuous rain or snow may be expected within a few hours.

Altocumulus (Ac) (Figure 4015d through Figure 4015p) are middle level clouds consisting of a layer of large, ball-like masses that tend to merge together. The balls or patches may vary in thickness and color from dazzling white to dark gray, but they are more or less regularly arranged. They may appear as distinct patches similar to cirrocumulus, but can be distinguished by having individual patches which are generally larger, showing distinct shadows in some places. They are often mistaken for stratocumulus. If altocumulus thickens and lowers it may produce thundery weather and showers, but it does not bring prolonged bad weather. Sometimes the patches merge to form a series of big rolls resembling ocean waves, with streaks of blue sky between. Because of perspective, the rolls appear to run together near the horizon. These regular parallel bands differ from cirrocumulus because they occur in larger masses with shadows. Altocumulus move in the direction of the short dimension of the rolls, like ocean waves. Sometimes altocumulus appear briefly in the form shown in Figure 4015m and Figure 4015n, sometimes

Figure 4014k. Cirrostratus covering the whole sky.

Figure 4014l. Cirrostratus, not increasing, not covering the whole sky.

before a thunderstorm. They are generally arranged in a line with a flat horizontal base, giving the impression of turrets on a castle. The turreted tops may look like miniature cumulus and possess considerable depth and great length. These clouds usually indicate a change to chaotic, thundery skies.

4016. Low Clouds

Cumulus (Cu) (Figure 4016a through Figure 4016c) are dense clouds with vertical development formed by rising air which is cooled as it reaches greater heights. They have a horizontal base and dome-shaped upper surfaces, with protuberances extending above the dome. Cumulus appear in patches, never covering the entire sky. When vertical development is not great, the clouds resemble tufts of cotton or wool, being popularly called "woolpack" clouds. The horizontal bases of such clouds may not be noticeable. These are called "fair weather" cumulus

Figure 4014m. Cirrostratus, not increasing, not covering the whole sky.

Figure 4014n. Cirrocumulus alone, and/or Cirrus and Cirrostratus.

Figure 4015a. Altostratus, semitransparent, Sun or Moon dimly visible.

Figure 4015b. Altostratus, semitransparent, Sun or Moon dimly visible.

Figure 4015c. Altostratus, dense enough to hide Sun or Moon, or nimbostratus.

because they commonly accompany stable air and good weather. However, they may merge with altocumulus, or may grow to cumulonimbus before a thunderstorm. Since cumulus are formed by updrafts, they are accompanied by turbulence, causing "bumpiness" in the air. The extent of turbulence is proportional to the vertical extent of the clouds. Cumulus are marked by strong contrasts of light and dark.

Figure 4015d. Altocumulus, semitransparent, cloud elements change slowly, one level.

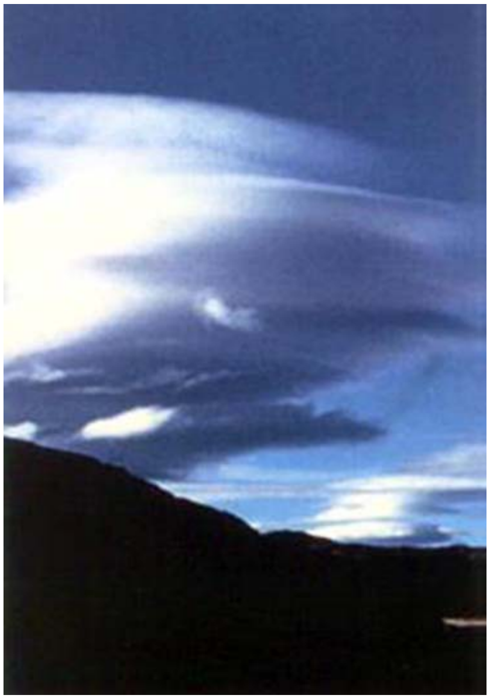


Figure 4015e. Altocumulus patches, semitransparent, multilevel, cloud elements changing, also Altocumulus Lenticular

Stratocumulus (Sc) (Figure 4016d through Figure 4016g) are low level clouds appearing as soft, gray, roll-shaped masses. They may be shaped in long, parallel rolls similar to altocumulus moving forward with the wind. The motion is in the direction of their short dimension, like ocean waves. These clouds, which vary greatly in altitude, are the final product of the characteristic daily change taking place in cumulus clouds. They are usually followed by clear skies during the night.

Stratus (St) (Figure 4016n through Figure 4016p) is a low cloud in a uniform layer resembling fog. Often the base is not more than 1,000 feet high. A veil of thin

Figure 4015f. Altocumulus patches, semitransparent, multilevel, cloud elements changing, also Altocumulus Lenticular

Figure 4015g. Altocumulus, one or more bands or layers, expanding, thickening.

Figure 4015h. Altocumulus, one or more bands or layers, expanding, thickening.

Figure 4015i. Altocumulus from the spreading of Cumulus or Cumulonimbus.

stratus gives the sky a hazy appearance. Stratus is often quite thick, permitting so little sunlight to penetrate that it appears dark to an observer below. From above it is white. Light mist may descend from stratus. Strong wind sometimes breaks stratus into shreds called “fractostratus.”

Nimbostratus (Ns) (Figure 4016h and Figure 4016i) is a low, dark, shapeless cloud layer, usually nearly uniform, but sometimes with ragged, wet-looking bases. Nimbostratus is the typical rain cloud. The precipitation which falls from this cloud is steady or intermittent, but not showery.

Cumulonimbus (Cb) (Figure 4016j through Figure 4016q) is a massive cloud with great vertical development, rising in mountainous towers to great heights. The upper part consists of ice crystals, and often spreads out in the shape of an anvil which may be seen at such distances that the base may be below the horizon.

Figure 4015j. Altocumulus from the spreading of Cumulus or Cumulonimbus.

Figure 4015k. Altocumulus, one or more layers, mainly opaque, not expanding, or Altocumulus with Altostratus or Nimbostratus.

Figure 4015l. Altocumulus, one or more layers, mainly opaque, not expanding, or Altocumulus with Altostratus or Nimbostratus.

Cumulonimbus often produces showers of rain, snow, or hail, frequently accompanied by lightning and thunder. Because of this, the cloud is often popularly called a "thundercloud" or "thunderhead." The base is horizontal, but as showers occur it lowers and becomes ragged.

Figure 4015m. Altocumulus with tower or turret like sproutings.

Figure 4015n. Altocumulus with tower or turret-like sproutings.

Figure 4015o. Altocumulus of a chaotic sky, usually with heavy broken cloud sheets at different levels.

4017. Cloud Height Measurement

At sea, cloud heights are often determined by estimation. This is a difficult task, particularly at night.

The height of the base of clouds formed by vertical development (any form of cumulus), if formed in air that has risen from the surface of the Earth, can be determined by psychrometer. This is because the height to which the air must rise before condensation takes place is proportional to

Figure 4015p. Altocumulus of a chaotic sky, usually with heavy broken cloud sheets at different levels.

Figure 4016c. Cumulus with moderate or greater vertical extent.

Figure 4016a. Cumulus with very little vertical extent.

Figure 4016d. Stratocumulus from the spreading out of Cumulus.

Figure 4016b. Cumulus with very little vertical extent.

Figure 4016e. Stratocumulus from the spreading out of Cumulus.

Figure 4016f. Stratocumulus not formed from the spreading out of Cumulus.

Figure 4016g. Stratocumulus not formed from the spreading out of Cumulus.

Figure 4016h. Nimbostratus formed from lowering Altostratus.

Figure 4016i. Nimbostratus formed from lowering Altostratus.

Figure 4016j. Cumulonimbus, tops not fibrous, outline not completely sharp, no anvil.

the difference between surface air temperature and the dew point. At sea, this difference multiplied by 126.3 gives the height in meters. That is, for every degree difference between surface air temperature and the dew point, the air must rise 126.3 meters before condensation will take place. Thus, if the dry-bulb temperature is 26.8°C, and the wet-bulb temperature is 25.0°C, the dew point is 24°C, or 2.8°C lower than the surface air temperature. The height of the cloud base is 2.8 126.3 = 354 meters.

Figure 4016k. Cumulonimbus, tops not fibrous, outline not completely sharp, no anvil.

Figure 4016l. Cumulonimbus with fibrous top, often with an anvil.

Figure 4016m. Cumulonimbus with fibrous top, often with an anvil.

Figure 4016n. Stratus in a sheet or layer.

Figure 4016o. Stratus fractus and/or Cumulus fractus of bad weather.

Figure 4016p. Stratus fractus and/or Cumulus fractus of bad weather.

Figure 4016q. The anvil (incus) of a Cumulonimbus cloud over Africa, taken from the International Space Station. Perhaps the most impressive of cloud formations, cumulonimbus (from the Latin for "pile" and "rain cloud") clouds form due to vigorous convection (rising and overturning) of warm, moist, and unstable air. Surface air is warmed by the Sun-heated ground surface and rises; if sufficient atmospheric moisture is present, water droplets will condense as the air mass encounters cooler air at higher altitudes. The air mass itself also expands and cools as it rises due to decreasing atmospheric pressure, a process known as adiabatic cooling. This type of convection is common in tropical latitudes year-round and during the summer season at higher latitudes. As water in the rising air mass condenses and changes from a gas to a liquid state, it releases energy to its surroundings, further heating the surrounding air and leading to more convection and rising of the cloud mass to higher altitudes. This leads to the characteristic vertical "towers" associated with cumulonimbus clouds, an excellent example of which is visible in this astronaut photograph. If enough moisture is present to condense and heat the cloud mass through several convective cycles, a tower can rise to altitudes of approximately 10 kilometers at high latitudes and to 20 kilometers in the tropics before encountering a region of the atmosphere known as the tropopause-the boundary between the troposphere and the stratosphere. The tropopause is characterized by a strong temperature inversion. Beyond the tropopause, the air no longer gets colder as altitude increases. The tropopause halts further upward motion of the cloud mass. The cloud tops flatten and spread into an anvil shape, as illustrated by this astronaut photograph. The photo was taken from a viewpoint that was at an angle from the vertical, rather than looking straight down towards the Earth's surface. The image, taken while the International Space Station was located over western Africa near the Senegal-Mali border, shows a fully formed anvil cloud with numerous smaller cumulonimbus towers rising near it. The high energy levels of these storm systems typically make them hazardous due to associated heavy precipitation, lightning, high wind speeds and possible tornadoes.

OTHER OBSERVATIONS

4018. Visibility Measurement

Visibility is the horizontal distance at which prominent objects can be seen and identified by the unaided eye. It is usually measured directly by the human eye. Ashore the distances of various buildings, trees, lights, and other objects can be used as a guide in estimating the visibility. At sea, however, such an estimate is difficult to make with accuracy. Other ships and the horizon may be of some assistance. See the Distance of the Horizon (Table 12).

Ashore, visibility is sometimes measured by a **transmissometer**, a device which measures the transparency of the atmosphere by passing a beam of light over a known short distance, and comparing it with a reference light.

4019. Upper Air Observations

Upper air information provides the third dimension to the weather map. Unfortunately, the equipment necessary to obtain such information is quite expensive, and the observations are time consuming. Consequently, the network of observing stations is quite sparse compared to that for surface observations, particularly over the oceans and in isolated land areas. Where facilities exist, upper air observations are made by means of unmanned balloons, in conjunction with theodolites, radiosondes, and radar.

4020. New Technologies in Weather Observing

Shipboard, upper air, buoy, radar, and satellite observations are the foundation for the development of accurate forecast computer models, both in the short and long term. New techniques such as Doppler radar, satellite analysis, and the integration of data from many different sites into complex computer algorithms provide a method of predicting storm tracks with a high degree of accuracy. Tornadoes, line squalls, individual thunderstorms, and entire storm systems can be continuously tracked and their paths predicted with unprecedented accuracy. At sea, the mariner has immediate access to this data through facsimile transmission of synoptic charts, satellite photographs, communications satellite contact with weather routing services, or through internet providers.

Automated weather stations and buoy systems provide regular transmissions of meteorological and oceanographic information by radio. Some of these buoys or stations can be accessed via the telephone. For further information, visit the National Data Buoy Center's web site at http://www.ndbc.noaa.gov. These buoys and stations are generally located at isolated and relatively inaccessible locations from which weather and ocean data are of great importance. Depending on the type of system used, the elements usually measured include wind direction and speed, atmospheric pressure, air and sea surface temperature, spectral wave data, and a temperature profile from the sea surface to a predetermined depth.

Regardless of advances in the technology of observing and forecasting, the shipboard weather report remains the cornerstone upon which the accuracy of many forecasts are based.

4021. Recording Observations

Instructions for recording weather observations aboard U.S. Navy vessels are given in NAVMETOC-COMINST 3144.1 (series).

Instructions for recording observations aboard merchant vessels are given in the National Weather Service *Observing Handbook No. 1, Marine Surface Observations*. The handbook is available online via the link provided in Figure 4021.

Figure 4021. Link to Weather Observing Handbook No. 1, Marine Surface Observations. http://www.vos.noaa.gov/ObsHB-508/ObservingHandbook1_2010_508_compliant.pdf

Force 0: Wind Speed less than 1 knot.
Sea: Sea like a mirror.

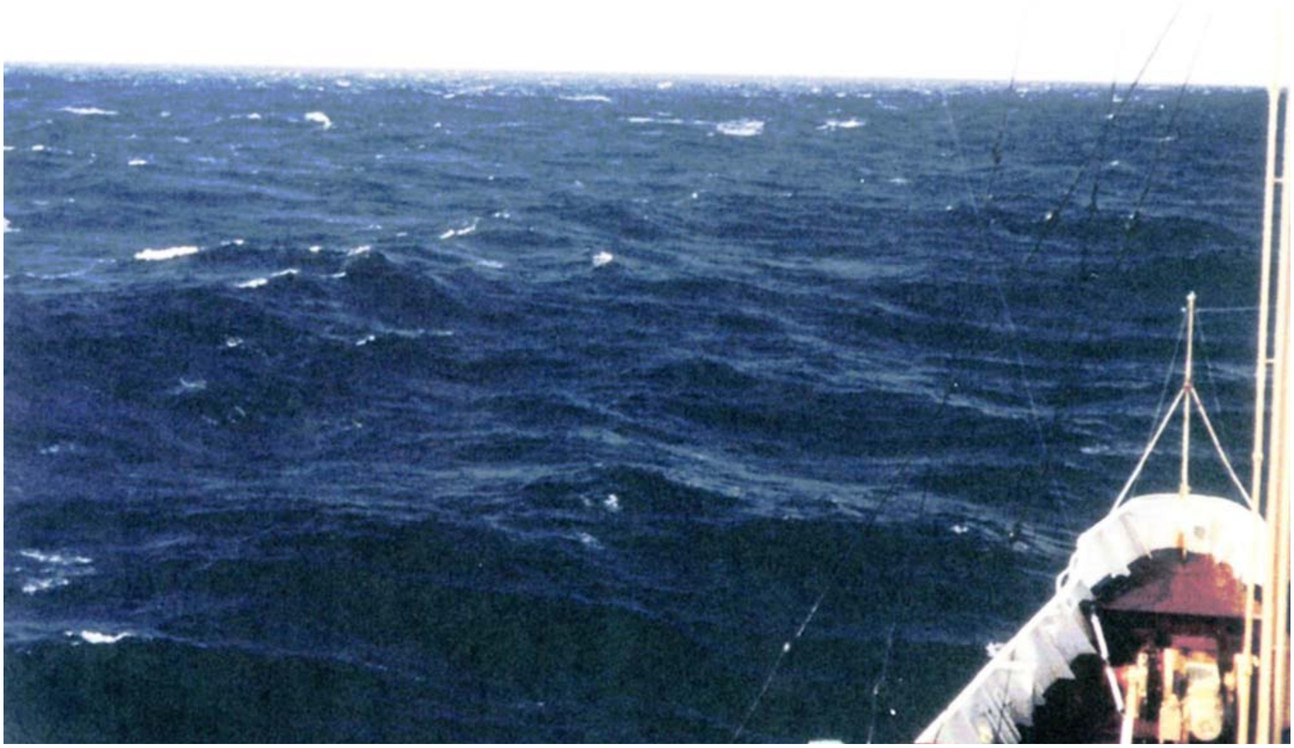
Force 1: Wind Speed 1-3 knots.
Sea: Wave height 0.1m (.25ft); Ripples with appearance of scales, no foam crests.

Force 2: Wind Speed 4-6 knots.
Sea: Wave height 0.2-0.3 m (0.5-1 ft); Small wavelets, crests of glassy appearance, not breaking.

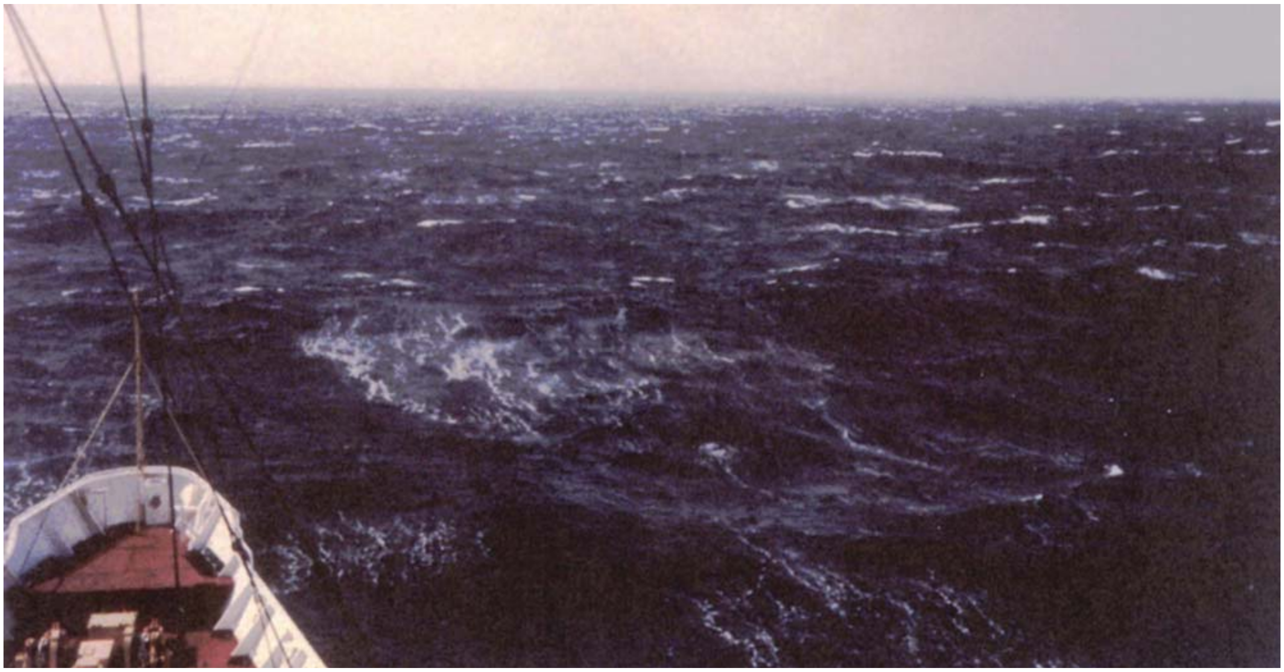
Force 3: Wind Speed 7-10 knots.
Sea: Wave height 0.6-1m (2-3 ft); Large wavelets, crests begin to break, scattered whitecaps.

Force 4: Wind Speed 11-16 knots.
Sea: Wave height 1-1.5 m (3.5-5 ft); Small waves becoming longer, numerous whitecaps.

Force 5: Wind Speed 17-21 knots.
Sea: Wave height 2-2.5 m (6-8 ft); Moderate waves, taking longer form, many whitecaps, some spray.

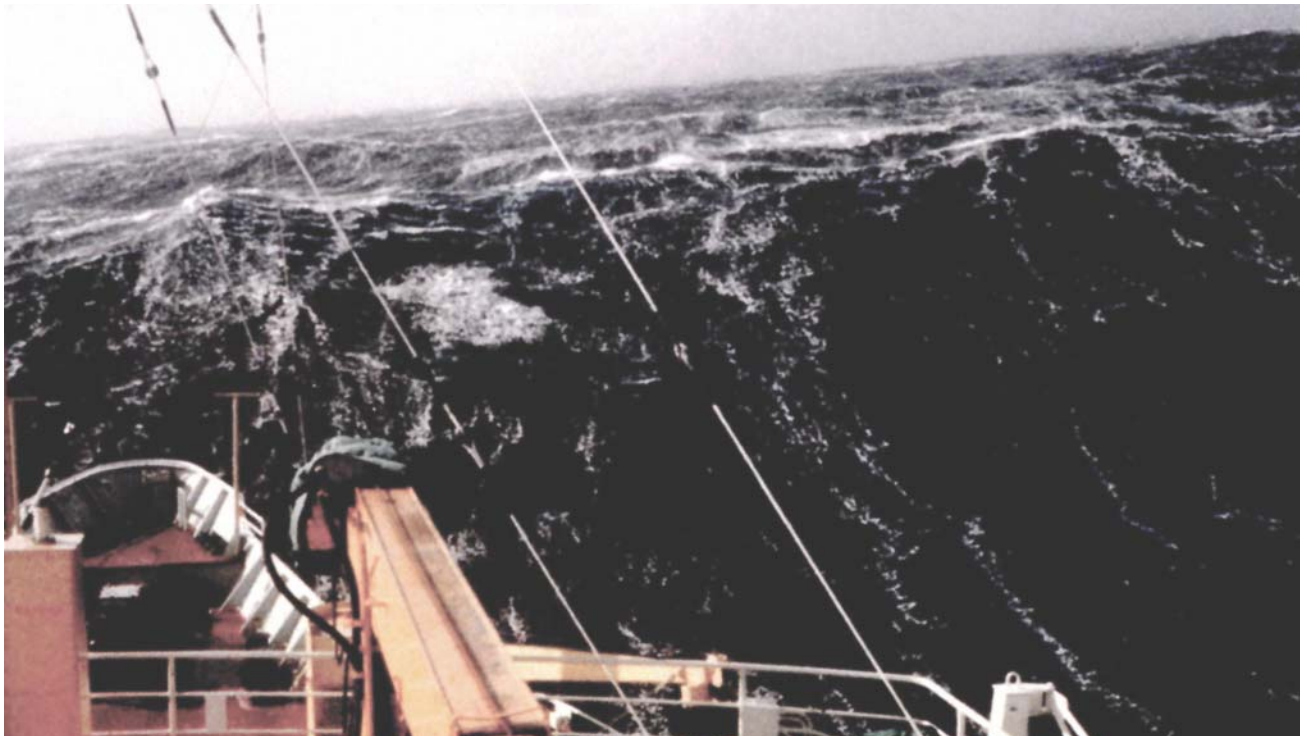


Force 6: Wind Speed 22-27 knots.
Sea: Wave height 3-4 m (9.5-13 ft); Larger waves forming, whitecaps everywhere, more spray.



Force 7: Wind Speed 28-33 knots.
Sea: Wave height 4-5.5 m (13.5-19 ft); Sea heaps up, white foam from breaking waves begins to be blown in streaks along direction of wind.

Force 8: Wind Speed 34-40 knots.
Sea: Wave height 5.5-7.5 m (18-25 ft); Moderately high waves of greater length, edges of crests begin to break into spindrift, foam is blown in well marked streaks.



Force 9: Wind Speed 41-47 knots.
Sea: Wave height 7-10 m (23-32 ft); High waves, sea begins to roll, dense streaks of foam along wind direction, spray may reduce visibility.

Force 10: Wind Speed 48-55 knots (storm).
Sea: Wave height 9-12.5 m (29-41 ft); Very high waves with overhanging crests, sea takes white appearance as foam is blown in very dense streaks, rolling is heavy and shocklike, visibility is reduced.

Force 11: Wind Speed 56-63 knots.
Sea: Wave height 11.5-16 m (37-52 ft); Exceptionally high waves, sea covered with white foam patches, visibility still more reduced.

Force 12: Wind Speed 64-71 knots.
Sea: Wave height more than 16 m (52 ft); Air filled with foam, sea completely white with driving spray, visibility greatly reduced.