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GUIDE TO OCEANOGRAPHIC AND MARINE METEOROLOGICAL INSTRUMENTS AND OBSERVING PRACTICES

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PREFACE

The Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices is the fourth publication to be issued by the Intergovernmental oceanographic Commission (IOC) in the series of Manuals and Guides. The provision of oceanographic data, in both real and non-real time, for collection and exchange requires the standardization of observing practices. This guide is intended to provide information on commonly used oceanographic instruments and accepted observing practices. Since many of the observations in this category require supporting meteorological data, relevant portions of the World Meteorological Organization (WMO) guide to instruments and observing practices have been included.

Preparation of this Guide was undertaken by the IOC-WMO Joint Group of Experts for IGOSS[1] and in particular, Commander V.M. Driggers of the United States Coast Guard, who prepared the draft manuscript. The IOC Working Committee for IGOSS and the WMO Executive Committee Panel on Meteorological Aspects of Ocean Affairs approved the Guide for publication in 1975 at their Fourth Joint Session (Paris, 4-12 February 1975).

This Joint Session also made provision for continual review of the guide as well as a mechanism for preparing revised editions as the need arises.

The Intergovernmental Oceanographic Commission wishes to express its thanks to the Secretary-General of the World Meteorological Organization for his permission to use certain sections of the WMO guide.

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1. Integrated Global Ocean Station System

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INTRODUCTION AND USE OF THE GUIDE

The IOC Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices has been prepared for use by Member States as a means of increasing the quality and quantity of marine data available for international exchange in both "real time" and "non-real time."

The guide has been prepared so that it may be used (1) directly by an observer, (2) as a basis for preparing national guides and instructions, and (3) as a tool for training personnel involved in oceanographic research and marine services.

Parts of this guide have been reproduced directly or with slight word changes from the WMO Guide to Meteorological Instruments and Observing Practices (WMO No.8; TP.3). Paragraphs which have been reproduced directly from the WMO guide are indicated by indentation and different type. These paragraphs also include the corresponding paragraph number from the WMO guide. Paragraphs from the WMO guide which have slight word changes in this guide, or paragraphs which have been approved for publication in the next edition of the WMO guide, have been noted by printing an asterisk after the WMO paragraph number. Since only a limited amount of meteorological information is presented in this guide, it is suggested that observers refer to the WMO guide (WMO No.8 TP.3) for more complete information on meteorological instruments and observing practices.

CHAPTER 1 - GENERAL

1.1 Oceanographic observations

1.1.1 Definitions

1.1.1.1 (1.2.1.1)* Oceanographic observation (Observation)

Evaluation or measurement of one or more oceanographic elements.

1.1.1.2 (1.2.1.2)* Sensory observation.

An observation taken by an observer without the use of a measuring instrument, but estimated by experience only.

1.1.1.3 (1.2.1.3)* Instrumental observation.

An observation made with the help of one or more measuring instruments or sensor-indicator systems, inclusive of necessary reductions, corrections and calculations connected therewith. The measuring instruments or systems should be installed under the specified conditions and according to the standard regulations.

1.1.1.4 (1.2.1.4)* Result of an observation.

The result of an observation is the numerical value of a parameter (quantitative result) or the description and classification of a phenomenon (qualitative result).

1.1.1.5 (1.2.1.5)* Reading

An observer's act of noting the information presented to him by an instrument.

1.1.2 (1.2.3)* Times of observation.

As general principle, the estimation or measurement of the elements comprising a synoptic observation should be made in as short a period of time as possible. Any detailed calculations or observational routines associated with but not required to complete the synoptic report should be carried out subsequently or previously.

1.1.2.1 (1.2.3.1.2)* Standard time of observation.

A time specified for making oceanographic observations. The term Greenwich Mean Time, abbreviated as GMT, is used as a synonym of the term Universal Time (UT).

1.1.2.2 Frequency of observations

Synoptic observations should be taken at 0000, 0600, 1200 and 1800 GMT. Observations should be made as close to the synoptic hours as practicable; however, it is the actual time of the observation which is recorded and transmitted.

Although a frequency of four daily oceanic observations is a desirable objective, this will be impractical at times. Measurement of oceanographic parameters are usually more sensitive to sea conditions than measurement of meteorological parameters; therefore, in storm areas several days may pass before aborted oceanographic operations can be resumed.

Some of the parameters cannot be observed by a vessel that either does not have the appropriate instrument or has an inoperative instrument. Secchi disc observations can only be made during daylight hours. Some observations, such as temperature and depth when determined by reversing thermometers, or salinity when determined by a shipboard salinometer, may involve several hours of processing in order to bring the raw data to a stage acceptable for transmission. Such data are still considered real-time and should be transmitted as soon as possible, even if this must be done during the next synoptic period.

1.1.3 Observers.

Competent observers should be provided for the following duties :

(a) Maintaining the instruments in good order;

(b) Changing the charts of self-recording instruments;

(c) Making the observations with the required accuracy;

(d) Coding and despatching the observations;

(e) Making the required returns of oceanographic data.

1.2 General requirements of instruments

1.2.1 (1.4.1)* Desirable characteristics

The most important requirements of oceanographic instruments are :

(a) Reliability;

(b) Accuracy;

(c) Simplicity of design;

(d) Convenience of operation and maintenance;

(e) Strength of construction.

With regard to (a) and (b) it is more important that an instrument should be able to maintain a known accuracy over a long period than have a very high precision initially without being able to retain it for long under operating conditions. Simplicity and convenience of operation and maintenance are important since most oceanographic instruments are in continuous use year in and year out and may be situated far away from good repair facilities. Robust construction is especially desirable for those instruments which are wholly or partially exposed to the weather.

1.3 Standardization of instruments

1.3.1 (1.5.1)* Definition of standards of measurement.

The word "standard" and other similar terms are frequently used to describe various instruments, methods, scales, etc. A uniform nomenclature for standards of measurement has become necessary because of their increased use in modern technological development and the International Organization for Legal Metrology (IOLM) has under consideration a draft terminology on the classification of standards. The definitions given below, which are based on the IOLM draft terminology on standard instruments, are used in this Guide.

A unit of measurement is a quantity taken as of a magnitude one, in terms of which other quantities of the same kind are measured. A standard is the physical embodiment of a unit. Thus the unit of length is a metre and the standard length is the international metre bar kept at Sevres, France. For measuring a quantity in terms of a standard or those derived from it, standard instruments are used. Unlike a standard, they measure over a range of values of the quantities involved. A standard method is a method of reproduction of the unit of measurement making use either of fixed values of certain properties of bodies or of physical constants.

Types of standard instruments

Standard (instrument). - An instrument or device to define, maintain or reproduce the unit of measurement (or its multiples and sub-multiples) in order to transmit it to other instruments or devices.

Collective standard. - A group of instruments which together serve as standard. The value of the collective standard is the arithmetical mean calculated from the values furnished by the various instruments.

Primary standard. - A standard instrument which possesses the highest degree of precision.

Secondary standard. - A standard instrument the value of which is fixed by direct or indirect comparison with a primary standard or by a standard method.

Working standard. - A standard instrument for the verification of a reference standard (see below) or for the verification of ordinary instruments the order of precision of which is the same as that of the reference standard.

Reference standard. - A standard instrument for the verification of other standards of the same order of precision.

Travelling standard.- A portable standard instrument which may be carried from one place to another and still retain its calibration.

International standard. - A standard instrument recognized by international agreement as the basis for all other standards of the given quantity.

Regional standard. - A standard instrument designated by Regional agreement as the standard for the Region.

National standard. - A standard instrument designated by a Member as the standard for its territory.

1.3.2 Procedures for standardization.

Instruments in operational use in a Service should be periodically compared directly or indirectly with the national standards. Comparisons of instruments within a Service should, as far as possible, be done at the time the instruments are issued and at such times thereafter as prescribed nationally.

1.4 Units and constants.

1.4.1 Units

The following units should be used for oceanographic observations :

(a) Temperature in degrees Celsius;

(b) Salinity in parts per thousand (‰);

(c) Wind wave period in seconds;

(d) Wind wave height in metres;

(e) Swell direction in degrees from north or on the scale 0-36, where 36 is the swell from the north and 09 the swell from the east;

(f) Swell period in seconds;

(g) Current direction in degrees from north or on the scale 0-36, where 36 is the current towards the north and 09 the current towards the east;

(h) Current speed in centimetres per second;

(i) Current measurement (drift method) period in hours;

(j) Current measurement (vector method) duration in minutes;

(k) Current measuring device depth in metres;

(l) Wind speed in surface observations in metres per second or in knots;

(m) Wind direction in degrees from north or on the scale 0-36 where 36 is the wind from the north and 09 the wind from the east;

(n) Atmospheric pressure in millibars;

(o) Radiative flux per unit area in langleys (g-cal. cm^{-2}) per minute;

(p) Precipitation in millimetres;

(q) Water transparency in metres.

1.5 Accuracy of measurements.

1.5.1 (1.7.1)* Definitions.

In physical measurement, accuracy is defined as the closeness with which an observation of a quantity, or the mean of a series of observations, is considered to approach the unknown true value of the quantity. To achieve accuracy in measurement, instruments should have and maintain a calibration under given conditions to within the desired accuracy; the errors under other conditions should be known and be constant in time within required limits.

An error of observation is the departure of a measured quantity from its true value. Such an error is, in general, partly "systematic" and partly "random" or "accidental". A systematic error, whether instrumental, or due to the personal equation of the observer, can usually be found experimentally and allowed for. The random errors present in a measurement can be reduced in magnitude by repeating an observation of an unchanging quantity n times and determining the mean of the n values.

In oceanographic measurements, the problem of errors of measured values, whether individual or mean values, is complicated by the fact that the measured quantities are not themselves constant, but are subject to change on various time-scales. Experiments can usually discriminate between random errors of measurement and short-period fluctuations of the measured quantity. It is, however, more difficult to distinguish a long-period change of systematic error from a genuine secular trend of the measured quantity.

To avoid confusion, the main terms relating to accuracy of measurements are defined as follows :

Precision of reading

The smallest unit of division on a scale of measurement to which a reading either directly or by estimation is possible.

Index error

The residual error of a measuring instrument or measuring system when calibrated against a standard instrument under prescribed steady-state conditions. The deviation of the index error about the mean may sometimes be required for a knowledge of the repeatability of a measurement.

Tolerance

The maximum index error permissible in an instrument over a part or whole of its range.

Personal equation

The error of an observer's readings of an instrument which is due to an unconscious tendency on his part to read too high or too low. The tendency is usually nearly constant for any given observer reading a given instrument. Parallax is a common source of personal equation.

Parallax

An apparent change in the position of an object caused by a change in the position of the observer. In connexion with the reading of oceanographic instruments, an error of parallax may arise whenever the indicator of the instrument, e.g. end of column of mercury or water, pointer, etc., and the scale against which the indicator is to be read are at a distance from one another which is comparable with the length of the smallest readable scale division; in such a case a movement of the observer's head may cause his line of vision to the indicator to intersect the scale at different points and so give rise to different readings. The error is eliminated by ensuring that the line of vision to the indicator is at right angles to the scale when the reading is made.

Response time (Lag)

The time which is necessary for a measuring instrument or measuring sensor-indicator system to register a specified percentage of any sudden change in the quantity being measured. The reference to response time is usually made in percentage - e.g. 90 per cent response time or 95 per cent response time, etc., as the case may be.

The term "lag coefficient" is commonly used in the measurement of a quantity to denote the time in seconds required for the difference of the quantity to be reduced to $\frac{1}{e}$ of its initial value.

Lag error

The error which an instrument may indicate due to the response time of the measuring system in a varying environment.

Over-all error of measurement

The over-all error of measurement of a parameter is estimated after taking into account all known errors, such as index error, errors due to sensors, observation, etc. This error may be experimentally studied by several methods including statistical methods. The value of the over-all error should be denoted always by the units in which the parameters are measured, e.g. °C, mb, m s^{-1}, and not by percentages or decimal fractions of the measured result.

1.5.2 Accuracy requirements

The accuracy with which an oceanographic parameter should be measured varies with the specific purpose for which it is required. Tables 1 and 2 give the best estimates of accuracies now obtainable for surface observations and subsurface observations respectively.

1.6 Data encoding and reporting

Collected oceanographic data should be encoded either on the "BATHY" Message Log or on the "TESAC" Message Log. These Message Logs are comprised of three parts : Part I - Identity Information; Part II - Environmental Information; and Part III - Radio Message Information. This Guide essentially describes how to obtain the data for Parts II and III. Instructions for completing all three parts, as well as disposition directions for the Message Logs, are contained in the IOC Manual on IGOSS Data Archiving and Exchange (Volume 1 of the IOC Series of Manuals and Guides). Further, Parts III of the "BATHY" and TESAC" Message Logs are delineated by code forms FM 63-V and FM 64-V respectively in the WMO Publication No.306, Manual on Codes, Volume 1.

CHAPTER 2 - SEA SURFACE TEMPERATURE

2.1 Sea-surface temperature

2.1.1 General

There are undoubtedly several so-called "representative levels of the sea" at which surface temperatures can be measured, such as the skin layer, the mixed layer and the injection layer. The temperature of the very thin skin layer is dependent on the relationship of micro-conditions between the top film of the water and the overlying air mass; these measurements are affected by the temperature difference, humidity, vapor pressure, salinity, precipitation, wind speed, colour of water, etc. This temperature sometimes differs from that of the immediate lower layer by more than 0.5°C.

2.1.2 (17.8.1)* Temperature to be observed

The temperature to be observed is the temperature of the sea surface representative of the conditions in the near surface mixed layer underlying the ocean skin. (This definition does not account for cases where near surface layers do not exist, i.e. summer season). Temperature observation should be made within the first 5 metres below the surface.

2.1.3 (17.8.2)* Methods of observation

The temperature of the sea surface may be obtained by :

(a) Taking a sample of the sea-surface water in a suitable receptacle and measuring its temperature (the "bucket" method);

NOTE : A simple canvas bucket is not considered to be a suitable receptacle.

(b) Reading the temperature of the condenser intake water either with a fluid thermometer or with an electrical remote-indicating device (the condenser intake method).

(c) Measuring electrically either the temperature of the sea water or of a device attached to the ship and displaying the sensed data at a site remote from the sensor. ("distant reading" technique). These techniques are of three general types :

(1) Measuring the temperature of the intake water or the water in a small tank below the water line and connected with the outside sea water by several holes (the tank method);

(2) Measuring the temperature of a device attached to the hull below the water line and at a place where the device is in equilibrium with the outside water temperature. The device may be outside the vessel (e.g. a resistance thermometer) or attached to the inside of the hull ("the limpet" method);

(3) Trailing in the water a thermistor in a suitable housing (trailing thermistor);

(d) Using an infra-red radiometer on the ship to measure the temperature of the "skin" or the uppermost 1 mm or so of the sea surface (the ship-board radiometer method).

The principal methods used are (a) and (b). In recent years, particularly as ships' speeds have increased, the alternative devices mentioned under (c) have been more widely used. The radiometer (d) is not routinely encountered.

Comparisons have shown that with reasonable care in the observing procedure, devices that measure directly the outside sea water temperature give the most consistent results. Because of the great differences in size and speed of ships and various considerations regarding cost, case of operation and maintenance, a standard device has not yet been adopted. However, of all the above techniques, the intake method is the least desirable because of the great care required to obtain the correct location of the sensor, adherence to observational procedures, etc.

2.1.4 (17.8.3)* Basic requirements

Sea-surface and air temperatures are difficult to measure, but must be observed very carefully as the difference between them, which is generally small, provides a measure of the stratification of the temperature and the humidity of the lower layers of maritime air masses, and of the stratification of their other characteristics.

The tolerances for sea water thermometers are the same as for ordinary thermometers.

Sea water temperatures should be read to the nearest 0.1°C.

Instruments which can be remotely read in convenient locations should be fitted wherever possible. Such instruments could be a hull-attached thermometer, trailing thermistor or intake thermometer (with appropriate sensors). The choice of the instrument would be determined by factors such as cost and characteristics of the ship concerned.

Where electrically remote readings are not made at engine room intakes, the thermometer used at the intake should be of high quality if its readings are to be used for meteorological purposes.

Only sea buckets of good construction and designed to eliminate errors due to radiation and evaporation should be used for meteorological purposes.

All instruments should be checked for performance at regular intervals. Precision sensors placed in the same environment as the operational instrument are preferable for checking purposes. Good sea buckets could be used periodically to provide a mutual check with other instruments which may be in routine use, without either being regarded as giving a "standard" reading.

Table 1 - Desired Accuracies and Best Estimates of Accuracies Obtainable in the period 1972-1975 - Surface Observations

Parameter	Range to which accuracies refer	Unit	Desired accuracy	Best Estimates: Ships, etc. Manual	Ships, etc. Automatic (attended)	Buoys (unattended 6 months)	Air-craft	Satel-lites	Remarks
Wind speed	1 - 10 > 10	$m.s^{-1}$ $m.s^{-1}$	± 0.5 or 0.05 V, whichever larger	±1.5 ±15%	±1.0 ±10%	±1.0 ±10%	- -	- -	
Wind direction	0 - 360	degrees	±15°	±15	±10	±15	-	-	
Atm. pressure	930-1050	mb	±0.1-0.5	±0.5	±0.5	±1.0	±2.0*)	-	*)Dropsondes
Air temperature*)	-25 to 45	°C	±0.1-0.5	±0.5	±0.5	±1.0	-	-	*)Except in icing condition
Sea surface temperature (as defined in para. 17.8.1 of CIMO Guide)	-3 to 40	°C	±0.1	±0.5	±0.5	±0.5	±0.5	±1.0	
Dew point temperature	-10 to 30	°C	±0.1-1.0	±1.0	±1.0	±2.0	-	-	
Precipitation amount	0-500	mm	±.2	15%	-	yes*)	-	yes**)	*) Only feasible for big buoys; indication of accuracy not possible. **) Gross amounts in three categories, by end of period 1972-1975.

Table 1 (Contd.)

Parameter	Range to which accuracies refer	Unit	Desired accuracy	Best Estimates: Ships, etc. Manual	Ships, etc. Automatic (attended)	Buoys (unattended 6 months)	Air-craft	Satel-lites	Remarks
Waves :								yes***)	***) Some information possible by 1975
Direction	0-360	degrees		±15	-	-	±15	-	
Height*)	0-20	m	±0.5 or 10% which-ever larger	±25%	±25%	±25%	-	-	*) Significant height or other statistically defined parameter; reported as processed data requiring elaborate instrumentation.
Period*)	0-20	sec	±0.5	±0.5	±1.0	±1.0	-	-	*) Note as for wave height.
Radiation flux	-	langleys/ min (mwatt per cm^2)	±.01	-	10%*)	10%*)	-	yes***)	*) Global solar radiation on stationary and some moving ships and possibly on large buoys. ***) Outgoing long-wave and reflected short-wave.

Table 2 - Desired Accuracies and Best Estimates of Accuracies Obtainable in the period 1972-1975 - Subsurface Observations

Parameter	Range to which accuracies refer	Unit	Desired accuracy	Best Estimates: Ships, etc. Manual	Best Estimates: Ships, etc. Automatic (attended)	Best Estimates: Buoys (unattended 6 months)	Best Estimates: Aircraft
Temperature versus depth	-3 to 40	°C	±0.03 Depth: within 1 1/2%	±0.2	±0.2	±0.1	±0.5
Salinity versus depth	20 to 40	‰	±0.03 Depth: within 1 1/2%	±0.02		±0.3	
Current speed	0.1 to 3.0	$m.s^{-1}$	±0.02 or 0.03 V, whichever larger		±0.1		
Direction	0 - 360	degrees	±15°		±10.0		
Transparency	0 - 70	m	±1		±2.0		

2.1.5 (17.8.4)* Instruments, exposure and management

Sea buckets

A container ("bucket") is lowered over the side of the ship, a sample of water hauled on board and a thermometer is used to measure the temperature. It is important that only buckets of good construction should be employed. The design of the receptacle should be such as to ensure that the heat exchange due to radiation and evaporation is reduced to a minimum. Buckets are of two general types : those providing a means for sea water to circulate through the bucket and those which do not. The circulating type is preferable. Sea water thermometers used with the "bucket" method should have a quick response, be easy to read and, if not fixed permanently in the bucket, should have a small heat capacity.

When the "bucket" method is used, the sample should be taken from the leeward side and from a position well forward of all outlets. The temperature should be read as soon as possible consistent with the thermometer taking up the temperature of the sample. The thermometer should not be withdrawn from the container, however, if the thermometer must be withdrawn, then it should be provided with a cistern around the bulb; this cistern should have a small heat capacity when empty, but sufficient volume in order that the temperature of the sample of water withdrawn does not vary appreciably during the reading. The thermometer used must have a certificate and the accuracy of measurement should be $\pm 1°C$. The bucket used should be a receptacle deemed adequate for this purpose by the Member recruiting the ship. When not in use the bucket should be hung to drain in a shady place.

Sea buckets of good design (not simple buckets of canvas or of other construction) can be expected to show good mutual agreement in a wide variety of weather situations. However, they are less convenient to use than instruments attached to the ship and their use is sometimes restricted by weather conditions.

Intake (and tank) thermometers

Intake thermometers which measure the injection temperature of engine water intakes are to be found in a great variety of forms. They vary from simple thermometers located in intake pipes to meet the requirements of the engine room staff, to thermistors or platinum resistance thermometers which can be remotely read at convenient locations.

When high quality intake thermometers are well sited and care is taken in reading the thermometer, they can be expected to agree with sea bucket readings. The observers using the condenser intake method should be specially warned concerning the liability of parallax error when reading the thermometer, due to the relative inaccessibility of instruments in engine rooms. When ships are stationary and cooling water is not circulating, intake (and "tank") readings would be very suspect. In deep draught ships and in conditions when a marked temperature gradient exists, intake readings usually differ markedly from those taken close to the surface.

When the condenser intake method is used, a note should be made in the log indicating the location of the intake thermometer in the engine room, the depth of the intake below sea level, and the method used in obtaining a reading, e.g. whether or not the thermometer is removed from the well for the purpose of reading. The thermometer installation within the intake pipe to the engine room provided when the ship is built is normally not suitable for measurements of sea-surface temperature. In ships in which the condenser intake method is used, the Member recruiting the ship should install, with the permission of the shipping company concerned, a suitable certified thermometer with which the sea temperature may be read to the nearest 0.1° C. The thermometer should preferably be mounted in a special tube providing adequate heat conductivity between the thermometer bulb and the intake water.

The sea-chest or tank in the bottom of a ship is a specially designed cavity into which intake pipes from the main and auxiliary engines terminate. This is a favourite position for a distant-reading thermometer probe. As noted above, the water must be circulating through the tank for this technique to be useable.

Distant-reading thermometers

Distant-reading thermometers can be installed either as engine room equipment, with a dial in the engine room itself or alternatively with the dial on the bridge, the latter being more satisfactory from a meteorological point of view. The position of the sensor in a distant-reading installation is a vital factor. Various systems can be classified according as to whether the sensor is situated in the engine-room intake pipe, in a special sea tank, in direct contact with the ships hull or in direct contact with the outside sea water. The intake and sea tank methods are described above.

(a) Hull attached

The hull-attached sensors can be classified as of two general types;

(i) the internal or "limpet" in which the sensor unit is secured to the inside of the hull of the ship close to the water line. The "limpet" sensor is usually a copper block attached to the inside of the hull about 2 meters below the water line.

(ii) the external or the "through-the-hull" in which the sensor unit is attached to the hull externally. "Through-the-hull" sensors are of several types usually employing a resistance thermometer in direct contact with the outside.

Both types show very good mutual agreement, although the "through-the-hull" sensor exhibits a slightly quicker response.

In view of the optimum location of these instruments (near the stern and at depths of 1-2 metres below the water line), there could be considerable problems of fitting and wiring in some classes and sizes of ships when remote readings are to be taken on the bridge. It would be advisable to fit these instruments when ships are built. The retroactive fitting of "limpet" sensors should however be possible without undue difficulty in some ships. In the case of through-the-hull fittings, dry-docking would be required. If ships are liable to large changes of draught, the need could arise to fit more than one instrument in order to strive for a standard depth location.

Hull-attached thermometers, once fitting problems are solved, provide a very convenient and accurate means of measuring sea-surface temperature.

(b) Trailing thermistors

Basically, this technique consists of a thermistor at the end of a rope which is trailed from a convenient location on the ship. The thermistor data are transmitted by wire to the observer on the ship. The observer may have a direct reading dial or he may have to convert the signals from the thermistor into temperature data.

A correctly sited "trailing thermistor" samples the water in exactly the same position as a bucket but with considerable convenience of use. The readings are in good agreement with those of accurate sea buckets. As such, these instruments appear to have an advantage over sea buckets. However, experience with the use of these instruments is limited, as no information is yet available on their fouling by weed, etc. In one application, the instrument is streamed after getting underway and recovered before entering harbour. Streaming and recovering of this instrument for each reading would make its use laborious. In other applications, the instrument is streamed for each use.

Several versions of trailing thermistors are available : thermistor hose, thermistor bucket and thermistor bucket-on-hose.

(i) Thermistor hose

This instrument consists of a length of transparent garden hose (of 12 mm inside diameter) in which is inserted a two-pole electric conductor wire of suitable length. On the bottom end of the wire is attached a thermistor which is well insulated and sealed so that no moisture can enter the circuit. Along the last 2 or 3 metres of the hose, small holes (of 8 mm diameter) are punched so that when the instrument drags on the surface of the water, the hose becomes saturated and the thermistor is immersed in circulating water. The holes are spaced in such a manner as to allow ample water into the bottom end of the hose where a small hole allows the water to escape slowly. A length of rope at the end of the hose drags in the water and stabilizes the instrument, causing the thermistor section to slide along the surface without too much jostling about. The thermistor and the wire are loose inside the hose, so that the hose is free to stretch without damage to the electrical circuitry. The top end of the hose is fastened round a thimble which is secured firmly to some part of the ship like the wing of the bridge or the ship's rail. The wire from this end of the instrument is plugged into an electronic thermometer. To take a reading, the hose is lowered over the ship's side into the water, care being taken to ensure that the position selected is well forward of all engine-room discharge pipes. The wire is plugged on to the electronic thermometer and a button on the instrument pressed to complete the circuit. The temperature is then read off to the nearest 0.1°C.

(ii) Thermistor bucket

This instrument is an earlier version of the thermistor hose. This consists of a thickly braided nylon rope, inside of which is inserted a two-pole telephone wire of high tensile strength. To the lower end of the wire is fixed a small bucket. Inside the bucket and attached to the wire is the thermistor around which rubberized hog's hair is loosely packed to prevent any damage by shock or vibration. As in the case of the thermistor hose, the top end of the wire should be connected to an electronic thermometer. The procedure for taking a reading is the same as that of a thermistor hose. Trials at sea have proved the instrument to be reliable, but the cable is rather expensive.

(iii) Thermistor bucket-on-hose

The thermistor bucket-on-hose is a less expensive version of the thermistor bucket. Instead of using the relatively costly diver's telephone cable, the bucket is fixed at the end of a hose similar to an ordinary garden watering hose. A two-pole electric conductor wire passes down the centre of the hose on the bottom end of which is a thermistor anchored in the bucket. Plastic (PVC) hose can stretch to over 7% of its length under tension. Therefore, it is important that the coil should be free inside the hose. To eliminate any strain on the wire, the instrument is equipped with two thimbles. The top end of the hose is split into two, each half passing round a separate thimble. These are clamped together and so the wire is free to move between the thimbles. Either or both thimbles are secured to the side of the ship in the usual manner. The small bucket is designed so that it is not necessary for it to be submerged all the time during sampling. Two small holes at the bottom allow the water to escape slowly. It takes about 8 seconds to empty, so that periodic reboundings from one wave top to another, of two or three seconds, have no adverse effect on the data.

(c) Infra-red radiometers

Infra-red radiometers are used on only a few ships. A discussion of this technique is included here for the sake of completeness and to give information on the instrument should it be encountered.

Because of its temperature, any substance radiates (gives off) infra-red radiation (heat energy). The amount of energy and the wavelength of the energy radiated are dependent upon the temperature of the substance. Infra-red radiometers, then, can be used to measure the temperature of the sea surface. It is important to realize that the radiometer only measures the temperature of the uppermost 1 mm or so of the sea surface. This uppermost layer is often called the ocean "skin". Strong temperature gradients (coolest at the top) may exist in the first few centimetres of the ocean, especially in relatively calm conditions.

Radiometers can be hand-held pointing forward of the ship and down; mounted on the bow or a boom extending over the water; carried on an aircraft or a satellite. Radiometer measurements do not usually represent sea surface temperatures as defined in paragraph 2.1.2 (17.8.1)*.

2.2 Near Surface Reference Temperature (NSRT) System

The Near Surface Reference Temperature (NSRT) System provides an instantaneous readout of sea temperatures in the near-surface layers. Major components of the NSRT System consist of an intake thermistor probe usually mounted just inboard of the sea valve and a remote meter readout located in the ship's engine-room or on the bridge. The system has an accuracy in the vicinity of ± 0.3°C and a capability of operation under all ship speeds and weather conditions.

There also exists a portable version of this device which makes use of a drag probe towed behind the ship, connected with a meter or recorder. The probe can be either a thermistor or a platinum resistance thermometer, the latter being more accurate but also more expensive.

2.3 Thermosalinograph

The thermosalinograph is a measuring system that provides a continuous record of sea surface salinity and temperature along the cruise-track of a vessel.

The system consists of a recorder/controller unit electrically connected to a salinity sensor and a temperature sensor. The sensors, which are designed for continuous immersion in seawater, are mounted in any seawater supply line that provides a representative sample of the water through which the ship is cruising.

Complete system operation is performed at the recording unit which can be installed in the ship's laboratory, on the bridge, or any other convenient location.

The salinity sensor is contained in a corrosion-proof fiberglass housing with the transducers immersed in a special reservoir that bolts to the deck through a base flange, and connects to the seawater supply line through standard female adapters. The temperature sensor has a male fitting which can be threaded into the supply line. Each sensor is cabled individually to the recorder/controller, and can be positioned remotely from the other. Care must be taken to eliminate bubbles in the system. This may be done by (1) carefully regulating the inflow of water into the reservoir and (2) replacing the filter weekly, to eliminate particulate matter.

Salinity is measured by inductively sensing seawater conductivity and applying automatic compensation for temperature. The temperature transducer is a compensated thermistor probe. The accuracy of this system is to $\pm 0.1°C$ and to $\pm .03‰$.

The system records salinity and temperature automatically after being turned on and set to the ranges for the salinity and temperature of the geographic area being investigated. Ranges overlap, permitting them to be changed without painstaking scrutiny of the plotter pen positions. Time and position notations can be placed on the chart by the operator for later correlation of salinity and temperature data with geographic locations.

2.4 Remote sensing with infrared thermometers

2.4.1 Applications of remote temperature sensors

Infrared thermometers mounted in satellites and aircraft offer a fast method for mapping sea surface temperatures over large or remote areas. Infrared sensors have also been mounted over the bow of ships to collect continuous underway surface temperature data. In order to record surface temperature changes with time at a fixed point, instruments have been mounted on fixed platforms - a useful technique for rough nearshore waters.

2.4.2 Principles of infrared thermometry

An Infrared Radiation Thermometer (IRT) detects and measures the infrared radiation naturally emitted by certain objects. The intensity and spectral distribution of the energy are functions of the temperature of the object and the nature of its surface. Infrared energy emitted from the sea is transferred through the atmosphere in the form of electromagnetic waves localized within the wave length region between red light and microwaves. Because infrared energy has many of the characteristics of light, the radiation emitted by distant objects can be collected by conventional reflective and optical systems and concentrated upon an infrared detector.

Infrared radiation from the sea must pass through the atmosphere which contains gases, moisture, and particulate matter that modify radiation. To eliminate the atmosphere's attenuation effects, the detected radiation is usually limited by filters to the region between 8 and 13 microns. It is in this region that maximum radiation energy is emitted by ocean surfaces and in which there is a minimum of reflected solar radiation.

2.4.3 Thermometer characteristics

An infrared thermometer consists of a radiation sensing unit known as the optical "head" and an electronic processing unit. Optico-mechanical chopping supplies the detector alternately with radiation from the sea surface and with radiation from an internal reference standard at a precisely known temperature. Detector output is an alternating electrical signal proportional in amplitude to the difference between the two radiant energy levels. This output signal is stepped up by a preamplifier in the optical unit and transmitted to the electronic unit, where it is further amplified and processed to drive a panel meter calibrated in Celsius degrees.

In addition, the signal can also be supplied to a strip chart recorder to produce a permanent record of temperature against time. These data, together with navigation information, are used to plot sea surface temperature.

2.4.4 Data correction

As states previously, airborne infrared sensors are particularly sensitive to environmental conditions and data should be carefully examined for such effects. Surface winds should be gentle breezes or stronger to ensure that recorded values are representative of surface temperature rather than skin temperature (see para 2.1.1) but less than a strong gale when blown foam masks the surface. Data collected under conditions where intermittent fog and precipitation or low clouds occur (between aircraft and surface) may be biased. Altitude, air speed and ambient air temperature should be periodically recorded to facilitate correction of raw data. Recorded temperatures averaged over 1-minute intervals are often more representative of surface temperature than instantaneous readings, except in areas of strong horizontal gradients.

Various correction methods have been proposed to account for differences between recorded temperatures and actual temperatures. One such method is to compute correction tables using ambient air temperature, recorded sea surface temperature and altitude, with the assumption of a constant lapse rate. Another method compares differences between downward scanning and obliquely scanning sensors. Surface temperature from airborne expendable bathythermographs offer a reliable comparison. Separate corrections may be required for each water mass encountered.

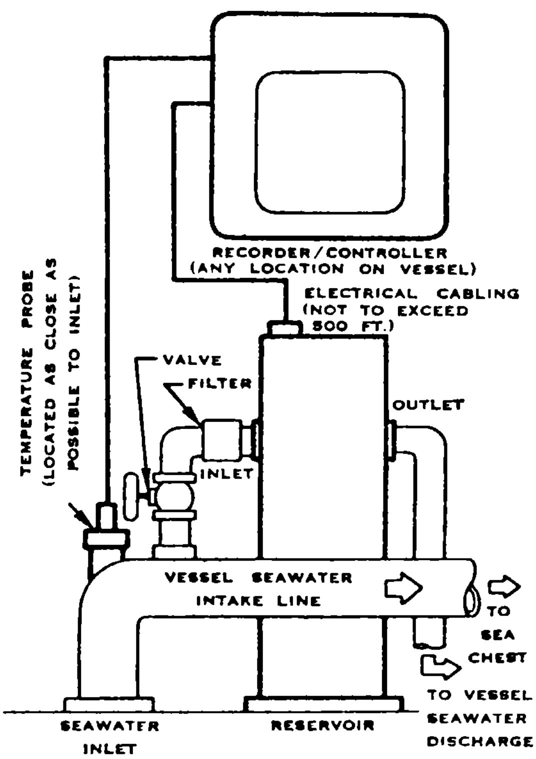


Diagram of a Thermosalinograph installation

CHAPTER 3 - SALINITY - AT SURFACE AND DEPTH

3.1 Definition of salinity

Salinity is defined as "the total amount of solid materials in grams contained in one kilogram of seawater when all the carbonate has been converted to oxide, the bromine and iodine replaced by chlorine and all organic matter completely oxidized". Titration with silver nitrate to determine chlorinity, which is directly related to salinity, is the classical method for salinity determination.

3.2 General

A sample of sea surface water for analysis of salinity may be collected by various means; bucket, engine-room intake, Nansen bottle, etc. Once collected, this sample should be analysed as soon as possible or stored in an airtight container to prevent evaporation. Salinity (or conductivity) may also be measured in situ, as described in paragraphs 2.3 and 3.7.

3.3 Salinometer

The induction salinometer offers a rapid method, accurate to within ±.003%, based on the electrical conductivity of a seawater sample. Electrical conductivity of sea water is directly proportional (although not strictly linear) to temperature and salinity. The salinometer in fact measures temperature and electrical conductivity of a sample to determine its salinity. Analysis begins by drawing a sample into the sample cell. The seawater acts as a single turn loop to provide a link coupling between the transmitter toroid and the receiver toroid for an oscillator signal. The degree of coupling is directly proportional to the conductance of the seawater loop. The coupling between the two toroids is varied by operator controlled transformers until two currents of equal magnitude but opposite phase are indicated on a nullmeter. The control settings are then translated to salinity with the help of tables.

Before samples are tested they should be near room temperature; and the salinometer must be calibrated. The standard used, called Copenhagen water, has a precisely known chlorinity. The salinometer is calibrated to read the conductivity of the standard, found in tables as a function of the chlorinity when introduced into the sample cell. After the instrument has been calibrated salinities of unknown samples can be measured. The conductivity and temperature of each sample are recorded. An uncorrected salinity is found in tables for the conductivity measured. Two corrections must then be made. The first is a correction for temperature. This correction is found in tables provided by the manufacturer of the salinometer by entering with the conductivity and temperature measured for each sample. The second correction is for drift, the difference in conductivity readings between succeeding Copenhagen water samples.

Portable salinometers are commonly used at sea. The data may be quality controlled by comparing with results obtained ashore with a different salinometer used by a different operator.

3.4 Hydrometer

A rough method of determining salinity makes use of a hydrometer. Among others, there are specific gravity (density) hydrometers and salinity hydrometers. In each case data must be reduced to the temperature for which it was calibrated (usually 15°C).

The temperatures of the liquid and of the surrounding atmosphere should be nearly equal during the observation; otherwise the temperature of the liquid will vary with resulting changes of density and doubt as to the actual temperature.

If an observation is made at some temperature other than that for which the hydrometer is designed the reading will be incorrect. The magnitude of the error will depend upon the thermal expansion of the hydrometer and, in some cases, of the liquid used.

The hydrometer should be clean, dry, and at the temperature of the liquid before immersing to make a reading. The liquid in which the observation is made should be contained in a clear, smooth glass vessel of suitable size and shape. The hydrometer should be slowly immersed in the liquid slightly beyond the point where it floats naturally and then allowed to float freely. The reading should not be made until the liquid and hydrometer are free from bubbles and at rest.

In reading the hydrometer scale, the eye is placed slightly below the plans of the surface of the test liquid; it is raised slowly until the surface, seen as an ellipse, becomes a straight line. The point where this line intersects the hydrometer scale should be taken as the reading of the hydrometer. Read to the nearest half scale division; this will normally be to .0001 for specific gravity and to 0.10°/₀₀ for salinity. At sea, where reading can be made difficult by the motion of the ship it is well to wait for the time of least movement. The temperature of the water must be determined at the same time as the hydrometer reading; read to within 0.5°C and preferably to 0.1°C.

Manufacturers normally supply tables for temperature reduction of hydrometer values. If a density hydrometer is used, salinity can be determined by entering appropriate tables with density and temperature.

3.5 Thermosalinograph

See paragraph 2.3 for a description of this instrument.

3.6 Refractometer

Light passing through an interface into a denser medium is refracted, or bent toward the normal. The ratio of the sine of the angle of incidence to the sine of the angle of refraction is called the refractive index. The refractive index of seawater is a function of the salinity and the temperature of the seawater and of the wavelength of the light used. Therefore, measurement of the refractive index of a seawater sample at a known temperature and for a given wavelength of light yields the salinity of the sample. An instrument used for this is a refractometer, which gives a direct reading of the refractive index. Light of a known wavelength is transmitted through the sample and the refractive index is read. For temperature measurement, a thermometer graduated in degrees Celsius is contained in the refractometer. Although variation of refractive index with temperature is small, for accurate results all samples must be at the same temperature. For this reason, most refractometers have some type of thermostat. A common refractometer is the Abbe refractometer. It requires only a few drops of sample and takes one or two minutes for each reading. The Abbe refractometer has limited use because of its gross accuracy (0.0001 in refractive index and about 0.5°/₀₀ in salinity). A more accurate instrument is the dipping or immersion refractometer (accurate to 0.00003 in refractive index and 0.15°/₀₀ in salinity). It requires about 15 ml of sample since the prism is completely immersed in the sample. The most accurate instrument used is the interferometer, which measures the difference between the refractive index of seawater and that of pure water, according to the following principles : A light beam, travelling through a seawater sample of thickness d, penetrates the optical path length $l = nd$. For pure water of the same thickness, however, the path length $l_o = n_o d$, where n and n_o are the corresponding refractive indices. Two light beams from the same light source, one passing through seawater, the other through pure water, show, therefore, the path difference $l - l_o = (n - n_o)d$. The interferometer measures this path difference. This is accomplished by bringing the two light beams into interference after passage through both media and by measuring the interference pattern. The interferometer has an accuracy of 0.00001 in refractive index and 0.05°/₀₀ in salinity.

Another version of this instrument is a hand-held refractometer/salinometer. Both a salinity and refractive index reticle scale are provided which allow readings in either scale according to requirements. The technique provides a trouble-free hand-held instrument capable of ±.05°/₀₀ accuracy with unskilled field or laboratory personnel. The handheld refractometer/salinometer is made of corrosion-resistant materials and is designed for use aboard open boats or within a "wet lab". Each instrument is supplied with a convenient carrying case. The instrument is usually held using a pistol-grip hand piece which provides thermal isolation between the hand and the instrument case. A tripod stand may be used for table mounting of the instrument for laboratory use.

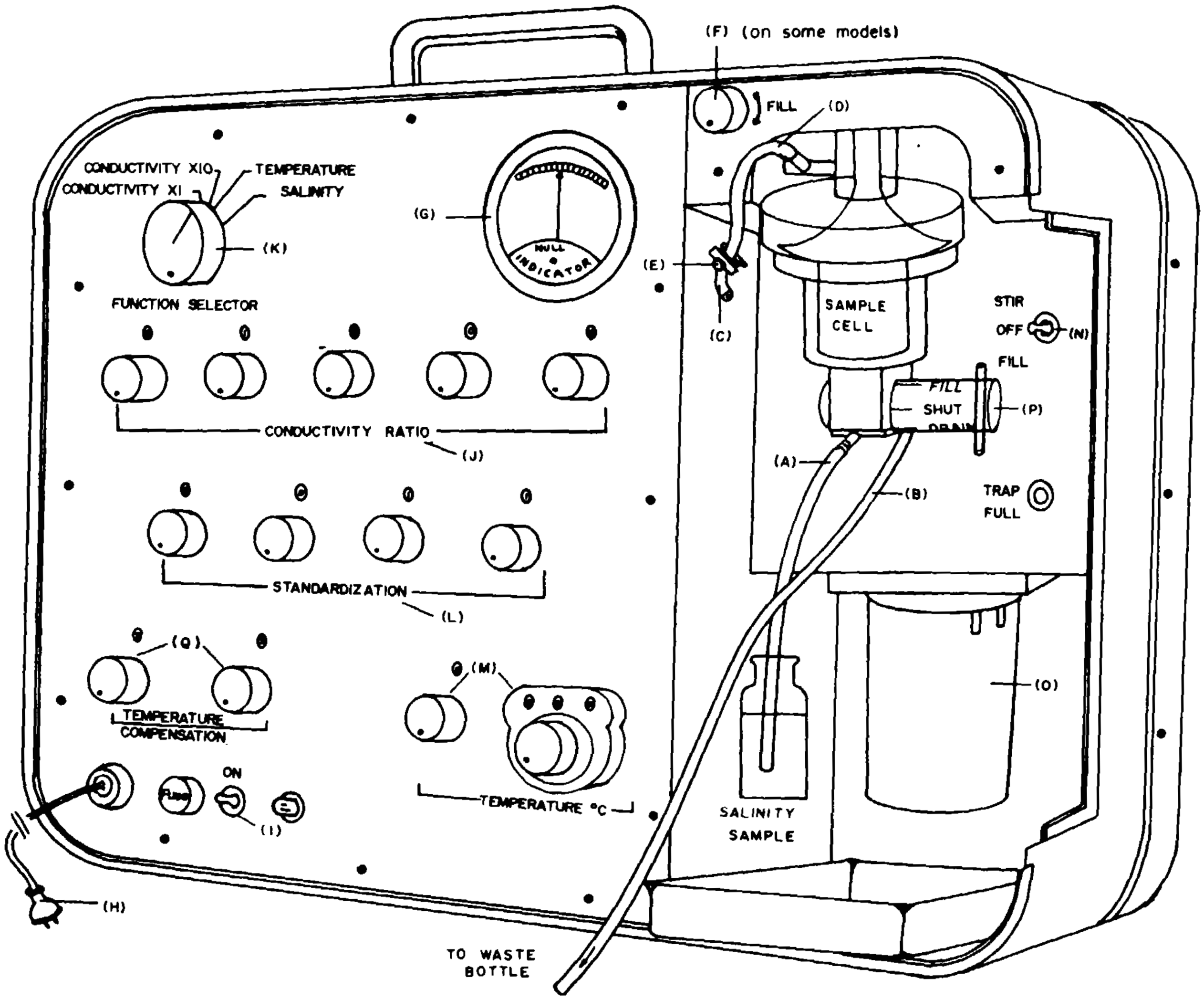
The instrument contains an internal green monochromatic filter to provide the sharpest readings of refractive index. The large prism surface area allows large surface area contact for the sample, thus reducing to a minimum the effect of sediments and marine life contained in the sample.

3.7 In situ salinometer

An in situ salinometer usually requires an accompanying temperature sensor of some sort. Many of the principles involved in an in situ salinometer are similar to those in an STD. In one model, a battery-powered instrument measures temperature and electrical conductivity yielding a salinity value accurate to 0.3°/₀₀ . All three parameters are read off a counter dial on the meter. The conductivity is measured by matching a current through a slide-wire to an induced current loop in seawater. This measurement and the temperature are combined in a computer circuit to give a reading of salinity. The seawater loop and the temperature measuring elements (a pair of thermistors) are housed in a cell, which is connected to the meter by a conductor cable. In operation, the cell is first lowered to a desired depth. Dials on the meter are then adjusted to give a null reading and the dial reading is recorded. The in situ salinometer, although providing rapid salinity determination, is limited in use because of accuracy and depth capability (maximum approximately 125 meters).

3.8 Salinity-Temperature-depth (STD) system

See paragraph 4.6 for a description of this system.



Salinometer set up for operation

CHAPTER 4 - TEMPERATURE VERSUS DEPTH

4.1 General

The measurement of ocean temperature with depth can be conducted by various methods, from simple bathythermographs to complex electrical and electronic sensors.

4.2 Mechanical bathythermograph (BT)

The BT is an instrument for obtaining a record of the temperature of seawater at moderate depths. The BT is lowered into the sea and retrieved by means of a wire rope. It can be operated while the ship is underway at speeds of up to 9 metres per second. It works more satisfactorily, however, at speeds of 6 metres per second or less.

a. How a bathythermograph works

The thermal element of the BT, corresponding to the mercury column in a glass thermometer, consists of about 15 metres of fine copper tubing filled with xylene. As the xylene expands or contracts with the changing water temperature, the pressure inside the tubing increases or decreases. This pressure change is transmitted to a Bourdon tube, a hollow brass coil spring, which carries a stylus at its free end. The stylus records, on a coated glass slide, the movements of the Bourdon tube as it expands or contracts with changes of temperature. The slide is held rigidly by the depth element assembly which is on the end of a coil spring enclosed in a copper bellows or sylphon. The temperature range of the BT is -2° to 32°C.

Water pressure, which increases with depth, compresses the sylphon as the BT sinks. This pulls the slide toward the nose of the BT, at tight angles to the direction in which the stylus moves; thus, the trace scratched on the coated surface of the glass slide is a combined record of temperature and depth. The depth range is stamped on the nose of the BT. It is usually either 60, 135, or 275 metres.

b. Taking a BT

Making a bathythermograph observation is described by the term "Taking a BT." It is a relatively simple operation; nevertheless, a new operator should practice lowering and recoveries with a dummy BT before undertaking the operation with an actual instrument.

Certain operations are necessary to ensure that good data are obtained. Taking a BT includes the following procedures :

Step 1. Check the operating instruction manual for the model of winch to be used. The hand lever on many winches serves both as a brake and clutch. It has three positions : (1) When it is vertical, the winch is in neutral and the drum can be turned in either direction; (2) When it is pushed outboard to the engaged (hoist) position, the motor turns the drum and winds on the wire; (3) When the lever is pulled inboard toward the operator, to the brake position, the drum is locked and cannot be rotated. Other models may operate differently, the operating lever and the brake are sometimes separate.

Examine the winch installation to assure that the wire comes across the top of the drum. Run the free end of the wire through the towing block at the end of the boom. This block may be of a special counterbalanced design for BT use. Make certain that the winch drum and block are properly lubricated.

Step 2. Connecting BT to lowering wire. Cut off rusted, kinked, or frayed wire and make a new connection using a thimble with three Nicopress sleeves or wire clips. Check the swivel and if the BT does not have a built in swivel include one in the connection. Connect the lowering wire thimble to the BT swivel with a shackle. Note : More BTs are lost by poor connections than from any other cause. Another important precautionary measure is to paint the last 15 metres of the BT wire a bright color. This will warn the operator during retrieval to be on the immediate lookout for the BT, preventing accidental "two-blocking" and loss of the instrument. It is unwise to trust the counter dial on any BT winch.

Step 3. Inserting slide in BT. It is important that the slide is inserted in the BT properly.

Slide the BT sleeve forward towards the BT nose. This will uncover the stylus assembly and slide holder.

Hold slide between thumb and index finger with coated side up.

Insert the slide into the hole on the side of the BT, and push the slide into its bracket. The edge of the slide with the beveled corner goes in first, with the bevel towards the nose of the BT.

Push the slide all the way in. Occasionally check the grooves of the slide holder to make sure they are clean and free of glass chips. Also, check the spring to assure that the slide is held firmly in position.

Move the sleeve back to cover the opening prior to putting the BT over the side. This will bring the stylus assembly in contact with the glass slide.

Step 4. Putting the BT over the side. When permission has been obtained from the bridge, the BT can be put over the side.

Hold the BT at the rail; take up the slack wire.

Lower the BT into the water to such a depth that it rides smoothly just below the surface.

Put on the brake and hold the BT at this depth for at least 30 seconds to enable the thermal element to come to the temperature of the surface water.

Turn on the motor, so that power is available instantly for the rest of the operation.

Set the counter on the winch to zero.

Step 5. Taking the sea surface reference temperature. When a sea surface reference temperature is required, it should be taken in the manner described in Chapter 2 for bucket temperatures.

Step 6. Lowering the BT. The following instructions apply to underway lowering :

CHECK THE DEPTH OF WATER JUST BEFORE MAKING EACH LOWERING.

Release the brake, and allow the wire to pay out freely. Success in reaching the maximum desired depth depends on paying out the wire as quickly as possible.

Watch the wire and the drum carefully. Once the dividing motion of the BT is arrested, it will not dive deeper regardless of the amount of wire payed out.

The correct amount of wire to be payed out will depend upon several factors, such as : speed of the ship, the type of BT and whether or not the nose sleeve is attached. Several lowerings should be made to obtain the ship-speed/wire-out ratio for the BT used.

Stop the winch when the counter indicates that the correct length of wire has been paid out. Apply the brake smoothly; avoid excessive herks which may part the wire. Note : Never pay out the last layer of wire on the drum.

Step 7. Retrieving the BT. As soon as the brake is applied, the BT will stop diving and return to the surface far astern.

Haul in the BT at full winch speed.

Guide the wire back and forth in even layers on the drum. If the winch does not have a level wind, use a wooden stick for proper spooling.

Decrease the winch speed when the BT is close astern. Continue to haul in until the BT begins to porpoise (breaking clear of the surface and swinging forward as the ship rolls or as wave crests pass). Note : This is the most critical point in the operation. To bring the BT alongside and raise it without too much swing requires practice.

Stop the winch with the BT a metre or so from the towing block. If the BT skips or swings forward of the boom, allow the BT to sink freely until it has passed clear astern, and try again.

Turn off the winch motor and commence bringing the BT aboard. The BT can be brought aboard in various ways, depending on how the boom is rigged. With the standard gate boom, the use of a retrieving line and ring is recommended. This consists of a metal ring an inch and a half in diameter through which the wire is passed between the towing block and the BT. The ring is attached to a retrieving line which is secured to the lifeline or rail. With the proper amount of slack, the ring will ride freely when the BT is being lowered and retrieved. By hauling in on the retrieving line while easing the brake, the BT can be brought to hand.

Step 8. Removing the BT slide. As soon as the BT is in hand, slack off the wire, set the brake, and remove the BT slide in the following manner :

Move the sleeve forward toward the BT nose to lift the stylus off the slide. Partially eject the slide by pushing against its edge with the forefinger, or a pencil, through the slide-ejecting part. Carefully, grip the slide with the thumb and forefinger holding the slide only by the edges. Be careful not to obscure the trace with smudges or fingerprints.

Place the BT in its deck rack,and notify the bridge that the BT is on deck.

Step 9. Securing equipment. If another lowering is to be made soon and there is no danger of overheating the BT, it may be left in the deck rack connected to the wire; otherwise, unshackle it and stow in a cool place. CAUTION : Never let the temperature of the BT exceed 40°C. If this temperature is exceeded, the instrument will be damaged and the calibration will be invalid. Never leave the BT on deck without protection from hot sun. Suitable protection to the thermal element can be afforded by keeping the BT covered with wet cloths.

Step 10. Labeling the BT slide. As soon as the BT slide is removed from the BT, examine it to be sure that a suitable trace has been obtained. With a sharp instrument or pencil, write the following information on the slide, being careful not to obscure or touch the temperature-depth trace.

Slide number and time group. Number slides consecutively. Use Greenwich Mean Time (0000 to 2359), giving the hour and minute at which the BT entered the water. Enter a dash between slide number and time. Slide number five taken at 2240 is marked : 5-2240.

Day-month, and year. Use Roman numerals for the month. 29 November 1974 is written : 29-XI-74.

BT instrument serial number. The serial number of the BT is stamped near the nose of the instrument. This number is very important as each BT has a calibrated grid, a duplicate of which is on file at the laboratory that will process the slide. Without the proper serial number, the information on your slide is valueless. Include any letter which precedes or follows the serial numbers; e.g., BT A-1257 or BT1216A.

Always enter the information on the slide in the order given above. Avoid the temptation to improve an apparently faint trace by enlarging or tracing over it at the time you enter the data. The processing laboratory can copy an actual trace, however faint, by the delicate photographic processes it uses, but a retouched trace will invariably be detected and rejected. After the slide is labeled, rinse in fresh water, read the slide, and record the data on the log sheet.

c. Reading the BT slide

The BT grid is connected to a magnifying grid mount viewer which facilitates holding and reading the BT slide.

Clean the grid with a cloth or tissue. Place the slide in the viewer with the coated surface toward the grid and the beveled edge toward the set screw. Gently push the slide down against the spring and into place so that the coated surface lies flat against the grid and snugly against the set screw.

To remove the slide from the grid, depress the spring to loosen the slide from the grid mount.

The trace scratched by the stylus is a temperature-depth record. Each point on the trace represents a value of temperature and depth which can be read off the appropriate line of the grid. The lines on the grid are established by actual test of the instrument. Each BT has its own grid for converting the stylus trace to temperature and depth readings. These grids are not interchangeable between instruments. Serial numbers of both grid and BT must agree. The surface temperature is read from the BT slide by noting the temperature of the point at which the trace starts downward from the surface. Temperatures should be read to tenths of a degree and depth to the nearest metre. When reading and interpreting the BT trace, include : (1) water temperatures at the sea surface and at the deepest point of the trace, and (2) sufficient inflection (flexure) points to describe the temperature structure and small irregularities in the surface layer.

d. BT maintenance

The BT requires very little maintenance, but careful handling is essential to maintain the accuracy of the delicate internal mechanisms.

After survey operations, the BT should be rinsed with fresh water. Never store a BT that is being withdrawn from use without thoroughly rinsing it.

Do not dismantle the BT. It is a precision instrument with delicate internal mechanisms, and even with the greatest care possible it is difficult to avoid damage if stripping is attempted aboard ship. If for any reason the BT fails to operate satisfactorily, it should be turned in for repair with a report indicating the symptoms to aid the repair shop in correcting the trouble.

e. Malfunctions

The BT normally is a very reliable instrument; however, the operator should be alert to several common malfunctions. Shocks which occur to the instrument during the handling and lowering may cause hysteresis, temperature error, and/or depth error.

(1) Hysteresis. - The stylus scratches its trace while the BT is diving and as it rises to the surface. Water conditions where it dives may be slightly different from where it rises. These conditions are usually negligible; however, the instrument may have hysteresis; i.e., there may be a slight lag in the movement of its thermal and depth elements. If the up and down traces are essentially similar, a slight divergence of the traces usually is immaterial. If the traces differ widely, change to another BT. The temperature reading at the given depth (if the water conditions are not changing) would be a point midway between the two traces. Nothing can be done aboard ship for hysteresis. Note : Closely spaced traces (less than 0.3°C) and double traces in strong gradients (layers of rapid change of temperature) are not considered as hysteresis.

(2) Temperature error. - It is advisable to make frequent comparisons between the BT surface temperatures and the sea surface reference temperatures. These temperatures should be approximately the same. If they differ slightly, the difference should remain constant over a long period of time. If this difference changes and if the amount of the difference then found continues for subsequent lowerings, it is an indication that the calibration has shifted. A shift in calibration, sometimes called a "shift in the zero points," should not affect the shape of any given trace. To calibrate the BT :

Load the BT with a slide and leave the sleeve open so that the stylus does not rest on the slide. Immerse the tail fins in a bucket of cold water (about) 4°C) deep enough to cover the thermal element and sleeve. Insert a thermometer into the water alongside the BT thermal element. Stir the water for about 30 seconds. Push the BT sleeve down to bring the stylus in contact with the slide and take a reading with the thermometer. Open the sleeve to raise the stylus off the slide. Add hot water to raise the temperature to about 16°C. Stir the water for about 30 seconds and close the sleeve to mark the slide as before. Read the thermometer. Again, add hot water to bring the temperature to about 27°C. Stir the water and repeat the procedures as before. Remove the slide from the BT, place it in the grid, and subtract the thermometer temperatures algebraically from the BT temperature. Average all differences as follows :

	(a)	(b)	(c)
BT Temperature (°C)	4.2	15.8	26.6
Thermometer Temperature (°C)	3.9	15.3	26.5
Error (°C)	+0.3	+ 0.5	+ 0.1
Average Error (°C)			

If the temperature error is greater than 2°, the instrument should be replaced.

(3) Depth error. - The BT, when on deck, usually has a different temperature from when in the water. The BT thermal element assembly moves the stylus assembly along the zero depth line to the surface water temperature position during the period the BT is being towed at the surface. Thus, the top of the trace is almost always a horizontal line which should be on the zero depth line of the grid when the slide is viewed. In order to determine the amount of correction to apply to depth for accurate work, the following procedures can be used :

Insert a slide and close the sleeve. Immerse the thermal element first in a bucket of cold (2° to 4°C) water and then in a bucket of warm (26° to 29°C) water. This will cause a long zero depth line to be drawn across the slide. The slide is then placed in the viewer and the difference, in metres, of the trace above or below the zero depth line on the grid is the error for which corrections must be made at all depth readings.

BTs that have a depth error of more than 3 metres for a 60 metre instrument, 6 metres for a 135 metre instrument, or 12 metres for a 275 metre instrument should be replaced.

(4) If the average temperature error is greater than 0.3°C or the depth error is greater than one metre as determined by the shipboard calibration tests described above, then the values read from the trace should be corrected accordingly prior to transmission; however, the temperature should not be corrected at each observation to the corresponding sea surface reference temperature.

4.3 Expendable bathythermograph (XBT)

Expendable bathythermograph system is used aboard ship for measuring the temperature of sea water in the water column from the surface down to a depth of 460 metres. (Measurements to depths of 760 or 1520 metres can be obtained with special probes and recorder modifications). The XBT can be used while the ship is hove to, but it is especially designed to be used while the ship is under way. The XBT includes three components : the launcher, the recorder, and the expendable probe.

The launcher includes the discharge tube, the breech, the stanchion, and the launcher/recorder cable.

The recorder is a conventional type analog recorder with a temperature scale from -2° to 35°C. Special depth/temperature scales chart paper is used in the recorder.

The expendable probe includes the canister, the probe with calibrated thermistor, two spools of wire, and the probe launch pin.

a. How the XBT works

The thermal element of the XBT is the probe. It is a ballistically shaped device containing a calibrated thermistor in its nose. The thermistor is connected to a very fine two-conductor wire. Approximately half of this wire is wound on a spool inside the probe, and the other half is wound on a spool inside the upper portion of the canister. The probe is held in place in the canister by the probe launch pin. To take an XBT, the canister case is placed in the breech of the launcher and the breech is locked, completing the electrical circuit from thermistor to recorder; then the probe launch pin is pulled, and the probe falls through the discharge tube and into the water. When the probe is launched, the fine wire from both spools is free to unwind, permitting the probe to fall freely through the water and the ship to move away from the station without breaking the wire. As the probe drops through the water, the resistance of the thermistor in the probe changes with the water temperature. This causes voltage changes at the recorder, and the temperature and depth are recorded on an analog chart. When all the wire on the spools is payed out, the wire breaks, and the probe drops to the bottom of the sea.

b. Installation of XBT launcher and recorder.

In locating the components on the ship, consideration should be given to protecting the recorder from weather and spray, to line voltages, ambient temperatures, and electrical noise, to garbage chute and waste outlet locations, and to the location of any devices being towed by the ship. XBT probes should be stored upright in a cool place out of direct sunlight.

c. Checking the XBT system

After the XBT launcher and recorder are installed and at least once weekly thereafter when in use, the recorder and the launcher to recorder circuit should be checked by performing the following steps :

Step 1. Plug in the recorder power cord (the instrument does not have an On-Off switch). This will cause the red reload indicator signal to light.

Step 2. After a 15-minute warm up period, open the launcher breech and clean contacts, using a clean rag and alcohol. Check the launcher discharge tube for salt deposit, and clean as necessary, using fresh water and a cloth swab. Insert the test canister. Note : Included with each XBT system is a test canister. The test canister should be calibrated every six months.

Step 3. Close the breech and lock securely. The reload light will go out, the chart drive will operate for 2 seconds, and the chart stylus will plot 16.7°C ± 0.1°C for that period. The chart drive will then stop, and the green launch light on the left of the temperature scale will go on. Note : Check for jitter on the plot and adjust the gain if necessary.

Step 4. Press and hold the 34.4°/-1.1° test switch in the 34.4° position for 30 or 40 seconds. The launch light will go out, the chart drive will start, and the chart stylus will plot 34.4°C ± 0.1°C.

Step 5. Release the test switch, and press and hold it in the -1.1° position. Now the stylus will plot -1.1°C ± 0.1°C. The chart paper will advance for 88 seconds ± 2 per cent, then the chart paper drive will stop and the reload light will go on.

Step 6. Press and release the recycle switch. The reload light will go out. The chart drive will operate for 2 seconds with the chart stylus at 16.7°C ± 0.1°C. Then the chart drive will stop and the launch light will go on.

Step 7. Repeat steps 4 and 5 several times to make sure that the chart stylus is recording temperatures within tolerances, that the signal lights are operating properly, and that the chart paper drive advance time (step 5 above) is between 86.2 and 89.8 seconds. When the test switch is changed from the 34.4° to the -1.1° position, the stylus should require 1 second for a full scale excursion. Excessive overshoot or sluggishness of movement will require gain adjustment. If any tolerances are exceeded or any malfunctions are noted, the recorder should be calibrated as described in the manufacturer's manual.

d. Development of the XBT

Take the XBT by performing the following steps. Note : One person can take the XBT, but this requires several trips between recorder and launcher; so, if two persons are available one should be stationed at the recorder and the other should be at the launcher.

Step 1. Plug in the recorder power cord. This will cause the red reload light indicator signal to light. Allow a 15-minute warm up period.

Step 2. Remove the canvas cover from the launcher, and open the launcher breech fully clockwise; remove the expended canister used when taking the previous XBT, making sure no scrap wire remains in or around the discharge tube or breech.

Step 3. Take a canister from the packing case, and remove the white end cover.

Step 4. Insert the canister into the breech, guiding the probe launch pin loop through the launch pin slot until the knurled end is on the breech castings.

Step 5. Close the breech and lock handle fully counterclockwise. This will cause the red reload light to go out at the recorder, and the chart drive to run for approximately 2 seconds. Check the chart paper to make sure that the "surface" line appears directly under the stylus. To adjust the paper, turn the knob at the lower left of the chart drive, ending with a clockwise motion to eliminate any blacklash error. It is imperative that the zero-setting of the recorder be accomplished only <u>after</u> the probe has been inserted into the launcher.

Step 6. When the green launch indicator signal goes on, pull the probe launch pin by grasping the loop and removing the pin with a firm continuous motion. Note : If the sea is high, try to deploy the probe so it will hit the water between wave crests.

Step 7. When the cart drive stops and the red reload indicator signal goes on, annotate the chart with the following information : ship, cruise, latitude, longitude, time (GMT), day/month/year, e.g., 19/VI/70, and consecutive observation number. If available, bottom depth should be indicated beside the trace.

Step 8. Leave the expended canister in the breech until the next use. This helps to protect the launcher contacts and breech.

Step 9. After the XBT observation is completed, charts may be left on the take-up spool in the recorder or removed individually. To remove XBT chart(s) from the recorder, cut the chart paper along the bottom of the chart paper locking plate with a penknife. To reconnect the chart paper, attach the chart-saver clip to the chart paper by stretching the clip elastic downward.

Step 10. Secure the XBT system by replacing the launcher canvas cover and disconnecting the recorder power cord.

Step 11. If the XBT system is not to be used within the next 4 hours, unplug the recorder power cord.

e. Reading the XBT trace

The trace should be read to the nearest tenth of a degree Celsius and to the nearest metre at significant inflection (flexure) points selected to fully describe the temperature structure, omitting small irregularities in the surface layer. Flexure points should be determined in such a way that linear interpolations fall within ±0.2°C of the original record. However, the significant depths in the upper 500 metres shall never be more than 20 in number, even at the cost of loss of detail. On entering the water, the probe takes a short time to adjust to the sea temperature. For this reason, the trace from 3 to 5 metres should be extrapolated upwards isothermally to obtain the surface temperature for encoding.

If probes are used in depths shallower than their rated depth, they may continue to record after striking the bottom. By using the echo sounder depth or best other depth determining means, the XBT trace should be examined at the appropriate level to identify any signs that the probe has hit the bottom; e.g., the trace may suddenly become isothermal or a jump in temperature may occur (caused by wire breakage or electrical leakage). The bottom temperature should be reported in conjunction with the bottom layer temperature indicator described in WMO publication No. 306, Manual on Codes, Volume 1.

f. XBT maintenance

The launcher discharge tube should be checked periodically for salt buildup. Any salt should be removed with fresh water and a cloth swab.

The insulation around the canister contacts in the launcher breech should be inspected for contamination before inserting a canister. Any contamination should be removed with a cloth dipped in alcohol.

Installation of a new chart roll, chart alignment, and preventive maintenance only should be performed by the operator. Recorder trouble shooting maintenance should be performed only by an electronic technician. The recorder and test canister should be calibrated every six months, and this calibration should be performed only by a calibration electronics technician.

It is important that the test canister is kept with the XBT system at all times. It should be considered an integral component of the system.

g. Airborne or helicopter XBT system

Probes can be deployed from a helicopter, either hovering or moving at a speed of 40 metres per second, and from a fixed wing aircraft up to a speed of 130 $m.s^{-1}$. Some miniaturization and reduction in weight, particularly in the length of the launcher, are the major differences compared to the shipboard system. The temperature accuracy of the probe is the same as for those used aboard ship : $\pm$ .2°C.

4.4 Deep sea reversing thermometers

The deep sea reversing thermometer is an instrument that provides oceanographers with accurate deep seawater temperatures as well as the depth at which these temperatures are taken. A deep sea reversing thermometer consists of an assembly of two thermometers, a main thermometer and an auxiliary, contained in a glass jacket. The main thermometer consists of a capillary with a special constriction a little above the main mercury reservoir, so that the mercury thread will separate at this construction when the thermometer is turned upside down. The higher the temperature when the thermometer is reversed the longer the mercury thread that is separated. Reversing thermometers are attached to Nansen bottles which require reversing action to collect a seawater sample. This action simultaneously reverses the thermometers. The auxiliary thermometer is a small ordinary mercury thermometer that is used to obtain the temperature of the reversing thermometer at the time the main one is read and in order to correct it. For depth measurement two different reversing thermometers are used; one is enclosed in a glass envelope to protect it against the environmental pressure of the sea. This "protected" thermometer gives the in situ temperature. The other thermometer is not protected against seawater pressure, so this "unprotected" thermometer reads higher than the true water temperature because of the effect of water pressure squeezing the mercury thread up the thermometer stem. The difference between the readings of the protected and unprotected thermometers, with appropriate corrections, will indicate the differential pressure and, therefore, the depth of reversal. This depth is accurate to ± 5 metres or .5 percent of the depth, whichever is greater. Calculation of this depth, the thermometric depth, to this accuracy requires thermometer accuracy of 0.01°C. To insure accuracy, protected thermometers are usually paired. The readings from the two thermometers are compared and a history sheet of all malfunctions is kept. To guard against error in reading, each thermometer should be read once, then re-read by a different person. The expected temperature difference between protected and unprotected thermometers at the desired depth is prepared prior to a cast. Thus malfunctions can be discerned immediately upon retrieval of the thermometers. The thermometric depth is also compared to the length of wire payed out as measured by a metre wheel attached to the cable.

Temperature data collected with reversing thermometers can be processed aboard the vessel or sent to shore facilities for processing.

4.5 Nansen bottle

The Nansen bottle enables measurement of salinity and other chemical properties of seawater at various depths in the ocean by bringing an uncontaminated water sample from a desired depth to the surface and permits the reversal of the attached deep sea reversing thermometers. Several Nansen bottles are simultaneously lowered to various desired depths by means of a winch, cable, A-frame, meter wheel, and associated gear. By the use of slotted cylindrical weights called messengers, the Nansen bottles are tripped and reversed. The reversing action closes plug valves at each end of the bottle and traps a water sample at the desired depths. Since each bottle contains a trapped sample of water, the salinity and other chemical properties can be determined in the laboratory. The depth of reversal is calculated in two steps. The length of wire payed out is measured by a meter wheel and the angle at which the wire enters the sea surface is measured at the time of reversal. This gives a good estimate of the depths reached. The second step is a calculation of depth based on pressure effects on thermometers, called the thermometric depth. Each Nansen bottle is fitted with a frame to hold two to four deep sea reversing thermometers. The reversing action of the bottle reverses the thermometers, which gives the in situ temperature. A combination of protected and unprotected thermometers at one level provides the information necessary for depth calculation.

A Nansen cast is normally performed while the ship is drifting with the platform to windward. An A-frame extends over the platform and supports the meter wheel, a block which measures wire payed out. The wire leads from the winch over the meter wheel, which is suspended from the A-frame, and then into the sea surface. A 50 kilogram block is attached to the end of the wire. The cast requires three men : platform man, winch operator and a bottle passer. The bottle passer removes the Nansen bottles from their rack on the bulkhead and hands them to the platform man. The platform man attaches bottles and messengers to the wire. The winch operator lowers the bottles to predetermined depths. The depths are determined by the characteristics of the water column. The number of bottles used is limited because of weight considerations. After the bottles are tripped, the reverse of the procedure described above is followed. When the Nansen bottles are again in their rack, the samples are drawn. The type of sample bottle used is dependent on the analysis to be made. The time involved in taking observations as described above in water 4000 to 5000 metres deep would be approximately three or four hours.

Although extremely simple, the process of rinsing and filling sample bottles must follow a strict routine. Bottles should not sit empty if at all possible but should contain at least a small amount of seawater during periods of non-use. When drawing samples for salinity analysis :

a. Empty previous contents of bottle;

b. Fill bottle about one-quarter full, taking care to keep fingers clear of the water and bottle top;

c. Replace cap loosely and shake vigorously;

d. Pour away water over the inside of the cap;

e. Repeat b., c., and d.

f. Fill bottle to just above shoulders. DO NOT FILL COMPLETELY.

g. Wipe the screw thread on the <u>outside</u> of the top of the bottle and the <u>inside</u> of the cap with a new tissue (and then throw it away). This action is to prevent the formation of salt crystals in the threads of the bottle and cap which will contaminate the sample when the bottle is opened for analysis. It is essential to use "once only" tissues; a cloth should not be used since it will quickly become contaminated itself if used more than once.

4.6 Salinity-temperature-depth (STD) system

Continuous vertical measurements of temperature and salinity to thousands of metres can be obtained by sensors which are incorporated in a vertical STD system. This electronic sensor system uses an ensemble of a recorder, <u>in situ</u> sensors, and associated equipment for obtaining accurate and continuous profiles of these basic oceanic properties. Since salinity and conductivity are empirically related, some systems on the market are called CTDs, since they record conductivity and not salinity. Other sensors, such as sound velocity, ambient light, and bottom proximity, can be added to the STD system. Most systems in the field are of the STD type and utilize shipboard recording devices instead of <u>in situ</u> recorders;therefore, this discussion will be limited to this basic system configuration.

a. Major system components

The STD system consists of an underwater sensing package weighing about 40 kilograms, called a "fish", and surface terminal equipment. It also includes a winch, conducting cable with end termination, winch slip rings, winch to recorder cable, and recorder. Many shipboard systems require the use of a voltage regulator at the surface terminal equipment between the ship's power source and the STD system electronics. A safety cable should be linked between the sea cable and fish to prevent loss of the fish if the sea cable end termination should fail.

To maintain, operate, and calibrate properly such a system requires trained personnel having access to standard mechanical and electronic test equipment.

b. How an STD works

Solid-state electronics in the fish convert the sensed parameters into a composite FM data signal which is transmitted to the shipboard terminal equipment for processing and recording. The terminal equipment separates individual data signals from the FM composite signal and records the data on chart paper in the plotter and/or on magnetic or paper tape.

Seawater salinity is determined <u>in situ</u> by sensing conductivity, temperature, and pressure. Conductivity is measured by sensing the conductivity of dissolved solids in seawater which provides an inductive loop that couples two transformers in the conductivity head. Seawater conductivity is a complex function of temperature, pressure, and salinity. The STD system automatically compensates for these parameter changes and thus provides an output which is a direct function of salinity.

The temperature transducer is a platinum resistence thermometer which forms one leg of a bridge. Variations in temperature change the resistance of the platinum conductor and, consequently, change the voltage dropped across it. This ultimately generates an output signal for temperature.

The depth system incorporates a pressure transducer containing a strain-gage bridge which is in balance at atmospheric pressure and becomes increasingly umbalanced as pressure increases. Resistance changes in the bridge circuit result in an output signal for depth as a function of pressure.

The electronic circuitry of the fish results in an FM composite signal that permits continuous and simultaneous transmission of all sensor data to the terminal equipment in a single conductor sea cable.

The terminal equipment provides the means to separate and amplify the received signals for recording. To permit maximum realistic data presentation, the recorders have several overlapping ranges for salinity, temperature, and depth. Senso' power from the terminal equipment is supplied to the winch slip rings, which transfer the excitation voltage down the sea cable to the fish. The multiplexed FM data signal is returned by the same path and eventually separated into salinity, temperature, and depth frequency signals.

c. STD system accuracy

The sensor accuracies indicated below are usually valid over normally encountered oceanic conditions, and include nonlinearity, repeatibility, temperature effects, hysteresis, and recorder errors.

Salinity sensor accuracy is generally considered about ± 0.02 parts per thousand. The salinity range in the ocean usually lies between 30 and 40 parts per thousand.

Temperature sensor accuracy is generally considered to be about $\pm 0.02°C$. The temperature range usually runs from $-2°C$ to $+36°C$.

Depth sensor accuracy is about $\pm 0.25°/_{oo}$ of full scale. Depth ranges usually cover 0 to 3000 or 6000 metres.

In addition to sensor accuracy, one must consider other hardware or data gathering techniques that affect overall system accuracy. For the analog recorder, an accuracy of about ± 0.007 parts per thousand in salinity is claimed, while $\pm 0.02°C$ for temperature and $\pm 0.5\%$ of full scale for depth are common.

d. Quality control requirements

A means to verify the validity of the values recorded by the STD system is necessary to ensure data quality. This may be done by comparing STD values with comparable values obtained simultaneously by other means. It is the usual practice to make periodic concurrent Nansen casts or, more commonly, to attach at least two Nansen or similar sampling bottles with deep sea revering thermometers on the STD cable so as to obtain temperature, salinity, and thermometric depth data at the surface and maximum STD depth. Upon comparison of the STD obtained data with the data acquired by other means, corrections can be applied to the STD data or STD system problems can be detected and possibly corrected.

e. Taking an STD cast

The STD system under discussion should not be towed. It utilizes an analog trace as one of the means to record data. Taking an STD cast includes the following procedures :

(1) Pre-cast

(a) The STD recorder operator checks terminal equipment frequencies using test equipment and procedures outlined in STD operating manual.

(b) The Vessel should be hove to with wind on the system's side before the cast is commenced. Controllable overboard discharges should be minimized.

(c) Communication is established between bridge, winch recorder, and deck supervisor. A cast team of five is common and consists of a deck supervisor (safety officer), winch operator, recorder operator and two deck handlers.

(d) When ready, the STD fish is placed in the water at the surface to soak for at least one minute to stabilize system electronics. A quality control bottle with thermometers is often placed just above the fish.

(e) Power is supplied to the fish and all recorders are properly set for recording, i.e., proper ranges selected, pens aligned, cast identification data inserted, etc.

(2) During the cast

(a) When ready, the STD fish can be lowered through the water column. Cast descent rate should be limited to about 20 to 50 metres per minute until through the higher gradient waters. Once into relatively isothermal and isohaline water, the descent rate can be increased to about 80 metres per minute without adversely effecting data quality.

(b) During cast descent, the recorder operator adjusts recorder ranges and annotates the records as necessary.

(c) Prior to reaching the maximum desired depth of the cast, a surface quality control bottle with thermometers is often placed on the STD cable, and then the fish is lowered to the maximum sampling depth with the quality control bottle at the surface.

(d) After maximum cast depth is obtained and necessary quality control data collected, the cast can be retrieved. It is of value to make recordings upon cast retrieval, since these can often be used to verify or interpret questionable data points on the records taken during the fish's descent. Descent rate criteria apply to ascent rates if meaningful data are to be obtained.

(e) The STD fish should be stopped just below the surface upon retrieval so that the data recorders can be properly secured to prevent erratic and partially obliterated records at the surface.

(f) When ready, the STD fish can be brought aboard and stowed. Rinsing with fresh water reduces potential problems associated with salt buildup and corrosion.

(3) Post-cast

(a) All data records should be properly labelled and any supplementary information recorded.

(b) Read temperature to one hundredth of a degree Celsius, salinity to one to hundredth of a part per thousand, and depth to the nearest metre. A set of plastic overlays with the various temperature and salinity scales may be helpful in reading the trace. Flexure points should be determined in such a way that linear interpolations fall within $\pm.03°C$ and $\pm.04°/_{oo}$ of the original record. However, the significant depths in the upper 500 metres shall never be more than 20 in number, even at the cost of loss of detail.

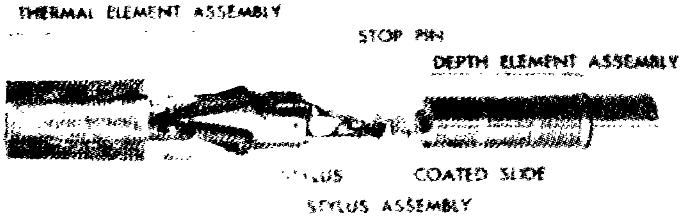
4.7 Thermistor array

A rather sophisticated temperature recorder is the Temperature Recorder or "chain" developed by Richardson. This consists of a string of 30 to 40 thermistor temperature sensitive elements mounted at intervals along a faired cable of 180 to 270 metres length. This "chain" hangs below the ship at it steams along, the weight of the cable itself together with a 1000 kg or more weight at the end helping to keep it close to the vertical even at $3m.s^{-1}$ speed. An instrument on deck measures the temperature at each thermistor in turn, interpolates between their values, and draws a continuous graph of whole number temperature values (isotherms) as a function of depth and time along a continuously moving chart.

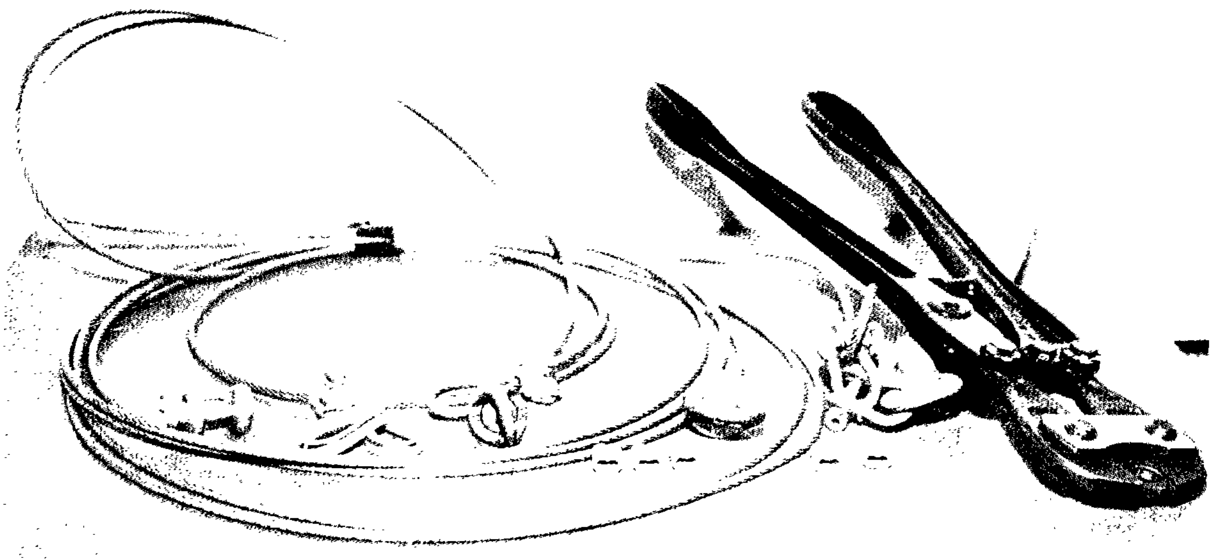
A less elaborate thermistor array can be suspended from an anchored ship or buoys or stationary platforms. The thermistor is a thermally sensitive resistor that exhibits a change in electrical resistance with a change in water temperature. The basic thermistor is a hard ceramic-like electronic semiconductor which has a relatively large negative temperature coefficient of resistance (positive temperature coefficient of resistance devices are available but are rarely used in thermistor arrays). Common problems with a thermistor array are leakage of water into the electrical circuitry either around the thermistor or other electrical wires or connectors, marine growth surrounding the thermistor causing false readings to occur and increasing the drag causing additional strain to be put on to the upper portion of the array and the termination. Termination problems are usually caused by motion of the surface device causing either shock loading or abrasion of the electrical conductors and the termination. Rough handling during immersion or retrieval also accounts for thermistor failures.

4.8 Other temperature sensors

Many other ocean temperature sensing devices may be found on the market to-day. A temperature sensor similar to that found in the STD, accompanied by a depth sensor, can give a vertical distribution of temperature through a conductor cable leading to an on deck recorder for direct readout. Another type sensor records temperature and depth internally on a pressure sensitive strip chart. The accuracy of these usually depends on whether a thermistor or a platinum resistance thermometer is used.

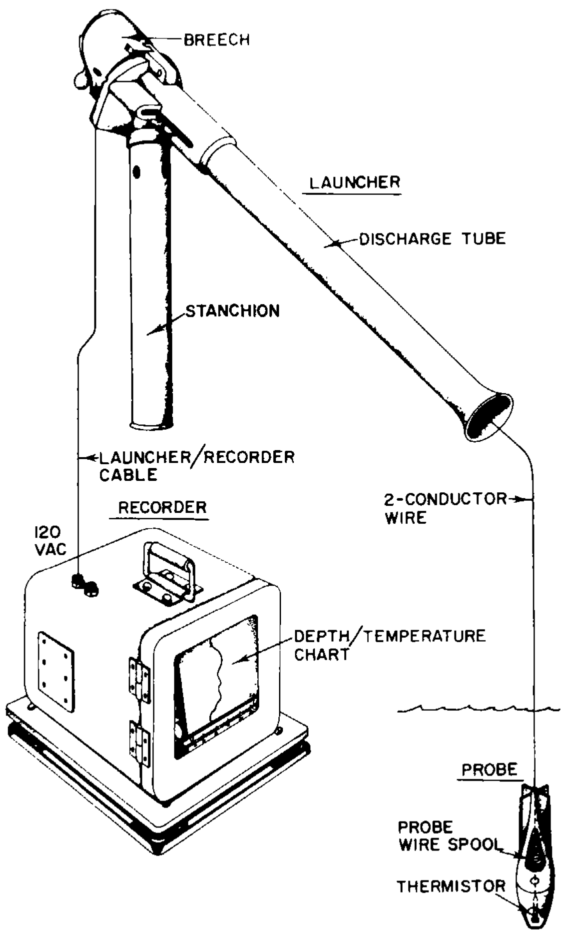


BT thermal element, depth element, and stylus assemblies

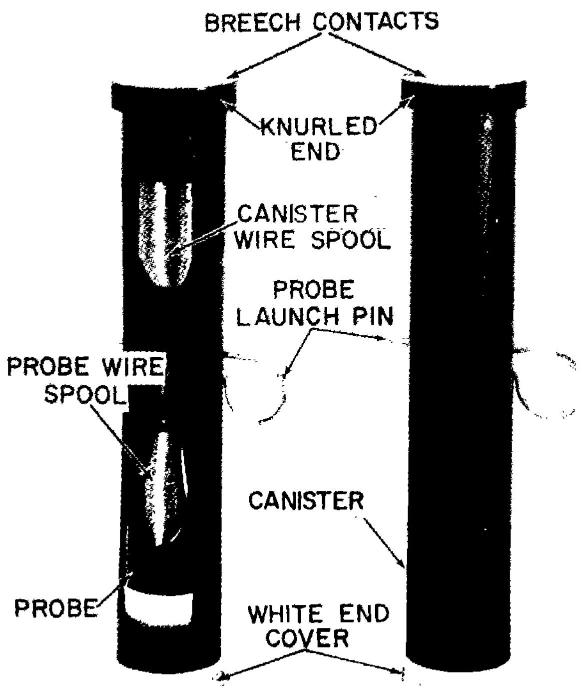


The Nicopress tool and sleeves, wire rope, thimbles, swivels, wire clips and shackles

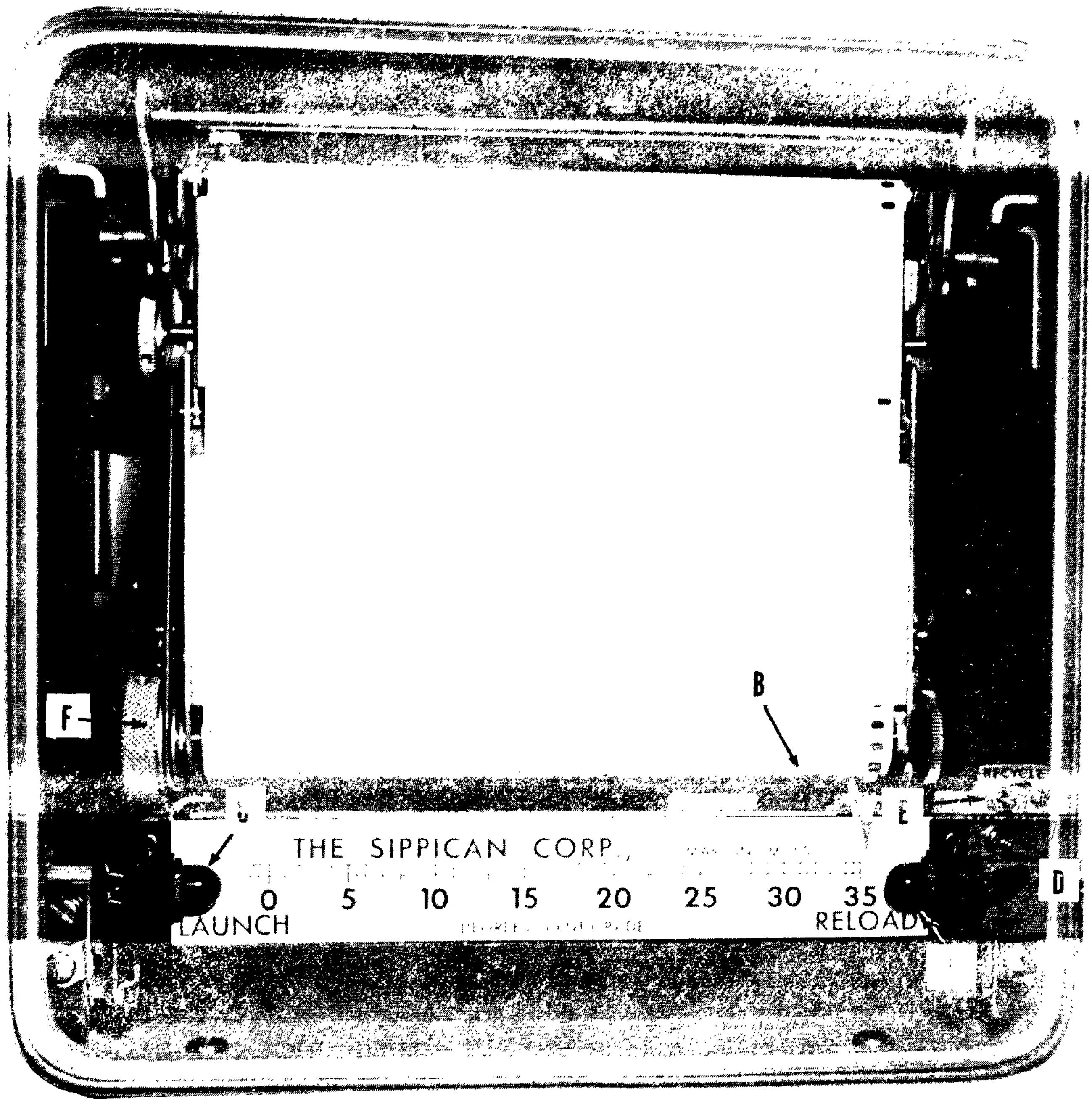
Labelling the BT slide



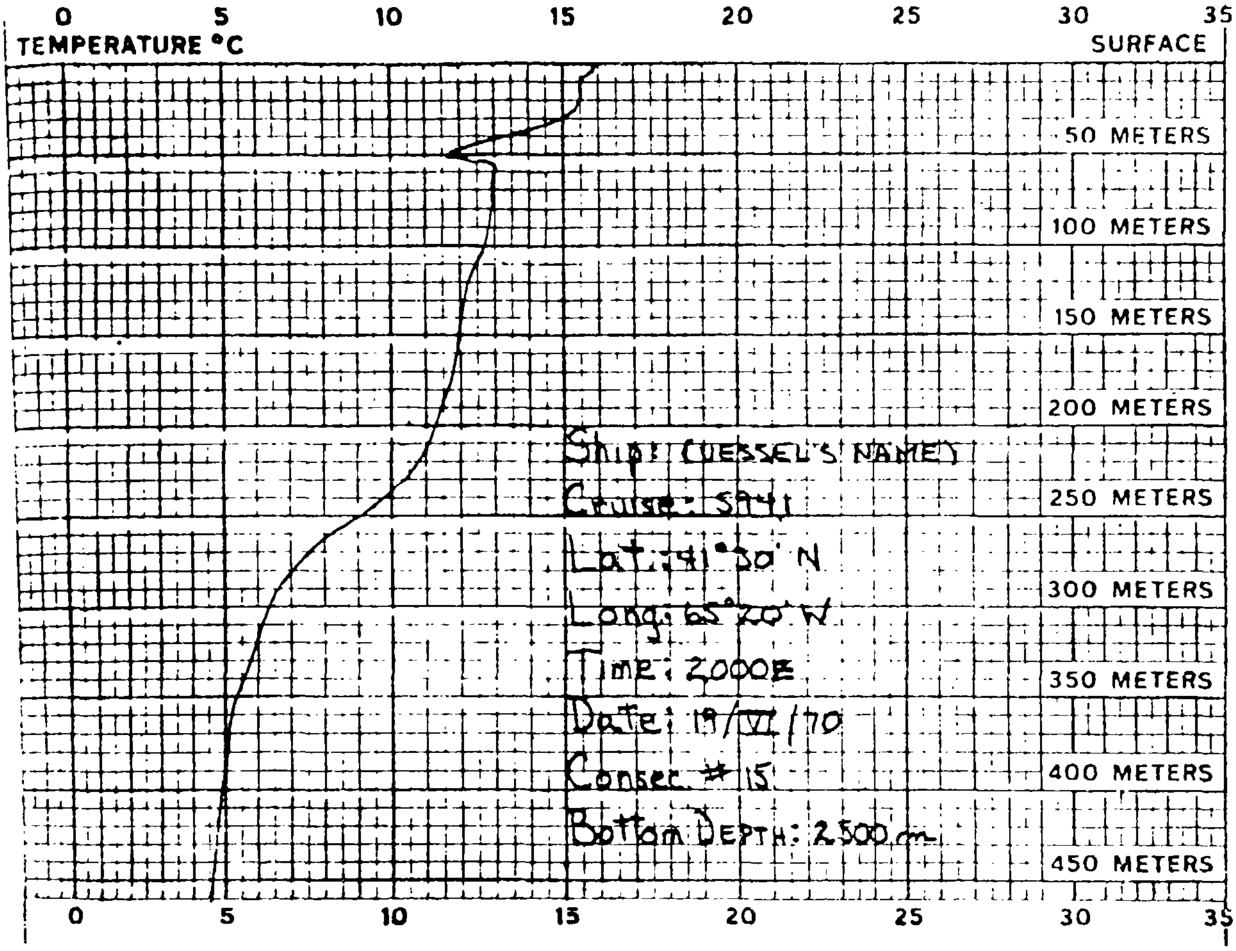
Expendable bathythermograph (XBT) system



Expendable probe and canister (cutaway view at left)



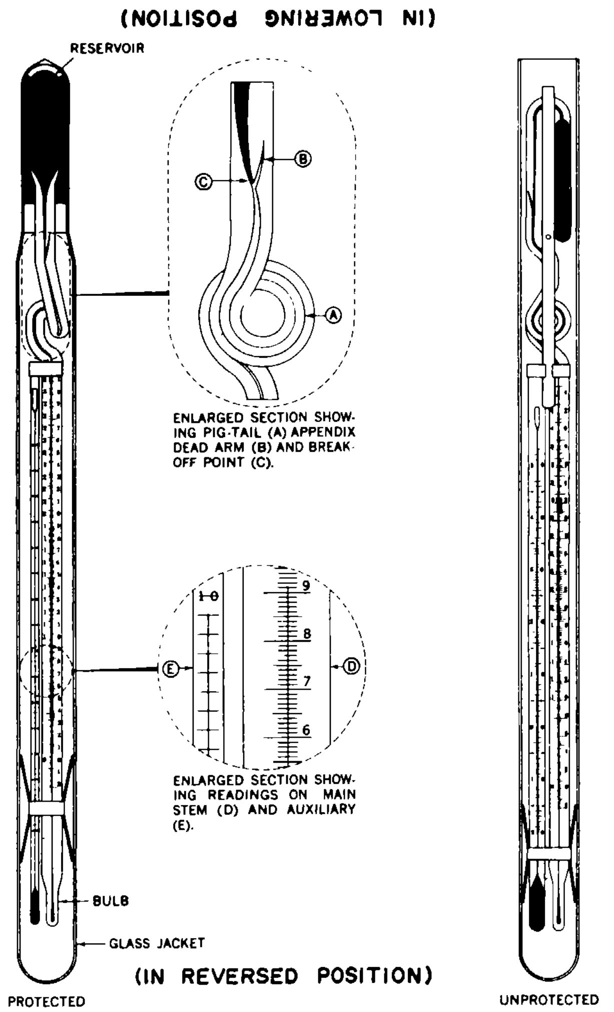
XBT recorder panel



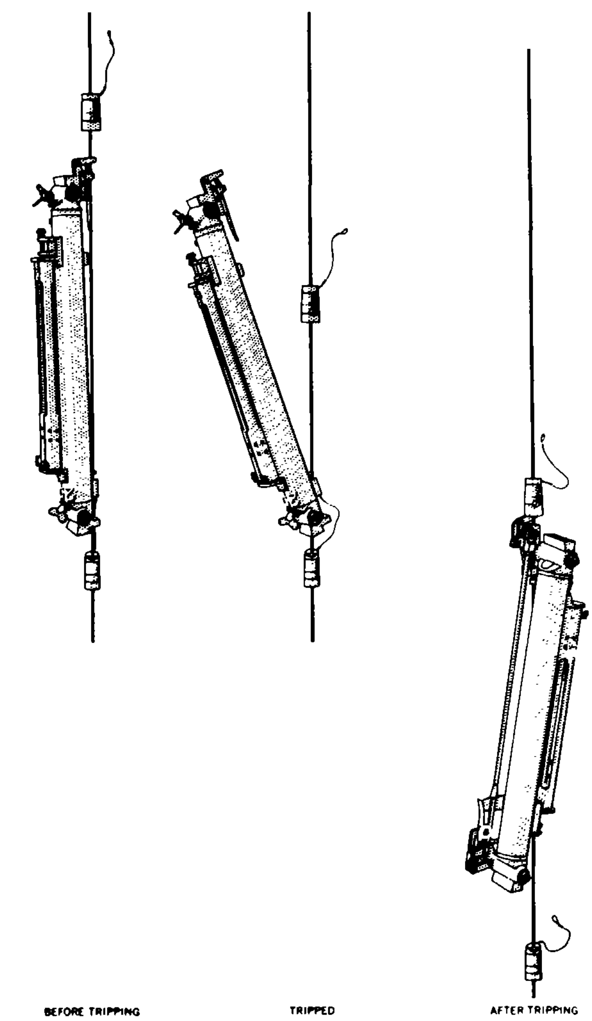
Sample annotated XBT trace

Depth (metres)	Temp (°C)	Depth (metres)	Temp (°C)
0	15.8	150	12.0
8	15.5	210	11.1
20	15.5	240	9.8
30	15.0	280	7.1
51	11.7	360	5.2
59	13.1	460	4.6
78	12.9		
100	12.7		
120	12.2		

Data read from above XBT trace



Protected and unprotected deep sea reversing thermometers



Nansen bottle in three positions - before tripping, during tripping and after tripping

CHAPTER 5 - WIND WAVES AND SWELL

5.1 17.9.1 *Definitions*

Sea	System of waves observed at a point which lies within the wind field producing the waves.
Swell	System of waves observed at a point remote from the wind field which produced the waves, or observed when the wind field which generated the waves no longer exists.
Breaker	The collapse of a whole wave resulting from its running into very shallow water (of the order of twice the wave height).
Surf	The broken water between the shore line and the outermost line of the breakers.
Breaking sea	The partial collapse of the crest of a wave caused by: (*a*) Action of the wind; (*b*) Steepening of waves due to their encountering a contrary current or tidal stream; (*c*) Steepening of waves due to their running into shoal water, not shallow enough to cause a breaker.
Wave length	The horizontal distance between successive crests or troughs. (It is equal to the wave period multiplied by the wave speed.)
Wave height	The vertical distance between trough and crest.
Wave period	The 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.)

For meteorological purposes the average value of each of the last four characteristics is used, as obtained from the larger well-formed waves of the wave system being observed.

5.2 17.9.2 *Methods of observation*

The observations should include measurement or estimation of the following characteristics of the wave motion of the sea surface in respect of each distinguishable system of waves, i.e. sea and swell (principal and secondary):

(*a*) Direction (from which the waves come) on the scale 01–36 as for wind direction;

(*b*) Period in seconds;

(*c*) Height.

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

5.2.1 17.9.2.1 *General*

Wind-generated ocean waves occur in large systems which are defined in connexion with the wind field which produced the waves and also with the relative position of the point of observation. Bearing in mind the distinction between *sea* and *swell* as defined in paragraph 17.9.1, the observer should differentiate between the recognizable wave systems, on the basis of the direction, the appearance and the period of the waves.

The graph in Figure 17.1 is a typical record drawn by a wave recorder. It shows the height of the sea surface above a fixed point against time, i.e. 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 "sea".

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 a "sea" than in a "swell". Furthermore — and this cannot be shown by a wave record — groups consisting of two or more well-formed waves in a "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 rather a 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. 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 "sea" resemble swell waves by their comparatively long crests and large periods. He might be tempted to split the assembly of waves of different heights, periods and directions (together forming the system of a "sea") into two different wave systems and consider the smaller waves as "sea" and the larger waves as "swell", but this is not what should be done.

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

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

(b) *Appearance and period.* When typical swell waves, characterized by their regular appearance and long-crestedness, arrive approximately, i.e. within 20°, from the direction of the wind, they should be considered as a separate wave system if their period is at least four seconds greater than the period of the larger waves of the existing "sea".

For measuring the mean period and height of a wave system, *characteristic* waves should be considered; these are the higher waves in the centre of each group of well-formed waves (Figure 17.1). The flat and badly formed waves (A) in the area between the groups must be entirely omitted from the record.

What is required is the mean period and the mean height of about 15–20 well-formed waves from the centres of the groups; of course these waves cannot be consecutive. The smaller wave-like disturbances (B) which can clearly be

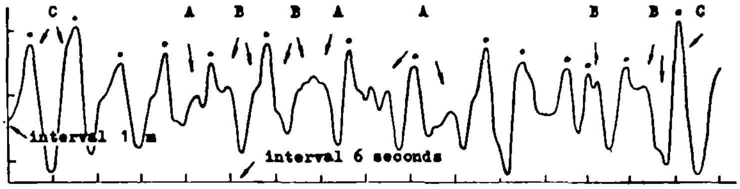


FIGURE 17.1

seen to be forming under the action of the wind on top of the larger waves are also to be omitted from the record.

Occasionally waves may be encountered which literally stand out above the environmental waves (C). Such waves may occur singly or in a group of two or three together. 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 15–20 waves he 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 an average the actual height of one out of about ten waves will exceed the height to be reported.)

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

The above considerations have to be taken into account in all methods of observation described below.

5.2.2 17.9.2.2 *Observations from ordinary merchant ships*

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

(*b*) *Period:* This is the only element which can actually be measured on board moving merchant ships. If a stop-watch is available, only one observer is necessary; otherwise two observers and a watch with a second hand are required. The observer notes some small object floating on the water at some distance from the ship; if nothing better is available, a distinctive patch of foam can usually be found which remains identifiable for the few minutes required for the observations. He starts his watch when the object appears at the crest of the wave. As the crest passes on, the object disappears into the trough, then reappears on the next crest, etc. 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 by the object becoming too distant to identify, due to 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 he reaches 15 or 20 at least.

With observations of a period less than five seconds and small wind velocity, the above observation may not always be easily made, but one has to take into account that these waves are less interesting than those with longer periods.

(*c*) *Height:* With some experience fairly reliable estimates can be made.

For estimating the height, the observer should take up a position as low down in the ship as possible, preferably amidships where the pitching is least, and on that 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. The above relates to the waves the lengths of which are relatively small with regard to the length of the ship.

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 vertical, the oncoming waves appear just level with the horizon (see Figure 17.2). The wave height is then equal to the height of the eye of the observer above the level of the water beneath him (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 vertical*, otherwise the estimate of height will be too large (b).

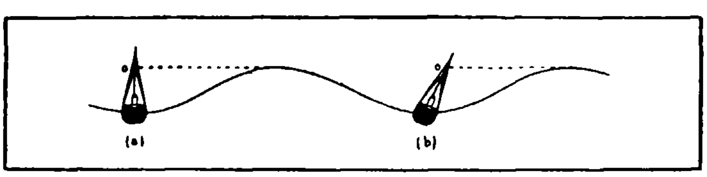


FIGURE 17.2

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 the water as possible, but even then the observation can only be rough.

5.2.3 17.9.2.3 *Observations from ocean station vessels and special ships in a position to make accurate observations*

When instrumental observations are not possible, the above procedure should be followed and in addition the ship should heave to with the waves coming from directly ahead. For measuring *period*, an object can be thrown over the side. For measuring *height*, marks should be painted amidships on the ship's side (half-metre apart) and the height of the waves from trough to crest, as indicated in paragraph 17.9.2.2 (*c*), measured with their aid.

The methods described by Froude could also be used to determine *height* and *period* of waves.

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

Velocity. By noting the time of the passage of a wave from the stern to the buoy the velocity can be obtained, allowance being made for the ship's speed.

However, it is hoped that ocean station vessels will be provided with suitable recording instruments.

5.2.4 17.9.2.4 *Measurement of waves from coastal stations*

At coastal stations it is important to observe the waves at a spot where they are not deformed either by the water being very shallow, i.e. a depth of only a low multiple of the wave height, or by the phenomena of reflection. This means that the spot chosen for observations should be well outside the breaker zone, not on a shoal or in an area where there is a steep bottom gradient, nor in the immediate vicinity of a jetty or steep rocks which could reflect waves back on to the observation point. The observation point should be fully exposed to seaward, i.e. not sheltered by headlands or shoals.

For accurate observations it is desirable to have a fixed vertical graduated line against which the movement of the water surface can be measured. If a convenient pier exists, a pile at its seaward end, suitably painted with alternate black and white bands, will be found most convenient. Alternatively, a spar may be mounted vertically and well stayed (at low water). This can be used for observations when the tide is up sufficiently to bring it beyond the breaker zone. In either case the movement of water against the graduated pole must be observed with glasses since the restrictions of the preceding paragraph imply that the pole is several hundred metres from the beach.

If the arrangement of the preceding paragraph is impossible, then the measurements may be taken on a floating buoy. The up-and-down movement of the buoy is observed through a theodolite or rigidly mounted binoculars fitted with a graticule. Knowing the angle subtended by the graticule graduations and the distance of the buoy from the theodolite, the vertical height that the buoy is being carried up and down by the waves can readily be deduced; e.g., if the apparent movement of the buoy from trough to crest of the wave is "n" graduations, each representing "*r*" minutes of arc, while the horizontal range of the object from the theodolite is R, then the height of the wave is $Rnr/3438$.

When using this method, the buoy must project high enough above the water for its top not to become hidden behind the crest of the preceding wave when it falls into the trough; or alternatively the observer must be at a considerable height above the water. In the latter case the wave height from the above formula should be corrected by multiplication by the factor $\sec^2 D$, where D is the angle of depression of the buoy from the theodolite.

If the observations are to be of use for wave research it is important that:

(*a*) They should always be taken at the same place, so that correction for refraction, etc., can later be applied;

(*b*) The exact mean depth of water at the place and time of observation should be known, so that corrections for change of height with depth can be applied.

The waves should be chosen for observation in the same way as has already been suggested for ship's observations, i.e. only the well-developed waves in the centres of the groups should be observed. The flat and badly-formed waves between the groups should be entirely omitted, from both period and height observations.

The mean period and height of at least 20 waves, chosen as above and hence not consecutive, should be recorded.

5.3 17.9.3 *Specifications for sea and swell waves*

The following specifications are recommended for use other than inclusion in coded messages, such as supplying weather information and forecasts for shipping, publications, pilots, etc.:

(*a*) For length of *swell* waves:

Short	0 – 100 metres
Average	100 – 200 metres
Long	over 200 metres

(*b*) For height of *swell* waves:

Low	0 – 2 metres
Moderate	2 – 4 metres
Heavy	over 4 metres

(*c*) For height of *sea* waves:

Calm (glassy)	0
Calm (rippled)	0 – 0.1 metre
Smooth (wavelets)	0.1 – 0.5 metre
Slight	0.5 – 1.25 metre
Moderate	1.25 – 2.5 metres
Rough	2.5 – 4 metres
Very rough	4 – 6 metres
High	6 – 9 metres
Very high	9 – 14 metres
Phenomenal	over 14 metres

In all cases the exact bounding length or height is included in the lower category, e.g. a sea of four metres 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.

5.4 Wave measurement instrumentation

Wave instrumentation can be grouped in several general categories depending upon the principle used to define wave height; the advantages and disadvantages of each category are briefly mentioned.

Category 1. Pressure. These types of instruments are composed of either a Bourdon tube, strain gauge, or bellows to measure the pressure exerted by the water column above the instrument. These are good for measurement of waves in areas with much traffic where no surface projection is allowed. Recording depends upon depth and wave period. There is a loss of sensitivity as depth increases; it is very difficult to analyse the records made by such instruments.

Category 2. Barrier. These instruments are of the acoustic laser, or infra-red family and depend upon the sea-air interface barrier for determination of the wave height. The acoustic instrumentation is anchored below the surface of the water whereas the laser instrumentation is normally placed above the water surface. These instruments are expensive and difficult to interpret. In the case of the inverted echo sounder, the beam spread creases with depth and this may cause problems.

Category 3. Conductivity. This is probably the largest category of wave measuring instrumentation and is composed of wave staff instrumentation that depends upon the conductivity of seawater to short out a portion of the wave staff. The transducer portion of the wave measuring instrumentation should be firmly attached to a stationary member of a platform. These are required to be maintained in a stable position relative to the mean water level and hence are expensive to set up. However, they are usually very accurate and reliable and ideal for stable platforms such as drilling rigs, etc.

Category 4. Accelerometers. Accelerometers are used to measure accelerations along one axis in many types of vehicle, even in inertial guidance systems for spacecraft. Typically, a linear accelerometer is a mass which is free to move in one direction only and against a restraining spring. If the free period of oscillation of the accelerometer is less than that of the acceleration, the deflection of the spring is proportional to acceleration. It is common practice to employ viscous damping with liquid, air, or electromagnetic devices.

The acceleration can be converted to velocity and displacement by double integration, making reasonable assumptions for the value of the time constant. When used in the vertical axis on a floating buoy, this displacement is a measure of wave height.

An accelerometer buoy is small and easy to handle because the instrument package is small. It can be either moored, equipped with a recorder or transmitter, or connected to a recorder and display unit on a ship by a slack cable, free from the motion of the ship as both drift. It has proved to be a reliable and accurate instrument. Accelerometers usually require a data transmission link so that communication noise is a problem. Mooring problems are experienced in severe or deep locations.

CHAPTER 6 - CURRENT - AT SURFACE AND DEPTH

6.1 General

Probably more types of instruments are used for measuring currents than for any other single oceanographic measurement. Such devices range from the simple drift bottle to sophisticated electronic instruments.

Current-measuring instruments may be divided into four broad and general categories : free-floating, fixed, tethered, and shipboard. Those in the first category include dye marks and floats or drogues that can be observed from ship, shore, or aircraft. Those in the second category include instruments that are attached to piers, towers, or beacons, or placed on the bottom of rivers, bays, estuaries, and other nearshore areas. Those of the third category include buoys in either deep or shallow water, and those of the fourth category include instruments that can be operated when the ship is underway or anchored.

6.2 Free-floating instruments and methods

6.2.1 Dye marks

A dye, such as Rhodamine B, can be used to determine current patterns in coastal and oceanic waters. This technique involves releasing quantities of the dye at a given point and checking the dispersion of the dye by means of visual observation, color photography, or fluorometric measurement. In some applications, divers carry the containers of dye to a predetermined depth where the dye is released, while in others, the dye may be dumped over the side of a vessel or from an aircraft.

6.2.2 Parachute drogues

The parachute drogue method of measuring current speed and direction has become increasingly important during recent years.

In making these observations, an improvised array consisting of a parachute connected by a length of wire rope to an illuminated buoy equipped radar reflector, is launched from a ship and tracked. Since the parachute sinks to a predetermined depth, opens, and moves with the prevailing current at that depth, tracking the surface buoy and recording time and position results in a record of current speed and direction. This method is very satisfactory for measuring surface and shallow water current velocity, but, because of drag force and depth uncertainty, drogues are not satisfactory for deeper observations. The technique of launching a series of drogues with parachutes at various depths is especially useful where counter currents exist, or where topography may have an influence on currents. The path followed by the drogue will be that of the general water mass, and internal waves or minor current fluctuations generally will not affect the drogue; however, by recording positions at more frequent intervals, rotating tidal currents and changing current patterns can be detected.

The parachutes are usually obtained from surplus stock and the aluminium TV antenna poles, styrofoam block, radar reflector and light, chains,connectors, cables and weights are all relatively inexpensive. Concrete blocks often are used for weights.

6.2.2.1 Tracking the drogue

The most important phase of drogue current measurement operations is tracking the drogue. A position should be taken at the time of launching, and at hourly intervals as long as the drogue is afloat. The best positioning technique is to have the ship come alongside each buoy and take a position; however, an alternative technique is to take ranges and bearings to the buoys. Accurate records of time and position are extremely important. Often, a marked change in drift or a different attitude of the float indicates that a parachute has been lost or has either opened or closed.

6.2.3 Neutrally buoyant floats

A device developed by J.C. Swallow has provided measurements of current velocities at great depths. The "Swallow float" consists of two sealed aluminium tubes (one with weights, batteries and a pulse-generating circuit inside) and a sound-generating device that hangs on the outside of the two tubes. This sound-generating device sends out a steady series of pulses.

With the proper number of small weights placed inside the second tube, the float can be designed to sink to any selected depth below the surface and stay at that depth. The two tubes are each 3 metres long, and, if designed to float at a 1000-metre depth, for example, they must have 38 grams of negative buoyancy at the surface. At the surface, the float sinks since it weighs more than the seawater it displaces. The entire float system can be thought of as having an effective density, as if it were a homogeneous body instead of metal cylinders with air, batteries, and electronic instruments inside. This density is simply the total mass of the device divided by the total volume it displaces. For the same total mass, the density of the float can be increased if the cylinders of the float are compressed so that less volume is occupied. As the float sinks its "density" increases because the increasing pressure of the seawater compresses the aluminium cylinders, but the density does not increase with depth as rapidly as the density of seawater. At the desired depth, the density of the float is equal to the density of the seawater, and the float becomes neutrally buoyant. If displaced to a greater depth, it becomes less dense than the surrounding seawater and rises; if displaced to a lesser depth, it becomes denser than the surrounding seawater and sinks.

As stated above, the Swallow float sends out sound pulses, or pings, at fixed intervals. A ship on the surface with precision navigation gear, such as one of the improved varieties of loran, tracks the float for as many days as possible by listening for the pings. Direction-finding techniques are used to find the azimuth of the float with reference to the ship. If a float has been set to remain at a depth of, say, 4000 metres, this movement then describes the motions of the water at that depth. A limitation with this instrument is that one ship can follow only a very small number of floats at one time.

6.2.4 Aircraft-launched probes

An inexpensive, expendable probe is launched from an aircraft and, on contacting the sea surface, a dye package separates and floats on the surface. The remainder of the probe (presently limited to about 1500 metres) is carried to the bottom by its weight and from its fixed location on the bottom releases two floats at separate, predetermined times. The floats return to the surface under their own buoyancy. At the surface the three parts (surface marker and two floats) emit dye which can be photographed or otherwise relatively positioned.

Drops are usually made through a tube installed in an aircraft at an angle of about 15° below the horizontal. Holes are drilled in the protecting tube of the probe to facilitate rapid filling when the instrument strikes the water.

Within a few seconds after contact, the surface dye package, which is held to the instrument with water-soluble plastic tape, detaches itself and the instrument fills and sinks (approximately 4 metres/sec). The surface dye package is visible after about 3 minutes.

The timing mechanism, similar to a simple kitchen timer, releases two floats, at separate times, which return to the surface at identical rates (approximately 2.5 metres/sec); each float releases dye. When all the parts have returned to the surface, a photographic run is made using high-speed color film. The heading and altitude of the aircraft are logged when the photograph is taken. Data reduction consists of measuring the coordinates of the dye splotches on the film, rotating these to x and y, establishing the scale from the aircraft altitude and camera focal length, and solving several equations for the current speed, direction and transport.

6.3 Fixed, tethered, and shipboard instruments and methods

6.3.1 Classes of transducers and other considerations

Several general classes of transducers are used to register water flow velocity. They are : resistive, propeller (impeller), rotor, acoustic, and electromagnetic.

a. Type 1 - (resistive) meters expose a fixed surface on which drag forces produce a displacement force.

b. Type 2 - (propeller/impeller) meters utilize a multi-bladed arrangement about the axis of revolution so that the flow imparts torque to the blades.

c. Type 3 - (rotor) meters cause a volume of water to be trapped, extracting maximum kinetic energy from the current stream so as to impart a high rotational velocity.

d. Type 4 - (acoustic) meters sense the differential velocity of sound in opposing directions or measure the velocity of drifting anomalies, such as particle matter and density fronts by the Doppler effect.

e. Type 5 - (electromagnetic) meters sense water flow with a transducer that has no moving parts. A magnetic field is generated by an electromagnet within the transducer. The flowing water acts as a conductor that traverses the magnetic field flux, thus producing an electromotive force in the water which is proportional to flow speed (Faraday's principle). This voltage is detected by the use of two orthogonally positioned pairs of electrodes mounted on the surface of the transducer.

The majority of current meters usually has some arrangements for determining direction of flow either through orientation of the sensor itself or through some vane arrangement. It should be noted that water flow direction is the opposite of the meteorological term for air flow direction. That is, a water current flowing towards the north is a northern current, whereas air coming from the north is a northern air flow.

Most instruments that are self-recording use an "O" ring for keeping them watertight and a battery for a power source. Failures in either of these two items have probably accounted for more false data than any other combination of component failures in self-recording current meters. Batteries should always be checked under load to ensure sufficient power to operate the instrument for the duration of the observation period. If there is any doubt, new batteries should be used. The "O" rings should be inspected each time the instrument's pressure case is opened. The "O" ring should be replaced if there is any deviation from nonuniformity such as a cut or a flattened place. The current meter should be tested before being taken to sea, or if the facilities on board the ship are suitable, the current meters can be checked on board. For Type 2 (propeller/impeller) meters all that is required in a fan to activate the impeller or propeller mechanism. The test data can be analysed to determine the repeatability and serviceability of the current meters. When mooring the current meters, all obstacles restricting the flow to the current meters should be avoided. This includes wires and cables in the near proximity to the current meters since these wires and cables can cause turbulence.

6.3.2 Methods of data recording

Several methods are used to record data collected by a current meter:

a. mechanical dials

b. mechanical compartments

c. photography, on 16 mm film for example

d. magnetic tape

e. strip chart

f. conductor cable leading to a deck readout unit

For most of the above methods, processing of data to obtain current speed and direction is required, either manually or by computer. This might not be accomplished for several months after collection if, for example, a current meter had been moored unattended for a considerable length of time.

6.3.3 Types of current meters

A few representative current meters are described below.

6.3.3.1 Propeller (impeller) meters

6.3.3.1.1 Ekman current meter

The Ekman current meter was developed by Dr. V. Walfred Ekman, whose original design, although modified, remains basically unchanged. The meter is designed to give current speed and direction at any depth. (Use of a magnetic compass at the surface may give rise to large errors). The speed-measuring mechanism consists of an impeller, or screw, and a shaft connected to a set of dials which indicate impeller revolutions. The direction device consists of a magnetic compass and a compass-ball receptacle. The receptacle is divided into 36 chambers, each representing 10° of azimuth. As the impeller rotates, bronze balls fall, one at a time, from their reservoir onto the top of the compass needle and, depending on the heading of the meter, are guided to one of the 10° direction chambers. This gives the direction toward which the current is flowing.

The current meter can be lowered by either the oceanographic or bathythermograph winch, using several sizes of wire. The impeller is locked while lowering and hoisting. One messenger is sent down the wire to unlock the impeller and set the meter in operation. A second messenger is sent down to lock the impeller before hoisting. The platform from which the Ekman current meter is suspended should be anchored to obtain valid measurements.

6.3.3.1.2 Plessey current meter

The Plessey Model MO.21 Current Meter is a self-contained instrument package designed to measure the speed and direction of waterflow in oceans, lakes and rivers. It also includes a suspension frame and swivel assembly for mooring the meter at a maximum depth of 200 m. The autonomy of the meter may be up to 80 days depending upon the number of physical parameters to be measured and the frequency of the sampling rate. The standard meter is designed to measure current speed and direction, but sensors for other measurements (temperature, pressure) may be added.

As normally supplied, the meter is arranged to make a series of four measurements every 10 minutes. The measurements, in a pure binary code of long and short pulses, are simultaneously recorded on standard size magnetic tape and transmitted by an acoustic transducer. Transmissions from this transducer may be monitored by a tuned hydrophone as a check on correct functioning of the meter after installation, or used as a means of locating the meter should the moorings have broken.

The instrument is switched on or off by a removable, external magnet that operates an internal reed switch. An external output socket is also provided for direct connection of a data recording device. Operating power is supplied by six 1.5 volt dry cells with non-magnetic cases or by a Kalium battery pack.

6.3.3.2 Rotor meters

6.3.3.2.1 Aanderaa current meter

The Aanderaa Model 4 Current Meter is a self-contained instrument for recording speed and direction of ocean currents, water temperature and conductivity, and instrument depth. It is based upon a rotor type current velocity sensor, a magnetic compass for direction determination and a thermistor for temperature sensing. An electro-mechanical encoder samples and converts the measurements to binary digital signals which are then recorded on standard size magnetic tape. The binary signals are also transmitted to the surface by means of an acoustic transducer, thus permitting <u>in situ</u> monitoring. An internal quartz crystal clock actuates the instrument at regular intervals. Power is provided by batteries capable of up to 12 months operation.

The instrument consists of two main parts; the recording unit and the vane assembly. The latter has a spindle which can be shackled into the mooring line of a surface or sub-surface buoy. The motion of the velocity sensing rotor is transmitted through the case of the recording unit via a magnetic coupling. The magnetic compass is housed inside the recording unit. The velocity measurement is in integrated form, while the direction measurement is momentary.

6.3.3.2.2 Geodyne (EG&G) current meter

The Geodyne Model 102 current meter records data on 30 metre rolls of standard 16 mm photographic film in digital format. The meter consists of a Savonius rotor for the sensing of current speed, a vane for sensing of direction, a pressure case with end caps and tie rods to hold them secure, an instrumentation system inside the pressure case, and bales at either end for attachment to cables. The major parts of the instrumentation package include a camera and motorized drive, a timer, an electric control unit, a battery, a magnetic compass against which vane readings are referenced in order to determine vane direction and the apparatus for converting rotor motion and vane position to light pulses. The film is advanced through the camera by a stepping motor; all data are read out during a one minute sampling interval and recorded on this small increment of film.

Tilting of the meter produces a reduction in the accuracy of the current meter speed measurements; thus, the instrument is sometimes fitted with a tilt sensor that measures in 5° increments.

The operating period depends primarily on the sampling rate being used. With the lowest sample rate available of 1 per hour, battery life permits recording 10,000 reading sets in up to 14 months. With the timer set for continuous operation, the drive motor advances 30 metres of film in 166 hours (almost 7 days).

6.3.3.3 Acoustic meters

6.3.3.3.1 Doppler current meter

Many measurements of currents at a fixed point depend on rotors or propellers. The Doppler current meter depends, in contrast, on the presence of small scattering objects in the water. A high-frequency sound transmitter sends a narrow pulsed beam of sound that is viewed by a receiver that sees a small volume of the space through which the sound travels. Objects in the path of the sound beam reflect this sound. If these objects are moving, they will more with the velocity of the fluid in which they are found, and the frequency of the reflected sound is changed according to Doppler's principle. Proper detection of the Doppler shift, then, permits the study of rapid changes in velocity as measured with respect to a very small volume.

6.3.3.4 Electromagnetic meters

6.3.3.4.1 Comex current meter

The Comex MK III electromagnetic current meter consists of an underwater transducer, a six-conductor shielded cable connecting the transducer to a junction box, and a deck unit containing the signal conditioning electronics. Power (12- to 16 VDC/65 ma) is supplied to the deck unit which in turn provides a 30 Hz A.C. sine wave signal to the coil within the transducer. The voltages detected by the electrode pairs, corresponding to orthogonal components of current speed, are amplified and conditioned within the deck electronics to yield a full-scale output of $\pm$ 2 volts with an internal impedance of 2000 ohms. The deck electronics feature a test switch to determine proper operation of the electronics on each channel, X and Y zero adjustments, and X and Y gain adjustments. The current vector is determined by the relation $V = (X^2+Y^2)^{1/2}$ for magnitude and $Q = \tan^{-1}\frac{X}{Y}$ for direction relative to the transducer.

6.3.4 Current meter implantment

Current meters can be used in both deep and shallow water. Some meters are moored on bottom-mounted tripods in shallow water, which permits divers to inspect them from time to time to insure that the rotor and vane are functioning, to remove any organisms that may be fouling the meter, and to listen with a stethoscope to insure that the internal mechanism is operating. In deeper waters, the most satisfactory method of measuring currents at multiple depths with the meters is the mooring array. Nylon lines or their equivalent are shackled to the meters, and anchor-first and free-fall techniques both have been used successfully in planting current meter arrays.

6.3.5 The Geomagnetic Electrokinetograph (GEK)

The GEK is a shipboard current measuring device designed to record the electrical potential developed by the movement of an electrical cable and an electrolyte (seawater) through the earth's magnetic field.

The GEK measures the net current (i.e., the surface current minus the average currents to the bottom).

The essential physical equipment constituting the instrument is :

1. A matched pair of electrodes mounted 100 metres apart on a two-conductor cable long enough (ordinarily two or three times the length of the ship) so stream them astern, away from the magnetic and electrochemical influences of the ship.

2. A recording potentiometer assembly to which the cable is connected.

3. A gyrocompass repeater, mounted above or close to the recorder assembly.

With the above equipment, observations of the potential difference developed in the cable are made when the ship is underway. These potential differences result from the athwart-ship motion both of the cable and of the water through the earth's magnetic field. They are rigidly related to the set and drift of the ship and thus of the trailing cable. The potential difference changes sign when currents set the ship to port or starboard. The magnitude of the potential difference depends on the rate of drift normal to the course, on the length of cable between electrodes, on the local strength of the vertical component of the earth's magnetic field, and on the vertical distribution of water velocities at the location. By making measurements of the potential differences on two courses nearly at right angles, the drift or component velocities in these two directions are determined. The vector sum or resultant of these velocities is the net current vector for that locality.

NOTE : Near the magnetic equator where the vertical component of the earth's magnetic field is very small, small vertical water motions may interact with the horizontal component of the earth's magnetic field to produce large fictitious GEK signals. If measurement errors from this source are to be kept below 10 percent, it is advisable not to rely on GEK measurements made within approximately 200 miles of the magnetic equator.

The primary function of the cable is to bring aboard a signal from far enough astern to be unaffected by the ship's magnetic field. The clearance between the ship and towpoint should be sufficient to allow the cable to pass clear of the stern even during rapid turns. An outhaul to the end of the boom permits convenient handling in streaming and retrieving the cable when underway. In streaming the cable, it is necessary to avoid kinks and to keep the cable clear of the screw. The cable may be towed in the ship's wake without adverse effect on the data because the turbulence in the wake usually is too small and too rapid to be resolved. Nevertheless, towing from a port or starboard boom is the preferred practice since it causes less damage to the cable.

The electrodes have been specially lagged in order to withstand repeated changes of salinity and temperature. Allow at least 30 minutes wetting time on deck before the first towing of the electrodes. The electrodes then will require only about 5 to 10 minutes towing before they respond. It is not necessary to rewet the electrodes before additional towing even though they may have been on deck several hours.

NOTE: Care must be exercised not to inadvertently apply an electric potential to the GEK-towed electrodes, either from an external source such as an ohmmeter or from galvanic effects, since the electrodes may become polarized and exhibit a permanent bias potential beyond the range which the equipment can accommodate. For this reason, the following precautions must be observed : Do not ground the electrodes or the towing cables at any point; do not allow wet electrodes to come into contact with a metal surface, such as the ship's deck, because of galvanic potentials that may be developed; when electrodes are being soaked in salt water on deck prior to or between launchings, be sure that the contained holding the salt water is of non-metallic material (e.g. a plastic or wooden bucket).

The course that the ship is required to steer for a GEK observation is determined by the following requisites : (a) That potentials must be measured on at least two headings at right angles if possible and (b) that because of electrode polarization, the electrodes must be reversed end for end for each current fix to determine the zero point. This zero point is the average of the two voltages obtained by making a 180° course change. A current fix is accomplished by executing the following steaming pattern :

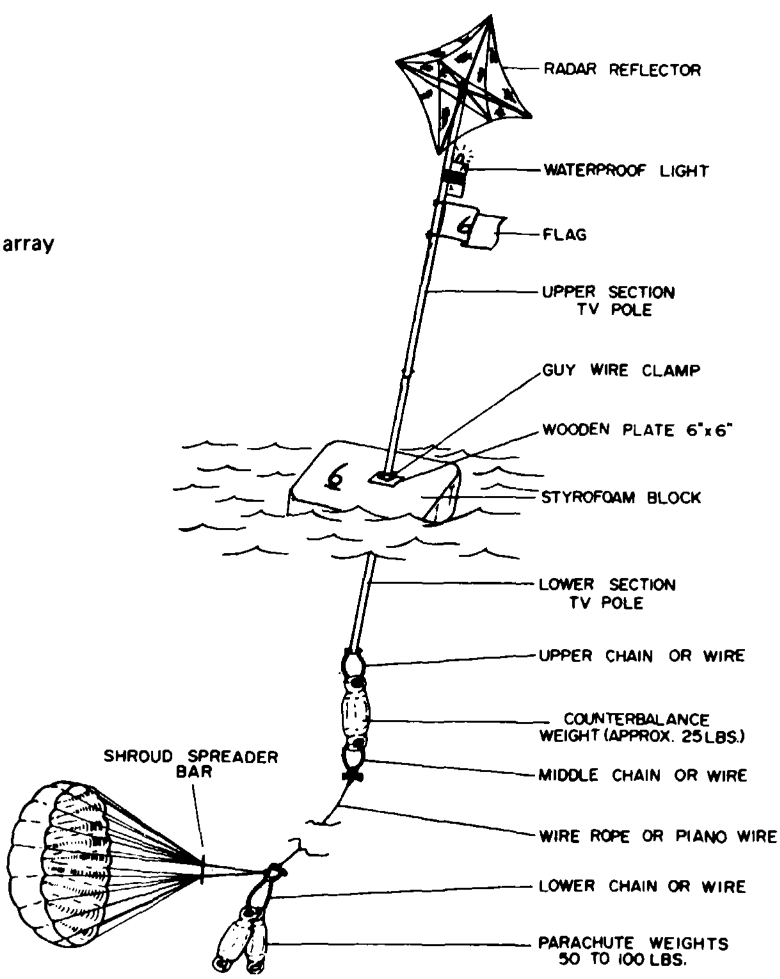
Step 1. After the electrodes have become thoroughly soaked and the pen motion has steadied, remain on base course for 4 minutes.

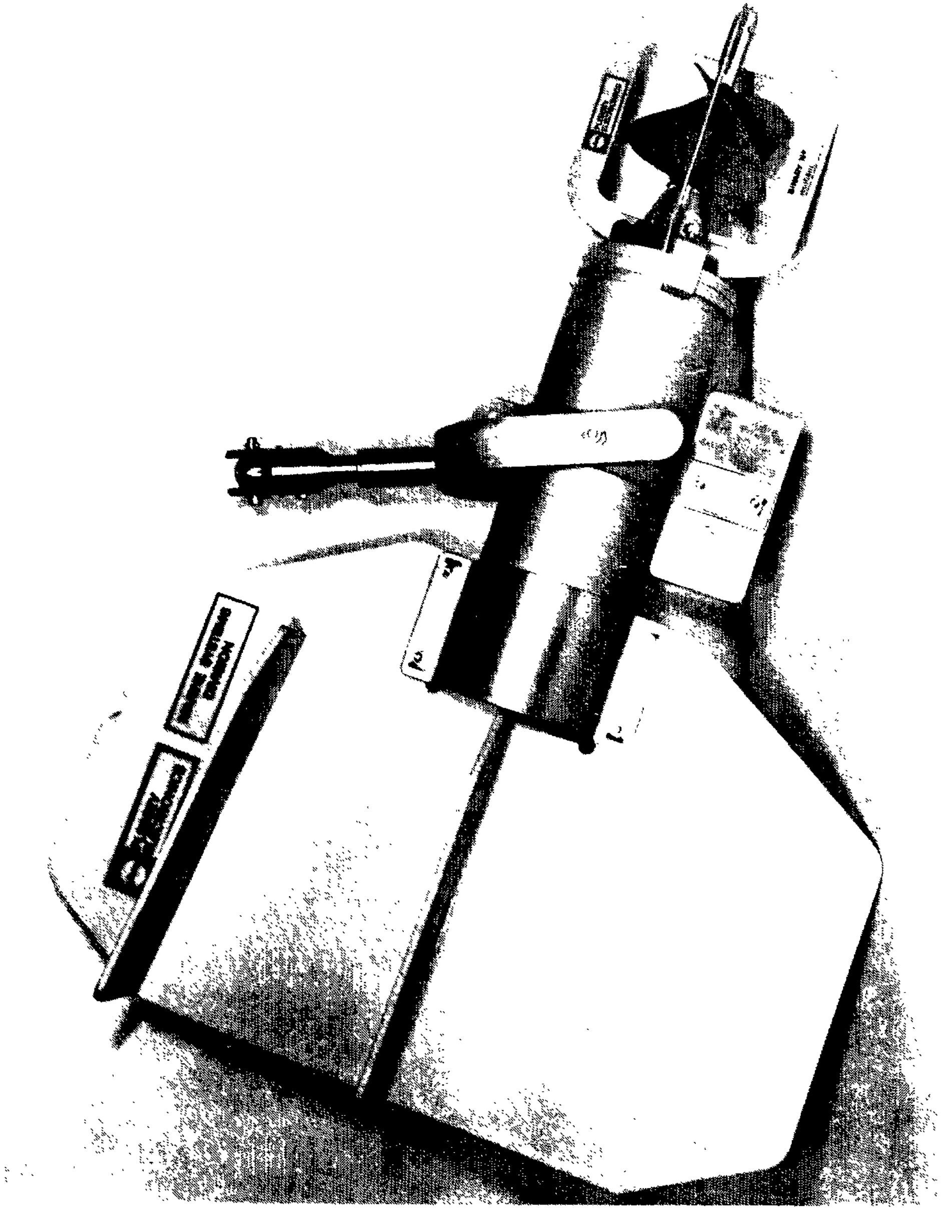
Step 2. Change course 90° and run for 4 minutes after the electrodes have become steady on the new course. This is the first fix-course.

Step 3. Change course 180°, turning in the direction of the base course, and run for 4 minutes after the electrodes have become steady on the new course. This is the second fix-course.

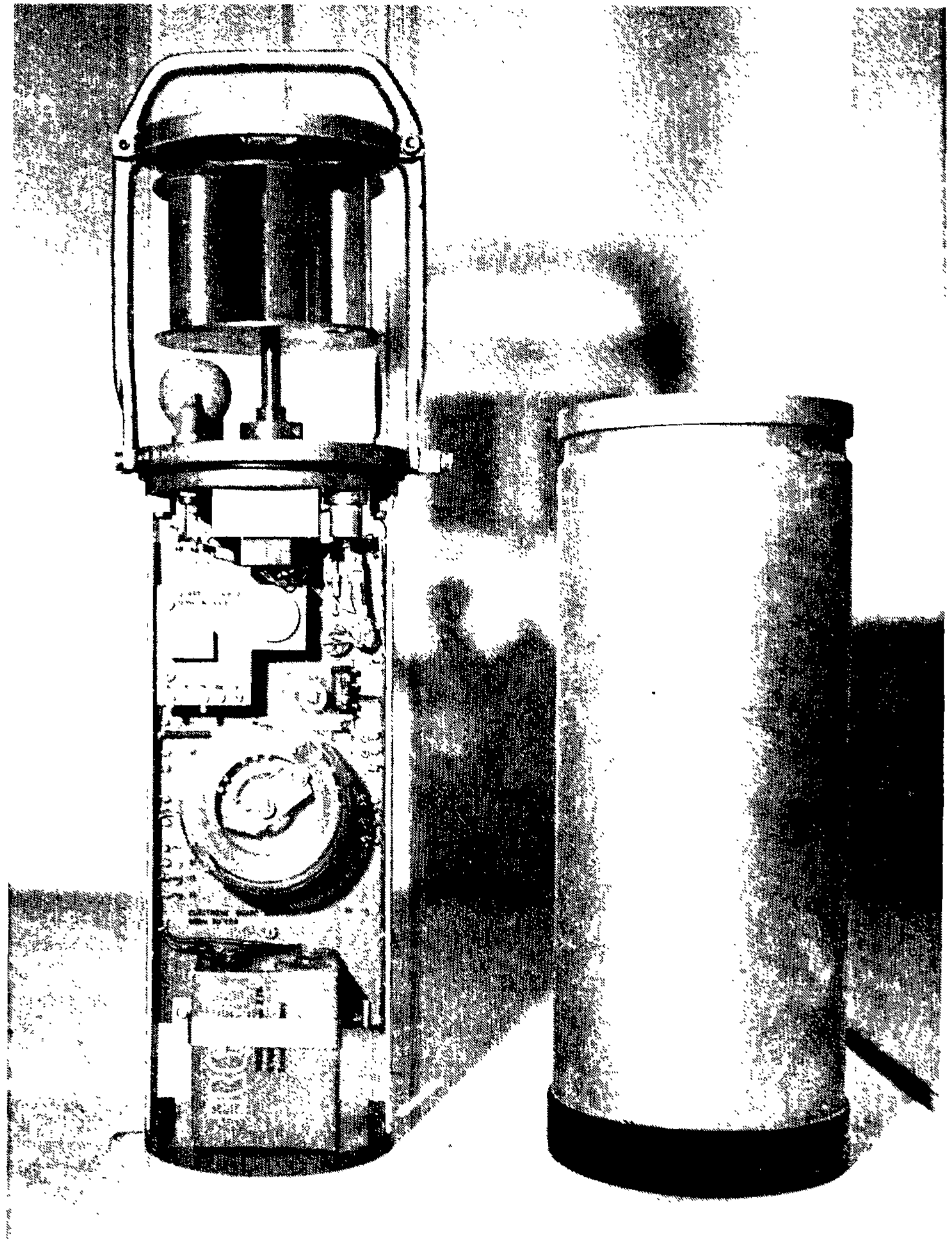
Step 4. Change course 90° and resume the base course. Run for 4 minutes after the electrodes have become steady on the base course to obtain the resumed base-course data.

Parachute drogue array

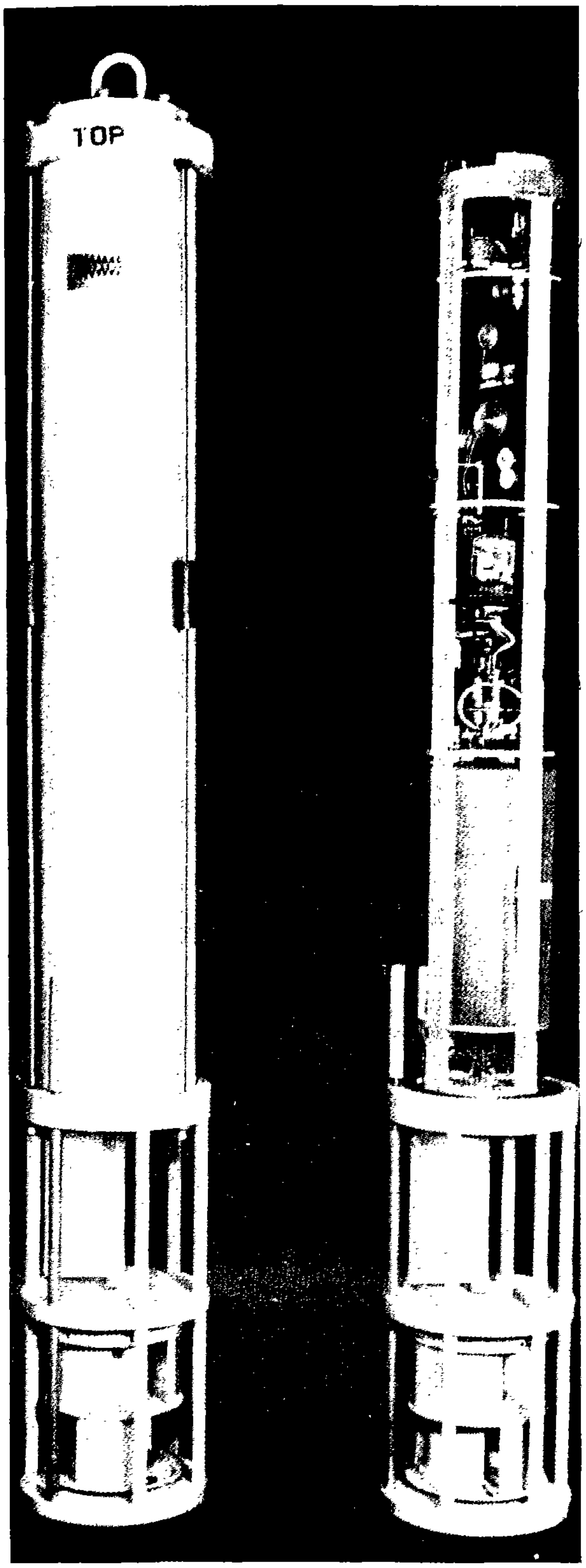




Plessey current meter

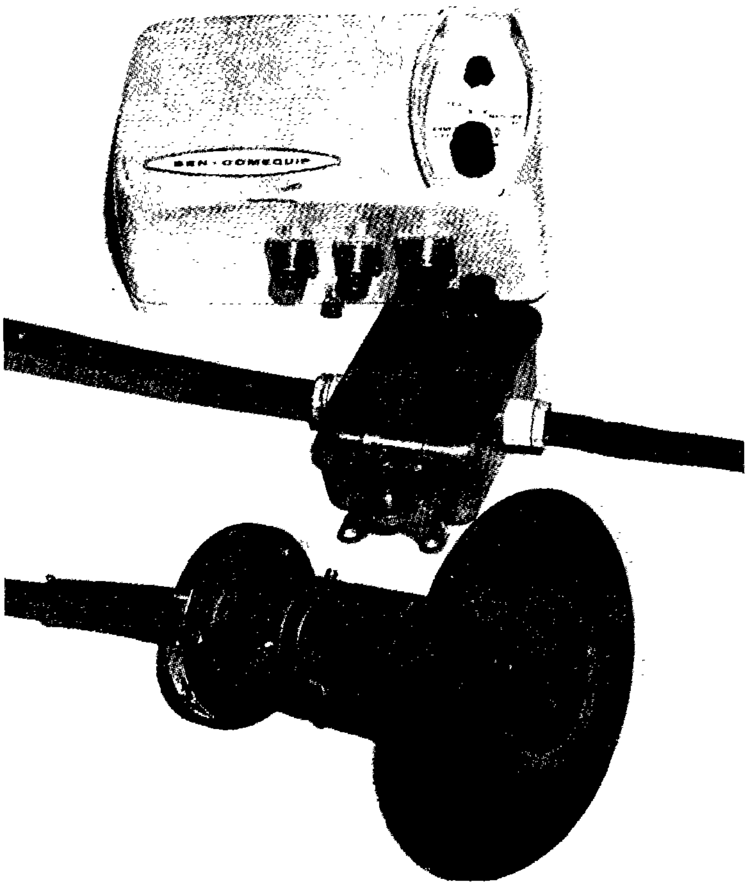


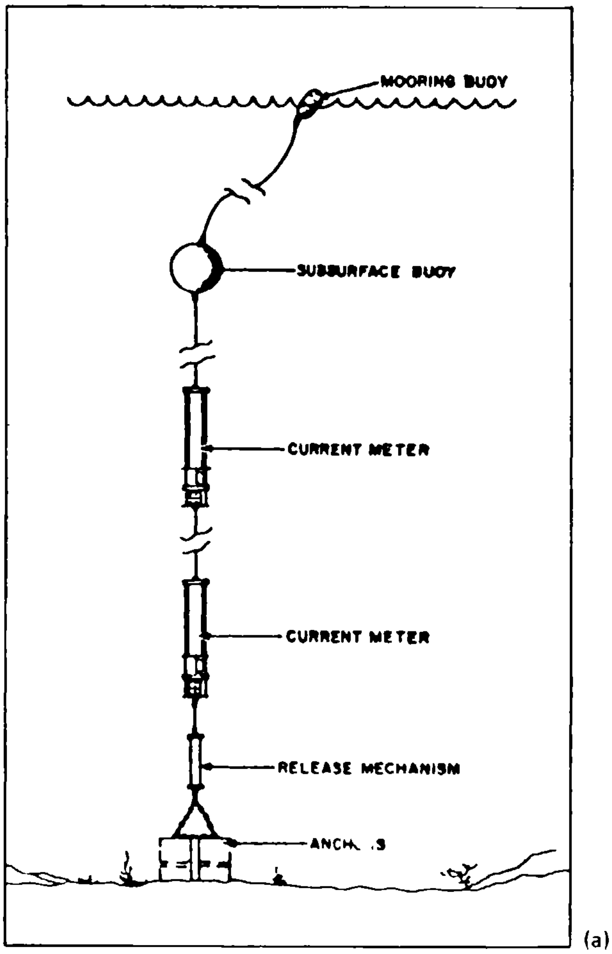
Aanderaa current meter

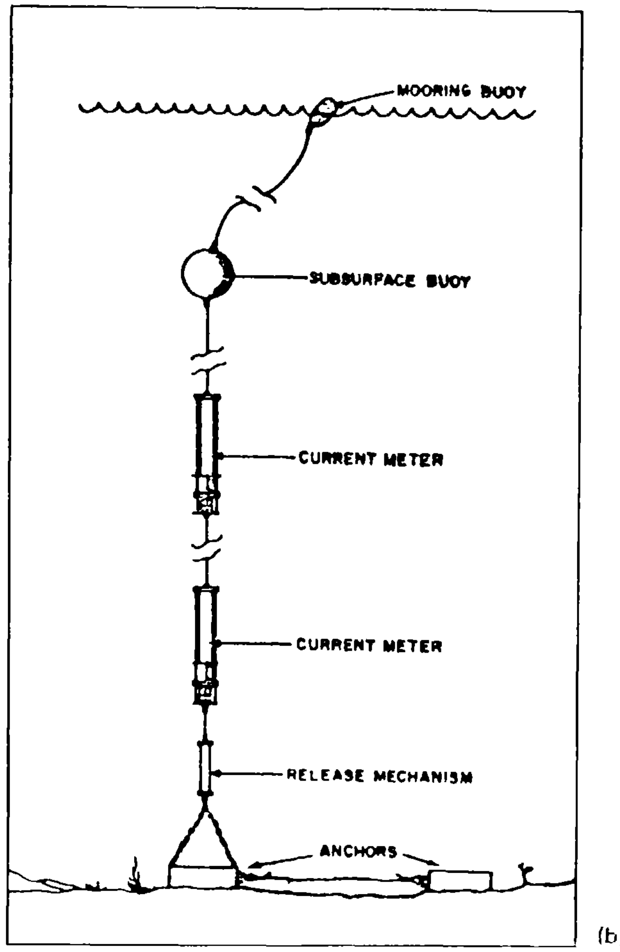


Geodyne (EG & G) current meter

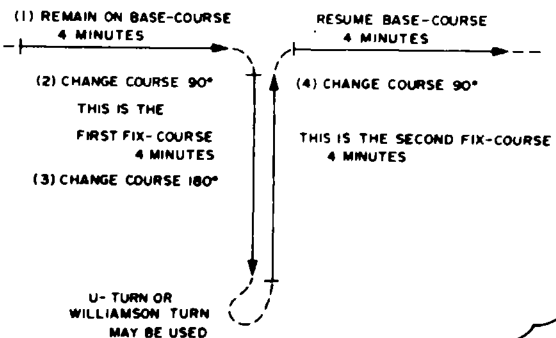
Comex current meter





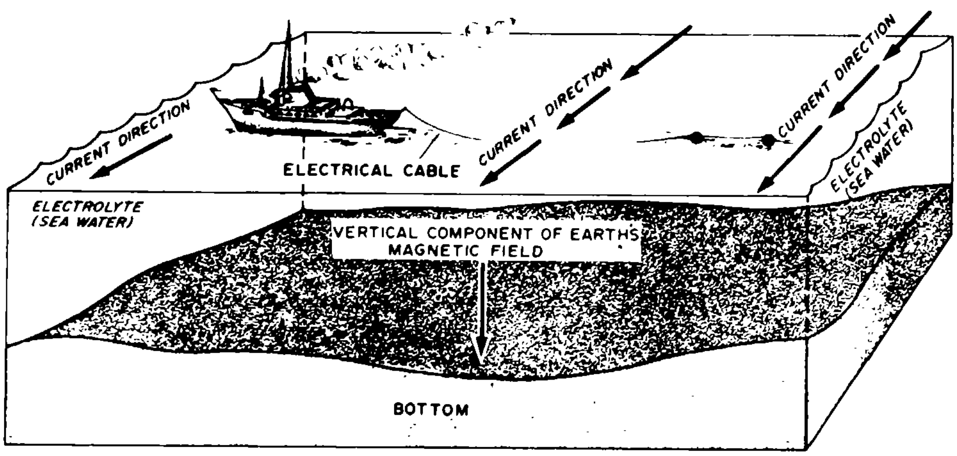


Current meter array: (a) with anchors in a cluster, or (b) with anchors separated (for easier recovery if dragging is necessary)



Directions for executing a GEK current fix

Measuring currents with the GEK



CHAPTER 7 - WIND SPEED AND DIRECTION

7.1 17.2.1 *Methods of observation*

The observation of wind speed and direction may be made either by visual estimates or by means of anemometers or anemographs.

Visual estimates will normally be based upon the appearance of the surface of the sea. The wind speed is obtained by reference to the Beaufort scale and the specifications for each number (see Table 17.1). The wind direction is determined by observing the orientation of the crests of sea waves, i.e. wind-driven waves and not waves raised by the wind in a distant area, or the direction of streaks of foam which are markedly blown in the direction of the wind. The specifications of the Beaufort scale numbers refer to conditions in the open sea and are an extract from Captain Peterson's criterion tables which also include other effects used by experienced seamen in estimating the force of the wind, e.g. sound effects.

Inexperienced observers should be aware that the wave height in itself is not always a reliable criterion since the wave height also depends on the fetch and duration of the wind, the depth of shallow waters and the presence of swell running through a sea.

Factors which in general must be taken into account in estimating wind speeds are the lag between the wind increasing and the sea getting up, the smoothing or damping down of wind effects on the sea surface by heavy rain, and the effect of strong surface currents (for instance, 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 is invisible, e.g. on dark nights, the Beaufort force of the relative wind on shipboard 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.

In ships fitted with cup counter anemometers or anemographs, observations should be the mean reading over a ten-minute period. When observations are taken from a moving ship, it is necessary to distinguish between the relative wind and the true wind; for all meteorological purposes the true wind should be reported. It is advisable to draw a simple vector diagram or to use a special table for computing the true wind from observations of the relative wind and ship's speed and course.

7.2 17.2.2 *Units of measurement*

Wind direction, i.e. direction *from* which the wind is blowing, should be reported in tens of degrees from true north.

Wind speed should be reported in knots. When observations are made visually, the Beaufort force should be converted into knots by use of a table of equivalents (see Table 17.1).

7.3 17.2.3 *Basic requirements of wind instruments*

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

7.4 17.2.4 *Exposure and management of instruments*

It is difficult in most cases to obtain a really good exposure for ship-borne wind instruments. The local effects produced by the superstructure, mast and spars should be minimized as much as possible by siting the instrument as far forward and as high as practicable. If fitted on a yard it may be preferable that the speed and direction heads should form separate units, as a more even

Table 17.1

WIND SPEED EQUIVALENTS

(For an effective height of ten metres above sea level)

BEAUFORT NUMBER	DESCRIPTIVE TERM	Mean wind speed equivalent in knots	SPECIFICATIONS Sea	SPECIFICATIONS Coast	Probable wave height * in metres
0	Calm	< 1	Sea like a mirror	Calm	—
1	Light air	1 – 3	Ripples with the appearance of scales are formed, but without foam crests	Fishing smack just has steerage way	0.1 (0.1)
2	Light breeze	4 – 6	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break	Wind fills the sails of smacks which then travel at about 1–2 miles per hour	0.2 (0.3)
3	Gentle breeze	7 – 10	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses	Smacks begin to careen and travel about 3–4 miles per hour	0.6 (1)
4	Moderate breeze	11 – 16	Small waves, becoming longer; fairly frequent white horses	Good working breeze, smacks carry all canvas with good list	1 (1.5)
5	Fresh breeze	17 – 21	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray)	Smacks shorten sail	2 (2.5)
6	Strong breeze	22 – 27	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray)	Smacks have double reef in mainsail; care required when fishing	3 (4)
7	Near gale	28 – 33	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind	Smacks remain in harbour and those at sea lie to	4 (5.5)
8	Gale	34 – 40	Moderately high waves of greater length; edges of crests begin to break into the spindrift; the foam is blown in well-marked streaks along the direction of the wind	All smacks make for harbour, if near	5.5 (7.5)
9	Strong gale	41 – 47	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple, tumble and roll over; spray may affect visibility	—	7 (10)
10	Storm	48 – 55	Very high waves with long overhanging crests; the resulting foam, in great patches, is blown in dense white streaks along the direction of the wind; 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 (12.5)
11	Violent storm	56 – 63	Exceptionally high waves (small and medium-sized ships might be for a time lost to view behind the waves); the sea is completely covered with long white patches of foam lying along the direction of the wind; everywhere the edges of the wave crests are blown into froth; visibility affected	—	11.5 (16)
12	Hurricane	64 and over	The air is filled with foam and spray; sea completely white with driving spray; visibility very seriously affected	—	14 (—)

* This table is only intended as a guide to show roughly what may be expected in the open sea, remote from land. It should never be used in the reverse way, i.e. for logging or reporting the state of the sea. In enclosed waters, or when near land, with an off-shore wind, wave heights will be smaller and the waves steeper. Figures in brackets indicate the probable maximum height of waves.

distribution of the weight on the yard can be obtained, and it may then be possible to fit the instruments further outboard. Whether fitted on a yard or on a bracket fixed to the foremast, each unit should be mounted in a position at least ten diameters of the mast away from it. 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 most freely exposed. The top of the foremast, if available, is generally thought to be the best site for an anemometer.

17.2.5 *Portable wind instruments*

Various types of portable anemometers are on occasion used at sea. The main disadvantage to the use of these instruments is that they can hardly be given a representative exposure (see paragraph 17.2.4). Only an observer who understands the nature of the air flow over the ship in different circumstances is able to choose the best place for making such observations and may arrive at satisfactory results. This method may be useful if visual estimates of wind force are difficult or impossible, e.g. with light winds at night.

CHAPTER 8 - ATMOSPHERIC PRESSURE

8.1 17.3.1 *Methods of observation*

Pressure may be measured either by a precision aneroid or by a mercury barometer. In the case of the latter, the "pumping" effect, i.e. rapid and regular changes in the height of the mercury, should be allowed for when a reading is made. This is done by taking the mean of two or three sets of readings, each set consisting of the highest and lowest points reached during the oscillation of the mercury in the tube.

The characteristic and amount of the pressure tendency in the past three hours are obtained from a barograph, preferably an open-scale instrument graduated in divisions of one millibar. Alternatively, the amount of pressure tendency may be obtained from successive readings of the mercury barometer at the beginning and end of the three-hour interval.

Pressure and tendency should be reported in millibars and tenths of a millibar.

8.2 17.3.2 *Basic requirements of barometers and barographs*

8.2.1 17.3.2.1 *Mercury barometers*

The mercury barometers used on board ships are mostly of the fixed cistern pattern. In addition to possessing the requirements of a good station barometer (see paragraph 3.2.1), a marine barometer should have an appropriate lag in order to reduce pumping of the mercury column. This can be conveniently arranged by constricting the bore of the tube for the lower and greater part of its length by means of capillary tubing.

The lag coefficient of a marine barometer can be measured by tilting the instrument so that it is reading 50 mb above the actual pressure and noting the time taken for this difference to fall to 18 mb. This falling time should be between four and nine minutes.

8.2.1.1 3.2.1 ***Basic requirements***

The basic principle of the mercury barometer is that the pressure of the atmosphere is balanced against the weight of a column of mercury. In some barometers the mercury column is weighed on a balance, but for normal meteorological purposes the length of the mercury column is measured on a scale graduated in units of pressure.

There are several types of mercury barometers in use at meteorological stations, the fixed cistern and the Fortin types probably being the most common. The length to be measured is the distance between the top of the mercury column and the upper surface of the mercury in the cistern. Any change in the length of the mercury column is of course accompanied by a change in the level of the mercury in the cistern. In the Fortin barometer the level of the mercury in the cistern can be adjusted to bring it into contact with an ivory pointer, the tip of which is at the zero of the barometer scale. In the fixed-cistern barometer, often called the Kew pattern barometer, the mercury in the cistern does not have to be adjusted as the scale engraved on the barometer is contracted to allow for changes of the level of the mercury in the cistern.

Barometers for meteorological purposes are calibrated by comparison with working or reference standard barometers which have themselves been checked against primary or secondary standard barometers which are usually installed in the major national centres for physical standards.

The main requirements of a good station barometer are the following:

(*a*) Its accuracy should not vary over long periods of time;

(*b*) It should be easy and quick to read;

(*c*) It should be transportable without loss of accuracy;

(*d*) The bore of the tube should not be less than 8 mm and should preferably be 9 mm;

(*e*) The tube should be prepared and filled under vacuum;

(*f*) The actual temperature for which the scale is assumed to give true readings (at standard gravity) should be engraved on the barometer; the scales should preferably be calibrated to give correct readings at 0°C;

(*g*) The meniscus should not be flat;

(*h*) In calibration against a standard barometer whose index errors are known and allowed for, the following tolerances for a station barometer should not be exceeded:

Maximum permissible error at about 1 000 mb	±0.3 mb
Maximum permissible error at any other pressure for a barometer whose range:	
(i) Does not extend below 800 mb	±0.5 mb
(ii) Extends below 800 mb	±0.8 mb
Difference between errors over an interval of 100 mb or less	0.3 mb

(*i*) For a marine barometer the error at a point should not exceed . . . . ±0.5 mb

The lag of mercury barometers for land stations is usually very small compared with that of marine barometers and with that of instruments for measuring of temperature, humidity and wind.

8.2.2 17.3.2.2 *Aneroid barometers and barographs*

All aneroids should conform to the general requirements given in paragraph 3.3.1 and should be supplied with a certificate giving the corrections (if any) which must be applied to the readings of a particular instrument. Aneroids should be capable of being read to 0.1 mb. The limit of accuracy should be ±0.5 mb and the scale errors should remain within this tolerance for at least a year. The general requirements of barographs are given in paragraph 3.6.1. To avoid frictional errors, the control extended by the actuating element should be relatively powerful. A built-in damping device, e.g. an oil bath containing the aneroid box or a dash pot connected to the lever mechanism, should be provided to avoid the wide trace produced by rapid pressure variations caused by gusty winds and excessive movement of the ship.

8.2.2.1 3.3.1 ***General requirements***

Though less reliable, the aneroid barometer has the great advantage over the mercury barometer of compactness and portability, which make it particularly convenient for use at sea or in the field. The two essential parts of an aneroid barometer are a closed metal chamber, completely or partly evacuated, and a strong spring system which prevents the chamber from collapsing due to the external atmospheric pressure. At any given pressure there will be an equilibrium between the force due to the spring and that of the external pressure. The aneroid chamber may be made of materials (steel or beryllium copper) which have such elastic properties that the chamber can itself act as a spring.

The chief requirements of a good aneroid barometer are as follows:

(*a*) It should be compensated for temperature so that the reading does not change more than 0.5 mb for a change of temperature of 30°C;

(*b*) The scale errors at any point should not exceed 0.5 mb and should remain within this tolerance over periods of at least a year, when in normal use;

(*c*) The hysteresis should be sufficiently small to ensure that the difference in reading before a change of pressure of 50 mb and after return to the original value does not exceed 0.5 mb;

(*d*) It should be capable of withstanding ordinary transit risks without introducing inaccuracies outside the limits specified above.

3.6.1 ***General requirements***

Of the various types of barographs only the aneroid barograph will be dealt with here. It is recommended that charts for barographs for synoptic purposes should be:

(*a*) Graduated in mb;

(*b*) Readable to 0.1 mb;

(c) Have a scale factor of 10 mb to 1.5 cm on the chart.
In addition, the following requirements are desirable for the barograph:

(d) It should employ a first-class aneroid (see section 3.3);

(e) It should be compensated for temperature, so that the reading does not change more than 1 mb for a change of temperature of 20°C;

(f) Scale errors should not exceed 1.5 mb at any point;

(g) Hysteresis should be sufficiently small to ensure that the difference in reading before a change of pressure of 50 mb and after return to the original value does not exceed 1 mb;

(h) There should be a time-marking arrangement which allows the marks to be made without lifting the cover;

(i) The pen arm should be pivoted in a "gate", the axis of which is inclined in such a way that the pen rests on the chart by gravity. Adjustment should be provided for setting the position of the pen.

8.2.2.2 3.2.4 *Exposure and management*

It is important that the location of the barometer at a station be selected with great care. The main requirements of the place of exposure are uniform temperature, good light, a solid and vertical mounting and protection against rough handling. The instrument should therefore be hung or placed in a room in which the temperature is constant or changes only slowly and in which gradients of temperature do not occur. It should be shielded from direct sunshine at all times and should not be placed near any heating apparatus nor where there is a draught. It is also always preferable to hang the mercury barometer on an inside wall.

A stratification of temperature is often found in a room which is otherwise suitable; the top of the mercury column of the barometer may then be as much as two or three degrees warmer than the cistern. For very accurate work the best position would be in a windowless, unheated basement room with a small electric fan to prevent any stratification of temperature.

8.3 17.3.3 *Exposure and management*

8.3.1 17.3.3.1 *Mercury barometers*

It is usually very difficult to give a marine barometer an exposure which satisfies the requirements specified in paragraph 3.2.4. The barometer should be mounted in gimbals in a position as near as possible to the centre of flotation, where it can swing freely, is not liable to interference from passing traffic, and where the temperature is as nearly uniform as possible. If the barometer is put into a box for protection between the hours of observation, care must be taken that the instrument is put down in a free position at least half an hour before the observation is made.

In order to obtain uniform conditions for reading the barometer, it is advisable to use artificial lighting for all observations. For this purpose some sort of illuminator, which can provide a white and slightly luminous background for the mercury meniscus and, if necessary, for the fiducial point, may with advantage be provided. If no illuminator is used, care should be taken that the meniscus and the fiducial point are provided with a light background, by means of pieces of milk glass, white celluloid or a sheet of white paper. Artificial light should also be provided for reading the barometer scale and the attached thermometer. Care should, however, be taken to guard against heating of the barometer by the artificial light during a barometer reading.

The barometer should be mounted in a place where it is not subjected to vibration, preferably on a solid wall. The instrument must be exactly vertical. Errors due to departure from verticality are more important in the case of unsymmetrical barometers. Such a barometer should be mounted with its axis of rotation vertical. This condition can be ensured by so mounting the instrument that a true setting of the mercury surface to the fiducial point remains correct after rotation of the barometer through any angle.

To protect the barometer from rough handling, dust and air currents, it is recommended that the instrument be placed in a box furnished with a hinged door. A barometer will not give a true reading of the static pressure if it is influenced by a gusty wind and its reading will fluctuate with the wind speed and direction, the magnitude and sign of the fluctuations depending also on the nature of the openings of the room and their position in relation to the direction of the wind. At sea the error is always present due to the ship's motion. A similar problem will arise if the barometer is installed in an air-conditioned room.

It is possible to overcome this effect to a very large extent by making the cistern of the barometer air-tight except for a lead to a special "head" exposed to the atmosphere and designed to ensure that the pressure inside it is the true static pressure.

Great care should be taken when transporting a mercury barometer. The safest method is to carry the barometer upside down in a leather or wooden case furnished with a sling. • If the barometer cannot be accompanied by a responsible person, it ought to be transported in a suitably sprung crate with the cistern uppermost. The barometer should not be subjected to violent movements, and it must always be turned over very slowly. Special precautions have to be taken for some individual types of barometer before the instrument is turned over.

8.3.2 17.3.3.2 *Barographs*

Aneroid barometers and barographs should be mounted on shock-absorbing material in a position where they are least likely to be 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 athwartships (to minimize the risk of the pen arm swinging off the chart).

8.4 17.3.4 *Corrections* (see also paragraph 3.2.6)

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

Mercury barometers

(*a*) Index error;

(*b*) Temperature of the instrument;

(*c*) Latitude (gravity);

(*d*) Reduction to sea-level.

These corrections may be combined in a single table with the temperature of the attached thermometer and the latitude as arguments, or a Gold correction slide may be used. This special slide rule is attached to the barometer and incorporates the attached thermometer. It gives the total barometer correction and reduction to sea-level in one operation.

Aneroid barometers

(*a*) Scale error;

(*b*) Reduction to sea-level;

(*c*) Temperature (if appropriate tables are provided).

Aneroid barometers should be adequately compensated for temperature. Unless this is the case, instruments should be provided with a temperature correction table and means should be provided for measuring the temperature.

8.4.1 3.2.6 *Correction of barometer readings to standard conditions*

In order that barometer readings made at different times and at different places should be comparable, the following corrections should be made:

(*a*) Correction for index error;

(*b*) Correction for gravity;

(*c*) Correction for temperature.

For any particular barometer used in a fixed position these corrections may conveniently be combined in a single table with the values of pressure and temperature as arguments.

8.5 17.3.5 *Sources of error*

In addition to the errors discussed in paragraph 3.2.7 appreciable errors may be caused by the effect of the wind on the pressure in the compartment in which the barometer is placed. These may be reduced by enclosing the instrument in a chamber connected with a static pressure vent.

With a mercury barometer another source of errors is the regular oscil'ation of the barometer when hanging freely. The amount of the error depends on the position of the point of suspension, the period of swing of the barometer and the amplitude of the oscillation from the true vertical (which may be much smaller than the oscillation about an axis fixed relative to the ship). A barometer which is mounted in gimbals and is oscillating regularly for a considerable time (15 minutes or more) with a swing of about ten degrees may read as much as 4 mb too high. If, however, the amplitude of the swing were only two degrees the error would be reduced to about 0.2 mb.

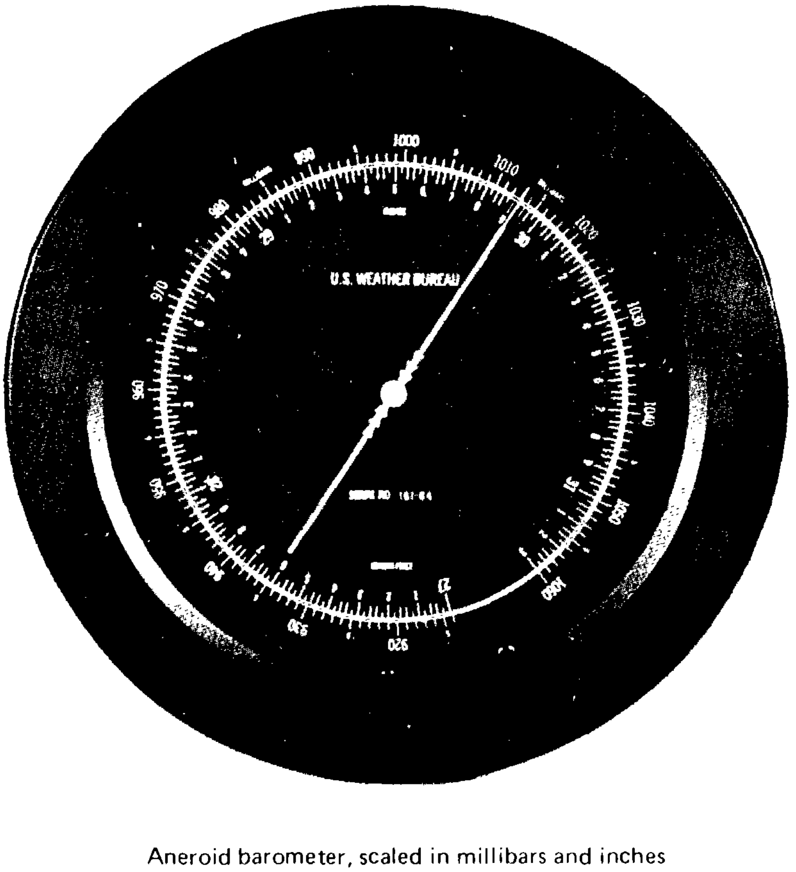
On account of the lag of the barometer, the fluctuations due to the pressure variations caused by the lifting and sinking of the barometer (rolling and pitching) are of less importance. The pumping of the mercury meniscus will largely be due to the varying acceleration to which the barometer is subjected by the movements of the ship.

The error of a single corrected barometer reading on board ship may vary from ± 0.2 mb to a few millibars according to circumstances.

8.6 17.3.6 *Checking with standard instruments*

The mercury barometer should be frequently checked against standard instruments on shore (at least once every three months), and a permanent record of all such checks should be kept on a suitable card or in a special log.

Aneroid barometers and barographs should be checked as frequently as possible against a mercury barometer or a hypsometer, and against standard instruments on shore at least once every three months. A permanent record of all such checks should, if possible, be attached to the instrument, and should include such information as the date of the check, temperature and pressure at which the check was made. It is particularly important that aneroid barometers and barographs should be checked as frequently as possible, because of the zero drift to which these instruments are liable especially when they are new



Aneroid barometer, scaled in millibars and inches

CHAPTER 9 - AIR TEMPERATURE AND HUMIDITY

9.1 17.6.1 *Methods of observation*

Temperature and humidity observations should be made by means of a psychrometer with good ventilation. Other humidity-measuring instruments are at present not generally suitable. A single fixed screen is not satisfactory.

9.2 5.2.1 *General requirements*

Equipment used for psychrometric observations should, as far as practicable, conform with the following recommendations:

(*a*) The wet and dry bulbs should be ventilated and protected from radiation by a minimum of two polished unpainted metal shields which are separated from the rest of the apparatus by insulating materials; or alternatively by a louvered screen plus one polished metal shield;

(*b*) At sea-level air should be drawn past the bulbs at a rate not less than 2.5 metres per second and not greater than ten metres per second, if the thermometers are of the types ordinarily used at meteorological stations. For appreciably different altitudes, these air-speed limits should be adjusted in inverse proportion to the density of the atmosphere;

(*c*) Separate ducts should be provided for the two thermometers;

(*d*) If the second of the alternatives (*a*) above is used, the entrance of the ducts should be located so as to give the true ambient temperature, and the air should be delivered above the screen in such a position as to prevent recirculation;

(*e*) The greatest care should be taken to prevent significant amounts of heat from a motor being communicated to the thermometers;

(*f*) The water reservoir and wick should be so arranged that the water will arrive at the bulb with sensibly the wet-bulb temperature;

(*g*) Measurements should be taken at a height between 1.25 and 2 metres above ground level.

To obtain high accuracy with psychrometers it is desirable to arrange for the wet and dry bulbs to have approximately the same lag coefficient. With thermometers having the same size of bulb the wet bulb has an appreciably smaller lag than the dry bulb (see section 4.3). The fabric covering the wet bulb should be a good fit round the bulb, and extend at least two centimetres beyond the bulb.

9.2.1 4.3 Response time of thermometers

For routine meteorological observations there is no advantage in using thermometers which have a very rapid response. The temperature of the air is continually fluctuating up to a degree or two within periods of a few seconds. To obtain a representative reading with a quick acting instrument it would be necessary to take the mean of a number of readings, whereas a more sluggish thermometer smooths out the rapid fluctuations. Too slow a response, however, may result in errors due to lag when long period changes of temperature occur. It is considered that the lag coefficient, defined as the time required by the thermometer to respond to 63 per cent of a sudden change of temperature, should be between 30 and 60 seconds in a wind speed of 5 m s^{-1}. The lag coefficient is roughly inversely proportional to the square root of the wind speed.

9.3 17.6.3 *Exposure and management*

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

Sling or aspirated psychrometers exposed on the windward side of the bridge have been found to be satisfactory.

If manually-operated psychrometers are used, the thermometers must be read as soon as possible after ventilation has stopped.

For the general management of psychrometers the recommendations of paragraph 5.2.4 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 fresh water.

If a louvered screen is used for this observation it should be a portable one. Before the observation is made the screen should be hung to the windward side of the ship, completely exposed to the air current and without being influenced by artificial sources of heat.

9.4 5.2.4 *Management of psychrometers*

9.4.1 5.2.4.1 *General*

The following recommendations have been made by WMO:

(*a*) The fabric used to cover the wet bulb should be thin but closely woven. Before installation it should be washed thoroughly in pure soap and water and rinsed several times in distilled water. If a wick is used, it should be similarly treated;

(*b*) Any visible contamination should be considered an absolute indication of the necessity of replacement. Great care should be used in handling the fabric and wick, to prevent contamination from the hand;

(*c*) Distilled water should be used for the wet bulb.

The observers should be encouraged to change the muslin and wick regularly. The replacement should be made at least once a week for all psychrometers which are exposed continuously. At places near the sea and in dusty districts, it may be necessary to change the muslin and wick more frequently. The water supply should frequently be checked and replaced.

9.4.2 5.2.4.2 *Operation of wet bulb below freezing*

A wick cannot be used to convey water from a reservoir to the wet-bulb covering by capillarity when the wet-bulb temperature is below 0°C. Under these conditions care should be taken to form only a thin layer of ice on the covering.

The water used should, as far as possible, have a temperature near the freezing point. If there is a button of thick ice at the lowest part of the bulb, it should be immersed in water long enough to melt the ice.

The time required for the wet bulb to reach a steady reading after the muslin is wetted depends on the ventilation and on the actual wet-bulb temperature. An unventilated thermometer usually requires from a quarter to three quarters of an hour, while an aspirated thermometer will need a much shorter time. It is essential that the formation of a new ice film on the bulb be made at an appropriate time. If hourly observations are being taken with a simple psychrometer, it will usually be preferable to form a new coating of ice just *after* each observation. If the observations are at longer intervals, the observer should visit the screen sufficiently early before each observation and form a new ice film on the bulb. The wet bulb of the aspirated and sling psychrometers should be moistened immediately before use.

The evaporation of the ice film may be prevented or slowed down by enclosing the wet bulb in a small glass tube or by stopping the ventilation inlet between the observations.

The effect of supercooled water on the wet bulb can be dealt with in two ways:

(*a*) By using different tables when the wet bulb is coated with ice and with supercooled water, respectively. To find out which table should be used, the wet bulb must be touched with a snow crystal, a pencil or other object, just after each observation is completed. If the temperature rises towards 0°C, and then commences to fall again, it can be assumed that the water on the wet bulb was supercooled at the time of observation;

(*b*) By using a table which assumes ice cover on the wet bulb and inducing the supercooled water to freeze in the same way as in method (*a*). In order to save time and to ensure that the wet bulb is ice-covered, the observer should make a point of initiating the freezing of the water at each observation as early as possible after the moistening of the bulb. From the behaviour of the wetted thermometer at the freezing point it may usually be determined whether the bulb is covered with ice or supercooled water. The recommended procedure, however, is to initiate the freezing of the water at each observation when the wet-bulb temperature is assumed to be below 0°C, regardless of whether the observer has watched the behaviour of the thermometer after the moistening or not.

The first method is usually the quicker one but it involves the use of two tables and this may cause some confusion.

CHAPTER 10 - PRECIPITATION

10.1 17.7.1 *Methods of observation*

The complete measurement comprises the determination both of the amount and of the duration of precipitation. The amount of precipitation should be measured with a raingauge adapted for use aboard ship. Readings should be made preferably every six hours. Amounts of precipitation up to ten millimetres should be read to 0.2 mm and larger amounts to two per cent of the total (Technical Regulation 3.4.8.3). The required accuracy of the measurement should be the same as for reading. However, it should be borne in mind that due to the particular difficulties in making rainfall measurements on shipboard, the present accuracy of those measurements is liable to be much less than desired. The duration of precipitation should be recorded in rounded units of five minutes.

10.2 17.7.2 *Basic requirements*

It is difficult to obtain reliable measurements of precipitation on board ship, owing to the aerodynamic effects due to the superstructure of the ship, the influences of roll and pitch, the capture of spray, and the movement of the ship.

The raingauge used on ships should, therefore, be constructed and exposed in such a manner that the first three effects of the four mentioned above are avoided or minimized as far as possible.

11.1 17.5.2 *Estimation of visibility*

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

CHAPTER 12 - WATER TRANSPARENCY AND COLOUR

12.1 Water transparency

12.1.1 Secchi disc - general

The Secchi disc, a low cost and convenient "instrument", provides an approximate average index of transparency of seawater and is dependent upon the available illumination which varies with the time of day, cloud formation, and amount of cloud cover.

12.1.2 Secchi disc - description

The Secchi disc is a white circular plate, having a standard diameter of 30 centimeters. A ring attached at the center of the disc allows a graduated line to be secured. A 2 to 4 kilogram weight is attached to the disc so it will sink rapidly and vertically. The line attached to the disc should be marked off in 1-metre intervals to at least 50 metres. A line with minimal stretching characteristics should be used.

12.1.3 Secchi disc - procedures

To obtain Secchi disc readings, the disc is lowered, white side up, into the water from the shaded side of the vessel until the disc is just perceptible; the distance from the sea surface to that depth in metres is recorded. The lowering is then continued for approximately 5 metres more. The disc is next slowly raised until it is again barely visible; the distance from the sea surface to that depth is also recorded. The average of the UP and DOWN readings is the desired value. It is recommended that the extreme end of the disc line be secured on deck before lowering over the side to avoid loss of the disc.

12.2 Water colour

12.2.1 Forel scale

The standard Forel scale consists of a series of 11 small vials containing ammoniacal copper sulphate and neutral potassium chromate in such proportions that a different graduation of colour is imparted to each vial. These vials are numerically designated and are compared directly with the water in the manner described below.

The water colour is most easily determined in conjunction with the Secchi disc. After completion of the transparency measurement described above, raise the white Secchi disc until it lies approximately 1 metre below the surface. The number of the vial that blends most closely with the water colour against the Secchi disc is the water colour descriptive number. The whiteness of the disc provides the background to which the colour is referred; this colour may not be the colour of the sea surface visible away from the ship. The vials must be shaded from open sunlight when the determination is being made.

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