Data Buoy Cooperation Panel

10.3- Guidelines to Oceanographic Instruments

Document Change Record

Version	Date	Originator	Change Comments
1.0	7Sep2016	Venkatesan	First draft
2.0	29 Oct2017	Venkatesan	Revised Draft for Finalization
2.0	DBCP 32 session		Discussed with members

Review Cycle

Version	Next Due	POC	Change Comments
2.0	29 October 2016	Chair of Action Group R Venkatesan (Chair) Luca Centuriani, David Meldrum, K Ramesh (India) Florence Salvetat IFREMER Brest (France) and the Secretariat	15 June 2018 Points suggested Dr Florence on specific vocabulary for metrology as per the document "international metrology vocabulary" (see the website of BIPM). Comments : Document is a generic document to help people to discover the field and is considered as a first step in order to homogenize practices. The document is pretty complete on temperature, salinity and quality topics.
	17 Nov 2017	The Best Practice Working Group "*Evolving and Sustaining Ocean Best Practices Workshop* at UNESCO IOC Paris 15	Discussed with experts

Background

DBCP 31 session

6.3.8 The Panel agreed that DBCP guidelines on instrument standards ought to be developed. The Panel agreed that the following should initially be undertaken: (i) checking existing materials (e.g. WMO No. 8, Guide to Meteorological Instruments and Methods of Observation), (ii) agreeing on the scope of the guidelines document, and the methodology for producing it, and then (iii) proposing a work-plan, and who should contribute. The guidelines document could include instrument classes, and information on traceability requirements, while certification could simply be undertaken at the DBCP level through a committee to be established for that purpose.

The Panel requested R. Venkatesan to lead such developments, with assistance from Luca Centuriani, David Meldrum, and the Secretariat in the view to make a proposal (possibly a draft guidelines document) at the next Panel Session (***action; R. Venkatesan; DBCP-32***).

DBCP 32 draft guidelines was presented addressing the points suggested such as checking existing materials (e.g. WMO No. 8, Guide to Meteorological Instruments and Methods of Observation),, defining the scope of the guidelines document, and the methodology for producing it and clarity on the work plan was getting emerged (Action DBCP 33)

DBCP Session 33 Rec 8.7/2: DBCP guidelines for oceanographic instruments (draft) was presented and urged members to review and finalize before DBCP 34 Action 9.2/3: (DBCP Panel; DBCP-34)

Content

Summary

The Guidelines for Oceanographic Instrument standards and Methods of Observation aids in instrumentation and measurement techniques used to make ocean observations. DBCP 31 session agreed that DBCP guidelines for instrument standards ought to be developed. The Panel agreed that the following should initially be undertaken: (i) checking existing materials (e.g. WMO No. 8, Guide to Meteorological Instruments and Methods of Observation), (ii) agreeing on the scope of the guidelines document, and the methodology for producing it, and then (iii) proposing a work-plan, and who should contribute. The guidelines document could include instrument classes, and information on traceability requirements, while certification could simply be undertaken at the DBCP level through a committee to be established for that purpose. The Panel requested R. Venkatesan (India) to lead such developments, with assistance from Luca Centuriani, David Meldrum, and the Secretariat in the view to make a proposal (possibly a draft guidelines document) at the next Panel Session . The Panel requested R. Venkatesan to lead such developments, with assistance from Luca Centuriani, David Meldrum, and the Secretariat in the view to make a proposal (possibly a draft guidelines document) at the next Panel Session

During DBCP 32 a draft guidelines was presented addressing the points suggested such as checking existing materials (e.g. WMO No. 8, Guide to Meteorological Instruments and Methods of Observation),, defining the scope of the guidelines document, and the methodology for producing it and clarity on the work plan was getting emerged (Action DBCP 33)

Further DBCP Session 33 discussed and recommended Rec 8.7/2 to pursue this work and: DBCP guidelines for oceanographic instruments (revised draft) was presented and urged members to review and finalize before DBCP 34 Action 9.2/3

In oceanography, much is still to be learned through observation and instrumentation is often the limiting factor to observation. It is essential to develop skill in the utilization of oceanographic instrumentation and to specify or invent new instrumentation that will aid observation. Better techniques of measurement lead to greater and more accurate understanding of the natural system. The short term benefit of such understanding is the ability to predict the response of the ocean and the long term benefit is a change in our own behaviour as a society that leads to opportunities for human use and individual appreciation to society's benefit.

The ocean observations have immense societal value through various climate and weather applications, such as forecasts of droughts, tropical cyclones and associated storm surges, and projections of decadal to multidecadal climate variability and change. These observations provide vital information in the management of ocean ecosystems and human adaptation activities in response to climate variability and change. But there is no concrete guide for Oceanographic Observations and Instruments, such as CIMO guide for the Meteorological Instruments, which is already well established by World Meteorological Organization (WMO). Thus, standardization of methodologies and instrumentation in oceanographic observation has remained a key concern in the oceanographic community. Industries of oceanographic sensors from many countries have attempted to develop standardized ocean observation techniques and new technology in instrumentation and these attempts are sparse and not wide spread.

The oceanographic instruments were developed by small companies and have been taken over by big companies nowadays. The standardization of protocols used to control and configure the instruments, and to retrieve their data are minimal. Hence an attempt is made to detail the specifications of instruments, practices and procedures for data collection, quality control of data and standardization of instruments. The aim of this guide is to fill the void that has occurred from few decades in ocean

observation instrumentation and standardized methodologies based on the experience and knowledge gained by the scientific community.

The process of standardisation required in various stages from Instrument to data reception is described below

1. **Instrument**
2. **Integration of Instruments to Observing Platform** & **Real time Data Transmission**
3. **Data and Met Data format :** *Standardization efforts in the marine research community have largely focused on this standard formats for data and meta-data to ensure interoperability between data producers andconsumers*

Instrument to Data

1. Instrument standard

- Instrument Protocol: RS232 and RS485 serial are the dominant physical layer protocols and has been increasingly displaced by Ethernet nowadays; the syntax and command sets for the instruments are exclusively designed by the manufacturer.
- Some Instruments return data in a readable format, typically as ASCII-encoded decimal numbers separated by commas or tab characters. However, there are many other formats, with varying degrees of complexity, compatible to the characteristics of each instrument. These may include fields defined by fixed or delimited formats, and binary encoding of various integer and floating-point number types. Different data fields within a packet may be encoded differently.
- A single instrument may also produce multiple packet formats within the same data stream. For example, an instrument may report “housekeeping” data in separate packets, and at different rates, from its primary measurement data. The contents of a data field could even indicate the length or a format of subsequent data within the same packet.

2. Integration of Instruments to the Observing Platform and Data Transmission:

- The oceanographic instruments are often integrated into an observing system or a sensor network, which provides software infrastructure for many useful functions, such as instrument data acquisition, data logging, and data transfer to other locations via wired or wireless telemetry links. Most observational systems use generic or standard protocols for these functions.
- A driver software that translates between specific instrument and generic system protocols must be written for each kind of instrument.
- The driver must be configured properly as soon as the instrument is installed onto a communication port on the observing system.
- A definition of the raw instrument protocol exchanged between the instrument and the data acquisition system is essential

  Real time data transmission from Observing Platform
- After instruments are connected to an observing system’s network, the real - time remote access to instrument data via the Internet is provided. Few instruments provide communications in a standard command protocol format—thus observatory or shore-based software is required to transform the instrument data format to a standard form.
- Standardization is required to minimize the need for software development and manual configuration steps, thereby reducing system complexity, development and operational cost.

3 Data and Met Data:

- Standardization efforts in the marine research community have largely focused on the standard formats for data and meta-data to ensure interoperability between data producers and consumers.

- In terms of metadata formats, most viable standards are based on XML, and use the ISO19115 schema for describing geographic information, with some extensions to cover characteristics of marine data.
- The International Oceanographic Data and Information Exchange (IODE) of the Intergovernmental Oceanographic Commission (IOC) of UNESCO promote XML and ISO19115 for metadata encoding, with the World Meteorological Organization (WMO) Core Metadata Profile.

This definition may be noted for reference throughout this document

- Sensor – that measures a desired parameter
- Instrument – a sensor or collection of sensors
- Components – Data loggers, communications and positioning equipment, power supplies, ancillary cables and connectors, mounting hardware, etc.
- Platform – physical structure on which components are deployed in the field (e.g., ship, mooring, drifters, floats, gliders etc.)

Existing standard

- Many navigational marine instruments implement NMEA 0183 or NMEA 2000, but the standard's restrictions to ASCII formats and a 4800 baud serial data bus have limited its application to "scientific" instruments.
- Marine instrumentation most commonly uses serial links, so IEEE 1451.2 would apply. IEEE 1451.2 is fully compatible with an RS232 instrument, using the communication and measurement services described in IEEE 1451.0. Different protocols are addressed by different branches of the standard, for example,1451.2 for RS232, I_2 C, and SPI; 1451.4 for analog sensors, 1451.6 for controller area network (CAN), etc. IEEE 1451 uses the term transducer interface module (TIM) to refer to a sensor or actuator, and a network capable application processor (NCAP) to mean a controller interfacing to one or more TIMs. Data from the non-IEEE 1451 instruments are processed to input data into an IEEE 1451.0 server. This server publishes data using the HTTP 1451 standard.
- The IEEE 1451 Smart Sensor Interface Standard provides a common communications architecture with sensors over different communication protocols at the physical level. This standard has not yet been widely used, especially in marine sensors, and the lack of software tools for implementation limits its adoption. However, it has some capabilities that may be useful in marine networks.
- Standard
- In the measurement context considered here, the word "standard" is used with two meanings. Firstly, it refers to a calibrationstandard – a method which is used to provide traceability back to a common benchmark. Secondly, it may refer to aspecificationstandard – a written procedure describing the method for undertaking a measurement. Here we propose specification standard, as calibration standards are comparatively better well established.

Specification standards

- Specification standards are documents describing procedures to be followed when undertaking measurements. The highest of such standards are international standards produced under the auspices of organisations such as ISO (International Organization for Standardization) and IEC (International Electrotechnical Commission).ISO produces standards which cover physical measurements; with regard to underwater acoustics including environmental noise or noise radiated from specific sources such as ships. IEC produces standards that cover electrical measurements, including the calibration of instruments such as hydrophones. ISO and IEC standards are typically adopted as national standards within member countries

The need of standardisation of Instrument to Observing platform

Standardizing the installation and operating processes can dramatically reduce costs, as well as the risk of failures due to manual errors.

Standardization also facilitates easier maintenance and replacement of observatory instruments, and traceability of the data they generate.

Standardization will ensure manufacturers a well-tested technology.

Equation of state of Seawater

The equation of state of seawater is a function from which the thermodynamic properties of seawater can be derived mathematically. A Gibbs function for this has been developed by Working Group 127 "Thermodynamic and Equation of State of Seawater" as a collaboration of the Scientific Committee on Oceanic Research (SCOR) and International Association of the Physical Sciences of the Oceans (IAPSO). The particular Gibbs function, or Gibbs potential, is a function of absolute salinity, temperature and pressure. This equation is presented in the following work together with statements of basic thermodynamic properties and such derived properties as potential temperature, potential enthalpy, conservative temperature, potential density, among others. The equation was adopted by the Intergovernmental Oceanographic Commission in June 2009, replacing a series of algorithm dating from 1978. These historical references include the Practical Salinity Scale (PSS-78) and the International Equation of State of Seawater (UNESCO 1981) as well as other algorithms for the specific heat capacity of seawater at constant pressure, sound speed of seawater, and freezing-point temperature of seawater. Details are given in the cited manual.

Of special note is the use of Absolute Salinity, expressed in SI units, in the Gibbs function. This quantity is derived from the measurements underlying Practical Salinity in combination with other measurements and correlations. It is recommended by IOC that Practical Salinity remain the standard quantity for storing in national databases.

Chapter 1 describes about the Instrument Systems and Limits to Measurement. Chapter 2 is on Seawater Temperature, calibration and data. Chapter 3 deals with measurement of conductivity, calibration and data. Chapter 4 describeseasurement of precipitation and incoming shortwave radiation and Chapter on Centralrocessing Unit and finally References and further reading are given. This guidelines document structured presently with few parameters and other parameters can be added in the updated version in future

Reference

1. IEEE Ocean Engineering Society http://ieeeoes.org/page.cfm/page/357/General-Introduction-to-Standards
2. http://www.teos-10.org/pubs/TEOS-10_Manual.pdf (last viewed 29 July 2013).
3. "The international thermodynamic equation of seawater – 2010: Calculation and use of thermodynamic properties," Intergovernmental Oceanographic Commission, Manuals and Guides No. 56, UNESCO (English), 196 pp.
4. "Getting started with TEOS-10 and the Gibbs Seawater (GSW) Oceanographic Toolbox," Version 3.0, May 2011, available at http://www.teos-10.org/pubs/Getting_Started.pdf (last viewed 29 July 2013).
5. A primer: R. Pawlowicz, "What every oceanographer needs to know about TEOS-10 (The TEOS-10 Primer)" is available at http://www.teos-10.org/pubs/TEOS-10_Primer.pdf (last viewed 29 July 2013).

CHAPTER-1

Preamble

Instruments and measurement techniques extend direct observation for the benefit of understanding and prediction. Understanding is the powerful aid to prediction. Models lead to understanding and observations ground models. In oceanography, much is still to be learned through observation and instrumentation often limits observation. Developing skill in the utilization of oceanographic instrumentation and knowledge to specify or invent new instrumentation is essential to aid in observation. Better techniques of measurement lead to greater and more accurate understanding of the natural system. The short term benefit of such understanding is the ability to predict the response of the ocean. In the long term, understanding would change our own behaviour as a society thereby leading to opportunities for human use and individual appreciation to society's benefit.

Instrument Systems and Limits to Measurement

An instrument system is completely defined by its input and output specifications and it might measure, record, and display a physical variable. The exact way this is done is unimportant as long as the specifications are met. An instrument system is composed of sensors, amplifiers, or recorders, but in general, these are not complete and their characteristics depend on what they are connected to.

The concept of a system being defined by its specification is useful because it frees us from thinking about specific implementations. The input to an instrument system is the physical variable to be sensed. Thus the input to a thermometer is temperature, to an acoustic receiver is sound pressure, and to a current meter is velocity field.

For simple measurements, there may be minimal benefit in thinking of the physical variable independent of the sensor but in more complicated measurements there is an advantage. For example, the physical quantity may be highly variable and require a long observation to obtain the desired statistical significance. This must be recognized immediately and not be masked by the averaging characteristics of some sensor. Furthermore, a clear understanding of the physical variable will aid in sensor design.

Sensor

The sensor in an instrument system that converts the physical signal to a more easily manipulated form. The term signal in this context implies a separation of the physical variable into a meaningful part, the physical signal, and a non-meaningful part, noise. This separation often starts in the sensor. Any introduction of false information at the sensor or loss of true information is generally impossible to correct with subsequent processing. So the behaviour of the sensor is one of the most critical concerns in an instrument system.

The physical signal is composed of direct variations in a physical property such as pressure, concentration, or temperature. The output of the sensor is a voltage, displacement, resistance change, or other easily amplified, averaged, or stored characteristic.

After the physical signal is transformed to some other form by the sensor, it can be conditioned by amplifying, filtering, correlating, or sampling. Amplifying can generally be done with little degradation of signal to noise ratio. The term signal to noise ratio defines the ratio of useful information to unwanted information. Extra information added by the amplifier is unwanted and is considered as noise. Similarly if in addition to amplifying the signal, it loses a part of it, this reduces the signal to noise ratio.

When the signal has been filtered, it is often sampled. In modern instruments, it is generally digitized because the signal to noise ratio for digitized data is very high and can be stored and processed subsequently with minimal degradation. The problem of aliasing arises at this point. The sampled data contains limited information about signal at frequencies higher than the sampling frequency. Signal received at higher frequency than the sampling frequency will appear as energy at some lower frequency and degrade the data at the lower frequency, which is almost always undesirable. The solution is to filter before sampling and sample at twice the frequency of the high frequency limit of the signal passed by the filter. The high frequency limit may be imposed by the nature of the physical signal, by the response of the sensor or by a filter in the signal conditioner.

The output of a system is defined by how it is coupled with a human observer either directly or indirectly through subsequent processing it might be a display or a data port. But before final presentation, some human engineering is required to match the display to the capabilities of the observer. Modern commercial instruments do this reasonably well but prototype instruments are sometimes incomplete in this area.

Recording in temporary form is required in a large class of unattended and submerged instruments used in oceanography. Other systems must deal with permanent data storage. Recorders are used to do this storage. They have data limits. In fact the increase in data capacity of hard drives and compact flash memory brings home the realization that the bottleneck in data capacity may be the human ability to unpack and absorb stored data.

Data telemetry in real time or in delayed transmission still presents a data bottleneck, particularly satellite data communication. This data throughput limit is partly the bandwidth of the channel and partly power limit in the transmitting instrument. For any technology, acoustic, radio, optical, at various range and noise environments, there is a cost of energy per bit transmitted. Even for optical fiber there is some cost, although in observatories, much of the charm is the extreme economy of data transmission. There is still some need to be conservative in data quantity. When data are presented in graphic or tabular form in publications or reports their information less than 2 MBytes.

CHAPTER-2

SEAWATER TEMPERATURE

2.1. GENERAL

2.1.1. Definition of temperature

Temperature is a physical quantity characterizing the mean random motion of molecules in a physical body. Temperature is the property of a material by the virtue of which two bodies in thermal contact tend to attain the same temperature. Thus, temperature is the representation of the thermodynamic state of a body, and its value is determined by the amount and direction of the net flow of heat between the two bodies.

2.1.2. Units and Scales

Many physical processes are temperature dependent, of which a few can be used to define absolute temperature. The unit of temperature is Kelvin (K). Some of the fundamental processes, used for defining an absolute temperature scale over the range of temperatures found, are mentioned here: 1) the gas laws that relate pressure and temperature of an ideal gas with some necessary correction in density; and 2) the voltage noise of a resistance.

The temperature measurement using an absolute scale is difficult and is usually made by national standards laboratories. The absolute measurements based on the temperature of a few fixed points and interpolation devices that are calibrated at the fixed points, are used to define a practical temperature scale.

The temperature at which ice, water, and water vapour exist in equilibrium is called the triple point of water. The temperature scale in Kelvin T [K] is related to the temperature scale in degrees Celsius t [°C] by:

$$t\ [°C] = T\ [K] - 273.15$$

In 1887, 1927, 1948, 1968, and 1990, the practical temperature scale was revised as more accurate determinations of absolute temperature got accepted. The most recent scale is the International Temperature Scale of 1990 (ITS-90). It differs slightly from the International Practical Temperature Scale of 1968 IPTS-68. At 0°C they are the same, and above 0°C ITS-90 is slightly cooler; t90 - t68 = -0.002 at 10°C, -0.005 at 20°C, 0.007 at 30°C and -0.010 at 40°C.

2.1.3. Oceanographic requirements

2.1.3.1. General

Following are the primary oceanographic requirements for temperature measurements:

(a) The water temperature at the sea surface;

(b) The water temperature at various depths of the sea;

Daily spatially-complete global Sea Surface Temperature (SST) maps can be created by combining the SST measurements in various ways, which is used for weather prediction, ocean forecasts, and for coastal applications such as fisheries forecasts, pollution monitoring, and tourism. SST maps are also widely used by oceanographers, meteorologists, and climate scientists for scientific research.

The very slow and gradual change of sea water temperature and its stability plays an important role in moderating global climate. Ocean currents move the heated water from the equator towards the poles and the cold polar water towards the equator, thus moderating the seawater temperature.

Generally, seawater temperature decreases with increasing depth. The density of cold water is more than warm water and thus it sinks, causing stratification in the deep water. The surface sea water temperature and the stratification is mainly influenced by factors like tides, winds, freshwater discharge etc. The region of transition between the dynamic surface layer and the deep ocean, where the rate of decrease of temperature with increase of depth is the largest, is known as thermocline.

In some coastal regions high winds cause upwelling. The warmer surface waters are driven away from the coast by strong seasonal winds, and thus the cold, nutrient rich water moves up to the surface from beneath the thermocline. This process is termed upwelling. The regions where upwelling occurs show high productivity and are therefore of economic significance. The impact of seawater temperature on marine organisms and the use seawater temperature and wind measurements to study upwelling and climate change are of great interest to the researchers.

2.1.3.2. Operational requirements

The following are the operational requirements concerning observation of the subsurface temperature at different depths till 12000 m (~1200 bar).

Accuracy -The accuracy of ameasurement is the closeness of agreement between a measured quantity value and a true quantity value of a measurand. A temperature sensor might be specified as having an accuracy of 0.003°C over one year. However, most manufacturers list the specifications of a prototype or laboratory development sensor which may be quite different from the actual production model. The best method of determining accuracy is to calibrate and establish a sensor calibration history.

Resolution - The ability of a sensor to identify changes in value. Generally, the resolution is smaller than the accuracy. The sensor can change slowly with time, and have a poor accuracy, but still have a good resolution. The temperature sensor with an accuracy of 0.003°C might easily have a resolution of better than 0.001°C. That is, you can determine that there is a temperature change of 0.001°C.

Repeatability- repeatability condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time, the closeness of agreement of measurements taken under constant (defined) conditions defines the repeatability. It explains the ability of a sensor to duplicate a previous output with the same input.

Random error limits the repeatability whereas the systematic error defines the drift in the sensor. People talk about short-term and long-term stability. They are just using expressions to let you know how long a time the instrument is repeatable and how stable it is in long duration.

2.1.3.3. Range

The operational range for the observations would be from −5 to +35°C.This applies to momentary values, averages and to the extremes because the likelihood of temperature below-5°C or above +35°C is negligible.

2.2. MEASURING INSTRUMENTS AND CALIBRATION

2.2.1. Mercury in glass tube thermometer

Mercury in glass tube thermometer consists of mercury in a bulb attached to a glass tube of narrow diameter where the volume of mercury in the tube is much less than the volume in the bulb which is nearly out-dated in oceanography. The volume of mercury changes slightly with temperature where this small change in volume drives the narrow mercury column a relatively long way up the tube. The space above the mercury may be filled withnitrogenor it may be at less thanatmospheric pressure, a partialvacuum. The tube has markings in degrees, and the level of the fluid is calibrated to read the temperature. These sensors have an accuracy of about 0.02 °C when used properly.

The reversing thermometer is one type of glass thermometer used in oceanographic measurements which is designed in such a way that it can hold the temperature of the thermometerwhen it is reversed or tipped upside down at the required depth of measurement. There are two types of reversing thermometers; one comes with pressure protected shield and the other is unprotected. In the pressure protected version, the thermometer is completely enclosed in a glass tube so that there are no pressure effects on the reading and in the unprotected version; the seawater is allowed to compress the glass tube and mercury reservoir and so in this case reading changes with pressure. The proper calibration of the difference in temperature between the protected and unprotected thermometer gives the pressure value at the depth where the thermometer is reversed. In standard practice, where several bottles with reversal thermometers are lowered on the wire at one time, the depth of each thermometer is estimated by measuring the length of the wire out from the winch and the angle of the wire with the ship.

With the early CTDs, reversing thermometer temperatures were taken as a stability check on the electronic instruments like platinum resistance thermometers or thermistors. The stable reference was the mercury reversing thermometers, and the electronic temperature was used to interpolate the vertical temperature structure between thermometers. However, the accuracy and stability of temperature sensors on most CTDs and oceanographic instrumentation are better than reversing thermometers. Therefore, reversing thermometers are rarely used today.

2.2.2. Platinum Resistance Thermometer (PRT):

The Platinum Resistance Thermometer (PRT) provides accurate temperature measurement and is used as the laboratory standard.Generally, platinum-resistance thermometer is used as an interpolation device, for the temperatures commonly found in the ocean. It has a loosely wound, strain-free, pure platinum wire whose resistance is a function of temperature. In a standard laboratory by using a good temperature controlled Resistance Bridge with mercury wetted contacts and a polarity reversing switch, the temperature can be measured up to the accuracy level of 0.0001 °C repeatedly. PRT has special characteristic that proper making of the sensor ensure the high quality of the sensor compared to other types of sensor.PRT with a long platinum wire is normally used to get a good output signal because the resistance per unit length of platinum wire is low and the change in resistance per unit length of wire is also very minimal. This mass of wire has a thermal mass and hence a time constant. The longer the platinum wire sensing element, the greater the resistance change per unit temperature change which is good because it gives greater accuracy and resolution, but the longer wire has longer time constant which reduces the sensitivity of the sensors. These older PRTs had a time constant of approximately 1 second. The newer PRTshave the time constants as fast as 100 ms, but the stability when cycled to full ocean depths is not yet clear. The pressure proof case on the PRT is necessary to remove any pressure effects and assure accuracy and stability, but we have to compromise with time constant because the time constant will increase with the inclusion of the pressure case. Pressure protected thermistor sensors are cheaper and nearly as accurate, so are commonly used in oceanographic instruments.

2.2.3. Thermistors:

Thermistors are mostly used because of low cost compared to other temperature sensors. Thermistors differ from Resistance Temperature Detectors (RTDs) based on the material used such as the ceramic or polymer, whereas RTDs use pure metals. So, a thermistor stays within a define specification, the thermistor is often checked at a single point, and then shipped.

Thermistors are housed in a stainless steel casing to protect it from the ambient pressure changes.The two leads from the thermistor to the bridge circuit are short and permanently connected together to reduce thermal effects in the leads, and changes in capacitance caused by geometric changes. These factors are necessary to ensure the stability of the sensor. Calibration histories show that the drift rate of thesesensors start off with less than a 5 m°C per year and decreases with time, so that after 10 years it is less than 3 m°C per year and more typically 1 or 2 m°C. Thus, the temperature can be measured to within 2 m°C over periods as long as one year by knowing the drift rate from calibration histories.

2.2.4. Quartz thermometers:

Quartz thermometer is not used widely because of the high price of the crystal. The heart of this type of sensors is the quartz crystal oscillators which can be made temperature sensitive. So, this temperature sensing crystal element is used to construct a low-power crystal oscillator where the problem of cable attenuation is eliminated. The sensor can resolve up to µ°C change of temperatures and its sensitivity is constant with time. The crystal will be dislocated when subjected to shock, which creates absolute temperature shifts. A triple-point-of-water-cell is required for standardization to assure that no shift has occurred and to obtain the best accuracy. Also, the mass of the crystal in its pressure case enables long time constant measurements.

2.2.5. Calibration

Calibrations: calibration operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication.A good sensor can produce very poor results if it is not calibrated properly, but a poor sensor will always provide relatively poor data with the best calibration. So, a good measurement requires both good sensors and good calibrations. Both good static and dynamic calibration are required for a good sensor to obtain optimum results. A major part of any calibration is a sensor's past calibration and performance history.

Generally PRT sensors are calibrated at fixed points between the triple point of Mercury at -38.8344°C, the triple point of water at 0.010°C, the melting point of Gallium at 29.7646°C, and the freezing point of Indium at 156.5985°C.

Procedure

The calibration system requires a bath temperature control system called constant temperature water chamber/bath, a telecommunication system and standard sensors. Stirring of the bath fluid is very important for stable temperature control where the fluid must be mixed well for good temperature uniformity and fast controller response. The stirrer is precisely adjusted for optimum performance.Generally, the temperature sensors are calibrated by selecting several different temperature conditions. The environment around the bath is maintained stable at a constant room temperature. The temperature sensors are then calibrated using a standard sensor to the specified accuracy and a sensor is considered to be "good" when temperature measurements fall within the thresholds. Usually, calibration should be performed just before shipping to research vessels and immediately after the retrieval from the deployed location.

The basic demand for a standard sensor for temperature is better trueness, precision and drift compared to the instrument to be controlled and the data quality requested. The reference instrument is expected with a demand accuracy of 1mK, the mercury thermometer restrict reading accuracy to about 2 mK is not preferred. It should be noted that Ocean is not as homogenous as a stirred calibration bath.

2.2.6. Certification

Manufacturer should provide a dated certificate stating that the sensor manufactured with appropriate standard or actual resistance at fixed points in the temperature range to check the uncertainty in the measuring instruments.

2.2.7. Other important considerations in temperature measurements

2.2.7.1. Pressure sensitivity

Thermistors and PRTs are very sensitive to pressure and pressure protected tubes are used to eliminate the effect of pressure from the sensing elements. But these protective tubes increase the mass of the sensor and reduce the frequency of response. Therefore, an optimized approach to gain low drift and fast response is attempted using one protected PRT for stability and accuracy along with an unprotected thermistor for fast response. Based on the lowering rate (i.e. the flushing rate which controls the frequency response of the PRT and thermistor), the thermistor signal is high pass filtered with a cut-off that matches the response of the PRT, and added to the PRTsignal to get a measurement of true temperature with higher frequency response. But if the data from these two temperature sensors has been added together improperly, it can't be sorted out and corrected. Therefore, it is preferable (and most instruments with multiple sensors) to record all the data and do the combination of response times later in a computer under proper control of the user, and where any addition of sensor outputs is not irreversible.

2.2.7.2. Self-heating

The thermistor or PRT is heated by the current required to make the measurement, and the measurement will be erroneous. So, a bridge circuit is used to minimize the current flow through the sensor in order to minimize the heating. With the thermistor controlled Wien bridge oscillator, about 75 mW is used in the sensor, but aminimum of about 10^{-7} watts is dissipated in the thermistor itself, to reduce self-heating error to less than 0.0001 °C. Impact of self heating in the measurement could be measured during calibration and to be added in the uncertainty budget.

2.2.7.3. Sensor Signal to Noise Ratio

The terms used to describe the signal to noise ratio are drift, resolution and repeatability. The ability of a sensor can be describedby measuring the environment using signal to noise ratio. The full sensor noise spectrum is seldom given by scientists or manufacturers, but instead they refer to such quantities as drift, resolution and repeatability. In reality, it is essential to plot the signal being measured against the noise of the sensor. Geophysical signals have higher energy at low frequency and lower energy at higher frequency. The sensor noise level can be determined by several means. The low frequency part of the sensor noise, is often referred to as "drift" or long-term stability, and is also reflected in the parameter known as accuracy. The high frequency part of the sensor noise spectrum is related to "repeatability" and resolution or short-term stability.

2.2.8. Sources of error

2.2.8.1. Sensor

- Interchangeability
- Insulation Resistance
- Stability
- Repeatability
- Thermal EMF
- Hysteresis
- Self-Heating

2.2.8.2. Installation

- Time Response
- Stem Conduction

- Lead Wire
- Radio Frequency Interference(RFI)/ Electro-Magnetic interference (EMI)
- Electrical interference

2.2.8.3. Instrumentation

- Transmitter
- Controller/PLC

2.2.8.4. Other sources can produce errors but are difficult to analyse without installation unique information

- Vibration
- Mechanical Shock
- Thermal Shock
- Thermal Radiation

2.2.9. Testing Standards for measuring instruments

2.2.9.1. Environmental Testing

The ability of a product to withstand the environment within which it has to operate, be stored or transported is critical to its success. The environmental testing ensures whether the product is fit for purpose and will survive the most extreme conditions encountered in its lifetime.

The environmental testing can be classified as

- Dynamic Testing - Vibration, Inclination and Shock (Mechanical and Thermal Shock)
- Climatic Testing - Temperature, Humidity and Salt Mist
- Ingress Protection (IP) Testing

2.2.10. Maintenance

Regular field checks should identify any changes in system calibration. These may occur as a result of long-term changes in the electrical characteristics of the thermometer, degradation of the electrical cables or their connections, changes in the contact resistance of switches or changes in the electrical characteristics of the measuring equipment. Identification of the exact source and correction of such errors will require specialized equipment and training, which should be undertaken only by a maintenance technician.

2.3. DATA

2.3.1. Quality Control:

2.3.1.1. General:

It is very difficult to do research in complex environments like Earth’s natural systems as we have to take into consideration many of the natural factors. In the marine environment where so many research obstacles have to be overcome especially the deep, dark and turbulent conditions. For good research, good quality of data is needed by adopting good quality control methods. Data can be reliable only after a good quality control methods applied on it. And after that process the data can be incorporated into databases or distributed to the users via national or international exchange.

The objectives of the quality control of oceanographic data are to ensure data consistency, the quality and errors of the data are apparent to the user who has sufficient information to assess its suitability for a task. The advantages of the quality controls are:

Maintaining Common Standards

A minimum level of quality control is essential for all oceanographic data. A little point banking data is available just because they have been collected; the data must be qualified using additional information on methods of measurement and subsequent data processing that is of use to the potential users. Standards are imposed on the quality and long-term value of the data that are accepted. If the guidelines are available, data are maintained to this degree, keeping common standards to a higher level.

Acquiring Consistency

All the data from the different sources should be consistent with each other as much as possible within a data centre to ensure easy access of data by the external user. A user will be able to search a data more successfully if he is able to identify his required data quickly, though the original sources of that data are very different on national or international level.

Ensuring Reliability

To build a good reputation to the national and international community, a data centre has to provide good quality of services. The data must be reliable to serve the purpose of the research community and this is possible only if the data goes through a proper processing of quality control to a ‘universal’ standard. Many national and international programmes or projects involve investigations across a broad field of marine science that includes complex information on the marine environment. Many large-scale projects were also conducted by some of the commercial industries such as oil and gas and fishing. As an outcome of these projects, many significant decisions have been taken and theories formed, to assure data reliability and compatibility, even when they come from multiple sources.

2.3.1.2. Requirement of quality control

In order to achieve a standardized approach, the current best practice should be published and distributed widely. This includes a variety of automatic tests that are often carried out in real time and a more scientific quality control method checking for unexpected anomalies in the time series or profile, or in derived parameters. The quality control extends beyond these procedures to include the documentation of the data sets.

Quality control is also related to some issues such as the availability of data in real-time. Data are inspected every day in advanced systems and be flagged for errors by using an automatic software which would enable fixing of faults quickly. This quality check is in contrast to the more traditional form of carrying out all of the procedures in delayed mode quality control, where errors are detected a considerable time after they occur.

2.3.1.3. Information to accompany data

The location (longitude, latitude, depth, height) from where the data was collected and the time (UTC) at which data is collected should be recorded. The longitude and latitude are checked for validity i.e. latitude should be in the range of -90 to 90 and latitude should be in the range of -180 to 180. The observation latitude and longitude from the profile measurement must be located in an ocean. A test should be done to ensure that observed parameter values are within the expected extremes encountered in the oceans as well as that in the particular regions. The date and time of the observation should be valid i.e. the year should be of 4 digits, month should be between 1 and 12, day should be in range expected for the month, hour should be between 0 and 23, minute should be between 0 and 59. The vertical profiles do not contain pressures higher than the highest value expected in the deployment.

The sampling method, analytical techniques, instrument types etc. used for the collection of data should be mentioned. The present state of the data i.e. the details of processing and calibrations applied, algorithms used to compute derived parameters etc. should be highlighted and the problem encountered and the comments on data quality should be included.

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CHAPTER-3

MEASUREMENT OF CONDUCTIVITY

3.1. GENERAL

3.1.1. Definition of conductivity

Conductivity of a substance is defined as the ability to transfer (conduct) electric current. It is the reciprocal of electrical resistivity (ohms). In oceanographic terms, conductivity is used to measure the concentration of dissolved matter (salts) ionized in a solution (seawater).

3.1.2. Units and Scale

The common unit of seawater conductivity is micro or millisiemens per centimeter (µS/cm or mS/cm) but are seldom reported in micromhos or millimhos/centimeter (µmhos/cm or mmhos/cm) where one siemen is equivalent to one mho. Microsiemens per centimeter is commonly used as a standard unit for freshwater measurements and seawater conductivity usesmillisiemens/centimeter.

Pure water has very low concentration of dissolved ions, thus, the measured conductivity falls below a value of 1 µS/cm. Thus, they can be expressed as whole numbers compared to fractions which are inverse of each other commonly referred to as "mega-ohms" or simply “ohms”.

3.1.3. Oceanographic requirements

3.1.3.1. General

Salinity is one of the most useful and required parameter to measure water quality, which is derived from Conductivity. Density, a derived parameter from temperature and salinity is important to understand the thermohaline circulation where changes in temperature and salinity can alter the circulation, thereby, affecting the climate. Thus conductivity as the basis of salinity calculations serves as an indicator of change in a water system. Almost all water bodies have constant conductivity values, which can be used as a reference line for future measurements where any substantial change detrimental to water quality could be identified.

Conductivity is measured easily using direct methods discussed below. The strong correlation between conductivity and salinity is an important factor used in algorithms estimating salinity from conductivity measurements. Salinity affects the solubility of dissolved oxygen where the salinity level is inversely proportional to the dissolved oxygen level. Thus seawater shows lower dissolved oxygen concentration than freshwater.

Salinity measurement based on the satellites, Soil Moisture and Ocean Salinity (SMOS) by ESA and NASA’s Aquarius needs to be calibrated using in situ measurement under Global

Ocean Surface Salinity Calibration and validation programs. Therefore, in situ conductivity measurement remains primordial.

3.1.3.2. Range

The operational range for the observations would be from 0to 70mS/cm. This applies to momentary values, averages and to the extremes, as the likelihood of conductivity below 0 or above 70mS/cm is negligible.

3.1.3.3. Accuracy

The conductivity cell has a nominal accuracy of better than 0.05mS/cm.

3.2. Types of Measurements

Many underlying sensing technique have emerged due to the technological advancements, however, practical implementation in the field plays a major role. These practicalities include the ability to perform adequate static calibrations in a laboratory as well as acceptable response characteristics and adequate sensor stability (less drift) during long deployments. As with all technologies, continued improvement is driven by customer needs. More mature sensing technologies inductive and conductivity cell are discussed.

3.2.1. Conductivity cell:

Conductivity is calculated from the conductance measured by the sensor using a scale factor or cell constant that reflects the ratio of length and cross-sectional area of the sampled water volume in which the electrical current actually flows.

The conductivity derives from the relationship:

$R = \rho\ l/A$

where:
R = resistance in ohms = 1/conductance
ρ = resistivityohmmetre = 1/conductivity
L = length of sampled water volume in meter
A = cross-sectional area of sampled water volume in cubic meter

Conductivity cells can be constructed to have either internal or external electrical fields. The conductivity cell has zero external fields by connecting its outer electrodes together; no voltage difference exists to create an external electrical current. This is a two-terminal cell in which the electrode resistances are in series with (and indistinguishable from) the cell resistance proper. As the electrode resistances are low and the cell resistance high, errors resulting from changes in the electrode resistances are minimal. The sample volume -- entirely determined by the cell's hard parts -- is immune to proximity errors and readily protected from fouling by anti-biology (toxic) gatekeepers placed at the ends of the cell.

In order to calculate salinity, temperature and conductivity should be measured simultaneously, as these two parameters are linked to each other closely. Sensor response time is considerably important to have high level of accuracy.

Errors and corrections

a. Factors such as flow rate of the sample water through the cell, temperature of the cell and heat capacity of the materials that make up the sensor, electrode condition and stability of the cell geometryinfluence the response characteristic of conductivity cells.

b. Stable cell geometry is important for an accurate conductivity measurement. Cell contaminated with oil, bio fouling or other foreign materials will reduce cell geometry causing error in the measurement. Bio fouling will reduce the cell area leading to the under estimation of conductivity. The Anti-Foulant Device (tributyltin) is an expendable device that could be installed on each end of the conductivity cell, so that any water that enters the cell is treated. Anti-Foulant Devices have no effect on the calibration, because they do not affect the geometry of the conductivity cell in any way. Frequent anti-foulant replacement is advisable when high biological activity and strong current flow are present.

c. Conductivity cells are made of glass. If a cell is cracked, it typically causes a salinity shift or erroneous data. Cell damage leads to over estimation of the conductivity.

d. Air bubble in the conductivity cell may cause an erratic reading. Check the air bleed valve to see if it is clogged; clean out the small hole with a piece of fine wire.

e. Conductivity cell type sensor is relatively poor flushing in low-flow environments. A constant flow, provided by a pump, guarantees a constant response time for the conductivity cell based sensor.

f. If response time of the conductivity and temperature sensor differ the flow has to be controlled to have the same water parcel sampled by each sensor with adequate response time.

3.2.2. Inductive or Toroidal:

The inductive sensor operates bypassing a controller and supplies a high frequency reference voltage through the drive transformer, which induces an electric current in the seawater that passes through the central hole in the cell. The induced current in the seawater in turn induces a current in the signal transformer which is measured and is proportional to the conductance of the seawater. The magnitude of both induced currents depends solely on the electrical field density of the field paths through the hole in the cell. The controller converts the signal from the sensor to specific conductivity of the process liquid.

Errors and corrections

a. Overall, 20% of the seawater conductance is measured external to the central hole of the inductive cell. This significant dependence on the external portion of the electrical field to the overall accuracy of the measurement can result in significant errors in conductivity caused by nearby objects such as guards, struts, sensor housings or marine growth, which can distort the external field.

b. This dimensional stability must be maintained despite distortion from fluctuations in temperature and pressure and coatings from sea surface oils, mineral deposits, marine growth and the application of anti-foulants.

c. Antifoulant-bearing materials placed close enough to be effective also distort the external field, and in a way that will change as the antifoul material leaches out, as it must.

d. Calibration is awkward because clearance in the calibration baths must be provided for the external field. Calibration is especially inconvenient if the sensor is already mounted to a relatively large companion package.

3.3. Calibration

Best practices for the calibration are in pre-deployment and post-recovery. Pre-deployment calibration ensures the accuracy of the sensor. Post recovery calibration coefficient indicates the quality of the data being collected over the deployed period. This coefficient could be used for data correction.

Conductivity calibration can be performed in two ways

1. Using different salinity baths
2. Single salinity with varied temperature

Natural seawater should be used in both the cases for obtaining the best possible results.

1. At least, four tubs with different salinity values are required to calibrate using different salinity baths method. The reference SPRT sensor (temperature measurement)is placed close to the conductivity sensor into the tub, without causing interference. Salinity of the sample water is measured using the Standardised Salinometer (calibrated with IAPSO standard Seawater). Obtain stable readings and record the values from conductivity sensor, SPRT and salinometer. Repeat the same in the next salinity baths (different salinity values). Using the bath temperature as measured by the SPRT and salinity measured by salinometer, calculate the conductivity of the salinity baths at the time of measurement. This reference conductivity value will be used to calibrate conductivity sensor (DUT).

2. A precision temperature controlled water bath which is suitable for seawater is requiredto perform the calibration on Single salinity with varied temperature. Uniformity and stability of temperature are important characteristics of the bath, which should be high enough for this calibration. Conductivity is very sensitive to changes in temperature. Hence, single salinity with variation in bath temperature provides the variation in conductivity. It is important that the conductivity sensor (DUT) and standard temperature probe (SPRT) are equilibrated at each temperature before taking measurements. Air bubble will lead for erratic reading hence calibration is done in the descending order of temperature to avoid the degassing of the seawater. Salinometer is used to find the salinity of the sample water at each calibration point, bath temperature and salinity at each calibration points is used to calculate conductivity. This value is the reference for the calibration of DUT.

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CHAPTER-4

MEASUREMENT OF PRECIPITATION

4.1. GENERAL

4.1.1 Definition of Precipitation

Precipitation is defined as the liquid or solid products formed by the condensation of water vapour falling from clouds or deposited from air onto the ground. It includes rain, hail, snow, dew, rime, hoar frost and fog precipitation. The total amount of precipitation that reaches the ground in a stated period is expressed in terms of the vertical depth of water (or water equivalent in the case of solid forms) to which it would cover a horizontal projection of the Earth's surface.

4.1.2 Units and Scale

The measurement unit of rainfall intensity is linear depth per hour, usually in millimetres per hour (mm/hour). Rainfall intensity is normally measured or derived over one-minute time intervals due to the high variability of intensity from minute to minute. Less than 0.1 mm of rainfall is generally referred to as a trace.

4.1.3 Oceanographic requirements

Precipitation measurements with large spatial coverage are very critical for climate related studies. Freshwater fluxes are an indirect measure of local latent heating, which drives atmospheric circulation. The release of latent heat by condensation of water vapour is a major component of Earth's energy budget. They form the upward branches of Hadley cell and Walker cell with significant role in mixed layer temperature and stratification. We rely on combination of satellite and insitu measurements, often in the form of blended products, as a measure of global precipitation. Although satellite data provides large spatial coverage, it requires complicated algorithm to convert to rainfall amount. While insitu rain gauges are potentially more accurate with widespread application in research related to climate variability.

4.1.3.1 Range

The rain rate typically calculated from the accumulated rain water in a catchment container. The operational range for the observations would be from 0to 50mm.

4.1.3.2. Accuracy

The precipitation sensor has nominal accuracy of ±1 mm.

4.2 **Types of Measurements**

4.3 Few sensor technology are only appropriate for the marine environment even though there are many conventional sensor technology available for land based system for measuring precipitation (tipping bucket, weighing, capacitance, optical, disdrometer, and acoustical sensors). Rain gauge that can operate on a moving platform, like a buoy, should directly measure the volume and not the weight of the precipitation, as is done by the tipping-bucket design.

Capacitive sensor

Precipitation is collected in a catchment funnel which has a cross sectional area of 100 cm^2. Captured precipitation drains from this funnel into a measuring tube which has a cross sectional area of 20cm^2 . Since the area of the catchment funnel is 5 times that of the measuring tube, 1mm of captured precipitation produces a 5mm column of water in the measuring tube. A capacitive transducer in the centre of the measuring tube senses the height of the water column. A self-contained electronic circuit converts the capacitance value to a calibrated voltage output that is proportional to the collected precipitation. Periodic interrogation by a data logging system allows computation of total precipitation and rate of precipitation. The full column height of the measuring tube is 250mm representing 50mm of collected precipitation. Additional precipitation starts a self-siphoning process which empties the measuring tube in approximately 30 seconds. The water column in the tube returns to a level representing 0mm of precipitation and the voltage output goes to 0 VDC. Additional precipitation begins filling the measuring tube again and the cycle is repeated. Evaporation of water remaining in the measuring tube is negligible between siphoning events. Capacitive type of Precipitation Gauge has an advantage of no moving parts like conventional gauges.

Errors and corrections

The effects on the wind field of the immediate surroundings of the site can cause local excesses and deficiencies in precipitation. In general, objects should not be closer to the gauge than a distance of twice their height above the gauge orifice.

These error estimates do not take into account underestimates in accumulations due to effects of wind speed on the catchment efficiency, which, though substantial, may be correctable.

Estimated errors due to evaporation and sea spray, on the other hand, are found to be insignificant.

The most important requirements of a gauge are as follows:

a. The rim of the collector should have a sharp edge and should fall away vertically on the inside, and be steeply bevelled on the outside

b. The area of the orifice should be known to the nearest 0.5 per cent, and the construction should be such that this area remains constant while the gauge is in normal use

c. The collector should be designed to prevent rain from splashing in and out. This can be achieved if the vertical wall is sufficiently deep and the slope of the funnel is steep (at least 45 percent)

d. The container should have a narrow entrance and be sufficiently protected from radiation to minimize the loss of water by evaporation.

4.4 Calibration

a. Flow bench

A standard and known quantity of water is pumped from the reservoir to the sensor by microprocessor based peristaltic pump that is continuously monitored by a computer. The overall function of the system is to have a precise control over the flow of water using a computer and the data measured by each sensor is compared with the water flow. Thus the final calibration comparison is done between the standard and the precipitation gauge. The accuracy of the flow bench should be ± 2 ml. For example, if the flow bench pumps 50 ml of water. The measured volume should be 50±2 ml.

The pump should be controlled by a microprocessor to achieve closed loop control of the flow rate. The pumping of the fluid is done by flow rate input value fed to the pump by the user. Based on the input to the pump by the user, the flow rate should be measured with an inbuilt flow meter. Any change in the head during the running of the pump should be taken care by the pump and by adjusting and settingthe flow rate. The pump flow meter should be traceable to any national standard authority.

Although the medium is water, proper tubing is to be installed with corrosion resistant material so that there is no accumulation of fluid in the tubing during the operation of pump, which may cause pump troubles.

b. Calibration check using 500 ml graduated cylinder and 25 ml syringe

Electronic calibration

i. Prime gauge

Pour water slowly into catchment funnel until the unit self-siphons.

ii. Calibrate voltage output for zero

Turn ZERO trimpot on circuit board until a positive change is observed in the voltage output.

Then turn trimpot until voltage output just reaches 00.0 volts. Do not turn it any further.

iii. Calibrate voltage output for full scale

Pour 450 ml into catchment funnel.

Adjust GAIN trimpot for 4.50 VDC on the output. Output voltage is now scaled for 20 mV per millimeter of water depth in the measuring tube which equals 100 mV per millimeter of precipitation.

iv. Check output linearity

Pour water slowly into catchment funnel until unit self-siphons.

Add 50 ml of water and observe output voltage.

The output voltage is calculated using the ratio of 500 mV per 50 ml. Gauge accuracy is specified as ± 1 mm of collected precipitation. Measured output voltage should be within ± 100 mV of the calculated value.

Continue adding water in 50 ml increments and observing voltage output until measuring tube is full at 500 ml total volume. Measured output voltage should be within ± 100 mV of the calculated value at each 50 ml increment.

c. Rain Gauge Calibrator

The calibrator includes a calibrated 1000 ml water bottle with a constant head adapter and calibrated flow nozzles for various flow rates. The calibrator can be used for Young Tipping Bucket and Siphon rain gauges.

Calibration procedure

1. The rain gauge must be properly leveled before calibration.
2. Select the appropriate nozzle for the desired rainfall rate. Attach nozzle to constant-head adapter.
3. Fill water bottle to the desired level. Maximum accuracy is obtained by using a laboratory balance to weigh the water (1ml = 1 gm).Reasonable accuracy may be obtained by using the bottle graduations. Attach adapter with nozzle.
4. Position bottle stand in rain gauge funnel and carefully invert the calibration bottle and place on a stand. Water should flow from nozzle.
5. Allow water in the bottle to flow through rain gauge until empty. Record rainfall value. With the rain gauge.
6. If the error is outside specifications, adjust the rain gauge calibrating screws to bring the rain gauge into specification. Screws should be adjusted equally.

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CHAPTER 5

MEASUREMENTOFINCOMING SHORTWAVE RADIATION

6.1. GENERAL

6.1.1. Definition

Incoming shortwave radiation is the radiation received directly or indirectly from the sun by a horizontal plane at the earth's surface per unit area per unit time, integrated over all wavelengths in the shortwave interval. Shortwave radiation is primarily in the wavelength range 0.25-4μm. Solar radiation flux density varies significantly between regions due to season, time of the day, elevation of the surrounding terrain and obstructions. Shortwave solar radiation can be separated into two components, direct (S) and diffuse (D) beam. Diffuse beam is the portion of the radiation that has been scattered by gas molecules and suspended particles in the atmosphere and reaches the earth's surface from multiple directions. The direct beam is the portion of radiation that reaches the earth's surface in relatively parallel beams. The direct component depends on the solar zenith angle, (θ=90°-solar elevation angle), $S=I\ \cos\theta$; where I is the solar radiation at the surface through a surface perpendicular to the solar beam.

Units and Scale

The shortwave radiation incident on a horizontal surface from all directions is called irradiance and has the units of Wm^{-2}.

6.1.2. Oceanographic Requirement

The evapotranspiration process is determined by the amount of energy available to vaporize water. Solar radiation is the largest source of energy that causes evaporation of water into water vapour in large quantities. The potential amount of radiation that can reach the evaporating surface is determined by its location and the time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb major parts of the radiation. When assessing the effect of solar radiation on evapotranspiration, not all available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile.

Variability in the heat economy of the Earth is mainly based on the radiation to and from the earth's surface. Radiation measurement is mainly carried to study the distribution and variations of incoming, outgoing and net radiation. It requires a widely distributed regular series of records of solar and terrestrial surface radiation components and the derivation of representative measures of the net radiation.

6.1.3. **Operational requirements**

6.1.3.1. **Accuracy -**. The pyranometer generally has the uncertainty of < 10 Wm^{-2} and resolution depends on signal conditioning that is used to amplify the signal from the thermopile.

6.1.3.2. **Range:** The operational range for the observations would be from 0 to 2000 Wm^{-2}

MEASURING INSTRUMENTS

Pyranometer:

The instrument needed for measuring solar radiation from a solid angle of 2π sr into a plane surface and a spectral range from 300 to 3000 nm is the pyranometer. Pyranometers normally use thermo-electric, photoelectric, pyro-electric or bimetallic elements as sensors. This sensor responds to the total energy absorbed by a unique black surface coating, which is spectrally non-selective. The absorbed irradiance by the black body creates the temperature differences which induces a small voltage by the sensors. Temperature in the black body may get affected by the wind, rain and thermal radiation losses hence the sensor should be shielded by domes. These domes should allow the direct solar radiation component for every position of the sun in the hemisphere above the sensor. The solar irradiance can come from any direction within the hemisphere above the radiometer and therefore the domes should be designed to minimize errors in measurement at all incident angles. Pyranometers should have adjustable feet and can be levelled using the integral bubble level. Aspyranometers are exposed continually to all weather conditions, they must be robust in design and resist the corrosive effects of humid air (especially near the sea). The sensor has to be fixed permanently, wherein casing must be easy to take off so that any condensed moisture can be removed. A desiccator is usually fitted at the base of the instrument. The properties of pyranometers which are of concern when evaluating the uncertainty and quality of radiation measurement are: sensitivity, stability, response time, cosine response, azimuth response, linearity, temperature response, thermal offset, zero irradiance signal and spectral response. Further advice on the use of pyranometers is given in ISO (1990c) and WMO (1998).

Error and correction

Sensorlevelling

Dynamic nature of the measuring platform can cause significant offsets in the measurement of down welling shortwave radiation due to tilting of the instrument thereby changing the angular orientation of the direct component of sunlight to the instrument. For the proper correction of this tilt, a priori knowledge of the partitioning between the direct and diffuse components of the total shortwave should be applied for the correction of tilt. Without a proper tilt correction, even data limited to 5° of tilt can still exhibit large error greater than 10 Wm^{-2}.

For accurate global radiation measurements with a pyranometer, it is essential that the spirit level indicate when the plane of the thermopile is horizontal. This can be tested in the laboratory on an optical levelling table using a collimated lamp beam at about a 20° elevation. The levelling screws of the instrument are adjusted until the response is as constant as possible during the rotation of the sensor in the azimuth. The spirit-level is then readjusted, if necessary, to indicate the horizontal plane. This is called radiometric levelling and should be the same as physical levelling of the thermopile. However, this may not be true if the quality of the thermopile surface is not uniform.

Change of sensitivity due to ambient temperature variation

Thermopile instruments exhibit changes in sensitivity with variations in instrument temperature. Some instruments are equipped with integrated temperature compensation circuits to maintain a constant response over a large range of temperatures. The temperature coefficient of sensitivity may be measured in a temperature-controlled chamber. The temperature in the chamber is varied over a suitable range in 10 °C steps and held steady at each step until the response of the pyranometers has stabilized. The data are then fitted with a smooth curve. Ifthe maximum percentage difference due to temperature response over the operational ambient range is 2% or more, a correction should be applied on the basis of the fit of the data.

If no temperature chamber is available, the standardization method with pyrheliometers can be used at different ambient temperatures. Attention should be paid to the fact that not only the temperature but also, for example, the cosine response (namely, the effect of solar elevation) and non-linearity (namely, variations of solar irradiance) can change the sensitivity.

Variation of response with angle of incidence

The dependence of the directional response of the sensor upon solar elevation and azimuth is usually known as the Lambert cosine response and the azimuth response, respectively. Ideally, the solar irradiance response of the receiver should be proportional to the cosine of the zenith angle of the solar beam, and constant for all azimuth angles. For pyranometers, it is recommended that the cosine error (or percentage difference from ideal cosine response) be specified for at least two solar elevation angles, preferably 30° and 10°.

Only lamp sources should be used to determine the variation of response with the angle of incidence, because the spectral distribution of the sun changes with the angle of elevation. Using the sun as a source, an apparent variation of response with solar elevation angle could be observed which, in fact, is a variation caused by the non-homogeneous spectral response.

Installation

Very special care should be taken when installing equipment on such diverse platforms as ships, buoys, towers and aircraft. Radiation sensors mounted on ships should be provided with gimbals because of the substantial motion of the platform. Radiation sensors should be mounted as high as is practicable above the water surface on ships, buoys and towers, in order to keep the effects of water spray to a minimum.

Particular attention must be paid during installation, especially for systems that are difficult to access, to ensure the reliability of the observations. It may be desirable, therefore, to provide a certain amount of redundancy by installing duplicate measuring systems at certain critical sites.

Calibration:

By reference to a standard pyrheliometer

The self-calibrating Absolute Cavity Pyrheliometer sensor consists of a balanced cavity receiver pair attached to the circular wire-wound and plated thermopile. The blackened cavity receivers are fitted with heater windings that allow absolute operation using the electrical substitution method, which relates radiant power to the electrical power in SI units. The forward cavity views the direct beam through a precision aperture. The precision aperture area is nominally 50 mm^2 and is measured for each unit. The rear receiver views an ambient temperature blackbody. The HF radiometer element with baffle tube and blackbody are fitted into an outer tube, which acts as the enclosure of the instrument.

The operation of the cavity radiometer and the measurement of the required parameters are performed using an appropriate control box. The control functions include setting of the calibration heater power level, activation of the calibration heater, selection of the signals to be measured and control of the meter measurement functions and ranges. The measured parameters include the thermopile signal, the heater voltage and the heater current, which is measured as the voltage drop across a 10 Ohms precision resistor. The instrument temperature may also be measured using an internally mounted thermistor. The meter resolution of 100 nV allows for a thermopile signal equivalent in radiation of approximately 0.1 Wm^{-2}.

The control box can operate either one radiometer in the measurement mode or two radiometers in the comparison mode. Shuttering, calibration heating and measurement functions are automatically controlled using a computer. Calculation and data storage are done using a computer. Programs for independent, automatic measurement and cavity radiometer comparison are supplied along with automatic units.

Although these are absolute devices, the radiometers are compared with the reference cavity radiometers, which could be participated in the International Pyrheliometric Comparison (IPC) and other intercomparisons and are directly traceable to the World Radiometric Reference (WRR).The responsibility for the calibration of radiometric instruments rests with the World, Regional and National Radiation Centres, Furthermore, the World Radiation Centre (WRC) at Davos is responsible for maintaining the basic reference, the World Standard Group (WSG) of instruments, which is used to establish the World Radiometric Reference (WRR). During international comparisons, organized every five years, the standards of the regional centres are compared with the WSG, and their calibration factors are adjusted to the WRR. They, in turn, are used to transmit the WRR periodically to the national centres, which calibrate their network instruments using their own standards.

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CHAPTER 6

CENTRAL PROCESSING UNIT

6.1. GENERAL

The Central processing unit (CPU) collects the time series data from the sensors at predetermined time intervals. A suite of meteorological, oceanographic and water quality sensors are interfaced to the CPU. The CPU activates the respective sensors at pre-determined time intervals to acquire data for a certain period at a certain frequency. Some sensors sampling may be done concurrently. Thus acquired raw data need to be processed and averaged. The averaged single value for each parameter in encrypted format is sent through a satellite transmitter using satellites to the Shore Station.

6.2. CENTRAL PROCESSING UNIT

Data acquisition, data processing, data storage and data transmission are the key functions of the CPU and the CPU's Hardware mainly depends on the complexity and level of the functions that needs to be performed. It is basically a microprocessor based system with relevant software enclosed in a container.

6.2.1. Data acquisition

The output of the signal from the sensor may be analog or digital. Signal conditioning is the important function of the data acquisition process and it is the interface medium between the sensors and processor.

Analog sensor:

Analog signal from the sensors entering the CPU might include unwanted noise. A proper selection of cable and connector will reduce the signal to noise ratio. Shielded cables and the use of a pair of wires between the signal cables and the interference source reduce the noise and electromagnetic coupling. Analog isolator like, flying capacitor, optical coupling or transformer coupling are used to decouple the ground loops and removal of large common mode signals. The range of analog output for the sensors may differ, however, the analog to digital converter (A/D) require a high level signal to get better resolution in the sensor output. Hence, variable gain amplifiers are used in the signal conditioning unit to get uniform input to the A/D from all the analog sensors. Low pass are used to separate the original signal from the undesirable signal, it has a cut off portion of frequency spectrum where the original signal does not exist. The number of analog channel could be designed based on the requirement of the analog sensors. The main task of the data acquisition is scanning the particular channel of the sensor and displaying the parameters in auser readable format. Signal A/D converter is used to serve many analog inputs (from sensor) by switching the channel. Software can control these switches to select the channel based on the user configuration. The resolution of the sensor reading is mainly dependant on the number of bits of the A/D converter. An A/D resolution of 12 bits corresponds to approximately 0.025%, 14 bits to 0.006%, and 16 bit to 0.001 5% of the A/D full range or scale.

Digital sensor:

Discrete nature of the digital signal is highly immune to noises compared to Analog signal. Serial digital ports in the processor are directly interfaced with sensor output. Conventional digital interface device RS232 is used for short distance communication and RS422/485 are used in long distance communications.

Passive sensor:

Some sensor output may be with variable resistance. In such a cases a special module converts the resistance into a linearized output voltage signal.

6.2.2. Data processing

Data processing is the main function of the CPU, it handle the Input/output data from the sensors. Microprocessor is the main hardware of the CPU along with highly sophisticated software, which makes the measurements easier, faster and more reliable, and provides the instrument with higher capabilities, especially in data handling. CPU consists of different memory to handle data and program, Random access memories RAM is used for handling data and non-volatile programmable read only memories (PROM) is used for program storage and non-volatile Electrically Erasable PROM (EEPROM) used for storing the constants. Real Time Clock (RTC) is an essential component of the data processing. It is a 24h real time clock powered by a battery and the clock is synchronized with a Global Positioning System (GPS)

6.2.3. *Data transmission*

The main communication between land and offshore system is carried by the data transmission system in the CPU. Real time data from the offshore can be transmitted via cable or by a variety of radio systems. The selection is based on the distance of the offshore system, bandwidth required, cost and energy required for the transmission. Satellite communication is the only realistic option if the offshore system is very far from the land and any other communication is possible if the system close to the land.

6.2.4. Data storage

Data measured from the offshore system is stored in a memory cell with time stamp and after initial quality control, this data base has to be updated in real time. The size of the memory design is based on the maximum possible number of sensors, sampling interval, derived quantities and the deployed duration of the system. Circular memory management shall be implemented as old data needs to be overwritten by new incoming data after the memory is full and the database structure should allow easy access for data transfer and download of data from the CPU. Host port in the CPU should allow the user to communicate to the CPU via personal computer to make self-test and investigate the CPU.

6.3. SOFTWARE

System software and application software are the two main software required for an offshore system. The software design has to consider the additional requirements of inclusion of new sensors, changes in quality control criteria in near future to avoid expensive development charges.

6.3.1. System software

According to the user requirement, the software should be developed and stored in PROM of the CPU in a non-readable format, generally called as firmware. Due to the technological advancement, many industries allow the user to develop their own application software using programming languages like C, linux, or pascal, thereby providing the user more insight and control over the system.

6.3.2. Application software

Remote system interface software:

Application software may be designed using Graphical User Interface (GUI) which allows the user to program their requirement such as deployed position of the system, the sensors need to interface for monitoring with initialization time period, sampling time of the sensor, calibration co-efficient, number of samples to be measured, averaging, data reduction, message formatting, data storage, and configuration of data transmission system details such as destination and mode of communication. This program is generally operated via a personnel computer and finally these requirements will be installed in the CPU for its execution.

Reception software:

Reception software is developed to receive the data from the remote station, decode the data in a readable format, quality control the received data and store the data in the database. This software could be operated using windows or linux based operating systems.

Two-way communications:

The application software may have the option for two-way communication wherein, the remote station may poll from shore station. Time slot for this communication may be configurable in remote station for polling data and troubleshooting the systems.

6.4. SYSTEM QUALIFICATION TEST

Following qualification tests shall be conducted on the CPU when it is developed newly.

a. Initial insulation & isolation resistance

b. Initial visual examination and performance check.

c. Protection category: IP67 Test

d. Vibration test : MIL-STD-810E-514.4

e. Shock test : MIL-STD-810E-516.4

f. Climatic tests : QM333

- Dry heat test
- Cold test
- Rapid temperature cyclic test
- Damp heat (Steady state) test
- Damp heat (Cyclic state) test

g. EMC test :IEC6100

h. EMI Test

- Radiated Susceptibility Test
- IEC 61000,4-3,2006
- Electrostatic Discharge Immunity
- IEC 61000,4-2,2001
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