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CHAPTER 4. MARINE OBSERVATIONS

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 air above the sea surface. 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.

This chapter discusses observations at the air–sea interface made in-situ, which include the usual surface parameters that are also measured over land and discussed in that context in Volume I of this Guide. This chapter also considers other observations of importance to marine physics and physical oceanography, including: sea-surface temperature; ocean waves; sea ice, icebergs and ice accretion; and salinity. Upper-air measurements are taken using techniques that are essentially the same over the sea and over land.

Detailed formal requirements for observations from sea stations are given in the *Manual on the WMO Integrated Global Observing System* (WMO, 2015). Advice on requirements and procedures is given in the *Guide to Marine Meteorological Services* (WMO, 2001). In situ marine 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, light vessels, moored buoys, drifting buoys, towers, oil and gas platforms and rigs, island automatic weather stations (AWS), and ship-borne AWS systems. The type of platform generally determines the range of elements measured and reported. Thus, ships of the VOS, using both automated and manual observation techniques, report the full range of observations required for synoptic meteorology. In contrast, moored buoys provide only automated observations, but of a wide range of variables which may include: surface air pressure, air temperature and humidity, wind speed and direction, wave height and period, and sea surface temperature (SST). The majority of drifting buoys report up to three parameters, namely, position, atmospheric pressure at sea surface, and sea-surface temperature (SST). A smaller fraction of the array measures sea surface salinity, directional wave spectra, subsurface temperatures through the mixed layer, and wind speed and direction.

Observations from voluntary observing ships are most commonly compiled and transmitted to shore in a nationally agreed ship-to-shore transmission format, and then distributed internationally in appropriate WMO codes (for example, FM 94 BUFR). WMO codes are documented in the *Manual on Codes* (WMO,2011*a*, 2011*b*);general information is found in Volume I.2, Part B, and templates specific to particular types of marine observations are documented in Volume I.2, Part C[1]. Further information can be found in the proceedings of a 2009 meeting on the ocean observing system (Hall et al., 2010), including information on VOS (Kent et al., 2010), research vessels (Smith et al., 2010), ship-based oceanographic measurements (Goni et al., 2010), profiling floats (Freeland et al., 2010), buoys (Meldrum et al., 2010; McPhaden et al., 2010; Send et al., 2010; Dohan et al., 2010; Keeley et al., 2010), and waves and sea-level (Swail et al., 2010*a*; Swail et al., 2010*b*; Merrifield et al., 2010). On the recommendation of the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM), a network of WMO/Intergovernmental Oceanographic Commission (IOC) Regional Marine Instrument Centres (RMICs) has been set up to facilitate adherence of observational data and processed observational products to higher level standards for instruments and methods of observation, by providing (i) facilities for the calibration and maintenance of marine instruments and the monitoring of instrument performance; and (ii) assistance for instrument intercomparisons, as well as appropriate training facilities complementing what the manufacturers are also providing. Their terms of reference and locations are given in Annex 4.A.

4.2 OBSERVATIONS FROM SHIPS

This section contains detailed guidance and advice for taking measurements and making observations on ships. Reference WMO (1991*a*) is another source. Details on surface observations to be carried out within the framework of the JCOMM VOS Scheme are provided in WMO (2001), Chapter 6. Studies of the quality of observations from ships are given in WMO (1991*b*, 1999), Kent et al. (1993), WMO/IOC (2003*a*, 2003*b*), Kent and Berry (2005), Ingleby (2010), and Kennedy et al. (2012). A discussion of good observing practice from the research community is presented by Bradley and Fairall (2006) and information on sensors used in the marine environment by Weller et al. (2008). In all instances, the safety of the crew member taking the observation takes priority over the taking, recording, and dissemination of the observations in whole or in part.

4.2.1 Operation of the WMO Voluntary Observing Ship Scheme

The VOS Scheme is operated by National Meteorological and Hydrological Services (NMHSs) under the guidance of the JCOMM Ship Observations Team (SOT) and in particular the SOT VOS Panel (VOSP). Full information on the VOS Scheme is given in WMO (2001). VOS Programme Managers work with Port Meteorological Officers (PMOs) and technicians who typically act as the link between the VOS operator and the ship. An essential first step in recruiting VOS is to obtain the permission of the owners and master of the vessel. When permission has been granted and the ship has been identified, PMOs and technicians should do the following:

(a) Install calibrated instruments ensuring best exposure;

(b) Install electronic logbook software;

(c) Train observers on instrument care and operation;

[1] The *Manual on Codes*, Volume I.1 also presently describes the traditional alphanumeric codes (TAC) that have been used to circulate data for many years over the Global Telecommunication System (GTS), principally in the VOS context referring to the FM 13 SHIP code. WMO, however, is in the process of fully discontinuing the TAC for GTS transmission. Therefore, the *Manual on Codes* may in the future be restructured to omit the first volume altogether.

(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 as required for WMO (WMO, 2015);

(g) Demonstrate methods of report transmission for ships not equipped with an AWS (conventional ships);

(h) Explain NMHS marine forecast products.

Once a ship has been recruited, the PMO should ideally endeavour to visit it at least every three months (subject to shipping movements and staff resources; if not practicable, less frequent visits can be considered) to check the accuracy of the instruments, update electronic logbook software, and renew the supply of forms, documents and so on. Automatic weather stations and digital sensors may allow a longer checking period of one year. The PMO should take the opportunity to foster interest in meteorology and explain the mutual value to seafarers and meteorologists of accurate weather observations.

In some instances, a company operating a ship or platform takes observations/measurements for its own use and makes them available on the GTS without much participation from a PMO. The installation, maintenance and training on the meteorological and oceanographic equipment may be done under contract. In cases where the vessel/station was not recruited by a PMO, efforts should be made to ensure that the relevant metadata are made available through the appropriate WMO channels.

4.2.2 Voluntary Observing Ship observations

4.2.2.1 Elements observed

Ships participating in the VOS[2] Scheme undertaking meteorological observations should ideally observe, at times described in 4.2.2.4, the following elements:

(a) Ship position (from ship's navigation system);

(b) Ship course and speed (from ship's navigation system);

(c) Wind speed and direction;

(d) Atmospheric pressure;

(e) Pressure tendency and its characteristics;

(f) Air temperature;

(g) Humidity;

(h) Sea-surface temperature;

(i) Present and past weather, and weather phenomena;

[2] http://sot.jcommops.org/vos/; http://www.bom.gov.au/jcomm/vos/resources.html

(j) Cloud amount, type and base height;

(k) Precipitation;

(l) Visibility;

(m) Ocean wind waves and swell, including height, period and direction;

(n) Sea-ice and/or ice accretion on board ship, when appropriate;

(o) Special phenomena.

Above listed observations are measured, observed or visually estimated based on the capabilities of the measuring equipment onboard the ship.

Some specially equipped ships, for example research vessels, may make instrumentally measured observations and reports of precipitation, radiation, visibility, cloud parameters, wave parameters and others if applicable.

In general, instrumental observations requiring the use of a light at night should be ideally made after non-instrumental ones, so that the observer's eyes can adapt to the darkness without being impaired.

Where time and conditions warrant, or other factors, of highest priority for meteorological observations are items a) through f).

4.2.2.2 Equipment required

The following instruments are suitable for use on ships:

(a) A precision aneroid, dial aneroid or electronic digital barometer (Volume I, Chapter 3);

(b) A barograph, preferably open scale (desirable but not mandated) or a digital barometer that includes a barometric tendency trace (Volume I, Chapter 3);

(c) A liquid-in-glass[3] or electrical resistance thermometer (Volume I, Chapter 2);

(d) A hygrometer or psychrometer (Volume I, Chapter 4);

(e) A sea-temperature thermometer and suitable receptacle for obtaining a sample of seawater, or a continuously immersed sensor (for example, engine intake thermometer) or hull contact sensor with remote indicator.

The use of anemometers with suitable exposure as an alternative to the visual estimation of the wind speed (for example, using the Beaufort Wind Force Scale) is encouraged, provided that such instruments are routinely checked to ensure that they remain within acceptable tolerance determined by calibration. Additionally when using anemometers, observations of speed over ground, course over

[3] Mercury-in-glass thermometers should not be used any more, as the United Nations Environment Programme (UNEP) Minamata Convention on Mercury came into force globally in August 2017, and bans all production, import and export of mercury-based instruments (see Volume I, Chapter 1, 1.4.2).

ground, and heading of the ship are needed to accurately calculate a true (Earth-referenced) wind (see 4.2.2.6.2). Precipitation gauges are rarely provided for use on VOS.

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 (or on behalf of) the NMHSs concerned.

4.2.2.3 Automation of ship observations

Automatic weather stations or partially automated systems are increasingly being used on observing ships for both observation and data transmission purposes. Two basic modes of operation are used, as follows:

(a) The observation is made automatically using AWS techniques, as described in Volume III, Chapter 1. The position, course and speed of a ship are taken from its navigation system 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;

(b) The observations making up the marine report 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).

4.2.2.4 Times of observation

When done manually, the observation of elements other than pressure should be made within 10 min preceding the standard time for the synoptic observation. Atmospheric pressure, however, should be read at the exact time or as close as possible to the standard time.

Surface observations on board ships are typically made as follows:

(a) Synoptic observations from staffed ships are accepted at any time; however, they are traditionally made at main standard times: 0000, 0600, 1200 and 1800 UTC and/or at one or more of the intermediate standard times: 0300, 0900, 1500 and 2100 UTC;

(b) Hourly or more frequent observations should be made when an automated system is used (augmented as frequently as possible with the additional visual elements);

(c) Observations should be made more frequently whenever storm or stronger conditions threaten or prevail;

(d) When sudden and dangerous weather developments are encountered, observations should be made for immediate transmission without regard to the standard times of observation (for example, within 300 nautical miles of a named tropical system);

(e) Marine observations are just as valuable in coastal zones as in the open ocean and observations should be continued during the whole journey.

4.2.2.5 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 methods are most commonly used for conventional VOS:

(a) Commercial satellite systems through the INMARSAT-C system which is carried by most oceangoing ships for compliance with the International Convention for the Safety of Life at Sea (SOLAS) and Global Maritime Distress and Safety System (GMDSS) requirements. Weather observations are normally sent to a suitable Land Earth Station (LES) via a special access code (SAC) 41 message, which allows the costs of the report to be borne by the NMHS. A list of the acceptable LESs for SAC messages is maintained on the WMO website at http://www.wmo.int/pages/prog/amp/mmop/inmarsat_les.html. INMARSAT-C has near-global coverage, except in very high latitudes which are not covered. However, other dedicated SACs are now being set up to allow ship-to-shore messages to be sent in a compressed format, thereby allowing NMHS to reduce the transmission costs of their national observing fleets.

(b) E-mails from the ship, regardless of communication system, provides free transmission for the NMHS as the cost are born by the ship.

For automatic weather stations:

(a) Commercial satellite services such as Iridium are increasingly used for shipboard AWS systems. The Iridium Short Burst Data system using binary formatted messages can significantly reduce transmission costs. Iridium has the advantage of providing global satellite coverage and can also improve data timeliness;

(b) The INMARSAT-C data reporting service is also used for sending compressed meteorological data from certain AWS systems on non-automated manually reporting observing ships; http://www.wmo.int/pages/prog/amp/mmop/inmarsat_les.html.

(c) 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 GTS (WMO/IOC, 1995) but there can be several hours of delay, depending on the location of the observing station and the land receiving station. Costs can also be significant when compared to other satellite systems. It is typically used for small drifting buoys, although it is increasingly being replaced by Iridium. A few autonomous shipboard AWS systems also use Argos for data transmission.

(d) 3G/4G LTE based technologies may also be used to relay data from VOCs when it is close to shore to a central receiver at port or directly to the synoptic data reception server. This technology enables to transfer huge data as the bandwidth is comparatively higher and cost of transmission is cheaper.

(e) The International Data Collection System through the meteorological geosynchronous (GOES, METEOSAT, MTSAT) satellites. This system, funded mainly by NMHSs, 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 primarily used in connection with moored buoys but is also used for some shipboard AWS systems;

4.2.2.6 Wind

Observations of wind speed and direction may be made either by visual estimates or by anemometers. Winds should be measured only if using a well-maintained and recently calibrated instrument sited in a well-exposed location away from the influence of the superstructure, mast and spars. Reports of wind speed should be recorded in m s^{-1}, while for some purposes knots might still be used.

4.2.2.6.1 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 below).The Beaufort number obtained by estimation is converted into m s^{-1} or knots by the use of the wind speed equivalent columns of the Beaufort scale, so the wind speed is reported at a specific value in metres per second or knots according to the best estimate of the observer from within those equivalent ranges. National instructions may give guidance on preferred practice. The wind direction is determined by observing the orientation of the crests of wind 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 (for example, 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).

4.2.2.6.2 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). 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 are therefore increasingly being used on ships.

Beaufort scale in operational use for WMO reports of estimated wind referenced to 10 m above sea level

TABLE: Table horizontal lines

Beaufort number (force)	*Descriptive term*	*Mean equivalent wind speed*		*Wind speed equivalent range*		*Specifications for observations*	*Probable height of waves*	*Probable maximum height of waves*
		knots	*m s⁻¹*	*knots*	*m s⁻¹*	*On board ship (open sea)*	*m*	*m*
0	Calm	0	0	< 1	0–0.2	Sea like a mirror		
1	Light air	2	0.8	1–3	0.3–1.5	Ripples with the appearance of scales are formed, but without foam crests	0.1	0.1
2	Light breeze	5	2.4	4–6	1.6–3.3	Small wavelets; still short but more pronounced; crests have a glassy appearance and do not break	0.2	0.3
3	Gentle breeze	9	4.3	7–10	3.4–5.4	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	1.6	1.0
4	Moderate breeze	13	6.7	11–16	5.5–7.9	Small waves, becoming longer; fairly frequent white horses	1.0	1.5
5	Fresh breeze	19	9.3	17–21	8.0–10.7	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	2.0	2.5
6	Strong breeze	24	12.3	22–27	10.8–13.8	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	3.0	4.0
7	Near gale	30	15.5	28–33	13.9–17.1	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	4.0	5.5
8	Gale	37	18.9	34–40	17.2–20.7	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	5.5	7.5
9	Strong gale	44	22.6	41–47	20.8–24.4	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	7.0	10.0
10	Storm	52	26.4	48–55	24.5–28.4	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; on the whole, the surface of the sea takes a white appearance; the "tumbling" of the sea becomes heavy and shock-like; visibility affected	9.0	12.5
11	Violent storm	60	30.5	56–63	28.5–32.6	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	11.5	16.0

						of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected		
12	Hurricane	64 and over	32.7 and over	64 and over	32.7 and over	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	14 and over	–

Note that wave heights are indicated as a guide to show roughly what might be expected in the open sea. These wave heights should never be used for logging or reporting the state of the sea. In enclosed waters, or when near land, with an offshore wind, wave heights will be smaller and the waves steeper.

Source: OMI-CMI (1947)

It is difficult to obtain a good exposure for ship-borne wind instruments (WMO/IOC, 2003*b*; Yelland et al., 2001; Moat et al., 2005; Moat et al., 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 yardarm, it may be preferable that the speed and direction heads should form separate units, as a more even distribution of the weight on the yardarm can be obtained, and it may then be possible to fit the instruments farther outboard. Whether fitted on a yardarm or on a bracket fixed to the foremast, 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 foremast, and always to use the one which is more freely exposed. The top of the foremast, if available, is generally thought to be the best site for an anemometer. Ultrasonic wind sensors are efficient and provide good accuracy when installed on the top of the main mast.

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 (Kent et al., 1993). Only an observer who understands the nature of the airflow 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.

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. Relative wind should be transmitted if possible. The procedure for the calculation of true wind speed and direction from relative wind speed, relative wind direction, ship speed, course and heading is described in detail in WMO/IOC (2003*c*). It should be noted that the ship's course and the ship's heading may be significantly different particularly at low ship speeds or with large leeway. 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, 2002). These additional elements are preferably obtained from a magnetic compass and the ship’s speed information. They can also be obtained from the ship movement derived from a GPS receiver, but in that case the drift is not taken into account. In the past, this vector conversion was a frequent source of error in reported winds. However, increasing use of electronic logbook software that computes true wind will have reduced this source of error. For AWS, all of the required information is likely to be directly obtained from the anemometer and ship's navigation system.

The reported wind speed and direction will be the mean speed and direction measured over the 10 min period immediately preceding the observation. However, when the 10 min period includes a discontinuity in the wind characteristics, only data obtained after the discontinuity shall be used for reporting the mean values, and hence the period in these circumstances shall be correspondingly reduced.

The recording of ship metadata for WMO No. 1160 is particularly important for wind observations (Yelland et al., 2001). Metadata should be provided to indicate the instrumentation used, how it is installed onboard the ship (where on the ship and at what height), as well as details about the type of vessel (Kent et al., 2007). Metadata are used in particular to interpret the data correctly and increase data coherence (for example, bias correction) and permit traceability to standards.

4.2.2.7 Atmospheric pressure, pressure tendency and characteristic of pressure tendency

4.2.2.7.1 Methods of observation

Pressure can be measured either by a precision aneroid, a dial aneroid or an electronic digital barometer. The barometer reading shall be taken as close to the observation time as possible. In a manual observation, the barometer will be read last and entered into the observation just prior to completion of the report. Automatic systems should have an averaging period of 1 min (Volume I, Chapter 1, Annex 1.A). Most ships should report pressure to one decimal place.

With visual observation, the characteristic and amount of the pressure tendency in the past 3 h is 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 automatically.

4.2.2.7.2 Instruments

All barometers should conform to the general requirements given in Volume 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 Volume I, Chapter 1, Annex 1.A. The required measurement uncertainty is better 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 conditions inside. If this is not possible, instructions should be given to ensure that the bridge wing doors are opened prior to taking an observation. This is especially important on ships with pressurized accommodation blocks or on vessels that are carrying hazardous cargoes where the wheelhouse may be hermetically sealed.

In general, many NMHSs set their 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 can be calculated automatically with electronic logbook software or by an AWS.

4.2.2.7.3 Exposure and management

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 athwartships (to minimize the risk of the arm swinging off the chart).

4.2.2.7.4 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 or AWS that are capable of automatically applying the height correction (Bowditch, 2002, Tables 29–34).

4.2.2.7.5 Sources of error

Errors are discussed in Volume 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 should be minimized by enclosing the instrument in a chamber connected to a static pressure head or by connecting the device directly to this static pressure head.

On non-automated barometers, 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).

4.2.2.7.6 Checking with standard instruments

Aneroid barometers and barographs should be checked, wherever possible, at approximately three-monthly intervals against the standard barometer of a PMO 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 PMO, and a label attached to the barometer showing the barometer check date and the correction to be applied. Standard barometers should be calibrated, regularly.

Digital barometers have a much better stability and the length of time between calibrations may be as large as two years for some models.

4.2.2.8 Air temperature and humidity

Temperature (Volume I, Chapter 2) and humidity (Volume I, Chapter 4) observations are considered together as they are often measured by psychrometric methods with paired wet- and dry-bulb thermometers. With the increasing use of AWS, however, it is becoming more common for these parameters to be measured independently with a thermometer and separate hygrometer. Whichever method is used, the instruments should have good and long enough ventilation (to allow adaptation) and 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.

For visual 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 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.

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. Handheld hygrometers require several minutes to be acclimated to the open environment if they have been stored indoors before use. Acclimatization is reached, when the readout of the instrument is stable for a period of up to one minute.

For the general management of psychrometers, the recommendations of Volume 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.

With AWS or a distant digital display, a manual reading of the instruments inside the screen is no longer necessary and a single screen typically can be installed far enough from the ship's structure to provide good exposure. This means, however, that the filling of wet-bulb reservoirs becomes difficult, and consequently electronic temperature and relative humidity sensors are typically used with AWS. These instruments require calibration on a regular basis[4]. The AWS should report both air temperature and humidity as 1-min averages.

Humidity can be represented by several different variables, for example dewpoint temperature, wet-bulb in combination with dry-bulb temperature or relative humidity (Volume I, Chapter 4) and should be recorded as the variable measured. Any conversion between humidity variables adds uncertainty and will be affected by any errors in other variables used and by truncation to fit transmission formats. For psychrometric measurements, both dry-bulb and wet-bulb temperature are reported with a resolution of 0.1 °C. The dewpoint should be calculated using standard tables issued nationally or using standard WMO formulae (Volume I, Chapter 4, Annexes 4.A and 4.B) and the psychrometric coefficient appropriate to the instrument being used. Dewpoint temperature should also be reported to 0.1 °C resolution. Conversion of measurements of wet-bulb or dewpoint temperature to relative humidity recorded in whole percent introduces significant uncertainty and should be avoided. When directly measuring relative humidity (for example, using an AWS), relative humidity should be reported with resolution of 1 %.

4.2.2.9 Sea-surface temperature

The routine measurement is to take the seawater temperature from near or just below the sea surface. More rarely the radiometric temperature of the surface skin of the ocean is measured.

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. 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 considerations.

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[4] The filters on humidity sensors should be replaced on a 3 monthly basis. The complete sensor will probably require cleaning and recalibration in a laboratory every 12 months as a minimum.

The SST 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 sea-water 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;

(e) Using an expendable bathythermograph.

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. More recent studies suggest that this warm bias has reduced over time (Kent and Taylor, 2006). This study reported that the details of the intake temperature installation have a significant impact on the quality of observation. 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 (WMO, 1991*b*; Kent et al., 1993), however the location of the senor on the hull is critical. It should not be mounted in locations where there are significant heat sources such as the engine room. The use of radiometers is rarely encountered on VOS but may be used on some research vessels or on offshore platforms. Of all these methods, the condenser intake technique is the least desirable because of the great care needed to obtain good results.

4.2.2.9.1 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 out of the direct sunlight. When not in use, the bucket should be hung in the shade to drain.

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 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.

4.2.2.9.2 Intake and tank thermometers

The thermometer provided within the intake pipe when the ship is built is normally not suitable for the measurement of SST to the required accuracy. Thus, the organization recruiting the ship should, with the permission of the shipping company concerned, install an appropriate thermometer. The thermometer should be mounted in a special tube providing adequate heat conductivity between the thermometer bulb and surrounding seawater, and positioned close to the water intake, although this may not always be practical.

When a direct-reading thermometer is installed in cramped conditions, the observer should be warned of the possibility of reading 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 load or ballast condition. Lastly, of course, the intake temperature should not be recorded 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 SST sensor can often be time-consuming and complicated, often forcing PMOs or technicians to work in a 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 SST, a modal filtration algorithm may be used to exclude the extreme readings from the computed average.

4.2.2.9.3 Hull-attached thermometers

Hull-attached thermometers provide a very convenient and accurate means of measuring SST. 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. In case of internal sensor, magnetic probes are preferable than glued sensors for an easier installation and maintenance, but only for steel hulls.

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.

4.2.2.9.4 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. 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. Trailing thermistors are rarely used by the VOS but are more common for research applications (Fairall et al., 1997; Bradley and Fairall, 2006; Weller et al., 2008).

4.2.2.9.5 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 handheld (pointing forward and downward), mounted on the bow or on a boom extending over the water. Radiometer measurements represent the evaporative surface-skin temperature and are used on only a few ships (Barton et al., 2004; Donlon et al., 2008).

4.2.2.10 Clouds and weather

4.2.2.10.1 Amount of cloud and cloud type

Visual cloud observations should follow the same rules as those applicable to a land station (see Volume I, Chapter 15 and WMO, 2017a). Detailed instructions should be provided by the PMO. Pictorial guides and coding information are available from many sources, such as WMO (2017a), as well as from publications of NMHSs. Most electronic logbook software include extensive pictures of clouds to assist with cloud type identification. Additionally, the template for reporting SHIP observations (WMO, 2011b, Part C) provides specific information on how to make and code VOS cloud reports.

The assessment of the total amount of cloud consists in estimating how much of the total sky area is covered with cloud and should be reported in per cent (%); however, oktas can still be used per national requirements. In BUFR FM 94 code (WMO, 2017b) total cloud cover is given in percentage (113 indicating sky obscured by fog and/or other meteorological phenomena).The assessment of low cloud amount is performed in a similar way and reported in oktas for both ship-to-shore transmission and onward transmission in FM 94 BUFR. If no low cloud is present, the amount of medium cloud is reported instead. The type of low, middle and high cloud shall be determined as specified in the *International Cloud Atlas* (WMO, 2017a), or by identifying the appropriate cloud type from the photographs displayed in the electronic logbook software.

4.2.2.10.2 Cloud-base height

The cloud-base height is normally estimated by the VOS. 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.

Some specialized ships may have instruments installed to measure cloud-base height. 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 Volume I, Chapter 15). It should be installed so that it can be operated and read by the officer on watch on the navigation bridge.

4.2.2.10.3 Present and past weather

Present and past weather are primarily meant to serve as a qualitative description of weather events. Most VOS reports of present and past weather are made by visual and auditory observations and follow the same rules as those applicable to a land station (see Volume I, Chapter 14). There are 100 categories of present weather for VOS manual observations (the first 100 codes in FM 94 BUFR code table 0 20 003). Past weather is reported in 10 categories (the first 10 codes in FM 94 BUFR code table 0 20 004 and 0 20 005). Two past weather categories should be reported which have been selected to give as complete a description of conditions over the reporting interval as possible. Manual on Codes (WMO, 2017b) provides specific information on how to make and code VOS weather reports.

For observers using electronic logbook software, further guidance is likely to be available from the software.

4.2.2.11 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 (for example, the foremast) for estimation when the visibility is very low, but it should be recognized that these estimates may be in error since the ship may affect the air. For the higher ranges, the appearance of the land when near the coast is a useful guide, and, if fixes can be obtained, the distance of landmarks, just as when 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 Volume 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 forward-scatter meters. Unfortunately, the heating effect of the ship, and its exhaust, may lead to unrepresentative measurements.

4.2.2.12 Precipitation

The VOS do not normally report information on precipitation within coded reports on weather types (see 4.2.2.10). However, precipitation measurements can be reported from fixed stations or vessels equipped with a precipitation gauge. The measurement of precipitation at sea is discussed in WMO (1962, 1981) and in the context of observations from research vessels by Bradley and Fairall (2006) and Weller et al. (2008), who also describe newer measurement systems, such as optical raingauges, not typically used for routine observations. As an aid to observers on ships, descriptions of precipitation at sea, for use in reporting present weather, are given in Annex 4.B.

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.

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. For a shipboard raingauge, placing the instrument as far forward and as high as practicable seems to be most effective. However, other exposures may be found in particular cases to provide for easier management (Bradley and Fairall, 2006).

Precipitation measurements from ships “on station” (for example, light vessels, research vessels, holding a near stationary position) are particularly valuable because the effect of ship speed is eliminated and the data can, thus, be included in climatological analyses without reduction. However, any 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. This 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

Several 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 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.

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 et al., 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.

Optical disdrometer

Because of the inherent wind and turbulence induced undercatch problems with conventional gauges onboard ships and their inability to measure snow, considerable effort went into developing optical distribution droplet meters (disdrometers). A comprehensive overview on existing instruments and measurement principles is provided by Michaelides (2008).

One of the biggest advantages of optical disdrometers over conventional gauges is in measuring the precipitation rate through particle size distributions, which, in case of rainfall, is commonly referred to as the drop size distribution. An optical disdrometer for shipboard operation preferably has a cylindrical measurement volume that is homogeneously illuminated (i.e. by an infrared light diode). Hydrometeors that pass through this volume cause a light extinction proportional to their cross selectional area. Typically hydrometeors are counted and sorted into size bins during an integration time, thus allowing derivation of rain, snow and mixed-phase precipitation occurrence, intensity and accumulation (Klepp, 2015).

Precipitation radar

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.

4.2.2.13 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 4.3 on moored buoys, although they are applied on other types of platforms, too.

4.2.2.13.1 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 (see Volume I, Chapter 5);

(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.

ELEMENT 1: Floating object (Automatic)

ELEMENT 2: Picture inline fix size

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Figure 4.1. Typical sea and swell waves as shown by a wave-height recorder

END ELEMENT

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.

4.2.2.13.2 Visual observations from 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 normal 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, and 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), 4.4.1 and 4.4.2 of WMO (2001), and 4.3.4 to 4.3.6 of this chapter.

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.

The recommended procedures for the reporting of swell by manually reporting ships are found in Annex 4.C.

Wave period

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 wave height 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).

ELEMENT 3: Floating object (Automatic)

ELEMENT 4: Picture inline fix size

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Figure 4.2. The effect of the ship's roll on the estimation of wave height

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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.

4.2.2.13.4 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 (1991*b*).

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.

4.2.2.13.5 Terminology for sea and swell waves

The following terminology is recommended for uses other than the inclusion in coded messages, such as supplying weather information and forecasts for shipping, publications, pilots, and so on:

TABLE: Table as text NO space

For the length of swell waves:	
Short	0–100 m
Average	100–200 m
Long	over 200 m
For the height of swell waves:	
Low	0–2 m
Moderate	2–4 m
Heavy	over 4 m
For the height of sea waves:	
Calm (glassy)	0 m
Calm (rippled)	0–0.1 m
Smooth (wavelets)	0.1–0.5 m
Slight	0.5–1.25 m
Moderate	1.25–2.5 m
Rough	2.5–4 m
Very rough	4–6 m
High	6–9 m
Very high	9–14 m
Phenomenal	over 14 m

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.

4.2.2.14 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 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.

4.2.2.14.1 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 (1991*b*), 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, 2011*a*, 2011*b*), 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.

4.2.2.14.2 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 ice 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 % 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% 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.

4.2.2.14.3 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.

4.2.2.14.4 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 (that is 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 radio-facsimile transmission of ice data.

4.2.2.15 Observations of special phenomena

Marine observers can make reports of natural phenomena using either traditional or some electronic logbooks. However, such special observations cannot normally be circulated over the GTS owing to international format limitations. The observations can take the form of written descriptions, sketches or photographs, or a combination. A wide range of phenomena can be reported, including:

(a) Astronomical phenomena (for example, eclipses, comets, zodiacal light, sunspots and novae);

(b) Phenomena of the high atmosphere (for example, high-frequency radio fadeouts or blackouts, magnetic disturbances and storms, airglow, aurorae, meteors and fireballs, and noctilucent clouds);

(c) Phenomena of the lower atmosphere (for example, abnormal refraction and mirages, glory or brocken spectres, coloured suns and moons, coronae, St Elmo's Fire, crepuscular rays, dustfall, the green flash, halo phenomena, iridescent cloud, lightning, rainbows, scintillation, unusual sky colouration and waterspouts). Note that when describing waterspouts, the direction of rotation should always be given as if seen from above;

(d) Sightings of marine mammals, birds, fish, invertebrates and mass plankton effects such as bioluminescence, red tides and discoloured water;

(e) Other marine phenomena (for example, abnormal occurrences of compass deviations, changes in sea level or waves).

National publications, or information provided with electronic logbooks, provide information about the kinds of phenomena that are of interest and the information that is required for reporting particular types of phenomena.

4.3 MOORED BUOYS

Moored buoys come in a wide variety of configurations (for example, 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 currently functioning systems, focuses on the requirements for marine meteorological measurements from operational metocean moored buoys. Information regarding other systems addressing the requirements for other applications and research can be found in other publications (for example, Bradley and Fairall, 2006) and websites:

- JCOMMOPS: http://www.jcommops.org/
- ATLAS tropical moored buoys: http://www.pmel.noaa.gov/tao/proj_over/mooring.shtml
- Ocean Climate Stations: http://www.pmel.noaa.gov/OCS/
- TRITON tropical western Pacific moored buoys: http://www.jamstec.go.jp/jamstec/TRITON/real_time/php/top.php
- Global Tropical Moored Buoy Array: https://www.pmel.noaa.gov/gtmba/
- OceanSITES reference moored buoys: http://www.oceansites.org
- Tsunami buoys: http://www.ndbc.noaa.gov/dart/dart.shtml
- Wave buoys: http://www.jcomm.info/wet

More recent Indian Ocean m-TRITON moored buoys: http://www.jamstec.go.jp/iorgc/iomics/index.htmlA typical metocean moored buoy 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 may include:

(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 CO_2 concentration.

(j) Ocean surface pH

(k) Photosynthetically Active Radiation (PAR)

(l) Fluorescence and Turbidity

(m) Water quality parameters

For waves, the following variables are generally measured or estimated using the following definitions (see also 4.2.2.13 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 locations to identify when they go adrift so that the appropriate authorities can be notified so that they do not provide a hazard to shipping. It is also useful to monitor various housekeeping/engineering parameters to aid data quality control and maintenance. Moored buoy technology has now matured to the extent that it is possible to maintain a buoy on station for as long as two years, 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 24 month intervals. General practices to minimizing fouling in buoy systems include using copper tape, and zinc oxide paste on instruments every 24 months.

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 (for example, Bourras, 2006).

Recently established moored buoy networks have a suite of subsurface measurements for better understanding of air sea interaction.

Reliable performance is the key requirement for instruments used in offshore moored buoys for cyclone monitoring, as under performance of the sensors can have a serious impact on the societal protection, and in addition, lead to costly repair and reinstallations. Recent developments in instrument selection and application practices based on the experiences of the global scientific community, improved their performances at sea (Venkatesan et al., 2015).

Typical measurement uncertainties obtained from operational metocean buoys are as follows:

TABLE: Table as text NO space

Wind speed	1 m s^{-1} or 5 % above 20 m s^{-1}
Wind direction	10°
Air temperature	0.2 °C
Sea-level pressure	0.2 hPa
Sea-surface temperature	0.2 °C
Dewpoint temperature	0.5 °C
Significant wave height	10 % or 0.2 m
Wave direction	10°
Wave period	1 s

The standard suite of sensors on operational metocean moored buoys measure wind speed, peak gust (for example, 3 to 5 second gust depending on national requirements), wind direction, barometric pressure, air temperature, water temperature, and significant wave height and peak (or average) wave period. Some buoys also measure (directional or non-directional) wave energy spectra.

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 barometers (see Volume I, Chapter 3). The following pressure measurements are made:

(a) Station pressure is the actual measurement made by the barometer on the moored buoy 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 measurement height in units of hPa. For moored buoys deployed at sea this is very close to the station pressure. However, there can be a large difference 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 (for example, 1 008 hPa in the tropics). The semi-diurnal pressure variation could be used for detection of cyclone. As air pressure exhibits two peaks and two low values in a day. The highest and the lowest pressure values are almost repeated at the same time during the semi-diurnal oscillations. The reduction in semi-diurnal oscillation during a cyclone passage could be utilised in detecting a cyclone/low pressure system. This method can improve the cyclone detection algorithm,

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.

Wind can often cause dynamic changes of pressure which affects the reading of barometer. The inlet port of the barometer should be placed at location with minimal effect of wind. The barometric pressure is generally measured from the inlet port located at 3 m from the sea surface

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 (usually a standard 10 min) period.

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 or a cup anemometer and a wind wane. To avoid mechanical wear, ultrasonic wind speed and direction sensors with no moving parts are now commonly used on moored buoys where the wind direction measurement is normally associated with a compass bearing so the direction relative to the buoy can be corrected to True. The wind sensor height will vary for different sized buoys so it is important that the sensor height (3 m above MSL) is reported in the BUFR (TM3-15-008) data exchanged on GTS so that users can derive the equivalent 10 m wind speed.

Some members typically use 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 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 the moored buoys of some countries the wind measurements are made at 3 m or 4 m, wind speeds at 10 m above site elevation and 20 m above site elevation are derived from an algorithm (Liu et al., 1979) that uses the height of the anemometer, the wind speed, a constant relative humidity of 85 %, a constant sea-level pressure of 1 013.25 hPa, and the air and water temperature. If either the air or water temperature is unavailable, then the neutral stability is assumed, taking into account that neutral stability can introduce an error of up to 5 %. If both are missing then neither 10 nor 20 m wind speeds are determined.

The some members operating 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 prior to the top of 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 have now been replaced with a new wind system utilizing a sonic anemometer and electronic compass. To further improve reliability the UK moored buoys all have dual wind systems to provide increased resilience in the event of anemometer failure (Turton and Pethica, 2010).

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 (NDBC, 2003). Air temperature is sampled at some rate during the sampling period (typically 1 Hz or 0.1 Hz). Air temperature is generally measured along with relative humidity and the resolution is 0.1 °C. Some buoy operators use high resolution temperature sensors used for underwater application with high resolution of the order of 0.000 1°C.

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 often 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 sea surface temperature of the water. This value may also biased due to biofouling. Most of the sensors for long term underwater temperature measurement offer high resolution of the order of 0.000 1 °C. The temperature values indicated by other sensors such as current meters mounted at different location can be compared for better estimation. ITS 90 Scale is generally followed for measurement surface

4.3.4 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, 2009) provide for complete details on wave measurements made by the National Oceanic and Atmospheric Administration's National Data Buoy Center (NOAA-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 (Frigaard et al., 1997), 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 spectral directional components defined by the mean l wave direction, the spread, skewness and kurtosis defining the four Fourier coefficients (functionally related to each frequency) that centres disseminate through the WMO FM-65 WAVEOB alphanumeric codes (WMO, 2011*a*, 2011*b*).

4.3.5 Non-directional ocean wave estimates

Most buoys use accelerometers or motion sensors to measure buoy heave motion. The sensors are, 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 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_{m0}, is estimated from the variance of the wave displacement record obtained from the displacement spectrum according to following equation:

$$H_{m0} = 4\left[\int_{f_1}^{f_u} S(f)\,df\right]^{\frac{1}{2}}$$

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.

4.3.6 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 et al., 2010*a*; Swail et al., 2010*b*) 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 estimates the infinite series describing 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 evaluate and validate wave measurements derived from high-frequency and X-Band radar instruments and space-based instruments.

4.3.7 Water-column height for tsunami detection

Most buoy tsunameters 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.

4.3.8 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.

4.3.9 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, Photosynthetically active radiation, turbidity, CDOM and dissolved oxygen. Buoy data are quality controlled in real time and where possible these data are distributed over the WMO Global Telecommunication System.

4.3.10 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/satellite measurement. Most buoys acquire these measurements using buoy-mounted acoustic Doppler samplers. Sampling interval should be in such a way to eliminate the current due to wave orbital velocity.

4.3.11 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 platforms, and validation for ocean models. These data are currently acquired from downward-looking, buoy- or cage-mounted systems. On offshore oil platforms, the current profiles may be downward looking from a number of levels in the water column, or upward-looking from a bottom-mounted system.

Most buoys use ADCP (Acoustic Doppler Current Profiler) technology as the primary sensor for collection of ocean current profile data. They emit short-duration, high-frequency pulses of acoustic energy along narrow beams. Scatterers (assumed to be passive nekton and plankton) within the water column return the backscattered energy and the instruments resolve the along-beam Doppler frequency shifts into orthogonal earth coordinates to obtain ocean currents at various levels in the water column. ADCP with 150 kHz or 75 kHz are generally used independently or along with the buoy system to profile the required depth of measurement.

4.3.12 Salinity

Salinity is required to initialize ocean models that provide ocean forecasts and predict ocean circulations (which are largely density driven). Salinity is usually derived from measurements of the conductivity of seawater. Some instruments provide the salinity directly (through internal calculations) and others provide the conductivity, temperature and depth required to calculate the salinity. Salinity measurements are based on the practical salinity scale using the empirical relationship between the salinity and conductivity of seawater (although a new international thermodynamic equation of seawater-2010 (TEOS-10) was recently endorsed by the Intergovernmental Oceanographic Commission of UNESCO through its Assembly Resolution XXV-7). The salinity units are reported in practical salinity unit. Measurement of conductivity is carried by two types of sensing methodology: a) by using a inductive coil to sense the amount of conductive ions, and b) to take a known amount of sea water in a glass tube and measure the conductivity by measuring the change in resistance of the platinum electrode. Bio fouling in the instrument is a limiting factor to provide an accurate salinity measurement from the moored buoy.

4.3.13 Precipitation

Siphon raingauges have been installed in order to eliminate the effect precipitation measurements with large spatial coverage are very critical for climate related studies. Freshwater fluxes are indirect measure of buoy movement local latent heating, which drives atmospheric circulation. Precipitation is collected in rain data the catchment funnel and drains into a measuring tube which has a capacitive type static transducer that provides the linear output. Self-siphon process empties the measuring tube once it is filled. Siphon rain gauges Siphon rain gauges are gauges have been installed in the buoy systems. The sampling interval is 1Hz for calculation of rain rate. These sensors are slightly affected due to the electromagnetic field generated by the transmission antennae and sufficient clearance space to be provided on some moored buoys.

4.3.14 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 micro mols per square metre per second. Buoy systems are equipped with long wave and short wave radiation sensors with analog and serial outputs

4.3.15 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 LIGHT VESSELS

In most respects, these platforms can be regarded as being similar to moored buoys as they unmanned and rely on automated observing systems. 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 visibility sensors can be affected by sea spray generated by the vessel itself. Also, because light vessels are much larger than moored buoys, care has to be taken in the siting of wind sensors to avoid obstructions from the vessels structure, similar to that described earlier for VOS (see 4.2.2.6.2). However, in most conditions, performance is equal to that of instruments deployed on land-based automatic weather stations.

Wave measurements have been made from light vessels in waters near the UK for many years, with records dating back to 1962.These measurements were originally made using Shipborne Wave Recorder (SBWR) instruments mounted on the light vessels that used accelerometers and (water) pressure sensors to provide information on wave heights and periods. Since the 1990s, the wave measurements have been using made using heave (‘hippy’) sensors on the light vessels. However, it has long been suspected that the present wave measurements from the light vessels are less accurate than those from the Met Office’s moored buoys. This is because the present light vessel wave measurements light vessel wave measurements are made using a heave sensor sited near the centre of the vessel which only measures the vertical displacement, whereas the earlier SBWR measurements were based on accelerometers to measure vessel heave and pressure sensors (below the waterline) to measure changes in the sea level relative to the vessel. Hence, the SBWR measurements took account of the inertia (that is the light vessels are too large to accurately follow the rise and fall of each wave) of the vessel, while this is presently neglected. This results in the present heave sensor only measurements underestimating the significant wave height and overestimating the average wave period (Anderson et. al., 2016).

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 Volume III, 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-submersibles rigs, and drill ships, could be considered stationary platforms as they are moored or dynamically positioned to remain in one place while in operation. The majority of offshore platforms now carry automated weather stations that are operated by the offshore industry so fall into the category of '3rd party data' where they may (or may not) be made available via the WMO GTS.

On some platforms and rigs the automatically 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 4.2. However, there are cases where different 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 measurements of wave parameters: significant wave height and some measure of wave period in their weather report, using output from a nearby wave buoy or from an on-board 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. Wave data however could be susceptible to the location of the fixed gauge location, such as a leg of a platform. Interaction of the physical structure and the incoming waves would generate interference or reflection patterns in the up and down-wave conditions.

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 supplementary data, removing the need to deploy moored buoys in those regions.

4.6 DRIFTING BUOYS

Drogued drifting buoys (Niiler, 2001; Maximenko et al., 2013, Centurioni, 2018) 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.

Nearly all of the Lagrangian surface drifting buoys (drifter, hereafter) operating within the Global Surface Drifter Array report sea-surface temperature, geo-location and time of the observations. Since the drifters are drogued to a depth of 15 m, the geo-location data and times are used to compute 15 m depth currents when the drogue is present.

The presence of the drogue is often determined with a strain-gauge sensor. However, methods to recover near-surface ocean currents when the drogue is lost also exist. At the time of writing, over half of the drifters in the global array also measure sea-level atmospheric pressure, and a few drifters, deployed in support of special process studies and/or ocean-tropical cyclones interaction studies, measure sea surface salinity, horizontal sea-level wind velocity and subsurface temperature, typically to a depth of 150 m. A subset of experimental undrogued drifters is also being deployed, and they are designed to measure the directional spectra of surface gravity waves. 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*a*). See also the annual reports and workshop proceedings of the DBCP, such as WMO/IOC (2004*a*, 2004*b*).

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 drifter with a drogue centred at 15 m depth and designed to measure near-surface currents in the upper-ocean mixed layer and equipped to measure sea-surface temperature with an accuracy ranging between ±0.1 °C and ±0.05 °C has been developed and deployed in large numbers over the world's oceans;

(b) 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:

(c) The SVP-B drifter (see also Centurioni et al., 2016), which is a modification of the SVP drifter described in a) with an air pressure sensor added. The barometer has a typical accuracy of ±0.4 hPa ;

    (i) The SVP-BW drifter, which is essentially an SVP-B drifter with wind-measuring capability using a sonic anemometer. The wind direction is measured with an internal compass, with an accuracy of ±2°;

    (ii) The wind, pressure and temperature vertical profile buoy, or Autonomous Drifting Ocean Station (ADOS), which is a derivation of the SVP-BW drifter with a subsurface thermistor chain for the measurement of temperature profile to depths of 150 m;

    (iii) The salinity SVP (SVP-S) drifter is an SVP or SVPB drifter with a conductivity sensor that at a depth of approximately 0.45 m and an accuracy of the order of ±0.000 3 S/m. The accuracy of the surface temperature sensor for these drifters is of the order of ±0.002 °C.

    (iv) The Directional Wave Spectra (DWS) drifter (Centurioni et al., 2017) is an undrogued drifter designed to measure directional wave spectra parameters using GPS technology. This experimental technology is becoming increasingly popular due to good accuracy of spectra directional spectra observations and low cost.

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), although the SVP-BW drifter technology that uses the sonic wind sensor is yet to be assessed.

The typical measurement uncertainties of operational systems are as follows:

TABLE: Table as text NO space

Sea-surface temperature	0.21 °C[a]
Air pressure	0.84 hPa[b]
Wind speed	3.5 $m\ s^{-1}$ or 10 %[abc]
Wind direction	18.5°[b]
Subsurface temperature	0.05 °C

Notes:

a *Source*: O'Carroll et al. (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.

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Over the years drifting buoys have become the dominant source of in-situ surface air pressure and sea-surface temperature (SST) measurements over the global oceans. The pressure data are critical for global NWP (Centurioni et al., 2017) and, despite their limited accuracy, the SST data now form a key part of the climate record and are also used to calibrate/validate satellite derived SST products. There is presently a joint initiative between the DBCP and satellite community to evaluate drifters with higher accuracy SST sensors (to ±0.05 K or better) to determine whether (with reporting the time of measurement to ±5 minutes and location to ±5 km) they could lead to more accurate satellite SST products.

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[5] 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[6];

(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[7] 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;

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[5] Recommended by the Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology at its third session, held in 2009.

[6] Basically in situ geophysical instruments deployed in the surface marine environment or subsurface.

[7] JCOMM is the body that formally proposes new RMICs and proposes any authority to do evaluations.

(b) An RMIC must participate in, or organize, JCOMM and/or regional instrument intercomparisons, 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 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.

3. The following centres have been designated as RMICs:

TABLE: Table horizontal lines

Region	*Centre*	*Location*
Asia-Pacific	National Center of Ocean Standards and Metrology	Tianjin, China
North America, Central America and the Caribbean	United States National Data Buoy Center	Stennis Space Center, Mississippi, United States

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ANNEX 4.B. DESCRIPTIONS OF PRECIPITATION FOR USE BY SHIP-BORNE OBSERVERS OF PRESENT WEATHER

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 the *International Cloud Atlas*, (WMO, 2017a):

Drizzle: Fairly uniform precipitation of very fine drops of water very close to one another that falls from a cloud.

Drizzle drops have a diameter of usually less than 0.5 mm. The drops appear almost to float, and so make even slight movements of the air visible. Drizzle falls from a layer of Stratus, usually low, sometimes touching the ground (fog). The amount of precipitation in the form of drizzle can be considerable (up to 1 mm/h), especially along coasts and in mountainous areas. The drops falling on the edge of a rain zone or during light rainfall may be as small as drizzle drops, owing to their partial evaporation. In this situation, raindrops are distinguished from drizzle drops in that they are more scattered.

Identification of the precipitating cloud as Stratus also distinguishes rain from drizzle. 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 that falls from a cloud. The number density and size distribution of raindrops vary considerably with the intensity and nature of the precipitation. 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, singly or stuck together, that falls from a cloud. The form, size and concentration of snow crystals differ considerably according to the temperature and supersaturation at which they develop. A fall of snow usually includes various types of snow crystals and almost all types of crystal may be observed during a single fall of snow. Small droplets of frozen water are often attached to snow crystals. If present in great numbers, these can obscure the crystalline structure of the snow. At temperatures warmer than about –5 °C, the crystals generally stick together to form snowflakes.

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 convection 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 that falls from a cloud. These particles are generally conical or rounded, and their diameter may be as large as 5 mm. Snow pellets are composed of a central nucleus covered with frozen cloud droplets. They form when a particle of ice, usually a crystal, collects cloud droplets, which rapidly freeze. Their density is generally low, less than 0.8 g cm^{-3}, due to air gaps between the nucleus and frozen droplets. Snow pellets are brittle and easily crushed. When they fall on hard ground, they bounce and often break. Showers of snow pellets fall from Cumulus or Cumulonimbus. The showers usually consist of snow pellets and snowflakes together, and normally occur when temperatures near the surface are close to 0 °C. Crystals can be observed that are not completely surrounded by droplets; this is the intermediate stage between a snow crystal and a snow pellet. 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 particles of ice (hailstones). These can be either transparent, or partly or completely opaque. They are usually spheroidal, conical or irregular in form, and generally 5−50 mm in diameter. The particles may fall from a cloud either separately or agglomerated in irregular lumps. Falls of hail always occur as showers. They are 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 that falls from a cloud. These particles are almost always spherical and sometimes have conical tips. Their diameter may approach and even exceed 5 mm. Small hail always occurs in showers from Cumulonimbus. Small hail consists of snow pellets totally or partially encased in a layer of ice. Gaps within the snow pellets are filled with ice, or ice and water; a thin shell only may be frozen. The water may come from cloud drops or partial melting of snow pellets. The density of small hail is relatively high; it ranges from 0.8 g cm^{-3} to, in rare examples, 0.99 g cm^{-3}. Usually, small hail is not easily crushable; when it falls on hard ground it bounces with an audible sound on impact. Small hail is an intermediate stage between the snow pellet and the hailstone. It differs from the snow pellet in its partially smooth surface and its higher density. It differs from the hailstone particularly in its smaller size.

Ice pellets: Precipitation of transparent ice particles that falls from a cloud. These particles are usually spheroidal or irregular, and rarely conical. Their diameter is less than 5 mm. Ice pellets originate as raindrops or snowflakes (less common) that generally fall from Altostratus or Nimbostratus. They fall into a subcloud layer of warm air where the snowflakes melt or partially melt, and then fall into a cold layer of air (below 0 °C) where they freeze and reach the ground as frozen precipitation. Ice pellets of the form of frozen raindrops are transparent, the less common refrozen snowflakes are, in parts, transparent and, in parts, opaque, depending on whether the snowflake melted or only partially melted. Ice pellets are not easily crushable. When they fall on hard ground, they generally bounce with an audible sound on impact. Ice pellets may be partly liquid. Their density is usually close to, or above, that of ice (0.92 g cm^{-3}). 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 that falls from a cloud. These particles are fairly flat or elongated. Their diameter is generally less than 1 mm. Although frozen and occurring when the temperature is between approximately 0 °C and −10 °C, the other properties of this precipitation correspond to drizzle. When the grains hit hard ground, they do not bounce. Snow grains fall mostly from Stratus or from fog, and never in the form of a shower. Except in the mountains, snow grains usually fall in small quantities. As there is only one code specification which refers to snow grains, it is not necessary to classify intensity.

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ANNEX 4.C. RECOMMENDED PROCEDURES FOR THE REPORTING OF SWELL BY MANUALLY REPORTING SHIPS

The recommended procedures for the reporting of swell by manually reporting ships, as agreed at the fifth session of the Ship Observations Team (SOT-V) in 2009 (WMO/IOC, 2009*b*), and implemented with the agreement of the Expert Team on Marine Climatology (ETMC; WMO/IOC, 2010), are given below:

(a) When swell is not determined, meaning no observation has been attempted, the swell groups will be omitted from the observation;

(b) When no swell is observed owing to a calm sea, the direction of the main swell and the direction of the secondary swell will be reported as calm. The period and height of the main swell and secondary swell can then be omitted, because if a calm sea is reported it is inferred that these elements will also be calm, in which case they provide no additional information;

(c) When the swell direction is indeterminate, confused swell is reported. When the period and height of the swell are also confused, this will be included in the observation. The period and height of the secondary swell can be omitted;

(d) When the swell is confused but the period and height can be estimated, the swell direction is reported as confused, and the period and height of the primary swell is included in the report. The period and height of the secondary swell can be omitted;

(e) When only one swell is observed, the direction, period and height of this swell is reported. The period and height of the secondary swell can be omitted;

(f) When two swells are observed, both the swell direction and the period and height of each are included in the observation.

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