4.1 **GENERAL**

Marine observations in the broadest definition cover any meteorological and related environmental observations at the air-sea interface, below the sea surface and in the atmosphere above the sea surface (upper-air measurements). Detailed formal requirements for observations from sea stations are given in WMO (2010b). Advice on requirements and procedures is given in WMO (2001).

This chapter considers observations at the air-sea interface, which include the usual surface measurements made also over land and discussed in that context in other chapters. This chapter also considers some subsurface measurements of importance to marine physics and physical oceanography. Upper-air measurements are taken using techniques that are essentially the same over the sea and over land; these will not be considered in this chapter.

Measurements and observations of waves are not described elsewhere in this Guide. Visual methods are discussed in section 4.2.12. Automated methods are referred to in section 4.3, although the techniques are applied on other types of platforms.

Observations can be made using fixed or moving platforms, and be in situ or remote, using surface- or space-based techniques. In situ measurements are essentially single-point observations intended to be representative of the surrounding sea area, as for synoptic meteorology. Remote-sensing techniques lead to large area or volume representation, which is particularly appropriate for observations of sea ice.

**In situ measurements**

These measurements or observations are made from a variety of platforms. They include ships recruited by WMO Members to participate in the Voluntary Observing Ship (VOS) Scheme), ocean weather stations, manned and unmanned light vessels, moored buoys, drifting buoys, towers, oil and gas platforms and rigs, island automatic weather stations (AWS) and shipborne AWS systems. The type of platform generally determines the range of elements measured and reported. Thus, ships of the VOS, using both measured and manual observation techniques, report the full range of observations required for synoptic meteorology. These observations are most commonly compiled and transmitted to shore in FM 13 SHIP code or non-conventional format, and then distributed internationally in appropriate WMO code (for example, FM 94 BUFR as of 2012). By contrast the majority of drifting buoys report only up to three parameters, namely, position, atmospheric pressure at sea surface, and sea-surface temperature.

On the recommendation of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM),1 a network of WMO/IOC Regional Marine Instrument Centres (RMICs) has been set up to facilitate standardization of observational data, metadata, processed observational products, and higher level standards for instruments and methods of observation. These RMICs provide facilities for: (a) the calibration and maintenance of marine instruments and the monitoring of instrument performance; (b) assistance for instrument intercomparisons; and (c) training facilities. Their terms of reference and locations are given in Annex 4.A.

**Remotely sensed measurements**

Marine measurements can be made remotely from surface- and space-based systems. At present, surface-based remote-sensing systems are available to measure or observe precipitation (weather radar), near surface winds (Doppler radar), surface ocean currents, surface wind, and sea state (microwave radar for short-range and high-frequency radar for long-range, for example, “over the horizon”, sensing). These techniques are described in Part II, Chapter 9. In addition, the techniques for remote detection and location of lightning, described in Part II, Chapter 7, are applicable to the marine environment.

Remote sensing from space is used for the measurement of many surface marine variables. As technology advances, remote sensing from spaceborne platforms is increasingly providing the bulk of sea state and sea-surface wind and temperature data over the world’s oceans. It should be noted,

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however, that in situ measurements are essential to validate and calibrate these satellite data. Remote-sensing systems from space are described in Part II, Chapter 8.

4.2 OBSERVATIONS FROM SHIPS

This section contains detailed guidance and advice for taking measurements and making observations on ships. Reference WMO (1991a) is another source. Details on surface observations to be carried out within the framework of the WMO VOS Scheme are provided in WMO (2001), Chapter 6. Studies of the quality of observations from ships are given in WMO (1991b; 1999), Kent, Taylor and Josey (2003), Taylor and others (2003) and Kent and Berry (2005). A discussion of good observing practice from the research community is presented by Bradley and Fairall (2007).

4.2.1 Elements observed

Ships which undertake meteorological observations should typically be equipped for observing the following elements:

- All ships:
  - Ship position;
  - Ship course and speed;
  - Atmospheric pressure;
  - Air temperature;
  - Humidity (dewpoint);
  - Wind speed and direction;

Ships making manual observations should typically report the above elements as well as the following (observations estimated visually or measured with instruments and then recorded manually):

- Present and past weather, and weather phenomena;
- Clouds (amount, type and base height);
- Visibility;
- Visibility;
- Precipitation;
- Sea-surface temperature;
- Ocean sea waves and swell – height, period and direction;
- Sea-ice and/or ice accretion on board ship, when appropriate.

As regards the order of observing these elements, in general, instrumental observations requiring the use of a light at night should be ideally made after non-instrumental ones, so that to the observer’s eyes can adapt to the darkness without being impaired.

When manually observed, the observation of elements other than pressure should be made within 10 minutes preceding the standard time for the synoptic observation, whereas atmospheric pressure should be read at the exact time or as close as possible to the standard time.

4.2.2 Equipment required

The following instruments are suitable for use on ships:

- A precision aneroid, dial aneroid or electronic digital barometer;
- A hygrometer or psychrometer;
- A barograph, preferably open scale (desirable but not mandated) or a digital barometer that includes a barometric tendency trace;
- A sea-temperature thermometer and suitable receptacle for obtaining a sample of seawater, or a continuously immersed sensor (or a hull contact sensor) with remote indicator.

The use of anemometers with suitable exposure as an alternative to the visual estimation of wind force is encouraged, provided that such instruments are routinely checked to ensure that they remain within calibration. Precipitation gauges are rarely provided for use on observing ships.

The instruments used on ships should conform to the requirements laid down or recommended in other chapters of this Guide, apart from the modifications described in the following sections of this chapter. Instruments supplied to ships should be regularly tested and inspected by the Meteorological Services concerned.

4.2.3 Times of observation

Surface observations on board ships are typically made as follows:

- Synoptic observations from manually reporting observing ships should be made at main standard times: 0000, 0600, 1200 and 1800 UTC. When additional observations are required, they should be made at one or more of the intermediate standard times: 0300, 0900, 1500, and 2100 UTC;
- Hourly observations should be made when an automated system and a binary formatted message is used (using manual input, ship observers may in addition provide complete synoptic observations at synoptic times, including the additional visual elements);
- When operational difficulties on board ships make it impracticable to make the synoptic observation at a main standard time;

2 These elements are often estimated visually.
(d) Observations should be made more frequently than at the main standard times whenever storm conditions threaten or prevail;
(e) When sudden and dangerous weather developments are encountered, observations should be made for immediate transmission without regard to the standard times of observation (i.e. within 300 nautical miles of a named tropical system);
(f) Marine observations are just as valuable in coastal zones as in the open ocean and observations should be continued during the whole journey.

4.2.4 Automation of observations on ships and data transmission

4.2.4.1 Automation of ship's observation
Automated AWS or partially automated systems on board ships are increasingly being used for both observation and data transmission purposes. Three basic modes of operation are used, as follows:
(a) The observation is made manually, typically entered into an electronic logbook on a computer, coded, as necessary, and formatted for automatic or manually initiated transmission;
(b) The observation is made automatically using standard automatic weather station techniques, as described in Part II, Chapter 1. The position, course and speed of a ship are taken from its navigation system (e.g. gyro compass) or computed independently using a satellite navigation system, usually the Global Positioning System (GPS). The transmission of such observations can be either purely automatic or initiated manually according to the communications facilities;
(c) The observations are a combination of automated and manual observations, namely, automated observations augmented with visual observations entered by the observer before transmission (i.e. adding visibility, weather codes, cloud amounts, types and heights, wave heights, periods and directions, ice parameters and wind speed and direction where not measured using an anemometer).

4.2.4.2 Transmission of ship's observations
Satellite communication systems are now in widespread use for disseminating ship observations. Details are given in WMO (2001), section 6.6. The following four methods are available:
(a) The International Data Collection System through the meteorological geosynchronous (GOES, METEOSAT, MTSAT) satellites. This system, funded mainly by meteorological agencies, allows for purely automatic data communication at predetermined time slots, once an hour. Data transmission is one-way only and error rates can be significant. It is typically used in connection with certain shipboard AWS systems and on moored buoys;
(b) Commercial satellite systems through the Inmarsat-C system which is carried by most ocean-going ships for compliance with the requirements of the International Convention for the Safety of Life at Sea (SOLAS). Weather observations are normally sent to a land earth station as a special access code 41 or a regional variation of SAC41, although the Inmarsat data reporting service is also used for sending compressed AWS data. Inmarsat is used by a majority of non-automated stations;
(c) Commercial satellite services such as the Iridium Short Burst Data using binary formatted message to reduce costs and improve data timeliness;
(d) Service Argos: This system is primarily designed for location as well as data transmission and is limited by the number and the orbital characteristics of the polar-orbiting satellites carrying the Argos payload. The Argos system is used both for the communication and for the processing of ship observations onto the Global Telecommunication System (WMO/IOC, 1995) but there can be several hours’ delay and costs are significant. It is typically used for small autonomous shipboard AWS systems and for drifting buoys.

To reduce communication costs, some National Meteorological Services use compression methods to reduce the volume of data transmitted from ship-to-shore in each observation. This service is generally provided through a special arrangement between the National Meteorological Services and a communications service provider.

4.2.5 Wind
Observations of wind speed and direction may be made either by visual estimates or by means of anemometers or anemographs. Measured winds are preferable to visual estimates.

On ships fitted with instruments, the observations should consist of the mean reading over a 10 min period. When observations are taken from
a moving ship, it is necessary to distinguish between the relative and the true wind; for all meteorological purposes the true wind must be reported (although for VOS Climate class ships the apparent wind is also reported). A simple vector diagram or a table may be used for computing the true wind from observations of the relative wind and ship speed and course (Bowditch and NIMA, 2002). In practice, this vector conversion is a frequent source of error in reported winds. Electronic logbook software, e.g. TurboWin, will usually compute True wind automatically.

AWSs compute true wind using the relative wind measurements and the course and speed of the ship. This latter information is preferably obtained from a magnetic compass and the ship’s speed information. It can also be obtained from the ship movement derived from a GPS receiver, but in that case the drift is not taken into account.

The recording of ship metadata (type of wind observation, ship type, size, position of the anemometer and height) is particularly important for wind observations. Metadata are used in particular to interpret the data correctly and increase data coherence (e.g. bias correction) and permit traceability to standards.

### 4.2.5.1 Visual observations

Visual estimates are based on the appearance of the sea surface. The wind speed is obtained by reference to the Beaufort scale (see table). The wind direction is determined by observing the orientation of the

<table>
<thead>
<tr>
<th>Beaufort number (force)</th>
<th>Descriptive term</th>
<th>Wind speed equivalents</th>
<th>Specifications for observationa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Calm</td>
<td>0–0.2</td>
<td>&lt;1 Sea like a mirror</td>
</tr>
<tr>
<td>1</td>
<td>Light air</td>
<td>0.3–1.5</td>
<td>1–3 Ripples with the appearance of scales are formed, but without foam crests</td>
</tr>
<tr>
<td>2</td>
<td>Light breeze</td>
<td>1.6–3.3</td>
<td>4–6 Small wavelets; still short but more pronounced; crests have a glassy appearance and do not break</td>
</tr>
<tr>
<td>3</td>
<td>Gentle breeze</td>
<td>3.4–5.4</td>
<td>7–10 Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses</td>
</tr>
<tr>
<td>4</td>
<td>Moderate breeze</td>
<td>5.5–7.9</td>
<td>11–16 Small waves, becoming longer; fairly frequent white horses</td>
</tr>
<tr>
<td>5</td>
<td>Fresh breeze</td>
<td>8.0–10.7</td>
<td>17–21 Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)</td>
</tr>
<tr>
<td>6</td>
<td>Strong breeze</td>
<td>10.8–13.8</td>
<td>22–27 Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)</td>
</tr>
<tr>
<td>7</td>
<td>Near gale</td>
<td>13.9–17.1</td>
<td>28–33 Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind</td>
</tr>
<tr>
<td>8</td>
<td>Gale</td>
<td>17.2–20.7</td>
<td>34–40 Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind</td>
</tr>
<tr>
<td>9</td>
<td>Strong gale</td>
<td>20.8–24.4</td>
<td>41–47 High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility</td>
</tr>
<tr>
<td>10</td>
<td>Storm</td>
<td>24.5–28.4</td>
<td>48–55 Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; the surface of the sea takes a white appearance; the “tumbling” of the sea becomes heavy and shock-like; visibility affected</td>
</tr>
<tr>
<td>11</td>
<td>Violent storm</td>
<td>28.5–32.6</td>
<td>56–63 Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected</td>
</tr>
<tr>
<td>12</td>
<td>Hurricane</td>
<td>32.7 and over</td>
<td>64 and over The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected</td>
</tr>
</tbody>
</table>
crests of sea waves (that is, wind-driven waves, and not swell) or the direction of streaks of foam which are blown in the direction of the wind. The specifications of the Beaufort scale numbers refer to the conditions in the open sea. In practice, wind directions made by visual methods are of good quality.

The wave height in itself is not always a reliable criterion since it depends not only on wind speed, but also on the fetch and duration of the wind, the depth of shallow waters, and the presence of swell running through a sea. The Beaufort scale, therefore, makes use of the relation between the state of the sea and the wind speed. This relation is, however, affected by several other factors which should, in principle, be taken into account in estimating wind speeds. These factors are the lag between the wind increasing and the sea rising, the smoothing or damping down of wind effects on the sea surface by heavy rain, and the effects of strong surface currents (such as tidal currents) on the appearance of the sea. Sea criteria become less reliable in shallow water or when close inshore, owing to the effect of tidal currents and the shelter provided by the land. At these locations, or when the surface of the sea cannot be clearly seen (e.g. at night), the Beaufort force of the relative wind on the ship may be estimated by noting wind effects on sound, on ship-borne objects such as flags, and on funnel smoke. In the latter case, the direction of the relative wind may also be estimated, for example, by observation of the funnel smoke. From these estimates, the speed and direction of the true wind can be computed (United Kingdom Meteorological Office, 1995). If no other means are available to estimate the wind direction, low-level cloud movement can be a helpful tool.

4.2.5.2 Measurements with instruments

If instruments for measuring wind are installed on ships, the equipment should give both wind speed and direction and should be capable of minimizing roll effects (suitably designed cup anemometers and damped wind vanes are capable of rendering the effects of pitch and roll insignificant).

Metadata should be provided to indicate the instrumentation used, how it is installed on-board the ship (where on the ship and at what height), as well as details about the type of vessel as wind measurements are influenced by the air-flow over the ship’s structure (Yelland, Moat and Taylor, 2001).

In most cases, it is difficult to obtain a good exposure for ship-borne wind instruments (Taylor and others, 2003; Yelland, Moat and Taylor, 2001; Moat, Yelland and Molland, 2006). The local effects produced by the superstructure, mast and spars should be minimized as much as possible by siting the instrument as far forward and as high as practicable. If fitted on a yard, it may be preferable that the speed and direction heads should form separate units, as a more even distribution of the weight on the yard can be obtained, and it may then be possible to fit the instruments farther outboard. Whether fitted on a yard or on a bracket fixed to the foremost, each unit should be mounted in position at a distance of at least 10 mast diameters away from the mast. If this is impracticable, a good technique is to fit two instruments, one on each side of the foremost, and always to use the one which is more freely exposed. The top of the foremost, if available, is generally thought to be the best site for an anemometer.

The marine environment is harsh so cup or propeller anemometers require regular maintenance and calibration in order to produce reliable wind data. Ultrasonic anemometers have no moving parts, require less maintenance, and therefore are increasingly being used on ships.

Various types of portable anemometers are on occasion used at sea (often to assist with ship berthing). Their main disadvantage is that they can hardly be given representative exposure, and, in practice, measurements taken with them show substantial scatter. Only an observer who understands the nature of the air-flow over the ship in different circumstances would be able to choose the best place for making such observations and thus arrive at satisfactory results. This method may be useful if visual estimates of wind force are difficult or impossible, for example, with light winds at night.

4.2.6 Atmospheric pressure, pressure tendency and characteristic of pressure tendency

4.2.6.1 Methods of observation

Pressure can be measured either by a precision aneroid, a dial aneroid or an electronic digital barometer.

With manned observation, the characteristic and amount of the pressure tendency in the past 3 h are usually obtained from a marine barograph, preferably an open-scale instrument graduated in
divisions of 1 hPa. However, digital barometers that include an LCD display of the pressure tendency are increasingly being used.

With AWS, the characteristic and amount of the pressure tendency in the past 3 h are calculated from the four last hourly pressure values (H, H-1, H-2, H-3).

4.2.6.2 Instruments

All barometers should conform to the general requirements given in Part I, Chapter 3, and should be supplied with a certificate giving the corrections (if any) that must be applied to the readings of each individual instrument. Barometers should be capable of being read to 0.1 hPa. The operational measurement uncertainty requirements and instrument performance are stated in Part I, Chapter 1, Annex 1.D. The required measurement uncertainty is less than 0.1 hPa (after reduction to sea level: < 0.2 hPa). The achievable measurement uncertainty should never be worse than 0.3 hPa. Marine barographs should have a built-in damping device, for example, an oil bath containing the aneroid box or a dash pot connected to the lever mechanism, to prevent the wide trace produced by rapid pressure variations caused by gusty winds and movement of the ship. Both the barometer and barograph should also be vented to the outside with a static pressure head so that readings can be taken more accurately and are not affected by sealed bridges or indoor wind impacts. If this is not possible instructions should be given to ensure that the bridgewing doors are opened prior to taking an observation. This is especially important on newer ships with pressurised accommodation blocks or on vessels that are carrying hazardous cargoes where the wheelhouse may be hermetically sealed.

In general, most (but not all) National Meteorological Services set their precision aneroid and electronic barometers to “station level” pressure and therefore the observations need to be corrected for the height of the barometer to give a sea-level pressure output. This height correction is calculated automatically with electronic logbook software such as TurboWin. Dial aneroid barometers are typically set to indicate sea-level pressure.

4.2.6.3 Exposure and management

Digital and aneroid barometers and barographs

Barometers and barographs should be mounted on shock-absorbing material in a position where they are least affected by concussion, vibration or movement of the ship. The best results are generally obtained from a position as close to the centre of flotation as possible. Barographs should be installed with the pen-arm oriented athwart ships (to minimize the risk of its swinging off the chart).

4.2.6.4 Corrections

Provision should be made for the application of the following corrections:

(a) Instrument error (bias);
(b) Reduction to sea level as appropriate;
(c) Temperature (if applicable and appropriate tables are provided).

Barometers should be adequately compensated for temperature, otherwise the instruments should be provided with a temperature correction table and means should be provided for measuring the temperature. A table for reducing to sea-level pressure should be supplied when barometers are set to the station height, although this is not necessary for ships that use electronic logbooks that are capable of automatically applying the height correction (Bowditch and NIMA, 2002, Tables 29–34).

4.2.6.5 Sources of error

Errors are discussed in Part I, Chapter 3, but on ships in particular appreciable errors may be caused by the effect of the wind on the pressure in the compartment in which the barometer is placed. Where possible, these errors should be minimized by enclosing the instrument in a chamber connected to a static pressure head or by connecting the device vent directly to this static pressure head.

On non-automated observing systems, the most frequent (human) errors are due to an absence of reduction to the sea level, a bad appreciation of the barometer height or a non-intentional double correction (correction applied on a barometer which already gives sea-level pressure).

4.2.6.6 Checking with standard instruments

Analogue barometers and barographs should be checked whenever possible, but at the minimum at approximately three-monthly intervals against the standard barometer of a Port Meteorological Office or a Transfer Standard barometer. However, as shipping movements can be highly dynamic this may not always be possible. A report of all comparisons should be logged by the Port Meteorological Officer, and a calibration label attached to the barometer
showing the barometer check date and the correction to be applied.

Digital barometers have a much better stability and calibration periods may be as large as two years for some models.

4.2.7  Clouds and weather

Visual cloud and weather observations should follow the same rules as those applicable to a land station (see Part I, Chapters 14 and 15) (see also Annex 4.B for descriptions of forms of precipitation). Detailed instructions and tips on how to make these observations should be provided by the Port Meteorological Officer, bearing in mind that most observers at sea are voluntary observers. Most electronic logbook software includes extensive pictures of clouds to assist with cloud type identifications.

In the absence of instrumental aids, the cloud-base height must be estimated. In order to improve their ability to do this, observers should be encouraged to take every opportunity to check their estimates against known heights, for example, when a cloud base is seen to intercept a mountainous coast, although in such circumstances the cloud base may be lower at the mountain than out at sea.

The cloud-base searchlight is of limited value on a ship because of the short baseline. An instrument which does not require a baseline is to be preferred, such as a laser ceilometer (see Part I, Chapter 15). It should be installed so that it can be operated and read by the officer on watch on the navigation bridge.

4.2.8  Visibility

At sea, the absence of suitable objects makes it impossible to estimate visibility as accurately as at land stations.

On a large ship, it is possible to make use of objects aboard the ship (e.g. the foremast) for estimation when the visibility is very low, but it should be recognized that these estimates may be in error since the air may be affected by the ship. For the higher ranges, the appearance of the land when coasting is a useful guide, and, if fixes can be obtained, the distance of landmarks, just as they are appearing or disappearing, may be measured from the chart. Similarly, in open sea, when other ships are sighted and their distances known, for example, by radar, the visibility may be estimated. In the absence of other objects, the appearance of the horizon, as observed from different levels, may be used as a basis for the estimation. Although abnormal refraction may introduce errors into such methods of estimation, these methods are the only ones available in some circumstances. At night, the appearance of navigation lights can give a useful indication of the visibility.

When the visibility is not uniform in all directions it should be estimated or measured in the direction of least visibility and a suitable entry should be made in the log (excluding reduction of visibility due to the ship’s exhaust).

Information about visibility meters is given in Part I, Chapter 9. Only those types of visibility meters which can be used with a baseline or light-path short enough to be practicable on a ship are suitable. This is the case of forwardsscatter meters. Unfortunately, the heating effect of the ship, and its exhaust, may lead to unrepresentative measurements.

4.2.9  Air temperature and humidity

Temperature and humidity observations should be made by means of a hygrometer or psychrometer which has good ventilation.

The instruments must be well exposed in a stream of air, directly from the sea, which has not been in contact with, or passed over, the ship, and should be adequately shielded from radiation, precipitation and spray.

Sling or aspirated psychrometers exposed on the windward side of the bridge have been found to be satisfactory. If manually operated psychrometers are used, the thermometers must be read as soon as possible after ventilation has stopped. Hand-held hygrometers require several minutes to be acclimated to the open environment if they have been stored indoors before use.

Capacitive hygrometers have been found to perform satisfactorily, even given the high salt environment. Electronic humidity and temperature sensors should be used with AWSs and can be used for manual observation. They provide higher accuracy and need a recalibration every year.

For manned observations, if a louvred screen is to be used, two should be provided, one secured on each side of the vessel, so that the observation can also be made from the windward side. In this way, thermometers in the hygrometer can be completely exposed to the air-stream and are uninfluenced by
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artificial sources of heat and water vapour. As an alternative, a single portable louvred screen can be used, which is hung on whichever side is windward to gain the same exposure. The muslin wick fitted to a wet-bulb thermometer in a louvred screen should be changed at least once each week, and more often in stormy weather.

With AWSs or a distant digital display, a manual reading of the instruments inside the screen is no longer necessary and a single screen can be installed and exposed far enough from the ship’s structure, to provide representative air relative humidity and temperature measurements.

For the general management of psychrometers, the recommendations of Part I, Chapter 4 should be followed. Distilled water should be used for the wet-bulb thermometer. If this is not readily available, water from the condenser will generally be more suitable than ordinary freshwater. Water polluted by (traces of) seawater should never be used because any traces of salt will affect the wet-bulb temperature significantly.

4.2.10 Precipitation

The measurement of precipitation at sea is discussed in WMO (1962; 1981). As an aid to observers on ships, descriptions of precipitation at sea, for use in reporting present weather, are given in Annex 4.B.

While not normally reported by the VOS, signalled by the $i$ code figure = 4, precipitation measurements can still be reported from fixed stations or vessels equipped with a precipitation gauge, by using the appropriate $i$ code figure.

4.2.10.1 Measurements and instruments

The complete measurement comprises the determination of both the amount and the duration of precipitation. The amount of precipitation should be measured with a raingauge adapted for use aboard a ship. Readings should be made preferably every 6 h. Amounts of precipitation up to 10 mm should be read to 0.2 mm. Larger amounts should be read to 2 per cent of the total. The required accuracy of the measurement is the same as is given for the resolution of the reading. The duration of precipitation should be recorded in rounded units of 5 min.

It is difficult to obtain reliable measurements of precipitation on board a ship, owing to the aerodynamic effect of the superstructure of the ship, the influence of roll and pitch, the capture of spray, and the changes in ship position. The equipment used on ships for the measurement of precipitation should be constructed and exposed in such a manner that the first three effects mentioned above are avoided or minimized as far as possible.

Precipitation measurements from fixed stations (lightships, ocean station vessels, large buoys, towers, etc.) are particularly valuable because the effect of ship movement is eliminated and the data can, thus, be included in climatological analyses without reduction. However, the problems of platform motion and salt contamination must still be considered.

Gimbal-mounted raingauge

The most common instrument used on board ships for the measurement of precipitation is the gimbal-mounted raingauge, an arrangement that is not very effective, especially during bad weather, as it is not able to keep the gauge horizontal at all times. An efficient gimbal arrangement is very complicated and expensive and is used only aboard special ships. Generally, when a raingauge is used, a fixed installation with a remote measurement arrangement seems to be a better option.

Conical marine raingauge

The conical marine raingauge is normally fixed high up on a mast. A plastic tube leads the water to a remotely placed collector on the deck, or in the wheelhouse. This can be a useful device for measuring precipitation, provided that the installation precautions are taken into account. The raingauge orifice should be fixed in a plane parallel to the ship's deck.

Recording raingauge

Three types of recording raingauges have been developed for use at sea. In one type, the collector is installed in the open while the recorder is mounted indoors. The rainwater is channelled along a pipe from the collector to a reservoir near the recorder. A pen linked to a float in the reservoir records the change of water level therein on a chart on a rotating drum. The reservoir is emptied automatically by a siphon when the total collected corresponds to 20 mm of rainfall.

In the electrical contact type of raingauge, the connection between the gauge and the recorder is made by electrical means. The rainwater caught by the collector is stored temporarily in a reservoir. After an amount corresponding to 0.5 mm of
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rainfall has been received, the rising surface touches a needle to close an electric circuit. A motor then closes the inlet valve and simultaneously opens a drain valve. After the water has drained away, the valves revert to their original state and a single pulse is sent to the recorder. Errors occur when the motion of the ship or buoy causes the water level to fluctuate rather than to rise steadily. This limitation can be overcome by using a peristaltic pump. This device drains a fixed quantity of water (rather than all the water available) each time the contact is made and, therefore, is less sensitive to fluctuations in water level; there are also no valves to maintain.

The observation of precipitation by radar requires the use of narrow radar beams and calibrating raingauges together with the addition of specialized equipment to monitor the state of the radar and to apply corrections. Radars provided on board ships for other purposes do not have these features and their use for the quantitative observation of precipitation is not normal practice.

A third type of recording raingauge is a specifically designed ship raingauge that uses a horizontal and a vertical omnidirectional collector to allow for rainfall measurements at high wind speeds (Hasse and others, 1998). By measuring the amount of water that is collected by the vertical collector surface, a correction for the wind effect is possible by using the wind speed measured simultaneously at the site of the instrument. Rainfall intensities and amounts are measured and calculated separately for the top and the side collectors and corrected rainfall values are obtained as a wind-speed-dependent weighted average.

4.2.10.2 Precipitation intensity at sea

A recording raingauge can, of course, be used for measuring precipitation intensity. Attempts have been made to facilitate visual estimation of rainfall intensity by establishing a relationship with visibility. A relationship was found in slight to moderate rates of precipitation falling from more or less continuous cloud. In other conditions, such as showery weather, however, no reliable relationship has been found. Even for the former conditions, observers should be aware that estimates of visibility at sea are difficult to make with sufficient precision for the rate to be estimated satisfactorily.

4.2.11 Sea-surface temperature

The temperature to be observed is that of the sea surface representative of conditions in the near-surface mixing layer underlying the ocean skin.

The sea-surface temperature should be very carefully measured. This is because, among other things, it is used to obtain the difference with air temperature, which provides a measure of the stratification of temperature and humidity and of other characteristics of the lower layers of maritime air masses. For these reasons, the temperature of the seawater thermometer should be read to 0.1°C.

It has not been possible to adopt a standard device for observing sea-surface temperatures on account of the great diversity in ship size and speed and because of cost, ease of operation and maintenance consideration.

Sea-surface temperature may be observed by:
(a) Taking a sample of the sea-surface water with a specially designed sea bucket;
(b) Reading the temperature of the condenser intake water;
(c) Exposing an electrical thermometer to seawater temperature either directly or through the hull (for example, using an internally mounted hull contact sensor);
(d) Using an infrared radiometer mounted on the ship to look down on the sea surface.

The principal methods used for many years have been (a) and (b). Studies of the difference in temperature provided by the two methods have been made (WMO, 1972) in which it is reported that intake temperatures average 0.3°C greater than those measured by sea-bucket samples. In recent years, as the speed and height of ships have increased, method (c), which gives the most consistent results, has been more widely used. The use of radiometers is rarely encountered on ships but may be used on some offshore platforms. Of all these methods, the condenser intake technique is the least desirable because of the great care needed to obtain good results.
4.2.11.1 Sea buckets

A sea bucket is lowered over the side of the ship to obtain a sample of seawater. The bucket is hauled back on board and a thermometer is then used to measure the temperature of the water. The sample should be taken from the leeward side of the ship, and well forward of all outlets. The thermometer should be read as soon as possible after it has attained the temperature of the water sample, ensuring that it is read away from direct sunlight. When not in use, the bucket should be hung in the shade.

A sea bucket should be designed to ensure that seawater can circulate through it during collection and that the heat exchange due to radiation and evaporation is minimized. The associated thermometer should have a quick response and be easy to read and should preferably be fixed permanently in the bucket. If the thermometer must be withdrawn for reading, it should have a small heat capacity and should be provided with a cistern around the bulb such that the temperature of the water withdrawn with it does not vary appreciably during the reading. The design of the bucket should be deemed adequate for its purpose by the organization recruiting the ship for observations.

Measurements from sea buckets of good design (not simple buckets of canvas or other construction) can be expected to agree well over an extensive range of conditions. However, sea buckets are less convenient to use than instruments attached to the ship and their use is sometimes restricted by weather conditions or by the size or speed of the ship.

4.2.11.2 Intake and tank thermometers

The thermometer provided within the intake pipe when the ship is built is normally not suitable for the measurement of sea-surface temperature. Thus, the organization recruiting the ship should ideally, with the permission of the shipping company concerned, install an appropriate thermometer. Although this is rarely a practical option nowadays, the thermometer should preferably be mounted in a special tube providing adequate heat conductivity between the thermometer bulb and positioned close to the water intake.

When a direct-reading thermometer is installed in cramped conditions, the observer should be warned of the possibility of readings errors due to parallax. A distant reading system with the display elsewhere (for example, in the engine room or on the bridge) overcomes this problem. The observer should also be aware that, for ships of deep draught, or when a marked temperature gradient exists within the sea-surface layer, intake temperature readings usually differ considerably from those close to the sea surface, and will vary according to the ship's ballast loading condition. Lastly, of course, the intake temperature should not be taken when the ship is stationary, otherwise the cooling water is not circulating. It should be noted that the installation of retrofit intake, or hull contact Sea Surface Temperature (SST) sensor can often be time-consuming and complicated, often forcing Port Meteorological Officers or technicians to work in difficult environment (interior of ships, with limited access, etc.)

The sea chest in the bottom of a ship is a cavity in which the intake pipes may terminate and which may be used to observe the intake temperature. It is a favoured position for the sensor of a distant-reading thermometer. The limitations already mentioned apply to such installations.

Although the majority of intake thermometers will only provide instantaneous temperature readouts, some ships may be equipped with temperature probes that can sample the measurements at a given frequency and average them over a period of time. In that case, and in order to provide for measurements that are more representative of the sea-surface temperature, a modal filtration algorithm may be used to exclude the extreme readings from the computed average.

4.2.11.3 Hull-attached thermometers

Hull-attached thermometers provide a very convenient and accurate means of measuring sea-surface temperature. They are necessarily distant-reading devices, the sensor being mounted either externally in direct contact with the sea using a “through-the-hull” connection, or internally (the “limpet” type) attached to the inside of the hull, except if the hull is a twin hull. Both types show very good mutual agreement, with the “through-the-hull” type showing a slightly quicker response.

The sensors must be located forward of all discharges at a depth of 1 to 2 m below the water line. When large changes of draught can occur, more than one sensor may be needed. There can be considerable problems of fitting and wiring, which is best done when the ship is being built. For subsequent fitting, the limpet-type thermometer avoids the need for drydocking the ship.
4.2.11.4 Trailing thermometers

Several means have been devised for trailing the sensor of a distant-reading thermometer in the sea at a point from which a sea bucket would take its sample. The differences concern the way in which the connecting cable is brought on board and the arrangement for exposing the sensor to the sea.

The cable must be able to withstand the drag of the sensor, while providing a good electrical connection despite the stretch that can occur. An early design used a thickly braided nylon rope inside which was inserted a twin telephone cable of high tensile strength. Other designs have used a PVC garden watering hose with a twin-wire conductor passing loosely within.

To expose the sensor, a small bucket has been used with loosely packed rubberized hog's hair to prevent damage by shock or vibration. The bucket has two small holes to let the water escape slowly and does not need to be submerged all the time. It takes about 8 s to empty so that periodic wave motions of 2 or 3 s have no adverse effect on the temperatures obtained.

In an alternative design, the sea bucket is dispensed with by arranging for the hose to provide the exposure and protection required by the sensor. Along the last 2 to 3 m of the hose, which has an internal diameter of 12 mm, holes of 8 mm in diameter are punched. The end of the hose is closed, apart from a small drainage hole. A length of rope attached to the end of the hose stabilizes the instrument and allows it to slide smoothly along the sea surface with water entering to flow past the sensor.

These devices provide readings that are in good agreement with those of an accurate sea bucket and can be used readily. However, since experience is limited, no information is available on their possible fouling by weeds, and so on. Thus, streaming and recovery may be necessary on each occasion as for a sea bucket.

4.2.11.5 Radiometers

Because of its temperature, any substance gives off heat energy as infrared radiation. The amount of energy and the wavelength of the radiation depend upon the temperature of the substance and its emissivity. Thus, radiometers which respond to infrared radiation can be used to measure the temperature of a substance. When directed at the sea surface, a radiometer measures the temperature of only the uppermost 1 mm or so, because the emissivity of water is near unity. This uppermost layer is often called the ocean skin. Large temperature gradients, with the coolest temperature at the top, may exist in the first few centimetres of the ocean, especially in relatively calm conditions.

Radiometers can be hand held (pointing forward and downward), mounted on the bow or on a boom extending over the water, or carried on an aircraft or satellite. Radiometer measurements do not usually represent sea-surface temperatures as defined above, but rather the evaporative surface skin temperature. They are used on only a few ships.

4.2.12 Ocean waves

The main topics of this section are the definitions and behaviour of waves and the visual methods of observing them. Automated methods are briefly mentioned in section 4.3 on moored buoys, although they are applied on other types of platforms.

4.2.12.1 Definitions and descriptions of waves

Fetch: Distance along a large water surface trajectory over which a wind of almost uniform direction and speed blows.

Wind wave or wind sea: Waves raised by the wind blowing in the immediate neighbourhood of an observation site at the time of observation.

Swell: Any system of water waves which has left its generating area (or observed when the wind field that generated the waves no longer exists).

Wave length: Horizontal distance between successive crests or troughs. It is equal to the wave period multiplied by the wave speed.

Wave height: Vertical distance between the trough and crest of a wave.

Wave period: Time between the passage of two successive wave crests past a fixed point. It is equal to the wave length divided by the wave speed.

Wave speed: The distance travelled by a wave in a unit of time. It is equal to the wave length divided by the wave period.

The observation should include the measurement or estimation of the following characteristics of the wave motion of the sea surface in respect of each
distinguishable system of waves, namely, sea and swell (principal and secondary):
(a) Direction (from which the waves come) on the scale 01–36 as for wind direction;
(b) Period in seconds;
(c) Height.

The following methods of observing wave characteristics of separate wave systems should be used as a guide.

Wind-generated ocean waves occur in large systems which are defined in connection with the wind field that produced the waves and also with the relative position of the point of observation. Bearing in mind the distinction between sea and swell, the observer should differentiate between the recognizable wave systems on the basis of direction, appearance and period of the waves.

Figure 4.1 shows a typical record drawn by a wave-height recorder. It shows the height of the sea surface above a fixed point against time, namely, it represents the up-and-down movement of a floating body on the sea surface as it is seen by the observer. It gives a representation of the sea surface in its normal appearance when it is stirred by the wind to form a wind wave.

Waves invariably travel in irregular groups with areas of slight wave development of two or more wave lengths between the groups. The irregularity is greater in the wind wave than in a swell. Furthermore, and this cannot be shown by a wave record, groups consisting of two or more well-formed waves in the sea can be seen to travel in directions which may differ as much as 20° or 30° from each other; as a result of interference of crossing waves, the crests of sea waves are rather short. Swell waves have a more regular appearance. These waves travel in a rather regular succession and well-defined direction with generally long and smooth crests.

Undisturbed typical swell waves may be observed in areas where there has been little or no wind over a period of several hours to a day or more. In most areas, sea and swell are intermixed.

4.2.12.2 Visual observations from merchant ships

In trying to observe the wave characteristics of each of the recognizable wave systems (sea and swell) separately, the observer should be aware of the fact that the higher components of a wind wave resemble swell waves by their comparatively long crests and large periods. It may seem possible to split the assembly of waves of different heights, periods and directions (together forming the system of a wind wave) into two different waves systems and consider the smaller waves as wind waves and the larger waves as swell, but this may not be correct.

The distinction between wind waves and swell should be made on the basis of one of the following criteria:

Wave direction: If the mean direction of all waves of more or less similar characteristics (in particular, height and length) differs by 30° or more from the mean direction of waves of different appearance (in particular, height and/or length), the two sets of waves should be considered to belong to separate wave systems.

Appearance and period: When typical swell waves, characterized by their regular appearance and long crestedness, arrive approximately, namely, within 20°, from the direction of the wind, they should be considered as a separate wave system if their period is at least 4 s greater than the period of the larger waves of the existing wind wave.

For measuring the mean period and height of a wave system, significant waves should be considered.
only; these are the higher waves in the centre of each group of well-formed waves (Figure 4.1). The flat and badly formed waves (A) in the area between the groups must be omitted from the record.

The mean period and the mean height of about 15 to 20 well-formed waves; from the centres of the groups is actually required; of course, these waves cannot be consecutive. The smaller wave-like disturbances (B) which can be seen clearly to be forming under the action of the wind on top of the larger waves are also to be omitted from the record.

Occasionally, waves may be encountered which literally stand out above the environmental waves (C). Such waves may occur singly or in a group of two or three. The observer should not concentrate on these maximum waves only; in order to arrive at a measure for the mean period and mean height of about 15 to 20 waves, he or she should also consider groups of well-formed waves of medium height. Consequently, the reported wave height will be smaller than the maximum height obtained by the observed waves. On average, the actual height of 1 out of about 10 waves will exceed the height to be reported. It is common practice to define the significant wave height measured by wave height recorders as the average height of the highest one third of the waves; it should approximate the wave height, which would be estimated by a manual observer.

The observer must bear in mind that only measurements or quite good estimates are to be recorded. Rough guesses have little value. The quality of the observations must have priority over their quantity. If only two, or even only one, of the three elements (direction, period, height) could be measured, or really well estimated, for example, at night, the report would still be of value.

The above considerations must be taken into account in all methods of observation described below. More details on waves are provided in WMO (1998) and WMO (2001), section 4.4.1.

Wave direction

The direction from which the waves are coming is most easily found by sighting along the wave crests and then turning 90° to face the advancing waves. The observer is then facing the direction in which the waves are coming.

Wave period

This is the only element that can actually be measured on board moving merchant ships. If a stop-watch is available, only one observer is necessary; otherwise, two observers and a watch with a second hand are required. The observer notes some small object floating on the water at some distance from the ship: if nothing is available, a distinctive patch of foam can usually be found which remains identifiable for the few minutes required for the observations. The watch is started when the object appears at the crest of the wave. As the crest passes, the object disappears into the trough, then reappears on the next crest, and so forth. The time at which the object appears to be at the top of each crest is noted. The observations are continued for as long as possible; they will usually terminate when the object becomes too distant to identify, on account of the ship's motion. Obviously, the longest period of observation will be obtained by choosing an object initially on the bow as far off as it can be clearly seen.

Another method is to observe two or more distinct consecutive periods from an individual group while the watch is running continuously; with the passage of the last distinct crest of a group or the anticipated disappearance of the object, the watch is stopped, then restarted with the passage of the first distinct crest of a new group. The observer keeps count of the total number of periods until it reaches at least 15 or 20.

Observations can also be made by watching the pitch and roll of the ship's bow. The observer picks the point which is at the highest or lowest in the cycle and starts the timer from there. When it returns to the same point, the observer records the time. By repeating this process several times, a reliable observation can be determined. This also works during night-time observation for which the observer feels the rise and fall within his or her body.

With observations of a period less than 5 s and low wind velocity, the above observation may not be easily made, but such waves are less interesting than those with longer periods.

Wave height

With some experience, fairly reliable estimates can be made. For estimating the height of waves having wave lengths much shorter than the ship, the observer should take up a position as low down in the ship as possible, preferably amidships where the pitching is least, and on the side of the ship from which the waves are coming. Use should be made of the intervals which occur every now and
then, when the rolling of the ship temporarily ceases.

In cases of waves longer than the ship, the preceding method fails because the ship as a whole rises over the wave. Under these circumstances, the best results are obtained when the observer moves up or down in the ship until, when the ship is in the wave trough and upright, the oncoming waves appear just level with the horizon (Figure 4.2). The wave height is then equal to the height of the observer above the level of the water beneath him or her (a). If the ship is rolling, care should be taken to ensure that the approaching wave is in line with the horizon at the instant when the ship is upright, otherwise the height estimate will be too large (b).

By far the most difficult case is that in which the wave length exceeds the length of the ship, but the wave height is small. The best estimate of height can be obtained by going as near to the water as possible, but even then the observation can be only a rough estimate.

4.2.12.3 Observations from ocean station vessels and other special ships

Ocean station vessels are normally provided with suitable recording instruments. However, if visual observations are made, the above procedure should be followed; in addition, the ship should heave with the waves coming directly from ahead. For measuring wave period, an object can be thrown over the side of the vessel. For measuring wave height, marks should be painted amidships on the ship’s side (half a metre apart).

Length can best be observed by streaming a buoy for such a distance astern that the crests of two successive waves simultaneously pass the buoy and the observer. The distance between the two is the wave length.

The velocity can be obtained by noting the time of the passage of a wave from the stern to the buoy, with allowance being made for the ship’s speed.

4.2.12.4 Waves in coastal waters

The following are additional definitions applying to sea surface in coastal waters:

Breaker: The collapse of a whole wave resulting from its running into very shallow water, of a depth of the order of twice the wave height.

Surf: The broken water between the shoreline and the outermost line of the breakers.

Breaking sea: The partial collapse of the crest of a wave caused by the action of the wind; steepening of waves due to their encountering a contrary current or tidal stream; or steepening of waves due to their running into shoal water not shallow enough to cause a breaker.

Wave observations made from a coastal station cannot be expected to be representative of conditions in the open sea. This is because the waves are affected by the depth of the water, by tidal influence and by reflection from objects such as steep rocks and jetties. In addition, the location may be sheltered by headlands or, less obviously, by shoals, both of which may affect the height and direction of travel. An extensive account of these phenomena is given in WMO (1991b).

When observations are to be made despite these difficulties, the waves should be chosen in the same way as at sea. If they are required for wave research, the exact mean depth of water at the time of observation and the time itself should both be stated.

4.2.12.5 Terminology for sea and swell waves

The following terminology is recommended for uses other than the inclusion in coded messages,

![Figure 4.2. The effect of the ship’s roll on the estimation of wave height](image-url)
such as supplying weather information and forecasts for shipping, publications, pilots, and so on:

For the length of swell waves:

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short</td>
<td>0–100 m</td>
</tr>
<tr>
<td>Average</td>
<td>100–200 m</td>
</tr>
<tr>
<td>Long</td>
<td>over 200 m</td>
</tr>
</tbody>
</table>

For the height of swell waves:

<table>
<thead>
<tr>
<th>Type</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0–2 m</td>
</tr>
<tr>
<td>Moderate</td>
<td>2–4 m</td>
</tr>
<tr>
<td>Heavy</td>
<td>over 4 m</td>
</tr>
</tbody>
</table>

For the height of sea waves:

<table>
<thead>
<tr>
<th>Type</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calm (glassy)</td>
<td>0 m</td>
</tr>
<tr>
<td>Calm (rippled)</td>
<td>0–0.1 m</td>
</tr>
<tr>
<td>Smooth (wavelets)</td>
<td>0.1–0.5 m</td>
</tr>
<tr>
<td>Slight</td>
<td>0.5–1.25 m</td>
</tr>
<tr>
<td>Moderate</td>
<td>1.25–2.5 m</td>
</tr>
<tr>
<td>Rough</td>
<td>2.5–4 m</td>
</tr>
<tr>
<td>Very rough</td>
<td>4–6 m</td>
</tr>
<tr>
<td>High</td>
<td>6–9 m</td>
</tr>
<tr>
<td>Very high</td>
<td>9–14 m</td>
</tr>
<tr>
<td>Phenomenal</td>
<td>over 14 m</td>
</tr>
</tbody>
</table>

In all cases, the exact bounding length or height is included in the lower category, namely, a sea of 4 m is described as rough. When the state of the sea surface is so confused that none of the above descriptive terms can be considered appropriate, the term “confused” should be used.

4.2.13 **Ice**

Several forms of floating ice may be encountered at sea. The most common is that which results from the freezing of the sea surface, namely sea ice. The reporting of sea ice is discussed in WMO (1970).

The other forms are river ice and ice of land origin. River ice is encountered in harbours and estuaries where it is kept in motion by tidal streams and normally presents only a temporary hindrance to shipping. Ice of land origin in the form of icebergs is discussed separately below.

Both icebergs and sea ice can be dangerous to shipping and always have an effect on navigation. Sea ice also affects the normal processes of energy exchange between the sea and the air above it. The extent of sea-ice cover can vary significantly from year to year and has a great effect both on adjacent ocean areas and on the weather over large areas of the world. Its distribution is therefore of considerable interest to meteorologists and oceanographers.

Broad-scale observations of the extent of sea-ice cover have been revolutionized by satellite photography, but observations from shore stations, ships and aircraft are still of great importance for detailed observations and for establishing the ground truth of satellite observations.

At present, observations of floating ice depend almost entirely on visual estimation. The only instrumental observations of floating ice are carried out by conventional radar and new techniques, such as passive microwave sensors or sideways-looking airborne radar. However, icebergs are poor reflectors of radar energy and cannot always be detected by this means.

4.2.13.1 **Observations of ice accretion**

Ice accretion can be extremely hazardous because of its effects on small ships, particularly on vessels of less than about 1 000 gross tonnage. Even on larger ships, it can cause radio and radar failures due to the icing of aerials. Visibility from the bridge may also be affected. Problems have occurred due to icing on the deck cargoes of large container ships. Apart from its possible effect on stability, it may cause difficulty in unloading cargo at the port of destination when containers and their lashings are frozen solidly to the deck. Fishing vessels are particularly vulnerable to ice accretion. Further information is given in WMO (1991b), while a detailed consideration of the meteorological aspects appears in WMO (1974).

There are two main types of icing at sea: icing from seawater and icing from freshwater. Icing from seawater may be due either to spray and seawater thrown up by the interaction between the ship or installation and the waves, or to spray blown from the crests of the waves, or both. Icing from freshwater may be due to freezing rain and/or drizzle, or occasionally when the occurrence of wet snow is followed by a drop in temperature, or it may be due to freezing fog. Both types may occur simultaneously.

The most important meteorological elements governing ice accretion at sea are wind speed and air temperature. The higher the wind speed relative to the ship and the lower the air temperature, the greater the rate of ice accretion. There appears to be no limiting air temperature below which the icing risk decreases.

 Provision is made in the WMO code form for ships (WMO, 2010a), used for radio weather reports
from ships at sea, for the inclusion of reports of ice accretion. This may be done either in code or in plain language. The coded form, in a single five-figure group, provides for reports of the cause of icing, the ice thickness and the rate of accretion. Plain-language reports must be preceded by the word ICING and are particularly encouraged for indicating features of the icing which are dangerous to vessels.

4.2.13.2 Formation and development of sea ice

Ice less than 30 cm thick

The first indication of ice formation is the appearance of small ice spicules or plates in the top few centimetres of the water. These spicules, known as frazil ice, form in large quantities and give the sea an oily appearance. As cooling continues the frazil ice coalesces to form grease ice, which has a matt appearance. Under near-freezing, but as yet ice-free, conditions, snow falling on the surface may result in the sea surface becoming covered by a layer of slush. These forms may be regrouped by the action of wind and waves to form shuga and all are classified as new ice. With further cooling, sheets of ice rind or nilas are formed, depending on the rate of cooling and on the salinity of the water. Ice rind is formed when water of low salinity freezes into a thin layer of brittle ice which is almost free of salt, whereas when water of high salinity freezes, especially if the process is rapid and the wind is very light, the ice has an elastic property which is characteristic of nilas. The latter form of ice is subdivided, according to its thickness, into dark and light nilas; the second, more advanced form reaches a maximum thickness of 10 cm.

The action of wind and waves may break up ice rind or nilas into pancake ice, which can later freeze and thicken into grey and grey-white ice, the latter attaining a thickness of up to 30 cm. These forms of ice are referred to collectively as young ice. In rough conditions this ice may be broken up into ice cakes or floes of various sizes.

Ice 30 cm to 2 m thick

The next stage of development is known as first-year ice and is subdivided into thin, medium and thick categories. Thin first-year ice has a thickness of 30 to 70 cm. Medium first-year ice has a range of thickness from 70 to 120 cm. In polar areas, thick first-year ice may attain a thickness of approximately 2 m at the end of the winter.

Old ice

Thick first-year ice may survive the summer melt season and is then classified as old ice. This category is subdivided into second-year ice or multi-year ice, depending on whether the floes have survived one or more summers. The thickness of old ice is normally in the range of 1.2 to 3 m or more before the onset of the melt season. Towards the end of the summer melt season, old ice may be considerably reduced in thickness. Old ice may often be recognized by a bluish surface, in contrast to the greenish tint of first-year ice.

Snow cover

During winter, ice is usually covered with snow which insulates it from the air above and tends to slow down its rate of growth. The thickness of the snow cover varies considerably from region to region as a result of differing climatic conditions. Its depth may also vary considerably within very short distances in response to variable winds and to ice topography.

Decay of sea ice

While the snow cover persists, almost 90 per cent of the incoming radiation is reflected back into space. Eventually, however, the snow begins to melt as air temperatures rise above 0°C in early summer, and the resulting freshwater forms puddles on the surface. These puddles absorb about 90 per cent of the incoming radiation and rapidly enlarge as they melt the surrounding snow or ice. Eventually, the puddles penetrate to the bottom surface of the floes and are known as thaw holes. This slow decay process is characteristic of ice in the Arctic Ocean and seas where movement is restricted by the coastline or islands. Where ice is free to drift into warmer waters (for example, the Antarctic, East Greenland and the Labrador Sea), decay is accelerated in response to wave erosion as well as warmer air and sea temperatures.

Movement of sea ice

Sea ice is divided into two main types according to its mobility. One type is drift ice, which is continually in motion under the action of the wind and current; the other is fast ice, attached to the coast or islands, which does not move. When ice concentration is high, namely seven tenths or more, drift ice may be replaced by the term pack ice.
Wind stress in the drift ice causes the floes to move in an approximately downwind direction. The deflecting force due to the Earth's rotation (Coriolis force) causes the floes to deviate about 30° to the right of the surface wind direction in the northern hemisphere. Since the surface wind is itself deviated by a similar amount but in the opposite sense from the geostrophic wind (measured directly from isobars), the direction of movement of the ice floes, due to the wind drift alone, can be considered to be parallel to the isobars.

The rate of movement due to wind drift varies not only with the wind speed, but also with the concentration of the drift ice and the extent of deformation (see subsection below). In very open ice (1/10–3/10) there is much more freedom to respond to the wind than in close ice (7/10–8/10), where free space is limited. Two per cent of the wind speed is a reasonable average for the rate of ice drift caused by the wind in close ice, but much higher rates of ice drift may be encountered in open ice. Since it is afloat, a force is exerted on drift ice by currents that are present in the upper layers of the water, whether these are tidal in nature or have a more consistent direction due to other forces. It is usually very difficult to differentiate between wind- and current-induced ice drift, but in any case, where both are present, the resultant motion is always the vector sum of the two. Wind stress normally predominates, particularly in offshore areas.

**Deformation of sea ice**

Where the ice is subject to pressure, its surface becomes deformed. On new and young ice, this may result in rafting as one ice floe overrides its neighbour; in thicker ice, it leads to the formation of ridges and hummocks according to the pattern of the convergent forces causing the pressure. During the process of ridging and hummocking, when pieces of ice are piled up above the general ice level, large quantities of ice are also forced downward to support the weight of the ice in the ridge or hummock. The draught of a ridge can be three to five times as great as its height, and these deformations are major impediments to navigation. Freshly formed ridges are normally less difficult to navigate than older weathered and consolidated ridges.

### 4.2.13.3 Icebergs

Icebergs are large masses of floating ice derived from glaciers, including ice shelves. The depth of a berg under water, compared with its height above, varies widely with different shapes of bergs. The underwater mass of an Antarctic iceberg derived from a floating ice shelf is usually less than the underwater mass of icebergs derived from Greenland glaciers. A typical Antarctic tabular berg, of which the uppermost 10 to 20 m is composed of old snow, will show one part of its mass above the water to five parts below. However, the ratio for an Arctic berg, composed almost wholly of ice with much less snow, is typically 1:8.

Icebergs diminish in size in three different ways: by calving, melting and wave erosion. A berg is said to calve when a piece breaks off; this disturbs its equilibrium and as a result it may drift at a different angle or capsize. Large underwater projections, which may be difficult to observe, are a usual feature of icebergs. In cold water, melting takes place mainly on the water-line, while, in warm water, a berg melts mainly from below and calves frequently. It is particularly dangerous to approach a berg melting in warm water for it is unstable and may fragment or overturn at any time. There are likely to be many growlers and bergy bits around rapidly disintegrating icebergs, thus forming a particular hazard to navigation.

Bergs are poor reflectors of radar energy and cannot always be detected by this means. Their breakdown fragments (bergy bits and growlers) are even more difficult to detect with a ship's radar since they are often obscured by the background clutter from waves and swell. These smaller fragments are especially dangerous to shipping. Despite their low profile, they contain sufficient mass to damage a vessel which comes into contact with them at normal cruising speed. Some growlers consisting of pure ice hardly break the sea surface and are extremely difficult to detect.

### 4.2.13.4 Observations of sea ice and icebergs

The key to good ice observing lies in familiarity with the nomenclature and experience. WMO (1970), with its illustrations, is the best guide to the mariner for ice identification.

The four important features of sea ice which affect navigation are as follows:

(a) **Thickness:** the stage of development (i.e. new ice, young ice, first-year ice or old ice and their subdivisions);

(b) **Amount:** concentration (estimated according to the tenths of the sea surface covered by ice);

(c) **The form of the ice,** whether it is fast or drift ice and the size of the constituent floes;
(d) Movement: particularly with regard to its effect on deformation.

Since icebergs represent such a hazard to navigation, particularly at night or in poor visibility, it is also important to report the number in sight at the time of the observation, especially in waters where they are less frequently observed.

Sea ice can be reported in plain language or by the use of codes. WMO has adopted two sea-ice codes for international use. The simplest is the ICE group appended to the SHIP code format. The ICEAN code has been developed for specialist use for the transmission of sea-ice analysis and prognoses.

There are two basic rules for observation from ships and shore stations:
(a) Obtain a large field of view by making the observation from the highest convenient point above the sea surface (for example, the top of a lighthouse, the bridge or crow's nest of a ship);
(b) Do not attempt to report sea-ice conditions beyond a radius of more than half the distance between the point of observation and the horizon.

WMO has developed a set of symbols for use on maps depicting actual or forecast sea-ice conditions. These symbols are intended for the international exchange of sea-ice information and for radiofacsimile transmission of ice data.

4.2.14 Observations of special phenomena
When describing waterspouts, the direction of rotation should always be given as if seen from above.

4.2.15 Operations of the voluntary observing fleet
An essential initial step in recruiting Voluntary Observing Ships is to obtain the permission of the owners and master of the vessel. When permission has been granted and the ship has been identified, Port Meteorological Officers should do the following:
(a) Install calibrated instruments ensuring best exposure;
(b) Issue stationery or install electronic logbook software;
(c) Train observers on instrument care and operation;
(d) Train observers in all aspects of observing practices;
(e) Demonstrate use of electronic logbook software and compilation of the observation;
(f) Record the required ship metadata, in the format as given in the current International List of Selected, Supplementary and Auxiliary Ships (WMO-No. 47);
(g) Demonstrate methods of observation transmission;
(h) Explain NMS marine forecast products.

Once a ship has been recruited, the Port Meteorological Officer should ideally endeavour to visit it at least every three months (subject to shipping movements and staff resources; if not practicable, annual visits can be considered) to check the accuracy of the instruments and to renew the supply of forms, documents, and so on. The Port Meteorological Officer should take the opportunity to foster interest in meteorology, to explain the mutual value to seafarers and meteorologists of accurate weather observations.

AWS and digital sensors may allow a longer checking period of one year.

Full information on the WMO VOS Scheme is given in WMO (2001).

4.2.16 Other voluntary observations out of the scope of the Voluntary Observing Ship Scheme
In some instances, a company (usually oil or gas) operating a ship or platform takes observations/measurements for its own use and makes them available on the Global Telecommunication System with little participation from a Port Meteorological Officer. The installation, maintenance and training on the metocean equipment should normally be done under contract. In case the vessel/station was not recruited by a Port Meteorological Officer, efforts should be made to ensure that the relevant metadata are also made available through the appropriate WMO channels.

4.3 Moored buoys
Moored buoys come in a wide variety of configurations (e.g. in terms of mooring design, sensor types, sampling schemes, mounting techniques and telemetry) serving a wide variety of operational and research applications and disciplines. This section, which does not reflect the wide variety of possibilities used in currently functioning systems, is
focusing on requirements for marine meteorological measurements from operational meteorological moored buoys. Information regarding other systems addressing the requirements for research applications can be found in other publications and websites, for example:

- ATLAS tropical moored buoys: http://www.pmel.noaa.gov/tao/proj_over/mooring.shtml
- Ocean Climate Stations: http://www.pmel.noaa.gov/OCS/
- NOAA guide to making climate quality meteorological and flux measurements at sea (Bradley and Fairall, 2007)

A typical moored buoy designed for deep ocean operation is equipped with sensors to measure the following variables:

(a) Wind speed;
(b) Wind direction;
(c) Atmospheric pressure;
(d) Sea-surface temperature;
(e) Wave height and period;
(f) Air temperature;
(g) Dewpoint temperature or relative humidity.

Additional elements measured by some moored buoys are as follows:

(a) Maximum wind gust
(b) Wave spectra (directional or non-directional);
(c) Solar radiation (downward short-wave radiation);
(d) Surface current or current profiles;
(e) Surface salinity;
(f) Subsurface temperature and salinity down to 500 m or 750 m;
(g) Atmospheric visibility;
(h) Precipitation;
(i) Surface CO₂ concentration.

For waves, the following variables are generally measured or estimated using the following definitions (see also section 4.2.12.1 to complement these definitions):

**Significant wave height:** Estimate of the average height of the one-third highest waves;

**Maximum wave height:** The maximum single wave height which is observed in a certain time period;

**Mean zero crossing wave period:** The wave period corresponding to the number downward zero-crossing of the surface elevation. It can also be estimated from the second frequency moment of the wave energy spectrum;

**Peak height:** The wave height corresponding to the peak of the wave energy spectrum (the part of the spectrum with the highest wave energy);

**Peak period:** The wave period corresponding to the peak height of the wave energy spectrum;

**Spectral wave period:** The wave period corresponding to the mean frequency of the spectrum.

In addition to the meteorological and oceanographic measurements, it is necessary to monitor buoy location and various housekeeping parameters to aid data quality control and maintenance. Moored-buoy technology has matured to the extent that it is expected to obtain six months to as long as two years of unattended operation even in the most severe conditions. Operational life is largely determined by the life of the sensors, with sensor exchanges often carried out at 12 to 18 month intervals.

The observations from moored buoys are now considered to be better quality than ship observations with regard to the accuracy and reliability of measurements (Wilkerson and Earle, 1990; Ingleby, 2010). Indeed, moored buoys are generally regarded as providing the highest quality observations of a wide range of marine meteorological variables and, in addition to their use by forecasters and assimilation into numerical weather prediction models, the data are also used to provide information on the climatology of oceanic areas, “ground truth” reference data for satellite calibration/validation and estimates of surface fluxes (e.g. Bourras, 2006).

Typical measurement uncertainties obtained from operational buoys are as follows:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind speed</td>
<td>1 m s⁻¹ or 5%</td>
</tr>
<tr>
<td>Air temperature</td>
<td>0.2°C</td>
</tr>
<tr>
<td>Sea-level pressure</td>
<td>0.2 hPa</td>
</tr>
<tr>
<td>Sea-surface temperature</td>
<td>0.2°C</td>
</tr>
<tr>
<td>Dewpoint temperature</td>
<td>0.5°</td>
</tr>
<tr>
<td>Significant wave height</td>
<td>10% or 0.2 m</td>
</tr>
<tr>
<td>Wave direction</td>
<td>10°</td>
</tr>
<tr>
<td>Wave period</td>
<td>1 s</td>
</tr>
</tbody>
</table>

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The standard suite of sensors on moored buoys samples wind speed, peak gust (e.g. 3 to 5 second gust depending on national requirements); wind direction; barometric pressure; air temperature; water temperature; and non-directional ocean wave energy spectra, from which significant wave height and peak (or average) wave period are determined. For tsunameters, water-column height is the standard measurement.

4.3.1 Atmospheric pressure

Atmospheric pressure and its variability in both time and space are crucially important for numerical weather prediction and for analysis and forecasting. Most buoys measure atmospheric pressure by means of digital aneroid barometers. Pressure is found from the electrical capacitance across parallel pressure-sensitive plates. The capacitance between the plates increases as pressure increases. The following pressure measurements are made:

(a) Station pressure is the actual measurement made by the barometer at the station elevation in hPa. In some cases two barometers may be used and their values averaged.

(b) Sea-level pressure is the pressure reduced to sea level from the station pressure in units of hPa. For buoys deployed at sea this is very close to the station pressure. A large difference is observed between sea-level pressure and station pressure from buoys deployed in lakes at high elevations. The conversion to sea-level pressure is made using the procedures described in WBAN (United States Weather Bureau, 1963).

Many buoys that are deployed in regions subject to hurricanes or intense low-pressure systems have the capability of measuring supplemental 1 min average pressure data. These data are recorded after the hourly pressure data fall below a predetermined threshold (e.g. 1008 hPa in the tropics). Supplemental pressure data are identified as follows:

(a) The minimum 1 min barometric pressure in hPa from the primary (and secondary if one is installed) barometer is the minimum 1 min mean barometric pressure for the entire hour;

(b) The time is the minute within the hour that the minimum pressure occurred.

4.3.2 Wind measurements

Wind measurements are one of the most important measurements made from moored buoys. They are essential for the marine weather forecaster.

Definitions:

Wind direction is the direction from which the wind is blowing in degrees clockwise from true north. It is a unit vector average of the record of wind direction;

Wind speed is the scalar average of the wind speed over the sampling interval (usually 10 min);

Wind speed maximum is the highest wind speed in the wind record. Gusts are determined from the highest running mean of the record over a short time interval (for example, 5 s).

The wind measurements are generally made by a propeller-vane (e.g. United States and Canada) or a cup anemometer and a wind wane (United Kingdom, Ireland and France). To avoid mechanical wear ultrasonic wind speed and direction sensors with no moving parts are starting to be used on moored buoys. Wind direction measurement is normally associated with a compass so the buoy relative wind direction can be corrected to True.

The United States and Canada typically used four-blade, impeller-driven, wind-vane sensor on their meteorological moorings. The final measurements are statistical estimates of the wind from time series of instantaneous wind samples taken at a minimum rate of 1 Hertz (Hz) over a particular length of time. The sampling rate is a function of the payload. Most moored buoys use an 8 min acquisition period. The following standard wind measurements are produced each hour.

Some Members (e.g. the United States and Canada) have their meteorological moored buoys perform statistical processing at the end of an acquisition period, and the output message is updated with the new statistics and six 10 min segments. Statistical processing includes the calculation of the mean for both direction and speed and the standard deviation of the speed. The hour’s data do not represent data from minute 0 to min 59. Rather, these represent the latest, complete six 10 min segments before the end of the last acquisition. The 10 min segments are, however, bounded by minutes 0, 10, 20, etc.

For United States and Canadian moored buoys, wind speeds at 10 m above site elevation and 20 m above site elevation are derived from an algorithm (Liu and others, 1979) that uses the height of the anemometer, the wind speed, a constant relative humidity of 85 per cent, a constant sea-level pressure of 1013.25, and the air and water temperature. If either the air or water temperature is unavailable,
then the neutral stability is assumed. Assuming neutral stability can introduce an error of up to 5 per cent. If both are missing then neither 10 nor 20 m wind speeds are made.

The United Kingdom, French and Irish K-series moored buoys have traditionally used a cup anemometer and a self-referencing wind vane to measure the speed and direction over a 10 min acquisition period each hour. However, during operation, salt water permeates the seals and eventually failure of the instruments occurs when salt crystals form in the lubricant leading to mechanical failure of the moving parts. These moored buoys have dual wind systems to provide increased resilience in the event of anemometer failure. To further improve reliability the United Kingdom is replacing these with a new wind system utilizing a sonic anemometer and electronic compass.

4.3.3 Temperature

Temperature is one of the basic meteorological measurements. Electronic thermistors are generally used to make all temperature measurements which are provided in degrees Celsius (°C). Temperature measurements can also be used for deriving sea-level pressure and standard-height wind speed from non-standard height atmospheric pressure and wind measurements, respectively.

4.3.3.1 Air temperature

Air temperature measurements are generally very reliable; however, it is important to note that the physical position of temperature sensors can adversely affect measurements. Air temperature housings can lead to non-representative readings in low wind conditions. Air temperature is sampled at some rate during the sampling period (e.g. United States and Canada use a rate of 1 Hz, and the French, United Kingdom and Irish K-series buoys 0.1 Hz over a sampling period of 10 s).

4.3.3.2 Water temperature

While there are generally few problems with water temperature measurements, it should be noted that the depth of water temperature sensors varies with buoy hull, and that the temperature probes on buoys are attached to the inside of the hull. Since buoy hulls are highly thermally conducting, the temperatures measured may reflect the average temperature of the water around the submerged hull rather than the temperature of the water nearest the probe. In highly stratified water, especially during afternoon hours in calm wind conditions, the water temperature reported from a buoy may be 2°C to 3°C below the skin temperature of the water.

4.3.6 Ocean wave estimates

Sea-state estimates are probably the most complex measurements made from moored buoys and are extremely important to marine forecasters, mariners, ocean engineers and scientists. On a buoy, all of the basic wave measurements are derived in some way from the time series of the buoy’s motion. NDBC (2003) provides for complete details on wave measurements made by the United States National Data Buoy Center (NDBC).

Sea state is a description of the properties of sea-surface waves at a given time and place. This might be given in terms of the wave spectrum, or more simply in terms of the significant wave height and some measure of the wave period (AMS, 2000). Many moored buoys provide a measurement of the spectral variance density (IAHR, List of Sea State Parameters) which will be referred to as spectral wave density. Most buoys derive all non-directional wave parameters, heights and periods, steepness, and so on, from spectral wave densities. Furthermore, many buoys measure the directional wave spectrum and from that derive mean and principal wave directions, and first and second normalized polar coordinates from the Fourier coefficients that centres disseminate through the WMO FM-65 WAVEOB alphanumeric codes (WMO, 2010a).

4.3.7 Non-directional ocean wave estimates

Most buoys use accelerometers to measure buoy heave motion. Accelerometers, fixed to remain vertical relative to the hull or stabilized parallel to the earth vertical, are used in buoys and make the vast majority of ocean wave measurements. Vertical stabilization, when used, is achieved through use of heave, pitch and roll sensor which reference plane is mounted on a gravity stabilized platform and provides for a natural period in the order of 40 s. This type of equipment is expensive, and has a built-in mechanical system for keeping the accelerometer vertical as the buoy and sensor tilt.

Operational non-directional wave measurement systems report estimates of acceleration or displacement spectra. If not directly reported, displacement

3 The United Nations National Data Buoy Center no longer makes wave measurements at C-MAN stations using laser wave height sensors.
spectra are derived from acceleration spectra as part of the calculations involved in the shore-side processing of the wave data. From these spectra, average wave period, dominant wave period, significant wave height, and steepness are calculated. These non-directional wave parameters are defined as follows.

Average wave period, in seconds, can be computed in different ways. It can be such that it corresponds to the wave frequency that divides the wave spectrum into equal areas or it can be based on the second frequency moment of the non-directional spectral density. It can also be estimated using a zero crossing method.

Dominant wave period or peak wave period, in seconds, is the wave period corresponding to the centre frequency of the frequency band with the maximum non-directional spectral density.

Significant wave height, \( H_{\text{mp}} \), is estimated from the variance of the wave displacement record obtained from the displacement spectrum according to the following equation:

\[
H_{\text{mp}} = 4 \left[ \int_{f_1}^{f_u} S(f) df \right]^2
\]

where \( S(f) \) is the spectral density of displacement; \( df \) is the width of the frequency band; \( f_u \) is the upper frequency limit; and \( f_1 \) is the lower frequency limit.

### 4.3.8 Directional ocean wave estimates

Directional wave measurement systems require, in addition to the measurement of vertical acceleration or heave (displacement), buoy azimuth, pitch and roll. These allow east-west slope and north-south slope to be computed. Most buoys use several different methods and sensor suites for the measurement of these angles.

It is recommended (Swail and others, 2010) that in order to serve the full range of users, directional spectral wave measuring systems should reliably estimate the so-called “First 5” standard. Technically, this refers to five defining variables at a particular wave frequency (or wave period). The first variable is the wave energy, which is related to the wave height, and the other four are the first four coefficients of the Fourier series that defines the directional distribution of that energy. At each frequency band, not only is the wave direction defined but also the spread (second moment), skewness (third moment) and kurtosis (the fourth moment). The skewness resolves how the directional distribution is concentrated (to the left or right of the mean) and the kurtosis defines the peakedness of the distribution. Obtaining these three additional parameters (spread, skewness and kurtosis) for each frequency band yields an improved representation of the wave field.

Wave measurements from moored buoys are also used to validate wave measurements derived from high-frequency radar instruments.

#### 4.3.9 Water-column height for tsunami detection

Most buoy tsunamieters use DART® II technology and report water level (actually water-column height) based on pressure and temperature measurements made at the sea floor and converted to a water-column height by multiplying the pressure by a constant 670 mm per pound per square inch absolute.

#### 4.3.10 Relative humidity

Humidity sensors used by buoys employ a circuit that measures humidity through the change in capacitance of a thin polymer as it is exposed to variations in water vapour. A gas-permeable membrane protects the electronic parts from spray and particulate matter but allows air to enter the instrument housing. The sensor is temperature-sensitive and incorporates a temperature probe to provide a temperature correction in the calculation of relative humidity. The sensor is sampled at some rate during the sampling period (e.g. 1 Hz for the United States and Canadian meteorological moored buoys). For the United Kingdom, French and Irish K-series buoys, an instantaneous value is taken from the electric hygrometric circuit element at the observing time.

#### 4.3.11 Ocean sensors

In order to understand and predict the ocean, its properties must be monitored. Many buoys help to monitor the ocean by also measuring surface currents, ocean current profiles, near-surface temperature and water quality parameters. Included in the water quality parameters can be turbidity, redox potential (Eh), pH, chlorophyll-a, and dissolved oxygen. Buoy data are quality controlled in real time and where possible these data are distributed over the Global Telecommunication System.
4.3.11.1 Surface ocean currents

Surface currents are collected to support commerce, safety of operation, search and rescue, oil spill response, and currents near harbour entrances that have an impact on ocean transportation. Surface currents measured from buoys are also used to validate surface currents derived from high-frequency radar instruments. Most buoys acquire these measurements using buoy-mounted acoustic Doppler samplers.

4.3.11.2 Ocean current profiles

Ocean current profiles provide the motion of the ocean at different levels in the water column. This information is essential for assessing oil spill dispersal, search and rescue, stresses on offshore infrastructure, and is therefore of interest to scientists and engineers. Ocean current measurements taken at the surface have been used to calibrate visible range radiometers aboard satellites. The sensor is placed as high as possible on the platform to avoid shadows. Solar radiative flux is measured in watts per square metre and photosynthetically active radiation is measured in micromols per square metre per second.

4.3.12 Precipitation

Siphon raingauges have been installed on some moored buoys.

4.3.13 Solar radiation measurements

Solar radiation is an important influence on physical, biological and chemical processes near the air-sea interface, and is therefore of interest to scientists and engineers. Solar radiation measurements taken at the surface have been used to calibrate visible range radiometers aboard satellites. The sensor is placed as high as possible on the platform to avoid shadows. Solar radiative flux is measured in watts per square metre and photosynthetically active radiation is measured in micromols per square metre per second.

4.3.14 Visibility

Visibility sensors have been placed on some stations where visibility is a critical concern for safe navigation. The sensor measures the extinction of light across a small volume of air between an emitter and a collector. It is important to note that these are measurements at a single point, and that there are several similar but different definitions.

4.4 Unmanned Light Vessels

In most respects, these platforms are similar to moored buoys. However, because of their larger dimensions and the feasibility of carrying a large instrument payload, it is more straightforward to deploy additional sensors, such as visibility sensors. In severe weather, such sensors can be affected by sea spray generated by the vessel itself. However, in most conditions, performance is equal to that of instruments deployed on land-based automatic weather stations.

4.5 Towers and Platforms

On towers (usually in relatively shallow waters close to shore), and on platforms in more remote areas, it is possible to operate standard automatic weather stations, similar in design to land automatic weather stations (see Part II, Chapter 1). Additional sensors are often deployed, for example, wave sensors and sensors for measuring mean water level above a reference point, ceilometers and visiometers. Fixed platforms can include large gravity based
structures, and mobile jack-up rigs and semi-submersible rigs. Jack-up and semi-submersible rigs, and drill ships, could be considered stationary platforms as they are moored or dynamically positioned to remain in one place while in operation. On manned platforms and rigs, measured data can be supplemented by visual observations of cloud, visibility and weather, thus allowing full synoptic reporting. Visual observations from oil/gas platforms should be made according to the procedures recommended under section 4.2. However, there are cases where difference procedures apply. For example, a platform may include wave data from a nearby moored wave buoy, and sea-surface temperature from a nearby supply vessel.

Some manned fixed or stationary (offshore oil and gas) platforms may include significant wave height and some measure of wave period in their weather report (using the same parts of the FM 13 SHIP code as the moored buoys), using output from a nearby wave buoy or from an onboard wave radar.

Platforms and towers make convenient structures for mounting meteorological sensors. Installation and maintenance can be less complicated and more economical than for a moored buoy making data frequency and reliability better. Data quality is unaffected by ship or buoy motion and is less susceptible to errors from sensors damaged by wave action.

However, temperature and humidity sensors need very careful positioning as often there are heat and exhaust sources that will modify the local environment making values unrepresentative of environmental conditions. Wind measurements might be taken at heights in excess of 100 m above mean sea level and require correction to the equivalent 10 m surface wind (note that ideally it would be best to also have the actual observation and its height). In the case of towers close inshore, tide height can significantly alter the effective height of the wind sensor.

In conclusion, therefore, fixed towers and offshore platforms can provide a cost-effective source of data-releasing moored buoys to be used in more remote areas where there are no alternatives.

4.6 DRIFTING BUOYS

Drifting buoys have been used for many years in oceanography, principally for the measurement of sea-surface currents. However, the development of reliable satellite tracking and data relay systems (WMO/IOC, 1995) has led to a dramatic increase in the numbers of ocean drifting buoys deployed, and significant development has taken place in the sensor capabilities of drifters for meteorological and oceanographic purposes.

A description of drifting buoy systems and operations is given in UNESCO (1988). More recently, the WMO/IOC Data Buoy Cooperation Panel (DBCP) published the Global Drifter Programme Barometer Drifter Design Reference (WMO/IOC, 2009). See also the annual reports and workshop proceedings of the DBCP, such as WMO/IOC (2004a and 2004b).

The evolution of drifting buoy technology has been driven by the needs of oceanographic research, on the one hand, and operational meteorology, on the other. Thus, three main distinct types of buoys can be characterized as follows:

(a) For oceanographic research, and especially for the World Ocean Circulation Experiment (Surface Velocity Programme, SVP, 1988–1993), a surface-current-following drifter equipped also to measure sea-surface temperature has been developed and deployed in large numbers over the world’s oceans;

(b) For operational meteorology, a drifting buoy design has evolved based on those developed for the First Global Atmospheric Research Programme Global Experiment. These buoys primarily measure air pressure, sea-surface temperature and air temperature;

(c) For polar applications, different ice floats have been designed to measure traditional atmospheric variables as well as ice and snow conditions (ice/snow temperature and temperature profiles in the ice, ice thickness, ice stress, water conditions below ice). By tracking the buoy position on the ice it is possible to estimate ice motion. Efforts have been made to develop buoys that meet the combined requirements of oceanographic research and operational meteorology, which has resulted in the development of:

(i) The SVP-B drifter, which is essentially a surface-current-following drifter with an air pressure sensor added;

(ii) The SVP-BW drifter (or Minimet), which is essentially an SVP-B drifter with wind-measuring capability using so-called Wind Observation Through Ambient Noise (WOTAN) technology;

(iii) The wind and temperature profile buoy, which is basically a meteorological
drifter with added wind speed sensor and subsurface thermistor chain for the measurement of temperature profile to depths of 100 m or so. Wind direction is measured on these buoys by orienting the whole buoy into the wind using a profiled mast or fixed wind vane;

(iv) The addition of salinity sensors to SVP drifters.

Drifting buoys are expendable devices, thus performance is a compromise between the requirements and the cost of ownership. As well as hardware costs, it should be noted that the cost of data processing and dissemination throughout the Argos satellite system is significant and can be a limiting factor, although the more recent use of an Iridium satellite data telecommunication system is helping to resolve this problem. However, the performance of drifting buoy sensors is adequate for the purposes of synoptic meteorology and oceanography, as appropriate. Note that the quality of wind speed observations is questionable, resulting in their non-use by operational centres (Ingleby, 2010).

The typical measurement uncertainties of operational systems are as follows:

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea-surface temperature</td>
<td>0.21°C^a</td>
</tr>
<tr>
<td>Air pressure</td>
<td>0.84 hPa^b</td>
</tr>
<tr>
<td>Wind speed</td>
<td>3.5 m s⁻¹ or 10%^abc</td>
</tr>
<tr>
<td>Wind direction</td>
<td>18.5°^b</td>
</tr>
<tr>
<td>Subsurface temperature</td>
<td>0.1°C</td>
</tr>
</tbody>
</table>

^a Source: O’Carroll, Eyre and Saunders (2008).
^b Source: buoy monitoring statistics, European Centre for Medium-Range Weather Forecasts, January 2012.
^c Because of the low sensor height (approximately 1 m above sea level) these uncertainties apply to low wind speed and low sea states only.
ANNEX 4.A

WMO/IOC REGIONAL MARINE INSTRUMENT CENTRES

1. Considering the need for high-quality marine meteorology and oceanographic measurements from the world oceans to address the requirements of WMO and UNESCO/IOC programmes and co-sponsored programmes, the need for facilities for the regular calibration and maintenance of marine instruments and the monitoring of instrument performance, on a regional basis in order to address adherence of ocean observations and associated metadata to high level standards for instruments and methods of observation, the need for documenting methods of measurements, for understanding biases introduced by each type of instrumentation, and for developing methods to correct such biases, in order to achieve delivery and use of coherent datasets, it has been recommended that:

Regional Marine Instrument Centres (RMICs) should have the following capabilities to carry out their corresponding functions:

Capabilities:
(a) An RMIC must have, or have access to, the necessary facilities and laboratory equipment to perform the functions necessary for the calibration of meteorological and related oceanographic instruments deployed to address the common requirements of WMO and UNESCO/IOC marine-related programmes and co-sponsored programmes;
(b) An RMIC must maintain a set of meteorological and oceanographic standard instruments or references and establish the traceability of its own measurement standards and measuring instruments to the International System of Units (SI);
(c) An RMIC must have qualified managerial and technical staff with the necessary experience to fulfil its functions;
(d) An RMIC must develop its individual technical procedures for the calibration of meteorological and related oceanographic instruments using its own calibration equipment;
(e) An RMIC must develop its individual quality assurance procedures;
(f) An RMIC must participate in, or organize, inter-laboratory comparisons of standard calibration instruments and methods;
(g) An RMIC must utilize the resources and capabilities of its region of interest according to the region’s best interests, when appropriate;
(h) An RMIC must apply international standards applicable for calibration laboratories, such as ISO/IEC 17025, to the extent possible;
(i) A recognized authority must assess an RMIC, at least every five years, to verify its capabilities and performance.

Corresponding functions:
(a) An RMIC must assist Members/Member States of its region in calibrating their national meteorological standards and related oceanographic monitoring instruments according to the RMIC capabilities;
(b) An RMIC must participate in, or organize, JCOMM and/or regional instrument inter-comparisons, following relevant JCOMM recommendations;
(c) An RMIC must make a positive contribution to Members/Member States regarding the quality of measurements;
(d) An RMIC must advise Members/Member States on enquiries regarding instrument performance, maintenance and the availability of relevant guidance materials;
(e) An RMIC must actively participate, or assist, in the organization of regional workshops on meteorological and related oceanographic instruments and measurements;
(f) The RMIC must cooperate with other RMICs in the standardization of meteorological and related oceanographic measurements and sensors;
(g) An RMIC must regularly inform Members/Member States and report, on an annual basis, to the JCOMM Management Committee on the services offered to Members/Member States and the activities carried out. JCOMM in turn should keep the Executive Councils of WMO and UNESCO/IOC informed on

5 Basically in situ geophysical instruments deployed in the surface marine environment or subsurface.

6 JCOMM is the body that formally proposes new RMICs and proposes any authority to do evaluations.
the status and activities of the RMICs, and propose changes, as required.

2. The mechanism for formal WMO and UNESCO/IoC designation of RMICs implies the following:
   (a) Governance for defining the functions and adoption of an RMIC is proposed by JCOMM and endorsed by the WMO and UNESCO/IoC Executive Councils;
   (b) A candidate RMIC is required to produce a statement of compliance, list capabilities of the proposed centre, state the suite of instrument expertise offered, state the formal commitment to voluntarily host the centre, and demonstrate capability to JCOMM;
   (c) The establishment of RMICs is initiated by JCOMM, and the designation process is coordinated by JCOMM and the WMO/IoC Secretariats according to the process endorsed by JCOMM and documented in JCOMM Technical Report No. 53;
   (d) Where more than one RMIC is established within a WMO and/or IoC Region, there should be coordination amongst the Centres to minimize duplication of services.

3. The following centres have been designated as RMICs:

<table>
<thead>
<tr>
<th>Region</th>
<th>Centre</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asia-Pacific</td>
<td>National Center for Ocean Standards and Metrology</td>
<td>Tianjin, China</td>
</tr>
<tr>
<td>North America, Central America and the Caribbean</td>
<td>United States National Data Buoy Center</td>
<td>Stennis Space Center, Mississippi, United States</td>
</tr>
</tbody>
</table>
Precipitation occurs either in a more or less uniform manner (intermittent or continuous) or in showers.

All precipitation other than showers must be reported as intermittent or continuous.

Non-showery precipitation usually falls from stratiform clouds (mainly altostratus and nimbostratus). Showers fall from large convective clouds (mainly cumulonimbus or cumulus of moderate or strong vertical development) and are usually characterized by their abrupt beginning and ending and by variations in the intensity of the precipitation. Drops and solid particles in a shower are generally larger than those occurring in non-showery precipitation.

The drops of precipitation can be supercooled (i.e. the temperature of the drops is below 0°C). On impact with a surface, drops of supercooled rain form a mixture of water and ice having a temperature near 0°C.

Forms of precipitation

The descriptions given below are compatible with the definitions given in Part III.2, Volume I, of the International Cloud Atlas (WMO, 1975):

Drizzle: Fairly uniform precipitation in the form of very small drops of water. The diameter of the drops is normally less than 0.5 mm. The drops appear almost to float, thus making visible even slight movements of the air. Drizzle falls from a continuous and fairly dense layer of stratiform cloud, which is usually low, sometimes touching the surface (fog). For coding purposes, drizzle must be classified as slight, moderate or heavy, which are defined as follows:

(a) Slight drizzle can be readily detected on the face of wheel-house windows, but produces very little runoff from deck, roofs, and so on;
(b) Moderate drizzle causes windows, decks and superstructures to stream with moisture;
(c) Heavy drizzle: same as for moderate drizzle. It also reduces visibility to below 1 000 m.

Rain: Precipitation of drops of water, which falls from a cloud. The diameter and concentration of raindrops vary considerably according to the intensity, and especially the nature, of the precipitation (continuous rain, rain shower, downpour, etc.). Continuous rain usually falls from a more or less uniform layer or layers of thick stratiform cloud. For coding purposes, rain must be classified as slight, moderate or heavy. These terms are defined as follows:

(a) Slight rain may consist of scattered large drops or numerous smaller drops. The rate of accumulation on a deck is low and puddles form very slowly;
(b) Moderate rain: Individual drops are not clearly identifiable. Rain spray is observable. Puddles form rapidly. Sounds from roofs range from swishing to a gentle roar;
(c) Heavy rain: A downpour which makes a roaring noise on awnings and deckheads and forms a misty spray of fine droplets by splashing on deck surfaces.

Snow: Precipitation of ice crystals, separately or agglomerated, which falls from a cloud. The form, size and concentration of snow crystals vary considerably according to the conditions prevailing at the time of the snowfall. The intensity is coded as slight, moderate or heavy.

Showers: These are characterized by their abrupt beginning and end, and by the generally rapid and sometimes violent variations in the intensity of the precipitation. Drops and solid particles falling in a shower are generally larger than those falling in non-showery precipitation. Whether the precipitation (rain or snow) occurs as showers or not depends on the clouds in which it originates. Showers fall from large convective clouds and are defined as follows:

(a) Rain and snow showers must be classified for coding purposes with regard to intensity as either slight, moderate or heavy. The description is the same as for slight, moderate or heavy rain or snow. It must be remembered, however, that the visibility in showery weather shows a much greater variability than for the same category of continuous rain;
(b) Violent showers are exceptionally heavy or torrential rain showers. Such showers occur mostly in tropical regions.
Snow pellets: Precipitation of white and opaque ice particles which falls from a cloud. These particles are generally conical or rounded. Their diameter may attain 5 mm. These grains, having a snow-like structure, are brittle and easily crushed; when they fall on a hard surface they bounce and often break up. In most cases, snow pellets fall as showers, often together with snowflakes, normally when temperatures near the surface are close to 0°C. For recording purposes, the intensity of snow pellets, when they occur alone, is determined according to the visibility in the same manner as for snow.

Hail: Precipitation of transparent, or partly or completely opaque, particles of ice (hailstones), which are usually spherical, conical or irregular in form and have a diameter generally between 5 and 50 mm (smaller particles of similar origin may be classified either as small hail or ice pellets), and fall either separately or agglomerated into irregular lumps. Hail always occurs in the forms of showers and is generally observed during heavy thunderstorms. For coding purposes, hail must be classified as either slight, moderate or heavy. The intensity is determined by the rate of accumulation of stones as follows:

(a) Slight hail: Few stones falling, no appreciable accumulation on flat surfaces;
(b) Moderate hail: Slow accumulation of stones. Fall sufficient to whiten the decks;
(c) Heavy hail: Rapid accumulation of stones. Rarely experienced in temperate latitudes at sea.

Small hail: Precipitation of translucent ice particles which falls from a cloud. These particles are almost spherical and sometimes have conical tips. Their diameter may attain and even exceed 5 mm. Usually, small hail is not easily crushable and when it falls on a hard surface it bounces with an audible sound on impact. Small hail always occurs in showers. For coding purposes, small hail must be classified as either slight, moderate or heavy. The intensity is determined by using the accumulation rate given for hail.

Ice pellets: Precipitation of transparent ice particles which falls from a cloud. These particles are usually spherical or irregular, rarely conical. Their diameter is less than 5 mm. Usually, ice pellets are not easily crushable, and when they fall on hard surfaces they generally bounce with an audible sound on impact. Precipitation in the form of ice pellets generally falls from altostratus or nimbostratus. The intensity of ice pellets is determined in the same manner as for hail.

Snow grains: Precipitation of very small opaque white particles of ice which falls from a cloud. These particles are fairly flat or elongated; their diameter is generally less than 1 mm. When the grains hit a hard surface they do not bounce. They usually fall in small quantities, mostly from stratus or from fog and never in the form of a shower. This precipitation corresponds to drizzle and occurs when the temperature is approximately between 0°C and –10°C. As there is only one code specification which refers to snow grains (ww – 77), it is not necessary to classify intensity.
REFERENCES AND FURTHER READING


